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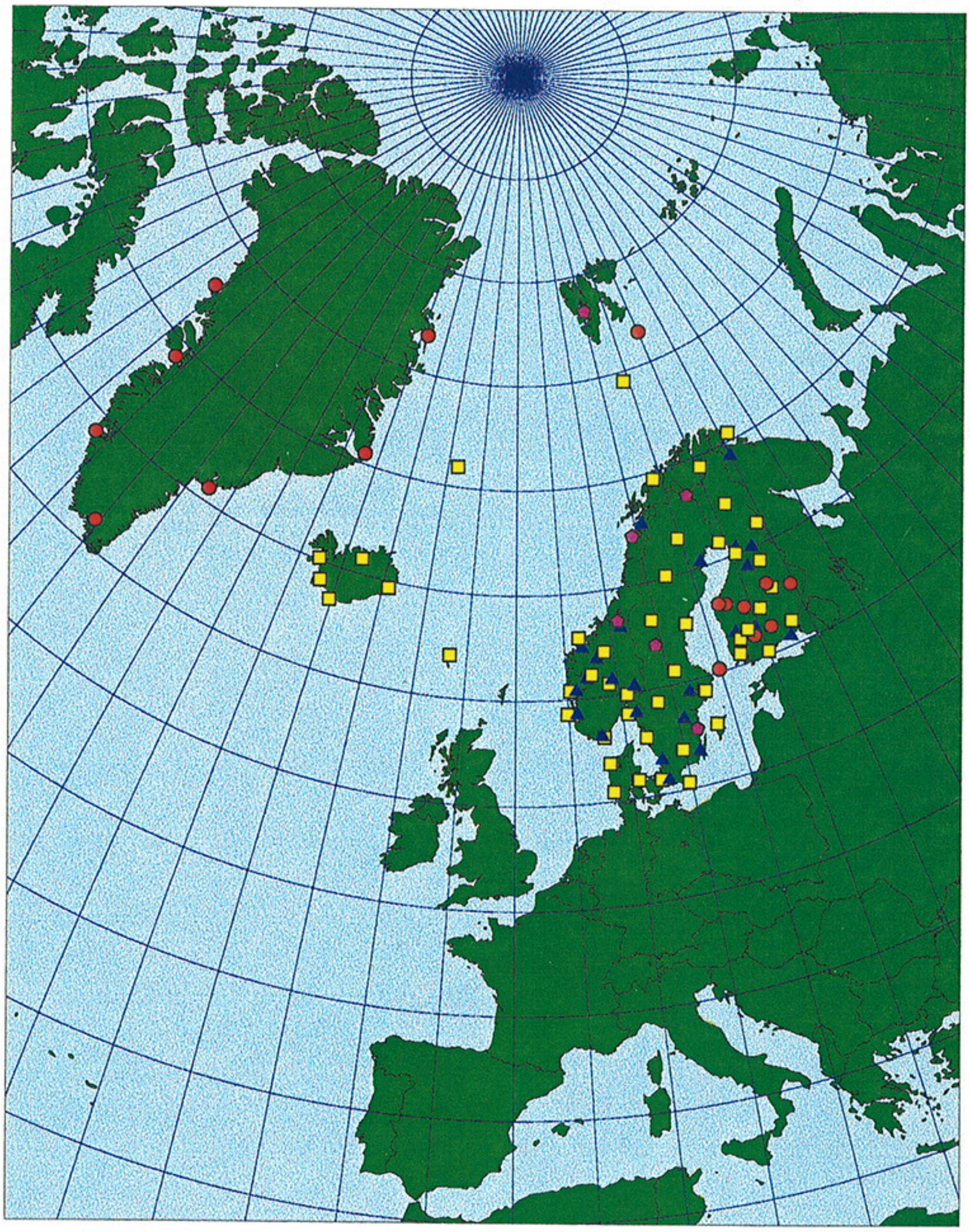
REWARD: - Relating Extreme Weather to Atmospheric circulation using a Regionalised Dataset

FINAL REPORT (1996-1998)

REPORT NR: 17/98

Eirik J. Førland, Hans Alexandersson, Bengt Dahlström, Achim Drebs, Povl Frich, Inger Hanssen-Bauer, Raino Heino, Jaakko Helminen, Trausti Jónsson, Per Øyvind Nordli, Thóranna Pálsdóttir, Torben Schmith, Heikki Tuomenvirta, Ole Einar Tveito, Haldo Vedin



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PROJECT CONTRACTORS

Nordic Council of Ministers (Contract FS/HFj/X-93001)

National Meteorological Institutes in Denmark, Finland, Iceland, Norway & Sweden

Abstract

Within the REWARD-project, 69 long-term series of monthly values of maximum and minimum temperature, and 84 monthly series of maximum 1-day precipitation were digitized, quality controlled and compiled in a consistent dataset. The majority of the series were more than 100 years long. The dataset comprises series for all parts of the Nordic region, including the Faroe Islands, Greenland and the Norwegian Arctic stations.

In Fennoscandia, the minimum and maximum temperatures have increased during this century, and the trends are in good accordance with those of the Northern Hemisphere. The West-Greenland temperature trends behave opposite to those of Fennoscandia and the Northern Hemisphere. The diurnal temperature range (DTR) has decreased in all parts of the Nordic region. The long-term series of maximum 1-day precipitation show no distinct large scale trend pattern in the Nordic region, although there is a tendency of higher values in the 1930s and increasing values during the latest two decades.

The correspondence between variations in climatological extremes and atmospheric circulation was studied by using multiple linear regression models based on geostrophic winds. The large geographical variation of climatic extremes in the Nordic region are mapped in a «*Nordic Atlas of Climatic Extremes*».

SIGNATURE

Eirik J. Førland (signature) .... Bjørn Aune (signature) ....

Eirik J. Førland — Project coordinator

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CONTENTS

Summary

Changes in the frequency or intensity of extreme events will have profound impacts on society and the natural environment. The Second Assessment report of IPCC stressed the importance of answering the question: *Has the climate become more variable or extreme,* but realised that the available data and analysis were poor and not comprehensive. This lack of data and analyses of climatic extremes had earlier been recognised also by Nordic climatologists. In the project *REWARD (Relating Extreme Weather to Atmospheric circulation using a Regionalised Dataset)*, special focus was put upon whether the observed global warming has caused any changes in extreme climatic events in the Nordic countries.

A total of 69 long-term series of monthly values of absolute and mean maximum and minimum temperature, and 84 monthly series of maximum 1-day precipitation were digitised, quality controlled and compiled in the «REWARD dataset, Version 1.0». The majority of the series was more than 100 years long. The dataset comprises series from all parts of the Nordic region, including the Faroe Islands, Greenland and the Norwegian Arctic stations.

Linear trends of mean maximum (Tx), minimum (Tn) and diurnal temperature range (DTR) were studied for the Nordic region. In Fennoscandia the minimum and maximum temperatures have increased during this century, and the trends are in good accordance with the Northern Hemisphere trends. However, only the spring increase in Tn is statistically significant. The West-Greenland temperature trends are opposite to Fennoscandia and the Northern Hemisphere. These opposite trends are in accordance with the strengthening of the North Atlantic Oscillation (NAO) over the period 1950-1995. The DTR has decreased in all parts of the Nordic region, and statistically significant trends are found in all seasons.

Analysis of the long-term series of maximum 1-day precipitation (Rx) showed no distinct large scale trend pattern in the Nordic region, although there is a tendency of higher values in the 1930s and increasing values during the latest two decades. For most parts of the Nordic region, also the highest frequencies of «extraordinary» precipitation (i.e. Rx events with a return period exceeding 5 years) occurred in the 1930s and in the two latest decades, i.e. in decades with high regional summer temperatures. For Western Norway however, there was no local maximum in the 1930s;- but instead the two latest decades have evidently had the highest number of extraordinary precipitation events. During this period, Western Norway has experienced a substantial increase in orographic precipitation.

One of the main objectives of REWARD was to study whether the variation in climatological extremes could be explained by variations in the atmospheric circulation. A multiple linear regression model based on geostrophic winds was developed. Both for Rx, Tx and Tn the model gave reasonably high correlations by using geostrophic winds, sea level pressure and monthly mean temperature as predictors.

The large geographical variation of climatic extremes in the Nordic region has been mapped in a «*Nordic Atlas of Climatic Extremes*». For some selected elements a spatial interpolation routine was applied to estimate continuous fields. The range of climatic extremes in the Nordic region is large: The lowest and highest recorded temperatures range from -53 °C to +38 °C, and the highest observed 1-day precipitation is about 250 mm.

