DNMI DET NORSKE METEOROLOGISKE INSTITUTT

klima

TRENDS AND VARIABILITY IN ANNUAL PRECIPITATION IN NORWAY

I. HANSSEN-BAUER, E.J. FØRLAND AND O.E. TVEITO

REPORT NO. 27/95 KLIMA

ISSN 0805-9918

REPORT NO.
27/95 KLIMA

DATE
25.10.1995

DNMI-RAPPORT

THE NORWEGIAN METEOROLOGICAL INSTITUTE
P.O. BOX 43 BLINDERN 0313 OSLO 3

PHONE: +47 22 96 30 00

TITLE

TRENDS AND VARIABILITY IN ANNUAL PRECIPITATION IN NORWAY

AUTHORS

I. Hanssen-Bauer, E. J. Førland and O. E. Tveito

PROJECT CONTRACTOR

The Norwegian Research Council
and
The Norwegian Meteorological Institute

SUMMARY

Two different methods were applied to estimate long-term precipitation trends representative for different regions in Norway. Comparative trend analysis (CTA) of 142 homogeneous precipitation series of 70-100 years, lead to the identification of 12 precipitation trend regions. Principal component analysis (PCA) was applied on a set of 30 series during the period 1896-1994. The results from both analyses were used to estimate precipitation trend series at several locations. The estimates based upon the PCA were of same quality as the esimates based upon the CTA.

In all regions, the present level of annual precipitation is higher than the level around 1900. In most parts of Norway, this increase lies between 8 and 14%. There are, however, substantial differences between regions in different parts of the country regarding the period during which the precipitation has increased. In eastern regions the increase happened mainly before 1930. In western regions, it happened mainly after 1960. In northern coastal regions, the increase was more evenly ditributed throughout the century, while the increase in the northern inland region mainly took place during 1945-1965.

The influence on regional trend curves of using inhomogeneous data was investigated. The conclusion was that a trend curve based upon unadjusted series not necessarily is seriously affected by inhomogeneities. However, the "noise level" of the input data is considerably higher than for a homogeneous dataset, and a larger "signal" is thus needed to detect eventual climate changes.

SIGNATURE

Inger Hanssen-Bauer .... Bjørn Aune ....

Inger Hanssen-Bauer
Senior Scientist

Bjørn Aune
Head of Climatology Division

Contents:

1. INTRODUCTION

1.1 Background.

Precipitation amount and variability may differ largely over small distances, because of orographic effects which are sensitive to small differences in circulation patterns. A denser network of stations is thus needed for analysing precipitation variability, than for similar analyses of air pressure or temperature. Presently, a high quality set of precipitation series for the period 1895-1994, covering the Norwegian mainland has been completed. This dataset is used to deduce precipitation trends representative for different parts of Norway. The problem is approached in two ways: by defining regions of common precipitation trends and variability ("comparative trend analysis"), and by applying principal component analysis. In the present report, results from these analyses are summarized and compared to each other.

1.2 Data.

The dataset consists of series of monthly precipitation from 142 stations (figure 1). Some relevant information about the stations is given in Appendix. In order to cover the northernmost parts of Norway in a satisfactory way, 2 Finnish series are included in this dataset. The series were all homogeneity tested on an annual basis using the standard normal homogeneity test (Alexandersson 1986). Some general results from these tests were reported by Hanssen-Bauer and Førland (1994). A subset of the series was also homogeneity tested on a seasonal basis.

The importance of using homogeneous series in trend studies is evaluated in the present investigation (section 2.4).

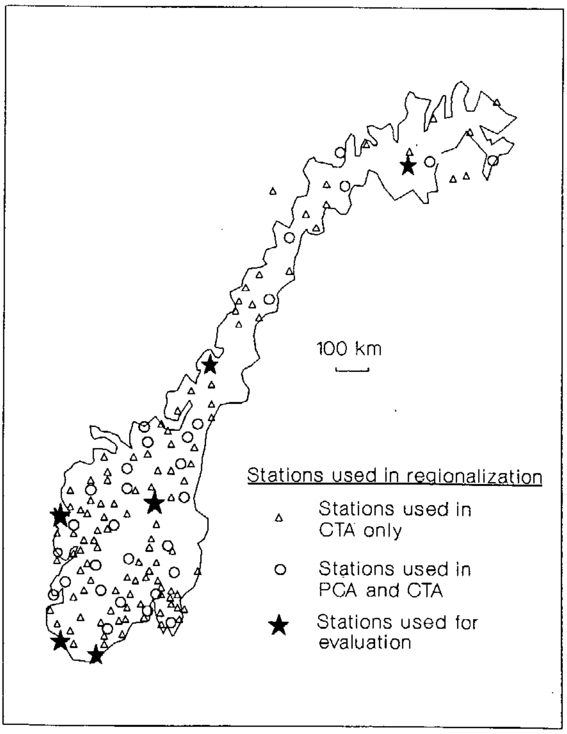


Figure 1. Approximate position of the 142 stations which were used in the regionalization.

2. COMPARATIVE TREND ANALYSIS

2.1 Methods

In Norway, mean annual precipitation varies from less than 300 mm at some stations to nearly 4000 mm at other stations. To suppress the influence of the large differences in annual precipitation, all precipitation series were standardized by dividing by their respective 1961-1990 average, i.e. the normal value $PN_{61\text{-}90}$. The reason for standardizing in this way (rather than using the common statistical standardizing including standard deviation), is that it is easy to reverse the process and extrapolate a time series (in mm) for any location just by multiplying by the official normal values $PN_{61\text{-}90}$ (Førland 1993). It is also convenient to standardize all series by comparing with data from the same period, as differences between stations in working periods would otherwise affect the relative levels of the curves.

Two low pass filters (F1 and F2) including Gaussian weighting coefficients were used to describe variability and trend of the precipitation series. The standard deviation of the Gaussian distribution was 3 years for filter F1, and 9 years for filter F2. The filtered curves were cut 5 years from either ends of the time series. The ends of filtered curves are very dependent on the first or last few values, which may thus influence the trends unreasonably much.

The comparative trend analysis (CTA) includes subjective grouping together of standardized and filtered precipitation series showing similar trends. This method has the advantage of not demanding complete data series from all stations. Consequently, series from all 142 stations were used in this analysis. Some results from the CTA were reported by Hanssen-Bauer and Førland (1994). However, homogeneous series from the northernmosts parts of the country were then still missing.

2.2 Precipitation trend regions.

Comparative trend analysis of the 142 precipitation series resulted in 12 groups with different patterns of precipitation variation in time. The groups include from 4 to 30 series. Two examples of groups of filtered series are shown in figure 2. The upper diagrams show annual precipitation in mm for all stations within each group, while the lower diagrams show standardized curves.

It was possible to identify each of the 12 groups with a region. The 12 regions are shown in figure 3. Regions 3 and 4 are corresponding to the groups presented in figure 2. Note the major differences between the precipitation patterns in these neighbouring regions.

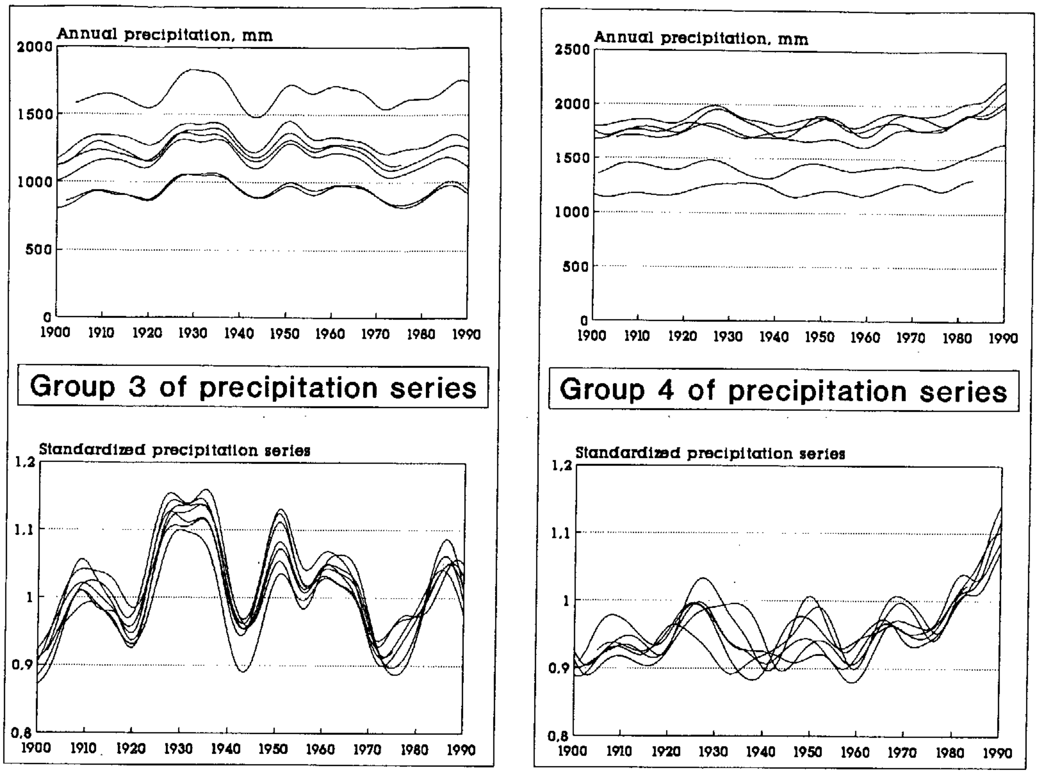


Figure 2. *Two examples of groups of precipitation series showing similar trends. Upper graphs: precipitation in mm. Lower graphs: standardized curves. All curves are smoothed by filter F1.*

There were, however, similarities between the precipitation trends in some neighbouring regions, and the 12 regions were divided into 5 regional groups: an eastern group (regions 1-3), a western group (regions 4-6) , a central group (regions 7-9), a northern coastal group (regions 10 and 11), and a northern inland group (region 12). These are also shown in figure 3.

