NOTAT

Nr. 14

1998

Viel Ødegaard
Det norske meteorologiske institutt.

High Resolution Precipitation Forecasting with Initial and Boundary Conditions from Ensemble Forecasts

HYDRA

-ET FORSKNINGSPROGRAM OM FLOM

HYDRA - et forskningsprogram om flom

HYDRA er et forskningsprogram om flom initiert av Norges vassdrags- og energiverk (NVE) i 1995. Programmet har en tidsramme på 3 år, med avslutning medio 1999, og en kostnadsramme på ca. 18 mill. kroner. HYDRA er i hovedsak finansiert av Olje- og energidepartementet.

Arbeidshypotesen til HYDRA er at summen av alle menneskelige påvirkninger i form av arealbruk, reguleringer, forbygningsarbeider m.m. kan ha økt risikoen for flom.

Målgruppen for HYDRA er statlige og kommunale myndigheter, forsikringsbransjen, utdannings- og forskningsinstitusjoner og andre institusjoner. Nedenfor gis en oversikt over fagfelt/tema som blir berørt i HYDRA:

- Naturgrunnlag og arealbruk
- Tettsteder
- Flomdemping, flomvern og flomhandtering
- Skaderisikoanalyse
- Miljøvirkninger av flom og flomforebyggende tiltak
- Databaser og GIS
- Modellutvikling

Sentrale aktører i HYDRA er; Det norske meteorologiske institutt (DNMI), Glommens og Laagens Brukseierforening (GLB), Jordforsk, Norges geologiske undersøkelse (NGU), Norges Landbrukshøgskole (NLH), Norges teknisk-naturvitenskapelige universitet (NTNU), Norges vassdrags- og energiverk (NVE), Norsk institutt for jord- og skogkartlegging (NIJOS), Norsk institutt for vannforskning (NIVA), SINTEF, Stiftelsen for Naturforskning og Kulturminneforskning (NINA/NIKU), Norsk Regnesentral (NR), Direktoratet for naturforvaltning (DN), Østlandsforskning (ØF) og universitetene i Oslo og Bergen.

HYDRA - a research programme on floods

HYDRA is a research programme on floods initiated by the Norwegian Water Resources and Energy Administration (NVE) in 1995. The programme has a time frame of 3 years, terminating in 1999, and with an economic framework of NOK 18 million. HYDRA is largely financed by the Ministry of Petroleum and Energy.

The working hypotesis for HYDRA is that the sum of all human impacts in the form of land use, regulation, flood protection etc., can have increased the risk of floods.

HYDRA is aimed at state and municipal authorities, insurance companies, educational and research institutions, and other organization.

An overview of the scientific content in HYDRA is:

- Natural resources and land use
- Urban areas
- Databases and GIS
- Risk analysis
- Flood reduction, flood protection and flood management
- Environmental consequences of floods
- and flood prevention measures
- Modelling

Central institutions in the HYDRA programme are; The Norwegian Meteorological Institute (DNMI), The Glommens and Laagens Water Management Association (GLB), Centre of Soil and Environmental Research (Jordforsk), The Norwegian Geological Survey (NGU), The Agriculture University of Norway (NLH), The Norwegian University of Science and Technology (NTNU), The Norwegian Water and Energy Administration (NVE), The Norwegian Institute of Land Inventory (NIJOS), The Norwegian Institute for Water Research (NIVA), The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF), The Norwegian Institute for Nature and Cultural Heritage Research (NINA/NIKU), Norwegian Computing Center (NR), Directorate for Nature Management (DN), Eastern Norway Research Institute (ØF) and the Universities of Oslo and Bergen.

Project Report

HYDRA-F7 b4

HIGH RESOLUTION PRECIPITATION FORECASTING WITH INITIAL AND BOUNDARY CONDITIONS FROM ENSEMBLE FORECASTS

Viel Ødegaard

Norwegian Meteorological Institute
PO Box 43, Blindern
N 0313 Oslo

November 1998

1. INTRODUCTION

The quality of flood forecasting depends strongly upon the precipitation forecasts. Large amounts of rainfall implies an increased risk of flooding. In order to avoid flooding damage an early warning is desired. Rainfall forecasting today is based on numerical weather prediction (NWP) models, in which a set of non-linear, coupled, partial differential equations are solved for the future state of the atmosphere. The solutions of the equations have shown to be highly dependent on initial conditions.

The initial conditions for a NWP forecast is an analysis of the meteorological observations into the model grid. However determining the state of the atmosphere at the initial time of the forecast is in no way straight forward. The comprehensive meteorological observational system can only describe selected points, levels and variables. The analysis is to a large extent an underdetermined problem. The deviation between the real initial state of the atmosphere and the analysis will cause a forecast error that grow in time. Thus the predictability of the atmosphere is limited, and dependent on the actual weather situation the forecast error due to the initial error increases significantly on a forecast range beyond three days.

In order to capture the possible developments of the weather due to differences in the initial state of the atmosphere, an ensemble prediction system (EPS) is developed at the European Centre for Medium Range Weather Forecasting (ECMWF) (Molteni et al., 1996). In this system 50 different analyses are used as initial state for the model and 50 additional forecasts are run. The 50 analyses represent 25 positive and 25 negative perturbations of the original analysis created by the analysis system. The forecast run on the original analysis is the control forecast.

51 forecasts contain a large amount of information which can be difficult to interpret in terms of the weather the next ten days. Clustering is a method for organizing the information (Molteni et al., 1996). In the clustering method the forecasts are grouped into a few clusters, each cluster being represented by its mean field. In clustering the mean field of all forecasts and the rms between the forecasted fields of geopotential height of 500 hPa is computed. Forecasts are grouped into clusters when the deviation between them is small. Forecasts which have the smallest deviation from the mean field are put into cluster one. In the procedure forecast days five to seven are focused. Originally the clustering was only performed on an area over the central Europe, but recently the clustering is also performed on the Scandinavian area.

The precipitation forecasts from numerical weather prediction (NWP) are affected by the horizontal resolution of the model grid. Increased horizontal resolution implies improved description of orography and increased possibilities in resolving cloud systems at smaller scales. In mountainous areas there is an enhancement of precipitation at the upwind side of the mountains. It is shown that increasing the model resolution, improves the precipitation forecasts in areas where the orographic modification of the precipitation pattern is important (Jensen and Ødegaard, 1997, Ødegaard, 1998). The improvement is on the geographical distribution of the precipitation, and on the maximum values.

The medium range forecasts (three to ten days) are run on a coarser resolution than the short range forecasts at DNMI. The quality of the higher resolution models would be preferred also on medium range forecasts, but on a medium range the initial error has usually grown and become more important than the error due to lower resolution. As long as computing resources is a limiting factor in NWP, it is a matter of priority whether the computing time should be used for increased resolution or for running large ensembles. Within the nearest future it is not likely that EPS should be run on a resolution down to ~20km, which would be required for a satisfactory description of orographic precipitation in Norway.

The scope of this work is to investigate a forecasting system that combines the information about the initial error from EPS with the advantages of the high resolution HIRLAM forecasts. Forecasts representing the clusters in an ensemble experiment are used as initial and boundary conditions for the HIRLAM model at DNMI. The scope is to improve the geographical distribution of the precipitation forecasts from EPS, and to improve the warning of large amounts of precipitation.

2. METHOD

An EPS forecast from 17 September 1998 12UTC is used as boundary values and initial state for the HIRLAM model at DNMI. The EPS has 6 clusters in this situation, thus 6 HIRLAM forecasts are run on data from one forecast in each EPS cluster.

The horizontal resolution of the EPS grid is approximately 85 km. Data are retrieved in a geographical grid with horizontal resolution 2° longitude and 1° latitude over an area covering 30° west to 50° east and 45° to 85° north. The Hirlam model is run with horizontal resolution 0.2° on 112x162 gridpoints. The area corresponds exactly to the area of the operational 0.1° model at DNMI, and is shown in figure 1-6. Initial and boundary data are given on 15 pressure levels. The vertical resolution of the model is 31 levels in a hybrid coordinate system. The coordinate system is terrain following at the surface and changes gradually to pressure at the top of the model. The boundary data are interpolated linearly between the pressure surfaces to the HIRLAM model surfaces.

The HIRLAM forecasts start with 72 hours EPS forecasts as analysis and is run 96 hours, thus the latest boundary values from EPS are 168 hours forecasts (7 days). The temporal resolution of the boundary values is 6 hours, as is also used in the operational HIRLAM runs at DNMI. The timestep is 360 sec. in HIRLAM and the boundary values are interpolated linearly in time.

The HIRLAM model used is equal to the operational HIRLAM version at DNMI. The model is run on a Cray T3E, which is very efficient. The experiments are run on 20 processors with a computation time of 624 to 660 seconds per. 96 hours forecast. For a complete description of the model we refer to HIRLAM documentation manual (Källen, 1996).

3. FORECAST DATA FROM HIRLAM

In the EPS forecast from 17 September the weather situation at forecast day three (+72h) is characterized by a low near Iceland and a high located in the North Sea/Northern Germany. The spread in the forecasts is significant already at this time. Forecasts are grouped in six clusters, thus the situation has low predictability.

