DET NORSKE METEOROLOGISKE INSTITUTT

REGIONALIZATION OF NORWEGIAN PRECIPITATION SERIES

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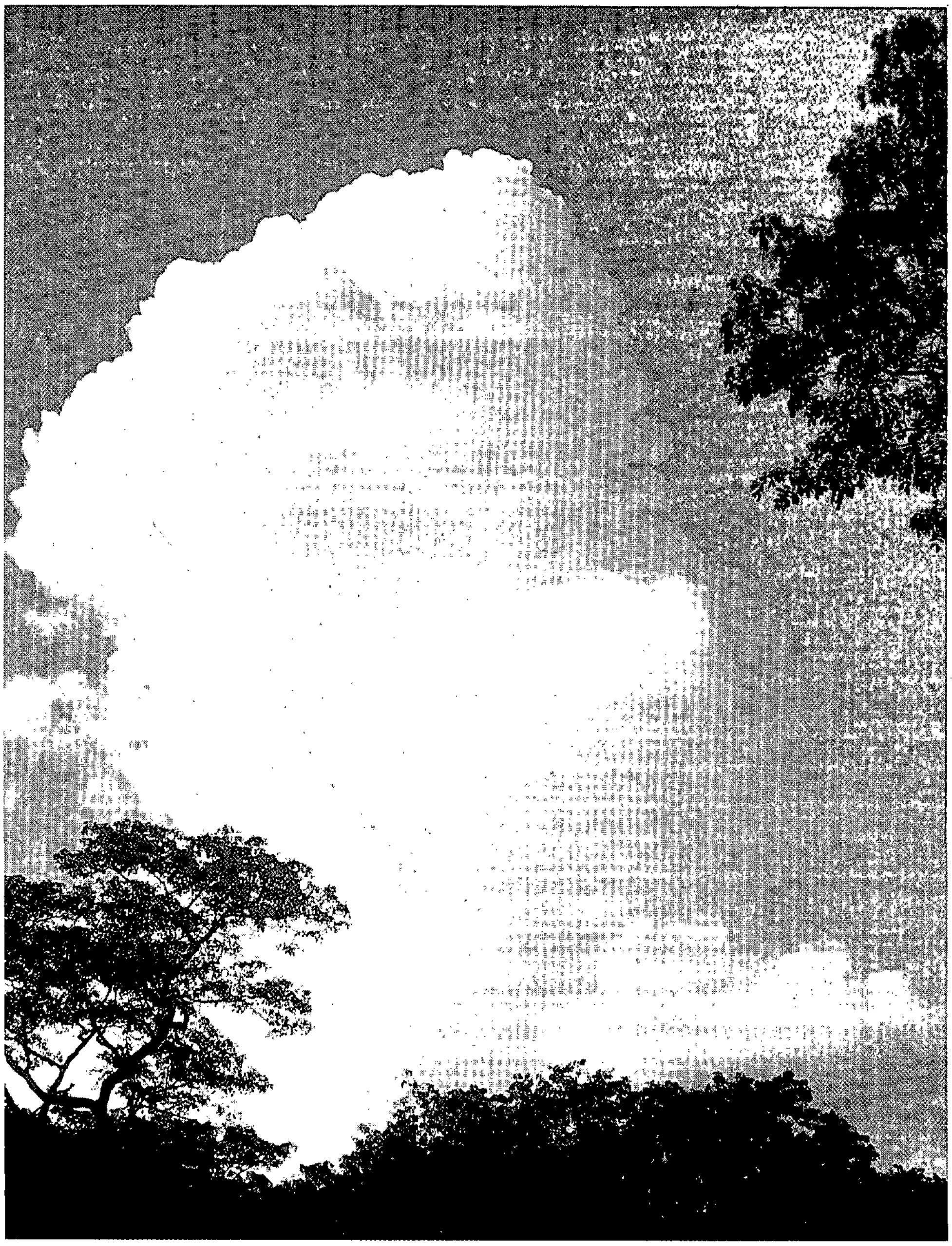

REGIONALIZATION OF NORWEGIAN PRECIPITATION SERIES

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PREFACE

The present report gives a summary of the regionalization of precipitation series which has been done under project A-176 in 1993-94. Project A-176 was executed by the Norwegian Meteorlogical Institute (DNMI) for the Norwegian Electricity Association. In addition to the grant from the Norwegian Electricity Association, DNMI's own contribution to this work has been considerable.

1. INTRODUCTION

1.1 Background.

Earlier analyses of long Norwegian precipitation series indicate that there are similarities between series from neighbouring stations, while there are substantial trend differences between series from different parts of Norway (Aune 1989, Førland et al. 1991 and 1992). In these analyses, however, no attempt was done to define exact regions for which a certain precipitation trend is valid. Nordø and Hjortnæs (1967) defined 4 precipitation regions based on precipitation as a function of pressure and temperature during the period 1931-1960. Presently, however, a high quality set of precipitation data exist for the period 1895-1990, which forms an excellent basis for a more detailed regionalization.

In the present report, homogeneous series of annual precipitation from 129 Norwegian stations were used to define regions for which the precipitation trends and variations have been similar during the period 1895-1990. The problem was approached in two ways: by correlation analysis, and by grouping together of filtered precipitation series showing similar trends. The correlation analysis is presented in chapter 2, while the comparative trend analysis is presented in chapter 3. Regional precipitation trends are presented in chapters 4 and 5. Some preliminary results from the trend analysis were published by Hanssen-Bauer and Førland (1993). The present report, however, includes the complete and final results of the analysis.

A weakness of the comparative trend analysis is that the method is subjective. As far as we know, however, this objection applies to some extent to all techniques for regionalization of time series which have been published. In addition to correlation analysis, cluster analysis and principal component analysis may be used as tools for regionalization. The analyses will nevertheless include subjective elements when it comes to draw the final borders between different regions.

As there exist no obviously superior method for regionalization, it is interesting to compare results from different analyses. The present report includes comparison of the results from the comparative trend analysis and the correlation analysis with results from an empirical orthogonal function analysis (Tveito and Hisdal 1994).

1.2 Data.

The precipitation series used in the present analysis were all homogeneity tested using the standard normal homogeneity test (Hanssen-Bauer et al. 1991). General results from these tests (Hanssen-Bauer and Førland 1994) demonstrate that inhomogeneous series may show major artificial trends, making them unsuitable for trend studies. Series with one inhomogeneity only were thus adjusted on an annual basis prior to the analysis, while series with multiple inhomogeneities were excluded. The 129 stations with acceptable series are listed in table 1, and their positions are indicated in figure 1.1. The figure shows that no acceptable series are available in the northernmost part of Norway. Irregularities at most stations in this region during the 2nd World War complicated the homogeneity testing. Consequently it is not possible at this stage to regionalize this area. In order to include the northernmost part of Norway in the analysis, it will be necessary to run homogeneity tests including series from neighbouring countries. To get a proper data coverage, it may also be necessary to adjust some series for more than one inhomogeneity.

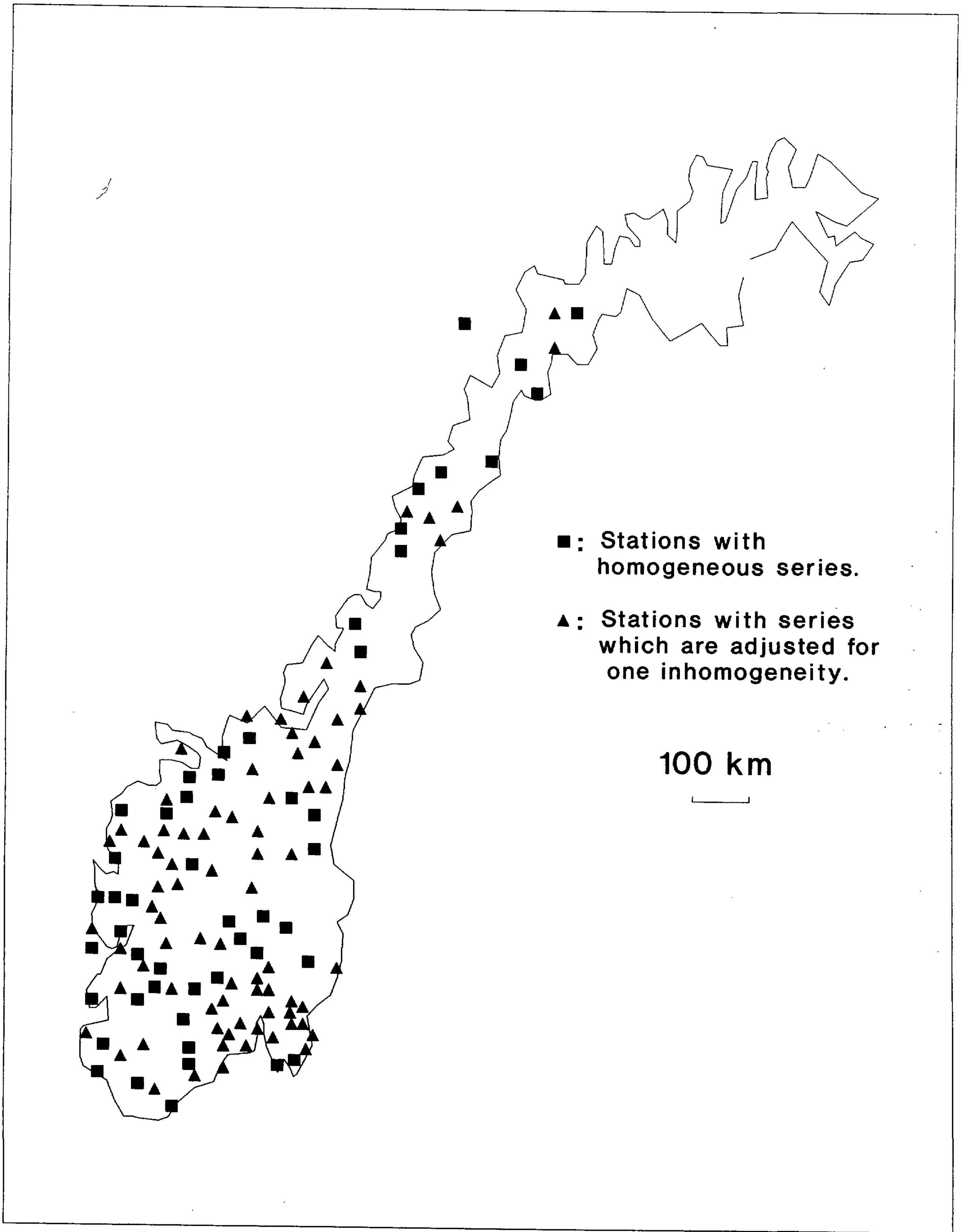


Figure 1.1. Approximate position of the 129 stations which were used in the regionalization.

TABLE 1. Precipitation stations used in the regionalization.

Column 1: Station number and name. Coloumn 2: Period investigated.
Column 3: Period of adjustment/adjustment factor for inhomogeneous series.
Column 4: Region, see fig. 3.2.

STATION	PERIOD	ADJUSTMENT		REGION	
0060 Gløtvola	1896-1993			7	M
0080 Tufsingdal	1896-1993			7	M
0108 Hvaler	1909-1993			1	E
0123 Halden	1896-1993			1	E
0165 Strømsfoss s.	1896-1993	1896-1933	1.11	1	E
0195 Ørje	1896-1993	1896-1906	0.93	1	E
0345 Haga i Eidsb.	1896-1993	1896-1975	1.09	1	E
0350 Svarverud	1907-1993	1907-1959	0.96	1	E
0378 Igsi	1909-1993	1909-1920	0.95	1	E
0393 Trøgstad	1909-1993	1909-1972	0.93	2	E
0405 Enebakk	1896-1993	1896-1926	1.06	2	E
0535 Nord-Odal	1896-1993			2	E
0580 Meldalen	1899-1993	1899-1952	1.06	2	E
0780 Øvre Rendal	1896-1978	1896-1945	0.92	7	M
0872 Atnasjø	1903-1993	1903-1922	1.07	7	M
0910 Foldal	1896-1993	1896-1907	1.13	7	M
1010 Os/Østerdal	1896-1993			7	M
1040 Røros	1896-1993	1896-1906	1.13	7	M
1075 Brekkebygd	1896-1985	1896-1916	1.22	7	M
1190 Biri	1896-1993			2	E
1252 Nes på Hedm.	1903-1993			2	E
1310 V. Gausdal	1896-1993	1896-1972	1.07	2	E
1506 Lom	1896-1993	1896-1967	1.09	7	M
1566 Skjåk	1896-1993	1896-1912	1.09	7	M
1725 Moss	1895-1993			2	E
1785 Ås	1895-1987			2	E
1845 Maridalsoset	1895-1993	1895-1934	0.95	2	E
1850 Bjørnholt	1895-1993	1895-1954	0.96	2	E
2012 Stubdal	1902-1986	1902-1951	1.06	2	E
2052 Lunner	1896-1993	1896-1912	1.18	2	E
2260 Lunde	1895-1975			2	E
2284 Reinli	1895-1993			2	E
2295 Nord-Aurdal	1895-1993			2	E
2564 Geilo	1895-1993	1895-1936	1.08	2	E
2624 Hiåsen/Sigd.	1901-1993	1901-1915	0.89	2	E
2730 Ramnes	1896-1993	1896-1914	1.10	2	E
2780 Hedrum	1895-1993	1895-1911	0.93	2	E
2892 Veggli	1896-1993			2	E
2960 Tunnhovd	1896-1993	1896-1936	1.05	2	E
3037 Besstul	1895-1993	1895-1953	1.05	2	E
3080 Tinnoset	1895-1985	1895-1972	0.94	2	E
3278 Høidalen/Sol.	1898-1993	1898-1917	0.94	3	E
3290 Høydalsmo	1895-1993	1895-1979	1.07	2	E
3325 Rauland	1895-1993			2	E
3460 Drangedal	1895-1993	1895-1901	0.90	3	E
3490 Postmyr i Dr.	1896-1993	1896-1911	1.07	2	E
3508 Egelands V.	1895-1979			3	E
3775 Fyresdal	1902-1993			2	E
3845 Herefoss	1895-1993	1895-1899	1.09	3	E
3860 Mykland	1895-1993			3	E
3880 Tovdal	1895-1993			3	E
3922 Mestad	1900-1993			3	E
4090 Bjåen	1896-1993	1896-1957	1.15	5	W
4135 Bjelland	1895-1972	1895-1965	1.09	2	E
4272 Bakke	1896-1993			4	W
4289 Skreådalen	1896-1993	1896-1932	1.12	5	W
4336 Egersund	1896-1993			4	W
4345 Helland	1895-1993			4	W
4464 Stavanger	1896-1988	1896-1949	1.11	4	W
4480 Sviland	1901-1993			4	W
4605 Ulla	1895-1993			5	W
4630 Suldalsvatn	1895-1993			5	W
4645 Røldal	1902-1993			5	W
4702 Nedstrand	1895-1993			4	W
4750 Etne	1895-1993	1895-1897	0.87	5	W

