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NORDIC PRECIPITATION MAPS

O.E.Tveito, E.J.Førland, B.Dahlström, E.Elomaa, P.Frich, I.Hanssen-Bauer, T.Jónsson, H.Madsen, J.Perälä, P.Rissanen, H.Vedin

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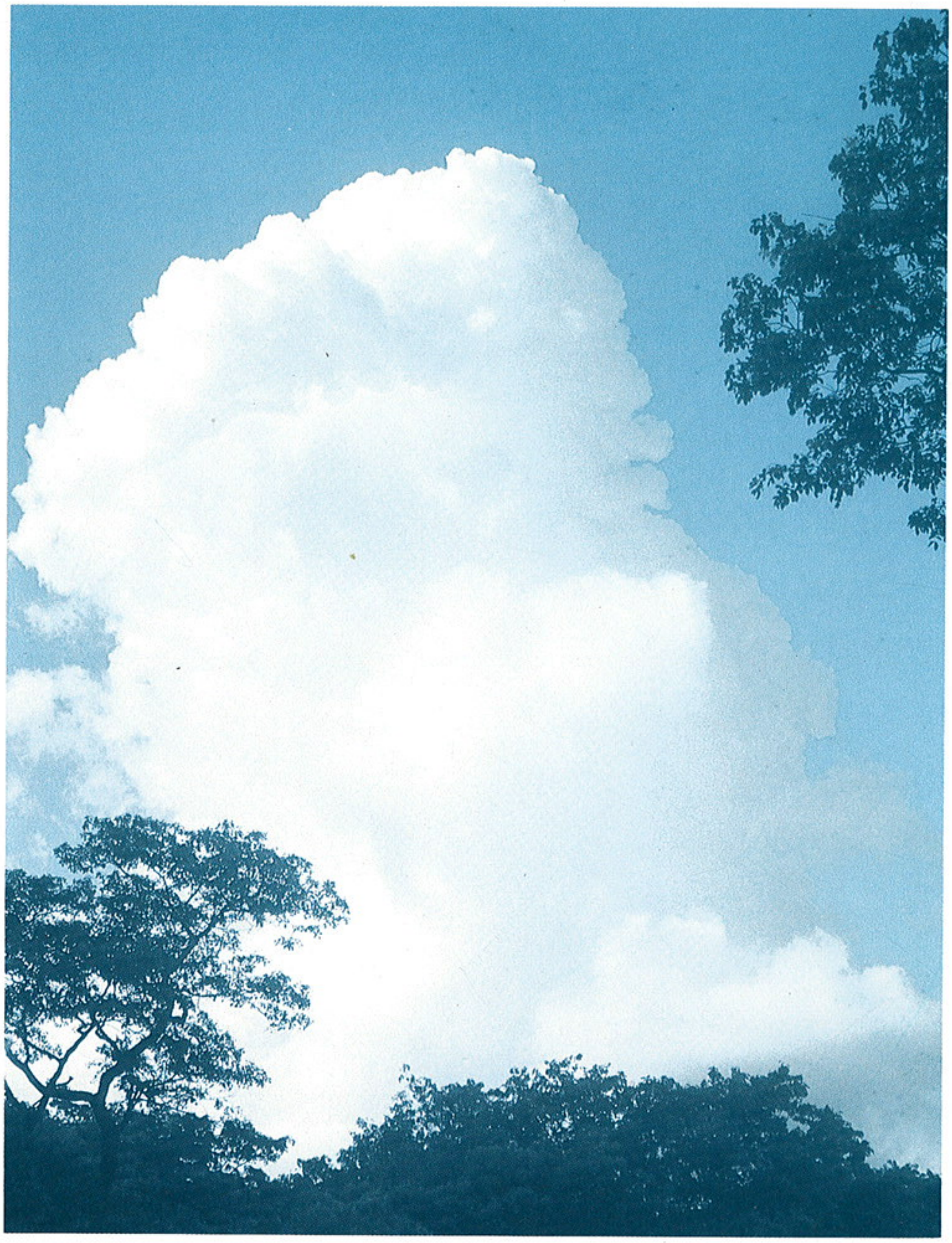

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TITLE

NORDIC PRECIPITATION MAPS

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PROJECT CONTRACTOR

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SUMMARY

Annual and seasonal maps of average measured precipitation for the Nordic countries during the standard normal period 1961-90 are presented. The maps are derived automatically by spatial interpolation in a geographical information system (GIS). Also maps showing differences between the 1961-90 and 1931-60 normals, as well as graphs showing running 30-year averages at selected stations in the Nordic area are presented and discussed. Maps of the seasonal precipitation as proportion of the annual normal precipitation are also presented.

This report is a result of a cooperation between the Danish Meteorological Institute (DMI), the Finnish Meteorological Institute (FMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Icelandic Meteorological Institute (VI) and the Norwegian Meterological Institute (DNMI), and was initiated by the Nordic Working Group on Precipitation.

SIGNATURE

Eirik J. Førland
PROJECT COORDINATOR

Bjørn Aune
HEAD OF DIVISION

Foreword

The initiative to prepare joint Nordic maps of annual and seasonal precipitation was taken by the Nordic Working Group on Precipitation (NWGP). The NWGP was a part of the framework of KOHYNO, the coordinating comittee for hydrology within the Nordic countries. In the last mandatory period (1995-96) the members of NWGP were:

Denmark:	Henning Madsen (DMI)
Finland:	Esko Elomaa (FMI)
	Jaakko Perälä (Finnish Environmental Agency)
	Pauli Rissanen (FMI)
Iceland:	Trausti Jónsson (VI)
Norway:	Eirik J. Førland (DNMI) (**Chairman**)
	Inger Hanssen-Bauer (DNMI)
Sweden:	Bengt Dahlström (SMHI)
	Haldo Vedin (SMHI)

Povl Frich, DMI has prepared the Danish precipitation data included in the analysis. The GIS-handling of the data is performed at DNMI's ARC/Info system by Ole Einar Tveito (DNMI).

Contents

1. Introduction

The standard normals for the period 1961-90 are calculated at the national Nordic meteorological institutes. For Norway, maps showing monthly and annual normals (1961-90) of *measured* precipitation was published as a part of the Norwegian National Atlas by Førland (1993b). Similar maps for Sweden were included in the National Atlas of Sweden (Raab &Vedin, 1995). Maps for Denmark have recently been produced (Frich et.al, 1997). The maps in the present report may deviate from national precipitation maps due to different interpolation techniques and different number of stations used.

The maps in this report are just showing the spatial distribution of *measured* precipitation. During snowfall and strong winds, the conventional precipitation gauges used in the Nordic countries catch just a small fraction of the «true» precipitation. As stated by e.g. Førland et al. (1996a), to get estimates of «true» precipitation, the monthly measured values have to be multiplied by a factor varying from 1.02 (rain, protected measuring sites) to 1.80 (snow, unsheltered locations in coastal or mountainous regions). For wind-exposed stations where a large proportion of the annual precipitation is snow (e.g. mountain areas and Spitsbergen), the true normal precipitation may be about 50% higher than the official uncorrected value (Hanssen-Bauer et al., 1996). At most other measuring sites in the Nordic countries, the ratio between true and measured precipitation will be lower than on Spitsbergen, but still the measured values at most sites give a significant underestimate of the true precipitation. As a consequence, Raab & Vedin (1995) in the National Atlas of Sweden have included even a map showing corrected annual precipitation in Sweden.

2. Climatological standard normal values

Normals are defined (WMO, 1989) as «period averages computed for a uniform and relatively long period comprising at least three consecutive ten-year periods». *Climatological standard normals* are defined as «averages of climatological data computed for consecutive periods of 30 years as follows: 1901-30, 1931-60, 1961-90 etc». In the case of series where some data are missing, provisional normals are calculated, based on comparisons with neighbouring stations with complete records. In this report «normals» are used synonymous with «climatological standard normals».

When the International Meteorological Organization in 1935 agreed to calculate «normals», one requirement was that the length of the normal period should be sufficient to reflect climatic changes. Too long periods might prove insensitive to real climatic trends, whereas too short periods would be over-sensitive to random climatic variations. It was feared that the 11-year sunspot periods might influence climatic variations. For these reasons it was decided to operate with an averaging period of 30 years. However, Førland et al. (1996b) have stated that in the Northern Europe there are substantial differences in annual and seasonal precipitation between the two last normal periods 1931-60 and 1961-90. To illustrate the variability of 30 year averages, maps of ratios between the last two standard normal periods and some time series of moving 30 year averages are presented.

3. Data and methods

3.1 Data

The maps are based on monthly precipitation normals from the Nordic countries, except Iceland, where only the annual precipitation sum is available. The maps are based on the measured precipitation, not adjusted for measuring errors.

Totally 2895 station values were used in the analysis, according to table 1.