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2. Background and main objectives.

Changes in the frequency or intensity of extreme events will have profound impacts on society and the environment. The Second Assessment report of IPCC (Nicholls et al., 1996) recognised the importance of possible changes in extreme meteorological events and attempted to answer the question: *Has the climate become more variable or extreme ?* Nicholls et al. (op.cit.) determined that there was no evidence that extreme weather events had increased in a global sense through the 20'th century, but that on regional scales there was clear evidence of changes in some extremes and climate variability indicators. However it was stressed that the available data and analysis were poor and not comprehensive. This lack of information concerning climatic extremes also complicates the use of model projections to assess the likelihood of future changes in extremes and variability (Kattenberg et al., 1996).

The lack of data and analyses of climatic extremes had earlier been recognised also by Nordic climatologists, and as a continuation of the EC/NMR-project «North Atlantic Climatological Dataset, NACD» (Frich et al., 1996, Dahlström et al., 1995) the Nordic meteorological institutes suggested a major effort to establish and analyse a comprehensive dataset of climatic extremes. The original plans for the suggested Nordic project were not fully approved, but a revised project was during 1996-1997 partly financed by the Nordic Council of Ministers (NMR, Contract FS/HFj/X-93001) and partly by own funding by the national meteorological institutes (Førland et al., 1996b). The project was named *REWARD - Relating Extreme Weather to Atmospheric circulation using a Regionalised Dataset.*

The main objectives of the REWARD-project were:

- ***Establish a consistent Nordic dataset of climatic extremes***
- ***Analyse long-term variations in extreme temperatures (maximum and minimum temperature and diurnal temperature range)***
- ***Analyse long-term variations in maximum 1-day precipitation***
- ***Study relations between atmospheric circulation and extreme climatic events***
- ***Evaluate appropriate extreme value distributions for Nordic series of climatic extremes***
- ***Work out a Nordic Atlas of climatic extremes***

3. Data, methods and activities

In the Nordic countries, just a few complete long-term climatological series are available in digital form before the 1950s. However, paper copies of monthly summaries (incl. maximum and minimum temperatures and maximum 1-day precipitation) are available. For selected stations these summaries were compiled and digitised. Totally 69 long-term series of maximum and minimum temperatures and 84 series of maximum 1-day precipitation were made available during the REWARD-project (cf. station list in Appendix). A detailed survey of stations and elements included in the REWARD-dataset is presented by Drebs et al (1998).

The geographical distribution (Figure 1) shows that the selected stations cover most parts of the Nordic region. The majority of the series is more than 100 years long. Most of the series consist of complete records, but for a few series, especially in Finland and Northern Norway during the 2nd World War,- some months are missing.

For some of the stations, inhomogeneities were earlier found in the series of mean temperatures and annual precipitation (Frich et al., 1996). For extreme temperatures some testing and adjusting of inhomogeneous data were performed (Tuomenvirta et al., 1998). As there are no obvious ways of adjusting daily precipitation extremes for inhomogeneities, some supplementary series found homogeneous on annual basis were selected in Finland and Norway. Most of the REWARD stations are also included in the NACD and Frich et al.(1996) have presented metadata for the mean temperatures and annual precipitation series. These metadata archives include year(s) for inhomogeneities, reasons for inhomogenities, and adjustment factors for inhomogeneities.

Besides inhomogeneity problems, recorded extremes may be influenced by measuring or reading errors. Most of these erroneous values are detected and corrected during the regular quality control at the national meteorological institutes, but in some cases it is difficult to judge whether a value is «true» or «false». E.g. in weather situations with heavy showers, the strong local gradients make it difficult to decide whether a suspiciously high precipitation value is true or due to a misreading.

In addition to the regular quality control at the NMSs, the REWARD dataset was carefully scrutinised within the project. Possible digitising errors were examined, and a special emphasis was laid on the documentation of outliers. As no adequate homogeneity testing procedures exist for series of maximum daily precipitation, the metadata for annual series were used to evaluate the quality of the series.

The project was organised in six main activities (PI=Principal Investigator):

1. **Organising of REWARD-dataset and publication of data-report**
   (PI: Achim Drebs, FMI)
2. **Trend studies for REWARD-series of Nordic extreme temperatures**
   (PI: Heikki Tuomenvirta, FMI)
3. **Trend studies for REWARD-series of Nordic extreme 1-day precipitation**
   (PI: Eirik J. Førland, DNMI)
4. **Connections between extreme values and atmospheric circulation**
   (PI: Hasse Alexandersson, SMHI)
5. **Extreme value distributions for Nordic series of climatic extremes**
   (PI: Jaakko Helminen, FMI)
6. **Nordic Atlas of climatic extremes**
   (PI: Ole Einar Tveito, DNMI)

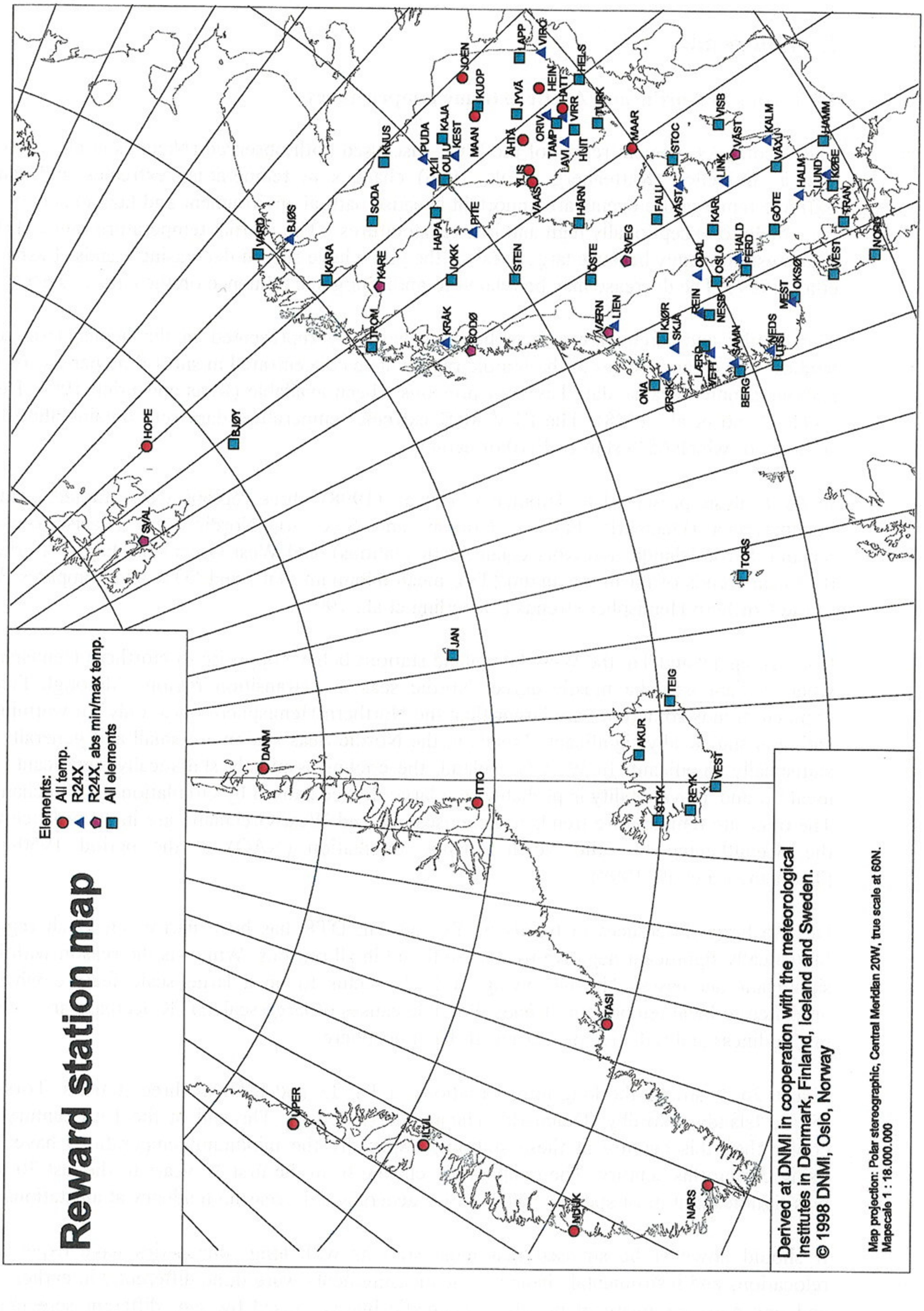


Figure 1. Stations included in the REWARD-dataset

(For abbreviations of station names, see Appendix)

4. Main results

4.1 Trends in Nordic and Arctic extreme temperatures

The Second Assessment report of the IPCC discussed both observed (Nicholls et al., 1996) as well as modelled (Kattenberg et al., 1996) changes in temperature extremes and range. Extreme temperature events are important because natural environment and human society are vulnerable to exceptionally high and low temperatures. The diurnal temperature range (DTR) is interesting mainly because large areas of the globe have shown decreasing trends (Easterling et al., 1997). The decrease may be related to anthropogenic influence on the climate system.

