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E.Førland, L.A.Roald, O.E.Tveito and I.Hanssen-Bauer

Report no. 19/00

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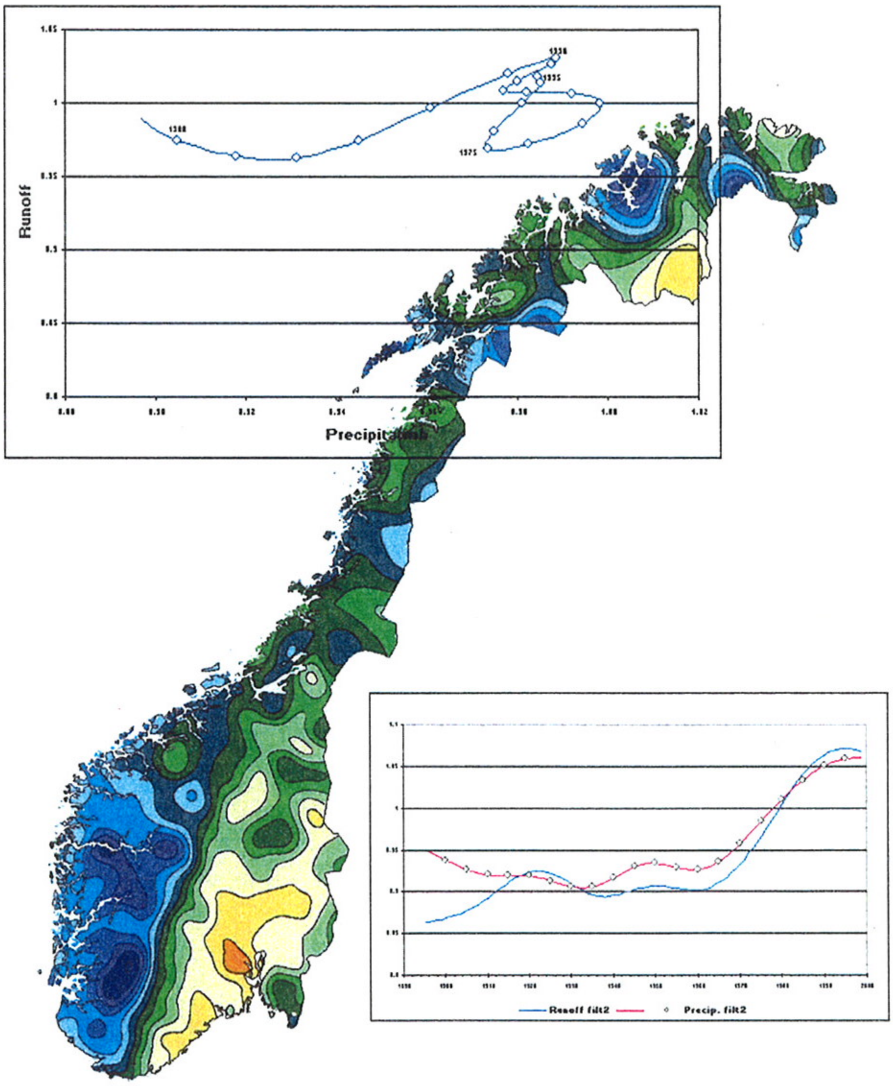

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Past and future variations in climate and runoff in Norway

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Norwegian Electricity Federation, Enfo (Contract H1.00.5.0),
Norwegian Meteorological Institute (DNMI), and
Norwegian Water Resources and Energy Directorate (NVE)

SUMMARY:

This project is a part of the Enfo-project "Hydropower production in Norway under a changing climate".

A survey is given of long-term variations during the 20th century of temperature, precipitation and runoff in all parts of the Norwegian mainland. It is concluded that Norway has experienced a distinct increase in temperature and precipitation. Also annual and seasonal runoff have undergone substantial variations during the 20th century.

A special focus is set on the anomalies in temperature, precipitation and runoff during the latest 20 years (1980-1999), and it is e.g. demonstrated that the winter precipitation in Western Norway is more than 25% higher during 1980-1999 than for the normal period 1961-1990.

The most recent scenarios from the RegClim-project for temperature and precipitation during the next 50 years, as well as scenarios for Denmark, Finland, Norway and Sweden (from the NordEnsClim-project) are also presented.

Detailed regional descriptions of long-term variations of temperature, precipitation and runoff are given as Appendices in DNMI Report 20/00 KLIMA

KEYWORDS:

Temperature, precipitation, runoff, long-term variations, scenarios

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Contents

1. Introduction

The Norwegian electricity production system is nearly 100 per cent based on hydropower, which makes it very sensitive to long-term variations in runoff (Fossdal & Sælthun, 1993). High inflows that cannot be stored in the reservoirs result in dump energy for the domestic market or export, or has to be spilled due to limitations on production capacity or export transmission capacity. In dry years the domestic hydro-energy reserves are very limited. Climate change will affect the energy system directly, through changes in runoff (total volume and seasonal distribution) and thereby hydropower production, and through changes in energy consumption for heating.

In Norway, both annual temperatures and precipitation have increased during the last 100-150 years. During the period 1896-1997 the annual precipitation in different regions have increased by between 5 to 18%. The precipitation development varies from region to region, but in most regions there is a substantial increase in precipitation after 1980 (Hanssen-Bauer & Førland, 1998). The increase in annual temperatures since 1876 is between 0.4 to 1.2 °C in different regions. After a period with decreasing temperatures from the 1930s, the annual temperature has increased in all regions since 1980 (Hanssen-Bauer & Nordli, 1998). Hisdal et al (1996) have shown a good correspondence between long-term variations in precipitation and runoff, and distinct regional patterns are found in the temporal development of runoff (Hisdal et al., 1995). Preliminary climate change scenarios for Norway (Førland & Nordeng, 1999) indicate that the tendency of increasing temperature and precipitation will continue also in the next decades.

In the Nordic research program “Climate change and energy production”, Sælthun et al. (1998) concluded that total runoff volumes after 100 years could increase by some 20% in the wettest areas (western Norway) and drop by some 20% in dry areas with large evapotranspiration (southern Sweden). The effects of climate change on runoff regimes (seasonal variability) proved to be very strong. Generally the winters become less stable, and the pronounced snowmelt peak in runoff is replaced by more evenly distributed runoff during winter in many areas. Total hydropower production is affected by changes in total runoff, and by changes in seasonal distribution of the runoff. Increased winter flow and reduced spring floods will allow more reservoir capacity to be used for flood attenuation, thus reducing spillage and increasing total production. The total impact and the relative importance of these effects vary regionally. The main scenario showed a nominal increase (+2.5%) in hydropower production in the Nordic region as a whole over 30 years.

As pointed out by Enfo (2000), changes in runoff will have serious consequences for most hydropower producers in Norway. This accounts for revision of older constructions, as well as for planning of new installations. For production planning, there is an increasing doubt whether the historical runoff statistics give a realistic basis for quantification and statement of value for present and future hydropower production.

This report gives an overview of the long-term variation in temperature, precipitation and runoff in Norway during the last 100 years. Both by analyses of time series (section 3) and ratios between recent decades and hydrological reference periods (section 4) are presented. In section 5, the covariance between long-term trends in climate and runoff are discussed, and in section 6 some climate change scenarios for Norway and the Nordic region are presented.

2. Data and methods

2.1 Data quality

2.1.1 Temperature and precipitation data.

The long-term variations in temperature and precipitation are based on high-quality, homogeneity tested series. Procedures and detailed results for homogeneity testing of Norwegian temperature series are reported by Nordli (1997), and for precipitation series by Hanssen-Bauer & Førland (1994a). The basic method for homogeneity testing was the Alexandersson (1986) test. This test detects the year with largest probability of an inhomogeneity, calculates the significance for the inhomogeneity and presents an adjustment factor for the first part of the series. The results are checked against metadata. In case of inhomogeneities, the series were adjusted. Series with multiple breaks were discarded from the analysis. The regional temperature series (section 3.1) are based on a network of 43 homogenised series. For the calculation of regional precipitation series (section 3.2), a network of 78 homogenised series was used. The precipitation series are based on measured values, i.e. not corrected for undercatch caused by effects around the gauge.

2.1.2 Runoff data

Runoff data is based on discharge data observed at permanent gauging stations in rivers and lakes as well as data from power stations. The current study is based on runoff series from natural catchments, as well as catchments affected by hydropower regulation. Series affected by regulations are corrected for diversions and storage in reservoirs in order to obtain a "naturalized" runoff series. (Details are given in an Annex-report (Roald et al., 2000)). These series are called "Tilsigserier" or inflow series. We will use the term runoff data both for data from natural catchments and for naturalized runoff data in this report.

Runoff data are available from the second part of the 19th Century at a few locations, in South Norway. Many of the longest data series started around 1916 in Mid and North Norway, although a few series start around 1908. The observed data are generally updated to 1999, but these data have not been corrected for the effect of hydropower regulations after 1990, except for a few series. A major effort is now under way to update 63 inflow series up to 1999. This work will be concluded at the end of 2000. The study requires that series represent all parts of Norway. Because of the lack of updated inflow series after 1990, it was decided to apply data from a common period between 1924 and 1990 for the present analysis. A total of 84 series has been used in the initial analyses. A list of the series used in the analysis is presented in the Annex-report (Roald et al., 2000), which also describes the data quality. The station network has later been extended substantially, especially from 1960 onward. These series are available for more detailed analyses, but are not considered in this report.

2.2 Calculation of regional series

2.2.1 Temperature

Regions which are fairly homogeneous concerning temperature variability on long-term time-scales, were defined by using a combination of principal component analysis (PCA) and cluster analysis (Hanssen-Bauer & Nordli, 1998). The main analyses were based on a network consisting of 46 stations (including 6 Swedish and 1 Finnish station) with long-term data series. As far as possible, homogeneity tested series from the North Atlantic Climatological Dataset (Frich et al., 1996) were used. As this network was quite sparse in some areas, additional analyses were run over shorter periods, using denser station networks. By using this technique, six "temperature" regions were defined (Figure 2.1).

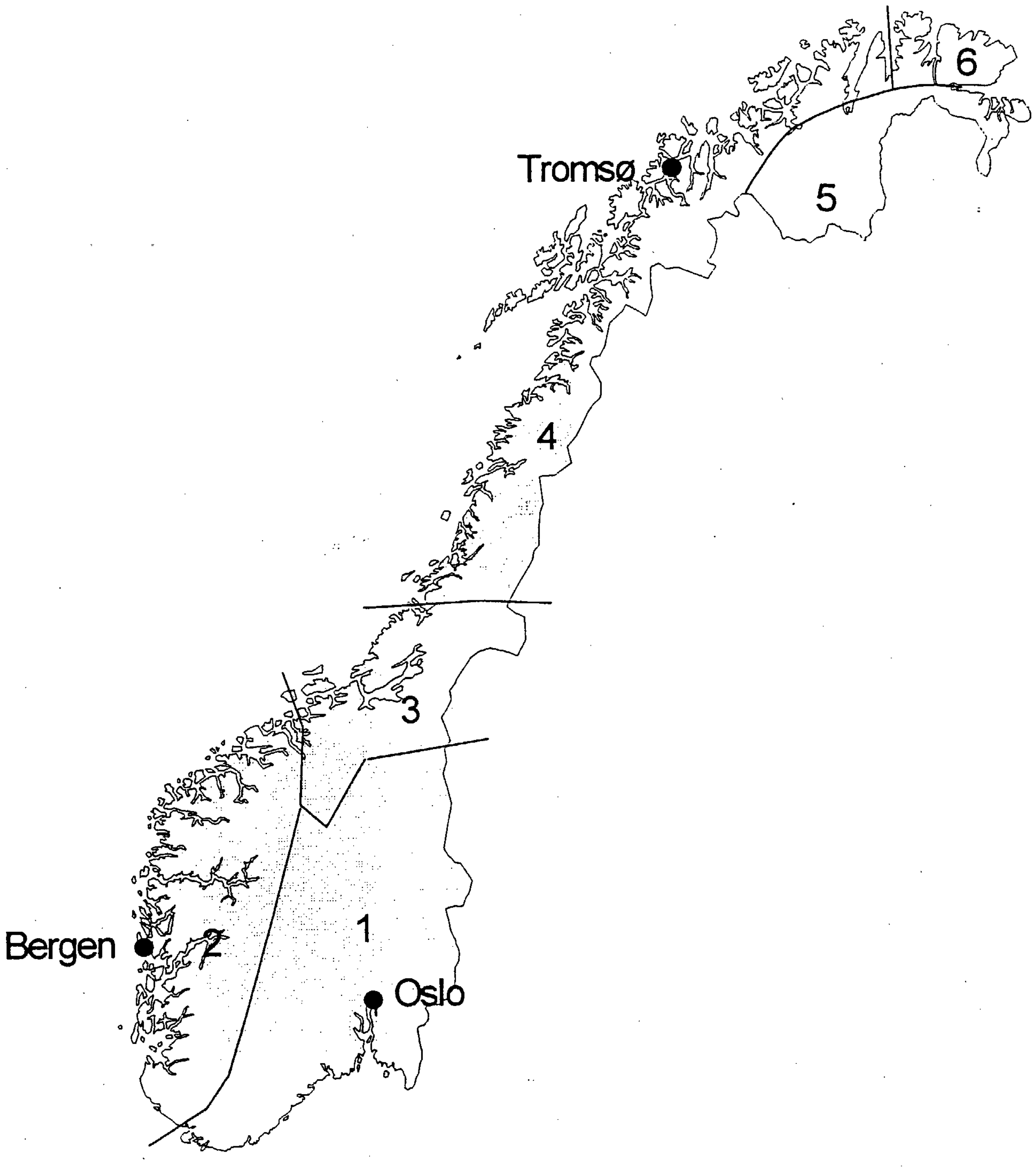


Figure 2.1 Six Norwegian regions for long-term **temperature** variations

Regional temperature series were calculated for each of the 6 regions covering the entire period 1876-1997. Series were defined based on annual, seasonal and monthly values. In order to allow the inclusion of series covering different periods, all series were standardized by subtracting the 1961-1990 average ("standard normals") μ and dividing by the standard deviation σ during the same period:

$$(2.1) \qquad ST_{m,i} = (T_{m,i} - \mu_{m,i}) / \sigma_{m,i}$$

where $ST_{m,i}$ is the standardized temperature series T from station *i* in region *m*. Standardized normals $\mu_{m,i}$ exist even for stations which were not running throughout the entire period 1961-90, while standard deviations $\sigma_{m,i}$ for the same period have to based on observations.

The standardized regional series may be used to estimate the temperature series (in °C) on annual, seasonal or monthly basis in an arbitrary area x in region m:

$$(2.2) \qquad T_{m,x} = ST_m * \sigma_{m,x} + \mu_{m,x}$$

where $\sigma_{m,x}$ is standard deviation and $\mu_{m,x}$ mean value of temperature during the period 1961-90 in area x. ST_m is the "regional standardized temperature series" for region m, defined as the average of the series within the region (Hanssen-Bauer & Nordli, 1998). Note that the variance of estimated series will be somewhat reduced compared to real measurements.

2.2.2 Precipitation

As for temperature (section 2.2.1), regions where the long-term trends and decadal scale variability is uniform, were defined. The precipitation pattern is far more influenced by the topography than the temperature pattern, and consequently it was concluded (Hanssen-Bauer & Førland, 1998) that 13 regions (Figure 2.2) were needed to describe the long-term precipitation variations in all parts of the Norwegian mainland. Time-series covering the period 1896-1997 from 78 stations were used to calculate regional precipitation series. The series were homogeneity tested by Hanssen-Bauer & Førland (1994a), and in case of inhomogeneities, the series were adjusted.

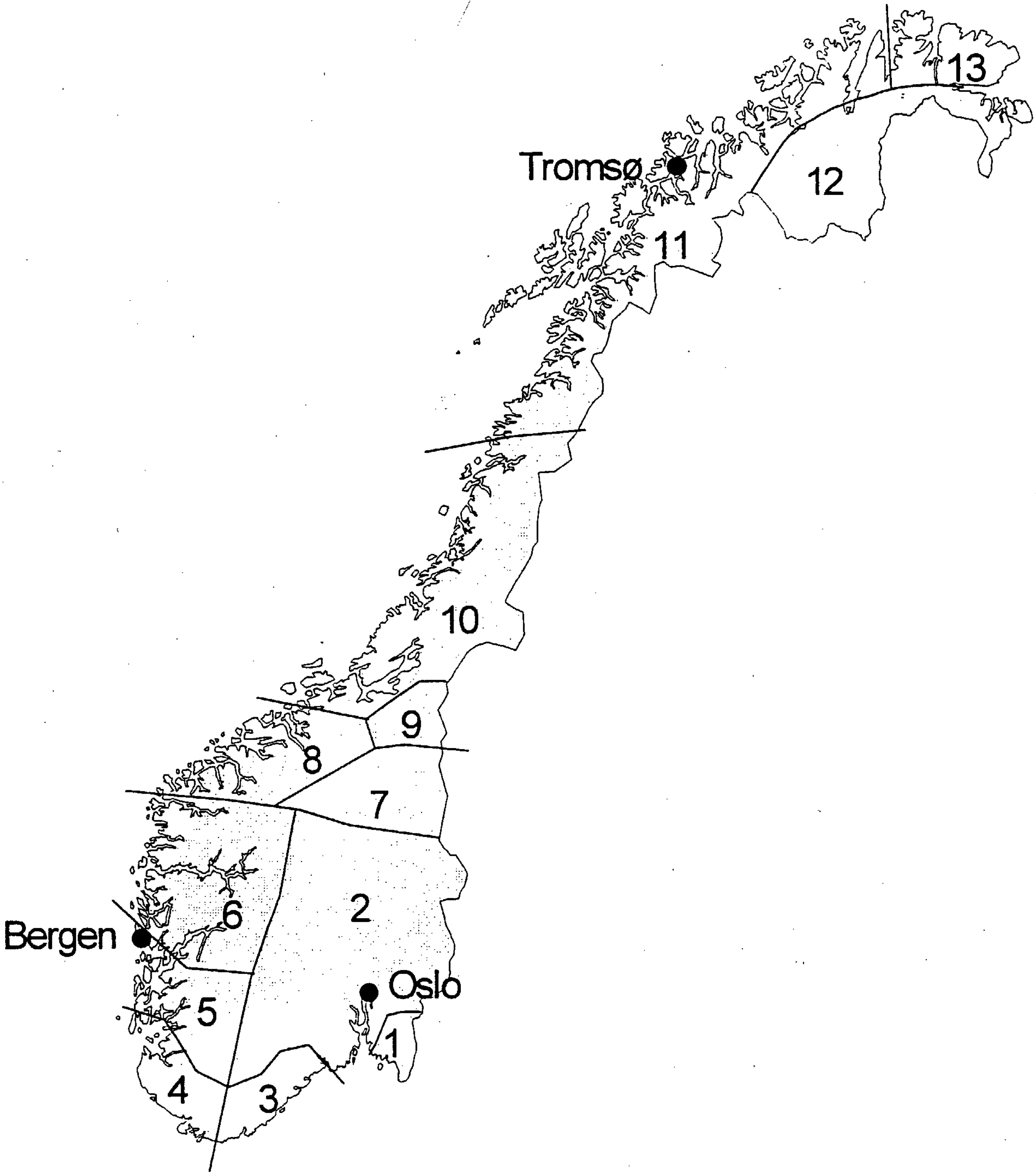


Figure 2.2 Thirteen Norwegian regions for long-term **precipitation** variations

The standardized precipitation $SP_{m,i}$ at station *i* in region *m* is defined as the observed precipitation ($P_{m,i}$) divided by the standard normal 1961-1990 for the station ($PN_{m,i}$):

$$(2.3) \qquad SP_{m,i} = P_{m,i} / PN_{m,i}$$

This definition is applied on annual, seasonal and monthly precipitation series. Such standardization makes it easy to reverse the process and extrapolate time series in millimeters at arbitrary locations. The precipitation evolution within region m can thus be described by one "regional standardized precipitation series" SP_m, which is defined as the average of n standardized series from region m:

$$(2.4) \qquad SP_m = 1/n^* \Sigma SP_{m,i}$$

The standardized series may be used to estimate the precipitation series in millimeters on annual, seasonal and monthly basis at an arbitrary site x in region m:

$$(2.5) \qquad PN_{m,x} = SP_m * PN_{m,x}$$

where $PN_{m,x}$ is the standard normal of precipitation during the period 1961-90 valid for the site x. This can be estimated for any site by using normal maps (Førland, 1993). Series of regionally averaged precipitation valid for region m, P_m can be calculated by substituting the regional averaged standard normal value into the equation.

2.2.3 Runoff data

The runoff (section 2.1.2) is observed at a point in a river or a lake, and is an integrated value of the entire upstream catchment area. The temporal pattern of the runoff is therefore dependent on the properties of the basin in addition to the climatic input. A total of 84 runoff series from the period 1924-1990 were grouped into 13 regions based on cluster analysis (Table 2.1). The boundary between each region was adjusted after a manual inspection, where also seasonal series were considered. The delimitation of the regions is shown in Figure 2.3. The groups will not completely overlap the precipitation regions. Since the long-term inflow series mostly are from medium sized to large catchments, some precipitation regions are covered by just one inflow series. This is the case for precipitation regions 1 and 13.

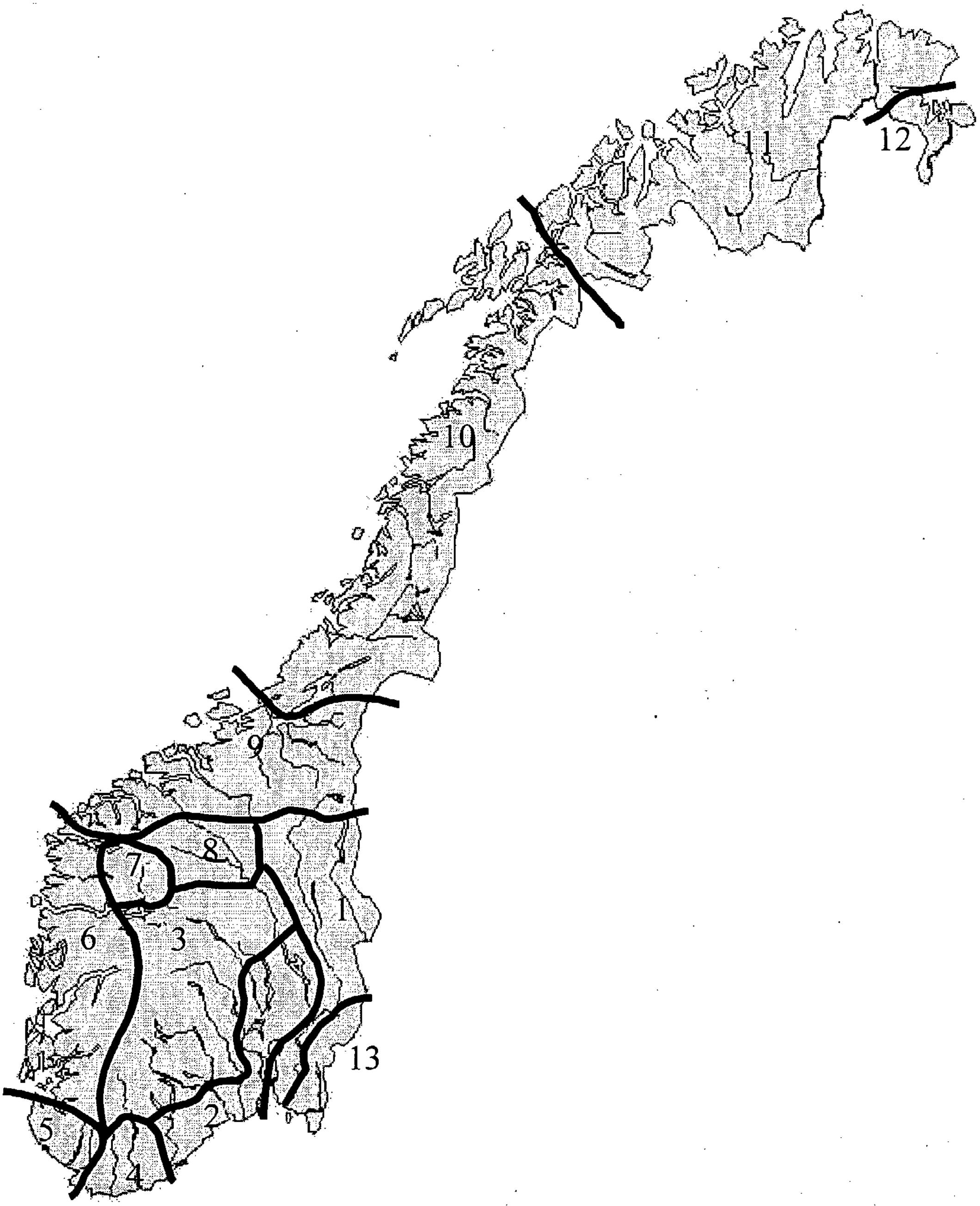


Figure 2.3 Thirteen Norwegian regions for long-term **runoff** variations

Precipitation region 3 is typical for a rather narrow zone of Sørlandet. The catchments of the runoff series extend further inland in this region, but has been defined as a separate runoff region 4. It is possible to construct an index series based on small catchments within this region, but it will be substantially shorter than the long-term series used in this study. The series on Jæren differ somewhat both from region 4 and the other series in West Norway and has been defined as region 5, which is equal to precipitation region 4. There is a gap in the coverage of suitable runoff series in Troms and the westernmost part of Finnmark. When the runoff series have been updated, this gap in the regional coverage will be filled.

Table 2.1 Overview of the runoff regions, with the number of series used in deriving the regional index series.

Region	Coverage	No. of series	Repr. series
1	Trysilelv – Glomma (except Vorma/Lågen)	9	2.119
2	Drammenselv (S) – Arendalsvassdraget (S)	9	12.68
3	Vinstra-Drammenselv (N)- Numedalslågen – Skienselv (N) (Mountain South)	11	2.144
4	Tovdalselv – Mandalselv (South Norway)	2	20.3
5	Jæren (South West Norway)	3	27.3
6	Suldalslågen – Eidselv (Hornindal) (except Glacier streams) (West Norway)	13	62.5
7	Glacier streams (Glacier)	4	75.2
8	Lågen (N)-Otta (Mountain North)	3	2.150
9	Sunnmøre- Stjørdalselv	10	123.20
10	Fosen- Nordland	15	152.4
11	Alta – Tana (Finnmark West)	4	223.1
12	Neiden (Finnmark East)	1	224.1
13	Vrangselv (South East)	1	313.10

The variability of each group is higher than the variability within the precipitation groups, and some series tend to fall in between well-defined groups, since the basins may be a member of more than one climatic region. Runoff generation is partly a result of release of accumulated water in the basin from the groundwater, soil-water and the snow storage. A comparison of the runoff based on monthly or seasonal data between a number of years will therefore result in a high variability compared to precipitation data. The individual series of each region display nevertheless a fairly high correlation with each other and with the regional series. Particular dry or wet years occur simultaneously in all series within each region, but there are short periods with a more chaotic variability within some regions.

The runoff series have been standardized similar to the precipitation series as described in Section 2.2.2. The standardization is applied on annual and seasonal runoff series. This way of standardizing makes it easy to reverse the process and extrapolate time series in m^3/sec, l/sec km^2 or millimeters per year or season at arbitrary locations, provided that the at-site mean can be estimated. Each regional index series were obtained as the arithmetic mean of all individual series within the region for each year.

