RAPPORT

09 1995

NVE
NORGES VASSDRAGS-
OG ENERGIVERK

Ole Einar Tveito
Hege Hisdal

DISAGGREGATION OF LARGE SCALE CLIMATOLOGICAL INFORMATION

HYDROLOGISK AVDELING

NORGES
VASSDRAGS- OG ENERGIDIREKTORAT
BIBLIOTEK

Omslagsbilde: Tegnekontoret NVE

NVE
NORGES VASSDRAGS-
OG ENERGIVERK

TITTEL Disaggregation of large scale climatological information	RAPPORT 09 95
SAKSBEHANDLERE Ole Einar Tveito Hege Hisdal	DATO 10.02.95 RAPPORTEN ER ÅPEN
OPPDRAGSGIVER Norges Forskningsråd	OPPLAG 50

SAMMENDRAG
I denne undersøkelsen er sammenhengen mellom storskala sirkulasjonsmønstre, representert ved lufttrykkserier, og lokale nedbørforhold studert. Empirisk ortogonale funksjoner (EOF) er benyttet for å se på variasjonene i tid og rom separat. Analysen viser at første amplitudefunksjon for trykk kan relateres til høytrykksituasjoner. Andre amplitudefunksjon inneholder informasjon om lavtrykksituasjoner. For nedbør er det omvendt. Dette resulterer i at det er høy negativ korrelasjon mellom første amplitudefunksjon for trykk og andre for nedbør i måneder hvor været er dominert av høytrykk, og mellom første nedbørfunksjon og andre trykkfunksjon i de resterende månedene. Det er ingen klare likheter i den romlige variasjonen mellom vektkoeffisientene til trykk og nedbør. Dette er heller ikke å forvente, siden nedbøren påvirkes kraftig av lokale forhold. Undersøkelse av vektkoeffisientene, viser at en regional gruppering basert på første og andre vektkoeffisient gir stabile sammenfallende regioner både for trykk og nedbør. Analysen viser at det eksisterer faste relasjoner mellom trykk og nedbør. Slike relasjoner er viktige for tolkninger av klimascenarier basert på globale sirkulasjonsmodeller. Studiet er en begynnelse i arbeidet med å nedskalere GCM resultater til lokale forhold.

ABSTRACT
The relation between large-scale circulation patterns, represented by air pressure series, and local precipitation is examined. Empirical orthogonal functions (EOF) are applied to separate the spatial and temporal variations. The analysis shows that the first amplitude function of air pressure can be related to high pressure events, while the second contains information about low pressure events, while for precipitation it is the other way around. This leads to a high negative correlation between the first amplitude function of pressure and the second function of precipitation in months dominated by high pressure, and between the first amplitude function of precipitation and the second function of pressure in the remaining months. There is no clear similarity in the spatial variation of the weight coefficients of pressure and precipitation. This is as expected, since the precipitation is strongly influenced by local conditions. Examination of the weight coefficients shows that regional grouping based on the first and second weight coefficient gives stable coinciding regions for pressure and precipitation. The analysis shows that fixed relations between pressure and precipitation exist. Such relations are important for interpretation of climate scenarios based on global circulation models. This study is a first step in downscaling GCM output to local conditions.

EMNEORD/SUBJECT TERMS	ANSVARLIG UNDERSKRIFT
Empirisk ortogonal funksjoner/Empirical orthogonal functions Nedbør/Precipitation Luftrykk/air pressure Klimaendringer/Climate change Regionale variasjoner/Regional variations	Arne Tollan Avdelingsdirektør

Kontoradresse: Middelthunsgate 29
Postadresse: Postboks 5091, Maj.
0301 Oslo
Telefon: 22 95 95 95
Telefax: 22 95 90 00
Postgiro: 0803 5052055

BL 1011

PREFACE

To find the connection between large-scale circulation and local precipitation, models for disaggregation of large-scale climate processes to local scale must be developed. This is especially important for better interpretation of local effects of future climate changes based on output from GCM scenarios.

