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# VERIFICATION OF PRECIPITATION BY MODEL OUTPUT STATISTICS (MOS)

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P. Ø. Nordli

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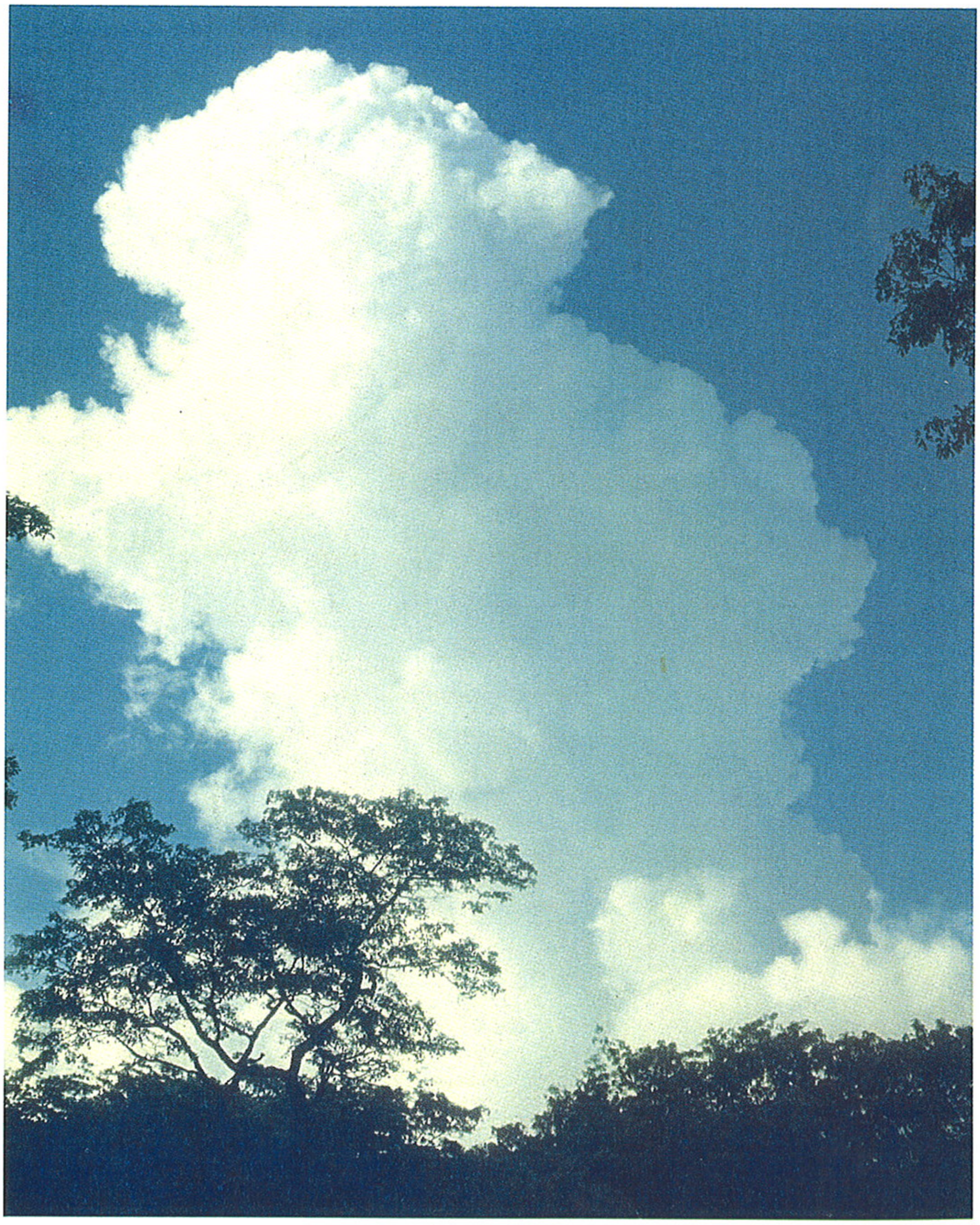

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# VERIFICATION OF PRECIPITATION BY MODEL OUTPUT STATISTICS (MOS)

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SUMMARY

Model one-day precipitation from the HIRLAM10 was compared to observed precipitation at 25 sites (measuring stations) in southern Norway concentrated geographically in five groups. On average modelled precipitation was overestimated by 24 %. The overestimation occurred in all seasons but to a different extent. In autumn the overestimation was only 10 %, while it was 16 %, 39 % and 38 % in winter, spring and summer respectively.

The weather situations in a training period as well as in a verification period were classified by the computerised Lamb weather type classification scheme. Model precipitation of the HIRLAM10 was verified at the 25 selected sites for the six weather types that gave the highest amounts of precipitation. Modelled precipitation was modified by Model Output Statistics (MOS). As method for modification was chosen linear regression analysis that was performed separately within each weather type.

For most of the sites modified model precipitation obtained higher scores compared with observations than non-modified precipitation. In particular this was true for precipitation amounts in the interval 2 – 4 mm, which were the most common precipitation heights. For smaller precipitation heights than 2 mm the modifications seem not to be realistic. For larger precipitation amounts than 5 mm MOS did not improve the model output, but this may be caused by a limited number of cases. The main conclusion is, however, that applying MOS-technique for different weather types seems to be a promising tool for improving prediction forecasts for specific sites.

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# *Verification of precipitation by Model Output Statistics (MOS).*

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# Verification of precipitation by Model Output Statistics (MOS).

## 1 Introduction

The quantitative precipitation prognoses are in general influenced by two main error sources: a). The actual weather situation becomes different from the situation forecasted by the numerical models (e.g. different development or movement of a low-pressure system), or b). The topographical influence on the precipitation process is different from the parameterisation in the model (e.g for specific wind directions the orographic precipitation enhancement is systematically stronger/weaker than prognosticated. In addition the topography is smoothed in the numerical models, and consequently local effects on a small scale is not sufficiently resolved in the forecasting models. Systematic differences between quantitative forecasts and observed precipitation is pointed out by several water power producers in Norway, and subjective rules are occasionally used to improve the forecasts.

In the EBL-Kompetanse project (2000-2001) "Improvement of quantitative precipitation prognoses by use of MOS-technique", systematic deviations between quantitative forecasts and observed precipitation caused by error source b) are studied. The results from the project are reported in the present report and in a report dealing with spatial analysis (Tveito, 2002).

Earlier Crochet and Ødegaard (2000) has studied the uncertainty of the HIRLAM model in 10 km horizontal resolution with respect to daily precipitation forecasted at 30 hours. The forecasts were compared to the spatial precipitation field derived by Kriging from the network of precipitation stations. HIRLAM was found to give more precipitation in the mountains than derived from the observations, and it also gave higher probability of precipitation. The probability of detection (POD) decreased for higher amounts of precipitation, but was in general high. The false alarm rate (FAR) increased from coast to inland.

In the present investigation an opposite approach is chosen. Instead of performing interpolations of the observed precipitation at the grid points of the model, the model field is used for interpolation of precipitation at the sites of the precipitation stations. At each site the precipitation is a bilinear interpolation based on the four nearest grid points of the model.

## 2 Data

The forecast data are a combination of two short time forecasts from the numerical weather prediction model HIRLAM. HIRLAM is run 00 UTC and 12UTC daily, and 24h accumulated precipitation is achieved by adding precipitation accumulated from 00+6 hours to 00+18 hours and 12+6 hours to 12+18 hours. The data set starts 1. January 1999.

The model has a horizontal resolution of 0.1 deg (~11km) on a spherical rotated grid and 31 vertical layers. The initial and boundary values are taken from runs with HIRLAM in 0.5 deg resolution.

The data period is defined by the start of the special HIRLAM data set, and the end is set by the newest data that could easily be used, i.e. 31 January 2002. The period was divided into a training period, from the start to 31. May 2001, and a validation period from 1 June 2001 to the end of the dataset. Only data prior to 1 June 2001 had gone through the quality control in the department of climatology at the Norwegian Meteorological Institute, i.e. the whole training data set had passed the final data control while the verification data set had not.

In the period there were 10 missing dates in the HIRLAM data set. These are:
1999: 1 Jan.
2000: 1 Jan., 7 Feb., 27 May, 17 Aug., 3 Dec.
2001: 1 – 2 Jan., 16 and 24 May.

From the whole network of stations that measure precipitation, 25 stations (sites) were chosen for verification. These are geographically concentrated in 5 groups representing different climates in southern Norway. Within each group stations were chosen to represent different exposures for the dominating wind directions. Each group comprises five stations, and to make validation possible, grid point model values were used for interpolation of model precipitation at the measuring sites, see table 2.1. In appendix 2 a short description of the stations' exposure to precipitation are given for different wind directions.

The skill of the model might depend on the weather situation. It might therefore be important to take the weather situation into account when model results are verified. This is done by grouping the data by weather types using a system attributed to Lamb (1950). This system was originally a subjective one, but a full scheme suitable for computerized classification was suggested by Jenkinson and Collision in 1977. Their classification rules are presented by Briffa (1995). The scheme is objective in the sense that once the criteria for classification are given, one has no influence on the classification. The scheme is further used by Chen et al. (1999). While Lamb's classification was originally developed for the British Isles, Chen moved the area towards Sweden and located the centre of the grid points used at 60 °N 15°E. For the present investigation the centre is located at 60°N 5 °E, which is at the western coast of Norway near Bergen. However, pressure data are used in the area 50 °N – 70 °N, 5 °W – 20 °E.

The 8 first weather types represent what is called directional flow, in table 2.2 denoted by intuitive letters. The two following types represent rotation of the atmosphere, cyclonic (C) type 9, anticyclonic (A) type 10. There are also possibilities of hybrid cases, combinations of any direct flow and the two rotational types that give rise to 16 additional types, see the types from No. 11 to 26 in table 2.2. Finally not all situations might be classified by the system and there is also possibility of an unclassified group, No. 27 (U). For details of the classification criteria, see Chen (1999) or Briffa (1995).

Table 2.1 Stations chosen for verification of model precipitation. The stations are grouped in geographically concentrated areas. The altitude is denoted for each station (m a.s.l.)

| Station No. | Name | Group | Altitude (m) |
|---|---|---|---|
| 04440 | Hakadal - Bliksrudhagan | No. 1 | 174 |
| 18500 | Bjørnholt | The Oslo | 360 |
| 18700 | Oslo – Blindern | area | 94 |
| 19100 | Kjelsås i Sørkedalen | | 319 |
| 19480 | Dønski | | 59 |
| 13050 | Gausdal - Skogli | No. 2 | 647 |
| 13140 | Fåvang | Southern | 187 |
| 13310 | Søre Brekkom | Gudbrandsdalen | 780 |
| 13450 | Hovdgrenda | | 666 |
| 14050 | Sjoa | | 330 |
| 41010 | Mandal - Eigebrekk | No. 3 | 10 |
| 41200 | Finsland | Southern | 275 |
| 41370 | Bjelland kraftverk | tip of | 110 |
| 41480 | Åseral | Norway | 278 |
| 41550 | Ljosland – Moen | | 504 |
| 52930 | Brekke i Sogn | No. 4 | 240 |
| 54120 | Lærdal – Moldo | Sogn | 24 |
| 55550 | Hafslo | and | 246 |
| 55840 | Fjærland - Skarestad | Fjordane | 10 |
| 56480 | Værlandet | | 15 |
| 62700 | Hustadvatn | No. 5 | 80 |
| 63420 | Sundalsøra | Nord-Møre | 6 |
| 63530 | Hafsås | and | 698 |
| 63750 | Mjøa | southern Trøndelag | 512 |
| 64550 | Tingvoll | | 69 |

Table 2.2 List of weather types based on circulation indices.

| No. | Type | Explanation | No. | Type | Explanation |
|---|---|---|---|---|---|
| 1 | N | Direct flow, north | 15 | CS | Cyclonic, south |
| 2 | NE | Direct flow, northeast | 16 | CSW | Cyclonic, southwest |
| 3 | E | Direct flow, east | 17 | CW | Cyclonic, west |
| 4 | SE | Direct flow, southeast | 18 | CNW | Cyclonic, northwest |
| 5 | S | Direct flow, south | 19 | AN | Anticyclonic, north |
| 6 | SW | Direct flow, southwest | 20 | ANE | Anticyclonic, northeast |
| 7 | W | Direct flow, west | 21 | AE | Anticyclonic, east |
| 8 | NW | Direct flow, northwest | 22 | ASE | Anticyclonic, southeast |
| 9 | C | Cyclonic flow | 23 | AS | Anticyclonic, south |
| 10 | A | Anticyclonic flow | 24 | ASW | Anticyclonic, southwest |
| 11 | CN | Cyclonic, north | 25 | AW | Anticyclonic, west |
| 12 | CNE | Cyclonic, northeast | 26 | ANW | Anticyclonic, northwest |
| 13 | CE | Cyclonic, east | 27 | U | Unclassified |
| 14 | CSE | Cyclonic, southeast | | | |

# 3 Verification without regard to weather situation

There are different processes causing precipitation, whose frequencies varies through out the year. For example precipitation from convective cells is frequent in inland districts, while orographic precipitation is most predominant during winter when the airflow pattern usually is at its strongest. Therefore the data is also grouped by season in order to catch up some of these differences. The seasons are (with the numbers used in the text, tables and figures): 1 Winter (Dec. – Feb.), 2 Spring (Mar. – May), 3 Summer (Jun. – Aug.), 4 Autumn (Sep. – Nov.).

