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The Changing Climate of Friesland, The Netherlands

A detailed meteorological data analysis and visualization

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Bachelor Thesis

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Second assessor: Unknown

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Due to limited formatting options for the data visualizations, page numbers are left out.

Introduction

Significance of the study

The purpose of this study is to investigate the effects of climate change in Friesland over the last decades and the impacts it has on environmental stakeholders. To this day, the information and literature that can be found about the changing climate in Friesland specifically is insignificant or completely unavailable. However, due to the unique agricultural landscape, within the Netherlands but also outside of it, it is important to gain more knowledge about this area.

Methods

In this study, the European and especially Frisian climate change trends are researched in depth. The goal is to identify what stands out in terms of temperature and precipitation, followed by researching the underlying explanatory factors. After discussing the impacts and challenges of the changing climate in a more general European context using report conducted by the IPCC, the goal is to zoom in to the perspective of the Netherlands. The purpose of this thesis is to identify the changes in the Frisian climate over the last decades. Therefore, I have conducted a detailed meteorological data analysis and visualization based on Friesland specifically. The data and information used in this research comes from several articles including the aforementioned IPCC report, followed by the in-depth research using the ERA5 Database provided by the Climate Change Institute of the University of Maine.

Literature review

IPCC

In the following paragraphs, the topic of climate and climate change in Europe is studied using the Special Report on Climate Change (2020). This is the first report produced by all three 'Working Groups' of the Intergovernmental Panel on Climate Change, in collaboration with the Task Force working on National Greenhouse Gas Inventories (TFI). This IPCC report puts focus on researching the topics of desertification, climate change, sustainable land management, land degradation, greenhouse gas fluxes in terrestrial ecosystems and lastly food security, demonstrating the interdisciplinarity of the report (Robinson, 2020).

From the industrial revolution onwards, the global mean surface land and ocean temperature has risen less than the observed mean land surface air temperature. The mean land surface air temperature has increased by approximately 1.53℃ (ranging from 1.38℃ to 1.68℃), from 1850-

1900 to 2006-2015, while the mean surface temperature of land and ocean (GMST) has risen by 0.87℃ (ranging from 0.75℃ to 0.99℃). The changing and particularly warming temperature has shown to result in an increase in the duration, intensity and frequency of heat-related weather events such as heat waves in most ‘land’ regions. In areas such as the Mediterranean, parts of Africa and South America, north-eastern Asia and west Asia, the intensity and frequency of droughts have increased. Globally, it is observed that heavy precipitation events have increased in intensity. Contradictory vegetation browning has been detected in several areas including the North of Eurasia, The Congo Basin and Central Asia, and parts of North America, as a result of water stress. In a number of dryland areas, desertification has grown due to an increase in evapotranspiration and land surface air temperature, together with a decrease in the amount of precipitation. The areas that experience consequences such as desertification include parts of East and Central Asia, Sub-Saharan Africa and Australia (Robinson, 2020).

The changing climate may for some regions bring along greater risks while for other regions might face new challenges that have not been previously anticipated. As the warming increases, the duration, frequency and intensity of heat related events, think of heatwaves for instance, are expected to increase over the course of the 21st century. This will have diverging impacts across different regions around the globe (Robinson, 2020).

Friesland

Due to the significant Frisian landscape of peatlands and a dominant agricultural land-use, it is interesting to study this area in depth. As mentioned before, the climate is believed to be changing which has pressing influences on our weather but also for our land. The Frisian landscape is known for its widespread agriculture, farms and meadows combined with its precious peatlands.

The national government has realized that the increasing subsidence of peatlands is believed to cause problems regarding building foundations, increased greenhouse gas emissions, the desiccation of nature reserves, a deteriorating surface water quality and increased costs for infrastructural maintenance and water management (Brouns et al, 2015)

For the Netherlands, but also for Friesland in particular, agriculture and livestock farming is one of the most important economic sectors, using approximately two-thirds of the total land area of the Netherlands for agricultural and farming purposes. Even though in the last years, the amount of farmers has slightly declined, the total area used for agriculture and farming has stayed relatively stable which indicates a growth in average acreage, or larger farms. Climate changes are generally expected to have a significant impact on agricultural areas, and thus in the Friesland

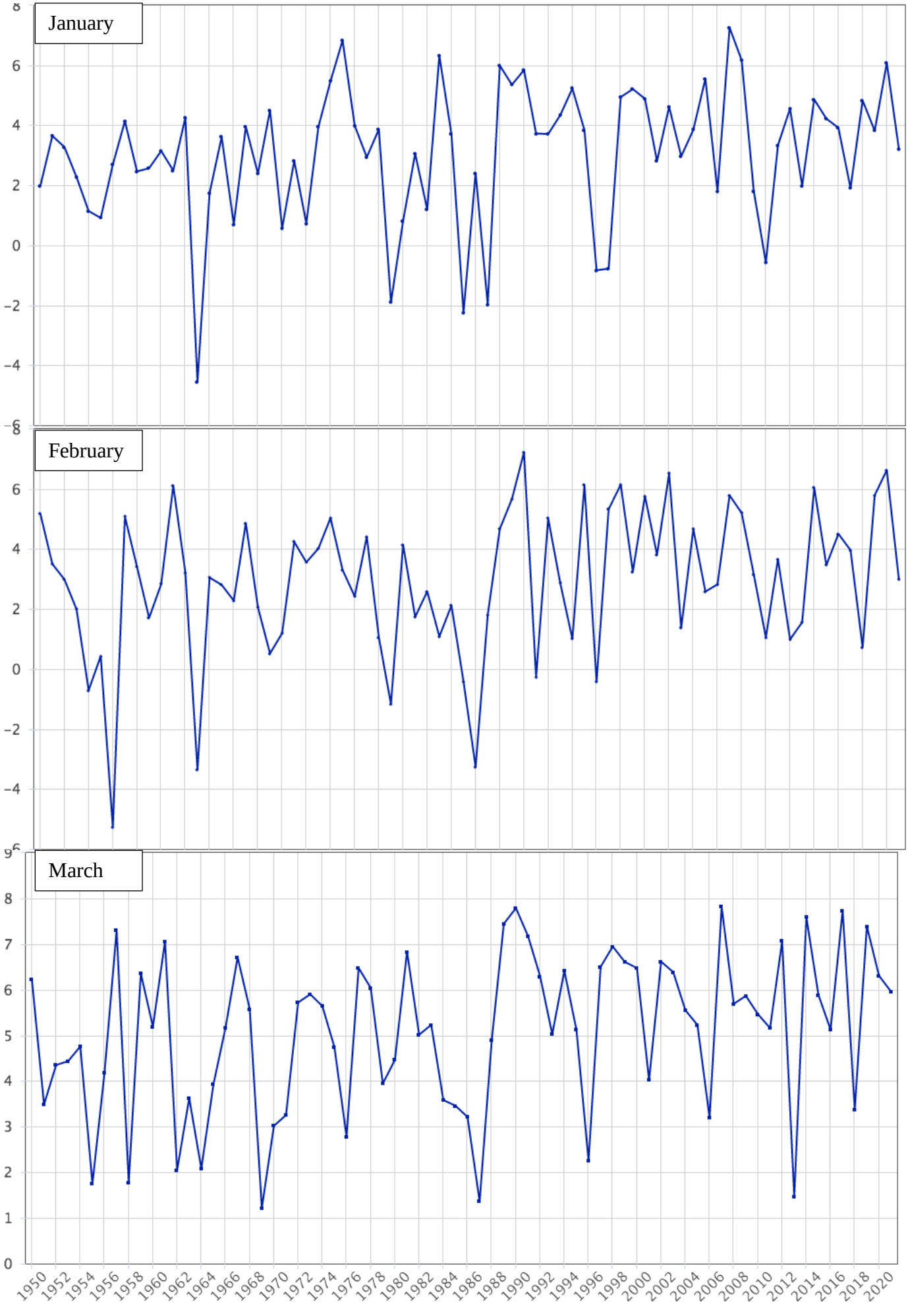
(where agriculture and livestock farming is the most dominant form of land use), it will have significant problematic impacts (Schaap et al, 2011). This is therefore part of the reason for a focus on Friesland in depth. The coming part of the research will include a meteorological data analysis and visualization

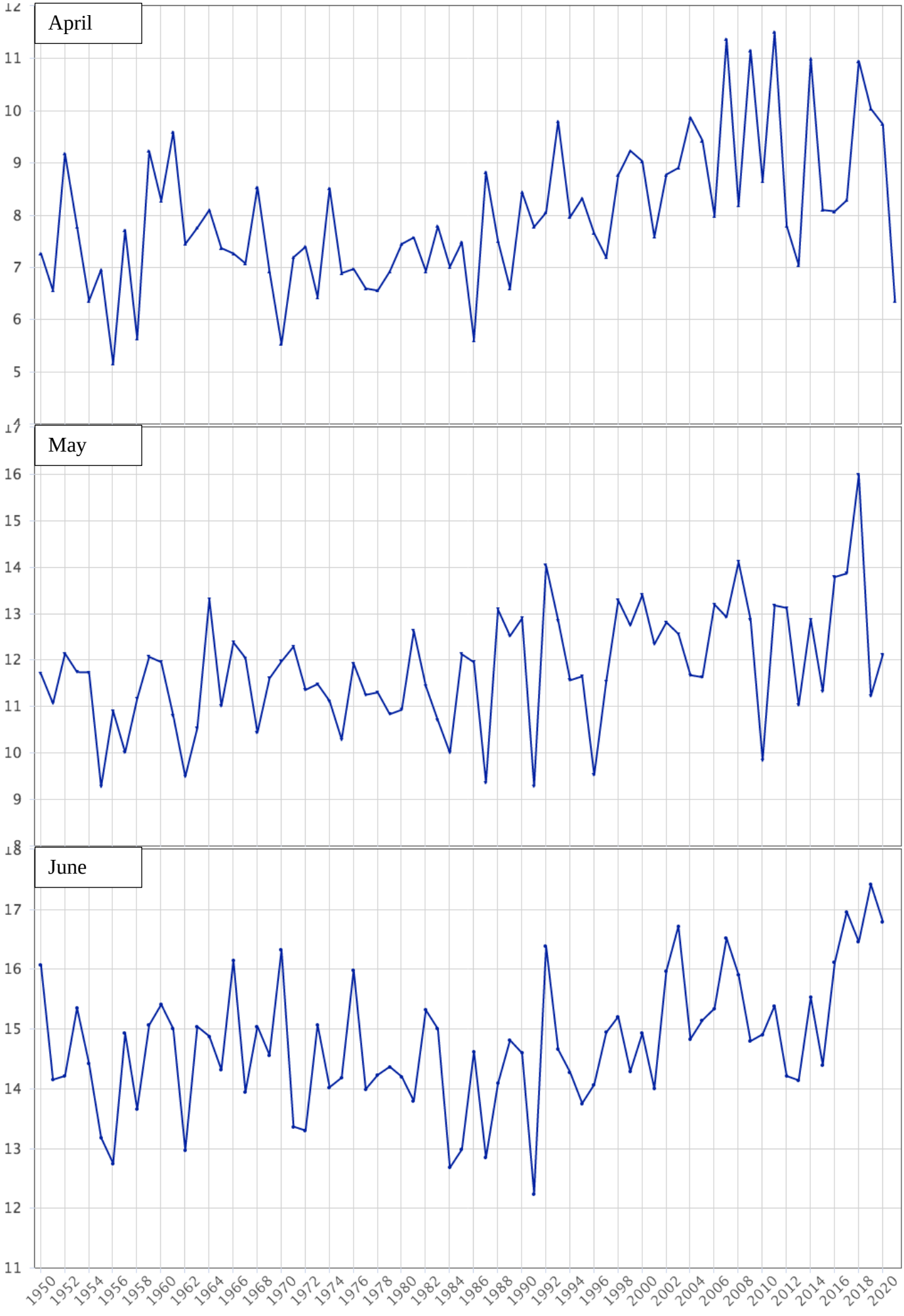
Results

2m Temperature Analysis

Using the data collected by the Climate Change Institute of the University of Maine, 16 maps were generated, showing the temperature in Celsius Degrees at a height of two meters. The areas of interest are Europe, The Netherlands, and Friesland in more detail. Over the course of this research, the coordinates used in order to specify the area of Friesland are 52.8266, 5.3917 and 53.4462, 6.2926. The time frame is the same for all plots, ranging from 1950 to 2020. The main aim is to take a closer look at each of the graphs and point out any peaks, trends or changes over the years; comparing all of the graphs to each other. Due to varying temperatures per month, the y-axis changes for almost every map in order to give a fitting overview. Below are the data visualizations per month, followed by corresponding commentation. After researching the changes in average temperature, more visualizations are used to investigate precipitation and temperature change explaining factor such as: Changes in atmospheric circulations, cloud cover and atmospheric CO2.

2m Temperature average in Friesland, The Netherlands in degrees Celsius

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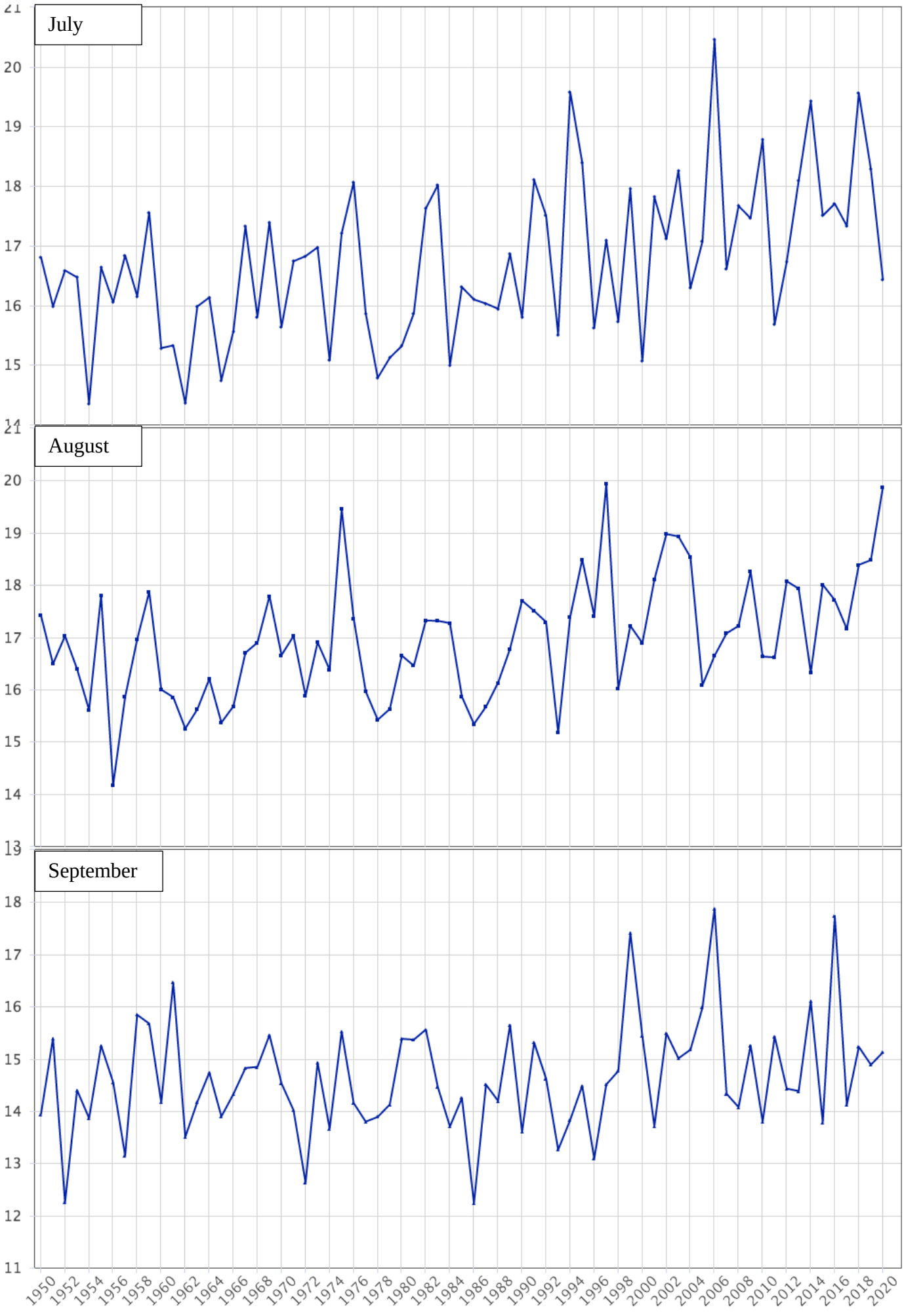
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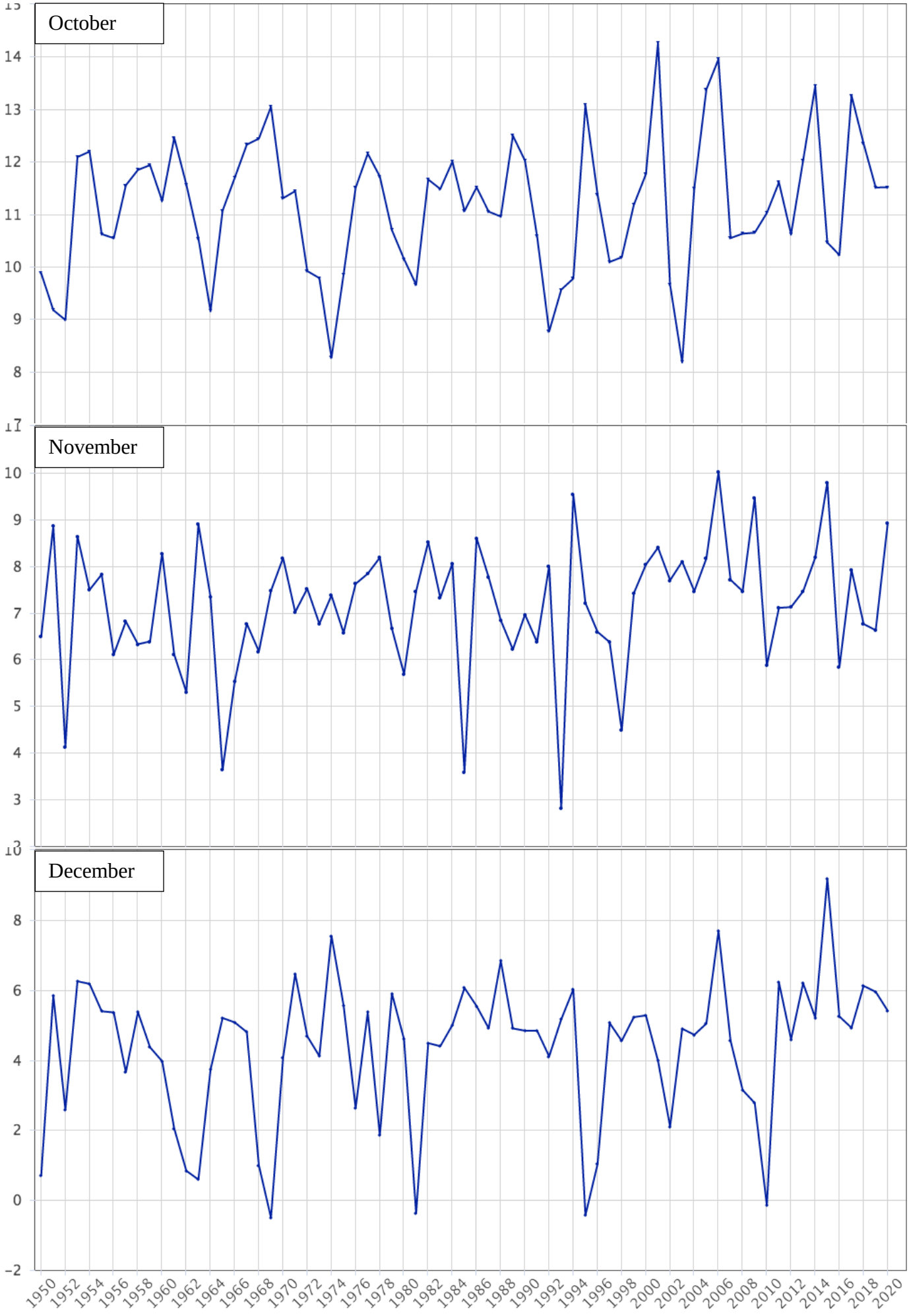
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2m Temperature January

