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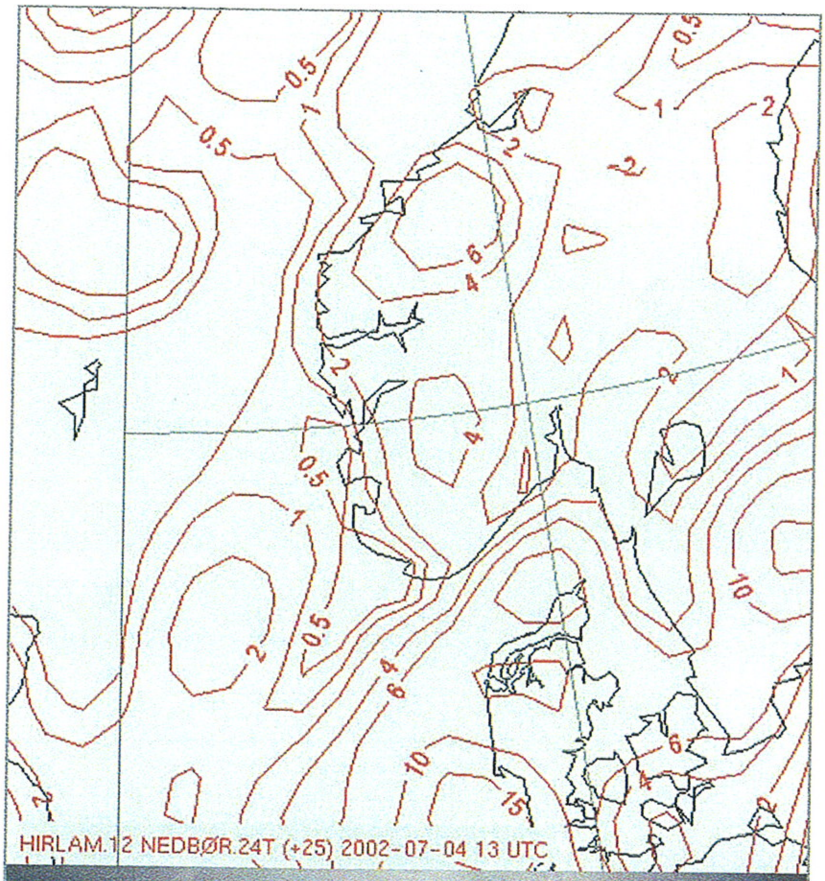
An objective comparison of observed and forecasted 24-hour precipitation, a spatial analysis

Ole Einar Tveito



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TITLE:

An objective comparison of observed and forecasted 24-hour precipitation, a spatial analysis

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PROJECT CONTRACTORS:

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Norwegian Meteorological Institute

SUMMARY:

The relation between the spatial distribution of daily precipitation and large-scale atmospheric circulation for the period 1979-1994 is analysed. Both the patterns of occurrence and amount are studied, revealing distinct differences in the spatial distribution of precipitation between different weather types. Also the influence of circulation indexes is analysed. Both annual and seasonal patterns are studied.

Precipitation forecasts are encumbered with errors, and in order to find systematic errors forecasted and observed precipiation fields are compared. The comparison shows that there are distinct variations in which areas where the precipitation predictions coincide with the observations. These variations can be related to the large-scale atmospheric circulation. The same features are also identified when studying cross-sections, where systematic differences are found in some profiles, especially near the coast for some circulation patterns

KEYWORDS:

Preciptation, spatial analysis, weather type classification, model output statistics (MOS), precipitation forecasts, precipitation observations.

SIGNATURES:

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CONTENTS

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The research presented in this report would not have been possible without valuable help and inspiration from my colleagues at *met.no,* especially Eirik Førland and Viel Ødegaard. The work is partly funded by EBL-Kompetanse.

1. Introduction.

Precipitation forecasts from numerical weather prediction models (NWPs) can be encumbered with large errors, especially in areas with large variations in topography. These errors are mainly to two different types:

- Wrong prediction of the weather situation.
- Non-representative representation of topography etc. in the NWP-model.

The latter error is a result of the model parameterization, resulting in systematic over or underestimation of precipitation for specific wind-directions. Another error related to topography is caused by the smoothed terrain representation in such models. The operational model in Norway, HIRLAM10, has a spatial resolution of 10x10 km^2. It has a smoothed representation of the terrain, which in some places differs from the actual terrain altitude with more than 1200 meters.

The NWP model gives quantitative predictions of weather elements that are integrated in time and space. Especially in space such integrations may result in systematic errors compared to observed weather elements, since local conditions not are likely to be covered by a grid cell with an area of 100 km^2 or larger. This makes verification of the NWP-estimates compared to point measurements difficult, and often more questions are raised after such "direct" verifications rather than giving a good verification.

Many users of precipitation forecasts, especially hydropower producers, have pointed out that the precipitation forecasts may be systematically too high or too low in many areas, partly depending on the wind direction. It has therefore been a request for an analysis examining the differences between observed and predicted precipitation in order to find systematic biases by some objective criteria. Two approaches have been tested; a continuous spatial analysis implying a spatial interpolation of observed precipitation, and a verification using homogeneous clusters of observation stations (Nordli, 2002). In the latter approach, five groups were defined with five observation stations selected in each group, covering regions with different precipitation characteristics. For these stations, precipitation forecasts were 24% higher than observed. The error varied with season and was largest in spring and summer, and less in the autumn. Regression expressions based on the linear relation between observed and forecasted precipitation within each Lamb weather type were established and used to adjust the forecasted precipitation. This adjustment improved the weather forecasts in most regions for daily precipitation amounts less than 5 mm.

In this report a spatial analysis of observed and forecasted precipitation is presented. The spatial distribution of occurrence and amounts of precipitation are strongly related to the large-scale atmospheric circulation, and several authors have used such information to describe precipitation characteristics. In this report observed precipitation patterns related to atmospheric circulations are analysed and discussed. Then are observed and forecasted precipitation analysed and compared.

2. Data

This study is based on four different sources of data; observations, predicted precipitation from HIRLAM and mean sea level (MSLP)-fields from HIRLAM50[1]-predictions and NCEP[2] reanalyses. For the verification of the HIRLAM10[3] forecasts, the time period studied is 01.01.1999-31.10.2001. In addition the precipitation climate in southern Norway related to the large-scale atmospheric circulation patterns in the period 1979-94 was studied.

2.1 HIRLAM50

MSLP-fields from the operational HIRLAM50 model, which covers a larger area than the fine-mesh HIRLAM10 are used for determining the weather types. Predicted MSLP-values from 16 gridnodes (see chapter 3.x) are used for this purpose. The HIRLAM fields have a time integration of 12 hours. This means two daily realizations are used.

2.2 NCEP

For the analysis of precipitation climate in southern Norway, a longer term (1979-1994) daily circulation patterns over southern Norway were defined using MSLP values from the gridded dataset NMC/NCAR ds195.5. This data set gives a good description of local pressure patterns (Benestad, 1999).

2.3 HIRLAM10

The predicted precipitation is based on short forecasts (30h) from the operational HIRLAM10 used at *met.no*. This forecast is based upon two forecasts of 18 and 12 hours lengths respectively (the first 6 hours are "spin up" time 00-06 UTC) The data are resampled to represent the precipitation day (06-06 UTC) 24 hr precipitation.

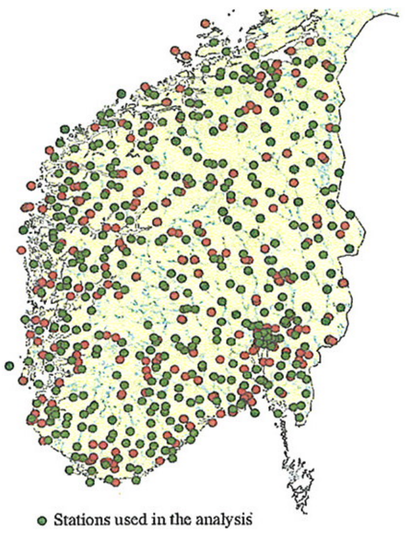


Figure 1. Stations used in the investigations

2.4 Observations

Observations are used in two parts of this investigation. First, the relation between large scale atmospheric circulation and precipitation in southern Norway is studied. This study covered the period 1.1.1979-31.12.1994. Altogether 742 stations (figure 1) have been operational within the period, but not all during the whole period or at the same time. After preliminary analysis, stations not operating throughout the entire period and stations

[1] HIRLAM50 – **HI**gh **R**esolution **L**imited **A**rea **M**odel 50x50km^2.
[2] NCEP - National Centers for Environmental Prediction
[3] HIRLAM10 – **HI**gh **R**esolution **L**imited **A**rea **M**odell 10x10km^2.

having irregular sampling intervals were discarded from the data sample. After this revision of the data set, 379 stations remained for the study. For verification, all available 1-day precipitation (06-06 UTC) observations for southern Norway are used. The majority of the stations are precipitation stations observing at eight o'clock in the morning, which is equal to 07UTC in winter and 06UTC in summer. The 1hour shift in accumulation period is an error source that probably is negligible in this analysis.

The values examined are observed precipitation, not corrected for undercatch due to wind effects around the gauge. For solid precipitation during strong winds such effects may cause a ratio between observed and "true" precipitation with a factor of two. This is an error that may influence verification of precipitation forecasts, especially in wind-exposed areas at the coast and in mountain areas.

Approximately 400 stations are available, including synoptic weather stations, climate stations and precipitation stations. The observations used are quality-controlled data selected from the *met.no* climate database.

3 Methods

31 Gridding of observed precipitation

Spatial interpolation of precipitation is complicated since precipitation is highly variable in space. In addition it is not continuous, neither in time and space, which lead precipitation interpolation to be a two-component problem; 1-precipitation or noprecipitation, and if precipitation, the amount of precipitation. A number of studies of more or less advanced methods have been carried out. Mestre (2002) gives an overview of such methods.

In this study, spatial interpolation of daily precipitation is done in a straightforward procedure applying triangular irregular networks. This method builds up a surface by establishing triangles between three observation points (fig 2a-b). The linear three-dimensional surfaces between the stations represent the precipitation field, and the value at each gridpoint is estimated from the surface (fig. 2c). The motivation for using this simple method instead of more complicated methods is to keep simplicity of the calculation. Applying more advanced interpolation schemes includes more uncertainties and rise new questions, which will be focused in future research.

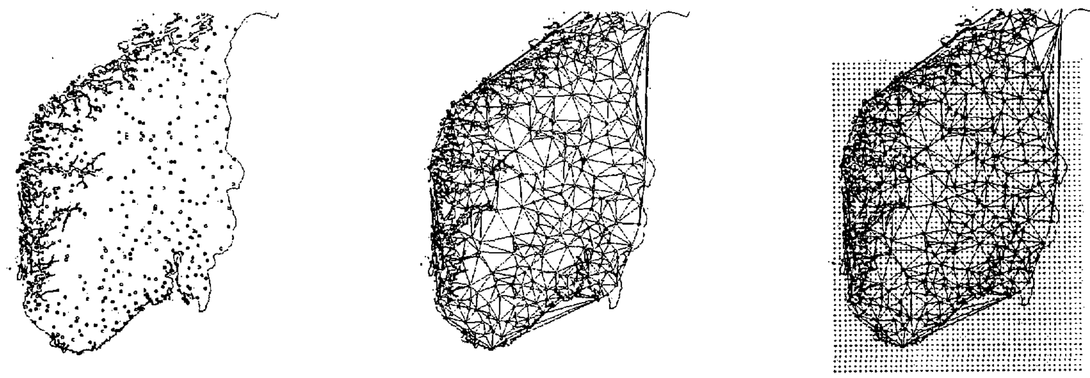


Figure 2. The TIN procedure to establish daily rainfall fields.

a) (left) Location of the observation points.
b) (middle) The TIN structure based on these points
c) (right) The location of the gridnodes (+) .

3.2 Weather type classification.

For identifying the atmospheric circulation patterns, an objective classification of Lamb circulation indexes was applied (Briffa, 1995, Jones et al, 1993, Chen, 1999). This classification in based on mean sea level pressure (MSLP) in 16 gridnodes, as shown in figure 3. The circulation index is defined by the directional flow components and the shear vorticity. The classification scheme results in 26 defined classes (Cyclonic and anticyclonic, 8 directional and 16 hybrid classes), and a class of undefined circulation. The frequency of the circulation indexes during 1979-1994 is shown in figure 4. One disadvantage of this classification scheme is that the two classes cyclonic and anticyclonic dominate. Daily circulation patterns over southern Norway were defined using MSLP values from the gridded dataset NMC/NCAR ds195.5. This data set gives a good description of local pressure patterns (Benestad, 1999).

The classification method is based on mean daily values of MSLP, and thus therefore not considers the change of circulation during the day. Precipitation sums integrated over 24 hours may have occurred during a short period of the day, caused by an atmospheric circulation pattern different from the one reflected in the mean daily pressure field.

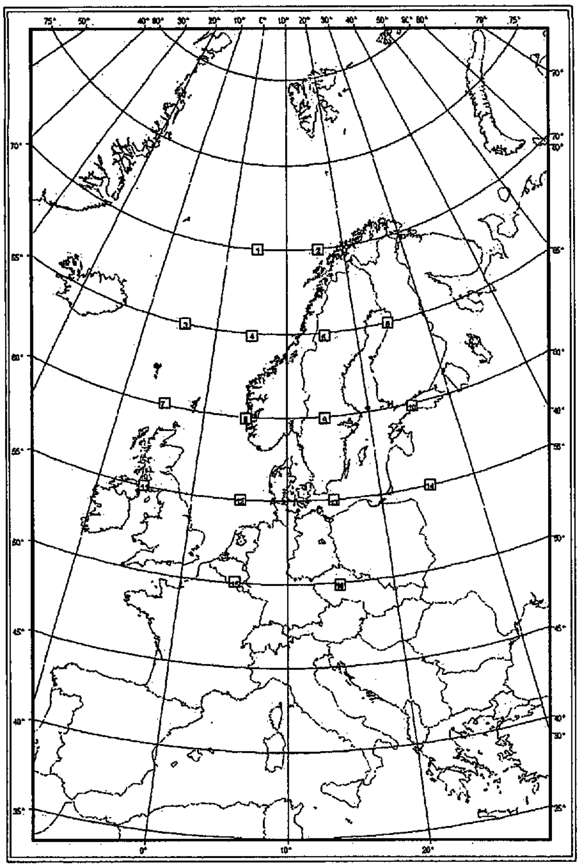


Figure 3. Nodes used in the classification of large-scale atmospheric circulation

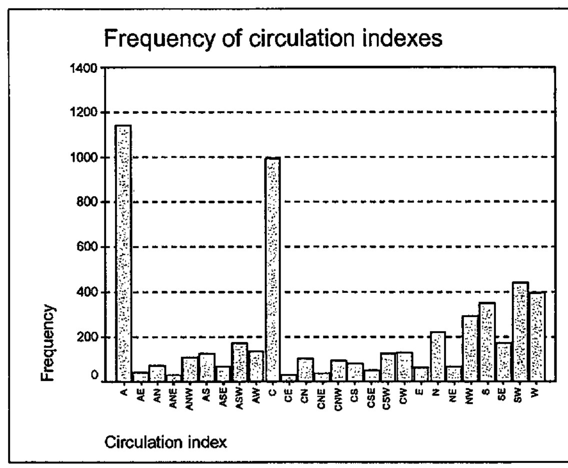


Figure 4. Frequency of daily circulation indexes 1979-1994.

Table 1. Objective Lamb classification (after Briffa (1995), Chen(1999), Jones et al. (1993))

Westerly flow:	W =	0.5 * (p(12) + p(13) - p(4) - p(5))	(zonal)
Southerly flow:	S =	0.499*(p(5)+(2*p(9))+p(13)-p(4)-(2*p(8))-p(12))	(meriodional)
Resultant flow:	F =	√((w*w)+(s*s))	
Shear vorticity:			
Westerly:	ZW =	(0.529*(p(15)+p(16)-p(8)-p(9)))-(.478*(p(8)+p(9)-p(1)-p(2)))	
Southerly	ZS =	0.499*(p(6)+(2*p(10))+p(14)-p(5)-(2*p(9))-p(13)-p(4)- (2*p(8))-p(12)+p(3)+(2*p(7))+p(11))	
Total:	Z =	zw + zs	
Direction	α =	ATAN(W/S)	

Criterias		Resulting circulation indexes.	
1. **Direct flow:**	|Z| < F	N, NE, E,......, W, NW	(8 possible)
2. **Cyclonic/anticyclonic:**	|Z| ≥ 2F		
Cyclonic circ.	Z > 0	C	
Anticyclonic	Z < 0	A	(2 possible)
3. **Hybrid categories:**	F < |Z| ≤ 2F		
Cyclonic circ.	Z > 0	CN, CNE, CE,..............., CW, CNW	(8 possible)
Anticyclonic	Z < 0	AN, ANE, AE, ..., AW, ANW	(8 possible)
4. **Unclassified:**	F < 6, |Z| < 6	U	(1 possible)

4. Precipitation patterns and large scale circulation.

Norway is a country characterized by large climatological gradients. Especially precipitation shows a large spatial variability. Close to the western coasts, mean annual precipitation exceeds 4000 mm, while on the leeward side of the Norwegian mountain ridge, approximately one hundred kilometres away, mean annual precipitation is less than 300 mm.

Several attempts have been made to give a climatological description of Norwegian precipitation conditions (e.g. Førland, 1979, 1984). These studies have been concentrated on smaller regions and/or single stations, but an objective analysis considering all stations covering a large area has not yet been carried out.

The spatial distribution of precipitation is related to large scale as well as local scale circulation. In this chapter both annual and seasonal patterns of observed precipitation in southern Norway related to the large scale atmospheric circulation are discussed.

Conditioned by the daily circulation patterns, the precipitation characteristics were analysed. Mean precipitation sum and the frequency of occurrence were estimated for each station. A thin plate spline spatialisation algorithm (TOPOGRID, ESRI 2001) was applied to establish continuous surfaces of these two values. All days are considered, also including days without precipitation. The analysis shows distinct regional patterns both for precipitation amount as well as for probability for precipitation.

4.1 Annual precipitation patterns.

Figure 5 shows the probability for precipitation for the circulation types SE-W. These circulation types represents a direct flow type, and the probabilities are shown to give an impression of how the precipitation conditions vary with slightly different atmospheric circulation. In this selection of precipitation patterns, the change in probability for precipitation in the different regions is quite large. The south-easterly circulation (SE) gives a high probability (> 60%) for precipitation at the south-eastern coast, and moderate probability in the eastern parts. Western and northern parts of the region have low risk for getting precipitation. However, as figure 6 shows, the average daily precipitation sums are not large. They do not exceed 10 mm even in the "wettest" areas. When turning to a southerly circulation type (S), the origin of the air-masses are more maritime than for the south-easterly circulation. The probability for precipitation increases for most of southern Norway, with probabilities of more than 80% in large areas. However, the mean daily precipitation is still rather low, not more than 15 mm in the areas with highest values. The pattern is quite distinct having a maximum zone close to the coastline, with the highest precipitation amounts at the southernmost part of the coastline. There also seems to be a shadow effect in the Stavanger/Boknafjord area.

When the circulation is southwesterly (SW), most of southern Norway experience precipitation. The probability for getting precipitation is above 60% for most of the region, except an inland area in the northeast, and some pockets caused by single stations in the eastern parts. The precipitation amounts are however largest at the west coast, where a large orographic precipitation enhancement occur. The precipitation amounts on the leeward side of the mountains are small, less than 5 mm as daily averages.

Westerly (W) flow is regarded as the circulation type giving most precipitation at the west coast. This circulation type is practically zonal, and the precipitation variability in western Norway shows high correlation with a zonal flow (Tveito, 1996), with a correlation up to 0.93 for monthly means. Compared to the southwesterly flow, the pattern of precipitation probability is much more distinct. On the leeward side of the mountains, the risk for getting precipitation is low. The maximum zone for precipitation is a distance (approx 40-50km) off the coastline, and as for the southwesterly circulation type, the maximum zone is parallel to the coast.

4.2 Seasonal patterns

The patterns described above reflect the mean conditions over the entire year. An analysis was also carried out to reveal any differences between the different seasons. Figure 7 shows the probability of precipitation ($\geq$ 0.1 mm) for the circulation type S. Most of the area south of Dovre should expect precipitation in all seasons when this circulation type occurs. There is however a higher probability in the south-eastern part in the winter season compared to the other seasons. In the summer season, the mountain areas (Hardangervidda and Jotunheimen) have a higher probability of precipitation. The eastern parts have fewer rainy days in spring and summer than during autumn and winter.

The mean seasonal precipitation amounts for circulation type S are shown in figure 8. The patterns are quite similar throughout the year, with two major features. The spring season is the driest, and the autumn season is wettest, especially in the southernmost area.

The probability for seasonal precipitation for days with southwesterly circulation is shown in figure 9. There is a large variation between the seasons. Especially the spring season differs, with lower probability of rainy days in eastern areas. This feature is also present during summer, but the patterns are patchier. Autumn and winter shows high probabilities for precipitation in most of the area, except in the northeast.

Figure 10 shows the expected precipitation amounts for the same circulation type. The differences between the seasons are well defined. The rainfall amounts are higher in winter and autumn than in spring and summer.

For the westerly ciculation type (W), seasonal probabilities for precipitation days are shown in figure 11. This circulation shows a distinct variation between the western and eastern areas. The western areas have a very high probability for getting precipitation. Most of the area west of the mountains has 100 % probability, and the extent of this area is more or less constant independent of the season. In the "rainshadow" in the east, probability for precipitation is higher in summer and autumn than in winter and spring seasons. At the southwestern coast, the probability is less in the spring and summer seasons than for winter and autumn.

Figure 12 shows the mean seasonal rainfall amounts for weather type W. As for the SW-type, the patterns are quite similar throughout the year, but also the W-type precipitation amounts are higher in winter and autumn. In the eastern parts, summer and partly autumn precipitation is higher than in other seasons, which is in accordance with the probability maps.

The northwesterly circulation type shows much of the same patterns as the westerly type, but shifted according to the wind direction. Probability for precipitation (figure 13) is high along the western coast and in Trøndelag for all seasons. In the winter and autumn season the 100% probability area covers the entire coastline from Jæren to Trøndelag. In spring and summer the southern part of the coastline has lower probability. One remarkable feature is the higher probability in the interior parts of southeastern Norway (Hedmark) in summer.

Figure 14 shows the mean precipitation amounts for the NW circulation type. The maps show that the precipitation overall is smaller than for the westerly circulation type (W). Winter and autumn show the highest precipitation values. The maximum zone is found along the western and northwestern coasts, a small distance inland the coastline. In the summer season precipitation values generally are small, with a small maximum area in northwest, where daily precipitation amounts in average are between 10 and 15 mm. The area where mean precipitation is higher than 1 mm is larger in the summer season than for the other season, matching the probability maps.

