

How are extreme temperatures changing in Sweden

Jakob Petersson

Department of Physics at Lund University

SUPERVISOR: MARKKU RUMMUKAINEN, LUND UNIVERSITY

2ND SUPERVISOR: ELNA HEIMDAL NILSSON, LUND UNIVERSITY

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Abstract

Global mean temperature has been observed to increase over the last hundred years; this increase is coupled with a global increase of warm extreme indices and a decrease in cold extreme indices. In this study, daily observations of mean and extreme temperatures from ten different weather stations in Sweden during the time period 1961-2010 were analyzed. A warming trend was identified for every data series for all stations at a statistical significance of 99.95% (with one exception at 99.9%). The tendencies differ between the stations where some show a higher increase in mean temperature while others a higher increase in extreme temperatures; the different rate of change is concluded to depend on local and regional weather effects. Northern Sweden is compared to Southern Sweden and the stations in Northern Sweden show a higher warming in cold extreme temperatures ($0.04^{\circ}\text{C}/\text{y}$ on average) than in the warm extreme temperatures ($0.028^{\circ}\text{C}/\text{y}$ on average). In Southern Sweden there is a higher warming in the warm temperature extremes ($0.037^{\circ}\text{C}/\text{y}$ on average) compared to the cold temperature extremes ($0.028^{\circ}\text{C}/\text{y}$ on average). During the time period, the stations show an increase of the warm extreme temperatures of $0.8\text{-}2.3^{\circ}\text{C}$ and $0.7\text{-}2.5^{\circ}\text{C}$ for the cold extremes.

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Abbreviations

°C – degrees in Celsius

AR4 – IPCC's Fourth Assessment Report

AR5 – IPCC's Fifth Assessment Report

GHG – Greenhouse Gas

IPCC - Intergovernmental Panel on Climate Change

RCP8.5 – Representative Concentration Pathway 8.5 (Where 8.5 stands for the radiative forcing caused by GHG)

SMHI - Swedish Meteorological and Hydrological Institute

UTC – Coordinated Universal Time/Temps Universel Coordonné

Introduction

Background

Global warming has become a hot topic in recent years. Scientists all over the World study the changes in nature around us and try to model the near and distant future in order to understand what we have to expect and what we have to prepare for. Due to the impacts of the changing climate it is very important for us to visualize these changes and prepare our societies for new potential threats. Many risks can be identified ahead of time with a greater understanding and proper means can be utilized in order to protect our interests.

It has been observed (Figure 1) that the global mean temperature has increased over the last hundred years with a stronger rate after 1970. It is also noted that the warming is more prominent over land than over ocean (Trenberth et al., 2007; Hartmann et al., 2013).

Sweden has four distinct seasons (spring, summer, autumn and winter) which demands a versatile infrastructure to deal with the various weather events. Every year the society is challenged by the varied amount of snowfall, local city floods caused by heavy precipitation, crops suffering from droughts and forests being thinned out by storms. The long range of temperatures demands a mixture of asphalt capable of resisting melting in hot weather and from ice cracks (water expansion when freezing).

It has always been popular in our history to believe that nature will solve our pollution and waste problems for us. Ever since man started manipulating nature to produce items for our own benefit we have effectively contributed to a changing climate. Nature will always adapt but these adaptations come with consequences. The industrialization leads to a steady increase of atmospheric carbon which serves as greenhouse gases. The increased industrialization on the planet to meet the demands

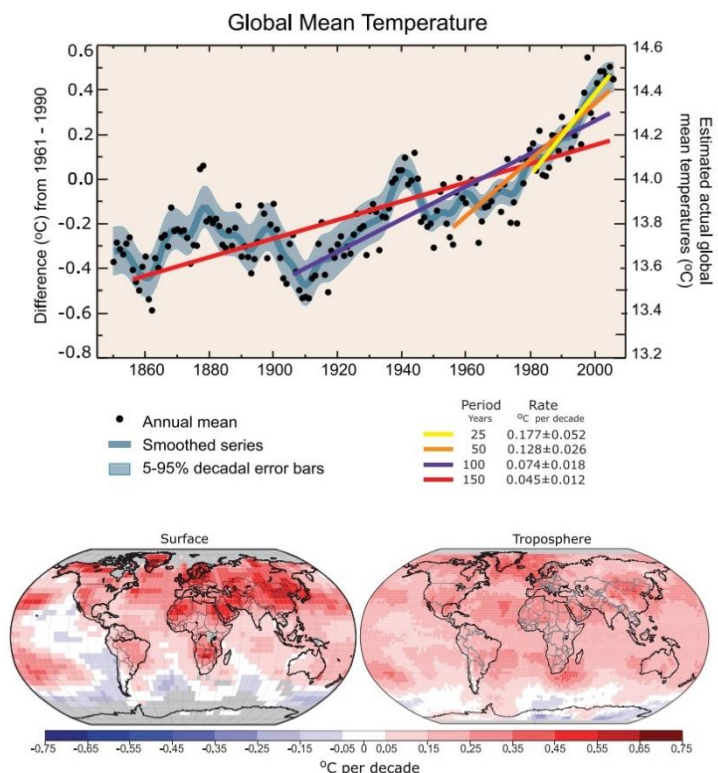


Figure 1: The trend of the global mean temperature (top) has steadily been increasing since 1860s. Four different period trends are visualized: 1981-2005 in yellow, 1956-2005 in orange, 1906-2005 in blue and 1856-2005 in red. (Bottom) Linear global temperature trends during 1979-2005 for surface (left) and the troposphere (right, to about 10km altitude) are visualized in colors, blue representing a decrease in degrees per decade and red for a warming trend (Trenberth et al., 2007).

of society leads to a further increase of GHG which in turn strengthen the radiative forcing; this results in an increasing global mean temperature (Hartmann et al., 2013).

In AR5, the IPCC model the trajectories of four different levels of GHG concentrations known as RCP. In these so called scenarios the mean global temperature is set to increase but at different rates depending on the GHG concentrations. In the scenario with the largest amount of atmospheric GHG, RCP8.5; the global mean temperature can rise with 4.8C by the end of the 21st century. This projection is in comparison to the time period 1986-2005. This warming leads to changes in temperature extremes (Hartmann et al., 2013).