2.3 Precipitation trends in the 12 regions

For each of the 12 precipitation regions, the standardized precipitation curve was defined as the average of the standardized precipitation curves from all stations within the region. Regional standardized precipitation curves smoothed by F1 and F2 are shown in figure 4 and 5, respectively. Standard deviations between the individual series within each region were also calculated, as a measure for the variation within the regions. In figures 4 and 5, the averaged curves are given +/- one standard deviation. The curves in figure 4 show typical regional variations on a 10 year time scale while the curves in figure 5 show the regional precipitation trends on a 30-year time scale.

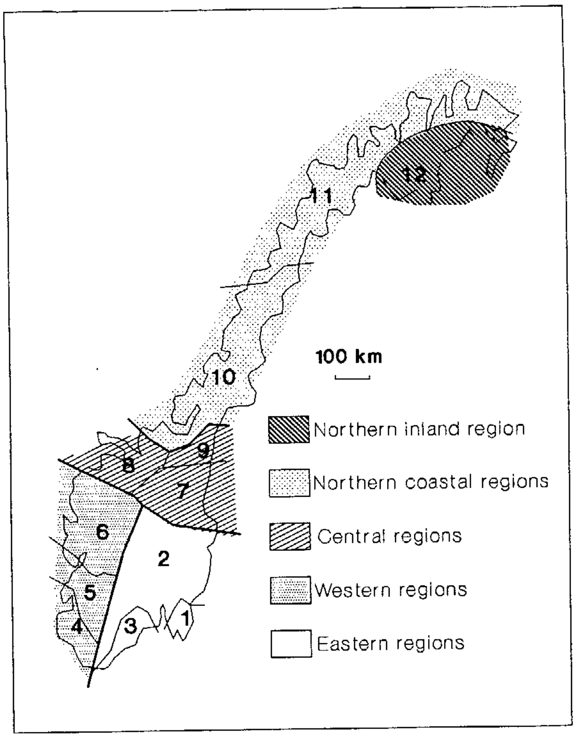


Figure 3. The 12 precipitation regions and 5 main groups of regions found by comparative trend analysis.

Figure 4 a-c show F1 curves for the 3 eastern regions. Their local maxima and minima occur more or less simultanously, but there are differences between the regions concerning the relative sizes of these extremes. In region 1, the absolute maximum occured in 1960's. In region 2, the maximum in the late 1920's was as high as the one in the 1960's. In region 3, the highest maximum occured in the 1930's. The influences of these differences on the long term precipitation trends are illustrated by the F2 curves (figure 5 a-c). All eastern regions showed an increasing precipitation trend in the period 1900-1930. In region 1 the increasing trend continued after 1930. In region 2, however, the precipitation level has been relatively constant afterwards, and in region 3 the trend was decreasing during the period 1930-1975.

Figure 4 d-f show F1 precipitation curves for the 3 regions in western Norway. There are differences between these regions in the amplitudes of the variations on the 10-year time scale, but many of the local extremes occur simultanously in all the western regions. The F2 curves (fig. 5 d-f) also show similar trends. The precipitation level was relatively constant during the period 1900-1960. After 1960, however, the precipitation level in the western regions has increased.

The F1 precipitation series for the 3 regions in central Norway (fig. 4 g-i) show distinct differences between these regions. Region 7 shows some similarities with the eastern regions, while region 8 resembles the western regions, and region 9 shows some similarities with the northern coastal regions. The central regions may thus be considered as a transition zone. However, there are some similarities between the groups concerning long term trends (fig. 5 g-i). There was a tendency to increasing precipitation in the first and last decades, while the precipitation level was relatively stable during 1930-1970.

Figures 4 j-l show F1 curves for the 3 northern regions. The "coastal regions" 10 and 11 show similarities in these figures as well as in figure 5 j-k, which show a positive trend in annual precipitation during most of the period. In the northern

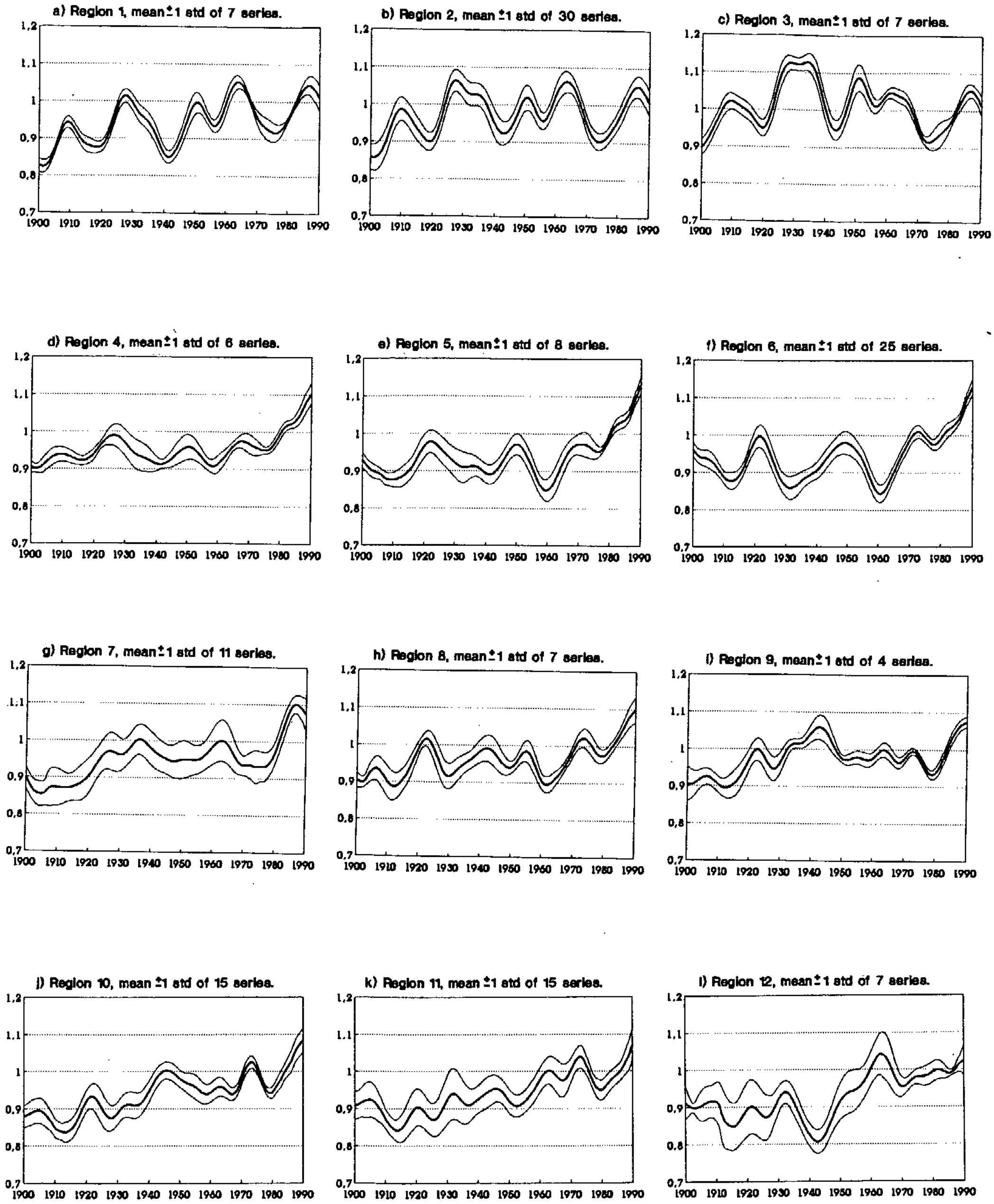


Figure 4. *Averages and standard deviations of the standardized F1 precipitation curves from stations within regions 1 (a), 2 (b), 3 (c), 4 (d), 5 (e), 6 (f), 7 (g), 8 (h), 9 (i), 10 (j), 11 (k) and 12 (l).*

