Updating the HIRLAM numerical weather prediction system at *met.no* 2000-2002

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1 Introduction

For some years the HIRLAM project and the Section for meteorology at *met.no* have been working on improving the quality of the HIRLAM version 2.7 forecasting system. There has been several attempts to upgrade the operational HIRLAM which has been difficult to beat in terms of verification scores. Comprehensive testing of model version 4.3 and 5.2 has been carried out. The different options in HIRLAM version 5.2 that have been tested, are described in part 2 and 4.

During the autumn 2001 important changes to the operational numerical weather prediction system at *met.no* was implemented. The data from 00UTC forecast from ECMWF was replaced by boundary values on frames only and the supercomputer CRAY T3E at NTNU was replaced by new supercomputing system SGI Origin 3800 with increased computing capcity. This led to the introduction of necessary and desired changes to the local numerical weather prediction system at *met.no*. Increased resolution in time and space of the boundary values to the limited area model has been regarded as important for improving the quality of the numerical forecasts. The dissemination of data on frames (the grid points along the boundaries of the limited area model) has made it possible to increase the resolution of the boundary values within the present limits of the line capacity between *met.no* and ECMWF. At the same time the new supercomputer gave the possibility of increasing the resolution of the limited area model significantly while the size of the area could be retained.

Each member state can acquire boundary values from ECMWF on two different frames. Boundary values are now produced for the 00, 06 12 and 18 UTC termins with a short cut off time. The forecasts are calculated from a 3D-Var analysis, while the main production run at 12 UTC from which the member states can make use of the full fields is based on a long cut off and a 4D-Var analysis. At present, the boundary values for HIRLAM50 at *met.no* are on a 0.5° horizontal resolution grid, 31 levels vertical resolution and three hours time resolution. Details about the boundary values and the optimum utilization of these are given in part 3 of this report.

The new super computers at NTNU have significantly increased capacity than the old machine. A 60 hours forecast from HIRLAM in 0.2° horizontal resolution with 40*468*378 gridpoints is produced in about 22 minutes. The large capacity has given us the possibility to perform a large number of test runs which are described in chapter 5. The outcome of the tests is better forecast products on with increased resolution.

2 The boundary values

Until autumn 2001 the horizontal resolution of the boundary values for HIRLAM50 was 2.5°. The boundary values were recieved on 15 pressure levels in six hourly time resolution. With the introduction of frames the horizontal resolution has increased to 0.5° and the time resolution has increased to 3 hours. The data are now on model levels interpolated directly to HIRLAM50 model levels contradictory to the earlier interpolation from ECMWF model levels to pressure surfaces and then to HIRLAM model levels which differ from the model levels in the ECMWF model by a different resolution in the planetary boundary layer and due to differences in orographic resolution. The information in the boundary values is better retained by interpolation from ECMWF model levels directly to HIRLAM20 model levels. The boundary data are also extended with cloud liquid water.

The forecast is a combined result of the initial data (observations and first guess), the boundary values and the model equations. Which of these having the main influence on the resulting forecast will depend on many factors in the total model system. The operational HIRLAM50 is run on quite a large area. It takes many integration steps from the weather systems enter through the boundaries until they arrive in the main forecasting area. The question that could be asked is: what is the optimum size of the area of the LAM when the objective is to reproduce as well as possible the synoptic evolution of the boundary data?

3 HIRLAM version 5.2

The reference version HIRLAM 5.2 represents a number of upgrades in different scientific fields compared to HIRLAM 2.7.

The initial data for the free atmosphere are improved by implementation of 3D-Var. 3D-Var has been run at *met.no* for a couple of years before it came into the HIRLAM reference. This is because a comprehensive work with implementation of the scheme into the HIRLAM reference has been performed at *met.no* by Ole Vignes. The 3D-Var implementation is not treated in this report. For more information about 3D-Var it is refered to Vignes (1999).

3.1 Initial surface data

The initial data for the surface are produced by the surface analysis in ISBA. T2m and rh2m are analyzed and used as predictor for the prognostic variables surface temperature (T_s), subsurface temperature (T_d), surface soil water (w_s), subsurface soil water (w_d) and snow depth. SST and sea ice are maintained during the forecast. A detailed description of the surface analysis system is given in the HIRLAM documentation manual (Undén et al. ed., 2002).

The HIRLAM model requires initial data for orography, surface class, albedo, topographic roughness, climatological deep soil temperature and climatological deep soil moisture in addition to the variables from the surface analysis. These are given as monthly mean fields. Surface classes include ocean, sea ice, lakes, bare land, low vegetation and forest. Global physiography databases e.g., from the U.S. Geological Survey are utilized to determine the fraction of a grid square covered by the different surface classes. Roughness is derived from surface class and topographic roughness. Albedo is determined from surface class and fraction of snow and updated due to changes in snow fraction during the forecast.

The first guess fields for the surface analysis are weighted fields of monthly mean and short time forecasts from HIRLAM. The monthly means might differ quite a lot from the real time fields. Also the short time forecast might contain forecast errors. The analysis of snow depth and SST is made by use of succesive corrections. This procedure is not coded for parallel computing and therefore consumes a relatively large part of the computing time. The analysis of T2m and rh2m utilizes an optimum interpolation procedure which runs much more efficient on the computer. Sea ice is diagnozed from SST. At *met.no* data are also available on a weekly basis from a subjective analysis of snow depth, SST and sea ice. These data can represent a preliminary workaround for the problem with the slow analysis and have been tested both as initial fields and as first guess fields.

3.2 Physical parameterization schemes

The parameterization schemes for surface processes, clouds and condensation and turbulence/vertical diffusion in HIRLAM 2.7 are replaced by new schemes in HIRLAM 5.2. Some of the schemes have quite significant influence on the model forecasts and the error characteristics while other changes have smaller impact. However there can be reasons for replacing an old scheme even if the impact is small e.g. if it simplifies coding or tuning or if it prepares the model for use of future data. Detailed documentation of the schemes and the equations are given in HIRLAM-5 Scientific Documentation (Undén ed., 2002.)

3.2.1 The surface parameterization scheme ISBA

For each surface class a separate flux computation is made and combined using the so called 'mosaic' approach. The surface parameterization scheme ISBA is used for each surface type in the grid square. The primary motivation for the tiling approach is to promote suitable balance enhancements in horizontal complexity and to increase the physical realism of modelled surface energy and water fluxes. The soil is divided in two layers: one surface layer, with a typical depth of 1cm, that responds to the diurnal cycle, and a total layer extending down to a depth of about 1m following a time scale of some days. Prognostic equations exist for T_s, T_d, w_s, w_d and rain(dew) water on vegetation. The sensible and latent heat fluxes from each surface type are weighted according to their fractional share of the grid square to form the total surface fluxes in each time step. The aggregated fluxes are used as lower boundary conditions for the boundary layer vertical diffusion and the radiation scheme. The surface fluxes are based on the differences in temperature and humidity between the lowerst model level and the surface values for each surface type.

The ISBA scheme has been introduced to the HIRLAM reference model after thorough testing in the HIRLAM project. The testing also covers parallel runs on a nordic domain. The test shows that the former surface parameterization scheme was suffering from a significant negative temperature mean error also in inland areas in the spring. The error was not only related to 2m temperature but was also penetrating into the free atmosphere. The parallel runs with ISBA and the old reference is documented by Rodriguez et al. (2003).

3.2.2 The turbulence parameterization scheme TKE-l

The planetary boundary layer is represented by the turbulence parameterization scheme. Formation of air masses, profiles of the wind, temperature and humidity in the lower atmosphere, boundary layer clouds, forecast of 2m parameters, fog and dew/frost formation depend on the formulations in the turbulence scheme. The turbulence scheme in HIRLAM 5.2 is based on prognostic turbulent kinetic energy combined with a diagnostic length scale: a TKE-l scheme. Compared to the former Louis scheme one advantage is that e.g. entrainment at the top of the boundary layer is represented. In addition, the TKE-l scheme is thought to be more suitable for higher resolution, short time range predictions as it includes prognostic equation of the turbulence including local and non-local (advective) terms in addition to prognostic equations for liquid water, u, v, theta and q. A known shortcoming of the scheme is the lack of cloud condensation effects. This leads to an underestimated mixing in the stratiform cloud top, and will give rise to shallow moist boundary layers.

3.2.3 Convective and stratiform condensation scheme STRACO

The scheme parameterizes both large scale and convective condensation and puts special emphasis in achieving gradual transitions between both regimes. The convection is based on a Kuo parameterization with moisture convergence closure. This means that the convection scheme is invoked when the convergence of moisture (including surface evaporation) into a grid box exceeds the amount required for establishing a convective cloud in the grid box environment. The top of the cloud is where the temperature profile in the grid box intersects the moist adiabat profile from cloud base. The microphysics closely follows the Sundqvist scheme (operational in HIRLAM50 at *met.no*). Reported shortcoming of the scheme is an overestimation of the cloud fraction.

