Climate Analysis using R,
A Case Study of Hornsund, Norway.

2022

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Abstract

Climate is the average atmospheric condition of a place over a relatively long period usually greater than 30 years. Over the past centuries, climatic conditions were relatively stable, until recently when the industrial revolution began to cause irreversible changes in climate. Against this background, this report presents the analyses conducted for two salient climate parameters in Hornsund Norway from 1975 to 2021. R programming language, embedded in R software version 4.1.2 was used as a tool for analysing the data obtained from the Global Surface Summary of the Day (GSOD) repository and the Royal Netherlands Meteorological Institute (KNMI) website. As such, different climatic parameters including mean daily temperature, minimum and maximum temperatures, and as well as precipitation were analysed. The results were presented using the plots, histograms, line graphs, and simple bar graphs generated with the aid of R software. The various climatic results obtained for the study area essentially agree with literatures regarding the climatic condition of Hornsund, and essentially with the Wladimir Köppen classification of the area. The results further revealed that there is significant annual variations in temperature between the years 1985 and 2021, though still within the limit defined by Köppen system. While it was difficult to characterise the trend observed for precipitation, increasing trend was apparent for mean annual temperature variations between the years 1985 to 2021.

1.0 Introduction

Climate is often defined as the average weather in a given area over a longer period of time (ClimateEurope, 2020). Another variety of definition sees it as the long-term pattern of weather in an area, typically averaged over a period of 30 years (Planton, 2013). Implicitly, it is the mean and variability of meteorological variables over a time spanning from months to millions of years (Shepherd, Shindell, & O'Carroll, 2005). The varieties of differences that exist across the globe are results of climatic differences. Biodiversity, species variations and abundance, ecological and vegetation difference are all results of differences in climate. Human activities are driving unprecedented changes in climate through fossil fuels burning, deforestation and intensive farming practices. This adds enormous amounts of greenhouse gases to those naturally occurring in the atmosphere, thereby increasing the greenhouse effect and global warming (European Commission, 2021). Whether it is in the tropics or in the temperate, the effects are already obvious. Although there are conflicting reports as to the magnitude and the scale of change, however, the varieties of available evidences points to the fact that the climate is changing. The latest IPCC Report affirmed that many of the changes observed in the climate are unprecedented, causing intense drought, storms, heat waves, and inducing sea level rise —at irreversible rates.

The effects of changes in climate is particularly severe in the polar regions, essentially due to the areas susceptibility to temperature fluctuations, since the bulk of the area is covered with glaciers. Arctic Climate, (2022) affirmed that the average temperature of the Arctic has increased 2.3°C since the 1970s, placing Ice dependent species such as narwhals, polar bears, and walruses at elevated risk with shrinking ice cover. Likewise, Norwegian Polar Institute, (2022) confirmed that the Arctic is warming three times as fast and the global average. This is mainly because melting of snow and ice exposes a darker surface and increases the amount of solar energy absorbed in these areas, thereby causing irreversible changes. The effects however is transboundary, as the ice melts, the water flows into the oceans and sea levels rise, consequently increasing the vulnerabilities of coastal communities with low elevation above sea levels. Against this backdrop, this report presents the analysis of salient climate parameters of Hornsund, Norway, located on the southwest tip of Svalbard where Precambrian, Paleozoic and Mesozoic rocks lies, and continually weathered by thawing and cooling of ice caps.

1.1 Overview of the Study Area

Hornsund as a point feature is situated at 76° 57′ 0″ N latitude, 15° 46′ 0″ E longitude. As shown in Figure 1, Hornsund has a unique geographic landscape composed of long, narrow inlet with steep cliffs, created by a glacier, often referred to as fjord that faces the Greenland Sea to the west. The geographic feature is 12 kilometre wide, and 30 kilometres long, with a mean depth of 90 metres, and the maximal depth is 260 metres.

As depicted in Figure 1, Hornsund has a landscape dominated by mountains and glaciers. A narrow band of plains and raised marine terraces covered with tundra vegetation, including various species of lichens, mosses, flowers, and shrubs, which stretches along the shores of the fjord. Reindeer, arctic foxes, polar bears and many bird species are native animal species of Hornsund. Hornsund is home to the famous Polish Polar Station, established in 1957. The Polish Polar Station in Hornsund focuses on delivering research and information about climate, glaciology, geophysical fields, permafrost and geomorphic processes, through the understanding of evolution of the high arctic environment with respect to climate change. This makes it an ideal site in the polar region, as the analysis will help to reveal the susceptibility of the area to fluctuations in climate parameters (temperature and precipitation) between 1985 to 2021. This will consequently aid in profiling the pattern of fluctuations, and help in understanding the likely effects of these fluctuations.

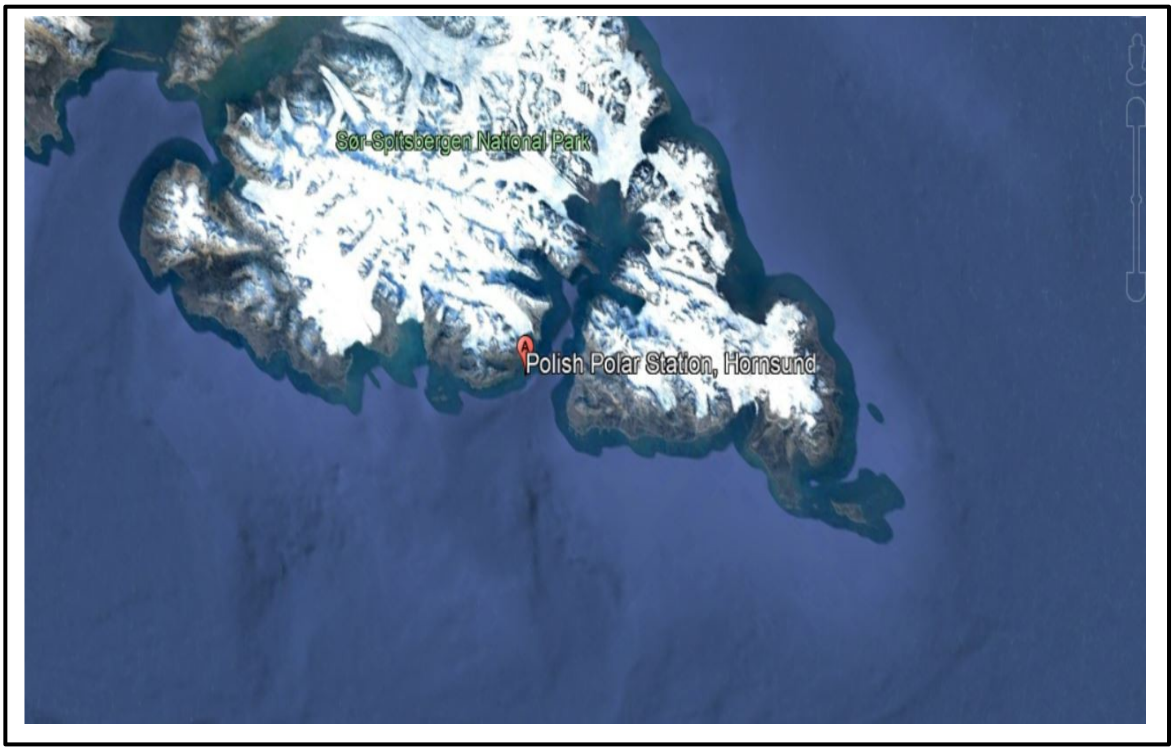

Figure 1: Showing Hornsund, as well as the Polish Polar Station.

Climate of Hornsund, Norway – According to Wladimir Köppen System of Classification.
Hornsund belongs to a broader group of Polar Climate *E*. Within this group, there are two subs groups namely, Tundra *ET* and Ice caps *EF*. This type of climates has an average temperature below 10 °C every month of the year (Beck, et al, 2018; Peel, Finlayson, & & McMahon, 2007). Tundra Climate is essentially different from Ice caps region in that, it has an average temperature of warmest month between 0 °C and 10 °C. Whereas, the Ice cap climate has average temperatures below 0 °C in all of its 12 months of the year with.

Specific Characteristics of Tundra Climate
For most of the year, the tundra region is a cold, frozen area, with a short growing season, followed by harsh conditions that the plants and animals in the region need special adaptations to survive (GeographyPoint, 2021; Paul, 2022).

I. it has cool summer with a temperature of about 10°C to 15°C
II. it has a short summer lasting 3 months.
III. it has a very long winter lasting up 8 months, and even 10 months in extreme cases
IV. it has a very large annual range temperature due to high drops of temperature
V. there is relatively permanent cover of snow and ice
VI. the areas are generally dry with low annual precipitation

2.0 Materials and Methods

This study harnesses the weather data provided by Global Surface Summary of the Day (GSOD) repository with the aid or R programming language embedded in R Software version 4.1.2. Hornsund meteorological data, which comprise of different parameters from 1985 to 2021 was obtained with the appropriate blocks of R codes. From the data, mean daily temperature, minimum temperature, maximum temperature, and precipitation sum of Hornsund were extracted by indexing the appropriate columns where each of the data is stored. All the missing data were identified and replaced as "NA", this was done to avoid parsing the initial values of those missing data into the respectively plots that were consequently created in the analyses. The result of the analyses were further supplemented with the climate data obtained from the Royal Netherlands Meteorological Institute (KNMI) national weather service website. The summary of the dataset obtained from GSOD repository and KNMI is therefore provided in Table 1a and 1b.

2.1 Data Sources

Table 1a: Summary of Dataset Used - GSOD

USAF	WBAN	Station	Longitude	Longitude	Elevation	BEGIN	END
010030	99999	HORNSUND	+77.000	+015.500	+0012.0	19850601	20201106

Source, Rowland's Analysis 2022

Table 1b: Summary of Dataset Sources

Source	Web Link
Global Surface Summary of the Day (GSOD)	https://www.ncei.noaa.gov
Royal Netherlands Meteorological Institute (KNMI)	https://climexp.knmi.nl/start.cgi

Source, Rowland's Analysis 2022

However, it should be noted that for the anomalies, the highest recoded temperature of the site is 21°C. This failed to meet the 25°C default criteria set in the sample code, however, considering the fact the daily average temperature of Hornsund ranges between -29.6 °C and 11.9°C, with a mean of -3.072 °C, a decision was made to set the threshold for hot days at 10° C for Hornsund in this analyses. The low temperature in Hornsund is a result of its location; North Pole is often cold because the region does not get any direct sunlight both in winter and summer seasons. The Sun is always low on the horizon, even in the middle of summer. In winter, the Sun is so far below the horizon that it doesn't stay overhead for months (CimateKids, 2022).

After deciding on the appropriate threshold value, several plots of basic statistics, time plots series, histograms, probability function and anomalies of temperature and precipitation were obtained using appropriate block of R codes. The plots are therefore presented and discussed in the subsequent sections.

3.0 Results and Discussion

This section deals with analyses of the various results obtained during the temperature and precipitation analysis conducted for Hornsund, Norway. The goal of this analysis is to better understand the past and present climate trend, and perhaps draw inferences necessary for making climate prediction for future plausible scenarios. As such, the various plots obtained, are discussed here.