The Nordic and Arctic areas have been inadequately represented in the hemispheric scale studies. The earlier studies in the Nordic region have concentrated in short time periods or few stations simply because data have not previously been available (Kaas and Frich 1995, Heino 1994, Heino et al., 1998). The REWARD extreme temperature data set contains almost 70 stations, of which 65% start in 1910 or earlier.

In the analysis presented in Tuomenvirta et al. (1998), three regions were studied, namely: Fennoscandia (Denmark, Finland, Norway and Sweden), Nordic Seas (East-Greenland, Iceland, Faroe Islands, and Norwegian Arctic stations), and West-Greenland. Figure 2a shows the linear trends of mean maximum (Tx), mean minimum (Tn), and DTR and compares them to the Northern Hemisphere trends (Easterling et al., 1997).

Concerning Tx and Tn, the West-Greenland stations behave opposite to Northern Hemisphere, whereas Fennoscandia mostly agree. Nordic seas is a transition region. Although Fennoscandian trends sometimes are larger than the Northern Hemisphere ones, only Tn warming in spring is statistically significant. Trends in the Nordic Seas region are small and generally not statistically significant. In West-Greenland, the cooling is mostly statistically significant. The local Tx and Tn variability is probably to a large degree caused by circulation pattern changes. The opposite temperature trends in Fennoscandia and West-Greenland are in accordance with the strengthening of the North Atlantic Oscillation (NAO) in the period 1950-1995 (Tuomenvirta et al., 1998).

Despite large differences in trends of Tx and Tn; DTR has been narrowing in all regions. Statistically significant negative trends are found in all seasons. Winter is the season with least significant decreases. The narrowing of DTR seems to be a large scale feature which is unrelated to local temperature trends. Possible causes of large scale DTR decrease are changes in cloudiness and radiative properties of the atmosphere.

Figure 2b illustrates the long-term variations in Tn, Tx and DTR at three stations: Tórshavn (Faroe Islands); Nordby (Denmark), Haparanda (Sweden). The end of the 19th century was cooler than this century at these stations. Especially the minimum temperatures have been rising during this century. The temperature change from the first 30 years to the last 30 years was significant at most stations. DTR shows generally a decreasing tendency at all stations.

It should however be stressed that most stations with long time series have experienced relocations and instrumental changes. The measurements were done differently in earlier days, and one must be aware of possible systematic biases caused by, e.g. different screening of thermometers (Nordli et al., 1997). The REWARD data set contains the best data available, but especially in areas/periods with a sparse station network it is difficult to evaluate the homogeneity of the series. The reliability of area-averages based on REWARD temperatures was estimated by Tuomenvirta et al. (1998). It turned out that the long-term area-averaged series for Nordic Seas and West-Greenland suffer from inhomogeneities, while Fennoscandian series are reliable at least from the beginning of the present century.

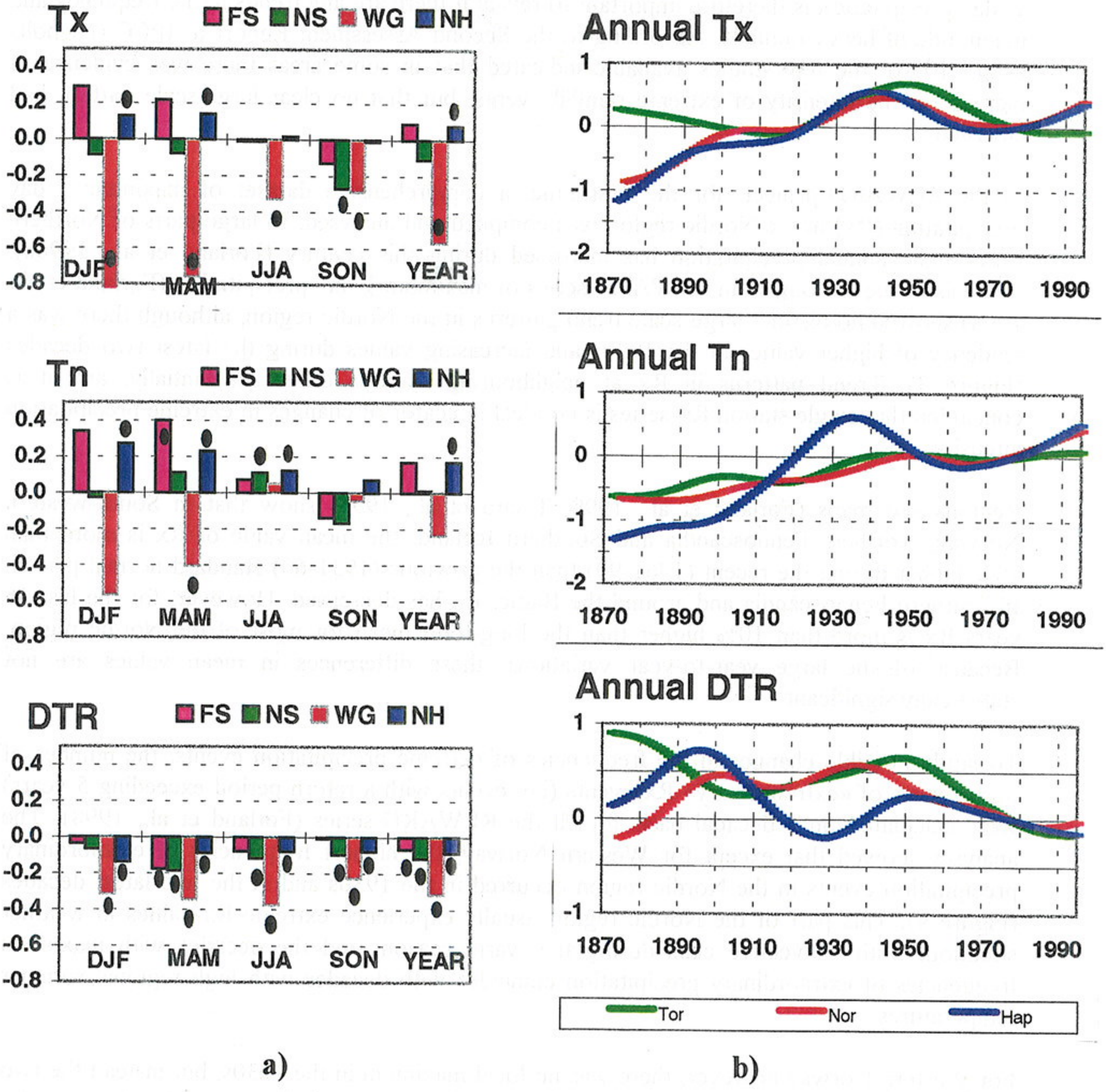


Figure 2. Long-term variations of Tx, Tn and DTR in the Nordic region

a). Linear trends (1950-1993) of Tx, Tn and DTR (°C/10 years) in Fennoscandia (FS), Nordic Seas (NS), West-Greenland (WG), and Northern Hemisphere stations (NH, from Easterling et al. 1997). The statistically significant trends (Mann-Kendall test at the 0.05 level) are marked with dots.

b). Smoothed annual anomalies (reference period 1961-1990) of Tx, Tn and DTR (°C) at Tórshavn, Nordby and Haparanda. (The series are smoothed by a Gaussian filter (std=9 years)).

4.2 Long-term variations in extreme 1-day precipitation in the Nordic countries

Heavy 1-day precipitation plays a crucial role in the flooding conditions in urban areas and small watersheds. Almost every year flooding connected to heavy precipitation causes serious damages on properties and on the environment. Monitoring long-term series of maximum 1- day precipitation is therefore important to reveal if there are any trends in the frequency and magnitude of heavy rainfalls. According to the Second Assessment Report to IPCC (Nicholls et al., 1996), the few studies available indicated that in some areas there was evidence of increase in the intensity of extreme rainfall events, but that no clear large-scale pattern had emerged.