Cluster 1 has 16 members, including the control forecast. The low is located over Iceland, 1000 hPa, a south-westerly flow in the Norwegian Sea, but little wind south of Stad. The high is located at the German coast of the North Sea. During the first 24 hours the low moves northeasterly and deepens 10 hPa. The wind shifts to westerly at the Norwegian coast and increases also from Stad to Hardangerfjorden. The accumulated precipitation is above 10mm from Vikna to Vest-Finnmark (Figure 1a). In the next 24 hours the low moves eastward and the flow along the Norwegian west coast turns north-westerly. The high expands to cover the North Sea and the coast from Trøndelag and southward. The model forecasts more than 10 mm from Stad to Finnmark for this 24h period (Figure 1b). Then in the following 24 hour period the low moves further east and a new low enters the integration area near Iceland. North-westerly flow affects the coast of Troms and Finnmark while south-westerly flow is dominant at the coast south of Trøndelag. The high is squeezed between the two lows but is dominant in Southern Norway up to Lofoten. Accumulated precipitation forecast is above 10mm from Salten to Finnmark (Figure 1c). The low moves from Iceland to the Norwegian Sea during the last 24 hours of the forecast. The flow is predominantly south-westerly from Sognefjorden to Lofoten and the high moves eastward, and for the last accumulation period Nordland gets the largest amounts of precipitation (Figure 1d).

Cluster 2 has 12 members. The low is located west of Jan Mayen and there is a high in the North Sea. The flow is south-westerly in the Norwegian Sea and along the Norwegian west coast from Stad to Troms. During the first 24 hours the lows gets 10hPa deeper and moves northward. The high moves into Southern Norway. South-westerly flow is influencing the Norwegian coast from Sognefjorden to Finnmark. The main precipitation is accumulated from Salten to Troms (Figure 2a). In the next 24 hours the low moves to Svalbard and is filling up. The high moves northward and is located between Great Britain and the Norwegian west coast. Along the Norwegian coast the flow is south-westerly from Vikna to Troms, and westerly in Finnmark. There is little wind south of Trøndelag. Precipitation is mainly accumulated from Vikna to Finnmark, with maximum in Nordland (Figure 2b). In the following period the low moves to east of Svalbard and gives a north-westerly to westerly flow from Finnmark to Trøndelag The High is located above the Hebrides and gives calm conditions in Southern Norway. Large amounts of precipitation is accumulated from Svartisen to Troms (Figure 2c). During the last 24 hours the low is filling up and moves further east and the high is building stronger. Still the low gives north-westerly flow and precipitation above 10mm from Nordland to Finnmark (Figure 2d).

Cluster 3 has 9 members. In this forecast the low is located west of Jan Mayen and the high has its centre in the North Sea but extends to Southern Norway as well. The flow is south-westerly in the Norwegian Sea and along the coast from Stad to Troms. During the first 24 hours the low moves slowly northward and the high moves towards the south of Sweden. The flow is still south-westerly from Stad to Finnmark, and the main precipitation accumulation is from Svartisen to Troms (Figure 3a). Then in the following 24 hour period, the low moves north east to Svalbard and a new low comes in north of Iceland. The high is not moving, and the flow is south-westerly from Sognefjorden to Lofoten. North of Lofoten the flow is westerly. Precipitation is accumulated from Vikna to Vesterålen (Figure 3b). In the next period the low north of Iceland has moved to Jan Mayen and dominates the integration area. It gives south-westerly flow from Hardanger to Finnmark, but the wind is calm. Precipitation exceeding 10mm occurs only at Svartisen and at the coast of Sogn (Figure 3c). In the last 24 hour period the low moves westward and gives strong south-westerly flow along the Norwegian coast from Stad to Troms. From Stad to Jæren the flow is westerly, and the precipitation is mainly accumulated from Stad to Hardanger, and in Nordland (Figure 3d).

Cluster 4 has 7 members. At the initial time the forecast has two lows; one west of Iceland and one west of Jan Mayen. There is a high in the North Sea and the flow is weak south-westerly along most of the Norwegian coast. During the first 24 hours of the forecast the low west of Iceland is catching up the other low, and the high moves westward. The flow is still south-westerly along the coast, and the precipitation is mainly accumulated at exposed locations like

Lofoten and Svartisen, and at the coast of Sogn (Figure 4a). After 48 hours forecast the low has moved out of the integration area north east of Svalbard, and westerly flow dominates the Norwegian coast. The high has moved to the North Sea again and precipitation amounts exceeding 20mm is accumulated in Nordland (Figure 4b). A new low is coming in south west of Iceland and is moving eastward to north of the Faeroes in the following 24 hour period. The flow is now mainly southerly at the Norwegian coast, and the precipitation is not exceeding 10mm except at the coast of Troms (Figure 4c). During the last 24 hours of the forecast the low is approaching the coast of Nordland. Westerly flow is followed by precipitation at the coast from Jæren to Møre, while south-easterly flow gives precipitation at the east side of the mountains in Nordland (Figure 4d).

Cluster 5 has 4 members. Initially the weather situation is characterized by a low north east of Jan Mayen. There is a high located over northern Germany, and the flow is south-westerly over Norway except Troms and Finnmark where it is southerly. In the first 24 hours of the forecast precipitation accumulation is significant over the Norwegian west coast from Hardanger to Troms. There is a strong south-westerly to westerly flow along the coast and the low near Jan Mayen has moved towards Svalbard. The high is now a ridge from Great Britain and eastward (Figure 5a). During the next 24 hours the low moves past Svalbard. The flow is westerly at the coast from Trøndelag to Finnmark and large amounts of precipitation is accumulated (Figure 5b). South of Trondheimsfjorden there is a weaker south-westerly flow and precipitation less than 10mm. Cyclonic circulation is developing near Iceland. This low moves rapidly eastward during the following 24 hours and reaches the coast of Nordland. It gives strong westerly flow from Trøndelag to Jæren. Accumulated precipitation amounts are more than 40mm maximum (Figure 5c). As the low moves further east, the flow gets strong north-westerly along this coastline. During these last 24 hours of the integration even more precipitation is accumulated in the same areas as the previous accumulation period (Figure 5d).

Cluster 6 has only 3 members. The low is located over Jan Mayen and the high is located in the North Sea between the Netherlands and Great Britain. South-westerly flow is on the coast form Stad to Salten. North of Salten and south of Stad the flow is southerly. During the first 24 hours of the forecast the low moves towards Svalbard and large amounts of precipitation is accumulated from Sognefjorden to Finnmark (Figure 6a). After 48 hours integration a low comes up south of Iceland. The front is approaching Southern Norway and precipitation is accumulated in the coastal areas of Sogn. The low near Svalbard moves south east. Westerly and south-westerly flow gives large amounts of precipitation from Vikna to Troms (Figure 6b). During the integration from 48 to 72 hours the low in the Norwegian Sea is filling up, but still gives some precipitation on the coast of Møre. The north-westerly flow in the north has given precipitation in Troms and northern Nordland. The high in the North Sea has nearly disappeared (Figure 6c). In the last 24 hours of the forecast, there is northerly flow along the Norwegian west coast. Precipitation accumulates in coastal areas from Stad to Trondheimsfjorden (Figure 6d).

4. PROBABILITY FORECASTS FROM EPS

Information from EPS can be organized in terms of probability. Probability fields are created by defining the requirements, e.g. 24-hours accumulated precipitation exceeding 1mm (or 5, 10 and 20), and calculating the percentage of forecasts which fulfil this requirement. This gives a probability for 24-hours accumulated precipitation exceeding the required amount in each model grid point.

Common for the forecasts based on all six clusters, is that precipitation is predicted at the western coast of Norway. In mountainous terrain flooding risks is tied to large amounts of precipitation, because the catchment areas are small. Probability of 24 hours accumulated precipitation exceeding 10 and 20mm will be investigated here.

EPS probability field for precipitation exceeding 10mm at 96 hours forecast has its maximum at Lofoten, with 80%. Probability at 120 hours forecast is also 80% in an adjacent, but smaller area. 144 hours EPS forecast has a probability of 20% in the same area, and the probability is 20% for precipitation exceeding 10mm at 168 hours in an area from Sognefjorden to Trøndelag. EPS probability for precipitation exceeding 20mm is 40% in Nordland south of Lofoten at 96hours forecast. at 120 hours it is 15% in the same area, and it is less than 5% for forecast lengths 144 hours and 168 hours.

5. PROBABILITY FORECASTS FROM HIRLAM

For comparison, a probability forecast is produced from the HIRLAM fields with the same method as used for the EPS probability fields. In gridpoints where precipitation exceeds the required limit, the probability is the fraction of forecasts in the cluster from which the initial state and the boundary values are taken. The probability field produced by this method is less continuous than the EPS-fields, since probability values are limited to the six fractions represented by the clusters and combinations of these.

HIRLAM probability field for precipitation exceeding 10mm at 96 hours forecast have maxima with less horizontal extension but the location is approximately equal to the EPS probability. It is 100% in Lofoten and Svartisen. At 120 hours the probability is 100% along the coast of Nordland from Vikna to Lofoten. At 144 hours the probability is 20% in some areas from Finnmark to Nordland. The last accumulation period has a probability of 20% on the coast of Troms and Finnmark, and on smaller areas all the way south to Jæren. The probability of precipitation amounts exceeding 20mm is in HIRLAM calculated to be 80% in Lofoten and Svartisen at 96 hours. At 120 hours it is 100% at Svartisen and 80% further north in Nordland. The probability is still 20%from Svartisen to Troms at 144 hours and 20% on the coast of Møre and the coast of Troms at 168 hours.