Correlation coefficients may be a useful tool for verification of forecasts, and some kinds of correlation measure will also be used here. However, correlation coefficients tell nothing about biases, only the spread of the forecasts compared to the observations. For example, a model that systematically forecast too much precipitation may get high scores if a correlation coefficient is the only evaluation measure, while in reality this overestimation of precipitation might have large consequences for the model users, for example economic losses.

## 3.1 Biases between observed and model precipitation

The first measure of skill will be biases defined as the ratio between modelled precipitation and observed precipitation. For the whole sample of sites during the period 1 January 1999 to 31 May 2001 this ratio is 1.24, or the model overestimates precipitation by 24 %. The overestimation occurs in all seasons but to a different extent. In autumn the overestimation is only 10 %, while it is 16 %, 39 % and 38 % in winter, spring and summer respectively.

A more detailed look at the biases is given by figure 3.1 where the results are split into five groups, see chapter 2. It appears that the overestimation of precipitation is predominant for all groups in spring and summer, and also through the whole year for three of the groups (1.The Oslo area, 4. Sogn and Fjordane, and 5. Nord-Møre and southern Trøndelag). In winter and autumn underestimation of precipitation is also seen in two of the groups: 2 southern Gudbrandsdalen, and 3 the southern tip of Norway). The most marked underestimation amounts to 18 % during winter in group 2. In this group the bias reach its minimum in summer, while the other groups have minimum biases in winter or in autumn.

If the five groups are compared without regards to season, precipitation is overestimated in all groups except in group 2 where no bias is seen. The biases vary to a large extent from group to group. While, as already mentioned, there is no bias in group 2, the bias in group 5 is especially large. In this group modelled precipitation exceeds observed precipitation by 64 %, and also in the groups 1 and 4 large biases occur, as overestimation amounts to 30 % in both groups. For group 3 overestimation is only 3 %, i.e. practically no biases at all.

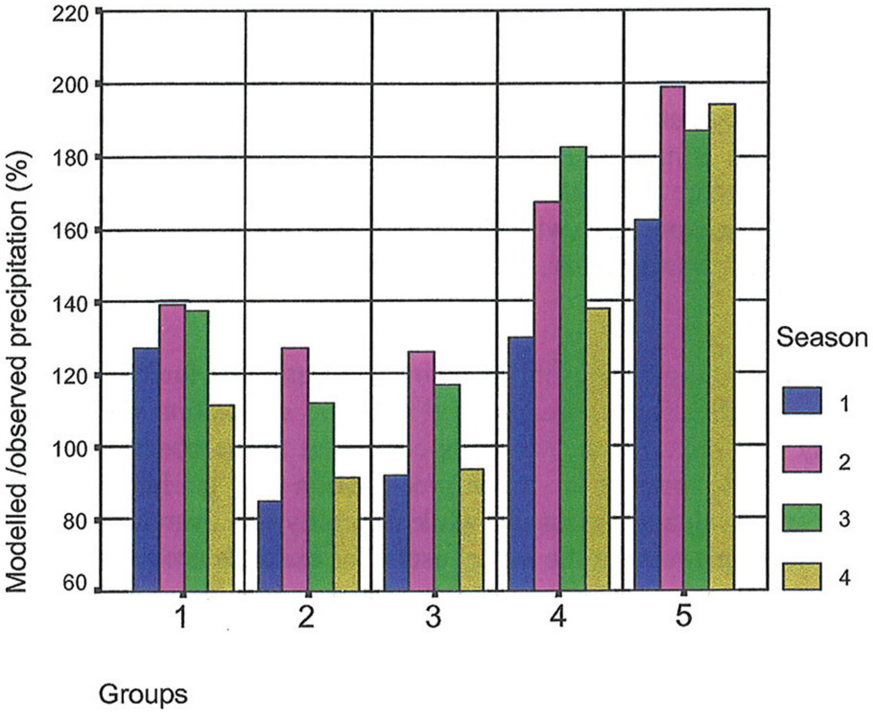
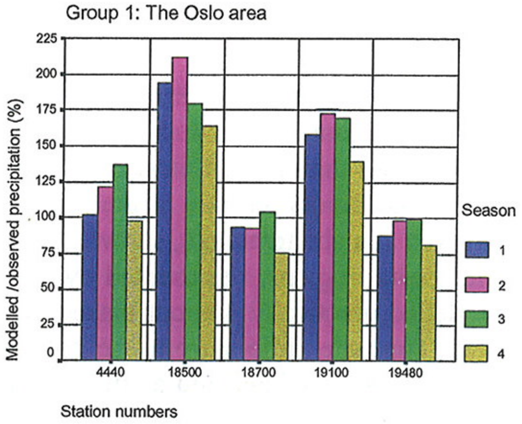


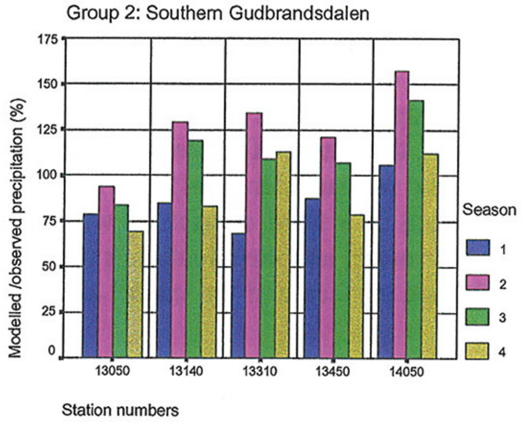
Figure 3.1 The ratio modelled to observed precipitation in the seasons: 1) Winter, 2) Spring, 3) Summer and 4) Autumn. The observations are also split into five different groups: 1) The Oslo area 2) Southern Gudbrandsdalen 3) Southern tip of Norway 4) Sogn and Fjordane 5) Nord-Møre and Trøndelag.

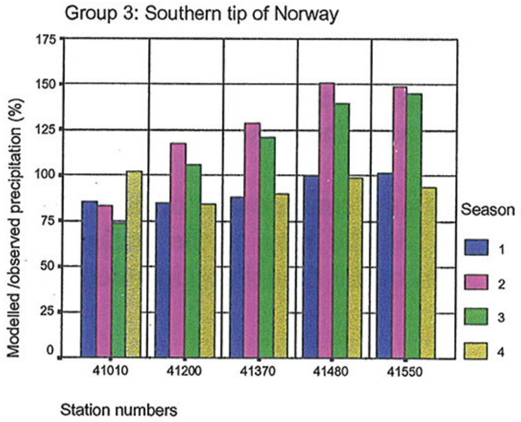
Having seen marked variations from group to group, it is perhaps not surprising that the biases also vary appreciably from station to station. This is seen in figure 3.2, where the results are grouped by station.

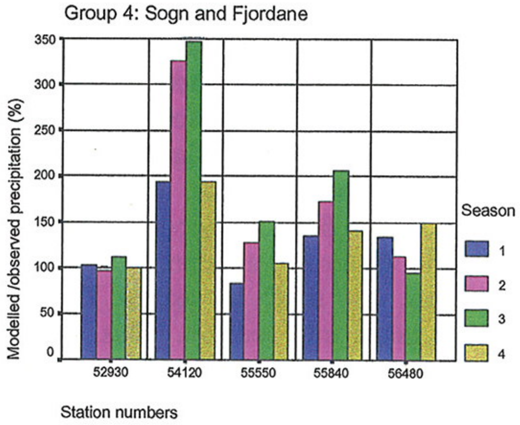
Group 1, the Oslo area, comprises the two low level stations 18700 Oslo – Blindern situated in Oslo city as well as 19840 Dønski situated in Bærum to the south east. Both stations have very small biases. The two stations 18500 Bjørnholt in the forest to the north of the city and 19100 Kjelsås i Sørkedalen to the northwest are situated over 300 m above sea level. Although the model altitude is larger than the actual altitude for both stations, the observed precipitation is overestimated by the model. For the station 04440 Hakadal – Bliksrudhagan to the northeast of Oslo, precipitation is slightly overestimated.

In group 2 (southern Gudbrandsdalen) the precipitation is overestimated by the model during spring and summer (except 13050 Gausdal – Skogli), while it is underestimated during winter and autumn (except 14050 Sjoa). At Skogli precipitation is overestimated throughout the year. The station is the southernmost in the group and the station's altitude is quite near the model altitude. For the station 13310 Søre Brekkom the bias is very much dependant of the season. Thus, the ratio modelled to observed precipitation varies from 68 % in winter to 134 % in spring. The station 14050 Sjoa is the northernmost station situated in the main valley in a sheltered position. The model overestimates by far the precipitation that might be explained by a large discrepancy between model altitude and station altitude.


Group 1: The Oslo area


Group 2: Southern Gudbrandsdalen


Group 3: Southern tip of Norway


Group 4: Sogn and Fjordane

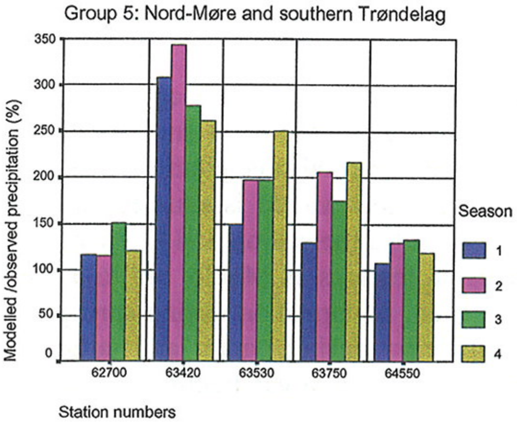

Group 5: Nord-Møre and southern Trøndelag

Figure 3.2 The ratio modelled to observed precipitation for five groups of stations split by individual stations. The stations are denoted by their numbers. The stations' names are seen in table 2.1.

Group 3 represents the southern tip of Norway from the coast to about 60 km inland. Like for many of the other groups, the model estimates quite well precipitation in winter and autumn and overestimates it during spring and summer. What specifically can be read out of the figure for this group, is that the estimation ratio in winter and autumn does not vary much from the coastal areas represented by 41010 Mandal – Eigebrekk to the innermost station 41550 Ljosland – Moen. In spring and summer, however, the overestimation by the model is marked at Moen, almost 50 %. The difference between model altitude and station altitude is about 400 m for 41480 Åseral, for the other stations the difference is less, and near the coast it is close to zero.

Group 4 covers a fjord/mountain area in Sogn and Fjordane Fylke (county). The exposure of the selected stations varies resulting in large variations of precipitation on a regional scale. Thus, the well exposed station 52930 Brekke i Sogn has a 1961 – 90 normal of 3575 mm for annual precipitation, while the most sheltered one, 54120 Lærdal – Moldo, has a normal less than 500 mm.