4 Test runs and verification

4.1 Data

The two testing periods are January and April 2002. Boundary values are ECMWF forecasts on 0.5° horizontal resolution. The periods chosen are expected to be a

Table 1: Experiment models

Model	version no.	analysis	resolution	boundaries
HIRLAM20	5.2	3D-Var, IS	0.2°,40L	EC 0.5° frames
HIRLAM20A	5.2	3D-Var	0.2°,40L	EC 0.5° frames
HIRLAM20B	5.2	3D-Var, sfana	0.2°,40L	EC 0.5° frames
HIRLAM20C	5.2	3D-Var, IS + sfana	0.2°,40L	EC 0.5° frames
HIRLAM50	2.7	3D-Var	0.5°, 31L	EC 0.5° frames
HIRLAM50A	5.2	3D-Var	0.5°, 31L	EC 0.5° frames
HIRLAM10	2.7	HIRLAM50	0.1°, 31L	HIRLAM50 0.5°
HIRLAM10A	2.7	HIRLAM50	0.1°, 31L	EC 0.5° frames

good test for the ISBA scheme. The very cold January temperatures have been a challenge to HIRLAM, and the difficulties with snow melting and difference between land surface skin temperature and SST in the spring have given origin to large model errors (Homleid and Ødegaard, 2000).

4.2 The model versions

The operational model at *met.no* by January 2003 is HIRLAM50 and HIRLAM10. Specifications and different model setups treated in this report are listed below. *IS* means that SST, snow data and sea ice from the Ice Service, *sfana* means analysis of the surface parameters SST, snow and sea ice is included. Analysis of T2m and RH2m is used in all experiments with version 5.2.

4.3 The reference version 5.2

The first test run is the comparison of HIRLAM20 and HIRLAM50A against the operational HIRLAM50 (see table 1). The model versions are verified against observations at Norwegian stations (57 synop stations) and at EWGLAM stations (270 synop stations and 100 temps). Figure 1 shows summary verification for the test period April 2002, mean error (ME) and standard deviation of error (SDE) as function of forecast length. Comparison of the curves marked 3 and 2 shows that there is a significant reduction of SDE and ME in mean sea level pressure (mslp) forecasts and in the ME of the T2m forecasts. The ME in T2m has a smaller but opposite (for EWGLAM stations) diurnal cycle in the new model version. For

Norwegian stations the SDE is reduced as well. The ME in cloud cover is changed from negative to slightly positive and has an increased SDE. ME in wind forecasts is changed from negative to positive at the EWGLAM station network, and from positive to negative at the Norwegian station network.

The verification of geopotential height, temperature and wind force on pressure surfaces for April 2002 are shown in Figure 2, 3 and 4 respectively. The upper and middle plots compare model versions 2.7 and 5.2 in $0.5°$ resolution. The ME in z is reduced. The temperature ME is reduced, and in the lowest levels it is also shifted in positive direction. On pressure levels the daytime ME is more positive (less negative) than the nighttime ME. SDE of temperature at level 925 hPa and 1000 hPa is also reduced. The wind force has very small ME in both models, and slightly reduced SDE in the new version.

4.4 Increased horizontal and vertical resolution

The aim has been to increase the horizontal resolution of the model in accordance with the increased resolution of the boundary data. Comparison of HIRLAM50 (curve marked 3 in Figure 1), HIRLAM50A (curve marked 2 in Figure 1) and HIRLAM20 (curve marked 1 in Figure 1) shows that the increase of horizontal resolution has a minor impact on the error level by lowering the ME and SDE of mslp. The ME in cloud cover and 2m temperature is slightly reduced by increased resolution while the SDE of cloud cover is further increased. The change in quality level of wind force forecasts is only due to change of model version in this period.

The vertical resolution is 31 levels in HIRLAM50 and HIRLAM50A and is increased to 40 levels in HIRLAM20. No specific tests are performed to determine the impact of the increased vertical resolution. The increased cloud cover in HIRLAM20 and the increased SDE of cloud cover (Figure 1) is probably related to the random overlap procedure in calculations of total cloud cover might give a higher percentage of total cloud cover with increased number of vertical levels.

4.5 The boundary values

HIRLAM50 has been tested in parallel with the high resolution boundary values of the ECMWF frames, and is now operational with these boundaries. Disappointingly the performance was not improved by improved resolution in the boundary values in space and time (not shown). An assumption has been that the boundaries are too far from the main verification area to have significant impact on the forecast performance. To investigate the dependency of area size on the reproduction of the boundary values in a numerical model the HIRLAM model was run on four different areas where the larger area equals the operational area while the smaller area is comparable to the area of *met.no*'s high resolution model HIRLAM10. The experiments used analyses as boundary values.

In the verification of the test there is a trend that the SDE in mslp is reduced with reduced size of area (not shown). The results suggest that the operational model on the small HIRLAM10 area will benefit from using ECMWF boundary values rather than nesting in HIRLAM50. The data on frames from ECMWF are available on sufficiently high resolution to be used directly on the boundaries of a $0.1°*0.1°$ model (Figure 6) thus the nesting procedure via HIRLAM50 is not necessary. Our main aim is to maintain the quality on the synoptic scale of the ECMWF forecasts and eventually add value by higher resolution. A parallel run of HIRLAM10 with ECMWF boundary values (HIRLAM10A) has been quasi operational for three months from November 2002 to medio February 2003. Figure 5 shows the verification for this parallel run. The SDE of mslp in HIRLAM10A is reduced to the level of the ECMWF model and the ME is reduced as well. Similarly HIRLAM10A has significantly better scores on 2m temperature. The 10m wind force verifies better than the ECMWF model itself when HIRLAM is run with ECMWF boundaries directly. This can be regarded as an added value from the higher resolution model.

4.6 The initial surface fields

The test setups are designed to answer the questions of how much impact does the daily surface analysis in ISBA has on the forecast and how much impact do we see from the weekly surface analysis from *met.no*'s Ice Service.

Figure 7 shows the verification of 2m temperature for HIRLAM20B and HIRLAM20A for January and April, EWGLAM and Norwegian network. The first guess field of surface and soil temperature, soil water, surface humidity and snow depth is a weighted mean of the monthly mean field and a short time forecast. Both models use HIRLAM's these fields while only in HIRLAM20B an analysis is performed to create the initial field. In this comparison it is clear that the surface analysis contributes significantly to improved verification scores of 2m temperature, particularly in January.

Figure 8 shows the verification of the model using the Ice Service's data as initial fields (HIRLAM20) compared to the reference with the ISBA surface analysis (HIRLAM20B) in January 2002 and the runs with climatological initial fields (HIRLAM20A). The surface analysis in ISBA gives better forecasts for T2m and mslp both in terms of ME and SDE than using the data from the Ice Service. Figure 10 shows similar verification for April also including a run with the Ice Service's data as first guess for the ISBA surface analysis (HIRLAM20C). In April the Ice Service data give at least as good score as HIRLAM20B in terms of SDE. The 2m temperature is lower leading to a less positive ME at EWGLAM stations and a more negative ME at Norwegian stations. Additional daily analysis of observations (HIRLAM20C) does not further improve the forecasts based on the Ice Service data. To summarize HIRLAM20 and HIRLAM20C show very similar verification. They both have slightly lower scores on 2m temperature particularly in January. In the future more observations of snow will be available in real time and it would be interesting to repeat the experiment with data from the Ice Service as first guess for the ISBA surface analysis.

at the moment.HIRLAM20 is more suitable for operational runs because the computing time for the successive correction method in HIRLAM20B is long.

4.7 Other tests

The combination of the Kain-Fritsch convection scheme and the Rasch-Kristjansson stratiform scheme is implemented in HIRLAM as an optional condensation package. It has been comprehensively tested inside the HIRLAM project and at *met.no*. The experiments give lower scores for mslp, reduced SDE of cloud coverage and a negative ME in the cloud cover (figures not shown). One aim of the HIRLAM6 project is to solve the problem with the poor synoptic scale quality and get the scheme implemented into the reference.

4.8 The surface parameterization scheme and the near surface parameters

HIRLAM20 has better scores for surface parameters than the operational HIRLAM50. In particular this is the case for mean sea level pressure. The wind and the temperature at coastal stations are difficult to forecast due to the varying influence of the sea and the land surface.

The operational HIRLAM50 had a weakness with too low temperatures along the

Table 2: 39 Norwegian synop stations

Model	ME January	ME April	SDE January	SDE April
HIRLAM20	0.1	-0.2	2.0	1.8
HIRLAM50	0.1	0.4	2.3	2.0
ECMWF	0.0	-0.3	2.3	1.9

Table 3: 15 Norwegian coastal synop stations

Model	ME January	ME April	SDE January	SDE April
HIRLAM20	-0.8	-0.8	2.5	2.0
HIRLAM50	-0.1	0.1	2.8	2.2
ECMWF	-0.9	-0.6	2.7	2.2

coast, in particular during spring, and too small amplitudes of the diurnal temperature cycle. HIRLAM20 has better scores for T2m in the coastal zone as in an example from Bodø in April 2002, Figure 9. The temperatures in the coastal zone are more affected by the land surface as seen in the observations. The negative temperature ME in HIRLAM50 is reduced from 2.8° C to 0.1° C in the new version.