Table 1: *Number of stations from each country.*

Country	Number of stations
Denmark	208
Finland	187
Iceland	121
Norway	1136
Sweden	1243

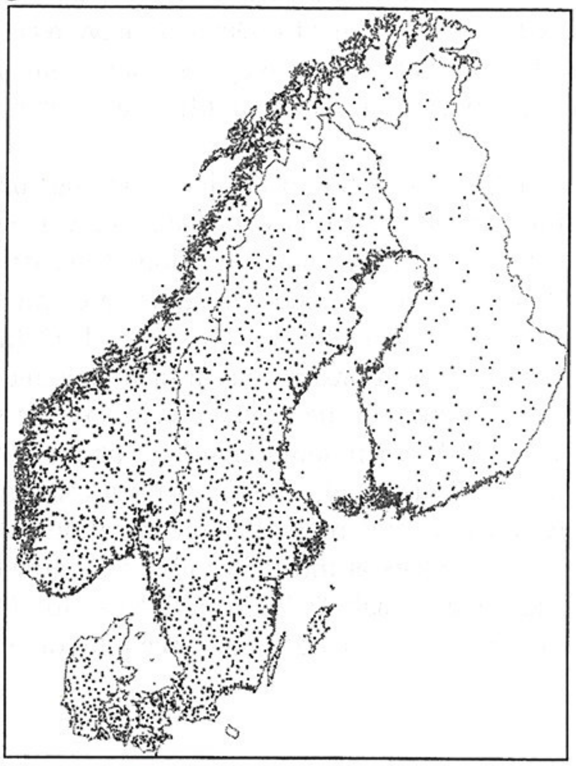


Figure 1a. *Location of precipitation stations in Fennoscandia.*

3.2 Method for analysis

The maps were produced in a geographical information system (GIS). Standard interpolation techniques implemented in the Arc/Info GIS-software was applied.

The monthly and annual precipitation from Denmark, Finland, Sweden and Norway was established as national datasets in Arc/Info. An Arc/Info datafile is called a coverage, and the data were represented as points. Secondly these covers were joined together to form one coverage for all the countries. This cover consists of 2774 stations, and their location is shown in map 1a.

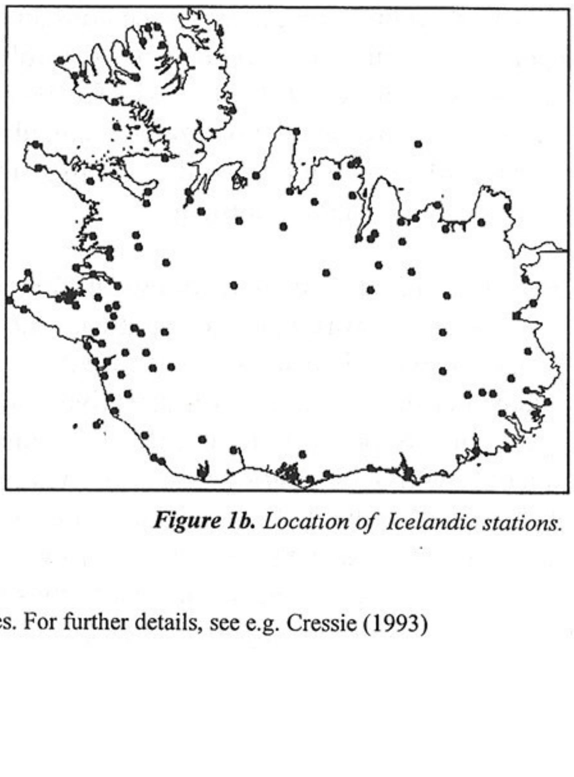


Figure 1b. *Location of Icelandic stations.*

The locations of the 121 Icelandic stations are stored in one separate coverage, and are shown in map 1b.

To establish a continous areal representation of the precipitation, spatial interpolation had to be carried out. The standard Arc/Info routine *KRIGING*[1] was used for this purpose.

[1] Kriging is a well known interpolation method within geosciences. For further details, see e.g. Cressie (1993)

Topography was not considered in the interpolation. This will influence on the results in several ways:

- precipitation in mountain areas are likely to be underestimated.
- The results depend highly on the input data, and the results are vulnerable to non-representative input values.

Anisotropy was not considered in the interpolation either. This means that the observations will have the same influence in all directions. For precipitation most of the anisotropy is caused by terrain variations, but also distance from coast may play a significant role.

The method will give satisfactory results in areas with a dense station network and small orographic effects.

4. Maps of normal (1961-90) precipitation

4.1 Annual precipitation

The mean annual precipitation map is presented in figure 2. The maximum annual station value of precipitation is 3575 mm at the Norwegian station 52930 Brekke i Sogn, situated 60 km north of Bergen in Western Norway (cf. Førland, 1993a). The lowest normal annual precipitation, 278 mm, is also at a Norwegian station, 15480 Skjåk II. This station is located at the leeward side of the Norwegian mountains.

Generally there is a zone of maximum precipitation close to the southern and/or western coasts in all Nordic countries. In Denmark and Finland most of the high precipitation along the coast is due to convergence caused by different friction effects over land and sea. Generally the highest precipitation occurs close to the west coast in Norway, Denmark and Sweden, due to advection of humid air from the west. In Norway this effect is strengthened by orografic lifting due to the steep terrain. In Finland and Sweden, most of the band of high precipitation along the Baltic and Finnish Bay coasts is due to convergence, but the maximum precipitation is also caused by additional orografic effects (Solantie, 1975). In Iceland there is a maximum zone along the western and southern coast, which is also due to advection and orographic lifting. The areas with lowest precipitation (<500 mm) are found on the leeward (eastern) side of the mountains in southern Norway, at the Swedish islands Gotland and Öland, and in northern Scandinavia. Also in Iceland the minimum precipitation zone is at the leeward (northern) side of the mountains.

Table 2 shows the national station number and precipitation sum for the stations having maximum and minimum precipitation sums within each of the countries. Figure 3 shows the locations of these stations, as well as stations holding the similar seasonal records.

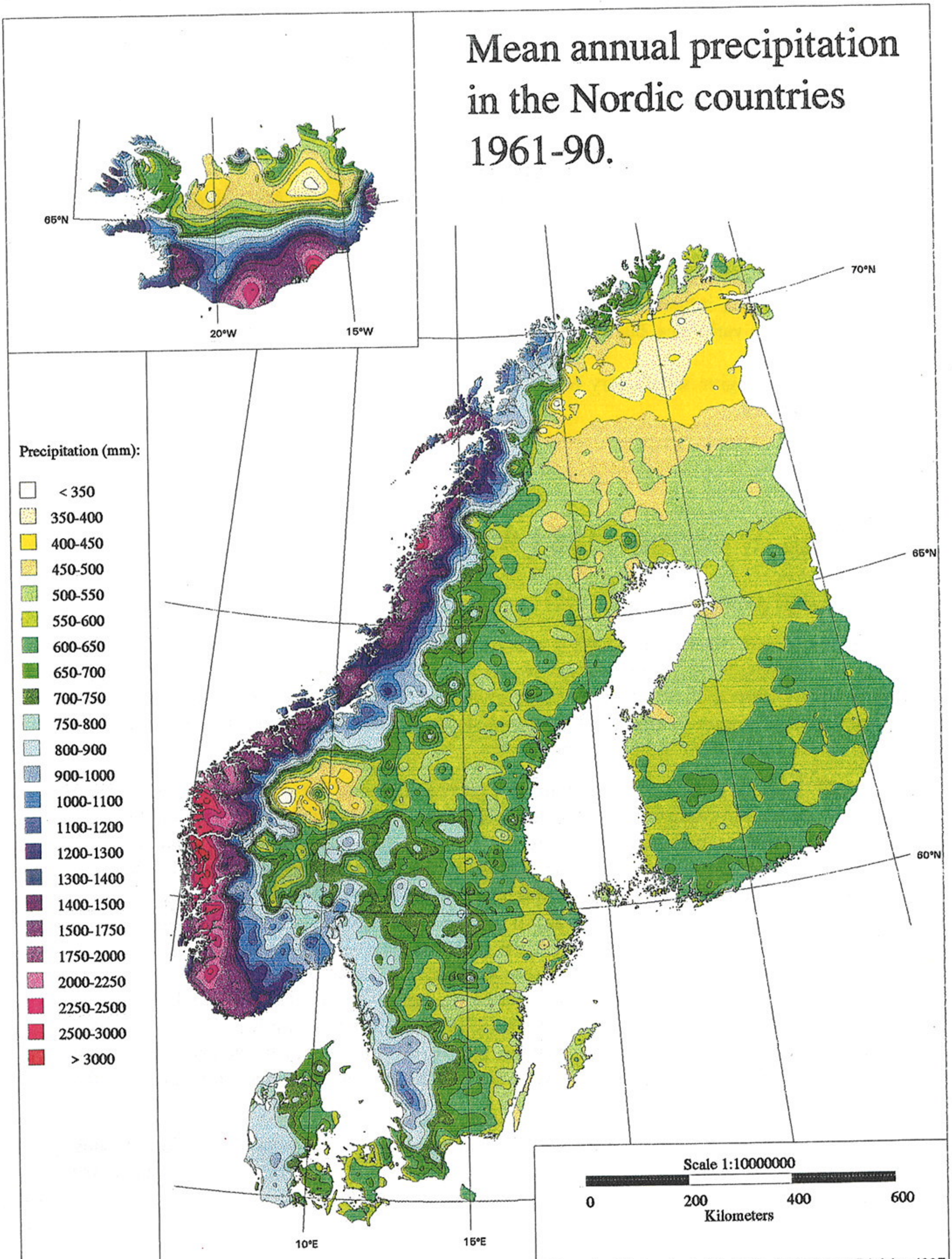


Figure 2. *Mean annual precipitation in the Nordic countries 1961-90.*

Table 2. Maximum and minimum annual precipitation in each country.

