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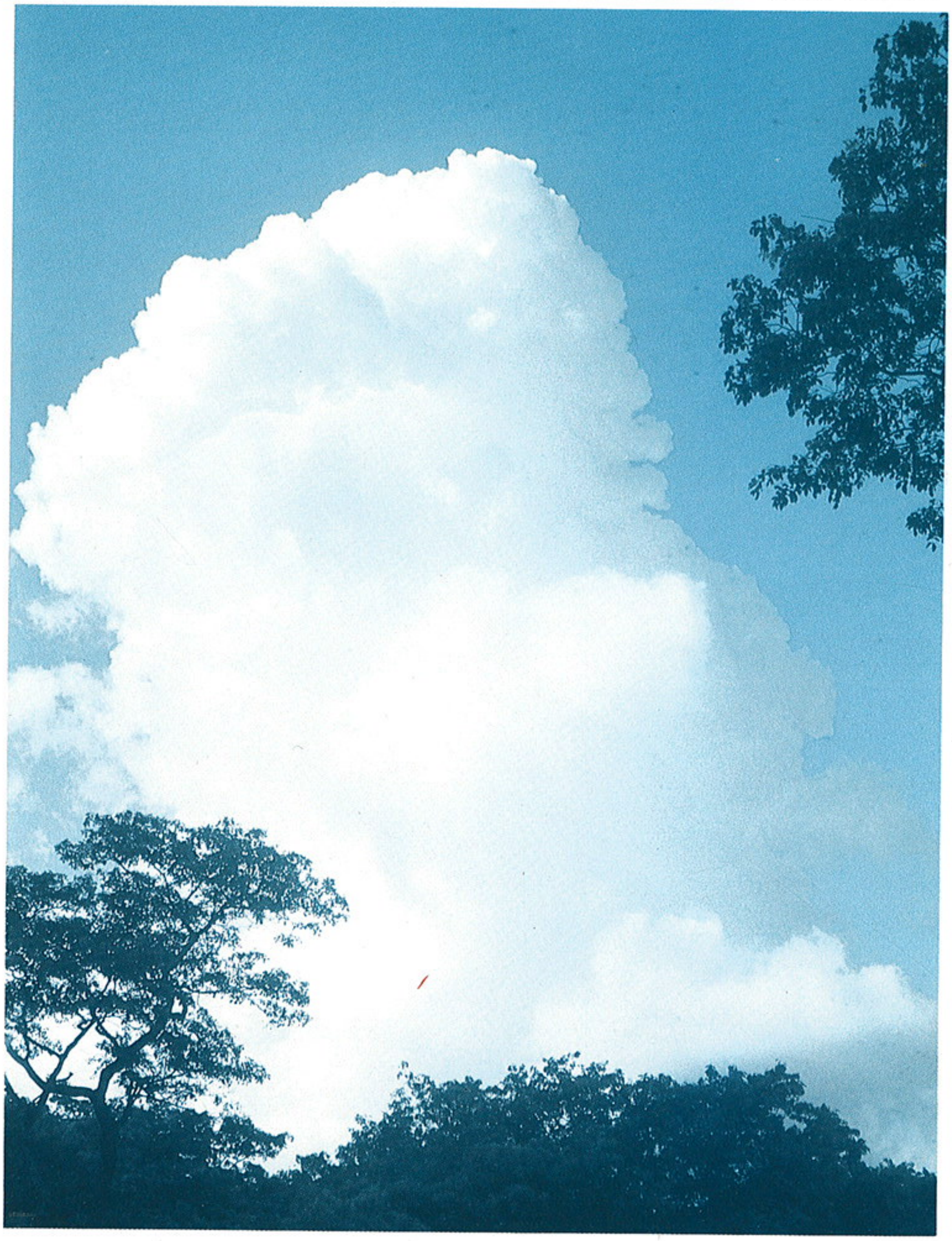

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TITLE

CHANGES IN "NORMAL" PRECIPITATION IN THE NORTH ATLANTIC REGION (Second edition)

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PROJECT CONTRACTORS

The Norwegian Research Council
and
The Norwegian Meteorological Institute

SUMMARY

Ten countries cooperating in the international NACD-project have provided national maps showing ratios between new (1961-90) and old (1931-60) precipitation standard normals on annual and seasonal basis. When the national maps were combined, it was quite easy to follow the main features of the anomaly pattern across the country borders.

The maps are showing that the standard normal precipitation has increased in most of the North Atlantic region on annual basis, as well as during autumn, winter and especially during spring. In some areas the new precipitation normals for the spring season are more than 30% higher than the previous normals. During the summer season however, the normal precipitation has decreased over most parts of the area. The significance of the differences is also evaluated.

The "normal"-concept is discussed, and it is concluded that

a). Normal values should be based on homogeneous series
b). 30-year moving averages may change rapidly within a few years
c). Standard normals may represent "abnormal" values among 30-year moving averages
d). Standard normals may deviate significantly from long-term means
e) The difference between standard normal periods does not give an unambiguous measurement for climatic change.

SIGNATURE

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Foreword

This report is a part of the cooperation (1993-1995) in the international NACD-project (North Atlantic Climatological Dataset). The main objectives of the NACD-project was to establish a homogenous climatological dataset for the North Atlantic region (50-80^{0}N, 60^{0}W-40^{0}E) for the period 1890-1990 (Frich et al., 1996). The dataset consists of monthly values of air temperature, precipitation, air pressure, cloud cover and number of days with snow cover from about 70 stations in the North-Atlantic region. Most of the participants in the NACD-project have contributed to this report, but the following persons have given the main contributions (national maps, data, figures, manuscripts, comments etc.) :

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Contents:

1. Introduction.

Widespread use of climatological **normal values** for the period 1961-90 has recently been recommended by the Commission for Climatology (WMO, 1993). Normal values are principally intended for comparative purposes between different stations or regions, but are also used as reference values for a number of purposes (engineering constructions, planning of agriculture, climate change analysis, etc.).

Work is still going on in many countries to calculate the new normal values. To increase the utilitarian value of the new normals, it is important to know if they differ from the previous normals. And if there is a difference: What is the magnitude of the difference, and are there any common regional features in the changes from the previous normal period.

Reliable estimates of historic changes in global-scale precipitation are considerably more difficult to obtain from measurements than changes in surface air temperature (Hulme,1995). As a consequence, large-scale considerations of precipitation are almost totally absent. This is probably due to the large spatial variability of precipitation and also to scepticism regarding the quality of precipitation data (see e.g. IPCC, 1992). A high spatial density of stations is also necessary to provide reliable analysis of variations and trends. High density data, however, are not readily available, because they are not exchanged through the global meteorological telecommunications network.

Bradley et al. (1987) and Diaz et al. (1989) have analyzed regional precipitation changes. They found that during the latest decades, precipitation increased in the mid-latitudes, especially over Russia. Studies of zonally averaged precipitation (Hulme, 1995), indicate a rising trend since 1940 in the Northern Hemisphere north of 50 °N. According to Vinnikov et al. (1990) the precipitation has remained largely unchanged in Europe, but they recognised a recent rising trend in Scandinavia. Similarly, Schönwiese & Birrong (1990) noted an increase of precipitation in Northern Europe.

Gruza et al. (1994) analyzed the differences between the 1931-60 and 1961-90 precipitation normals for Europe, using a network of about 700 stations. They found that in general the precipitation had increased about 10-25 mm/year. The maximum increase of the normals was in western (west of 10^0E, and generally in spring-winter period) and in eastern areas of Europe (east of 30^0E, in summer-autumn-winter period). Areas with decreasing precipitation normals were smaller, and were found in western part of the Mediterranean basin, England, central and northern regions of Europe.

The countries cooperating in the international project "North Atlantic Climatological Dataset" (Frich, 1994) have provided detailed maps showing differences in precipitation between the last two normal periods. In this report the national maps on annual and seasonal basis are combined (section 3 and 4). In section 5-8 it is discussed whether the ratios are significant, possible consequences of using inhomogeneous series, and whether the 30-year moving average is a useful tool in studying climatic variations. In the literature different "normal"-concepts are applied, representing different period lengths and different reference periods. In section 2 the "official" WMO-definitions of "normals" and "standard normals" are presented.