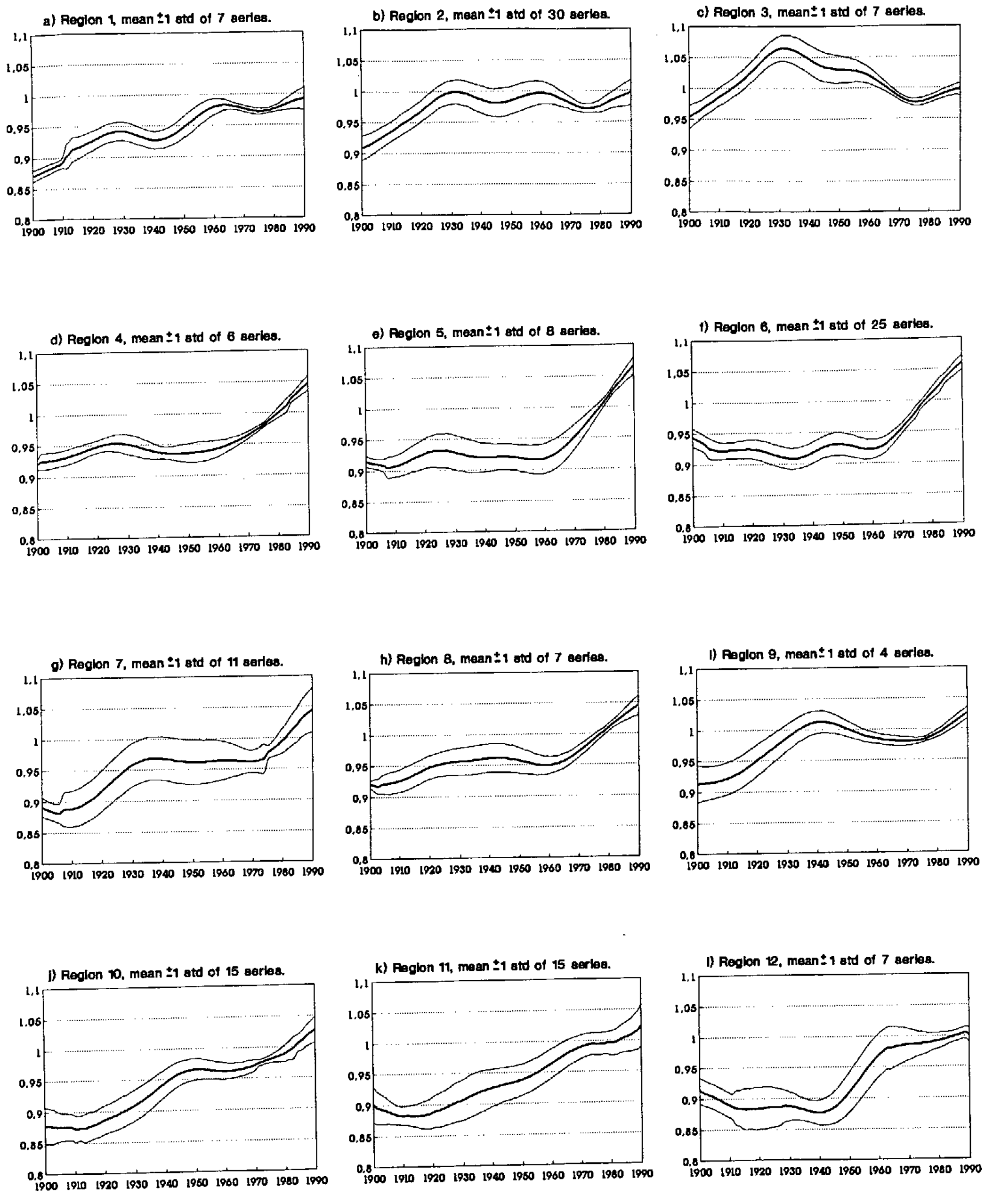


Figure 5. *Averages and standard deviations of the standardized F2 precipitation curves from stations within regions 1 (a), 2 (b), 3 (c), 4 (d), 5 (e), 6 (f), 7 (g), 8 (h), 9 (i), 10 (j), 11 (k) and 12 (l).*

inland region 12, however, the smoothed precipitation curves are quite different. Mean annual precipitation increased from the 1940's to the 1960's, while the level was relatively stable during the preceding and following decades.

For the regional F1 curves, the standard deviations are within 2-5% most of the time. For the F2 curves, the standard deviations are usually within 1-3%. The larger uncertainty is found for areas within the regions 7, 11 and 12. This is partly caused by real differences between the precipitation patterns in different parts of these regions. Particularly, it has been pointed out that region 7 is a "transitional zone" rather than a trend region. However, there are also other reasons for these larger standard deviations. In regions with small amounts of precipitation, the relative noise caused by random local variations and errors will be larger than in more humid regions. Regions 7 and 12 are the "dryest" regions in Norway. Another factor which should be considered, is the fraction of annual precipitation falling as snow. This fraction is at maximum in region 11. As the errors connected to measuring snowfall generally are larger than the errors connected to rainfall measurements, one should expect larger random variations in this region.

Using figures 4 - 5, the precipitation curve for any point within the defined regions may be estimated by multiplying the regional trend curve by the 1961-1990 precipitation average, which may be deduced from the official precipitation normal maps (Førland 1993). The standard deviations give a measure for the uncertainty of the estimate.

2.4 Long term trends in the 5 regional groups.

F2 curves for the 5 regional groups were calculated in order to give a survey of the precipitation trends on a larger scale. Figure 6 shows that the average level of annual precipitation has increased in all parts of Norway during the present century. In all regional groups, the increase was between 8 and 14%. The increase occured, however, not simultaneously all over the country. In the eastern group (fig. 6a) there was a positive precipitation trend (+8%) from 1900 to 1930, while the precipitation level has been relatively stable after 1930. In the western group (fig. 6b), the precipitation level was about the same from 1900 to the middle of the 1960s, after which there has been a positive trend (+13%). In the central group (fig. 6c), the precipitation level increased from 1900 to the 1930's (+7%) and from 1970 to present (7%), while there were only minor changes from the 1930's to 1970. In the northern coastal group (fig. 6d), the precipitation trend was positive from 1915 to the end of the series (+13%). In the northern inland region (fig. 6e) on the other hand, the precipitation level increased by about 10% in the period 1945 through 1965, while it was relatively constant before 1945 and after 1965.

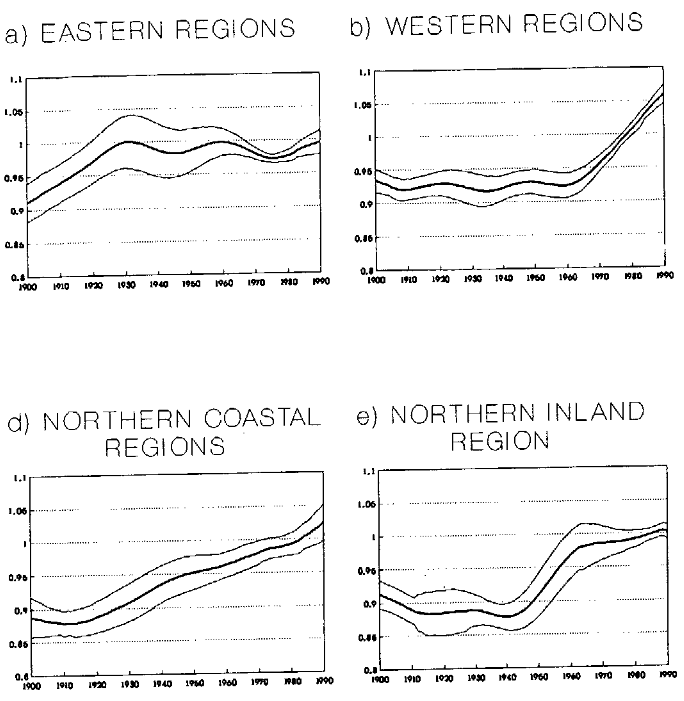


Figure 6. Averages and standard deviations of the standardized F2 precipitation curves within the different regional groups.

2.5 Influence of using inhomogeneous series in trend analyses

The main results from homogeneity testing of the present dataset were presented by Hanssen-Bauer and Førland (1994). Just 30% of the 165 tested series were found to be homogeneous, while 48 % passed the homogeneity test after one adjustment. 22% of the series contained several inhomogeneities. The adjustment factors for inhomogeneities in the dataset were in the range 0.8 - 1.3. Use of single, untested precipitation series in trend analyses may thus give erroneous results. Still, trend studies based upon the average precipitation from great numbers of stations would be unaffected by inhomogeneities if their adjustment factors were randomly distributed.

Hanssen-Bauer and Førland (1994) concluded that improvements of measuring equipment, as well as changes in the environments of the gauges, at average has lead to larger gauge catch. Thus the adjustment factors are biased, and consequently analyses based upon untested precipitation series may give artificial trends also for groups of series.

