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Uncertainty of Meteorological Parameters from DMI-HIRLAM

Contribution to RODOS(WG2)TN(99)12
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Alix Rasmussen
Jens Havskov Sørensen
Niels Woetmann Nielsen
Bjarne Amstrup

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Preface to the DMI edition

DMI participated in the RODOS project (Real-time On-line DecisiOn Support system) in the working group on Meteorology and Atmospheric Dispersion Activities in the period 1991 to 1999. The overall objectives of this working group were to develop and provide the decision support system with an integrated atmospheric transport dispersion model chain for now- and forecasting of radioactive airborne spread on all ranges from local to European scales.

DMI's general objectives were to provide forecast and analysed data from the DMI-HIRLAM model for the development and test of the RODOS Local Scale Model Chain and RODOS Long Range Model Chain, both for real-time and historical cases (e.g. Chernobyl and ETEX).

During the project DMI-HIRLAM has been validated in a number of studies both on direct validation of forecast data, and also indirect validation by the model simulation of the first ETEX experiment using the Danish Emergency Response Model of the Atmosphere (DERMA) utilising high-resolution data from the DMI-HIRLAM model as well as data from the ECMWF global model. The analysis showed in general that the use of DMI-HIRLAM data gave better results than use of ECMWF data, and in particular the use of DMI-HIRLAM data explains some of the observed mesoscale features in the tracer gas measurements.

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Alix Rasmussen, Jens Havskov Sørensen,

Niels Woetmann Nielsen and Bjarne Amstrup

Danish Meteorological Institute

Meteorological Research Division

Lyngbyvej 100

DK-2100 Copenhagen Ø, Denmark

Email: ar@dmi.dk, jhs@dmi.dk,nwn@dmi.dk,bja@dmi.dk

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Management Summary

HIRLAM, which stands for HIgh Resolution Limited Area Model, is a state-of-the-art analysis and forecast system for numerical weather forecasts. The project started in 1985 as cooperation of the Nordic Countries and the Netherlands, later on joined by Ireland, France and Spain. The cooperation is very active in a wide range of areas, improving the forecasting system, including such areas as precipitation, turbulence parameters and wind, which are of particular importance for the nuclear emergency preparedness.

The HIRLAM system is in operational use at most of the meteorological services participating in the HIRLAM cooperation for their routine weather forecasting, and at DMI it has been in operational use since 1990.

DMI-HIRLAM is not an integrated part of the RODOS system, but during the development of RODOS it has been an important part of the work, as DMI-HIRLAM data has been used extensively in the test of the RODOS Local Scale Model Chain and RODOS Long Range Model Chain, both for real-time and historical cases.

A description of the DMI-HIRLAM system and results of validation studies have previously been published in a number of RODOS-reports. This report is a conglomerate of these reports, and includes in addition recent results of the routine validation of DMI-HIRLAM.

In general, the resemblance between measurements and the DMI-HIRLAM analysis and forecast is quite good for mean sea level pressure (mslp), wind and temperature, while the quality of the precipitation forecasts are less good, especially in convective conditions.

In general there is an improvement in quality of the forecasts with higher resolution, especially going from 45 km horizontal resolution to 15 km, while there are only minor differences in the standard statistics going from 15 km to 5 km.

The root mean square error (rmse) of the 2 m-temperature is around 2.5 ^{o}C; for the 850 hPa temperature the rmse is about 1 ^{o}C for the analysis increasing to about 2 ^{o}C for a 48 hour forecast. For the 10 m-wind velocity the rmse is around 2 m/s; for the 850 hPa wind velocity the rmse is around 2 m/s for the analysis, increasing to about 4 m/s for a 48 hour forecast.

Sensitivity studies of vertical profiles from Jægersborg, Denmark, from the years 1994 and 1995, show in general that the diurnal variation of the DMI-HIRLAM temperature near ground is too small, and also the diurnal variation of the DMI-HIRLAM velocity is too small, especially DMI-HIRLAM does not reproduce well the nocturnal jet.

However, a new boundary layer parameterization, implemented in the DMI-HIRLAM together with a new physical package, seems to result in significant improvements, producing more realistic profiles and deeper unstable boundary layers.