Each regional index series were compared to each of the individual series of each region in order to verify the regionalization, and to identify longer series which could be used as a regional index to examine the variability of the full period covered by the meteorological data. It was found that the series from Elverum at River Glomma could be used as an index of runoff region 1, while the series from Bulken at River Vosso could be used as index of runoff region 6. The series from Fustvatn at River Fusta may be used as an index of runoff region 10.

2.3 Smoothing of time series

Time series of scattered individual values often give a rather chaotic impression (Cf. spread of single values in Figures 3.2 and 3.4). To condense the long-term variations, running means (see example in Figure 3.8) and smoothing of the series by a low-pass Gaussian filter (see example in Figure 3.2) are used. In the present report Gaussian filters with $\sigma = 3$ and 9 are chosen. These filters are favorable for studying variations on decadal respectively 30 years time scales. Note that the ends of the filtered curves are very dependent on the first or last few values, which may influence the trends seriously.

The series are also smoothed by 20 and 30 years running means. By calculating running means, all the values in the averaging period are given the same weight.

In the graphs in this report, the running means for the 20 and 30 years periods are plotted on the last year in the averaging period. The low-pass filtered graphs however are plotted on the central year in the averaging period.

2.4 Testing for trends

To test the significance of trends, the non-parametric Mann-Kendall test was used for temperature (Hanssen-Bauer & Nordli, 1998) and precipitation (Hanssen-Bauer & Førland, 1998) series. Time series may be tested successively by adding one by one year reapplying the test for each year. Using graphical representation of the standardized test statistic, the development of trends in the series may easily be traced. It has also proved to be valuable to apply the test by starting with the last year going backward in time.

3. Long-term variations in temperature, precipitation and runoff in Norway

3.1 Temperature

Globally averaged annual mean temperatures at the end of the 20th century were more than 0.6°C above those recorded at the end of the 19th century (WMO, 2000). The ten warmest years in the global instrumental period (1860-1999) have all occurred since 1983, and 1999 was the 21st consecutive year with an above normal (1961-90) globally averaged surface temperature. The 20th century and particularly the latest decades are probably the warmest during the last 1000 years in the northern hemisphere (Figure 3.1). However, it is important to note that the warming has not been globally uniform. A previous analysis (Hanssen-Bauer et al., 1996) showed that Norway is in an area where the increase in annual mean temperatures during the period 1890-1990 was not statistically significant even on the 5% level. Large inter-annual variability in this area results in a high noise level, which an eventual trend signal has to overcome.

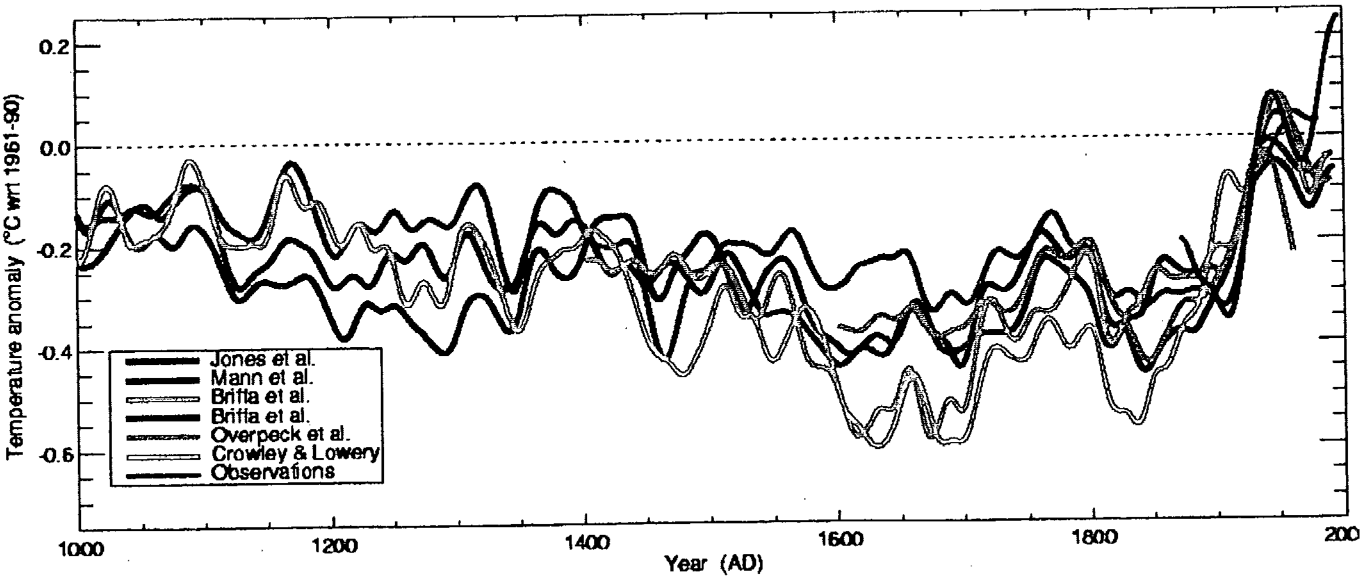


Figure 3.1 Millenial Northern Hemisphere temperature reconstruction, based on instrumental and proxy data (from Mann et al., 1999)
(Web-address: www.cru.uea.ac.uk/cru/info/milltemp)

3.1.1 Long-term variations of **annual** temperatures

Time series of annual and seasonal temperatures for all regions are presented in an Annex-report (Roald et al., 2000). The series are standardized as described in section 2.2.1. The units are thus temperature anomalies expressed in standard deviations. In the Annex-report, both single values as well as low-pass filtered curves are presented for all temperature regions. As an example of regional series converted to absolute temperatures (in °C), the long-term temperature development for Oslo (Region 1) is illustrated in Figure 3.2. The series for the Oslo-area are established by substituting regional values for ST_m and appropriate values for σ and μ (in this example σ and μ for Oslo-Blindern are used) into eq. 2.2. The long-term trends in the Oslo-series in Figure 3.2 are thus not influenced by local urban effects.

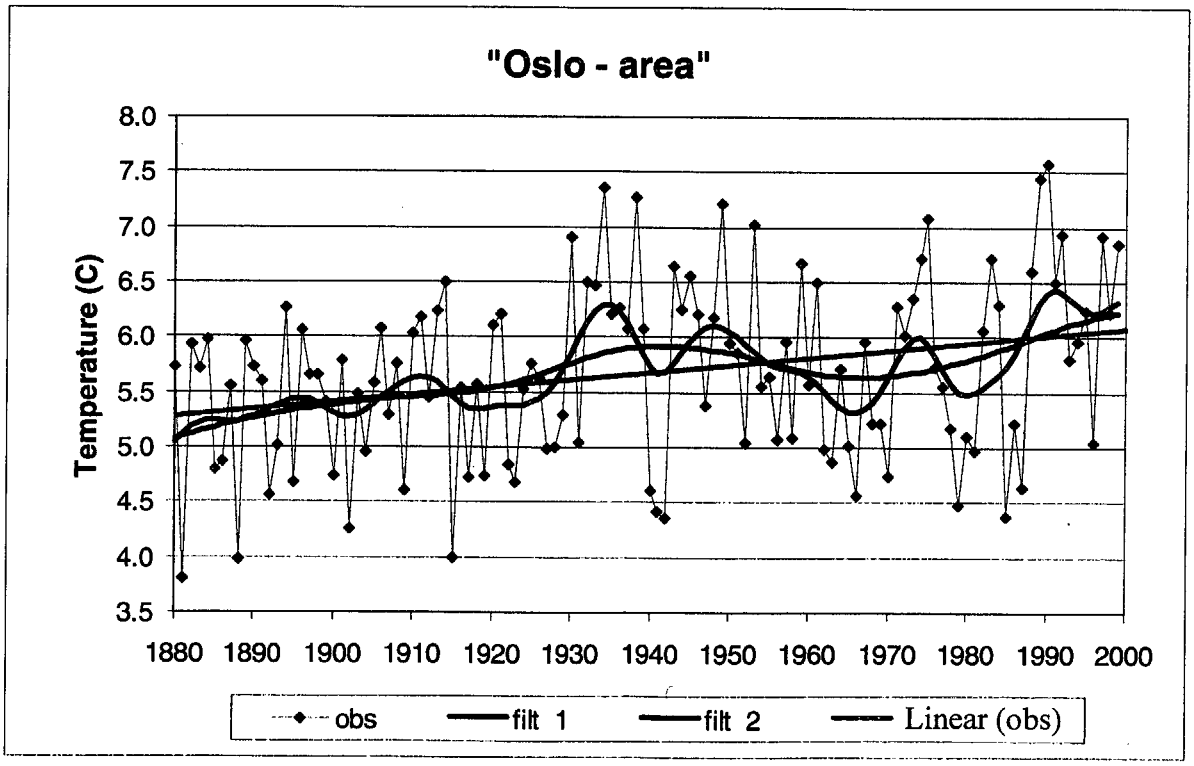


Figure 3.2 Low-pass filtered series of standardized annual temperatures for the Oslo-area. Filt.1 and 2 indicate low-pass Gaussian filters, favorable for studying variations on time scales of 10 resp. 30 years. Dots indicate values for single years. The linear trend (0.067C/decade) is indicated by green line. Note that the figure is based on observed μ and σ for Oslo-Blindern, inserted in the regionalised temperatures series for southeastern Norway.

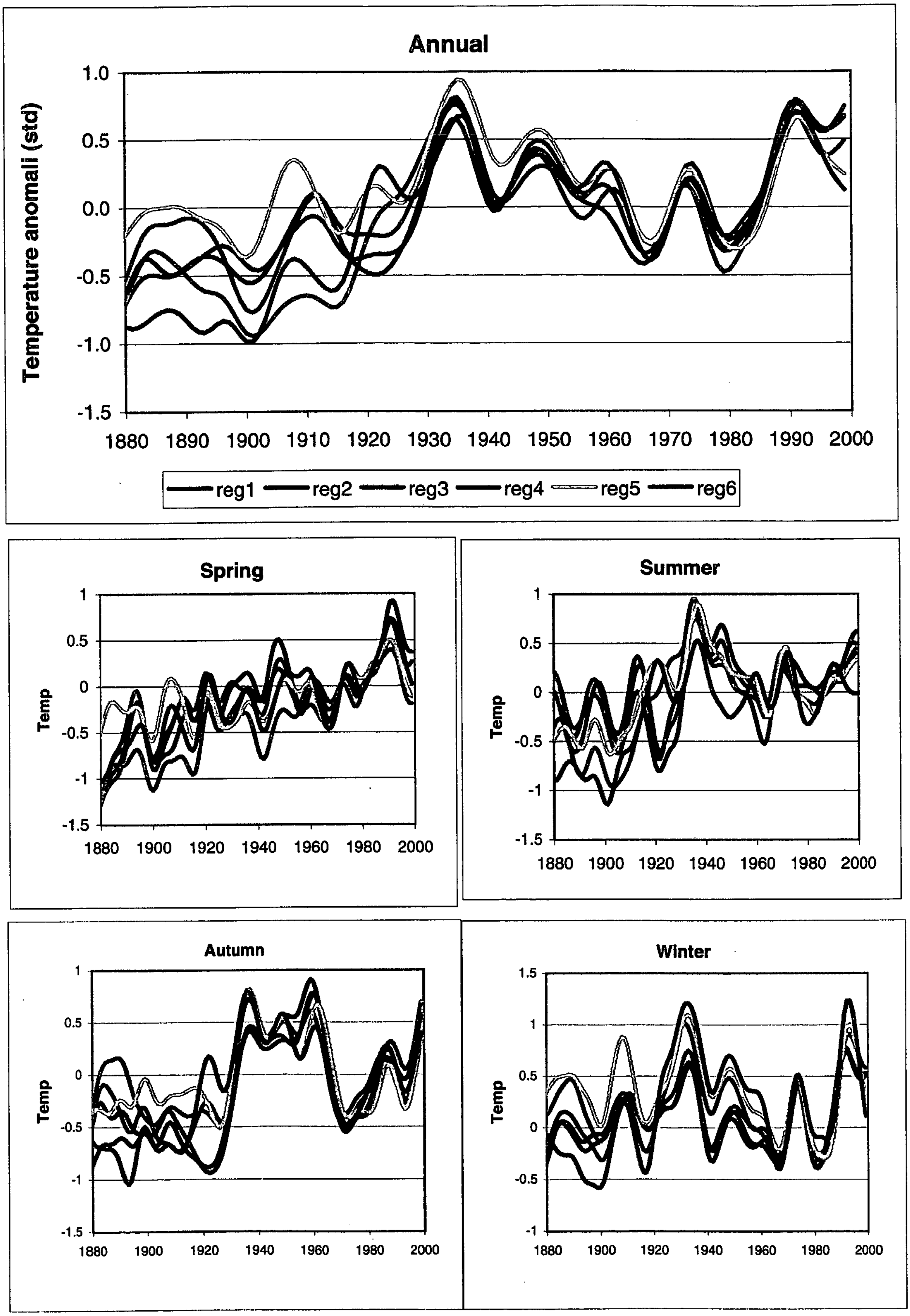
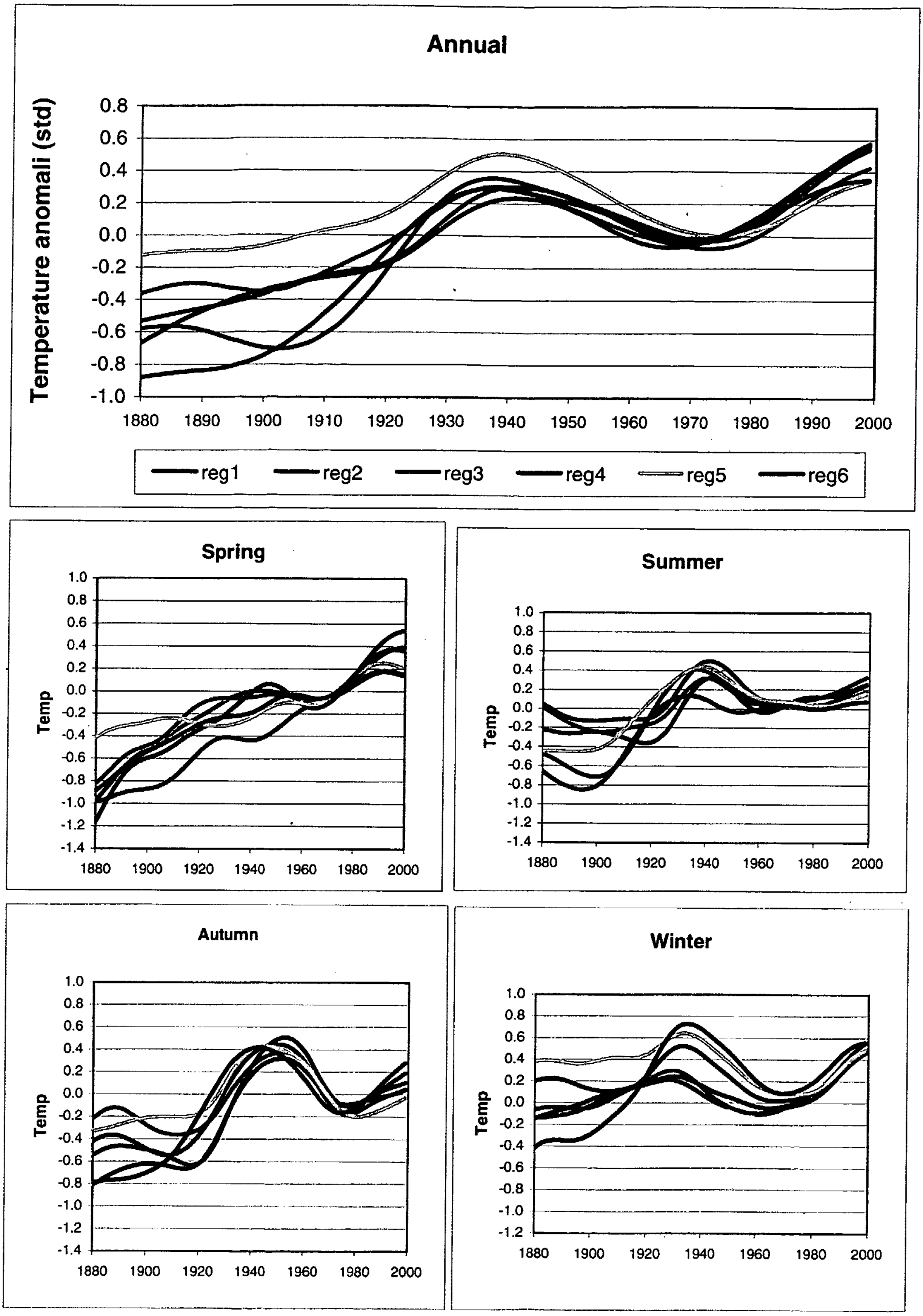


Figure 3.3 Low-pass filtered series of standardized temperatures for 6 Norwegian regions
The low-pass filters indicate variations on a decadal time scale



igure 3.4 Low-pass filtered series of standardized temperatures for 6 Norwegian regions
The low-pass filters indicate variations on a 30 years time scale

Figures 3.3-3.4 show low-pass filtered series (cf. section 2.2) of standardized regional temperature for all temperature regions, on annual as well as on seasonal basis. Some of the discrepancies between the regional curves during the first decades may be caused by the fact that the regional series are based upon a sparse station network in the 19th century. One should however, be aware the fact that the series are standardized using the period 1961-1990. The curves are thus "forced" into the same level during this period, and the apparent agreement especially in this period is thus to some degree the result of this choice.

Some common features in the centennial temperature variations are seen in all regions: Compared to the standard normal temperatures (1961-90), the period before 1920 was relatively cold in all regions except in northern inland region R5. The period 1931-1960, on the other hand, was relatively warm. The last decade in the 20th century was also a relatively warm period.

The similarities between the 3 southernmost regions concerning decadal scale variability are striking. On the decadal scale, 7-8 more or less pronounced minima and maxima are found. The absolute minimum is in the beginning of the series, 0.5-1.0 standard deviations below the 1961-90 average, while the highest maxima, 0.5-1.0 standard deviations above the 1961-90 average are found in the 1930s and around 1990. In the regions R2 and R3 these maxima are of similar size. In the southeastern-region R1, the absolute maximum is found around 1990.

The standardized temperature curves from regions R4, R5 and R6 are somewhat different from those from the southern regions, especially before 1930. The absolute decadal minimum in the northern regions occurred around 1900, mainly because of very low summer and winter temperatures. The northern curves also show a local decadal temperature maximum around 1922 which is not seen in the southern regions, and which is mainly caused by local maxima in summer and autumn temperatures. There are also internal differences between the northern regions during the first decades: Regions R4 and R6 are in average about 0.5 standard deviations colder than R 5 during the first 4 decades. After 1930, the curves for the northern regions are more internally similar, as well as similar to the southern curves: The warmest periods are found around 1935 and in the 1990s also in regions R4, R5 and R6. However, in these regions the 1935 decadal maximum is similar to or higher than the 1990 maximum. In region R5 both the decadal (Filt1) as well as the 30 years (Filt2) maxima are higher in the 1930s than the present-day level.

3.1.2 Long-term variations of **seasonal** temperatures

Figures 3.3-3.4 show that the local maxima and minima in the seasonal curves coincide to a large degree with those of the annual curves. However, there are major differences concerning the relative sizes of the maxima and minima. Note that the warm period in the 1930s was caused by warm autumns, winters and summer, while the warm period in the 1990s was caused by warm winters and springs. The highest winter maxima are, - as the annual temperature maxima, found in the 1930s and around 1990. In northern Norway the 1930s tends to be the absolute highest, while the 1990 maximum tends to be the highest in southern Norway.

The lowest decadal winter minima in southern Norway are found in the beginning of the series and around 1980. In northern Norway, the lowest winter minima are found around 1900 and 1966. Thus, the reason why the annual mean temperatures generally are lower in the beginning of the series than in the 1960s and 1980s is not a lack of cold winters, but rather that the other seasons (especially the spring) usually are warmer during these later decades.

3.1.3 Linear temperature trends

Results from Mann-Kendall tests (cf. section 2.4) of standardized annual and seasonal temperatures series for the period 1876-1997 are summarized in Table 3.1, where also linear trends of the series are given. All regions except the northern inland region R5 have experienced significant temperature increase during the period. The spring temperatures in these regions have increased significantly. Also the summers have become significantly warmer in northern Norway, while autumn has warmed significantly in the two southernmost regions. In winter, no significant trends are found. The winter temperature increase in R6 is close to the 5% significance level, while the other changes are far from being significant.

Table 3.1. Trends in annual and seasonal temperature series during 1876-1997.

Linear trends in the standardized regional series are given as "standard deviation per decade" Bold and regular types indicate trends significant at the 1 respectively 5 % level according to the Mann-Kendall trend test. Trends which are not significant are given within brackets.

Region	Annual	Winter	Spring	Summer	Autumn
1	**0.08**	(0.02)	**0.12**	(0.06)	**0.07**
2	**0.08**	(0.02)	**0.11**	(0.04)	0.07
3	0.06	(0.01)	0.10	(0.03)	(0.04)
4	**0.09**	(0.00)	**0.12**	**0.08**	(0.05)
5	(0.03)	(-0.02)	(0.06)	0.06	(0.02)
6	**0.10**	(0.07)	**0.10**	**0.09**	**0.08**

Trends expressed in °C may be deduced by multiplying the standardized trend in Table 3.1 by site-specific standard deviations. Appropriate standard deviations for a number of localities in Norway are given by Hanssen-Bauer & Nordli (1998). Examples of temperature trends in °C/decade deduced in this way are given in table 3.2.

Table 3.2. Linear temperature trends (°C/decade) during 1876-1997.

Trends which are not significant are given within brackets.

Locality	Region	Annual	Winter	Spring	Summer	Autumn
Røros	1	0.08	(0.07)	0.14	(0.05)	0.09
Oslo (Blindern)	1	0.07	(0.05)	0.13	(0.06)	0.06
Kristiansand (Kjevik)	1	0.08	(0.06)	0.13	(0.05)	0.06
Stavanger (Sola)	2	0.06	(0.04)	0.08	(0.03)	0.05
Bergen (Florida)	2	0.05	(0.04)	0.07	(0.03)	0.05
Ålesund (Vigra)	2	0.04	(0.03)	0.07	(0.03)	0.06
Trondheim (Værnes)	3	0.05	(0.03)	0.09	(0.03)	(0.04)
Bodø	4	0.06	(0.00)	0.11	0.09	(0.05)
Tromsø (VNN)	4	0.07	(0.00)	0.14	0.10	(0.05)
Karasjok	5	(0.04)	(-0.06)	(0.11)	0.08	(0.04)
Vardø	6	0.08	(0.08)	0.12	0.10	0.07

3.2 Precipitation

During the 20th century an increase in annual precipitation was observed at higher northern latitudes (Hulme, 1995, Dai et al., 1997, Karl et al., 1993). Recent studies of homogenized precipitation series indicate an increase also in Norway. Hanssen-Bauer & Førland (1998) found that in most parts of Norway the annual precipitation had increased by 5 – 18% during the period 1896-1997.

3.2.1 Long-term variations of **annual** precipitation

Standardized precipitation series on annual and seasonal basis for each of the 13 regions are presented in an Annex-report (Roald et al., 2000). As an example, Figure 3.5 illustrates the long-term precipitation development in region 6 (counties Hordaland & Sogn & Fjordane). The single values in the figure shows e.g. that in 1915 the annual precipitation was just 57% of the 1961-90 normal, while it in 1990 was 152%. Both low-pass filtered curves (Filt1 and Filt2) show maxima in the 1990s.

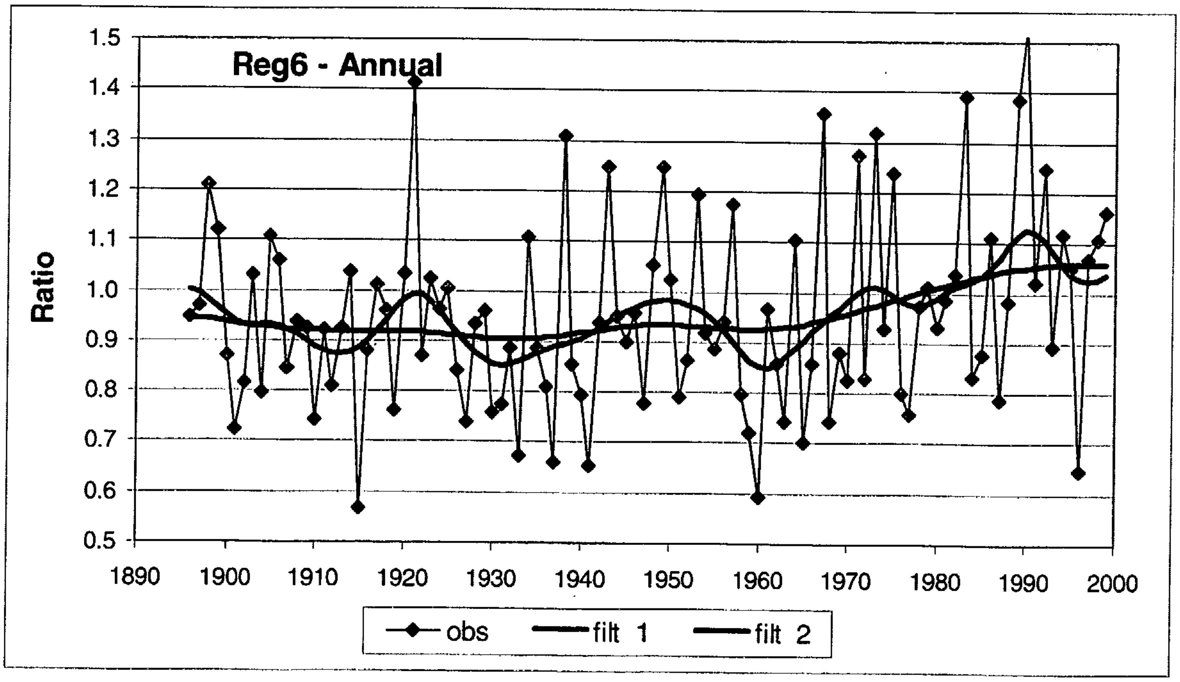


Figure 3.5 Low-pass filtered series of standardized annual precipitation in region 6 (Hordaland, Sogn & Fjordane). All values are expressed as ratios to the 1961-1990 normals. Filt.1 and 2 indicate low-pass Gaussian filters, favorable for studying variations on time scales of 10 resp. 30 years. Dots indicate annual values for single years.

Relatively high correlation is found internally between the south-eastern regions R1, R2 and R3, between the south-western regions R4, R5 and R6, between the central regions R8 and R9, and between the north-western regions R10 and R11 (Hanssen-Bauer & Førland, 1998). The central region R7, the northern inland region R12 and the north-eastern region R13 are rather different from all other regions. There is mainly a negative correlation between the south-eastern regions R1-R3 and the central and north-western regions R8-R11.

Figure 3.6 presents low-pass filtered series on decadal (Filt1) and 30 years (Filt2) time-scales of standardized regional precipitation on annual basis for all precipitation of regions (cf. map in Figure 2.2). One should note that the standardized curves are "forced" into the same level (1961-90 normals), and that the agreement in the later decades to some degree is the result of this way of standardizing.