To investigate the effect on regional trend curves of including inhomogeneous data, results from analyses based upon adjusted and unadjusted series were compared. Figure 7 shows that the trend curve in region 6 was not seriously affected by the inclusion of inhomogeous series. However, the standard deviation within the groups increased considerably when using unadjusted series. The main problem thus seems to be a generally increased "noise level" in the data. Consequently, an eventual "signal" of climatic change will be easier to detect when using homogeneous and/or adjusted series.

The probability of getting artificial trends is at maximum during the winter season, as changes in gauge catch generally are larger for snow than for rain (Førland and Aune 1985). Preliminary studies indicate that winter precipitation trend curves from eastern regions of Norway may be biased because of introduction of windshields at many stations. These series are classified as homogenous (or adjusted to homogeneity) on an annual basis, but may hide inhomogeneities during the winter season as snow acccounts for only about 20% of the annual precipitation in these regions. The "annual based" adjustment factors for installation of windshield will accordingly be too low during winter and too high during the summer season.

The conclusion is that the precipitation series should be homogeneity tested and adjusted on seasonal basis, prior to trend analysis on seasonal basis.

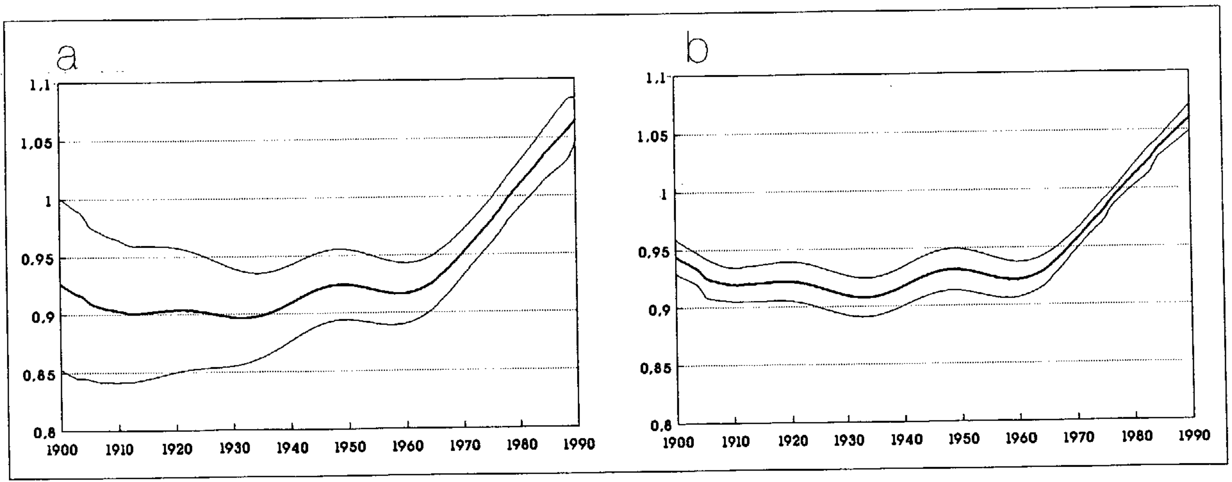


Figure 7. Trend curves, region 6, based upon a) unadjusted, and b) homogeneous or adjusted series.

3. Principal component analysis.

3.1 Methods

Principal component analysis (PCA) may be performed using the correlation matrix or the covariance matrix (Preisendorfer 1988). Tveito and Hisdal (1994) analysed Norwegian precipitation and runoff series using the correlation matrix, which should always be used for combined datasets. In the present work, however, the covariance matrix was used, which is suggested for univariate studies by several authors (i.e. Mills 1995). More information is retained in this way, and it also simplifies the estimation of precipitation trends (section 4). However, to avoid influence on the principal components of differences in precipitation levels, the standardization introduced in section 2.1 was applied.

PCA is less time consuming to accomplish than CTA (chapter 2). It is also basically an objective method, even if the interpretation of the results often will include subjective considerations. Contrary to the CTA, however, PCA demands complete series from all stations. The number of available data series thus rapidly decreases as the length of the analysed period increases. Results from PCA of 30 series (fig. 1) of annual precipitation during the period 1896-1994 are presented in section 3.2. In order to investigate the stability of the results, PCA has been applied on several periods and on station networks of different densities (sections 3.3 and 3.4).

3.2 Results from analyses of annual precipitation 1896-1994

The main results from the present analyses are in agreement with the results from Tveito and Hisdal (1994), in spite of differences in station network, time interval, standardization etc. In the present analyses, the 5 first principal components were needed to explain more than 80% of the variance of the original series. Eigenvalues and proportions of the total variance contained by the principal components are given in table 1.

The PCA produces loadings (weight coefficients) at each station, and time series of scores (amplitude functions) for each principal component. Figure 8 a-e show contour maps of the 5 first PC's, while figure 9 a-e show the PC scores smoothed by the low pass filters F1 and F2. Note that variance accounted for by the different PC's decreases successively (table 1). Consequently, the scores connected to the different PC's becomes gradually smaller, and gradually larger loadings are thus required to make a PC explain a certain percentage of the variance in the precipitation series. Table 2 shows the percentage of the variance explained by each of the 5 PC's at selected stations.

Table 1. Eigenvalues and proportion of total variance accounted for by the first 5 principal components from PCA of 30 series during 1896-1994.

	Eigenvalue	Proportion of total variance	Cumulative proportion
PC1	0.418	0.40	0.40
PC2	0.248	0.24	0.64
PC3	0.091	0.09	0.72
PC4	0.071	0.07	0.79
PC5	0.036	0.03	0.82

The loadings of the PC1 (fig. 8a) are at maximum in the western regions and in the western parts of the northern regions. Table 2 indicates that PC1 typically explains 60-85% of the variance in the western regions and 50-60% in regions 8-10. Further north, it explains 20-30%. In eastern regions the loadings of PC1 are close to zero. Figure 9a shows that the trend and variability in the score of PC1 are very similar to the precipitation curves of the western regions (cf. fig. 4 and 5 d-f). There are also similarities to the the curves representing regions 8-11 (fig. 4 and 5 h-k). The loadings of PC1 indicate that this component contains the variability connected to changes in the westerly winds. A suggestion is that positive score means high frequency of westerly winds, while high negative score means low frequency of these winds. High absolute loadings then implies that changes in the frequency or strength of these winds are of great importance for the annual precipitation at the place. Positive loadings means that the precipitation will be above average when the frequency is above average.

The loadings of PC2 (fig. 8b) are at maximum in the eastern and southern regions, and negative or close to zero in the northern regions. According to table 2, PC2 typically explains 70% of the variance at eastern stations, and 10-15% of the variance at the southwestern stations. In the northern region 11, it typically explains 5-10% of the variance. Note, however, that the loadings are negative in this area. The trends and variability in the PC2 score (fig. 9b) resemle the precipitation curves representing the eastern regions (fig. 4 and 5 a-c). A possible explanation is that PC2 score represent the frequency of southeasterly winds. Positive loadings thus means that high frequencies of southeasterly winds give above average precipitation. Negative loadings, on the other hand, mean that high frequencies of southeasterly winds give below average precipitation.

The loadings of PC3 (fig. 8c) are at maximum in the 2 northernmost regions. They are negative in western regions and positive in eastern regions. According to table 2, PC3 typically explains 30-40% of the variance in the northern stations, while it is of little importance elsewhere. The loadings of PC4 (fig. 8d) are at maximum in the central regions. They are negative in western regions and positive in eastern regions. PC4 typically explains 15-40% of the variance in the central regions, while it accounts for less than 5% in all other regions. The loadings of PC5 (fig. 8e) are at maximum in the northern region 12. According to table 2, PC5 typically explains 25% of the variance in this area. In the western region 4, it accounts for about 8%, however, the loadings are there negative.

Trends and variability in the scores of PC3, PC4 and PC5 (fig. 9 c,d,e) are not easily connected to one or more regional trend curves as were the cases for the first two components. Neither are the geographical patterns of the loadings (fig. 8 c,d,e) easily connected to a certain wind direction. No suggestion is thus made for a physical interpretation of PC3, PC4 and PC5. The interpretations of PC1 and PC2 are also highly speculative. Wind direction and strength are not sufficient for describing the precipitation regimes of Norway. The positions of the polar and arctic fronts are obviously of great importance for the distribution of precipitation.