Country	Max.prec.sum (mm)	Station no.	Name	Min.prec.sum (mm)	Station no.	Name
FIN	719	0203	Pohja Pohjankuru	374	9402	Utsjoki Outakoski
SWE	1190	6353	Fröslida	304	18880	Abisko
NOR	3575	52930	Brekke i Sogn	278	15480	Skjåk
DEN	964	25250	Slauggård	473	06159	Røsnæs Fyr
ICE	3421	740	Kvísker	352	490	Möðrudalur

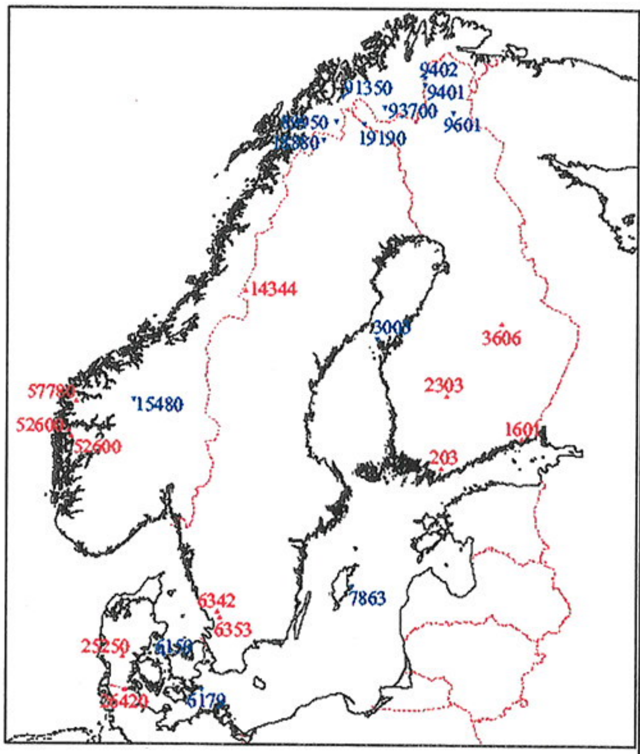


Figure 3 (above). Location of the stations with highest and lowest annual and seasonal precipitation normal 1961-90, stations

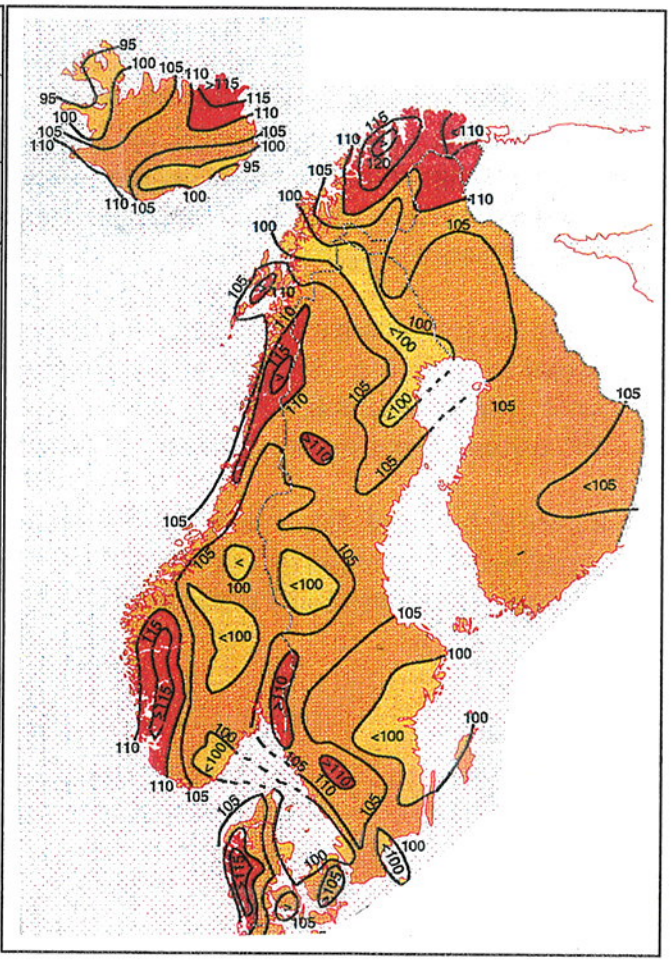


Figure 4 (right). Ratio (percent) between new (1961-90) and old (1931-60) annual precipitation normals (from Førland et al.,1996b)

The annual precipitation during the normal period 1961-90 is higher than during the previous normal period (1931-60) over large parts of the Nordic countries (Figure 4). The most pronounced increase (5-15 %) is found in western parts of Denmark, Sweden and Norway. This general increase is in accordance with global precipitation series presented by Hulme (1995), by which it can be deduced that the annual precipitation in the Northern Hemisphere north of 50°N has increased by 7% between the last two normal periods. In northern parts of Iceland, Finland and Norway the annual precipitation has increased by more than 10%. In western Norway the mean annual precipitation at some stations has increased by more than 300 mm/year.

However in eastern parts of Denmark (Jutland), southern Norway and Sweden, the normal annual precipitation is **lower** than in the previous normal period. In most of these areas the decrease is less than 5%.

The anomaly pattern in figure 4 indicates that the changes in normal annual precipitation are caused by changes in the circulation pattern. Areas exposed to orographic precipitation from the humid westerlies from the North-Atlantic have experienced increased precipitation. On the other hand, the annual precipitation has decreased in areas on the leeward side of the mountains in Norway and Sweden.

While the choice of length of the normal period was based on scientific considerations, practical reasons lay behind the choice of 1901 as the starting year in the first normal period. This year also decides the start of the succeeding standard normal periods (1931, 1961, ...). Would the normals in this century have been different if another starting year had been chosen? This may be illustrated by using 30-year running averages, as shown for some stations in figure 5. The figure indicates that 30-year averages may deviate significantly from long-term means,- more than 10% even on an annual basis. It also appears that some of the standard normals represent rather extreme values among 30-year running averages.

There are several interesting features in the various graphs in figure 5, e.g. steady increase in annual precipitation (Vestervig), large difference in seasonal precipitation sums (Karasjok), rapid changes in running 30-year averages (Samnanger & Uppsala), changes in relative order for seasons of maximum precipitation (Turku, Samnanger, Stykkisholmur), etc.

It should be noted that a series of consecutive mean values does not necessarily follow the variations of the original time series (Parkinson, 1989). Therefore, one should be careful in drawing conclusions about **climatic trends** just from graphs like figure 5.