2. Climatological standard normals.

The International Meteorological Committee in 1872 decided to compile mean values over a uniform period in order to assure comparability between data collected at various stations (WMO, 1989). In 1891 a Meteorological Conference in Munich urged the directors of the meteorological services all over the world to compute and publish long, periodically climatological means of the meteorological elements (Bruun, 1967). At the meeting of the "International Meteorological Organization" in Warsaw in 1935 it was agreed to calculate such mean values ("normals") for the period 1901-30. Succeeding normal periods were decided to be at 30-years intervals (i.e. 1931-1960, 1961-1990, etc).

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: 1 January 1901 to 31 December 1930, 1 January 1931 to 31 December 1960, etc." In the case of stations for which the most recent climatological standard normal is not available (either because the station has not been in operation for the period of 30 years or for some other reason), provisional normals should be calculated. (In the following sections of this report, "normals" are used synonymous with "standard normals").

When deciding the length of the normal period, 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.

In the following sections it will be investigated whether there are considerable differences in precipitation between the two last standard normal periods in the North Atlantic region.

3. Data and methods.

Because of strong gradients in mean annual precipitation (and also in the difference between means for different normal periods) in large parts of Europe, it is difficult to map precipitation changes as absolute values (i.e. mm/year). Analyses of precipitation **ratios** should be preferred, as these ratios are less influenced by orographic effects. Also the analyses should be based on homogeneous series or a dense station network, and primarily performed on a national basis by climatologists with knowledge of local precipitation patterns and the data-quality of the different stations.

Such analysis on a regional basis has been difficult to perform because of difficulties of organizing cooperation across the national borders. The international cooperation between 11 countries within the **NACD-project** (North Atlantic Climatological Dataset (Frich, 1994)) gave an excellent opportunity to carry out such analysis for the North-Atlantic region.

Maps showing the ratio between the two last normal periods were originally analyzed on a national basis, using an optimal dataset. The station density, data quality (homogeneous series, record length), analyzing procedure (manual, automatic) and smoothing technique behind the national maps varied from country to country.

Belgium

The analysis is based on data from 12 historical Belgian stations over three normal periods (Brugge, Ath, Leopoldsburg, Ukkel, Gembloux, Maredsous, Rochefort, Thimister, Stavelot, Hives, Chimay and Chiny). The data are not adjusted for changes in the instruments, procedures and possible other changes (relocations, etc.).

Denmark

The precipitation maps for Denmark are based on data from about 100 stations.

Finland

Precipitation records for 1931-1990 were available for about 120 stations, 53 of which were made homogenous by comparisons with neighbouring stations. Only these stations were used in the present analysis. Due to relatively sparse station network, the ratio patterns are smoothed. Also the results from a study on water balance in catchment areas (Hyvärinen et al., 1995) is used. The main source of inhomogeneity in Finnish precipitation records originates from changes of precipitation gauges, which have produced apparent increases in precipitation amount of up to 30% in winter (Heino, 1994). Even larger effects were caused by station relocations or changes in immediate surroundings of individual gauges.

Germany

The 1961-90 normals are based on data from nearly 5000 precipitation stations. The ratio maps are constructed by interpolation with spatially variable linear height-regression.

The statistics in table 3 is based on data from 14 German cities (Bayreuth, Berlin, Dresden, Emden, Erfurt, Frankfurt a.M., Gütersloh, Hannover, Karlsruhe, Kassel, Kiel, Kleve, München and Trier). The time series have not been tested with a standard homogeneity test, but have been carefully quality checked.

The Netherlands

The maps are based on data from 119 Dutch stations. The trend graph in Figure 9 is based on homogeneous series of data from 12 selected stations.

Norway

165 series covering the entire period 1931-90, and also some provisional normals were used in the analysis. Most of these series were not tested for possible inhomogeneities, but the ratios of about 50 homogeneous series were key values in the analysis. The maps were analyzed by hand, and detailed maps are presented in the Norwegian National Atlas (Førland, 1993). Because of large precipitation gradients and different trends in different parts of the country, it was not found useful to produce a joint Norwegian precipitation series in table 3.

Poland

Isolines for Poland north of 51° N were based on data from 48 stations. The data are carefully quality checked, but not tested for homogeneity. The maps are analyzed both by hand, and by computer analysis by mean "Triangle technique" and "Inverse distance to a Power" as well as typical smoothing. Final version is a result of comparison between all three methods. The statistics in table 3 are based on 8 homogeneous time series.

Sweden

The analysis is based on comparison between reference normals for the two normal periods 1931-60 and 1961-90 from about 650 stations. Data have been quality checked and for the later period also tested for homogeneity. The analysis was made by hand. As the data coverage is good, the analysis should be fairly reliable.

United Kingdom.

The UK maps are not based on homogenised series, but on a limited dataset of 39 stations with long records covering both normal periods. Some areas (Wales, the Hebrides and East Anglia) are poorly covered. These maps are therefore preliminary, and should not be regarded as "official" UK Met.Office maps.

4. Ratio between precipitation normals 1961-90 and 1931-60.

When the national maps were combined, some discontinuities in the isolines appeared along the country borders. The main impression was however that it was quite easy to follow the main features of the anomaly pattern across the country borders.

The maps presented in figure 1-5 are smoothed, and some local anomalies are excluded[1]. Some of these excluded anomalies and even some of the features shown in the maps may be caused by inhomogeneities in the series. Even if the annual series are checked (and adjusted) for inhomogeneities, some irregularities may still remain on a seasonal basis.

For stations with records not covering the whole normal period, the series are normalised by using neighbouring reference series (WMO,1989). Accordingly if a **reference** series should turn out to be inhomogeneous, it will influence the provisional normal values (and normal ratios) of all neighbouring stations which are normalised by this reference series. In this way neighbouring stations apparently may support each other in indicating a fictive "anomaly" area. Consequences of using inhomogeneous series are discussed further in section 6.

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[1] Note: As NACD mainly comprises Northern Europe north of 50°N, southern parts of Germany and Poland are not included in the analysis in figures 1-5.

It should be kept in mind that by describing the differences between the two normal periods by ratios, the anomaly pattern is vulnerable for the magnitude of the nominator. Accordingly in areas with low normal values, a minor change of precipitation (in millimetres) may cause a large change in the ratio. As winter and spring precipitation is rather low in some parts of the area, it is not surprising that the largest changes in precipitation ratios appear in these seasons. (For instance, in some leeward areas (e.g. in Norway) the winter or spring normal precipitation is lower than 30 mm. Thus a change in seasonal precipitation of just 3 mm, implies a change in ratios of 10 %).

Annual values.

The annual normal precipitation (figure 1) has increased over large parts of the area, and most pronounced (5-15 %) in western parts of both UK, Netherlands, Germany, 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 both UK, Belgium, Germany, 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%,- only some eastern areas in UK and some minor areas in Germany and Poland have experienced a decrease of more than 5%. Precipitation decrease over England during the last 20 years has also been pointed out by Woodley (1991).

The anomaly pattern in figure 1 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 hills and mountains in UK, Belgium, Norway and Sweden.