Contents

1 Introduction

The RODOS project (Real-time On-line DecisiOn Support system) began as a research project late 1990 as a major item of the Radiation Protection Research Action of the 3rd R&D Framework Programme (1991-1994). The objective was the development of an integrated and comprehensive real-time on-line decision support system for off-site emergency management after a nuclear accident in Europe. By access to local and national monitoring and forecast data from radiological and meteorological information networks, the system will make consistent predictions from the vicinity of the release and the early phase up to far distant areas and the later stages of an accident.

The development of RODOS continued during the 4th EU R&D Framework Programme (1996-1999) with strong efforts to make RODOS a fully operational system functional for the end-users in different countries.

The development of RODOS was organised in different working groups for:

- ⇒ System Development incl. Quality Assurance,
- ⇒ Meteorology and Atmospheric Dispersion,
- ⇒ Countermeasures and Consequences,
- ⇒ Hydrological Modelling,
- ⇒ Data Assimilation and Uncertainties incl. Source Term Estimation,
- ⇒ Training and Exercises,
- ⇒ RODOS users

DMI participated in the second group on Meteorology and Atmospheric Dispersion activities with the overall objectives to develop and provide the decision support system with an integrated atmospheric transport dispersion model chain for now- and forecasting of radioactive airborne spread on all ranges from local to European scales (RODOS Local Scale Model Chain and RODOS Long Range Model Chain). The model chain incorporates options for using data from local on-site weather stations and on-line numerical weather prediction data available at weather services.

DMI's general objectives were to provide forecast and analysed data from the DMI-HIRLAM model for the development and test of the RODOS Local Scale Model Chain and RODOS Long Range Model Chain, both for real-time and historical cases (e.g. Chernobyl and ETEX). This has e.g. been described in "*User's Manual For The Atmospheric Dispersion Module: Met-Rodos*", *RODOS(WG2)-TN(99)-10* and *"Numerical Weather Prediction Database HIRLAM", RODOS(WG2)-TN(99)-11.*

It is emphasised that DMI-HIRLAM is not an integrated part of the RODOS system, and RODOS end-users can choose to use forecast data from any other numerical weather prediction model.

During the project DMI-HIRLAM has been validated in a number of studies, cf. e.g. *RODOS(WG2)(97)10,-11,-13,-14,-16,-18,-19*, both on direct validation of forecast data, and also indirect validation by the model simulation of the first ETEX experiment using the Danish Emergency Response Model of the Atmosphere (DERMA) utilising high-resolution data from the DMI-HIRLAM model as well as data from the ECMWF global model. The analysis showed in general that the use of DMI-HIRLAM data gave better results than use of ECMWF-data, and in particular the use of DMI-HIRLAM data could explain some of the observed mesoscale features in the tracer gas measurements.

This report is a conglomerate of the above mentioned validation reports, and includes in addition some of the recent results of the routine validation of DMI-HIRLAM.

2 The HIRLAM system

The HIgh Resolution Limited Area Model (HIRLAM) is an advanced short-range numerical weather forecasting system, developed in a joint international research project. The project started in 1985 as a cooperation of the Nordic Countries and the Netherlands, later on joined by Ireland, France and Spain.

The HIRLAM level 1 system was established in 1988 (Machenhauer). The present operational system in the participating countries is mainly based on the HIRLAM-4 system, and is now used in routine weather forecasting by DMI, DNMI, FMI, IMS, KNMI, INM, and SMHI.

A reference version of HIRLAM is maintained at the European Centre for Medium range Weather Forecasts (ECMWF). All changes in the HIRLAM system are thoroughly tested before introduced to the reference system. This ensures a high degree of quality assurance.

The reference system consists of the following main components:

The analysis of surface pressure, atmospheric temperature, wind, and humidity is presently based on a optimum interpolation scheme, which has been derived from the one developed at ECMWF and adapted for use in a limited area model. Most institutes use a six hours data assimilation cycle, but some use a three hours cycle. The lateral boundary values are assumed to be given by a large scale (global) model such as the ECMWF model. Sea surface temperatures, ice and snow coverage are analysed with a successive correction method.

An implicit, adiabatic non-linear normal mode initialisation scheme is used.

HIRLAM is a hydrostatic primitive-equation grid-point model and the resolutions presently in use are from 55 to 5 km horizontally and from 16 to 31 levels in the vertical. The coordinate systems used are a rotated lat-long grid horizontally and a hybrid p-σ system in the vertical (Simmons and Burridge, 1981). Near the surface this is identical to the σ coordinate (σ=p/psurface), and it approaches the pressure p with increasing height.