3.1 Basic statistics and Time Series

3.1.1 Daily Average Temperature of Hornsund 1985-2021

This aspects attempts to combinedly present the daily average temperature and precipitation data of the study are, in a time series purview. This is done to give a wholistic understanding of the changing patterns of the various climate parameters considered for the study area. Thereafter, the parameters are separately discussed in subsequent sections.

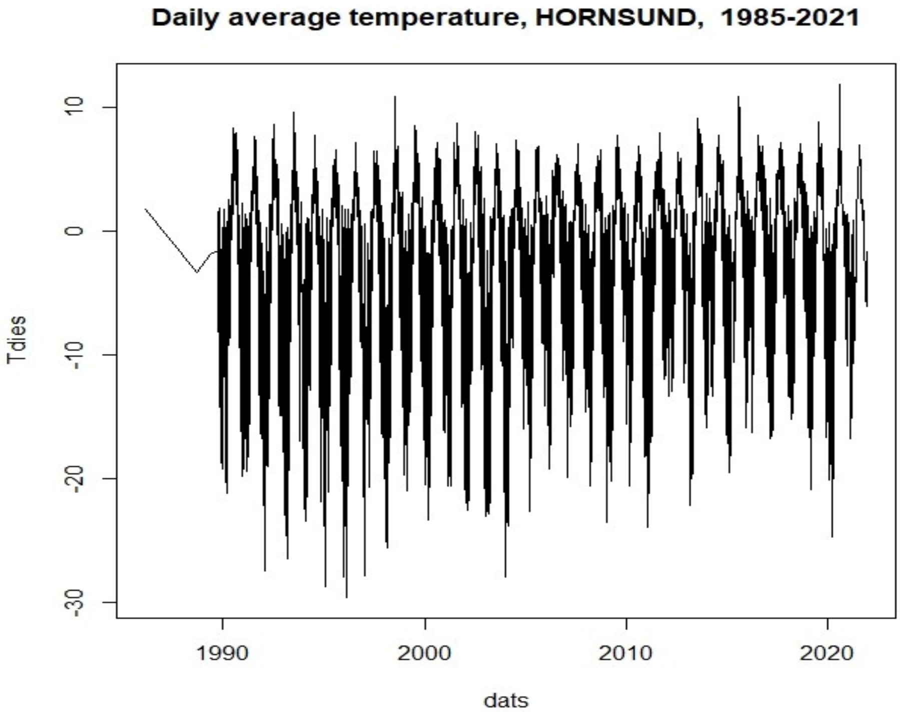

Figure 2a: Daily Average Temperature of Hornsund 1985-2021

Table 2: Summary of Daily Average Temperature Statistics

Minimum	1^{st} Quantile	Median	Mean	3^{rd} Quantile	Maximum
-29.6 °C	-7.7	-1.5 °C	-3.072 °C	2.6°C	11.9 °C

Source: Rowland's Analysis 2022.

As depicted in Figure 2a and Table 2, the daily average temperature of Hornsund varies between -29.6°C to a little above 10°C during the period considered, precisely 11.9°C, putting the temperature range to around 41°C. Obviously from Figure 2a, more than 50% of the data are below 0°C. in fact, the median of the data is below 0°C (that is, 1.5 °C), this implies that most of the times, the temperature in the region is cold across all the years considered. Although, there is significant variations in the daily average temperature over the years.

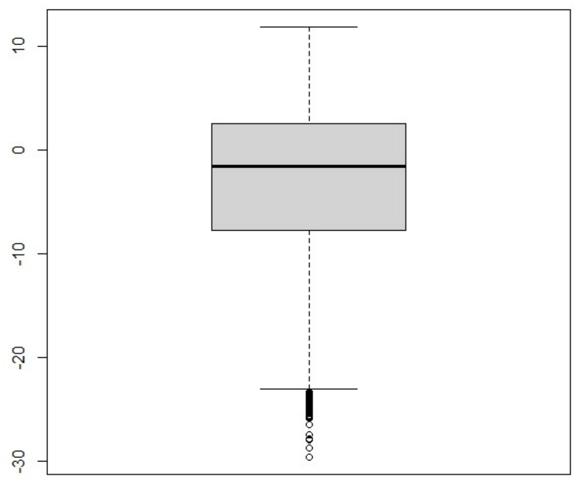

Figure 2b: Box Plot for Daily Average Temperature of Hornsund 1985-2021

Figure 2b reveals the data which deviate from the recorded daily average temperature. These outliers basically reflects extreme climate situations often called anomalies - the circles outside the data range reflects extreme temperature values.

3.1.2 Daily Maximum Temperature of Hornsund 1985-2021

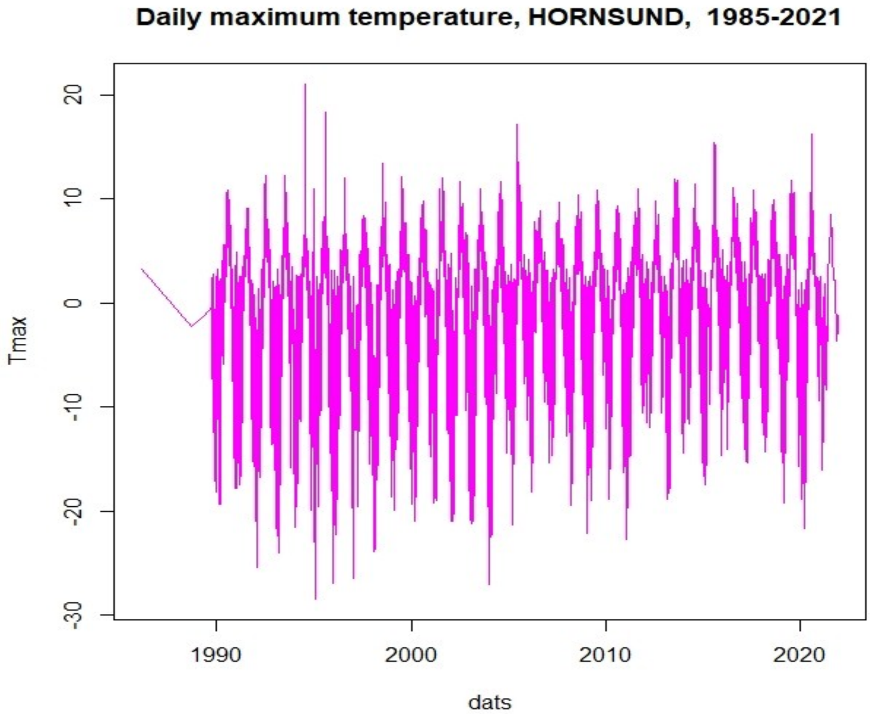

Figure 3a: Daily Maximum Temperature of Hornsund 1985-2021

Table 3: Summary of Daily Maximum Temperature Statistics

Minimum	1st Quantile	Median	Mean	3rd Quantile	Maximum
-28.4°C	- 5.375 °C	0.2 °C	-1.160 °C	4.1°C	21 °C

Source: Rowland's Analysis 2022.

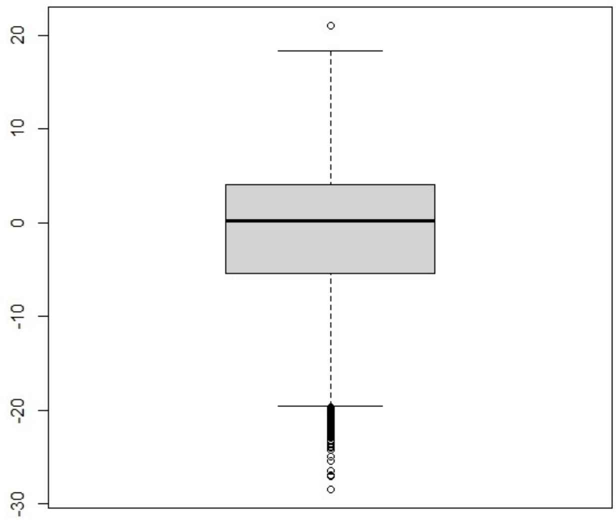

Figure 3b: Box Plot for Daily Maximum Temperature of Hornsund 1985-2021

For daily maximum temperature shown in Figure 3a and Table 3, the highest mean temperature between 1975 to 2021 is 21°C, while the lowest is -28.4°C. Like the daily average, the daily maximum temperature fluctuates across the years, with significantly higher temperature ranges when compared to the daily average ranges. In addition, across the continuum, there are outlies (both for low and high temperatures) as revealed by the small circles plots within the box plots in Figure 3b. However, the bulk of the outliers are within extremely cold temperature recordings.

3.1.3 Daily Minimum Temperature of Hornsund 1985-2021

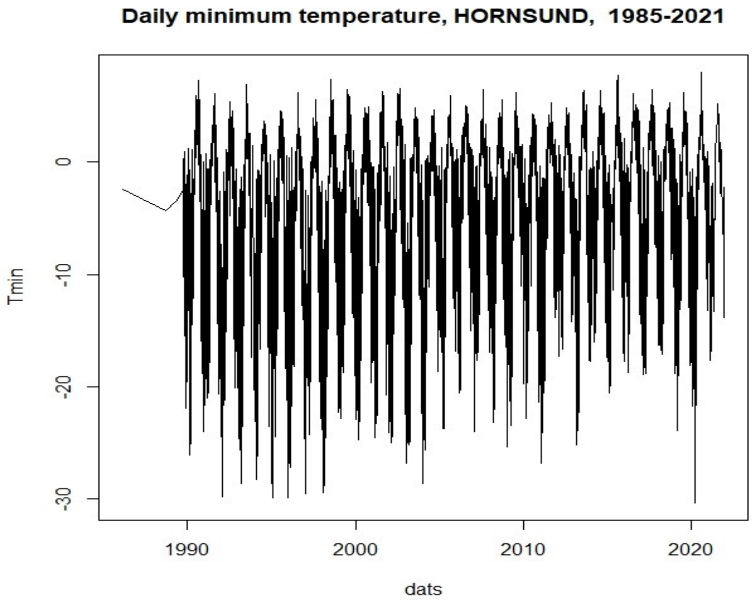

Figure 4a: Daily Minimum Temperature of Hornsund 1985-2021

Table 4: Summary of Daily Minimum Temperature Statistics

Minimum	1st Quantile	Median	Mean	3rd Quantile	Maximum	NA
-30.3°C	-10.7°C	-3.6°C	-5.335°C	1°C	8 °C	1

Source: Rowland's Analysis 2022.

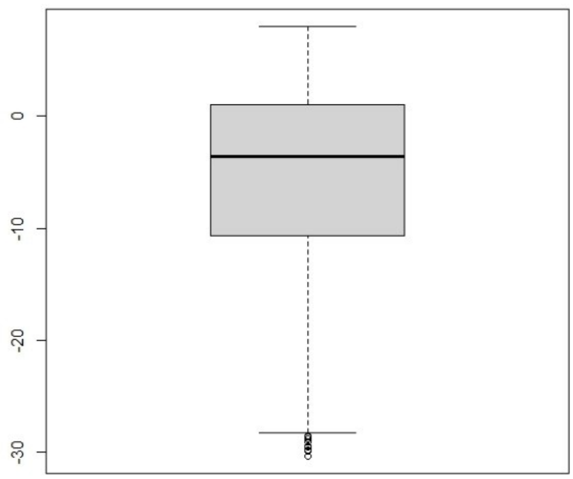

Figure 4b: Box Plot for Daily Minimum Temperature of Hornsund 1985-2021

As depicted in Figure 4a and Table 4, the majority of the daily minimum temperature recorded for Hornsund is either close to 8°C or several values below 0°C, This reveals that, in most cases, the temperature of the region is around freezing point, though still with some warm days. This to a great extent reflects the typical temperature of the north pole as identified by Köppen. As it was for other plots earlier discussed, there are variations in the values of temperature recorded across all the years, several factors, which are oblivious from the plots could be responsible for this.