In the REWARD-project, for the first time, a comprehensive dataset of maximum 1-day precipitation (Rx) in the Nordic region was compiled and analysed. In large parts of Northern Europe the annual precipitation has increased during this century (Førland et al., 1996a). Analysis of the 84 long-term REWARD series of maximum 1-day precipitation (Førland et al., 1998) showed no distinct large-scale trend patterns in the Nordic region, although there was a tendency of higher values in the 1930s and increasing values during the latest two decades (Figure 3). Trend patterns in Rx at neighbouring stations differ substantially, and it is concluded that single station Rx-series is no ideal indicator of changes in extreme precipitation intensity.

Regionalised maps (Førland et al., 1998; Tveito et al., 1998) show that in South-western Norway, Northern Fennoscandia and Southern Iceland, the mean value of Rx is more than 10% higher during the recent (1961-90) than the previous (1931-60) standard normal period. In southern Fennoscandia and around the Baltic, Rx has decreased. However, for the last 15 years Rx is more than 10% higher than the long-term mean for most of the Nordic region. Because of the large year-to-year variations, these differences in mean values are not statistically significant.

To study possible changes in the frequencies of extreme precipitation events, the number of occurrences of «extraordinary» Rx-events (i.e. events with a return period exceeding 5 years) were calculated on a decadal basis for all the REWARD-series (Førland et al., 1998). The analyses showed that except for Western Norway, the highest frequencies of extraordinary precipitation events in the Nordic region occurred in the 1930s and in the two latest decades (Figure 4). This part of the Nordic region usually experience extreme Rx-values in weather situations with convective cells during the warm season, and the decades with maximum frequencies of extraordinary precipitation coincides with decades with high regional summer temperatures.

For Western Norway however, there was no local maximum in the 1930s; but instead the two latest decades have evidently had the highest number of extraordinary precipitation events. During these two latest decades, Western Norway has experienced a substantial increase in orographic precipitation during autumn, winter and spring (Hanssen-Bauer, 1994).

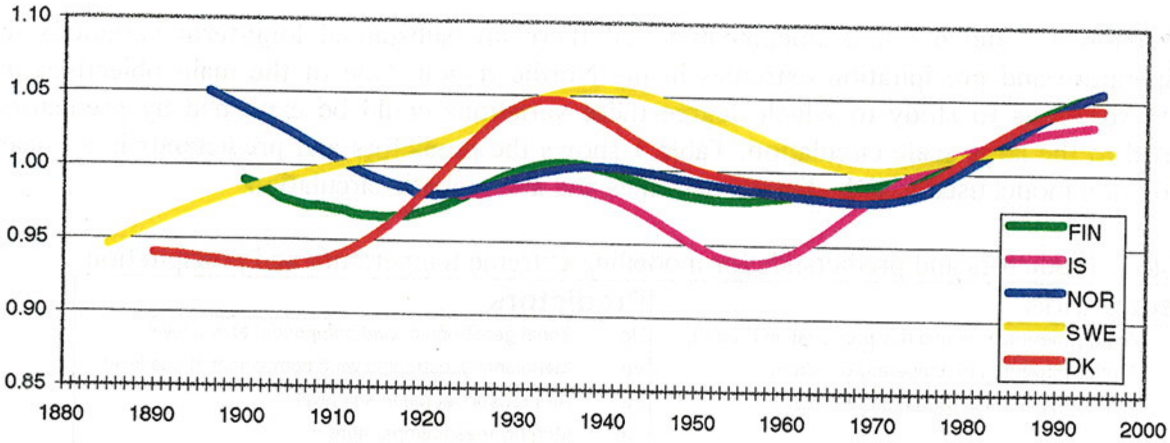


Figure 3. Average national trends of anomalis in maximum 1-day precipitation in the Nordic countries. (Reference period 1961-90).
The series are smoothed by a Gaussian filter (std=9 years)

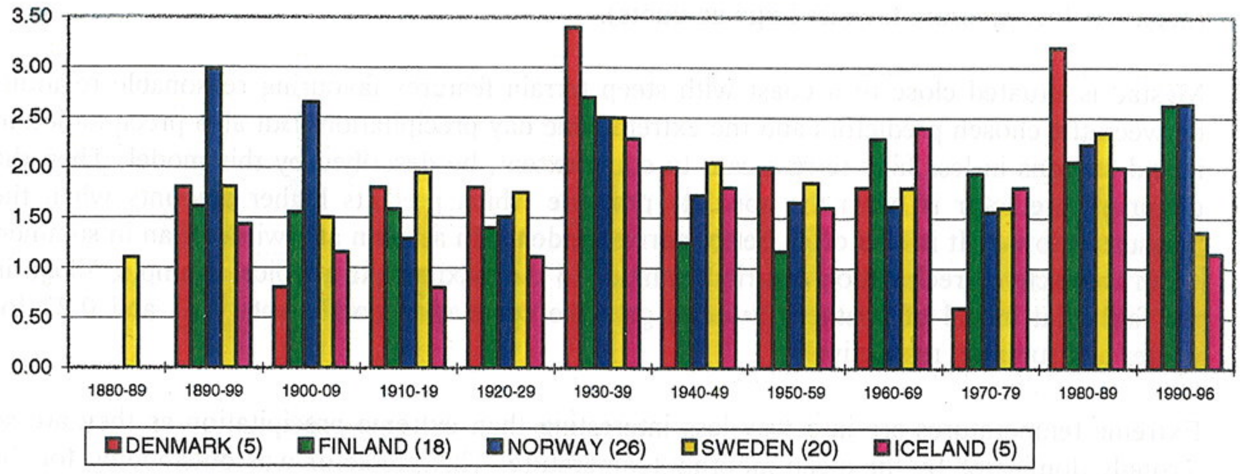


Figure 4 Number of «extraordinary» 1-day precipitation events per station and decade in the Nordic countries (In brackets: Number of stations analyzed)

4.3 Connections between extreme values and the atmospheric circulation

In section 4.1 and 4.2 it is documented that there are substantial long-term variations in temperature and precipitation extremes in the Nordic region. One of the main objectives in REWARD was to study to which degree these variations could be explained by predictors related to the large scale circulation. Table 1 shows the predictors and predictands in a linear regression model used to link climatic extremes and atmospheric circulation.

Table 1. Predictors and predictands for modelling extreme temperature and precipitation

Predictands		Predictors	
Rx	Monthly maximum of one day precipitation (+date).	Ug	Zonal geostrophic wind component at sea level.
Th	Monthly maximum of temperature (+date).	Vg	Meridional geostrophic wind component at sea level.
Tl	Monthly minimum of temperature (+date).	Pa	Air pressure at mean sea level.
		Tm	Monthly mean temperature.

Figure 5a shows the correspondence between observed and modelled winter values of maximum 1-day precipitation for Mestad in southern Norway. The correlation coefficient is 0.51. Significant predictors are Vg (positive, southerly winds favour large amounts), Tm (positive, mild winter months are favourable for high amounts) and, to a lesser extent, Pa (negative, low pressure favours large amounts).

Mestad is situated close to a coast with steep terrain features favouring reasonable relations between the chosen predictors and the extreme one day precipitation. But also precipitation at inland stations in less hilly terrain can, to some extent, be described by this model. Then the dominant predictor is often the absolute pressure which predicts higher amounts when the pressure is lower. It is also often better correspondence in autumn and winter than in summer, when convective precipitation contributes much to the maxima. As a typical example, Växjö in the fairly flat inland of southern Sweden gets the correlation coefficients 0.43 and 0.27 for winter and summer, respectively.

Extreme temperatures are in a way less interesting than extreme precipitation as they are so strongly dominated by the mean monthly temperature. This predictor was outstanding for the stations that were studied. However, for some stations and seasons the other predictors contributed with some improvements for the regression. For Stensele in northern Sweden, Figure 5b shows modelled versus observed absolute minimum temperatures for winter months 1900-1995. The correlation coefficient is as high as 0.74 and in this case inflating is used to get a better spread in the modelled values. The lowest modelled temperature, -48.1°C on 5 Feb 1966, is too cold as the observed value was -39.5°C. The lowest observed value, -45.5°C on 23 Dec 1915, is perfectly caught by the model (-45.2°C).

A similar model with Ug, Vg and Pa as predictors was tested on mean data from the Norwegian Arctic (Hanssen-Bauer & Førland, 1998). This model accounted for 30-50% of the variance in the seasonal mean temperatures, while about 40% of the variance in the annual temperatures were accounted for. The correlation between observed and modelled values was lowest for the summer season. For Svalbard Airport (Longyearbyen) the model accounted for 15-35% of the variance in seasonal precipitation sums and about 30% of the variance in annual precipitation.