In southeastern Norway (region R1-R3) there was a statistically significant increase in the annual precipitation during the period 1896-1939 and/or 1896-1967. However more stable conditions, or even a decrease in annual precipitation after 1970, makes the total change during the period 1896-1997 insignificant. Annual precipitation increased significantly in western Norway (R4-R6) from about 1960 to 1997, while the precipitation level was fairly constant in these regions from 1896-1960. In the northern regions, the increase in annual precipitation is clearly significant during the period 1910-1997. In the northeastern region R13, there was a statistically significant negative trend during the first couple of decades, making the increase during the whole centennial insignificant. In north-western regions, on the other hand, the conditions before 1910 were rather stable, and the positive trends are thus highly significant also for the total period. The central regions R7-R9 form a "transition zone between south-eastern, south-western and north-western regions, where R7 has most in common with the south-eastern regions, R8 with the south-western regions, and R9 with the north-western regions.

3.2.2 Long-term variations of **seasonal** precipitation

Figure 3.7 shows low-pass filtered seasonal series. The series show a dramatic increase in **winter** precipitation in R4-R6 from its minimum level around 1965 to its maximum level around 1990. In the south-eastern regions R1-R3, the increase from the winter precipitation minimum around 1980 to the end of the series is not statistically significant. However, in R2

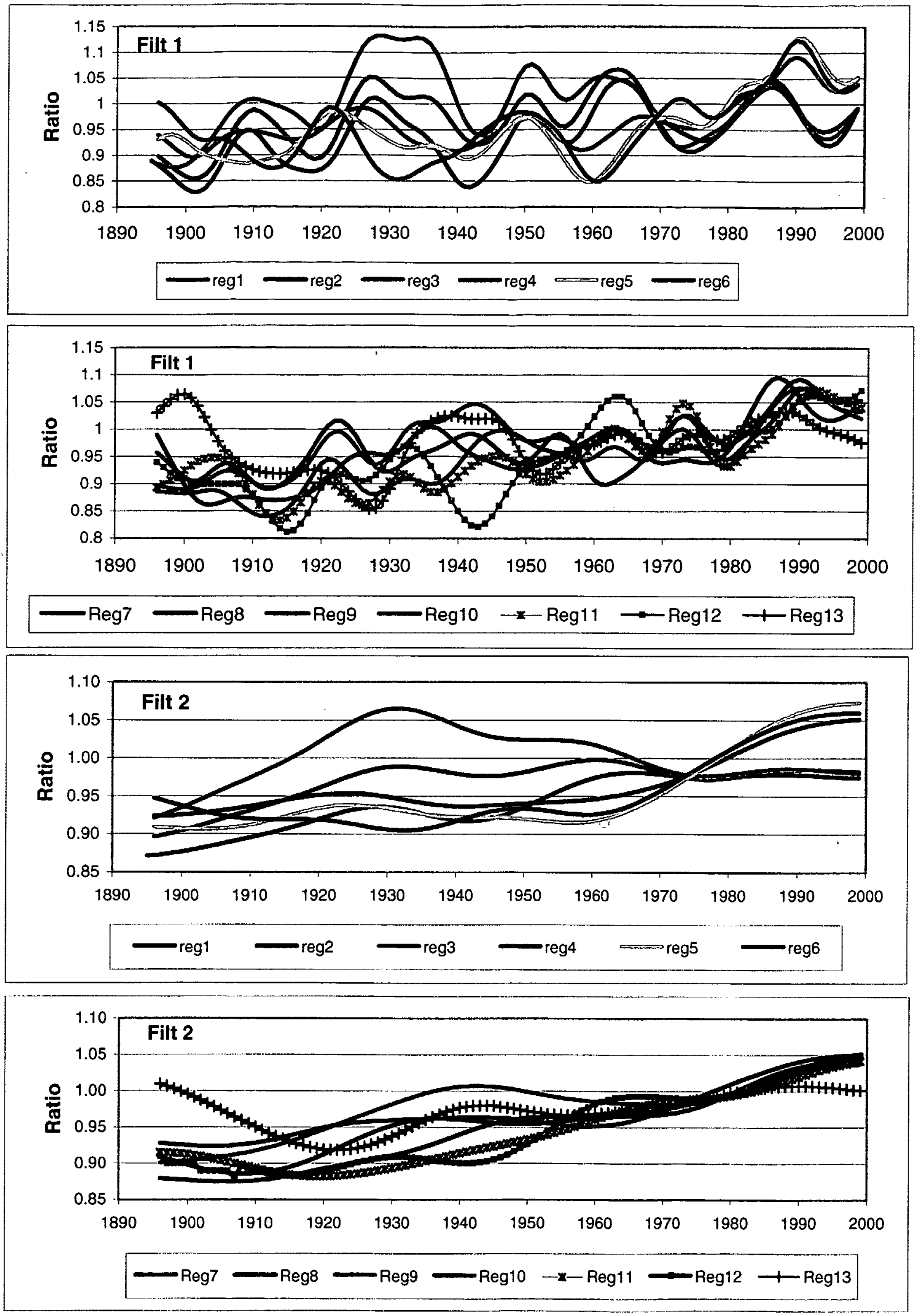


Figure 3.6 Low-pass filtered series of standardized annual precipitation for 13 Norwegian regions. All values are expressed as ratios to the 1961-1990 normal value.
Upper and lower graphs show low-pass filters indicating variations on decadal respectively 30 years time scales

and R3 there was a significant increase in winter precipitation from 1896 to the absolute maximum in the early 1930s. Negative trends in winter precipitation in these regions from the 1930s to around 1980 give no significant trend from 1896 to 1997. In regions R9-R12, the winter precipitation increased significantly from about 1915 to 1997. Decreasing winter precipitation during the first decades, however, prevents the positive trend during 1896-1997 from being significant in R9 and R10. The north-eastern region R13 shows a highly significant decrease from maximum winter precipitation in the beginning of the series to a dry spell around 1930. Still, the negative trend from 1896 to 1997 is not significant, as there is a positive trend from the absolute minimum in the early 1950s to 1997.

Førland et al. (1996) found that the **spring** precipitation in south-eastern Norway was up to 35% higher during the recent standard normal period (1961-1990) than during the previous (1931-60). North-west of the mountain divide, on the other hand, the spring precipitation was lower (up to 15%) than in the previous normal period. In spite of these dramatic variations in spring precipitation, the filtered series (Figure 3.7) and the Mann-Kendall tests on seasonal basis demonstrate that the spring precipitation shows no significant increase in southern Norway during the period 1896-1997. Though the spring precipitation increased significantly in most of the southern regions from the 1930s to 1999, particularly the eastern regions experienced a significant decrease in spring precipitation during the period 1896-1940. The south-eastern regions also tend to show a negative trend from the 1980s to 1999.

The features found in the south-eastern regions are quite contrary to those found in the regions R9-R11: Here, the average spring precipitation was lower during 1961-1990 than during 1931-1960. Still, the all over trend is positive, because there was a precipitation increase significant at the 1% level during the first 5 decades or so. The spring precipitation also tends to increase during the last 2 decades in these regions. The tendency for opposite trends in spring precipitation in regions R1-R3 and regions R9-R11 is clearly seen in Figure 3.7.

The decadal scale variability in **summer** precipitation (Figure 3.7) is rather similar in the southern regions R1-R6: A maximum occurred in the early 1960s, while the summers were rather dry around 1900, 1915, 1975 and 1995. The former minima tend to be the absolute lowest in west, while the 1975 minimum tend to be the lowest in the east. Dry periods close to both ends of the series, make linear trends for the entire period small in all these regions. In the northern regions, on the other hand, summer precipitation tends to increase from a minimum around 1910-1915 and at least to the 1960s. In the northern inland region R12, summer precipitation decreased somewhat during the last decades. On the other hand, in region R10, R11 and R13, the positive trend in summer precipitation is significant also for the entire period (Table 3.3).

Autumn precipitation has increased in all regions, though not statistically significant everywhere (Figure 3.7). In the southern regions R1-R6, the driest periods occurred around 1900 and/or 1905, while the wettest periods mainly occurred around 1965 and/or 1980. After 1980, autumn precipitation has decreased in southern Norway. Still, the positive trends during 1896-1997 are statistically significant in all southern regions except R3, and even in this region it is significant during the period 1896-1993. In the northern regions, autumn precipitation tends to decrease in the very beginning of the series, and the increase during the later decades is not sufficient to make the trend statistically significant during the entire period.

It should be noted that there are large regional differences in the seasonal contributions to the annual precipitation in Norway. In some areas (e.g. parts of region 2) almost 50% of the annual precipitation is falling during the three summer months, and less than 15% during the three winter months (Tveito et al., 1997). In other areas (e.g. parts of region 5 and 11) autumn or winter are the seasons with highest precipitation, and summer the season with lowest (15-20%) contribution to the annual precipitation. As a consequence of these differences in seasonal contributions, the anomalies in the annual precipitation will tend to be dominated by the anomalies in one or two seasons.

3.2.3 Linear precipitation trends

Results from Mann-Kendall tests of standardized annual and seasonal precipitation series for the period 1896-1997 are summarized in Table 3.3, where also linear trends of the series are given. Though all regions except the south-eastern region R3 ("Sørlandet") have experienced an increase in annual precipitation during this period, the positive trends are statistically significant at the 5% level in only 6 of the 13 regions. The precipitation increase tends to be largest and most significant in the north-western regions, where the annual precipitation has

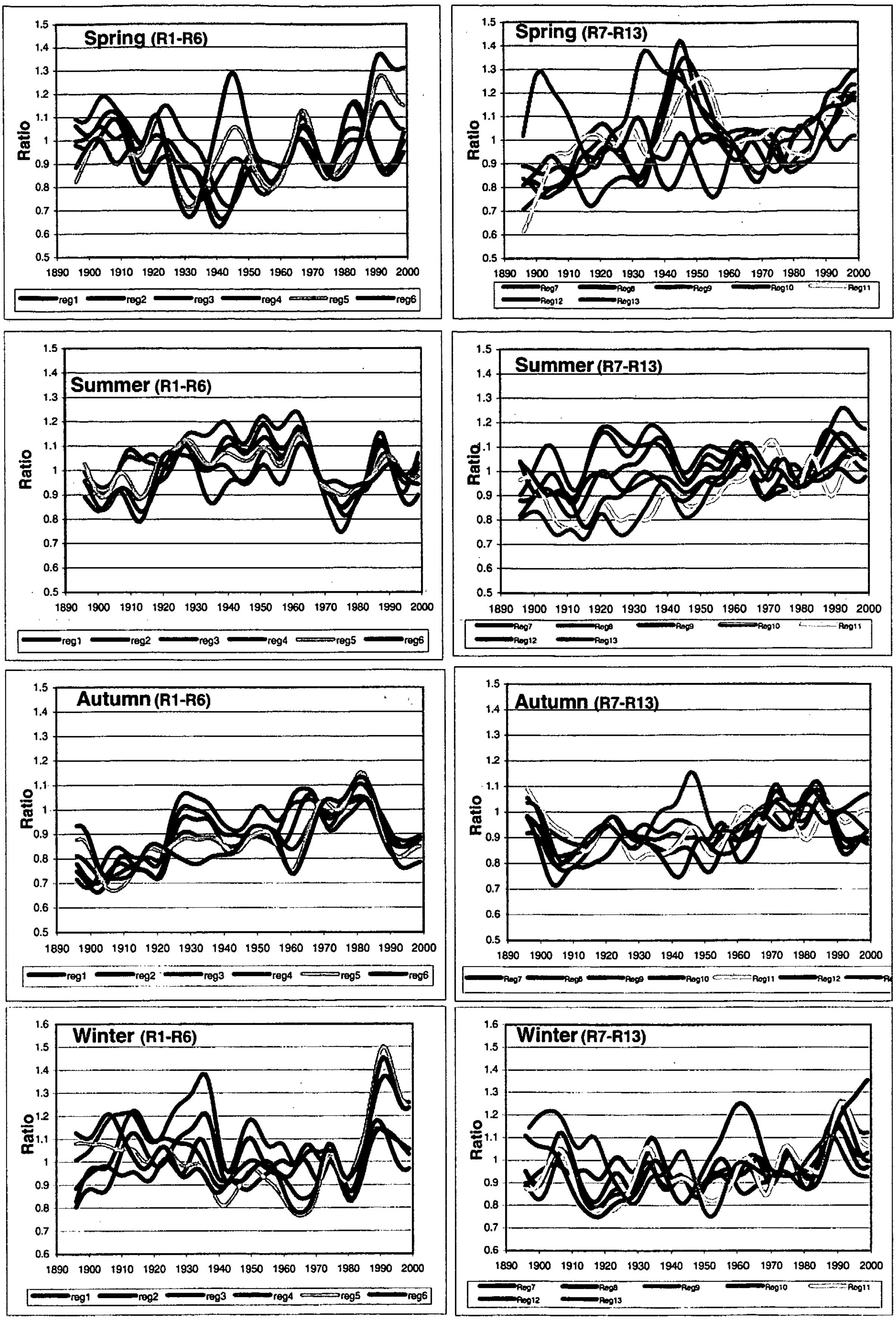


Figure 3.7 Low-pass filtered series of standardized seasonal precipitation for 13 Norwegian regions. All values are expressed as ratios to the 1961-1990 normal value.

a). Low-pass Gaussian filters, favorable for studying variations on decadal time scale

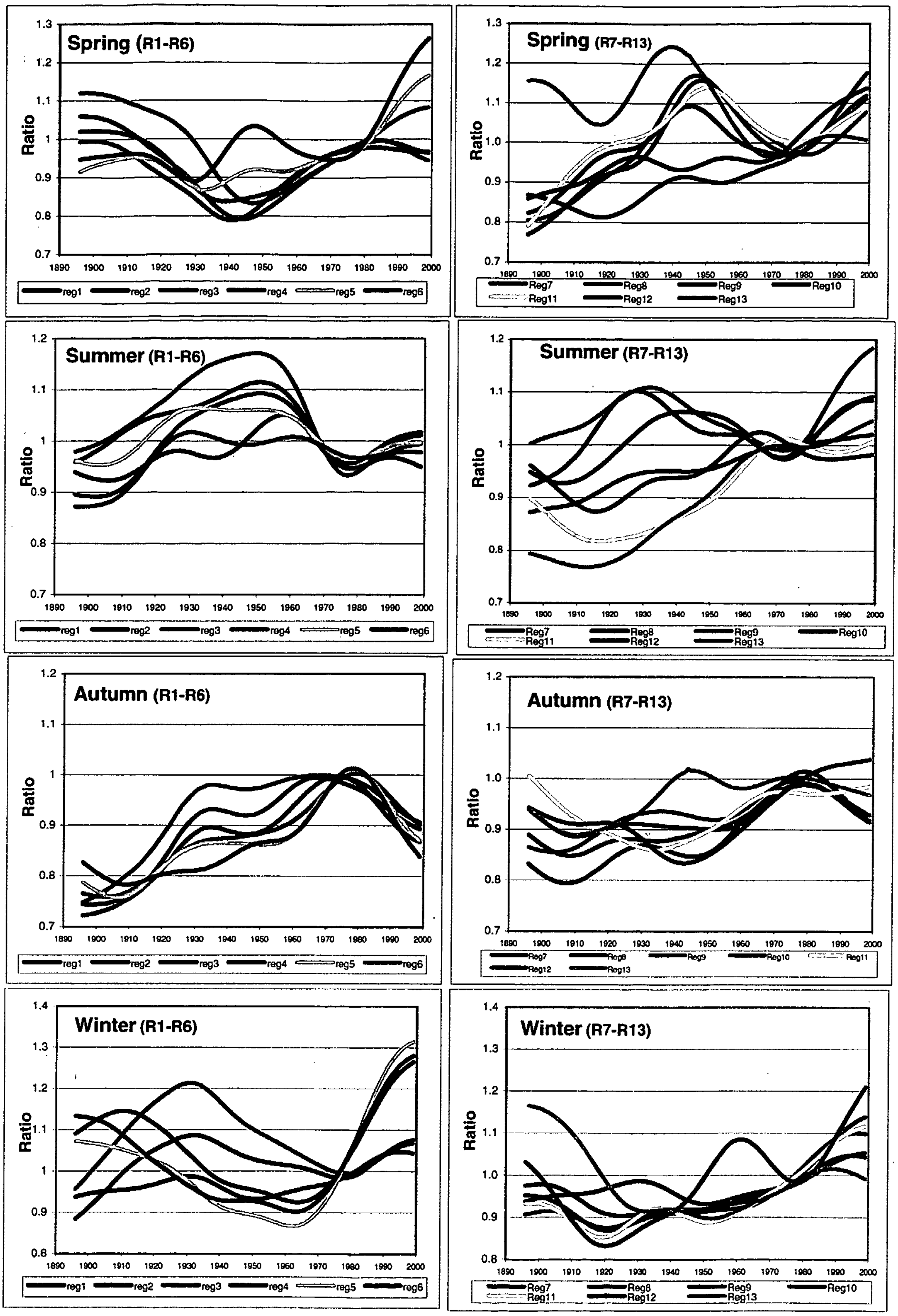


Figure 3.7 (contd) Low-pass filtered series of standardized seasonal precipitation for 13 Norwegian regions. All values are expressed as ratios to the 1961-1990 normal value. **b)**. Low-pass Gaussian filters, favorable for studying variations on 30-years time scale

increased by more than 15% during the 20th century. Table 3.3 shows that the regions with maximum precipitation increase at the Norwegian mainland, R10-R12, have experienced a statistical significant increase in the spring precipitation, as well as in winter and/or summer precipitation.

Table 3.3. Trends in annual and seasonal precipitation series during the period 1896-1997

Linear trends in the standardized regional series are given in %/decade of the normal value (1961-90). **Bold** and regular types indicate trends significant at the 1 respectively 5 % level according to the Mann-Kendall trend test. Trends which are not significant are given within brackets.

Region	Annual	Winter	Spring	Summer	Autumn
1	(1.0)	(0.7)	(-0.1)	(0.1)	2.3
2	(0.6)	(0.7)	(-0.8)	(-0.6)	2.3
3	(0.0)	(-0.5)	-2.1	(-0.9)	(2.0)
4	(0.9)	(-0.2)	(0.4)	(0.4)	**2.4**
5	1.2	(0.9)	(1.8)	(-0.2)	**2.2**
6	(1.2)	(0.3)	(2.2)	(0.7)	1.8
7	**1.4**	(0.5)	2.6	(1.0)	1.8
8	(1.2)	(1.3)	(2.4)	(0.5)	(1.0)
9	1.3	(1.5)	2.3	(0.4)	(1.4)
10	**1.8**	(2.0)	**3.0**	1.8	(1.2)
11	**1.7**	2.4	**2.5**	**2.0**	(0.6)
12	**1.6**	**2.3**	**2.3**	(1.3)	(1.1)
13	(0.5)	(-1.5)	(-1.6)	**3.3**	(1.1)

Autumn precipitation increased in all regions, but the increase was statistically significant only in southern Norway, in the regions R1, R2 and R4-R7. In all southern regions except R3, autumn is the only season in which the precipitation has increased significantly during the period 1896-1997. In summer and winter, only minor positive or negative changes are found during the period as a whole. Spring precipitation decreased significantly in region R3. This is the only statistical significant negative value in Table 3.3.

3.2.4 Running 20- and 30 year precipitation means

Running 20- and 30 years precipitation means on annual and seasonal basis for each of the 13 regions are presented in an Annex-report (Roald et al., 2000). As an example, the long-term precipitation development in region 6 (counties Hordaland and Sogn & Fjordane) is illustrated in Figure 3.8. The figure demonstrates that on annual basis the mean during the latest 20-years is 6% higher than the 1961-90 standard normal value, and that this most recent 20-years period is an absolute maximum during the last 100 years. Both the spring and winter values during the latest 20 years are representing maxima in the series, while the summer values had a maximum around 1940. The running 20-years winter means have increased by almost 40% since 1980.

The ratios between the most recent 20 and 30 years periods and standard normal values (1961-90) for the regions are summarized in Table 3.4. A more detailed spatial survey is given in section 4.2.

Table 3.4 Regional precipitation ratios between the latest 20- and 30 year periods and normal values during 1961-1990

	(1970-1999) /(1961-1990)					**(1980-1999) / (1961-1990)**				
Region	Annual	Spring	Summer	Autumn	Winter	Annual	Spring	Summer	Autumn	Winter
1	0.97	0.96	0.95	0.93	1.04	0.99	0.97	0.98	0.92	1.11
2	0.97	0.97	0.97	0.93	1.00	0.99	1.01	1.01	0.94	1.03
3	0.97	0.96	0.95	0.95	1.01	0.99	0.99	1.01	0.95	1.02
4	1.02	1.01	0.96	0.97	1.12	1.05	1.05	0.98	0.96	1.22
5	1.03	1.03	0.97	0.97	1.15	1.07	1.09	0.99	0.95	1.27
6	1.04	1.07	0.97	0.97	1.14	1.06	1.16	0.97	0.91	1.23
7	1.01	1.01	1.04	0.96	1.00	1.05	1.08	1.08	0.98	1.03
8	1.03	1.04	1.04	1.00	1.05	1.04	1.10	1.05	0.95	1.10
9	1.02	1.00	1.08	0.99	1.00	1.04	1.04	1.14	0.94	1.03
10	1.02	1.02	1.02	0.98	1.06	1.02	1.08	1.01	0.94	1.10
11	1.02	1.02	1.01	0.98	1.06	1.02	1.05	1.01	0.96	1.09
12	1.02	1.02	1.01	0.98	1.06	1.02	1.05	1.01	0.96	1.09
13	1.00	1.00	1.01	1.00	0.99	1.01	1.02	1.02	0.99	1.02

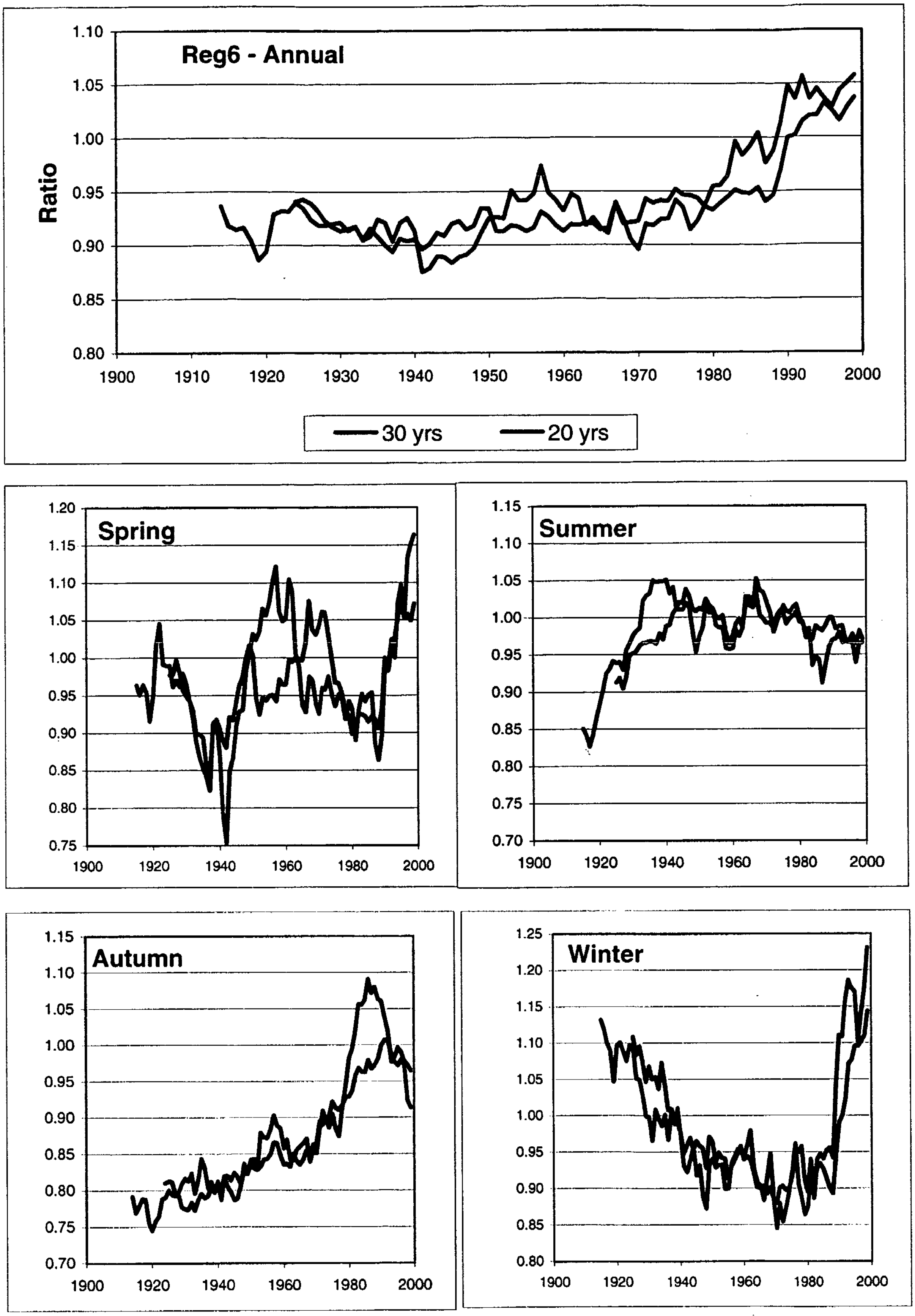


Figure 3.8 Running means (20 and 30 years) of standardized annual and seasonal precipitation in region 6 (Hordaland, Sogn&Fjordane).
The values are plotted on the last year in the averaging period.

3.3 Runoff

3.3.1 Long-term annual variations of the runoff

Annual and seasonal runoff series are presented in an Annex-report (Roald et al, 2000) for all runoff regions. The series were standardized as described in section 2.2.3, and represent the ratio between the value each year and the long term mean of the normal period 1961-90.

The regions of East Norway (region 1- 3) are characterized by wet periods from 1924-1931, 1934-38 and 1950-55, dry periods 1940-42, 1947 and 1968-1983, with an increasing discharge since then, peaking in 1989/90. The dry period in the 1970s is most pronounced in region 1, and is less severe in the western part of East Norway. Region 13 represents a lowland catchment in the Southeast corner of Norway and deviates in some degree from the other regions in East Norway. Figure 3.9 show the low-pass filtered annual series of regions 1-4 and 13.

The wet years in the 1920s is a primary cause for the negative trend of the runoff in East Norway. A composite series of daily runoff has been developed for River Glomma at Sarpsfoss gauging station for the period 1846-1998, and give additional information of the long-term variability. The data series is based on observed water levels at Sarpsfoss for the period 1851-1900, and a rating curve, which was established between 1880 and 1900. The water levels are from 1846-1851, and later gaps in the series has been filled in using observed water levels at other locations in the lower part of the river. From 1901 data from the gauging station at Langnes was applied until 1964, when data from Solbergfoss power station has been used. The annual runoff from Glomma is shown in Figure 3.10. The runoff had a pronounced wet period from the 1920s to 1967, although with some dry years in between, coinciding with the dry years of the shorter regional index series. There is a considerable uncertainty in applying the 1880-1900 rating curve in the early part of the series, but the variations are quite similar to the variations at Elverum further upstream.