Table 2. Percentage of the variance accounted for by each of the principal components for one station in each of the CTA trend regions.

station no.	CTA - region	% of variance accounted for by					
		P1	P2	P3	P4	P5	ALL
0123	1 east	1	68	6	0	2	77
1870	2 east	2	73	7	3	1	86
3880	3 east	1	75	1	2	2	81
4702	4 west	60	13	2	3	8	86
4750	5 west	69	12	3	3	3	90
5632	6 west	83	2	5	1	1	92
1040	7 central	17	8	4	37	0	66
6155	8 central	51	5	1	17	1	75
6955	9 central	55	5	0	21	0	81
7974	10 north coast	62	0	13	4	5	84
8980	11 north coast	33	9	39	2	3	86
9945	12 north inland	23	1	33	0	25	82

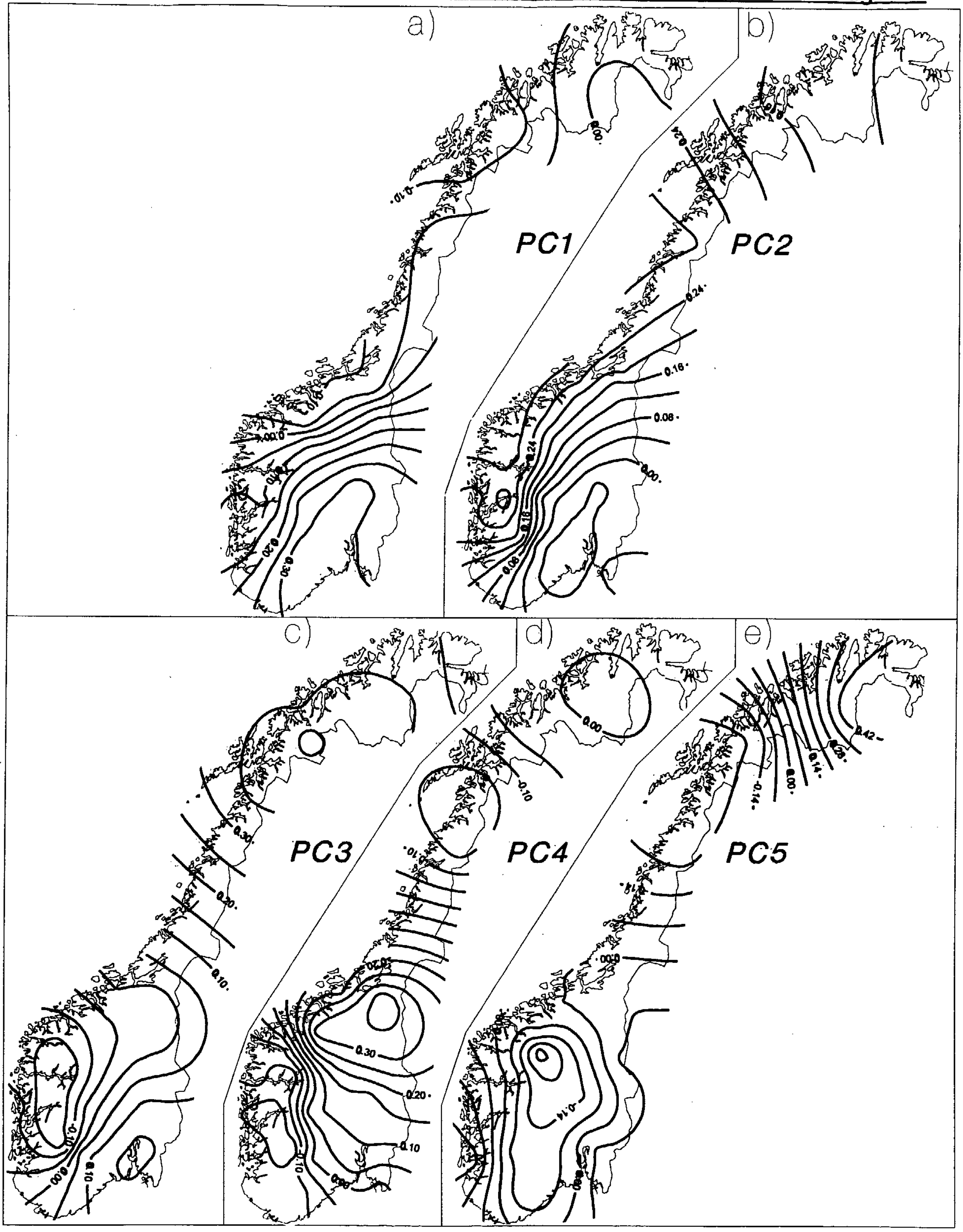
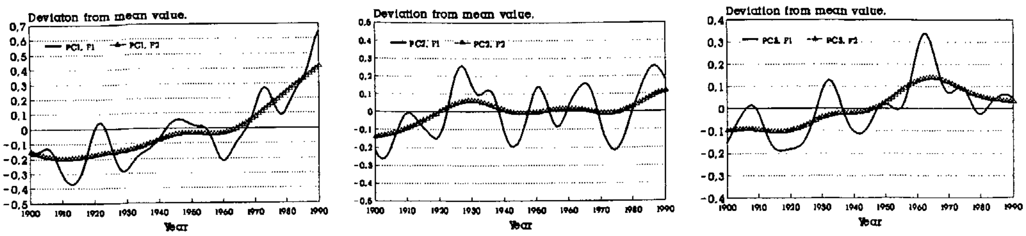
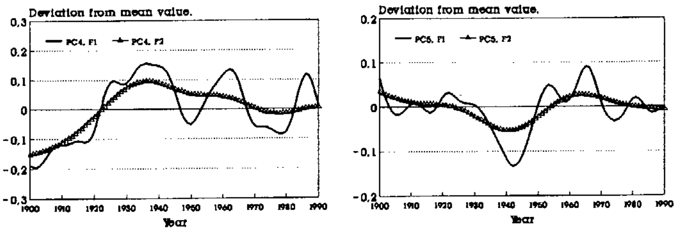


Figure 8. *Contour plots of loadings of a) PC1, b) PC2, c) PC3, d) PC4, e) PC5*



a) PC1 SCORES b) PC2 SCORES c) PC3 SCORES



d) PC4 SCORES e) PC5 SCORES

Figure 9. *Filtered (F1 and F2) timeseries of PC-scores of: a) PC1, b) PC2, c) PC3, d) PC4, e) PC5.*

More detailed studies of seasonal or monthly precipitation in connection with pressure anomalies are demanded to connect regional precipitation trends to variations in the general circulation pattern. However, Førland (1986) has documented that the precipitation pattern in western and central Norway is strongly dependent on the predominant wind direction.

3.3 Sensitivity of PCA to period of investigation and station density

In order to evaluate the temporal stability of the principal components, PCA was performed on the three 30-year periods 1901-30, 1931-60 and 1961-90. Contour plots of the first 5 PCs for each period showed patterns quite similar to those presented in figure 7. However, the variance accounted for by each of the PCs varied, and so did, as a consequence, the order of the PCs. Table 3 shows the variance accounted for by PC1 to PC5 for the three 30-year periods compared to the 99 year period. The PCs are given in an order corresponding to the contour plots of the 99 year period. The percentages are not directly comparable, as the contour plots for the periods are not identical. However, there are striking resemblaces between the plots corresponding to the components given at the same line in table 3 (i.e. the plot of PC 2 in the period 1931-1960 resembles the PC1 plots for the other periods).

Table 3. *Percentage of total variance acconted for by the 5 first PCs in analyses over different periods. PCs with similar contour plots are given at the same line.*

1896-1994		1901-30		1931-60		1961-90	
PC1	40%	PC1	41%	PC2	27%	PC1	51%
PC2	24%	PC2	25%	PC1	40%	PC2	16%
PC3	9%	PC4	5%	PC3	11%	PC3	11%
PC4	7%	PC3	8%	PC5	4%	PC4	8%
PC5	3%	PC5	4%	PC4	5%	PC5	3%

Note that the first 2 components for the period 1931-60 are in the opposite order compared to those of the other periods. This is in accordance with the results from PCA of a filtered set of precipitation series (Tveito and Hisdal 1994). One may suggest that southeasterly winds were more frequent during that period than during the others. Variation of the frequency or strength of such winds would then be an important factor for explaining variance in the precipitation data. The regional trend curve in the south-easterly region shows that the precipitation level was high there during the period 1931-60 (fig. 5c). This also indicates a period of relatively high frequencies of south-easterly winds.

During the period 1961-90, 51% of the variance was accounted for by the factor which was suggested to be connected to the westerly wind component. This would indicate that westerly winds were especially dominating during this period. The same conclusion may be drawn from studying the western regional trend curves (fig. 5 d-f), as these regions are exposed to heavy orographic precipitation when the on-shore wind component is strong.

The connection between wind conditions and contour plots is still speculative. However, the stability of the patterns of the contour plots shows that more or less the same components describe the precipitation variability throughout the entire series, though the relative importance of the components may vary somewhat.

The sensitivity of the PCA to station density was investigated by analysing a 80 station network during the period 1910-1994. The contour patterns of the PC1-PC5 were almost identical to the similar plots resulting from the 30 station study (figure 8 a-e). The 80 station contour plots, however, gave valuable additional information in areas of strong gradients. In areas with few long series, one may thus improve the results considerably by using contour maps based upon a denser station network over a shorter period as guidelines when drawing contours. One should, nevertheless, warn against using too short periods.