Even though the observed and modelled seasonal values in the Arctic in most cases were better correlated for temperature than for precipitation, the precipitation model accounted for more of the decadal scale variability and long-term trends than the temperature model. The precipitation model reproduced the observed positive precipitation trends during the period of measurements both on seasonal and on annual basis. Concerning decadal scale variability, most of the main observed features are modelled satisfactory. It was concluded that the major observed features concerning decadal scale variability and trends in precipitation at Svalbard Airport are connected to the atmospheric circulation pattern.

The Arctic temperature models reproduce the observed positive trends during the last 3 decades of the series of winter and spring temperatures, and also of annual mean temperatures. The very low temperature level before 1920 and the temperature optima in the 1930's and 1950's on the other hand are not modelled satisfactory. Thus, while the temperature increase in the Norwegian Arctic during the later decades can mainly may be explained as a result from changes in the average advection conditions,- the extremely low temperatures in the beginning of the century and the considerable temperature increase up to the 1930's cannot be explained in this way.

It may be concluded that it is with some success multiple linear regression models for calculating extreme values is tested. In addition such models offer an independent way of checking long-term trends in the time series of the extremes, and may be a useful tool for predicting changes in extreme values using downscaling of GCM data.

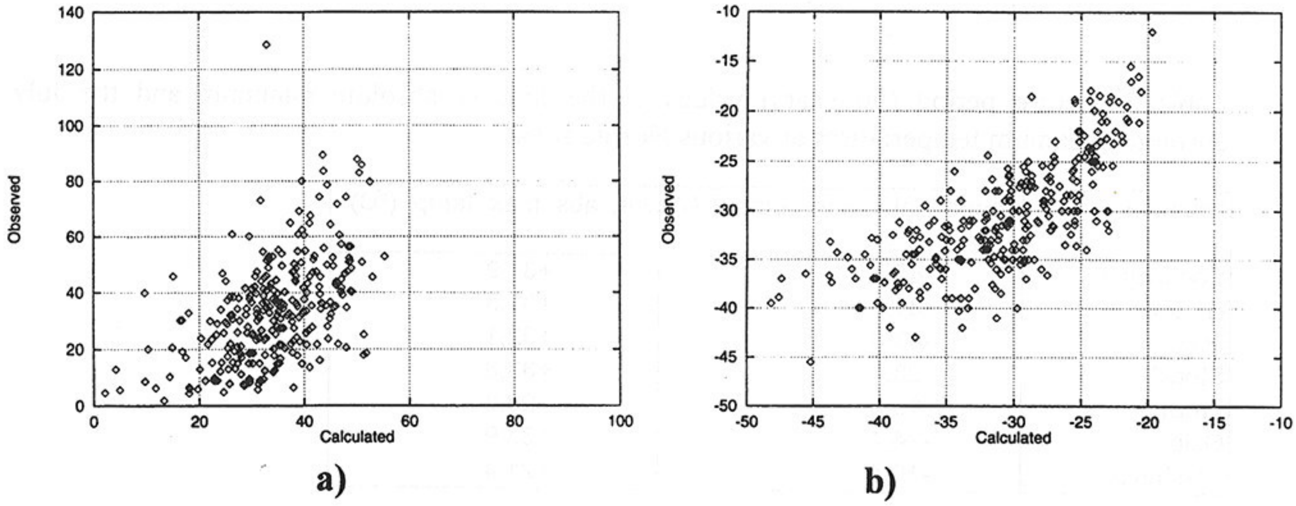


Figure 5: Modelled versus observed extreme values for Dec, Jan and Feb 1900-1995

a). Maximum 1-day precipitation (mm) at Mestad in Oddernes, southern Norway. (58°13'N, 7°54'E)

b). Absolute minimum temperatures (°C) for Stensele, northern Sweden (65°04′ N, 17°09′ E). (Inflating has been used.)

4.4 Extreme value distributions and return periods

Extreme value distributions and estimates of probable extremes with specific recurrence intervals for various meteorological variables are important e.g. within the context of climate impact studies. The high-quality long data series of the NACD and REWARD projects offer possibilities to test different extreme values distributions, and to update former estimates of extremes corresponding to different recurrence periods.

Regarding the extreme value distributions and return period values, the REWARD project has focused on the January absolute minimum and July absolute maximum temperatures (1890 - 1995), within the Fennoscandian region and at Tórshavn (Faroe Islands). The chosen return period of 50 years corresponds to a commonly used design value return period. The results presented here are a slight extension of a study by Helminen (1997).

The extreme value distributions of both the January absolute minimum and the July absolute maximum temperature followed the Weibull or Type III distribution, which converges asymptotically to a lower/upper limit in the case of absolute minimum/maximum temperature, respectively (cf. Figure 2 a-c). However, in Tórshavn (cf. Figure 2d) the extreme value distribution of the July absolute maximum temperature followed the Gumbel or Type I distribution, for which the return period values grow unlimited with the increasing return period. This feature has so far been the only exception of the general rule of a Weibull distribution fit, and may reflect some characteristics of the maritime environment.

Based on the extreme value distribution estimates, a first compilation of 50 year return period values of the January absolute minimum and the July maximum temperatures are presented in Table 2 for seven Nordic sites.

Table 2. Return period (50 years) values of the January absolute minimum and the July absolute maximum temperatures at various Nordic sites.

Location	January abs. min. temp. (°C)	July abs. max. temp. (°C)
Sodankylä	-45,8	+31,9
Helsinki	-31,9	+31,5
Jokkmokk	-43,0	+32,1
Stockholm	-23,1	+33,8
Tromsø	-16,8	+29,3
Oslo	-24,4	+33,9
Tórshavn	-10,4	+21,4