In this study, the method of empirical orthogonal functions (EOF-method) is used to study temporal and spatial variations in pressure and precipitation series. The resulting weight coefficients and amplitude functions are presented, and the relations between them are discussed and interpreted.

The study is carried out at the Norwegian Water Resources and Energy Administration, in cooperation with the Department of Geophysics, University of Oslo. The data required for this investigation was kindly provided by the Norwegian Meteorological Institute. The authors want to thank professor Lars Gottschalk at UiO and professor Nils Roar Sælthun (NVE/UiO) for advice and valuable comments, especially in the planning of this project.

Oslo, February 1995

Kjell Repp

Kjell Repp,
section manager

CONTENT

1. INTRODUCTION

During the last years climate change has been an important issue, both in politics and science. The scientific part of the discussion has mostly been concentrated on scenarios of future climate change given a certain exchange rate of climate gases to the atmosphere. These scenarios are a result of estimates from Global Circulation Models (GCM's). There is a large number of GCM's, with different scopes, giving varying results. All the models are equal concerning the coarse spatial resolution. The Nordic Countries typically are covered by only two to four grid-cells. From a hydrological point of view this is large scale. To make estimates of hydrological consequences of a climate change, techniques for distribution of the cell output within a grid cell have to be developed.

This type of analysis has been carried out (e.g., Sælthun et al. 1990) using the estimated change in mean temperature and precipitation as input to a conceptual water balance model. In the model the present precipitation series are used, adjusted by the ratio of estimated change in precipitation volume according to the GCM estimate. The variance remains unchanged in the simulations. Changes in local conditions and variability due to changes in circulation patterns are not considered.

Precipitation, and thereby runoff, is strongly connected to large-scale circulation patterns. At a specific location, the precipitation is also influenced by local effects, as topography, but the dominating factor is the large-scale circulation. Therefore, the local response can be expressed as a function of the circulation patterns. Hay et al. (1992) suggest the use of weather types, classifying synoptic observations into a few weather states, representing typical circulation situations. Hughes and Guttorp (1994) describe an approach relating synoptic atmospheric patterns to regional hydrological response using nonhomogeneous Markov models. Kaas (1993) has used empirical orthogonal functions (EOF) to establish relations between pressure gradients and at-site precipitation and temperature.

In Tveito and Hisdal (1994), the temporal and spatial variations in precipitation and runoff are studied using the method of empirical orthogonal functions. The study showed that the different components of runoff and precipitation are influenced by different dominating circulation patterns. In this study the aim is to find relations between large-scale circulation represented by air pressure series, and the spatial variability of precipitation.

In this report, the data used are described. Further a short presentation of the methods is given, and the results are presented and discussed.

2. DATA

Twelve monthly mean pressure series (hPa), reduced to sea level, are compared to twelve precipitation series. The locations of the series are shown in Fig. 1. Monthly values are used because of the lack of convenient pressure series for shorter time resolutions. This is also the reason why few series are used. The data set is regarded as sufficient for this preliminary study.

The pressure series cover the period 1961-90. Three of the series, 2487 Nesbyen, 1262 Lillehammer and 6250 Ona were not complete. Nesbyen and Lillehammer miss long periods of observations. These periods were not overlapping. For Ona a few values were missing. The EOF-method requires complete series. Linear stepwise regression was used to fill the gaps. The observed series from the other sites were used as independent variables. Only series entered at the first step was finally used to derive missing values. The regression equations are:

$$\mathbf{P}_{\text{Nesbyen}} = 0.9942 \cdot \mathbf{P}_{\text{Lilleham.}} + 5.88 \qquad r^2=98.7$$
$$\mathbf{P}_{\text{Lilleham.}} = 0.9928 \cdot \mathbf{P}_{\text{Nesbyen}} + 7.24 \qquad r^2=98.7$$
$$\mathbf{P}_{\text{Ona}} = 1.0280 \cdot \mathbf{P}_{\text{Værnes}} - 28.63 \qquad r^2=96.6$$

The coefficients of correlation between the pressure series are high. All the series in southern Norway have a pairwise correlation above 0.9. In northern Norway the correlations are lower.