STATION	PERIOD	ADJUSTMENT		REGION	
4875 Bondhus	1895-1976			6	W
4925 Jøsendal	1895-1973	1895-1925	0.97	6	W
4955 Kinsarvik	1895-1993	1895-1970	1.05	6	W
5025 Tysse	1901-1993	1901-1917	1.08	6	W
5035 Samnanger	1901-1993			6	W
5045 Fana Stend	1895-1993			5	W
5056 Bergen-Fr.	1904-1985	1904-1906	1.13	5	W
5147 Bulken	1895-1993	1895-1982	1.06	6	W
5217 Eksingedal	1895-1993	1895-1959	1.03	6	W
5230 Modalen	1895-1980			6	W
5270 Masfjorden	1900-1979			6	W
5275 Frøyset	1895-1993			6	W
5307 Vik i Sogn	1895-1993	1895-1948	0.96	6	W
5490 Vetti	1895-1993	1895-1935	1.08	6	W
5545 Jostedal	1895-1988	1895-1973	1.07	6	W
5555 Hafslo	1895-1993			6	W
5573 Sogndal	1895-1993	1895-1923	1.06	6	W
5578 Leikanger	1896-1989	1896-1910	0.92	6	W
5632 Lavik	1895-1993			6	W
5696 Haukedal	1895-1993	1895-1932	1.03	6	W
5711 Osland v/Sf	1907-1993	1907-1931	1.10	6	W
5748 Botnen/Førde	1895-1993	1895-1930	0.93	6	W
5768 Eikefjord	1903-1993	1903-1984	1.06	6	W
5787 Davik	1895-1970			6	W
5832 Myklebust	1895-1993	1895-1982	1.08	6	W
5848 Briksdal	1895-1993	1895-1939	0.81	6	W
5888 Sindre	1895-1993			6	W
5896 Hornindal	1899-1993	1899-1975	1.04	8	M
6030 Geiranger	1903-1993			8	M
6040 Norddal	1895-1993			8	M
6080 Ørskog	1898-1993	1898-1911	0.92	8	M
6155 Verma	1895-1993			8	M
6310 Øksendal	1895-1993			8	M
6350 Sunndal	1895-1977	1895-1908	0.89	10	N
6480 Surnadal	1895-1993			8	M
6522 Hemne	1895-1993	1895-1904	1.13	10	N
6607 Skjenaldfoss.	1907-1993	1907-1969	1.05	10	N
6610 Songli	1908-1993	1908-1938	1.11	10	N
6625 Hølonda	1895-1993	1895-1931	0.93	9	M
6685 Kvikne	1895-1993	1895-1938	0.90	7	M
6833 Lien i Selbu	1895-1993	1895-1903	1.15	9	M
6842 Aunet	1895-1993	1895-1909	1.10	9	M
6955 Østås/Hegra	1895-1993			9	M
7036 Sulstua	1895-1981	1895-1929	0.91	10	N
7048 Skjækerfossen	1906-1993	1906-1935	0.96	10	N
7180 Måmyr	1899-1974	1899-1908	1.11	10	N
7210 Namdalseid	1900-1993	1900-1965	1.10	10	N
7270 Overhalla	1896-1977			10	N
7510 Liafoss	1909-1993			10	N
7810 Drevja	1906-1993			10	N
7925 Umbukta fj.	1895-1984	1895-1951	1.17	10	N
7965 Nord-Rana	1896-1987	1896-1928	0.92	10	N
7974 Dunderlandsd	1896-1993			10	N
8020 Lurøy	1923-1993			10	N
8040 Nordfjordnes	1906-1973	1906-1954	1.12	11	N
8070 Glomfjord	1916-1993			11	N
8110 Beiarn	1900-1978			12	N
8190 Sulitjelma	1905-1993			11	N
8420 Skjomen	1907-1987			12	N
8445 Ankenes	1908-1993			12	N
8685 Barkestad	1896-1993			12	N
8810 Bones/Bardu	1907-1993	1907-1946	0.93	12	N
8915 Moen	1895-1978	1895-1925	1.10	12	N
8980 Øverbygd	1895-1993			12	N

2. CORRELATION ANALYSIS

2.1 Method.

One way of regionalizing precipitation series, is to study the spatial pattern of correlation coefficients. Earlier correlation analyses (e.g. Nordø and Hjortnæs 1967) have suffered from limited datasets and a mixture of homogeneous and inhomogeneous series. In the present work, the full correlation matrix for the 129 homogeneous series of annual precipitation presented in table 1 was computed. Clusters of stations with high correlation coefficients emerged in the matrix. Four stations which belonged to different clusters, were chosen as reference stations, and their correlation coefficients with all other stations were plotted and analysed.

The importance of using homogeneous series in correlation analysis may be illustrated by comparing correlation matrixes from the homogeneous and the original dataset, respectively. An example from the present dataset shows that the correlation coefficient between the series from stations 5035 Samnanger and 5848 Briksdal, which was 0.78 for the original data, increased to 0.90 for the homogeneous series. This is probably one of the larger changes in correlation coefficient, as the Briksdal series had to be adjusted by 20% due to a relocation in 1940 (Førland et al. 1991). A more systematic investigation of the effect of inhomogeneities on correlation coefficients (Peterson and Easterling 1990), however, supports the conclusion that inhomogeneties may affect the correlation coefficients seriously.

2.2 Results from the correlation analysis.

The 4 reference stations which were used in the correlation analysis are 0535 Nord-Odal (eastern Norway), 5035 Samnanger (western Norway), 6833 Lien (mid-Norway) and 7810 Drevja (northern Norway). The spatial pattern of correlation coefficients for these stations are shown in figures 2.1 a-b and 2.2 a-b,

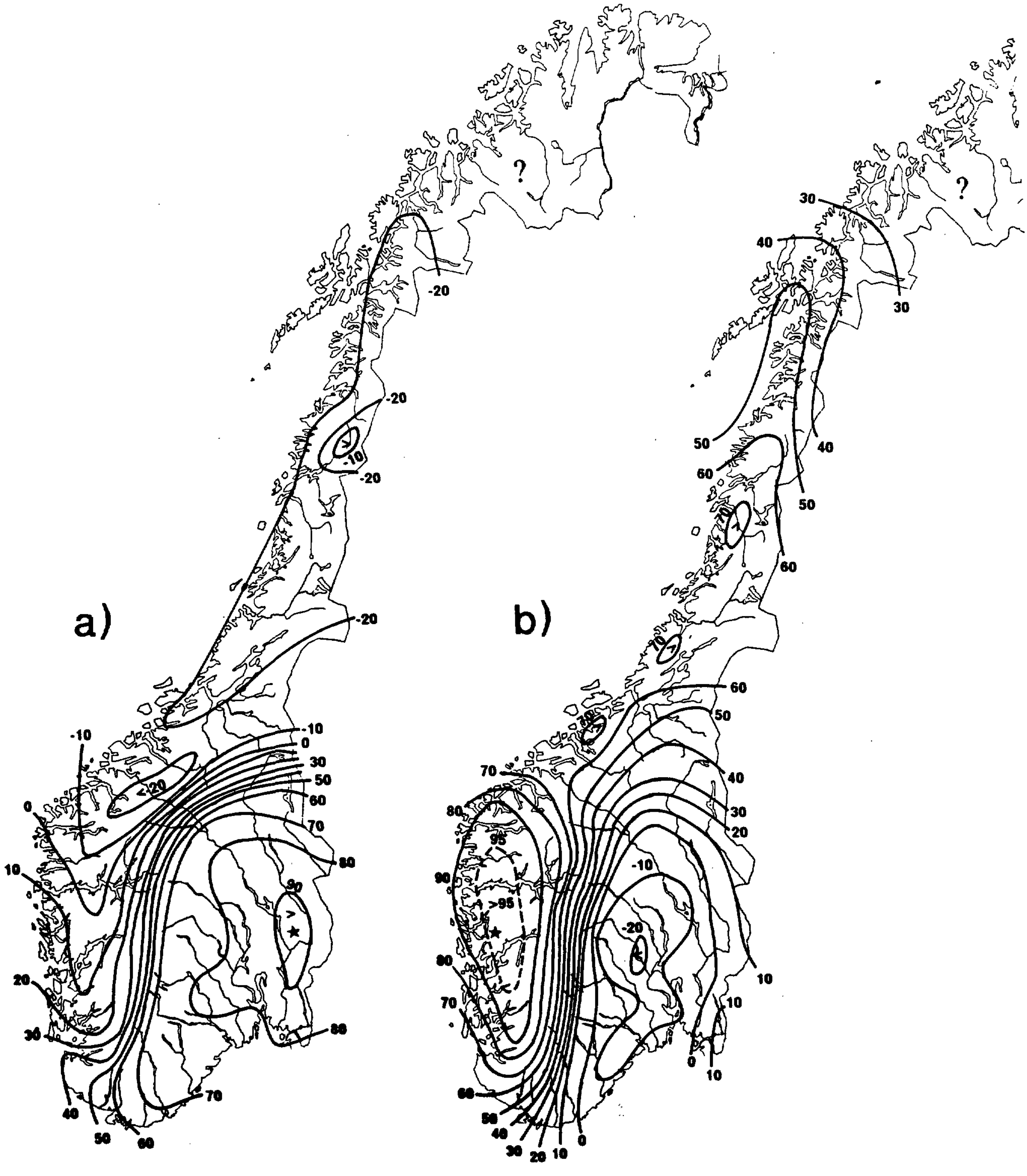


Figure 2.1. Spatial pattern of correlation coefficients for 0535 Nord-Odal (a), and 5035 Samnanger (b) based on correlation analysis of 129 homogeneous series of annual precipitation. The position of the reference station in each figure is marked with a star.

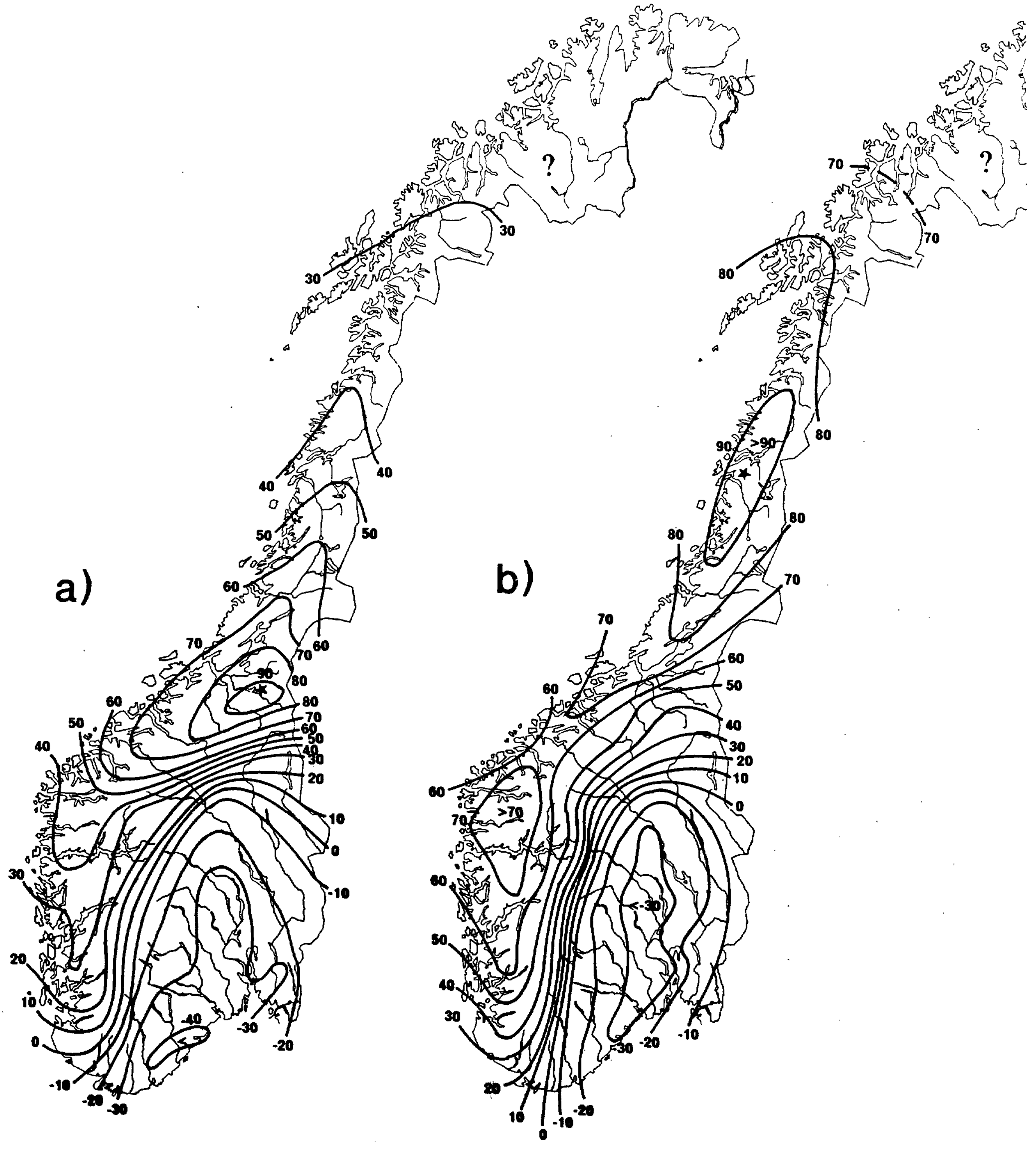


Figure 2.2. Spatial pattern of correlation coefficients for 6833 Lien i Selbu (a)and 7810 Drevja (b) based on correlation analysis of 129 homogeneous series of annual precipitation. The position of the reference station in each figure is marked with a star.

respectively. In contradiction to non-homogenized datasets, there is a smooth distribution of correlation coefficients: While there are large differences between different regions, there are good accordance between values at neighbouring stations.

The maps show that the correlation pattern is strongly influenced by the mountain divide. For the reference station in southeastern Norway (fig.2.1a), just a small area has correlation coefficients (r) exceeding 0.90, while a rather large area has r > 0.70. The same features apply to the reference station in mid-Norway (fig.2.2a). For the reference station in Western Norway (fig.2.1b), several stations have r > 0.95, and a rather large area has r > 0.90. One interesting feature is that despite large distances, there are high correlation coefficients between stations in western and northern Norway (figs. 2.1b and 2.2b).

It is also interesting to notice that for all four reference stations, there are areas with negative correlation coefficients on the opposite side of the mountain divide, i.e. there is a tendency of opposite variations in the time series of annual precipitation. The sudden drop in correlation across the mountain divide was also found by Nordø & Hjortnæs (1967), stating that "this abrupt change must be caused by the opposite orographic exposure of the stations, as the non-orographic precipitation field should have a much larger space scale". In the present study, the most pronounced differences in correlation coefficients occur for 6833 Lien i Selbu (fig. 2.2a), with r < -0.40 in an area in the southernmost part of Norway. Also for 7810 Drevja (fig.2.2b), however, a large area in southeastern Norway has correlation coefficients below -0.30.

From figures 2.1-2.2, it is possible to divide Norway coarsly into four precipitation regions (fig.2.3), where the correlation coefficient to the reference station in each region is higher than 0.60. Despite different datasets, different time periods and different approaches, the borders of the four regions in figure 2.3 are very similar to the conlusions drawn by Nordø & Hjortnæs (1967). Grouping based on correlation coefficients, however, depends on the choice of reference stations.

Figure 2.3. Precipitation regions based on the correlation analysis of 129 homogeneous series of annual precipitation. The positions of the reference stations are marked with stars.

3. COMPARATIVE TREND ANALYSIS

3.1 Standardization and filtering.

In Norway, 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 precipitation amounts, all precipitation series were standardized by dividing by their respective 1961-1990 average, i.e. the normal value PN_{61-90}. 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 station just by multiplying by the official normal values PN_{61-90} (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 curves were cut 5 years from either ends of the time series, as the ends of filtered curves are very dependent on the first or last few values, which thus may influence the trends unreasonably much.