The model shows excellent agreement with the observations in all seasons at Brekke, the most exposed site. At the most sheltered one, Moldo, modelled precipitation amounts to more than twice the observed precipitation, and in spring and summer more than three times. It should be mentioned that Moldo is situated close to the sea level and the model altitude at the station is 1185 m. Also the station 55840 Fjærland – Skarestad, situated at a sheltered site, shows many of the same features as Moldo, but to a lesser extent. In the coastal regions, represented by 56480 Værlandet, precipitation during spring and summer is modelled practically without biases, while precipitation during winter and autumn is overestimated. This site differs from the common pattern, where a larger fraction of model precipitation is observed in winter and autumn than in spring and summer.

Group 5 covers an east – west transect through Nord-Møre and the southern border districts of Trøndelag close to the Dovrefjell mountains. Like in group 4 this transect comprises a very rugged terrain with quite different expose for precipitation. In spite of these differences the model overestimates precipitation at all sites in all seasons. However, the extent of overestimation varies from about 25 % at the coastal district (62700 Hustadvatn) and not far inland (64550 Tingvoll) to a huge overestimation at 63420 Sundalsøra, which is situated in a fjord district. In winter and spring observed precipitation is overestimated by a factor 3 or more, and the situation is not much better in the other seasons. The station is situated near the sea surface and the model altitude is 1118 m.

In the comments so far the difference between station altitude and model altitude has been mentioned as a possible explanation of the model biases. In order to look at this closer the ratio observed precipitation to model precipitation was calculated for each of the 25 stations and correlated with the 25 differences between model altitude and station altitude. The correlation coefficient was 0.67 accounting for nearly half the variance and significant at the 1 % level. The low resolution of the model seems to be a significant contribution to the biases of the model.

On the other hand there are biases that cannot be interpreted as a consequence of the difference between model altitude and station altitude. One example is the bias at the station 18500 Bjørnholt where observed precipitation amounts to only 50 % of the model precipitation and the station altitude is quite close to the model altitude.

### 3.2 Measuring the spread of the model estimates

The model does not necessarily have an excellent fit to the observations, once the total amount of modelled precipitation is in agreement to the total amount of observed precipitation during a test period. The skill of the model also depends on the variability of the difference between observed and modelled precipitation. As a measure of this variability Pearsons correlation coefficient is chosen. The results resolved for groups and seasons are shown graphically in figure 3.3 and for details the correlation for each station is found in Appendix 1, tables 2a – 2c. The correlation coefficient varies between 0.52 during summer for group 1 (Oslo) to 0.81 during winter for group 3 (Sørlandet). Generally the correlation coefficient is highest in winter and autumn, but this is not true for group 5 (Møre/Trøndelag), where correlation does not vary much by season. There are also some variations among the groups when season is not taken into account. Thus, the best correlation (0.78) is obtained for group 3, Sørlandet, and poorest correlation (0.65) has group 2, Gudbrandsdalen. The entire list is shown in Appendix 1 table 1.

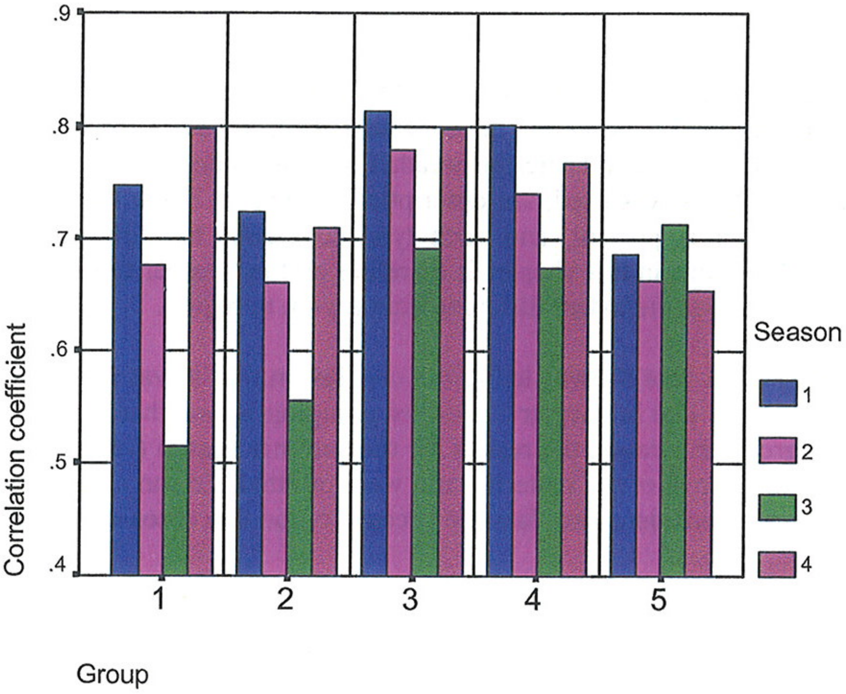


Figure 3.3 Correlation coefficient between observed and modelled precipitation in the seasons: 1) Winter, 2) Spring, 3) Summer and 4) Autumn. The observations are also split into five different groups: 1) The Oslo area 2) Southern Gudbrandsdalen 3) Southern tip of Norway 4) Sogn and Fjordane 5) Nord-Møre and Trøndelag.

If there are little spread between observed and modelled precipitation there is a potential for improving the forecast by Model Output Statistic (MOS), see for example Wilks (1996, 201 - 210). Especially the modifications could be effective for large biases. By combining figures 3.1 for the biases and figure 3.3 for the correlations, several cases of great potential for improvements are seen. In all seasons the group 5 (Møre/Trøndelag) had large biases while the spread of the forecast is quite small, and also for group 4 (Sogn and Fjordane) there is a great potential for improvements.

For group 1 (Oslo) precipitation is overestimated in all seasons while the spread in the forecast is relatively small in winter and autumn and to a certain extent in spring too. In these seasons it should be possible to improve the skill of the forecast. In summer, however, the bias is overestimated and the correlation is poor, it might be more difficult to achieve great improvements of the forecast.

# 4 Verification of the precipitation model under some predominant circulation types

In chapter 3 the whole material was considered without any regard to the type of circulation or its strength. These factors might, however, be important discriminators for model evaluation and should not be omitted. In order to bring the weather situation into consideration, a classification scheme of 26 weather types was used, see description in chapter 2. For the majority of the types little or no precipitation is present, and each type comprises too few cases to be used for statistical analysis. The focus in this chapter is therefore on the weather types that lead to frequent precipitation. These are to some extent different from region to region.

Preliminary investigations (not shown) led to the conclusion that it was not feasible to group the material into four seasons like in chapter 3. Further grouping by weather types would involve too few cases in each group. However, the results for the summer season (June – August) seemed to differ too much from the rest of the material, and were omitted. To run a separate analysis on the summer data was again considered not feasible because of too few cases in each group.

Also preliminary investigations were performed in order to choose the method for regression analysis. Linear least-squares regression like in chapter 3 was tried as well as linear least-distance regression. The last method was suggested to get more robust equations with respect to outliers, but it was concluded that the least-squares regression equations were the most stable ones and therefore chosen for further use. It was also considered leaving out cases with no modelled precipitation, but this did not seem to have any important effect, and the zero cases were kept.

## 4.1 Training of the regression

The weather types that were associated with the largest amounts of precipitation were the C, S, CS, SW, W, and NW, see tables 2.2 and 4.1. While the cyclonic type, C, is represented in all regions the northwesterly straight flow, NW, is represented only in the Nord-Møre and southern Trøndelag area. Straight westerly flow, W, contributed heavily to precipitation only in Sogn and Fjordane, and to some extent also in Nord-Møre and southern Trøndelag.

The results for all 25 stations are shown in table 4.1, and for the stations marked with an asterisk in the table (one in each region), the results are also visualised in figure 4.1. Each season is marked with colour in the diagram, red for winter, green for spring and blue for autumn. The regression line and its 95 % confidence interval are based on all observations within the three seasons.

In the Oslo area best correlation is in general obtained between modelled and observed precipitation for types C and S, while correlations for type CS is somewhat poorer except for the station 18550 Bjørnholt. For the large majority of the sites precipitation is overestimated, but some exceptions occur.

In southern Gudbrandsdalen the correlation between modelled and observed precipitation is best within the S weather type. For the site 13050 Gausdal – Skogli precipitation is underestimated for all circulation types, while for most of the other sites precipitation is more or less overestimated.

For the site 13450 Hovdgrenda an underestimation is present for weather type S, while the regression line is not significantly different from 1 for types C and CS, see figure 4.1 d, e, and f.

Table 4.1 Results from simple linear regression analysis, observed precipitation as predictand and modelled precipitation as predictor. The correlation coefficient (R), the standard errors of the estimate, the regression coefficient and constant are also shown. For the list of weather types, see table 2.2.

| Station | Type/ No. obs. | R | St.err. estimate | Regression coefficient | St. err. reg. coef. | Constant | St. err. const. |
|---|---|---|---|---|---|---|---|
| 4440 Hakadal - Bliksrudhagan | C/122 | .834 | 4.454 | .858 | .052 | .524 | .514 |
| | S/91 | .846 | 5.001 | .997 | .066 | .523 | .726 |
| | CS/31 | .645 | 6.813 | .686 | .148 | 3.902 | 2.087 |
| *18500 Bjørnholt | C/122 | .693 | 6.783 | .423 | .040 | 1.003 | .796 |
| | S/91 | .800 | 7.403 | .609 | .048 | .241 | 1.097 |
| | CS/31 | .761 | 9.025 | .628 | .098 | .770 | 2.834 |
| 18700 Oslo - Blindern | C/122 | .758 | 4.336 | .994 | .078 | 1.225 | .480 |
| | S/91 | .668 | 5.607 | .964 | .113 | 1.215 | .800 |
| | CS/31 | .419 | 6.133 | .497 | .197 | 5.761 | 1.681 |
| 19100 Kjelsås i Sørkedalen | C/122 | .768 | 5.030 | .552 | .042 | .508 | .589 |
| | S/91 | .810 | 5.754 | .678 | .052 | .873 | .845 |
| | CS/31 | .738 | 6.478 | .598 | .100 | 2.446 | 2.031 |
| 19480 Dønski | C/122 | .787 | 4.569 | .915 | .065 | .800 | .518 |
| | S/91 | .810 | 4.875 | 1.033 | .079 | .890 | .711 |
| | CS/31 | .591 | 8.741 | .978 | .244 | 4.891 | 2.592 |
| 13050 Gausdal - Skogli | C/122 | .723 | 4.146 | 1.365 | .119 | .372 | .483 |
| | S/91 | .783 | 4.695 | 1.232 | .103 | .561 | .703 |
| | CS/31 | .675 | 5.935 | 1.200 | .239 | 2.971 | 1.657 |
| 13140 Fåvang | C/122 | .714 | 2.381 | .976 | .087 | .319 | .280 |
| | S/91 | .787 | 2.919 | .947 | .078 | .669 | .409 |
| | CS/31 | .353 | 5.554 | .622 | .301 | 3.758 | 1.535 |
| 13310 Søre Brekkom | C/122 | .597 | 3.197 | .769 | .094 | .769 | .369 |
| | S/91 | .523 | 3.771 | .452 | .078 | 2.040 | .492 |
| | CS/31 | .394 | 4.866 | .532 | .227 | 2.744 | 1.312 |
| *13450 Hovdgrenda | C/122 | .609 | 2.361 | .847 | .100 | .686 | .271 |
| | S/91 | .819 | 3.461 | 1.596 | .118 | -.984 | .515 |
| | CS/31 | .371 | 4.381 | .635 | .290 | 2.667 | 1.230 |
| 14050 Sjoa | C/122 | .593 | 2.310 | .799 | .099 | .584 | .261 |
| | S/91 | .693 | 3.115 | .968 | .106 | -.472 | .451 |
| | CS/31 | .515 | 2.962 | .570 | .173 | 1.510 | .799 |