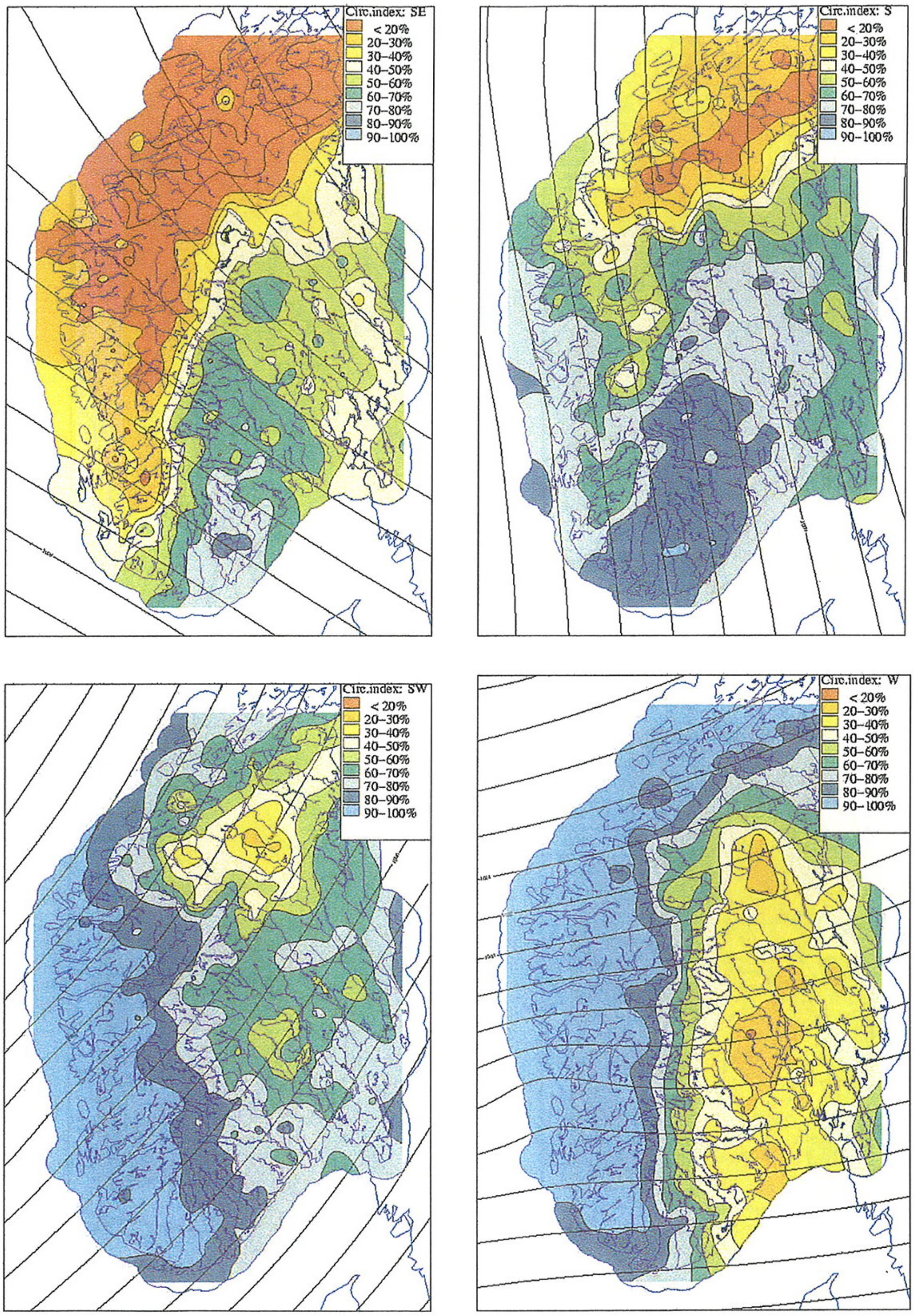


Figure 5. Probability (%) for precipitation for circulation types SE (top left),S (top right), SW (bottom left) and W (bottom right). The lines in the map are the isobars of the averaged sea level pressure field for the circulation type.

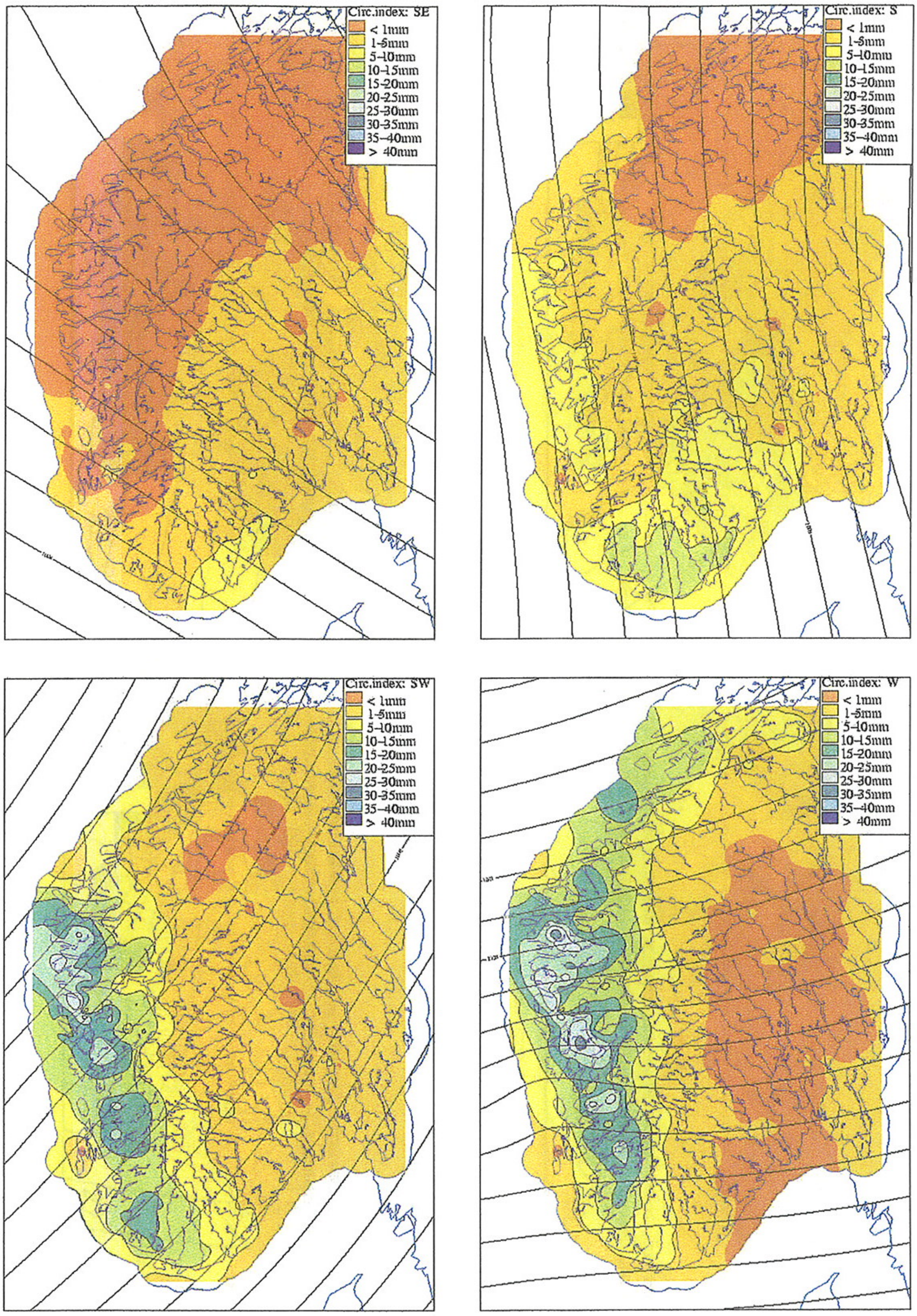


Figure 6. Mean daily precipitation (mm) for the circulation types SE, S, SW and W.

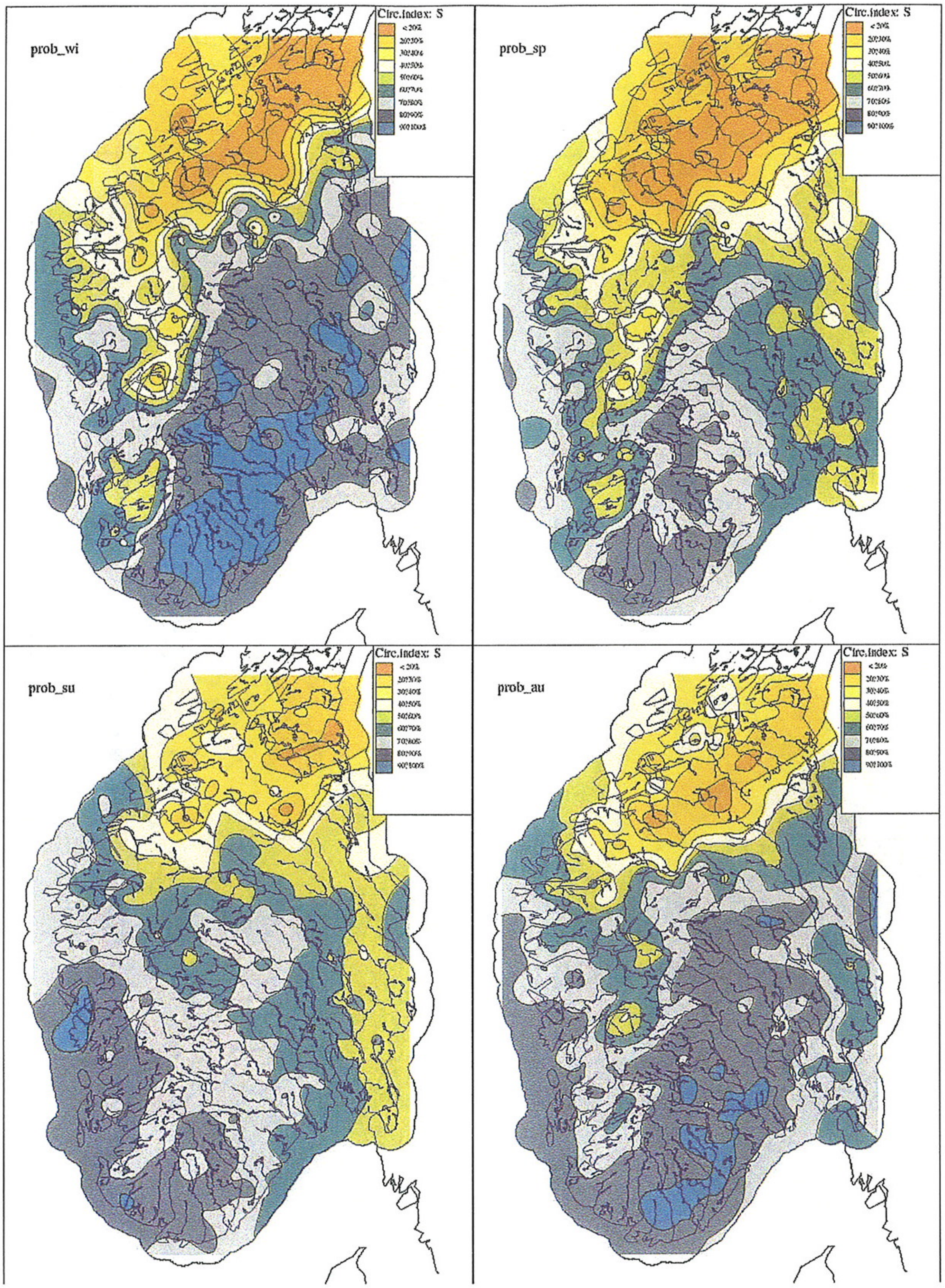


Figure 7. Seasonal daily precipitation probability (%) for weather type S:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

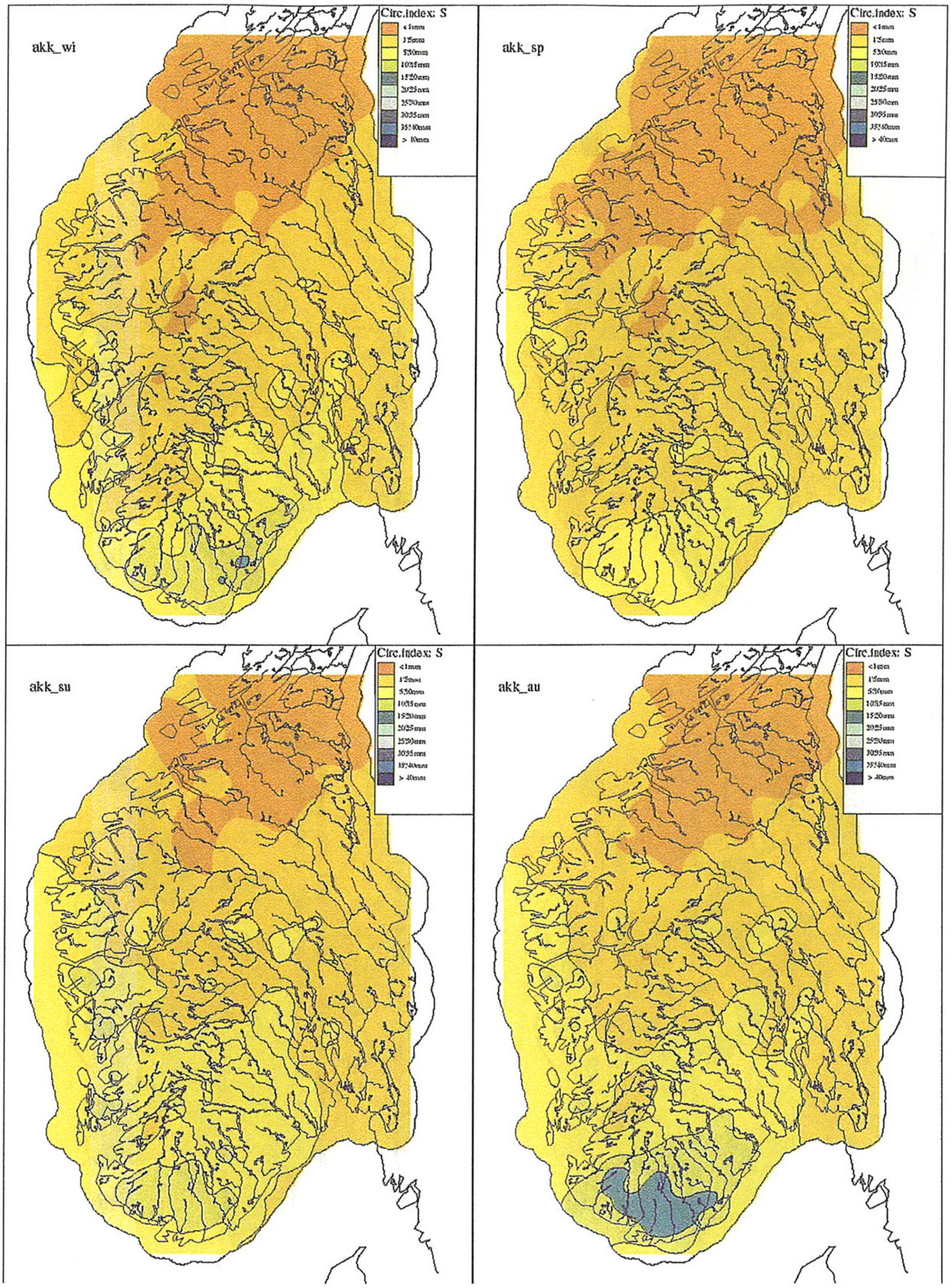


Figure 8. Seasonal mean daily precipitation for weather type S:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

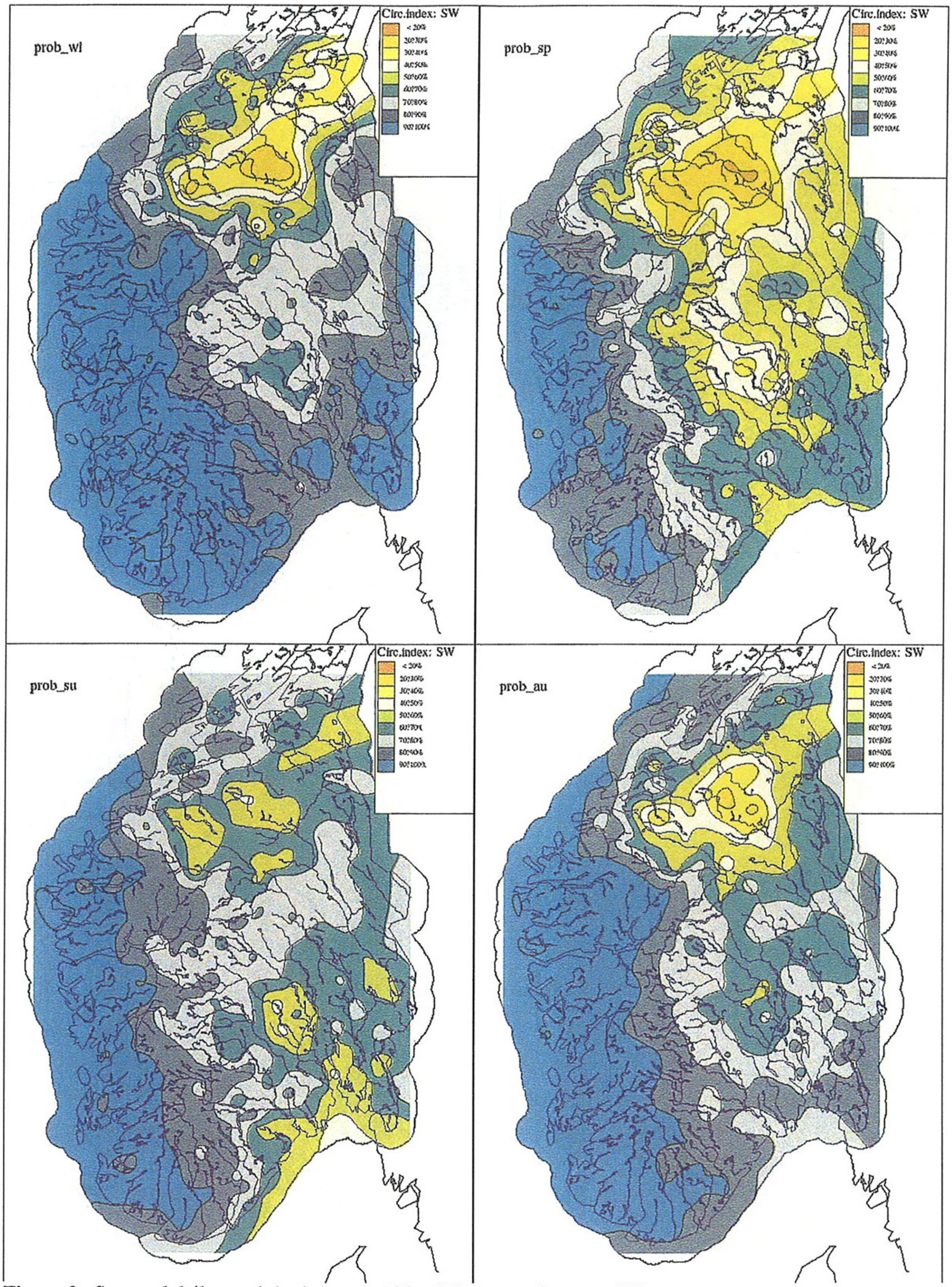


Figure 9. Seasonal daily precipitation probability (%) for weather type SW:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

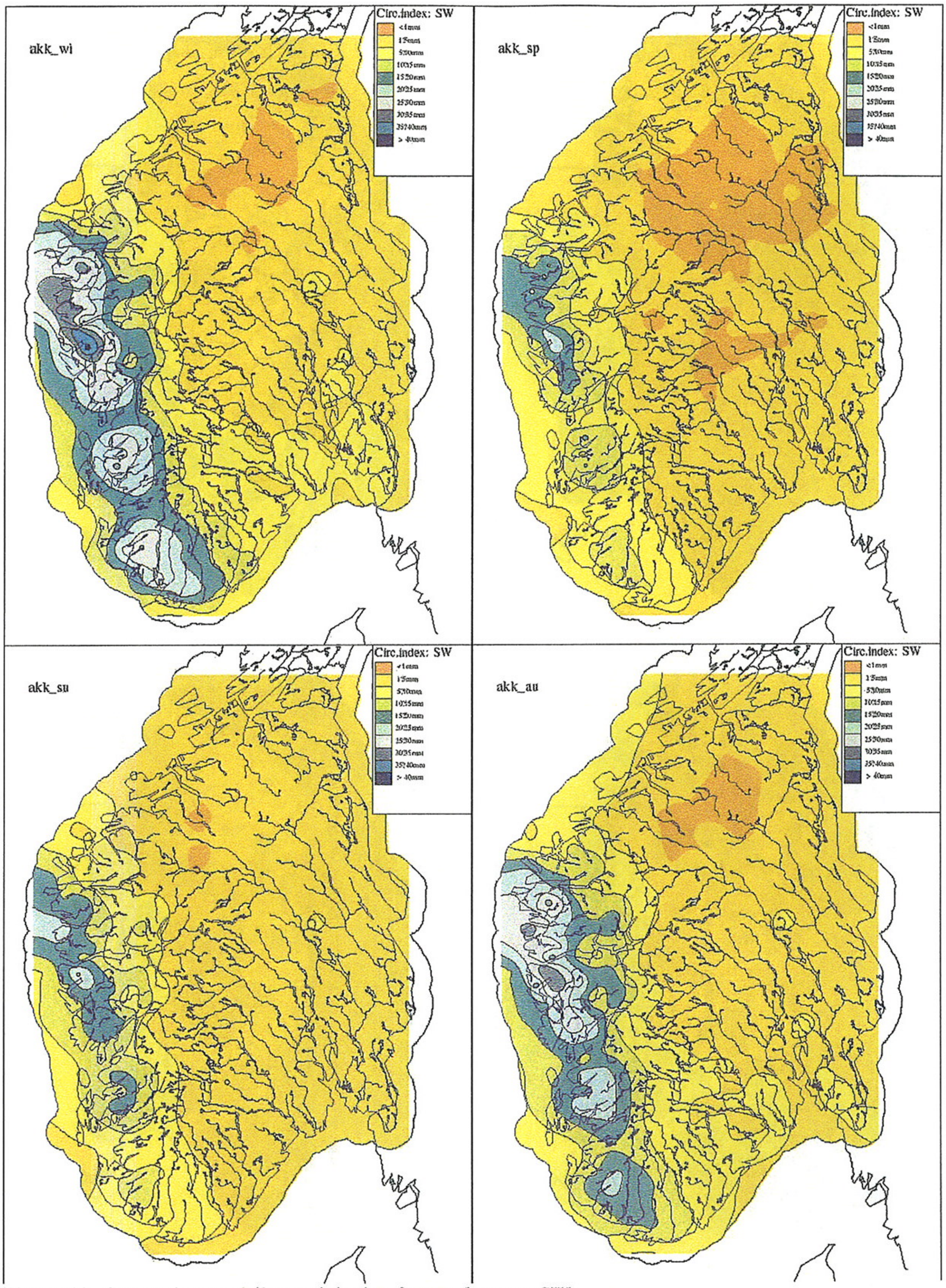


Figure 10. Seasonal mean daily precipitation for weather type SW:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