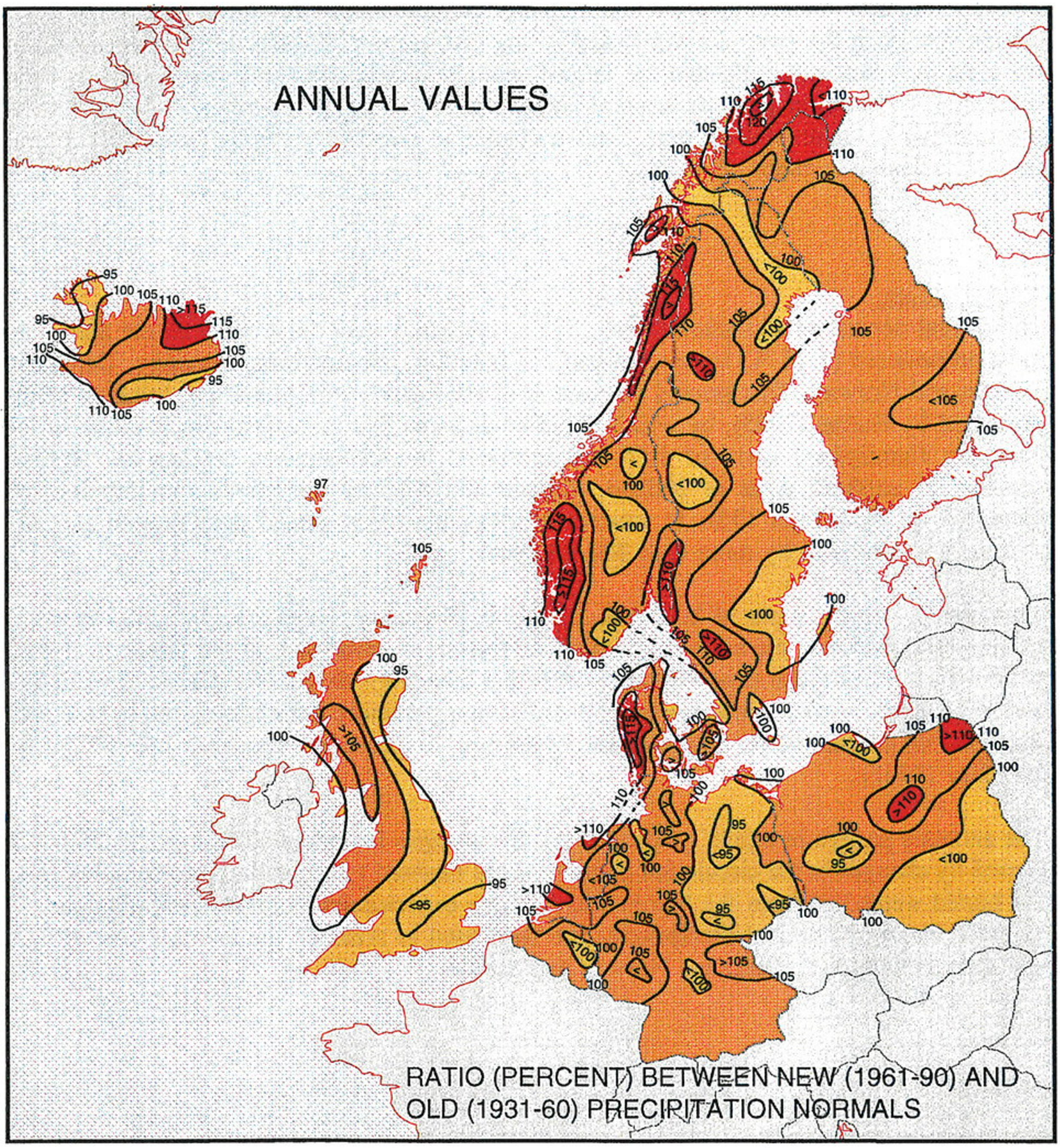

Figure 1. Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals.
ANNUAL VALUES

(Note: Southern parts of Germany and Poland are not included in the analysis)

Spring (March, April, May).
The changes in the spring months (figure 2) 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, Netherlands, Germany, 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 "abnormally" low, and that the new 1961-90 normals are at about the same level as the 1901-30 normals.

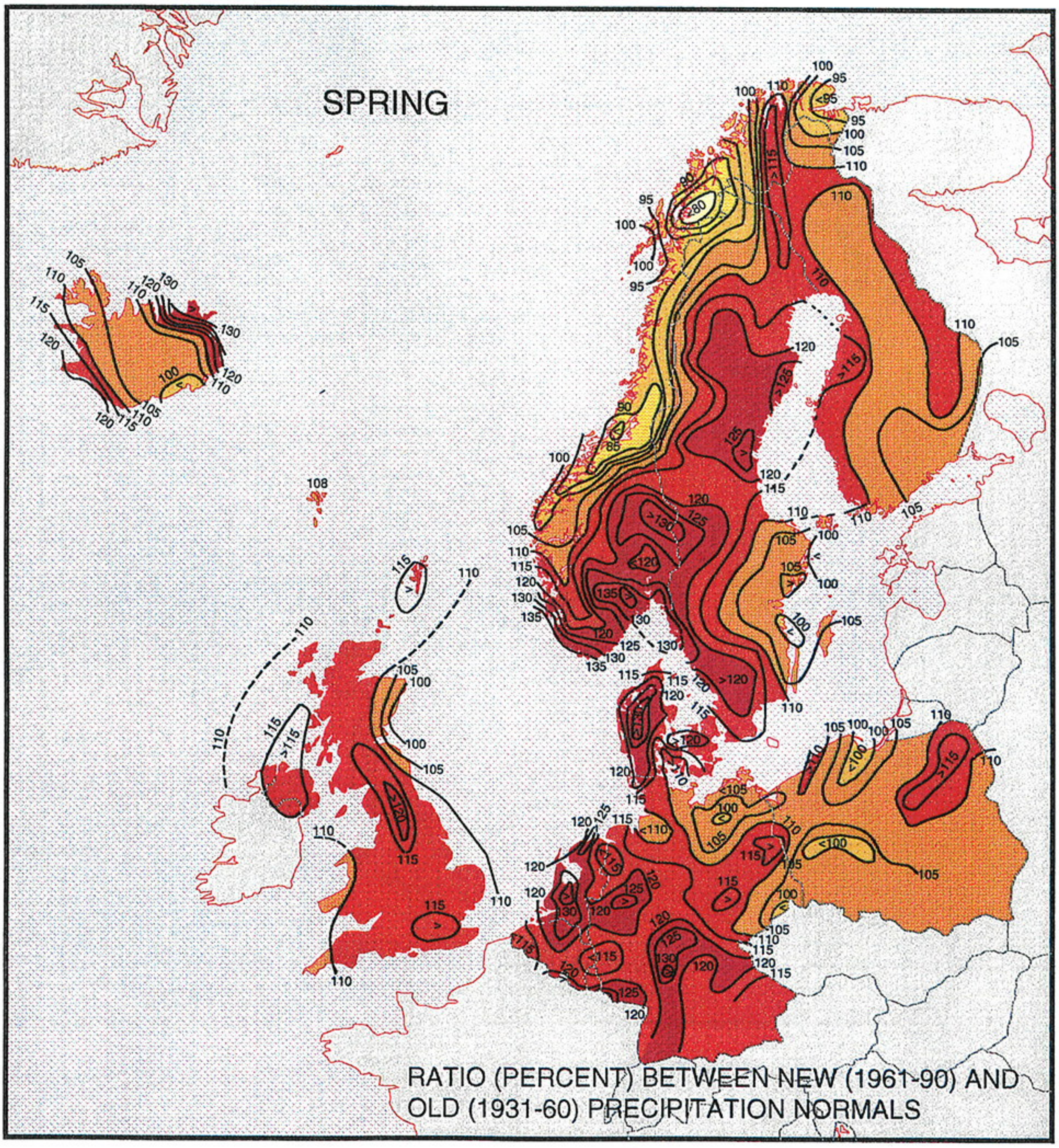

Figure 2. Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals. **SPRING** (March, April, May)

(Note: Southern parts of Germany and Poland are not included in the analysis)

Summer. (June,July, August)
The summer precipitation (figure 3) has decreased over most of the area. In minor areas in eastern parts of Scotland, eastern part of Germany, 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 southern parts of the Netherlands and in western Norway.