3. METHOD

Tveito and Hisdal (1994) found patterns of different weather systems in different principal components of precipitation. In this study the relationship between pressure series, representing large-scale weather systems, and precipitation is studied.

3.1 The EOF-method

Principal components of the time series are derived using the method of empirical orthogonal functions (EOF-method). A short presentation is given below. For a detailed description, see Preissendorfer (1988).

Fig. 1 Location of the series. ∇-precipitation, ×-pressure.

The method of empirical orthogonal functions has been applied for several purposes within the hydrosciences during the last three decades. This method is a powerful tool for analyzing large data sets of spatially correlated observations.

The principle behind the method is a linear transformation of a set of correlated spatially distributed time series into two new sets of orthogonal and thus uncorrelated functions. This transformation can be described as:

$$X(u,t) = \sum_{j=1}^{N} h_j(u)\beta_j(t) \qquad (1)$$

where $\beta_j(t)$ are amplitude functions and $h_j(u)$ are weight coefficients. N is the number of series included in the analysis.

The amplitude functions contain the temporal variations of the original time series. A few of these functions will contain most of the variation in the original series. They are arranged in descending order according to the proportion of variance explained by each function. Consequently, most of the variation will be explained by a few functions. Redundant information in the lower ranked amplitude functions can be removed.

The weight coefficients describe the contribution of the amplitude functions to the original series. These weights can be regarded as the spatial component of the process X(u,t).

3.2 Disaggregation

The aim is to disaggregate series from a GCM representing grid cells. For a grid cell, a process $X_G(t)$ can be described as:

$$X_G(t) = \sum_{i=1}^{M} \sum_{j=1}^{N} h_{ij} \beta_j(t) \qquad (2)$$

where M and N define the area of the grid cell. h_{ij} and $\beta_j(t)$ are the weight coefficients and amplitudefunctions from an EOF-analysis of the series within the grid cell, representing local patterns. i is the index of geographical position and j is the index number of the series. $X_G(t)$ can be considered as the aggregated series for this grid cell. This value has the same characteristics as the output value from a GCM.

There is no possibility of disaggregating the single series $X_G(t)$ to several local series (i=1,.....,M) by:

$$\sum_{j=1}^{N^*} h_{ij} \beta_j(t) = X_i(t) \qquad (3)$$

because we do not know the spatial variance within the grid cell. Therefore, the regional distribution of the series has to be found by another approach.

The EOF-method is a useful tool because the different components, (or amplitude functions) may represent different underlying processes. A closer examination of the amplitude functions is helpful in finding an optimal regional distribution. If a relation between large-scale circulation components and the components of the local precipitation/runoff can be established, an application for downscaling the output from GCM's to local scale series is found.

4. RESULTS

The coherence between the temporal variations of precipitation and pressure is studied by analyzing plots of the amplitude functions. Also, the correlation between the amplitude functions of pressure and precipitation in the twelve months is calculated. Contour maps and scatterplots of the weight coefficients describe the spatial distribution.

4.1 Spatial variation

The spatial variation is shown by contour plots. Contour plots of the first two weight coefficients of monthly mean pressure and precipitation is investigated. Special attention is given to the differences between the months and seasons.

The first component of pressure shows very stable spatial conditions throughout the year, with a minimum value region in central southern Norway. There are only small variations between the months. The most visible variation is the shift in position of the centre of this minimum zone and the variability of the weight coefficients. In February and the summer months May, June, July and August the contour plots show little variations in southern Norway (Fig. 2). In the remaining months there is a larger variation (Fig. 4).

The spatial distribution of the first weight coefficient of precipitation is more disorderly. This can partly be explained by the difference between the east and west side of the Oslo fjord, a phenomena also noticed in Tveito and Hisdal (1994). The first amplitude function reflects the precipitation caused by westerly weather systems. Due to local effects, the stations located east of the Oslo fjord deviate strongly from the series to west and north. As a result, the weight coefficients differ. The seasonal variation is the same as for pressure. In February and the summer months May, June, July and August the values of the first weight coefficient of precipitation are very stable in southern Norway (Fig. 3). In the remaining months larger variations occur, typical characterized by gradients normal to the coast line (Fig.5).