The IPCC has stated in AR4 (Trenberth et al., 2007) that “*it was very likely that a large majority of global land areas had experienced decreases in indices of cold extremes and increases in indices of warm extremes, since the middle of the 20th century, consistent with warming of the climate*” which is substantiated in AR5 (Hartmann et al., 2013) as can be observed in Figure 2. Looking at extreme events and temperatures gives an alternate picture compared to mean values. Many species as well as manufactured items may be resistant enough to a change in mean values but a shock in extreme values could prove fatal. Imagine a glass window; it will hold even if you start drumming slowly on it for a given time. But the burst force of a punch will shatter it into many pieces. Most structures in nature can better withstand an increase of mean values than endure extreme peaks rising above certain threshold values, such as the window and the punch. Another example of extreme value importance is that many plants are programmed to initiate its growing sequence and annual termination sequence by frost events.

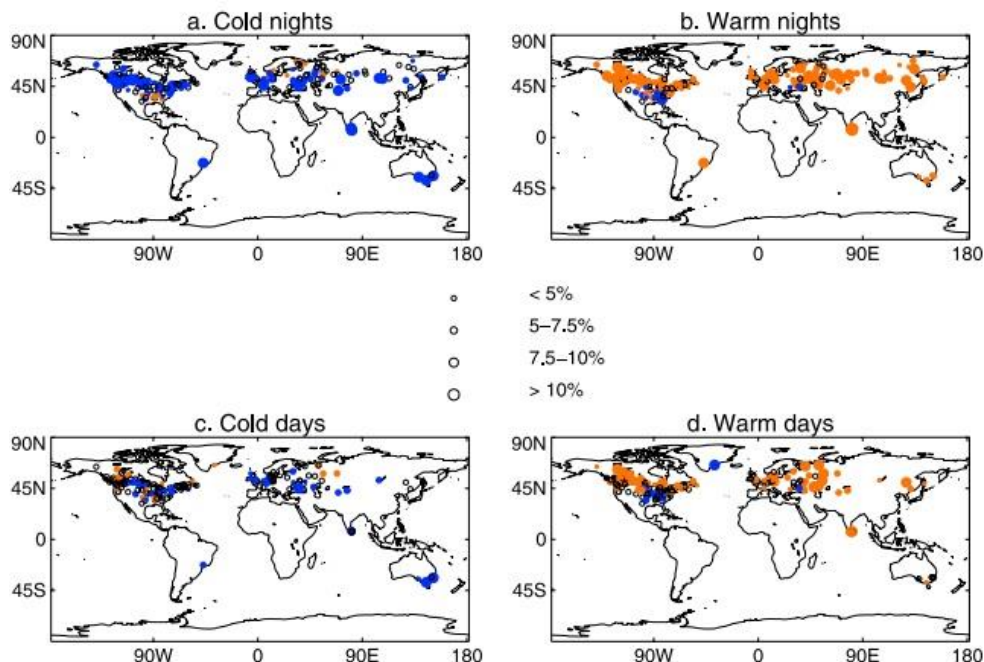


Figure 2: Percentile temperature indices trends representing cold nights (a), warm nights (b), cold days (c) and warm days (d) for the time frame 1901-2003. Stations fulfill a requirement of at least 80% complete data for the time period. The Blue dots represent a decreasing change, red dots an increasing change and black dots an insignificant change (Alexander et al., 2006).

As mentioned with the frost event, agriculture and plant life is extremely dependent on climate change. The temperature is closely coupled together with radiation balance, winds and cloud cover. A steady change of temperature will alter the water cycle; affecting evaporation and precipitation which have a major impact on agriculture production. (Tao et al., 2002)

Not only vegetation but also animal and insect species feel climate change. Severe droughts and weather events can cause populations to recolonize into less favorable habitats. Experiencing frequent forced adaptations to less optimal living leads to endangering species, for example in cases where hospitable habitats run scarce: the dispersal rate lowers and the extinction risk increases (Kindvall, 1995).

Purpose

The purpose with this analysis is to identify a possible trend of change in the annual warm and cold extreme temperatures in Sweden.

Questions:

- Do Swedish measurements indicate temperature change?
- How do trends, if any, compare for mean temperatures and cold/warm extremes?
- Is there a difference in trends in Northern Sweden compared to Southern Sweden?
- How does Sweden compare to other parts of the World on the same latitude?

Method

A selection of relevant articles and literature were chosen for their contribution to the subject in order to structure the theory and questions to achieve the purpose of the study, as well as to put the analysis of Swedish data into a wider perspective. The data were provided by the SMHI which is responsible for Sweden's temperature observations.

The subset of weather stations was chosen for being the limited few fulfilling the requirement of a complete record of temperature observations from January 1st of 1961 to December 31st of 2010. The station locations can be visualized in Figure 3b. The period of 50 years was chosen in order to compare it with other studies using the same time frame.

A Matlab code was written to investigate and interpret the data (Appendix A). The 18262 daily values for each variable (warm extreme temperature, mean temperature and cold extreme temperature) were first rounded up into 50 years (with the leap day taken into account) and then the annual average retrieved from the values in each year. A t-distribution was performed to obtain a statistical significance level in each data set. At last the code also produced averaged values for blocks of ten years, by using the first block as a reference period; the later blocks were used to give an alternative way to visualize potential temperature change.

Theory

Sweden's geography and temperature station placement

Sweden is located in Northern Europe; ranging from Smygehuk at the coast of the Baltic Sea in the south ($55^{\circ}20'13''N$ $13^{\circ}21'34''E$) to Tretriksörset (English: Three-Country Cairn) in the north ($69^{\circ}03'36''N$ $20^{\circ}32'55''E$) which borders to Norway and Finland. A simplified topographic chart over Sweden (Figure 3a) visualizes the stations different topography locations in Figure 3b.