Table 4.1 (continuation)

| Station | Type/ No. obs. | R | St.err. estimate | Regression coefficient | St. err. reg. coef. | Constant | St. err. const. |
|---|---|---|---|---|---|---|---|
| 41010 Mandal - Eigebrekk | C/122 | .653 | 6.181 | .843 | .089 | 2.172 | .697 |
| | S/91 | .654 | 7.177 | .587 | .072 | 3.981 | 1.072 |
| | CS/31 | .462 | 7.947 | .514 | .180 | 6.253 | 2.499 |
| | SW/71 | .636 | 3.605 | .474 | .069 | 1.844 | .564 |
| 41200 Finsland | C/122 | .753 | 5.562 | .850 | .068 | 1.842 | .628 |
| | S/91 | .788 | 7.423 | .787 | .065 | 4.071 | 1.188 |
| | CS/31 | .752 | 8.940 | .784 | .126 | 5.363 | 2.467 |
| | SW/71 | .796 | 4.381 | .740 | .067 | 1.813 | .700 |
| 41370 Bjelland kraftverk | C/122 | .801 | 5.445 | 1.057 | .072 | .963 | .614 |
| | S/91 | .773 | 7.361 | .794 | .069 | 2.661 | 1.186 |
| | CS/31 | .776 | 8.426 | .788 | .117 | 4.002 | 2.313 |
| | SW/71 | .826 | 4.030 | .735 | .060 | 1.926 | .660 |
| 41480 Åseral | C/122 | .750 | 6.491 | .870 | .070 | .569 | .738 |
| | S/91 | .784 | 8.135 | .805 | .067 | 1.769 | 1.417 |
| | CS/31 | .865 | 6.809 | .823 | .087 | 3.032 | 2.015 |
| | SW/71 | .815 | 5.089 | .875 | .074 | 1.012 | .914 |
| *41550 Ljosland - Moen | C/122 | .791 | 6.023 | 1.012 | .071 | -.064 | .689 |
| | S/91 | .685 | 8.355 | .707 | .079 | 3.098 | 1.467 |
| | CS/31 | .742 | 9.524 | .862 | .142 | 3.823 | 2.867 |
| | SW/71 | .728 | 5.649 | .882 | .099 | .883 | 1.066 |
| 52930 Brekke i Sogn | C/122 | .798 | 6.611 | .832 | .057 | 1.409 | .736 |
| | S/91 | .573 | 7.403 | .628 | .095 | 3.503 | 1.074 |
| | W/18 | .899 | 14.056 | 1.312 | .155 | -10.551 | 5.512 |
| | SW/71 | .601 | 14.999 | .630 | .100 | 10.268 | 3.375 |
| 54120 Lærdal - Moldo | C/122 | .595 | 3.142 | .475 | .058 | -0.092 | .350 |
| | S/91 | .332 | 1.124 | .086 | .026 | .266 | .144 |
| | W/18 | .745 | 5.586 | .505 | .110 | 2.035 | 1.777 |
| | SW/71 | .418 | 4.342 | .512 | .133 | 1.117 | .888 |
| *55550 Hafslo | C/122 | .675 | 3.357 | .985 | .098 | -.059 | .369 |
| | S/91 | .657 | 2.593 | .593 | .072 | .233 | .366 |
| | W/18 | .811 | 9.849 | 1.626 | .285 | -.505 | 3.298 |
| | SW/71 | .531 | 6.327 | .743 | .142 | 3.853 | 1.346 |
| 55840 Fjærland - Skarestad | C/122 | .796 | 3.755 | .622 | .043 | .000 | .423 |
| | S/91 | .714 | 2.942 | .349 | .036 | .356 | .426 |
| | W/18 | .833 | 12.302 | 1.537 | .247 | -7.700 | 5.807 |
| | SW/71 | .707 | 7.498 | .565 | .068 | 5.041 | 1.950 |
| 56480 Værlandet | C/122 | .612 | 4.917 | .580 | .068 | 1.485 | .567 |
| | S/91 | .468 | 5.222 | .333 | .066 | 3.010 | .685 |
| | W/18 | .509 | 8.639 | .377 | .155 | 2.300 | 3.104 |
| | SW/71 | .469 | 6.975 | .333 | .075 | 5.882 | 1.620 |

Table 4.1 (continuation)

| Station | Type/ No. obs. | R | St.err. estimate | Regression coefficient | St. err. reg. coef. | Constant | St. err. const. |
|---|---|---|---|---|---|---|---|
| 62700 | C/122 | .710 | 6.089 | .727 | .066 | 1.326 | .705 |
| Hustadvatn | W/18 | .580 | 12.505 | .897 | .305 | 1.319 | 6.227 |
| | NW/21 | .746 | 6.412 | .605 | .121 | 3.087 | 2.397 |
| | SW/71 | .581 | 8.017 | .739 | .124 | 3.652 | 1.521 |
| 63420 | C/122 | .727 | 3.373 | .420 | .036 | .093 | .398 |
| Sundalsøra | W/18 | .266 | 4.634 | .143 | .126 | 2.639 | 2.561 |
| | NW/21 | .523 | 4.595 | .233 | .085 | .858 | 2.075 |
| | SW/71 | .509 | 3.538 | .336 | .068 | -.078 | .626 |
| *63530 | C/122 | .520 | 4.510 | .641 | .096 | .017 | .534 |
| Hafsås | W/18 | .152 | 4.683 | .160 | .252 | 3.419 | 2.296 |
| | NW/21 | .630 | 7.977 | .904 | .249 | -1.630 | 3.076 |
| | SW/71 | .567 | 1.896 | .479 | .083 | -.238 | .333 |
| 63750 | C/122 | .402 | 3.172 | .531 | .110 | .681 | .361 |
| Mjøa | W/18 | .112 | 2.152 | .131 | .283 | 1.834 | 1.010 |
| | NW/21 | .560 | 5.938 | 1.014 | .335 | .114 | 1.974 |
| | SW/71 | .393 | 1.416 | .388 | .108 | .109 | .231 |
| 64550 | C/122 | .725 | 3.629 | .828 | .072 | 1.443 | .393 |
| Tingvoll | W/18 | .262 | 6.175 | .234 | .210 | 6.444 | 2.379 |
| | NW/21 | .467 | 6.128 | .423 | .179 | 3.524 | 2.447 |
| | SW/71 | .276 | 3.513 | .268 | .112 | 2.347 | .579 |

At the southern tip of Norway precipitation comes mainly with circulation types C, S, CS, as for southeastern Norway and also with southwesterly straight flow, SW. For most of the sites and weather types the model predicts precipitation without large biases, like for example for the site 41550 Ljosland – Moen that is shown in figure 4.1, g, h, i, j.

The topography in the Sogn and Fjordane area is very rugged and correlations between observed and modelled precipitation undergo large variations by site and weather type. The main weather types for precipitation are C, S, SW and also straight westerly flow, type W. For type W precipitation is underestimated for some of the sites, while for the rest of the types precipitation is predicted without biases or are overestimated. Thus, the site 55550 Hafslo shows up an overestimation for weather type S, see figure 4.1.l, an underestimation of type W, figure 4.1.m, and without biases for type SW, figure 4.1.n.

In the Nord-Møre and southern Trøndelag group correlation between observed and modelled precipitation is much poorer than for the other groups. In particular this is true for type W. Type S is not an important precipitation weather type in the area, while straight north westerly flow, NW, is important due to the orientation perpendicular to the coastal line, leading to orographic lifting of the air. Type NW is the only type that at least for some sites give unbiased estimations, like at 63530 Hafsås figure 4.1.q, while for the other types precipitation is overestimated, figure 4.1.o, 4.1.p and 4.1.r.

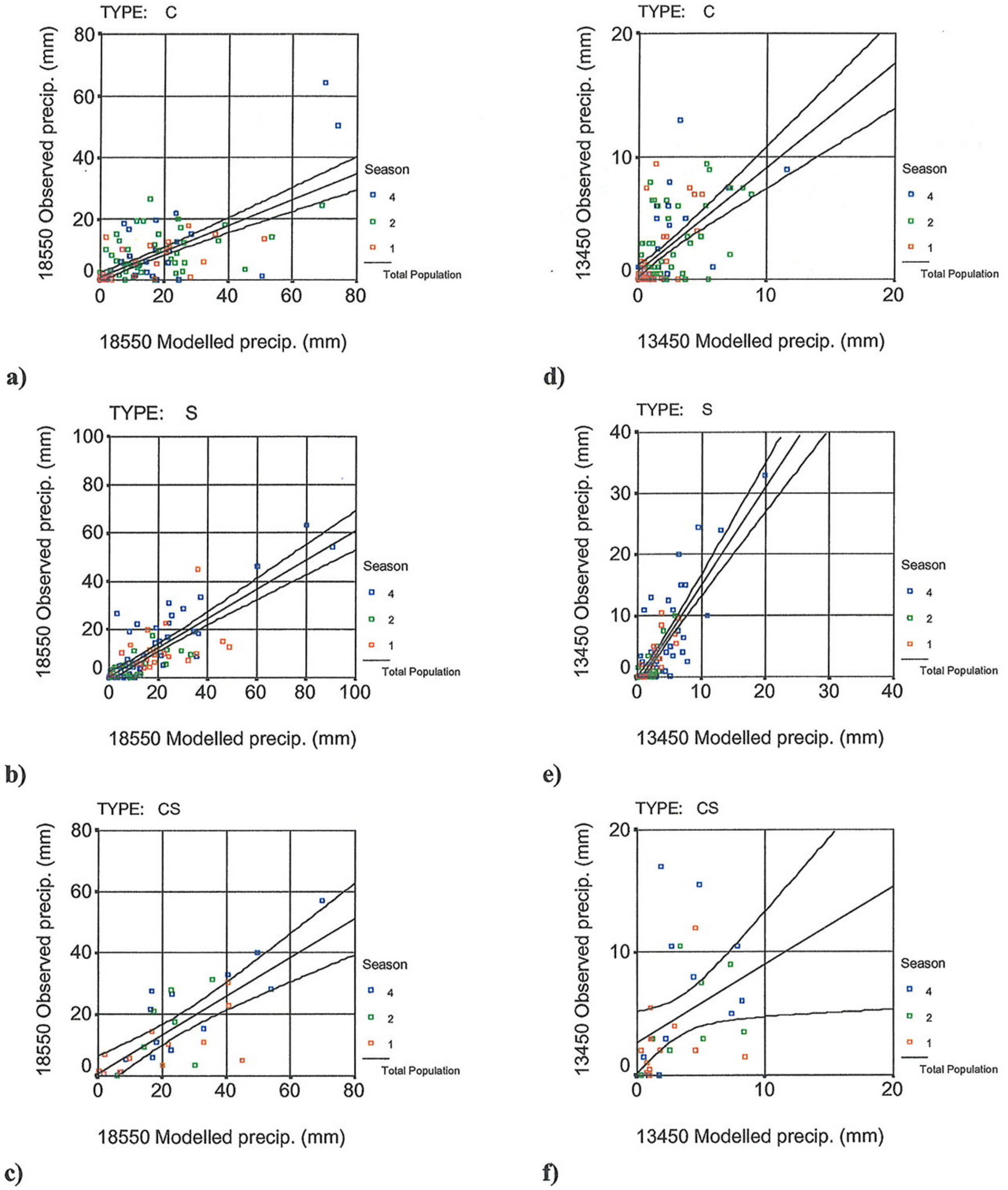


Figure 4.1. Regression analysis for observed precipitation (predictand) and modelled precipitation (predictor) for selected sites in Southern Norway. Each season is marked with colour in the diagram, red for winter, green for spring and blue for autumn. The regression line and its 95 % confidence interval are based on all observations without regard to season (figure continues next pages).