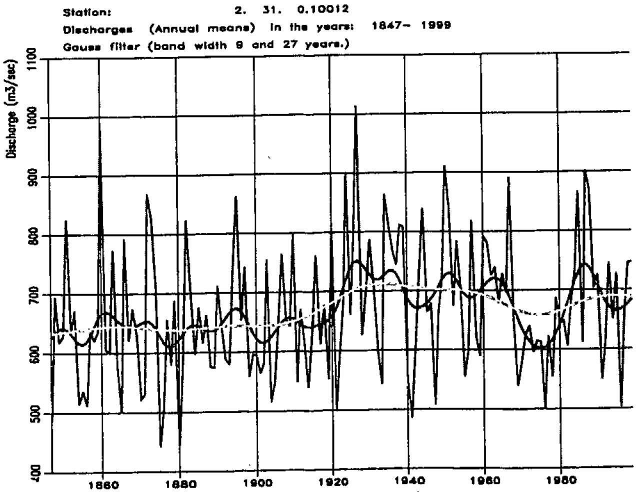


Figure 3.10. Annual runoff at Sarpsfoss 1847-1998

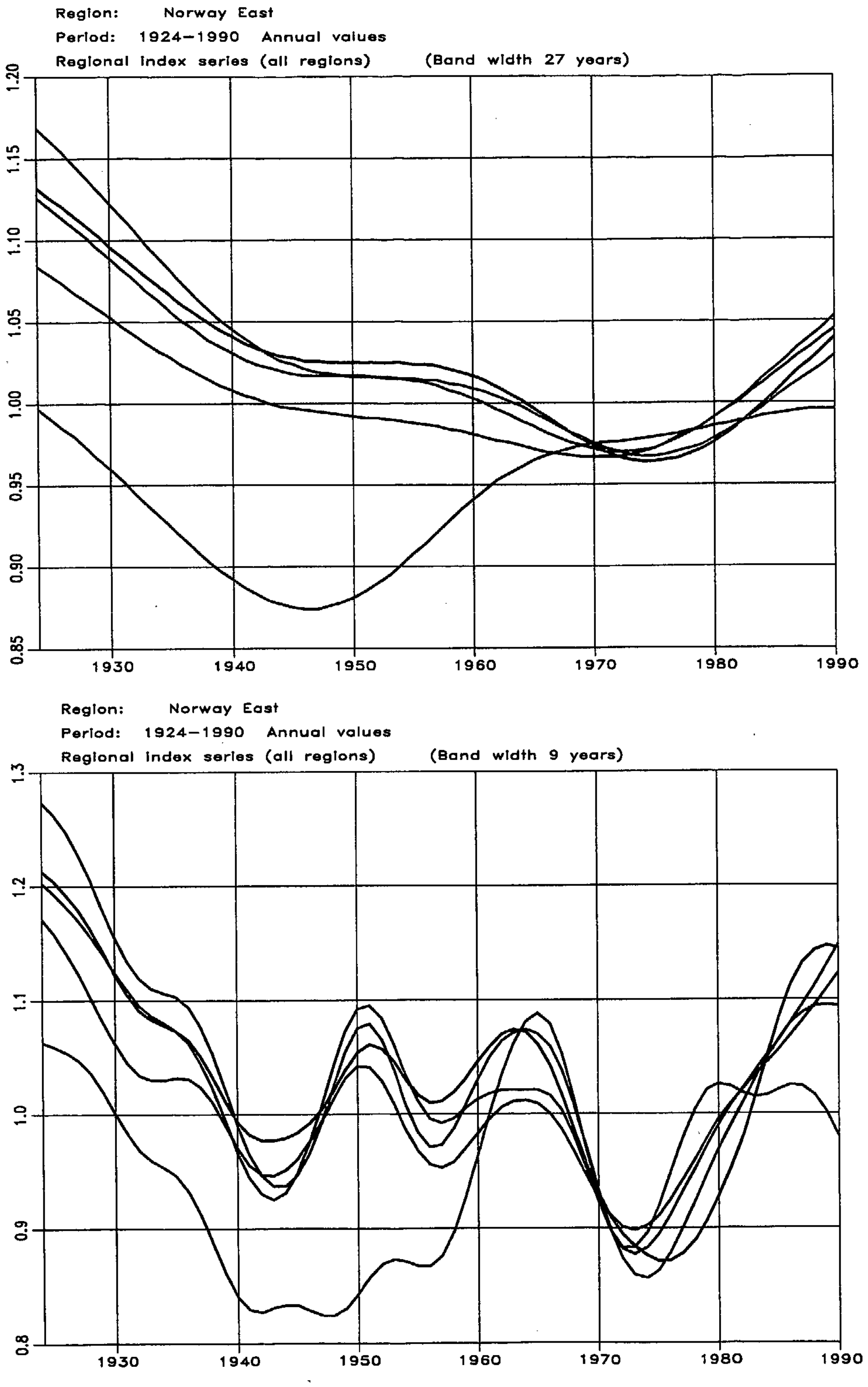


Figure 3.9. Regional index series for annual runoff in East Norway. Low-pass Gaussian filters, favourable for studying variations on decadal (lower) and 30-years (upper) time scales. Region 1: Black, Region 2: Red, Region 3: Green, Region 4: Blue, Region 13: Turquoise

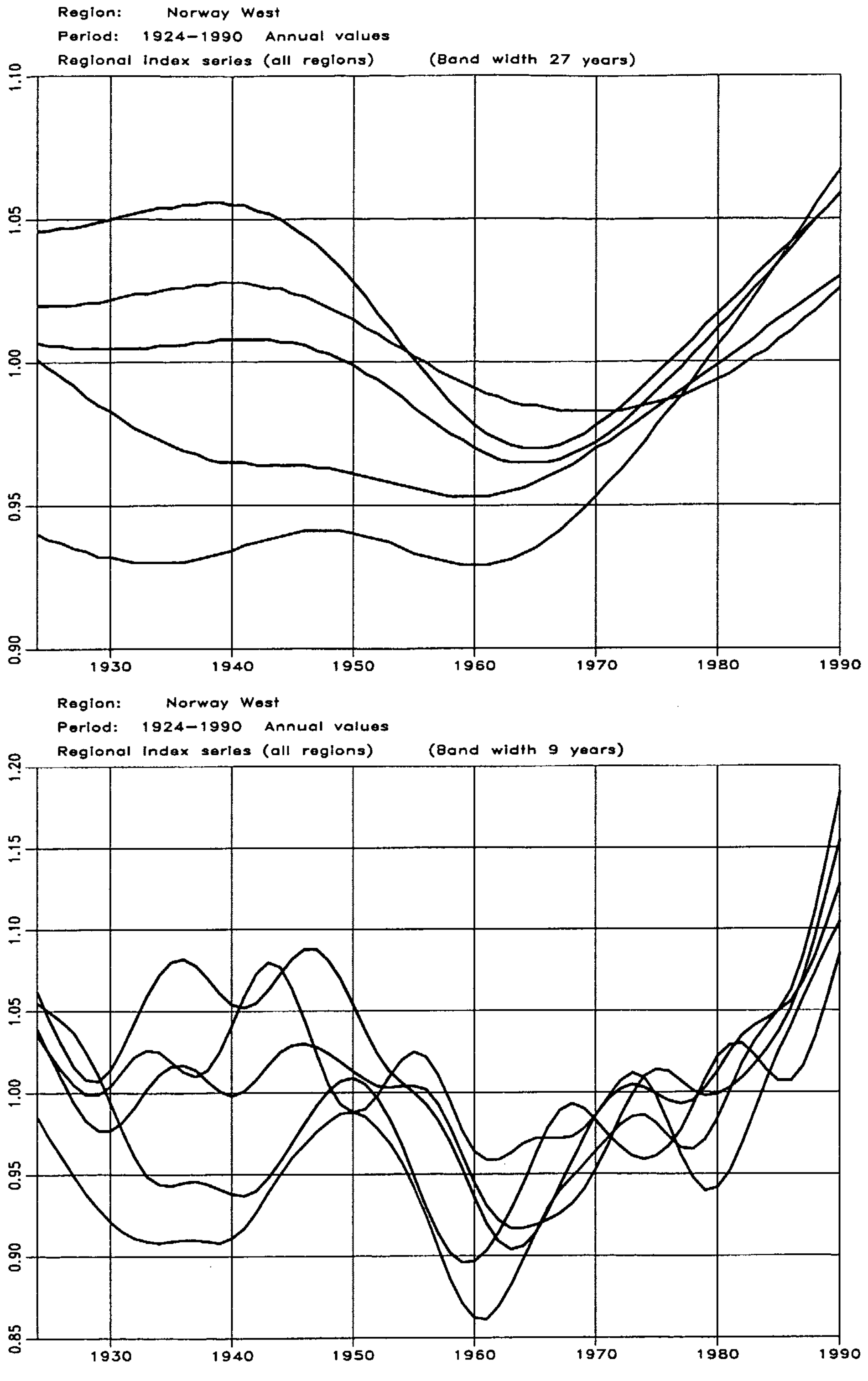


Figure 3.11. Regional index series for annual runoff in Western and Central Norway. Low-pass Gaussian filters, favourable for studying variations on decadal (lower) and 30-years (upper) time scales. Region 5: Black, Region 6: Red, Region 7: Green, Region 8: Blue, Region 9: Turquoise

The annual runoff in West Norway (region 6) is quite constant up to around 1960, when a rise occurs, similar to the increase of the precipitation. A series going back to 1892 indicates that it was wetter early in the series, the previous normal period 1931-60 is the driest 30- year period in the series, while the recent normal period has the wettest 30- year annual mean value. Some series do not have the recent increase in the discharge or inflow. This is only the case for one of the series defining the regional index series, but it has also been found for other shorter series in the region. A common property of these catchments is that they are oriented east-west. They are also located fairly close to the coast. Region 7 (Glaciers) is characterized by a high year-to-year variability. The 1930s were characterized by high flows with a pronounced dry period from 1960 to1983, and rising runoff since then. The series included in the region are from South Norway, but a similar pattern has been found for Svartisen Glacier in Nordland (Engeset et al., 1999). The year-to-year variability is also high in region 9 Mid Norway with at surplus until 1949, then a period with a deficit until the runoff started to rise from 1980 onward. Low-pass filtered series of annual runoff in Western and Central Norway are shown in Figure 3.11.

The regional inflow of region 10 Fosen-Nordland is a little low in the 1920s, but the series are otherwise fairly constant throughout the period. Some of the series indicate a rise similar to the increase observed in West Norway in recent years, while other are quite constant. Region 11 West Finnmark has low inflow in the 1920s, but is otherwise fairly constant. Region 12 East Finnmark comprises just one station, which had a deficit 1933- 1963. The more recent years are similar to region 11. The low-pass filtered series are shown in Figure 3.12.

3.3.2 Long-term seasonal variations of the runoff

The seasonal analysis of the inflow was based on the ratio between the seasonal mean of each year and the normal for the period 1961-1990 for each region. The analysis was performed for the same seasons as for temperature and precipitation. The subsequent overview of the results is based on results of the entire period used in the analysis. It is unfortunate that 1924 and 1927 were both wet years, which tend to give high values even to the two filters used on the index series early in the period. Figure 3.13 shows the seasonal pattern for the regions in East and West Norway. These two regions show the contrast in regional seasonal pattern of inflow variations between East and West Norway.

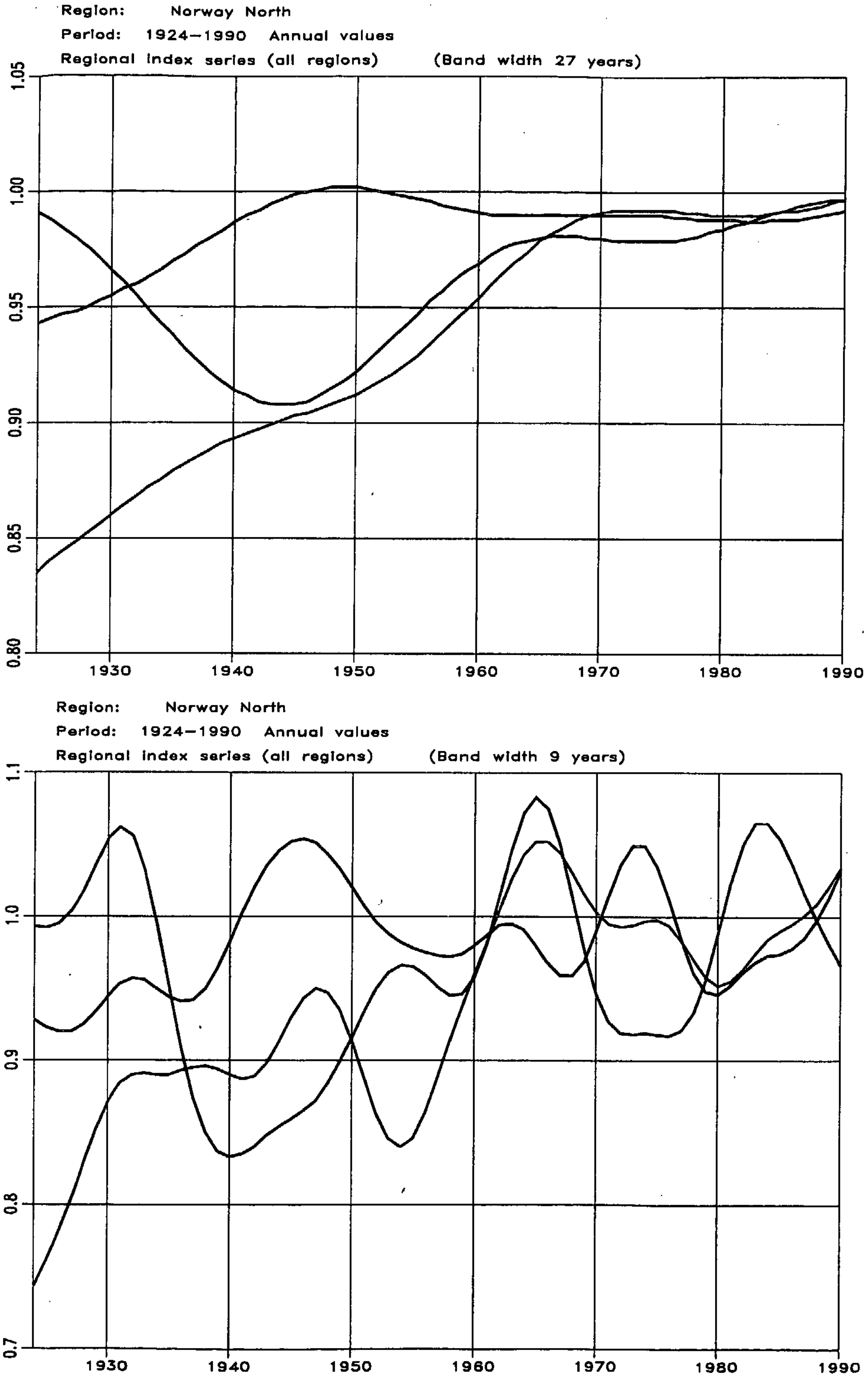


Figure 3.12. Regional index series for annual runoff in Northern Norway. Low-pass Gaussian filters, favourable for studying variations on decadal (lower) and 30-years (upper) time scales. Region 10: Black, Region 11: Red, Region 12

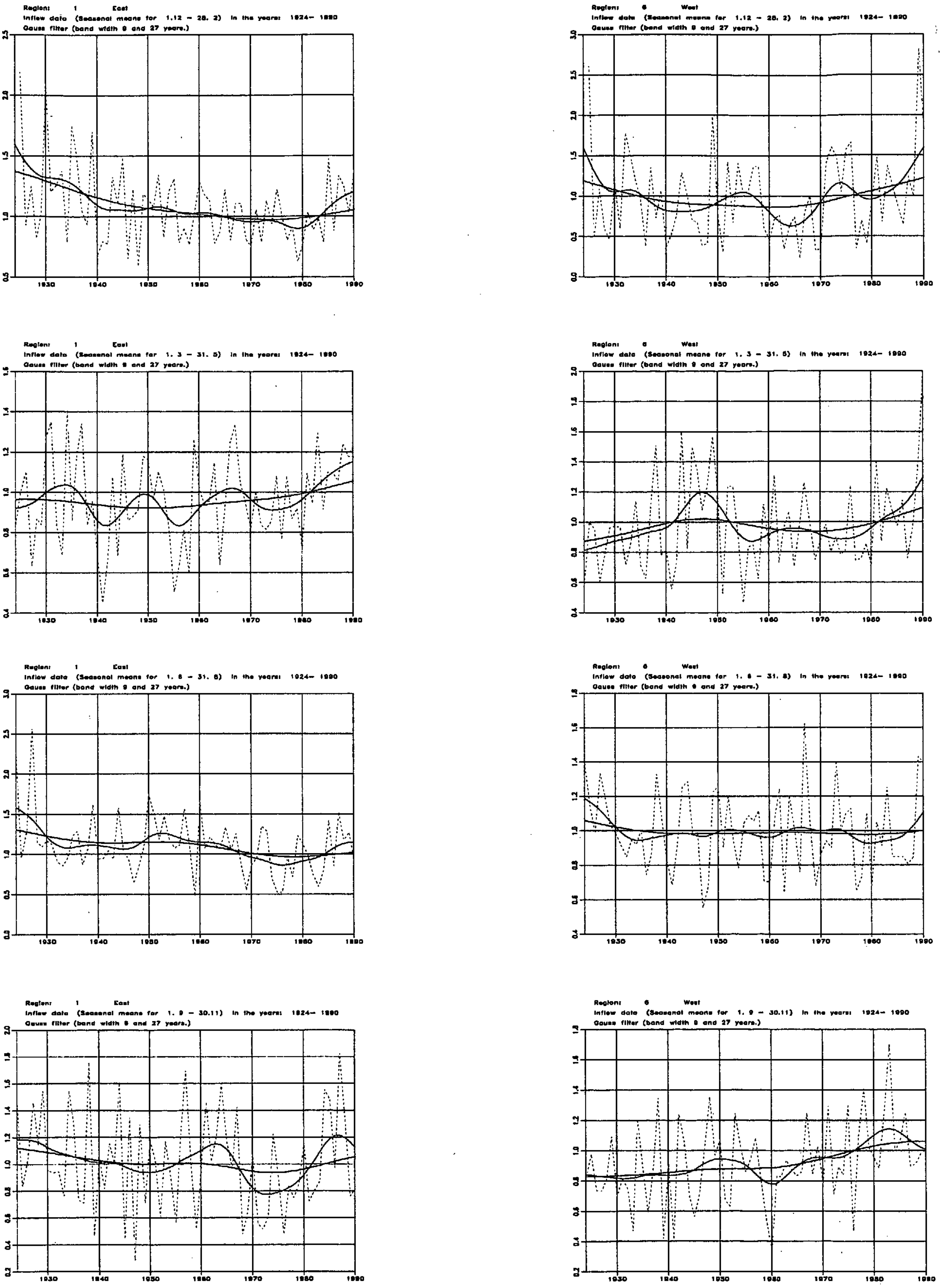


Figure 3.13. Seasonal index series for East and West Norway. Low-pass Gaussian filters, favourable for studying variations on decadal (red) and 30-years (green) time scales.

The seasonal pattern is rather similar in east Norway, but the year-to-year variability differs between each region. There is a general similarity between region 5 and 6, West Norway. The recent increase in the autumn is also present in Mid Norway, but the early part of the period was also more humid. Region 7 and 8 represent catchments in high mountains, with some or large influence of glaciers. Region 8 has more than 10 % glaciers of each catchment. These catchments are all located in West Norway. Both regions have a marked increase in the spring runoff. Both regions have also a general, but weaker increase in the autumn. The Glacier region has a remarkable decrease in the summer runoff, from the warm period in the 1930s to a period from 1960, when the maritime glaciers have had a change towards more positive mass balance over time, (Kjøllmoen, 2000; Andreassen, 2000). The summer runoff was high early in the period in region 7, and has recently reached about the same level, but the variability is fairly small.

The large region of Fosen-Nordland has a marked increase in the spring runoff and a moderate increase in the autumn. This is compensated by slightly declining runoff in the other seasons, resulting in a fairly stable annual runoff.

The results of the seasonal analysis can be summarized by:

- The **spring** runoff has increased in all regions, most obvious in region 7 and 8.
- The **summer runoff** has declined markedly in region 1- 4, 7 and 9, and is otherwise stable or has an insignificant reduction.
- The **autumn runoff** has increased markedly in regions 5 and 6, especially since 1960. Regions 7– 10 have a small increase, while region 1- 4 have a small decrease.
- The **winter** runoff is stable or indicates a weak decrease in most regions. The winter data based on the inflow is however more uncertain, because the values usually are small, and easily affected by weaknesses in the current procedure for calculating the inflow.

3.3.3 Linear trends of the runoff

Results from Mann-Kendall tests of standardized annual and seasonal runoff index series are summarized in Table 3.5. The values given in this table refer to the period 1924-1990 and cannot be directly compared to Table 3.3. Data series from Elverum and Bulken have been used as index series of runoff region 1 and 6 for the full period 1895-1999. Table 3.6 gives annual and seasonal trends of the series observed at the two stations. The runoff at Elverum is gradually affected by upstream regulations, which affects the seasonal means, especially in the winter. The seasonal trends are therefore not representative of the trends of the natural runoff within the region. The data from Bulken is less affected by upstream regulation, and the seasonal values should therefore be better indicators of the seasonal index series of region 6. There is however a significant variability in the seasonal distribution within the region, and the seasonal values of just one series cannot be expected to give a close estimate of the average annual cycle of the entire region.

Table 3.5 Trends in annual and seasonal inflow series during the period 1924-1990

Linear trends in the standardized regional series are given in % of the normal value per decade.
Bold and regular types indicate trends significant at the 1 resp, 5 % level according to the Mann-Kendall trend test. Trends, which are not significant, are given within brackets. The winter data has some suspicious data early in the period and has therefore not been included in the Table. Generally the winter inflow has a weak decline.

Region	Annual	Spring	Summer	Autumn
1	-2.0	1.4	-5.6	(-2.0)
2	-3.3	1.7	**-9.5**	(-0.9)
3	(-0.1)	**3.4**	-4.1	(0.1)
4	-2.7	1.2	**-6.6**	(-1.1)
5	(0.3)	(0.9)	-3.0	**6.8**
6	2.0	(1.0)	(+0.1)	**4.2**
7	(-0.6)	4.0	**-3.8**	2.1
8	(0.2)	**5.2**	(-0.1)	(1.0)
9	(-.3)	1.6	-3.3	(1.0)
10	(0.3)	2.6	(-0.9)	3.5
11	2.2	**6.3**	(-0.1)	(0.1)
12	(0.1)	**7.2**	(-0.7)	(0.0)
13	(0.1)	5.1	(-2.0)	(0.1)

Table 3.6. Trends in annual and seasonal inflow series during the period 1895-1999

Data from Elverum is used as index for region 1 and data from Bulken as index of region 2.
Linear trends in the standardized regional series are given in % of the normal value per decade.
Bold and regular types indicate trends significant at the 1 resp, 5 % level according to the Mann-Kendall trend test. Trends, which are not significant, are given within brackets.

Region	Annual	Winter	Spring	Summer	Autumn
1	(0.1)	**(8.8)** *	(-0.2)	(-3.2)	(1.1)
2	**2.9**	2.6	**2.5**	(1.3)	**2.5**

* Effect of regulation

3.3.4 Running 20- and 30 year means of the runoff

The ratio between the mean of most recent 20 and 30 years and the standard periods of 1961-90 and 1931-60 are shown in Tables 3.7 and 3.8. The seasonal values of region 1 and 10 are affected by regulations.

Table 3.7 Regional runoff ratios between the latest 20- and 30 year periods and normal values during 1961-1990 for region 1, 6 and 10 based on at-site data from Elverum, Bulken and Fustvatn.

	(1970-1999) /(1961-1990)					**(1980-1999) / (1961-1990)**				
Region	Annual	Spring	Summer	Autumn	Winter	Annual	Spring	Summer	Autumn	Winter
1 *	.99	.99	.98	.96	1.09	.99	.99	1.12	.93	.84
6	1.04	1.02	1.01	1.04	1.20	.94	.96	1.01	.85	.94
10	1.01	1.01	.93	1.02	.97	.97	.99	1.00	.90	1.01

* 1999 has a few missing values, which will be filled in later. This year has therefore been excluded in the calculation of the ratio.

Table 3.8 Regional runoff ratios between the latest 20- and 30 year periods and normal values during 1931-1960 for region 1, 6 and 10 based on at-site data from Elverum, Bulken and Fustvatn.

	(1970-1999) /(1931-1960)					**(1980-1999) / (1931-1960)**				
Region	Annual	Spring	Summer	Autumn	Winter	Annual	Spring	Summer	Autumn	Winter
1	.99	1.00	.88	1.03	1.28	1.00	1.01	.98	1.02	1.02
6	1.18	1.07	1.12	1.30	1.35	1.07	1.06	1.02	1.11	1.09
10	1.03	1.00	1.01	1.16	.87	.99	.98	1.01	1.02	.92

4. Anomalies for the 20-year period 1980-1999 compared to the reference periods 1961-90 and 1931-90

In chapter 3 it is documented that there are significant climate trends in Norway in the 20th century, and that in some regions the most recent decades exhibit quite large anomalies from the reference values ("normals"). For production planning, revision of older constructions or planning of new installations, the hydropower producers in Norway have to consider whether the reference values for inflow precipitation and temperature are giving adequate measures. In such considerations, it can be a useful tool to know the anomalies for e.g. the most recent decades compared to the common reference periods.

In the following chapters maps showing the spatial distribution of the differences between the period 1980-1999 and the reference periods 1961-90 (current normal period) and 1931-90 are shown. The period 1931-90 is applied since NVE and a number of hydropower producers use this period as reference period for discharge. Such maps can give an impression whether e.g. design values have to be reconsidered due to climate variability, or if the confidence intervals for such values should be reconsidered taking this variability into account.

These maps are based on observed values for the period 1980-1999. The reference values are based on the normal values 1961-90 (Aune, 1993, Førland, 1993) and 1931-60 (DNMI, 1985,1987). Maps are derived for annual and seasonal statistics.

4.1 Temperature

These maps are based on observations from 59 stations having complete series the entire period 1980-99. For five of these stations, normal values for the period 1931-60 were not available. Consequently these stations are not used in the 1931-90 maps.