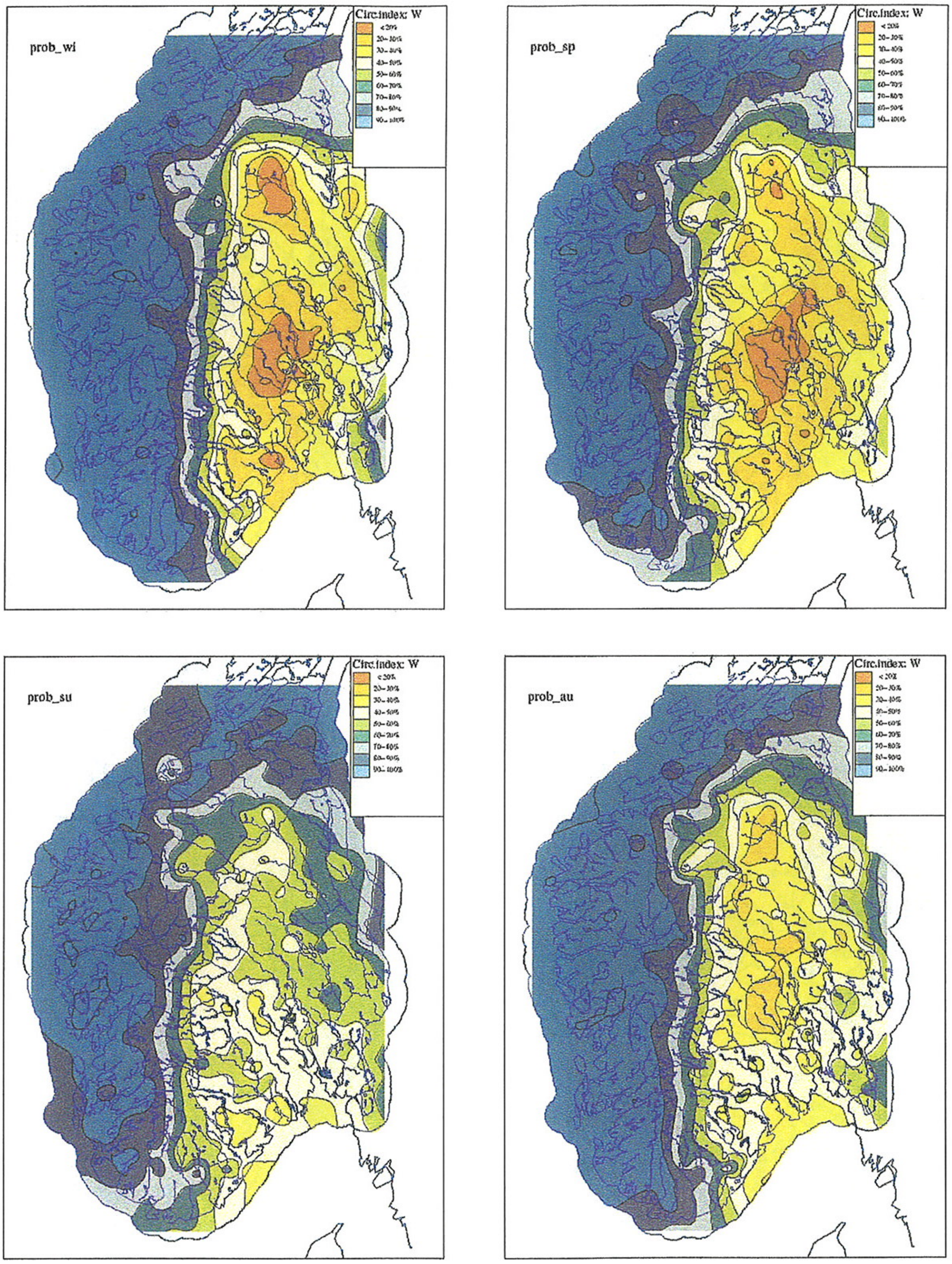


Figure 11. Seasonal daily precipitation probability (%) for weather type W:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

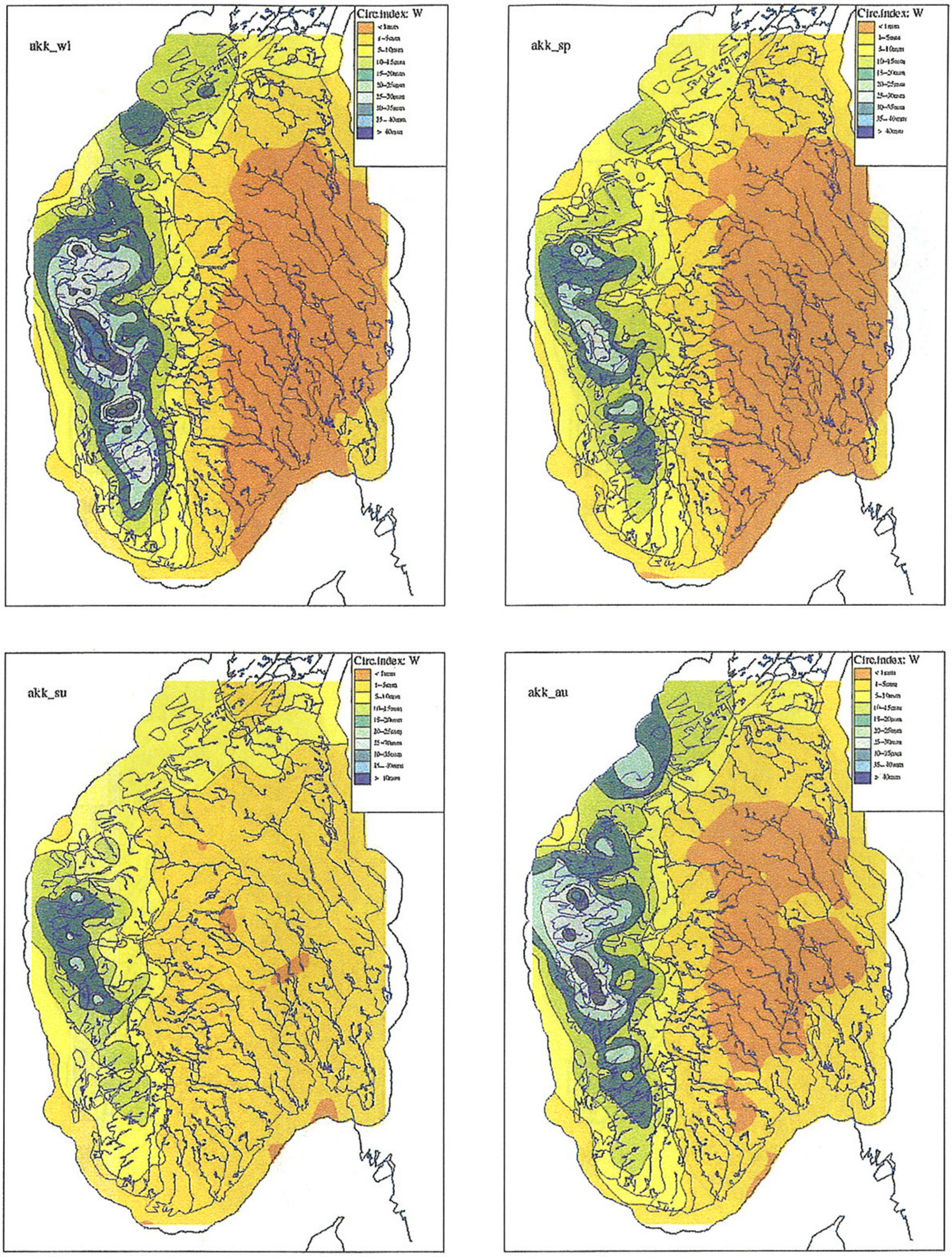


Figure 12. Seasonal mean daily precipitation for weather type W:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

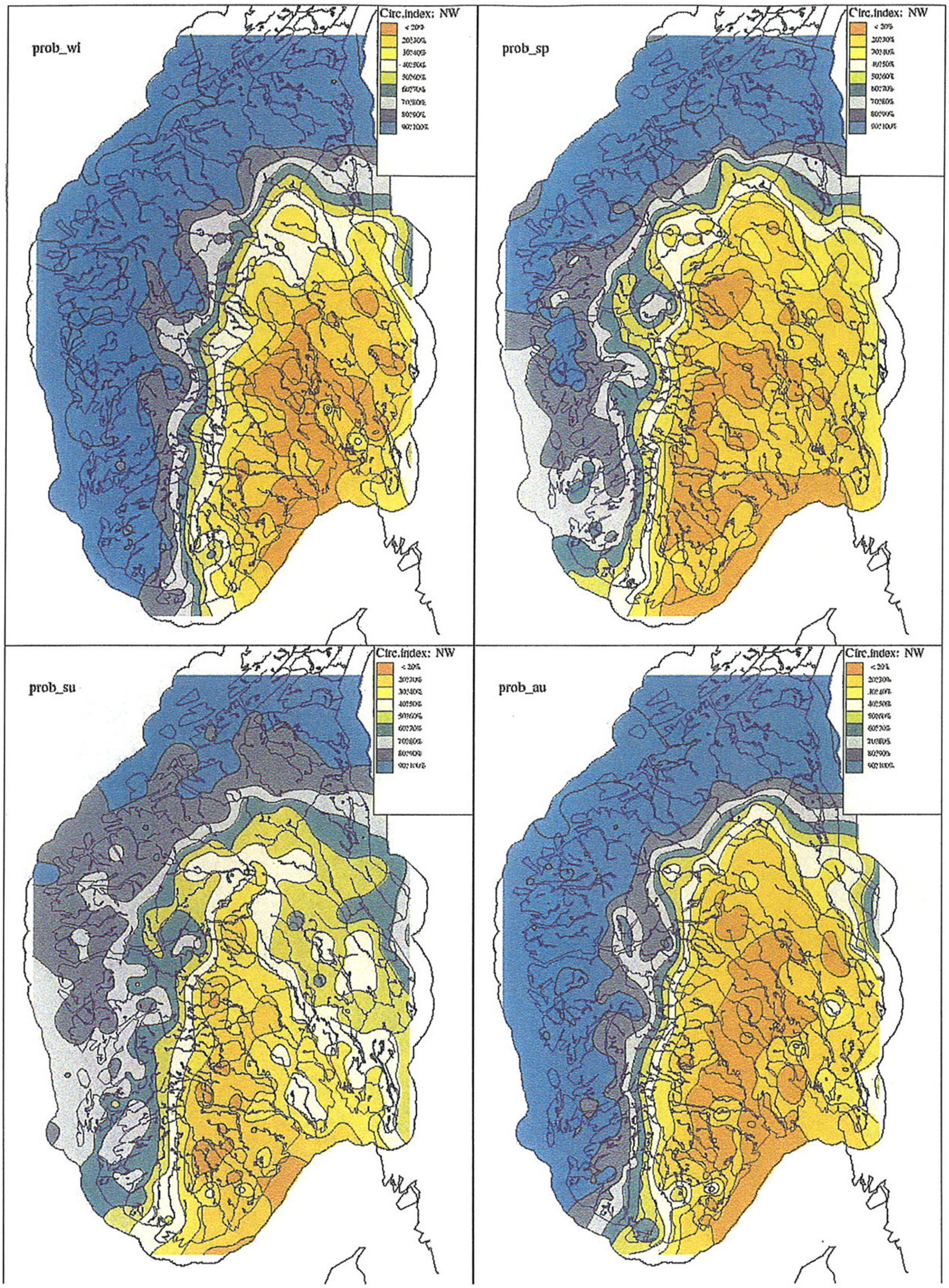


Figure 13. Seasonal daily precipitation probability (%) for weather type NW:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

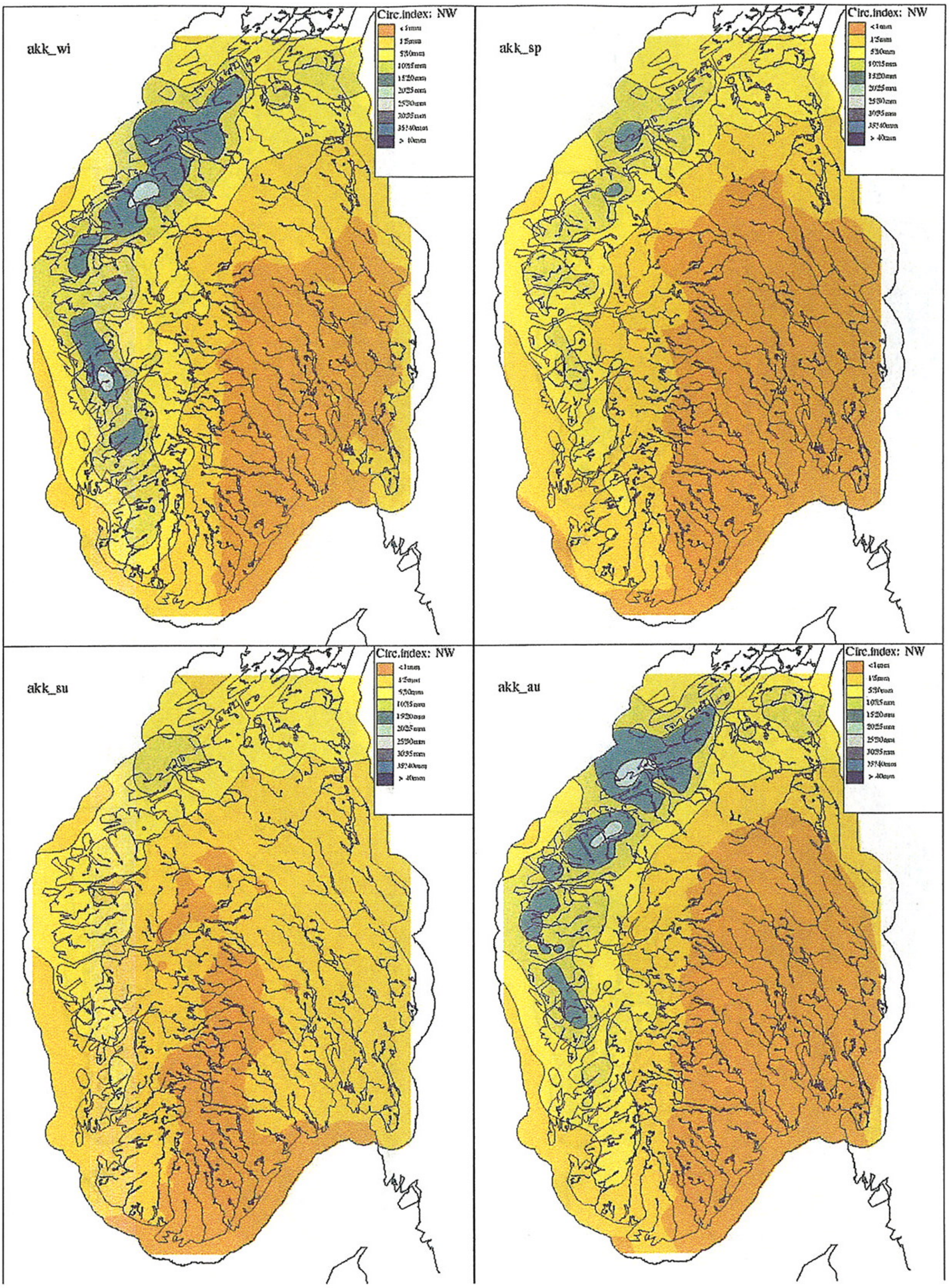


Figure 14. Seasonal mean daily precipitation for weather type NW:
Winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

5. Precipitation gradients.

For the westerly circulation type, a narrow cross-sector from the west coast to the Swedish border (figure 15) was examined closer. Figure 16a shows the probability for precipitation for the stations in the cross-section. The red line describes the large-scale terrain (average altitude within a 50 km circle around each station). The blue curve shows the probability of getting precipitation.

5.1 Annual variations

There is almost 100% chance getting precipitation when there is a westerly flow in the area from the coast and almost to the summit of the mountains. On the leeward side, the expectation for precipitation decreases rapidly. One interesting feature is that although the probability for precipitation is constantly high from the coastline to the mountain summit (figure 16a), the average intensity (figure 16b) varies considerably (from 5 mm/d at the coastline, to 30 mm/day in the maximum zone approximately 50 from the coastline and then decreasing to 5 mm/day at the summit. It is also worth noticing that despite having a 20-50% probability of getting precipitation in the eastern parts, the mean daily precipitation amounts are very low.

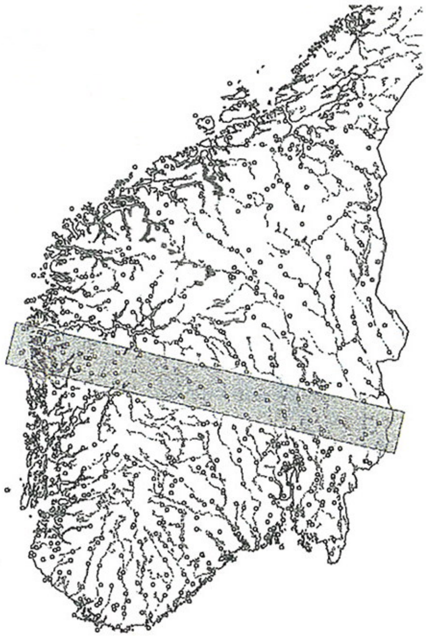


Figure 15. East-west cross-section.

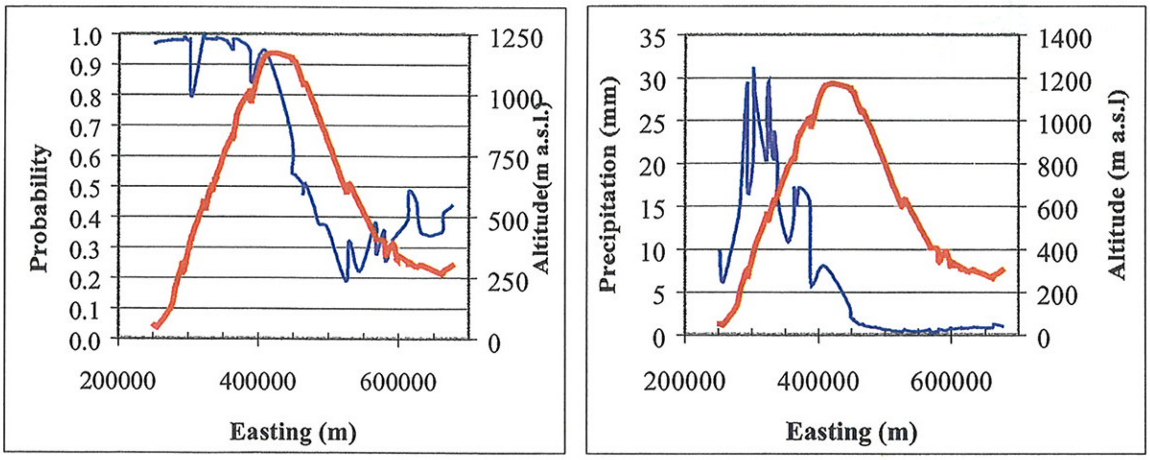
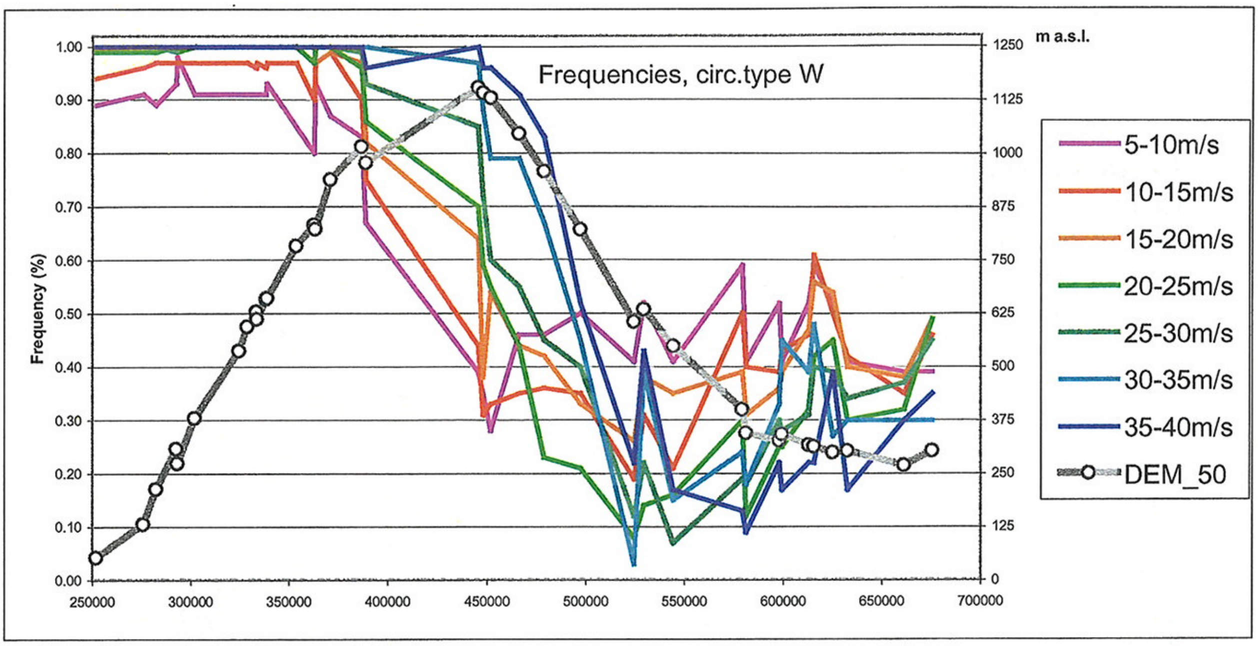


Figure 16. a) (left) The probability (%) of precipitation in the east-west cross-section (blue line), **b)** (right) Mean average precipitation (mm/day) in the east west cross-section (blue line), when the circulation type is W. The red line represents the large scale terrain.

In figure 17, these features are sorted by the zonal wind speed. Events for all seasons are included. The top panel shows the probability for precipitation when weather type W occurs. Close to the coast the probability is high for all wind speeds. The probability is lower for the two lowest wind speed classes. For velocities larger than 15 m/s, the probability is 1 until 120 km from the coastline, where the probability drops. The influence of precipitation covers a larger area inland with higher wind speeds. For the two highest wind classes, the 100% probability is kept all the way to the summit of the mountains. One remarkable feature is that for lower wind speeds, the probability for precipitation on the eastern side of the mountains is higher than for stronger wind speeds.