The new version has a negative ME of 2.6 m/s in wind force. The scores for ff10m in Bodø is better in HIRLAM50. The time series from Bodø in April (Figure 9) shows that the underestimation of the wind speed is larger in the new reference. It is possible that the characteristics of the wind over the ocean penetrate into the land surface to a larger extent than the characteristics of the temperature.

ME and standard deviation of error of wind force for Norwegian synop stations are shown in Table 2 and for Norwegian coastal synop stations in Table 3. Statistics from the ECMWF forecasts are included as a reference. The data are from the test period April 2002, but the numbers are not exactly equal to those plotted in Figure 8 and 7 due to different station lists and different forecast lengths (HIRLAM 00+30,+42 and ECMWF 12+42,+54).

In HIRLAM version 5.2 the 2m temperature and 10m wind are calculated separately for all surface classes; bare land, low vegetation, forest, water and ice. The final values are weighted with respect to fraction of each surface class. The optimum combination of computing results for each class and for each parameter could be obtained by statistical modelling. This possibility will be considered in the future.

4.9 Study of time series at selected stations

HIRLAM20 is run in parallel and is compared to the operational versions of HIRLAM50 and HIRLAM10 also for January and February 2003 at selected stations where the error is known to be large in HIRLAM50/HIRLAM10.

There are more clouds in HIRLAM20 than in HIRLAM50 and much more than in HIRLAM10. The ME was close to zero in April 2002 most places, while it was positive in January 2002 and 2003. In spite of lower ME the overall error is larger what is reflected by the higher SDE in HIRLAM20 compared to HIRLAM10/HIRLAM50. A typical example of the cloud cover forecasts is shown in figure 11. The total cloud cover in HIRLAM20 has a SDE which is 20
The wind forecasts in the coastal zone is not improved as the temperature forecasts. The wind force is decreasing too much close to the coast and is much smaller than observed on most stations. The wind speed in HIRLAM20 is far too low at Spitsbergen.

On inland stations there seems to be a problem with forecasting low enough temperatures in the really cold periodes which are experienced e.g. in Eastern Norway and in Finnmark. Even if clouds at high latitudes in January have a net warmning effect the temperature error seems to be partly independent of the cloud cover error i.e. it is visible also in clear sky situations as seen in Figure 12.

4.10 Extension of data fields

The amount of data from HIRLAM20 forecast is increased a lot compared to HIRLAM50. The vertical resolution is increased to 40 levels. The forecast length is increased to 60 hours. In addition six surface parameters (mslp, total precipitation, T2m, rh2m, u and v) are available on a one hourly time resolution. Total snow, convective and stratiform snow and albedo are additional parameters on three hourly time resolution. The snow forecasts are verified against observations in the entire Norwegian precipitation network. The results are shown in Figure 13 where all forecasts in case of observed rain (left), observed sleet (middle) and observed snow (right) are distributed on rain, sleet and snow. The verification shows that valuable information about precipitation type can be obtained from the model.

5 Discussion and summary

The reference version HIRLAM 5.2 which includes new schemes for physical parameterization, new packages for initial data (3D-Var for the free atmosphere which has been operational at *met.no* for two years before it was implemented into the reference, and analysis of surface parameters) has been tested. The verification results show that the new reference version is superior to the operational system at *met.no*. The improvement is significant for the 2m temperature but most important is the improvement in mslp and the forecasts on pressure surfaces. The new model version represents a better model for the synoptic scale.

The horizontal resolution is increased to 0.2° with retainance of the operational area. The improved quality due to increased resolution is smaller than the improvements due to change in model version. HIRLAM version 5.2 in 0.2°, 40L resolution is suggested as new operational model at *met.no*.

The boundary value project at ECMWF provides boundary values on frames with horizontal resolution 0.5° and vertical resolution of up to 60 model levels. The boundaries have shown to be particulary beneficial for the HIRLAM10 model due to the relatively small area of this model.

The subjectively analyzed surface data SST, snow depth and sea ice from *met.no*'s Ice Service in Tromsø are compared to the daily automatic analysis in HIRLAM and have shown to have slightly poorer forecast quality. The benefit of doing daily analysis of surface data when these data are used is limited. Due to reduced computing time the weekly data from the Ice Service will replace the succesive correction analysis of SST and snow depth and the diagnostic sea ice in the operational HIRLAM20. However observations of snow might be easier available in the future. The impact of daily analysis should be studied again when more data are available. The work with parallelization of the succesive correction code and with choosing the optimum first guess fields should be continued.

Surface parameters verify better in HIRLAM20. It is reasonable to believe that this is partly due to the weighting of computations over the different surface classes. At coastal stations however, the wind speed of HIRLAM20 is often too low. Larger weight on wind speed over sea could perhaps improve the forecasts of wind force in 10m at coastal stations.

The condensation scheme in HIRLAM20 has another error characteristic than the condensation scheme in HIRLAM50. Cloud coverage has a positive ME some times leading to smaller amplitude in the diurnal temperature cycle. The work with testing other condensation schemes has so far not been succesful. It is important that the forecasters are aware of the cloud cover error when they interpret the temperature forecasts.

More data are available from HIRLAM20. The forecast is run up to 60 hours. The long forecasts are not explicitly verified and should be interpreted with care. Verification of output of precipitating snow from the model has shown to provide valuable information about precipitation type.

References

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Rodriguez, E., B. Navascues, J.J. Ayuso, S. Jarvenoja, 2003, Analysis of surface variables and parameterization of surface processes in HIRLAM. PART I: Approach and verification by parallel runs, HIRLAM Technical Report No. **58**, Available from SMHI, S-601 Norrkoping, SWEDEN.

Undén, P., L.Rontu, H.Jarvinen, P. Lynch (ed.), 2002, HIRLAM-5 Scientific Documentation, Available from SMHI, S-601 Norrkoping, SWEDEN.

Vignes, O., 1999, A parallel test of the HIRLAM 3D-Var data assimilation system and the operational DNMI system, Research Report No. **90**, *met.no*.