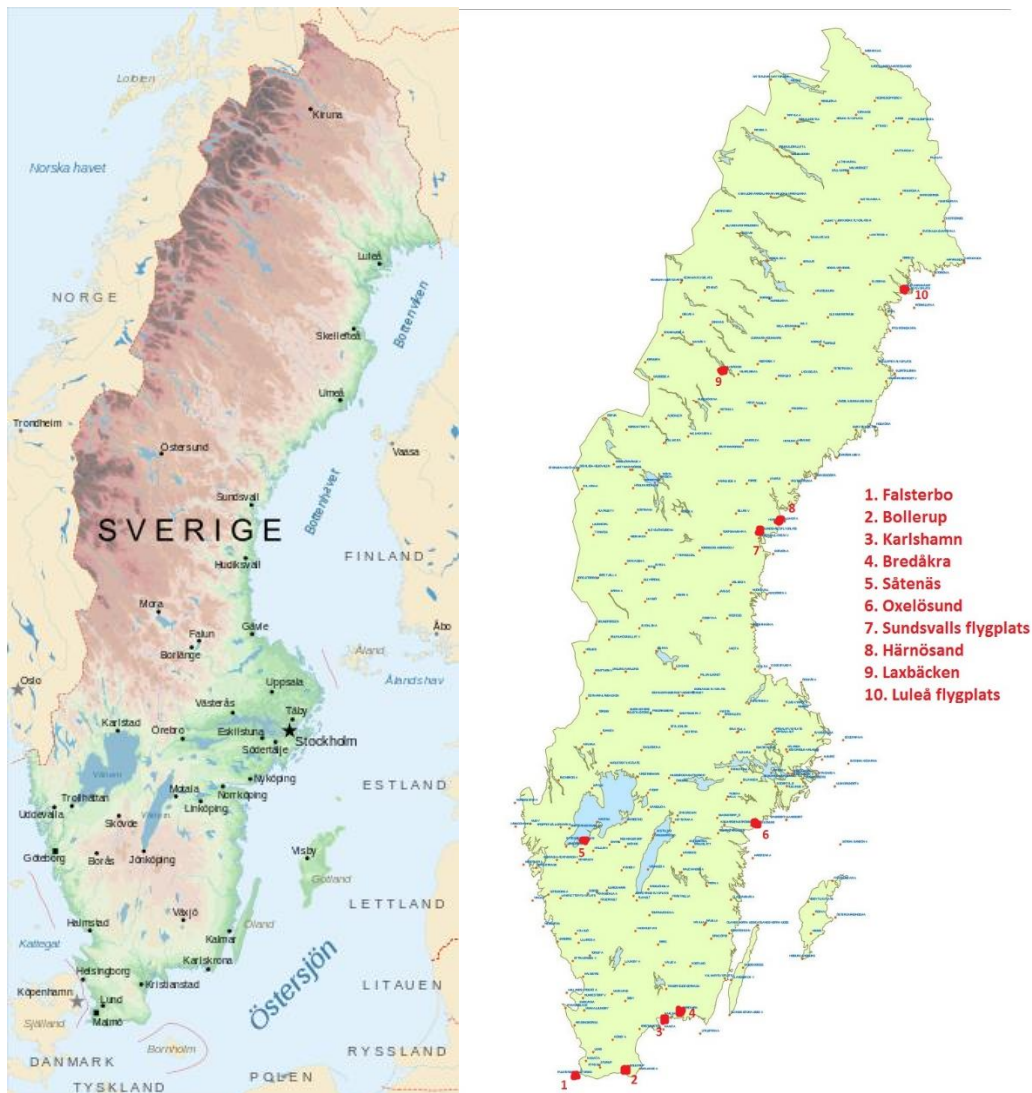


Figure 3a-b: In 3a (left) Sweden's topography is coded from a dark brown color for high elevations (such as The Scandies on North-Eastern border) to green/blue for sea-level altitudes. The locations of the ten stations are marked in figure 3b. Figure 3a is acquired from Koyos (2014) where the original source has expired and figure 3b is provided by SMHI.

Out of the ten stations, eight (1-4, 6-8 and 10) are located on the coastline while station 5 lies next to Sweden's largest lake Vänern. Station 9 is the most remote station; it lies on the rim of the mountain range, the Scandes. A more geographical observation is that stations 1-6 are located in Southern Sweden and stations 7-10 in northern Sweden. Station 3

and station 4 are located at a close distance from each other which is also true for station 7 and station 8.

Temperature records in Sweden

The warm records in summer are generally measured when high pressure systems over Eastern Europe are forcing tropical air masses up over the Scandinavian Peninsula. The highest measured temperature in Sweden is currently 38°C. It has been measured twice, once in Målilla (1947-06-29) and once in Ulltuna (1933-07-09). The measurements are both accepted but the one in Ulltuna was noted without a decimal and therefore the uncertainty ranges from 37.8°C-38.2°C (SMHI, 2011b).

The coldest measured temperature in Sweden took place in Vuoggatjålme (1966-02-02) reaching -52.6°C (SMHI, 2011b). Vuoggatjålme is in modern days a location for hunting and fishing. It is located on the rim of the polar circle and gets one polar night each year (the sun never rises above the horizon). Another private measurement was made in Malgovik (1941-13-12), Vilhelmina showing -53°C; it was later controlled by SMHI. Since the private thermometer used in Malgovik could not display decimals and the official SMHI-station in Vuoggatjålme presented an equally low observation, the Malgovik record is used as footer (SMHI, 2011a). Most cold records are noted when cold air blows in from the north or north-east and weakens; the air is then chilled down further as the ground radiates away the heat (SMHI, 2011b).

Measuring Temperature

Before the more sophisticated thermometers were put into use and carefully positioned, many record measurements have been scratched due to faulty or broken equipment. The thermometer must be protected in such a way that it is not struck by direct sunlight nor precipitation as well as it must experience a good exchange of air so that the thermometer reading will not be affected by an accumulated condition caused by for example isolation. The measurement station itself should not be positioned in a well-protected location because that would not give the appropriate readings, only the thermometer needs to be isolated from these conditions. The station should neither be positioned on a slope, in the vicinity of trees or other shading objects due to the changed solar radiation. In order to get as uniform readings as possible, the temperature is measured on a height between 1.5-2m above ground level which is covered by short grass (SMHI, 2013).

Changes in Extremes

Extreme temperature occurrence is connected with changes in the mean temperature. If the mean temperature is very low for a time period, it is probably joined by a higher than average number of cold extremes. The occurrence is also coupled with the variance and the shape of the probability distribution (Seneviratne et al., 2012). There are studies like Griffiths et al. (2005) that present a strong correlation between the change in mean temperature and the close change in extreme temperature. However, there are many

studies such as Clark et al. (2006) which point out that the changes in variability and shape of the probability distributions of different weather variables are of high importance together with the changing mean temperature. These weather and climate variables can be different feedback systems such as soil moisture or snow cover which act on a local or regional scale and change the mean temperature. A change in mean temperature will change the shape of the probability distribution and the occurrence of extreme temperatures (Seneviratne et al., 2012).