3.1.4 Daily Precipitation Sum Hornsund 1985-2021

A wet day is one with at least 0.04 inches of liquid or liquid-equivalent precipitation. The chances of wet days in North Pole varies throughout the time period as depicted in Figure 5a. The time series plots for precipitation depicted in Figure 5a reveals that precipitation rates in Hornsund is very low as the highest sum of precipitation is 200mm. In addition, the data appear less dense, as opposed to the dense ones obtained for temperature scenarios (earlier discussed). This is simply because unlike temperature, precipitation does not occur at every minutes of the day, but rather it happens occasionally. The highest sum of mean precipitation occurred around the year 1997 which is around 200mm – there is noticeable variations, and peaks in precipitation in the study area during the whole period considered – this is essentially due to seasonality of precipitation occurrences. Further still, the pattern observed in the precipitation box plot presented in Figure 5b reveals huge lack of precipitation data for the study are. It also reveals that there are lots of days with no precipitation.

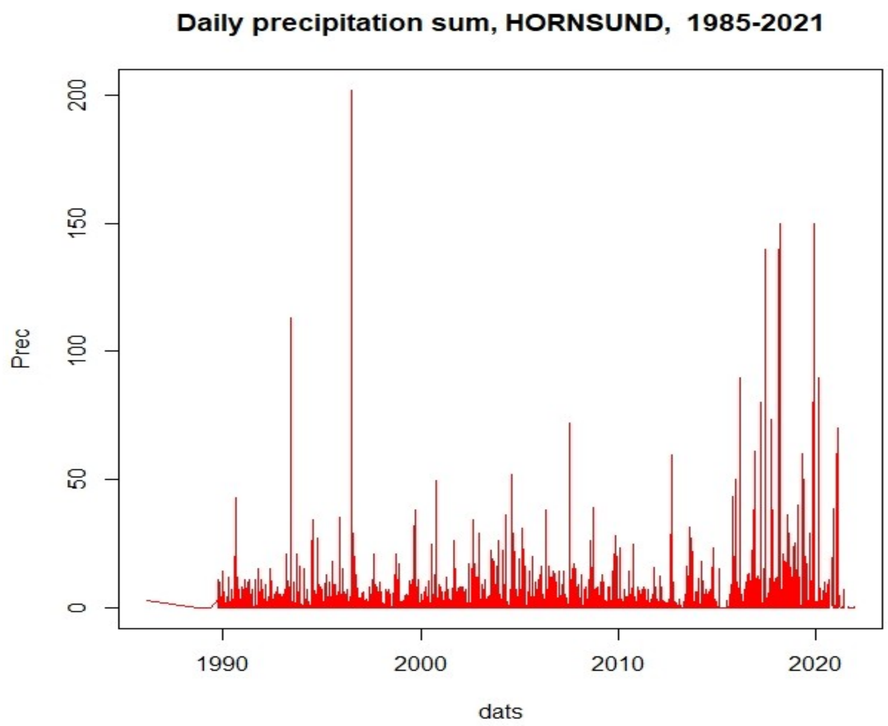

Figure 5a: Daily Sum of Precipitation Hornsund 1985-2021

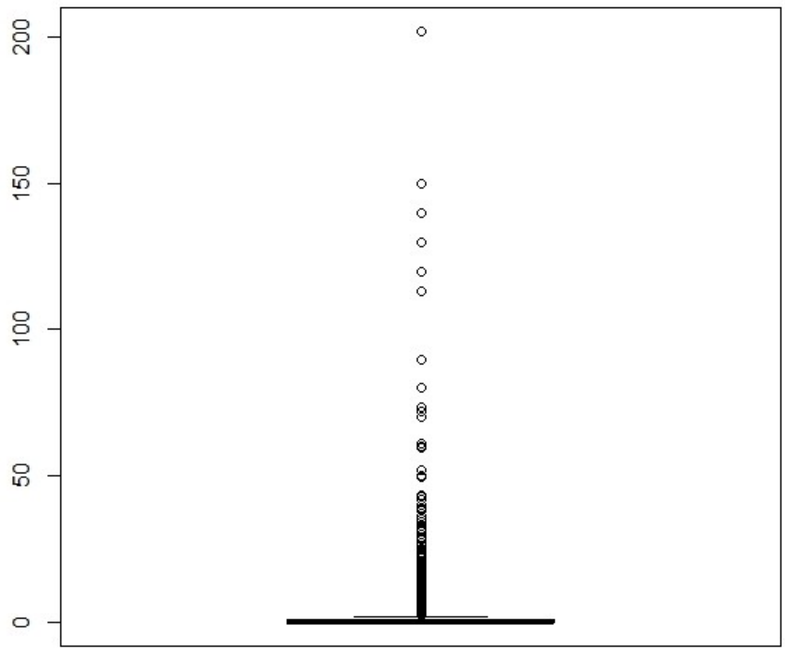

Figure 5b: Box Plot for Daily Sum of Precipitation Hornsund 1985-2021

3.2 Analysis of Temperature

3.2.1 Mean Daily Temperature

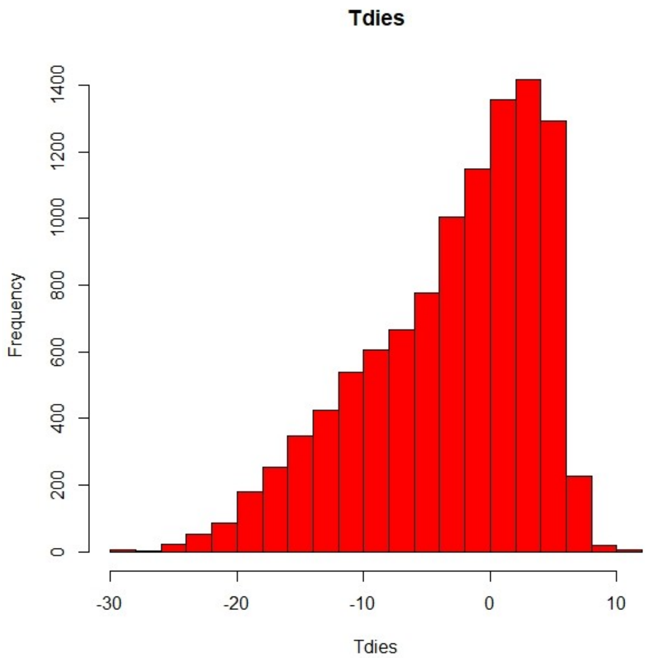

Figure 6: Histogram of Daily Temperature Hornsund 1985-2021

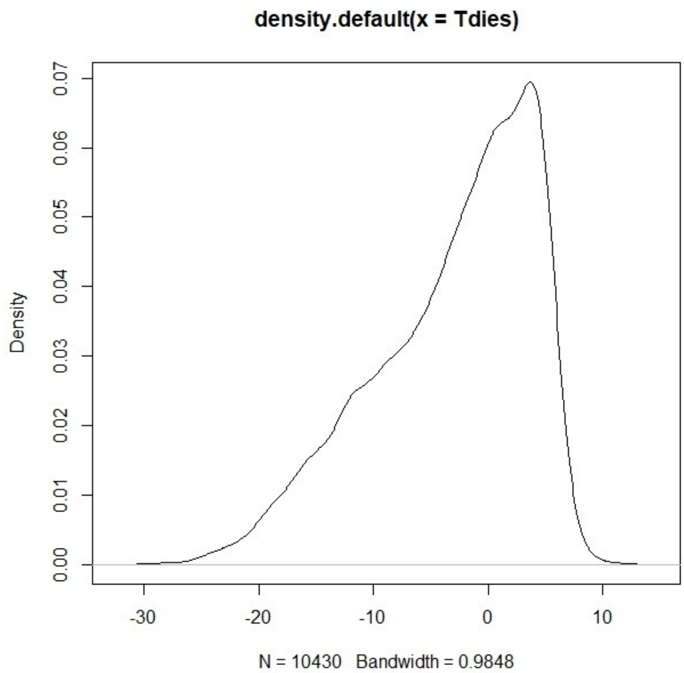

Figure 7: Probability Density Function of Daily Temperature Hornsund 1985-2021

As depicted in Figure 6 and 7, the histogram obtained for average daily temperature of Hornsund reveals the data is negatively skewed, as it tails towards the left. It should also be noted that the peak (1400) of the average daily temperature lies between 0°C to 10°C, which also happens to be the area where the bulk of temperature data lies. Majority of the data lies on the right hand side of the histogram shown in Figure 6. Figure 7 reveals the density of the various mean daily temperature ranges. Temperature ranges between 0°C and 10°C has the highest density which is 0.07 The inference that can be drawn from this is that, though, temperature sometimes drops up to several minus degrees in Hornsund, however, in most cases, the temperature is often between -10°C and 10°C in the study area.

3.2.2 Summer and Winter Temperature Variations

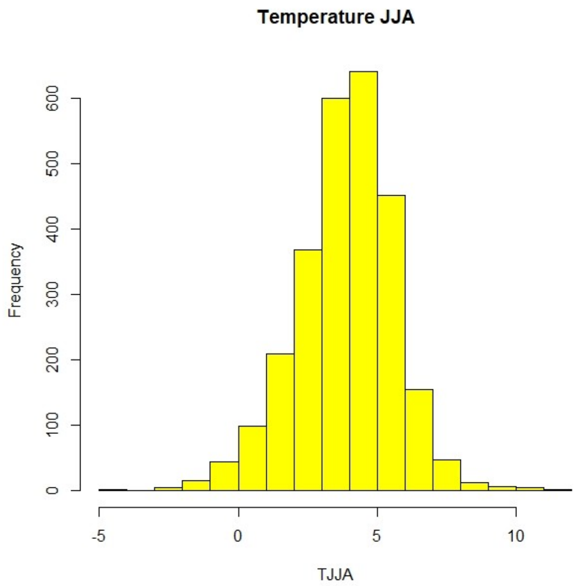

Figure 8: Histogram Summer Temperature Hornsund 1985-2021

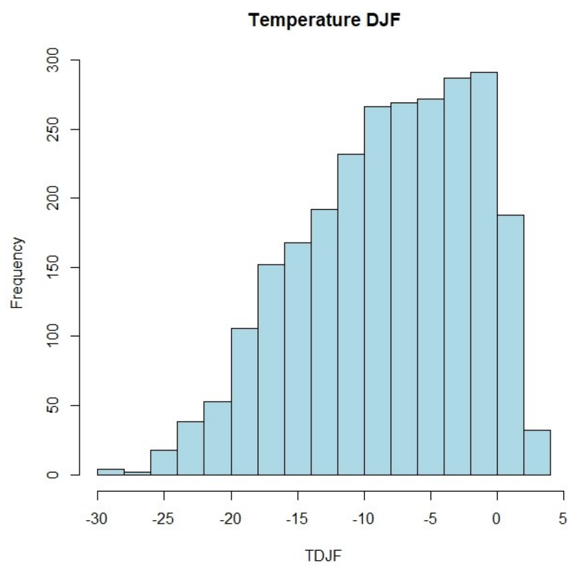

Figure 9: Histogram Winter Temperature Hornsund 1985-2021

Further attempt was made to examine mean temperature distribution for winter and summer seasons. As such, the mean and standard deviations of the daily temperature distributions of the two seasons is therefore depicted in Table 5.