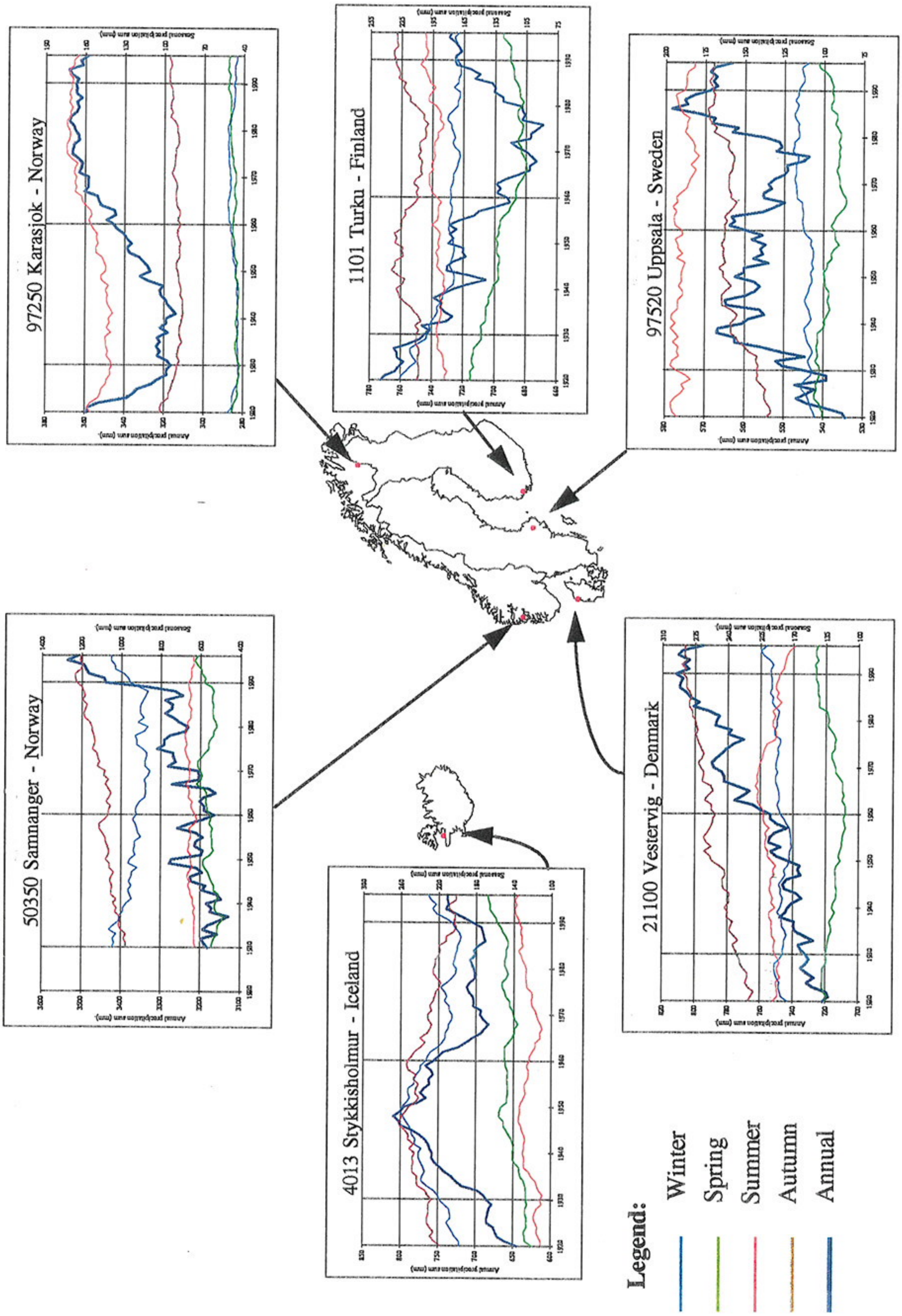


Figure 5. *Running 30-year averages of seasonal and annual precipitation at 6 Nordic locations. Years of standard normals are marked by vertical lines. (The 30-year averages are dated on the last year in the 30-year period.)*

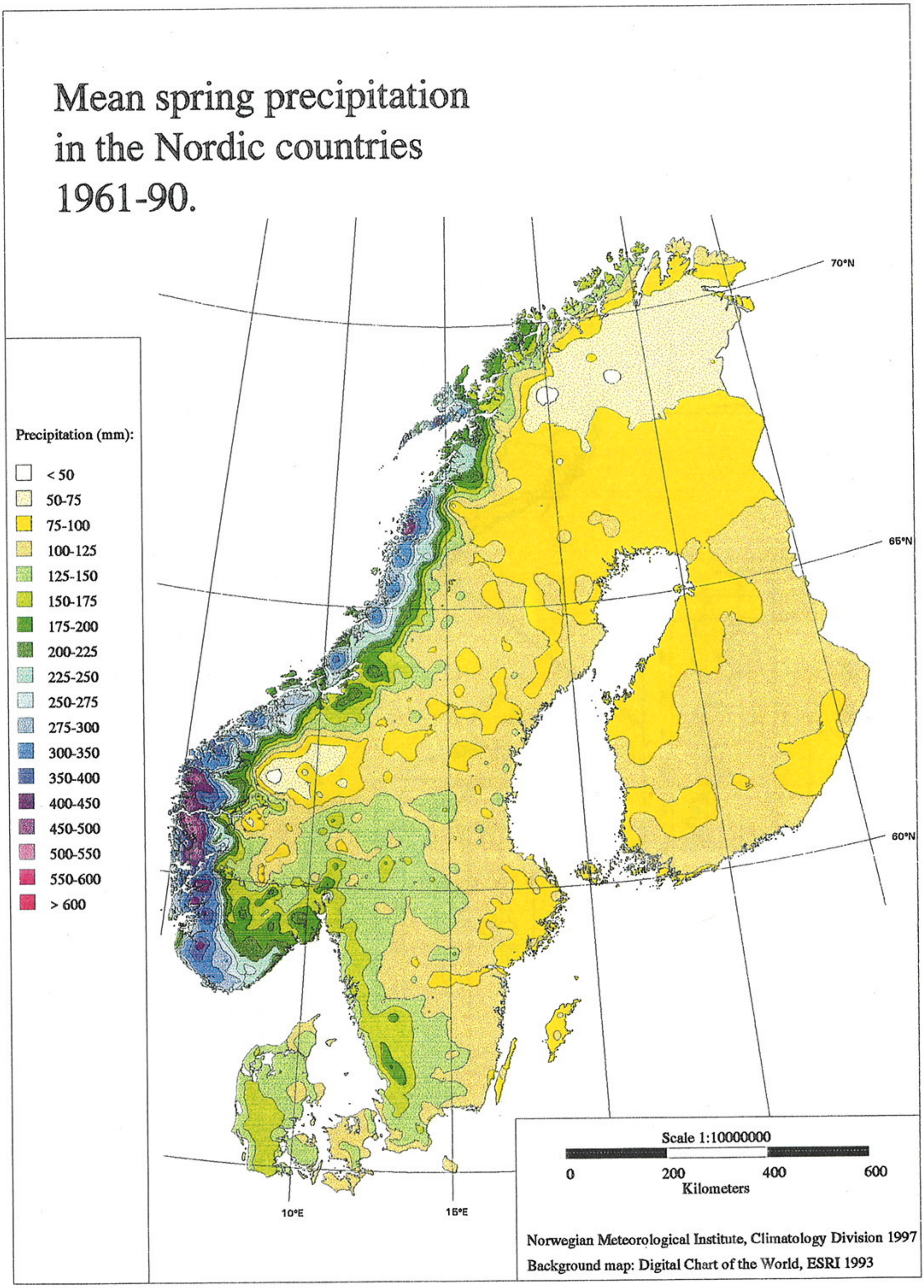


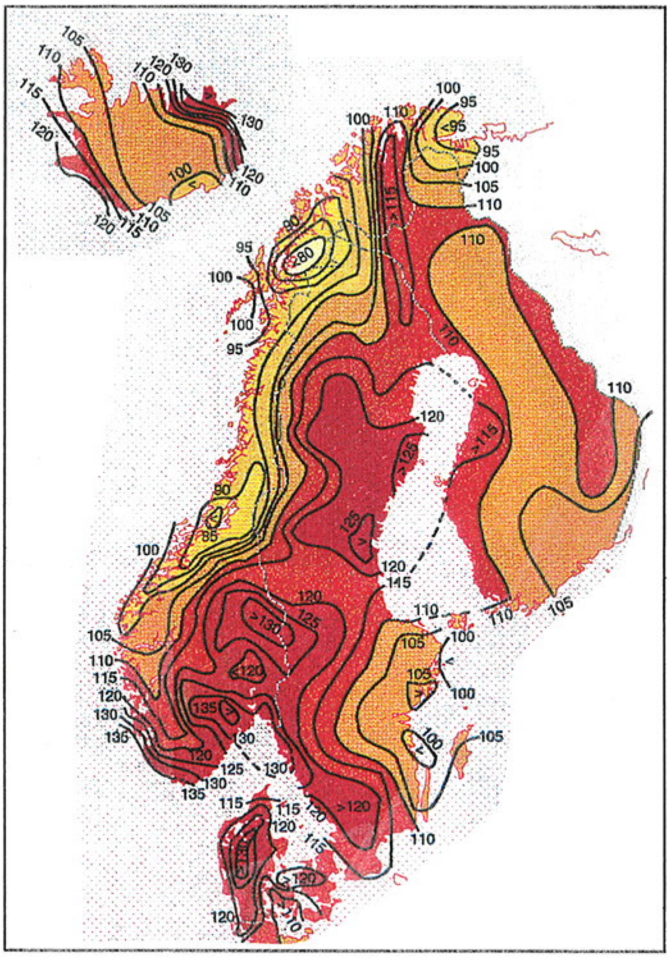
Figure 6. *Mean spring precipitation in the Nordic countries 1961-90.*

4.2 Spring

The map of normal spring season (March, April and May) precipitation is shown in figure 6. In this season the precipitation range is small, the highest seasonal sum is 614 mm at Haukeland in western Norway. The precipitation is generally low (< 200 mm) in the entire region, except near the west coast of Norway and a small area in Halland. Table 3 shows the max. and min. values. The location of the stations are shown in figure 3.