The temperature differences are expressed as the residual between the mean value 1980-99 and the periods 1961-90 and 1931-90 respectively by the expression:

$$\Delta T = T_{80\text{-}99} - T_{ref} \qquad (4.1)$$

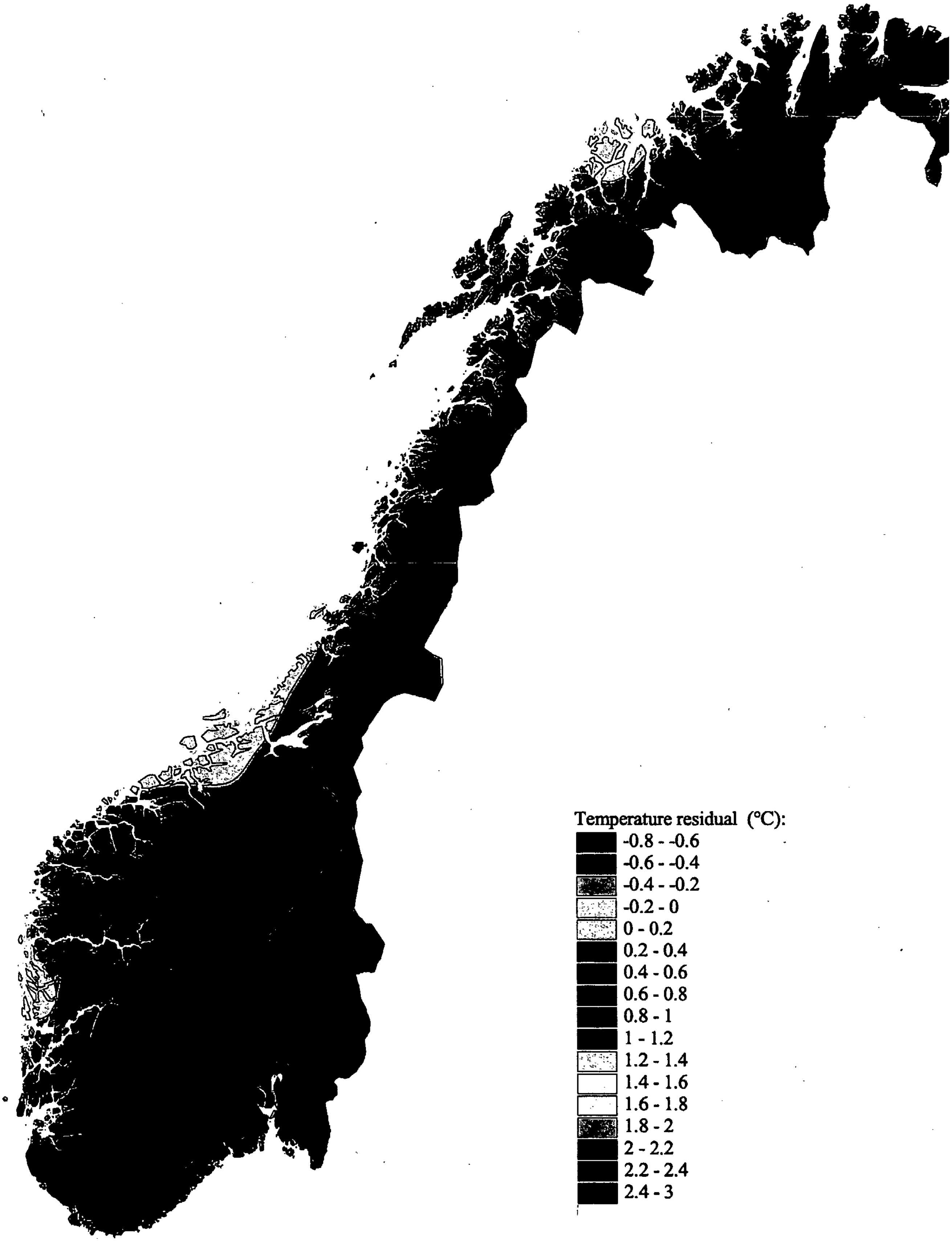
where ΔT is the temperature residual, T_{80-99} is the mean temperature 1980-99 and T_{ref} is the mean temperature in the reference period. In the maps, isotherm intervals are 0.2°C, but a dashed contour line is given for each 0.1°C. It should be noted that these maps present temperature anomalies directly in °C, while the graphs in chapter 3 are expressing anomalies as standard deviations.

4.1.1. The difference between the periods 1980-99 and 1961-90.

Figure 4.1 shows annual and seasonal maps of the difference in temperature between the last two decades and the current normal period. There is an overall increase in annual temperature. The increase is largest in inland areas, up to 0.8°C in an area close to the Swedish border. Most of this increase occurs in the winter season, where the temperature has increased about 1°C during the last 20 years compared to the 1961-90 period. Less temperature increase occur in the summer and autumn seasons, which also shows lower temperatures in central mountain areas and large areas in Troms and Finnmark.

4.1.2. The difference between the periods 1980-99 and 1931-90.

Figure 4.2 shows the difference between the last two decades and the reference period 1931-90. Also this map shows higher annual temperatures except in large parts of Troms and Finnmark. The seasonal maps show that most of the warming has occurred in winter and spring. However, in the winter season, the last 20 years have been up to 0.3°C colder in inner parts of Finnmark. In spring the whole country has been warmer. During summer and autumn the temperature differences are small. Northern Norway has experienced colder summers the last 20 years compared to the sixty years 1931-90. In autumn most of the country has become colder.

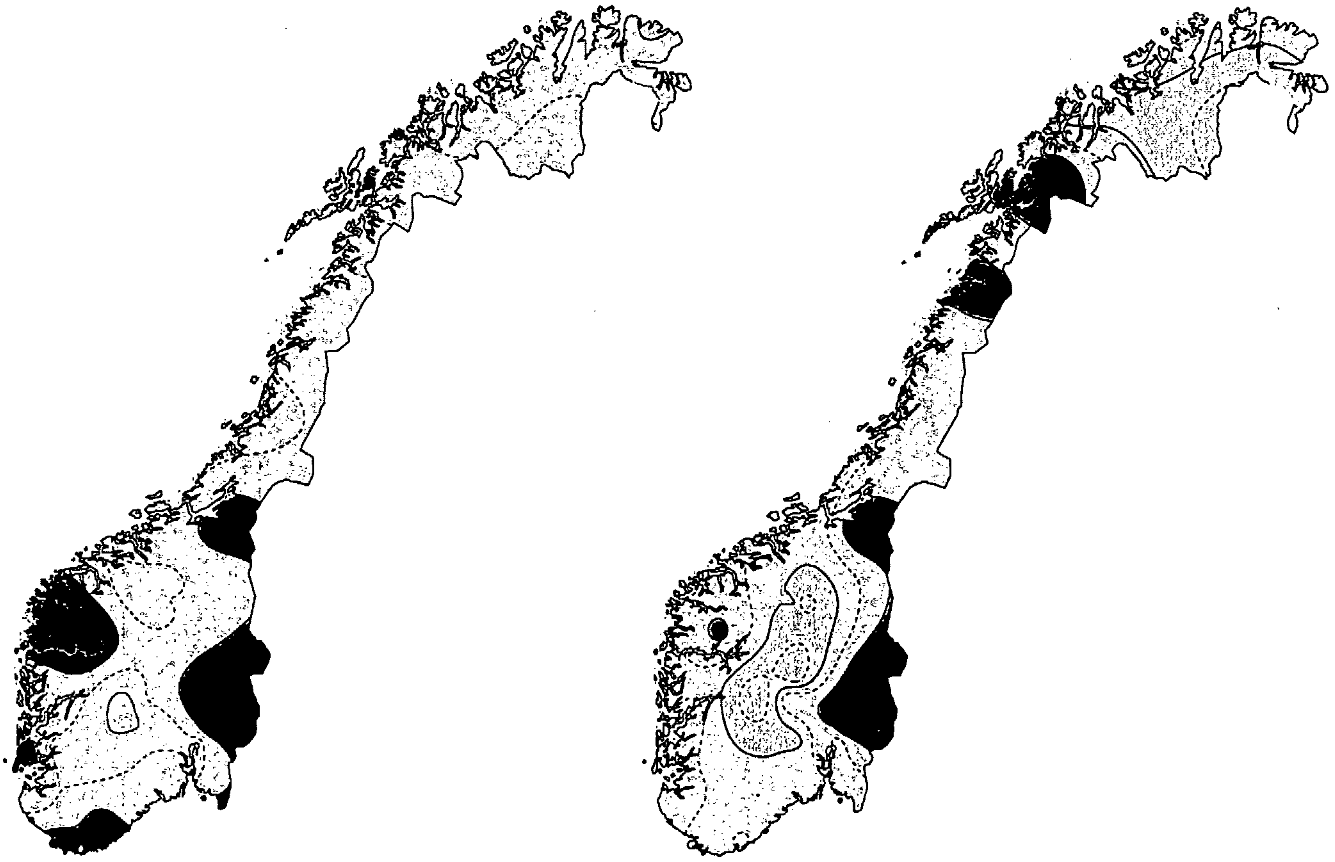


a) Annual

Figure 4.1 Annual and seasonal (next page) temperature differences between the periods 1980-99 and 1961-90.

b) Winter

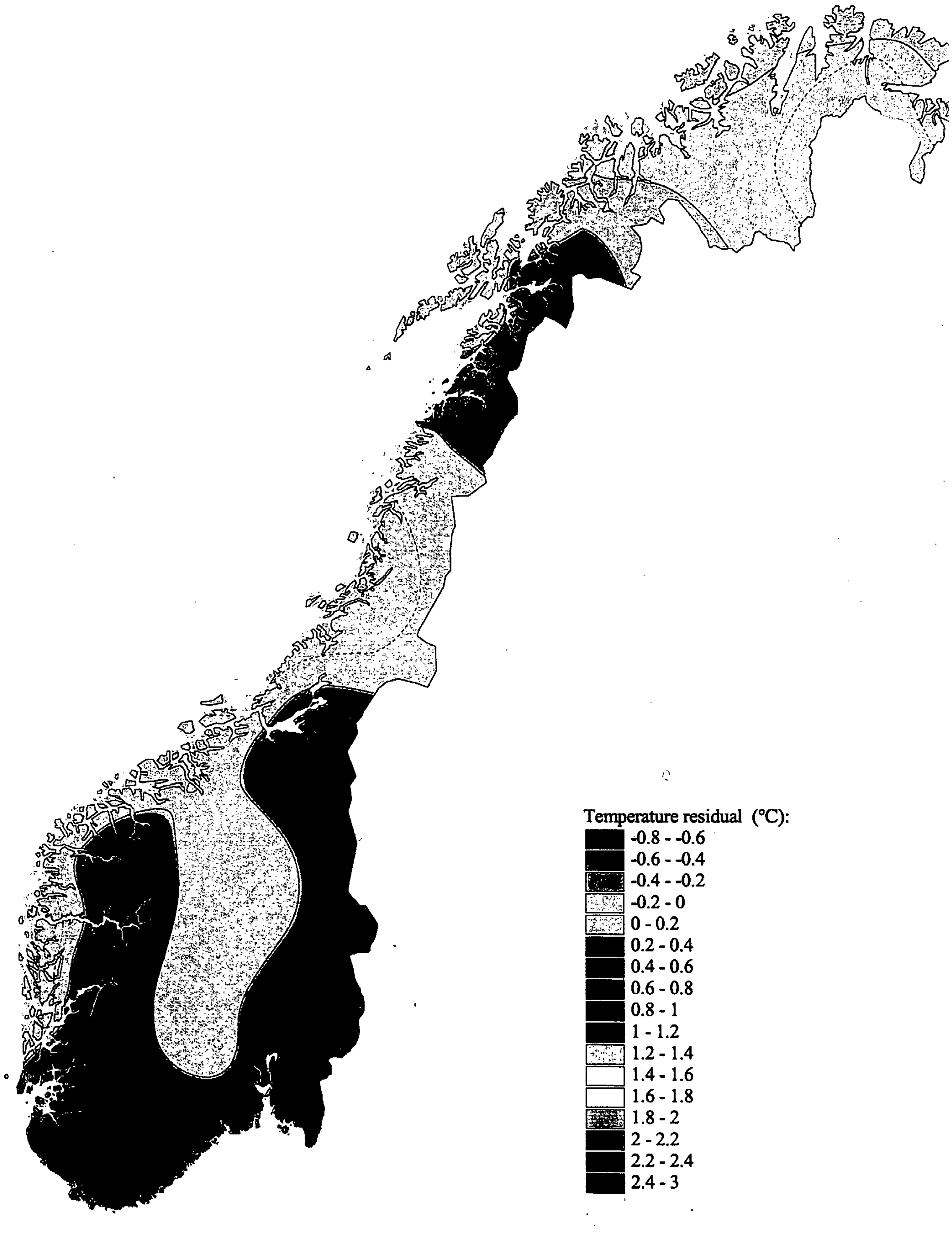
c) Spring



d) Summer

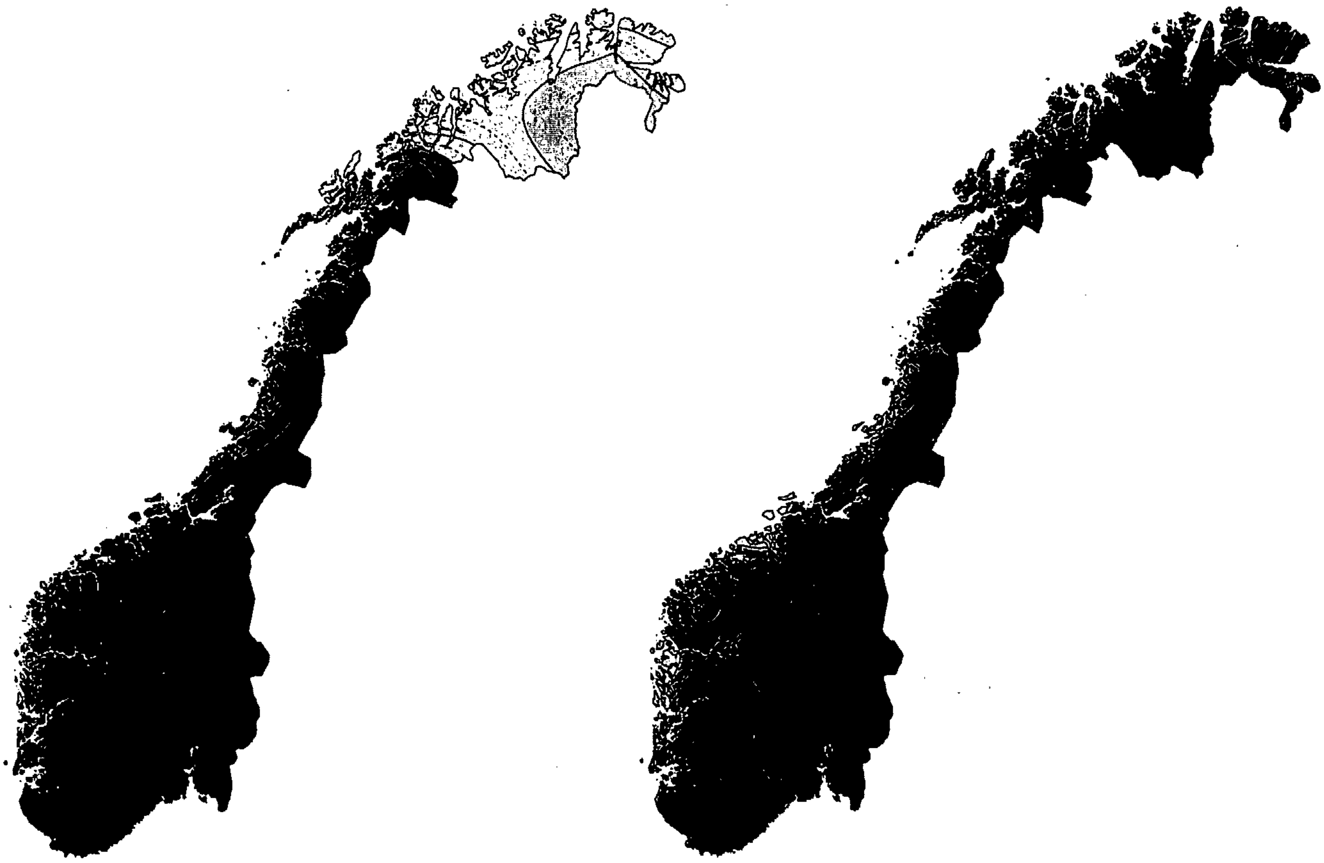
e) Autumn

(Fig 4.1 cont)



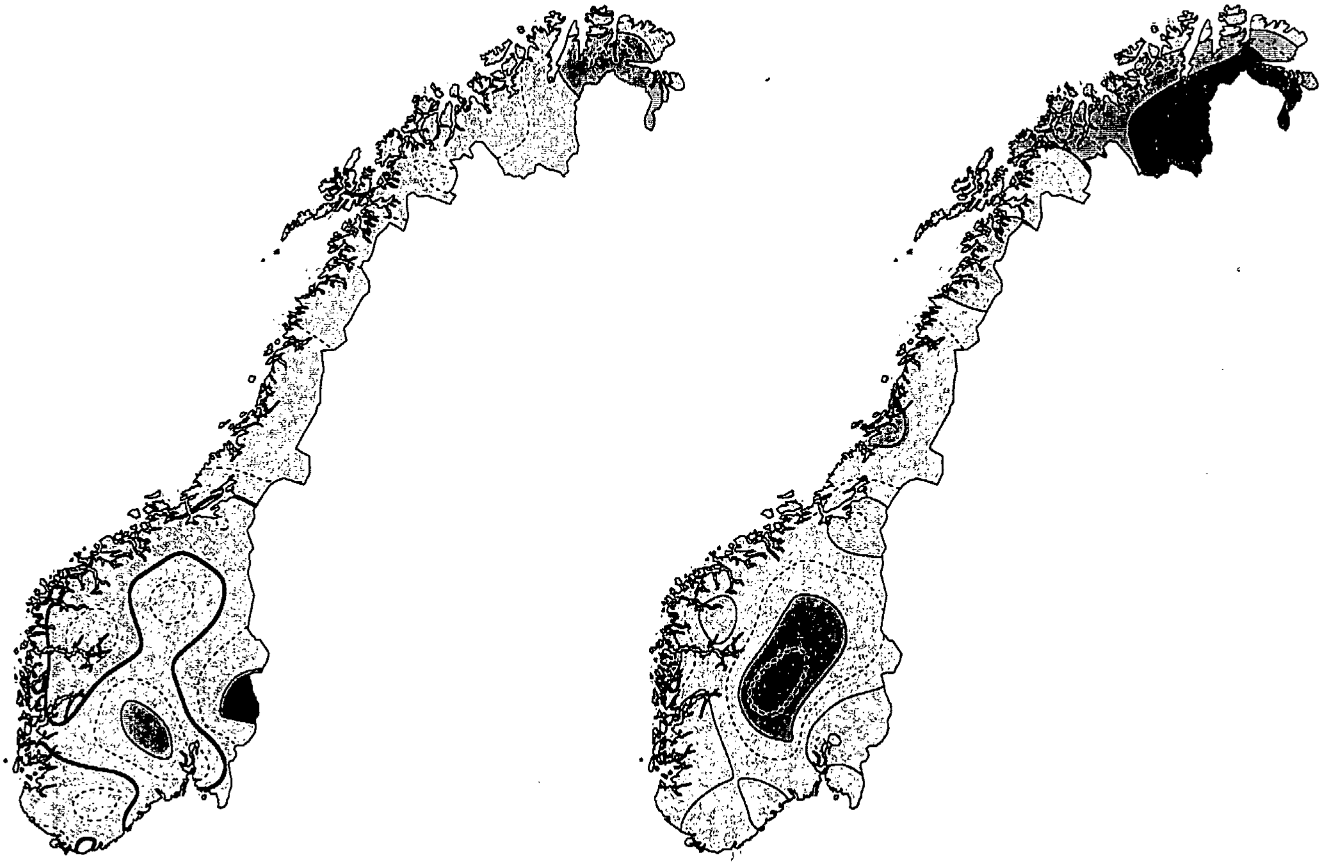
a) Annual

Figure 4.2 Annual and seasonal (next page) temperature differences between the periods 1980-99 and 1931-90.



b) Winter

c) Spring



d) Summer

e) Autumn

(Fig.4.2 cont.)

4.2 Precipitation

The precipitation maps are based on 516 precipitations series covering the entire period 1980-1999. 20 of these series lack normal values for the period 1931-60, and are excluded from the maps related to the 1931-90 period. The maps show the ratio between the twenty year period 1980-99 and the reference according to:

$$(4.2) \qquad R = \frac{R_{80-99}}{R_{ref}}$$

where R is the ratio, R_{80-99} the mean value of the period 1980-99 and R_{ref} is the mean value of the reference period. The maps have isohyet intervals of 0.05, representing 5% changes. The maps established contain a lot of details due to the large amount of stations included. Some of these stations may have characteristics deviating from the regional patterns due to local conditions like terrain etc. at the station locations. In the following only the large scale regional patterns are discussed.

4.2.1 Ratio between the periods 1980-99 and 1961-90.

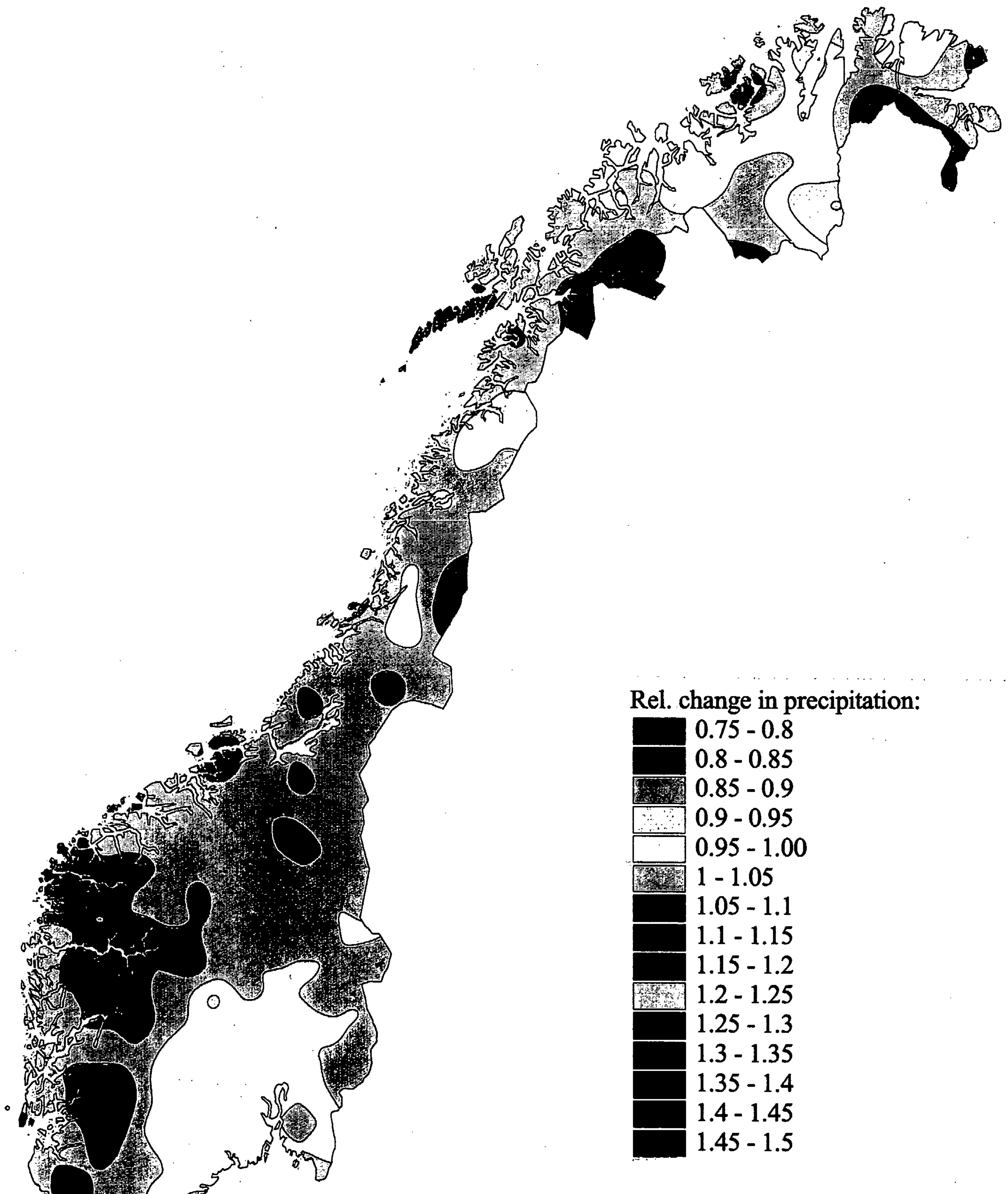
Figure 4.3 shows annual and seasonal maps of the ratio between the period 1980-99 and the current normal values. Annually the changes are small. There has been a moderate increase in precipitation at the western coasts. In southeastern Norway, there has been a small decrease in precipitation. In northern Norway, there are quite large variations. These variations are difficult to interpret, since the station coverage in this area is sparse, and single stations may dominate the pattern. The seasonal maps show a strong increase in winter precipitation in most parts of Norway, except an area in central eastern Norway, and a few areas in northern Norway. The maximum increase occur in western Norway, where the winter precipitation has been more than 20-25% higher in the period 1980-99 than in the normal period 1961-90 (cf. Table 3.4). In spring a similar pattern occur, but the variations are smaller.

In the summer and particularly the autumn seasons, precipitation sums for the last 20-year period are lower than the 1961-90 normals in large parts of Norway.

4.2.3 Ratio between the periods 1980-99 and 1931-90.

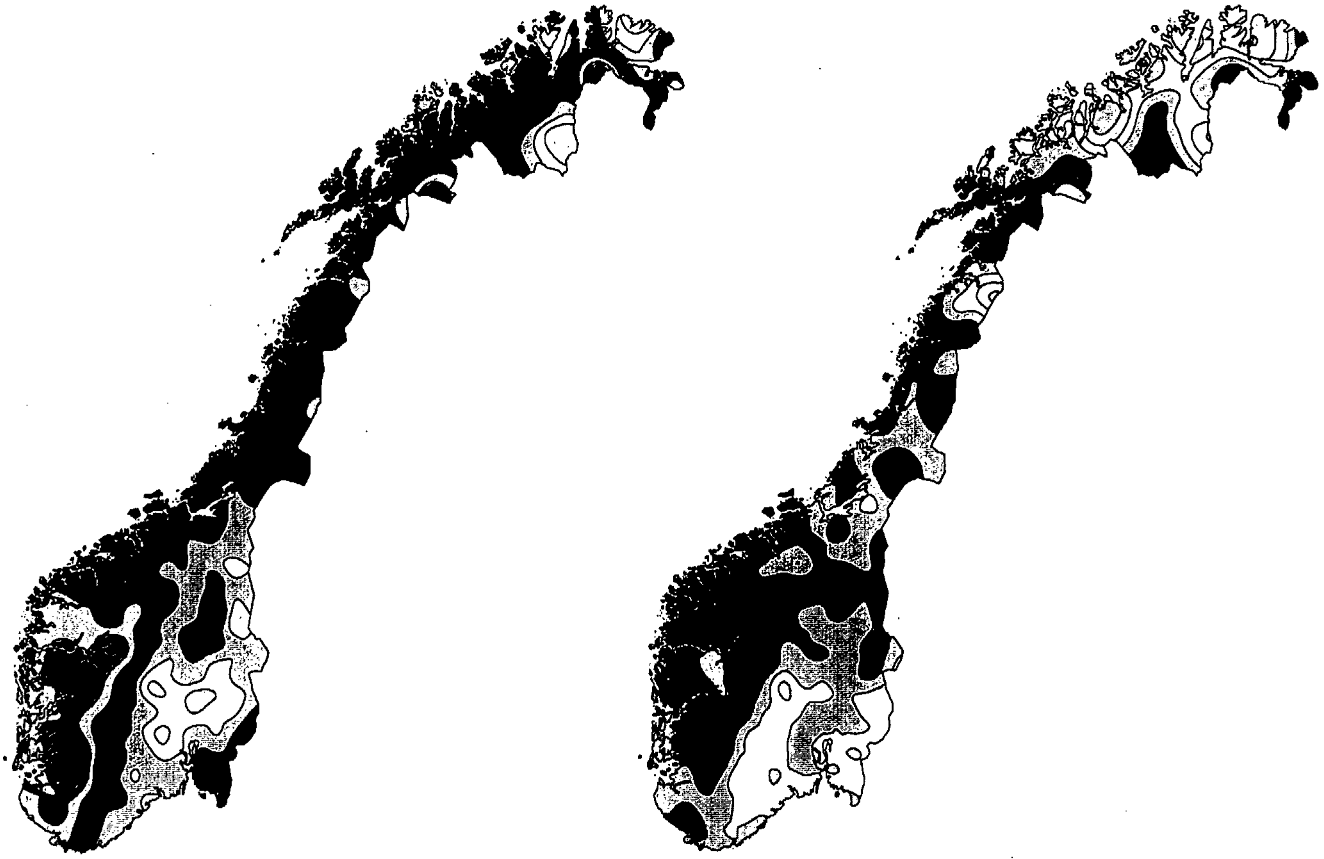
The ratio between the period 1980-99 and the long reference period shows a larger increase in annual precipitation (fig. 4.4) compared to the current 30-years normal period. The annual map shows a distinct gradient between western and eastern Norway, with increasing precipitation in western Norway, and a decrease in the eastern parts. In northern Norway the patterns are more scattered, but in general there is a weak increase in annual precipitation. Seasonally most of the annual patterns are recognized in the winter season map. This map shows a large increase in precipitation all over, except in eastern Norway. These patterns reflect weather situations dominated by westerly winds (Tveito et al., 2000), and indicate an increase of such circulation types. In the spring season most of southern Norway experience precipitation increase more than 5%. In northern Norway, the pattern is more scattered. Large parts of Troms have a large decrease, while other areas in northern Norway have just minor changes.