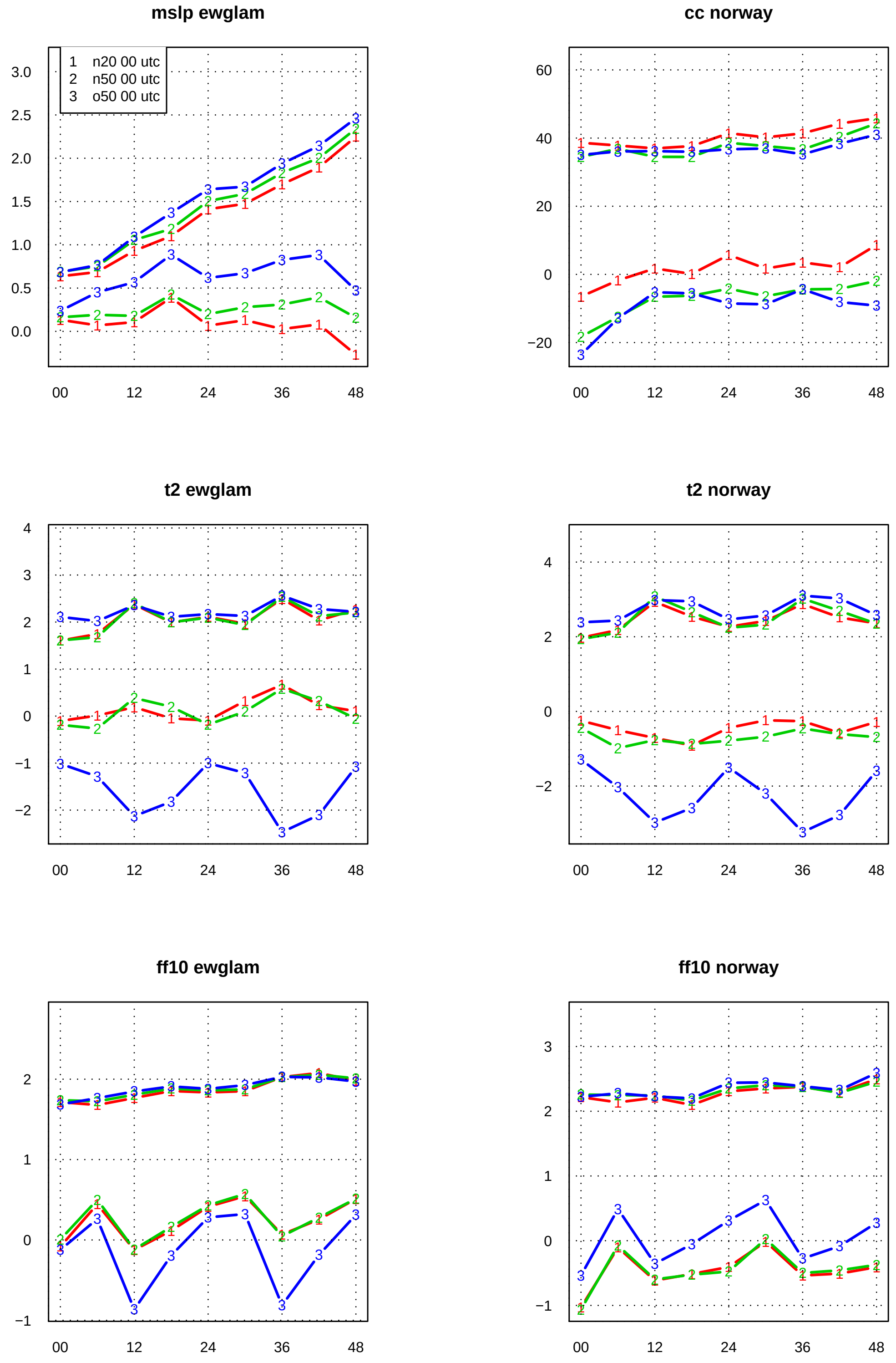


Figure 1: Summary verification of forecasts for April 2002 at the EWGLAM network (left) and norwegian network (right), ME and SDE as function of forecast lenght. HIRLAM50 (1), HIRLAM50A (2) and HIRLAM20 (3)

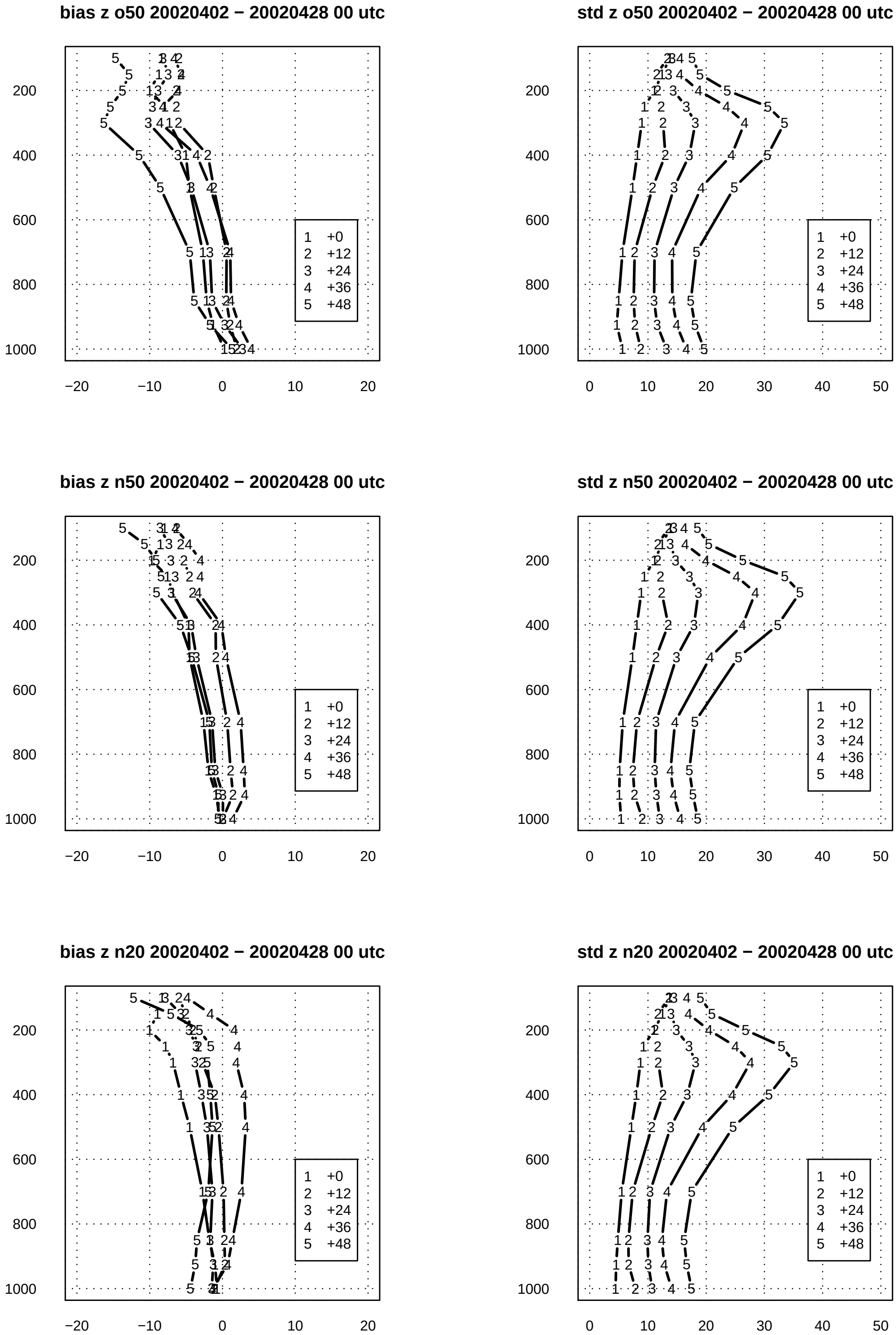


Figure 2: Summary verification of forecasts for April 2002 at the EWGLAM network, ME (left) and SDE(right) of geopotential on pressure levels. HIRLAM50 (top), HIRLAM50A (middle) and HIRLAM20 (bottom)

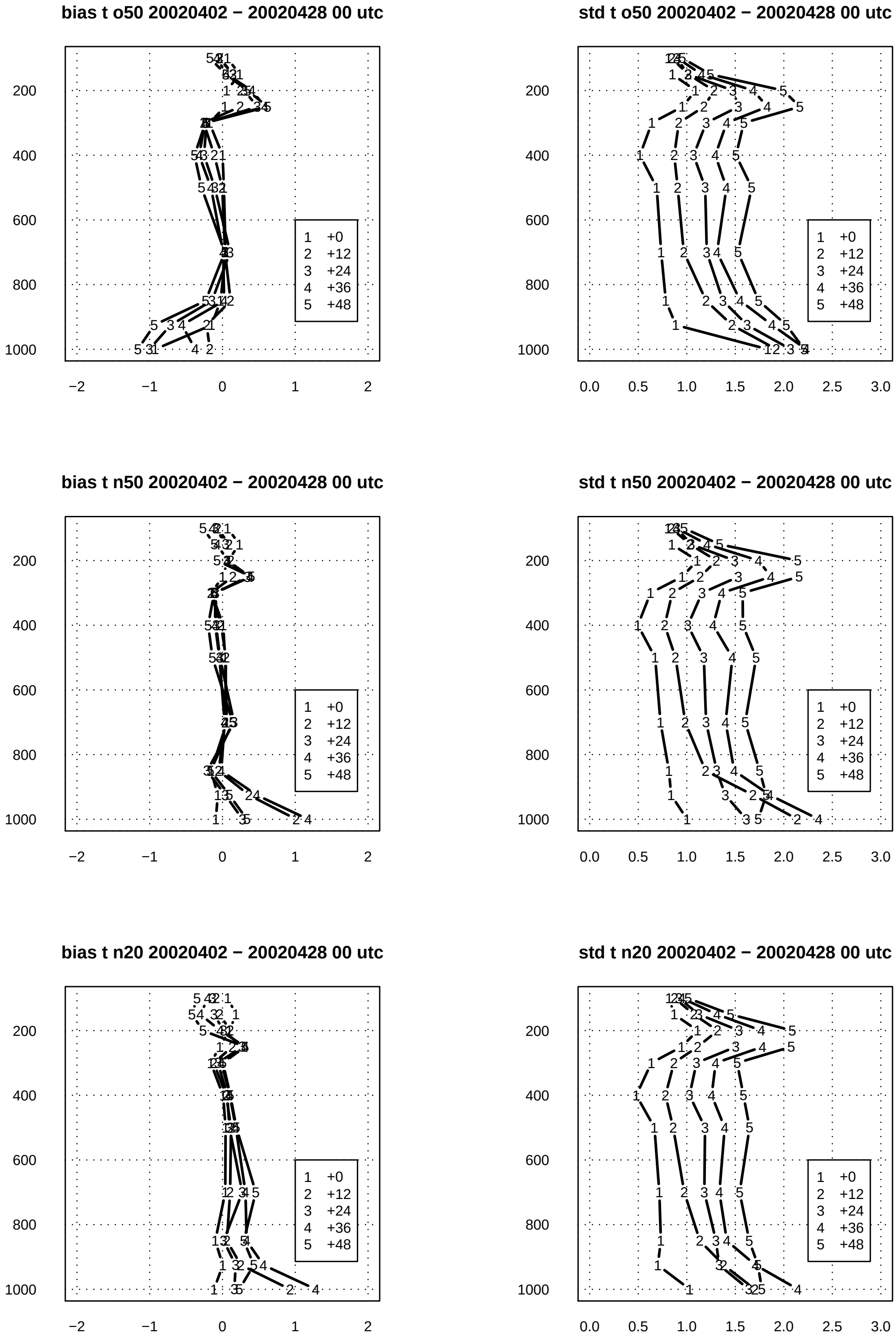


Figure 3: Summary verification of forecasts for April 2002 at the EWGLAM network, ME (left) and SDE(right) of temperature on pressure levels. Operational HIRLAM50 (top), HIRLAM50A (middle) and HIRLAM20 (bottom)