Probabilities for precipitation to exceed 10mm in 24 hours from EPS and HIRLAM are plotted together in Fig. 7.

6. OBSERVATIONS

Observations from the DNMI precipitation station network is retrieved for evaluation. Observation time at the precipitation monitoring stations is 6UTC. 24 hours accumulated precipitation is observed. The network contains more than 700 stations. Numbers of stations having observed precipitation amounts exceeding 1,5,10 and 20mm at 6UTC 22, 23 and 24 September are listed in table 1.

Date	no. of stations precip>1mm	no. of stations precip>5mm	no. of stations precip>10mm	no. of stations precip>20mm
22/09 6UTC	237	167	105	37

Date	no. of stations precip>1mm	no. of stations precip>5mm	no. of stations precip>10mm	no. of stations precip>20mm
23/09 6UTC	164	80	42	4
24/09 6UTC	203	120	77	38

Table 1. Number of stations where 24-hours accumulated observed precipitation at 6UTC 22, 23 and 24 September exceeds 1, 5, 10 and 20 mm.

On 22 September 6UTC precipitation is observed along the west coast of Norway from Stad to Finnmark. The largest amounts are observed from Møre to Troms. On 23 September 6UTC precipitation is observed from Stad to Trondheimsfjorden, and from Nordland to Finnmark. Maximum areas are Møre, Saltfjellet/Svartisen and Troms/Vesterålen. In the observations on 24 September 6UTC there is precipitation from Stad to Finnmark, but the largest amounts are observed in Troms and northern Nordland.

7. SCALED FORECAST

By combining the cluster information and the precipitation forecasts from HIRLAM with EPS boundaries a scaled precipitation forecast can be calculated. The precipitation value in each gridpoint is scaled with the fraction of forecasts in the corresponding cluster. The resulting field is a probability scaled precipitation forecast. In figure 8 the scaled precipitation forecasted is plotted. There is also a mark for each station having observed a precipitation amount exceeding the plotting line. The forecast times are adapted to the observation times, thus the accumulation periods represented by the lines and the crosses equal. Be aware that cases when the precipitation fields extend into Sweden and Finland can not be verified with the available observations from Norwegian precipitation monitoring stations.

The scaled forecast is produced in order to accommodate the users need for only one forecast. It could also be achieved by using the forecast with the largest probability, i.e. the forecast run on initial and boundary data from cluster 1. By scaling the forecast, the forecasts with low probability will have influence if the precipitation amount in this forecast is relatively large. In the present experiment the scaled forecast for 23 September 6UTC is underestimating the precipitation in Møre and Trøndelag (figure 8c, d). The forecast run on data from cluster 5 is predicting precipitation up to 30mm in this area, but the number of forecasts in cluster 5 (4) is too small to influence the scaled forecast. In this case information is lost in the attempt to give all the information in one single forecast.

8. DISCUSSION

All clusters have south-westerly or westerly flow along the coast in the most of the period, and precipitation is likely to occur. However the precipitation amount is varying between the forecasts, and also the horizontal extension and the time of maximum precipitation. Common to the forecasts is that precipitation is predicted for Troms and Nordland for the period from 20 to 22 September 12UTC, and from 23 to 24 September 12UTC. Neither of the forecasts have precipitation east of the main mountainous area in Southern Norway. Uncertainty is connected to how far south the precipitation will reach at the west coast. The probability for precipitation to occur from Trøndelag to Sogn is largest in the period from 21 to 22 September 12UTC and from 23 to 24 September 12UTC, and in Hardanger to Jæren in the period from 23 to 24 September 12UTC. In Finnmark precipitation is most likely to occur in the period from 21 to 22 September 12UTC. The probability results from forecast from more than one cluster. The predictability of the precipitation in this situation is larger than the existence of six clusters should indicate. Predominantly south-westerly flow exceeding 8-10 m/s tends to produce precipitation in the coastal mountains.

The most striking difference between the HIRLAM forecasts and the probability fields from EPS is, as expected, that the HIRLAM fields are more small scale. Due to the increased horizontal resolution, the variability in the precipitation pattern (and therefore the probability fields) is increased compared to the EPS fields. This gives a better demarcation of the precipitation area to the upwind side of the mountains. Climatological precipitation maxima are represented with higher probabilities in HIRLAM than in EPS, e.g. the coastal areas in Sogn, Saltfjellet/Svartisen and Hinnøya.

An alternative to clustering is to group the forecasts into tubes. In the case of tubing there is only one cluster, the so-called central cluster grouping those forecasts that are similar to the ensemble mean. The other forecasts are grouped into a few tubes indicating different deviations from the ensemble mean that can be found in the ensemble. Each tube is represented by its extreme, i.e. the forecast which is the most different from the ensemble mean in the direction of the tube. Generally each tube has a probability of 10% while the central cluster has a probability of 50% (ECMWF newsletter 79, 1998). Running the HIRLAM forecasts with initial and boundary data from tube extremes would ensure that the HIRLAM forecasts represent different weather regimes.

One advantage with the tubing method is that the forecasts are ranked due to distance from the ensemble mean. The information about each single forecast and its distance from other forecasts is not available from clustering, only information about which cluster the forecasts belong to. Therefore we can not know if a selected forecast is close to the cluster mean or if it is close to one of the selected forecasts from another cluster. On the other hand, from the cluster data the number of forecasts in each cluster is available. This information is useful for probability calculation and scaling.

Probability could be compared with frequency of occurrence, thus many cases are needed. Verification of a probability forecast on one case only makes little sense, and in this report there will not be made any attempt on verification of the probabilities from HIRLAM and EPS.

9. OPERATIONAL RUNNING

In the present situation HIRLAM medium range forecasts with boundary data from EPS is only possible on an experimental basis. The temporal resolution of the EPS forecast fields at ECMWF is 12 hours, while 6 hours has been used in the experiment presented here. To be able to capture the structures moving into the HIRLAM area over the boundaries, a temporal resolution of at least 6 hours is desirable. Thus access to the data needed for running HIRLAM with boundaries from EPS forecasts, requires a change in the routines at ECMWF. More comprehensive studies are needed to find out how useful these forecasts are, and how to extract the most useful information from these runs.

10. CONCLUSION

Running forecasts with initial and boundary data from EPS can be done with the operational

HIRLAM model at DNMI. The forecasts from HIRLAM give probability fields with more details and higher maximum values than EPS. The distribution of probability and scaled precipitation forecast have maxima that are well known in climatology, e.g. Svartisen and the coastal areas in Sogn.

The predictability of precipitation can be higher than indicated by the number of clusters in EPS, in particular on the Norwegian west coast. This is due to the fact that airflow with a westerly component towards the coastal mountains often produces precipitation in this area. The precipitation is more likely to be described by a model that have a good description of the mountains. Therefore the HIRLAM model can be able to capture the increased predictability of precipitation.

Though a forecast has small probability, it may contain useful information. More work should be done with methods for extracting and presenting the information from probability forecasts, both from HIRLAM and EPS.

More studies should be done on clustering versus tubing as organization of the EPS data for HIRLAM forecasting. One advantage with clustering is the possibility of calculating probabilities and scaled precipitation forecasts, while with tubing one can ensure that the forecasts represent entirely different weather developments.

The available data from EPS at ECMWF do not have the required temporal resolution for being boundary data for HIRLAM. Increased resolution in the operational data should be considered. This will require change in the ECMWF routines for storage and distribution of data, and this again will require that the usefulness of the HIRLAM probability forecasts must be thoroughly investigated.

Verification of probabilities can not be done on one single case. More cases must be studied to give a proper evaluation of the probability fields from HIRLAM and EPS.