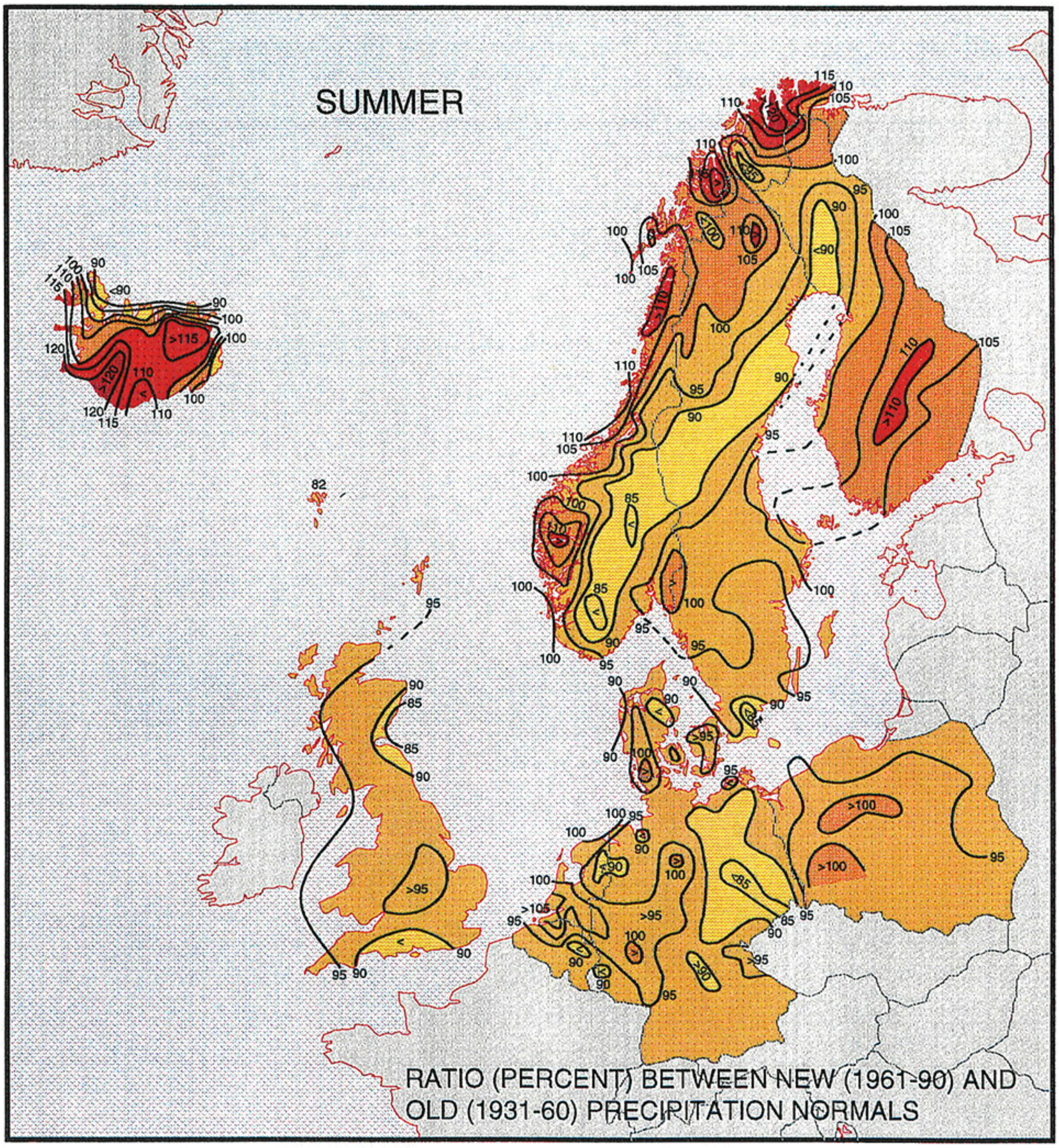

Figure 3. Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals. **SUMMER** (June, July, August)

(Note: Southern parts of Germany and Poland are not included in the analysis)

Autumn. (September, October, November)
In the Netherlands, Poland, Denmark, Finland, Norway and Sweden only tiny areas (figure 4) have lower normal values than in the previous normal period. Parts of Iceland, UK, Belgium and Germany are the only major areas where autumn precipitation has decreased. The main feature is however that in most parts of the area, the autumn precipitation has **increased** substantially. The largest relative increase (more than 20%) is found in Jutland, western Norway, and northern parts of Fennoscandia. At some stations in Scotland the normal autumn precipitation has increased by more than 100 mm and in some areas in western Norway by more than 200 mm.

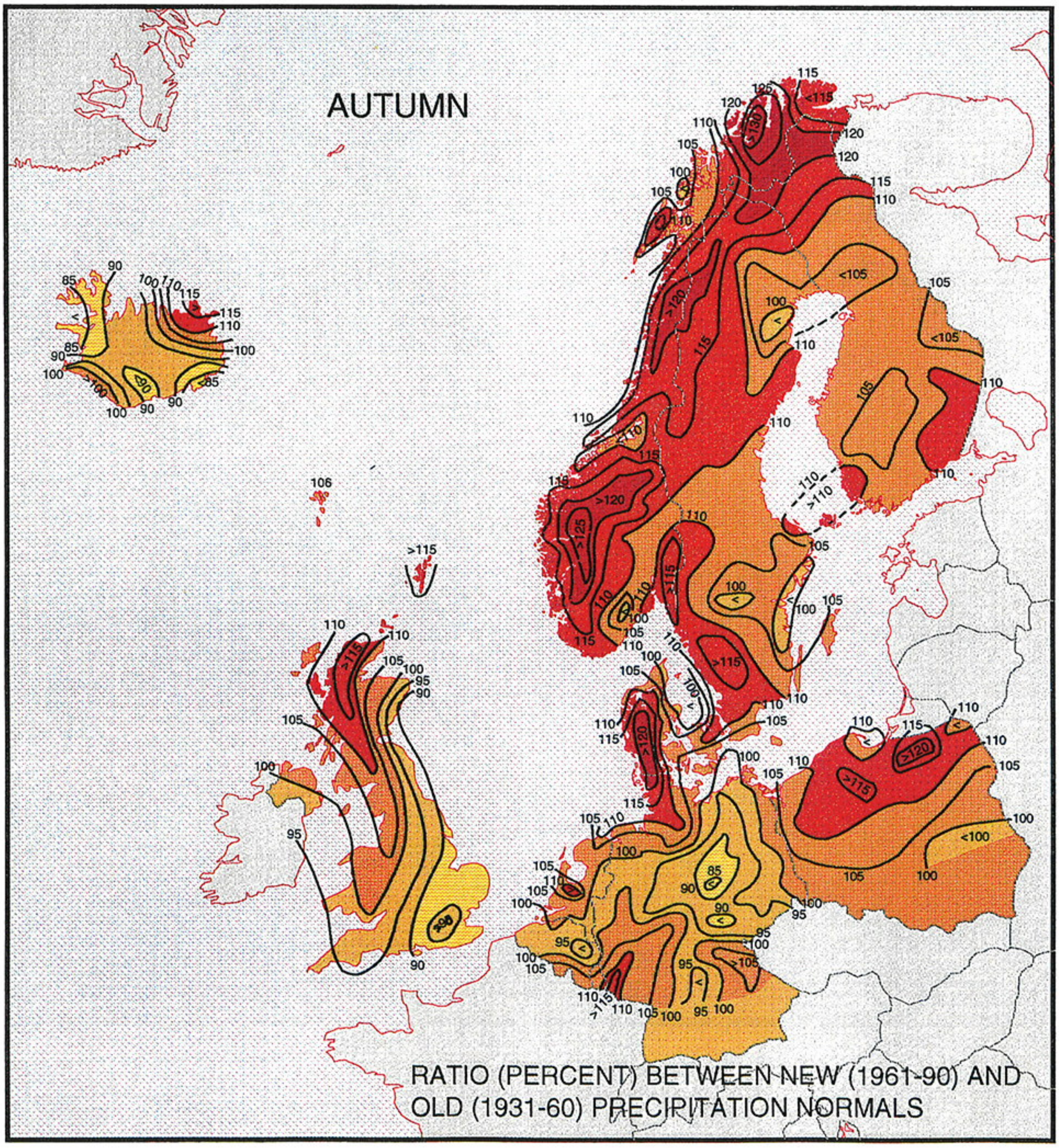

Figure 4. Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals.
AUTUMN (September, October, November)
(Note: Southern parts of Germany and Poland are not included in the analysis)

Winter (December, January, February)
There are large changes in the winter precipitation (figure 5). In some areas (in the Netherlands, Germany, Denmark, Norway, Finland and Iceland) 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.