The second amplitude function of pressure contributes with between 9 and 22 percent of the

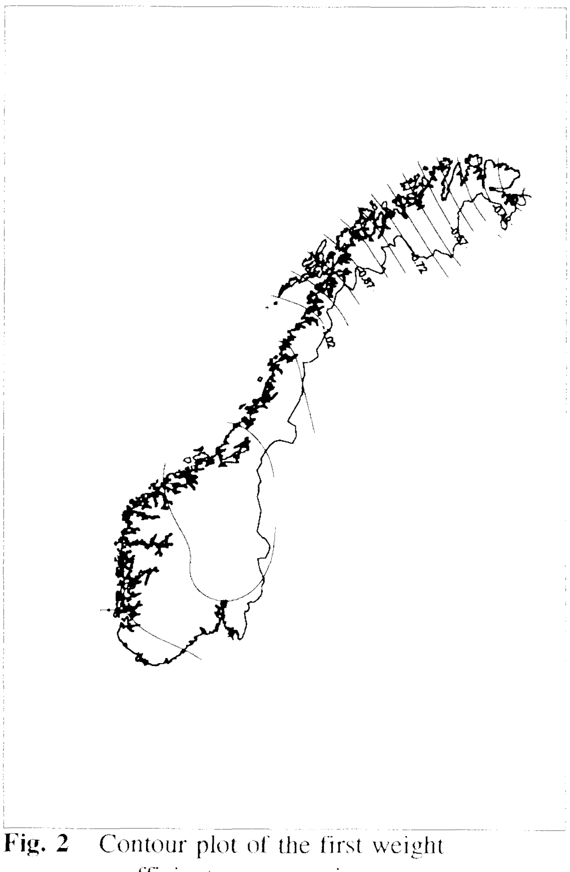

Fig. 2 Contour plot of the first weight coefficient, pressure, june.

Fig. 3 Contour plot of first weight coefficient, precipitation, june.

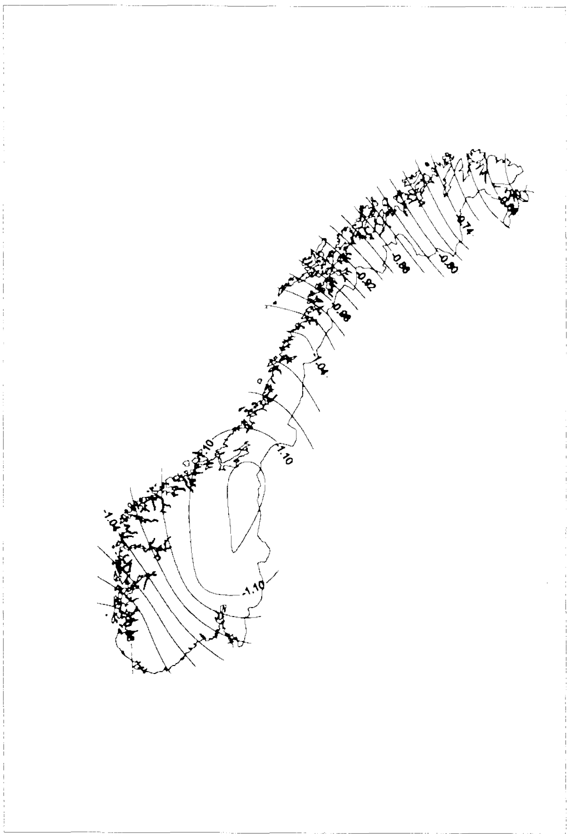

Fig. 4 Contour plot of first weight coefficient, pressure, october.

Fig. 5 Contour plot of the first weight coefficient, precipitation, october.

total variance, while the first function contains 73-90 percent. Pressure describes the large-scale circulation. The study area, in this connection, can be regarded as small scale, and the spatial variability is small. This is also seen by the large correlation between the pressure series. Therefore most of the variance in the pressure series will be in the first amplitude function, and the contribution from the second function will be small. The second weight coefficient of pressure has a very stable spatial distribution. There is a gradient in southwest-northeast direction (Fig. 6). The variation in the spatial pattern between the months is small. This is expected due to the small portion of the total variance.