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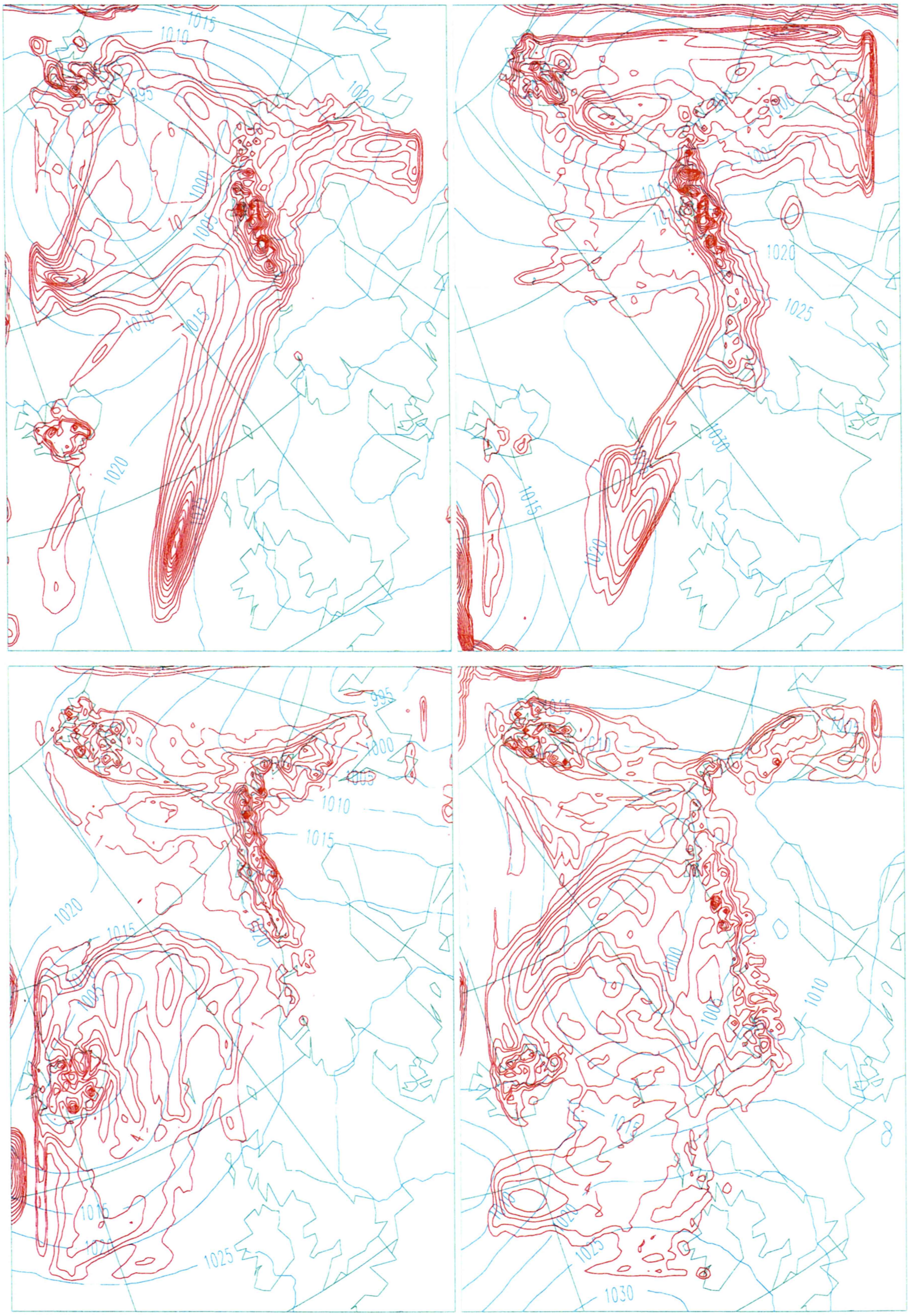

Figure 1. Forecasts of mean sea level pressure (blue) and 24 hours accumulated precipitation (red) from HIRLAM run with initial and boundary data from a forecast in cluster 1. a) 96 hours forecast valid 21 Sep. 12UTC b) 120 hours forecast valid 22 Sep. 12UTC c) 144 hours forecast valid 23 Sep. 12UTC d)168 hours forecast valid 24 Sep. 12UTC.

Figur 1. Prognoser for trykk ved midlere havnivå (blå) og 24-timers akkumulert nedbør (rød) fra HIRLAM, kjørt med initial- og randverdier fra en prognose i cluster 1. a) 96-timers prognose gjeldende for 21. sep. 12UTC b) 120-timers prognose gjeldende for 22. sep. 12UTC c) 144-timers prognose gjeldende for 23. sep. 12UTCog d) 168-timers prognose gjeldende for 24. sep. 12UTC.

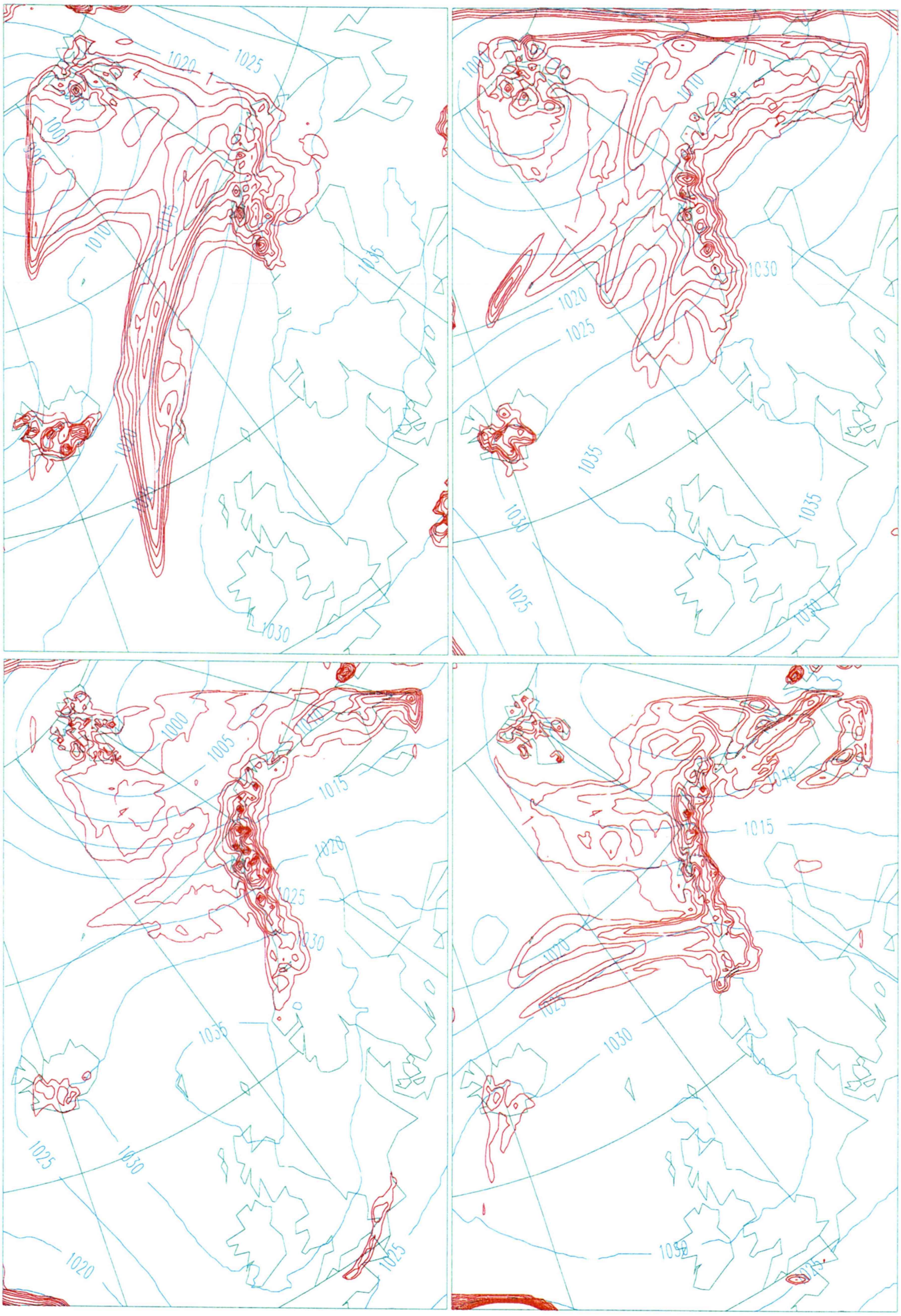

Figure 2. As figure 1 but with initial and boundary data from a forecast in cluster 2.
Figur 2. Som figur 1, men med initial- og randverdier fra en prognose i cluster 2.