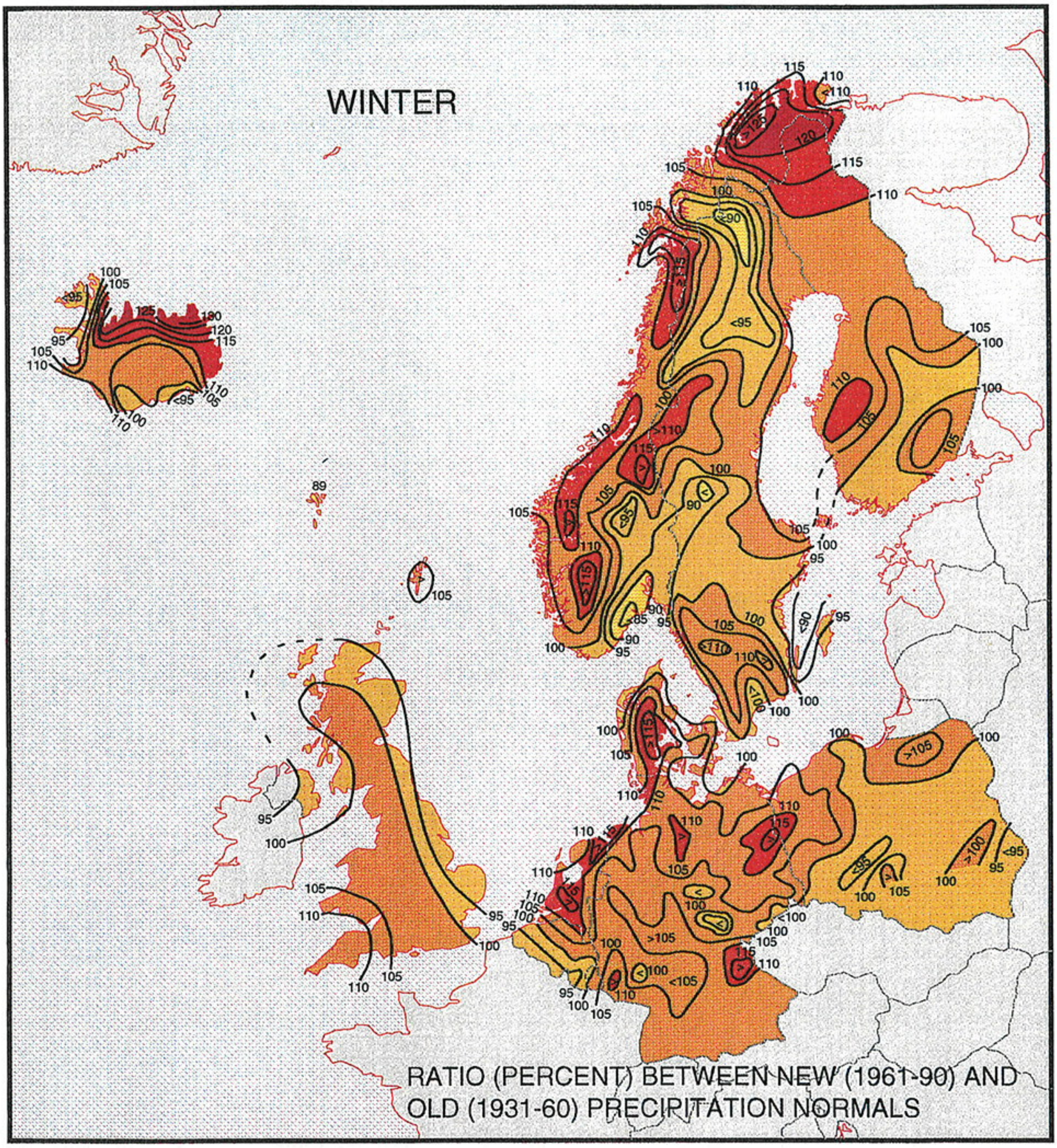

Figure 5. Ratio (percent) between new (1961-90) and old (1931-60) precipitation normals.
WINTER (December, January, February)
(Note: Southern parts of Germany and Poland are not included in the analysis)

Monthly values

The changes in standard normal precipitation are even more dramatic on a monthly than on the seasonal and annual basis. For instance most of the 30-35% increase in precipitation during the spring in southern Norway is caused by a substantial rise in the March precipitation (cf. figure 6). At several stations in southwestern and southeastern parts of Norway, the new precipitation normals for March are more than twice as high as the 1931-60 normal.

The March precipitation in this area for the three standard normal periods in this century is shown in table 1 for four long, homogeneous (or homogenised) series. For both Helleland and Sviland the March precipitation has increased by about 70 mm, and is almost twice as high as the 1931-60 value. However, table 1 also indicates that it is the 1931-60 normals that are "abnormal": the 1901-30 normals are at the same level as the 1961-90 normals.

Table 1. Standard normals of March precipitation (mm) for 4 homogeneous precipitation stations in southwestern Norway.
(Values in brackets are ratios (%) between new (1961-90) and old standard normals)

Period	Egersund	Helleland	Stavanger	Sviland
1901-30	100 (109)	133 (110)	74 (108)	119 (115)
1931-60	57 (191)	75 (195)	47 (160)	70 (196)
1961-90	109 (100)	146 (100)	80 (100)	137 (100)

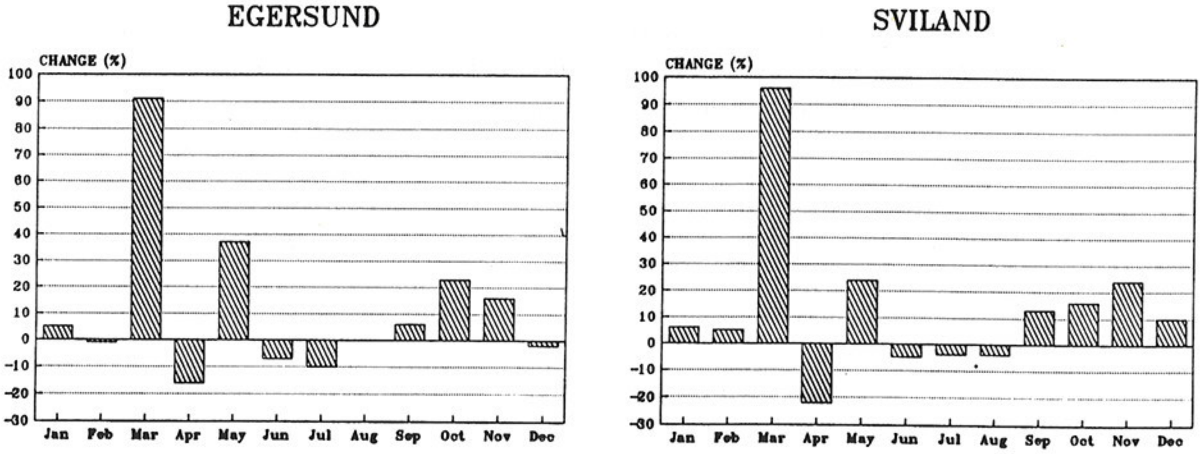

Figure 6. Monthly changes (percent) between new (1961-90) and old (1931-60) precipitation normals. The two series from southwestern Norway (Egersund and Sviland) are both homogeneous.

Figure 6 confirms that for single months, changes of normal values of more than 20% are not uncommon. Considering the spring precipitation at Sviland, the increase (+67 mm) in March precipitation is partly compensated by a decrease (-22 mm) in April.

Changes of mean monthly precipitation amounts at individual stations in Finland between the two latest normal periods are also in broad agreement with changes in the corresponding seasons (Table 2). Positive and negative changes are quite evenly distributed, although the differences in the latter half of the year (August-December) are more generally positive. The changes have been especially large in August. It is also worth noting that because precipitation has increased markedly in March, the driest month of the year has shifted from March to February at most stations in Finland.