Table 5: Mean and Standard Deviation of Temperature in Summer and Winter Seasons

Parameters	Summer	Winter
Mean	3.900529 °C	-8.246088°C
Standard Deviation	1.759961°C	6.478036°C

Source, Rowland's Analysis 2022

As depicted in Table 5, and Figure 8, the temperature distribution in summer has a mean of 3.900529 °C, and almost normally distributed (as reflected in its standard deviation which is 1.759961°C). This is because the temperature in this period is relatively constant. Between 1985 to 2021, the summer season has relatively warm days, that has most values of temperature between 2°C and 7°C, specifically having its modal occurrence at 5°C, with an occurrence rate of 600 between 1985 and 2021 (summer seasons). This is outrightly opposed to the distribution obtained for Winter season which has a mean temperature distribution of -8.246088°C, and a standard deviation of 6.478036°C, with a modal value of 0°C and occurrence rate of 300. As depicted in Figure 9, the temperature distribution is negatively skewed, with majority of the data falling below 0°C – this typically reflects the temperature drops associated with winter seasons caused by the tilting of the earth's axis away from the Sun. The result here essentially validates NISDC, (2022) affirmation that the average summer temperature in the north pole is usually less than 10 °C (50 °F).

3.2.3 Hot (Warm) Days – Days with Vegetation Temperature

It should be noted that the definition taken for hot days in this analysis are days with mean temperature values greater or equal to 10°C. This is due to the fact that temperature ranges in Hornsund are mostly between 10°C to -10°C. Therefore the 25°C threshold definition of hots days is not applicable to this study area. From the analyses, the highest recorded temperature was 21°C, which is an anomaly – an extreme case. As such, in this analysis, days with temperature of 10°C are referred to as warm days with vegetation temperature.

As depicted in Figure 10, the mean number of warm days across the 36 years varies greatly. several factors which are beyond the scope of this analyses could be responsible for the observed variations. Year 2020 has the highest number of warm days, which is around 9 days. Followed by year 2016 with 7 days, and year 2018 and 2013 with 6days. Generally, the number of warm days seem to be concentrated more in this century, than in the 1990s, this could perhaps be the result of climate change caused by increased warming due to increased greenhouse gasses emissions. Besides those years with higher warm days, which also happen to fall within this century, amongst other years, only year 1992 recorded a mean warm day value of up to 6. The deviation from the mean threshold depicted in Figure 11 revealed that the temperature recorded for the aforementioned years, are quite above the mean threshold for temperature in the study area.

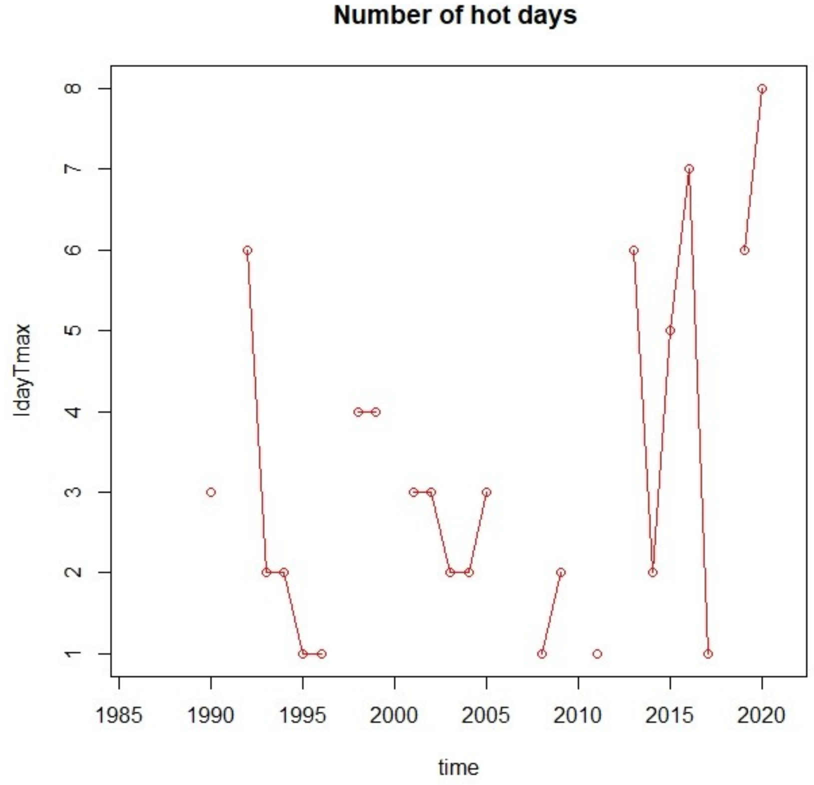

Figure 10: Hot Days Hornsund 1985-2021

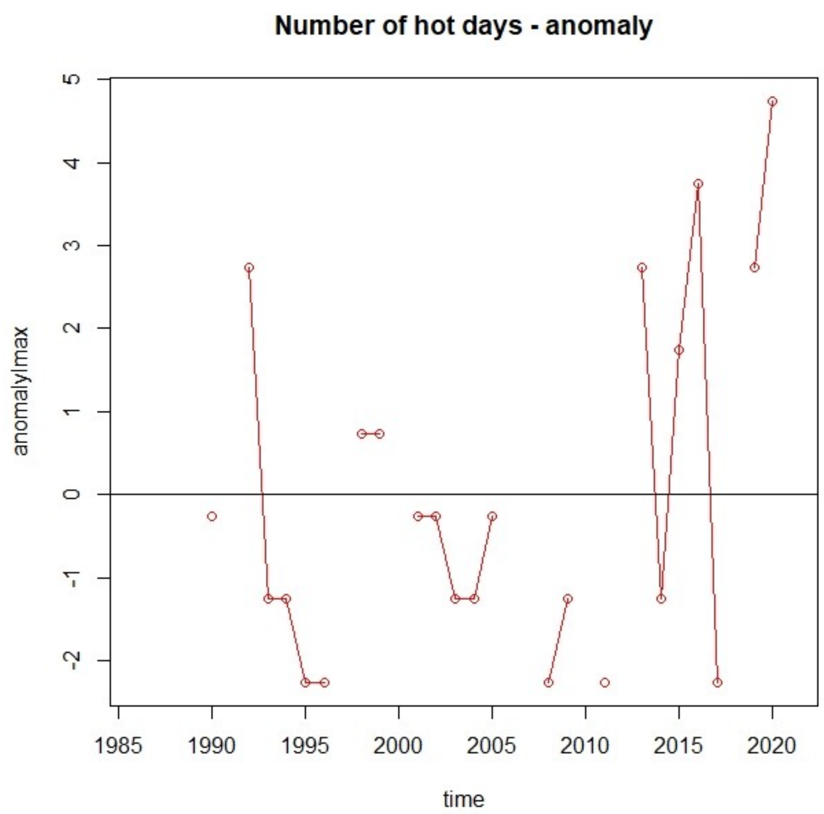

Figure 11: Hot Days Anomalies Hornsund 1985-2021

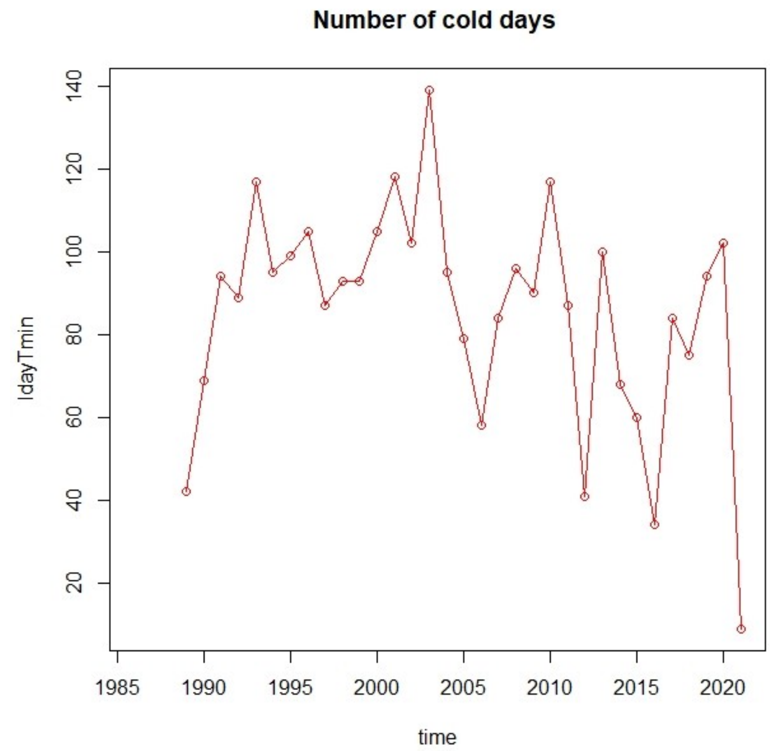

Figure 12: Cold Days Hornsund 1985-2021

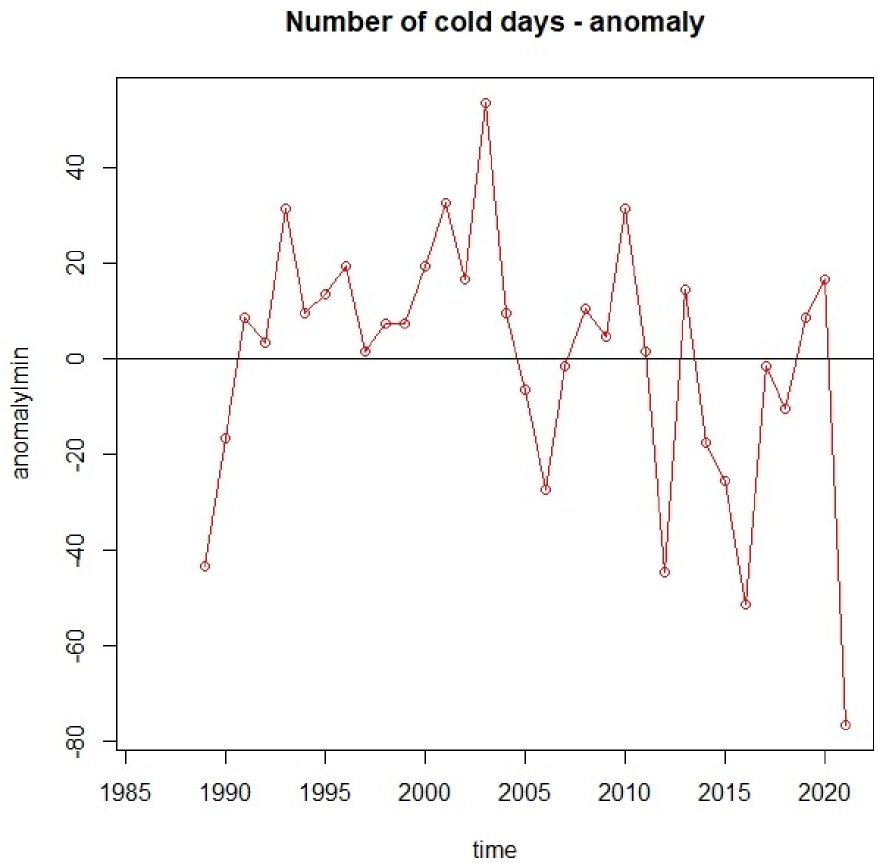

Figure 13: Cold Days Anomalies Hornsund 1985-2021

Further analysis was carried out to establish the annual mean number of cold days in the study area, over the period considered. Here, cold days are taken to be days with temperature less or equal to -10°C. The plots depicted in Figure 12 and 13 revealed that the majority of the days in the study area are cold days – also validating Köppen's classification, as the data appears more dense than that of the warm days earlier considered. Specifically, 2002 appears to be the year with the highest mean number of cold days with around 140days, while year 2021 recorded the least number of cold days which is around 10 days. This result appears extremely astonishing, and validates the result obtained for the warm days in 2021, which further points to possible increased in warming rates – since the number of cold days in the latter years appears to be significantly lesser than that in the earlier years. The deviations from the mean annual cold days, across the 36 years is therefore presented in Figure 13.