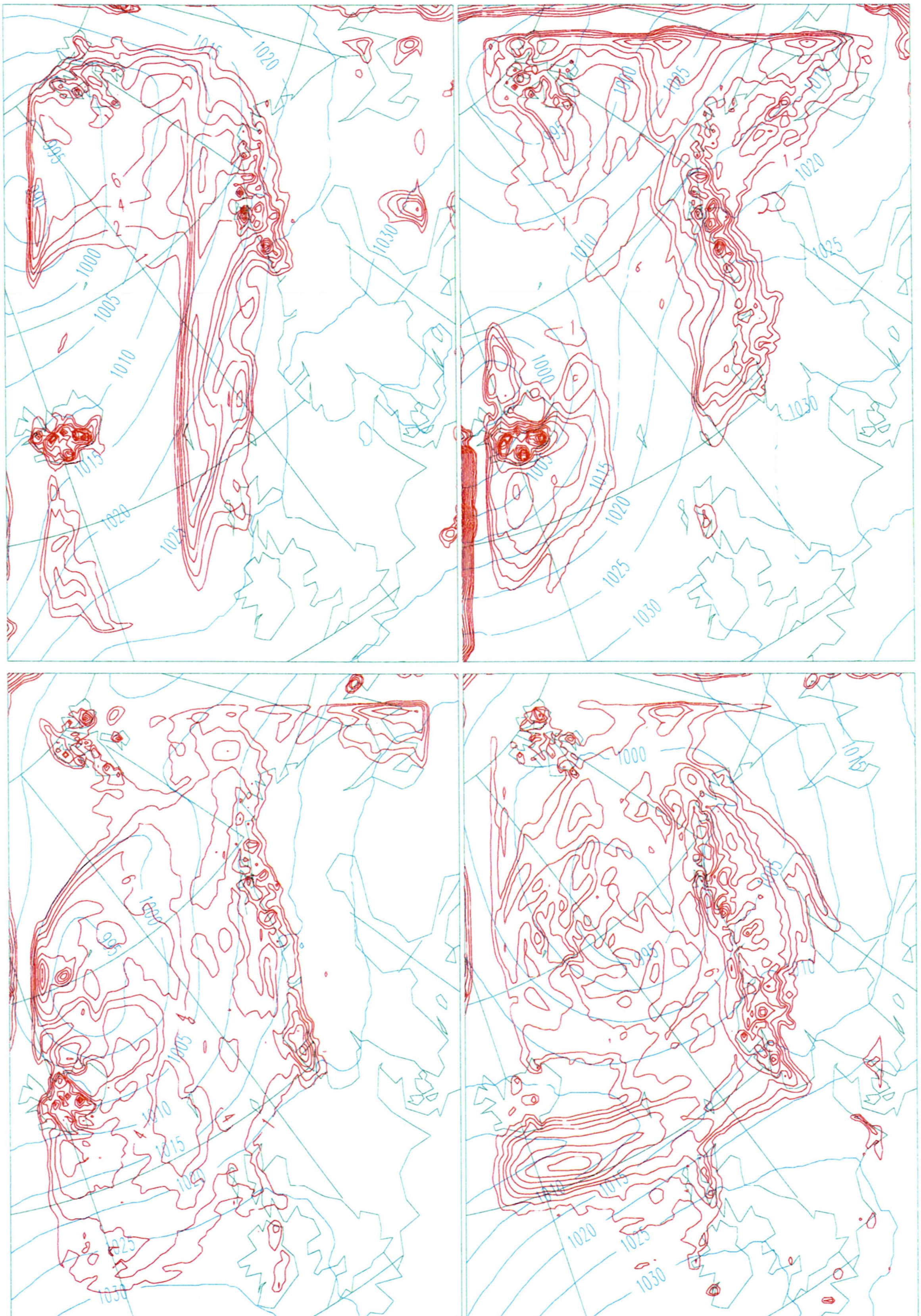

Figure 3. As figure 1 but with initial and boundary data from a forecast in cluster 3.
Figur 3. Som figur 1, men med initial- og randverdier fra en prognose i cluster 3.

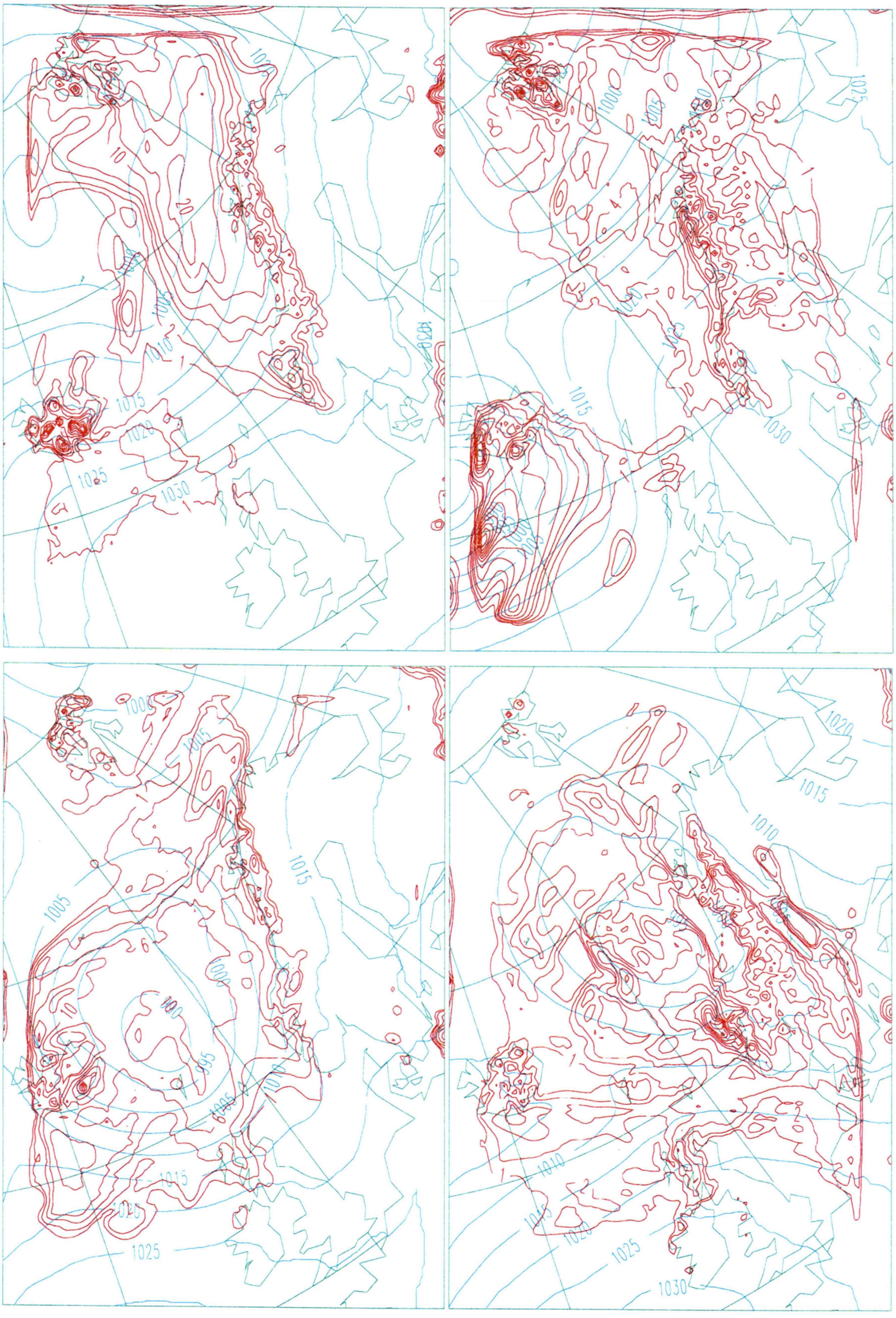

Figure 4. As figure 1 but with initial and boundary data from a forecast in cluster 4.
Figur 4. Som figur 1, men med initial- og randverdier fra en prognose i cluster 4.

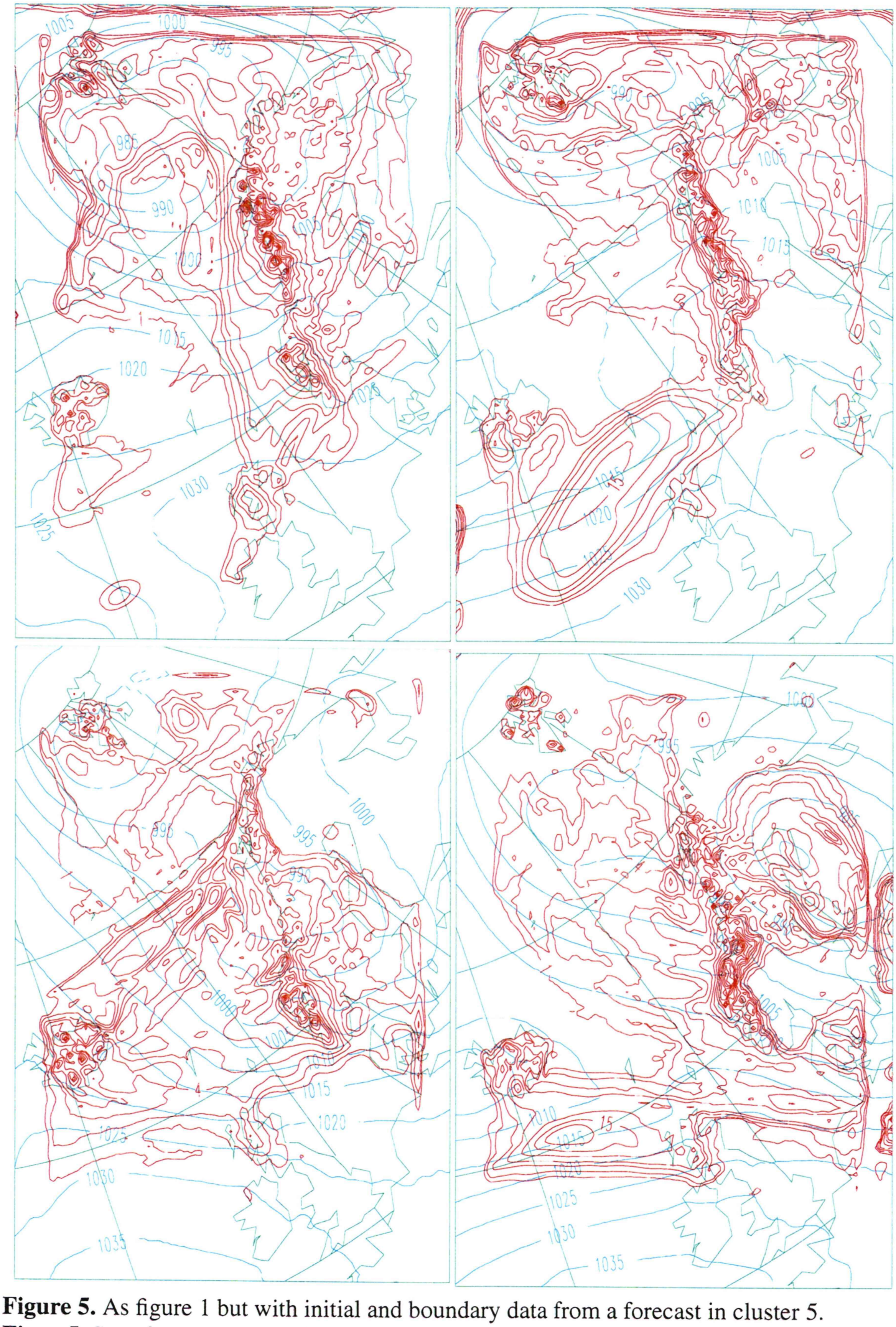

Figure 5. As figure 1 but with initial and boundary data from a forecast in cluster 5.
Figur 5. Som figur 1, men med initial- og randverdier fra en prognose i cluster 5.