3.2 Grouping of precipitation series by trend.

The 129 precipitation series were plotted, both as standardized annual sums and as filtered values. Series with similar precipitation variations and trends were then grouped together. This analysis was performed independently of the correlation analysis. Three examples of groups of standardized precipitation series showing similar variations are shown in figure 3.1 a-c, respectively. Filter F1 is used in this figure. The 129 precipatation series were divided into 12 groups with different patterns of precipitation variation in time, using the comparative trend method. The groups include from 3 to 29 stations. It was possible to identify each of the

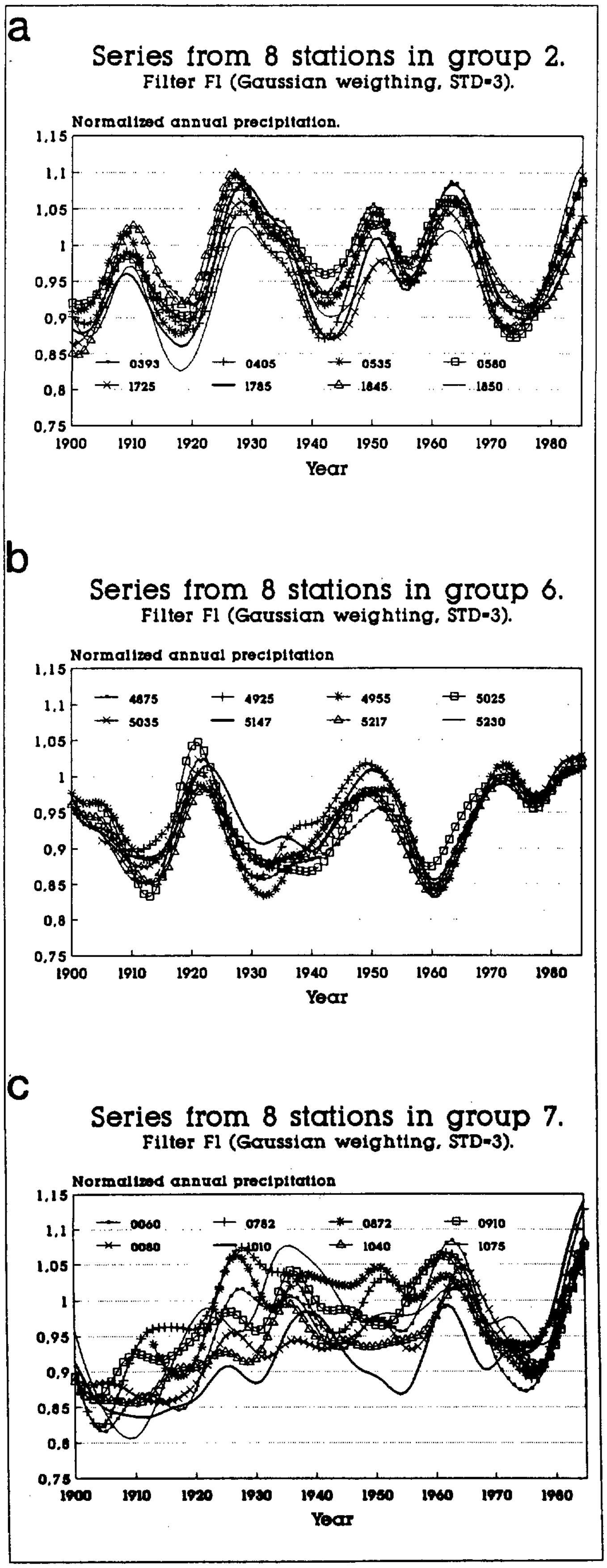


Figure 3.1. Groups of pecipitation series with similar trends.

12 groups with a geographical region. The 12 regions are shown in figure 3.2. Most regions consist of series showing a distinct variation pattern, with clearly definable local maxima and minima (e.g. figure 3.1 a and b). For such regions, it was generally easy to decide whether or not a station belonged to the region. The precipitation trend was similar from one end to another of these regions. These regions were thus defined as "precipitation trend regions". Group 7, however (figure 3.1 c), consists of series with a less distinct variation pattern, and the borders of the region were not easily definable. There also seems to be a systematic change of the trend curves from north to south and from east to west in the region. It may thus be classified as a "transitional region" rather than as a trend region.

There were still similarities between trend curves for regions within the same part of the country. This makes it possible to define groups of regions, or main regions, with certain common features (figure 3.2). The eastern group includes regions 1-3, the western includes regions 4-6 and the northern includes regions 10-12. Mid-Norway (regions 7-9) is again a transitional zone rather than a uniform group of regions.

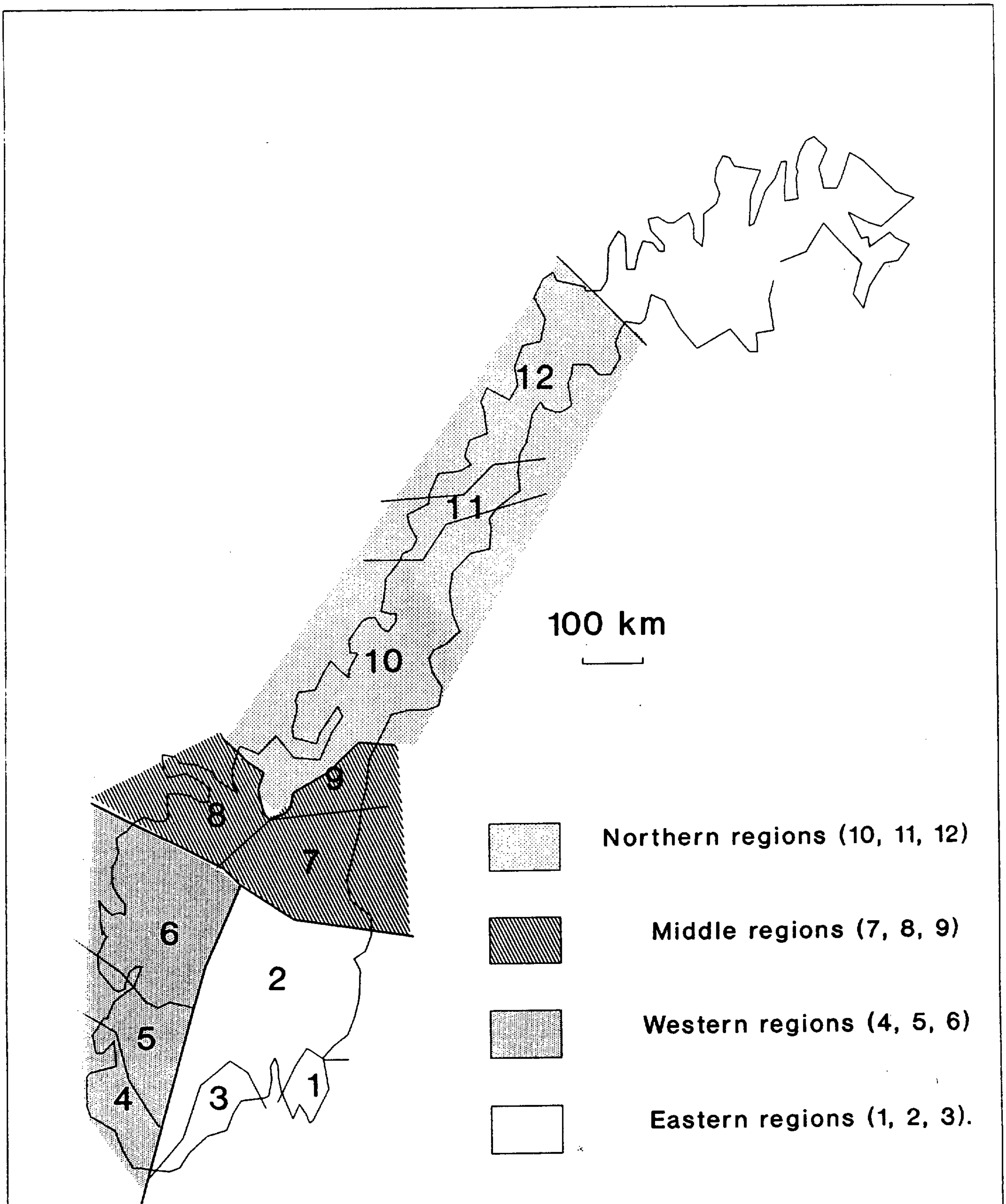


Figure 3.2. The 12 precipitation regions and the 4 main groups of regions found by using data from the 129 stations shown in figure 1.1.

3.3 Comparison of trend regions and correlation patterns.

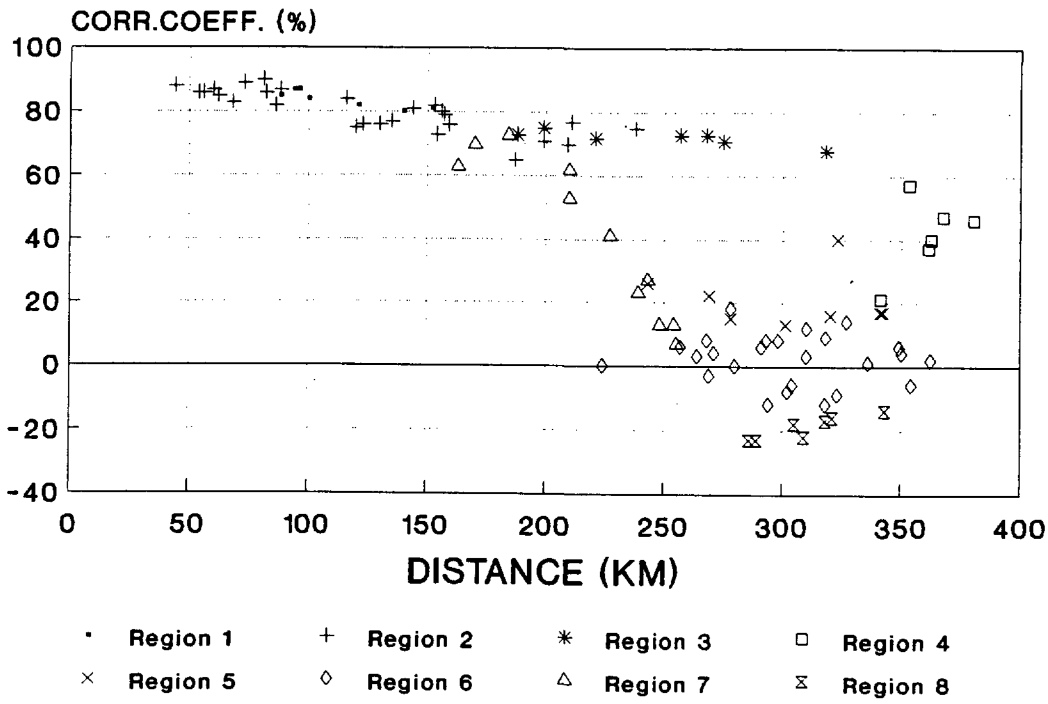
Figure 3.3 illustrates how the correlation coefficients varies with distance for precipitation series from the two reference stations, Nord-Odal (region 2) and Samnanger (region 6). Different markings are used for stations in eight of the different regions described in section 3.2.

Figure 3.3a shows that for regions 1, 2 and 3, the correlation coefficient decreases slowly with increasing distance from the reference station Nord-Odal. The correlations between the precipitation series from Nord-Odal and the stations in region 6, on the other hand, are nearly zero, and for the stations in region 8 they are even negative. Within most regions, the stations have rather uniform correlation coefficients with Nord-Odal. The main exception is the transitional region 7. The correlation coefficients between the series from Nord-Odal and the stations in this region span over a wide range, from 0.73 to 0.07.

Figure 3.3b shows that the precipitation at Samnanger is highly correlated to the precipitation at all stations in region 5 and 6. The correlation coefficients are also relatively high with the precipitation series in regions 4 and 8. For region 8, the correlation coefficient is higher than 0.60 for a station more than 300 km away. As a matter of fact, the correlation coefficient is about 0.50 even for stations more than 1000 km away, in region 12 (cf. fig.2.1b). For the stations in region 2, on the other hand, the correlation is about 0.20 even for stations less than 150 km from Samnanger. For the stations in region 2 and 3, most correlation coefficients are negative. As for Nord-Odal there is a large span in correlation coefficients (0.51 to -0.02) between Samnanger and the stations in region 7.

In section 2.3 the 12 trend regions were divided into four main groups (cf. figure 3.2). Nord-Odal belongs to the eastern group (region 1, 2 and 3). Fig. 3.4a confirms that these three regions have the highest correlation to Nord-Odal, but that a few stations in the transitional region 7 have as high correlation coefficients as some of the stations in region 2 and 3. The correlation decreases gradually

a) Reference station: 0535 NORD-ODAL



b) Reference station: 5035 SAMNANGER

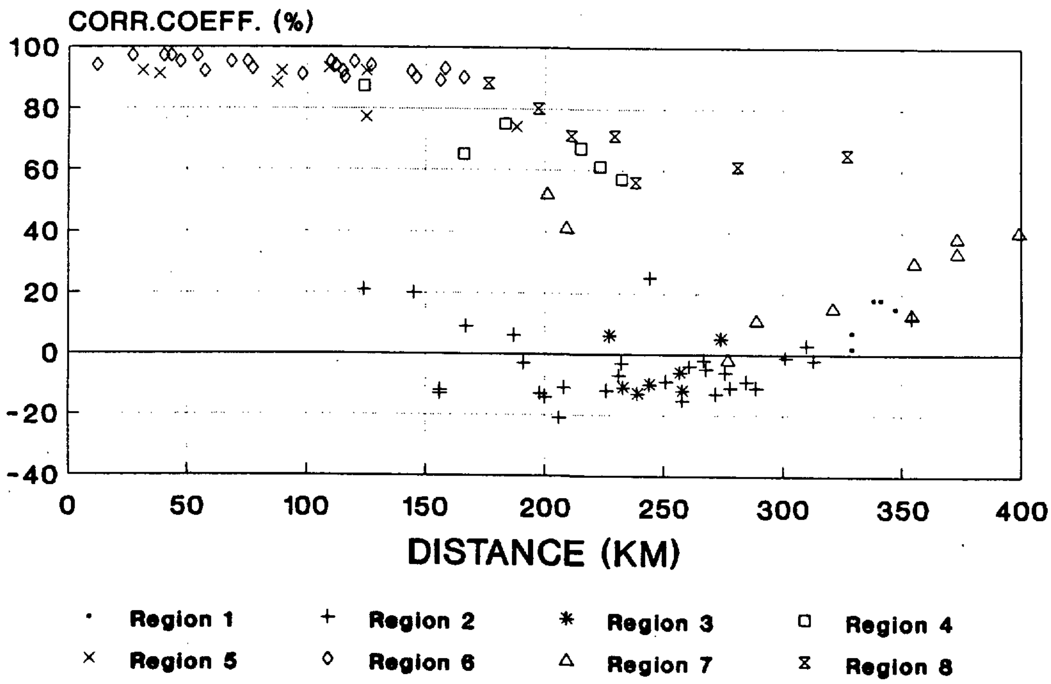


Figure 3.3. Correlation coefficient between the precipitation series from Nord-Odal (a) and Samnanger (b) and series from stations within 400 km, as a function of the distance between the stations. Different symbols are used for stations within different regions.