All points mentioned from the 2m Temperature maps are measured in degrees Celsius. Starting off with the first graph; 2m Temperature average of January from 1950-2020 in Friesland. Here we can see that the temperature scale reaches from minus six to eight degrees Celsius. Looking at the map overall, it becomes evident that the lowest temperature of the month January was measured around the year of 1963. This fits to information of the KNMI, the meteorological institute of the Netherlands; describing 1963 as the coldest year of the 20st century (ref). Furthermore, we can see five more of these low dips in the years 1979, 1985, 1987, 1996/7 and 2010. Some of the 'higher' peaks can be seen in 1975, 1983, 1988/9 and 2007. It is interesting to see that one of the lowest temperatures on average for the January months was in 1987, while one of the higher peaks was immediately the year after in 1988. The highest temperature of the month January until the year 2020 was measured in the year 2006. Taking a more general look at the map, I am not entirely sure if there is an increasing trend of the two meter temperature. It is however the case that at the beginning of the timescale, the temperature was set at two degrees while at the end this was three degrees. Besides the big peaks and dips, many smaller fluctuations become visible throughout the years. Looking merely at the last decade, we could state that there is an increasing trend regarding the temperatures.

2m Temperature February

Taking a closer look at the data on the February months of 1950 to 2020 regarding the 2m temperatures in degrees Celsius, we can immediately see that towards the second half of the timescale, the dips in temperature become less low than can be seen in the first 40 years. In the years until 1995 we can see several low points, reaching temperatures well below zero. However, looking at the years after that it becomes evident that the average temperatures of the February months are not reaching below zero anymore, resulting in less deep fluctuations. We can see for instance that for the years between 1990 and 2020, the temperatures stay between approximately zero and seven, whereas for the years before the temperatures reach from almost minus six to plus seven degrees, showing a decrease in difference between the higher and lower temperatures. The map starts with a temperature of five degrees Celsius in 1950 and three degrees in 2020, for the February months. Two times within this time series, we can see a decreasing trend in temperature over several years, when looking at the years of 1950 to 1955 and also in 1980 to 1986. Naturally there are many more decreases in temperature, but these two lasted for about five years in a row. When comparing the February temperatures to the ones of January, we can see that the maps are quite different but there are also some similarities. Looking at the 1963, 1979 and 1985 we can see the same kind of dips in temperatures as in the January

months. These dips are less low than in January, so the coldest February years were not as cold as those in January.

2m Temperature March

Looking at the map of March, what is important to notice is the fact that the temperature scale goes up to nine degrees from zero. It seems that fluctuations increase towards the end, during the last decade of the map. More in the middle of the map we can see less fluctuation, where temperatures slowly increase or decrease over several years instead of rapidly changing from year to year, as can be seen later in the graph. When comparing the months of March to those of February, it becomes evident that in both of the maps in the year of 1990 there was quite a peak in the average temperature, reaching up to almost 8 degrees average. What is striking here is that for the month of March, we do see a large decrease in temperature around the year 2013, whereas for the months of February and January, the last decade experienced less big fluctuations. Looking at all the years, we could say that there is an increasing trend in temperature, however I am not fully certain about this.

2m Temperature April

The months of April are shown by the hand of a timescale reaching from four to twelve degrees Celsius. What immediately stands out compared to the previous maps, is the rising trend in temperature. From approximately 1970 onwards, it seems like the temperatures (even though fluctuating to higher and lower) are following a rising trend until the year of 2018. After 2018 we can see a fall in temperature from eleven to almost six degrees Celsius. The fluctuations are not as high and low as we have seen in the previous months, in the months of April this is a bit more even. In the years of 2007 to 2011 we see some of the hottest years, but these warmer times are immediately alternated with colder ones. In the end however, it seems like the April months are the first one to really show a warming climate in Friesland. Therefore, the further research will (for a large part) be based on the last decade of April. The choice for this time frame is based on the idea that a study on these most recent years is relevant for future research and development.

2m Temperature May

Now taking a closer look at the time series of the month May, it becomes clear that in this period as well an increasing temperature can be analyzed over the years. The temperature scale reaches from eight to seventeen degrees. In this graph we can see several outliers, with one in particular. This one is the peak that can be seen in the year 2018, where the temperature reaches 16

degrees on average over the month of may in Friesland. Whereas the temperature in the previous years has always been lower than approximately fourteen degrees Celsius. This is quite a big difference, a change of two degrees Celsius. We can see that there are a few periods where the temperatures reach a bit lower than in other years. These periods can be seen in the years 1955 to 1962 and 1987 to 1996. In the year of 2010 we can see one last big low point in the graph, where the temperature falls below ten degrees Celsius on average in this month. When we compare this graph to the previous ones, we can see that almost every month until now has experiences colder times in the years between 1955 and 1957. What is striking in this graph is the fact that over quite a long time period, namely the years of 1965 until 1986, where the changes in temperature are a maximum of three degrees. This is striking as we can see in the other graphs that the fluctuations are usually of a larger number of degrees.

2m Temperature June

In the June graph we can first of all see that the scale of temperature reaches from eleven to eighteen degrees Celsius. The first aspect of the graph that stands out is the fact that in the last decade of the time series, we can see a rising trend of the temperatures. This rise seems to hold on until the end of the timescale. What is interesting on the other hand is the fact that in the first year of the graph, 1950 the temperature was also quite high, falling down a bit to twelve to thirteen degrees in the year 1955. This fall in temperature again fits to the trends that we have encountered before in the previous graphs, regarding the lower temperature in the years of approximately 1955 to 1957. In this graph we can also see this fall in temperature at different periods such as between the years 1983 to 1991. On the other hand, it is also evident that there are several warmer years, showing a rise in temperature. We can see peaks in the years of 1950, 1966, 1970, 1976, 1992, 2003, 2007 and as mentioned before in the years from 2017 to 2019. The biggest peak and hottest year for the month of June is the year of 2019, where the average temperature reaches well above seventeen degrees Celsius. The lowest temperature that we can see from the graph was in the year 1990 with a temperature of almost 12 degrees on average. Most of the years seem to have dealt with temperatures around fourteen to fifteen degrees Celsius. At the beginning of the graph, the temperature was set quite high at sixteen degrees whereas the last visible temperature in 2020 was measured at almost seventeen degrees Celsius, showing a bit of an increase. It is not certain that the graph shows a linear growth in temperature; it is staying horizontally for quite some time and really increasing only since 2013.

2m Temperature July

The graph of July’s temperature over the past 70 years shows quite an increase in temperature with many rough fluctuations. The temperature scale of July reaches from fourteen to 21 degrees

Celsius. The beginning of the graph, in the year 1950 starts off with a temperature of almost seventeen degrees Celsius, falling down a bit to fourteen degrees in the year of 1954. After this year, there is clearly an increasing trend in temperature until the year of 2018. After 2018 until the year 2020, the temperature falls back to approximately sixteen and a half degrees. The graph shows that there was quite a big peak in the year of 2005 where temperatures on average reached above twenty degrees, for the first time in at least 56 years. Furthermore, three other high peaks can be seen when looking at the years 1994, 2014 and 2018, where the temperature reached above nineteen degrees Celsius. Looking at the beginning of the graph, we can see that on average, the temperatures stay between fourteen and eighteen degrees. This is true for the years between 1950 and 1993. This means that for quite a long time period of 43 years (at least), temperatures have been significantly lower than the years after that. Since the year 1994, the temperatures have often reached above eighteen degrees Celsius on average, with a bit more but definitely bigger fluctuations. We can see that from approximately 1984, there is actually an increasing trend in temperature.

2m Temperature August

When we take a closer look at the graph of August, it becomes clear that quite a lot less fluctuations have occurred over the years when comparing it to the July graph. The temperature scale starts at thirteen degrees, reaching up to thirteen degrees. We know that July had a lot of big fluctuations over the years and we can see now that August in general is a bit more quiet. We do see some steep outliers to higher and lower temperatures. The three highest peaks can be seen in the years 1975, 1997 and lastly in 2020. There are also some years that experienced lower temperatures on average in the month of August, however the lowest temperature for this month was measured in the year of 1956. When comparing this fact to the previous months, we can clearly see that there is a trend of lower temperatures in general in the years 1954 to 1958. Generally, it seems that over the past years, the temperature has slowly increased. When looking at the past twenty years, we can see that the average temperature in August has not reached below sixteen degrees Celsius. The last five years of the last decade have not been lower than 17 degrees. None of the years has experienced average temperatures reaching above twenty degrees, as compared to the year 2006 in July.

2m Temperature September

Looking at the figure of September temperature at two-meter height; we can see that generally the fluctuations are happening quickly but are not very extreme, until the year 1998. From here on there are several highs and lows that show to be a bit more extreme. The highest temperatures in September were in the years 1999, 2006 and 2016, reaching almost eighteen degrees Celsius on

average. No other years than these three, have reached average temperatures above seventeen degrees and almost no years have even dealt with temperatures higher than sixteen degrees, except for the years 1961 and 2014 (and the three years mentioned above). Generally, we can see that the temperatures of September stay well between 16 and twelve degrees during the years of 1950 to 1998. After this long time period, the temperatures seem to have risen above the sixteen degrees threshold. On the other hand, we can see only three years with temperatures below thirteen degrees Celsius, namely in the years 1952, 1972 and 1986. After the year 1986 we can see that the lower temperatures have always stayed above thirteen degrees and the last four years have even been above fourteen degrees Celsius.

2m Temperature October

Looking at the months of October over the last years, it is difficult to identify an increasing trend regarding the average temperature. The October graph shows quite a few big peaks and drops in temperature, implicating big changes in temperature at two-meter height per year over the last years. When comparing the month October to the month of September for instance, we can see that the fluctuations are happening less ‘rapidly’ or in other words, less often. It is clear that in the October months, the differences between temperatures take more time to change over the years than it does in several other months. This becomes visible when we look at the width of the peaks and drops in the graph, they seem to be broader than in the previous months where these happen more frequently after one another. The temperature scale of October starts at seven degrees and ends at fifteen degrees. The average temperature over these 70 years seems to be around ten to twelve degrees Celsius, as most of the peaks and drops come back to this area. It is hard to see a clear linear trend in the whole of the timescale, however if we take a closer look at the later years, we can see that from approximately the year 2006 the temperatures have not dropped significantly anymore; until the year 2020 where the temperatures don’t reach below ten degrees. Therefore, we could even suggest that there is a small increasing trend to be spotted when comparing the beginning and end of the graph. The most significant period of temperature rises and falls was in the years between 2001 and around 2006.

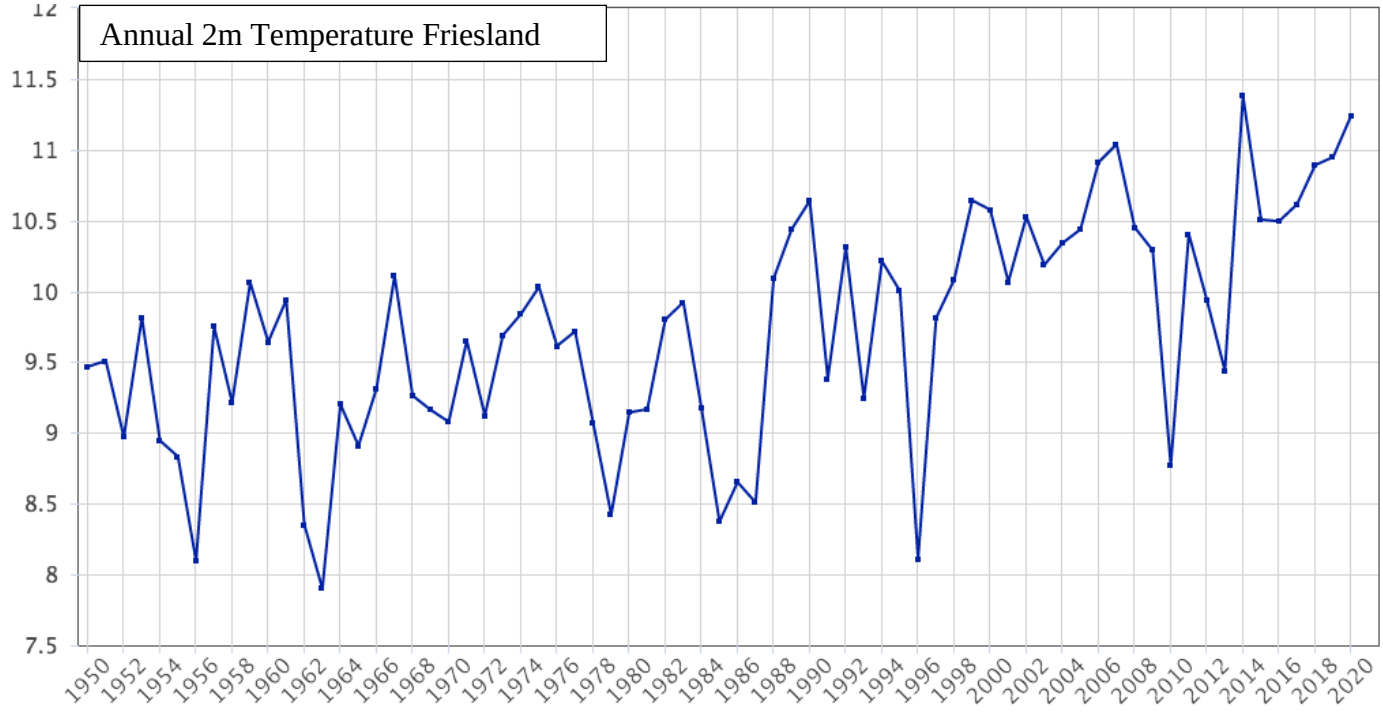
2m Temperature November

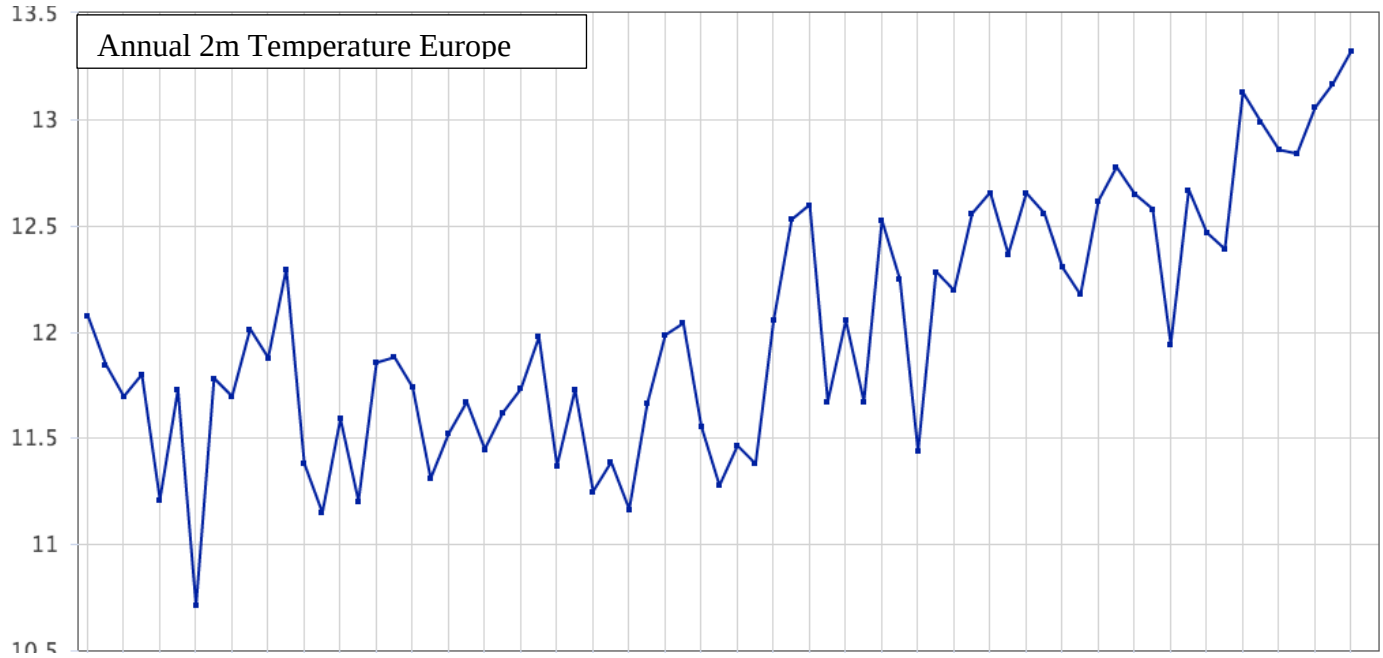
The months of November are interesting because we can see a clear change in the amount of temperature drops over the past years. First of all, we should notice that the timescale has changed again to a scale of two to eleven degrees Celsius. In the beginning two-thirds of the graph we can see several significant low temperatures measured, with a small period of higher temperatures in between. This period reaches approximately from the years 1986 to 1983. The years before and after that time period, until around 1998, show several large decreases in