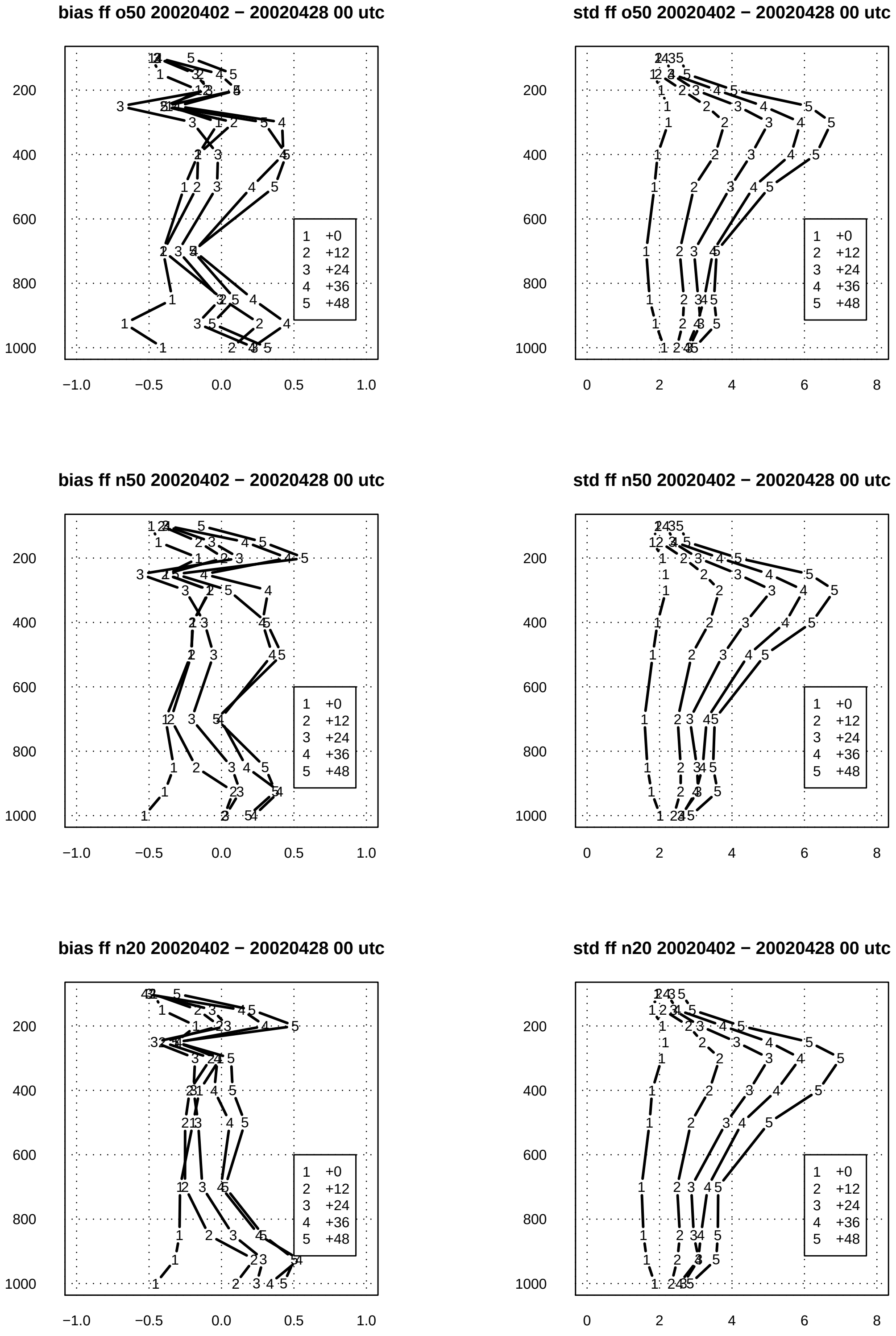


Figure 4: Summary verification of forecasts for April 2002 at the EWGLAM network, ME (left) and SDE(right) of wind force on pressure levels. Operational HIRLAM50 (top), HIRLAM50A (middle) and HIRLAM20 (bottom)

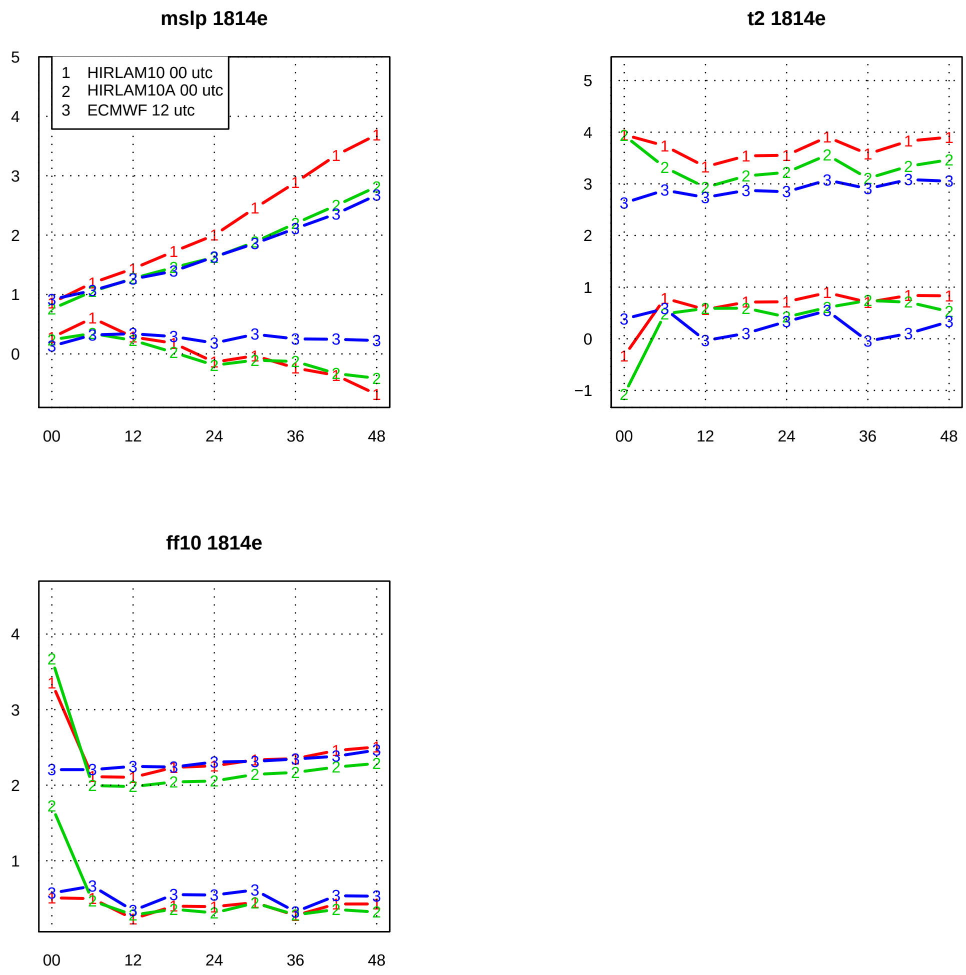


Figure 5: Summary verification for the EWGLAM network, ME and SDE of mslp, T2m and FF10m, HIRLAM10 (1), HIRLAM10A (2) and ECMWF (3)