It should be clarified that regional extremes do not always coincide with changes in global mean temperatures. There will always be the possibility that during a change in the global mean temperature to the warmer, some regions will experience a cooling trend that will lower the mean temperature and result in milder warm extremes and colder cold extremes. As an example of this a study by Petoukhov and Semenov (2010) introduces that a global warming of the mean temperature could melt sea ice in the northern hemisphere, a melting which can be followed by a cooling of regional mean temperatures that increases the number of cold extremes in the northernmost continents (Seneviratne et al., 2012).

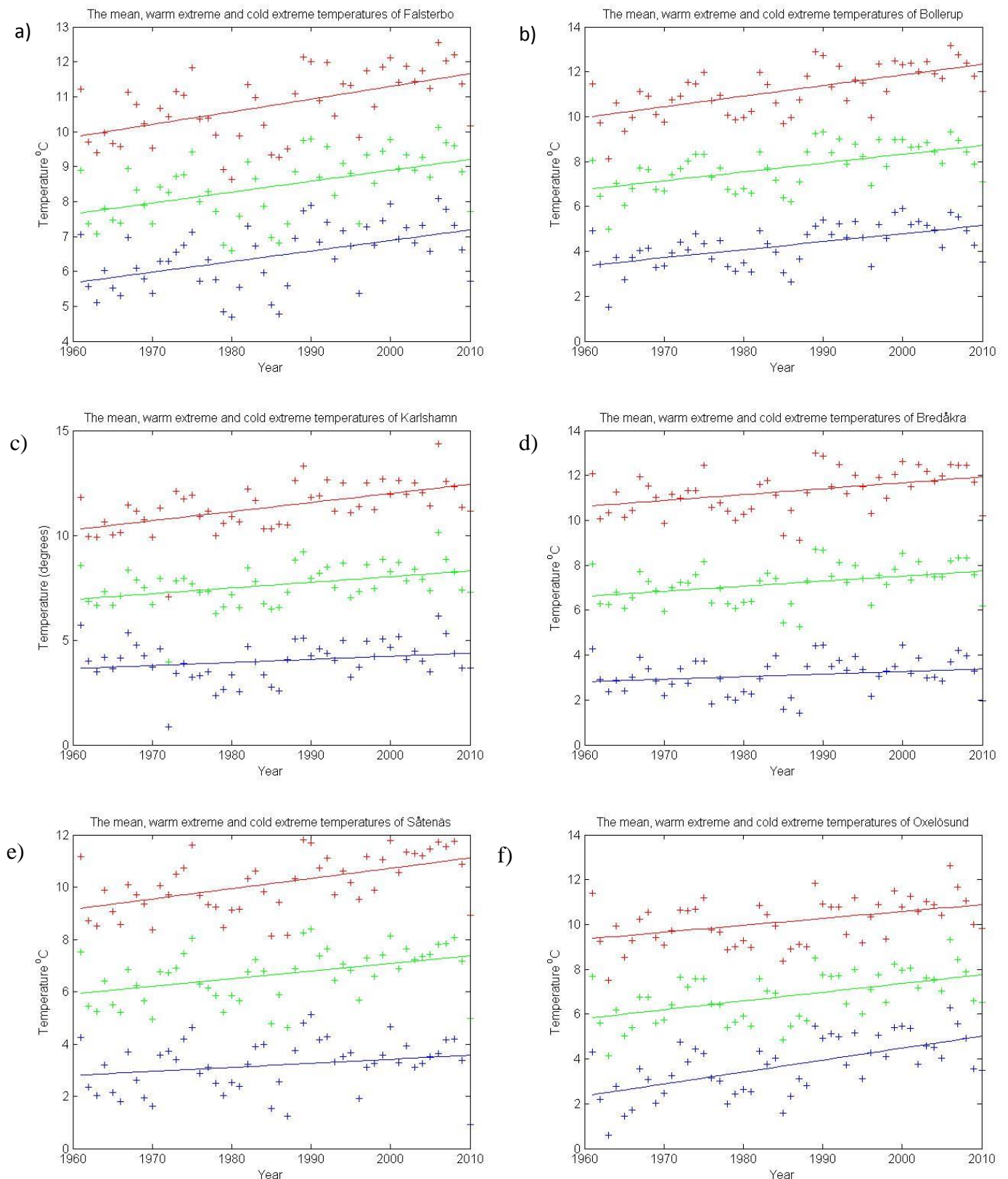
There is often a multitude of factors that result in the rate of extremes on local, regional or a global scale. The hydrological cycle is closely coupled to the feedback systems such as soil moisture and evaporation which enhances cloud cover and result in a change in the radiation. In wet or snow covered areas, solar energy that in a dry landscape is used to warm up the surface of the Earth is instead used for melting the snow or evaporating the water which results in a cooling of the temperature on a local scale. Surface air over snow covered areas may also be warmed up by the reflected solar energy from the high albedo snow cover. On a clear night the ground radiates a lot of energy and the surface temperature drops, the warm air above the cold surface air will act as an inversion layer over the cold air close to the surface preventing any mixing causing the temperature to stay colder than it would be with the mixing. Also different temperature contrasts such as increased local heating or land/sea contrasts affect circulation patterns which is associated with the temperature and therefore extreme temperatures (Seneviratne et al., 2012).

Feedback Systems

In a climate system, under ongoing change, interactions between processes can result in feedback which either enhances (positive feedback) or counteracts (negative feedback) a specific change or process. A positive feedback can be when a heat wave strengthens a drought, possibly leading to high extreme temperatures (Seneviratne et al., 2012). To explain this specific feedback, two causes have been pointed out by Seneviratne et al. (2010). First the soil experiences an increased drying rate triggered by evapotranspiration from incoming radiation and a higher vapor pressure deficit; this is followed by a heating of the surface air when the flux of moisture from the soil weakens.