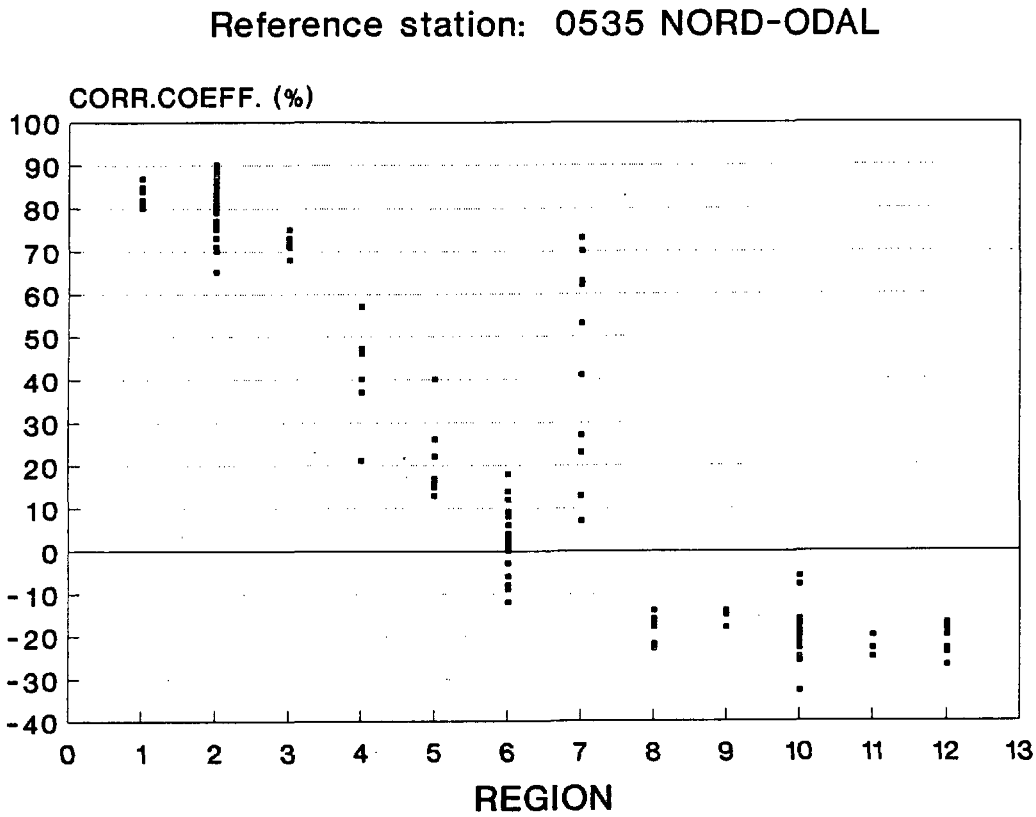
from region 4 to region 6, and for the regions 8 - 12 all correlations are negative.

Samnanger (region 6) belongs to the western group (regions 4, 5 and 6). Figure 3.4b shows that the correlation to most stations in region 5 and 6 are higher than 0.85. However, the range of correlations to the stations in region 4 is at the same level as for region 8. In this respect region 8 might have been included in the western group. The filtered annual time series for regions 4 and 8 are, however, quite different, and these two regions should therefore not be included in the same group. Figure 3.4b also shows that the precipitation at Samnanger is faily well correlated to the precipitation in region 9-12, while it is negatively correlated to most stations in regions 2 and 3. For regions 2 and 7, there is a large span in correlation coefficients.

One may conclude that the 4 main groups resulting from the comparative trend analysis, generally are supported by the results from the correlation analysis. The main difference is that the mid-Norway group defined by the comparative trend analysis is fairly large (figure 3.2), while correlation analysis alone would have given a smaller mid-Norway area (figure 2.3). Mid-Norway defined by the correlation analysis is, however, very dependent on the choice of reference station, as the correlation coefficients decreases rapidly with distance in this area (cf. figure 2.2a). The mid-Norway group resulting from the comparative trend analysis, on the other hand, is a transitional zone which consists of the remainder of the series after putting together the more uniform groups. The definition of this group is consequently less dependent on the precipitation variation at a single station.

Regarding the division of Norway into 12 regions, one may conclude that the results from the correlation analysis does not contradict this regionalization. It would, however, be difficult to identify different trend regions within the same part of the country using correlation coefficients alone. This is probably because the precipitation trends usually are small relatively to the year-to-year variability in the precipitation. Correlation analysis is thus unsuitable for distinguishing between areas of slightly different trends.

a)



b)

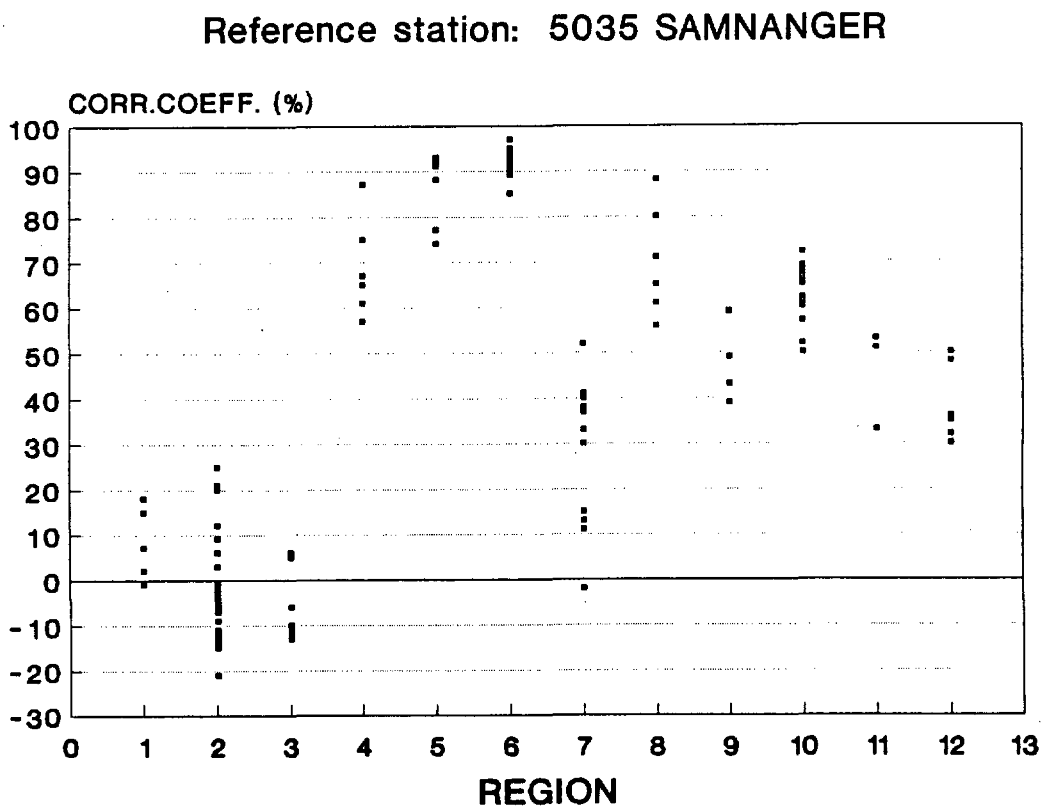


Figure 3.4. Correlation coefficient between the precipitation series from Nord-Odal (a) and Samnanger (b) and series from stations within different regions.

3.4 Trend regions and correlation regions contra EOF analysis.

Figure 3.5 shows regional grouping based on the first 2 weight coefficients resulting from an EOF analysis of runoff data for the period 1930-90 (Tveito and Hisdal 1994). The authors, who analysed both precipitation and runoff data, concluded that annual series of these data show very similar geographical variation. The regions in figure 3.5b may therefore be compared to precipitation regions.

Five regions were identified in figure 3.5. This rather coarse regionalization is thus comparable to the 4 correlation regions in figure 2.3, and to the 4 main trend regions in figure 3.2. The main difference between these regionalizations is that figure 3.5 shows a transitional region between east and west (region 2), which includes the inland parts of the western main region resulting from the present analysis, as well as parts of the mid-Norway group. The results from the comparative trend analysis do not support the definition of such a region, even when using the more detailed 12 region classification. The reason for this discrepancy is not known.

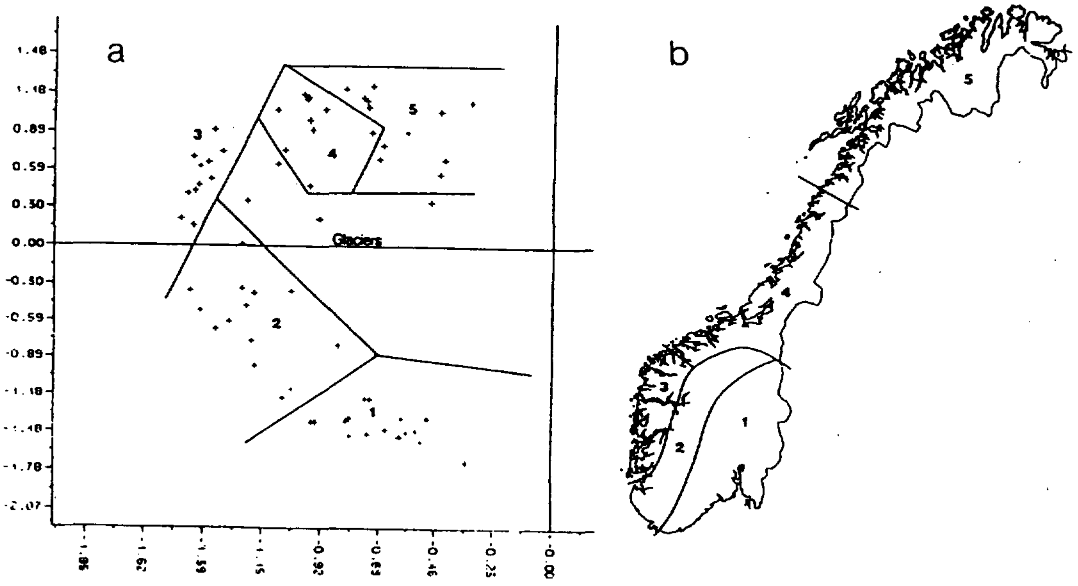


Figure 3.5 Regional grouping based on the first two weight coefficients of runoff. (Figure 4.4 in Tveito and Hisdal, 1994). a) Scatterplot. b) Resulting regions.

4. TRENDS IN ANNUAL PRECIPITATION

4.1 Calculation of regional precipitation curves.

For each region, the standardized precipitation curve was defined as the average of the standardized precipitation curves from all stations within the region. Regional series of single values as well as regional filtered series may be calculated in this way. In the present report, however, only filtered series will be presented. Figures 4.1 and 4.2 a-f show regional F1 curves of annual precipitation for the 12 regions defined in section 3.2, respectively. These curves show typical regional variations on a 10 year time scale. Figures 4.3 and 4.4 show the F2 curves of annual precipitation for the same regions. These show the regional precipitation trends on a 30-year time scale. Series of standard deviations between the individual curves within the regions were also calculated, in order to get a measure for the significance of regional precipitation variations relatively to the interregional variations. In figures 4.1-4.4, the regional curves are plotted +/- one standard deviation. The numbers of stations in each region are given in the figures. Jumps in the trend curve and the standard deviation may occure when one or more of the series in the region starts or ends within the investigated period (cf. figure 4.2a and 4.4a 1907-1908).

Using figures 4.1-4.4, the precipitation curve for any point within the defined regions may now 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 1993b). The standard deviations give a measure for the uncertaincy of the estimate.

4.2 Trends in the 12 precipitation regions.

Figures 4.1 a-c show F1 precipitation curves for the 3 regions in eastern Norway. They all have their local maxima and minima more or less simultanously. This is the reason for grouping them together in an eastern group.

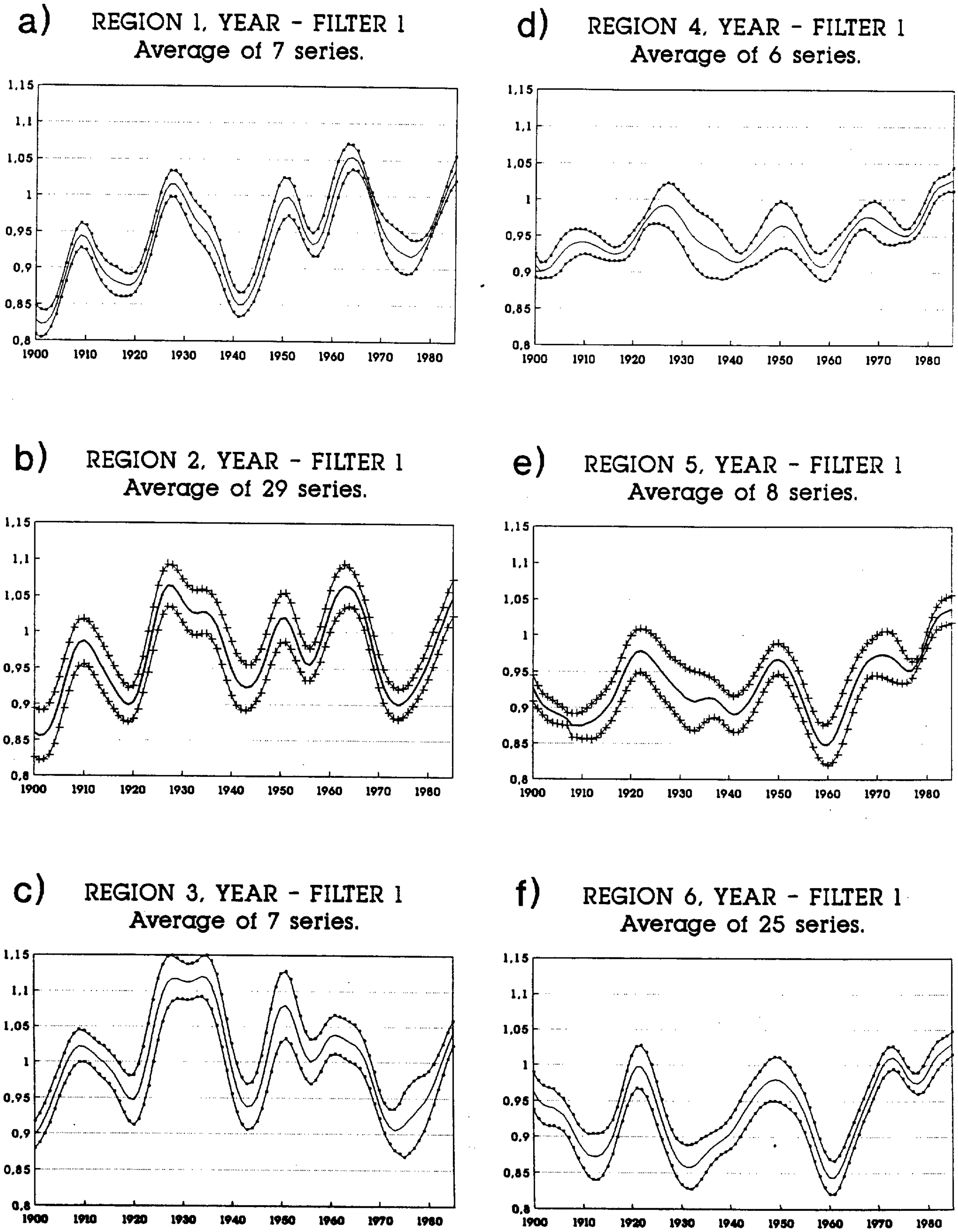


Figure 4.1. Averages and standard deviations of the standardized F1 precipitation curves from stations within regions 1 (a), 2 (b), 3 (c), 4 (d), 5 (e) and 6 (f).