temperature over the years. Four years in particular stand out, seeming to be colder on average than the rest, namely the years 1952, 1965, 1985 and 1993. What stands out is the fact that these greater drops stopped occurring after the year 1998, where the temperatures of the last 22 years have barely dropped below six degrees. This seems like quite a big change compared to the previous drops to below three degrees. Generally, it seems that the month November has experienced many fluctuations or changes in temperature over the year, since 1950. We can also see a few slight increases in temperature, with four years reaching above the nine degrees Celsius line. This is again interesting to see as all four of these peaks occur from the year 1994 on, which combined with the decreased drops in temperature might implicate an increasing general temperature. Generally, the absolute lowest temperature on average in November over the past 70 years is measured in the year of 1993 at approximately 2.8 degrees Celsius. Looking at the years between 1999 and 2009, it is visible that for the whole of ten years the temperature (on average) in Friesland has not dropped below approximately seven and a half degrees Celsius, which seems to be a long time compared to the many fluctuations happening in the time periods before and after this one.

2m Temperature December

The last individual month of this series is naturally December, described by the hand of a timescale that is indicated with the temperatures between minus two and eleven degrees Celsius regarding the average temperature in Friesland in the month of December. The first aspect of the graph that stands out is the many drops in temperature across the whole of the seventy-year period. We can see six significant decreases in temperature, in the years 1950, 1962, 1969, 1981, 1995 and 2010. When looking at the time period of the years 1953 and 1963, we can see that there was a decreasing trend in temperature over those ten years. When comparing the peaks and drops, it can be observed that the number of drops is significantly higher than the amount of high temperatures measured over the past seventy years. There has been only one year where the temperature reached above eight degrees, which occurred in the year 2015 with a temperature of nine degrees approximately. When we observe the temperatures of the last decade, we can see that temperatures have not reached below approximately five degrees. However, we have seen a similar event happening between 1981 and 1993, where temperatures haven’t reached below four degrees on average. Even though it is hard to identify an increasing linear trend in the graph of December, it might be the case that in the last ten years, temperatures have been slightly warmer than the previous years.





Annual 2m Temperature Friesland

After zooming into the individual months, it is interesting to take a look at the broader picture regarding the annual average temperatures between 1950 and 2020 in Friesland. In the annual temperature graph we can clearly see that there seems to be an increasing linear trend with regards to the temperature. The temperature scale that is used for this graph starts at 7.5 degrees Celsius and goes up to twelve degrees. We can see that in the base year 2050, the temperature was measured at approximately 9.5 degrees, falling down to almost eight degrees within six years. The average annual temperatures have risen to about 11.5 degrees in the year 2020. Over the course of the seventy years, we can clearly see that the temperatures, also on an annual basis,

have been fluctuating. However, the amount of fluctuation in temperature is not as much as we have seen before in several individual month graphs. Looking at the graph we can see that for a few years the measured temperatures have significantly fallen below 8.5 degrees. We can see two periods where the temperatures have stayed a bit higher than average for a while. The first period that shows this longer trend of increased temperatures was between the years 1966 and 1977 where temperatures stayed well above nine degrees Celsius for about eleven years. A similar trend has been observed in the years between 1998 and 2008, where temperatures have stayed above 10 degrees on average. This last trend is comparable to what we have observed in the November graph, where between the years 1999 and 2009, the temperatures (on average) in Friesland have not dropped below approximately seven and a half degrees Celsius. Especially in the last decade of the seventy-year period, a clear increasing trend can be observed, reaching from 12 degrees in 2010 up to 13.25 degrees in 2020.

2m Temperature Europe

Zooming out even further, we can take a look at the annual temperature of the whole of Europe and compare this to Friesland's annual and monthly average temperatures. I believe that this graph shows the most significantly increasing linear trend compared to all the previous maps. We can see that the temperature starts off at around twelve degrees Celsius, falling down to approximately 10.7 degrees six years later, leading to the lowest temperature of the whole seventy-year period. This trend has also been observed within the annual temperature graph of Friesland, implying that the Frisian climate in the beginning of the years followed somewhat a similar pattern as the whole of Europe. It seems as if Europe in general has experienced more frequent fluctuations than the area of Friesland in specific. A clear increasing trend in temperature can be observed from around the year 1996 onwards. Generally, we can see that there are approximately three time periods where temperatures have risen a lot in a period of four to six years. The first of these periods is from 1956 to 1961, the second from 1985 to 1990 and the third one from 1996 to 2000. The biggest change in temperature has been measured over the years 1956 to 1962, however this was not the largest increase that has been observed. The most prominent increase in temperature over the seventy-year period started off at the year of 2010 leading up to the end year of 2020. In other words, the largest increase resulting in the highest measured annual average temperature in Europe has occurred in the last decade of observation. The highest temperature recorded on average in Europe has been 13.25 degrees. Both of the annual graphs, Friesland and Europe, show similar patterns in peaks and troughs of temperature. The years 1956, 1996 and 2010 show similar drops in temperature when comparing these maps. When looking into the peaks, it can be clearly seen that the years 2014 and 2020 have been the hottest, not only in Friesland but across the whole of Europe.

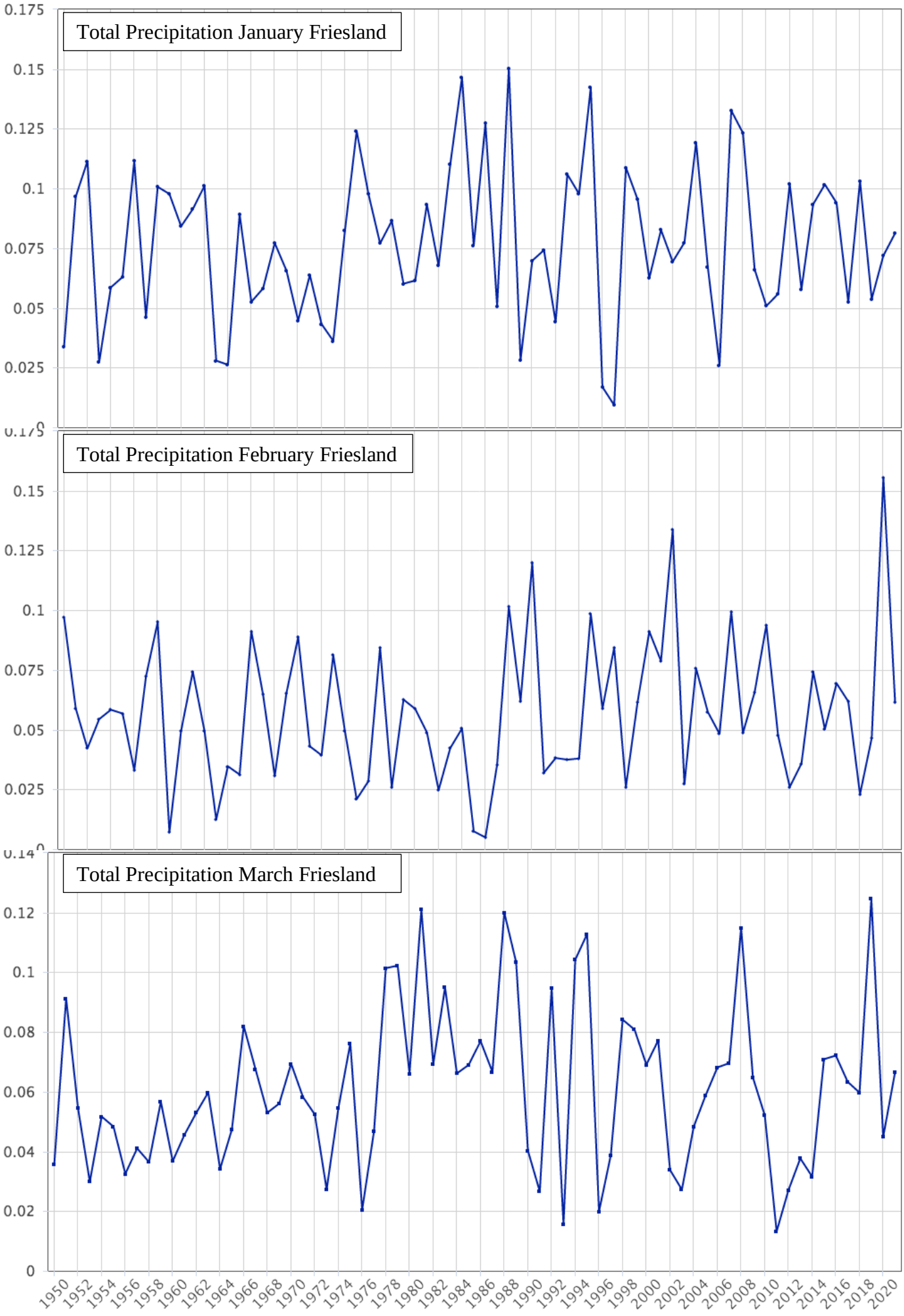
Changes in temperature

When considering the measurements from the ERA5 database, it can be stated that winters are not getting more extreme as is often stated in literature on climate change. After comparing all of the previous graphs regarding the 2m temperatures in Friesland as well as in Europe, it became visible that the summers and winters are both getting warmer, however the summer period experiences a faster increase in temperature compared to the other months. The warming climate is especially visible in the months of April, May and June, and will therefore be used in order to study the underlying mechanisms that causes this rising trend. These months are of interest in particular as those maps show the most alarming increase in temperature. In order to get a better understanding of these trends, we need to analyze the components that possibly lead to temperature changes. The factors that are of interest here entail: wind, land use change, atmospheric gasses, and precipitation. When analyzing the changing climate in a region, it is useful to analyze the wind dynamics over a certain period of time. As aforementioned, the temperature seems to get significantly warmer in the months of April, May and June, when considering the temperature measured at a height of two meters. April displays the most significant increase in temperature and therefore the following research concerns the wind dynamics behind the temperature changes in April in more detail.

Discussion

Total Precipitation Analysis

In order to understand the changes in the climate regime of the Netherlands better, it is useful to take a closer look at the underlying mechanisms. The coming research incorporates the influences that certain explanatory factors have on the changes in temperature that have been identified. The explanatory factors (or underlying mechanisms) studied in this paper include wind vector components (changes in atmospheric circulations), cloud cover and atmospheric CO2. Before studying the explanatory factors one by one, it is useful to take a closer look at total precipitation and investigate if the increased temperature might have an impact on this factor. Below are the data visualizations per month, followed by corresponding commentation. All points meantioned from the total precipitation maps are measured in meters.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Total Precipitation February Friesland
Total Precipitation March Friesland
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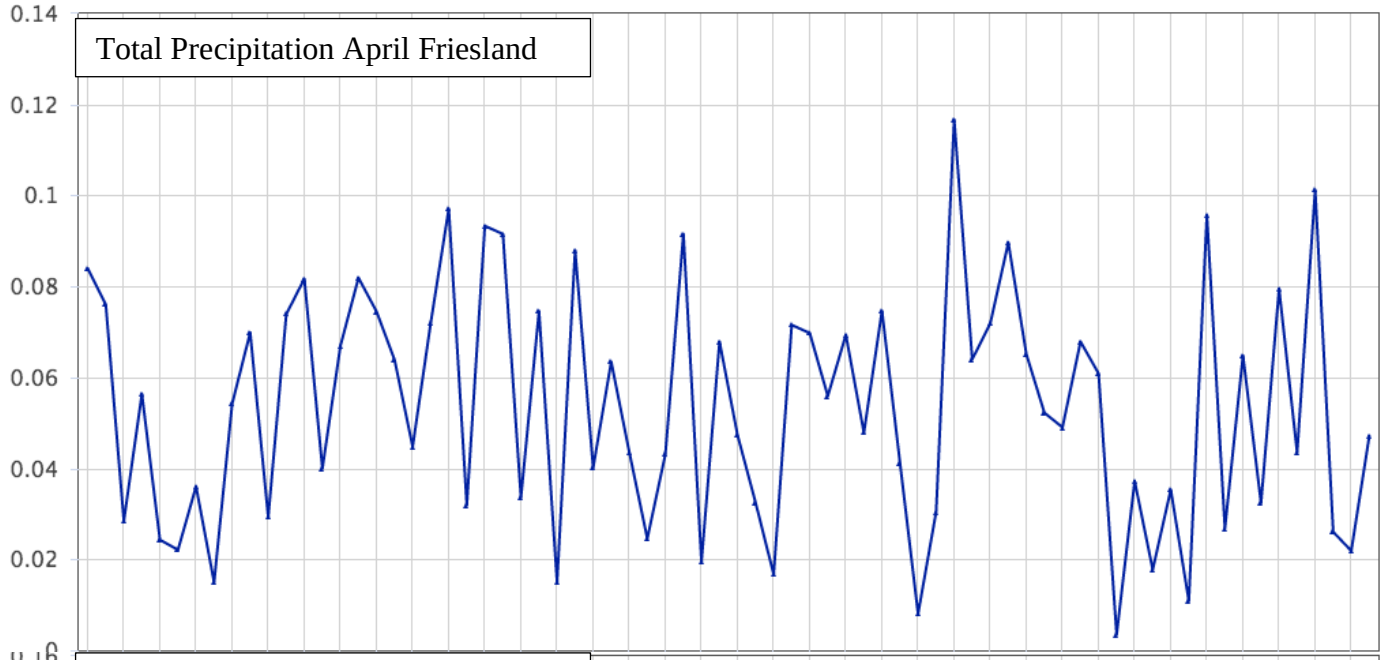
Total Precipitation April Friesland
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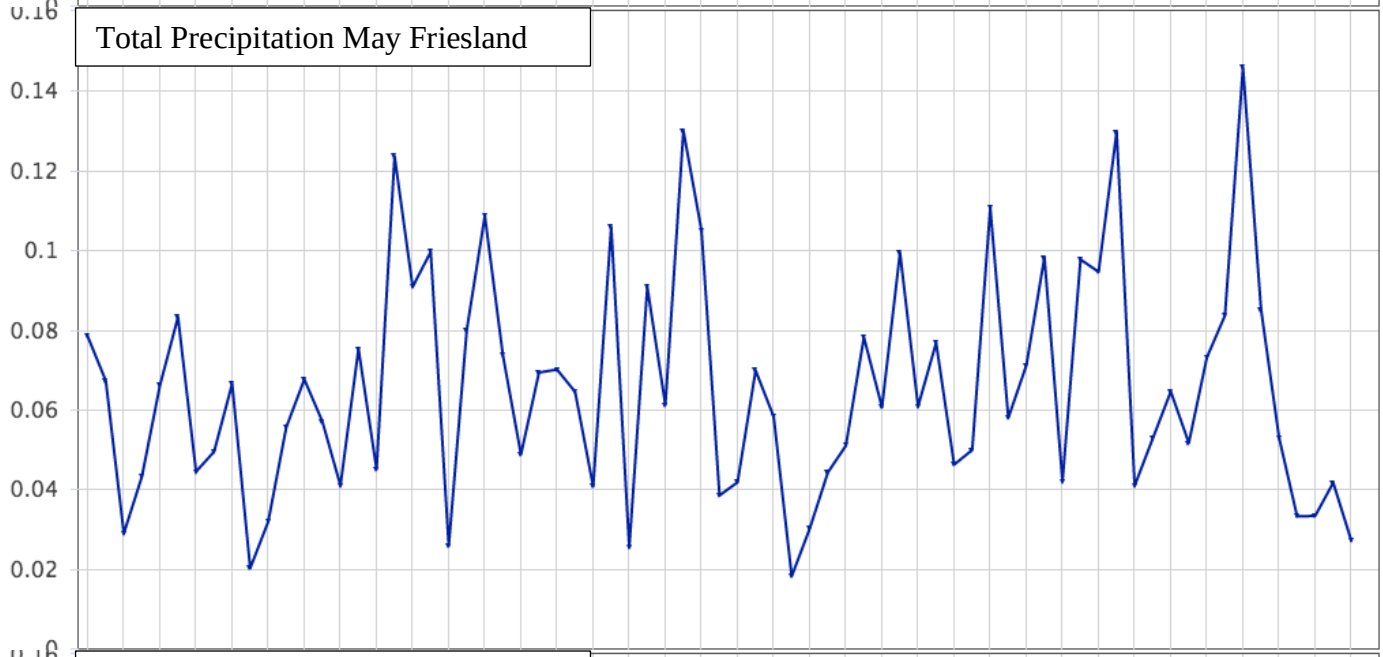
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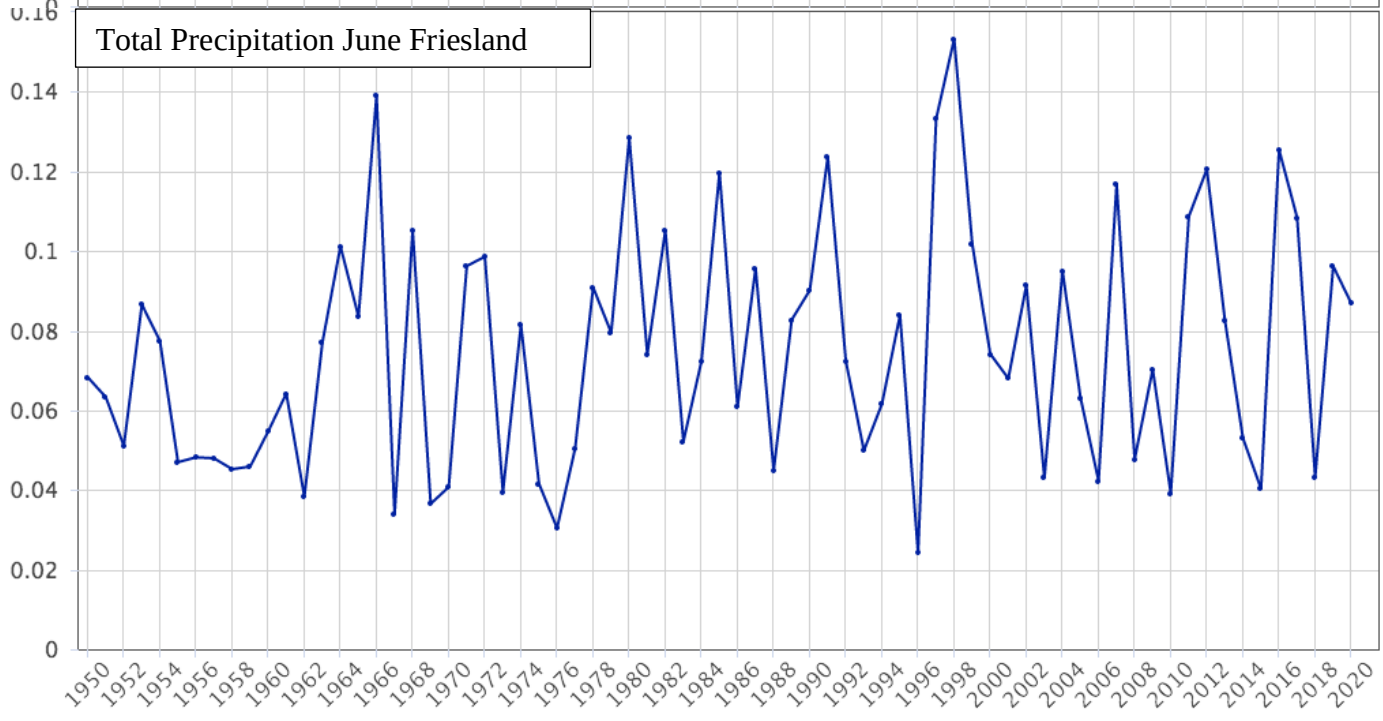
0.02
0