Results

The warmest (and coldest) observation for each day is noted as a warm (and cold) extreme and all the daily observations (including the mean temperature) for each year are averaged into annual means. The annual average (for warm extremes, mean temperature and cold extremes) for each year within the time frame 1961-2010 is plotted for every station in figure 4a-j to give a visualization of the changes.



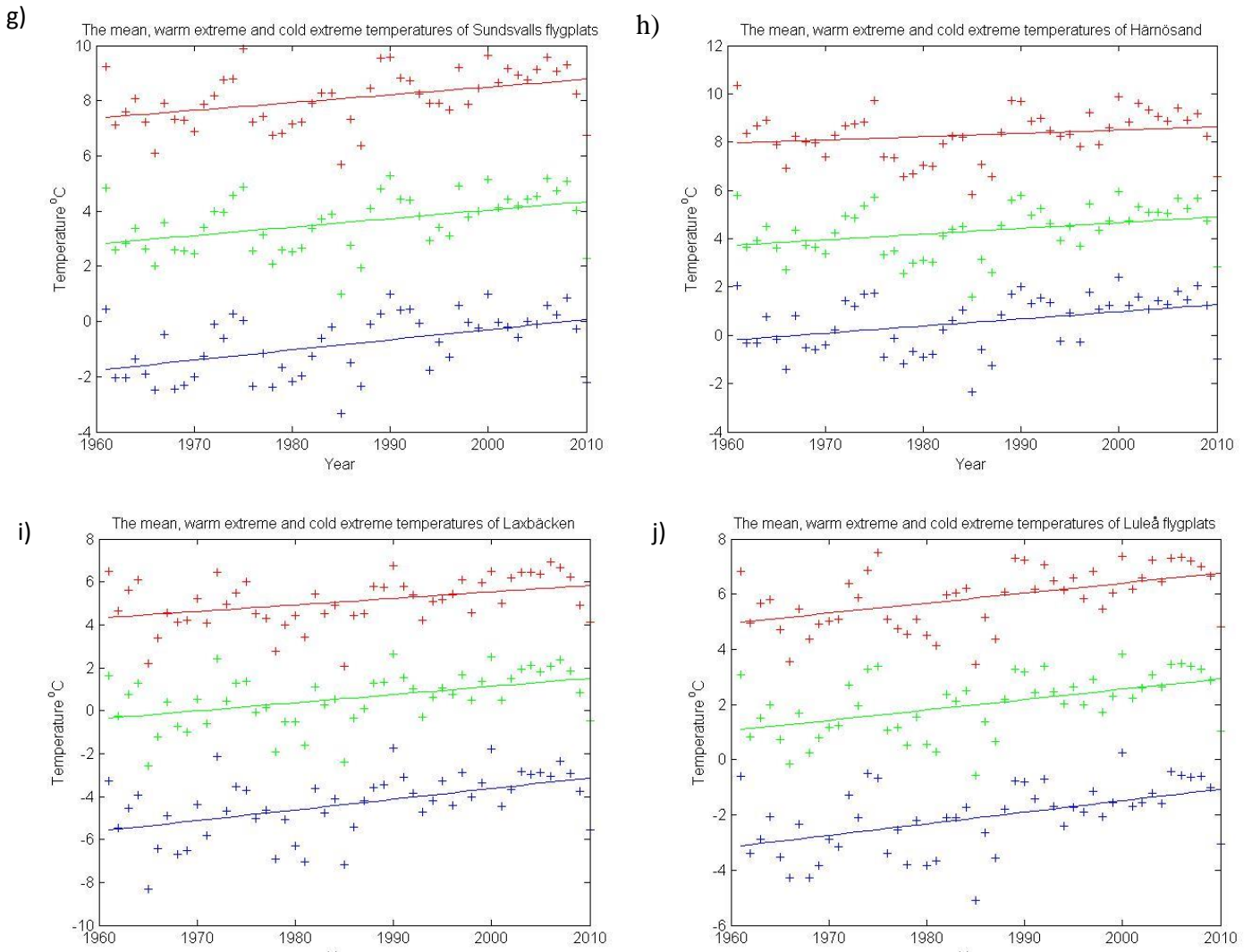


Figure 4a-j: The observation value for every day is averaged over a year and makes up for 50 marks representing the time frame 1961-2010. The data series are coded by color, red for warm extreme observations, blue for cold extreme observations and green for mean temperature observations. A trend line is applied through a least square fit method to each data series. 4a: 1. Falsterbo, 4b: 2. Bollerup, 4c: 3. Karlshamn, 4d: 4. Bredåkra, 4e: 5. Sätenäs, 4f: 6. Oxelösund, 4g: 7. Sundsvalls flygplats, 4h: 8. Härnösand, 4i: 9. Labäcken, 4j: 10. Luleå flygplats.

The significance for each data trend is validated by performing a t -distribution test for each data series; the t -distribution is applied to the 18262 data points and is visualized in figure 5a-b for two stations for their warm extremes (2. Bollerup and 8. Härnösand). The two stations were chosen for their different significance index value for the same variable (11.2769 for Bollerup and 3.3924 for Härnösand). The slope gradient for the 18262 values is multiplied by 365 to give the annual change of temperature (warm extreme, mean and cold extreme) and the significance for each series is noted in Table 1. According to the t -distribution index values in table found in Appendix B (for One Sided t -distribution which is used in this study), a value over 3.291 for an infinite amount of degrees of freedom (18262 data points gives 18260 degrees of freedom which is much larger than 120 which can be seen in appendix B) equals a significance of 99.95% which is achieved by all data series except Karlshamn (station 3) for which the cold extreme trend line is significant to 99.9% (within the index interval of 3.090-3.291).