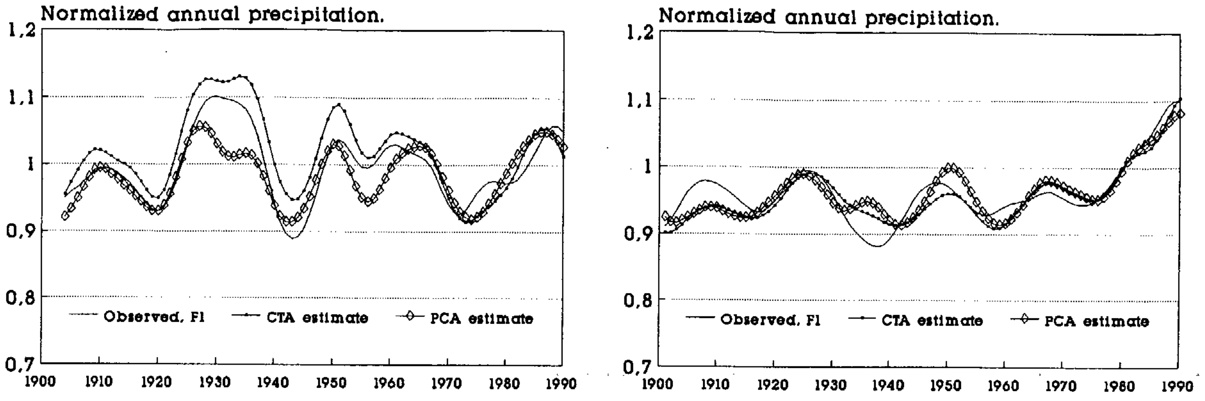
4. Estimation of precipitation time series using CTA and PCA.

The precipitation series of an arbitrary point may now be estimated in two different ways. Output from the CTA may be used as outlined in the last paragraph of section 2.3. Alternatively, the PC loadings found from maps (fig. 8), the PC scores (fig. 9), and the precipitation normal of the point (Førland 1993) may be used to make similar estimates based upon PCA. Estimates of the standardized precipitation were made for 6 stations (stars in fig. 1) using both techniques. None of these series were included in the PCA, and most of them are in areas of strong gradients in the PC loadings. Low pass filtered series of the estimated standardized precipitation are given in figures 10 and 11 (F1 and F2, respectively). The corresponding observed series are also shown.

Figures 10 and 11 illustrates that the PCA estimates generally are of the same quality as the CTA estimates, even if it is based upon a network of 30 series only. The estimates might have been even better if the contour maps were plotted, using contour plots from the 80 station PCA as guidelines. Correlation coefficients between the observed and estimated curves shown in figures 10 and 11 are given in table 4.

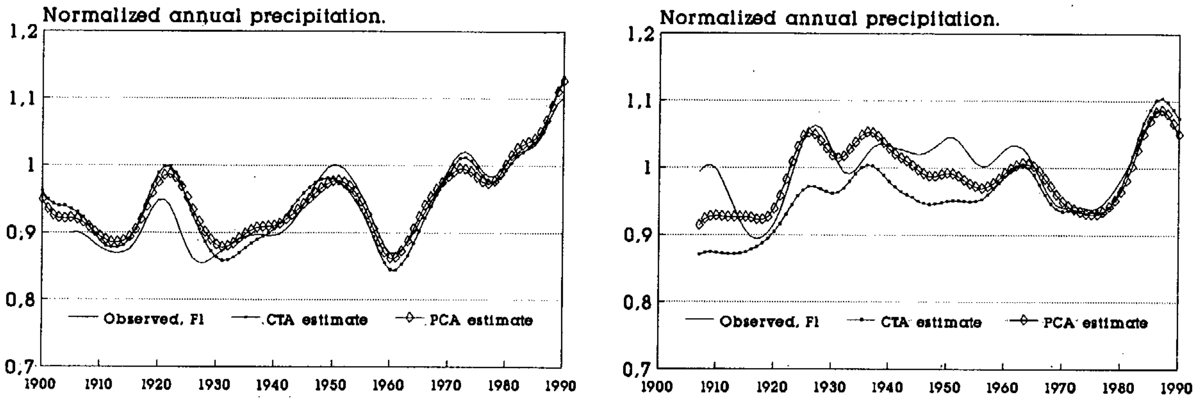
Table 4. *Correlation coefficients between filtered curves of observed annual precipitation at 6 stations and filtered precipitation curves estimated by comparative trend analysis and by principal component analysis for the same stations. Correlation coefficients are given for the filters F1 and F2.*

STATION	Comp.Trend Analysis		Princ.Comp.Analysis	
	F1	F2	F1	F2
3922	0.90	0.80	0.83	0.80
4336	0.89	0.95	0.85	0.95
5275	0.93	0.93	0.94	0.95
0872	0.72	0.73	0.83	0.89
7510	0.92	0.96	0.95	0.99
9330	0.90	0.97	0.88	0.92



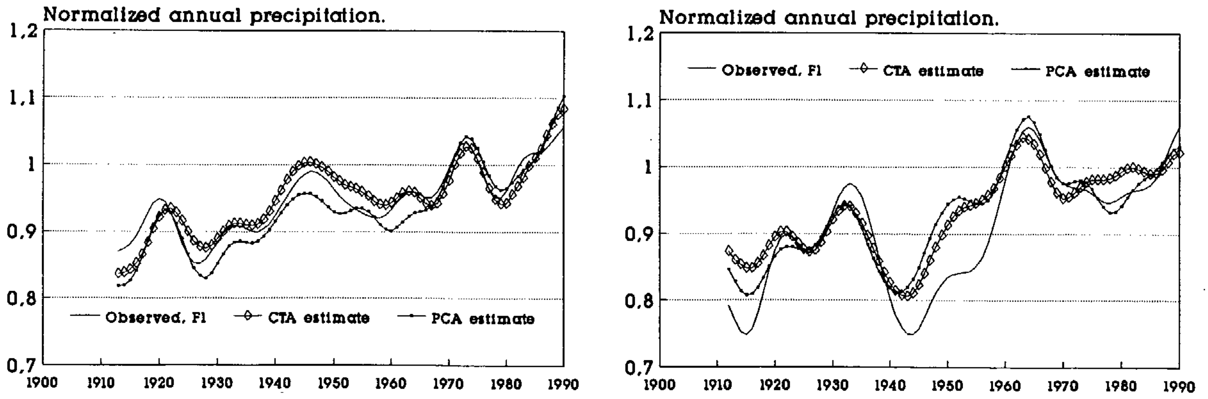
a) Station 3922, region 3 E.

b) Station 4336, region 4 W.



c) Station 5275, region 6 W.

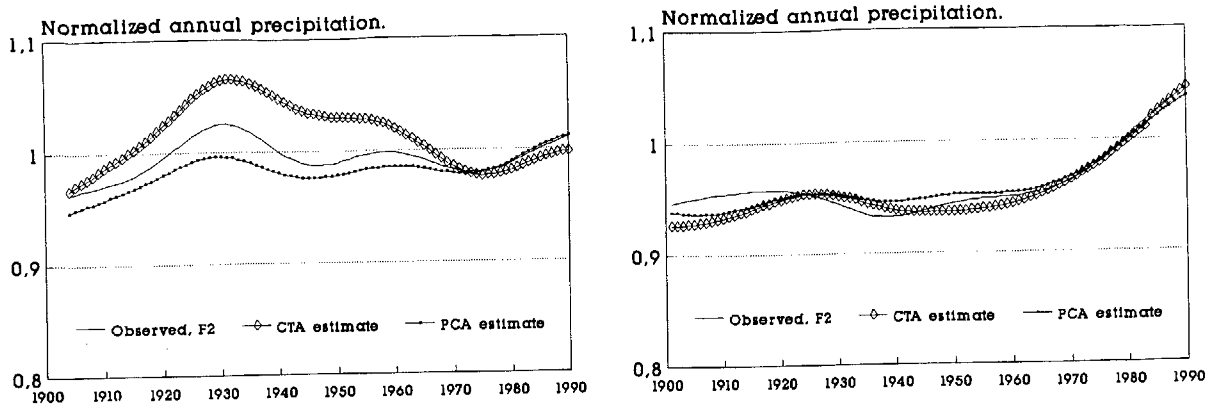
d) Station 0872, region 7 C.



e) Station 7510, region 10 NC.