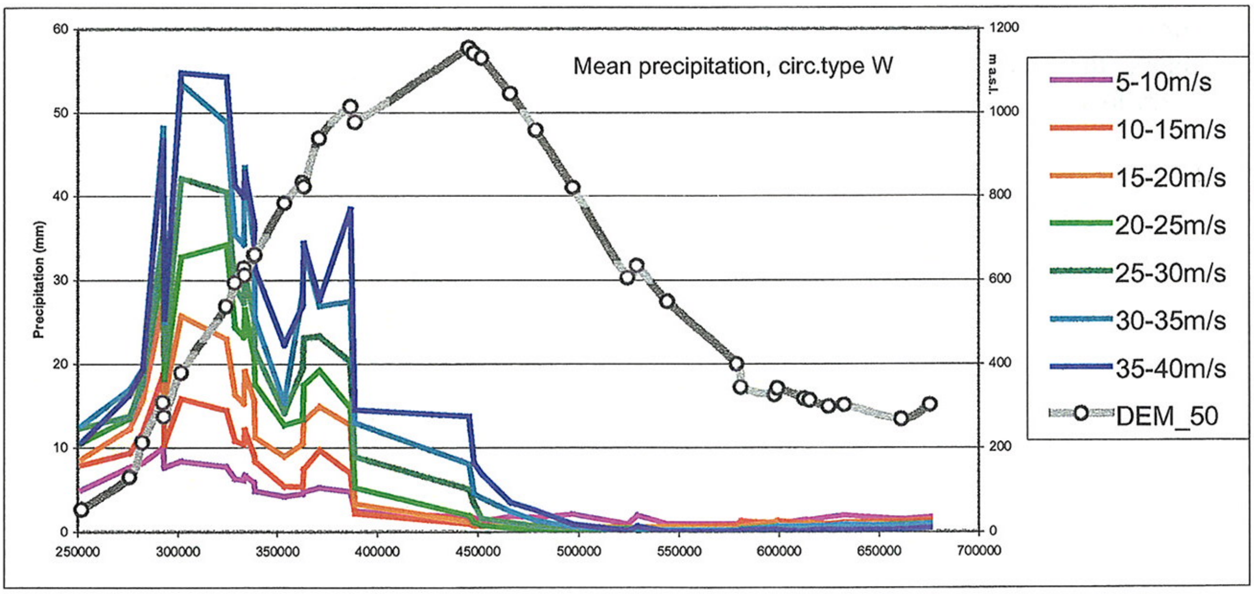


Figure 17. Frequency (top) and mean precipitation (Bottom) for weather type W sorted by the zonal wind speed for all seasons.

The lower panel in figure 17 shows the mean precipitation depth classified by the zonal wind component. This figure shows that the precipitation pattern is the same for all wind speed classes; it is only the magnitude of precipitation that differs. The maximum zone is relatively close to the coast (75-100 km inside the coastline). On the eastern side, precipitation depths are very small, which is also reflected by the spatial patterns in figure 5 and 6.

5.2 Seasonal variations

Are there any seasonal variations in the patterns? The westerly flow varies throughout the year, with a higher frequency in the months September to March (Figure 18). Figure 19 shows the frequency of precipitation similar to the ones in figure 16a, but classified by season. For the winter season, the probability for precipitation when the zonal wind component is between 5-10 m/s is around 75-80%. For wind speeds higher than 10m/s, the probability is 1 close to the coast. Else the pattern is similar to the annual pattern. The pattern of mean precipitation depth is also similar to the annual pattern.

In the spring season (figure 20), the probability is higher in the west for all wind classes, except 10-15 m/s. The precipitation amounts are generally lower than for the winter season.

In summer (figure 21) the zonal component is weak, only the three lowest categories occurred in the period. The probability pattern is similar to the other seasons. Rainfall depths are smaller. The precipitation in the eastern part is higher than for the other seasons, but less than 0.5 mm in average.

Autumn (figure 22) is the season with the highest precipitation amounts. For the highest zonal components average daily precipitation exceed 80 mm in some regions. For weak zonal components, precipitation probability is high also on the eastern side of the mountains (≈70%).

These figures show a seasonal variation in the precipitation patterns with season, especially concerning precipitation depths. The characteristics for the zonal wind component classes also vary with the seasons. This, in combination with different frequencies of circulation indices with the seasons should be investigated further in order to establish better spatial models for daily precipitation.

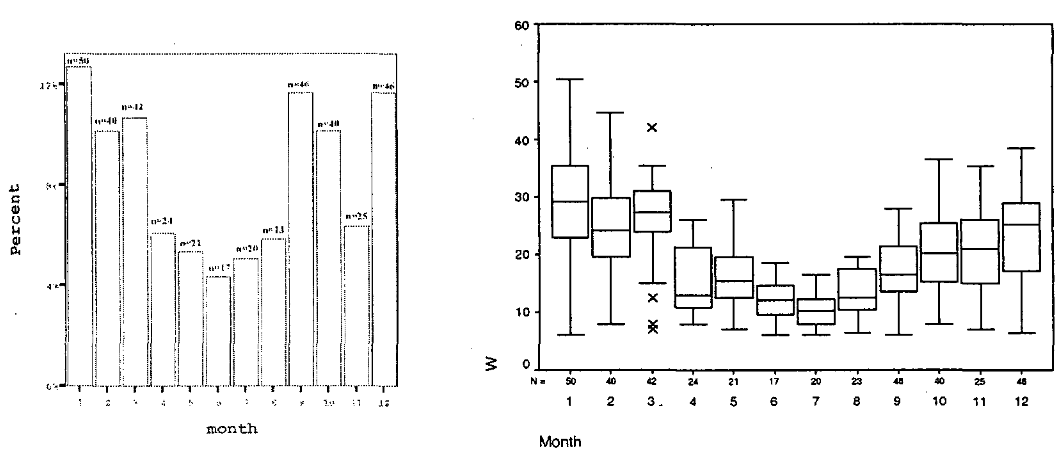
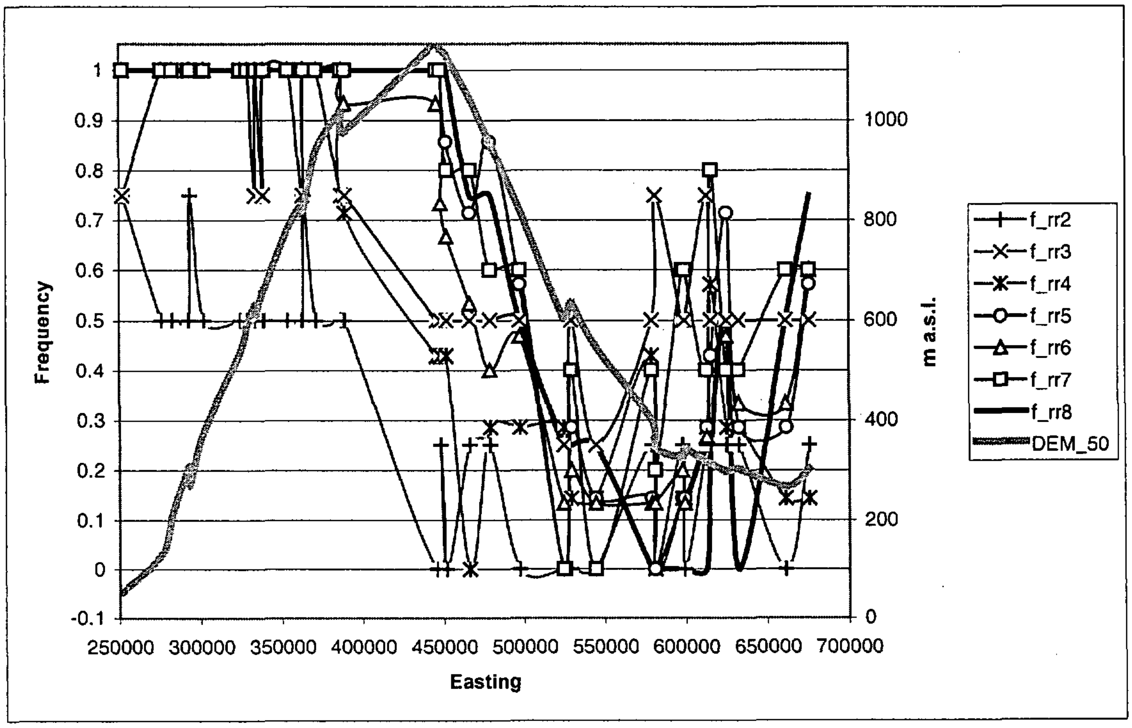


Figure 18: Frequency (% of total number of cases) and box-plot of the zonal component (m/s) when weather type W occurs.



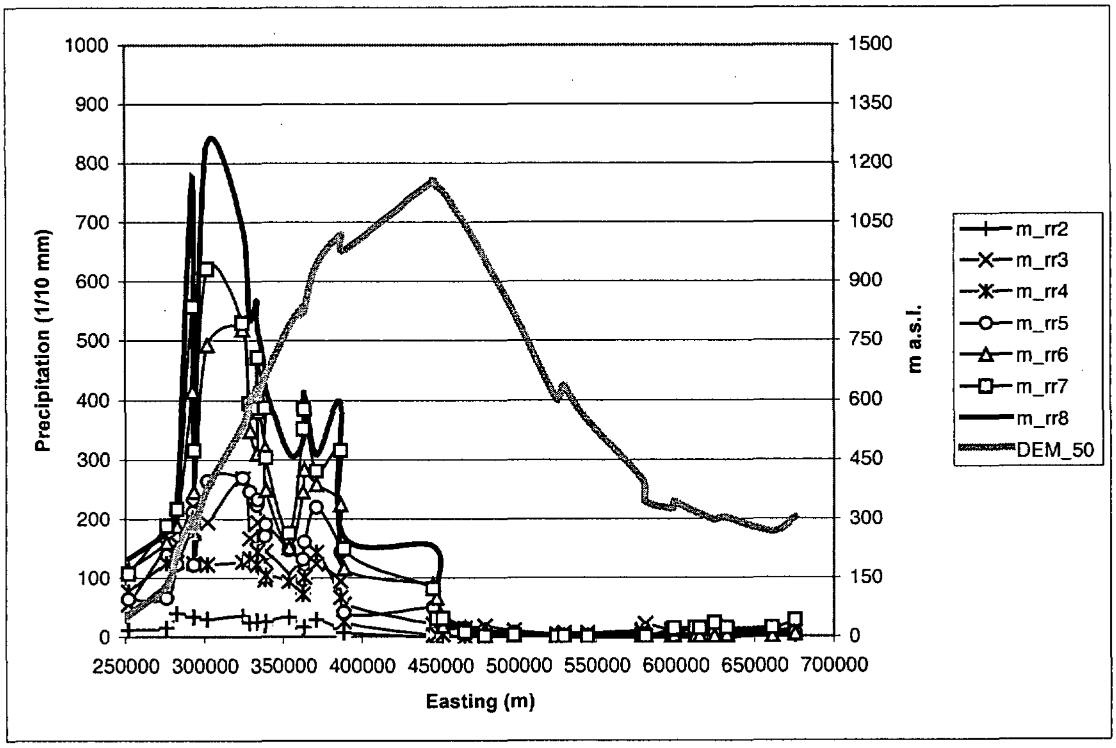
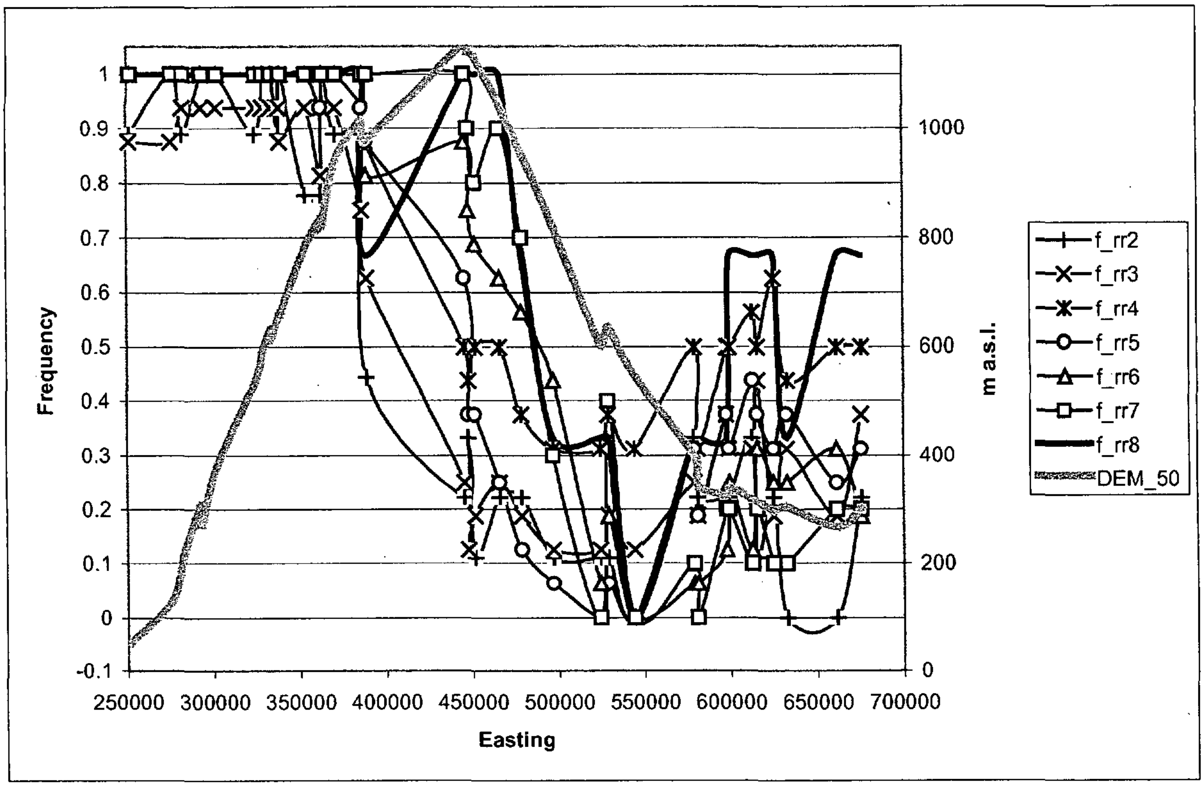


Figure 19. Frequency (top) and mean precipitation (Bottom) for weather type W sorted by the zonal wind speed in Winter.



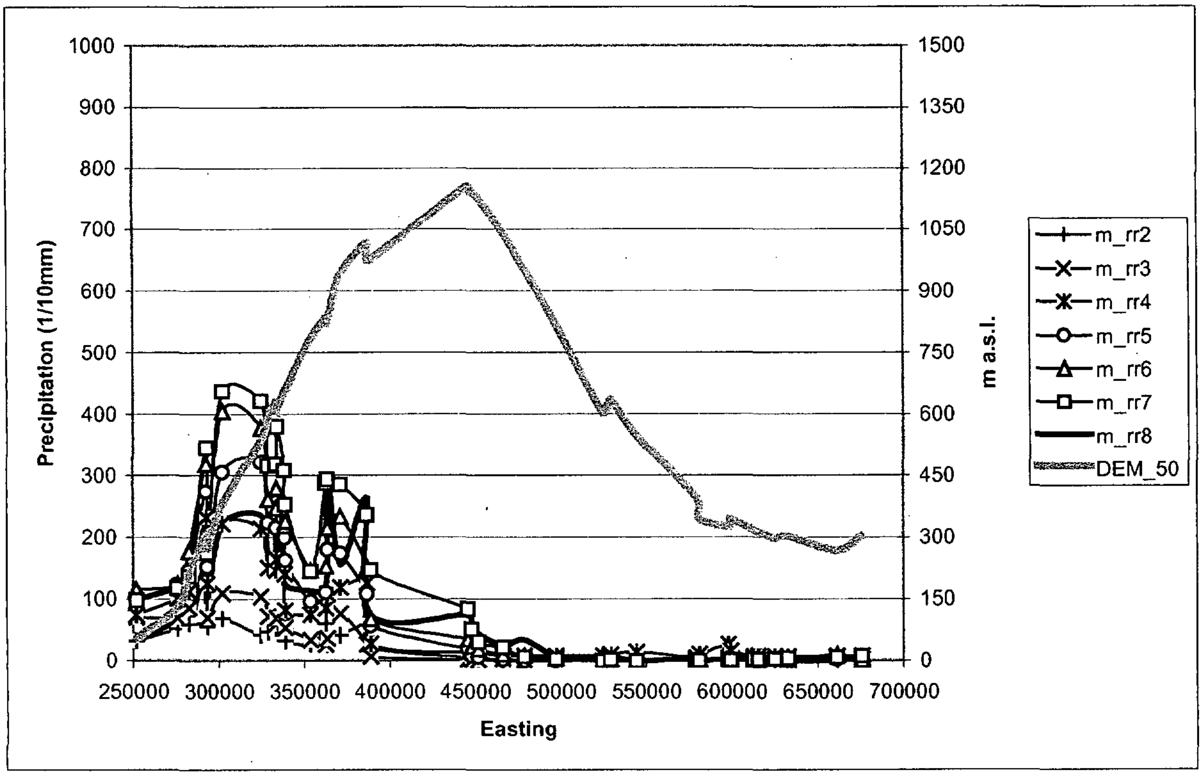
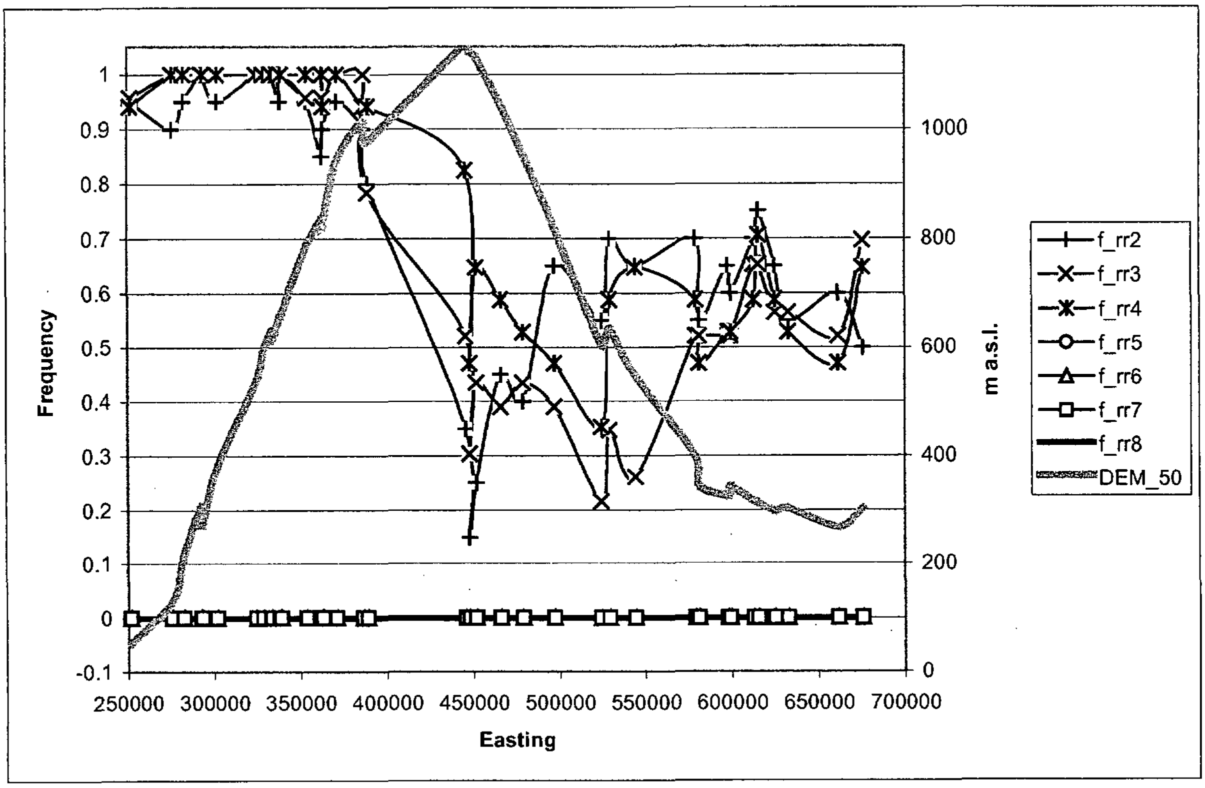


Figure 20. Frequency (top) and mean precipitation (Bottom) for weather type W sorted by the zonal wind speed in Spring.



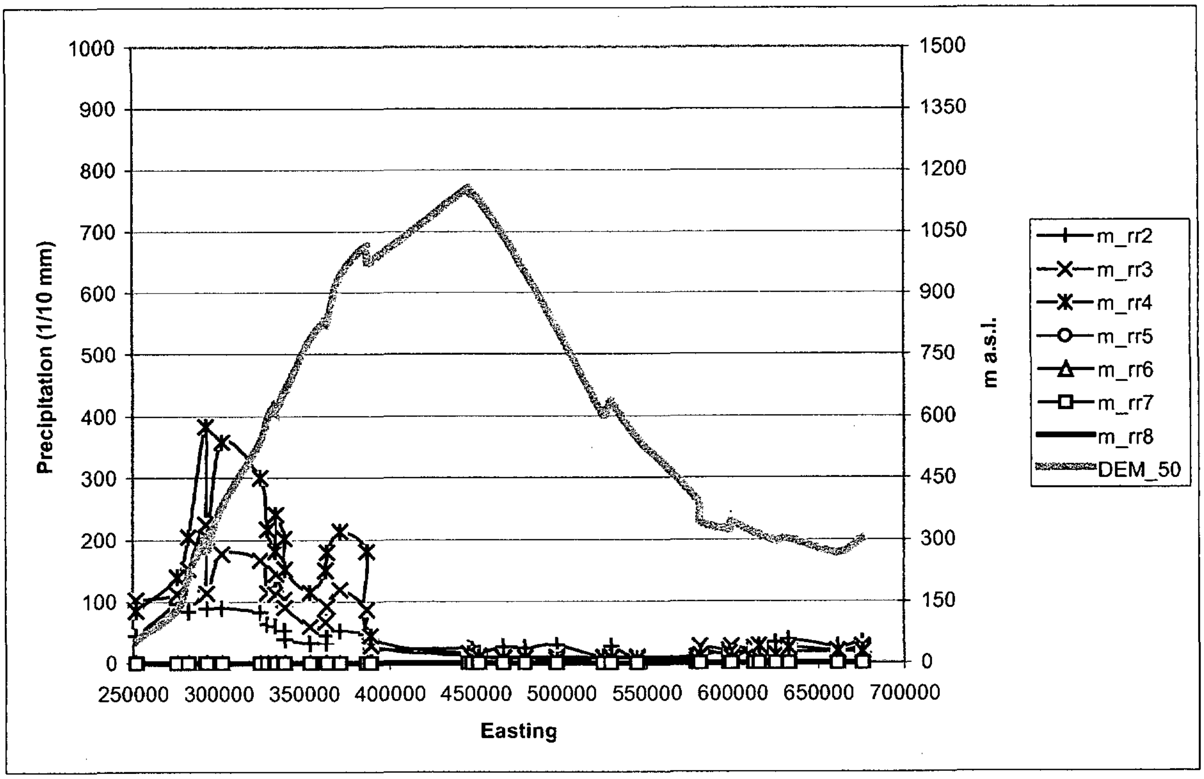


Figure 21. Frequency (top) and mean precipitation (Bottom) for weather type W sorted by the zonal wind speed in Summer.