Table 3. Maximum and minimum spring precipitation in each country.

Country	Max. prec. sum (mm)	Station no.	Name	Min. prec. sum (mm)	Station no.	Name
	128	3606	Varpaisjärvi Pitkälänmäki	55	9402	Utsjoki Outakoski
SWE	214	6353	Fröslida	40	18880	Abisko
NOR	614	52600	Haukeland	30	89950	Dividalen
DEN	178	25250	Slauggård	102	06159	Røsnæs Fyr



The changes in the spring precipitation (Figure 7) between the last two normal periods are quite dramatic: In large parts of the area the precipitation has increased by more than 15%, and even by more than 30% in small areas in Iceland, Denmark, southern Norway and western parts of Sweden. However, in central and northern parts of Norway, the spring precipitation has decreased by more than 15%.

The overall picture is however a large increase in spring precipitation in the whole area, except for parts of Norway. By considering also the 1901-30 normals, it seems as if the 1931-60 normals were among the lower 30-year avarges in the series, and that the new 1961-90 normals are at about the same level as the 1901-30 normals (cf. figure 5).

Figure 7. Ratio (percent) between new (1961-90) and old (1931-60) spring precipitation normals (from Førland et al., 1996b).

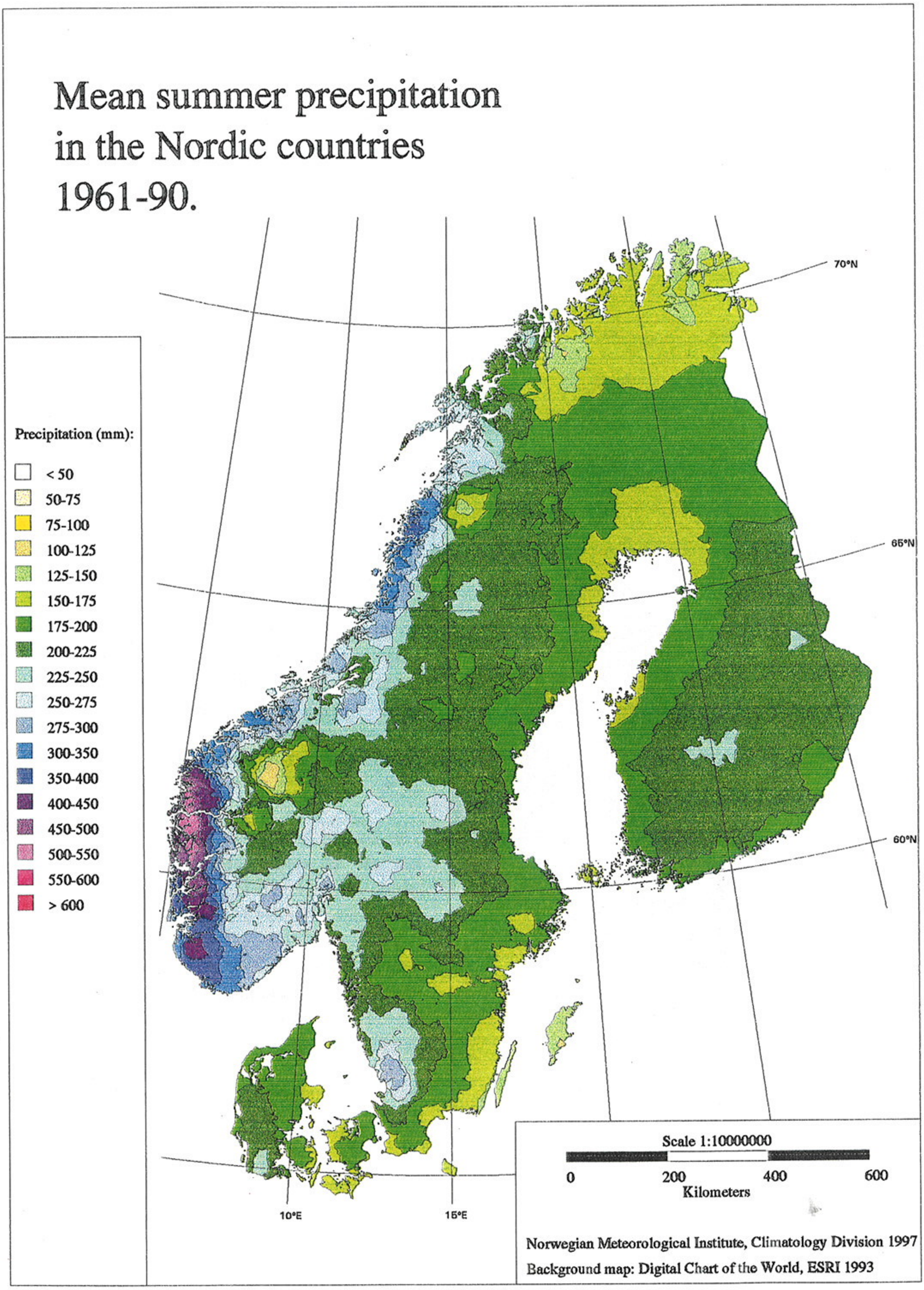


***Figure 8**. Mean summer precipitation in the Nordic countries 1961-90.*

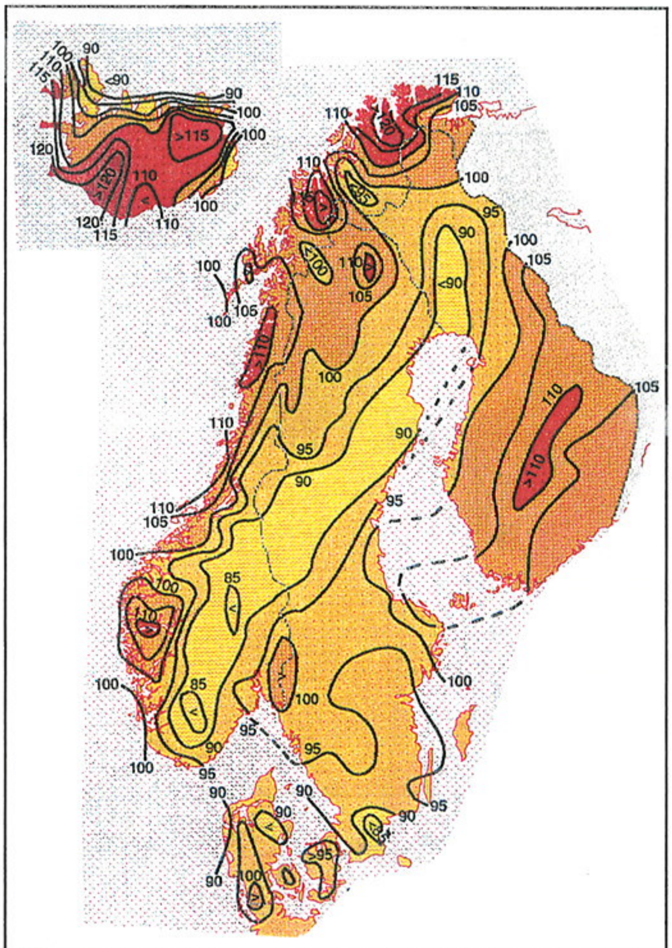
4.3 Summer

The map of precipitation in the summer season (June, July and August) (figure 8) is presented with the same colour scale as the spring map. Showers in the inland parts of the area make summer the season with the smallest spatial variability. Maximum and minimum values are presented in table 4.

Minimum precipitation is found around the Baltic sea, Northern Scandinavia and in central parts of southern Norway.

Table 4. Maximum and minimum summer precipitation in each country.

Country	Max. prec. sum (mm)	Station no.	Name	Min. prec. sum (mm)	Station no.	Name
FIN	246	2303	Juupajoki Hyytiälä	123	3003	Mustasaari Valassaaret
SWE	324	6353	Fröslida	91	7863	Östergarn
NOR	680	52930	Brekke i Sogn	79	91350	Skibotn
DEN	254	26420	Bov	136	06159	Røsnæs Fyr



The summer precipitation has decreased over most of the area (Figure 9). In minor areas in southeastern Sweden and southern Norway, the summer precipitation is more than 15% lower than in the previous normal period. However, large areas in Iceland, Finland and northern parts of Norway and Sweden have experienced **increased** summer precipitation. The summer precipitation has also increased in western Norway.