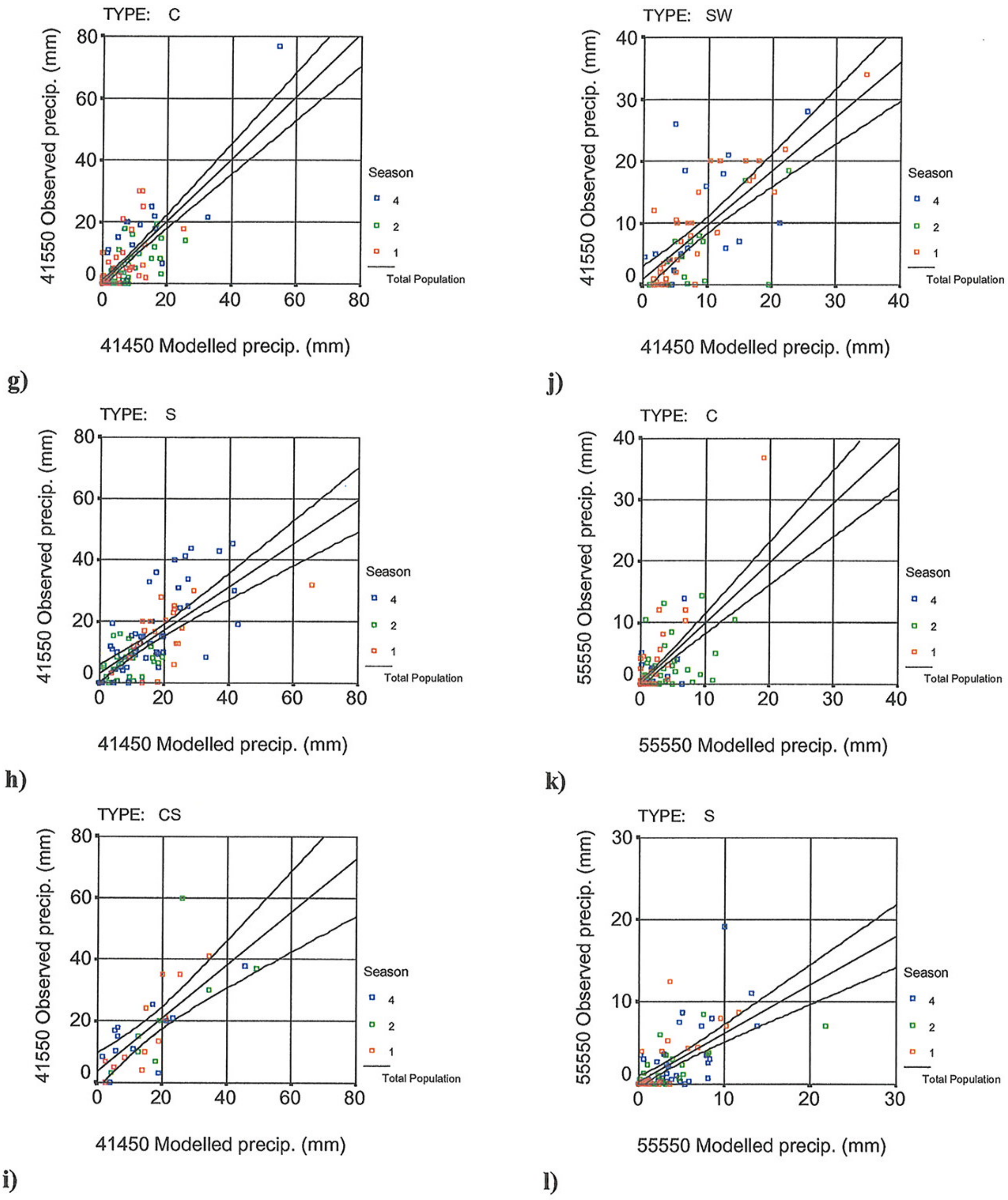
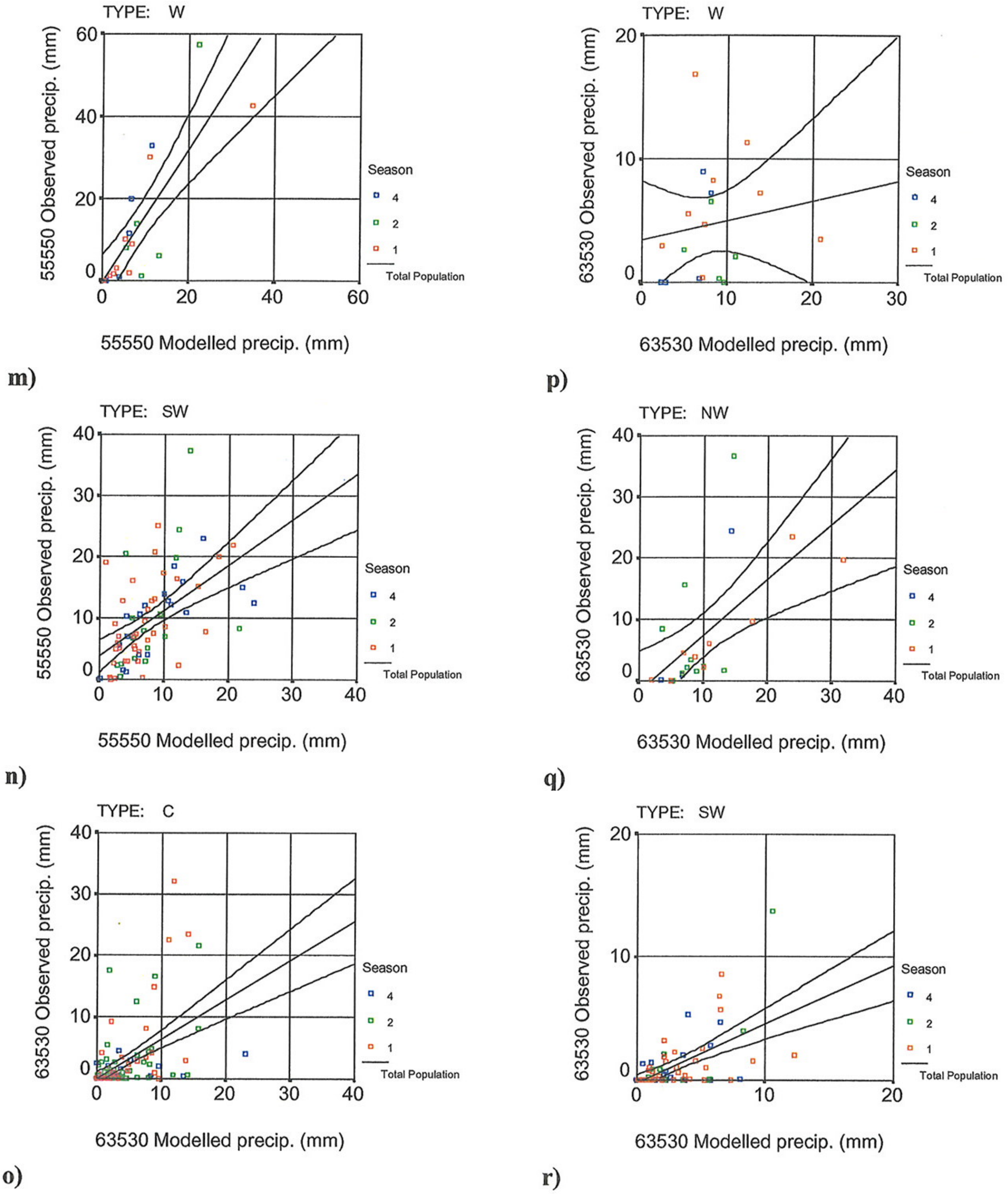


Figure 4.1. (continuation from previous page). Regression analysis for observed precipitation (predictand) and modelled precipitation (predictor) for selected sites in Southern Norway. Each season is marked with colour in the diagram, red for winter, green for spring and blue for autumn. The regression line and its 95 % confidence interval are based on all observations without regard to season (continues next page).



m) p)

n) q)

o) r)

Figure 4.1. (continuation from previous pages). Regression analysis for observed precipitation (predictand) and modelled precipitation (predictor) for selected sites in Southern Norway. Each season is marked with colour in the diagram, red for winter, green for spring and blue for autumn. The regression line and its 95 % confidence interval are based on all observations without regard to season.

So far the strength of the flow has not been taken into consideration, as the grouping criteria for the weather types only deals with the relative strength between the flow components. A further grouping of the weather types by the strength of the flow is therefore desirable but statistical problematic because of too few cases in each group. The further grouping was therefore restricted to the weather types that comprise the largest number of cases, i.e. the S and SW types. These were subdivided into two groups, one containing observations of geostrophic flow < 20 m/s, and the other containing the rest of the observations. The two groups were denoted weak and strong respectively. The grouping criteria were chosen so that nearly half of the cases fell into each subdivision, see table 4.2.

Table 4.2 Results from simple linear regression analysis, observed precipitation as predictand and modelled precipitation as predictor. The standard errors of the estimate, regression coefficient and constant are also shown. For the list of weather types, see table 2.2. The regression is performed for the most common precipitation weather types subdivided into two groups, one called weak (< 20 m/s) and strong (≥ 20 m/s) geostrophic flow respectively.

| Station | Strength of field | Type/ No. obs | R | St.err. estimate | Regression coefficient | St. err. reg. coef. | Constant | St. err. const. |
|---|---|---|---|---|---|---|---|---|
| 18500<br>Bjørnholt | Weak | S/46 | .829 | 5.681 | .695 | .070 | -1.110 | 1.133 |
| | Strong | S/45 | .755 | 8.860 | .556 | .074 | -1.796 | 2.064 |
| 13450<br>Hovdgrenda | Weak | S/46 | .765 | 3.369 | 1.931 | .243 | -1.270 | .688 |
| | Strong | S/45 | .844 | 3.514 | 1.553 | .151 | -1.196 | .832 |
| 41550<br>Ljosland - Moen | Weak | SW/37 | .667 | 4.498 | .675 | .126 | .128 | 1.091 |
| | Strong | SW/34 | .721 | 5.854 | .846 | .144 | 3.593 | 1.817 |
| | Weak | S/46 | .515 | 6.919 | .618 | .153 | 2.024 | 1.691 |
| | Strong | S/45 | .559 | 9.193 | .546 | .123 | 8.461 | 2.949 |
| 55550<br>Hafslo | Weak | SW/37 | .563 | 6.067 | .771 | .189 | 2.729 | 1.603 |
| | Strong | SW/34 | .425 | 6.586 | .601 | .227 | 6.219 | 2.384 |
| | Weak | S/46 | .590 | 2.103 | .539 | .110 | .427 | .437 |
| | Strong | S/45 | .678 | 3.066 | .618 | .102 | .089 | .619 |
| 63530<br>Hafsås | Weak | SW/37 | .412 | 1.266 | .197 | .073 | .246 | .304 |
| | Strong | SW/34 | .768 | 1.938 | .898 | .133 | -.992 | .501 |

The results are shown in table 4.2 and in figure 4.2 for a selected number of sites. For most of the sites the confidence interval of the regression line intersect to a large extent into each other, compare for example figure 4.2.a and 4.2.d. for Bjørnholt, or 4.2.b and 4.2.e for Ljosland – Moen. The strength of the field seems, however, to play and important role for the sites Hafslo (not shown in figure 4.2) and Hafsås, see figure 4.2.c and 4.2.f. for southwesterly straight flow. At Hafslo the model fit is best for weak flow, while for Hafsås the model is best for strong flow. At sites under large orographic influence like Ljosland – Moen under southerly flow, precipitation is positively correlated to the strength of the flow. Thus, the high precipitation cases tend to be located in the "strong flow" group, while the low precipitation cases tend to be located in the "weak flow" group.