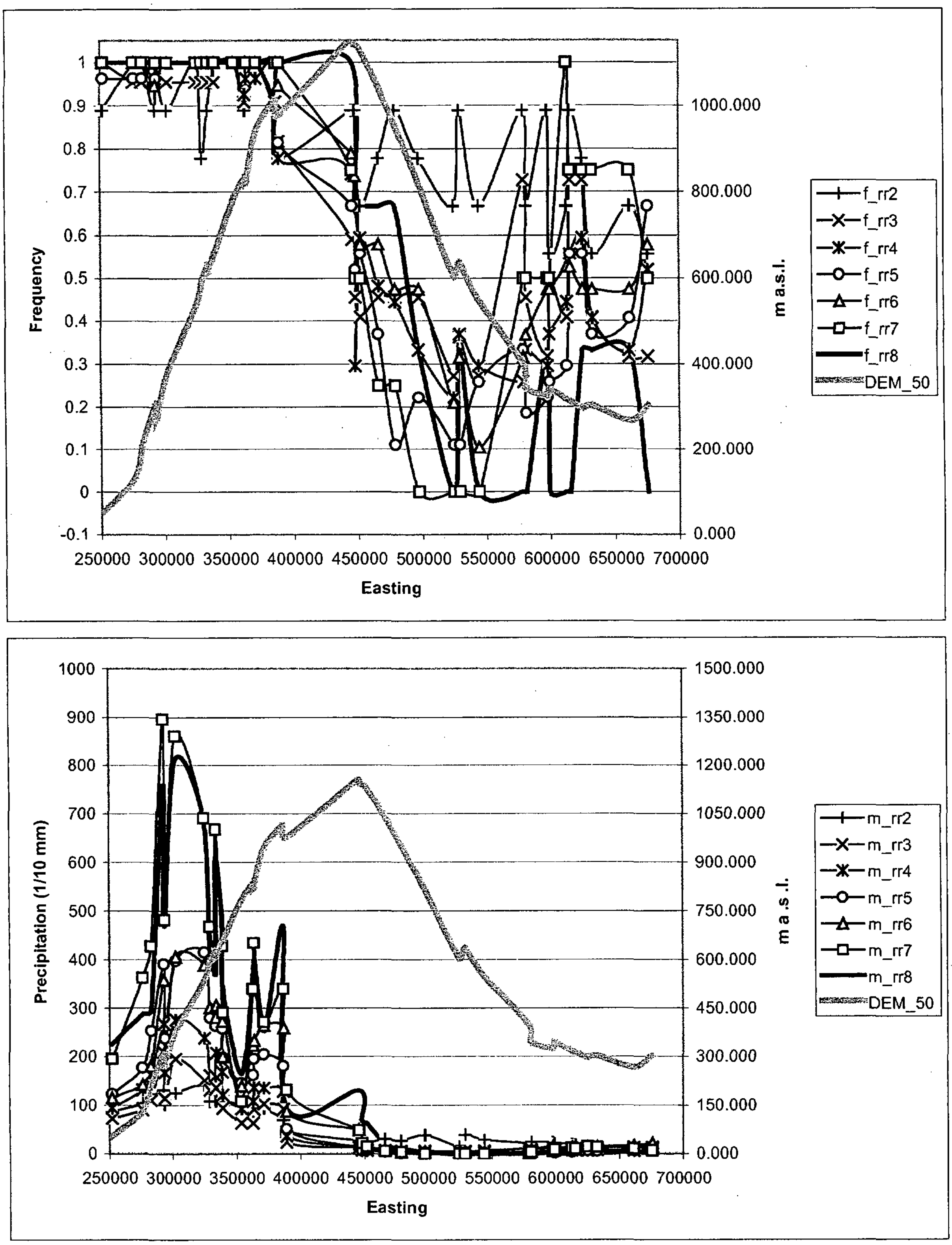


Figure 22. Frequency (top) and mean precipitation (Bottom) for weather type W sorted by the zonal wind speed in Autumn.

6. Comparing forecasted and observed precipitation fields.

It is expected that predicted precipitation fields are biased compared to observed fields due to the parameterization of the model. In this chapter a comparison of short-term prognostic precipitation values and observed precipitation is described. A spatial analysis, including a spatial interpolation of observed precipitation using a triangular network (see chapter 1 for description) is applied.

In the study both number of days with precipitation exceeding certain thresholds as well accumulated deviations are evaluated.

6.1 Number of days with precipitation.

Spatial modeling of precipitation, regardless of the whether model approach is dynamical or geostatistical consist of two sub-problems:

(i) Occurrence of precipitation
(ii) If precipitation, the amount of precipitation.

This issue is complicated. The state of the atmosphere is the leading factor. In some states, advective precipitation is dominant. This type of precipitation has a large geographic extent. In other states dominated by convective processes, the precipitation occurs more scattered. The latter one is very difficult to estimate, both regarding the amount and spatial patterns.

In this study, occurrence of precipitation above given thresholds are compared. These are 0.1 mm, 1.0 mm and 10.0 mm. The first threshold is the traditional definition of a precipitation day. In the comparison, the weather types defined in chapter 3 characterized the events. Figure 23 shows maps of the differences between HIRLAM-prognosis and observations for these thresholds for weather type S, southerly flow. The upper panel shows that for precipitation values ≥0.1 mm, the HIRLAM shows precipitation for most of the days The observed field shows that the area with more than 100 rainy days (out of 111) is smaller, and that the northern part of the study area has fewer precipitation days than the HIRLAM model estimate. The Trøndelag area experience up top 90 days less precipitation than forecasted by HIRLAM. In most of the area south of Dovre HIRLAM forecasts up to 10 days more with precipitation than observed. At the southeastern coast and in an area west of the Oslofjord, the model forecasts up to 10 fewer days with precipitation than observed.

For the second threshold (1.0 mm) the forecasts are a bit closer to the observed pattern. The model is still to wet in the notrthern areas and in the inner parts of southern Norway, especially at higher altitudes. It is also too dry in Østlandet (the area north of Oslo). Close to the coast, the model is to dry.

For the 10mm threshold, the spatial patterns are more scattered. The most regular pattern is that the areas closest to the coastline are too dry in the forecast model. Another repeating feature is that HIRLAM gives too high precipitation values in the mountain areas. This is however an uncertain "observation", since most of the precipitation stations are located at lower altitudes, in the valleys and along fjords.

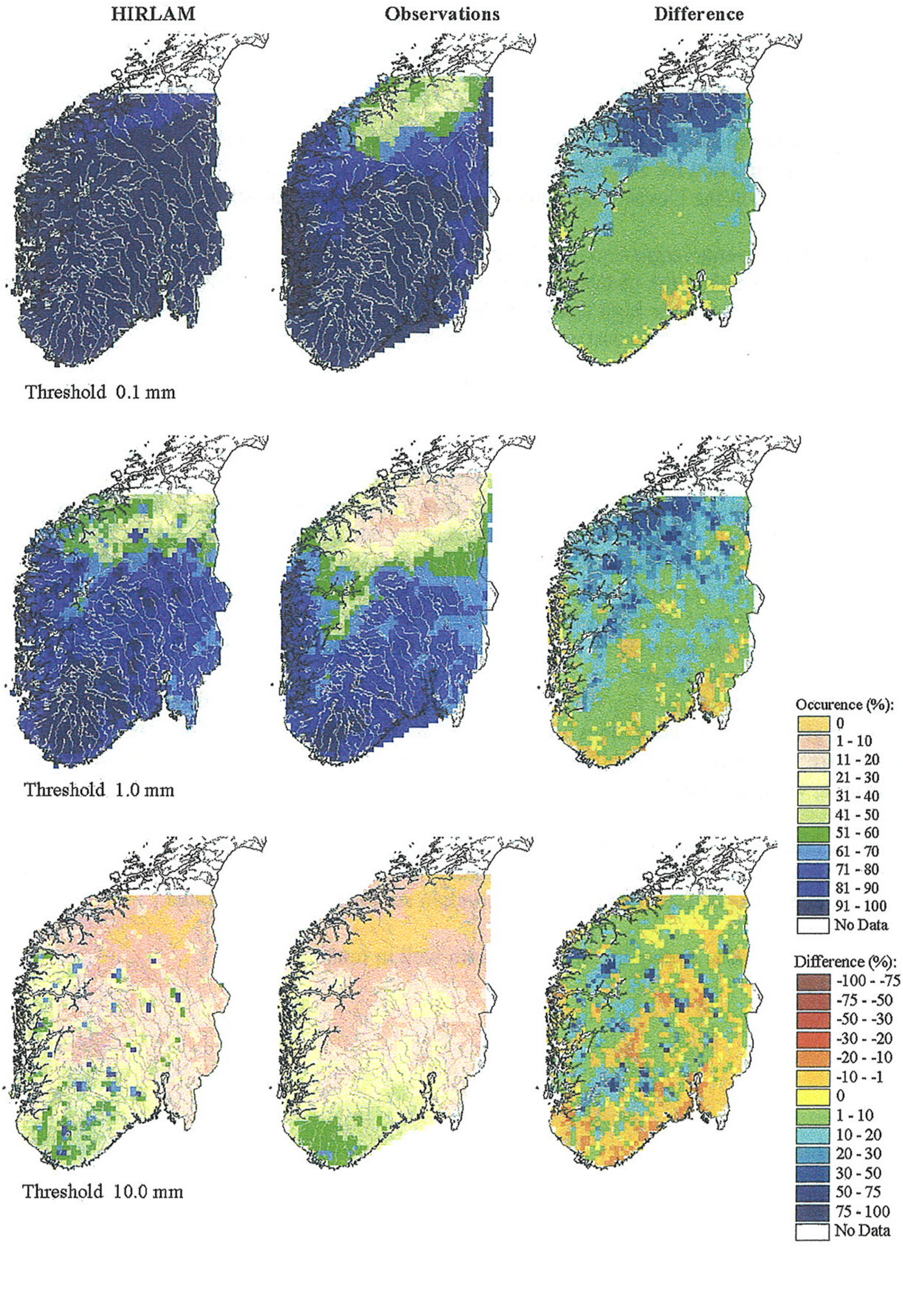


Figure 23. Comparison of observed and forecasted number of days with daily precipitation above the thresholds 0, 1 and 10 mm, weather type S.

Figure 24 shows the same information for weather type SW. As for the S-type, the forecast gives to many precipitation days, especially in the eastern parts. There is a distinct division on the leeward side of the mountain chain. At a few places in the western parts the model actually estimate fewer days than observed.

For precipitation values ≥ 1.0 mm, the patterns of days with precipitation are more similar. There is still a tendency for overestimating the precipitation, and the area where this happens most frequently is in the Dovrefjell-region in the northern part of the study area.

For precipitation events larger equal to 10 mm, the model is quite good. The HIRLAM field is a bit more scattered than the observed, especially in western Norway. The HIRLAM estimates indicate to many days in the high terrain in the Jotunheimen and Jostedal glacier area, while it is too dry at the northwestern coast and in the Hardangervidda area.

The patterns for weather type W is shown in figure 25. During days with weather type W the entire western Norway will experience precipitation. For amounts less than 1 mm HIRLAM predict precipitation all over southern Norway, while observations shows that there is a distinct division of precipitation occurrence east and west of the mountains. For precipitation amounts larger than 1.0 mm also HIRLAM is able to predict this pattern failry well. There is however a systematic overprediciton of precipitation occurrences, especially in a small belt just east of the high mountains. For days with precipitation above 10 mm, the observations indicate a wider area experiencing such events that predicted by the forecast model. HIRLAM overestimate number of events in the high mountains area in northern parts of the mountain chain. However is the number of observation stations in high mountain areas limited, which makes comparisons uncertain.
In figure 26 the patterns for the NW type is shown. As for the other weather types, the 0.1mm threshold gives too wet conditions in the HIRLAM field compared to the observations. The patterns are well defined, and HIRLAM performs well in the western and northwestern parts of the area, while the southeastern parts are far too wet.

For the 1.0mm threshold, the patterns are more smoothed out. The forecast model seems to give to many precipitation days in the mountain areas, but once again are these indications uncertain due to insufficient number of observation stations in the mountains.

For large precipitation events the model perform well in most areas.

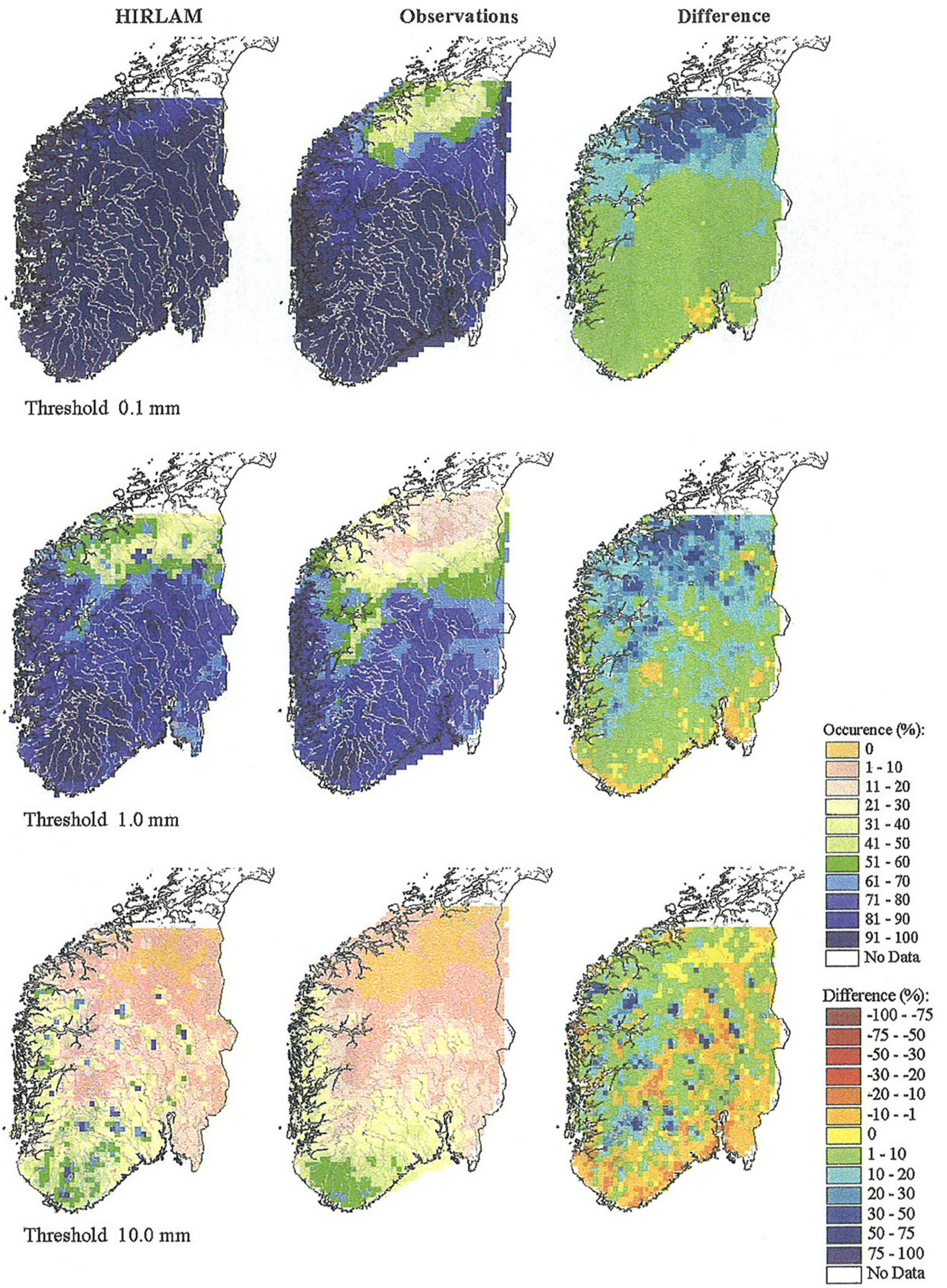


Figure 24. Comparison of observed and forecasted number of days with daily precipitation above the thresholds 0, 1 and 10 mm, weather type SW

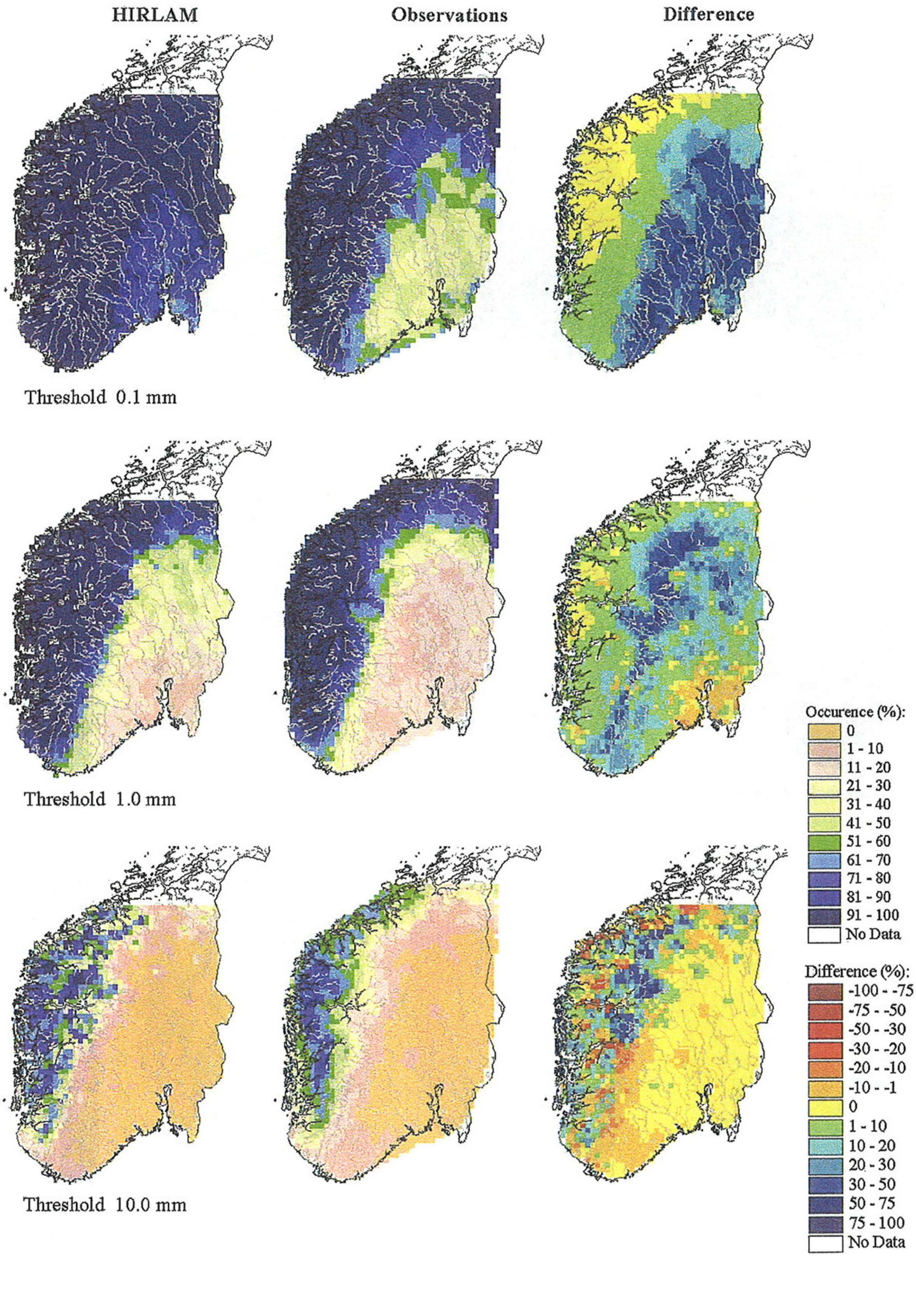


Figure 25. Comparison of observed and forecasted number of days with daily precipitation above the thresholds 0, 1 and 10 mm, weather type W

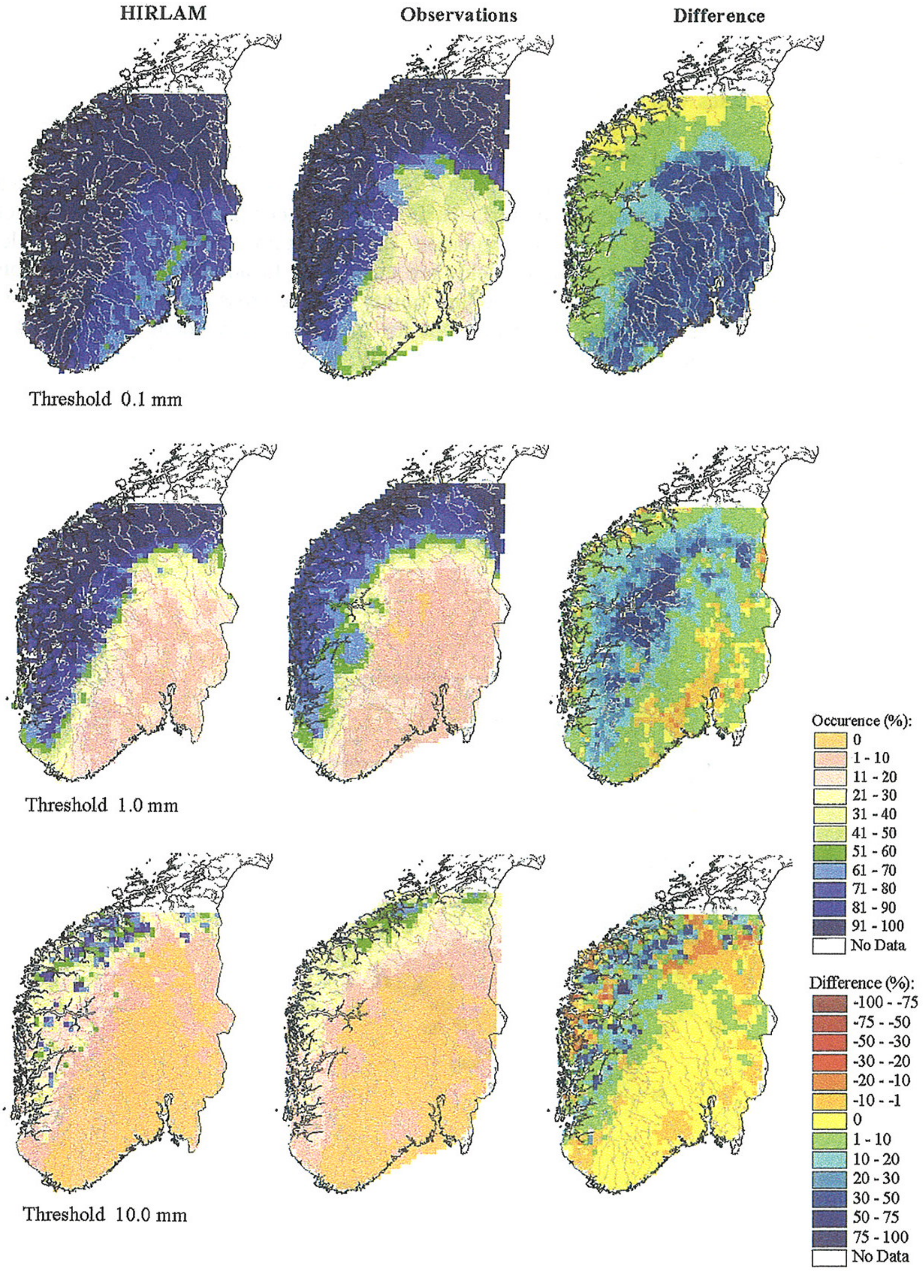


Figure 26. Comparison of observed and forecasted number of days with daily precipitation above the thresholds 0, 1 and 10 mm, weather type NW.