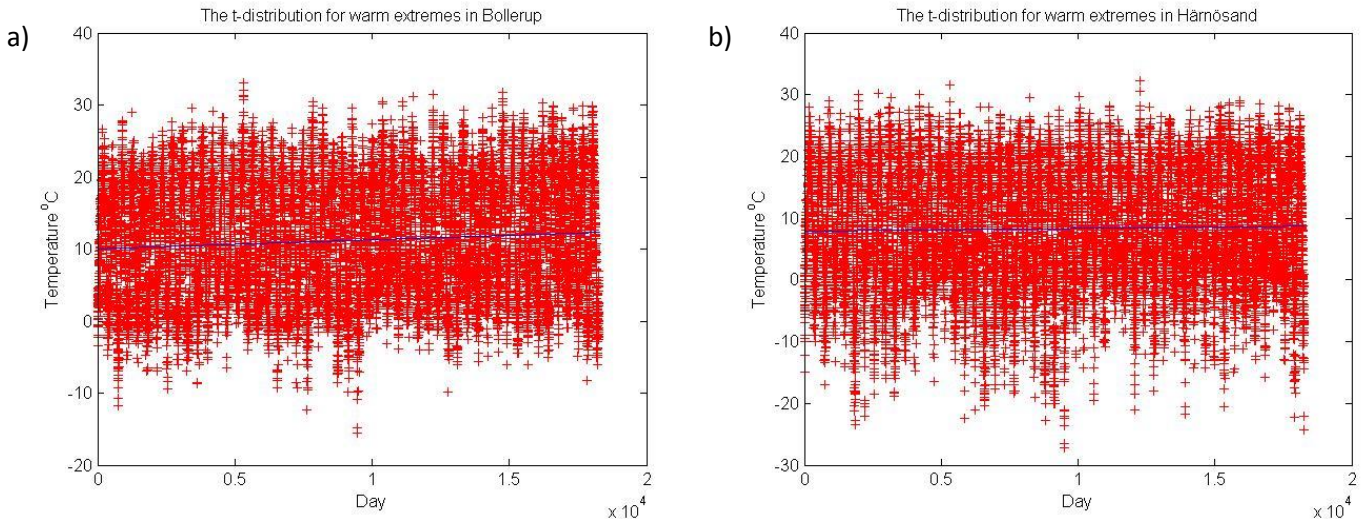


Figure 5a-b: A *t*-distribution test is applied to the 18262 observations of warm extremes in Bollerup and Härnösand, the red marks represent each daily observation between January 1st 1961 and December 31st 2010 and the blue line is the trend line from which the significance and slope value is found in Table 1.

The station with the overall highest combined extreme temperature change gradient is Luleå flygplats (station 10) which has experienced a rate of change of 0.039°C/y for the warm extremes and 0.046°C/y for the cold extremes. The smallest increase is found in station 4, Bredåkra, where the warm extremes rose on an average with 0.029°C/y and the cold extremes at a rate of 0.014°C/y. Station 1-5 all show a warm extreme change larger than the cold extreme change while station 6-10 show a cold extreme change larger than the warm extreme change. This indicates that Northern Sweden seems to experience a larger warming trend in the cold extremes compared to the warm extremes. There are four stations that show a larger difference in rate of change between warm and cold extremes than the others; station 3 (Karlshamn) where the warm extreme changed by 0.038°C/y and the cold extreme by 0.023°C/y (0.015°C/y difference), station 4 (Bredåkra) with the warm extreme slope being 0.029°C/y and the cold extreme slope 0.014°C/y (0.015°C/y difference), station 8 (Härnösand) with the cold extreme change of 0.033°C/y and the warm extreme change of 0.016°C/y and at last station 9 (Laxbäcken) which showed the changes of 0.028°C/y for warm extremes and the highest noted change for cold extremes; 0.049°C/y.

Table 1: The value of the slope for the three temperature data series from each station and the significance index of the trend line.

The slope gradient and significance for each data series for every station						
Station	Warm extreme slope ($\frac{^{\circ}\text{C}}{\text{y}}$)	Warm extreme trend line significance index	Mean temperature slope ($\frac{^{\circ}\text{C}}{\text{y}}$)	Mean temperature trend line significance index	Cold extreme slope ($\frac{^{\circ}\text{C}}{\text{y}}$)	Cold extreme trend line significance index
1. Falsterbo	0.037	10.0954	0.032	9.5951	0.032	9.6021
2. Bollerup	0.046	11.2769	0.038	10.7715	0.035	10.7985
3. Karlshamn	0.038	9.5143	0.011	6.2169	0.023	3.1677
4. Bredåkra	0.029	6.6511	0.025	6.5723	0.014	3.9058

5. Såtenäs	0.042	9.7333	0.018	8.1948	0.032	4.8383
6. Oxelösund	0.027	6.4222	0.051	9.0652	0.036	12.9644
7. Sundsvalls fl.	0.030	6.0388	0.040	6.8680	0.033	8.2699
8. Härnösand	0.016	3.3924	0.026	5.8094	0.033	7.1131
9. Laxbäcken	0.028	5.2163	0.036	6.6072	0.049	8.5326
10. Luleå fl.	0.039	7.1858	0.041	7.5067	0.046	8.0763

There are four stations that show a change in mean temperature that does not seem to correlate well to the changes in extreme temperatures, these are stations 3, 5, 6 and 7; where the mean temperature slope is far from an imagined average between the warm extreme slope and cold extreme slope. The other six stations (1, 2, 4 and 8-10) all have a change in the mean temperature fairly close to an average between the extreme temperature slopes. Station 3 and 4 are very close geographically but they do not share the same trends; station 3 (Karlshamn) shows a greater warming of both warm and cold extremes but station 4 (Bredåkra) reveals a mean temperature trend that is larger than that of station 3.

Similarly to stations 3 and 4, stations 7 and 8 are located very close and to some extent show similar patterns of change having a cold extreme slope being equal to 0.033°C/y but station 7 (Sundsvalls flygplats) indicate a warming in warm extremes as well as mean temperature that is much larger than station 8 (Härnösand). Looking at tables 2-4, station 7 shows average values for the reference period 1961-1970 that is 0.8°C (warm extreme), 1°C (mean temperature) and 1.7°C (cold extreme) lower than for station 8. According to tables 2-4 station 8 experiences a cooling in warm extremes in the time frame 1971-1990 compared to the reference period, a minor warming in 1971-1980 in mean temperature and cold extreme but then cooling again in 1981-1990. Station 8 may have experienced a local warming excluding station 7 before the reference period or during the reference period and the two stations are now reaching a more uniform climate. However tables 2-4 provide no significant data analysis; they simply provide a decadal overview for discussion curiosity.