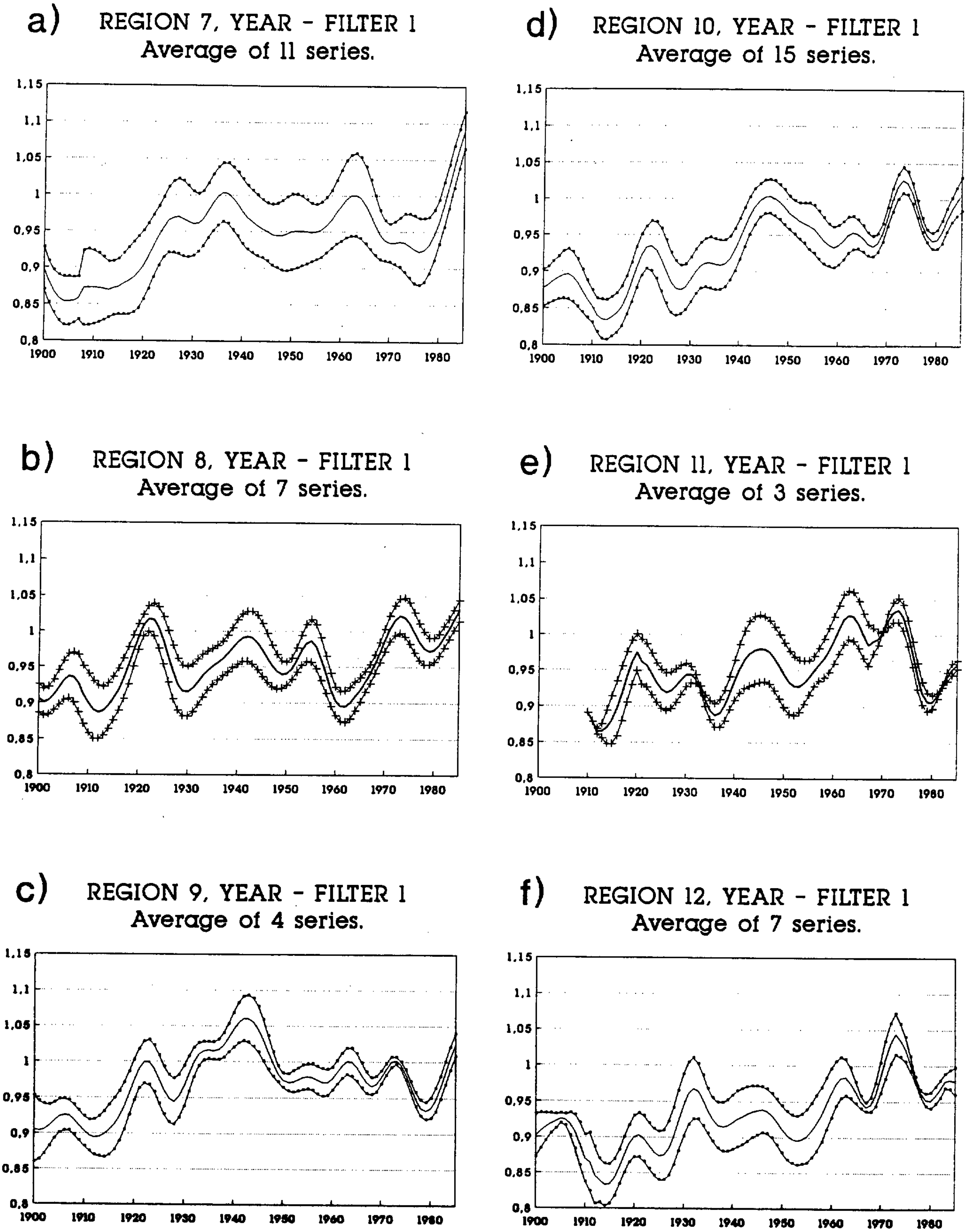


Figure 4.2. Averages and standard deviations of the standardized F1 precipitation curves from stations within regions 7 (a), 8 (b), 9 (c), 10 (d), 11 (e) and 12 (f).

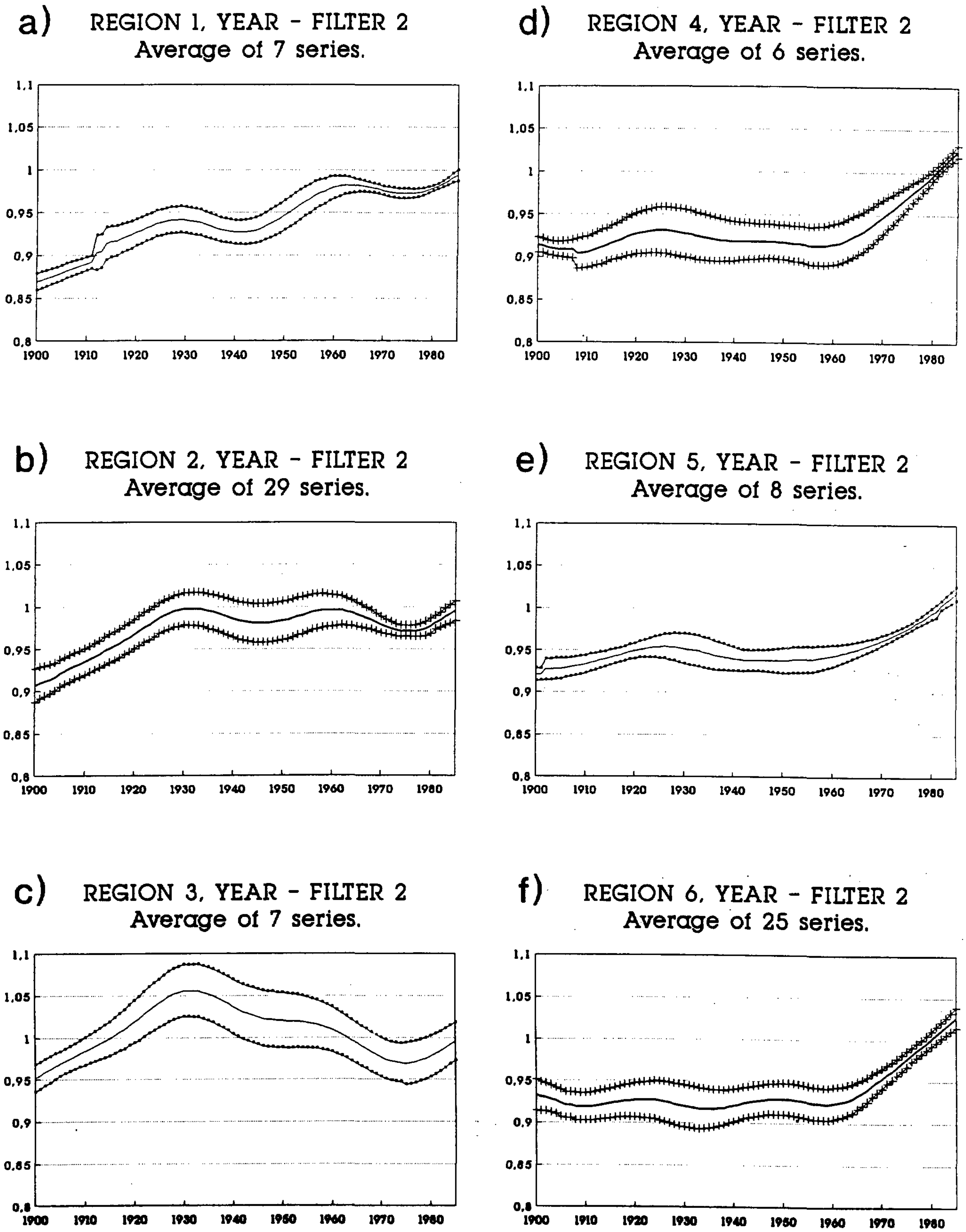


Figure 4.3. Averages and standard deviations of the standardized F2 precipitation curves from stations within regions 1 (a), 2 (b), 3 (c), 4 (d), 5 (e) and 6 (f).

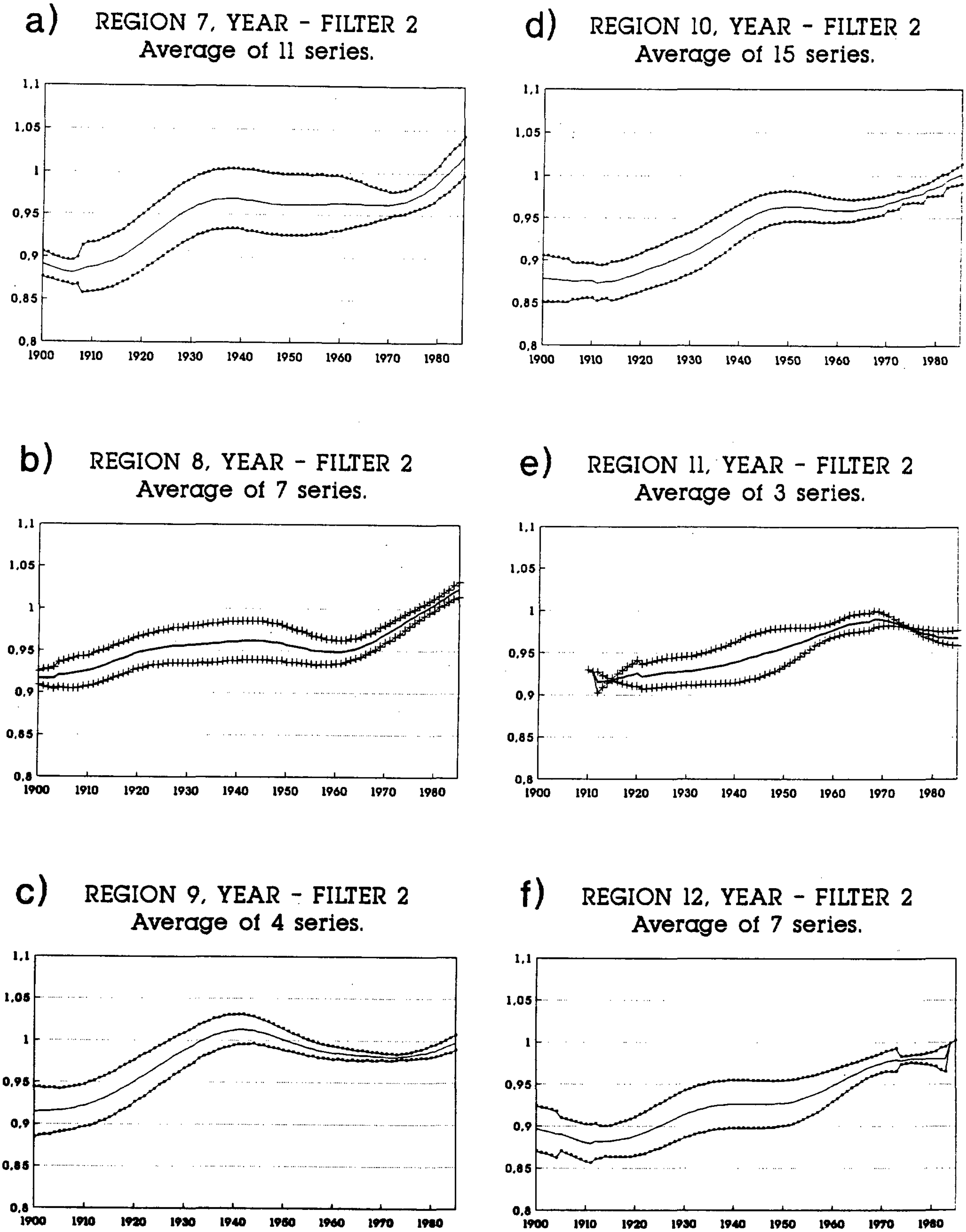


Figure 4.4. **Averages and standard deviations of the standardized F2 precipitation curves from stations within regions 7 (a), 8 (b), 9 (c), 10 (d), 11 (e) and 12 (f).**

There are, however, differences between the regions concerning the relative sizes of these extrema. 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 for the regions (figures 4.3 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.

Figures 4.1 d-e 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 extrema occur simultanously in all the western regions. For the western regions, the F2 curves (figures 4.3 d-e) 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.

Figures 4.2 d-e show F1 curves for the 3 regions in northern Norway. The variations on the 10-year time scale have smaller amplitudes in these regions than in most eastern and western regions. Again, however, many of the local extrema occur simultanously in all northern regions. The long term precipitation trends for the northern regions are described by the F2 series in figures 4.4 d-e. The precipitation level was increasing during most of the period in these regions.

The F1 precipitation series for the 3 regions in mid-Norway are shown in figures 4.2 a-c. There are clear differences between these regions. Region 7 shows some similarities with the eastern regions, while region 8 shows several "western" features, and region 9 shows some of the "northern" features. However, there are some similarities between the long term trends (figures 4.4 a-c). There was a tendency for increasing precipitation in the first and/or last decades, while the precipitation level was relatively stable during 1930-1970.

For most of the regional F1 curves, the standard deviations are within +/-3% most of the time. For the F2 curves, the standard deviations are usually within +/-2%. Precipitation trend curves for most places in Norway (except Troms and Finnmark) may thus be estimated with reasonable accuracy. Note, however, that the uncertaincy will be somewhat larger for areas within the transitional zone 7.

4.3 Trends in the 4 main regions.

Trend curves for the 4 main regions were calculated in order to give a survey of the precipitation trends on a larger scale. F1 and F2 curves are presented in figures 4.5 and 4.6, respectively.

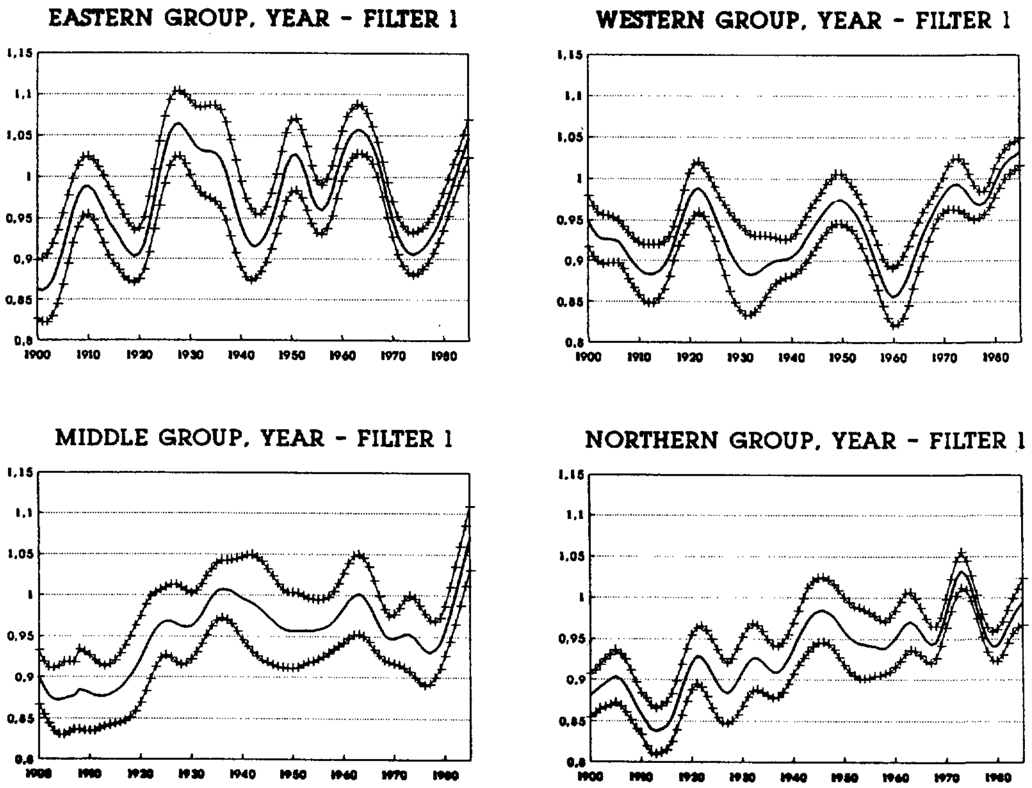


Figure 4.5. **Averages and standard deviations of the standardized F1 precipitation curves within the different geographical groups.**