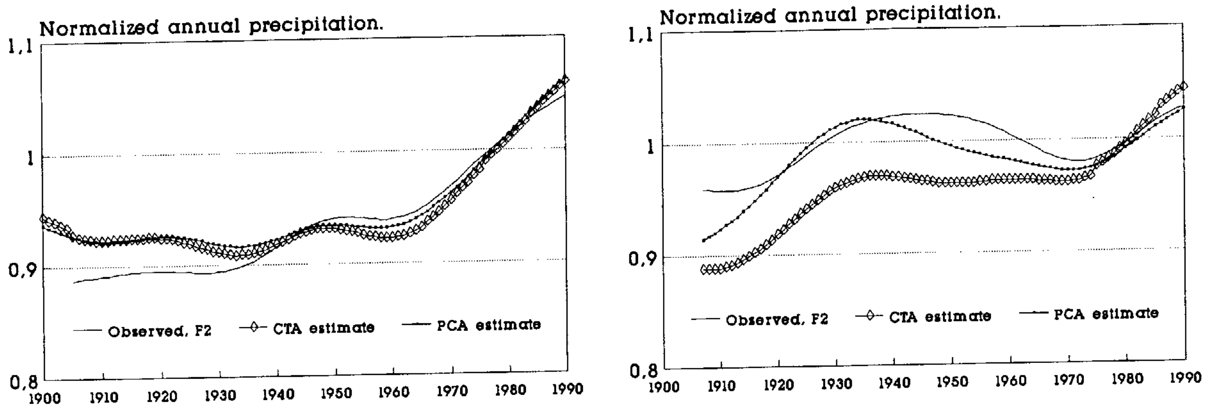
f) Station 9330, region 12 NI.

Figure 10. Observed and estimated precipitation curves smoothed by F1 at the 6 stations marked by stars in figure 1.



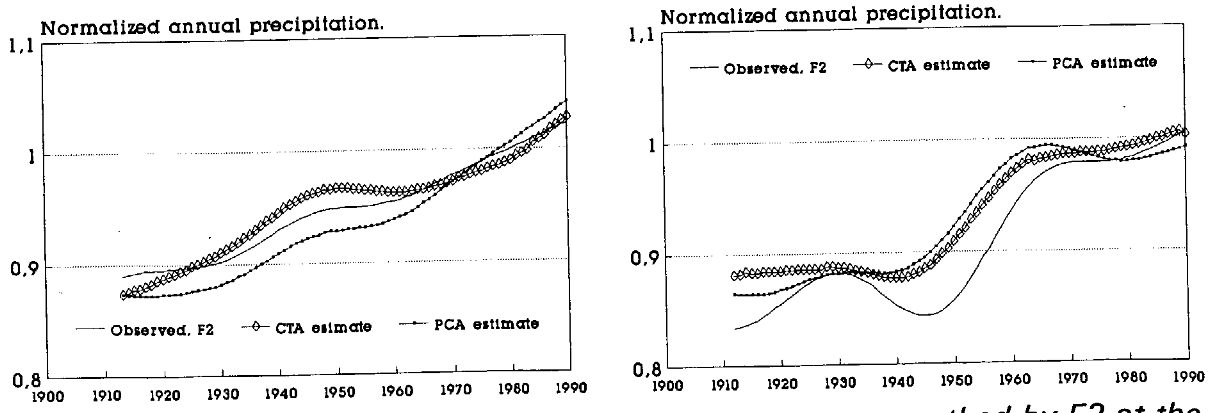
a) Station 3922, region 3 E.

b) Station 4336, region 4 W.



c) Station 5275, region 6 W.

d) Station 0872, region 7 C.



e) Station 7510, region 10 NC.

f) Station 9330, region 12 NI.

Figure 11. Observed and estimated precipitation curves smoothed by F2 at the 6 stations marked by stars in figure 1.

5. Conclusions.

- Comparative trend analysis (CTA) and principal component analysis (CPA) may both be used to estimate long term precipitation trends representative for any location in Norway.
- The analyses should be based upon homogeneous data, as the uncertainty of the estimate increases considerably by including inhomogeneous data.
- In Norway, the present level of annual precipitation is higher than the level around 1900. In most parts of Norway, this increase lies between 8 and 14%. There are, however, substantial differences between regions in different parts of the country regarding the period during which the precipitation has increased.
- Results from both CTA and PCA indicate that regional differences in precipitation trends and variability are connected to variations in the atmospheric circulation patterns. In order to investigate such connections closer, it will be neseccary to investigate seasonal or monthly data rather than annual.

Acknowledgments

This study was partly founded by the Norwegian Research Council through the Environmental Programme of the European Commission (Contr. EV5V-CT93-0277) and by the Nordic Environmental Research Programme NMR (Contr.FS/ULF/93001).

References

Førland, E.J., 1986: Orographic precipitation caused by high mountains. In: Dahlström, B. (ed.) *Estimation of Areal precipitation.* NHP-Report no 18, Oslo, Norway, pp 9-13.

Førland, E.J., 1993: Årsnedbør. (Annual precipitation.) *National Atlas for Norway, map 3.1.1,* Statens Kartverk, Hønefoss, Norway.

Førland, E.J. and B. Aune, 1985: Comparison of nordic methods for point precipitation correction. *Züricher Geographische Schriften,* 23 , 239-244.

Hanssen-Bauer, I. and E.J. Førland, 1994: Homogenizing long Norwegian precipitation series. *J. Climate,* Vol.7, No.6, 1001-1013.

Hanssen-Bauer, I. and E.J. Førland, 1994: Regionalization of Norwegian precipi tation series. *DNMI klima,* 13/94, 44pp.

Mills, G.F., 1995: Principal Component Analysis of Precipitation and Rainfall Regionalization in Spain. *Theor. Appl. Climatol.*, 50, 169-183.

Preisendorfer, R.W, 1988: *Principal Component Analysis in Meteorology and Oceanography,* Elsevier, 425 pp.

Tveito, O.E. and H. Hisdal: A study of regional trends in annual and seasonal precipitation and runoff series. *NVE report* 09 1994, .

APPENDIX

Some relevant information about the dataset.

Coloumn 1: Station number and name in national data archives.
Coloumn 2: Latitude (deg and min north) and longitude (deg and min east).
Coloumn 3: Period used in the present analysis.
Coloumn 4: Standard normal precipitation in the period 1961-1990.
Coloumn 5: Adjusted series? Y = yes, blank = homogeneous without adjustment.
Coloumn 6: Regional belonging according to the comparative trend analysis.
Coloumn 7: Used in principal component analysis? Y = yes,
* = not used in the analysis, but used for evaluation.

NATIONAL CODES ST. NO	NAME	LATIT N	LONGIT E	PERIOD USED IN ANALYSES	NORMAL 1961-90 (mm)	AD-JUS-TED?	CTA REG.	PCA ?
0060	GLØTVOLA	6151	1151	1896-1994	573		7M	Y
0080	TUFSINGDAL	6216	1147	1896-1990	568		7M	
0108	HVALER	5902	1102	1909-1994	740		1E	
0123	HALDEN	5907	1123	1896-1994	804		1E	Y
0165	STRØMSFOSS	5918	1139	1896-1994	884	Y	1E	
0195	ØRJE	5929	1139	1896-1994	829	Y	1E	
0345	HAGA	5932	1117	1896-1994	815	Y	1E	
0350	SVARVERUD	5932	1131	1907-1994	846	Y	1E	
0378	IGSI	5938	1102	1909-1994	829	Y	1E	
0393	TRØGSTAD	5940	1118	1909-1994	746	Y	2E	
0405	ENEBAKK	5946	1108	1896-1994	816	Y	2E	
0535	NORD-ODAL	6023	1133	1896-1994	753		2E	Y
0580	MELDALEN	6024	1221	1899-1994	720	Y	2E	
0780	ØVRE RENDAL	6154	1105	1896-1978	440	Y	7M	
0872	ATNASJØ	6153	1008	1903-1994	524	Y	7M	*
0910	FOLDAL	6208	1002	1896-1994	364	Y	7M	
1010	OS/ØSTERDAL	6231	1101	1896-1994	501		7M	
1040	RØROS	6234	1123	1896-1994	504	Y	7M	Y
1075	BREKKEBYGD	6240	1153	1896-1985	530	Y	7M	
1190	BIRI	6057	1035	1896-1994	754		2E	Y
1252	NES	6047	1057	1903-1994	528		2E	
1310	VESTRE GAUSD.	6121	0946	1896-1994	614	Y	2E	
1506	LOM	6150	0834	1896-1994	328	Y	7M	
1566	SKJÅK	6154	0810	1896-1994	316	Y	7M	Y
1725	MOSS	5926	1040	1895-1994	814	Y	2E	
1785	ÅS	5941	1047	1895-1987	785	Y	2E	
1845	MARIDALSOSET	5958	1047	1895-1994	839	Y	2E	
1850	BJØRNHOLT	6003	1041	1895-1994	1138	Y	2E	
1870	OSLO-BLINDERN	5957	1043	1895-1994	763	Y	2E	Y
2012	STUBDAL	6008	1024	1902-1986	870	Y	2E	
2052	LUNNER	6018	1034	1896-1994	790	Y	2E	
2260	LUNDE I ÅDAL	6034	1001	1895-1975	705		2E	
2284	REINLI	6050	0929	1895-1994	700		2E	Y
2295	NORD-AURDAL	6055	0925	1895-1994	622		2E	
2564	GEILO	6032	0809	1895-1994	747	Y	2E	
2624	HIÅSEN	6001	0930	1901-1994	872	Y	2E	
2730	RAMNES	5921	1014	1896-1994	1035	Y	2E	Y