In the summer season most of southern Norway has become drier, while the Trøndelag area is wetter. Large parts of Troms and western Finnmark has become drier, while there is an increase in precipitation in Eastern-Finnmark. In autumn there are small differences in most parts of the country, but Troms and Finnmark have got a wetter climate.

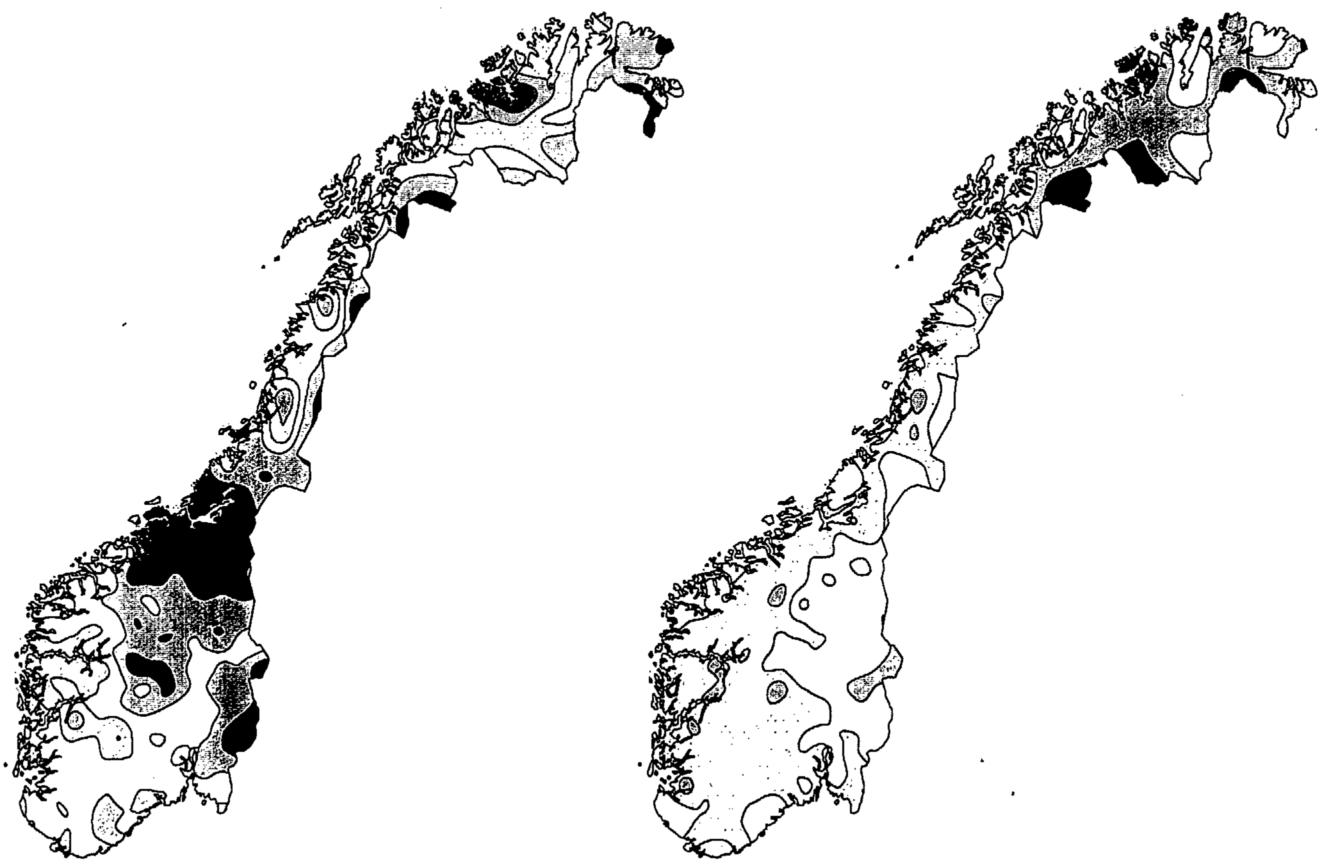


a) Annual

Figure 4.3 Annual and seasonal (next page) ratios between precipitation in the periods 1980-99 and 1961-90

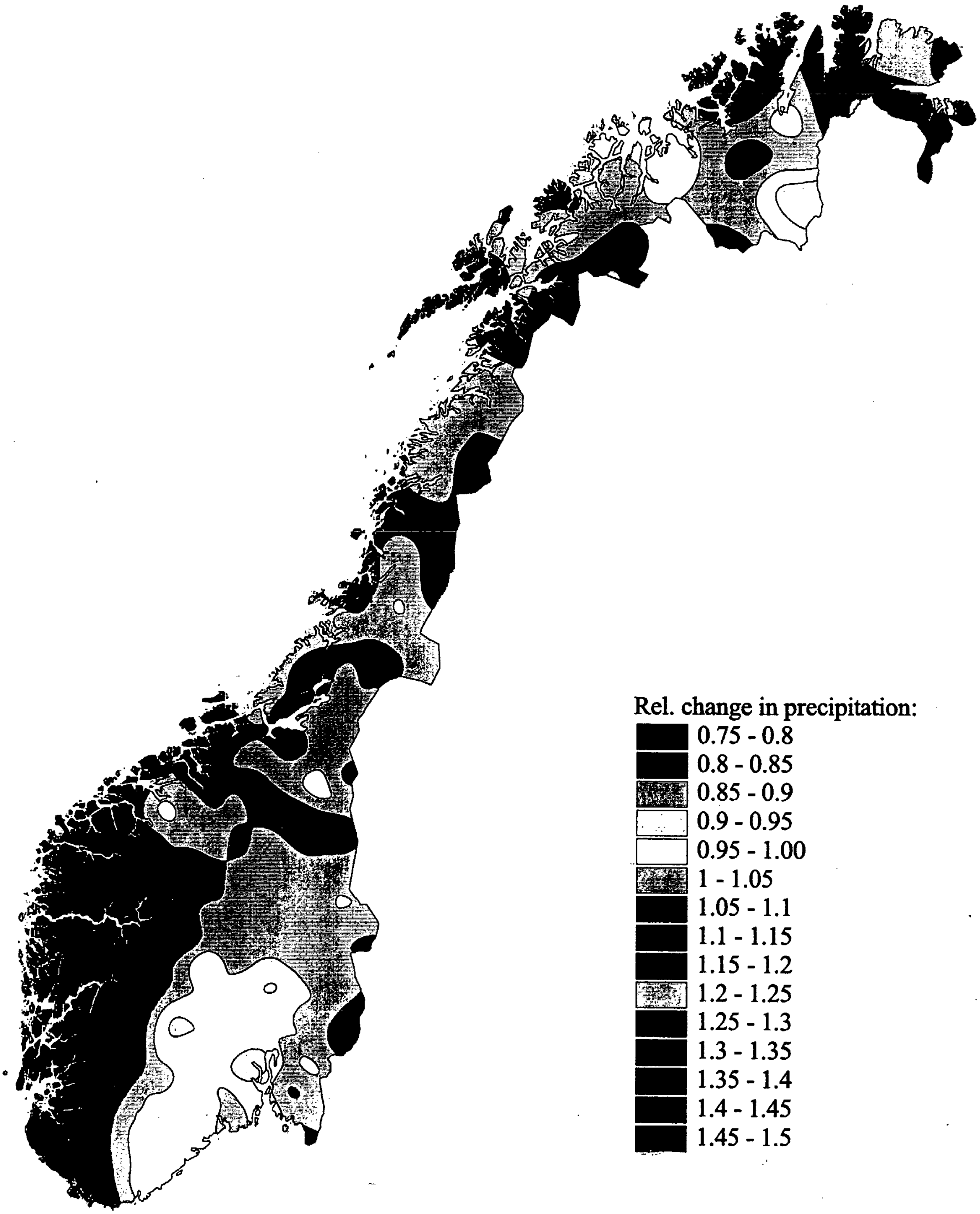


b) Winter c) Spring



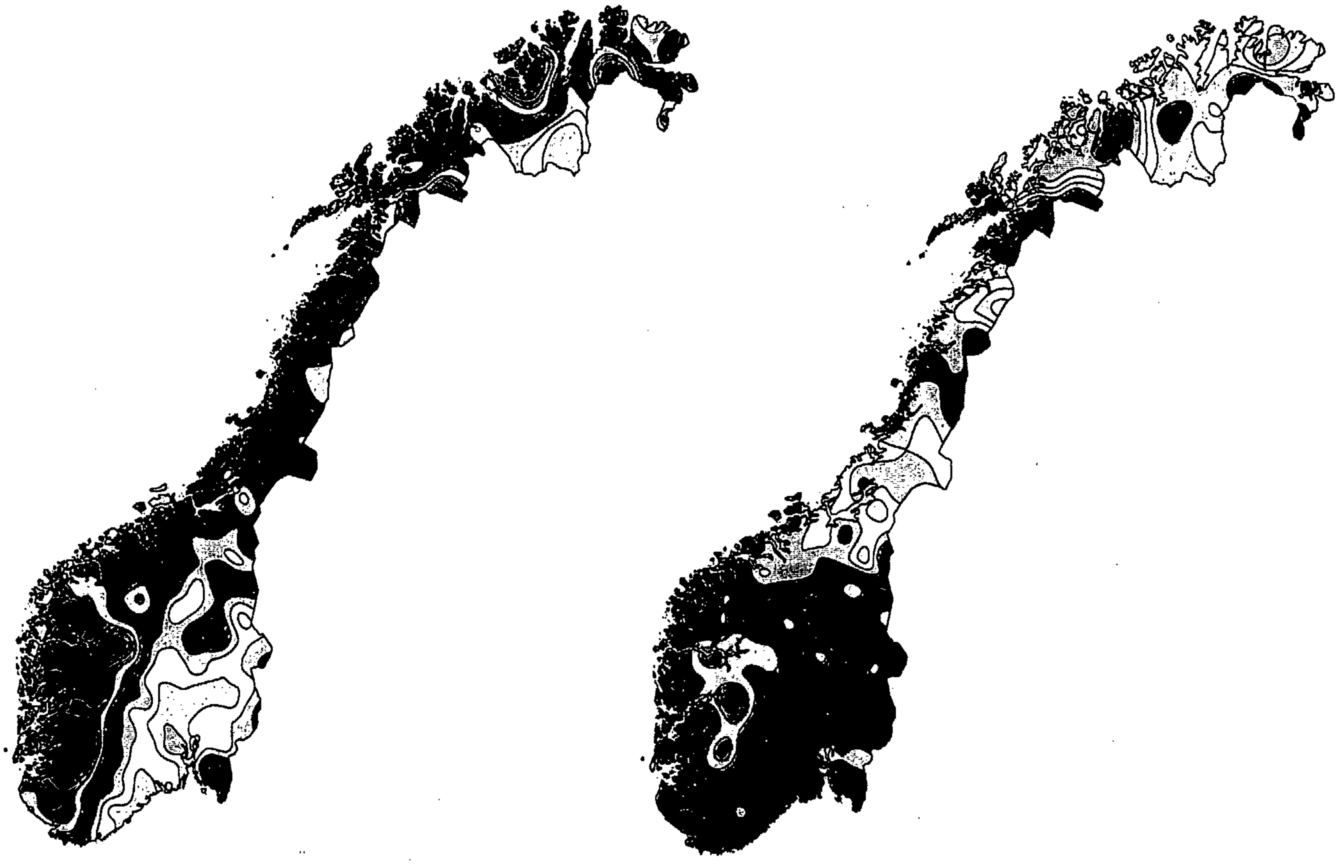
d) Summer e) Autumn

(Fig 4.3 cont.)



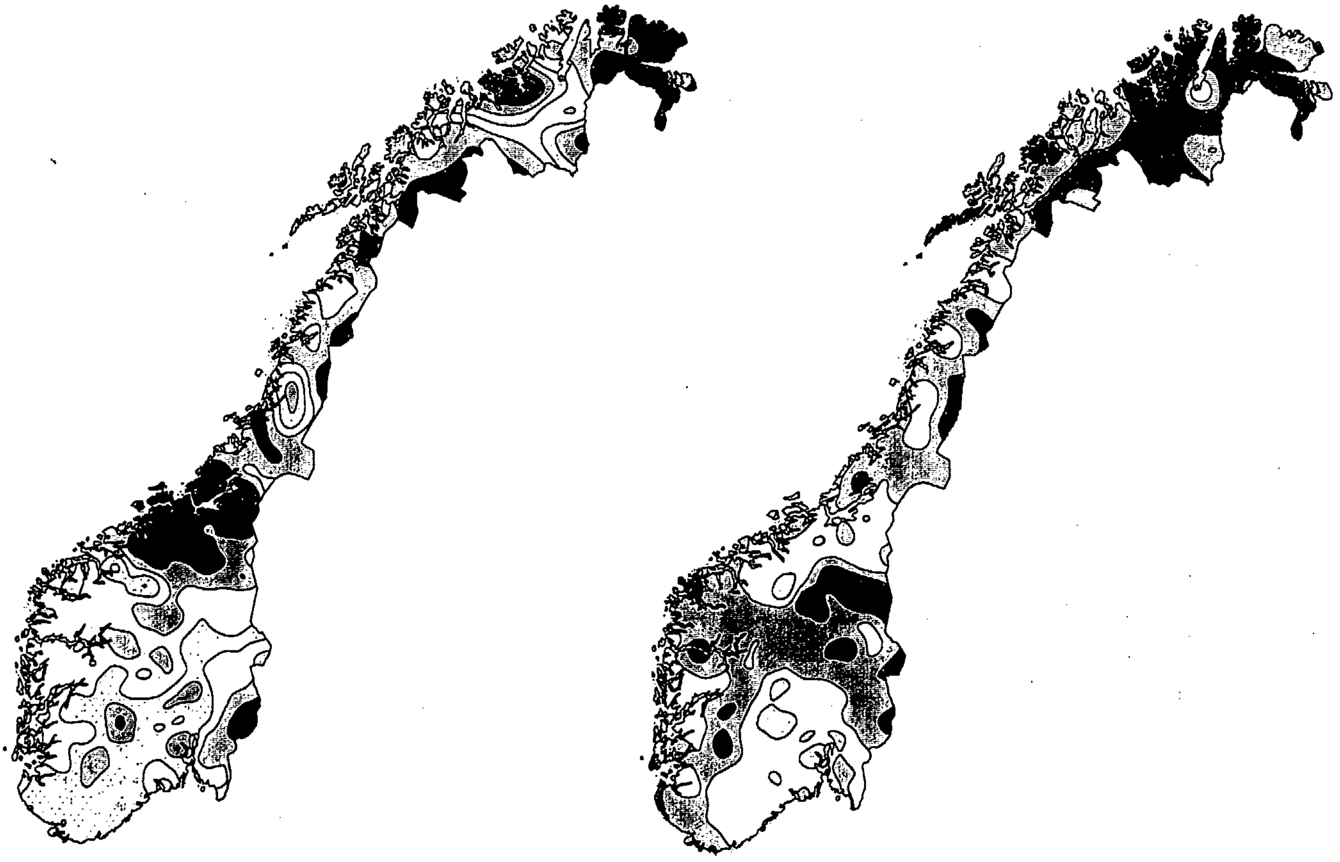
a) Annual

Figure 4.4 :Annual and seasonal (next page) ratios between precipitation in the periods1980-99 and 1931-90



b) Winter

c) Spring



d) Summer

e) Autumn

(Fig. 4.4 cont.)

5. Covariation between long-term variations in precipitation and discharge, some preliminary results

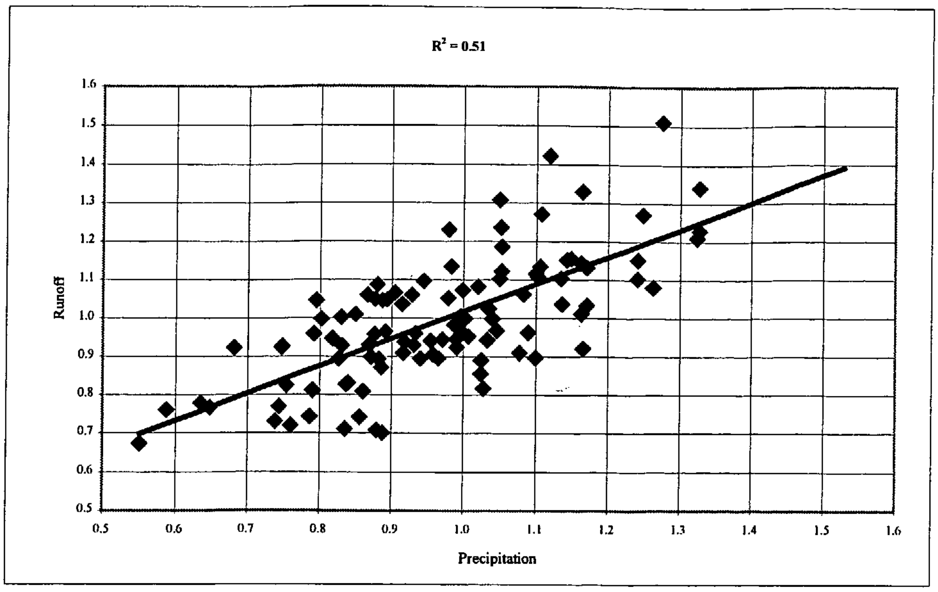
The covariation between long-term changes in climate and runoff has been studied in several European countries (Arnell et al., 1990, Grabs et al., 1997). The present study does not include linking of climate variations to variations in runoff. But the analyses presented in the previous sections allow some simple comparisons between long-term variations in precipitation and runoff. To extend the comparison beyond the period 1924-1990, long series from selected catchments are used. Figures 5.1-5.3 give examples for Southeastern Norway (precipitation region R2, catchment "Elverum" in runoff region D1), for Western Norway (R6, "Bulken" in D6), and for Central Norway (R10, "Fusta" in D7). The comparisons of annual values of precipitation and runoff during 1895-1999 are shown as: a) Scatter-plot of values for single years, b) low-pass filters favorable for studying variations on a 30-years time-scale (Filt2), and c) plots showing the time evolution of co-variation precipitation-runoff.

For Elverum (Figure 5.1) the correlation coefficient between annual precipitation and runoff is 0.71. The discrepancy in the first part of low-pass filters is caused by a few high-runoff values in the 1890s. The runoff-series show a maximum around 1930, while the precipitation curve has a maximum around 1940. The annual runoff has increased during the latest decades, while the precipitation level has been rather stable since 1930s.

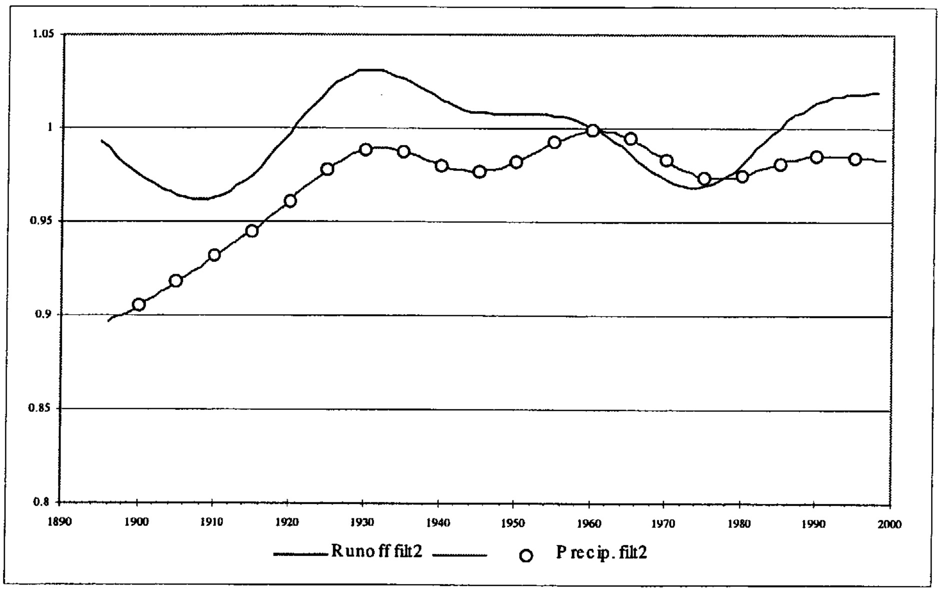
For Bulken (Figure 5.2) the correlation coefficient between annual precipitation and runoff is 0.88. Except for a discrepancy during the first two decades, there is a close similarity in the long-term variations for precipitation and runoff. The lower graphs shows that up to 1920 the precipitation decreased, and the runoff increased. From ca. 1920 to ca. 1935 there was a decrease in both precipitation and runoff, and since ca. 1935 both precipitation and runoff has increased at a rather steady rate.

In the Fusta catchment, the correlation coefficient between annual precipitation and runoff is 0.82. Both precipitation and runoff have increased in this region, with the highest levels at the end of the 20th century. The lower graph shows that both precipitation and runoff

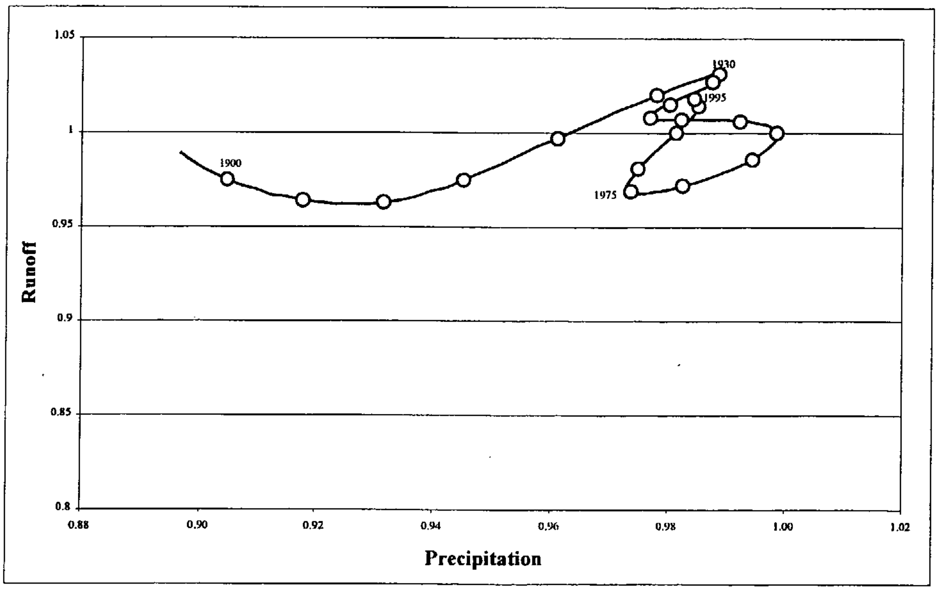
Figure 5.1 Co-variation between precipitation and runoff in **Southeastern Norway** (Catchment Glomma upstreams Elverum). Period 1895-1999



Scatter-plot of values for single years

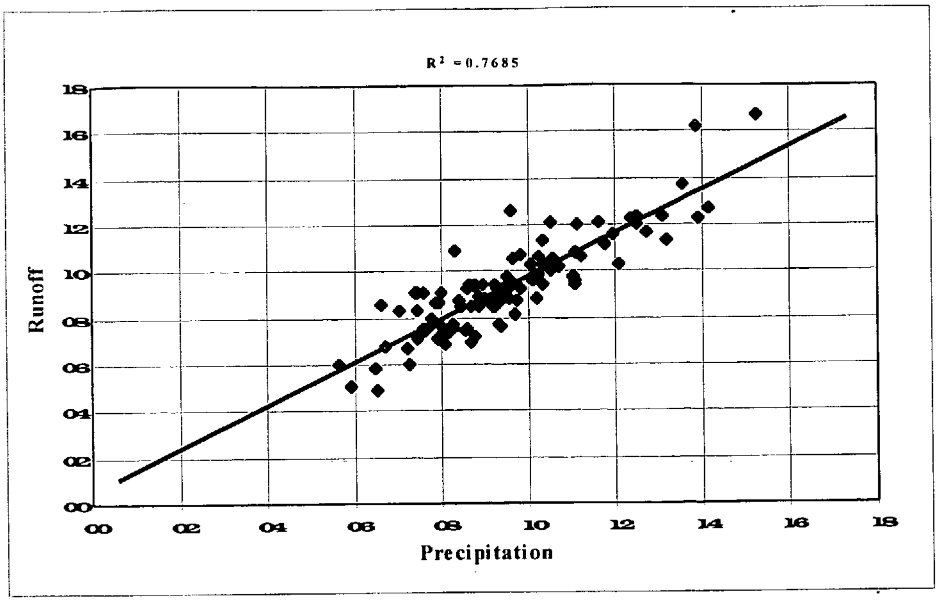


Low-pass filters favorable for studying variations on a 30-years time-scale (Filt2)

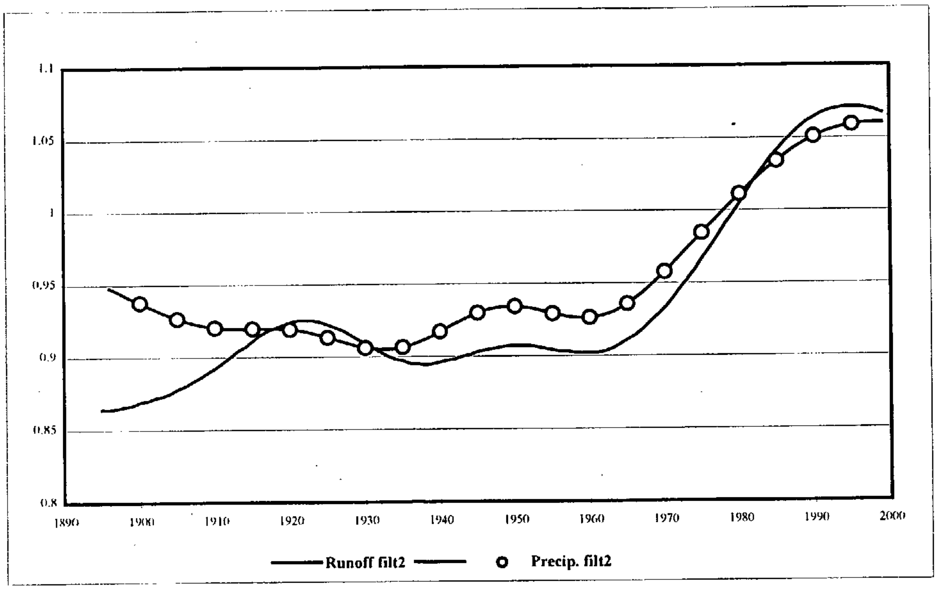


Plots for time evolution of co-variation precipitation-runoff. Open circles represent every 5th year (1900, 1905 etc.)