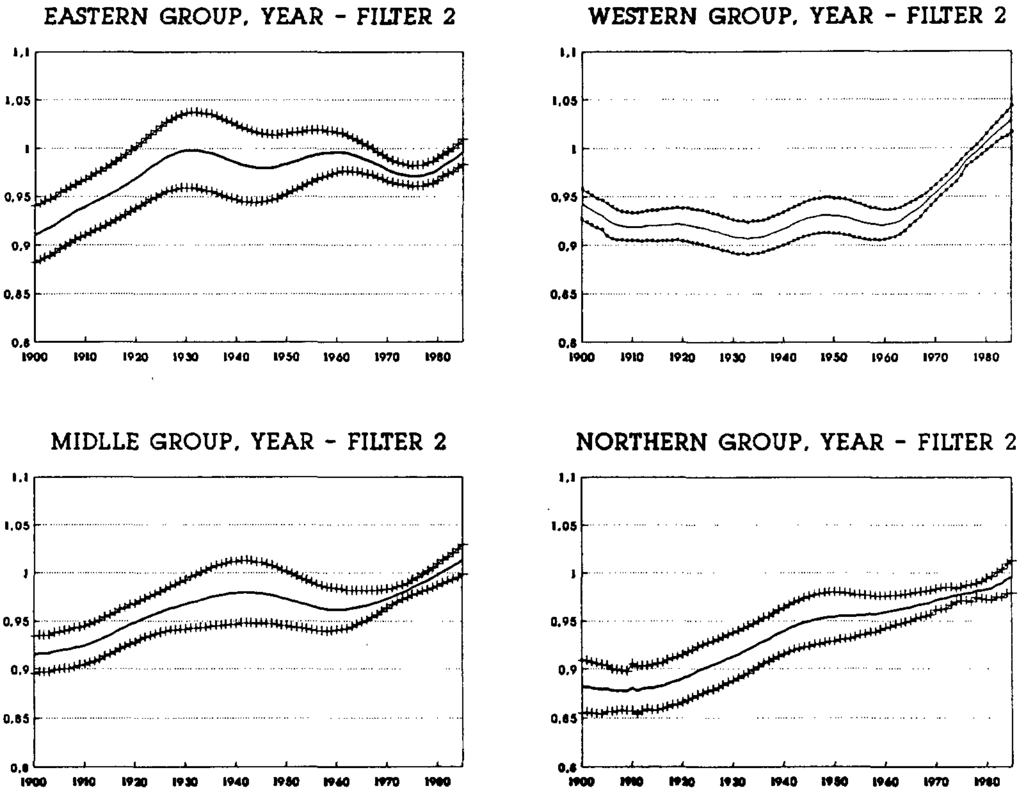


Figure 4.6. Averages and standard deviations of the standardized F2 precipitation curves within the different geographical groups.

F2 for the eastern group (E) shows increasing precipitation trend (+8%) from 1900 to 1930, while the precipitation level has been relatively stable after 1930. F1 shows that the variations about this level have been considerable (+/- 7%).

F2 for the western group (W) show a relatively constant precipitation level from 1900 to the middle of the 1960s, after which there has been an increasing trend (+10%). The short-term trend curve F1 for group W shows variations of +/- 5% around the long term trend F2.

The short term precipitation trend curves for the E and W groups are definitely not in phase. "Wet periods" in western Norway were frequently coupled to "dry periods" in eastern Norway and vice versa. This is probably caused by the orographic effects of the central mountain areas of southern Norway. For westerly and easterly winds, these effects are opposite for the eastern and western parts of the country. The short term trends in eastern and western Norway are, however, not systematically in antiphase. Around 1950, both eastern and western Norway were relatively "wet". It might be interesting to couple these results to an analysis of dominating circulation patterns during "dry" and "wet" periods in different parts of the country.

Filter F2 for the middle group (M) shows increasing precipitation trend up to the 1930's (+7%), followed by a relatively stable precipitation level. This is in accordance with the group E trend curve. There is, however, also an increasing trend towards the end of the series (+5%), which resembles the group W trend curve. Filter F1 for group M illustrate that the short time variations are less distinct within this group than in the eastern and western groups. The standard deviations for the F1 curve in group M are larger than the 10-year scale time variations, implying that these variations are not significant for the group. This is partly caused by the differences between the individual regional curves within the group. The reduced significance in the 10-year scale variations in middle Norway is, however, also a feature which to some extent is found in single curves (cf. figure 3.1, group 7). The reason is probably that many stations in group M (especially in region 7) lacks effective shelter against precipitation from any direction. The precipitation pattern in this group is therefore, to a smaller degree than the patterns in the eastern and western groups, dependent on changes in frequencies of different wind directions.

Filter F2 for the northern group (N) show an increasing precipitation trend from 1910 to the end of the series (+12%). Filter F1 shows that the short time variations are less distinct than in western and eastern Norway.

4.4 Trends in annual precipitation in Norway.

For all regions and for all groups of regions the F2 curves show that the precipitation level in the beginning of the series was lower than the level in the end. In region 3 the difference was less than 5%, as there was a decreasing trend from the 1930's to the 1970's. For region 11 there were no available high quality data in the beginning of the century. For the other regions, the precipitation levels around 1985 were 8-13% higher than the levels around 1900. The precipitation trends during 1900 - 1985 for different parts of the country show, nevertheless, clear differences. In eastern Norway the increase in the annual precipitation level occured mainly before 1930, in western Norway it occured mainly afterd 1960, while the increase in northern Norway has been more evenly distributed throughout the last 75 years. It is thus not advisable to calculate a common precipitation trend curve for Norway.

5. TRENDS IN SEASONAL PRECIPITATION

5.1 Quality of seasonal curves.

In the following sections, series of precipitation sums for seasons of 3 months duration are used to define seasonal trends for different parts of Norway. It should be emphasized that the homogeneity testing and the adjustments for inhomogeneities which were done prior to the present analysis were executed on an annual basis. As all the most common changes which have occured at the precipitation stations are more likely to affect snow measurements than rain measurements (Førland and Aune 1985), series from the snow seasons are probably less reliable than series from the other seasons. One might try to rise the quality of the winter series by running the homogeneity test on seasonal precipitation series. Experiments so far, however, indicates that winter testing does not improve detection of inhomogeneities. The inhomogeneities are probably larger during the winter than during the other seasons, but a similar increase in the general "noise level" for winter measurements prevents detections of inhomogeneities.

5.2 Trends in regional spring precipitation.

Figure 5.1 a-d shows the average F1 curves of standardized spring precipitation (March-April-May) for stations within the four regional groups E, W, M and N, respectively. Figure 5.2 a-d shows the similar F2 curves.

In eastern Norway (group E), the spring precipitation was generally decreasing until the 1940s. Around 1900, the spring precipitation level was slightly higher than the 1961-90 spring precipitation average. Around 1945, however, the level was about 25% lower. From the 1940s to present, the trend has been increasing, and the level of the spring precipitation is today similar to the level around 1900.

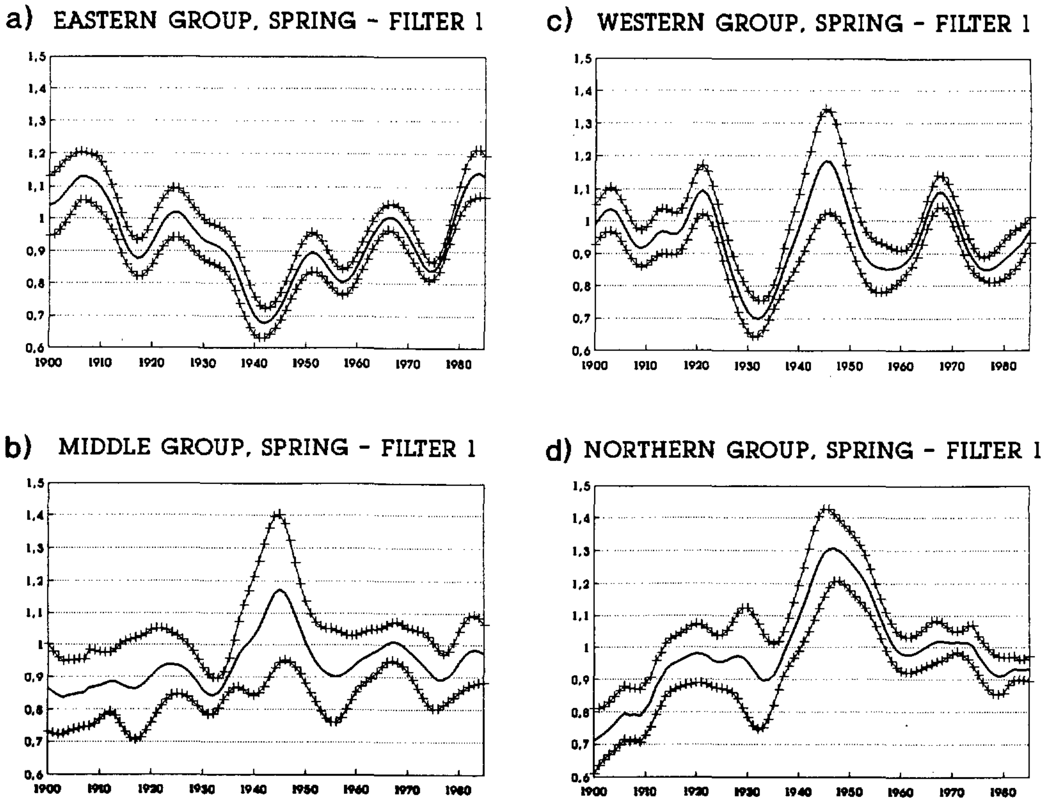


Figure 5.1 Averages and standard deviations of the standardized F1 spring precipitation curves within the 4 main regions.

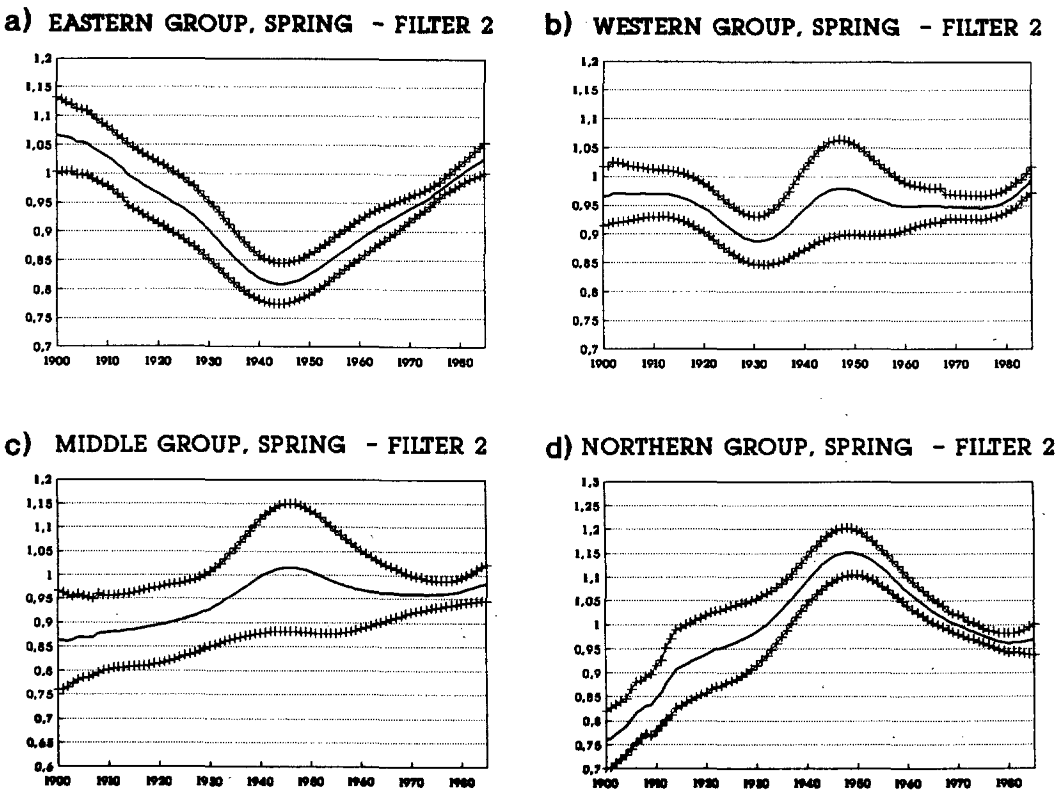


Figure 5.2 Averages and standard deviations of the standardized F2 spring precipitation curves within the 4 main regions.

In northern Norway (group N), the spring precipitation increased from a level 25% below the 1961-90 average around 1900, to a level 15-20% above this average in 1950. The trend has decreased after 1950, but the spring precipitation level is still about 20% above the 1900 level.

The tendency for opposite trends in the spring precipitation in south-eastern and northern parts of the country might be explained by a tendency for weakesr meridional and stronger longitudinal circulation in the spring than during the rest of the year. The central mountains would then make a barriere north-south rather than east-west. To investigate this, however, one should accomplish a detailed study of the connection between precipitation and circulation patterns in different part of the country, and for different seasons.

The avaraged curve for spring precipitation in western Norway shows variations around a more stable level. The standard deviations are large in the period 1940-1960. This is mainly caused by differences in spring precipitation between region 4 and the other western regions. The spring precipitation pattern in group 4 shows several similarities with the pattern in the eastern region. In regions 5 and 6, on the other hand, the spring precipitation was at minimum around 1930 and at maximum in 1945-1950. The present level of spring precipitation in western Norway is similar to the level around 1900.

The large standard deviations of the spring precipitation in the middle group are also mainly caused by inter regional differences. Regions 8 and 9 show the same pattern as the northern groups, while group 7 shows variations around a more stable level.

5.3 Trends in regional summer precipitation.

Figure 5.3 a-d shows the average F1 curves of standardized summer precipitation (June-July-August) for stations within the eastern, western, middle and northern groups, respectively. Figure 5.4 a-d shows the similar F2 curves. For summer precipitation the trend differences between different parts of the country (especially the eastern, western and middle) are not as pronounced as for the other seasons. The covariation between neighbouring stations, however, is relatively poor during summer. Cosequently, the standard deviations of the trend curves for regions and groups are relatively large. The reason for this is probably that much of the summer precipitation is connected to showers, while frontal precipitation is the more frequent in the other seasons.

In eastern Norway, there was a slightly increasing trend in the summer precipitation from 1900 to the 1950's. Totally, the level of the summer precipitation increased by about 10% during this period. From the 1950's to the 1970's, the level of the summer precipitation decreased by ca. 15%. After the 1970's, the trend in summer precipitation in eastern regions has been increasing, and the present level of summer precipitation is similar to the level around 1900.

Also in western and middle Norway, the trend in summer precipitation was increasing in the first decades of the 1900's. The increase was faster in these areas. However, it lasted only to about 1930, and the total increase was about 10% also in these regions. It was followed by 3 decades with relatively constant, or slightly decreasing, level of the summer precipitation. From 1960 to the 1970's, the trend was decreasing, while it has been slightly increasing from 1980. The present level of summer precipitation in these areas is about 5% above the level around 1900.

In northern Norway, the trend in summer precipitation has been increasing slightly during most of the 1900's. The standard deviation of this group is, however, large. This is mainly caused by variations within region 10, and between this region and regions 11 and 12. In regions 11 and 12, the level of summer precipitation increased with 15-20% from 1910 to 1970. From 1970 up to present, there has been a 5% decrease. In region 10, however, there was a 5-10% increase in the period 1900-1930, whereafter the summer precipitation level has been constant.