Figure 9. *Ratio (percent) between new (1961-90) and old (1931-60) summer precipitation normals (from Førland et al., 1996b).*

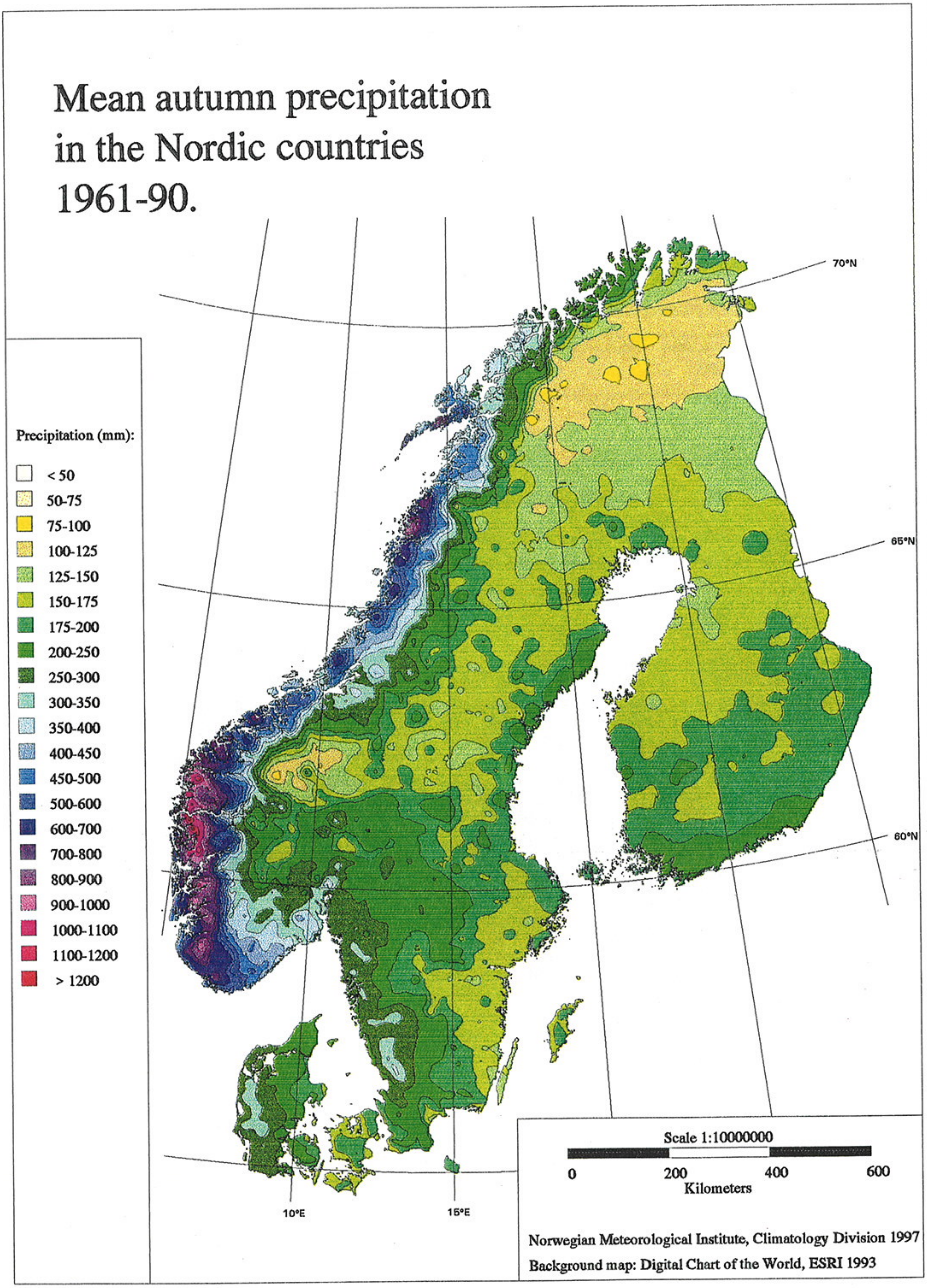


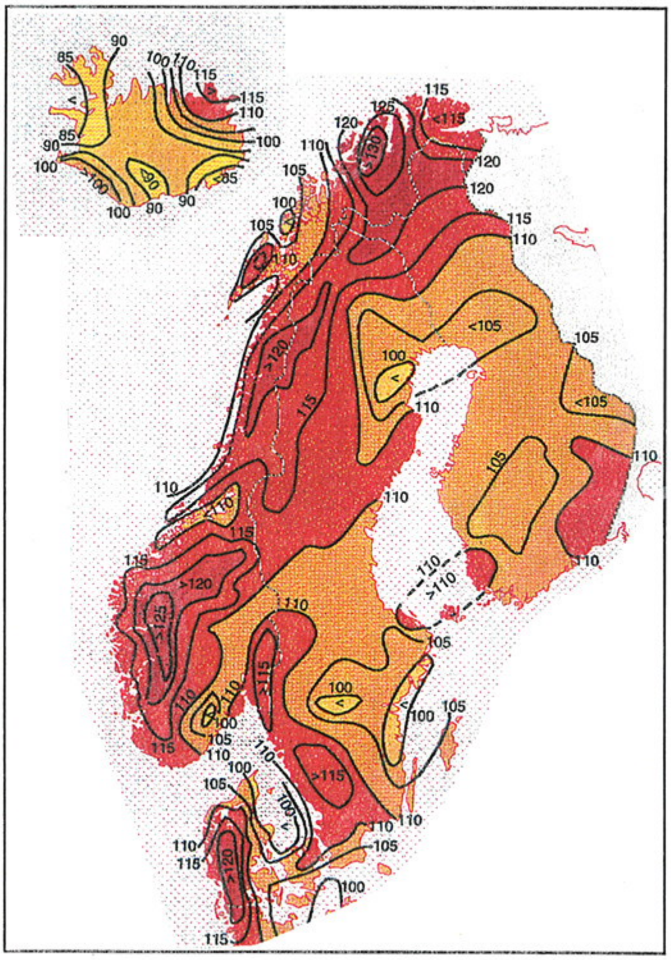
Figure 10. *Mean autumn precipitation in the Nordic countries 1961-90.*

4.4 Autumn

In the autumn (September, October and November) (figure 10) the precipitation pattern is similar to the annual map. Maximum zones are the same, western Norway, south-western Jutland, Halland and the south-coast of Finland. The minimum is found in the northern part, Lappland. In Denmark, the minimum is in the northwestern part of Zealand.

Table 5. Maximum and minimum autumn precipitation in each country.

Country	Max. prec. sum (mm)	Station no.	Name	Min. prec. sum (mm)	Station no.	Name
FIN	241	1601	Virolahti Ravijoki	101	9401	Utsjoki Karigasniemi
SWE	373	6342	Brunnshult	73	18880	Abisko
NOR	1305	52600	Haukeland	76	89950	Dividalen
DEN	323	25250	Slauggård	124	06159	Røsnæs Fyr



During autumn, the precipitation has increased substantially over most of Fennoscandia, only tiny areas have lower normal values than in the previous normal period (Figure 11). The largest relative increase (more than 20%) is found in Jutland, western Norway, and northern parts of Fennoscandia. At some stations in western Norway, the autumn precipitation has increased by more than 200 mm.

Figure 11. *Ratio (percent) between new (1961-90) and old (1931-60) autumn precipitation normals (from Førland et al.,1996b).*