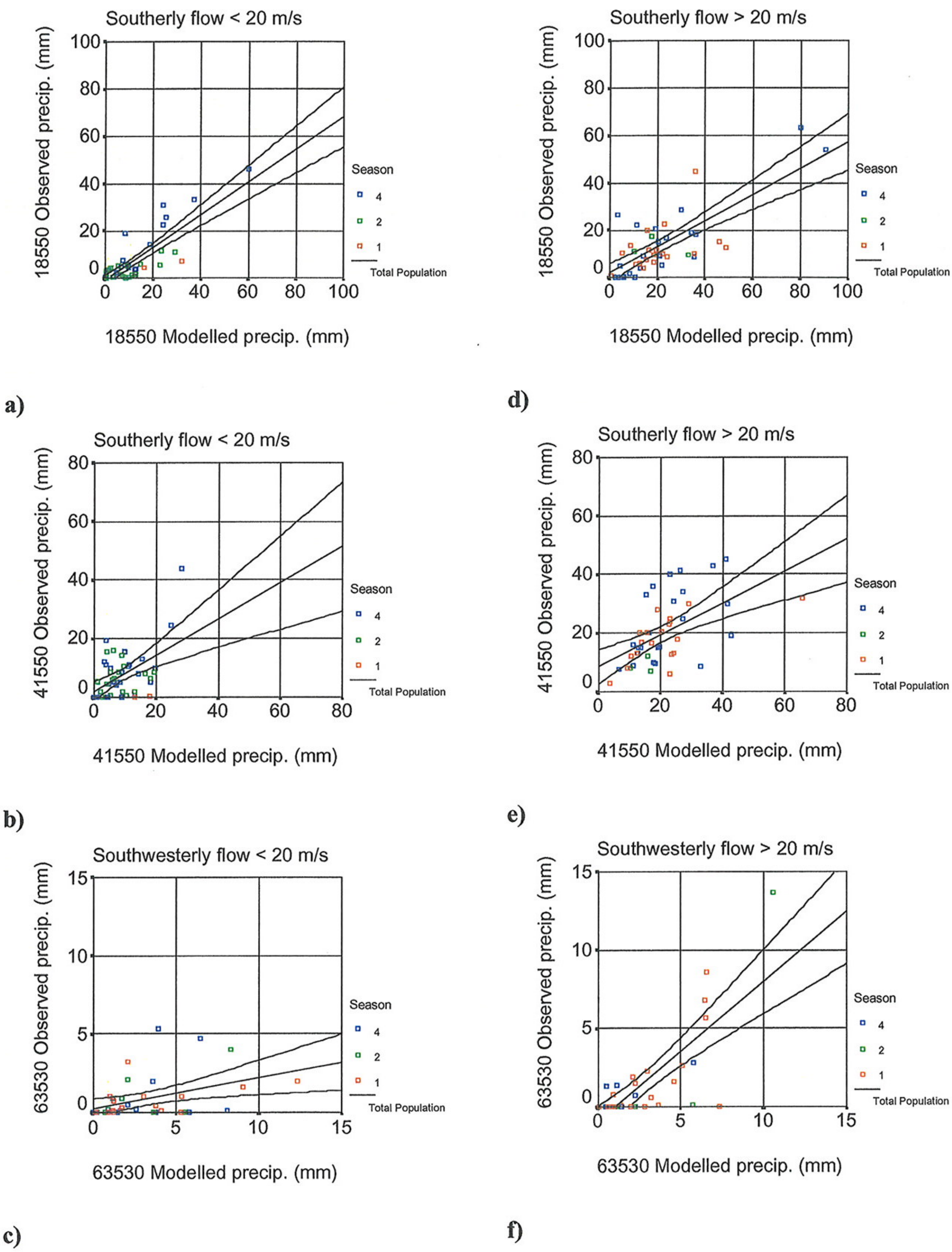


Figure 4.2 Regression analysis for observed precipitation (predictand) and modelled precipitation (predictor) for selected sites in Southern Norway. Each season is marked with colour in the diagram, red for winter, green for spring and blue for autumn. The regression line and its 95 % confidence interval are based on all observations within the three seasons.

### 4.2 Verification of the regression

It seemed to be little gained by further grouping of the data by the categories "weak" and "strong" flow because most of the regression lines were not significantly different. The verification dataset was therefore based on the main weather types without further grouping. Only for the weather types and sites showing biased modelled results, modification was performed if the regression line fulfilled an objective modification criterion. As criterion was chosen the intersect between 20 mm modelled precipitation and 20 mm observed precipitation. If this point fell outside the confidence interval of the regression line, modification was undertaken. A 99 % confidence interval was chosen for the regression line (note that in the figures, for instance in figure 4.1, a 95 % interval is used).

The criteria led to modification of the results from 43 sites/weather types out of a total of 90, i.e. 48 %, see also table 4.3 that gives a cross table for the sites and weather types. Those combinations that are marked with a cross (x) are subject to modification. It should be mentioned that the few crosses of type CS does not necessary mean that the model output of this weather type is less biased than for the other ones. Few cases or poor correlation between modelled and observed precipitation might also be reasons for exclusion. The yellow lines in table 4.3 mark combinations of weather types and study areas that were excluded already in the training data set because of too few cases of precipitation.

Table 4.3 Modification of model output by regression analysis. Modification is performed for the sites and weather types marked with a cross (x) in the table. Combinations not considered are marked with yellow lines.

| Group | Site | C | S | CS | SW | W | NW |
|---|---|---|---|---|---|---|---|
| 1 | 4440 Hakadal – Bliksrudhagan | | | | | | |
| | 18500 Bjørnholt | x | x | x | | | |
| | 18700 Oslo - Blindern | | | | | | |
| | 19100 Kjelsås i Sørkedalen | x | x | x | | | |
| | 19480 Dønski | | | | | | |
| 2 | 13050 Gausdal - Skogli | x | x | x | | | |
| | 13140 Fåvang | x | x | | | | |
| | 13310 Søre Brekkom | | x | | | | |
| | 13450 Hovdgrenda | | x | | | | |
| | 14050 Sjoa | | | | | | |
| 3 | 41010 Mandal - Eigebrekk | | x | | x | | |
| | 41200 Finsland | | | | x | | |
| | 41370 Bjelland kraftverk | | | | x | | |
| | 41480 Åseral | | | | | | |
| | 41550 Ljosland - Moen | | | | | | |
| 4 | 52930 Brekke i Sogn | | | | | | |
| | 54120 Lærdal - Moldo | x | x | | x | x | |
| | 55550 Hafslo | | x | | | | |
| | 55840 Fjærland - Skarestad | x | x | | x | | |
| | 56480 Værlandet | x | x | | x | x | |
| 5 | 62700 Hustadvatn | | | | | | x |
| | 63420 Sundalsøra | x | | | x | x | x |
| | 63530 Hafsås | x | | | x | x | |
| | 63750 Mjøa | x | | | x | x | |
| | 64550 Tingvoll | | | | x | x | x |

From table 4.3 it is readily seen that the potential for the MOS technique is greatest in group 4 and 5 while in group 3 the modelled precipitation was subject to modification only for four sites/weather types. During the period of verification, September 2001 – January 2002, the cyclonic weather type (C) was predominating, as this type alone comprised altogether 59 % of the cases that were subject to verification. The total number of cases used was 625 that represented 6 weather types and 19 of the 25 sites (precipitation stations). In the verification period the 6 weather types represented 78 out of 153 days. The rest of the days was governed by weather types that gave little or no precipitation over southern Norway.

Table 4.4 Frequency of weather types subject to validation by model output statistics (MOS)

| Weather types | Frequency | Percent |
|---|---|---|
| C | 369 | 59.0 |
| S | 100 | 16.0 |
| W | 18 | 2.9 |
| CS | 16 | 2.6 |
| NW | 12 | 1.9 |
| SW | 110 | 17.6 |
| Total | 625 | 100.0 |

For verification the observed as well as the modelled precipitation was categorised as precipitation above or below certain levels. Several levels were chosen and for each level a 2 x 2 contingency table was calculated. As measure for fit was used the contingency coefficient (cont.) as well as other measures often used for verification of categorical forecasts. These are: POD (probability of detection), TAR (the false-alarm rate), H (hit rate), CSI (critical success index) and B (bias), see Wilks (1995). The POD and TAR were also used by Crochet and Ødegaard (2000). The nomenclature used is schematically shown in figure 4.3, where **1** denotes precipitation and **0** no precipitation.

| | Observed precipitation no = **0** | Observed precipitation yes = **1** |
|---|---|---|
| Modelled precipitation no = **0** | **N(0,0)** | **N(1,0)** |
| Modelled precipitation yes = **1** | **N(0,1)** | **N(1,1)** |

Figure 4.3 Schematic cross-table of observed and modelled precipitation larger than certain levels with nomenclature of the number of cases in each category.

The *probability of detection* is the proportion of the occasions of observed precipitation that was also modelled. Whit the notations chosen, POD can be expressed:

$$(4.1)\quad POD = \frac{N(1,1)}{N(1,0) + N(1,1)}$$

The *false-alarm rate*, FAR, is the proportion of the modelled precipitation events that fail to materialise. It is therefore evident that low values of FAR are to be preferred. Thus, low values of FAR represent high scores. FAR can be expressed:

$$(4.2)\quad FAR = \frac{N(0,1)}{N(0,1) + N(1,1)}$$

The hit rate (or proportion correct) is the fraction of all cases that are correct modelled:

$$(4.3)\quad H = \frac{N(0,0)+N(1,1)}{N(0,0)+N(1,0)+N(0,1)+N(1,1)}$$

An alternative for the hit rate is the *critical success index* (CSI), where the N(0,0) cases are excluded. This is often an advantage when the precipitation event is much more rare than the alternative, the no precipitation event.

$$(4.4)\quad CSI = \frac{N(1,1)}{N(1,0)+N(0,1)+N(1,1)}$$

The *bias* is a comparison of the frequency of modelled precipitation with the frequency of observed precipitation. (This is not the same as the bias used in chapter 3 where the sums of modelled and observed precipitation were compared).

$$(4.5)\quad B = \frac{N(0,1)+N(1,1)}{N(1,0)+N(1,1)}$$

Due to a rather short verification period with relatively few precipitation days, the material does not allow statistical handling of individual sites. The overall results for all groups and sites are listed in table 4.5. For each level of precipitation modelled results without ("no") and with ("yes") modification are compared to observations.

Table 4.5 Cross tables of observed and modelled precipitation larger than certain levels. For the notations N(0,0), N(1,0), N(0,1) and N(1,1), see figure 4.3. The contingency coefficient (cont.), probability of detection (POD), false-alarm rate (FAR), hit rate (H), critical success index (CSI) and bias (B) is also calculated, see text. Observations are compared also with modelled results that have undergone modification by model output statistic (MOS).

| Level (mm) | MOS | N(0,0) | N(1,0) | N(0,1) | N(1,1) | cont. | POD | FAR | H | CSI | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | no | 110 | 30 | 119 | 366 | 0.42 | 0.75 | 0.25 | 0.76 | 0.71 | 1.22 |
| 1 | yes | 101 | 36 | 128 | 360 | 0.38 | 0.74 | 0.26 | 0.74 | 0.69 | 1.23 |
| 2 | no | 174 | 41 | 102 | 308 | 0.47 | 0.75 | 0.25 | 0.77 | 0.68 | 1.17 |
| 2 | yes | 184 | 52 | 92 | 297 | 0.47 | 0.76 | 0.24 | 0.77 | 0.67 | 1.11 |
| 3 | no | 227 | 42 | 99 | 257 | 0.49 | 0.72 | 0.28 | 0.77 | 0.65 | 1.19 |
| 3 | yes | 261 | 52 | 65 | 247 | 0.53 | 0.79 | 0.21 | 0.81 | 0.68 | 1.04 |
| 4 | no | 262 | 50 | 95 | 218 | 0.48 | 0.70 | 0.30 | 0.77 | 0.60 | 1.17 |
| 4 | yes | 299 | 63 | 58 | 205 | 0.52 | 0.78 | 0.22 | 0.81 | 0.63 | 0.98 |
| 5 | no | 300 | 56 | 82 | 187 | 0.48 | 0.77 | 0.30 | 0.78 | 0.58 | 1.11 |
| 5 | yes | 333 | 67 | 49 | 176 | 0.52 | 0.72 | 0.22 | 0.81 | 0.60 | 0.93 |
| 10 | no | 422 | 38 | 75 | 90 | 0.45 | 0.70 | 0.45 | 0.82 | 0.44 | 1.29 |
| 10 | yes | 466 | 66 | 31 | 62 | 0.43 | 0.48 | 0.33 | 0.84 | 0.39 | 0.73 |
| 15 | no | 497 | 31 | 55 | 42 | 0.39 | 0.58 | 0.57 | 0.86 | 0.33 | 1.33 |
| 15 | yes | 537 | 48 | 15 | 25 | 0.38 | 0.34 | 0.38 | 0.90 | 0.28 | 0.55 |
| 20 | no | 543 | 19 | 38 | 25 | 0.39 | 0.57 | 0.60 | 0.91 | 0.30 | 1.43 |
| 20 | yes | 577 | 33 | 4 | 11 | 0.38 | 0.25 | 0.27 | 0.94 | 0.23 | 0.34 |

For precipitation level 1 mm modification has not been a success. With MOS all measures of success shows lower scores than without MOS. However, already at the next level, 2 mm, this has changed. The probability of detection (POD) has increased slightly and the false-alarm rate (FAR) has fallen slightly, and the results are less biased (B). The success with MOS is even greater for the following levels, 3 and 4 mm. In particular there are positive results for FAR and B scores. While the modelled results was much biased, the MOS has taken away practically all bias.