Table 2. Distribution of the differences (D) in monthly precipitation amounts between normal periods ($D=P_{61-90}-P_{31-60}$) at 53 homogenous Finnish stations. (Heino, 1994)

D (mm)	J	F	M	A	M	J	J	A	S	O	N	D
$D \leq -5$	10	3	0	6	9	12	11	4	1	7	0	0
$-5 < D < 5$	32	48	12	45	38	35	29	6	26	33	16	36
$D \geq 5$	11	2	41	2	6	6	13	43	26	13	37	17

5. Significance of changes between the two normal periods.

To study the significance of the ratios in figures 1)-5), the following method has been used[1]: If x_1/x_2 is a ratio of two random variables and we assume that $x_2 > 0$, then an approximation to $var(x_1/x_2)$ is given (Kendall et.al, 1987, pp 325) as:

$$var\left(\frac{x_1}{x_2}\right) = \left[\frac{E(x_1)}{E(x_2)}\right]^2 \cdot \left[\frac{var x_1}{E^2(x_1)} + \frac{var x_2}{E^2(x_2)} - \frac{2cov(x_1, x_2)}{E(x_1)\ E(x_2)}\right]$$

In our application:

x_1 = average seasonal or annual precipitation 1931-1960 ($n_1 = 30$ years)

x_2 = average seasonal or annual precipitation 1961-1990 ($n_2 = 30$ years)

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[1]We are grateful to T.A. Buishand (KNMI) for drawing our attention to the expression for the variance of a ratio.

Under the null hypothesis of a constant climate over the period 1931-1990 we have:

$$E(x_1) = E(X_2) = \mu$$

$$var x_1 = \sigma^2/n$$

$$var x_2 = \sigma^2/n$$

where $n = n_1 = n_2 = 30$

For two non-overlapping periods $cov(x_1,x_2)=0$. By substitution we get:

$$var\left(\frac{x_1}{x_2}\right) = \left[\frac{\sigma^2/n}{\mu^2} + \frac{\sigma^2/n}{\mu^2}\right] = \frac{\sigma^2}{\mu^2}\cdot\frac{2}{n}$$

$$\sigma(x_1/x_2) = \frac{\sigma}{\mu}\cdot\sqrt{2/n}$$

which can be estimated as:

$$s(x_1/x_2) = \frac{s}{\bar{x}}\cdot\sqrt{2/30}$$

where s is an estimate of the standard deviation of the seasonal or annual precipitation, and $\bar{x}$ is the sample mean.

Under the assumption that Q is approximately normally distributed, the ratio (Q in %) between two normal periods of 30 years is significantly different from 100 at the 5 % level if $|Q-100|-2s_q > 0$, where

s_q = standard deviation of ratios (s_q=s*[sqrt(2/30)]/x) where
$\bar{x}$ = sample mean value (1931-90)
s = estimated standard deviation

The test is almost equivalent to the t-test on equality of the means of two normal populations.

Table 3. *Significance of ratios between normal periods (1961-90)/(1931-60).*

	Netherlands (119 stat.)	Norway (Samnanger)	Poland (8 stations)	Germany (14 stations)
Annual values				
$\bar{x}$ (mm)	772	3442	568	716
s (mm)	131	786	85	99
2sq (%)	9	12	8	7
Q-100 (%)	+7	+9	+2	+1
Sign. (5%)	No	No	No	No
Spring				
$\bar{x}$ (mm)	152	586	114	158
s (mm)	45	286	33	35
2sq (%)	15	25	15	11
Q-100 (%)	+23	+7	-3	+14
Sign. (5%)	Yes	No	No	Yes
Summer				
$\bar{x}$ (mm)	213	663	203	228
s (mm)	65	200	45	49
2sq (%)	16	16	11	11
Q-100 (%)	-1	+6	-8	-7
Sign. (5%)	No	No	No	No
Autumn				
$\bar{x}$ (mm)	222	1227	172	172
s (mm)	67	339	53	46
2sq (%)	16	14	16	14
Q-100 (%)	+4	+15	+9	0
Sign. (5%)	No	Yes	No	No
Winter				
$\bar{x}$ (mm)	186	966	109	158
s (mm)	57	441	31	46
2sq (%)	16	24	15	15
Q-100 (%)	+11	+4	+3	+4
Sign. (5%)	No	No	No	No

Table 3 shows that some of the differences between the two normal periods (e.g. Germany and the Netherlands during spring, Western Norway during autumn), are significant at the 5% level. This indicates that on this time scale, a real climatic change has occurred.

6. Consequences of inhomogeneous series.

An important requirement for correct normal values is that the data series are **homogeneous.** A series for a climatological element is homogeneous if it is measured by the same method, with the same instruments, at the same location and observation time, and in unchanged environment. All these requirements are seldom fullfilled for long climate series, and statistical methods have to be used to reveal inhomogeneities. In the NACD project all participating countries have agreed to use the "Standard Normal Homogeneity Test (SNHT)" (Alexandersson, 1986) as the main method to detect inhomogeneities.

Inhomogeneities in precipitation series may seriously influence the ratios between succeeding normal periods. For instance, the series from Lom in central Norway was inhomogeneous because of changes in environment around the gauge in 1968. The annual adjustment factor was 1.09 (Førland & Hanssen-Bauer, 1992). Figure 7 shows the 30-year moving averages for both the original and adjusted (homogenised) series. The adjusted ratio between the two last standard normal periods is 1.03, while the unadjusted ratio is 1.10.

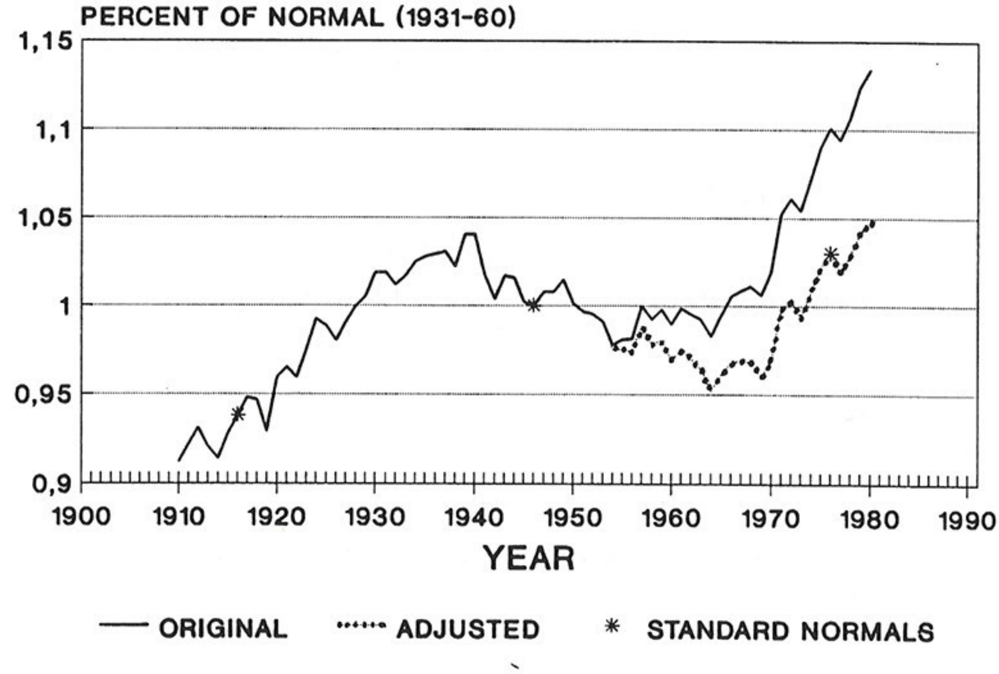

Figure 7. Moving 30-year averages for a station (Lom, Norway) with inhomogeneous precipitation series (see text for details).

To evaluate the consequences of inhomogeneities for such ratios, it is important to know how often significant inhomogeneities occur in long precipitation series, what is the magnitude of the adjustment factors, and if the distribution of adjustment factors are biased. An example from Norway may illustrate this:

In Norway more than 165 long (~100 years) precipitation series were checked for homogeneity, and just 30% of these series were found to be homogeneous (Hanssen-Bauer & Førland, 1994a). 80% of the inhomogeneities could be explained by changes described in the metadata-archives for the station. The most important reasons for breaks in the precipitation series were relocations (47% of the breaks), changes in environment (17%), installation of windshield (9%) and new observer (4%).