The time stepping is semi-implicit Eulerian with a fourth order linear horizontal diffusion. The radiation scheme has been developed in the HIRLAM project (Savijaervi), vertical diffusion is formulated through a non-local first-order closure scheme (Holtslag), and condensational processes are handled by the Sundqvist scheme (with STRACO, a Smooth-TRAnsition Kuo type COnvection). Surface processes over land are handled in a two layer scheme with snow, ice and soil moisture included.

The HIRLAM reference system has been designed for portability. The source code is written in Fortran-77 with some extensions (automatic ("Fortran-90") arrays) and the scripts are in Unix Bourne shell syntax. Input to the system is in WMO standard BUFR (for observations) and GRIB (for fields). Output fields are in GRIB.

The complete system has run on Cray, Convex, SGI (f77 and f90), Fujitsu, and Dec Alpha, as well as GNU fortran supported machines, e.g. NEXT and Linux. Ports to massively-parallel architectures (with MPI) exist, but these are not (yet) available in the reference system.

The joint research and development project for HIRLAM is in its fourth phase, HIRLAM-4, and is very active in many areas. The research areas presently pursued in HIRLAM are as follows:

- ◊ Semi-Lagrangian time integration scheme.
- ◊ Spectral formulation.
- ◊ Lateral boundary conditions, reduced resolution near the boundaries.
- ◊ Radiation.
- ◊ Clouds and condensation.
- ◊ Turbulence parameterisation.
- ◊ Surface parameterisation.
- ◊ Physiography.

- ◊ Non-hydrostatic formulation.
- ◊ OI analysis.
- ◊ Development of variational analysis system (3D-VAR, 4D-VAR)
- ◊ Satellite data.
- ◊ Surface parameter analysis.
- ◊ Case studies and verification.
- ◊ Ports to massively parallel architectures.
- ◊ Documentation tools.

More information on HIRLAM can be found on:.

http://www.knmi.nl/hirlam/ (official HIRLAM homepage), and

http://www.dmi.dk

2.1 The operational DMI-HIRLAM system

The first DMI-HIRLAM system was implemented in autumn 1990, and it has subsequently been updated and tuned according to scientific progress and available computer resources. The DMI-HIRLAM forecasting system consists of pre-processing, analysis, initialization, forecast, post-processing and verification (Sass 1994, 1998,1999).

During the last year several updates of the system have taken place:

- ◊ new parametrization of precipitation and clouds (the STRACO scheme) with cloud water as a prognostic variable (Nielsen et. al. 1998)
- ◊ improved surface flux computations over sea as described in Nielsen (1998,1999)
- ◊ AIREPS (AMDAR) with a cutoff of plus/minus 30 minutes are available for the analysis
- ◊ high resolution physiographic data orography, land/sea mask, albedo and surface roughness (Sattler, 1999)
- ◊ upgrade of climate files

The operational system consists of several nested models named "G", "N", "E" and "D". The model areas are shown in Fig. 1. The properties of the models with respect to resolution, time step, and boundaries are specified in Table 1.

Fig. 2 shows the surface roughness of the models "E15" and "D05". It appears that "D05" is much more detailed than "E15".

Fig. 3 shows the vertical resolution of the DMI-HIRLAM system with 31 layers for all the model versions. It can be seen that the resolution is not very high in the boundary layer, and there are definite plans to increase the number of vertical layers in near future.

The operational time schedule is given in Table 2. The approximate arrival times of ECMWF boundary files are indicated. The runs are identified by 3 characters followed by a forecast length. The first character is the model identification, the two digits apply to the initial hour, e.g. G00+48h means an analysis at 00 UTC with model "G" followed by a 48 hour forecast.

The model "G" is used both to provide boundary values to the high resolution model "N" for Greenland, and to the high resolution model "E" over Europe. Finally, "E" provides the boundary values for "D".

The following options and specifications apply to the DMI operational system:

- HIRLAM 4.3 physics.
- Eulerian dynamics option.
- Linear fourth order horizontal diffusion.
- Vertical diffusion operates on variables updated by dynamics
- The STRACO scheme is used to parameterize precipitation.