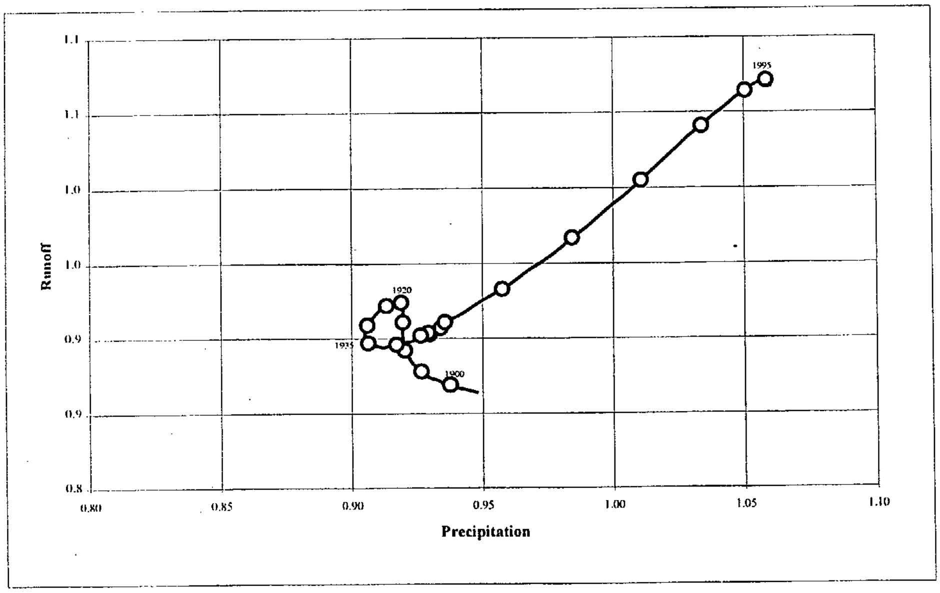
Figure 5.2 Co-variation between precipitation and runoff in **Western Norway** (Catchment Vosso upstreams Bulken).Period 1895-1999



Scatter-plot of values for single years

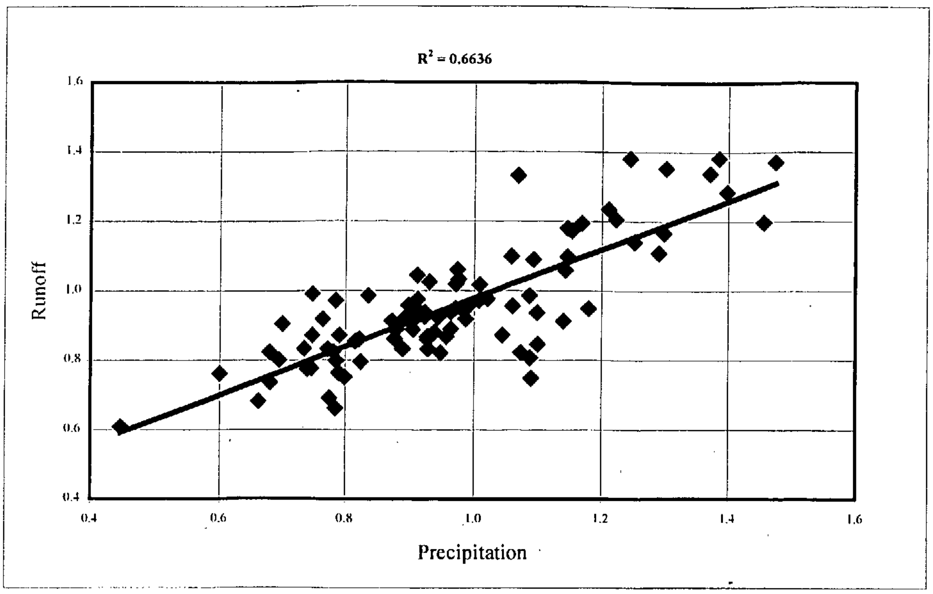


Low-pass filters favorable for studying variations on a 30-years time-scale (Filt2). Opencircles represent every 5th year (1900, 1905 etc.)

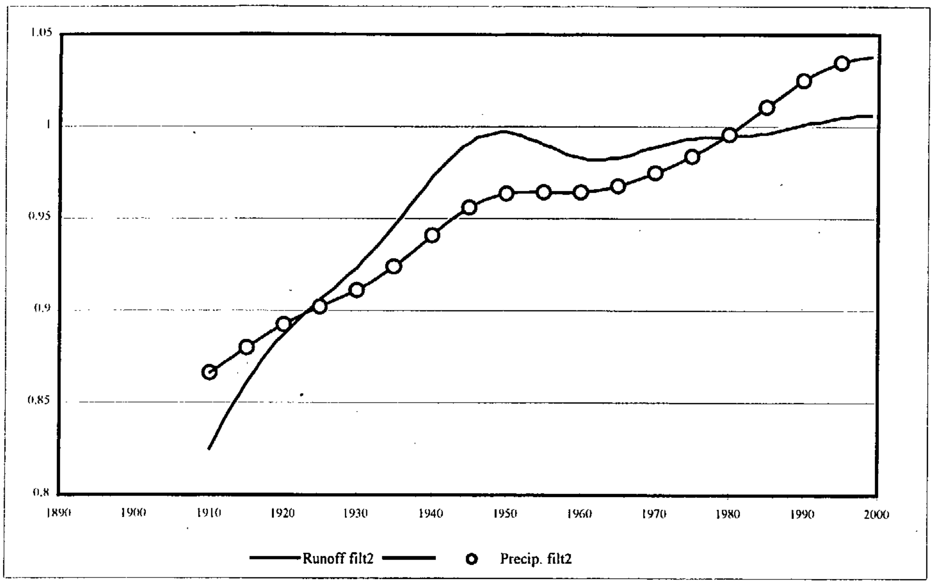


Plots for time evolution of covariation precipitation-runoff. Open circles represent every 5th year (1900, 1905 etc.)

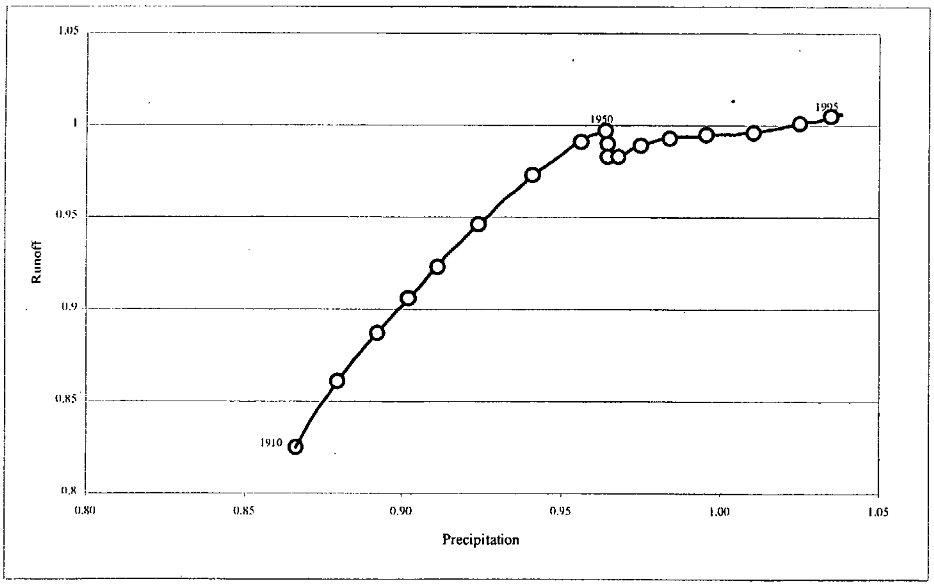
Figure 5.3 Co-variation between precipitation and runoff in **Central Norway** (Catchment Fusta upstreams Fustvatn). Period 1910-1999



Scatter-plot of values for single years.



Low-pass filters favorable for studying variations on a 30-years time-scale (Filt2). Open circles represent every 5th year (1910, 1915 etc.)



Plots for time evolution of co-variation precipitation-runoff. Open circles represent every 5th year (1910, 1915 etc.)

increased steadily from 1908 to ca. 1950. During the 1950s, the precipitation was rather stable, while the annual runoff decreased. Then, from ca. 1965 to present days, the annual precipitation has increased by almost 10%, while there is just a small increase in the annual runoff.

The long-term variations in runoff will necessarily differ from the precipitation because of the various storages within the catchment, which may differ in seasons and in timing between years. The runoff has not risen significant in the winter. The series used in this study has mostly parts of the catchments at high elevation levels. The increase of the runoff in the spring may be caused by a rise in the amount of snow available for melting in the spring season. Increasing winter precipitation is likely to lead to increasing runoff in the spring rather than the winter season. The subsequent decline in the summer runoff may also indicate a change in the timing of the spring flood. Another possibility of the decline in the summer is changes in the evaporation losses. Decadal variability in the groundwater storage may also explain some of the changes in the summer, especially in eastern Norway.

It is thus not unexpected that the co-variation precipitation-runoff for the catchments in Figures 5.1-5.3 is stronger in western regions (where evaporation << precipitation) than in southeastern Norway. The change around 1960 in the relationship precipitation-runoff in the Fusta-catchment is more puzzling.

Although the simple relationships in Figures 5.1-5.3 reveal interesting features concerning discharge implications caused by climate variations, it is necessary to study this by using hydrological models, which takes into account the effect of different storages.

6. Scenarios for temperature and precipitation in Norway and the Nordic region up to 2050

6.1 Background for Norwegian climate scenarios for the next 50 years.

Scenarios for future climate development are based on comprehensive global climate models. These so called General Circulation Models (GCM) have a typical spatial resolution of a few hundred kilometers, and give a quite realistic description of the large-scale climate. But the results from such models are too coarse to be used directly to describe climate development in different regions in Norway. The Norwegian RegClim project (Iversen et al., 1997) is applying an Atmosphere-Ocean GCMs (AOGCM) from the Max-Planck Institute, and in this model the land-sea mask and elevation resolution is as shown in Figure 6.1. To deduce detailed local and regional climate scenarios, so called *downscaling* techniques have to be used.


a)

b)

Figure 6.1 a). Land-sea mask and b). Topography in MPIs ECHAM4/OPYC3.

In RegClim two different downscaling approaches are used:

In *empirical downscaling* statistical relationships are developed between local climate elements (e.g. temperature and precipitation) and observed large-scale atmospheric fields (e.g. sea level pressure pattern). These historical relationships are then applied on large-scale fields simulated by global AOGCMs.

Dynamical downscaling is using AOGCM results as input to a regional (Northern Europe) atmospheric model (HIRHAM) with better resolution than the global models. In RegClim, both present and future climates are simulated by such a model.

The present report will focus on results from downscaling the Max-Planck Institute's AOGCM ECHAM4/OPYC3 GSDIO integration (Roeckner, 1999) over the Nordic region. This GSDIO-integration is including greenhouse gases, tropospheric ozon, and direct as well as indirect sulphur aerosol forcing. For the period 1860-1990 the GSDIO-integration is based on historical variations in greenhouse gases and aerosols, and for the period 1990-2050 the IPCC scenario IS92a is used. The IS92a scenario implies a doubling of the CO_2 concentration from 1980 to 2050.

The analyses within RegClim have demonstrated that this model gives a realistic description of the temperature conditions over Norway, but that it e.g. in making scenarios for precipitation has to be taken care of too weak westerlies of the Nordic region (Hanssen-Bauer, 2000). In Europe also the Hadley Center (HC) in UK is running global AOGCMs. The simulations from HC give a stronger warming over Norway than the MPI GSDIO-run. One of the reasons is that HC is using a lower scenario for aerosol emissions than MPI (cf. section 6.4).

The present results from RegClim analyses indicate a good accordance between scenarios based on empirical and dynamical downscaling (Førland & Nordeng, 1999). The presentations in this report are mainly based on dynamical downscaling results (Bjørge et al., 2000). The dynamical downscaling with the HIRHAM-model was based on 12-hourly boundary data from the GSDIO simulation. The simulations were run on a present-day period (1980-1999) and on a scenario period 2030-2049.

6.2 Scenarios for temperature

The difference in annual temperature between the present-day and scenario period is shown in Figure 6.2a. The change is between 1 °C and 1.5 °C in most of Northern Europe, but increasing towards the Arctic. An area of maximum warming (>6.5 °C) east of Spitsbergen (not shown) is found in the similar field from the global model as well and is related to the northward movement of the sea-ice border. The corresponding seasonal scenarios for Norway are shown in Figure 6.2 b)-d). The structure of the changes is much the same, with increasing values northward and to some extent eastward. Larger increase is seen in the winter season than in the summer season. A regional summary of the temperature scenarios (Førland & Nordeng, 1999) is presented in Table 6.1.

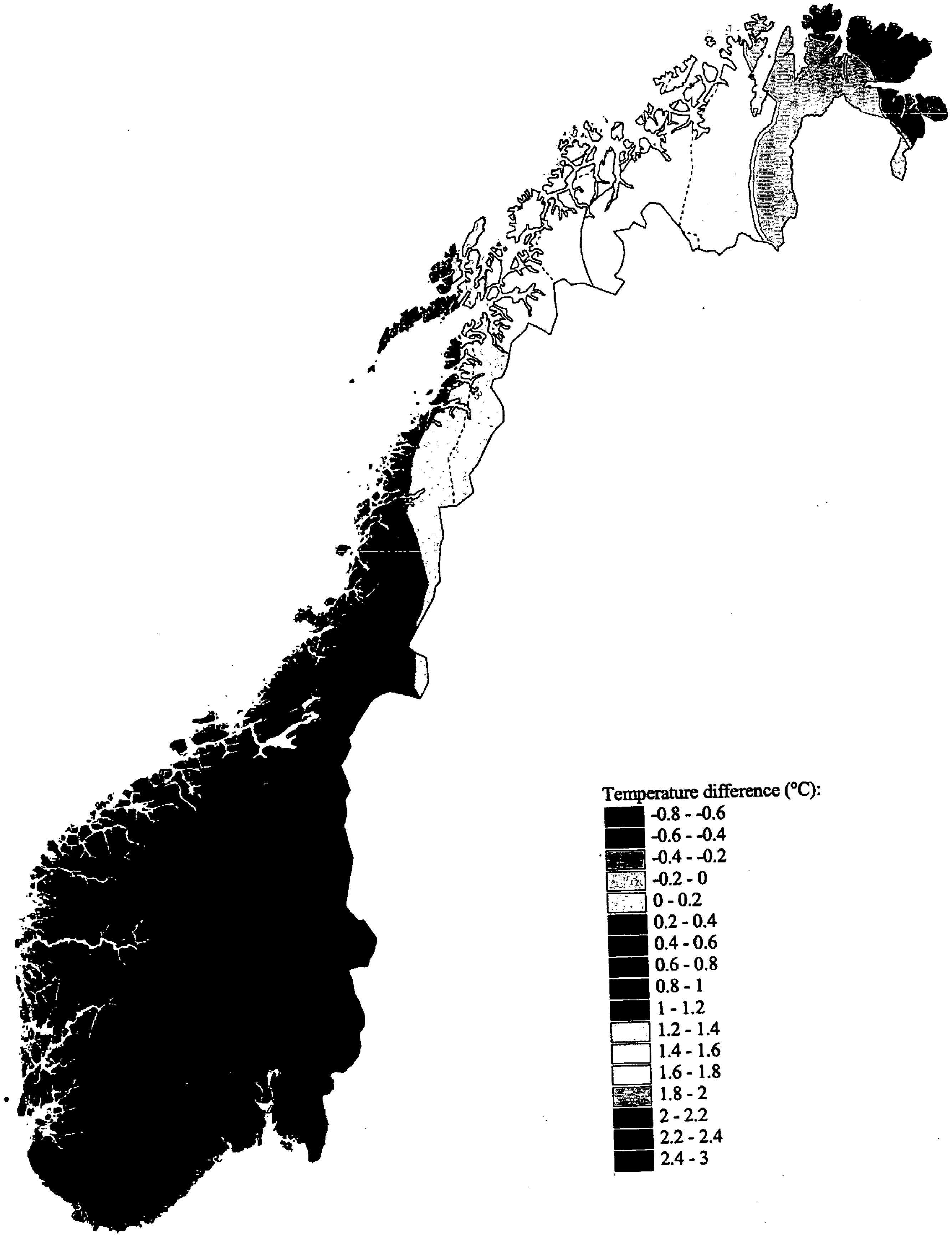
Table 6.1. Average temperature increase (°C) from (1980 - 2000) to (2030 - 2050)

	Norway	Northern Norway	Western Norway	Southeastern Norway
Annual	**1.2**	**1.6**	**1.0**	**1.1**
Spring (mar-may)	**1.1**	**1.4**	**0.9**	**1.0**
Summer (jun-aug)	**0.9**	**1.2**	**0.7**	**0.6**
Autumn (sep-nov)	**1.4**	**1.7**	**1.1**	**1.3**
Winter (dec-feb)	**1.6**	**2.0**	**1.2**	**1.3**

6.3 Scenarios for precipitation

The precipitation scenarios for the next 50 years are computed as the relative change from present-day to the scenario period 2030-2049 (Bjørge et al., 2000). Figure 6.3a) shows the simulated change in annual precipitation in percent. An increase of 5-10% can be found in large parts of the North Atlantic and the Scandinavian area, increasing to even higher values in the Arctic. It seems to be correlated with the increase in temperatures displayed in Figure 6.2. In southern Europe areas of negative changes are found. The seasonal variation of the increase (Figure 6.3 b-d) show relatively large changes over Norway. In particular the increase during the late summer and autumn in Western Norway is found to be significant. Western Norway and the coast further northward, which today is highly exposed to orographic lifting and release of precipitation, might experience a further increase in a warmer climate, locally up to 30% increased precipitation. For the other seasons the results indicate that changes are less significant compared with the natural variability.

A regional summary of the precipitation scenarios (Førland & Nordeng, 1999) is presented in Table 6.2. For the Norwegian mainland the precipitation will increase in all seasons, and particularly during autumn (17%) but with small changes during spring. In Western Norway the increase autumn precipitation is ca. 23%. In southeastern Norway, the spring precipitation will decrease (-4%). Southeastern Norway differs from the rest of the country as the strongest

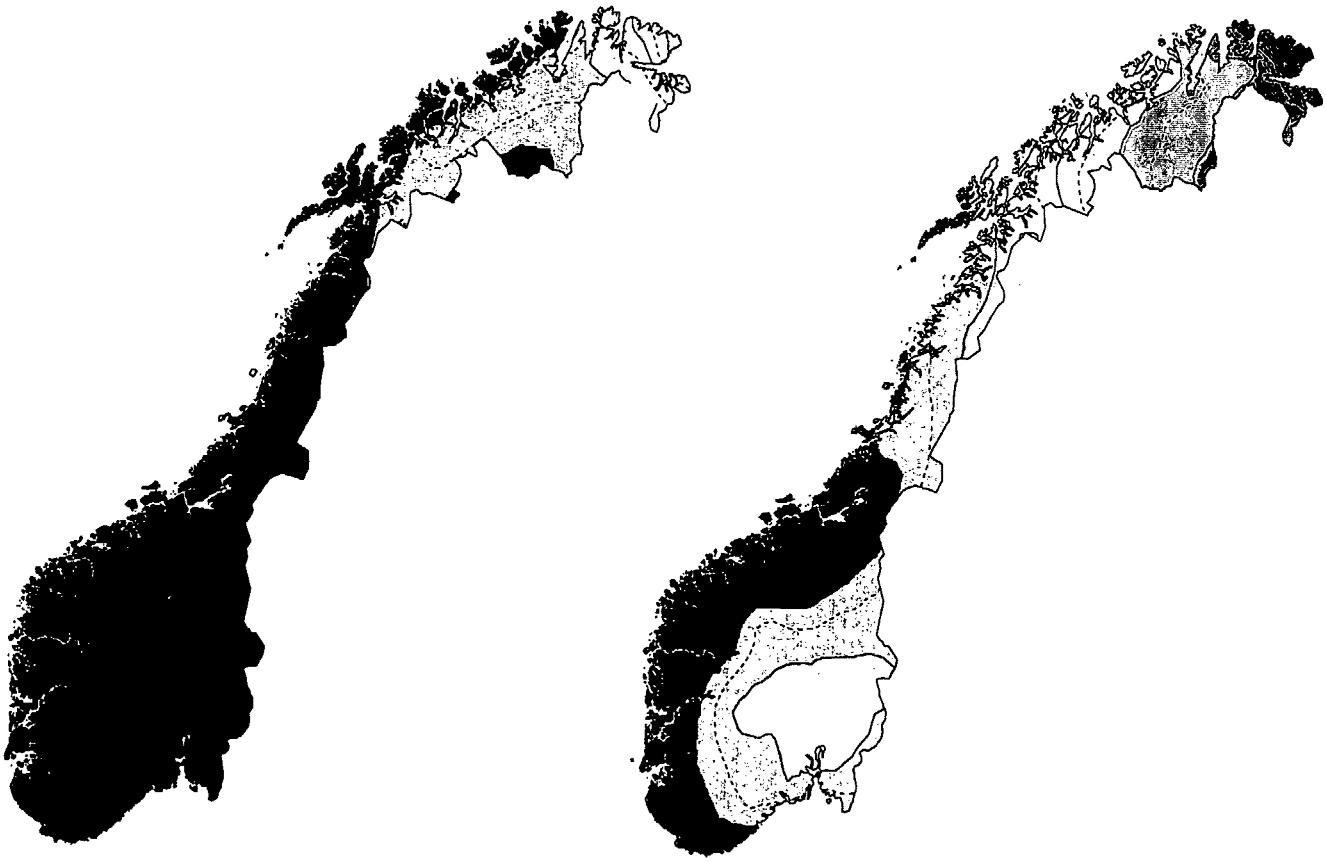


a) Annual

Figure 6.2 Annual and seasonal (next page) temperature differences between the period 1980-99 and HIRHAM GSDIO scenarios 2030-2049. (From Bjørge et al., 2000)

b) Winter

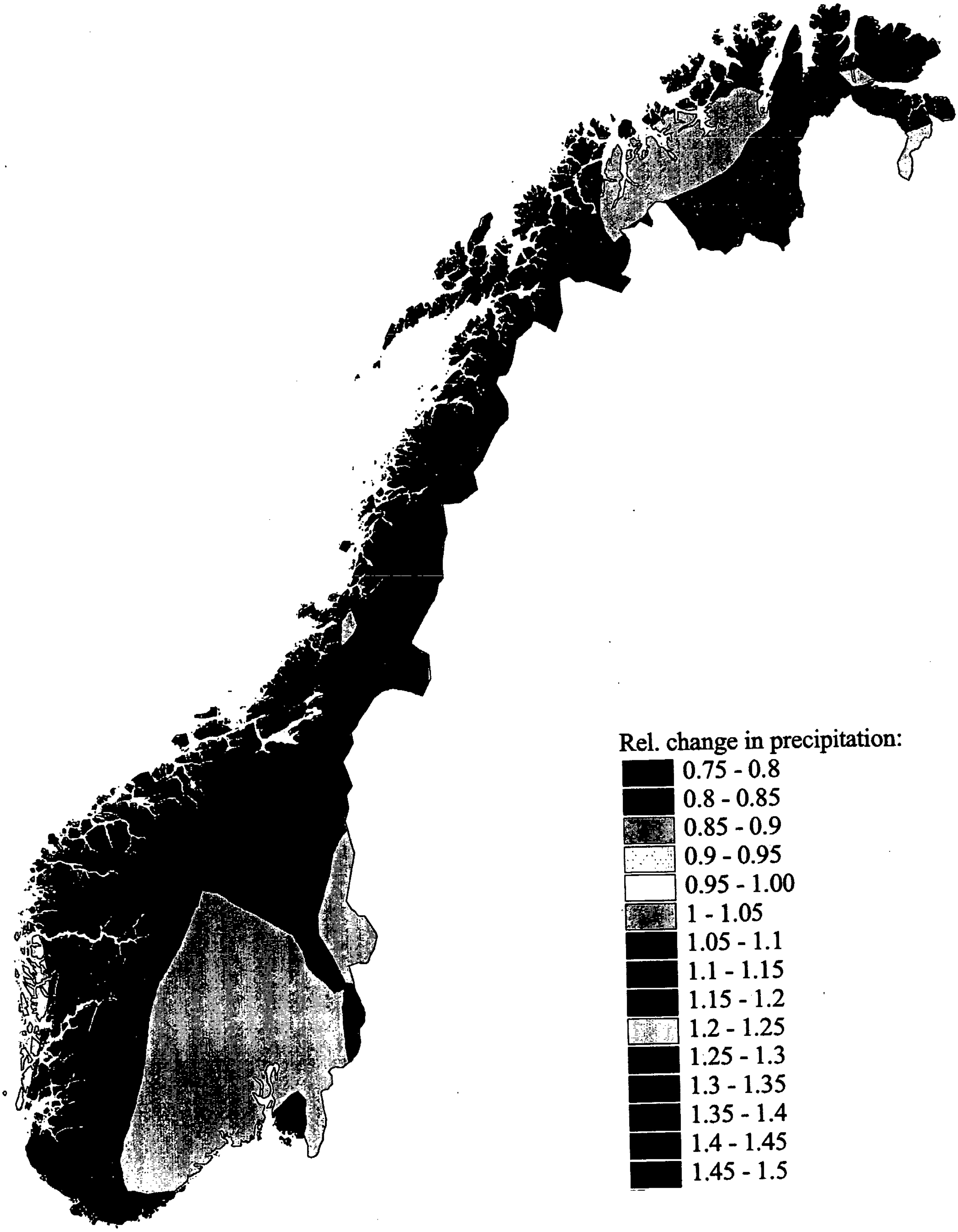
c) Spring



d) Summer

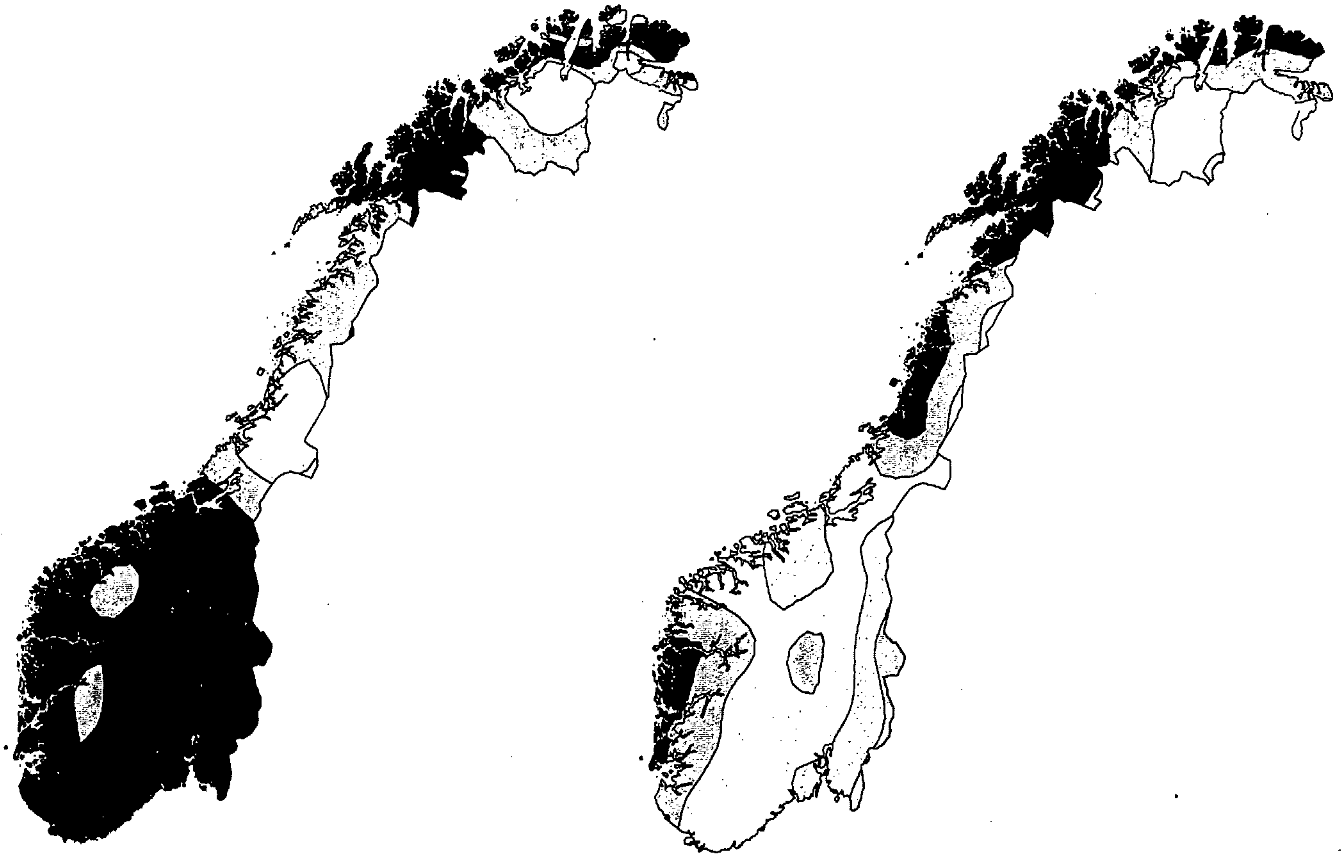
e) Autumn

(Fig. 6.2. cont.)