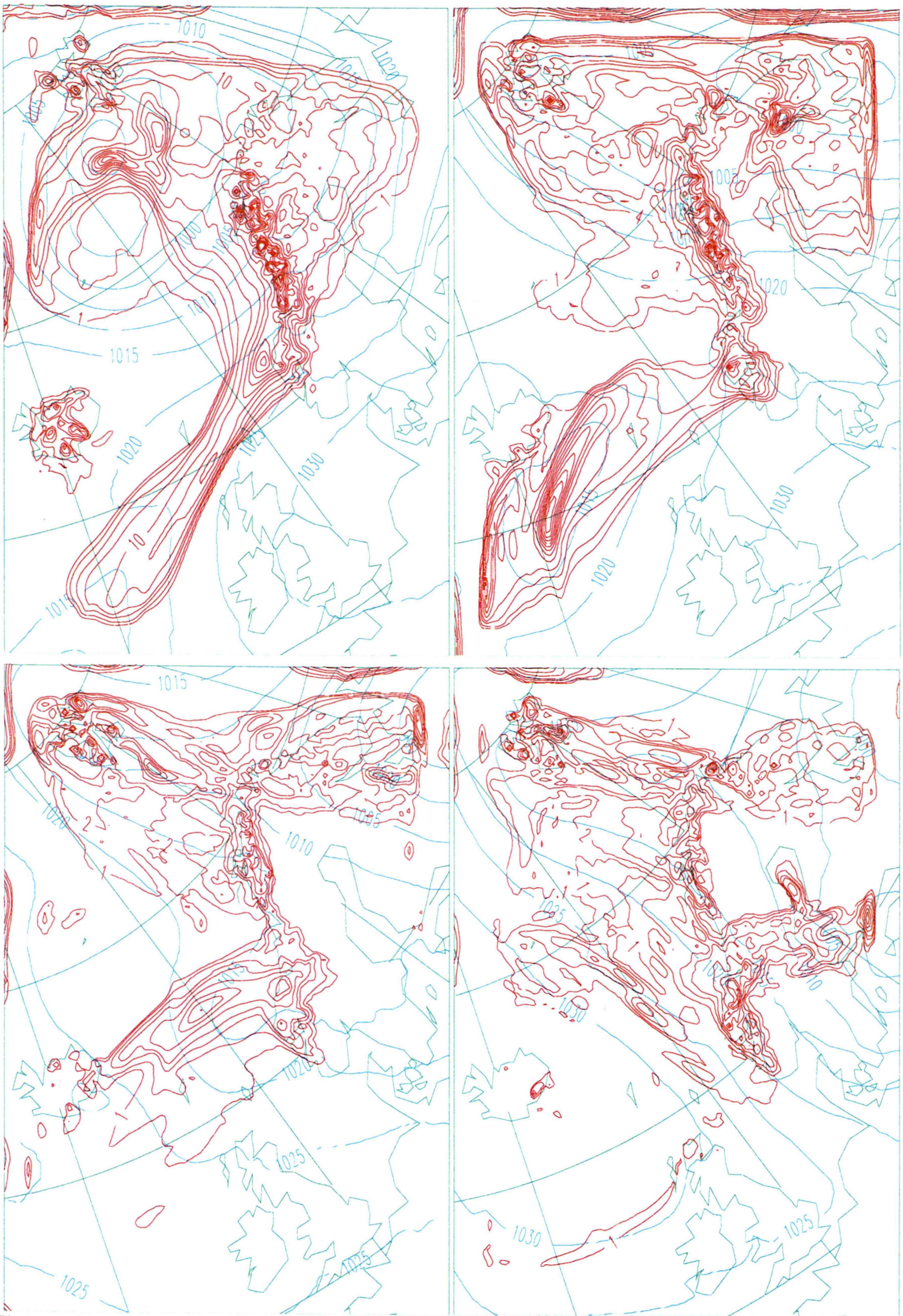

Figure 6. As figure 1 but with initial and boundary data from a forecast in cluster 6.
Figur 6. Som figur 1, men med initial- og randverdier fra en prognose i cluster 6.

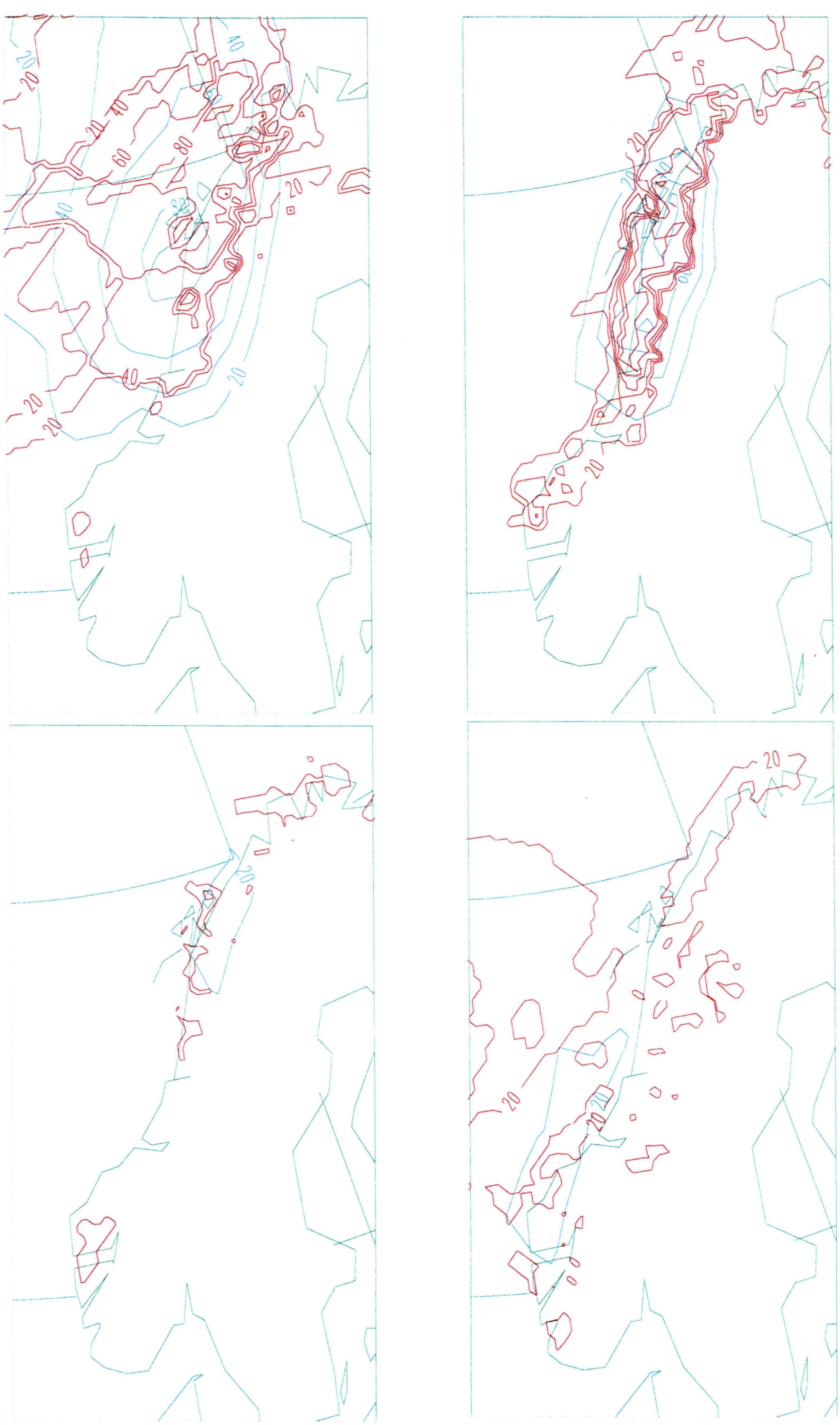

Figure 7. Probability forecasts from EPS (blue) and from HIRLAM (red). Contour intervals 20%. a) 96 hours forecast valid 21 Sep. 12UTC b) 120 hours forecast valid 22 Sep. 12UTC c) 144 hours forecast valid 23 Sep. 12UTC d)168 hours forecast valid 24 Sep. 12UTC.
Figur 7. Sannsynlighetsprognoser fra EPS (blå) og fra HIRLAM (rød). Plotteintervall 20%. a) 96-timers prognose gjeldende for 21. sep. 12UTC b) 120-timers prognose gjeldende for 22. sep. 12UTC c) 144-timers prognose gjeldende for 23. sep. 12UTC og d) 168-timers prognose gjeldende for 24. sep. 12UTC.