- "Cloud Condensate" and "Turbulent Kinetic Energy" (TKE) are prognostic variables
- Turbulence parametrization based on TKE (Cuxart, Bougeault and Redelsberger, 1999)
- Convection closure based on "moisture convergence"
- Cloud Scheme (STRACO=Soft TRAnsition Condensation) based on statistical distributions of moisture (Sass, 1999)
- Microphysics and precipitation (Sundquist, 1993)
- Radiation scheme based on Savijaervi (1990
- Surface fluxes over sea includes the effect of "free convection"
- Use of ECMWF SST-data to update sea surface temperature and for diagnosing ice fraction as an alternative to the HIRLAM surface analysis programme NASU.

More information on the system can be found in Sass (1999).

2.2 DMI operational model areas.

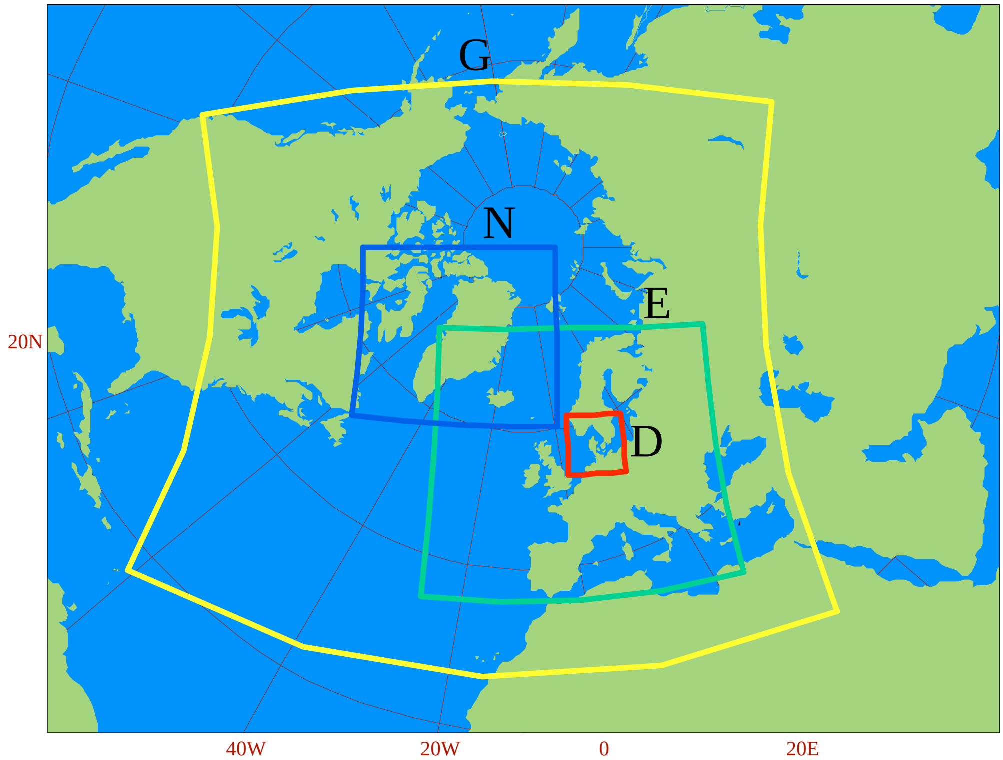

Fig. 1. Areas for the operational DMI-HIRLAM, since October 1997. The inner areas (E and N) are nested inside the outer area (G); and D is nested inside E. The boundary fields for the largest area version (G) are obtained from the European Centre for Medium-Range Weather Forecast (ECMWF). The model properties are given in table 1.

	G	N	E	D
grid points (mlon)	202	194	272	182
grid points (mlat)	190	210	282	170
No. of vertical levels	31	31	31	31
horizontal resolution	0.45°	0.15°	0.15°	0.05°
time step	240 s	90 s	90 s	30 s
boundary age	12 h	0 h	0 h	0 h
boundary frequency	1/(6h)	1/(1h)	1/(3h)	1/(1h)