The second amplitude function of precipitation explains a larger portion of the total variance. The spatial pattern is therefore more irregular than for pressure. The variance contribution is between 19 and 32 percent. February and the summer months May, June, July and August, have the same spatial pattern (Fig. 7). These patterns are equal to the patterns of the first weight coefficient in the remaining months. This shows that even if other processes dominate the precipitation pattern, the westerly winds influence significantly in these months as well.

The use of this method for downscaling the large scale process to local response, requires spatially stable weight coefficients. Stable spatial variation will give clusters of stations with weight coefficients of approximately the same magnitude. The first and second weight coefficient were plotted, and the regional grouping was compared. The clusters of the series were the same for all months, showing stable conditions (Fig. 8).

Fig. 6 Contour plot of the second weight coefficient, pressure, january.

Fig. 7 Contour plot of the second weight coefficient, precipitation, june.

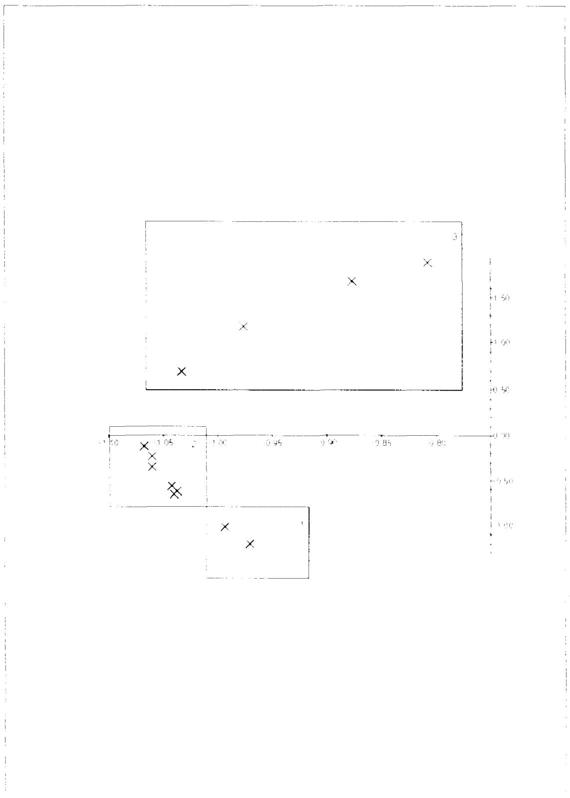

Fig. 8a Clustering of pressure series, january.

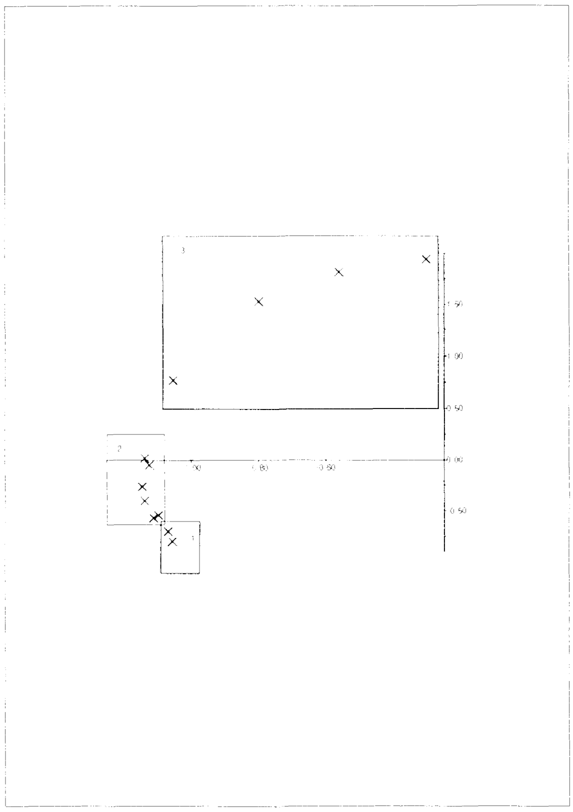

Fig. 8b Clustering of pressure series, june.