Total Precipitation June Friesland
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
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2002
2004
2006
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2010
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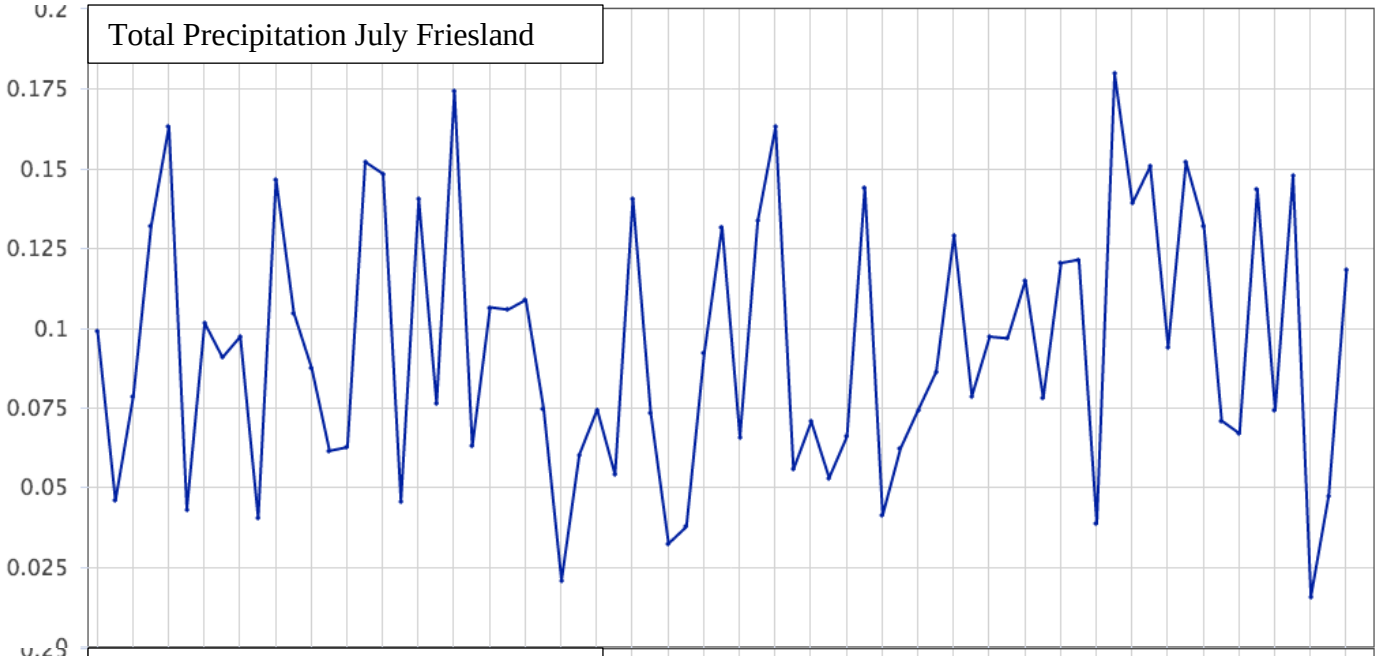
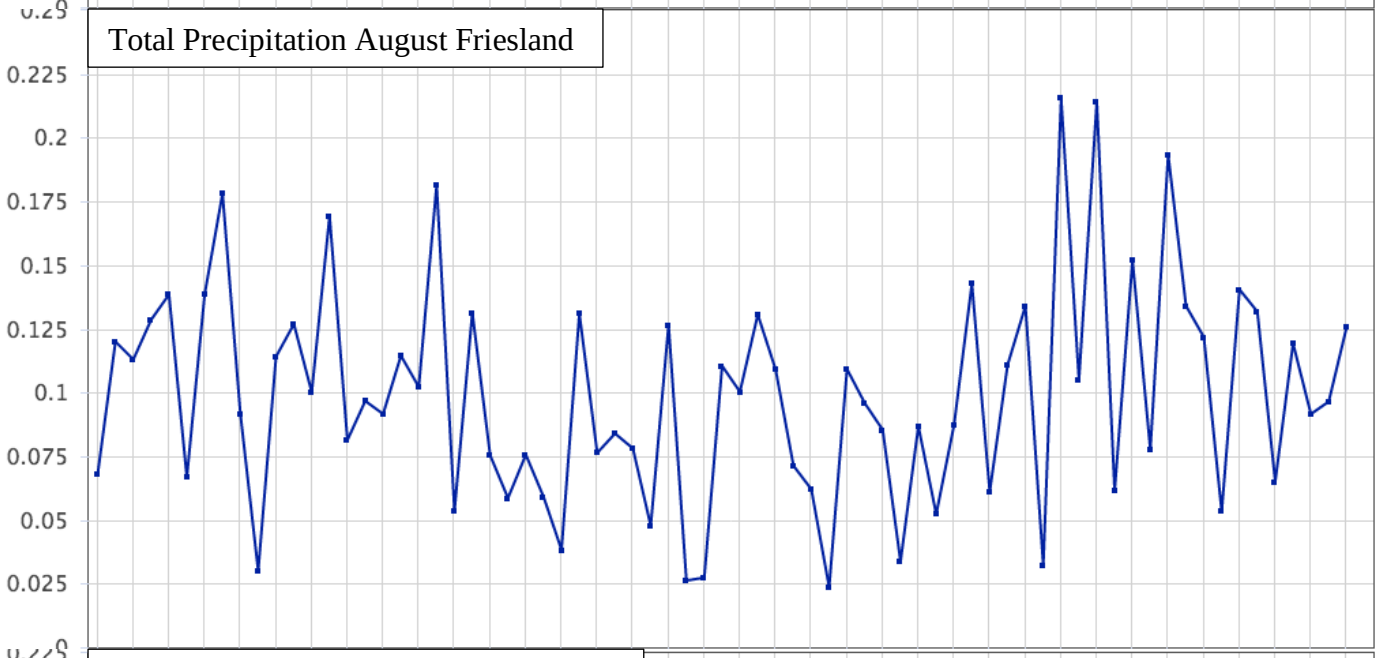
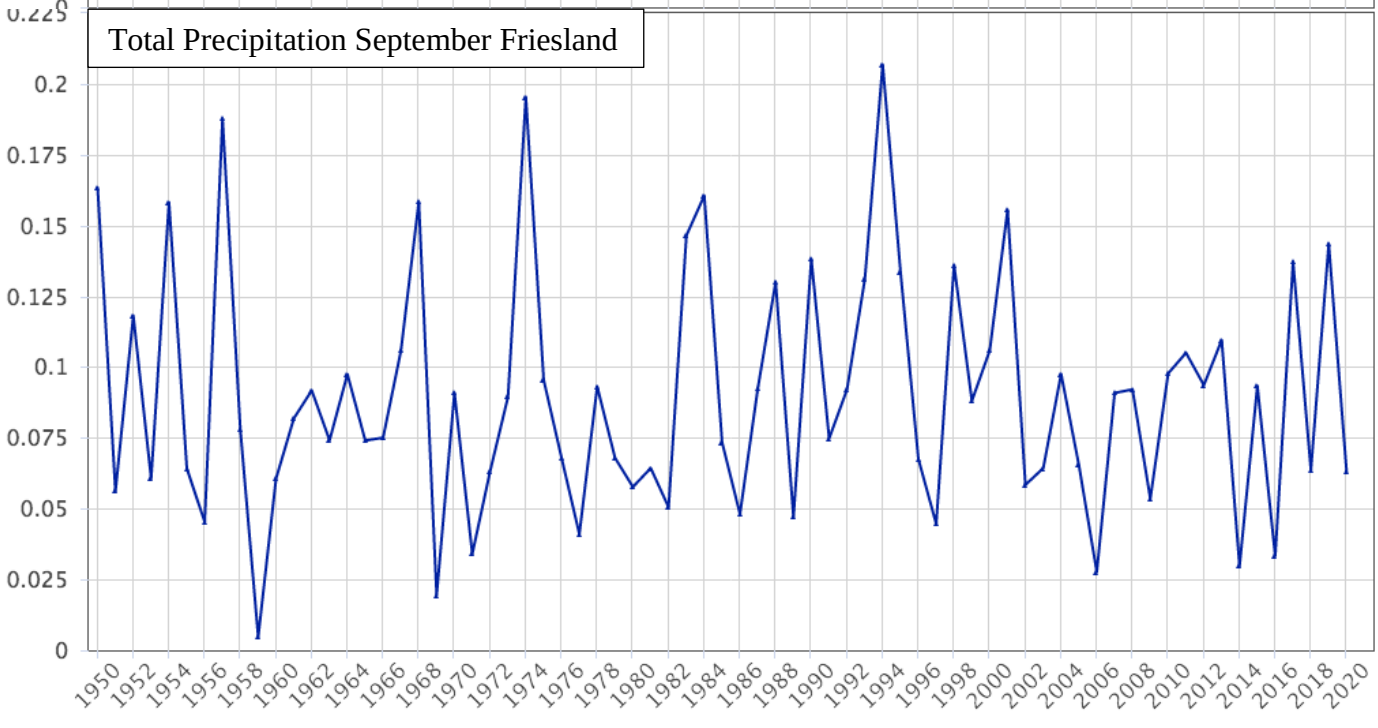
2014
2016
2018
2020


Total Precipitation July Friesland
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0


Total Precipitation August Friesland
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0


Total Precipitation September Friesland
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
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1972
1974
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1978
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1982
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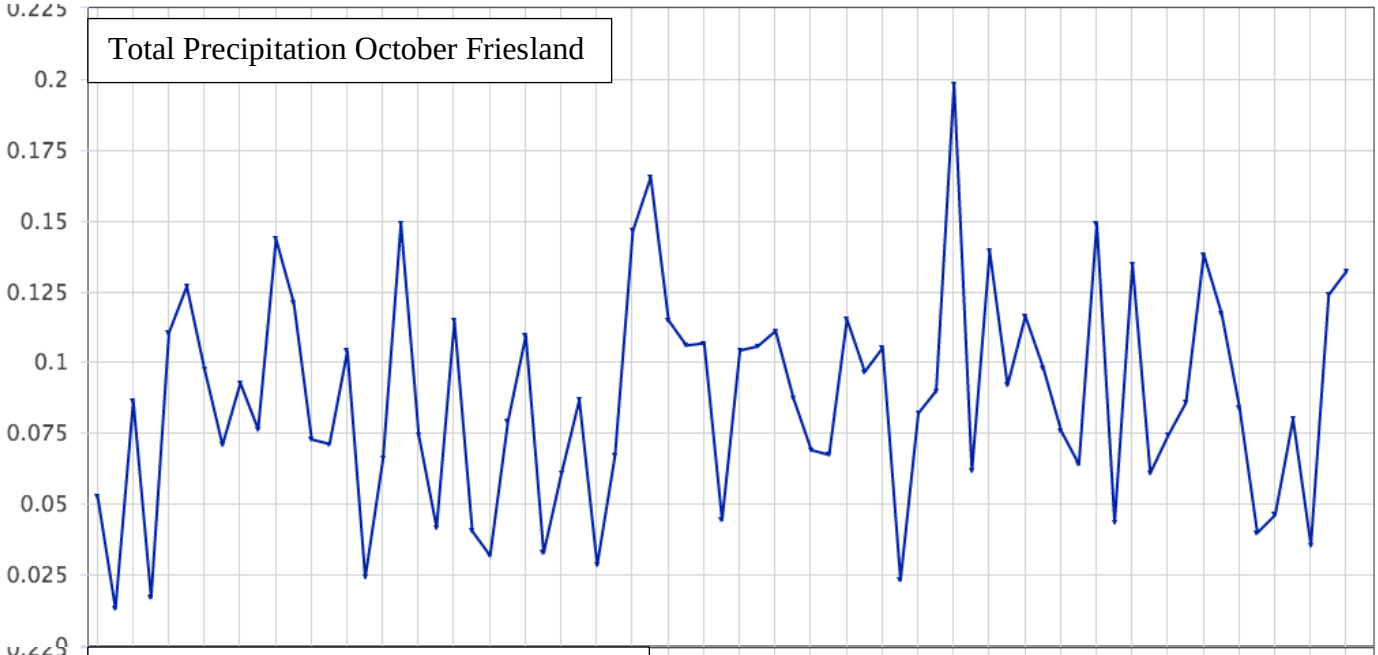
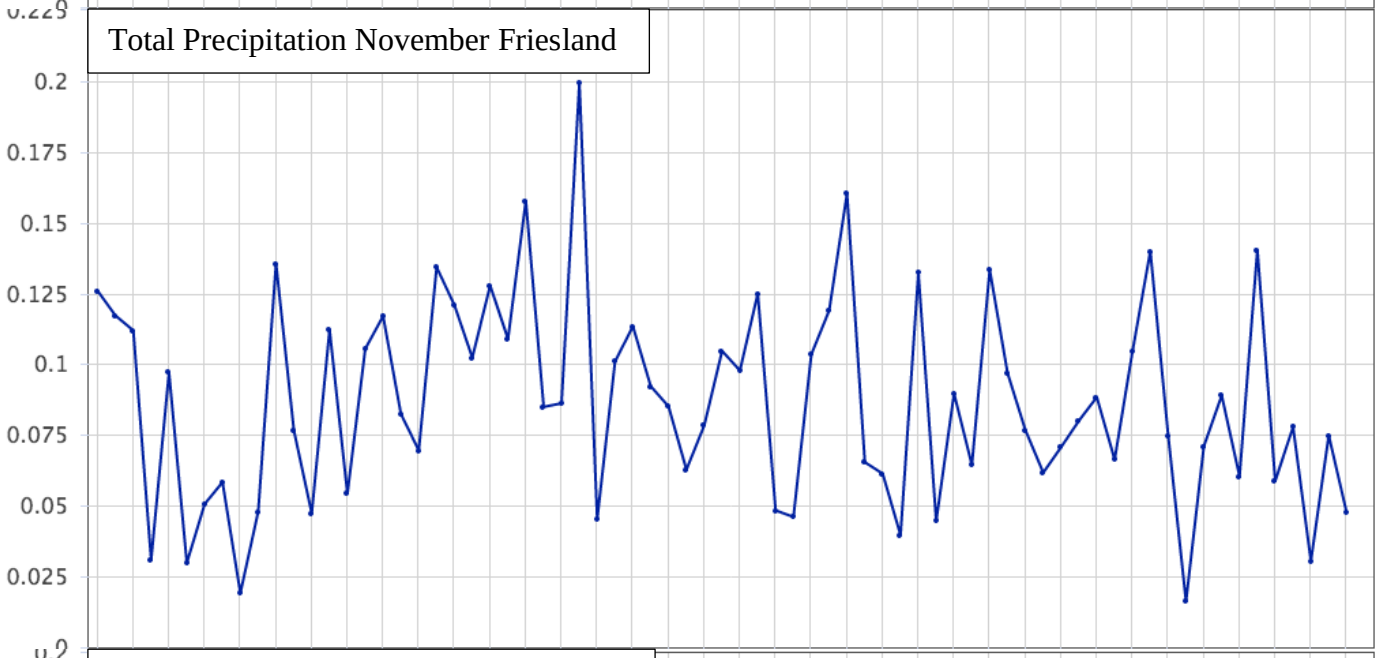
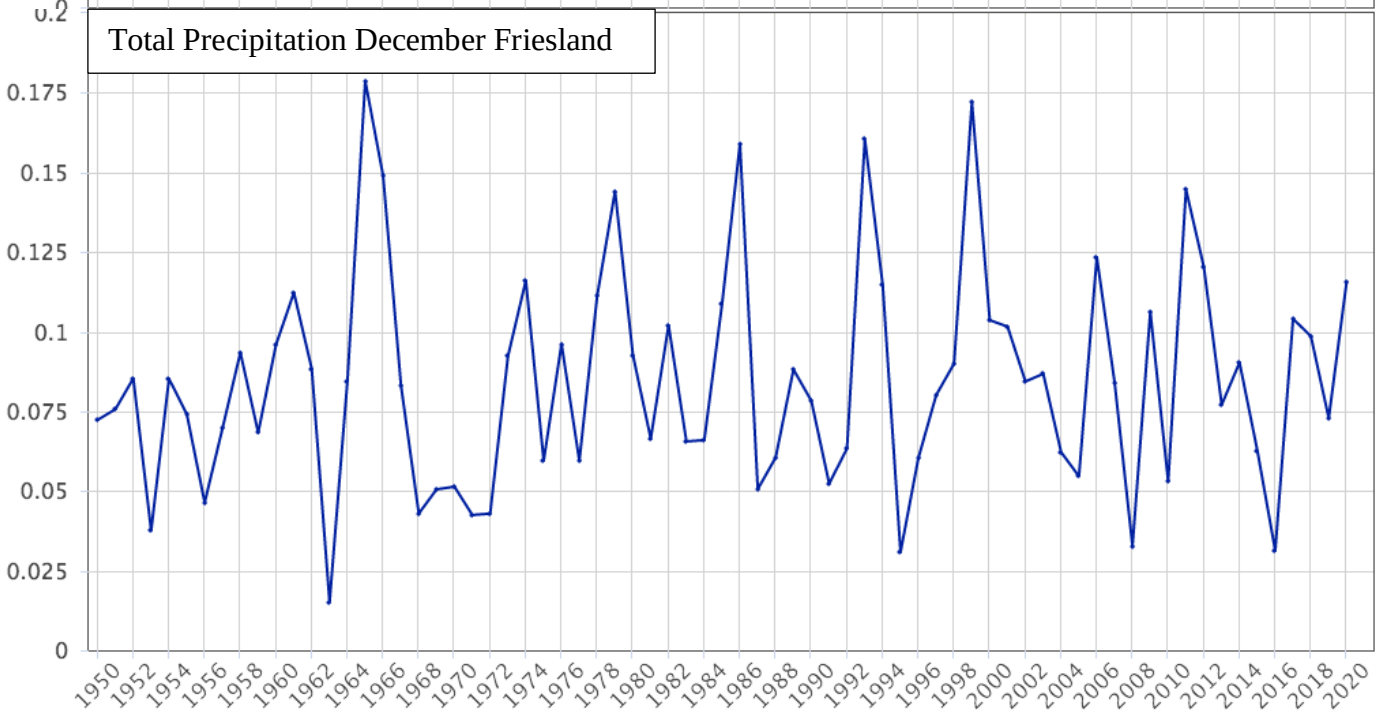
2018
2020