At the next level, 5 mm, the results are not unequivocally positive. However, except for POD all measures of success show more positive results with MOS than without MOS. The regression lines reduce model precipitation for most of the sites and weather types. This increases N(1,0) cases by 11, but reduces the N(0,1) cases by 33, leading to a somewhat larger POD and much smaller FAR.

At higher levels, 10, 15 and 20 mm the contingency coefficient is slightly lower with MOS than without MOS, and MOS also gets lower CSI-scores. The model results lead to a positive bias of precipitation at these levels, while MOS seems to exaggerate the corrections leading to negative biases. However, there are rather few cases of largest precipitation in the verification dataset. Precipitation larger than 20 mm is only represented by 44 cases in the data set that represents only a few days of precipitation. A longer verification period is necessary to get reliable results.

The results are broken up into two regions, southeastern Norway (groups 1 and 2) and western and northwestern Norway (groups 4 and 5). Precipitation limits larger than 10 mm would have resulted in too few cases and was omitted, see table 4.6. For southeastern Norway the MOS leads to positive results for levels of precipitation from 3 – 10 mm. Both the contingency coefficient and the CSI is higher with MOS. In this respect the results from southeastern Norway differ from the results using the whole material.

In Western and northwestern Norway the MOS leads to positive results for precipitation levels 2 – 5 mm, where the contingency coefficient is higher and the biases are reduced with MOS. For the 10 mm limit the contingency coefficient is lower with MOS and the POD is substantially lower. The model results are much positively biased without MOS, while they are much negatively biased with MOS.

For all weather types and sites where MOS was used, precipitation is summed for the verification period. The total sum of observed precipitation is 3839 mm while the model estimated the precipitation to 4744 mm, i.e. an overestimation of 24 %, see table 4.7. When MOS was used, the overestimation was turned to an underestimation, but the bias was reduced to 18 %. The standard deviation was also reduced from 8.1 mm to 6.2 mm by using MOS.

For the five groups of stations the results was quite different. For four of the five groups the biases as well as the standard deviation was reduced by using MOS, while for the group 3 (Southern tip of Norway) the bias increased. For the Sogn and Fjordane and Nord-Møre and Trøndelag, the biases was reduced to nearly the half, while for group 2 (Southern Gudbrandsdalen) the negative bias was reduced by MOS. Best results with MOS was obtained within the Oslo area where a very large overestimation by the model was reduced to a quite acceptable level.

Table 4.6 Cross tables of observed and modelled precipitation larger than certain levels for some sites in Eastern Norway (groups 1 and 2) and some sites in western and northwestern Norway (groups 4 and 5). For the notations N(0,0), N(1,0), N(0,1) and N(1,1), see figure 4.3. The contingency coefficient (cont.), probability of detection (POD), false-alarm rate (FAR), hit rate (H), critical success index (CSI) and bias (B) is also calculated, see text. Observations are also compared with modelled results that have undergone modification by model output statistic (MOS).

| Groups | Level (mm) | MOS | N(0,0) | N(1,0) | N(0,1) | N(1,1) | cont | POD | FAR | H | CSI | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 and 2 | 1 | no | 33 | 13 | 25 | 118 | 0.45 | 0.90 | 0.17 | 0.80 | 0.76 | 1.09 |
| | 1 | yes | 21 | 9 | 37 | 122 | 0.35 | 0.93 | 0.23 | 0.76 | 0.73 | 1.21 |
| | 2 | no | 48 | 15 | 19 | 107 | 0.52 | 0.88 | 0.15 | 0.82 | 0.76 | 1.03 |
| | 2 | yes | 47 | 15 | 20 | 107 | 0.51 | 0.88 | 0.16 | 0.81 | 0.75 | 1.04 |
| | 3 | no | 64 | 18 | 23 | 84 | 0.49 | 0.82 | 0.21 | 0.78 | 0.67 | 1.05 |
| | 3 | yes | 65 | 15 | 23 | 87 | 0.51 | 0.85 | 0.21 | 0.80 | 0.70 | 1.08 |
| | 4 | no | 70 | 23 | 25 | 71 | 0.44 | 0.76 | 0.26 | 0.75 | 0.60 | 1.02 |
| | 4 | yes | 72 | 24 | 23 | 70 | 0.45 | 0.74 | 0.25 | 0.75 | 0.60 | 0.99 |
| | 5 | no | 80 | 25 | 27 | 57 | 0.40 | 0.70 | 0.32 | 0.72 | 0.52 | 1.02 |
| | 5 | yes | 86 | 25 | 21 | 57 | 0.45 | 0.70 | 0.27 | 0.76 | 0.55 | 0.95 |
| | 10 | no | 126 | 16 | 24 | 23 | 0.37 | 0.59 | 0.51 | 0.79 | 0.37 | 1.21 |
| | 10 | yes | 139 | 17 | 11 | 22 | 0.46 | 0.56 | 0.33 | 0.85 | 0.44 | 0.85 |
| 4 and 5 | 1 | no | 70 | 15 | 90 | 208 | 0.41 | 0.93 | 0.30 | 0.73 | 0.66 | 1.34 |
| | 1 | yes | 77 | 27 | 83 | 206 | 0.38 | 0.88 | 0.29 | 0.72 | 0.65 | 1.24 |
| | 2 | no | 115 | 26 | 76 | 176 | 0.44 | 0.87 | 0.30 | 0.74 | 0.63 | 1.25 |
| | 2 | yes | 132 | 37 | 59 | 165 | 0.46 | 0.82 | 0.26 | 0.76 | 0.63 | 1.11 |
| | 3 | no | 149 | 22 | 71 | 151 | 0.48 | 0.87 | 0.32 | 0.76 | 0.62 | 1.28 |
| | 3 | yes | 188 | 37 | 32 | 136 | 0.54 | 0.79 | 0.19 | 0.82 | 0.66 | 0.97 |
| | 4 | no | 175 | 24 | 66 | 128 | 0.48 | 0.84 | 0.34 | 0.77 | 0.59 | 1.28 |
| | 4 | yes | 213 | 38 | 28 | 114 | 0.54 | 0.75 | 0.20 | 0.83 | 0.63 | 0.93 |
| | 5 | no | 201 | 27 | 53 | 112 | 0.50 | 0.81 | 0.32 | 0.80 | 0.58 | 1.19 |
| | 5 | yes | 229 | 41 | 25 | 98 | 0.53 | 0.71 | 0.20 | 0.83 | 0.60 | 0.88 |
| | 10 | no | 271 | 18 | 46 | 58 | 0.48 | 0.76 | 0.44 | 0.84 | 0.48 | 1.37 |
| | 10 | yes | 300 | 45 | 17 | 31 | 0.39 | 0.41 | 0.35 | 0.84 | 0.33 | 0.63 |

Table 4.7 Precipitation sums of modelled precipitation compared to observed precipitation for selected weather types during the period of verification Sept. 2001 to Jan. 2002. Modelled precipitation is presented also with MOS modification.

| Region | Sum of observed precip. (mm) | Sum of modelled precip. (mm) | Sum of modelled precip. with MOS (mm) |
|---|---|---|---|
| The Oslo area | 853 | 1250 (+397±9.3, +47 %) | 803 (-50±6.8, -6 %) |
| Southern Gudbrandsdalen | 392 | 242 (-150±4.3, -38 %) | 305(-87±4.3, -22 %) |
| Southern tip of Norway | 488 | 371 (-117±8.9, -24 %) | 340 (-148±10.1, -30 %) |
| Sogn and Fjordane | 1215 | 1594 (+379±7.7, +31 %) | 1024 (-191±5.5, -16 %) |
| Nord-Møre and southern Trøndelag | 891 | 1287 (+396±7.9, +44 %) | 669 (-222±5.8, -25 %) |
| All sites | 3839 | 4744 (+905±8.1, +24 %) | 3141 (-698±6.2, -18 %) |

## 5 Discussion

In the present report an effort has been made to modify model output of the HIRLAM10 in order to improve the forecasts for the sites of the precipitation stations. Precipitation at selected measuring stations is important, as the sites might represent precipitation in certain area of interest.

Modelled precipitation at the sites was interpolated by use of the model field. At the sites the model precipitation was compared to observations by regression analysis for some weather types, which contributed to the largest amount of precipitation. The comparison was performed without Model Output Statistical modification (MOS) as well as with MOS.

For most of the sites modified model results obtained higher scores than the not modified ones. In particular this was true for precipitation from 2 – 4 mm that were the most common precipitation heights.

For smaller precipitation heights than 2 mm the modifications seem not to be realistic. To improve the model output for small amounts of precipitation it is suggested that these should be separated from the rest of the material and thus be handled separately.

For the large precipitation amounts the MOS did not improve the model output. However, the number of cases was limited in particular in the verification data set, and it is not clear whether this result is caused by the limited number of cases or the reason is caused by the method itself. A straight line adopted by the linear regression method might not be the best approximation to the observations. With so few cases available, it is at present not possible to conclude about this.

Summing up the modelled precipitation with and without MOS, the bias of the HIRLAM10 model was reduced by MOS for 4 out of 5 test areas.

In the verification period the six weather types that was subject to investigation comprised 76 % of the precipitation. It should be considered for further work the possibility of joining some of the weather types in order to get a sufficient large sample for statistical handling. A larger fraction of the precipitation could then be subject to MOS modification.

## 6 Summary and conclusions

Modelled one-day precipitation from HIRLAM10 was compared to observed precipitation at 25 sites (measuring stations) in southern Norway concentrated geographically in five groups. In the training period from 1 January 1999 to 31 May 2000 precipitation was on average overestimated by 24 %. The overestimation occurred in all seasons but to a different extent. In autumn the overestimation was only 10 %, while it was 16 %, 39 % and 38 % in winter, spring and summer respectively. It appeared that the overestimation of precipitation was predominant for all groups in spring and summer, while in winter and autumn precipitation was underestimated in groups 2 (southern Gudbrandsdalen) and 3 (southern tip of Norway).

Comparing the five groups without regards to season, precipitation was overestimated in all groups except in group 2 (southern Gudbrandsdalen) and group 3 (southern tip of Norway) where practically no biases were seen. The bias in group 5 (Nord-Møre and southern Trøndelag) was especially large. In this group modelled precipitation exceeded observed precipitation by 64 %, and also in the groups 1 (the Oslo area) and 4 (Sogn and Fjordane) large biases were seen, as overestimation amounts to 30 % for both groups.

The biases were also analysed for individual stations. At sites where the station's altitude by far exceeded by model altitude, there was a tendency that the precipitation was much overestimated by the model. However, the ratio modelled to observed precipitation did not show a very strong correlation to the difference between model altitude and station altitude (r = 0.67).

The weather situations in the training period as well as in the verification period were classified by the computerised Lamb classification scheme. Model precipitation of the HIRLAM10 was verified at the 25 selected sites during a period of verification from 1 September 2000 to 31 January 2001 for the six weather types that gave the highest amounts of precipitation. Verification was done with unmodified model output as well as with Model Output Statistics (MOS). As method for modification was chosen linear regression analysis that was performed separately within each weather type.

For most of the sites modified model results obtained higher scores than the not modified ones. In particular this was true for precipitation from 2 – 4 mm that were the most common precipitation heights. For smaller precipitation heights than 2 mm the modifications seems not to be realistic. For the larger precipitation amounts than 5 mm MOS did not improve the model output, but this may be caused by a limited number of cases.

Summing up the modelled precipitation with and without MOS, the bias of the HIRLAM10 model was reduced by MOS for 4 out of 5 areas in question. Another positive results was that the MOS scored high for the most common precipitation heights, those of 2 – 4 mm

Although the analysis is based on a limited data sample, the main conclusion is that applying MOS-technique for different weather types seems to be a promising tool for improving prediction forecasts for specific sites. The potential for improving the quantitative precipitation forecasts by this technique will be investigated further for an enlarged data set where also areas in northern Norway will be included.