6.2 Precipitation quantities.

Daily precipitation amounts are difficult to examine. Traditional statistical measures like mean or median values will not reflects systematic biases in modeled precipitation related to the observed. Standard deviation will say something about the ability to reproduce the variability, but once again it will not give evidence of systematic differences. These measures may however give important information. In hydrology are accumulated precipitation biases (represented by the mean value) of importance in order to keep the hydrological budgets correct. Therefore maps of mean precipitation derived from observed and modeled precipitation and the difference of these fields are examined. In addition, 8 cross sections (figure 27) are defined, and statistics for the grid points in these cross sections are examined more thoroughly. The examination is carried out for all days, independent of atmospheric conditions as well as for days with weather type S, SW, W and NW in order to reveal any systematic biases.

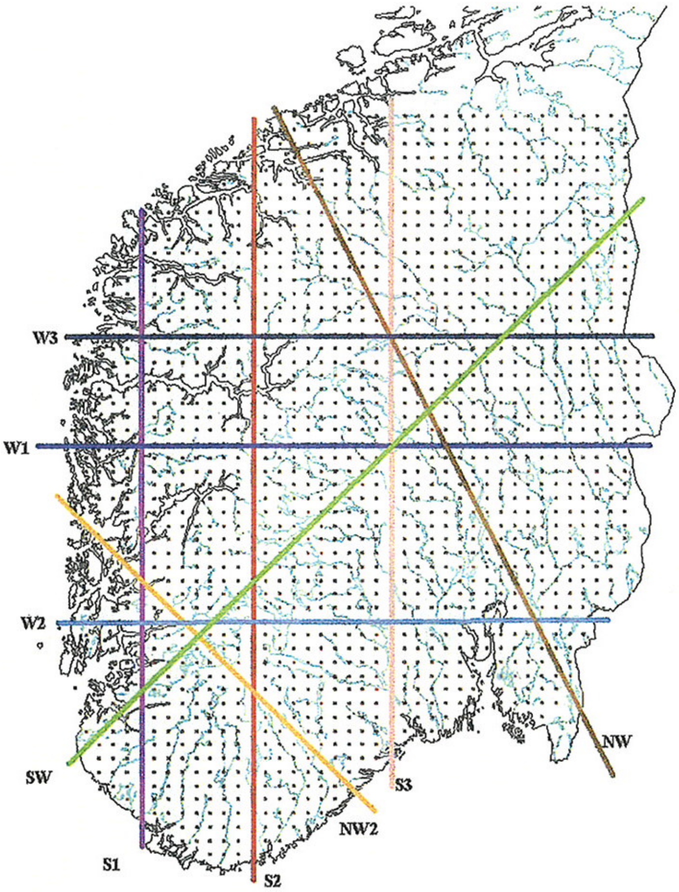


Figure 27. The 8 cross-sections.

6.2.1 Weather type S.

Weather type S represents a southerly flow that gives precipitation in most of southern Norway. Figure 28 show the mean characteristics and differences between forecasted and observed precipitation. The forecast model gives too high precipitation values in the northern regions, a pattern that is reflected by occurrence of precipitation described in the previous chapter. Observed precipitation is higher than the forecasted along the southern coast, while it is lower northwards. In the interior the patterns are more scattered. The standard deviation of the difference shows highest values along the western coast. In addition there are some single cells that have very high standard deviations for all weather type. This feature will be commented on later.

The correlation between daily precipitation forecasts and observations is high along the southern coastline and in a belt northwards in southeastern Norway. This reflects that the dynamics of the observed precipitation is well reproduced by the forecasted precipitation. In most other areas the correlation is lower, less than 0.6. Another criterion for evaluating the performance of the forecast model is the Nash-Sutcliffe efficiency criterion (Nash and Sutcliffe, 1970). This criterion is widely applied for validating hydrological models, and is ranging from minus infinity to +1, with higher values indicating better performance. This criterion describes the fraction of variance of the observed values described by the model:

$$NS = 1 - \sum_{t=1}^{n} (O_t - H_t)^2 / \sum_{t=1}^{n} (O_t - O_{mean})^2$$

This criterion takes the quantities of precipitation more into account than the correlation coefficient, but they generally reflect the same conditions. The Nash-Sutcliffe criterion shows the highest values along the southern coast and in some parts of the interior eastern Norway.
The cross-sections show distinct different characteristics (figure 29). For the east-west section, section w2 and w3 shows the largest deviations. The southernmost section, w2, is generally wetter in HIRLAM than observed. Especially the westernmost gridpoints are too wet. The variance represented by the 95% confidence limits around the mean is also larger than the observed. In the northern section, w3, the gridpoints in the Jostedalen/Joutnheimen area are too wet. The HIRLAM precipitation is far too high in some gridcells in very high terrain (line gridpoints 536-537).

In the north-south cross-sections, the tendency is similar between observed and forecasted precipitation. Generally HIRLAM–values are a bit higher than the observed precipitation, and there are some gridpoints where the precipitation is far too high. Common for all this is that they are located in high terrain, and that the unrealistic precipitation values are due to the parametrisation of the HIRLAM model which may cause such strange results in very high terrain. For the easternmost north-south cross-section, HIRLAM is not able to reproduce as high precipitation as observed on the southern parts of the section.

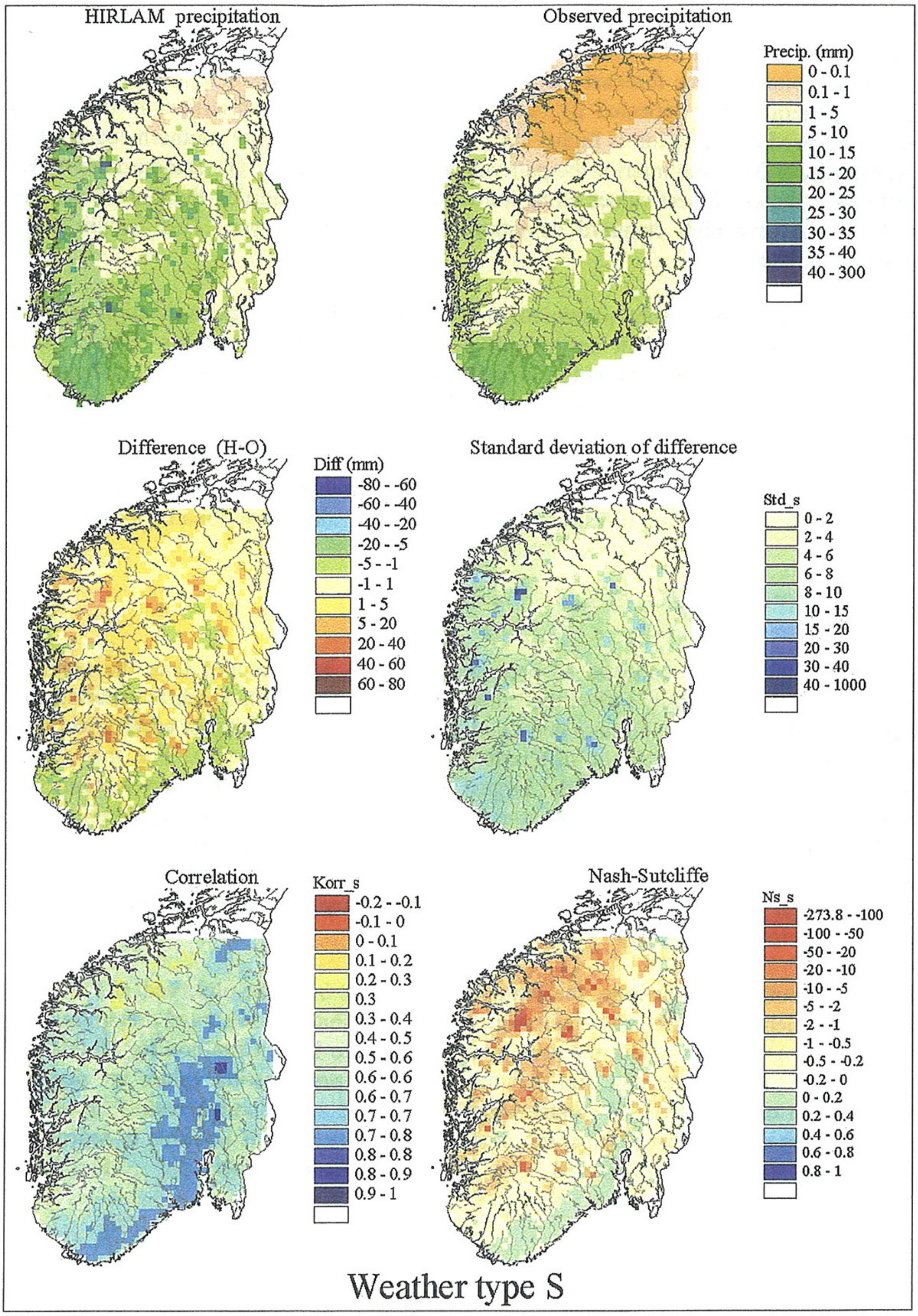


Figure 28. Comparison statistics between observed and forecasted precipitation weather type S.

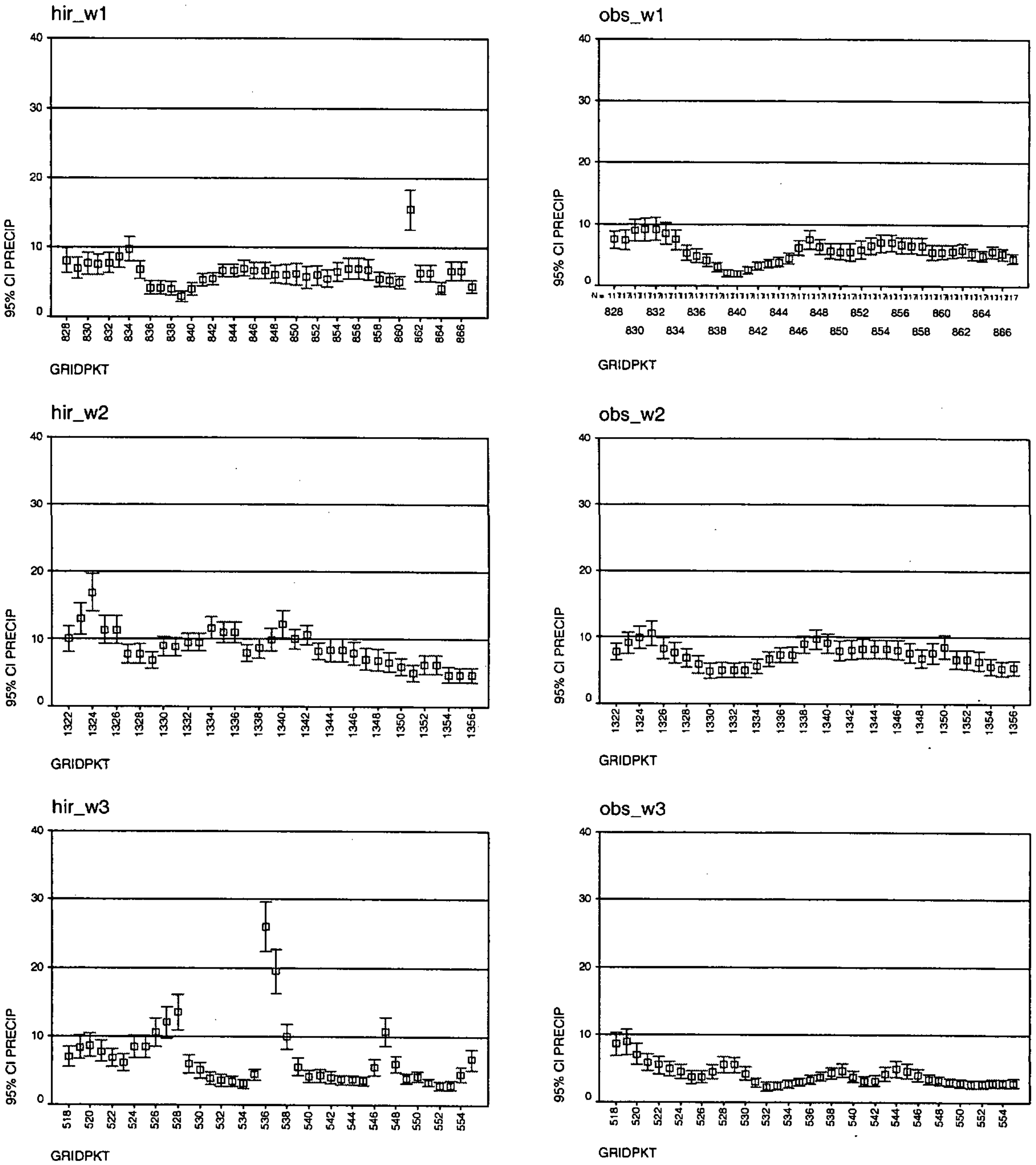


Figure 29. Forecasted and observed precipitation (median and 95% confidence intervals, mm) for the crosssections for weathertype S.

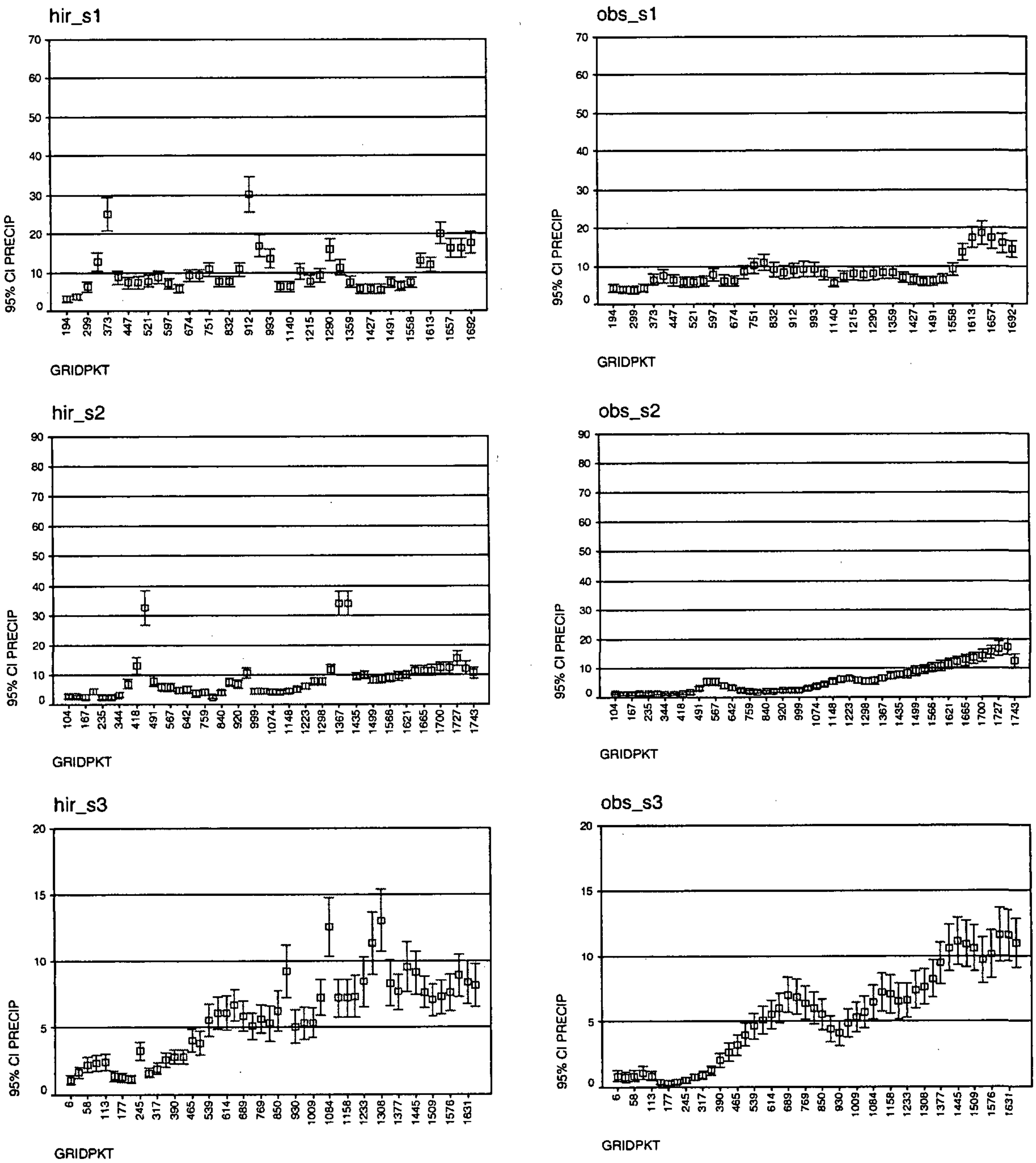


Figure 29 cont...

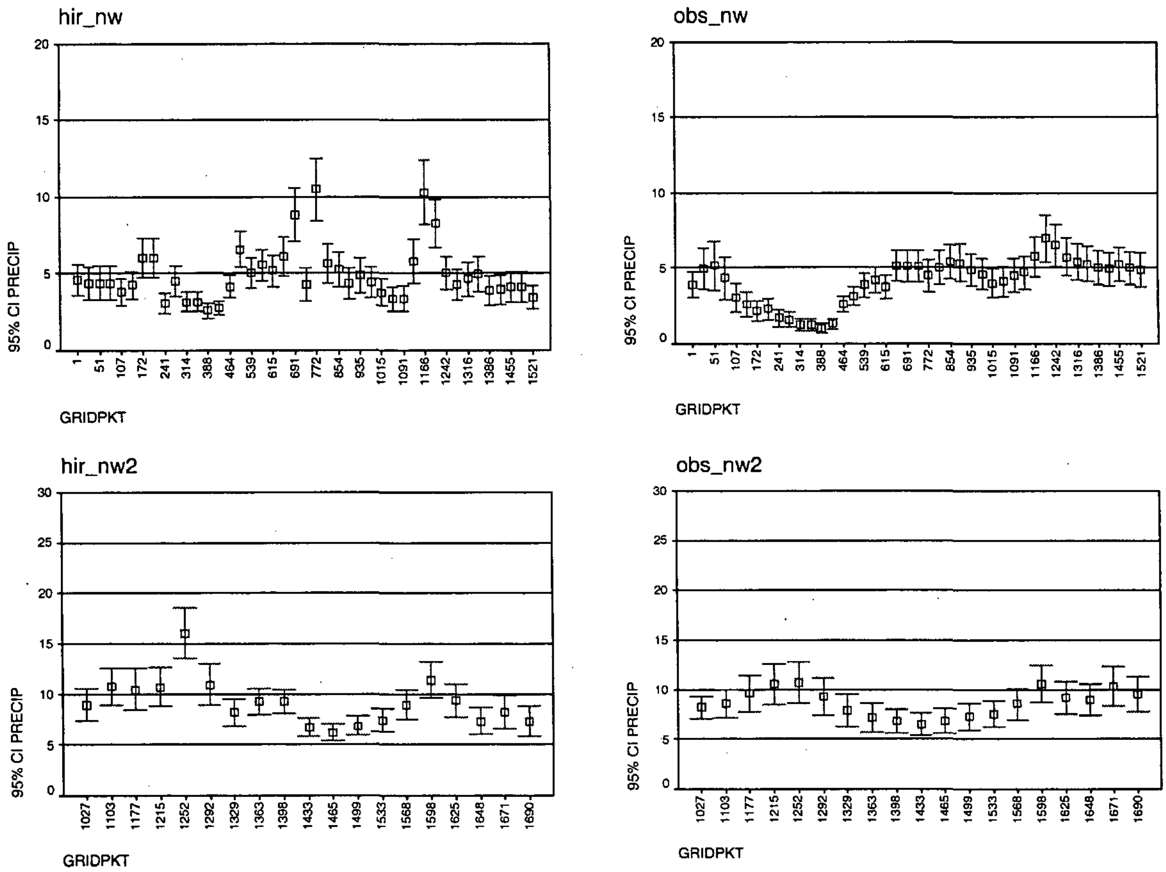


Figure 29 cont...

6.2.2 Weather type SW.

This weather type gives high precipitation along the western coast (figure 30). The HIRLAM-model generally underestimates precipitation in large areas north of the Hardangerfjord. Nearest the coastline the forecast model gives too high precipitation values. The standard deviation of the errors is highest along the western coastline, and highest close to the coast. The correlation and Nash-Sutcliffe criterion shows best performance of the forecast model in the southwestern part of Norway, and in a sector parallel to the coast south of the Sognefjord , along the precipitation maximum zone.

The cross-sections reveal some of the same characteristics (figure 31). Close to the western coastline, the HIRLAM-model gives more precipitation than the observation. This is especially significant for the section w3 and w1. For the northernmost section, w3, HIRLAM is actually drier than the observation. The westernmost north-south gradient is very irregular. Generally HIRLAM is somewhat drier than the observations in this cross-section, which is located along the precipitation maximum zone. However are there some peaks where the terrain is highest.

For the northwest-southeast sections, the main features are quite similar.

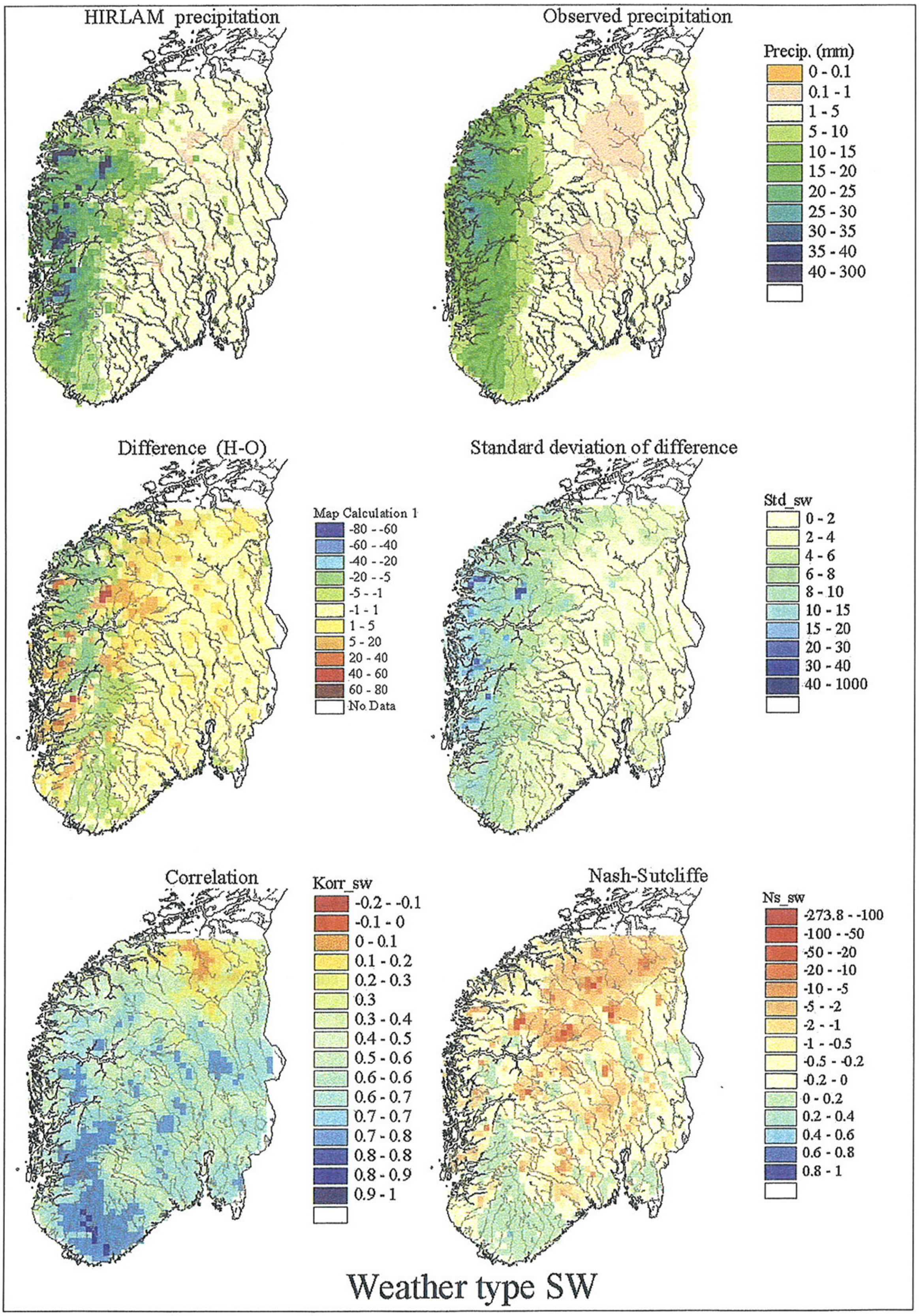


Figure 30. Comparison statistics between observed and forecasted precipitation weather type SW.