Total Precipitation October Friesland
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025


Total Precipitation November Friesland
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025


Total Precipitation December Friesland
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
1950
1952
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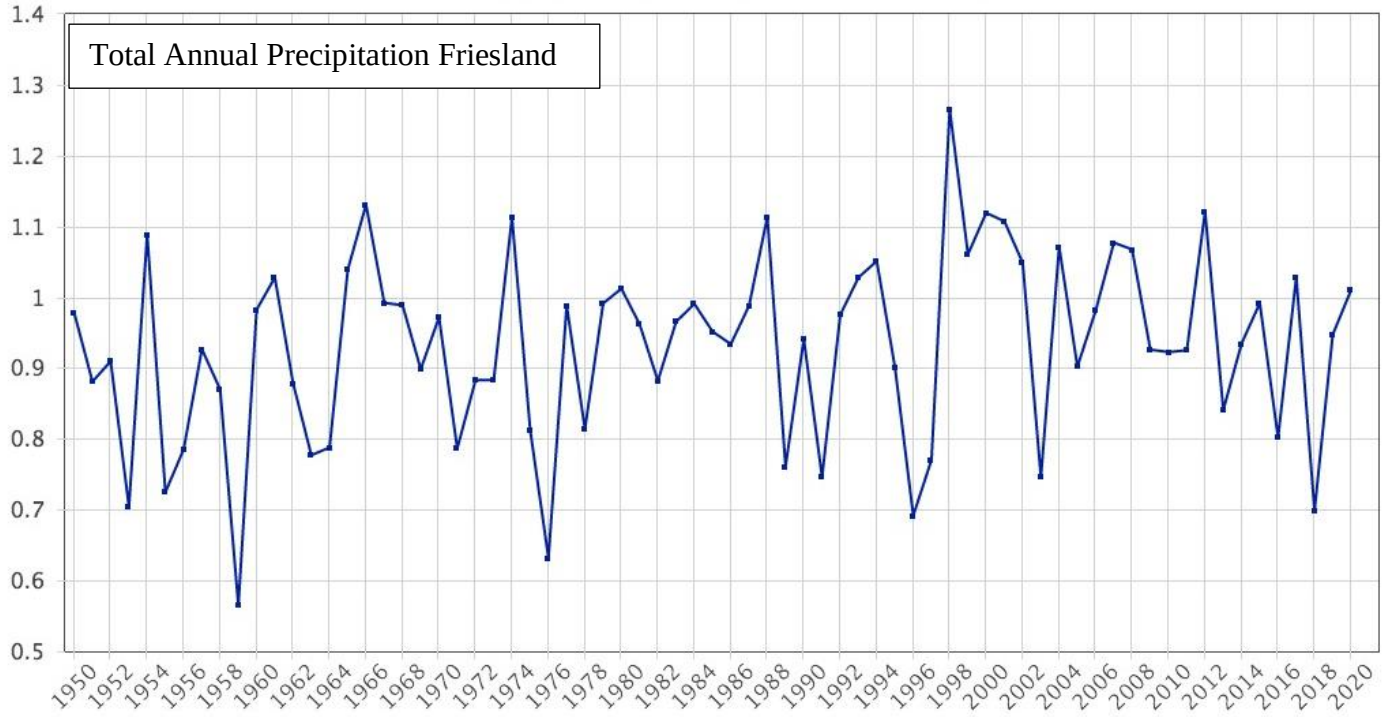
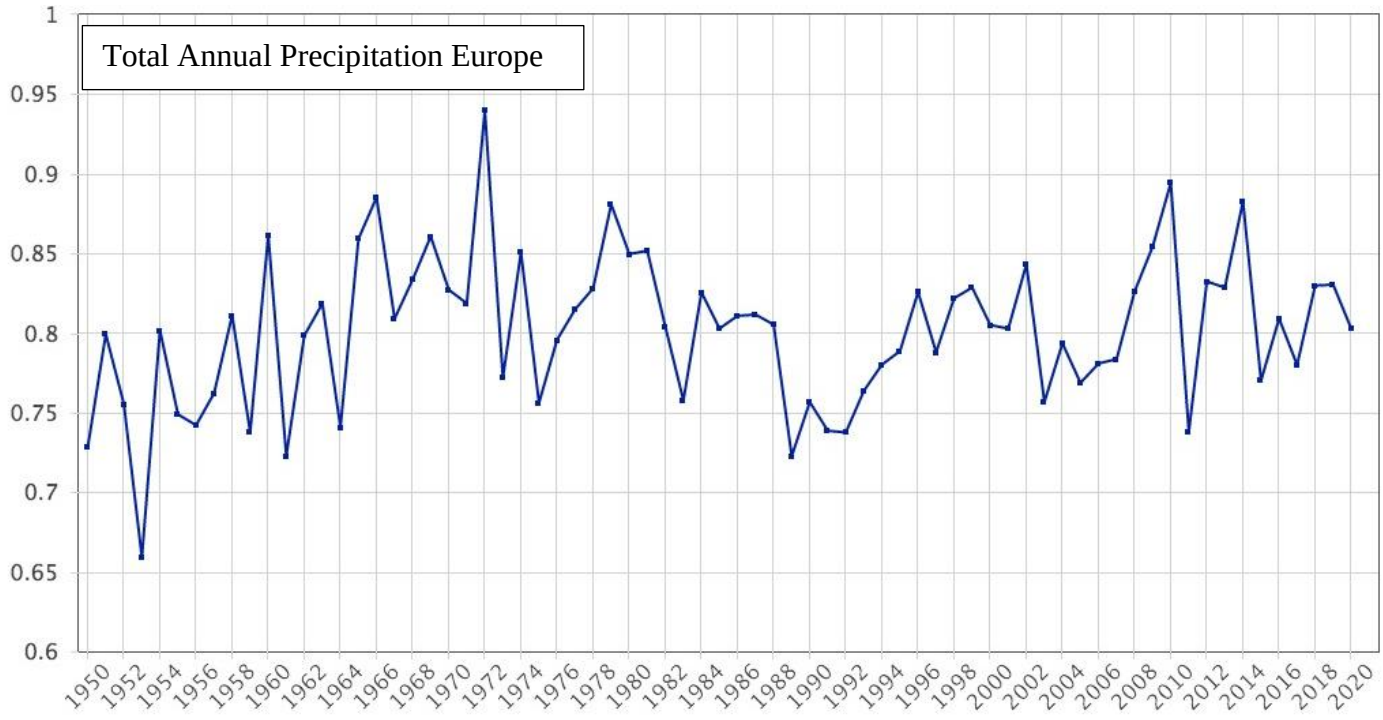

Total Annual Precipitation Friesland
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020


Total Annual Precipitation Europe
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

Total Precipitation January

Starting off with the first graph, it becomes clear that there are many fluctuations over the course of the January months. Similar to the temperature maps, it is important to note that while the x-axes remain the same over the twelve months, the y-axis varies quite a lot. For January we can see that the highest peaks and dips are in approximately in the middle of the seventy-year timeframe. The four highest peaks are measured in the years 1of 1984, 1988, 1995 and 2008, which were the only years with a total precipitation above 0.125. Interestingly, from the years 1952 to 1973 a decreasing trend in total precipitation in Friesland can be identified. A similar decrease is happening currently as we can see when looking at the years from 2008 to 2020. The year 2008 measured an average precipitation of 0.13, falling down to an amount of approximately 0.08 in the last measured year. It was only in the year 1997 that the total precipitation fell below 0.025 for the January months. It is hard to identify a clear trend pointing out a general in- or decrease, however we can clearly state that the amount of total precipitation seems to have declined towards the last decades.

Total Precipitation February

With regards to the February months, the first thing that catches the eye is the large peak in the year of 2020 where precipitation reached to almost 0.16. Such a big peak has not been measured before in February over the course of the seventy years. Generally, only three times the amount of precipitation has reached above an average of 0.1, which happened in the years 1990, 2002 and 2020. When comparing February to January, a similar decrease in total precipitation can be identified when looking at the years from 2002 to 2019. What becomes clear is that the amount of total precipitation is decreasing from an average of 0.13 in 2002 to 0.025 in 2018. The lowest amount of precipitation in the months of January are measured in the years of 1960, 1963 and 1968. Another interesting event can be seen from the years of 1950 to 1986, where the total precipitation was generally lower than in the following years, never reaching above an amount of 0.1. When comparing the fluctuations happening in both January and February, there is not a clear trend to be identified as almost all peaks and dips differ between both months.

Total Precipitation March

Taking a closer look at March, we can clearly see that after the year of 1976, more extreme fluctuations are measured. In the previous months we identified a period of declining precipitation at the beginning of the time period and this can be said for March as well. From 1950 to the year 1976, we could see a slight decrease in total precipitation. Something that stands out in the graph

is the period of time between of 1978 to 1989, where the amount of precipitation on average does not fall below 0.06. Afterwards, the fluctuations become a lot more extreme in a sense that the peaks and dips are reaching higher and lower than we could see in previous years. In the years of 1993 and 2011, the amount of precipitation was the lowest of all, staying just below 0.02. In the years from 2011 to 2019 we identify an increasing trend with regards to the precipitation. This increase starts off low at 0.018 in 2011 and reaches up to an amount of approximately 0.125 in the year 2019. In some of the spring months we can see that towards the end of the graph there is a sharp fall in total precipitation. This is true for the months of February, March, April and May.

Total Precipitation April

When looking at the April graph, we can see that in the years from 1950 to 1997, the total average precipitation in Friesland never reached above an amount of 0.1. After this period more extreme fluctuations appeared, of which the first big peak can be seen already in 1998 reaching almost 0.12. Between the years of 1998 and 2011 there has been a significant period of decrease in precipitation. This period started off at approximately 0.12 in 1998 and fell to almost zero in 2011 and started rising again until around the year 2018, reaching 0.1 again. After the year 2018, we can see quite a drop in total precipitation in 2019 falling to almost 0.02. As mentioned before, a similar drop can be spotted in some of the other months. Over the whole of the seventy-year period, it is difficult to identify a clear increasing trend. For the later decades however, this does seem to be the case.

Total Precipitation May

The months of May started off quite in the middle of the y-axes in the year 1950 at 0.08 but quickly drops to 0.03 one year later. These drops happen a lot over the years, in this month, and the biggest drops to be identified occurred in the years: 1959, 1970, 1980, 1989 and a lot later in 2019. For all of these years, the total amount of precipitation dropped to approximately 0.02 on average. Furthermore, something that stands out significantly are the high peaks in several years. These peaks reach well above a precipitation of 0.12 in the years of 1967, 1983 and 2007. One of those peaks goes up even higher; reaching above 0.14 in the year of 2014. This increasing trend in precipitation started around the year of 2008 at approximately 0.04. However, quickly afterwards that increasing trend stops and that high peak drops towards 0.03 in only 5 years. This seems to be the biggest fall that has occurred in May over the years. Between the years of 1991 and 2016, it becomes clear that the amount of precipitation has not fallen below 0.04; pointing out a possible increase in total precipitation.

Total Precipitation June

Taking a closer look at June over the past years, it seems that there was generally more precipitation happening than in the May months for instance. June experiences many significant fluctuations, meaning that there are high peaks and low drops occurring quickly after one another. In the start of the time period, it is visible that over the course of almost twelve years, the total amount of precipitation has been quite low without a lot of fluctuation; staying consistently between 0.09 and 0.04 for over a decade. The greatest peaks have occurred in the years of 1966 and 1998 reaching 0.14 and above 0.15 respectively. In this graph, it is hard to identify a true linear trend. However, with respect to the time period between 1997 and 2020, the total amount of precipitation has stayed above 0.04, where in the years of 1967, 1969, 1976 and 1996 the average precipitation did drop below 0.04 for the month of June. The largest (and quickest) fluctuation in June occurred between 1996 and 1998, where the average amount of precipitation increase from 0.025 to 0.15.

Total Precipitation July

July shows several big peaks and drops; however, they seem to be less significant than what occurred in June. Taking a look at the graph, it becomes clear that for only two years the total amount of precipitation fell below 0.025. This occurred in the years of 1976 and some decades later in 2018. In the middle of the graph, it seems that the total precipitation has been slightly less over a big period of time (with an exception in the year of 1988). Between the years of 1971 and 2006, the precipitation has stayed well below 0.15 and in many years even below 0.1. Similarly, to April, July experiences a big fall in precipitation around the year 2017. However, in July the total precipitation shoots up again in 2018, similarly to what happened in June. Interestingly, July shows a clear increasing trend over the last years. Between the years of 2007 and 2018, average precipitation has dropped from approximately 1.18 to 0.015.

Total Precipitation August

The first significant trend to be mentioned in August is similar to what has occurred in July. In July it became clear that in the middle of the time period, there was a decrease in precipitation measured in many years. This seems to be a trend that is happening in August as well, as the same event occurred over the years between 1970 and 2003 where the precipitation levels again stayed between 0.025 and 0.15. As we have seen in July, there was a clear decreasing trend happening towards the end of the time period. The same goes for August, where between the years of 2004 and 2019, the total precipitation has decreased significantly.