3.2.4 Mean Annual Temperature

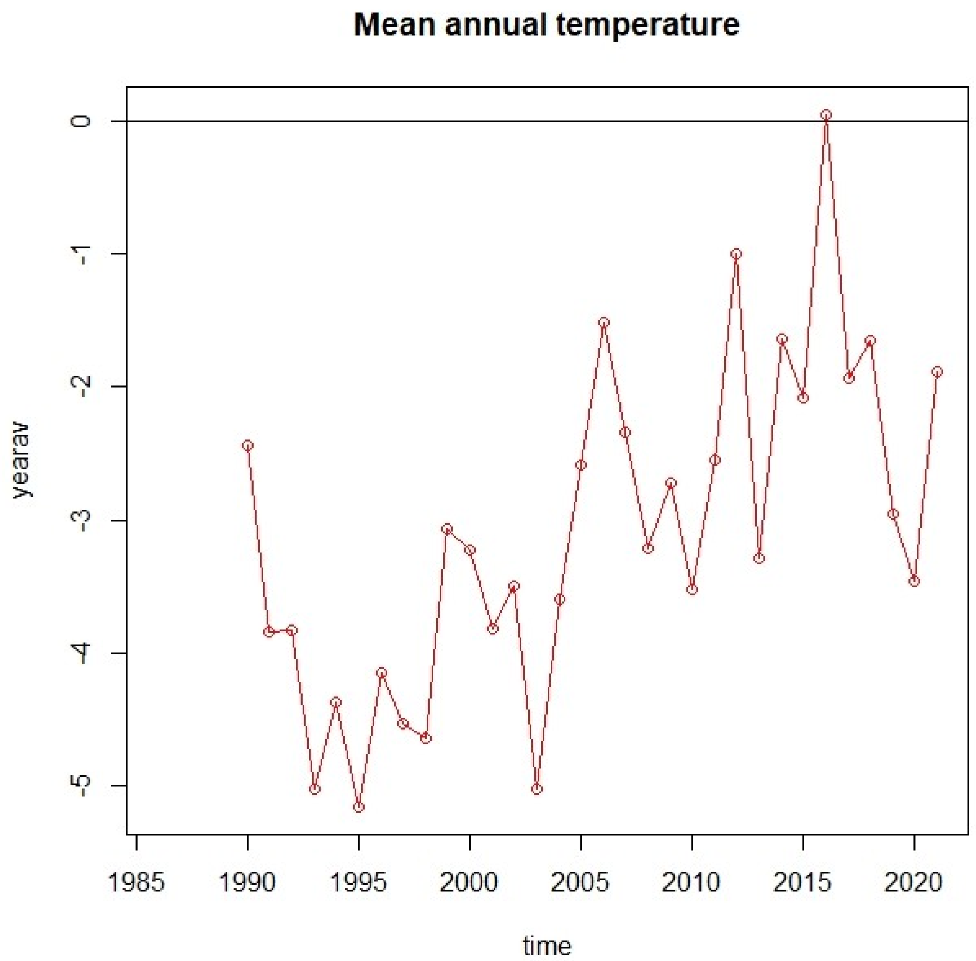

Figure 14: Mean Annual Temperature Hornsund 1985-2021

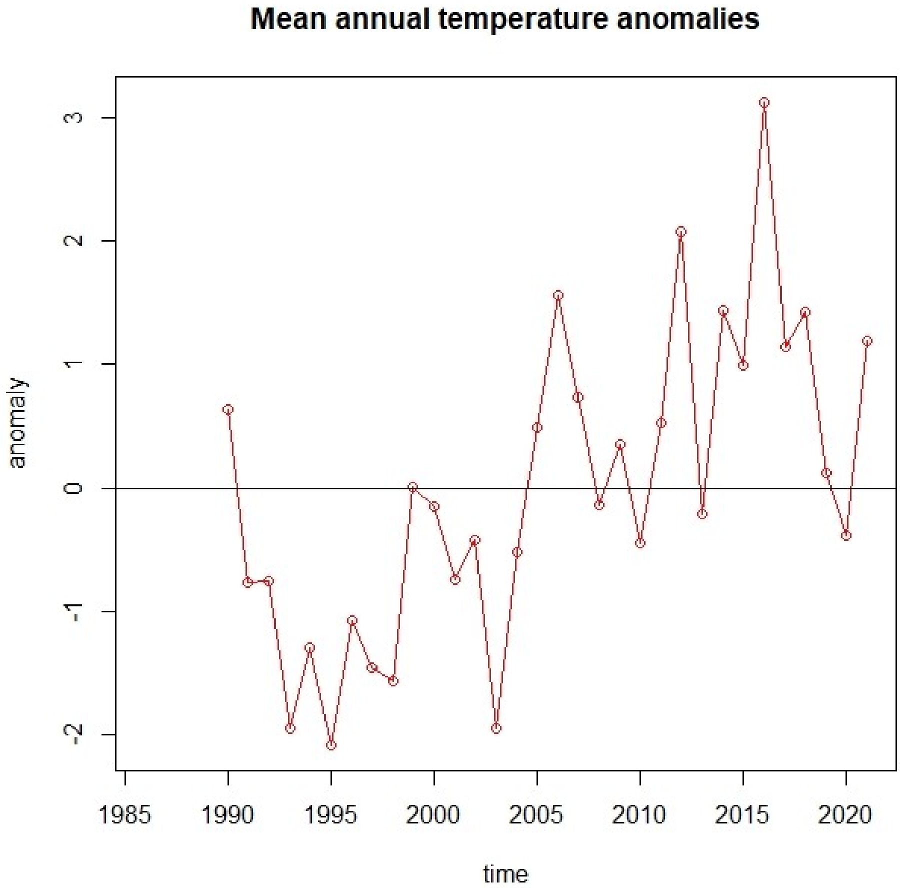

Figure 15: Mean Annual Temperature Anomalies Hornsund 1985-2021

Over a period of 36 years (that is, 1985 – 2021), as depicted in Figure 14, 2016 recorded the highest mean annual temperature of a little above 0°C. In most of the years, the mean annual temperature falls below 0°C, this is essentially due to the fact that in Hornsund, there is generally longer periods of very cold days than warm days, as the temperature is averagely cold all through the year, except some few cases, where the temperature can reach 10°C and few extreme cases where the temperature can rise above 20°C. The highest mean annual temperature deviation depicted in Figure 15 also occurred in same year 2016 with 3°C above the threshold value, and in 1995, which has around -2.5°C below the threshold value. It is obvious from Figure 14 that there is an increasing trend in annual temperature variations, as earlier years generally have lower temperature than recent years, also evident in the anomalies depicted in Figure 15.
The tundra climate region occurs between 60° and 75° of latitude, mostly along the Arctic coast of North America and Eurasia and on the coastal margins of Greenland.

3.2.5 Multi-Annual Temperature Variability – Data from the Royal Netherlands Meteorological Institute (KNMI) Data

Further analysis was carried out to validate the various plots discussed previously with the mean monthly temperature data obtained from the KNMI, climate explorer website. The data available for the study area only span through the periods of 1985 to 2020. Therefore, the various plots obtained for mean monthly temperature, maximum temperature and minimum temperature are discussed in this section

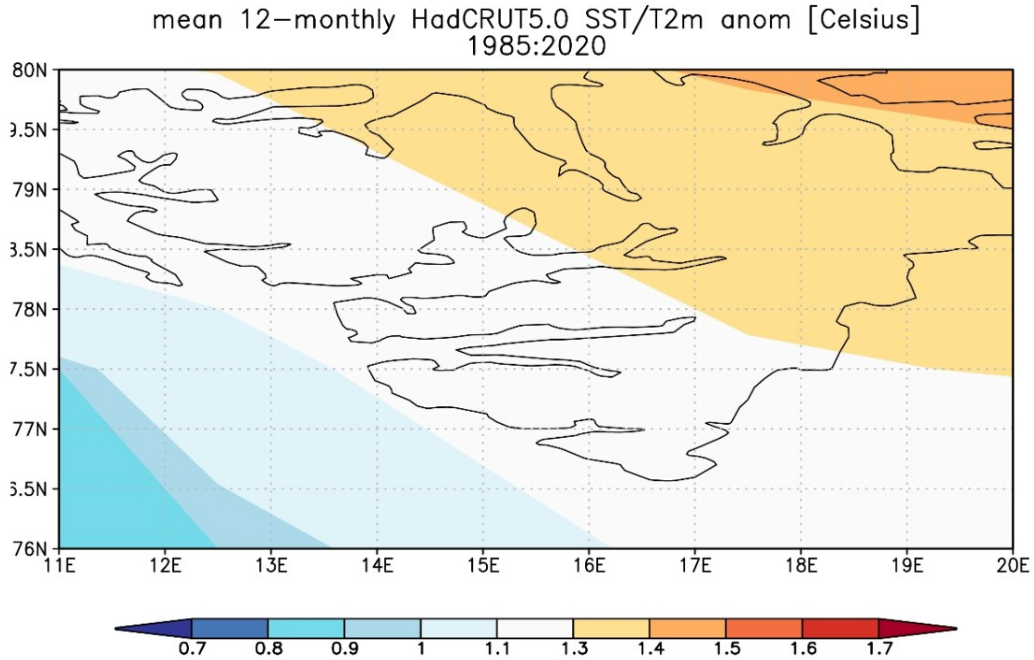

Figure 16: Mutil-annual Mean Temperature KNMI Hornsund 1985-2020

From figure 16, the annual temperature variability in the area (pictured in Figure 7) is between 0.7°C and 1.7°C. However, more specifically the mean temperature for where Polish Polar Station sited in 76°57'N and 15°46'E is around 1.3°C. This value further validates the result obtained for mean daily temperature, and other cases earlier considered, and as well as Köppen climate classification of Tundra Polar Climate for the region – that characteristically specifies that temperatures may be below 0 °C [32 °F] for up to 10 months in a year