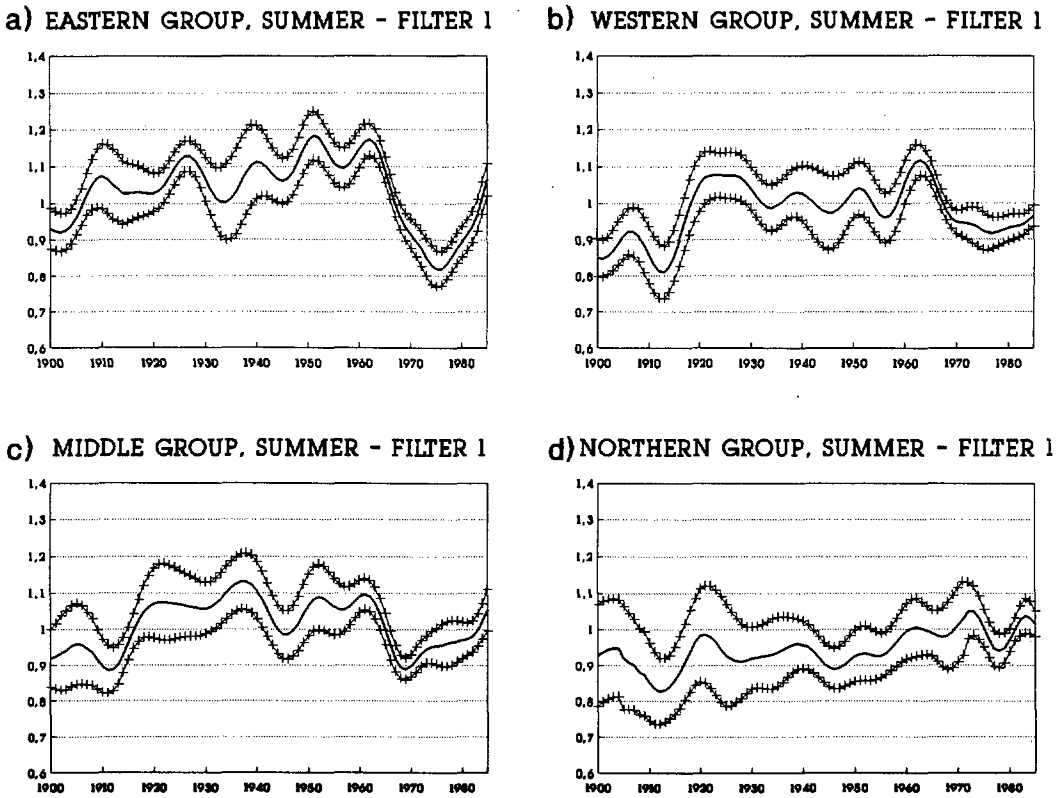


Figure 5.3 Averages and standard deviations of the standardized F1 summer precipitation curves within the 4 main regions.

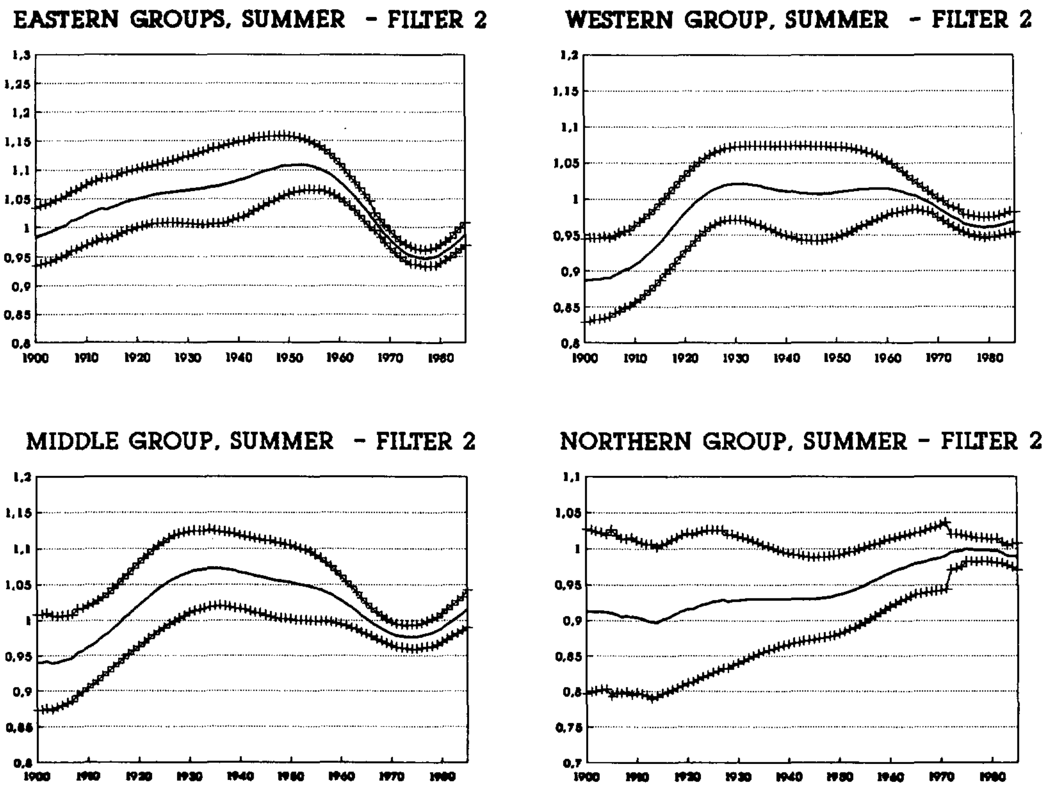


Figure 5.4 Averages and standard deviations of the standardized F2 summer precipitation curves within the 4 main regions.

5.4 Trends in regional fall precipitation.

Figure 5.5 a-d shows the average F1 curves of standardized fall precipitation (September-October-November) for stations within the eastern, western, middle and northern groups, respectively. Figure 5.6 a-d shows the similar F2 curves. For fall precipitation the standard deviations are small for all groups. This indicates that the differences between precipitation pattern at different stations within the groups are small.

In eastern Norway, the present level of fall precipitation is almost 25% above the level around 1900. The major part of this increase took place before 1930. Figure 5.5 a indicates an abrupt increase in the level of fall precipitation in the 1920's. Also in the western regions, there has been a 25% increase in fall precipitation from 1900 to present. However, most of this increase took place after 1960. In the northern regions, the increase in fall precipitation has been smaller (~10%). The increase in these regions took place in the period from 1940 to present. In middle Norway, the present fall precipitation level is ~15% above the 1900 level. Most of the increase took place after 1950.

5.5 Trends in regional winter precipitation.

Figure 5.7 a-d shows the average F1 curves of standardized winter precipitation (December-January-February) for stations within the eastern, western, middle and northern groups, respectively. Figure 5.8 a-d shows the similar F2 curves. For winter precipitation the standard deviations are relatively large for all groups. This is partly caused by the problems connected to measurements of snow precipitation mentioned in section 3.1.

In eastern Norway, there was a 15-20% increase in the level of winter precipitation from 1900 to the 1930's. This was followed by 5 decades with decreasing winter precipitation. Presently, the winter precipitation is about 5% above the 1900 level.

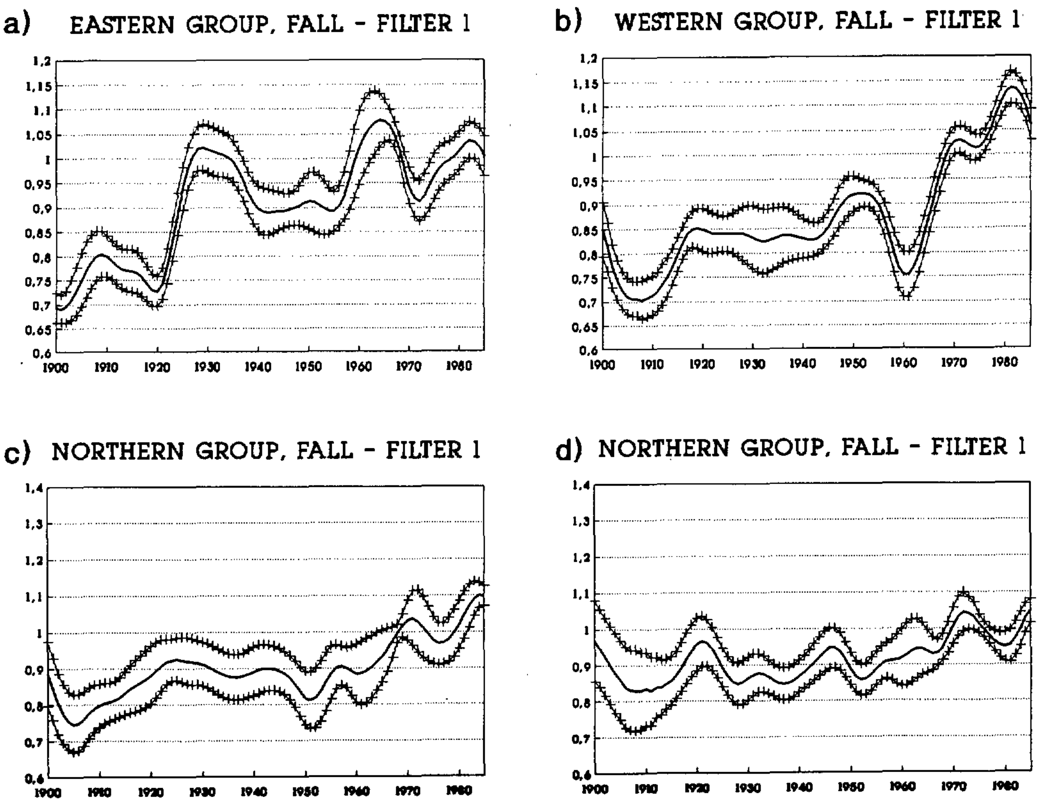


Figure 5.5 Averages and standard deviations of the standardized F1 fall precipitation curves within the 4 main regions.

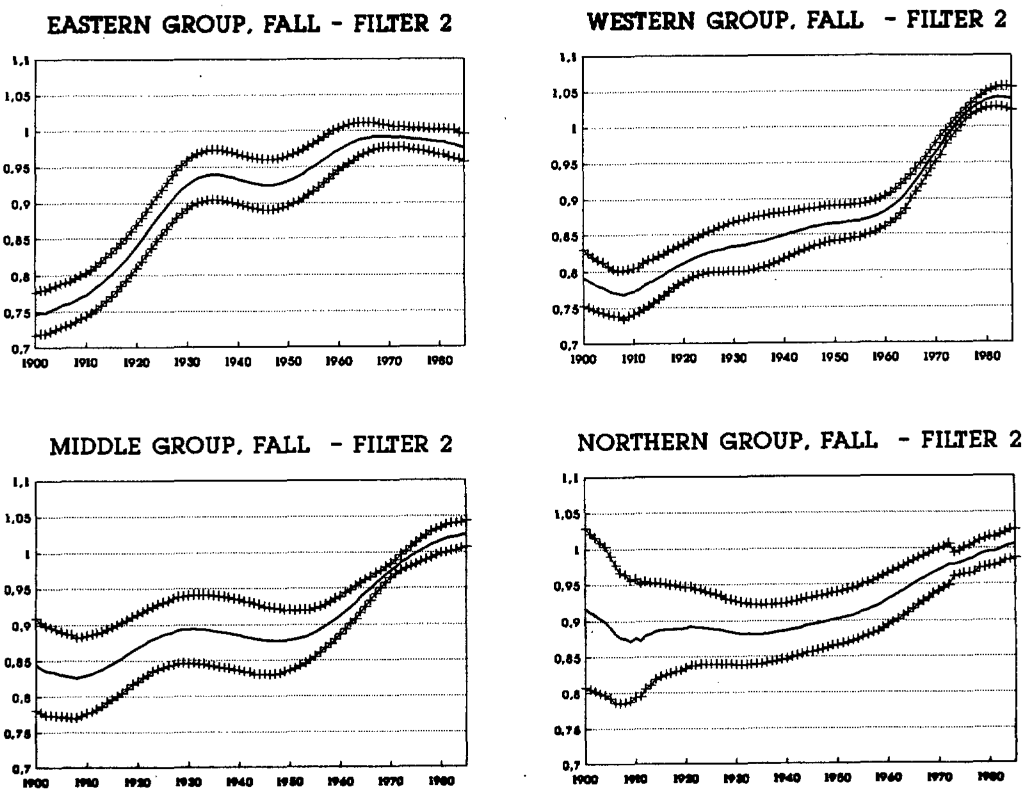


Figure 5.6 Averages and standard deviations of the standardized F2 fall precipitation curves within the 4 main regions.

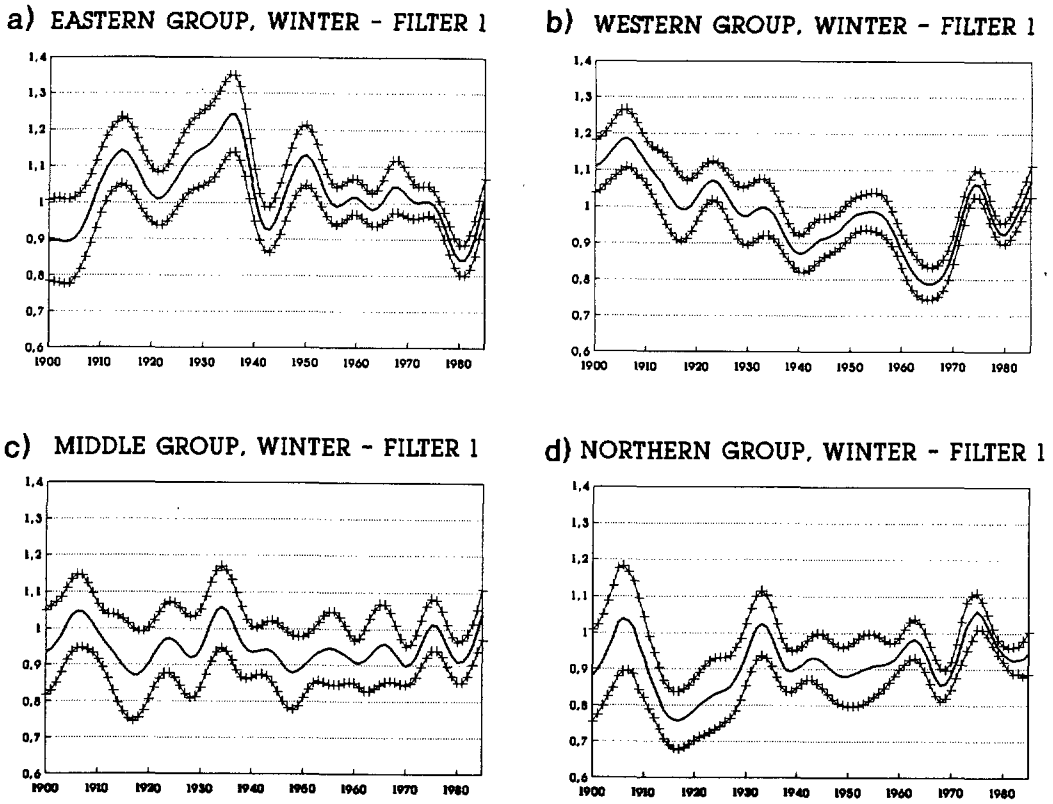


Figure 5.7 Averages and standard deviations of the standardized F1 winter precipitation curves within the 4 main regions.