Total Precipitation September

The September months show several very high peaks and low drops. However, after the biggest peak in 1994 where the total precipitation peaked around 0.2, the precipitation has dropped and became the fluctuations became less extreme. Over the long period of time between 1996 and 2019, it is clear that the amount of precipitation stays almost perfectly between 0.025 and 0.15. This might imply that, similarly to August and July, there is evidence for a decreasing trend in precipitation over the last years. The three highest peaks occurred in the years 1957, 1974 and 1994 where the average total precipitation was around 0.2. In September of the year 1959, there was almost zero precipitation and after that it was the year 1969 with the littlest amount of precipitation, around 0.02.

Total Precipitation October

In October it is clear that the amount of precipitation over the last seventy years was less than in the previous month. In only two years has the precipitation reached above 0,175, whereas for the rest of the seventy years, it stayed below this number. When comparing the graph to the previous months, it becomes clear that a similar trend happens in October as in July, August and September. As explained before, in these months the precipitation has shown a decreasing trend over the last years. The same is true for October as between the years 1998 and 2018, the precipitation has decreased from 0.2 to 0.035. Another similar trend can be identified, as many of the graphs show a clear increase in precipitation, right after a decreasing trend. This is the case for the months of July, August, September and October. In all of these months there was a clear decreasing trend occurring, followed by a (sometimes sharp) increase towards the last year of the time period.

Total Precipitation November

The year 1977 is quite significant for the graph of November, as this is the only year where the precipitation reaches 0.2. All of the other years (except for two) experiences precipitations amounts well below 0.15. Between the years 1958 and 1977, an increasing trend can be observed where precipitation levels rose from 0.02 towards 0.2. In the years of 1974 and 1992, precipitation levels were around 0.155. Only in the years 1958 and 2011 did the precipitation fall below 0.025. Another interesting aspect of this graph is that when looking at the full time period, it seems that precipitation in most of the years was measured between 0.125 and 0.5, which is a relatively small range. After the year 1992 we can see that the precipitation in November over the years has fallen

until 2019, from 0.16 to 0.05. This is the same trend as we have identified in some of the previous months; however, for this month the precipitation level does not shoot up again in the last year.

Total Precipitation December

For the December months, there is less of a decreasing trend occurring towards the end of the graph, as was seen in many of the previous months. Taking a closer look at December we can see that in the year of 1965 there was a great peak occurring where the total amount of precipitation on average reached above 0.175. Interestingly, this amount quickly dropped to below 0.05 in the year 1968 and stayed below this level for about four years. Furthermore, in the years of 1986, 1993 and 1999 there were some peaks that reached above 0.15. The lowest precipitation level is measured in the year 1963, right before the biggest peak. Between the years 1998 and 2005 there was a decrease in precipitation for almost a decade. After this period of time, the level of precipitation increased again and kept fluctuating a lot until the end of the time period.

Annual Total Precipitation Friesland

After studying every month separately, the following analyses regard total precipitation of all months combined, starting off with the area of Friesland. The biggest peak of precipitation occurred in the year of 1998, reaching approximately 1.25. For all other years the precipitation has stayed below 1.15. The years with the lowest amount of total precipitation were 1959 with a measured amount of 0.55 and 1976 with an amount around 0.6. After the peak in 1998, the total amount of precipitation immediately dropped and has been lower until the end of the timeframe. During the years of 2004 to 2012, precipitation amounts have not fallen below 0.9 which is not significantly different from previous years. The period of lower precipitation does therefore not necessarily show a decreasing trend in precipitation.

Annual Total Precipitation Europe

Zooming out, it is evident that the total amount of precipitation in Europe differs from what can be observed in Friesland. First of all, it is important to consider that the scale on the y-axis is less wide, ranging from only 0.6 to 1, as compared to 0.4 to 1.4 for Friesland. For Europe the lowest drop in total precipitation occurred in the year 1953, falling to almost 0.65. After this year the amounts of precipitation have stayed well above 0.7, showing generally more precipitation than the graph of Friesland. After the drop in 1953, amounts have increased up till almost 0.95 in 1972. After this year, total precipitation has decreased, staying below 0.85 between 1982 and 2008. However, this increases again and there is no decreasing trend to be identified over Europe.

Explanatory Factors

In some cases, winds from the east (easterly winds) can cause weather that is cold and clear in winter with temperatures sometimes well below zero, but in warm and dry in summer; resulting in a more continental type of weather compared to the existing maritime climate (influenced by the Atlantic Ocean and North Sea). To understand more about wind as an underlying mechanism of the Dutch climate, the next pages will consider data based on U and V wind components, or wind vector components. As there is a lack of higher resolution maps that help us to see the Netherlands alone, we will take the map of Europe for this. Furthermore, as explained before this research goes into depth with regards to April in particular.

Changes in atmospheric circulations

The graphs below show these U and V wind vector components, which are indicators of wind direction or dynamics. All wind component maps are expressed in measurements of meters per second (m/s). The components are northward and eastward wind vectors that are indicated by the variables V and U. The variable V indicates the northward wind and the variable U the eastward. The U wind component is in theory parallel to the X-axis whereas the V wind component is parallel to the Y-axes. Both of the components and be described as positive or negative when considering the x or y variable. A negative U wind, meaning below zero on the x-axis, comes from the east. This wind is thus blowing from east to west and can be called a westerly wind. Contrarily, a positive U wind component, meaning a number above zero on the x-axis, describes a wind blowing from west to east which can be called an easterly wind. The same goes for the V wind component, where a negative V component is identified by a number below zero on the y-axis, describing a wind that blows from North to South (a southerly wind). A positive V wind comes from the south and blows to the north, being indicated by a number above zero on the y-axis. Looking back at the 2-meter temperature map of April, we could see that the coldest temperature of April over the whole of 1950-2020 was measured in the period between 1970 and 1980 and showed an increasing trend between 1990 and 2008. This is the reason that the first U and V wind component maps are based on these time frames. The aim is to find changes in the wind dynamics of one period contrary to another period, therefore this part of the research is based on anomalies in contrast to the averages used in the 2-meter temperature graphs.

Wind vector anomaly: Time period 1990-2008 compared to 1970-1980

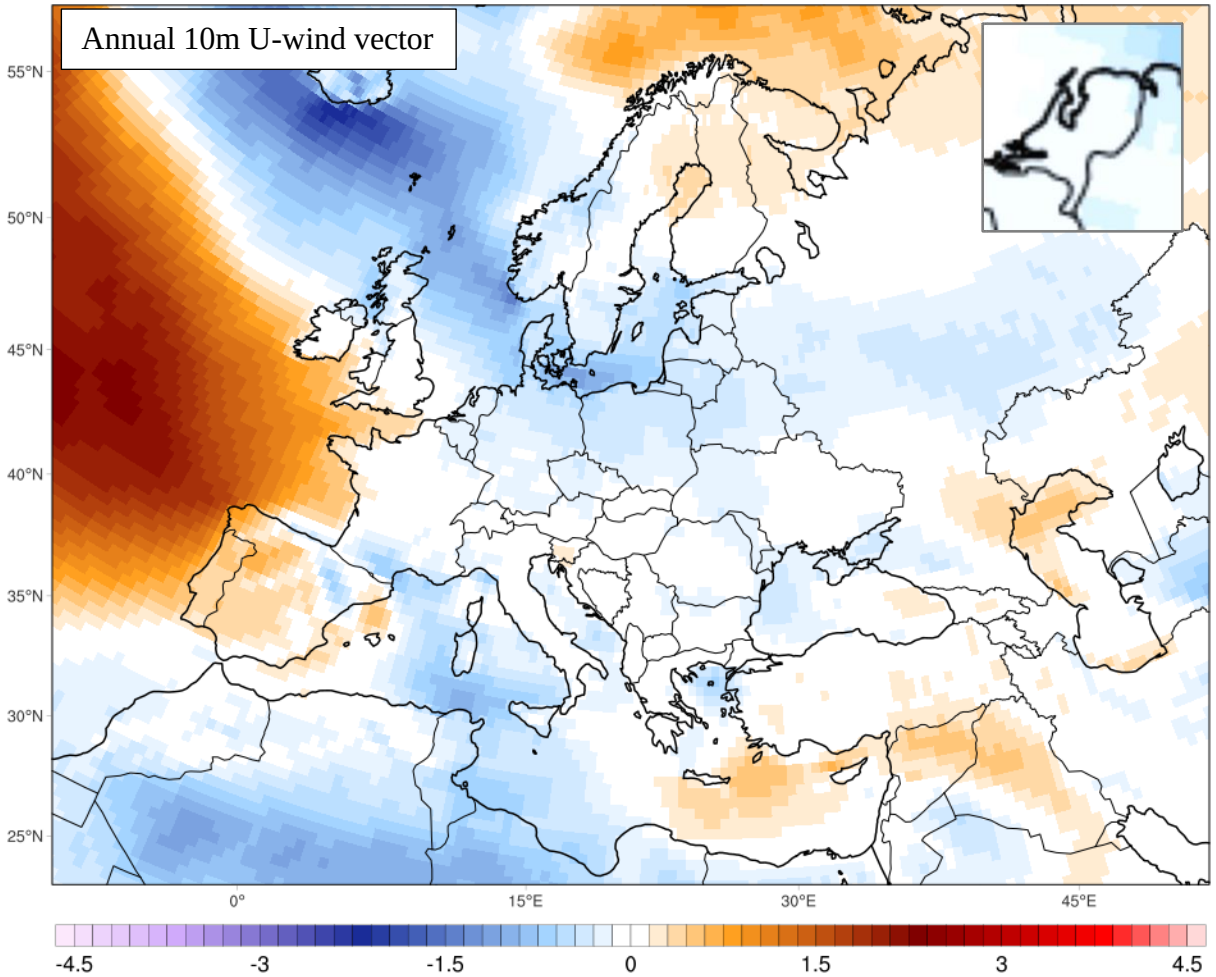
Looking at the wind component anomaly maps of the time period 1990-2008, as opposed to that cold period between 1970 and 1980, it becomes evident that the wind dynamics are changing and

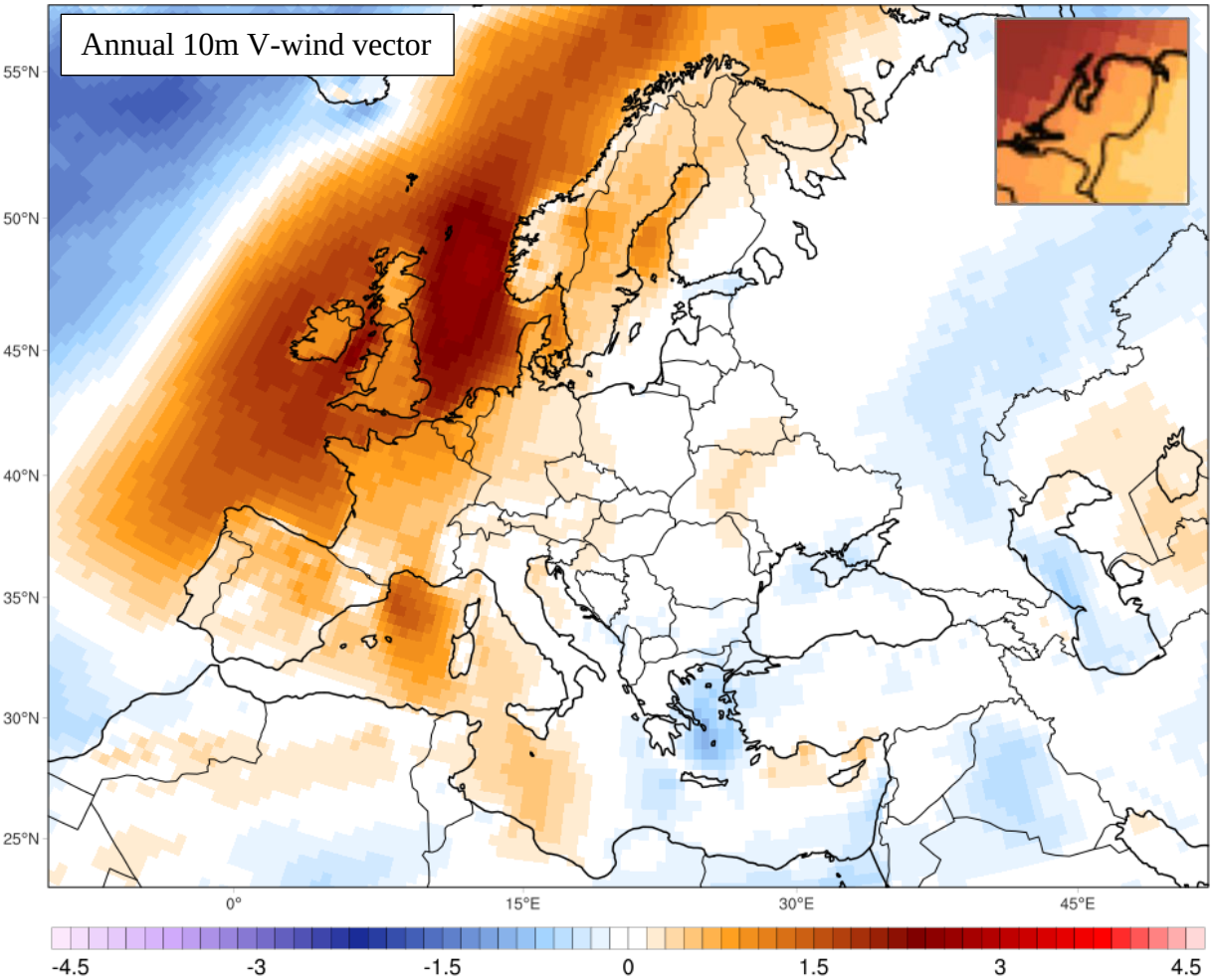
shifting towards a more North-West direction. What can be derived from the first graph is that the U-component over the Netherlands is negative and thus an easterly wind. This means that the there is a continental wind, blowing from east to west, potentially bringing a warmer more land-like climate to the Netherlands. The same event can be spotted when considering the V-wind component in the second graph. Above the Netherlands we can see an orange color, indicating a positive number of around 1.3 (m/s). This number explains that the V-component, following the y-axes, is positive and therefore following a more South to North direction. This again means that continental winds blow towards the oceans and over the Netherlands, potentially increasing the temperature.

Wind vector anomaly: Time period 2011-2020 compared to 1950-2020

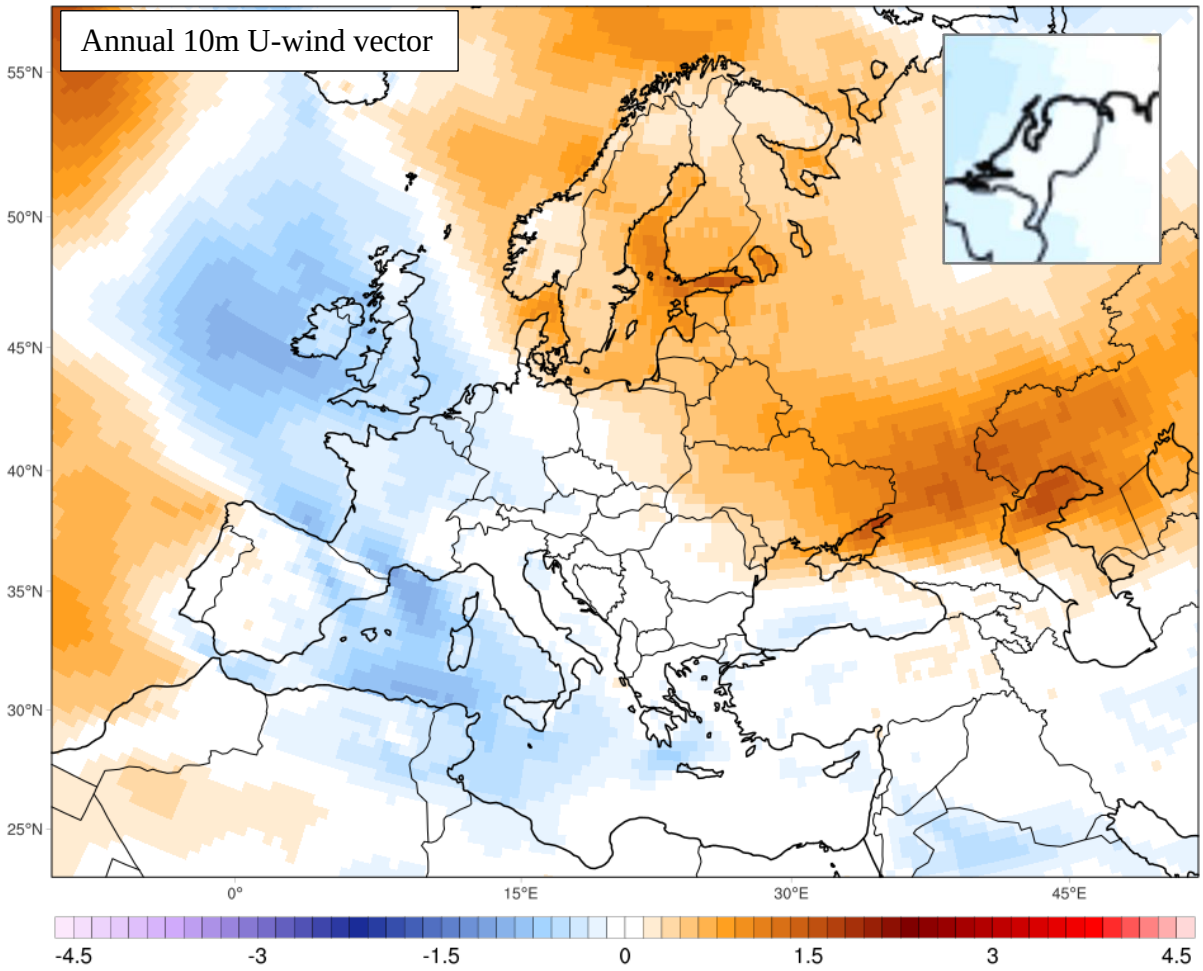
After contrasting the coldest period from the April months to the period showing the largest increasing trend, the coming results are based on the most recent contrasted to the full time period used in this study, 1950-2020. Taking a closer look at the U- and V-components regarding the previous decade, a similar event can be spotted to the previous maps, however it is less strongly displayed. The anomaly shown in the second U-wind component shows that the wind direction over the Netherlands has slightly shifted. The U-component in this area has a faint blue color, indicating a negative U-wind component, which indicates the presence of a n easterly wind. The wind is thus blowing from the inland towards the ocean side of the Netherlands, again potentially bringing warmer temperatures along with it. The V-component is slightly orange above the Netherlands which indicates a positive V-wind component and a wind that blows from South to North. This again means that, similarly to the previous studies time period, a more continental wind is blowing over the Netherlands, experiencing a more North-Western wind as compared to the time periods of 1970-1980 and 1950-2020. These findings could help to explain the increasing trend that can be seen in for instance the month of April, as well as in other months. Besides wind dynamics, wider atmospheric disturbance might be caused by other factors which have to be studied in order to better understand the underlying causes of the temperature changes.