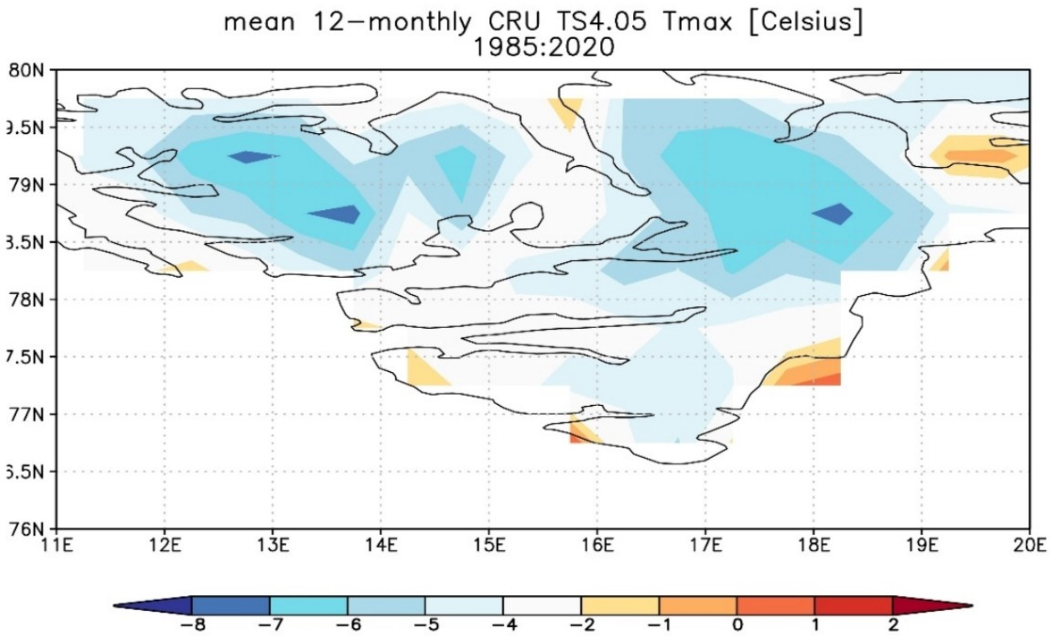

Figure 17: Multiannual Maximum Temperature KNMI Hornsund 1985-2020

Like the previous plots discussed, the Multiannual Maximum Temperature variations depicted in Figure 17 also agrees with the features of Polar Tundra Climate identified by Köppen climate classification. From Figure 17, it is obvious that the mean maximum temperature in the study area from year 1985 to 2020 varies between -8°C and 2°C. And specifically for Polish Polar Station sited in 76o57’N and 15o46’E, the mean monthly maximum temperature is around -2°C and -1°C.

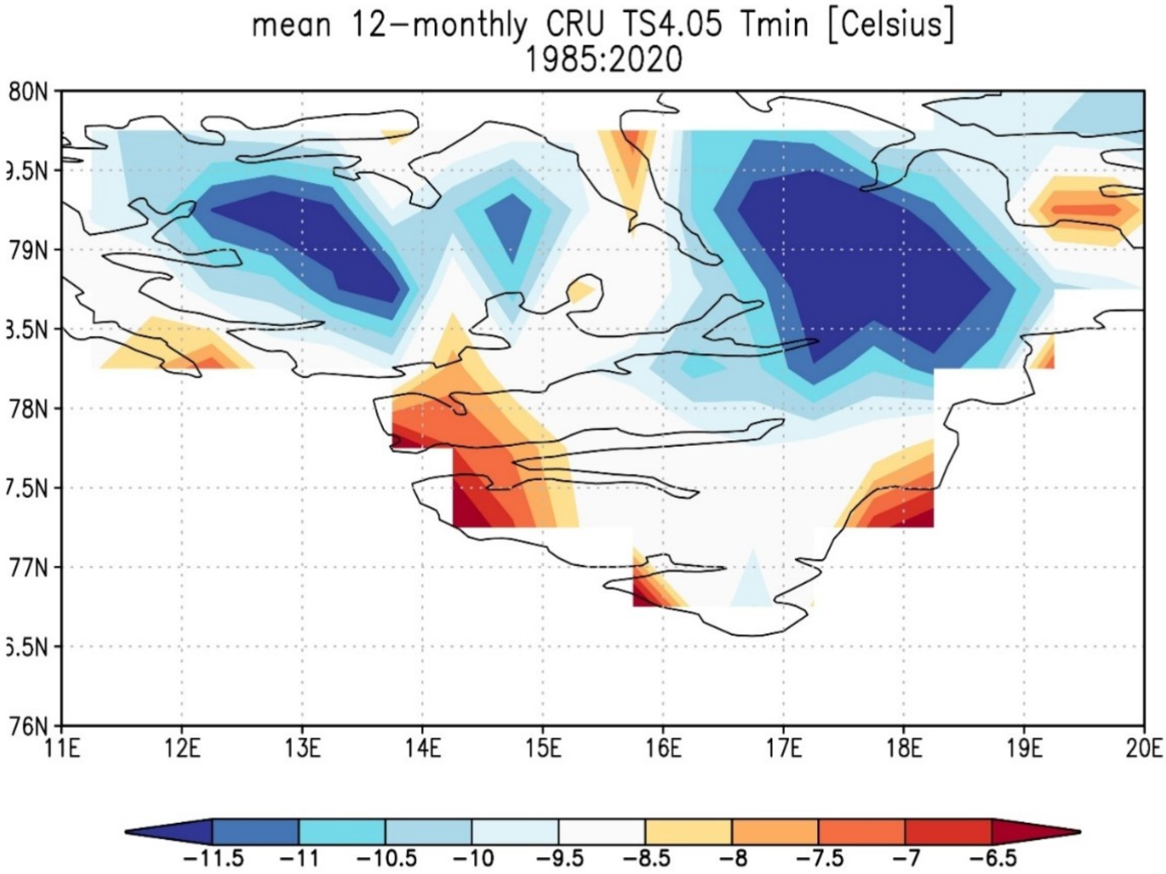

Figure 18: Multi-Annual Mean Minimum Temperature KNMI Hornsund 1985-2020

Figure 18 shows the multi-annual mean minimum temperature variations from the period of 1985 to 2020, for the plot, it is obvious that the mean annual minimum temperature recorded for the study area during the period considered varies between temperature ranges -11°C and -6.5°C. this points to that fact that the study area is cold at default, owing much of this to its location in the north pole, which is typically characterized by relatively cold days, long cold winters and short, cool summers as identified by Köppen climate classification.

3.3 Analysis of Precipitation

3.3.1 Daily Precipitation Sum

This section deals with the analyses of the various plots obtained for precipitation, the time series of the daily precipitation sum was previously discussed in section 3.1 (3D), where the highest daily sum occurred around year 1997 with a volume of 200mm.

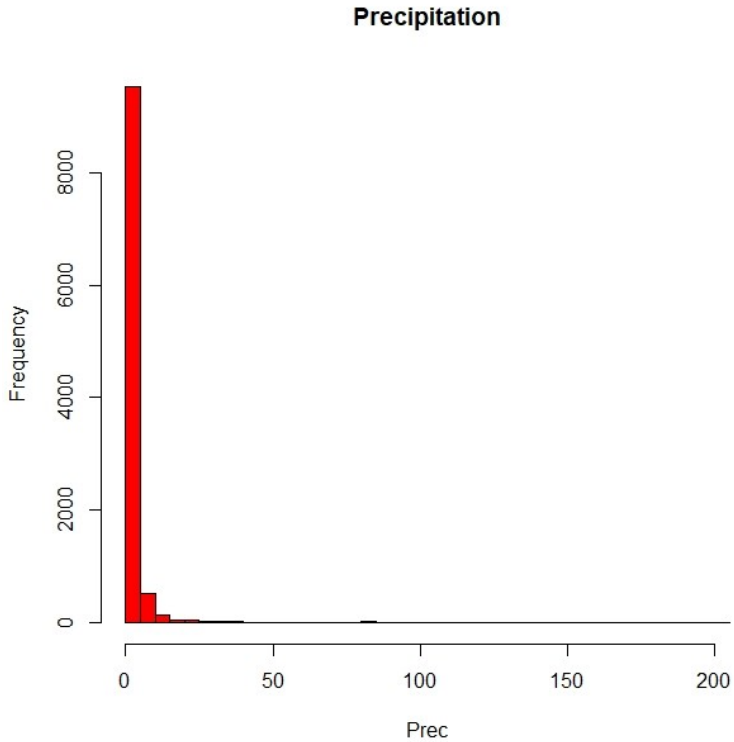

Figure 19: Histogram for Daily Precipitation Sum Hornsund 1985-202

Figure 19 depicts the precipitation recorded for the study area between 1985 to 2021. Obviously from the Figure, the modal precipitation volume fall greatly below 20mm which occurred more than 800 times. The reason for this is simply because of acute lack of vegetation and greenery. In an area of dense vegetation with free flowing rivers and lakes, water from plants, soil, and water bodies evaporates back into the atmosphere from these features. There it forms clouds and returns to the earth surface as precipitation. This is not the case for the Arctic region, over much of the Arctic where Hornsund lies, have low precipitation volumes because the region is devoid of vegetation, free flowing river and other features that could facilitate heavy down pour. As a result, these areas receive little precipitation, though sometimes frequently, but always for a short period. In addition, the general occasional occurrence of precipitation is one of the reasons for the shape of the histogram obtained. As shown in Figure 20, precipitation volume with the highest density also falls below 20mm, with a density of 1.5. The result obtained in Figure 20, is simply influenced by the modal precipitation shown in Figure 19.

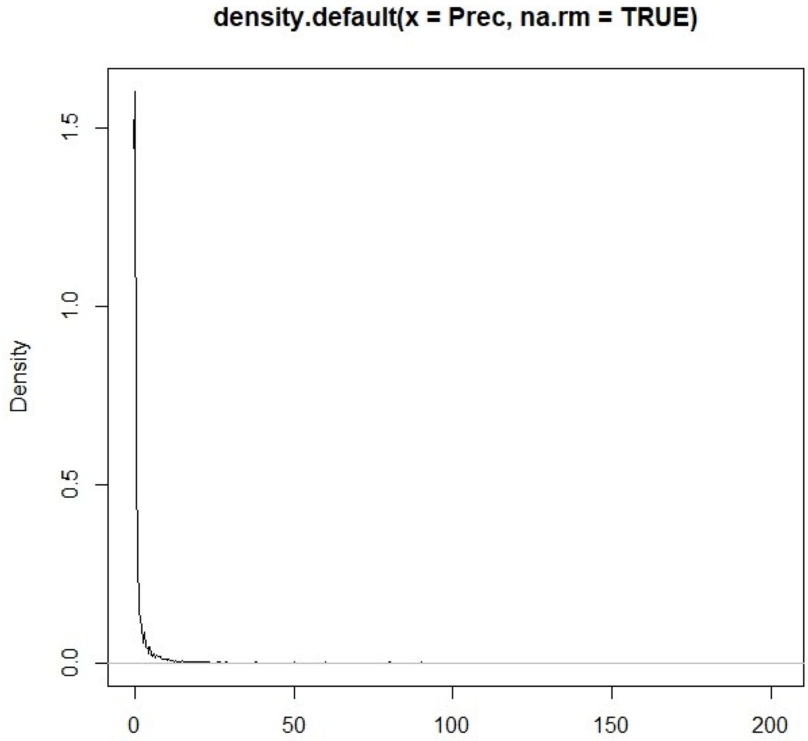

Figure 20: Histogram for Daily Precipitation Sum – Density Hornsund 1985-2021

3.3.2 Winter and Summer Precipitation Variations

Further analyses was done to compare the precipitation volumes in Winter and Summer seasons (specifically, June, July and August referred to as JJA, with December, January and February, Jointly referred to as DJF). The result of the two seasons is therefore shown in Figures 21 and 22.