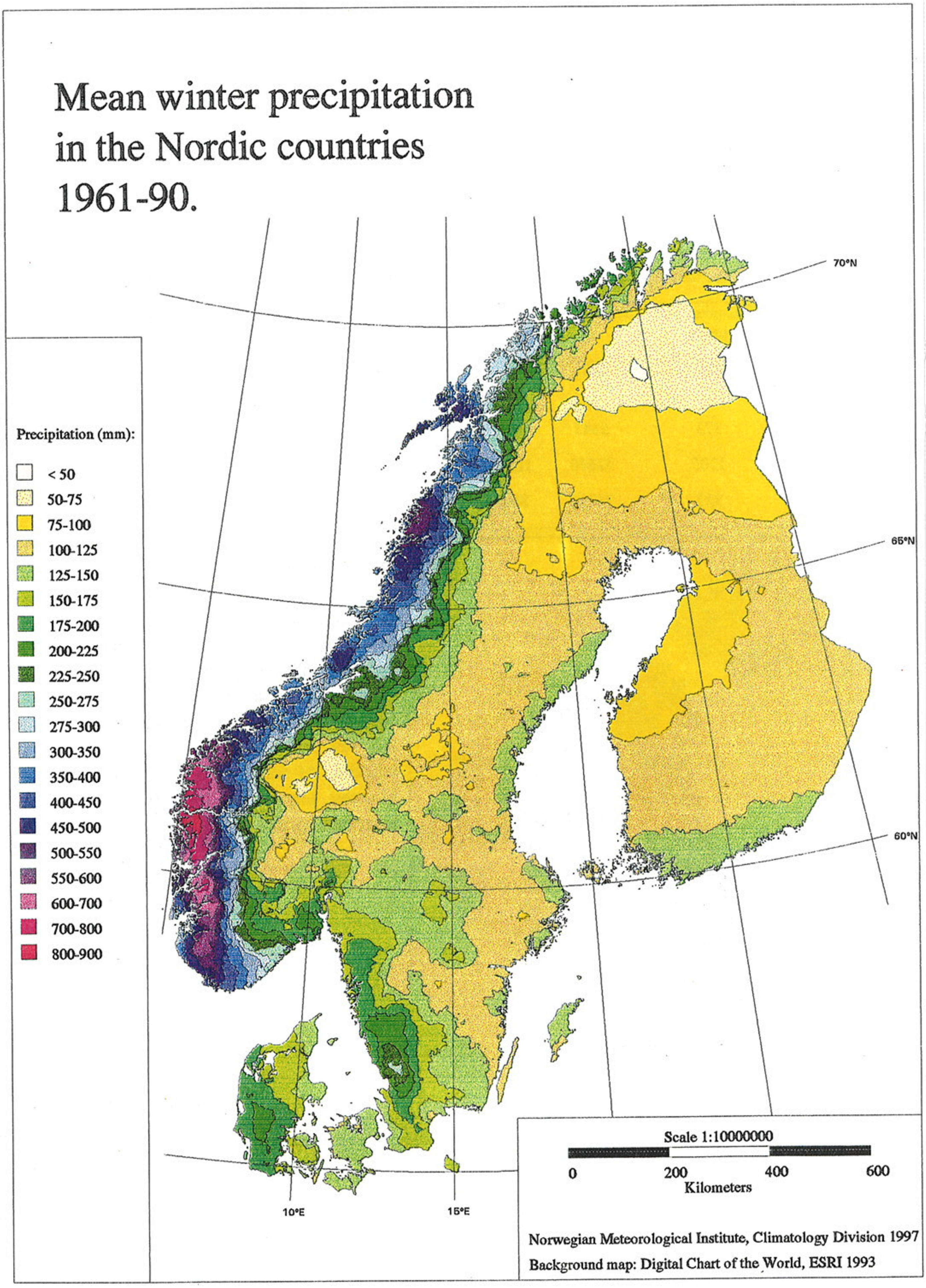


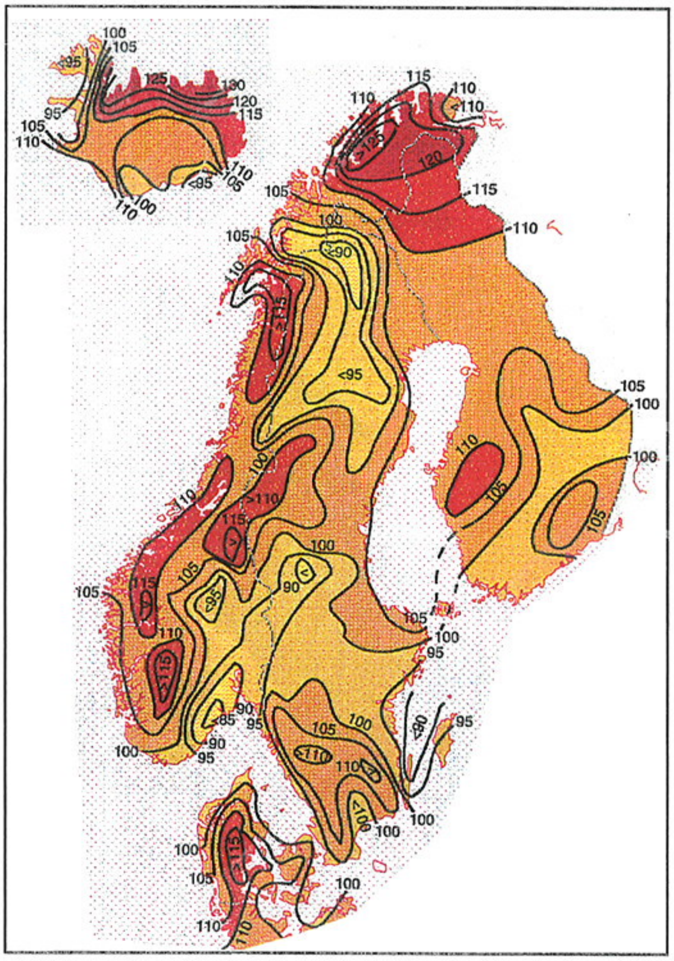
Figure 12. *Mean winter precipitation in the Nordic countries 1961-90.*

4.5 Winter

The winter season (December, January and February) (figure 12) is characterized by the same features as the autumn and annual maps: Maximum zones at the Norwegian west coast, in Halland in Sweden, western parts of Denmark and southern Finland. The minimum is found in northern Sweden, Finland and Norway, in an area having continental climate.

Table 6. Maximum and minimum winter precipitation in each country.

Country	Max. prec. sum (mm)	Station no.	Name	Min. prec. sum (mm)	Station no.	Name
FIN	164	0203	Pohja Pohjankuru	58	9601	Inari/Ivalo
SWE	285	14344	Jormlien	63	19190	Naimakka
NOR	1036	57780	Grøndalen	26	93700	Kautokeino
DEN	231	25250	Slauggård	101	6179	Møn Fyr



There are large changes in the winter precipitation (figure 13) during the last two normal periods. In some areas in Denmark, Norway and Finland the winter precipitation has increased by more than 15%. On the other hand, it has decreased by more than 10% in southeastern Norway, and in eastern and northern parts of Sweden.

Figure 13. *Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals (from Førland et al., 1996b).*

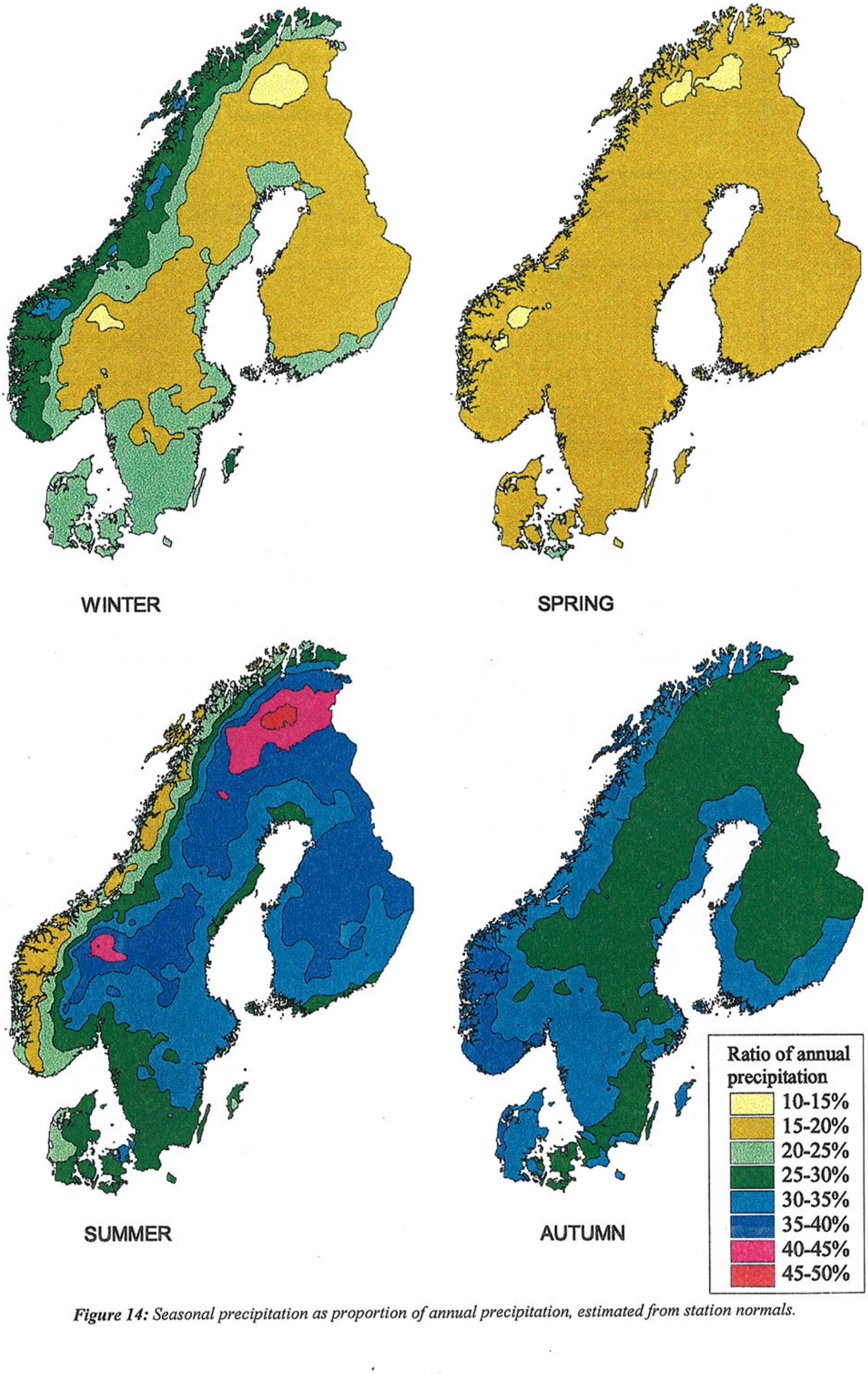


Figure 14: Seasonal precipitation as proportion of annual precipitation, estimated from station normals.