The adjustment factor for annual precipitation varied from 0.8 to 1.2. For breaks caused by relocations, the average adjustment-factor was 1.0, while for breaks caused by changes in environment or installation of wind shield it was significantly **higher** than 1.0. This implies that if the series were not adjusted for inhomogeneities, a **fictive** tendency of increased precipitation would have been the consequence. Also for the former USSR, successive changes in gauge designs have led to increased snowcatch, and hence exaggerated increases in precipitation (Groisman et al., 1991).

The effect of gauge changes on winter precipitation is demonstrated in figure 8 with reference to the longest record in Finland (Helsinki), which comprises observations from four different gauge types. It should be pointed out that the Helsinki records have always represented a well sheltered observing site and the corrections are much higher for open sites.

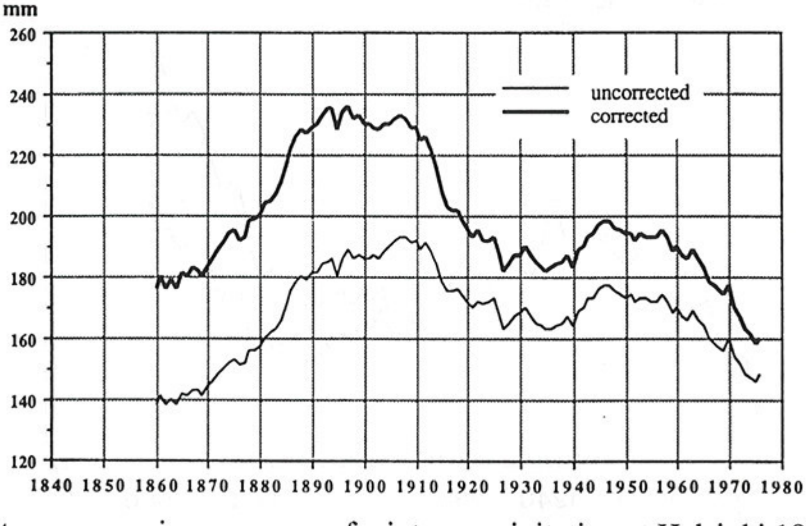

Fig. 8. Thirty-year moving averages of winter precipitation at Helsinki 1845-1993. Thin line: published, uncorrected data. Thick line: corrected data (gauge changes only).

As demonstrated by e.g. Groisman et al. (1991) and Hanssen-Bauer & Førland (1994a), improved gauge designs have led to increased gauge catch efficiency, and accordingly an overestimated increasing precipitation trend. This kind of inhomogeneities at single stations will not influence the ratio patterns in Figure 1-5, as small local anomalies are smoothed out in these maps. However, if such changes (e.g. new gauge design, installation of wind shield) are introduced simultaneously at several stations, the consequent inhomogeneities will not be detected by the conventional homogeneity tests. In some of the NACD-countries (e.g. Finland (Heino, 1994)), such changes have occurred. Although the precipitation series have been adjusted according to results from comparison measurements, new gauge designs may have influenced the ratios in some areas in figures 1-5.

7. Variation of 30-year moving averages.

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. Would the normals in this century have been different if another starting year had been chosen ??

This may be illustrated by using 30-year moving averages, as shown for some stations in figure 9 and 10. The graph for Samnanger in Western Norway (figure 9) shows that the 30-year average was quite stable (3130-3310 mm/year) between the periods 1901-1930 to 1958-87. However in the last six 30-year periods it increased to resp. 3341 mm (1960-89), 3441 mm (normal period 1961-90), 3445 mm, 3483 mm, 3490 mm, 3496 mm and finally to 3537 mm in the period 1966-1995. For Samnanger the standard normal precipitation for the 1931-60 period is one of the lowest 30-year averages in this century, while the 1961-90 standard normal is one of the highest. The 30-year average for 1966-95 is more than 250 mm (8 %) higher than the long-term mean for the whole 1901-1994 period.

From figure 9 it may be concluded that:
a). The 30-year moving averages may change rapidly within a few years
b). Standard normals may represent "abnormal" values among 30-year moving averages.
c). Standard normals may deviate significantly from long-time means

The difference between the new and old standard normal values is based solely on two points on graphs like the ones presented in figure 9, and does not give an unambiguous measurement for climatic change. This should be kept in mind when considering maps like figures 1-5.

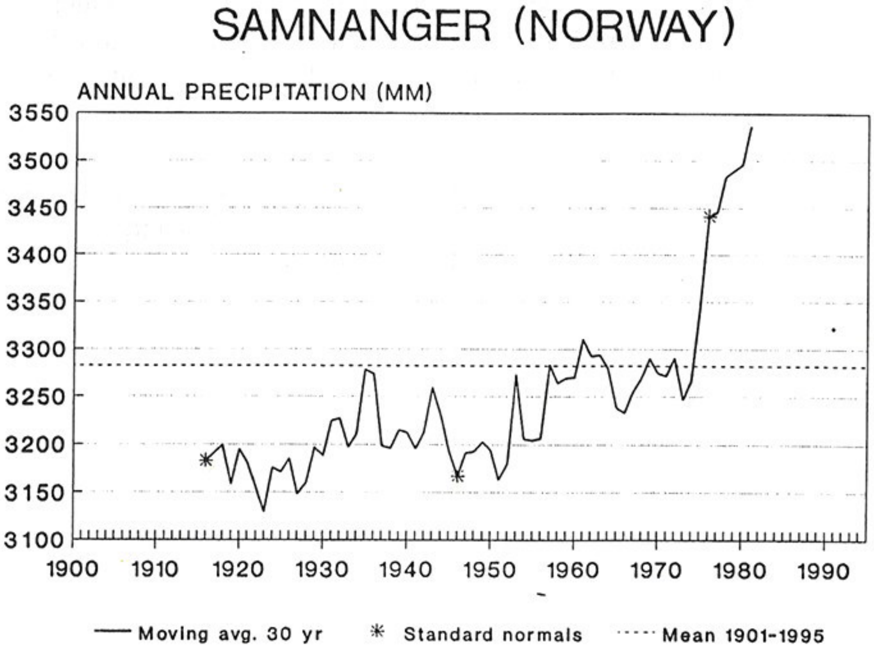

Figure 9. Moving 30-year averages for homogenous series of annual precipitation. (Averages are plotted on the central year in the averaging period).

8. Trend analysis.

Another feature of moving 30-year averages is that a time 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 9. In the NACD-project it was decided to use low pass filters, including Gaussian weighting coefficients to illustrate variability and trend of precipitation series. Such graphs for some **homogeneous** precipitation series or groups of series within the NACD-area are shown in figure 10. The applied standard deviation of the Gaussian distribution is 9 years, corresponding to an averaging period of about 30 years. The ends of filtered curves are highly dependant on the first or last few values in the series, which may thus influence the trends unreasonably much.

Figure 10 confirms the impression from figure 1 that the annual precipitation trends differ substantially over the North Atlantic region.

For the **Netherlands** the average annual precipitation for the period 1900-94 shows an upward trend (figure 10) that is just significant at the 5% level. Also in western **Denmark** (Vestervig) there has been a positive trend during most of century, while the precipitation increase in **Germany** occurred in the period 1900-1950. However both in **Scotland** (Braemar) and at the Baltic Sea coast of **Poland**, the current precipitation level is lower than in the first half of this century.

In western **Norway** (Samnanger) the trend curve shows a relatively constant precipitation level from 1900 to the middle of the 1960s, after which there has been an increasing trend of about 10%. Analyses of 129 precipitation series from Norway, showed that the normalised trend curves of **homogeneous** neighbouring stations exhibit almost identical trend curves, while there are large differences between different regions (Hanssen-Bauer & Førland, 1994b). For Norway, 5 main regional groups of trend curves were identified (Hanssen-Bauer et al., 1995). For all regions, the trend curves showed that the precipitation level at the beginning of this century was lower than in the end.