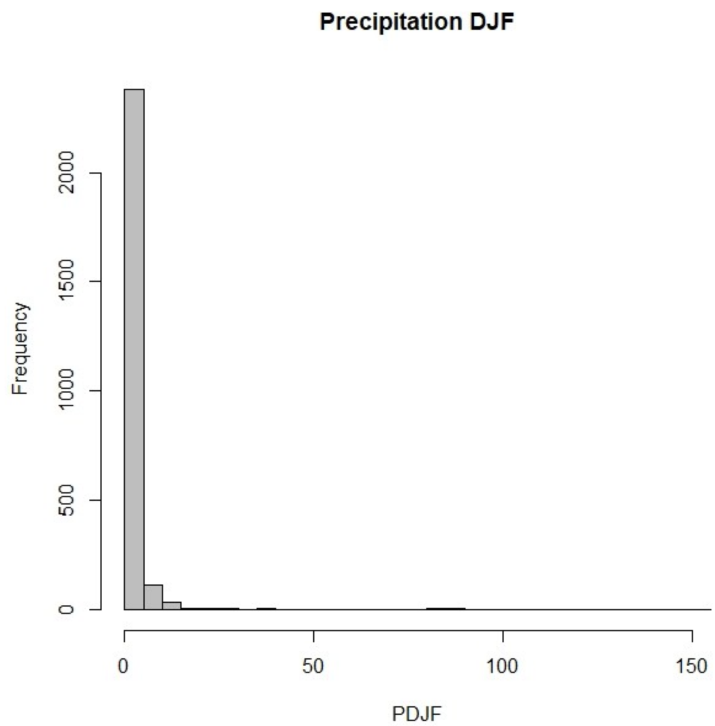

Figure 21: Histogram for Daily Precipitation Winter Precipitation Hornsund 1985-2021

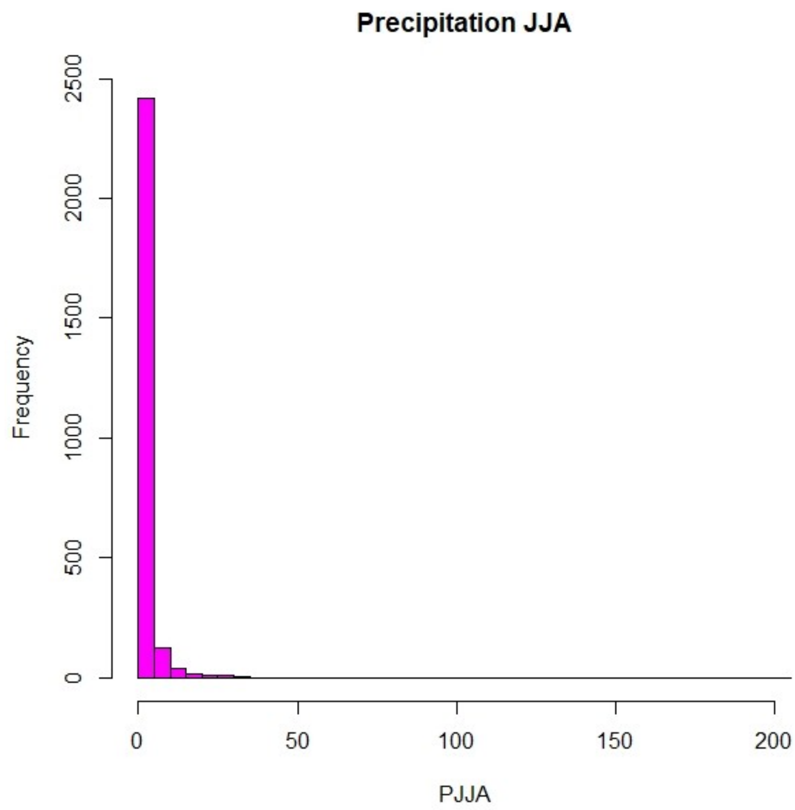

Figure 22: Histogram for Daily Precipitation Summer Hornsund 1985-2021

There is no much difference in the daily precipitation sum for Winter and Sumer seasons depicted in Figure 21 and 22 as the precipitation distribution is positively skewed. In both seasons, the modal volumes of precipitation is significantly below 30mm, though, in Winter, there is a very slight occurrence of precipitation up to around 80mm volumes. As expected, the volume of precipitation in summer has its peak higher than that of winter, This is due to the fact that the atmosphere can hold more moisture in air temperatures, than winter seasons when the air temperature is very low. The differences in the two season's daily precipitation sum if further presented in Table 6.

Table 6: Mean and Standard Deviation of Precipitation in Summer and Winter Seasons

Parameters	**Summer**	**Winter**
Mean	47.54325 °C	39.85847 °C
Standard Deviation	7.369 °C	6.161107 °C

Source, Rowland's Analysis 2022

For Table 6, it can be inferred that the temperature in precipitation in summer season is higher than that of the winter season as reflected in their means – this is simply because evaporation rates are higher in summer, and consequently increasing the chances and occurrence of precipitation. The higher standard deviation obtained for summer precipitation also reflects the very dry days, and the very wet days that are often associated with summer, as opposed wo winter season where the alternation between wet and dry days are not so pronounced.

3.3.3 Wet Days – With Precipitation Greater or Equal to 25mm

This section deals with the number of days with precipitation exceeding or equal to 25mm. The detail description of the plots is therefore presented here.

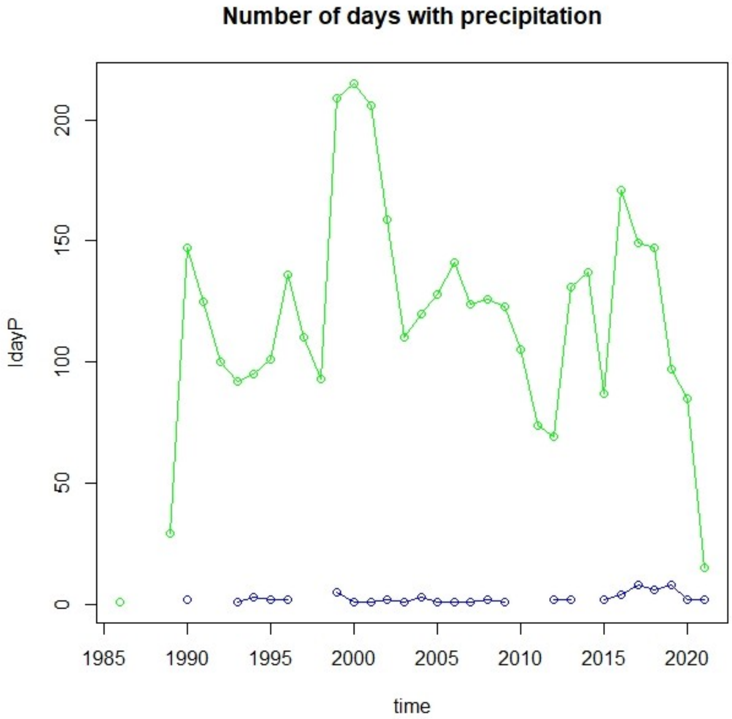

Figure 23: Days with Precipitation exceeding 25mm Hornsund 1985-2021

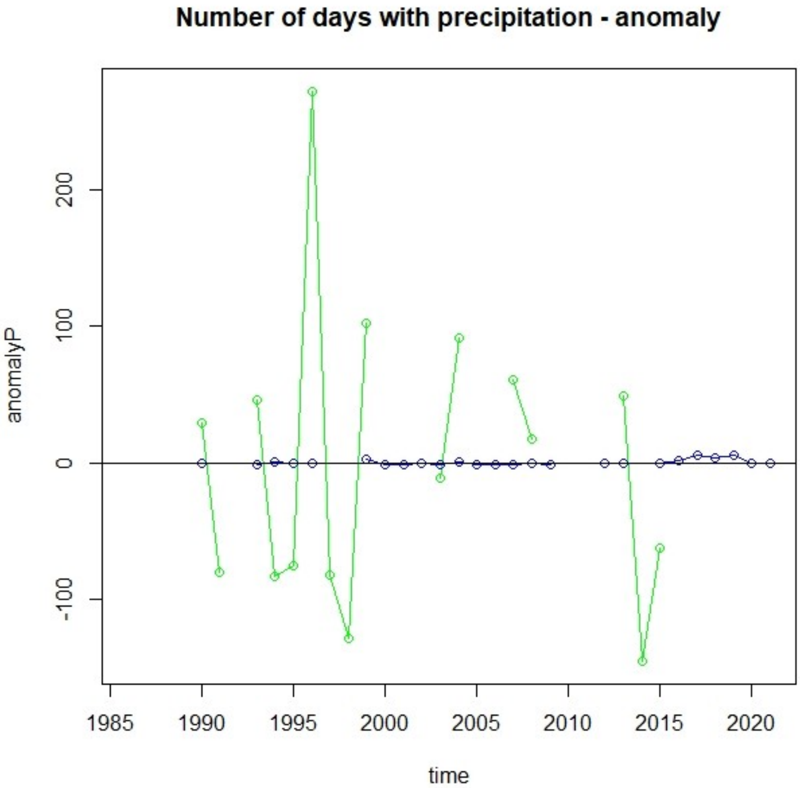

Figure 24: Precipitation Anomaly Hornsund 1985-2021

From Figures 23, it is obvious that there are some extreme precipitation days in the study area, and that the rate of precipitation across the years is not uniform. Specifically, year 2000 has the highest precipitation recorded which is about 225 days, followed by year 1998 and year 2001 – that jointly have almost 220 days of precipitation. Other years have significant precipitation days, but not as much as the three years mentioned. There appears to be a relationship between the extreme precipitation and anomalies depicted in Figure 24. As the days with the highest anomalies occurs between years 1995 and 2000, which also happens to be close to the years with the most extreme precipitation days.

3.3.4 Mean Annual Precipitation

This section deals with the mean annual precipitation, the anomalies, and as well as the mean monthly precipitation in Hornsund. As such, the plots obtained are therefore presented here.