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# Appendix 1

Table 1 Persons correlation coefficient, R, and the ratio observed / modelled precipitation for group of stations 1) The Oslo area 2) Southern Gudbrandsdalen 3) Southern tip of Norway 4) Sogn and Fjordane 5) Nord-Møre and southern Trøndelag. The seasons are 1) Winter 2) Spring 3) Summer 4) Autumn

| Group | Season | R | Observed/ modelled |
|---|---|---|---|
| all | all | 0.739 | 0.808 |
| 1 | all | 0.717 | 0.768 |
| 2 | | 0.647 | 1.000 |
| 3 | | 0.783 | 0.973 |
| 4 | | 0.764 | 0.773 |
| 5 | | 0.687 | 0.610 |
| all | 1 | 0.779 | 0.864 |
| | 2 | 0.718 | 0.722 |
| | 3 | 0.638 | 0.723 |
| | 4 | 0.778 | 0.907 |
| 1 | 1 | 0.748 | 0.760 |
| | 2 | 0.676 | 0.703 |
| | 3 | 0.515 | 0.723 |
| | 4 | 0.798 | 0.858 |
| 2 | 1 | 0.723 | 1.220 |
| | 2 | 0.661 | 0.824 |
| | 3 | 0.556 | 0.921 |
| | 4 | 0.710 | 1.150 |
| 3 | 1 | 0.813 | 1.090 |
| | 2 | 0.779 | 0.798 |
| | 3 | 0.691 | 0.849 |
| | 4 | 0.799 | 1.070 |
| 4 | 1 | 0.802 | 0.841 |
| | 2 | 0.740 | 0.752 |
| | 3 | 0.675 | 0.654 |
| | 4 | 0.767 | 0.791 |
| 5 | 1 | 0.686 | 0.665 |
| | 2 | 0.663 | 0.585 |
| | 3 | 0.713 | 0.563 |
| | 4 | 0.655 | 0.622 |

Table 2a. Persons correlation coefficient, R, and the ratio observed / modelled precipitation for individual stations in the Oslo area and in southern Gudbrandsdalen. The seasons are 1) Winter 2) Spring 3) Summer 4) Autumn

| Station No0. and name | Season | R | Observed/ modelled |
|---|---|---|---|
| 4440 | 1 | 0.878 | 0.979 |
| Hakadal - | 2 | 0.739 | 0.824 |
| Bliksrudhagan | 3 | 0.520 | 0.732 |
| | 4 | 0.860 | 1.019 |
| 18500 | 1 | 0.740 | 0.515 |
| Bjørnholt | 2 | 0.675 | 0.472 |
| | 3 | 0.618 | 0.558 |
| | 4 | 0.834 | 0.611 |
| 18700 | 1 | 0.796 | 1.067 |
| Oslo - | 2 | 0.720 | 1.076 |
| Blindern | 3 | 0.515 | 0.960 |
| | 4 | 0.736 | 1.312 |
| 19100 | 1 | 0.800 | 0.633 |
| Kjelsås i | 2 | 0.748 | 0.578 |
| Sørkedalen | 3 | 0.545 | 0.590 |
| | 4 | 0.851 | 0.716 |
| 19480 | 1 | 0.856 | 1.136 |
| Dønski | 2 | 0.788 | 1.016 |
| | 3 | 0.405 | 1.003 |
| | 4 | 0.802 | 1.233 |
| 13050 | 1 | 0.818 | 1.274 |
| Gausdal - | 2 | 0.738 | 1.066 |
| Skogli | 3 | 0.542 | 1.191 |
| | 4 | 0.786 | 1.441 |
| 13140 | 1 | 0.759 | 1.174 |
| Fåvang | 2 | 0.682 | 0.774 |
| | 3 | 0.639 | 0.840 |
| | 4 | 0.746 | 1.208 |
| 13310 | 1 | 0.651 | 1.464 |
| Søre Brekkom | 2 | 0.568 | 0.745 |
| | 3 | 0.585 | 0.919 |
| | 4 | 0.616 | 0.884 |
| 13450 | 1 | 0.660 | 1.139 |
| Hovdgrenda | 2 | 0.655 | 0.826 |
| | 3 | 0.501 | 0.934 |
| | 4 | 0.757 | 1.270 |
| 14050 | 1 | 0.583 | 0.945 |
| Sjoa | 2 | 0.606 | 0.636 |
| | 3 | 0.539 | 0.707 |
| | 4 | 0.687 | 0.891 |

Table 2b. Persons correlation coefficient, R, and the ratio observed / modelled precipitation for individual stations at the southern tip of Norway and in Sogn and Fjordane. The seasons are 1) Winter 2) Spring 3) Summer 4) Autumn

| Station No0. and name | Season | R | Observed/ modelled |
|---|---|---|---|
| 41010 | 1 | 0.712 | 1.172 |
| Mandal - | 2 | 0.749 | 1.202 |
| Eigebrekk | 3 | 0.716 | 1.356 |
| | 4 | 0.662 | 0.978 |
| 41200 | 1 | 0.810 | 1.174 |
| Finsland | 2 | 0.815 | 0.852 |
| | 3 | 0.698 | 0.944 |
| | 4 | 0.851 | 1.187 |
| 41370 | 1 | 0.840 | 1.138 |
| Bjelland | 2 | 0.819 | 0.776 |
| kraftverk | 3 | 0.687 | 0.828 |
| | 4 | 0.823 | 1.114 |
| 41480 | 1 | 0.862 | 1.006 |
| Åseral | 2 | 0.798 | 0.663 |
| | 3 | 0.712 | 0.718 |
| | 4 | 0.822 | 1.008 |
| 41550 | 1 | 0.793 | 0.987 |
| Ljosland - | 2 | 0.737 | 0.670 |
| Moen | 3 | 0.678 | 0.689 |
| | 4 | 0.782 | 1.068 |
| 52930 | 1 | 0.817 | 0.979 |
| Brekke I | 2 | 0.798 | 1.033 |
| Sogn | 3 | 0.815 | 0.900 |
| | 4 | 0.842 | 0.999 |
| 54120 | 1 | 0.710 | 0.516 |
| Lærdal - | 2 | 0.597 | 0.306 |
| Moldo | 3 | 0.391 | 0.288 |
| | 4 | 0.486 | 0.515 |
| 55550 | 1 | 0.781 | 1.190 |
| Hafslo | 2 | 0.632 | 0.781 |
| | 3 | 0.601 | 0.662 |
| | 4 | 0.701 | 0.950 |
| 55840 | 1 | 0.826 | 0.739 |
| Fjærland - | 2 | 0.776 | 0.581 |
| Skarestad | 3 | 0.767 | 0.483 |
| | 4 | 0.839 | 0.711 |
| 56480 | 1 | 0.695 | 0.747 |
| Værlandet | 2 | 0.666 | 0.890 |
| | 3 | 0.520 | 1.045 |
| | 4 | 0.625 | 0.667 |

Table 2c. Persons correlation coefficient, R, and the ratio observed / modelled precipitation for individual stations in Nord-Møre and southern Trøndelag. The seasons are 1) Winter 2) Spring 3) Summer 4) Autumn.

| Station No0. and name | Season | R | Observed/ modelled |
|---|---|---|---|
| 62700<br>Hustadvatn | 1 | 0.817 | 0.853 |
| | 2 | 0.798 | 0.871 |
| | 3 | 0.815 | 0.663 |
| | 4 | 0.842 | 0.828 |
| 63420<br>Sundalsøra | 1 | 0.710 | 0.324 |
| | 2 | 0.597 | 0.290 |
| | 3 | 0.391 | 0.361 |
| | 4 | 0.486 | 0.382 |
| 63530<br>Hafsås | 1 | 0.781 | 0.670 |
| | 2 | 0.632 | 0.506 |
| | 3 | 0.601 | 0.505 |
| | 4 | 0.701 | 0.398 |
| 63750<br>Mjøa | 1 | 0.826 | 0.776 |
| | 2 | 0.776 | 0.482 |
| | 3 | 0.767 | 0.571 |
| | 4 | 0.839 | 0.462 |
| 64550<br>Tingvoll | 1 | 0.695 | 0.923 |
| | 2 | 0.666 | 0.776 |
| | 3 | 0.520 | 0.750 |
| | 4 | 0.625 | 0.840 |

Tables 3 Cross-tabulation counts of yes/no precipitation, modelled (rows) and observed (columns) for two stations in Sogn, the most exposed measuring site for precipitation Brekke i Sogn and the sheltered site Lærdal - Moldo. No-precipitation is denoted by 0 and precipitation by 1. T is the number of total counts.

| Station and season | | 0 | 1 | T | Contingency coefficient |
|---|---|---|---|---|---|
| 52930 | 0 | 45 | 4 | 49 | 0.588 |
| Brekke I Sogn | 1 | 21 | 163 | 184 | |
| Season 1 | T | 66 | 167 | 233 | |
| 52930 | 0 | 62 | 6 | 68 | 0.500 |
| Brekke I Sogn | 1 | 52 | 153 | 205 | |
| Season 2 | T | 114 | 159 | 273 | |
| 52930 | 0 | 50 | 8 | 58 | 0.504 |
| Brekke I Sogn | 1 | 30 | 95 | 125 | |
| Season 3 | T | 80 | 103 | 183 | |
| 52930 | 0 | 30 | 5 | 35 | 0.475 |
| Brekke I Sogn | 1 | 31 | 116 | 147 | |
| Season 4 | T | 61 | 121 | 182 | |
| 54120 | 0 | 51 | 7 | 58 | 0.338 |
| Lærdal - Moldo | 1 | 82 | 93 | 175 | |
| Season 1 | T | 133 | 100 | 233 | |
| 54120 | 0 | 63 | 4 | 67 | 0.341 |
| Lærdal - Moldo | 1 | 110 | 96 | 206 | |
| Season 2 | T | 173 | 100 | 273 | |
| 54120 | 0 | 35 | 4 | 39 | 0.358 |
| Lærdal - Moldo | 1 | 62 | 82 | 144 | |
| Season 3 | T | 97 | 86 | 183 | |
| 54120 | 0 | 46 | 3 | 49 | 0.379 |
| Lærdal - Moldo | 1 | 65 | 68 | 133 | |
| Season 4 | T | 111 | 71 | 182 | |

# Appendix 2

## The stations' exposure with respect to the main wind directions for precipitation

### Group 1. The Oslo area

04440 Hakadal
18500 Bjørnholt
18700 Oslo – Blindern
19100 Kjelsås i Sørkedalen
19480 Dønski

All stations are quite good exposed to precipitation, in particular to precipitation coming in with southerly wind. Exposure is also in general good from wind from southwest, maybe with an exception of the station 04440 Hakadal – Bliksrudhagan.

### Group 2. Southern Gudbrandsdalen

13050 Gausdal - Skogli
13140 Fåvang
13310 Søre Brekkom
13450 Hovdgrenda
14050 Sjoa

The area represents inland south-eastern Norway and the stations are generally more sheltered by mountains, and thus less exposed than those in the Oslo area. Exposure is best for southerly winds and are somewhat better in the southern part of the area than in the northern part. Locally the stations are also quite different situated compared to the valley. While Fåvang and Sjoa are situated near the valley floor, the three other ones are situated rather high up in the valley side.

### Group 3. The southern tip of Norway

41010 Mandal - Eigebrekk
41200 Finsland
41370 Bjelland kraftverk
41480 Åseral
41550 Ljosland – Moen

From the southern tip of Norway the altitude of the terrain is increasing causing orographic precipitation with southerly wind. All stations are quite well exposed to precipitation from that direction. The area also gets much precipitation from south-west while the valleys are mainly orientated north-south. This causes some differences in exposure among the stations.

### Group . Sogn and Fjordane

52930 Brekke i Sogn
54120 Lærdal – Moldo
55550 Hafslo
55840 Fjærland - Skarestad
56480 Værlandet

The area has a very rugged topography and exposure varies very much among the stations. Most of the stations are best exposed to westerly winds, but Fjærland and in particular Lærdal are much sheltered also to precipitation from that direction. The station Brekke are much exposed to precipitation from west and south-west and is the wettest measuring site in Norway.

### Group . Nord-Møre and southern Trøndelag

62700 Hustadvatn
63420 Sundalsøra
63530 Hafsås
63750 Mjøa
64550 Tingvoll

Generally the stations are most exposed to wind from north-west, i.e. perpendicular to the coastal line. But the terrain is rugged and the direction of the valleys varies much. The station Hustadvatn near the coast is better exposed to precipitation than the other ones. In particular Mjøa is sheltered by mountains in almost all directions.