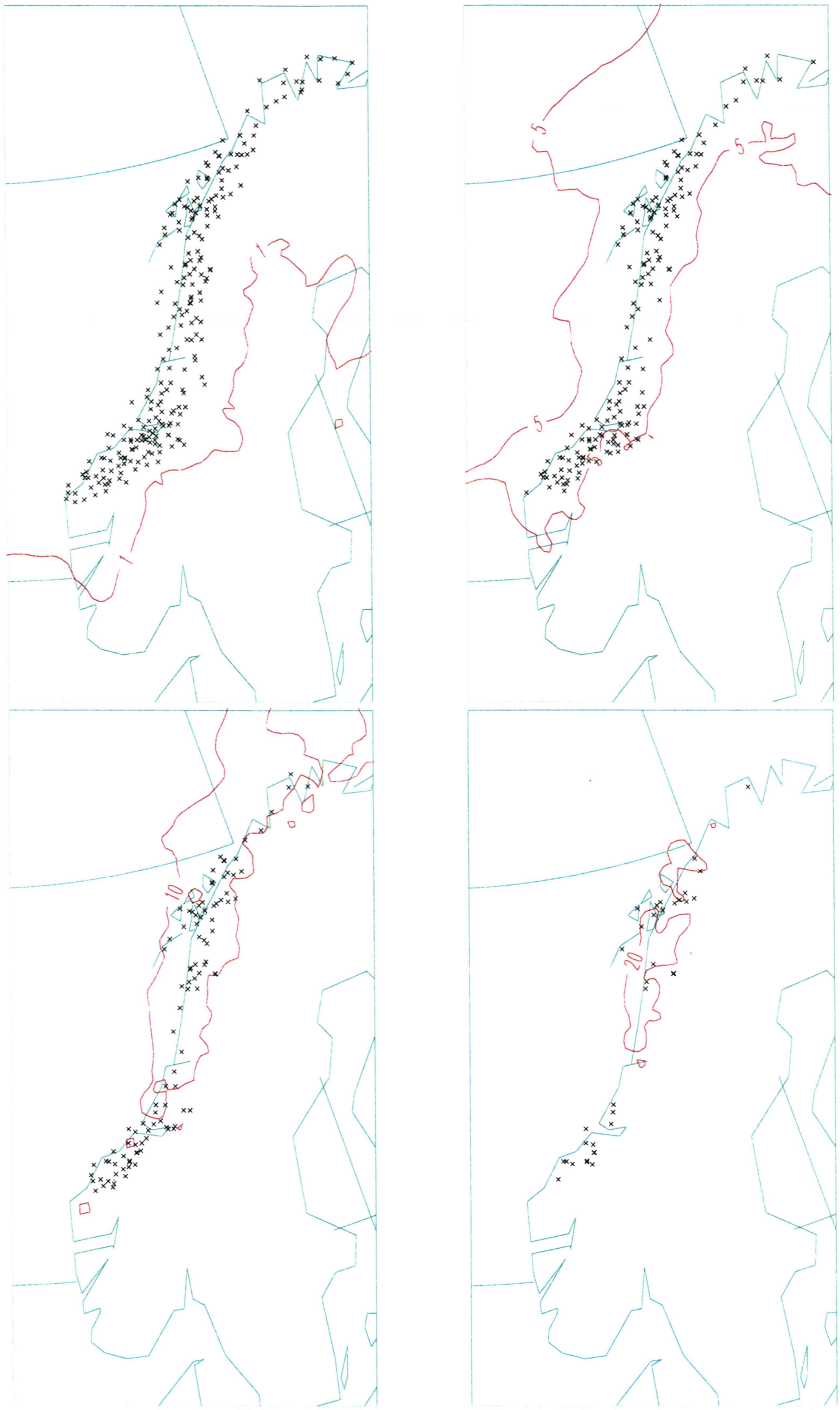

Figure 8. Scaled 114 hours forecasts of 24 hours accumulated precipitation (red) from HIRLAM valid 22 Sep. 6UTC. Crosses represent stations where observed amount exceeds the contour line in the plot. a) contour line 1mm, b) contour line 5mm c) contour line 10mm d) contour line 20mm.

Figur 8. Vektet 114-timers prognose for 24-timers akkumulert nedbør (rød) fra HIRLAM gjeldende 22. sep. 6UTC. Kryssene markerer stasjoner der observert mengde er minst lik plottelinjen a) plottelinje 1mm b) plottelinje 5mm c) plottelinje 10mm og d) plottelinje 20mm.

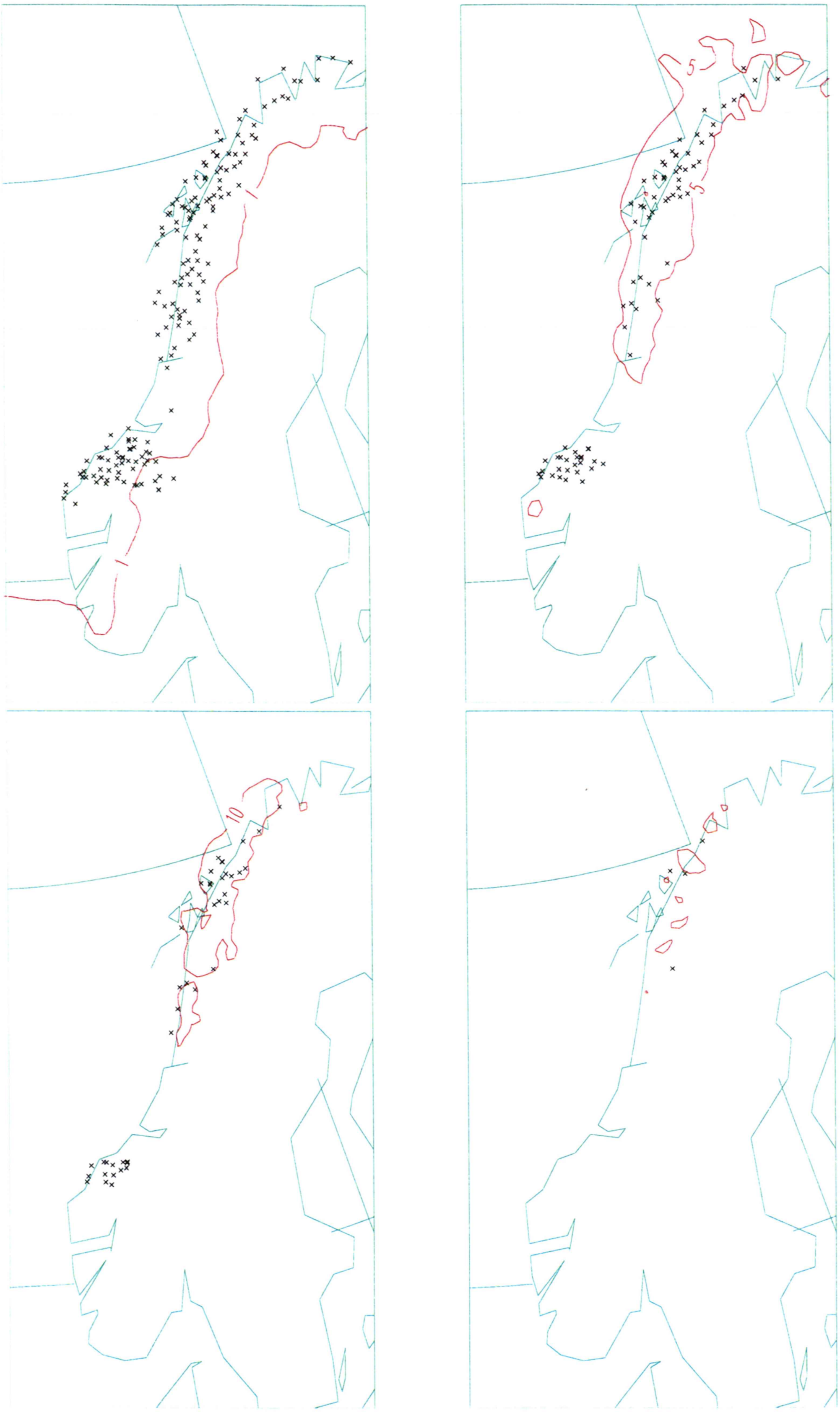

Figure 9. Scaled 138 hours forecasts of 24 hours accumulated precipitation (red) from HIRLAM valid 23 Sep. 6UTC. Crosses represent stations where observed amount exceeds the contour line in the plot. a) contour line 1mm, b) contour line 5mm c) contour line 10mm d) contour line 20mm.

Figur 9. Vektet 138-timers prognose for 24-timers akkumulert nedbør (rød) fra HIRLAM gjeldende 23. sep. 6UTC. Kryssene markerer stasjoner der observert mengde er minst lik plottelinjen a) plottelinje 1mm b) plottelinje 5mm c) plottelinje 10mm og d) plottelinje 20mm.