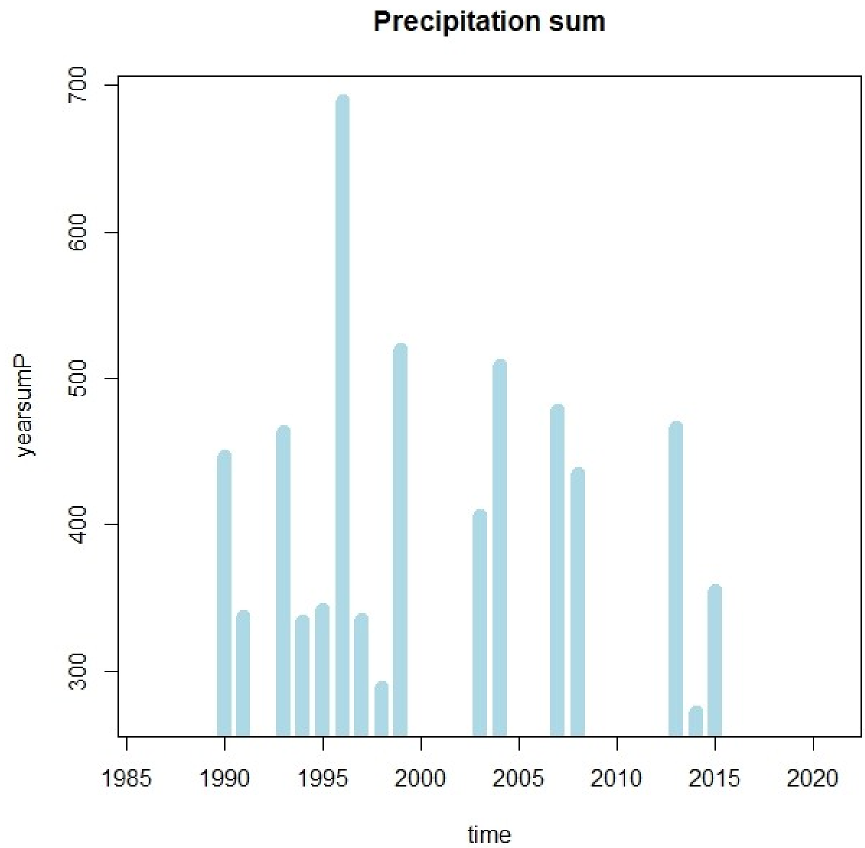

Figure 25: Annual Precipitation Hornsund 1985-2021

As depicted in Figure 25, the highest annual sum of precipitation recorded in Hornsund within the period of 36 years is around 700mm obtained in the year 1996, while the lowest is around 200mm obtained in the year 2014. There is obvious variations in sum of precipitation amongst the years considered in this analyses. The data appears less dense which was partly a result of lack of measurement and seasonality of precipitation. The highest deviation from the mean precipitation rate depicted in Figure 26, occurred in the year 1996, which also happens to be the year with the highest temperature sum, with almost 280mm above the threshold, while the lowest deviation also occurred in 2014, with around -100mm below the threshold value.

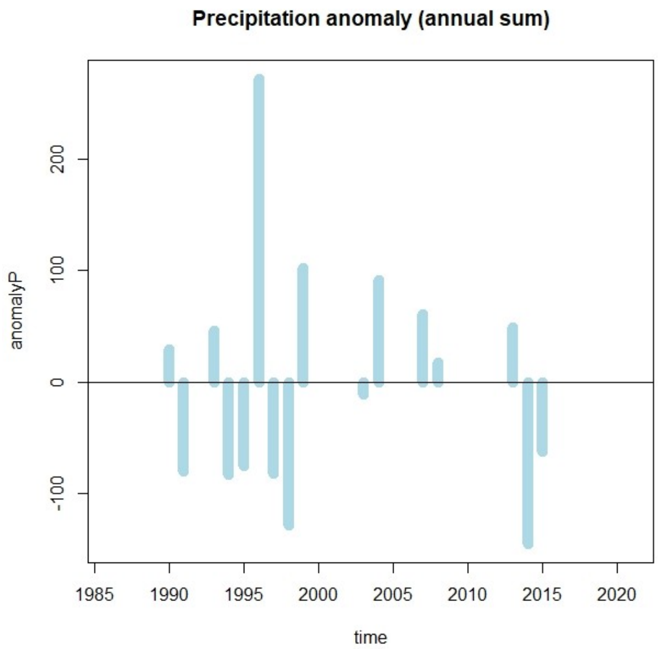

Figure 26: Mean Annual Precipitation Anomalies Hornsund 1985-2021

3.3.5 Multi-Annual Precipitation Variability – Data from the Royal Netherlands Meteorological Institute (KNMI) Data

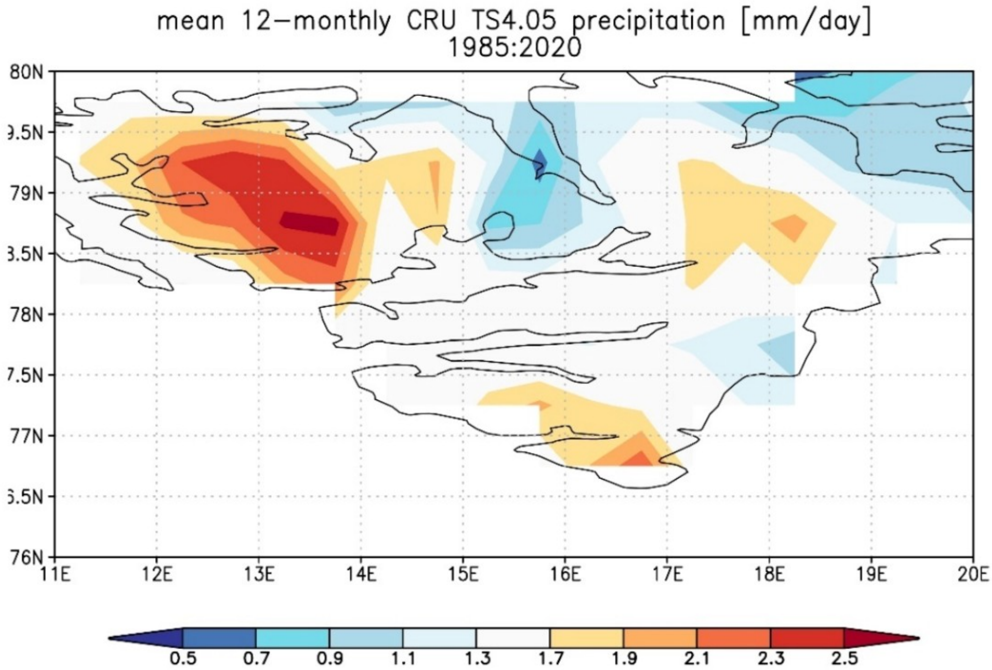

Figure 27: Multi-Annual Mean Precipitation Hornsund 1985-2021

Figure 27 annual mean variability of precipitation in the study area between the periods of 1985 -2021. There are days that essentially lacks precipitation, this was earlier established by the previous plots obtained for precipitation. It is however worth noting that, the annual variation in precipitation volumes in the study area is between 0.5mm and 2.5mm.

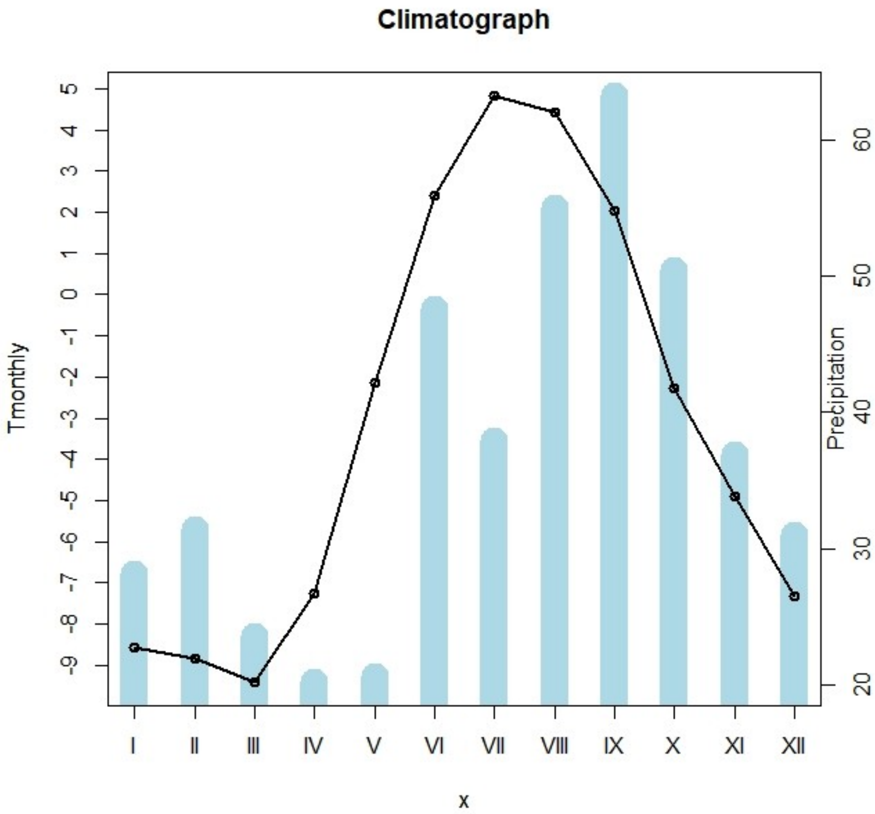

Figure 28: Climatograph of Average temperatures and precipitation of Hornsund 1985-2021

Figure 8 displays the monthly average of temperature and precipitation for each of the months (January to December) for between year 1985 to 2021. For all the years, September has the maximum precipitation with a modal value of 65mm, followed by August and October with 55mm and 52mm monthly average respectively. April and May have the lowest monthly precipitation with around 25mm. Generally, months in the months in the second half of the year has higher precipitation rates than those in the first half of the year. For temperature, the highest monthly average occurs around July. Generally, as shown in the climatograph, the warmest months are June, July and August, while the coldest months are December, January, February and march. The result graphically displayed in the climatogrph essentially agrees with the Köppen climate classification for the region. In Köppen'c classification, Hornsund is categorised as Polar climate region, often denoted with *ET* to indicate tundra climate, to differentiate it from the other group, essentially referred to as ice caps region within the broad polar climate classification. In the Köppen climate system, polar climates has the warmest temperature of any month below 10 °C (50 °F). Specifically, the average temperature of the warmest month in Tundra climate (ET) is between 0 and 10 °C. These climates occur on the northern edges of the North American and Eurasian land masses (generally from north of 70 °N upwards), and on nearby islands. The result graphically displayed in Figure therefore validates Köppen climate system classification for Hornsund.

4.0 Conclusion

The various analyses conducted have revealed that there are significant variations in annual temperature ranges in Hornsund. Although in most years, the temperature ranges and variations are within the threshold values defined by Köppen climate classification for Tundra Climate, though, with some marked extreme cases in few years. The temperature analysis revealed a number of things notably including the fact warm days are concentrated in this century (the 2000s), than in the 1990s, this could perhaps be the result of climate change caused by increased warming rates due to increased greenhouse gas emissions. In addition, the number of cold days in the later years (the 2000s) appears to be significantly lesser than in the earlier years (1990s). There is an increasing trend in annual temperature variations, though still within the ranges defined by Köppen. For precipitation, there appears to be no long-term trend that could infer changing climate, however, it is worth noting that, the annual precipitation sum in Hornsund over the years considered also follows closely with the threshold defined by Köppen. Mulita-annual variations in mean temperature and precipitation are within little order of magnitude. It is safe to conclude that, though increasing global warming is impacting the temperature pattern in Hornsund, nevertheless, its climatic conditions are mainly influenced by processes associated with its location in the Polar Tundra Climate.

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