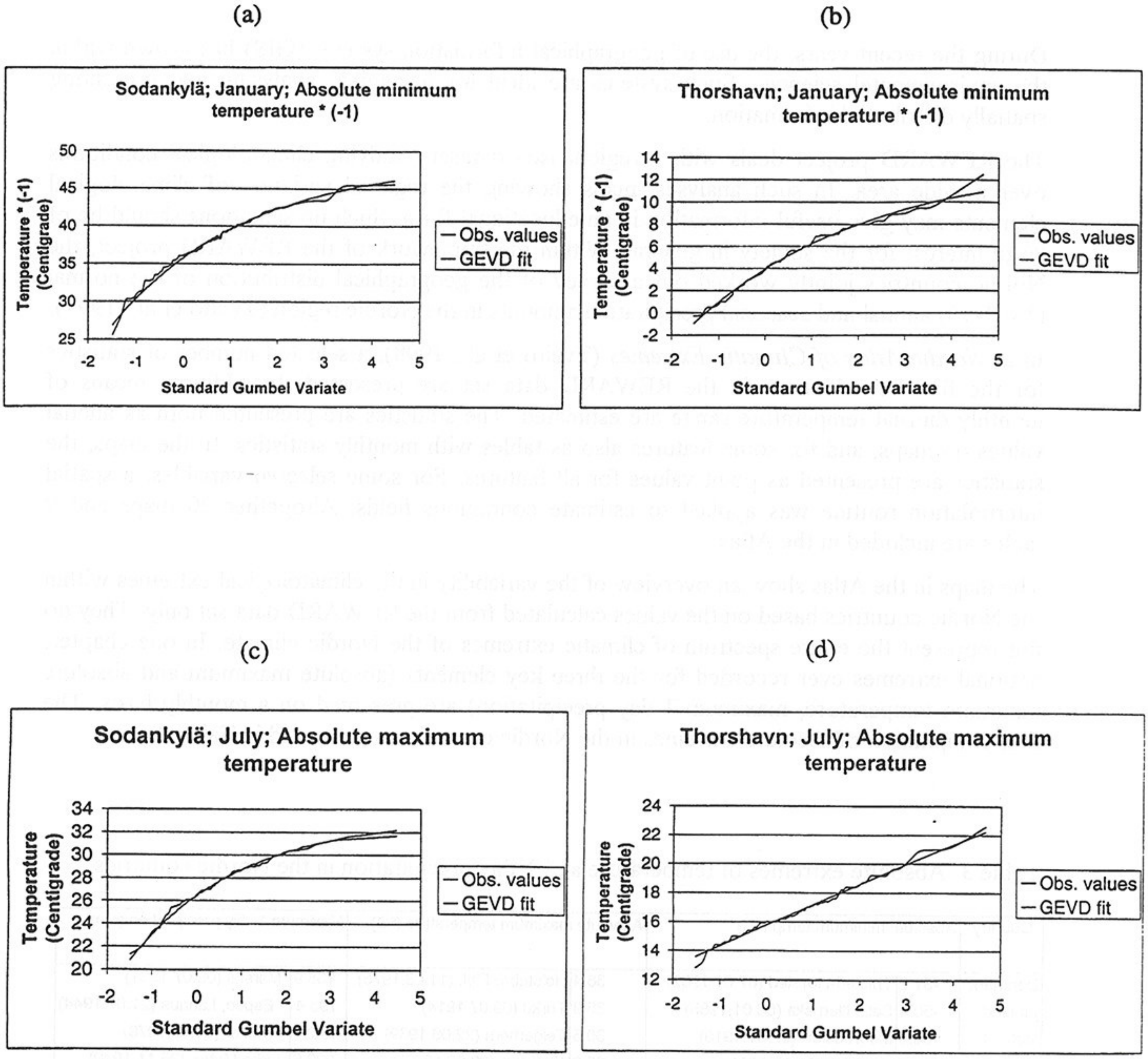


Figure 6. January absolute minimum and July absolute maximum temperature distributions for Sodankylä (a,c) and Tórshavn (b,d) based both on the observed values and on a generalized extreme value distribution fit

(Note: In case of the minimum temperatures the temperature scale should be multiplied by -1);

4.5. Nordic Atlas of climatic extremes

During the recent years, the use of geographical information systems (GIS) has grown within the environmental sciences. Such systems are ideal for managing, analysing and presenting spatially distributed information.

The REWARD project deals with a regionalised dataset, studying climatological conditions over a wide area. In such analyses, maps showing the regional variation of climatological elements may give useful information in an educational form. Such presentations should be of large interest for the society in general. Within the framework of the REWARD-project, the Nordic countries jointly worked out a survey of the geographical distribution of the normal (1961-90) annual and seasonal precipitation amounts in the Nordic region (Tveito et al., 1997).

In a *Nordic Atlas of Climatic Extremes* (Tveito et al., 1998), a selected number of statistics for the five key elements in the REWARD data set are presented. In addition, means of monthly diurnal temperature range are estimated. The statistics are presented both as annual values on maps, and for some features also as tables with monthly statistics. In the maps, the statistics are presented as point values for all features. For some selected variables, a spatial interpolation routine was applied to estimate continuous fields. Altogether 20 maps and 9 tables are included in the Atlas.

The maps in the Atlas show an overview of the variability in the climatological extremes within the Nordic countries based on the values calculated from the REWARD data set only. They do not represent the entire spectrum of climatic extremes of the Nordic climate. In one chapter, national extremes ever recorded for the three key elements (absolute maximum and absolute minimum temperature, maximum 1-day precipitation) are presented on a monthly basis. The first compilation of absolute extremes in the Nordic countries is presented in Table 3.

Table 3. Absolute extremes of temperature and 1-day precipitation in the Nordic countries

Country	Absolute minimum temp (°C)		Absolute maximum temperature (°C)		Maximum 1-day precipitation (mm)	
Denmark	-31.2	Thisted-Hørsted (07.01.1982)	36.4	Holstebro Flpl. (11.08.1975)	168.9	Marstal (09.07.1931)
Finland	-50.4	Salla Naruska (06.01.1985)	35.9	Turku (09.07.1914)	198.4	Espoo, Lahnus (21.07.1944)
Iceland	-38.0	Möðrudalur (22.01.1918)	30.5	Teigarhorn (22.06.1939)	242.7	Kvísker (01.10.1979)
Norway	-52.4	Karasjok (01.01.1886)	35.6	Nesbyen (20.06.1970)	229.6	Indre Matre (26.11.1940)
Sweden	-52.6	Vuoggatjålme (02.02.1966)	38.0	Målilla (29.06.1947)	198*	Fagerheden (28.07.1997)

*) Unofficial maximum recording: 237 mm at Karlaby, 06.08.1960

The production of the maps was carried out at DNMI by use of GIS. ArcView desktop GIS was used for the map presentation, while ArcInfo was used in processing the analysed fields. As an example Figure 7 is showing the maximum 1-day precipitation recorded at the REWARD-stations.

The Atlas produced within REWARD will also be presented on the world wide web (www).

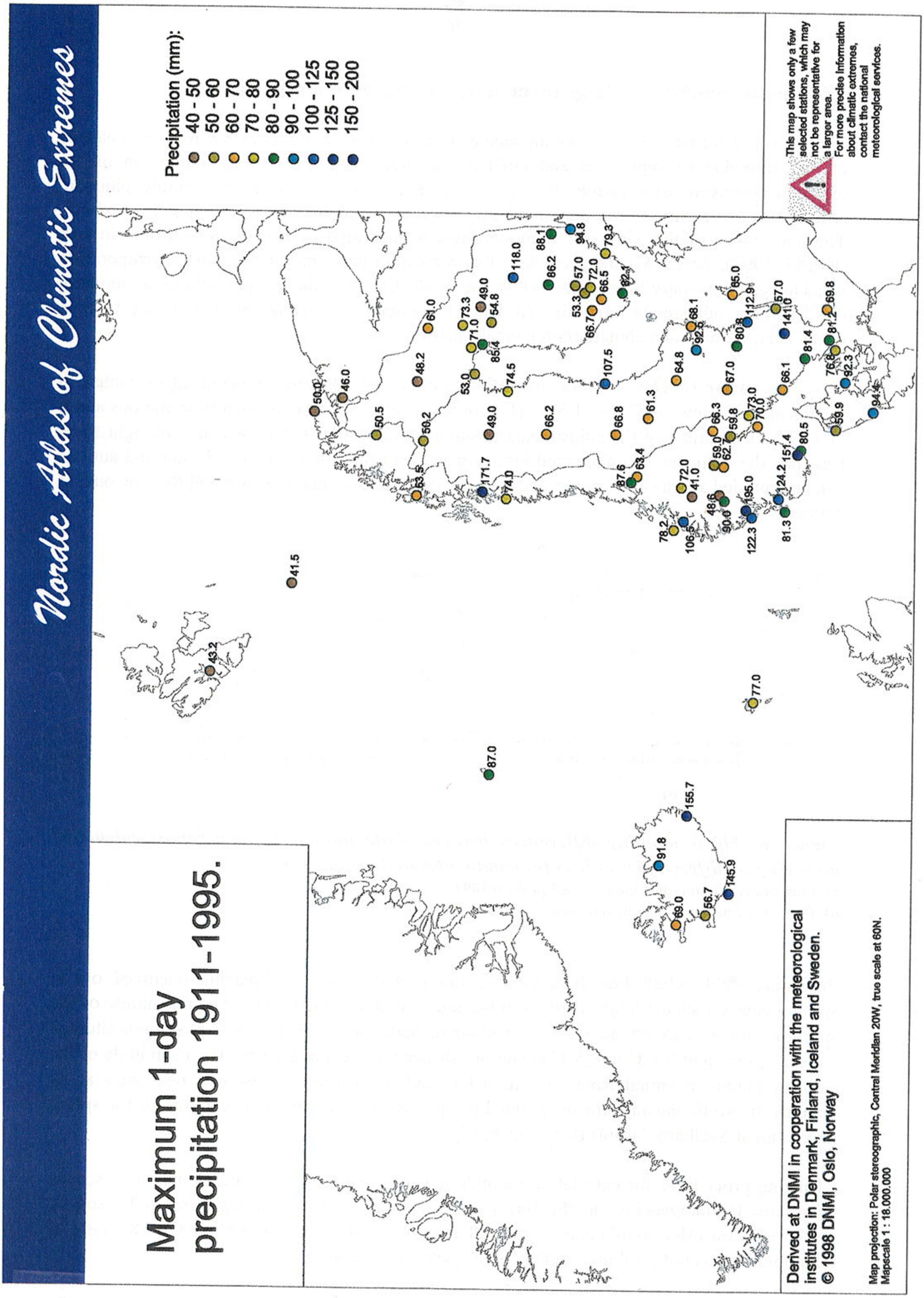
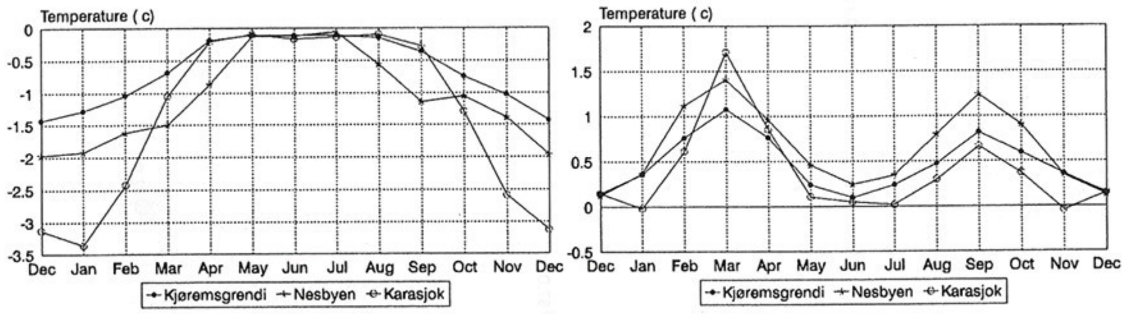