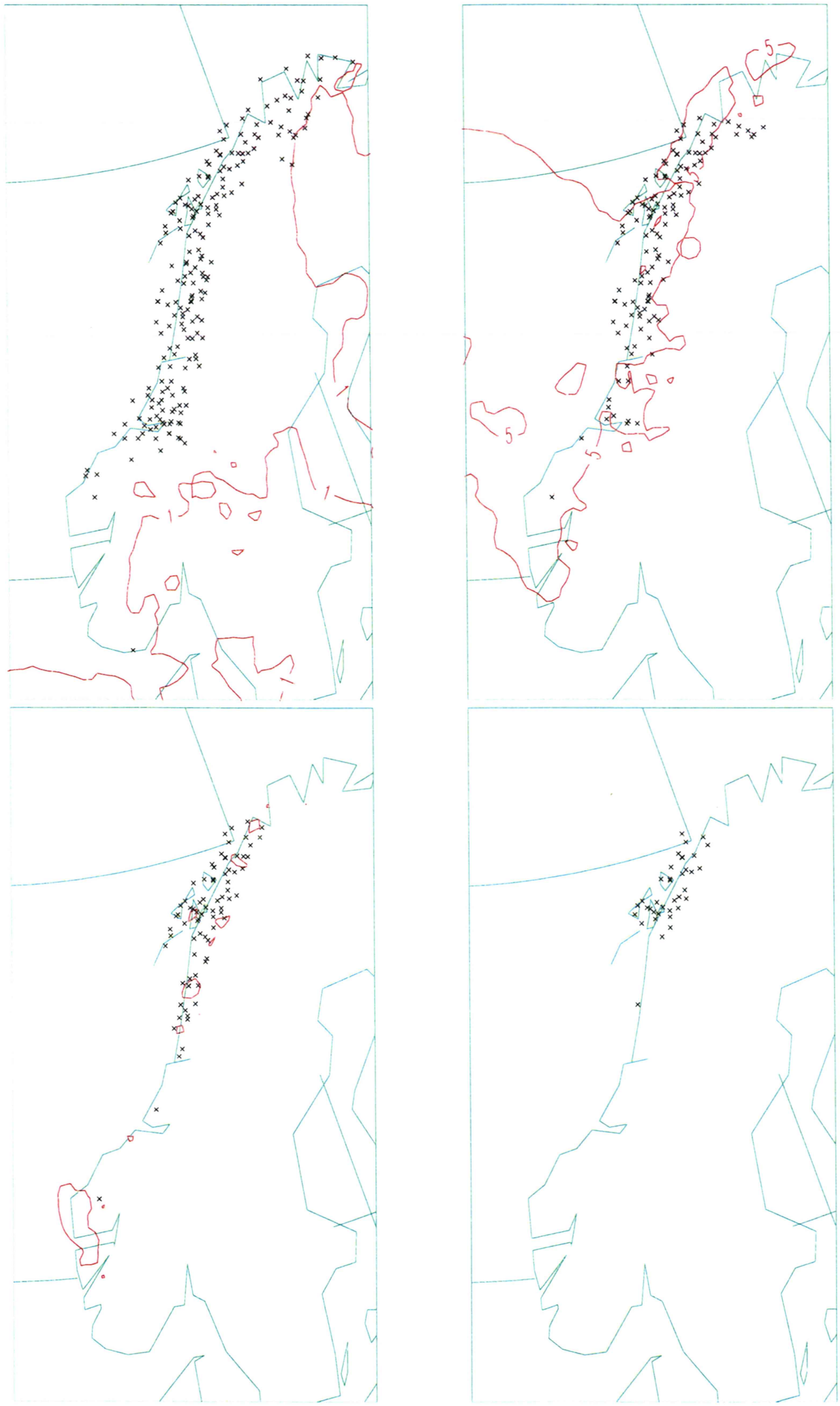

Figure 10. Scaled 166 hours forecasts of 24 hours accumulated precipitation (red) from HIR-LAM valid 24 Sep. 6UTC. Crosses represent stations where observed amount exceeds the contour line in the plot. a) contour line 1mm, b) contour line 5mm c) contour line 10mm d) contour line 20mm.

Figur 10. Vektet 166-timers prognose for 24-timers akkumulert nedbør (rød) fra HIRLAM gjeldende 24. sep. 6UTC. Kryssene markerer stasjoner der observert mengde er minst lik plottelinjen a) plottelinje 1mm b) plottelinje 5mm c) plottelinje 10mm og d) plottelinje 20mm.

UTGITTE NOTAT I HYDRA-SERIEN

1/97 **Metoder for kvantifisering av hydrologiske prognosefelts representativitet.**
Kai Fjelstad, NLH (diplomarbeid).

2/97 **Effekter av flomsikringstiltak. En gjennomgang av litteraturen.**
Magne Wathne, SINTEF.

3/97 **Virkningen av lokal overvannsdisponering på tettstedsflommer.**
Dag Rogstad og Bjørn Vestheim, NLH (hovedoppgave).

4/97 **Forslag til kravspesifikasjon av vassdragsmodell.**
Lars A. Roald, NVE.

5/97 **A note on floods in high lattitude countries.**
Lars A. Roald, NVE.

6/97 **Climate change and floods.**
Nils Roar Sælthun, NIVA.

7/97 **Flomdemping i Gudbrandsdalslågen. Programstruktur og systembeskrivelse.**
Magne Wathne og Knut Alfredsen, SINTEF.

8/97 **Klima, arealbruk og flommer i perspektiv.**
Arnor Njøs, Jordforsk.

9/97 **Flood forecasting in practice.**
Dan Lundquist, GLB.

1/98 **Bruk av ensembleprognoser til estimering av usikkerhet i lokale nedbørprognoser.**
Marit Helene Jensen, DNMI.

2/98 **LANDSKAP OG ESTETIKK –et kulturelt perspektiv.**
Oddrun Sæter, Byggforsk.

3/98 **Betydning av vårflommens størrelse for tetthet av laks- og ørretunger i Saltdalselva.**
Arne J. Jensen og Bjørn Ove Johnsen, NINA.

4/98 **Pure Model Error of the HBV-model.**
Øyvind Langsrud, Arnoldo Frigessi and Gudmund Høst, Norwegian Computing Center (Norsk Regnesentral)

5/98 **Analyse av effekter av urbanisering og avrenningsutjevnende tiltak i Svebestadfeltet – Sandnes kommune.**
Jadranka Milina, SINTEF.

6/98 **Virkning av urbanisering på avrenningsforhold i Storånavassdraget.**
Jadranka Milina, SINTEF.

7/98 **Metodebeskrivelse for flomsoneanalyse med eksempler fra Flisa og Kirkenær.**
Søren Elkjær Kristensen og Astrid Voksø, NVE.

8/98 **Statistical Forecasting of Precipitation Conditional on Numerical Weather Prediction Models.**
John Bjørnar Bremnes, DNMI

9/98 **1995-flommens volum, stigningstid og varighet i Gudbrandsdalslågen.**
Jan Ove Søderholm (Hovedfagsoppgave ved Geografisk Institutt, Universitetet i Oslo, våren 1998).

10/98 **Vårflommer i Glomma. Modellering av maksimalvannføringen på bakgrunn av volum og flomhydrogrammets form.**
Grete Orderud Solberg (Hovedfagsoppgave ved Geografisk Institutt, Universitetet i Oslo, våren 1998).

11/98 **Flomvolum Østlandet våren 1995. Frekvens og regional fordeling.**
Grete Orderud Solberg og Kjell Nordseth. Geografisk Institutt, Universitetet i Oslo.

12/98 **A Statistical Model for the Uncertainty in Meteorological Forecasts, with Applications to the Knappom and Røykenes Catchments.**
Turid Follestad og Gudmund Høst. Norwegian Computing Center (Norsk Regnesentral)

13/98 **Precipitation estimation using satellite remote sensing.**
Øystein Godøy, Det norske meteorologiske institutt.

14/98 **High Resolution Precipitation Forecasting with Initial and Boundary Conditions from Ensemble Forecasts.**
Viel Ødegaard, Det norske meteorologiske institutt.

HYDRA

Kontaktpersoner

formann i styringsgruppen: Fylkesmann Erling Norvik
Tlf. 69 24 70 00
E-post: erling.norvik@fm-os.sri.telemax.no

programleder: Arnor Njøs
Jordforsk
Tlf. 64 94 81 70 (Jordforsk)
Tlf. 22 95 90 98 (NVE)
E-post: arnor.njos@jordforsk.nlh.no
E-post: xarn@nve.no.

naturgrunnlag og arealbruk: Arne Grønlund
Jordforsk
Tlf. 64 94 81 09
E-post: arne.gronlund@jordforsk.nlh.no

Noralf Rye
Universitetet i Bergen
Tlf. 55 58 34 98
E-post: noralf.rye@geol.uib.no

tettsteder: Oddvar Lindholm
Norges Landbrukshøgskole
Tlf. 64 94 87 08
E-post: oddvar.lindholm@itf.nlh.no

flomdemping, flomvern og flomhandtering: Dan Lundquist
Glommens og Laagens Brukseierforening
Tlf. 22 54 96 00
E-post: danlund@sn.no

skaderisikoanalyse: Nils Roar Sælthun
Norsk institutt for vannforskning
Tlf. 22 18 51 21
E-post: nils.saelthun@niva.no

miljøvirkninger av flom og flomforebyggende tiltak: Olianne Eikenæs
Norges vassdrags- og energiverk
Tlf. 22 95 92 24
E-post: oli@nve.no

databaser og GIS: Lars Andreas Roald
Norges vassdrags- og energiverk
Tlf. 22 95 92 40
E-post: lars.roald@nve.no

modellarbeid: Ånund Killingtveit
Norges teknisk-naturvitenskaplige universitet
Tlf. 73 59 47 47
E-post: aanund.killingtveit@bygg.ntnu.no

programadministrasjon: Olianne Eikenæs
Norges vassdrags- og energiverk
Tlf. 22 95 92 24
E-post: oli@nve.no
Hjemmeside: http://www.nve.no

Per Einar Faugli
Norges vassdrags- og energiverk
Tlf. 22 95 90 85
E-post: pef@nve.no