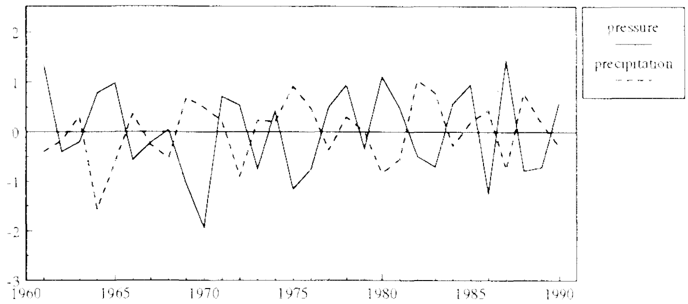

Fig. 9a Amplitude functions, january.

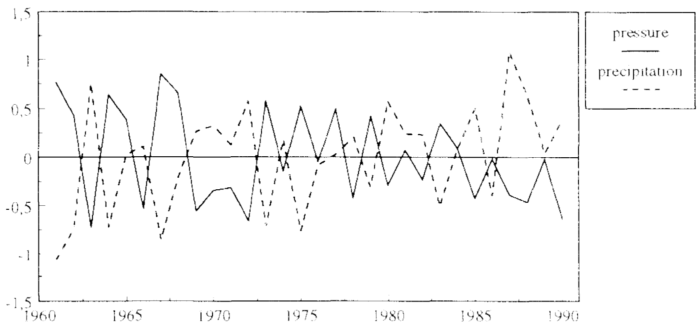

Fig 9b Amplitude functions, june.

4.2 Temporal variation

The main purposes of this project was to find relations between large-scale climate, represented by pressure, and local processes, represented by point precipitation. The amplitude functions represent the temporal variations. Tveito and Hisdal (1994) showed that the different amplitude functions of precipitation represent different weather systems. These systems, resulting in dominating wind directions, are results of the circulation. Therefore, the coherence between the amplitude functions of pressure and precipitation is studied.

A comparison of the amplitude functions and estimated series at three locations using the weight coefficients to estimate the local response of large-scale weather systems was carried out. Comparisons between estimated series of both pressure and precipitation was also done. In this way both the general conditions in the amplitude functions and the local events are examined.

The correlation between the amplitude functions of pressure and precipitation is shown in table 1.

The first amplitude function of precipitation has a strong negative correlation to the first amplitude function of pressure in February and the summer months May-August, and to the second amplitude function of pressure in the remaining months. Simultaneously the second amplitude function of precipitation is correlated to the second function of pressure in the summer months and February, and to the first function of pressure in the other months, see the bold and shaded values in table 1. To find an explanation it is useful to evaluate the characteristics of the amplitude functions in relation to the observed process. The amplitude functions are negatively correlated (Fig.9).

Table 1: Correlations between pressure and precipitation components.

Prec	1			2			3		
Pres	1	2	3	1	2	3	1	2	3
jan	-.23	**-.90**	.01	**-.83**	.31	.24	.13	.13	-.09
feb	**-.82**	-.22	.15	-.16	**.84**	.16	-.11	.27	-.03
mar	-.08	**-.90**	.10	**-.84**	.02	-.17	.07	.16	.30
apr	-.52	**-.75**	.16	**-.56**	.51	-.17	.04	.06	.26
may	**-.63**	-.44	.28	-.27	**.78**	.26	.02	.15	-.61
jun	**-.69**	.25	.25	-.22	**-.85**	-.18	.10	.10	-.08
jul	**-.52**	-.45	.26	.06	**-.68**	-.49	.05	.29	-.37
aug	**-.73**	-.48	.09	-.29	**.73**	.22	-.15	.15	-.23
sep	-.15	**-.84**	.33	**-.69**	.33	.38	.37	.09	.38
oct	-.23	**-.88**	.14	**-.75**	.26	.03	.15	.26	.21
nov	-.11	**-.81**	-.05	**-.68**	.28	.35	.14	.27	-.13
dec	-.13	**-.83**	-.27	**-.60**	.28	-.38	.04	.31	-.23

A result of high pressure is small amounts of precipitation, whereas low pressure is associated with high precipitation values. February and the summer months are the periods of the year normally having the most stable weather conditions, dominated by high pressure. This is especially the case in southern Norway. It looks like the first amplitude function of pressure accounts for the high pressure events, while the second includes the dynamics of the low pressure. The first function of precipitation considers precipitation of the low pressure weather events, while the second map the precipitation in high pressure events.