Table 1. DMI-HIRLAM properties

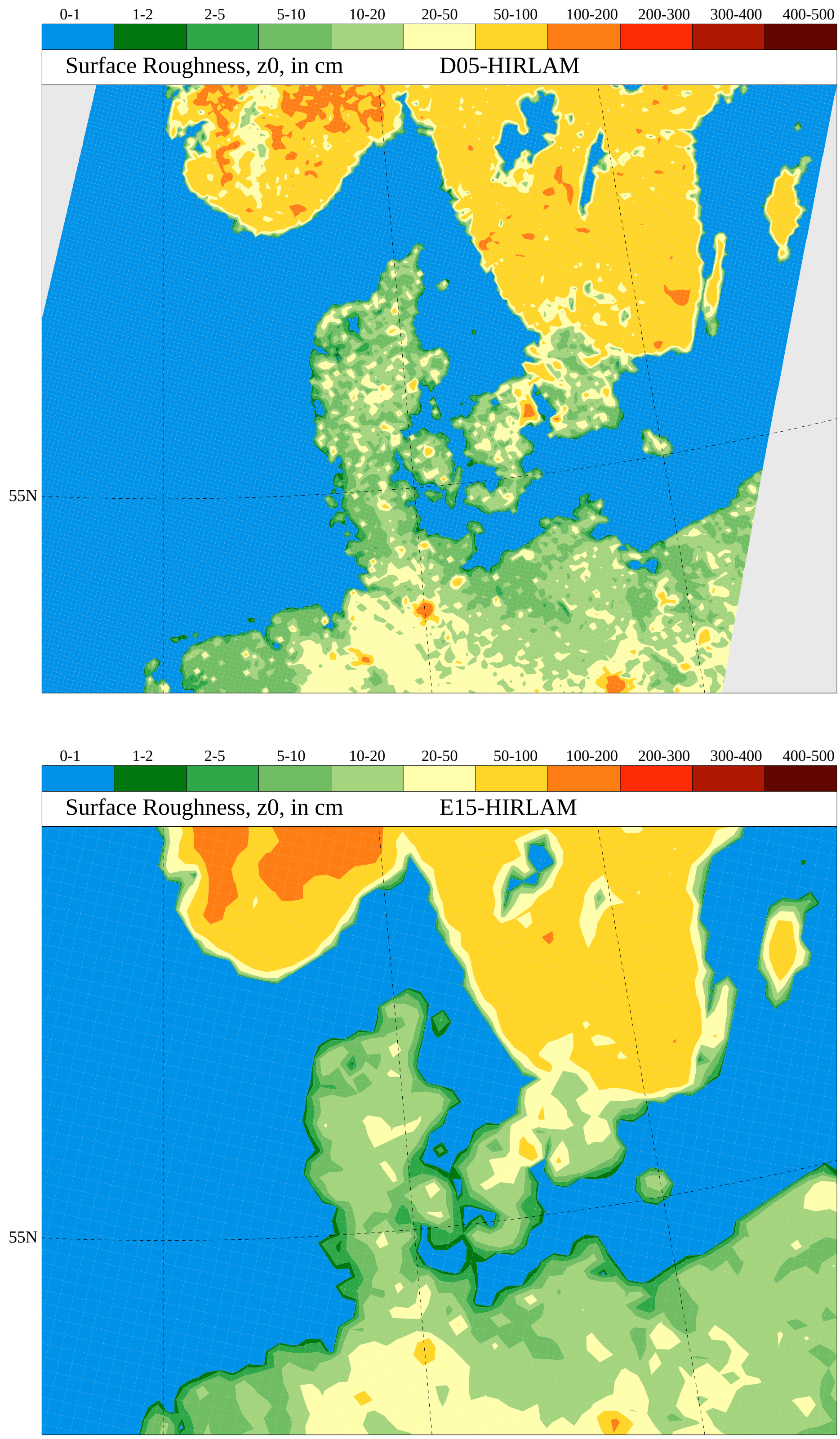

Fig. 2.a-b Surface roughness of the operational DMI-HIRLAM models "D05" and "E15". The roughness is based on high resolution physiographic data (Sattler , 1999).