Figure 10 also reveals that there is rather good correspondence between trend curves based on respectively 30-year moving averages and low pass filters. The largest deviations are found for Samnanger, but even for this station the main features of the precipitation variations in this century are the same for both curves.

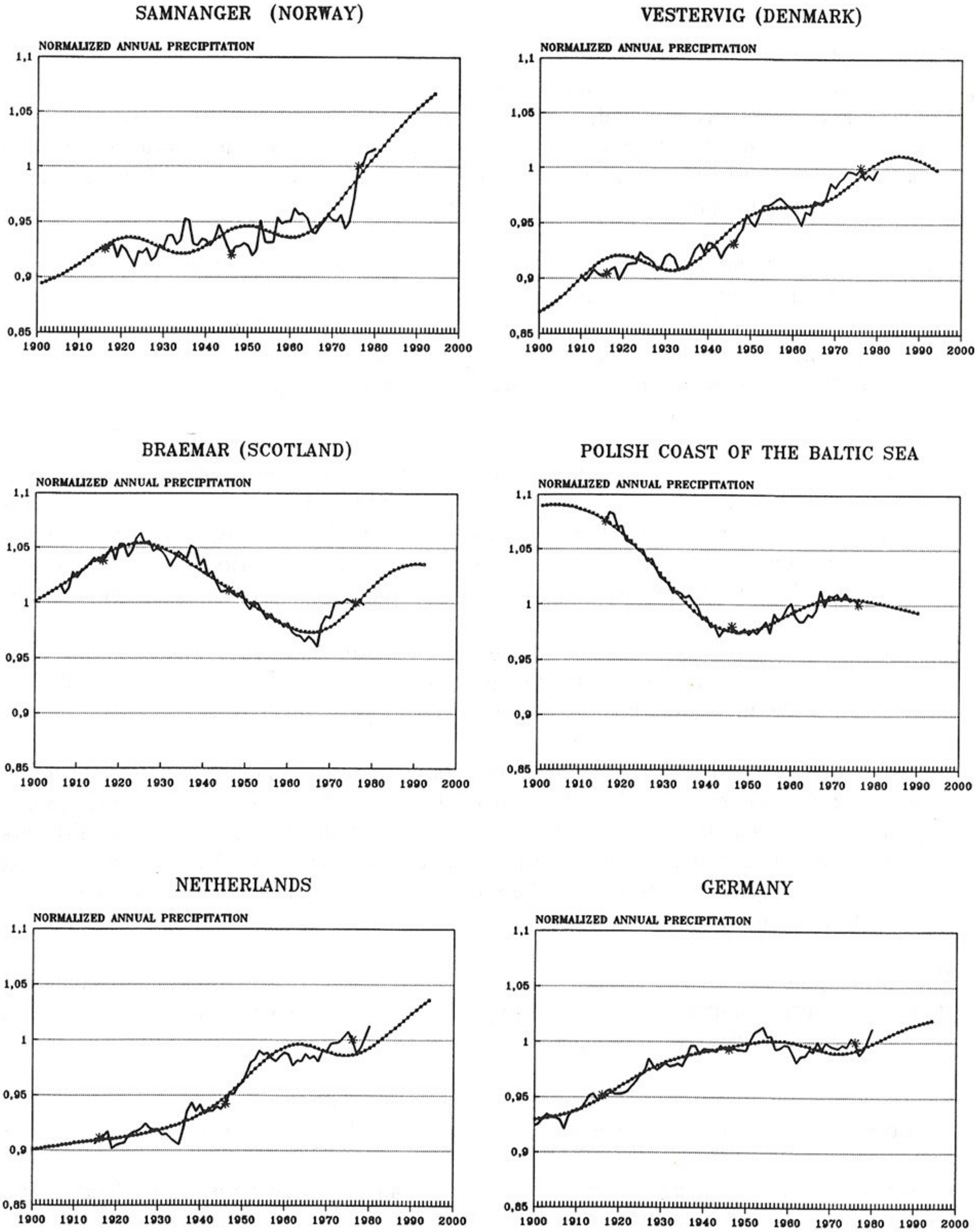

Figure 10. Moving 30-year average (—) and filtered (•••) annual precipitation values. Values are normalized by dividing by normal precipitation 1961-90 (PN_{61-90}). * indicate standard normal values (1901-30, 1931-60, 1961-90)

(PN_{61-90}: Samnanger=3441 mm, Vestervig=810 mm, Braemar=887 mm, "Polish coast"=574 mm, "Netherlands"=777 mm, "Germany"=719 mm)

9. Discussion.

The use of the word "normal" may not be proper, because it is often understood as the usual state or condition. In addition arithmetic mean (or normal) may be a misleading statistic for non-normal distributions (Førland, 1994a). Todorov (1985) concluded that normals were of limited use for many practical applications in the Sahel region, and criticized the often mechanical and uncritical acceptance of standard normals as descriptors of current rainfall conditions. From this paper it may be concluded that:

a). Normal values should be based on homogenous (or homogenised) series
b). The 30-year moving averages may change rapidly within a few years
c). Standard normals may represent "abnormal" values among 30-year moving averages
d). Standard normals may deviate significantly from long-term means
e). The difference between standard normal periods does not give an unambiguous measurement for climatic change

Is 30 years a reasonable length of the "normal periods" ? The significant differences between the two latest normal periods indicate that 30 years is a too short averaging period to get stable mean values. But on the other hand, normal values should reflect real climate changes (e.g. by increased greenhouse effect). By using longer averaging periods, it will be still more difficult to find homogeneous (or establish homogenised series) covering the whole period.

In spite of the criticisms presented above, the 30-year standard normal periods should therefore still be maintained in climatology. But bearing point a)-e) above in mind, the normal values should mainly be used for comparative purposes.

Although it is demonstrated that the difference between standard normal values does not give an unambiguous measure for climatic change, this difference is a convenient and common way of quantifying climate variations. In section 8 it is shown that there is a fairly good correspondence between moving 30-year averages and low-pass filter values. The main features in the maps in figure 1-5 are therefore indicating real differences between the last two standard normal periods.

The normal precipitation has increased in most of the North Atlantic region on annual basis, as well as during autumn, winter and especially spring. During summer, the seasonal precipitation has decreased over most parts of the area.

Increased precipitation may be due to real causes such as changes in circulation patterns or increased content of precipitable water in the atmosphere because of increasing temperatures.

However, as pointed out by Groisman et al. (1991) and Hanssen-Bauer & Førland (1994a), not adjusting for improvements in gauge design may lead to an exaggerated precipitation increase. Similarly, as demonstrated by Førland (1994b) increased winter temperature will increase the gauge catch efficiency, especially in wind exposed areas with large proportions of solid precipitation. The correction factor for aerodynamic catch deficiency is substantially larger for solid than for liquid precipitation. In wind exposed areas the correction factor is typically 1.8 for solid precipitation and just 1.1 for liquid precipitation (Førland et al., 1995).

Thus, even if there is no change in true precipitation, increased temperature would imply less solid precipitation and more in the liquid form. Accordingly by increasing temperature, the catch efficiency of the precipitation gauges will increase, causing a **fictive** increase in the measured precipitation during the winter season. For the wind exposed arctic areas in Norway a temperature increase of 3°C would give a fictive precipitation increase of about 15% during the winter season (Førland, 1994b).

The anomaly patterns in figures 1-5 are indicating that changes in atmospheric circulation probably are the main reasons for the different precipitation normals in the two last standard normal periods. For annual values and even more pronounced for autumn and winter values, there is a tendency of increasing precipitation in western parts of UK, Netherlands and Scandinavia. These features are indicating that the rising precipitation trend is caused by increased zonal flow. Similarly the ratio pattern in figure 2 (e.g. opposite changes south and north of the central Norwegian mountains) indicates that changes in circulation patterns also are the reason for the dramatic rise in spring precipitation. Concerning possible connections to increased greenhouse effect, it should be kept in mind that in large parts of the area, the 1961-90 spring normals are at the same level as the 1901-30 normals.

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