A weather type is a result of large-scale circulation, and different precipitation processes occur due to different weather systems. The result suggests that different weather systems are reflected in the amplitude functions of pressure, as in the amplitude functions of precipitation. This is also seen in Tveito and Hisdal (1994). The patterns are rough due to few stations, coarse time resolution and a large variability due to local influence on the precipitation series.

To verify the ability of the three first amplitude functions to reflect the original data, series of these variables for three locations were estimated. The correlation coefficient was used to quantify the degree of covariation between the precipitation and pressure series. To show the local differences and the variation between the different months, the correlation coefficients between estimated precipitation and pressure in the three locations are calculated (Table 2).

The best fit between pressure and precipitation occurs on the west coast. Not surprising, since this part has the most stable precipitation conditions. The low correlation in mid-Norway is mostly caused by sparse cover of observations, and therefore low representativity. The most dominating weather systems are the westerly and northwesterly winds, giving precipitation maximum at the west coast, with a strong orographic effect. The eastern Norwegian series have a different dominating precipitation. Both precipitation volume and frequency are smaller, and not directly connected to one specific weather situation. The dominating processes change through the year. In the summer period convective events dominate. A clear relationship between precipitation and pressure is seen in eastern and southwestern Norway during most of the year.

Table 2: Correlation coefficient between pressure and precipitation. Ø-Eastern Norway, SV-south western Norway, TR-mid Norway.

	Estimated		
	Ø	SV	TR
jan	-.62	-.76	-.47
feb	-.79	-.73	-.31
mar	-.54	-.67	-.55
apr	-.65	-.68	.01
may	-.54	-.67	.07
jun	-.62	-.50	-.25
jul	-.44	-.53	-.32
aug	-.62	-.72	-.39
sep	-.44	-.54	-.27
oct	-.38	-.57	-.35
nov	-.37	-.53	-.22
dec	-.33	-.41	-.39

The first pressure component covers most of the variance in most parts of Norway (above ~90%). A lower contribution from the first amplitude function (~80-89%) is seen in the southwestern part. The two northernmost stations have the smallest values (<~80%). As mentioned above, the relation between the stations is stable throughout the year. The degree of explanation varies between the months, reflecting the variability of the weather. In the autumn the contribution from the first pressure component is at its smallest, reflecting a large variability in the weather. Generally, the second amplitude function of pressure contributes little to the total variance. It gives a significant contribution at the southwestern coast and in northern Norway.

The variance contribution from the amplitude functions of precipitation is more difficult to interpret. Precipitation contains a lot more variability, and this is reflected in the amplitude functions. According to Tveito and Hisdal (1994), the first amplitude function covers the precipitation due to a westerly weather direction. This component gives a high degree of explanation at the western coast south of Bergen and in eastern Norway. The second amplitude function explains more of the variance at the northwestern coast and northwards. Some variations occur throughout the year. The border between a dominating first or second component at the west coast changes between the months, from Bergen to Nordfjord. The variance contribution in northern Norway also varies. If the border is in the southern position, the second amplitude function explains most of the variance from Bergen and northwards. The degree of explanation in northern Norway decreases compared to months where the border has moved northwards.

Deviations in the results can easily occur due to characteristics of the input series. How the components contribute depends on the series entered the EOF-analysis. These results suggest a relation between pressure, representing large-scale climate and local scale precipitation. A too wide interpretation of these results should be avoided until more adequate data are analyzed.

5. CONCLUSIONS AND FURTHER RESEARCH

This study is a first step in finding methods for downscaling GCM-results to local conditions.