2.3 Vertical resolution of the operational DMI-HIRLAM

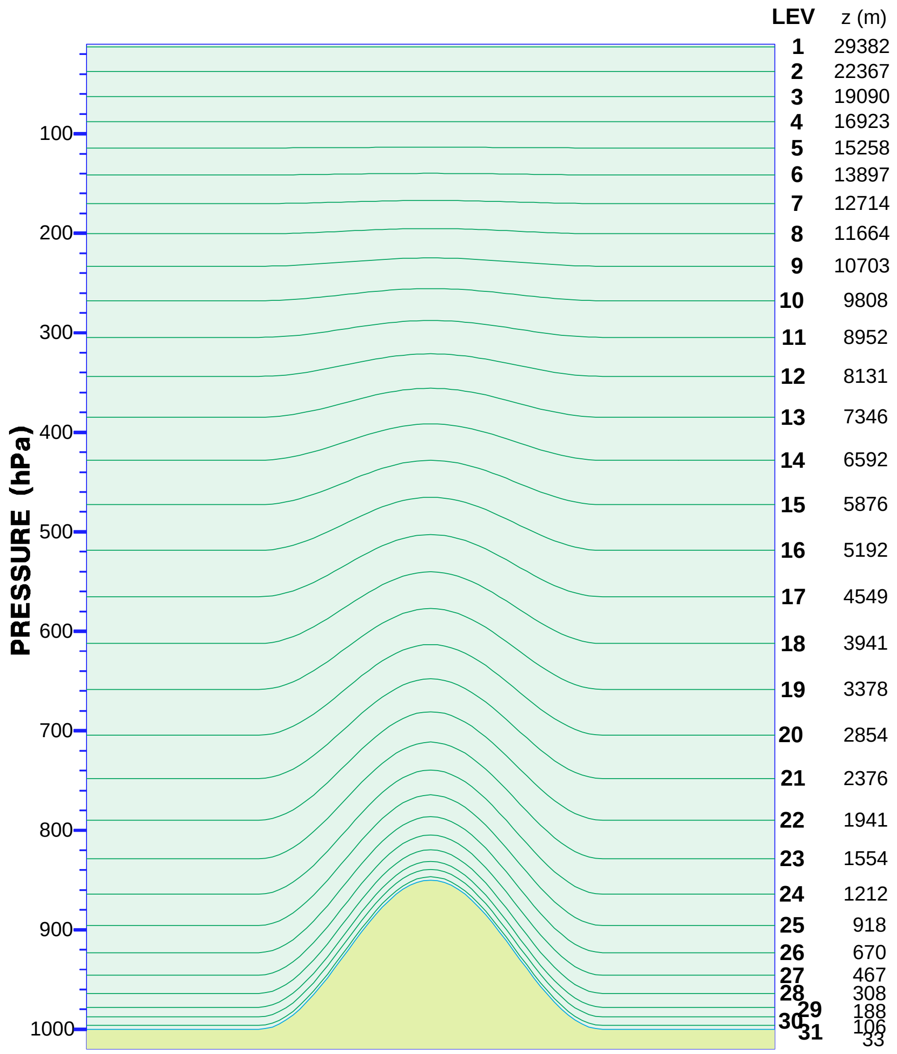

Fig. 3. Vertical resolution of the DMI-HIRLAM system. Full model levels are shown for surface pressure varying from 1000 hPa to 850 hPa. Values of z are given for a surface pressure of 1000 hPa and standard atmosphere temperature. The vertical resolution is the same for the different DMI-HIRLAM versions.

2.4 Operational time schedule

UTC	G	N	E	D
1:40	G00+48h			
1:50			E00+48h	
2:15				D00+36h
2:45	G00+60h			
3:00		N00+36h		
ECMWF 00 UTC				
7:40			E06+48h	
10:40	G06+06h			
10:45			E06+06h	
10:50				D06+06h
10:55		N06+06h		
13:40	G12+48h			
13:50			E12+48h	
14:15				D12+36h
14:45	G12+60h			
15:00		N12+36h		
19:40			E18+48h	
ECMWF 12 UTC				
22:40	G18+06h			
22:45			E18+06h	
22:50				D18+06h
22:55		N18+06h		

Table 2. Operational DMI-HIRLAM schedule

3 Verification methods

For numerical weather prediction it is difficult to construct an objective verification system that can handle the validation of the many different meteorological variables in time and space. Therefore mesoscale verification still relies on subjective evaluation, where value is put on the usefulness and guidance, rather than on the accuracy of forecasts, e.g. a correct model prediction of the development of a severe deep low - but somewhat out of phase in time and space - can be more valuable than just a prediction of an ordinary low development. However, in most objective verification systemsthe forecast out of phase will not get a high score.

The current objective verification systems are generally based on simple statistics (bias, rmse, and correlation) of the modelled values and measured values ("obs-verification") or comparison of model field values with analysed field values ("field-verification"). The baseline reference in any field-verification should ideally be independent of the model verified, e.g. analysis and short-range forecast from the ECMWF model.

At most European meteorological services the objective verification systems are based on the guidelines from the European Working Group on Limited Area Modelling (EWGLAM), cf. Hall (1987) with selected parameters, levels and a common list of radiosonde and synoptic stations, so that results can be intercompared.