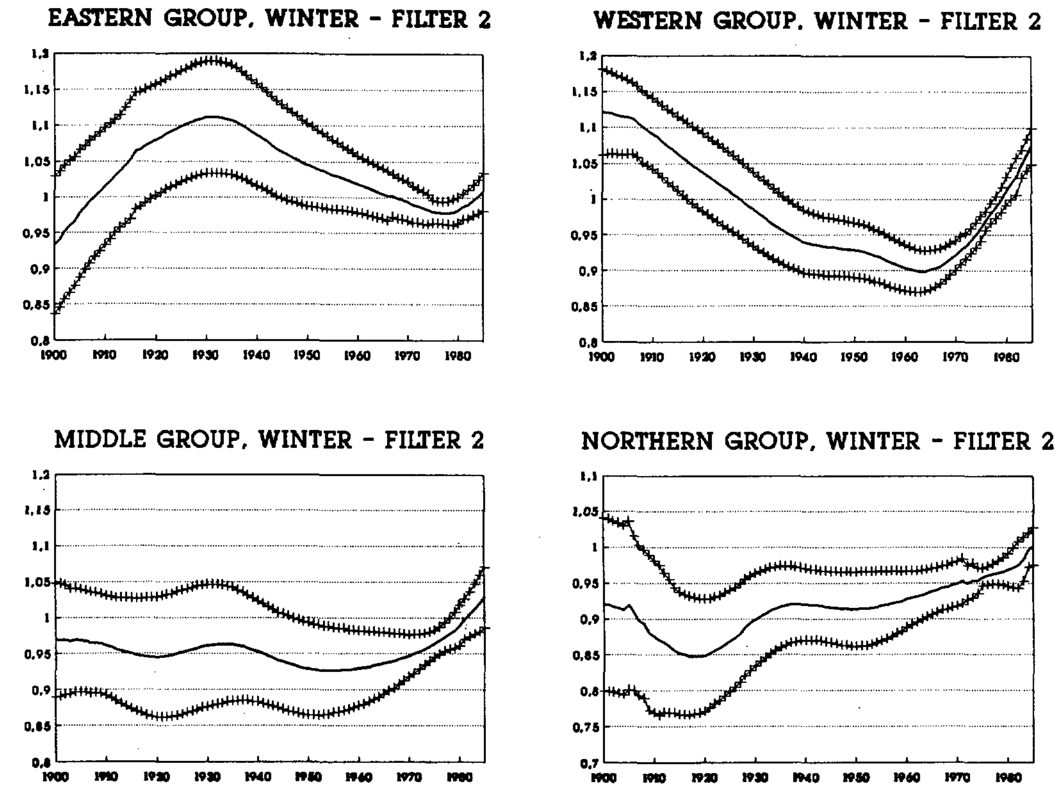


Figure 5.8 Averages and standard deviations of the standardized F2 winter precipitation curves within the 4 main regions.

In western Norway, the level of the winter precipitation decreased by about 20% from 1900 to the 1960's. From the 1960's to present, however, the level has increased by about 15%, and the present level is consequently only 5% lower than the 1900 level.

In middle and northern regions, the variations in the level of winter precipitation have been less dramatic. In middle Norway, the present level is about 5% above the 1900 level due to a slight increase in winter precipitation during the later decades. In Northern Norway, there was a decrease in winter precipitation in the period 1900-1920, followed by a slightly increasing trend. Today, the level of winter precipitation in northern Norway is ~8% higher than the 1900 level.

5.6 Contributions to the annual trend curves from the individual seasons.

To deduce the relative importance of changes in the precipitation levels for different seasons, it is necessary to know the percentage of annual precipitation which fall in the respective seasons. Maps of seasonal percentages of the annual precipitation for the period 1961-1990 (Førland, unpublished) show that these values vary considerably throughout the country. Spring is normally the dryest season everywhere in Norway. The wettest season are, however, fall and summer in most of the eastern regions, while fall and winter are the seasons with most precipitation in western and northern regions. The maps were used to pick out representative percentages for each season and for each of the 12 regions defined in figure 3.1. The percentages were multiplied with the seasonal trend curves, respectively. In figures 5.9 and 5.10 a-f, these seasonal trend curves are plotted for the 12 regions, respectively. As all curves from one region are plotted in percent of the 1961-1990 annual precipitation sum for the actual region, the relative importance of their size and variation may be read directly from the figures.

Figures 5.9 a-c show curves from the eastern regions 1-3, respectively. In all eastern regions, the main difference between the precipitation pattern around 1900 and present, is that the precipitation during fall has increased. The increase in fall precipitation represents 3/4 or more of the total increase in annual precipitation from 1900 to present. Summer and winter precipitation also increased during the first decades of the century, however, there has been periods of decreasing summer and winter precipitation later in the century, while fall precipitation has been stable, or even continued to increase during later decades. In region 3 it was thus mainly decrease in summer and winter precipitation which led to decreasing annual precipitation from the 1930's to the 1970's.

Figures 5.9 d-f show curves from the western regions 4-6. In all these regions winter precipitation was dominating around 1900, while the fall presently is the season with most precipitation. The increase in fall precipitation from 1900 to present represents the entire annual increase during the same period in western Norway. The increase in annual precipitation level from 1960 to present was, nevertheless, caused as much of increasing precipitation during winter as by increasing precipitation during fall. The winter precipitation, however, decreased during earlier decades of the century in a rate which compensated for the increasing fall precipitation. The net change in winter precipitation from 1900 to present is thus small.

Figures 5.10 d-f show curves from the northern regions 10-12. In opposition to the southerly regions, the increase in annual precipitation in regions 10-12 has not been dominated by increasing fall precipitation. Increase before 1950 was mainly caused by increasing spring precipitation, while increase after 1950 was caused by increase in precipitation during fall and winter.

Figures 5.10 a-c show curves from the mid Norway regions 7-9. These figures - illustrate that regions 7-9 do not form a relatively uniform group, as do the eastern, western and northern regions, respectively. In regions 7 and 9, the distribution of precipitation between seasons reminds most of the eastern innland region 2, with summer as the wettest season. In region 8, on the other hand, the seasonal distribution reminds of the western regions.

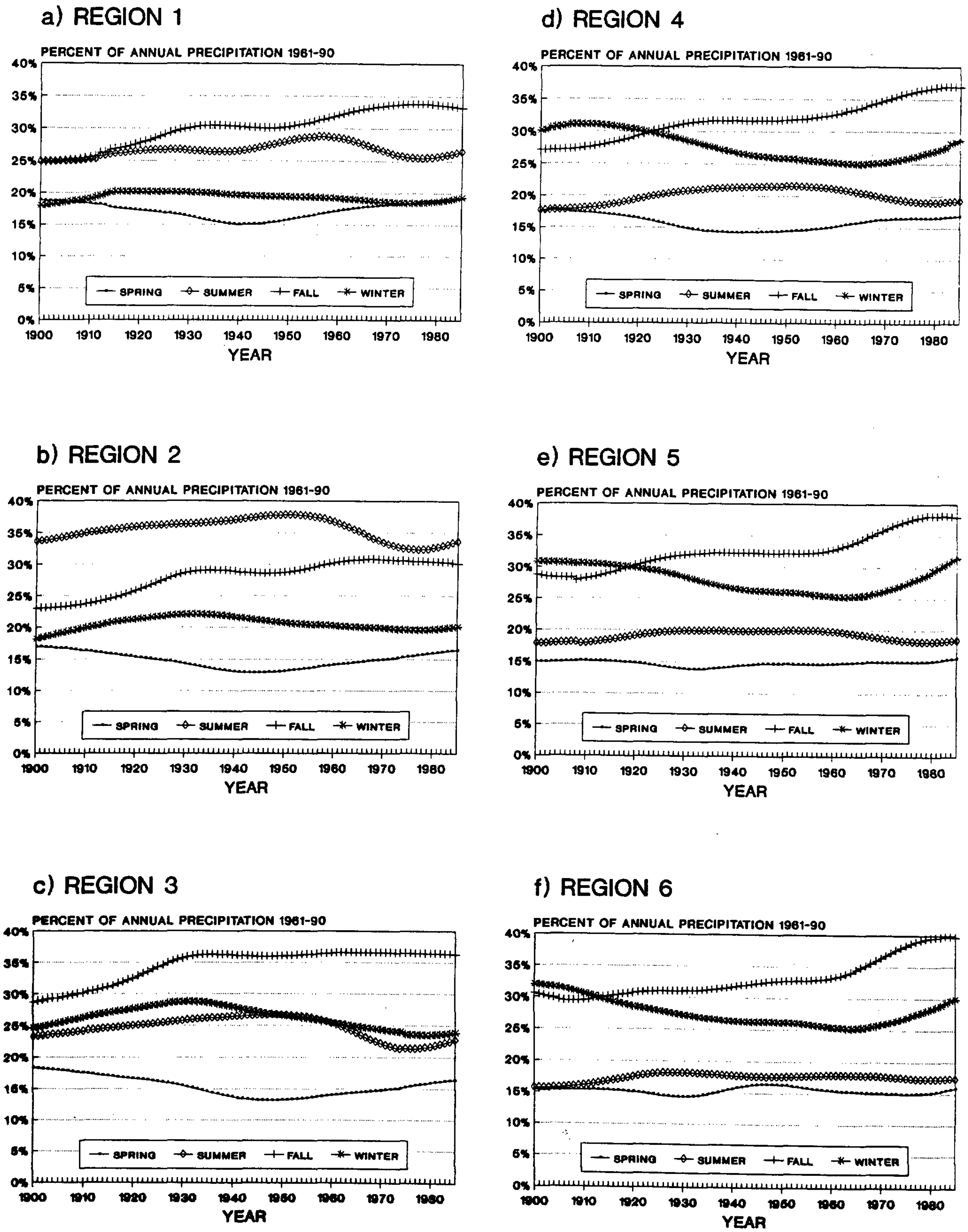


Figure 5.9. Regional time series of seasonal precipitation given in percent of the 1961-90 annual mean. Region 1 (a), 2 (b), 3 (c), 4 (d), 5 (e), 6 (f).

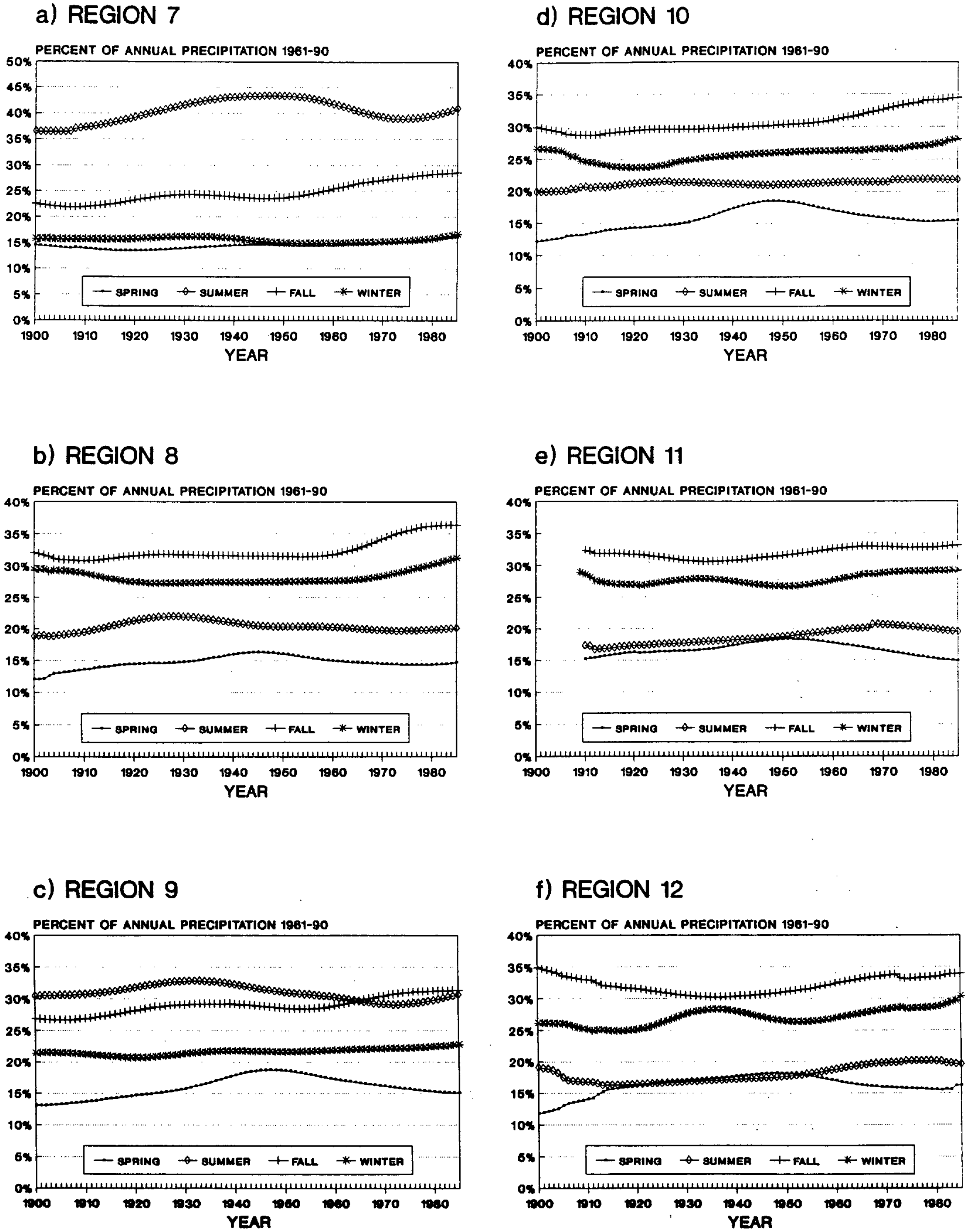


Figure 5.10 Regional time series of seasonal precipitation given in percent of the 1961-90 annual mean. Region 1 (a), 2 (b), 3 (c), 4 (d), 5 (e), 6 (f).

The fall was, however, the wettest season during the whole period. In region 7 the increase in annual precipitation from 1900 to present was caused by increase in fall and summer precipitation. The increase in precipitation before 1940 was mainly caused by increasing precipitation during summer, while precipitation during fall increased mainly after 1950. In regions 8 and 9 the increase in annual precipitation was caused mainly by increased precipitation during fall and spring. The increase before 1950 was mainly due to increased spring precipitation, while increasing fall precipitation has contributed most to the increase in annual precipitation during the last decades.

In chapter 4 the conclusion was that annual precipitation in most parts of Norway presently is 8-13% higher than around 1900. The above paragraphs indicate that in southern Norway (regions 1-6), it is mainly the fall that has become wetter. In northern Norway (regions 10-12) the increase has been more evenly distributed between the seasons.

6. SUMMARY AND CONCLUSIONS

Homogeneous precipitation series from 129 Norwegian stations were used to define regions for which the precipitation trends and variations have been similar during the period 1895-1990. Twelve regions with different precipitation regimes were identified using the comparative trend technique. Representative trend curves were calculated for each of these regions. Using the regional trend curves in combination with a map showing the 1961-90 precipitation averages for Norway, it is now possible to estimate precipitation curves for any point within the investigated area.

Similarities between regions within the same part of the country made it meaningful to define an eastern, a western and a northern group of regions. Between these groups, mid-Norway forms a fourth group, which should be regarded as a transitional zone rather than an area with similar precipitation regime.

All regions and groups of regions have experienced an increase in the precipitation level during the last century. There are, however, substantial differences between trend curves from regions in different parts of the country, both regarding the period, and regarding the seasons during which the precipitation has increased. In order to explain the observed precipitation variations and trends in different parts of the country, it will be necessary to connect the regional precipitation curves to changes in frequencies of different patterns of the general circulation.

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