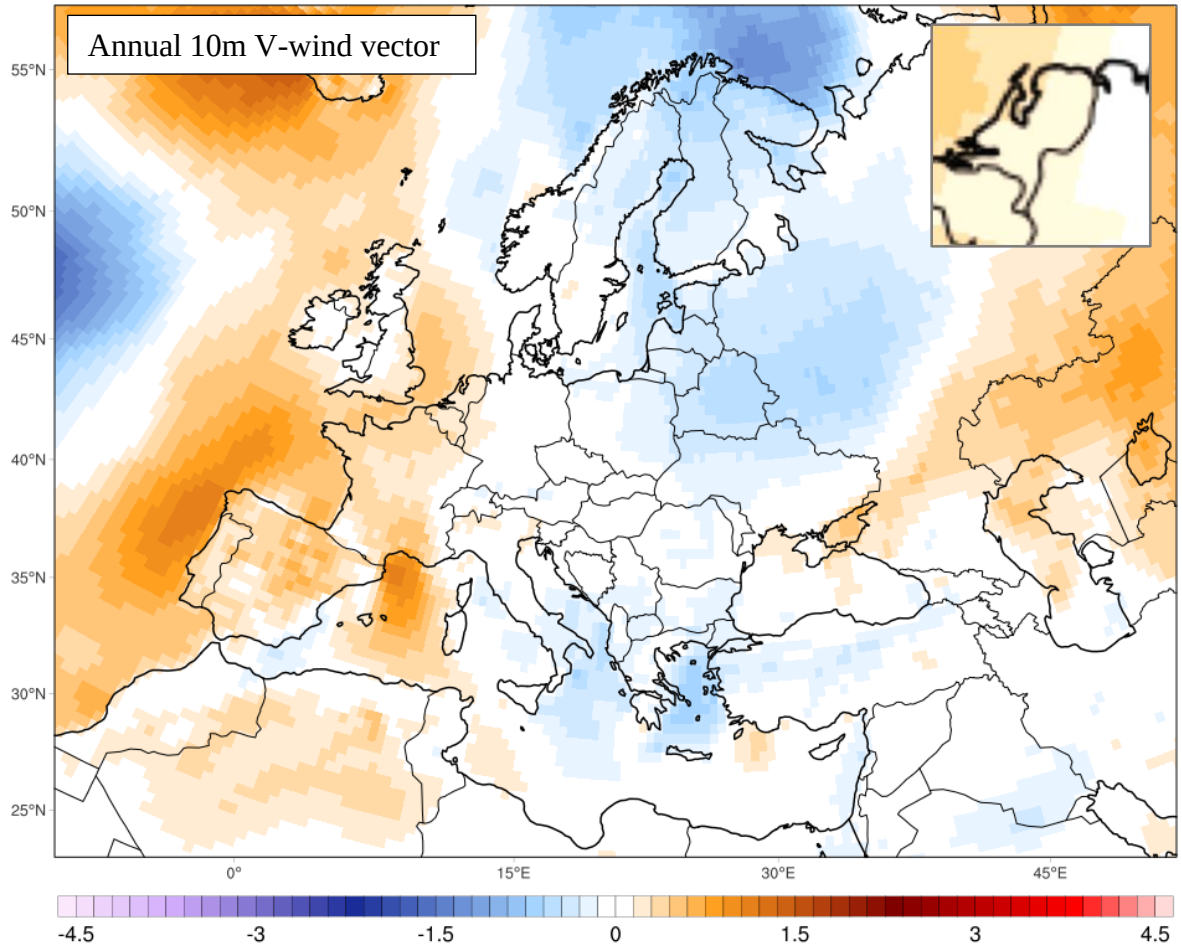
10m U- and V-wind component anomaly (m/s): 1990-2008 over 1970-1980





10m U- and V-wind component anomaly (m/s): 2011-2020 over 1950-2020



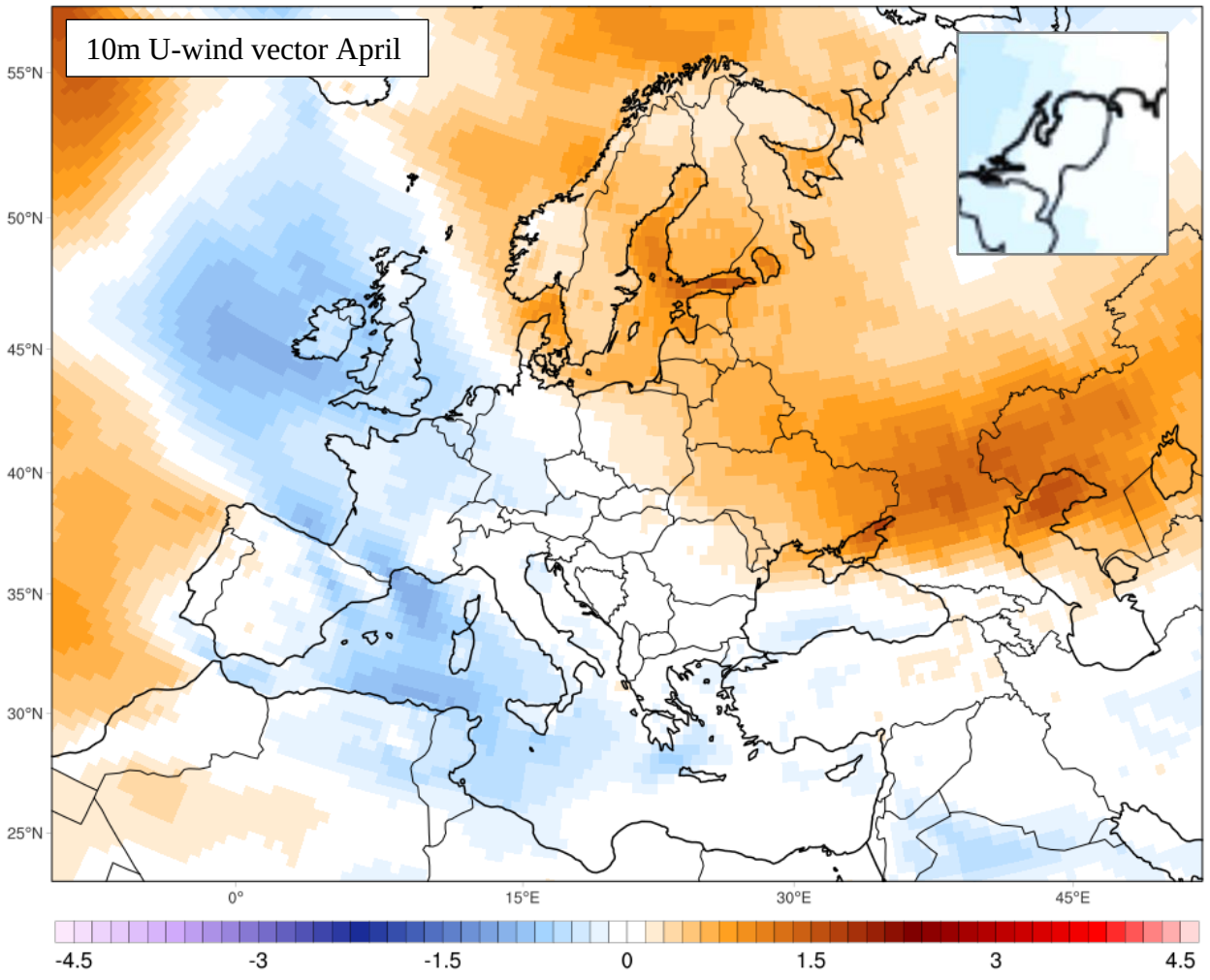


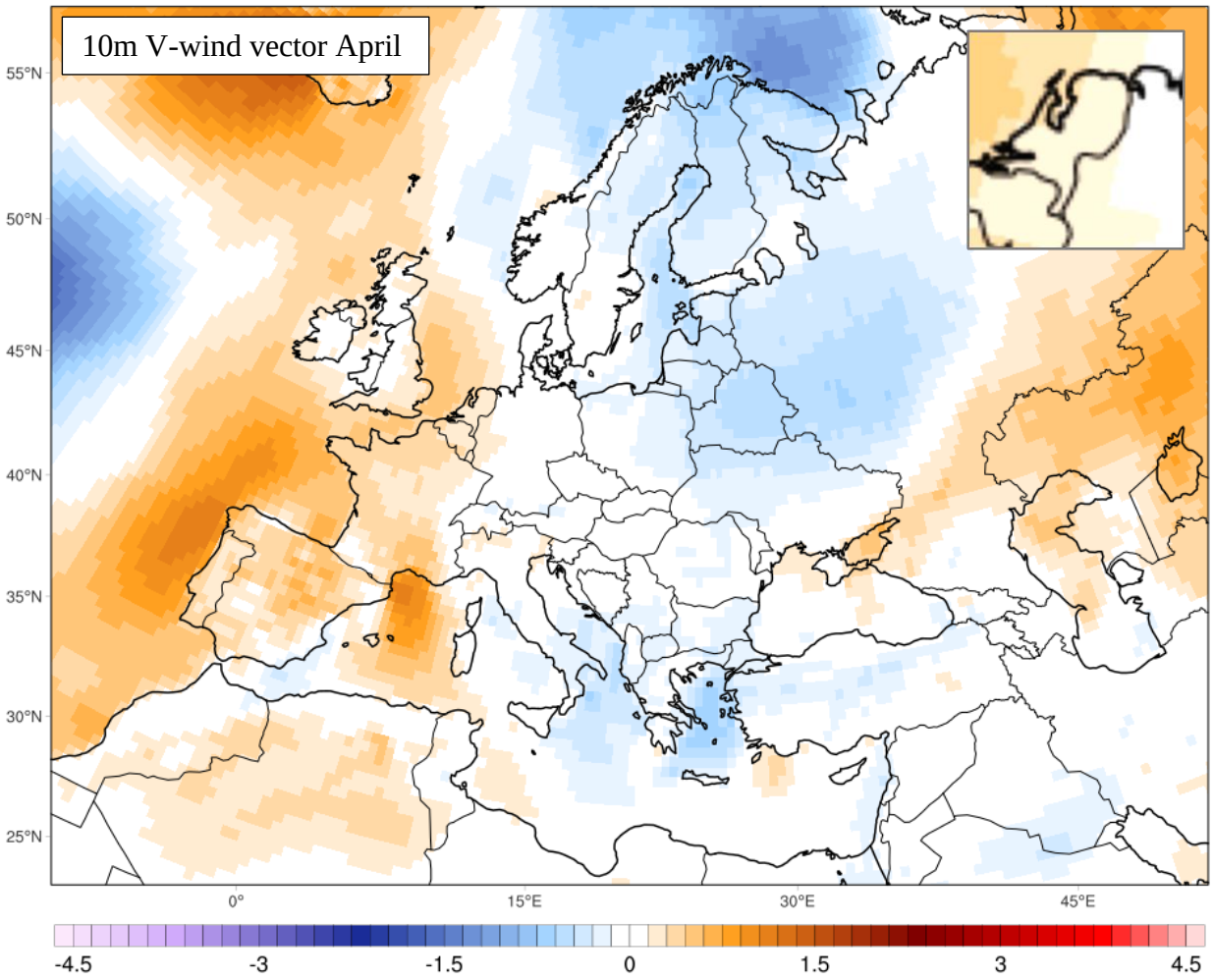
Wind vector anomalies of April

After studying the annual changes with regards to the U- and V-wind components, it is interesting to take a closer look at the month of April in particular to try and discover an explanation for the increased 2m temperatures in this month. Starting off with the U-wind component, a light blue color can be observed in the map over the Netherlands. This color corresponds to a negative U-wind vector, which means that for the month of April over the years 2011-2020, a shift in wind direction from east to west is measured. In other words, the atmospheric circulations have slightly changed brining more continental easterly winds to Friesland and the Netherlands as a whole.

When interpreting the second graph for April, a light orange color can be seen which corresponds with a positive V-wind component. A positive V-wind component, as aforementioned, describes wind that shifts towards a south to north direction. This means that on average, when comparing the years 2011-2020 to the whole of 1950-2020, more continental northerly winds blow over the Netherlands in April. When combining both of these maps, it can be stated that the general wind direction in April has shifted, blowing from the south-east towards the a more north-west direction.