Figure 7. Maximum 1-day precipitation (1911-1995) at the REWARD-stations

4.6 Inhomogeneities in long-term series of extreme temperatures

There are several reasons for inhomogeneities in series of extreme temperatures, e.g. changes of exposure due to vegetation and buildings, changes in screen design, relocation of the temperature screen, urbanisation of the suroundings, etc. For series of mean monthly minimum temperature, one curious reason for inhomogeneities is *changes in calculation procedures*. The importance of this kind of inhomogeneities is illustrated by a case study from Norway (Nordli, 1997). At DNMI the procedure for calculating mean monthly minimum temperature was changed 1 January in the years 1894 and 1938. By using the old procedures on modern, digitised data, adjustment terms for old data were assessed. These adjustments varied by time of the year, latitude and climate (continental - maritime).

Procedure **prior to 1894**: For all stations the largest adjustments occurred in winter, at continental stations -3°C to -1.5°C (Figure 8a), and at coastal or maritime stations about -1°C. The magnitude of the adjustments in summer was about -0.2°C, which is thought to be less than the influence of undetected inhomogeneities from other sources. Spring and autumn can be regarded as transition zones between the high adjustments in winter and the low ones in summer.



a). ***b).***

Figure 8. Mean monthly differences between daily minimum temperature calculated according to different definitions for continental stations in Norway

a) Present definition minus the one used prior to 1894

b) Present definition minus the one used in the period 1894 - 1937

Procedure **1894 - 1937**: For all stations but one in Arctic, two local maxima occurred, one in spring being somewhat larger than the other one in autumn (Figure 8b). The magnitude of the spring maximum was 1°C to 1.5°C at continental stations, 0.6°C to 0.8°C at stations situated in inner fjords, and 0.1°C to 0.5°C at stations situated in coastal districts. The magnitude of the summer minimum varied from zero to 0.3°C and the winter minima was near zero at all stations. In Arctic the adjustments seemed to be close to zero with an exception for the spring maximum at Svalbard Airport (0.5°C in April).

Changing procedures for calculating monthly mean of extreme temperatures may be a source of serious inhomogeneities in the series from several countries. Having been addressed by participants on IMO conferences at more than one occasion, it is very likely that this kind of inhomogeneity is not attributed to the Norwegian series only.

4.7 References

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5. Nordic collaboration within REWARD

During the project period there has been a close collaboration between climatologists at the meteorological institutes in Denmark, Finland, Iceland, Norway and Sweden. Four project meetings were arranged:

Oslo, 4-5. March 1996
Norrköping, 16-18 October 1996
Helsinki, 25-27 February 1997
Reykjavik, 10-12. November 1997

The project meetings were partly funded by NorFA, partly by NMR/REWARD and partly by the national meteorological institutes.

In combination with all the REWARD-meetings, *Nordic Climate Workshops* with extended participation were arranged. The meeting in Helsinki included a visit to Tallinn, to discuss climate change topics with Estonian climatologists.

In addition to the project meetings, there has been special group meetings within some of the activities.

The work within the REWARD-project has been organised in 6 main activities (see section 3) with a multinational participation within each activity. The close co-operation within the project has initiated close personal relationships amongst climatologists in all Nordic countries. The joint efforts within the project have made it possible for the Nordic countries to compile a unique dataset on climatic extremes, and perform pilot studies on possible changes in extreme meteorological events. Thus the Nordic countries have contributed to make more data and analyses available for the next stage of the International Panel on Climate Change, IPCC.

The REWARD-dataset of climatic extremes includes data for all Nordic countries, including the Faroe Islands and Greenland. Standardised routines of quality checking and homogeneity testing have been used, and the final dataset is compiled according to the guidelines outlined in the NACD-project (Frich et al., 1996).

Through the partly NMR-financed projects NACD and REWARD, the Nordic countries jointly have established a unique climatological dataset of monthly values for:

- ***10 climatic elements (temperature, precipitation, air pressure, snow cover, cloudiness)***
- ***> 50 stations, representing all parts of the Nordic region***
- ***~ 100 years (mainly 1890-1996 (to 1990 in NACD))***

6. REWARD-Publications

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Appendix: Station list for REWARD-dataset (for further details, see Drebs at al.,1998)

Name	Country	St.nr. WMO	St.nr. nat.	Lat.	Long.	Mean max. temp. (111)	Abs.max. temp. (112)	Mean min. temp. (121)	Abs. min. temp. (122)	Max 24h precip. (602)	Init
Hammerodde Fyr	DK	6193	6193	55.30	14.78	1890-1995	1890-1995	1890-1995	1890-1995	1890-1995	HAMM
Vestervig	DK		21100	56.77	8.32	1890-1995	1890-1995	1890-1995	1890-1995	1890-1995	VEST
Nordby	DK		25140	55.43	8.40	1874-1995	1874-1995	1874-1995	1874-1995	1890-1995	NORD
Tranebjerg	DK		27080	55.85	10.60	1890-1995	1890-1995	1890-1995	1890-1995	1890-1995	TRAN
København	DK		30380	55.68	12.53	1890-1995	1890-1995	1890-1995	1890-1995	1890-1995	KØBE
Maarianhamina	FIN		1	60.12	19.90	1908-1995	1908-1995	1908-1995	1908-1995		MAAR
Helsinki	FIN	2978	304	60.17	24.95	1882-1995	1882-1995	1882-1995	1882-1995	1882-1996	HELS
Turku	FIN	2972	1101	60.52	22.27	1903-1995	1903-1995	1902-1995	1903-1995	1891-1996	TURK
Huittinen Lauttakylä	FIN		1103	61.17	22.78	1901-1995	1901-1995	1901-1995	1901-1995	1894-1996	HUIT
Tampere	FIN		1202	61.47	23.75	1902-1995	1902-1995	1902-1995	1902-1995	1891-1996	TAMP
Hattula Leteensuo	FIN		1303	61.07	24.23	1925-1995	1925-1995	1925-1995	1925-1995		HATT
Heinola Plaani	FIN		1506	61.22	26.05	1909-1995	1909-1995	1909-1995	1909-1995		HEIN
Virolahti	FIN	1601	1601	60.53	27.55					1894-1996	VIRO
Lappeenranta	FIN	2958	1701	61.08	28.15	1906-1995	1906-1995	1906-1995	1906-1995	1886-1996	LAPP
Lavia	FIN	2104	2104	61.62	22.55					1903-1996	LAVI
Virrat	FIN	2211	2211	61.22	23.83					1909-1996	VIRR
Orivesi	FIN	2306	2306	61.55	24.53					1909-1996	ORIV
Jyväskylä	FIN		2425	62.20	25.72	1902-1995	1902-1995	1902-1995	1902-1995	1891-1996	JYVÄ
Vaasa	FIN		3001	63.05	21.77	1908-1995	1908-1995	1908-1995	1908-1995		VAAS
Ylistaro Pelma	FIN		3101	62.93	22.50	1928-1995	1928-1995	1928-1995	1928-1995		YLIS
Ähtäri Myllymäki	FIN		3301	62.53	24.22	1910-1995	1910-1995	1910-1995	1910-1995		ÄHTÄ
Kuopio	FIN		3602	62.90	27.68	1902-1995	1902-1995	1902-1995	1902-1995	1891-1996	KUOP
Maaninka	FIN		3603	63.15	27.32	1930-1995	1930-1995	1930-1995	1930-1995		MAAN
Joensuu	FIN		3801	62.67	29.63	1933-1995	1933-1995	1933-1995	1933-1995		JOEN
Kestilä	FIN	4509	4509	64.35	26.28					1909-1996	KEST
Kajaani	FIN	2897	4601	64.28	27.67	1903-1995	1903-1995	1903-1995	1903-1995	1886-1996	KAJA
Oulu	FIN		5404	65.03	25.48	1905-1995	1905-1995	1903-1995	1905-1995	1891-1996	OULU
Yli-Ii	FIN	5407	5407	65.37	25.85					1912-1996	YLII
Pudasjärvi Korpis.	FIN	5605	5605	65.10	27.53					1909-1996	PUDA
Kuusamo	FIN	2896	6801	65.98	29.22	1909-1995	1909-1995	1908-1995	1909-1995	1908-1996	KUUS
Sodankylä	FIN	2836	7501	67.37	26.65	1908-1995	1908-1995	1908-1995	1908-1995	1907-1996	SODA
Torshavn	FR	6011	6011	62.02	-6.77	1873-1995	1873-1995	1873-1995	1873-1995	1890-1995	TORS
Upernavik	G	4210	4210	72.78	-56.17	1890-1995	1890-1995	1890-1995	1890-1995	1949-1985	UPER
Ilulissat Airport	G	4221	4221	69.25	-51.67	1894-1995	1890-1995	1890-1995	1890-1995		ILUL
Nuuk	G	4250	4250	64.17	-51.75	1890-1995	1890-1995	1890-1995	1890-1995	1921-1995	NUUK
Narsarsuaq	G	4270	4270	61.18	-45.42	1890-1995	1890-1995	1890-1995	1890-1995	1890-1995	NARS
Danmarkshavn	G	4320	4320	76.77	-18.77	1949-1995	1949-1995	1949-1995	1949-1995	1949-1995	DANM
Ittoqqortoormiit	G	4339	4339	70.48	-22.00	1924-1995	1924-1995	1949-1995	1949-1995	1949-1995	ITTO
Tasilaq	G	4360	4360	65.60	-37.63	1897-1995	1894-1995	1894-1995	1894-1995	1897-1995	TASI
Stykkisholmur	IC	4013	4013	65.08	-22.73	1952-1995	1952-1995	1952-1995	1952-1995	1890-1996	STYK
Reykjavik	IC	4030	4030	64.13	-21.90	1949-1995	1949-1995	1949-1995	1949-1995	1924-1996	REYK
Vestmannaeyjar	IC	4048	4048	63.40	-20.28	1949-1995	1954-1995	1949-1995	1949-1995	1890-1996	VEST
Akureyri	IC	4063	4063	65.68	-18.08	1949-1995	1949-1995	1949-1995	1949-1995	1925-1996	AKUR
Teigarhorn	IC	4092	4092	64.68	-14.35	1965-1995	1965-1995	1965-1995	1965-1995	1890-1996	TEIG
Halden	N		1230	59.12	11.38					1895-1996	HALD
Nord-Odal	N		5350	60.38	11.55					1895-1996	ODAL
Skjåk	N		15660	61.90	8.17					1896-1996	SKJÅ