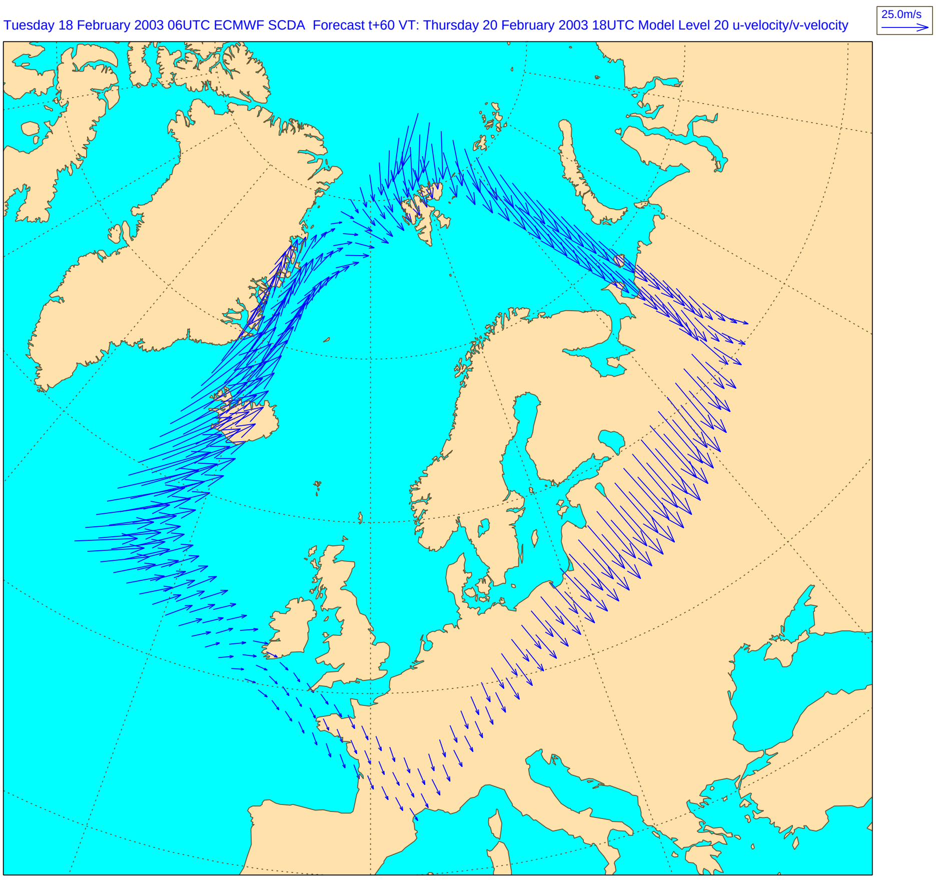


Figure 6: ECMWF wind on frames covering the boundaries of HIRLAM10A.

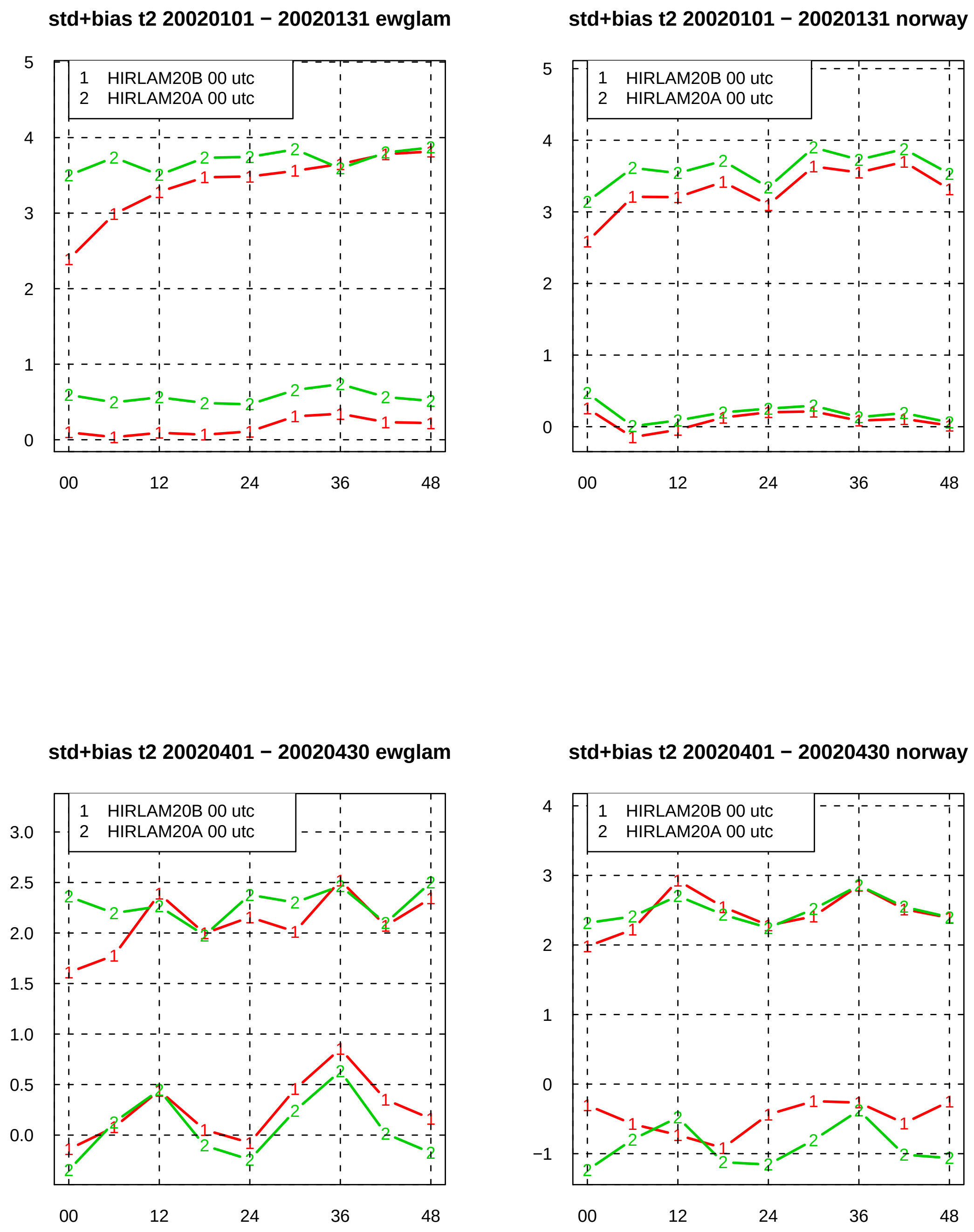


Figure 7: Summary verification of forecasts for January 2002 (upper) April 2002 (lower) at the EWGLAM network and the Norwegian network, ME and SDE of t2m, HIRLAM20B (1) and HIRLAM20A (2)