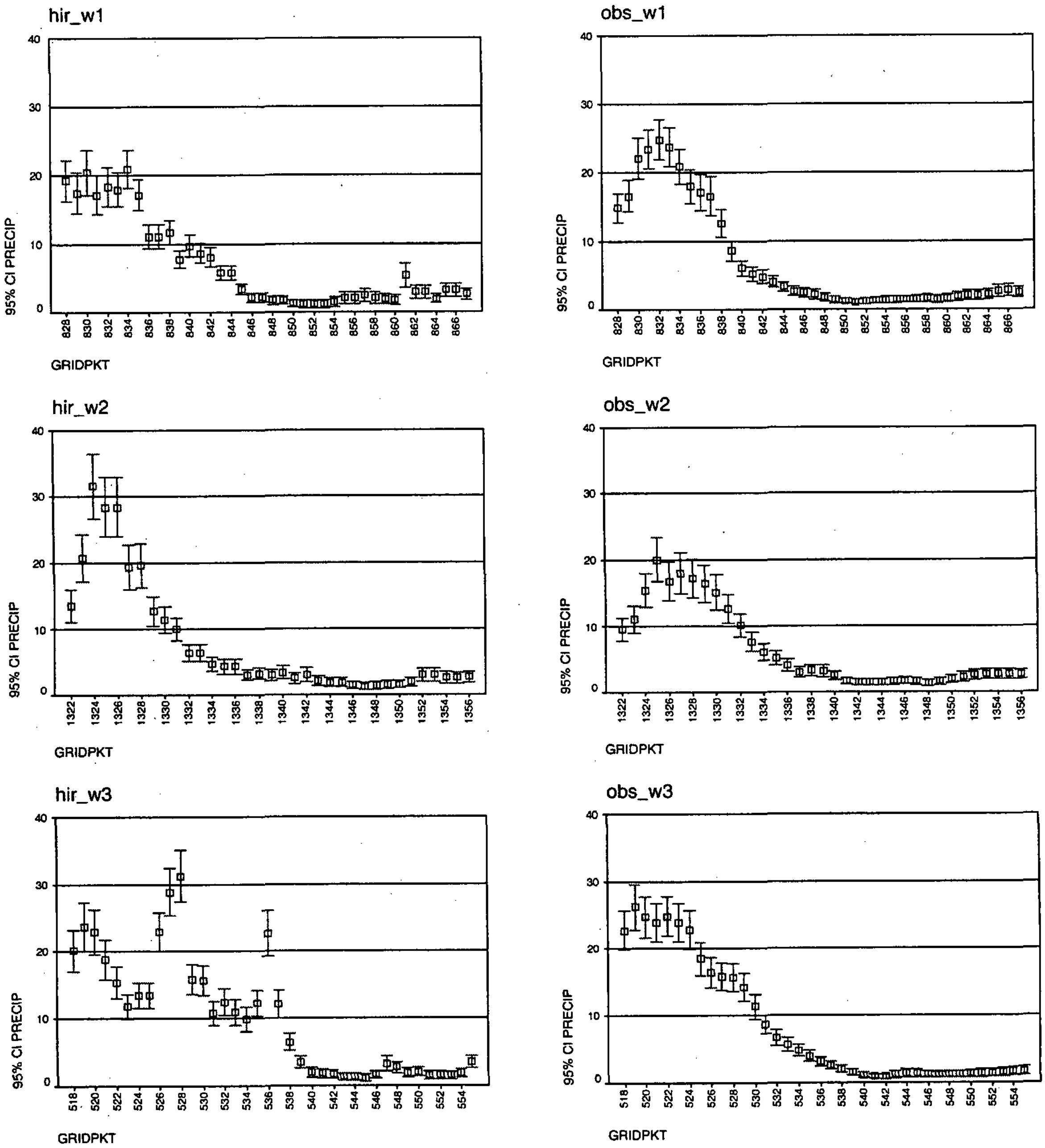


Figure 31. Forecasted and observed precipitation (median and 95% confidence intervals, mm) for the crosssections for weathertype SW.

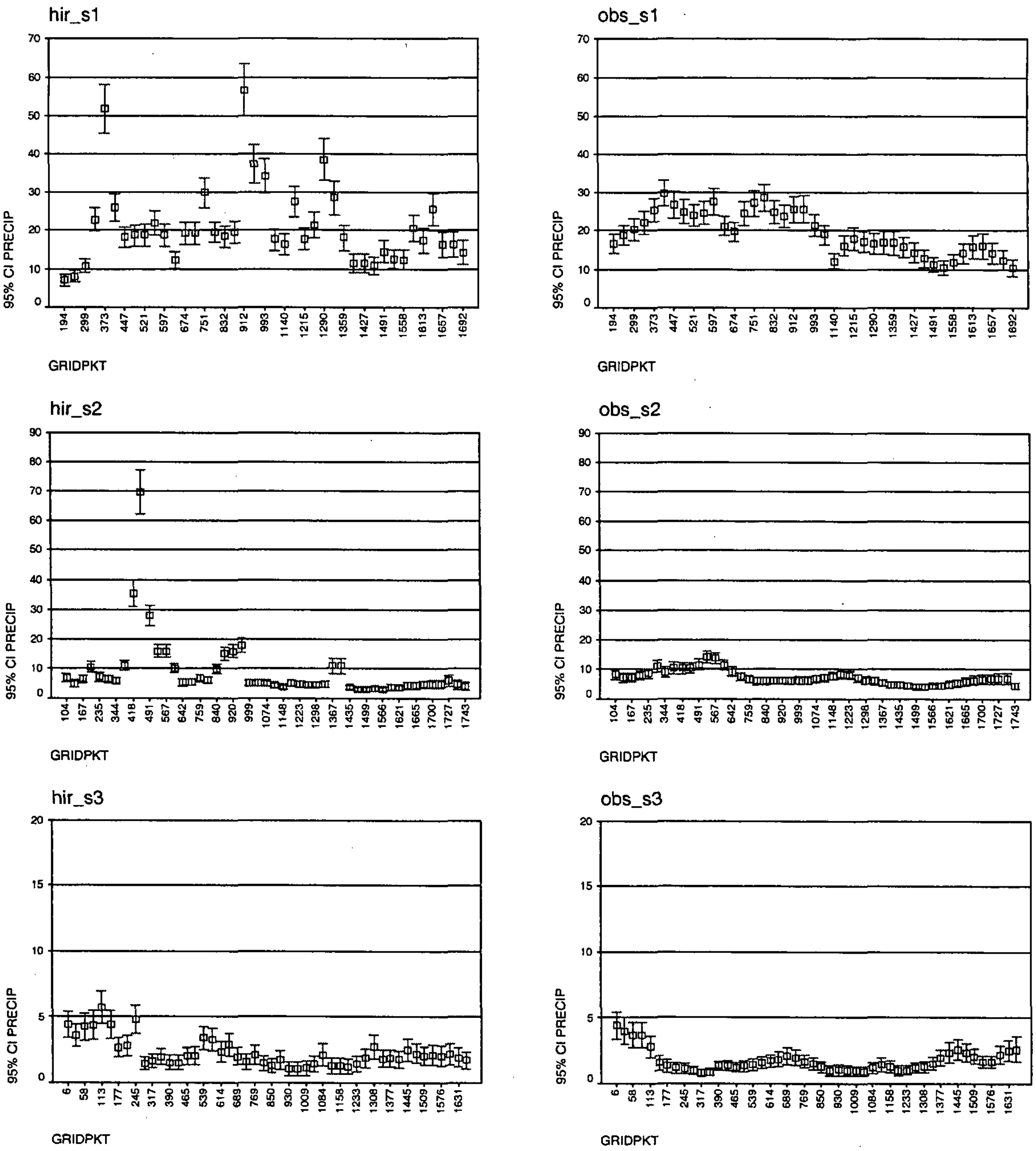


Figure 31 cont....

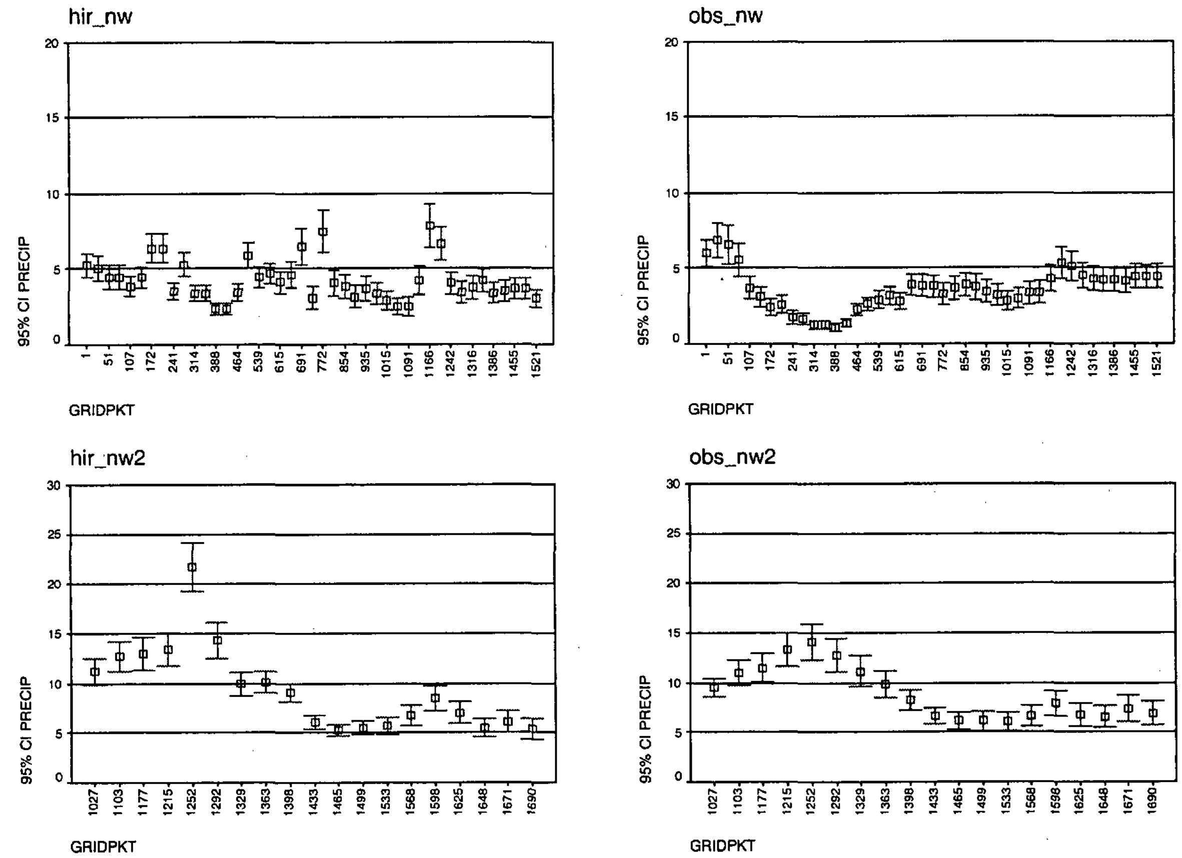


Figure 31 cont….

6.2.3 Weather type W.

Weather type W represents a direct zonal circulation type towards the western coast, and is the circulation giving the highest average precipitation values along the western coast (see chapter 4).

Figure 32 shows the mean daily precipitation for weather type W. In general, the differences are small, within ±1 mm. The differences occur mainly in the northwestern part of the study area.

Standard deviations of the difference are highest along the western coast. The correlation is high in most of western Norway, including the mountain areas. There are also some areas in eastern Norway where the correlation is high. This is also reflected by the Nash-Sutcliffe criterion. The best fit is found in Rogaland in southwestern Norway. Generally the fit is better some distance from the coastline, reflecting the forecast model to be too wet close to the coast. The t-test shows that the means are not significantly different for most of the area, but the variance is significantly different in most parts.

6.2.4 Weather type NW.

For weather type NW (Fig 34) HIRLAM generally gives too high precipitation in most of northwestern Norway. The standard deviation of the difference/error is also highest in this area. The correlation is high along the western coast, and very high in the eastern part. The Nash-Sutcliffe criterion shows the best score in this area.

The variances are significantly different for most of the area, except in the northwestern regions, while the difference in mean values are significant in the central mountain areas.

For cross-section w1, HIRLAM has too much precipitation close to the coastline. It is not able to reproduce the maximum precipitation zone some 50 km from the coastline, where the observed precipitation is 50% higher than forecasted. For crossection w2, the forecasted precipitation is higher than the observed. Near the coast, HIRLAM-precipitation shows good fit. For the northernmost west-east cross-section, HIRLAM tends to underestimate, except for the high altitude gridpoints where it is close to the observed.

Section S1, which is the precipitation maximum zone along the west coast shows quite similar characteristics.

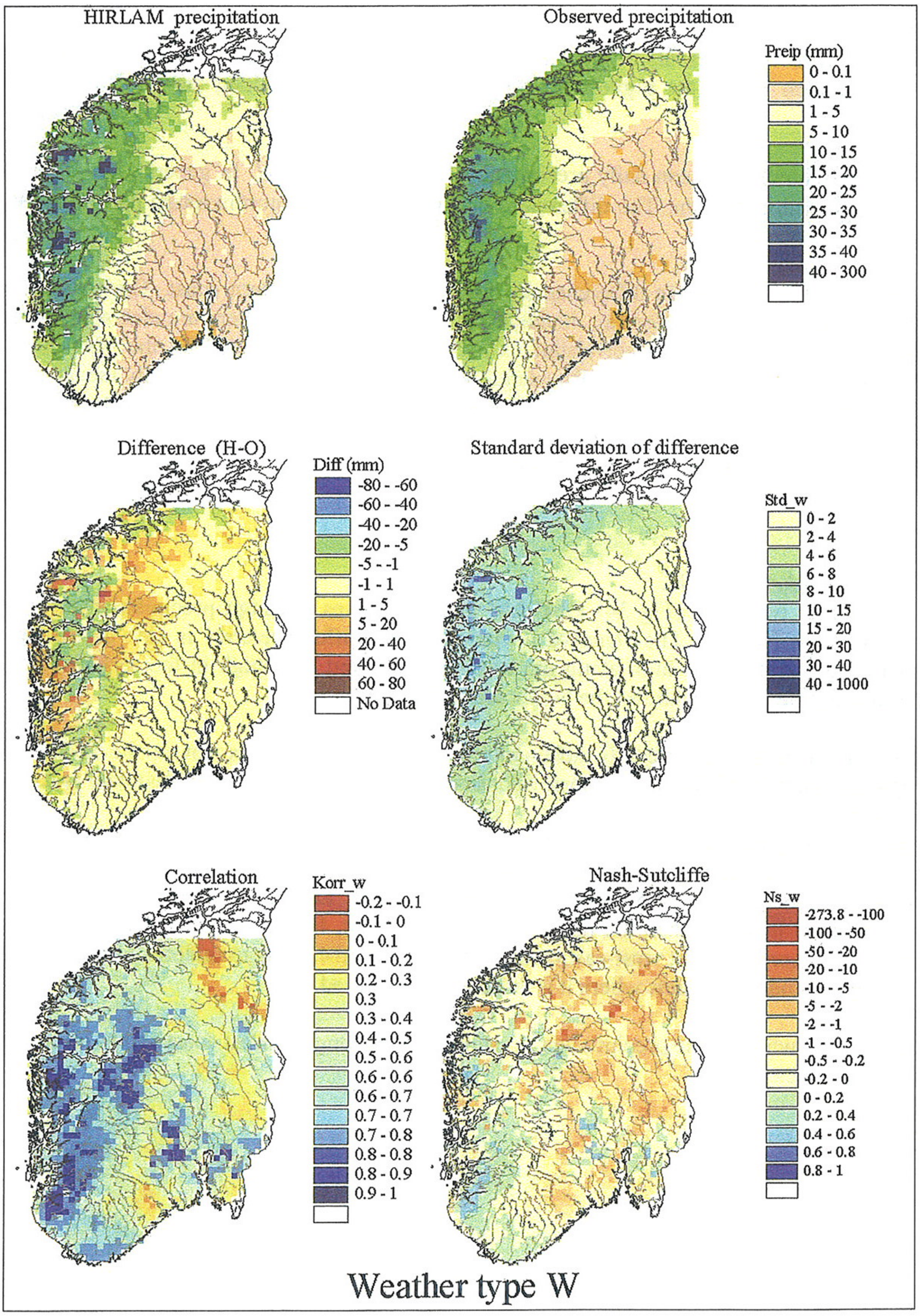


Figure 32. Comparison statistics between observed and forecasted precipitation weather type W.

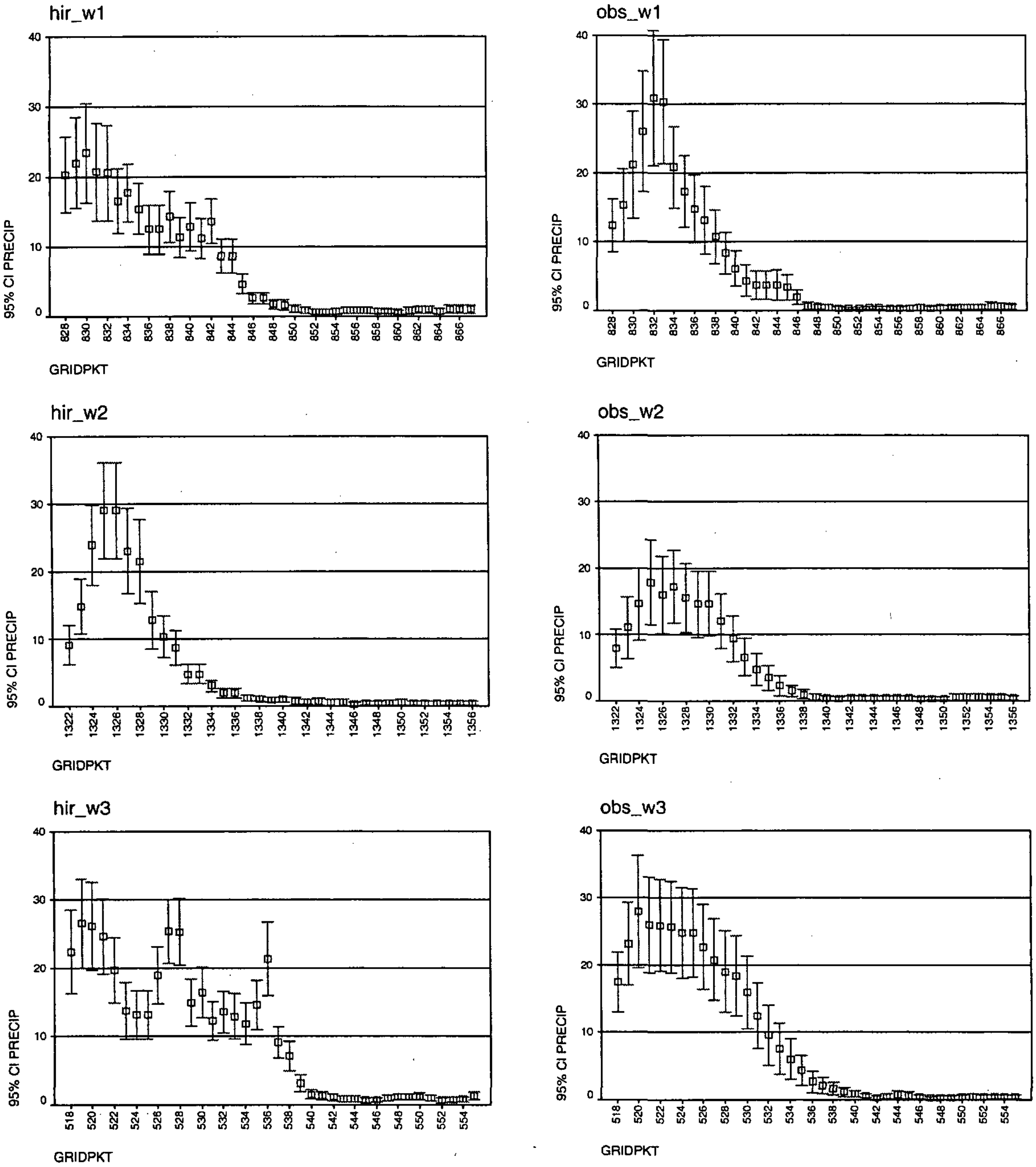


Figure 33. Forecasted and observed precipitation (median and 95% confidence intervals, mm) for the crosssections for weathertype W.