10m U- and V-wind component anomaly April (m/s): 2011-2020 over 1950-2020

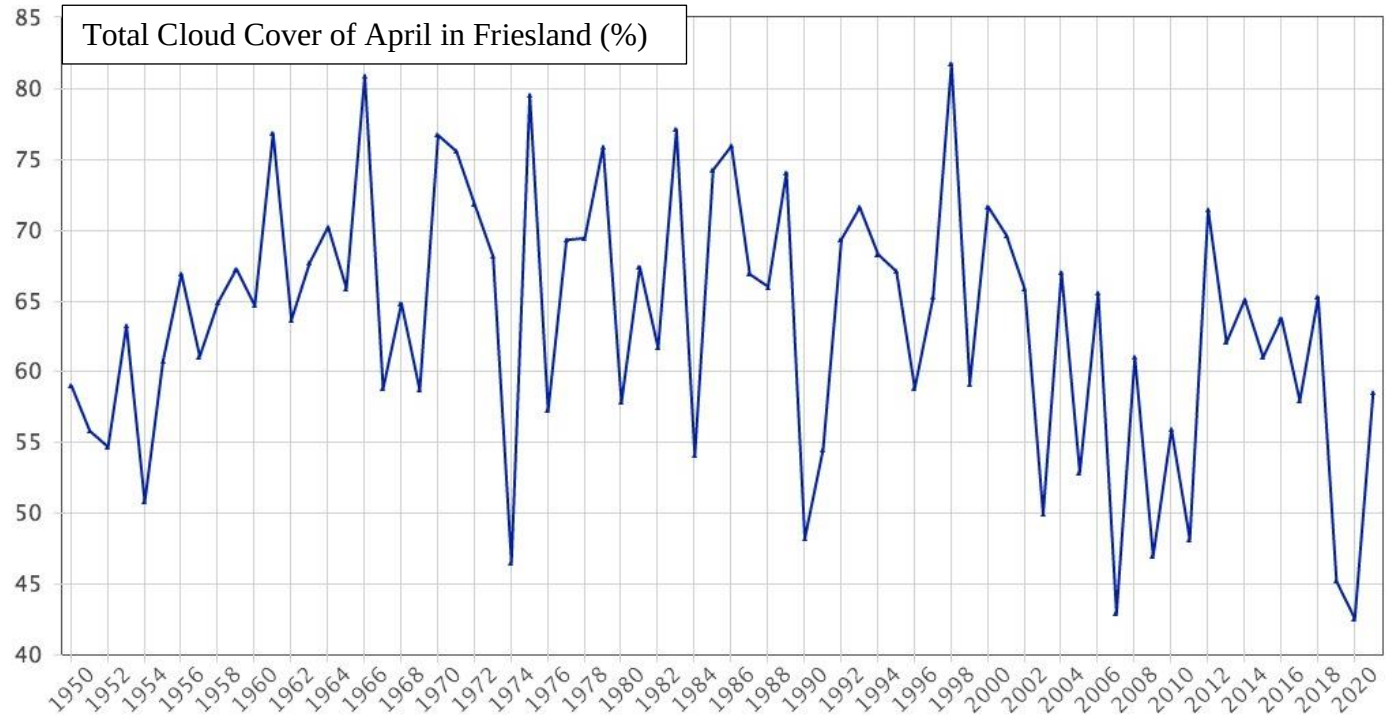


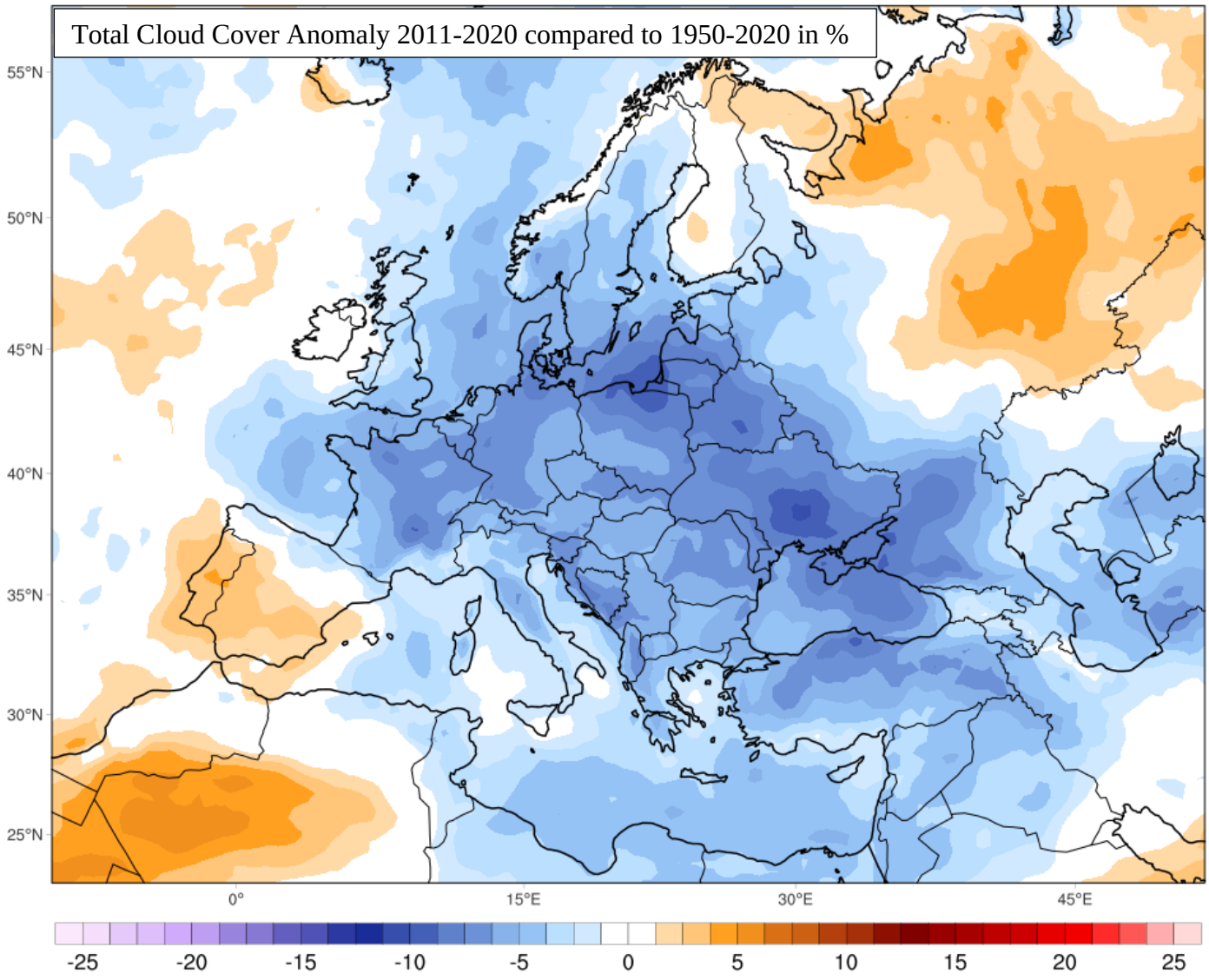


Cloud Cover

In order to further explain the increasing temperature that has been identified particularly in April, the coming research studies the changes in total cloud cover over the area of Friesland. Changes in cloud cover have specific effects, depending on the area. Clouds above the Netherlands have a strong albedo affect, more dominant than the warming of the greenhouse effect. A reduction in cloud cover over this area results in significantly less reflection of sunlight, which means that the temperatures shall rise. Taking a closer look at the graph below, many fluctuations of the total cloud cover can be observed. The graph shows many great peaks and drops, with the highest total cloud cover measure din the year 1998. Keeping in mind the relation between cloud cover and temperature changes; we can see that the temperature of April in this year has been evidently less than the following decades, staying just below 9 degrees Celsius. When considering the fact that in April, an increasing trend in temperature was identified over the last decade, it is not at all a coincidence that the total cloud cover has decreased in April over the last decade. In other words, there might be a connection between the decreased cloud cover and increased temperatures for April over the past decade. Looking at the anomaly map, the same occurrence can be observed; the Netherlands are indicated with a blue color which corresponds to a decreasing total cloud cover regarding the period of 2011-2020. Generally, a minimal decrease in cloud cover in April

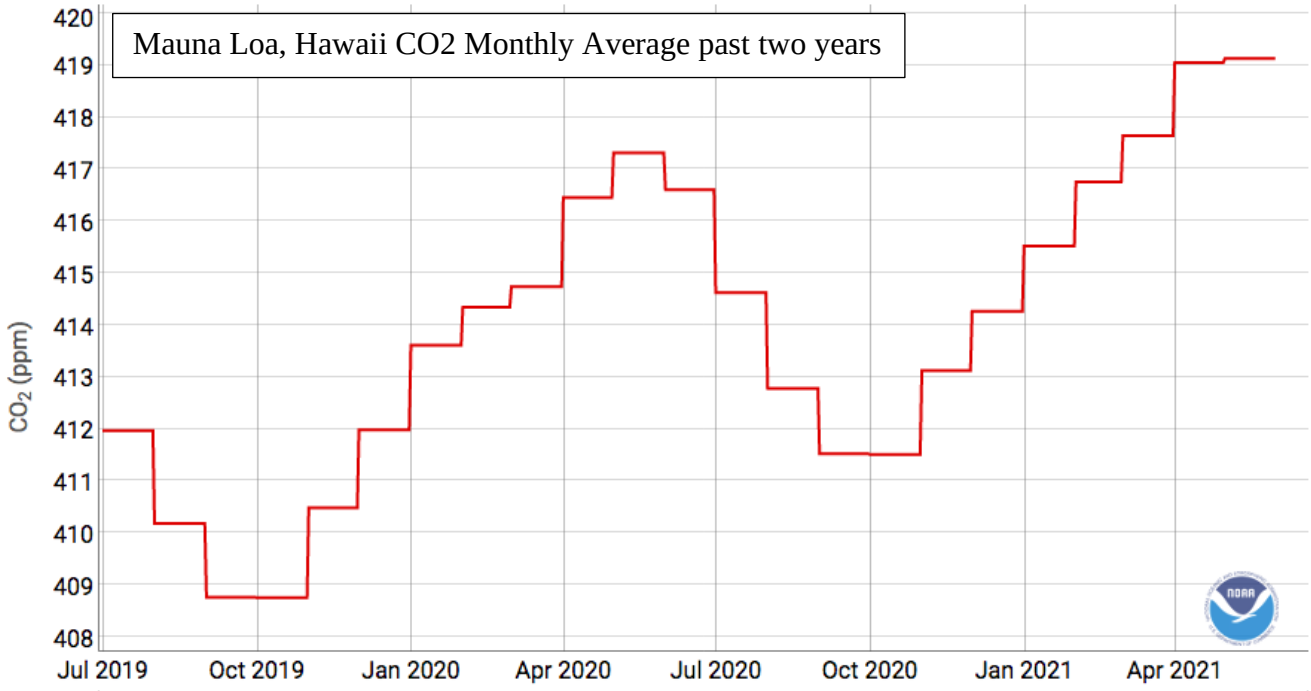
over the last decade can be identified. Even though this decrease is relatively little at such a large scale, it might support the increase in temperature of April besides the other explanatory factors.





Atmospheric CO2

After carefully examining the changes in atmospheric circulations and cloud cover, it is useful to take a closer look at the CO2 levels over the past years, specifically for the month of April. The graph describes CO2 levels measured in ppm units; expressed in parts per million. The levels of atmospheric CO2 have great influences on local temperatures and temperature changes and is therefore an essential part of this research. When looking at the CO2 timeseries below, a similar trend can be identified to what has been observed before, namely atmospheric changes in April. This graph shows monthly CO2 level fluctuations over the last two years in Mauna Loa, Hawaii. Even though the area is located far away from the area of interest (Friesland), the expectation is that it can be used as a representative due to similarities of the Northern Hemisphere, where both areas are located. The reason for using this is caused by a lack of available data with regards to CO2 levels in Friesland. When considering the data of Mauna Loa over the past two years, it becomes clear that the peaks happen in the months of April and May. In other words, CO2 levels show seasonal changes with peaks that are most significant in April and May. Therefore, there is a strong believe that these CO2 peaks have been of influence to the increasing temperature trend in April. More extensive data can be found in the appendix A; showing the peaks in CO2 occurring most significantly in April and May over the years of 1958 to 2018.



Source: NOAA-ESRL (2018) *NOAA Monthly Data*. Co2.Earth

Conclusion

After analyzing the ERA5 temperature data, it became evident that an increasing trend in temperature could be identified in the months of April over the last years as compared to the whole period between 1950 to 2020. This fits to the IPCC expectations regarding future climate change and the accompanying temperature increases. Furthermore, the total precipitation changes over the last seventy years have also been studied. The outcome of this study is that the total precipitation in Friesland has not changed significantly over the past decade as compared to the last seventy years. For some months stronger dips in precipitation have been observed as well as times of less precipitation, however no real decreasing trend could be identified. In order to explain the increasing temperatures in the month of April over the past years, we have looked into several underlying mechanisms. These explanatory factors included cloud cover, changes in atmospheric circulations and CO2 levels. After studying the changes in cloud cover in more depth, I came to believing that the temperature increase in the April months may partially be caused by a decreasing trend in cloud cover. Furthermore, the same can be stated for the factor of atmospheric circulations. The changes in atmospheric circulations have been measured by the hand of U- and V-wind vector components and the shifts they have displayed over the past decade as compared to the broader period of 1950-2020. What could be observed was a shifting atmospheric circulation with wind turning towards the North-West, bringing along warmer continental winds in April. This, combined with the deceasing cloud cover might be of influence to the increasing temperatures. At last, the CO2 levels have been studied over a representative area in order to identify a relation between CO2 levels and an increasing temperature for April. What has been observed is a seasonal CO2 change which resulted in CO2 peaks occurring mostly in April and May. Due to the nature of CO2 and it’s the knowledge we have on its’ impact, it is believed that this might be the most significant explanation to the increasing temperature in the months of April. In conclusions, the monthly warming of April can be explained by a threefold of factors with the main cause being atmospheric CO2 peaks.

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Appendix A.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	407.98	408.35	409.46	410.26	411.24	410.79	408.71	**406.99**	0.00	0.00	0.00	0.00
2017	406.13	406.42	407.18	409.00	409.65	408.84	407.07	**405.07**	403.38	403.64	405.14	406.82
2016	402.52	404.04	404.83	407.42	407.70	406.81	404.39	**402.25**	401.03	401.57	403.53	404.42
2015	399.98	400.28	401.54	403.28	403.96	402.80	401.31	**398.93**	397.63	398.29	400.16	401.85
2014	397.85	398.01	399.77	401.38	401.78	401.25	399.10	**397.03**	395.38	396.03	397.28	398.91
2013	395.55	396.80	397.43	398.41	399.78	398.61	397.32	**395.20**	393.45	393.70	395.16	396.84
2012	393.12	393.86	394.40	396.18	396.74	395.71	394.36	**392.39**	391.11	391.05	392.98	394.34
2011	391.33	391.86	392.60	393.25	394.19	393.73	392.51	**390.13**	389.08	389.00	390.28	391.86
2010	388.71	390.20	391.17	392.46	393.00	392.15	390.20	**388.35**	386.85	387.24	388.67	389.79
2009	386.94	387.48	388.82	389.55	390.14	389.48	388.03	**386.11**	384.74	384.43	386.02	387.42
2008	385.52	385.82	386.03	387.21	388.54	387.76	386.36	**384.09**	383.18	382.99	384.19	385.56
2007	382.89	383.90	384.58	386.50	386.56	386.10	384.50	**381.99**	380.96	381.12	382.45	383.95
2006	381.38	382.19	382.67	384.61	385.03	384.05	382.46	**380.41**	378.85	379.13	380.15	381.82
2005	378.46	379.73	380.77	382.29	382.45	382.21	380.74	**378.74**	376.70	377.00	378.35	380.11
2004	377.00	377.87	378.88	380.35	380.62	379.69	377.47	**376.01**	374.25	374.46	376.16	377.51
2003	374.88	375.64	376.45	377.73	378.60	378.28	376.70	**374.38**	373.17	373.14	374.66	375.99
2002	372.53	373.20	374.12	375.02	375.76	375.52	374.01	**371.85**	370.75	370.55	372.25	373.79
2001	370.59	371.51	372.43	373.37	373.85	373.21	371.51	**369.61**	368.18	368.45	369.76	371.24
2000	369.29	369.54	370.60	371.82	371.58	371.70	369.86	**368.13**	367.00	367.03	368.37	369.67
1999	368.18	369.07	369.68	370.99	370.96	370.30	369.45	**366.90**	364.81	365.37	366.72	368.10
1998	365.26	365.98	367.24	368.66	369.42	368.99	367.82	**365.95**	364.02	364.40	365.52	367.13
1997	363.09	364.03	364.51	366.35	366.64	365.59	364.31	**362.25**	360.29	360.82	362.49	364.38
1996	362.07	363.24	364.17	364.57	365.13	364.92	363.55	**361.38**	359.54	359.58	360.89	362.24
1995	359.92	360.86	361.83	363.30	363.69	363.19	361.64	**359.12**	358.17	357.99	359.45	360.68
1994	358.24	358.92	359.99	361.23	361.65	360.81	359.38	**357.46**	355.73	356.07	357.53	358.98
1993	357.00	357.31	358.47	359.27	360.19	359.52	357.33	**355.64**	354.03	354.12	355.41	356.91
1992	356.25	357.11	357.86	359.09	359.59	359.33	357.01	**354.94**	352.96	353.32	354.32	355.57
1991	354.84	355.73	357.23	358.66	359.13	358.13	356.19	**353.85**	352.25	352.35	353.81	355.12
1990	353.80	355.04	355.73	356.32	357.32	356.34	354.84	**353.01**	351.31	351.62	353.07	354.33
1989	352.91	353.27	353.96	355.64	355.86	355.37	353.99	**351.81**	350.05	350.25	351.49	352.85
1988	350.39	351.64	352.41	353.69	354.21	353.72	352.69	**350.40**	348.92	349.13	350.20	351.41
1987	348.52	348.73	349.73	351.31	352.09	351.53	350.11	**348.08**	346.52	346.59	347.96	349.16
1986	346.56	347.28	348.01	349.77	350.38	349.93	348.16	**346.08**	345.22	344.51	345.93	347.22
1985	345.21	346.16	347.74	348.34	349.06	348.38	346.72	**345.02**	343.27	343.13	344.49	345.88
1984	344.10	344.79	345.52	346.84	347.63	346.97	345.53	**343.55**	341.40	341.67	343.10	344.70
1983	341.68	342.90	343.33	345.25	346.03	345.63	344.19	**342.27**	340.35	340.38	341.59	343.05
1982	340.96	341.73	342.81	343.97	344.63	343.79	342.32	**340.09**	338.28	338.29	339.60	340.90
1981	339.29	340.55	341.61	342.53	343.03	342.54	340.78	**338.44**	336.95	337.08	338.58	339.88
1980	337.90	338.34	340.01	340.93	341.48	341.33	339.40	**337.70**	336.19	336.15	337.27	338.32
1979	336.14	336.69	338.27	338.95	339.21	339.26	337.54	**335.75**	333.98	334.19	335.31	336.81
1978	334.95	335.25	336.66	337.69	338.03	338.01	336.41	**334.41**	332.37	332.41	333.75	334.90
1977	332.66	333.13	334.95	336.13	336.93	336.17	334.88	**332.56**	331.29	331.27	332.41	333.60
1976	331.59	332.75	333.52	334.64	334.77	334.00	333.06	**330.68**	328.95	328.75	330.15	331.62
1975	330.73	331.46	331.90	333.17	333.94	333.45	331.98	**329.95**	328.50	328.35	329.37	330.59
1974	329.35	330.71	331.48	332.65	333.20	332.16	331.07	**329.12**	327.32	327.28	328.30	329.58

1973	328.54	329.56	330.30	331.50	332.48	332.07	330.87	**329.31**	327.51	327.18	328.16	328.64
1972	326.77	327.63	327.75	329.72	330.07	329.09	328.05	**326.32**	324.93	325.06	326.50	327.55
1971	326.17	326.68	327.18	327.78	328.92	328.57	327.34	**325.46**	323.36	323.57	324.80	326.01
1970	325.03	325.99	326.87	328.13	328.07	327.66	326.35	**324.69**	323.10	323.16	323.98	325.13
1969	324.00	324.42	325.64	326.66	327.34	326.76	325.88	**323.67**	322.38	321.78	322.85	324.11
1968	322.57	323.15	323.89	325.02	325.57	325.36	324.14	**322.03**	320.41	320.25	321.31	322.84
1967	322.07	322.50	323.04	324.42	325.00	324.09	322.55	**320.92**	319.31	319.31	320.72	321.96
1966	320.62	321.59	322.39	323.87	324.01	323.75	322.39	**320.37**	318.64	318.10	319.79	321.08
1965	319.44	320.44	320.89	322.13	322.16	321.87	321.39	**318.81**	317.81	317.30	318.87	319.42
1964	319.57	320.07	320.73	321.77	322.25	321.89	320.44	**318.70**	316.70	316.79	317.79	318.71
1963	318.74	319.08	319.86	321.39	322.25	321.47	319.74	**317.77**	316.21	315.99	317.12	318.31
1962	317.94	318.56	319.68	320.63	321.01	320.55	319.58	**317.40**	316.26	315.42	316.69	317.69
1961	316.93	317.70	318.54	319.48	320.58	319.77	318.57	**316.79**	314.80	315.38	316.10	317.01
1960	316.43	316.97	317.58	319.02	320.03	319.59	318.18	**315.91**	314.16	313.83	315.00	316.19
1959	315.62	316.38	316.71	317.72	318.29	318.15	316.54	**314.80**	313.84	313.26	314.80	315.58
1958			315.71	317.45	317.50	317.10	315.86	**314.93**	313.20	312.66	313.33	314.67