Name	Country	St.nr. WMO	St.nr. nat.	Lat.	Long.	Mean max. temp. (111)	Abs.max. temp. (112)	Mean min. temp. (121)	Abs. min. temp. (122)	Max 24h precip. (602)	Init
Kjøremsgrendi	N	1235	16740	62.10	9.05	1931-1995	1890-1995	1876-1995	1890-1995	1890-1996	KJØR
Oslo-Blindern	N	1492	18700	59.95	10.72	1937-1995	1890-1995	1876-1995	1890-1995	1890-1996	OSLO
Reinli	N		22840	60.83	9.50					1895-1996	REIN
Nesbyen	N	1372	24880	60.57	9.12	1954-1995	1897-1995	1897-1995	1897-1995	1897-1996	NESB
Ferder Fyr	N	1482	27500	59.03	10.53	1931-1995	1890-1995	1885-1995	1890-1995	1890-1996	FERD
Oksøy Fyr	N	1448	39100	58.07	8.05	1931-1995	1890-1995	1876-1995	1890-1995	1890-1996	OKSØ
Mestad	N		39220	58.22	7.90					1900-1996	MEST
Nedstrand	N		47020	59.35	5.80					1895-1996	NEDS
Utsira Fyr	N	1403	47300	59.30	4.88	1931-1995	1890-1995	1876-1995	1890-1995	1920-1996	UTSI
Samnanger	N		50350	60.47	5.90					1901-1996	SAMN
Bergen-Florida	N	1317	50540	60.38	5.33	1904-1995	1890-1995	1876-1995	1890-1995	1890-1996	BERG
Lærdal	N	1355	54130	61.07	7.52	1953-1995	1890-1995	1876-1995	1890-1995	1890-1996	LÆRD
Vetti	N		54900	61.00	7.02					1895-1996	VETT
Ørskog	N		60800	62.48	6.82					1895-1996	ØRSK
Ona	N	1212	62480	62.87	6.53	1931-1995	1890-1995	1876-1995	1890-1995	1919-1996	ONA
Lien i Selbu	N		68330	63.22	11.12					1895-1996	LIEN
Værnes/Trondheim	N	1271	69100	63.47	10.93		1890-1995		1890-1995	1890-1996	VÆRN
Bodø	N	1152	82290	67.27	14.43		1890-1995		1890-1995	1890-1996	BODØ
Kråkmo	N		83500	67.80	15.98					1895-1996	KRÅK
Tromsø	N	1026	90450	69.65	18.93	1931-1995	1890-1995	1876-1995	1890-1995	1890-1996	TROM
Karasjok	N	1065	97250	69.47	25.52	1950-1995	1890-1995	1877-1995	1890-1995	1890-1996	KARA
Vardø	N	1098	98550	70.37	31.08	1931-1995	1890-1995	1876-1995	1890-1995	1893-1996	VARD
Bjørnsund	N		99450	69.45	30.07					1895-1996	BJØS
Bjørnøya	N	1028	99710	74.52	19.02	1937-1995	1921-1995	1921-1995	1921-1995	1926-1996	BJØY
Hopen	N	1062	99720	76.50	25.06	1948-1995	1945-1995	1945-1995	1945-1995		HOPE
Svalbard Airport	N	1008	99840	78.25	15.47		1957-1995		1957-1995	1957-1996	SVAL
Jan Mayen	N	1001	99950	70.93	-8.67	1937-1995	1921-1995	1921-1995	1921-1995	1922-1996	JAN
Lund	S		5343	55.70	13.20					1885-1996	LUND
Halmstad	S		6240	56.67	12.92					1885-1996	HALM
Växjö	S	2640	6452	56.87	14.80	1873-1995	1885-1994	1873-1995	1885-1995	1885-1996	VÄXJ
Kalmar	S	2672	6641	56.72	16.28					1885-1996	KALM
Göteborg	S	2516	7147	57.77	11.88	1881-1995	1885-1995	1881-1995		1885-1996	GÖTE
Västervik	S	2559	7647	57.72	16.47		1885-1995		1885-1995	1885-1996	VÄST
Visby	S	2592	7840	57.67	18.33	1879-1995	1885-1995	1879-1995	1885-1995	1885-1996	VISB
Linköping	S	2582	8524	58.40	15.53					1885-1996	LINK
Karlstad	S	2584	9322	59.35	13.47	1881-1995	1885-1995	1881-1995	1885-1995	1885-1996	KARL
Västerås	S	2418	9635	59.58	16.62					1885-1996	VÄST
Stockholm	S	2485	9821	59.33	18.05	1873-1995		1873-1995	1885-1995	1885-1996	STOC
Falun	S	2433	10537	60.62	15.62	1875-1995	1885-1995	1875-1995	1885-1995	1885-1996	FALU
Sveg	S	2324	12402	62.02	14.35		1885-1995		1885-1995	1885-1996	SVEG
Härnösand	S		12738	62.62	17.93	1879-1995	1885-1995	1879-1995	1885-1995	1885-1996	HÄRN
Östersund	S	2226	13411	63.18	14.48	1875-1995	1885-1995	1873-1995	1885-1995	1885-1996	ÖSTE
Stensele	S		15772	65.07	17.15	1885-1995	1885-1995	1885-1995	1885-1995	1885-1996	STEN
Piteå	S		16179	65.32	21.48					1885-1996	PITE
Haparanda	S	2196	16395	65.82	24.13	1873-1995	1885-1995	1873-1995	1885-1995	1885-1996	HAPA
Jokkmokk	S	2142	16988	66.62	19.63	1882-1995	1885-1995	1882-1995	1885-1995	1885-1996	JOKK
Karesuando	S	2080	19283	68.43	22.48				1885-1995	1885-1996	KARE