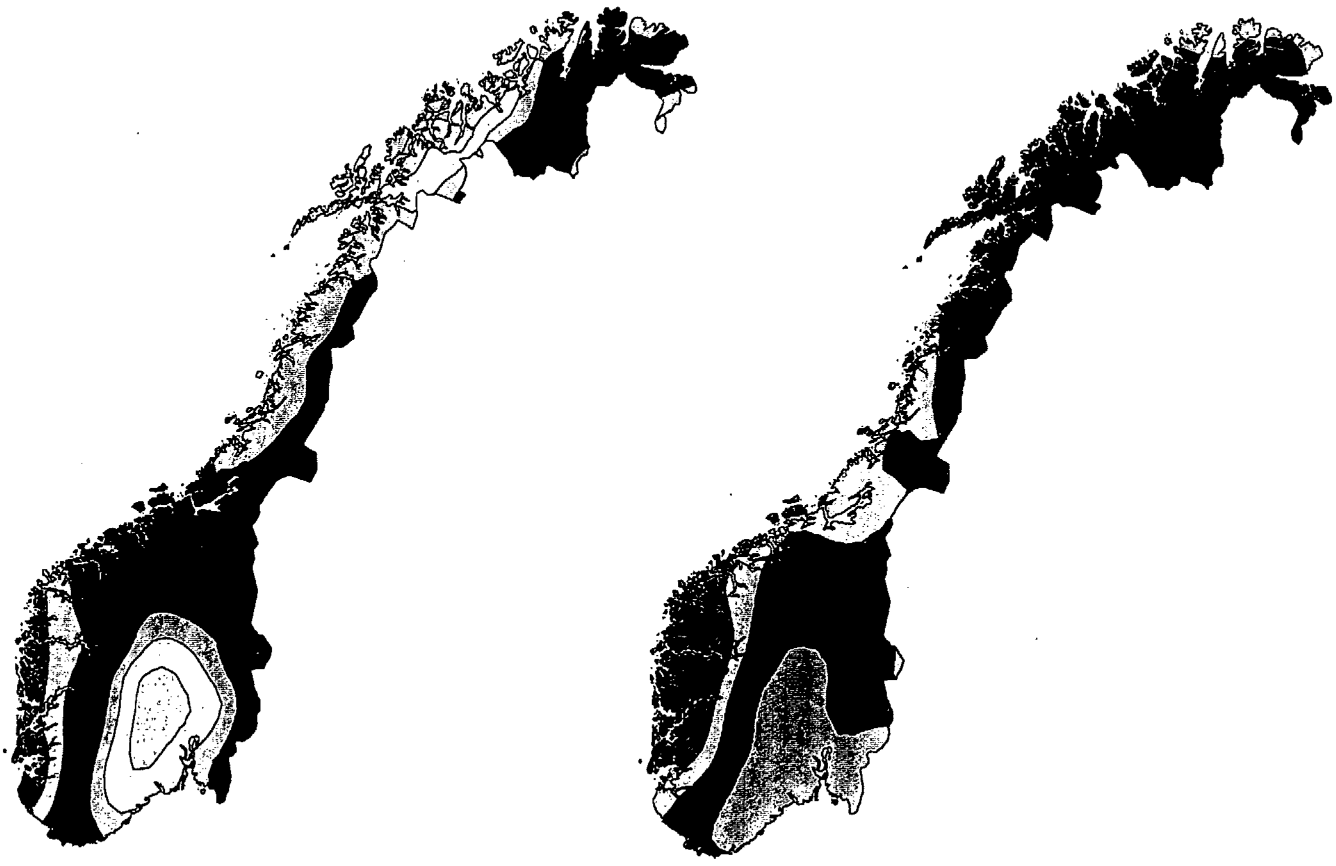
a) Annual

Figure 6.3 Ratios between annual and seasonal (next page) precipitation in the period 1980-99 and HIRHAM GSDIO scenarios 2030-2049. (From Bjørge et al., 2000)



b) Winter

c) Spring



d) Summer

e) Autumn

(Fig 6.3. cont.)

increase is expected in winter precipitation. It should be noted that the percentages in Table 6.2 are given as a total for the whole region. As indicated by Figures 6.2 & 6.3 there may be large local deviations.

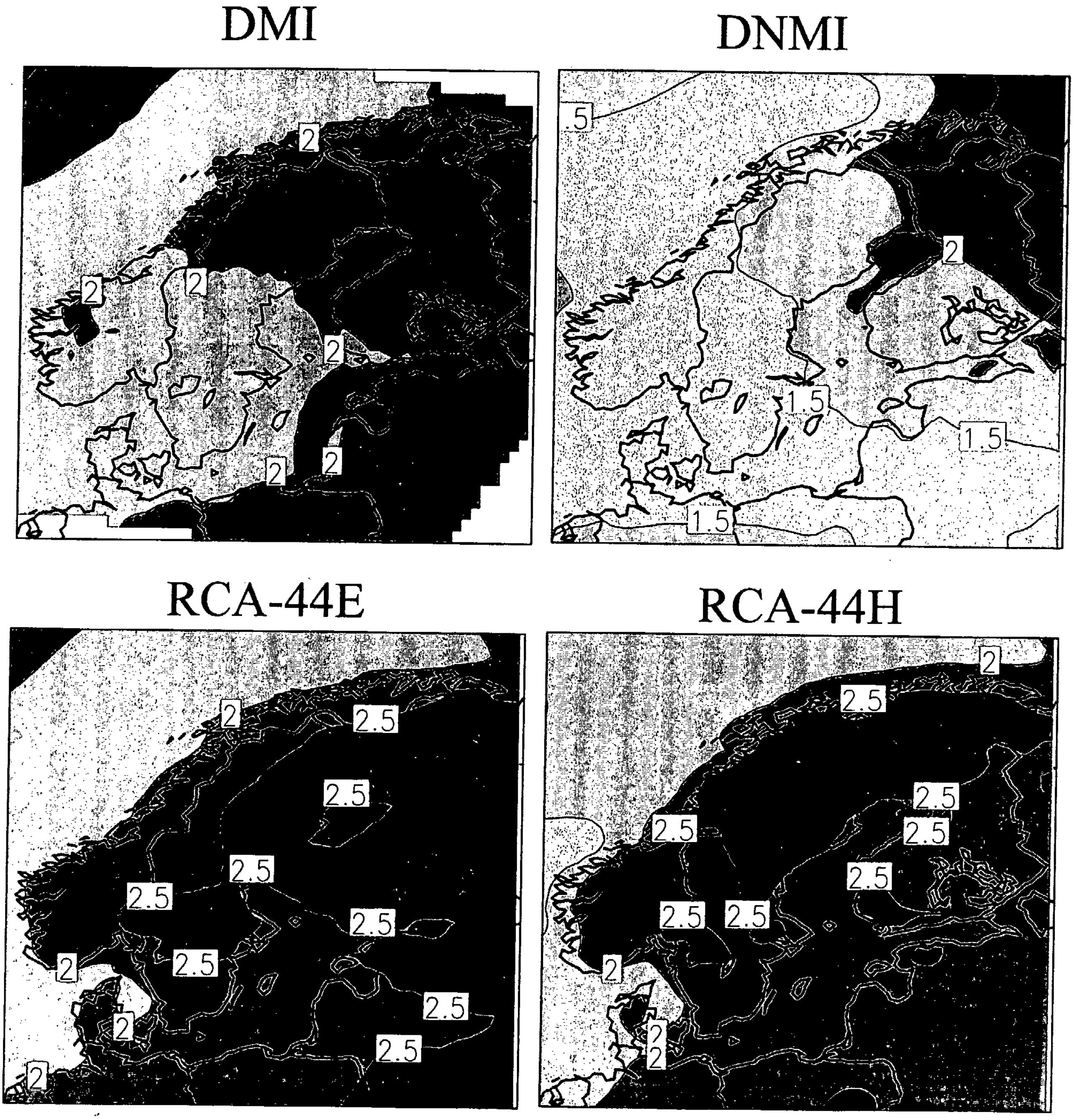
Table 6.2. Average precipitation change (%) from (1980 - 2000) to (2030 - 2050)

	Norway	**Northern Norway**	**Western Norway**	**Southeastern Norway**
Annual	**9.6**	7.8	13.5	4.3
Spring (mar-may)	**0.1**	5.0	1.2	-4.1
Summer (jun-aug)	**9.5**	1.5	18.2	1.7
Autumn (sep-nov)	**17.1**	18.2	23.5	6.9
Winter (dec-feb)	**9.4**	5.2	9.3	13.1

6.4 Nordic climate scenarios

Similar to the Norwegian RegClim-project, the Danish Climate Centre (DCC) and the Swedish Sweclim-project have been performing regional downscaling experiments. DCC is a part of the Danish Meteorological Institute (DMI), while Sweclim is a national climate project organized through the Rossby Centre which is hosted by the Swedish Hydrological and Meteorological Institute (SMHI). A comparison of results from the Nordic climate experiments are organized through the project *NordEnsClim* (Räisänen et al., 2000)

At DCC the HIRHAM model with 44 km horizontal resolution and 19 vertical levels has been used. The regional model utilizes boundaries from the MPI ECHAM4/OPYC3 GHG scenario run. In the Sweclim-project two parallel experiments have been conducted. In addition to the same boundaries as used by DCC, boundaries from the Hadley Center HadCM2 model have been utilized. Sweclim uses the HIRLAM model with modified physical parameterization such as new soil moisture scheme, modified runoff, soil freezing and evaporation. A lake model has been added, and the Baltic Sea is given special treatment to avoid spurious temperature anomalies there. Monthly means of a number of climatic variables have been compared, e.g. temperature (mean, max and min), precipitation (total, number of days), evaporation and mean sea level pressure.


DMI

DNMI

RCA-44E

RCA-44H

Figure 6.4 Change (°C) in annual mean temperature during 1990-2050
(from NordEnsClim-project, Bjørge et al., 2000)
DMI=Results from Danish Climate Center (DCC), DNMI=Results from RegClim-project,
RCA=Results from SweClim-project ("H" and "E" based on HadCM2 resp. ECHAM4 simulations)

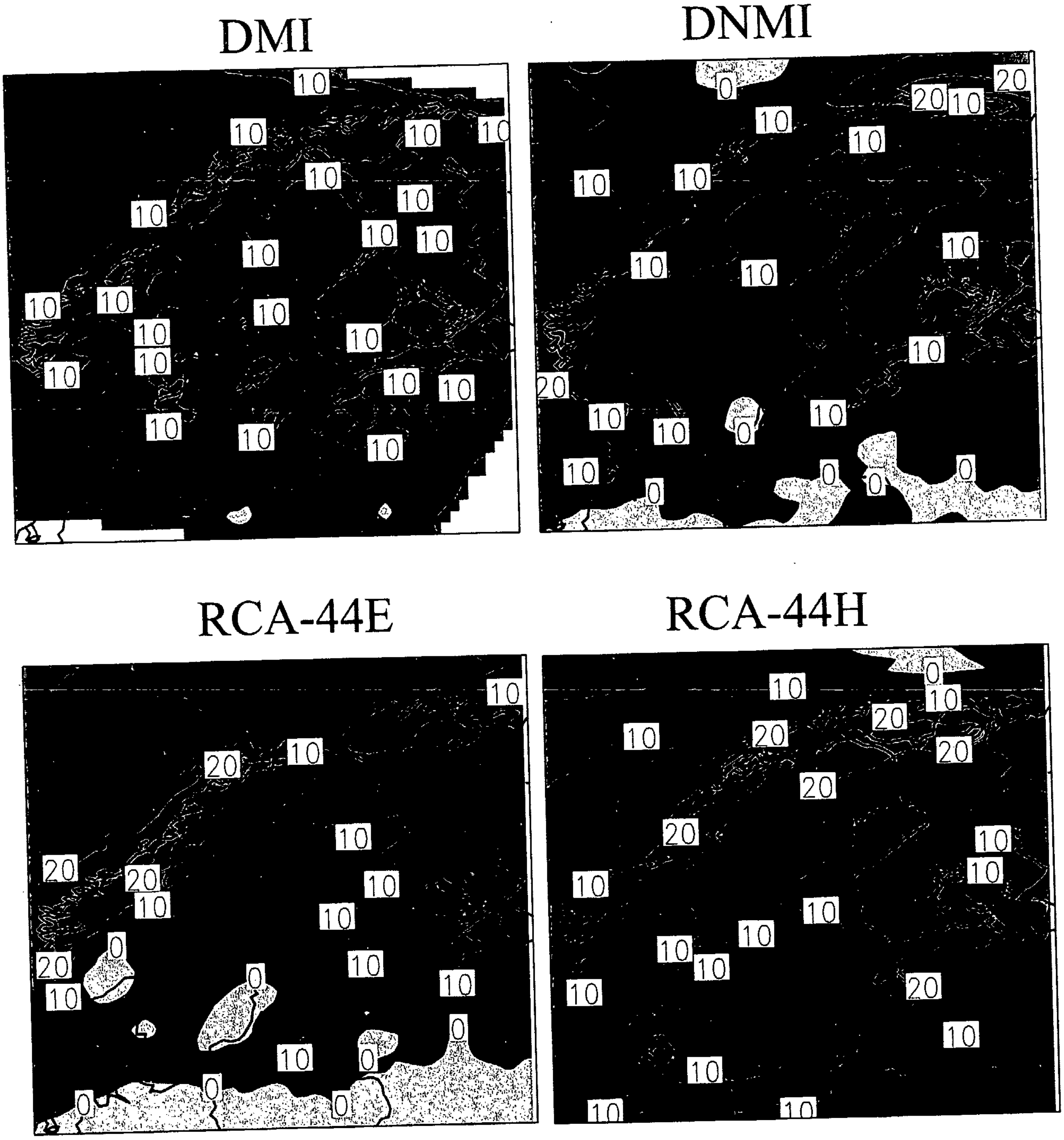


Figure 6.5 Change (%) in annual precipitation during 1990-2050
(from NordEnsClim-project, Bjørge et al., 2000)
DMI=Results from Danish Climate Center (DCC), DNMI=Results from RegClim-project,
RCA=Results from SweClim ("H" and "E" based on HadCM2 resp. ECHAM4 simulations)

In figures 6.4 and 6.5 the regional changes in annual mean temperature and precipitation developed within the NorEnsClim-project (Räisänen et al., 2000, Bjørge et al., 2000) are reproduced. Regarding the temperature, the four models show similar seasonal behavior. The largest warming is found in the northeastern part of the Nordic area. The details of the precipitation changes are more difficult to interpret, but all models indicate an increase in in annual precipitation over most of Fennoscandia. The changes of annual mean values over the Nordic region between scenario and present day are characterized by:

- The average increase of 2m-temperature of the four experiments is 2.2°C. Because the cooling effects of aerosols are included in MPIs GSDIO-integration used by RegClim, the "DNMI" results give the smallest increase with 1.6°C. The Nordic mean warming exceeds the global mean warming.
- Precipitation, evaporation and the difference between them increase in all four experiments. When looking at the mean values, the four experiments seem quite similar, but there are relatively large local differences.
- The number of days with light precipitation is reduced, while days with heavy precipitation increase in all the experiments.

6.5 NAO-index

The North Atlantic Oscillation (NAO) has long been recognized as one of the major features of the global climate system (Jones et al., 1997). Traditionally the NAO-index is defined as the difference in sea level pressure between the Azores and Iceland. It describes the dominant mode of atmospheric behavior in the North Atlantic sector, most pronounced during the winter season. Interest in the NAO has renewed recently, partly through the dominance of the positive phase of the oscillation since the early 1970s, and through the realization of its more widespread influence (Jones et al., 1997). Figure 6.6 shows the variation of the NAO-index since the 1820s.

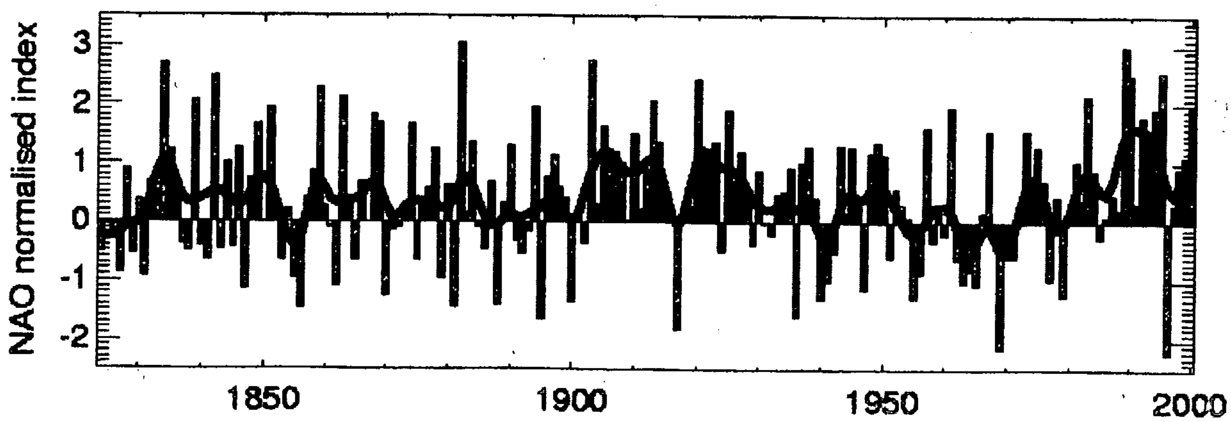


Figure 6.6 Winter NAO-index index updated to winter 1999/2000
Reproduced from: http://www.cru.uea.ac.uk/cru/info/nao/fig3.gif

During the winter half of the year, NAO provides a simple means of explaining much of the variability of surface temperature and precipitation over Europe. In a high index situation, indicating strong westerlies with an intense Icelandic low, the main low tracks will be directed northward into the Norwegian Sea. In the opposite situation with low NAO-index, the low tracks will be more southward directed into Central Europe. The relatively high NAO-index values since the 1970s have had large scale ramifications; i.e. milder and wetter winters in Scandinavia and large scale persistent drought in southern Spain, Portugal and North Africa (Stockton & Glueck, 1999).

6.6 Discussion

The expected increase in temperature, precipitation and cyclone activity over Norway and the adjacent sea areas is varying geographically and seasonally around the limit of statistical significance. Tests show highest significance for the temperature increase in northern Norway and for the precipitation increase during late summer and autumn for western coastal areas of Norway (Bjørge et al., 2000).

It should be stressed however, that the scenarios are influenced by large uncertainties, both concerning model background (future greenhouse gas and aerosol emissions), model (parametrization, influence of aerosols, ocean-atmosphere interactions etc), model performance (realism in description of climate over northern Europe and Arctic), and concerning downscaling techniques. Scenarios for Norway will probably be adjusted by improved models and downscaling techniques. It should also be stressed that the results in sections 6.2 and 6.3 are just based on one simulation (MPI's ECHAM4/OPYC3 GSDIO); simulations from other climate models (e.g. the Hadley Center's HadCM3) may give different results (cf. section 6.4). The results are based on just one realization of the future climate, and does not include uncertainty considerations.

In an evaluation of the ECHAM4/OPYC3 GSDIO simulations (Hanssen-Bauer, 2000, Hanssen-Bauer & Førland, 2000) it was concluded that the simulated grid point temperatures over Norway during the period 1871-1990 in most cases were realistic. The GSDIO simulation tends to give slightly too cold spring seasons and/or too warm autumns at some locations. Except for this, most differences between modeled and observed temperatures may be explained by differences between grid points and stations concerning altitude, influence of marine air masses and topography.

Hanssen-Bauer & Førland (2000) also found that the GSDIO "control climate" sea level pressure fields on average give a somewhat too weak westerly wind-field over Norway. The GSDIO "future climate" indicates an increase in the westerly wind component in this area. Observations after 1960 show an increase in the westerly wind field of the same magnitude as in the GSDIO results for the same period. An interesting question is if the predicted continuing intensification of the westerlies is realistic, taken into account that the modeled westerlies are too weak in the "control period". In other words: Is it reasonable to suggest that the model bias is constant when the climate is changing? Realistic simulations of the westerlies over Norway are crucial for the regional scenarios for both temperature and precipitation.

The observed connections between circulation and temperatures in Norway are satisfactorily reproduced in the GSDIO integration, particularly in winter (Hanssen-Bauer & Førland, 2000). The winter warming in the GSDIO integration (cf. section 6.2) may partly be explained by the increase in westerly wind component. For the Norwegian mainland, a linear regression model based on atmospheric circulation indices indicate that 1/3 to 2/3 of the warming in January is due to changes in the wind field. In July, the linear regression model does not account for any warming at all. The reason for this is that an intensified westerly wind field is associated with oceanic air masses, which are relatively mild in winter but cool in summer. It should be stressed however, that even the warming which is connected to changes in circulation, may be a response to the increased "greenhouse effect". Most probably also the circulation conditions over northern Europe will be affected by an enhanced greenhouse effect. The warming that is not accounted for by the linear regression model may be caused by non-linear processes (e.g. air-sea-ice interactions) or directly connected to changes in the climate forcing.

7. Summary

Temperature

- Annual temperatures have increased in all regions in Norway since 1876.
- In most areas the linear increase in annual temperature is between 0.04-0.08 °C/decade.
- The spring season has experienced the most pronounced increase (0.07-0.14 °C/decade). Summers have become significantly warmer in Northern Norway, while the autumn temperatures have increased in Southern and Western Norway.
- The mean value for the latest 20 years has been higher than the 1961-90 normals in all parts of the country during winter and spring, and also on annual basis. Also during summer and autumn most parts of the country have experienced positive anomalies since 1980. The largest anomalies (>1 °C) are found during winter in South-eastern Norway and interior areas in Troms and Finnmark.
- Scenarios from the RegClim-project for the next 50 years indicate a substantial warming in all regions and for all seasons. The most pronounced warming (annually >0.4°C/ decade) is found in the northernmost areas, and particularly during autumn, winter and spring. This warming is closely related to a modelled northward movement of the sea-ice border.

Precipitation

- Annual precipitation has increased in all regions (except “Sørlandet”) since 1896. The positive trends (linear increase between 0.5 and 1.8%/decade) are statistically significant in 6 of the 13 regions, and most pronounced in Nordland, Troms and parts of Trøndelag and Finnmark.
- Seasonal linear increase exceeding 2.5% is found in region 10 and 11 during spring, and in region 13 in summer. At “Sørlandet” there is a tendency to reduced precipitation during winter, spring and summer.
- The mean annual precipitation during the latest 20 years have exceeded the 1961-90 normals in all parts of Norway west and north of the mountain divide (Langfjella/Dovre). In Western Norway the annual precipitation has been 5-7% higher than the normals, and the winter values more than 25 % higher.
- Scenarios for the next 50 years from the RegClim-project indicate that the annual precipitation will increase in all parts of Norway, and most pronounced (ca.20%) in Western Norway.

- Autumn precipitation will increase in all parts of the country, while summer and particularly spring precipitation will be reduced in parts of South-eastern and Northern Norway.
- It should be noticed that the simulated increase in precipitation in Western Norway from 1980-99 to 2030-2049 amounts to ca. 4%/decade. The increase from 1960-79 to 1980-99 is equivalent to 6.5%/decade, i.e. larger than the scenario rate!

Runoff

- The main features of long-term variations of **annual** runoff are:
    - Southeastern Norway: Decrease from the 1920s to ca. 1975, increasing values from 1975 to present day
    - Western and Central Norway: Stable or decreasing values from the 1920s to ca. 1965, substantial increase since the mid 1960s
    - Northern Norway: Increasing values in Region11 (Troms/Finnmark) from the 1920s to ca. 1970. Stable values in all three regions since ca. 1970.
- The results of the seasonal analysis can be summarized by:
    - The **spring** runoff has increased in all regions, most obvious in the mountain regions
    - The **summer runoff** has declined markedly in Southeastern and Central Norway (regions 1- 4, 7 and 9), and is otherwise stable or has an insignificant reduction.
    - The **autumn runoff** has increased markedly in Western Norway (regions 5 and 6), especially since 1960. Central Norway and Nordland (regions 7– 10) have a small increase, while Southeastern Norway (regions 1- 4) have a small decrease.
    - The **winter** runoff is stable or indicates a weak decrease in most regions. The winter data based on the inflow is however more uncertain, because the values usually are small, and easily affected by weaknesses in the current procedure for calculating the inflow.
- The seasonal runoff will necessarily differ from the precipitation because of the various storages within the catchment, which may differ in timing between years. The increase of the runoff in the spring in high elevation catchments may be caused by a rise in the amount of snow available for melting. The decline in the summer runoff may indicate a change in the timing of the spring flood or changes in the evaporation losses. It is necessary to study this using hydrological models, which takes into account the effect of these storages.

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This report is worked out in close collaboration with the DNMI-activities within climate modeling. It meets the ambitions of the RegClim-project to make downscaled climate change scenarios available for impact studies in Norway.

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