Looking at table 2, all stations (except 2 and 8) show a similar warm extreme change in the time period 2001-2010 compared to the reference period but they all appear to experience heating in different decades. Stations 2, 5-7 and 10 show a rapid increase in the first block (1971-1980) but then only station 2 continues to warm up in 1981-1990 (now together with the geographically close station 3). Then in 1991-2000, each station experiences a warming of ~0.6°C (except for station 2 with ~0.3°C) and in the last decade every station has warmed by at least ~0.3°C (except station 8 and 10 at ~0.2°C). Station 8 stands out with the previously mentioned cooling and station 6 also shows a cooling in 1981-1990 compared to the prior decade.

Table 2: The mean warm extreme temperature change visualized by using the first decade (1961-1970) as a reference period and the following four decades to show during which decade the change has been the strongest.

Mean warm extreme change in 10 year periods with 1961-1970 as reference period					
Station	1961-1970 (°C)	1971-1980 (°C)	1981-1990 (°C)	1991-2000 (°C)	2001-2010 (°C)
1. Falsterbo	10.1163	0.20	0.46	1.11	1.48

2. Bollerup	10.1091	0.70	1.11	1.45	2.06
3. Karlshamn	10.5730	0.19	0.81	1.33	1.65
4. Bredåkra	10.8679	0.06	0.23	0.78	1.04
5. Sätenäs	9.3395	0.51	0.61	1.24	1.72
6. Oxelösund	9.5160	0.42	0.32	0.92	1.42
7. Sundsvalls fl.	7.4780	0.40	0.39	0.97	1.28
8. Härnösand	8.2704	-0.34	-0.40	0.36	0.53
9. Laxbäcken	4.6527	0.05	0.11	0.76	1.28
10. Luleå fl.	5.1266	0.44	0.46	1.28	1.55

In table 3 the mean temperature is treated. Station 3 stands out showing a cooling in the first decade after the reference period, whereas the two closest stations 2 and 4 display a warming trend. However station 3 is almost 0.5°C higher than both stations during the reference period. During 1981-1990 both station 2 and 3 show the pattern previously brought up with local heating excluding station 4. Stations 2, 5-7 and 10 have larger warming trends than the others in the first decade after the reference period but in 1981-1990 only station 3 indicates any significant warming. The time period 1991-2000 shows an increase in the mean temperature for all stations compared to the previous decade within the range of 0.45-0.85°C and the warming is continued for every station in the final decade.

Table 3: The mean temperature change visualized by using the first decade (1961-1970) as a reference period and the following four decades to show during which decade the change has been the strongest.

Mean temperature change in 10 year periods with 1961-1970 as reference period					
Station	1961-1970 (°C)	1971-1980 (°C)	1981-1990 (°C)	1991-2000 (°C)	2001-2010 (°C)
1. Falsterbo	7.8501	0.24	0.43	1.03	1.26
2. Bollerup	6.8192	0.67	0.84	1.58	1.59
3. Karlshamn	7.3530	-0.36	0.23	0.68	0.85
4. Bredåkra	6.7823	0.13	0.25	0.77	0.88
5. Sätenäs	5.9001	0.63	0.63	1.14	1.34
6. Oxelösund	5.8932	0.73	0.63	1.45	1.73
7. Sundsvalls fl.	2.9415	0.43	0.41	1.05	1.36
8. Härnösand	3.9305	0.12	0.00	0.81	1.01
9. Laxbäcken	-0.1188	0.33	0.46	1.18	1.58
10. Luleå fl.	1.1868	0.56	0.56	1.38	1.62

The cold extreme changes show different regional variations which can be seen in table 4. Station 3 and 4 show a local cooling in 1971-1980, a varied warming only to have increased the average by 0.11°C and 0.28 in the last decade compared to the reference period.

Stations 1-2 show a steady increase for each decade while stations 5-7 and 9-10 show an increase between 0.5-0.7 (station 6 with increase of 0.96) for the first decade after the reference period. Between the time periods 1981-1990 and 1991-2000, the stations in Northern Sweden increased with 0.8-1°C and the stations in Southern Sweden 0.3-0.8 except for Oxelösund that experienced an increase of 1.15°C. The stations in Northern Sweden experienced a warming of 1.23-1.99°C in the cold extremes in the final decade compared to the reference period whereas Southern Sweden experienced a very varied warming.

Table 4: The mean cold extreme temperature change visualized by using the first decade (1961-1970) as a reference period and the following four decades to show during which decade the change has been the strongest.

Mean cold extreme change in 10 year periods with 1961-1970 as reference period					
Station	1961-1970 (°C)	1971-1980 (°C)	1981-1990 (°C)	1991-2000 (°C)	2001-2010 (°C)
1. Falsterbo	5.8797	0.16	0.47	1.05	1.16
2. Bollerup	3.4907	0.47	0.61	1.44	1.39
3. Karlshamn	4.3241	-1.21	-0.50	0.05	0.11
4. Bredåkra	3.0126	-0.25	0.00	0.42	0.28
5. Sätenäs	2.5658	0.69	0.69	0.98	0.77
6. Oxelösund	2.4207	0.96	1.07	2.22	2.19
7. Sundsvalls fl.	-1.6676	0.53	0.66	1.49	1.51
8. Härnösand	-0.0081	0.26	0.16	1.12	1.23
9. Laxbäcken	-5.4439	0.66	0.93	1.88	1.99
10. Luleå fl.	-3.0085	0.65	0.58	1.57	1.78

Discussion

Each figure and table indicates that Sweden has indeed experienced a warming temperature trend in both extremes and in the mean temperature. However, it is difficult to map out the trend for each region in Sweden due to scarce data availability (for extreme temperatures). The stations used for this study were chosen as they all had complete data from the time period 1961-2010, while new stations have complete records but only from 1990s and onward. Therefore before putting the results from this study into a bigger perspective it is needed to point out that the stations are not representative for all parts of Sweden, the stations are mostly located on the south and eastern coast. To get a better visualization it would be preferred to have a few more stations in central mainland and in the north. Also these stations are point source observations and not (in this study) used for a gridded representation of Sweden, so comparing with studies that used a gridded data set will not be fully applicable.

The significance in each data series proved to be 99.95% except for the data series for cold extremes in Karlshamn that is significant to 99.9% and therefore they are all well acceptable. The significance indices range from 3-13 but are not interesting to investigate further since the significance of 99.95% for an infinite amount of degrees of freedom is reached at 3.291 and (like Karlshamn) the significance of 99.9% at 3.090 are satisfactory. It should also be clarified that Figure 4a-j is not treated by the *t*-distribution and together with Table 2-4 used exclusively for visualization of inclinations and discussion material.