APPENDIX

NATIONAL CODES ST. NO	NAME	LATIT N	LONGIT E	PERIOD USED IN ANALYSES	NORMAL 1961-90 (mm)	AD-JUS-TED?	CTA REG.	PCA ?
2780	HEDRUM	5912	0958	1895-1994	1027	Y	2E	
2892	VEGGLI	6015	0842	1896-1994	709		2E	
2960	TUNNHOVD	6028	0845	1896-1994	542	Y	2E	
3037	BESSTUL	5927	0932	1896-1994	1201	Y	2E	
3080	TINNOSET	5945	0901	1895-1985	770	Y	2E	
3278	HØIDALEN	5909	0916	1898-1994	931	Y	3E	
3290	HØYDALSMO	5930	0812	1895-1994	936	Y	2E	Y
3325	RAULAND	5942	0802	1895-1994	842		2E	
3460	DRANGEDAL	5906	0904	1896-1994	923	Y	3E	
3490	POSTMYR	5916	0846	1896-1994	1165	Y	2E	
3508	EGELANDS VERK	5849	0907	1895-1979	1230	Y	3E	
3775	FYRESDAL	5910	0802	1902-1994	900		2E	
3845	HEREFOSS	5831	0821	1896-1994	1293	Y	3E	
3860	MYKLAND	5838	0816	1896-1994	1139		3E	
3880	TOVDAL	5848	0814	1896-1994	1212		3E	Y
3922	MESTAD	5813	0753	1900-1994	1664		3E	*
4090	BJÅEN	5938	0726	1896-1994	990	Y	5W	Y
4135	BJELLAND	5822	0732	1895-1972	1575	Y	2E	
4272	BAKKE	5825	0639	1896-1994	1891		4W	
4289	SKREÅDALEN	5849	0642	1896-1994	2180	Y	5W	
4336	EGERSUND	5827	0600	1896-1994	1491		4W	*
4345	HELLELAND	5832	0609	1895-1994	1993	Y	4W	
4464	STAVANGER	5858	0544	1896-1988	1280	Y	4W	
4480	SVILAND	5849	0555	1901-1994	1829		4W	
4605	ULLA	5923	0631	1895-1994	2299		5W	
4630	SULDALSVATN	5935	0648	1895-1994	1820		5W	
4645	RØLDAL	5950	0649	1902-1994	1628		5W	
4702	NEDSTRAND	5921	0547	1895-1994	1897		4W	Y
4750	ETNE	5940	0558	1895-1994	1949	Y	5W	Y
4875	BONDHUS	6008	0617	1895-1976	2110		6W	
4925	JØSENDAL	5957	0636	1895-1973	2260	Y	6W	
4955	KINSARVIK	6022	0644	1895-1994	1320	Y	6W	Y
5025	TYSSE	6022	0545	1901-1994	2704	Y	6W	
5035	SAMNANGER	6028	0553	1901-1994	3442		6W	
5045	FANA - STEND	6016	0520	1895-1994	2041		5W	
5054	BERGEN-FL.	6023	0520	1895-1994	2260	Y	5W	Y
5147	BULKEN	6039	0613	1895-1994	1877	Y	6W	
5217	EKSINGEDAL	6048	0609	1895-1994	2463	Y	6W	
5230	MODALEN	6051	0556	1895-1980	2860		6W	
5270	MASFJORDEN	6056	0538	1900-1979	3027		6W	
5275	FRØYSET	6051	0513	1899-1994	2234		6W	*
5307	VIK I SOGN	6104	0635	1895-1994	1094	Y	6W	
5490	VETTI	6100	0700	1895-1994	899	Y	6W	
5545	JOSTEDAL	6141	0720	1895-1988	1367	Y	6W	
5555	HAFSLO	6118	0711	1895-1994	1048		6W	Y
5573	SOGNDAL	6120	0656	1895-1994	1543	Y	6W	
5578	LEIKANGER	6112	0652	1896-1989	979	Y	6W	
5632	LAVIK	6107	0532	1895-1994	2224		6W	Y
5696	HAUKEDAL	6125	0622	1895-1994	2259	Y	6W	
5711	OSLAND	6126	0513	1907-1994	3052	Y	6W	
5748	BOTNEN	6132	0603	1895-1994	2666	Y	6W	
5768	EIKEFJORD	6135	0528	1903-1994	2718	Y	6W	

APPENDIX

NATIONAL CODES ST. NO	NAME	LATIT N	LONGIT E	PERIOD USED IN ANALYSES	NORMAL 1961-90 (mm)	ADJUSTED?	CTA REG.	PCA ?
5787	DAVIK	6154	0533	1895-1970	2500		6W	
5832	MYKLEBUST	6143	0637	1895-1994	1718	Y	6W	
5848	BRIKSDAL	6142	0648	1895-1994	1372	Y	6W	
5888	SINDRE	6155	0632	1895-1994	1608		6W	Y
5896	HORNINDAL	6200	0639	1899-1994	1907	Y	8M	
6030	GEIRANGER	6205	0726	1903-1994	1351		8M	
6040	NORDDAL	6215	0714	1895-1994	965		8M	
6080	ØRSKOG	6229	0649	1898-1994	1585	Y	8M	
6155	VERMA	6221	0803	1895-1994	768		8M	Y
6310	ØKSENDAL	6241	0825	1895-1994	1196		8M	
6350	SUNNDAL	6234	0907	1895-1977	740	Y	10N	
6480	SURNADAL	6300	0900	1895-1994	1394		8M	Y
6522	HEMNE	6316	0900	1895-1994	1609	Y	10N	Y
6607	SKJENALDFOSS	6318	0945	1907-1994	1158	Y	10N	
6610	SONGLI	6320	0939	1908-1994	1483	Y	10N	
6625	HØLONDA	6307	1001	1895-1994	788	Y	9M	
6685	KVIKNE	6236	1016	1895-1994	533	Y	7M	
6833	LIEN I SELBU	6313	1106	1895-1994	833	Y	9M	Y
6842	AUNET	6303	1134	1895-1994	853	Y	9M	
6955	ØSTÅS I HEGRA	6329	1121	1895-1994	1205		9M	Y
7036	SULSTUA	6341	1201	1895-1981	950	Y	10NC	
7048	SKJÆKERFOSSEN	6350	1201	1906-1994	1316	Y	10NC	
7180	MÅMYR	6406	1031	1899-1974	2175	Y	10NC	
7210	NAMDALSEID	6415	1112	1900-1994	1320	Y	10NC	
7270	OVERHALLA	6431	1156	1896-1977	1375		10NC	
7510	LIAFOSS	6450	1157	1909-1994	1972		10NC	*
7810	DREVJA	6560	1325	1906-1994	1793		10NC	
7925	UMBUKTA FJ.	6611	1436	1895-1984	1080	Y	10NC	
7965	NORD-RANA	6626	1416	1896-1987	1530	Y	10NC	
7974	DUNDERLANDS.	6630	1454	1896-1994	1430	Y	10NC	Y
8020	LURØY	6623	1311	1923-1994	2935		10NC	
8040	NORDFJORDNES	6635	1329	1906-1973	2310	Y	11NC	
8070	GLOMFJORD	6649	1359	1916-1994	2069		11NC	
8110	BEIARN	6701	1435	1900-1978	1275		11NC	
8190	SULITJELMA	6708	1604	1905-1994	1067		11NC	
8350	KRÅKMO	6748	1559	1895-1994	1484	Y	11NC	Y
8420	SKJOMEN	6812	1734	1907-1987	700		11NC	
8445	ANKENES	6823	1725	1908-1994	862		11NC	
8685	BARKESTAD	6849	1448	1896-1994	1505		11NC	
8810	BONES I BARDU	6839	1815	1907-1994	846	Y	11NC	
8915	MOEN	6909	1837	1895-1978	745	Y	11NC	
8980	ØVERBYGD	6901	1916	1895-1994	659		11NC	Y
9045	TROMSØ	6939	1855	1867-1994	973	Y	11NC	Y
9175	NORDREISA	6944	2101	1895-1992	662	Y	11NC	
9330	SUOLOVUOPMI	6935	2331	1908-1994	456		12NI	*
9350	JOTKAJAVRE	6945	2356	1923-1994	453	Y	12NI	
9560	BØRSELV	7020	2533	1895-1984	435	Y	11NC	
9692	POLMAK	7006	2759	1895-1968	425		12NI	
9725	KARASJOK	6928	2530	1877-1994	366		12NI	Y
9840	MAKKAUR FYR	7042	3004	1924-1994	619		11NC	
9945	BJØRNSUND	6927	3004	1895-1994	454	Y	12NI	Y
9402	INARI RIUTULA	6857	2649	1909-1994	352	Y	12NI	
9502	INARI	6904	2707	1909-1994	458	Y	12NI	