4.6 Seasonal distribution of precipitation

The maps in figure 14 show that there are large differences in the seasonal contribution to the annual precipitation. In the winter and spring seasons, some areas get less than 15% of the annual precipitation, while some areas in northern parts of Fennoscandia get almost half the the annual precipitation during the summer season.

The spring contribution is rather conform, between 15-20% over most of the area. Just small areas in the north and in western Norway get less than 15%, while parts of the Danish islands Zealand, Fyn and Lolland get more than 20%.

In large parts of the area, summer is the season getting the highest proportion of the annual precipitation. Some areas in northern Fennoscandia and central Norway get almost 50% of the annual precipitation during this season. In these areas the annual precipitation is relatively low (see Figure 2), and the contributition from summer-showers has a large influence on the seasonal ratio. In western parts of Denmark and Norway, the summer ratio is lower than 25%.

During autumn, the seasonal proportion is between 25 and 40%, with highest ratios in western Jutland and southwestern parts of Norway. In winter most inland areas get less than 20% of the annual precipitation, while some areas in western and northern Norway get 30-35%.

Figure 15a shows that three different seasons are the seasons of maximum precipitation: In major parts of Finland and Sweden summer is the wettest season. This is also the case in parts of eastern and northern Norway, as well as part of the Danish islands. In some areas close to the Baltic coast, and in western parts of Fennoscandia, autumn is the season with maximum precipitation.

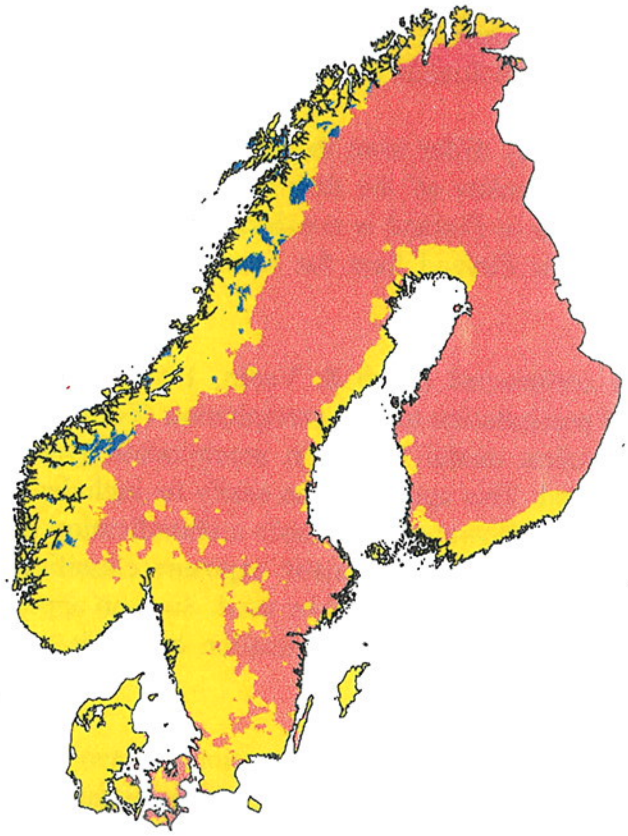


Figure 15a: Season with maximum precipitation.

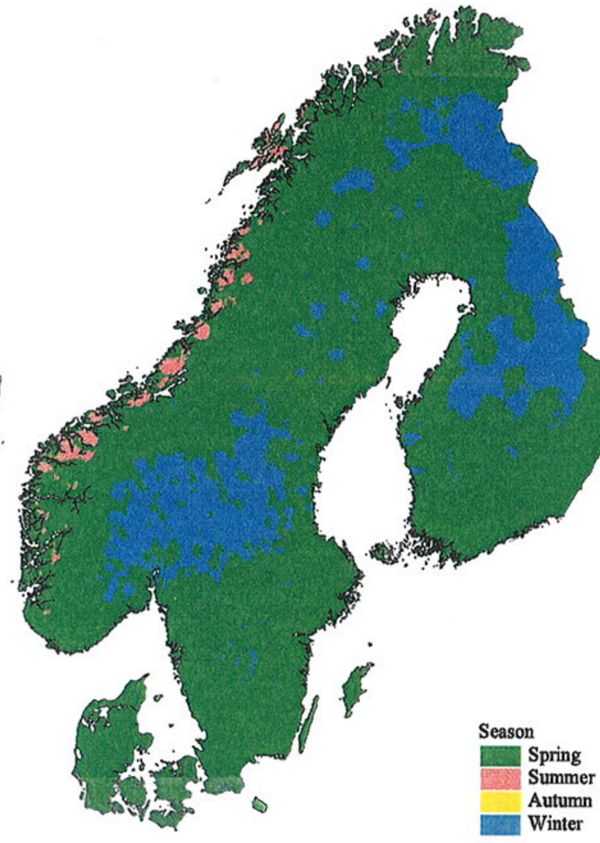


Figure 15b: Season with minimum precipitation.

However, in some inner fjord areas in western and northern Norway, and in the northern border areas between Norway and Sweden, winter is the season with the largest contribution to the annual precipitation. These areas may have been somewhat larger in the beginning of this century, as autumn has taken over from winter as the «wettest» season in some regions in Fennoscandia (cf. figure 5). In other regions (e.g. south-eastern Norway) summer was the wettest season during the 1931-60 period, while the autumn now (1961-90) has the highest seasonal precipitation.

In most areas spring is the driest season (figure 15b), but in a large area in interior parts of Finland, Norway and Sweden winter has the lowest seasonal precipitation. Along the western coast of Norway the summer season is the season with the lowest precipitation.

5. Discussion

This report presents maps of annual and seasonal precipitation in the Nordic countries for the standard normal period 1961-90. The maps show *measured* precipitation, and they are constructed using the interpolation method kriging. They are solely based on the station values (see Figure 1), and conditions like topography and distance to coast are not considered in the interpolation. The interpolation is carried out automatically by a geographic information system, and is not influenced by any subjective considerations.

The objective of this report has not been to evaluate various methods, or finding the optimal interpolation technique for precipitation mapping. There is a considerable potential for improving the maps by applying methods which can include topography and distance to coast. Such methods are however difficult to utilize in an area as complex and variable as the Nordic countries. The introduction of geographical information systems make however such methods more applicable, and further studies should be carried out within this field to obtain operational methods for spatial interpolation of climatological elements.

The precipitation maps presented in this report may differ from the official national normal maps, both due to interpolation technique and density of the data sample. In the present analysis the spatial cover of precipitation stations in Finland is considerably sparser than in the other countries, which gives less details for Finland than for Denmark, Norway and Sweden.

In Sweden, maps of true precipitation are constructed (Raab & Vedin, 1995). There are established methods for correcting measured precipitation to true precipitation (Førland et.al, 1996a). For monthly values a simple correction model based on precipitation type and exposure of the observation site is recommended. This approach can easily be included in a GIS approach, making maps of true precipitation. However, this needs a classification of all precipitation stations into exposure classes. Alternatively, automatic exposure classification applying GIS-algorithms on a high-resolution terrain model could be used. Such an approach needs however quite much effort, both in developing and in verification before it can be applied operationally.

This report is a result of the cooperation between climatologists at the national meteorological institutes in the Nordic countries, through the Nordic Working Group on Precipitation. The maps and text are discussed and approved as a teamwork, and shows the potential of Nordic cooperation within climatology. This Nordic cooperation should continue. First priority should be given to work out similar Nordic maps of normal temperature, - but also for other climatological elements coordinated Nordic maps should be elaborated.

6. Acknowledgements

The elaboration of the maps presented in this report would not have been possible without the support from :

- EnFO (Norwegian Water System Management Association) through the project «Regionalization of Climate Statistics»), and

- Nordic Council of Ministers through the joint Nordic project REWARD (**R**elating **E**xtreme **W**eather to Atmospheric circulation using a **R**egionalised **D**ataset).

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