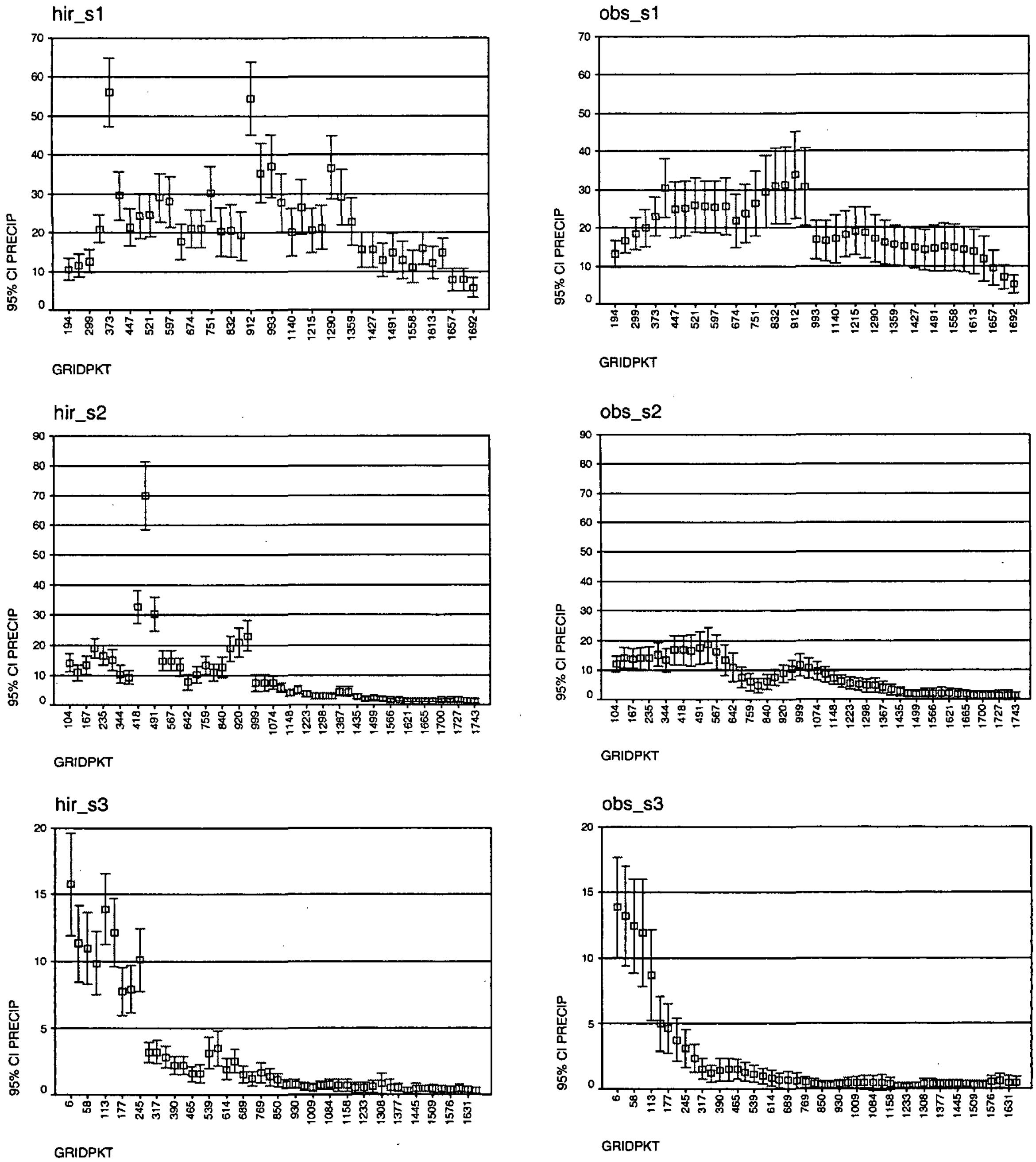


Figure 33 cont….

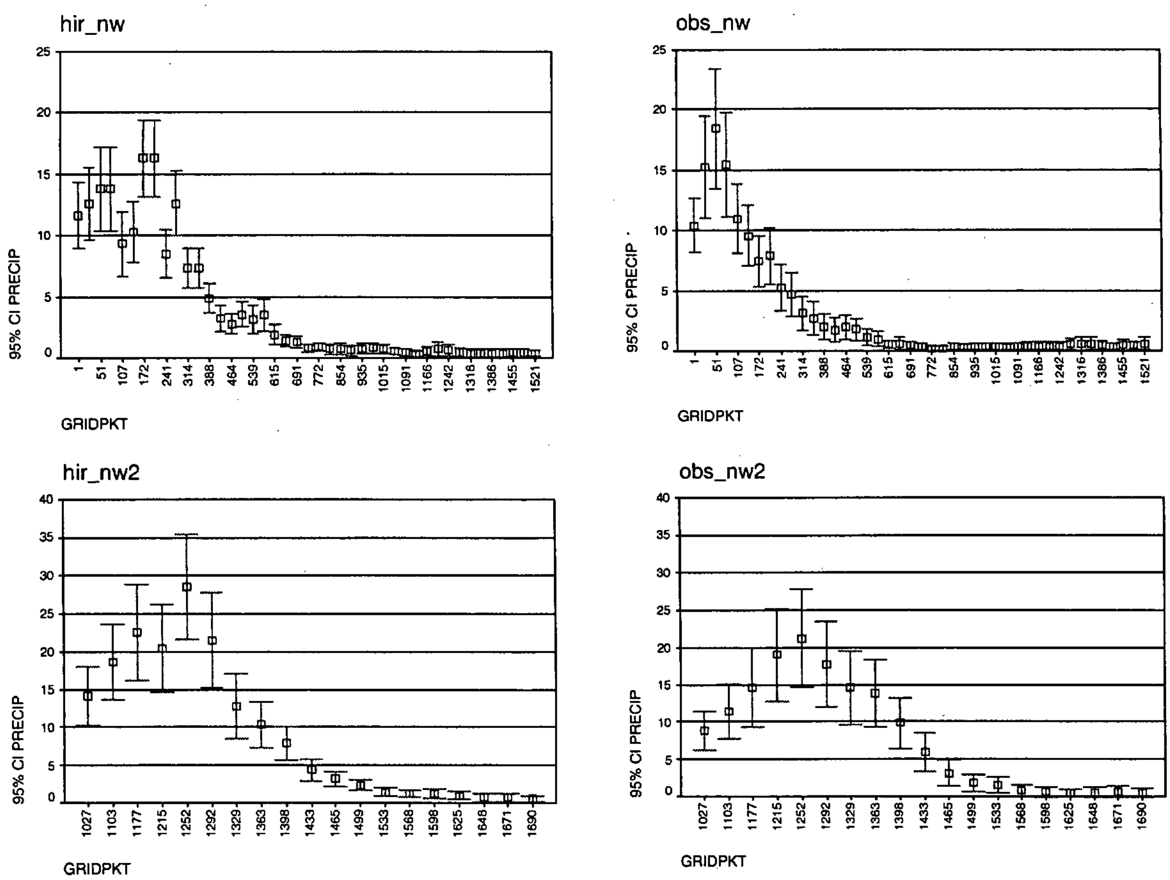


Figure 33 cont…

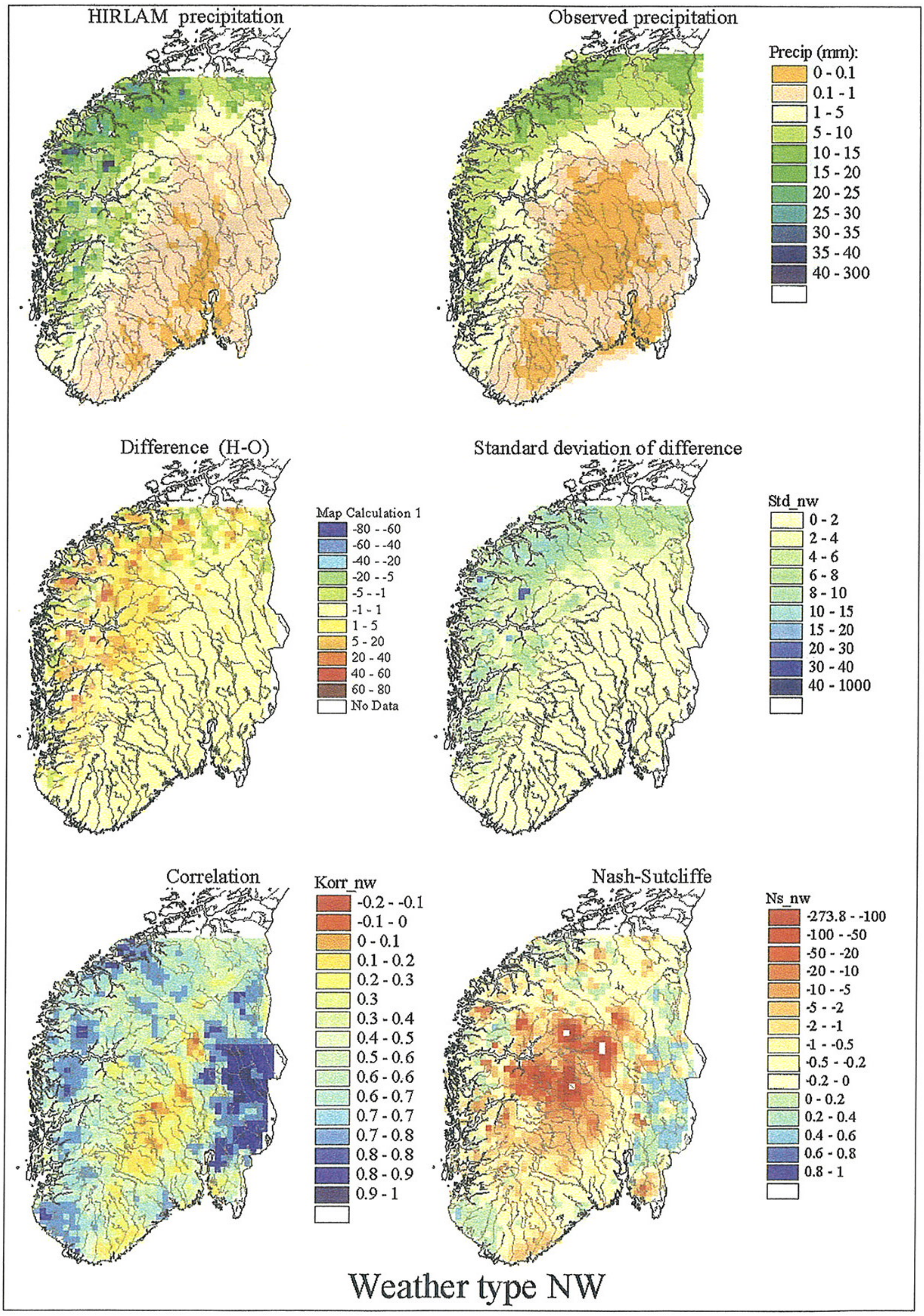


Figure 34. Comparison statistics between observed and forecasted precipitation weather type NW.

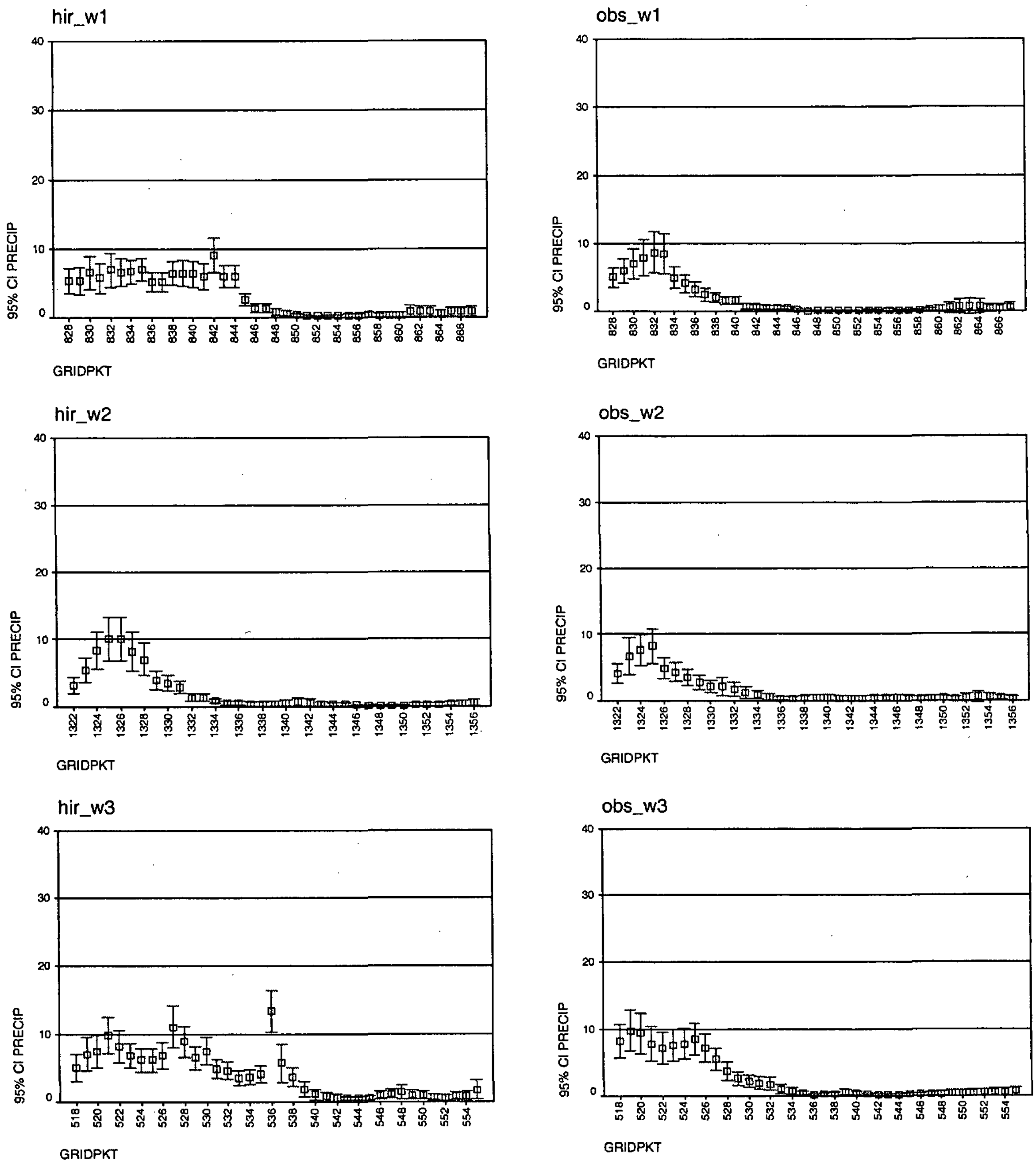


Figure 35. Forecasted and observed precipitation (median and 95% confidence intervals, mm) for the crosssections for weathertype NW.

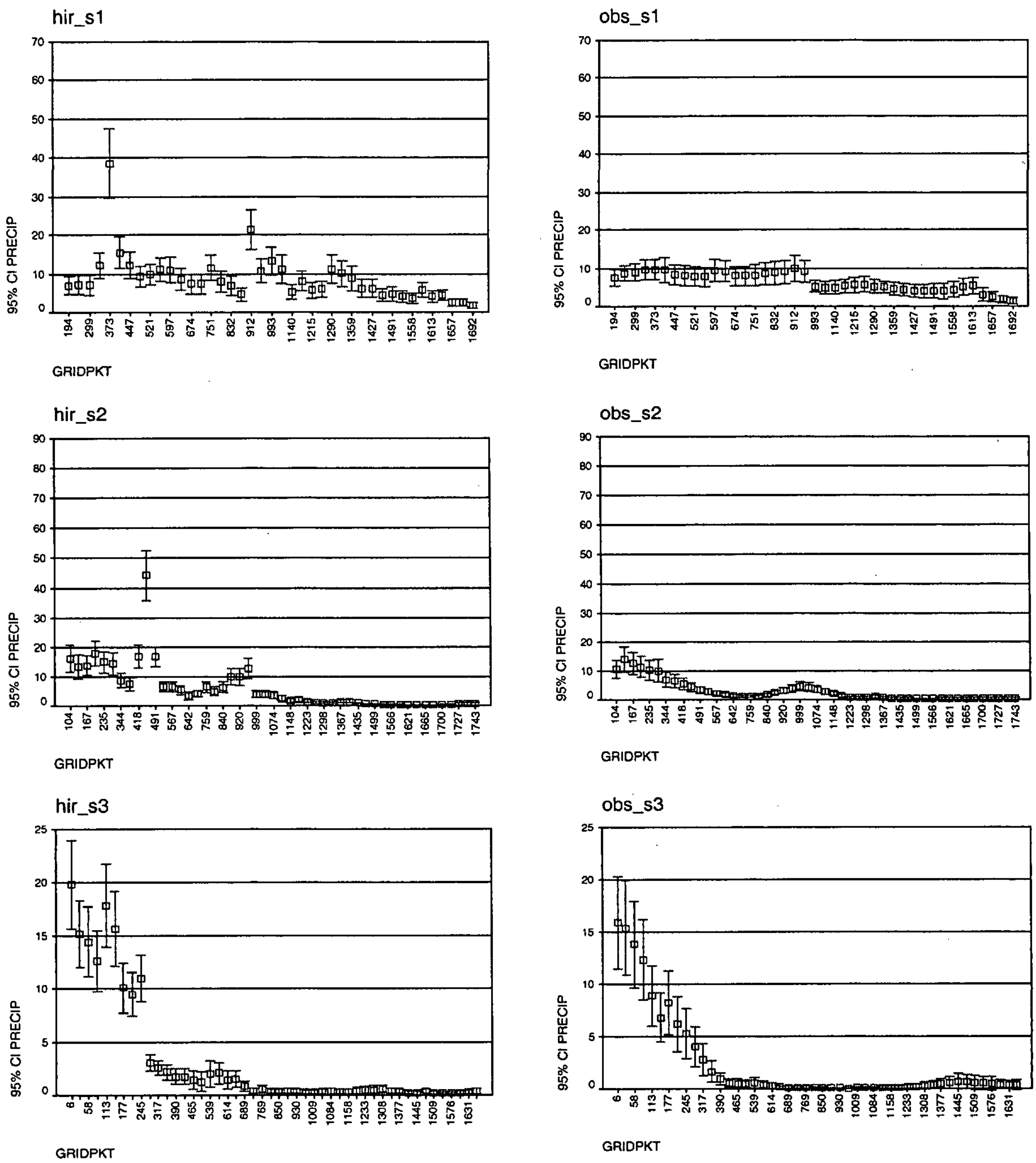


Figure 35 cont….

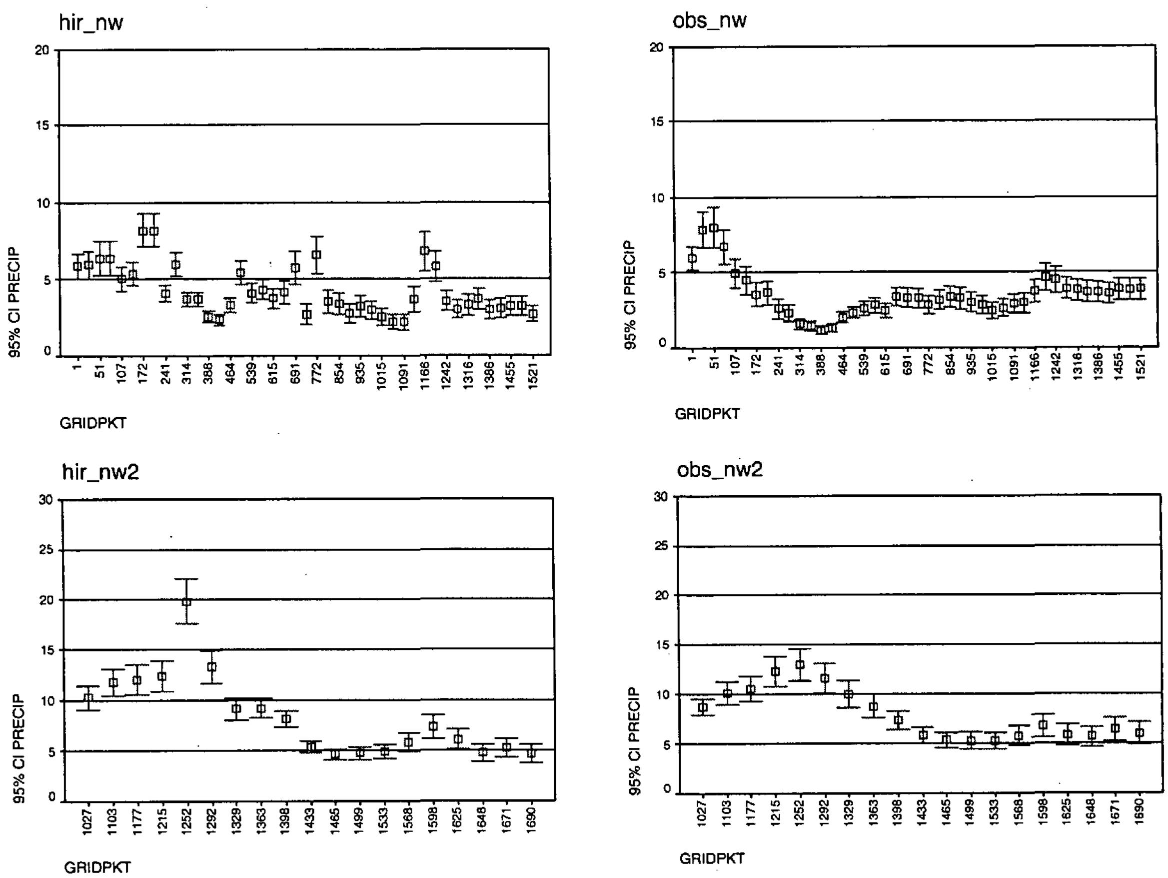


Figure 35 cont….

7. Conclusions

This paper presents results investigating the statistical features of daily precipitation conditioned by large-scale circulation patterns. Both the probabilities of getting precipitation as well as the mean average daily precipitation sums are considered. The results show distinct regional variations in both precipitation probability and expected amounts depending on circulation type. This information can be used as first guess fields in spatial interpolation schemes. Such interpolation schemes should utilize different information about terrain, continentality etc. Also information about the magnitude of the circulation components will be used to analyse systematic variations in the spatial patterns will be used in the further investigations

The differences between precipitation forecasts and observed precipitation are compared. Both the occurrence and amount of precipitation are analysed for different weather types. The forecast model, HIRLAM overestimates number of precipitation days. Especially it has a tendency to give too many days with small amounts of precipitation (less than 1.0 mm). For occurrences of days with precipitation above 1.0 mm there is a better fit between the observed and forecasted precipitation.
The spatial distribution of forecasted and observed precipitation amounts is compared by maps showing statistical features of the observed and predicted precipitation fields, as well as maps of the differences between the forecasts and the observations. A few cross-sections are also defined, along which the statistical distribution of the forecasts and observations, and their difference, is studied more in detail.

Generally these comparisons show that there are distinct variations in which areas where the precipitation predictions coincide with the observations. The variations can be related to the large-scale atmospheric circulation. These features are also identified when studying the cross-sections, where systematic differences are found in some profiles, especially near the coast for some circulation patterns. The study of the cross-section also gives information of the distributions of predicted and observed precipitation, information that should be focused in further research. For some grid cells HIRLAM predict unrealistic high values, which is an error that most probably is due to model parameterisation.

The methods used for spatial distribution of observed precipitation is very simple, and is not optimal for describing all the variability in precipitation. Since the precipitation network is biased towards lower altitudes, especially estimates for higher altitudes may be questioned. There exist therefore a strong need for better methods to describe the spatial variability of precipitation. This is ongoing research at *met.no*. These spatialisation schemes will be used to estimate daily precipitation fields based on observations and information about local terrain characteristics and large-scale atmospheric circulation. Alternative methods for classifying the weather situation will be tested. Methods including atmospheric thickness are assumed to give more information than methods only using sea level pressure. The weather type classification scheme used in this analysis cannot cover whole Norway in the same analysis. Therefore efforts will be made to find methods that can consider the classify weather types valid for the whole country. Research will be further elaborated in order to find relation that can explain systematic differences between observed and forecasted precipitation. The circulation indexes used to establish the weather types are variables that will be used for this purpose.

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