By only comparing the trends in Table 1 as noted in the result section, there are four stations where the mean temperature slope was showing a different tendency than the extreme slopes. This connects well to the study of Clark et al. (2006) that there is presumably a large role played by different weather variables on a local and regional scale. At station 3 (Karlshamn) and 5 (Såtenäs) the extreme temperature slopes are much higher than the mean temperature slope and for station 6 (Oxelösund) and 7 (Sundsvalls flygplats) the mean temperature slope is larger than that of the extremes. The idea of local effects are further substantiated when comparing station 3 (Karlshamn) with station 4 (Bredåkra) which are both geographically very close but indicate different tendencies. This is also the case for the second pair of stations at a close distance from each other; station 7 (Sundsvalls flygplats) and station 8 (Härnösand). As mentioned before station 3 shows a much higher increase in the extreme temperature slopes than the mean temperature slope but this pattern is not shared by station 4 where the mean temperature slope is in between the two extremes. Station 7 shows a mean temperature rate ($0.04^{\circ}\text{C}/\text{y}$) that is higher than the extremes (which are fairly equal at $0.03^{\circ}\text{C}/\text{y}$ and $0.033^{\circ}\text{C}/\text{y}$)

Tables 2-4 use a reference period and comparison periods of 10 years length which is quite short (with longer data series it would be possible to use a more appropriate and accurate reference period of 30 years), but within the data limit it could still provide interesting discussion as long as it is kept in mind that shorter time periods are more influenced by deviations. These tables were mainly used to see any indication of decadal temperature growth and to compare with the published observation by IPCC that the global

mean temperature is increasing with a higher rate after 1970 (Trenberth et al., 2007; Hartmann et al., 2013). Even if this study lacks temperature data prior to 1961 it could still reveal a trend of the changing temperature.

According to Orłowsky and Serenivatne (2012) the low temperature percentiles experience a stronger warming trend than the high temperature percentiles in the northern high latitudes (in the regions with taiga); most likely due to a snow retreat feedback system that changes the albedo. In this study it can be seen that the warm extreme slope values for all ten stations combined (from Table 1) add up to $0.33^{\circ}\text{C}/\text{y}$ and $0.33^{\circ}\text{C}/\text{y}$ for the cold extremes which disagrees with Orłowsky and Serenivatne (2012) if Sweden is considered to fully belong to the taiga region. If we instead look at the six first stations belonging to Southern Sweden which has less days with snow cover (50-100days) we get $0.22^{\circ}\text{C}/\text{y}$ ($0.037^{\circ}\text{C}/\text{y}$ on average) respectively $0.17^{\circ}\text{C}/\text{y}$ ($0.028^{\circ}\text{C}/\text{y}$ on average) for the warm and cold extreme slope values, indicating a larger warming trend in the top temperature percentiles. In Northern Sweden (station 7-10 where the snow cover ranges on average between 125-175 days) the trends show $0.11^{\circ}\text{C}/\text{y}$ ($0.028^{\circ}\text{C}/\text{y}$ on average) for the warm extremes and $0.16^{\circ}\text{C}/\text{y}$ ($0.04^{\circ}\text{C}/\text{y}$ on average) for the cold extremes, indicating that the cold extremes are experiencing a higher warming trend than the warm extremes. However Northern Sweden hasn't experienced a significant loss of days with snow cover whereas Southern Sweden has, the result of this analysis therefore disagrees with the study of Orłowsky and Serenivatne (2012) with the argument of a snow retreat feedback system. Station 5 (Såtenäs) and 6 (Oxelösund) which are located in Southern Sweden but quite far north compared to stations 1-4 show a mixed result where station 5 resemble the result of Southern Sweden but station 6 share a trend with Northern Sweden, it would be very interesting to analyze stations in between 5-6 to 7-10 to get a more covering analysis and see if the trends are distinctly warming in Southern Sweden and warming in Northern Sweden.

The warming trend identified in all stations support the result by Meehl and Tebaldi (2004) that the warm extremes are expected to become more frequent, longer and more severe in the future. In Sweden, visualized by the ten stations, this study show that the warm extreme temperatures have warmed between $0.8\text{-}2.3^{\circ}\text{C}$. Brown et al. (2008) has found that the greatest warming in the low temperature percentile is found in some regions in Russia and Canada warming up by 4°C , being on the same latitude as Sweden it is interesting to put the results from this study in a bigger picture (even though procedures from other studies and therefore results do not compile flawlessly). The rate of change in Table 1 for cold extremes show rates between $0.014\text{-}0.049^{\circ}\text{C}/\text{y}$ which for 50 years would translate into a warming of $0.7\text{-}2.5^{\circ}\text{C}$ where Northern Sweden ranges between $1.65\text{-}2.5^{\circ}\text{C}$. The reason why Sweden would experience less warming in the lower temperature percentiles could be because it is much more influenced by the large masses of surrounding water compared to Canada and especially Russia, being nations of vast areas of land which are more prominent to warming than ocean (Trenberth et al., 2007; Hartmann et al., 2013) and the greatest warming is limited to some regions.

Another study made by Vincent and Mekis (2006) conclude that the number of warm events has increased significantly and the number of cold events has decreased

significantly in Canada within the time period 1950-2003; warm events being warm nights, warm days and summer days while cold events being cold nights, cold days and frost days. These events are central in identifying climate trends and it would be a great follow up to this study; to make an extensive analysis of diurnal temperature and focusing on the mean temperature for a larger set of stations since the number of stations with a long data set for observing extreme temperatures in Sweden are quite few. In order to improve this study it would be required to write a more effective code (in e.g. Matlab) that can handle more sophisticated analyzes and to study more reports and incorporate their ideas into the research material. One very important variable to include and study would be precipitation since the hydrological cycle is closely related to the temperature through different feedback systems like albedo (clouds, snow and extensive water bodies) or the drying soil discussed by Seneviratne et al. (2010).

In this study, the environment surrounding the stations is not treated. I have assumed that the stations were positioned in such a way that future observations are not significantly affected by urbanization or changes in the local climate.

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