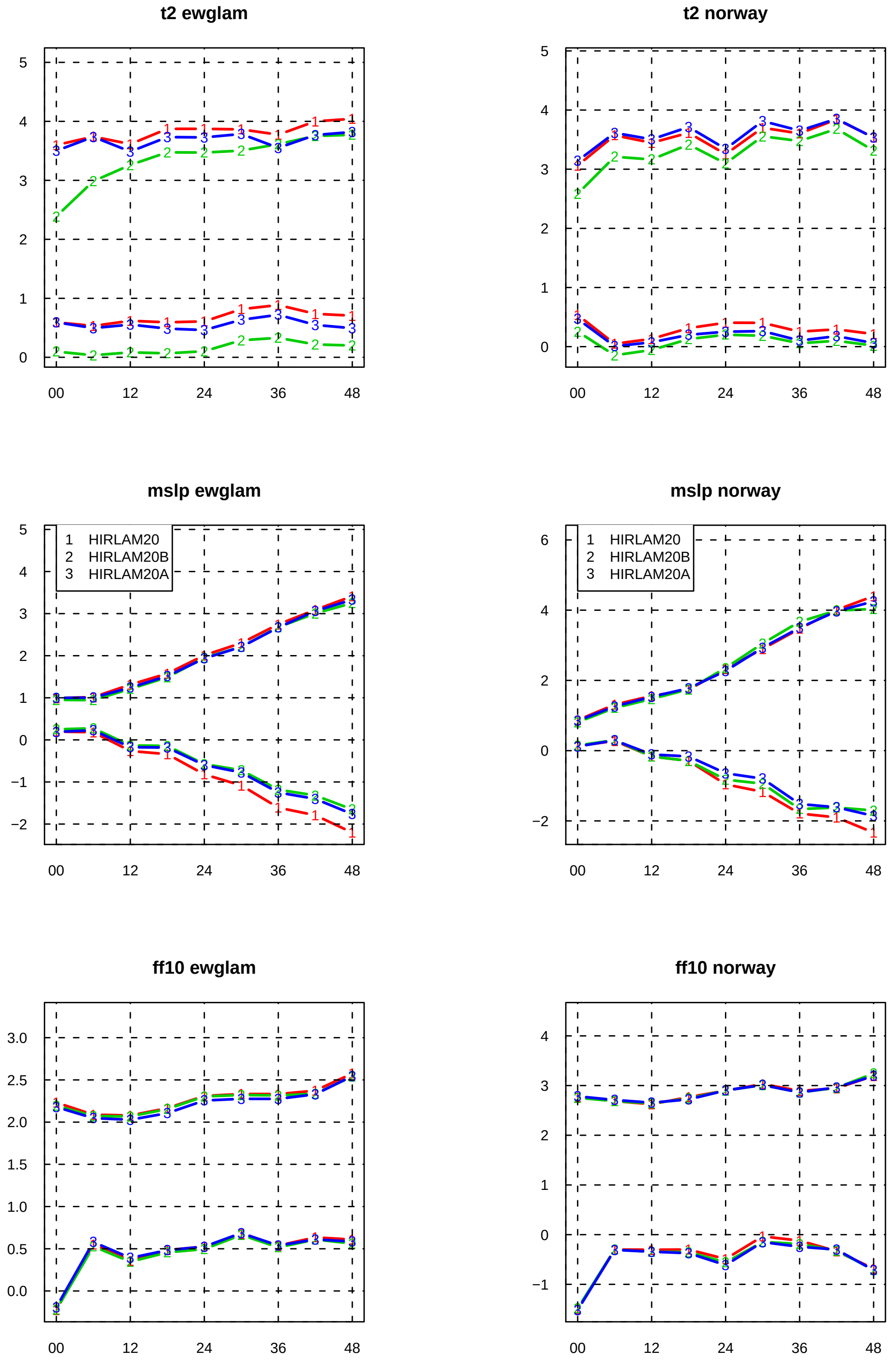
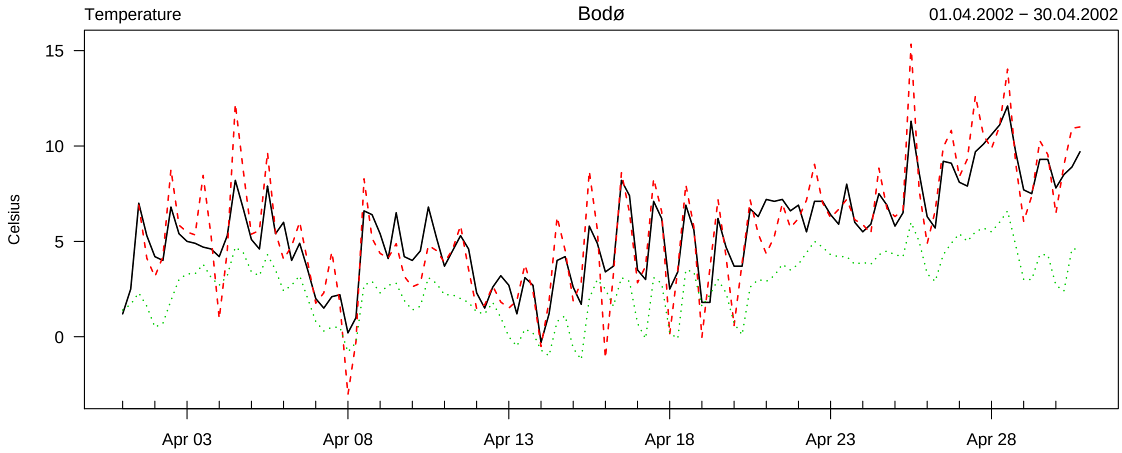
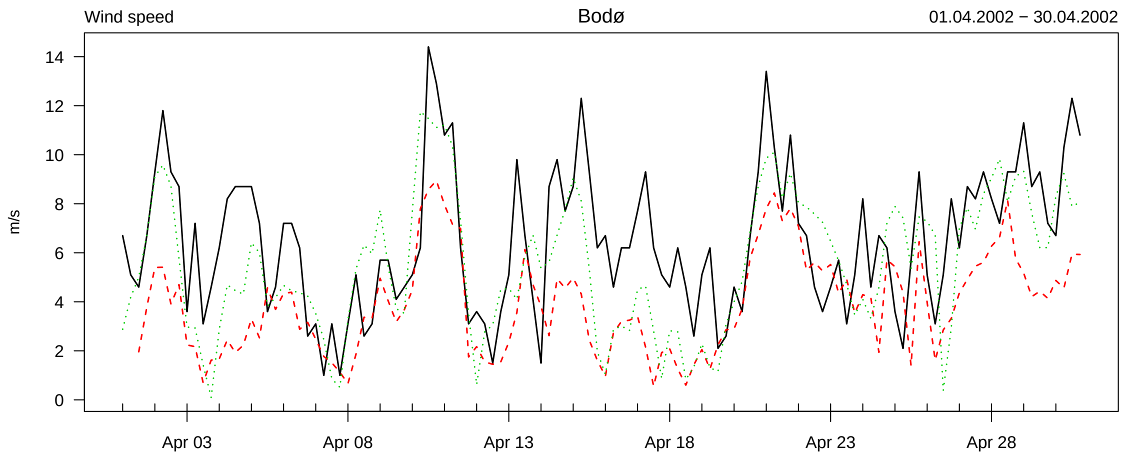


Figure 8: Summary verification of forecasts for January 2002 at the EWGLAM network, ME and SDE of mslp, T2m and FF10m, HIRLAM20 (1) and HIRLAM20B (2)



	Min	Mean	Max	Std	N
synop: 00,06,12,18	−0.3	5.5	12.1	2.6	120
Hirlam20: 00+12,+18,+24,+30	−3	5.6	15.3	3.2	118
Hirlam50: 00+12,+18,+24,+30	−1.2	2.7	6.6	1.7	120

	ME	SDE	RMSE	MAE	Max.abs.err.	N
Hirlam20 − synop	0.1	1.4	1.5	1.1	4.5	118
Hirlam50 − synop	−2.8	1.4	3.1	2.8	6.1	120



	Min	Mean	Max	Std	N
synop: 00,06,12,18	1	6.5	14.4	2.9	120
Hirlam20: 00+12,+18,+24,+30	0.6	3.9	8.9	2	118
Hirlam50: 00+12,+18,+24,+30	0.1	5.5	11.8	2.8	120

	ME	SDE	RMSE	MAE	Max.abs.err.	N
Hirlam20 − synop	−2.6	2.4	3.5	2.9	8	118
Hirlam50 − synop	−0.9	2.4	2.6	2.1	5.7	120

Figure 9: T2m (top) and FF10m (bottom) at station 1152 Bodø April 2002, observed (black), HIRLAM20 (red) and HIRLAM50 (green)