Time series of pressure and precipitation for twelve locations were decomposed using the EOF-method. The components in both time and space were calculated for each month.

Investigations of the stability of the regional grouping of the first two weight coefficients showed stable clustering. The same clusters were found for all months for both pressure and precipitation.

Studying the relationship between weight coefficients of pressure and precipitation, no clear common spatial pattern is seen. Due to the large variability in precipitation caused by local effects, further investigations are needed to find the exact influence of large-scale circulation to local precipitation. It is necessary to evaluate the influence of local conditions to the precipitation volumes, as well as to the circulation patterns themselves.

Studies of the coherence between the amplitude functions showed high negative correlations between the functions of precipitation and pressure. There is a shift in the correlation between months having the largest expectation of stable high pressure events, and the remaining months. The analysis shows that the first amplitude function of pressure can be related to high pressure conditions, while the second function contains information about low pressure events. For precipitation the opposite characteristics are found. The dependence of pressure and precipitation is strongly reflected in the amplitude functions.

The results suggest, as expected, a relation between large-scale circulation and precipitation volumes. However, the data used are not satisfactory. A high pressure event, with no precipitation may be stable over a long period, resulting in a high monthly mean pressure value. A few days of heavy rain within the same period, will give high precipitation values. Daily values would have given the direct relation between the variables. It would also have been an advantage to use the 1000 hPa and 500 hPa surface instead of the sea-level pressure to represent circulation patterns, because this gives a better description of the wind speed and direction. This data set is about to be established, and further investigations will be carried out.

6. REFERENCES

Hay, L.E., McCabe, G.J.jr., Wolock, D.M. and Ayers, M.A. (1992)
Simulation of precipitation by Weather Type Analysis, Water Res.Res., 27, pp 493-501.

Hughes, J.P. and Guttorp, P. (1994)
A class of stochastic models for relating synoptic atmospheric patterns to regional hydrologic phenomena, Water Res.Res. 30, pp 1535-1546.

Kaas, E. (1993)
Greenhouse induced climate change in the Nordic countries as simulated with the Hamburg climate model; part 2: Statistical Interpretation, Danish Meteorological Institute Scientific Report, 93-3

Preissendorfer, R.W. (1988)
Principal components analysis in Meteorology and Oceanography, Elsevier, Amsterdam.

Sælthun, N.R., Bogen, J., Flood, M.H., Laumann, T. , Roald, L.A., Tvede, A. and Wold, B. (1990)
Climate change impact on Norwegian water resources, NVE-publikasjon V42

Tveito, O.E. and Hisdal, H. (1994)
A study of regional trends in annual and seasonal precipitation and runoff series, NVE-rapport 09/1994.

Denne serien utgis av Norges vassdrags- og energiverk (NVE)
Adresse: Postboks 5091 Majorstua, 0301 Oslo

I 1995 ER FØLGENDE RAPPORTER UTGITT:

Nr 1 Lars-Evan Pettersson: Flomberegning Fossheimselva (087.B1Z). (11 s.)

Nr 2 Jim Bogen og Rolf Tore Ottesen: Suldalslågens sedimentkilder. (17 s.)

Nr 3 Lars-Evan Pettersson: Flomfrekvensanalyser for vestlandet. (15 s.)

Nr 4 Bjarne Krokli: Flomberegning for Finnbuavatn (036.CE) og Vasstølvatn (036.CC). (19 s.)

Nr 5 Randi Pytte Asvall: Mel kraftverk. Vanntemperatur i Vetlefjordelva etter utbygging. (17 s.)

Nr 6 Bjarne Krokli: Flomberegning for Austre og Vestre Middyrvatn (036.G). (19 s.)

Nr 7 Bjarne Krokli: Flomberegning for Votnamagasinet (036.F). Foreløpig rapport. (12 s.)

Nr 8 Leif J. Bogetveit: Vannføringsobservasjoner i Holobekken. (3 s.)

Nr 9 Ole Einar Tveito og Hege Hisdal: Disaggregation of large scale climatological information. (14 s.)