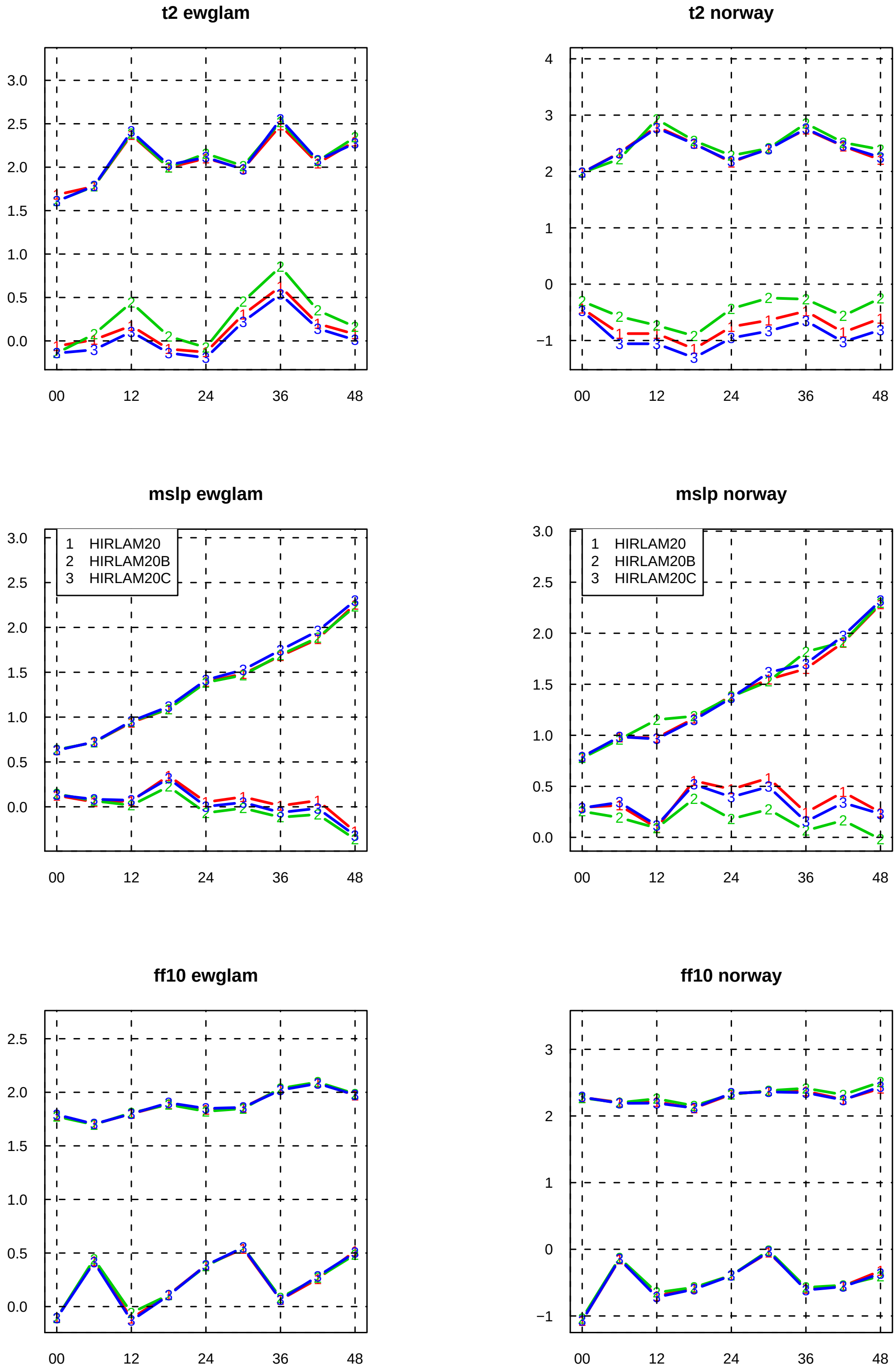
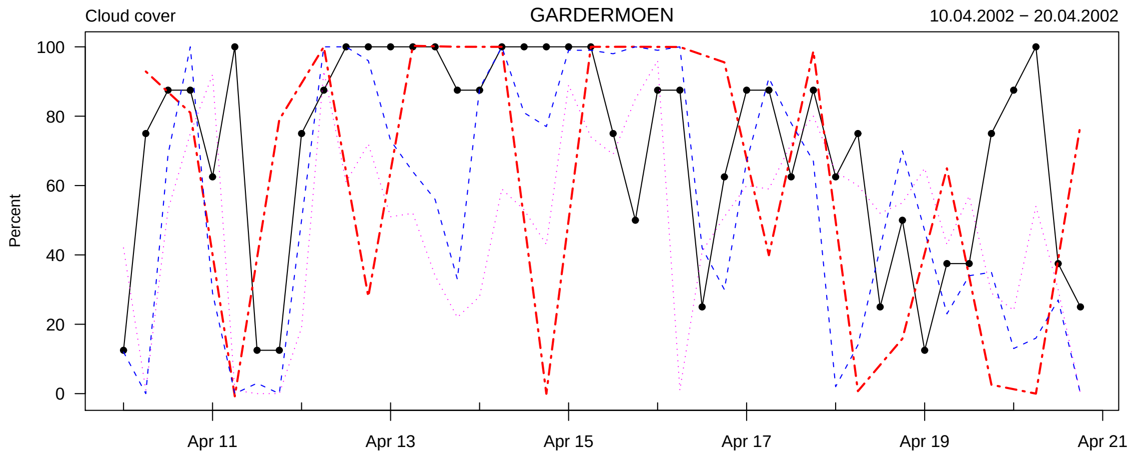


Figure 10: Summary verification of forecasts for April 2002 at the EWGLAM network, ME and SDE of mslp, T2m and FF10m, HIRLAM20B (legend at, HIRLAM20C (legend 2) and HIRLAM20 (legend 3)



	Min	Mean	Max	Std	N
synop: 00,06,12,18	12.5	71	100	29.6	44
Hirlam10: 00+18,+24,+30,+36	0	49.1	96	27.2	44
Hirlam20: 00+30,+42	−0.8	62.5	100.3	42.1	22
Hirlam50: 00+18,+24,+30,+36	0	55.1	100	36.1	44

	ME	SDE	RMSE	MAE	Max.abs.err.	N
Hirlam10 − synop	−21.9	34.7	41.1	33	99	44
Hirlam20 − synop	−14.2	52.4	54.3	41.1	100.8	22
Hirlam50 − synop	−15.9	32.4	36.1	26.4	100	44

Figure 11: Total cloud cover at station 1384 Gardermoen April 2002, observed (black), HIRLAM20 (red) and HIRLAM50 (blue) and HIRLAM10 (pink).

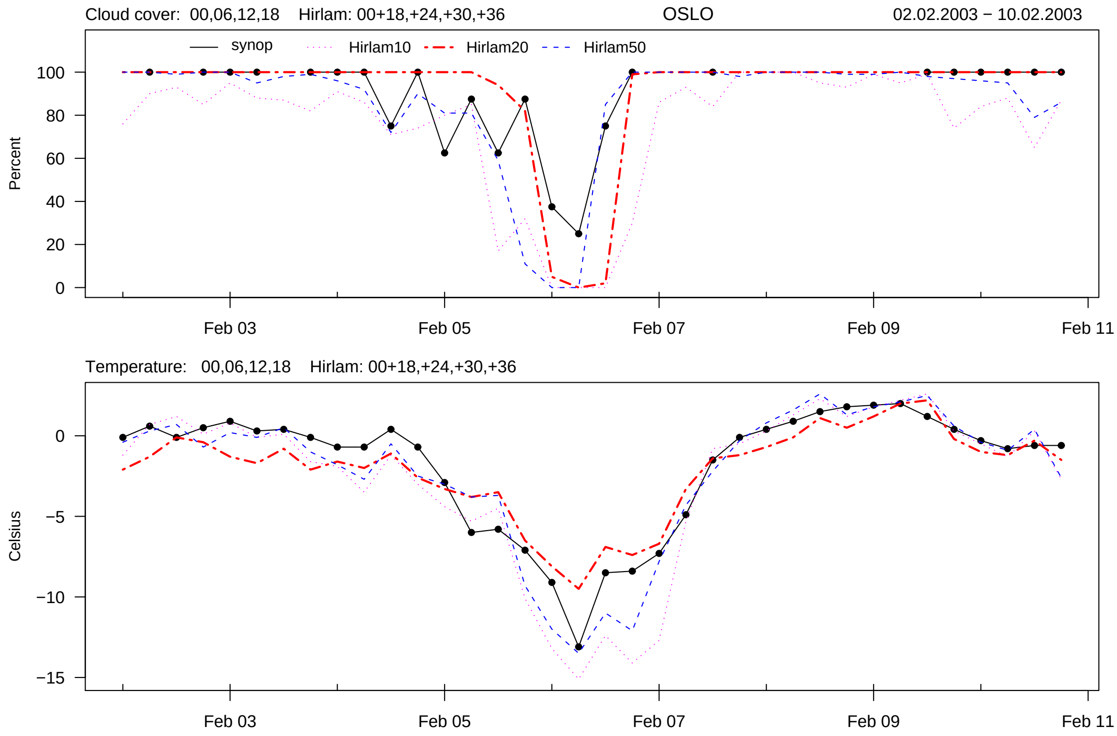


Figure 12: total cloud cover (top), 2m temperature (bottom) at station 1492 Oslo February 2003, observed (black), HIRLAM20 (red) and HIRLAM50 (blue) and HIRLAM10 (pink).

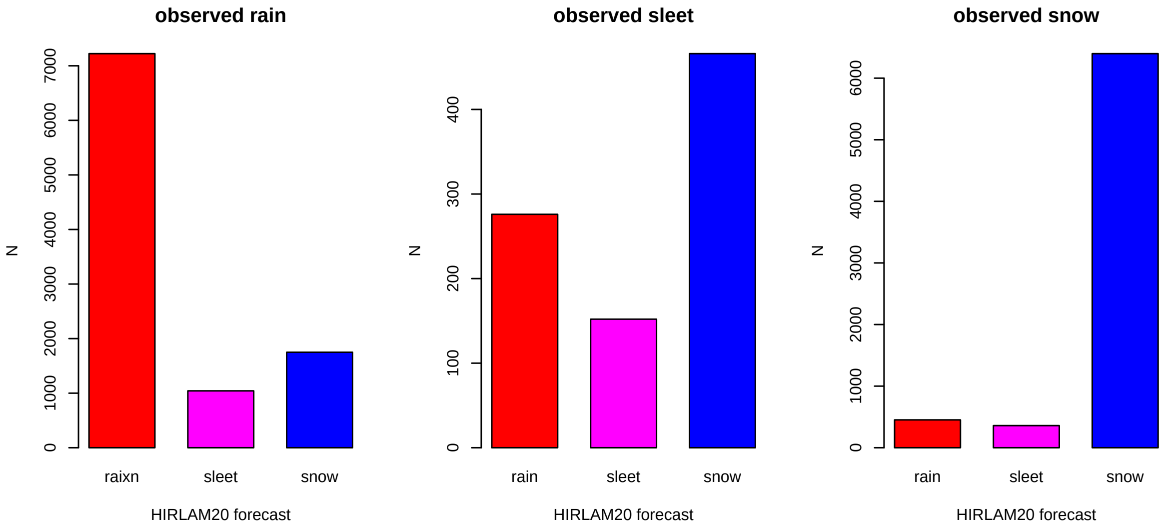


Figure 13: Summary verification of precipitation type at the Norwegian precipitation network