The obs-verification system is well established and is used extensively - and most results presented in this report are based on obs-verification. But especially with the very high resolution models it can be difficult to base an objective system only on obs-verication as the resolution of the observation network is limited compared to the model resolution. Also there is the general problem with data quality and data representativity. Therefore field-verification will be more widespread in the future.

For nuclear emergency purposes the design of an objective verification system of the meteorological input data should ideally be based on tracer experiments (as ETEX). But as these experiments are difficult and expensive to accomplish, it is necessary to rely on a more traditional solution based both on obs-verification and field-verification. For RODOS the LSMC (Local Scale Model Chain) needs estimates of local model wind compared with observed local wind, while the LRMC (Long Range Model Chain) more needs verification of e.g. the wind over a large area, and therefore field-verification can be advantageous.

For nuclear emergency correct precipitation forecasts are extremely important for the dispersion modelling, but unfortunately precipitation is both difficult to forecast correctly and the verification of precipitation is notoriously difficult. Rainfall exhibits extreme small-scale variability, which is reflected in the observations. Until the advent of calibrated radar rainfall rates, which is anticipated to occur in few years time, good area comparisons and field-verification will be difficult.

In numerical weather prediction there is much attention on the forecasting of extreme and rare events - especially the development of deep lows with strong devastating wind and extreme precipitation systems. For nuclear emergency these extreme events usually will be accompanied with strong dispersion, so concentrations in the air will be low, while wet deposition will be large. On the other hand a special transport in certain layers - e.g. in connection with internal inversion layers, nocturnal jet etc. - is meteorologically not so interesting, but can have large importance for the nuclear dispersion.

Therefore a verification system for nuclear emergency systems, e.g. RODOS, cannot only use the results from a traditional numerical weather prediction verification system, but have to design a special system, which takes into account the many special transport possibilities. This is a difficult task, as there are many parameters, cf. Table 5, which are very difficult to verify due to lack of observations.

4 Verification results

In this report the results presented are mainly based on obs-verification of some standard meteorological parameters at some standard levels (2-meter temperature, 10-meter wind velocity, 850 hPa height, 850 hPa temperature, 850 hPa wind velocity), precipitation and one example of a field-verification. This is only a limited part of the general routine standard verification performed at DMI (Nielsen and Amstrup, 1999). Also presented are previous results of a sensitivity study of profiles from Jægersborg.

The statistics presented are standard, e.g.:

$$\text{Mean Error (ME or bias)} = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)$$

$$\text{Root Mean Square Error (rmse)} = \sqrt{\sum_{i=1}^{N}\frac{1}{N}(y_i - x_i)^2}$$

where y_i is the value calculated by the model and x_i is the observed value.

4.1 Obs-verification of surface parameters

The obs-verification is based on recommendations from EWGLAM (Hall, 1987). The list of radiosonde and synoptic stations is given in Fig. 10. For radiosondes most of the stations only observe at 00 and 12 UTC, but data from the few stations also observing at 06 and 18 UTC are included in the verification. For the synoptic stations data from 00, 06, 12 and 18 UTC are included.

The verification results in section 4.1 and 4.2 are based on result for "E15", i.e. the DMI-HIRLAM E version with 0.15^{o} horisontal resolution, cf. Table 1.

For the comparison between model versions "E" and "D", cf. section 4.3, the stationslist is given in Table 6.

4.1.1 Mean sea level pressure (mslp)

Mean sea level pressure (mslp). Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (Pa)	14.4	-3.5	14.6	13.1	12.6	2.1	4.6	9.8	18.2
rmse (Pa)	70.1	111.4	140.8	170.7	198.1	227.9	256.1	285.8	317.1

The mean biases of the E15 mslp forecasts are small, up to about 0.2 hPa (or 18 Pa) for a 48 forecast.

The rmse increases from 0.7 hPa for the analysis to about 3.2 hPa for the 48 hour forecast.

Fig. 11 shows the bias and rmse for the quarters in 1998. The largest errors generally appear in the 1st quarter, where we usually have also the largest variation in the pressure. The smallest errors in bias and rmse are found in the 3rd quarter.

4.1.2 2-meter temperature

2-meter temperature. Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (^oC)	-0.75	-0.86	-0.84	-0.81	-0.80	-0.84	-0.86	-0.88	-0.90
rmse (^oC)	2.36	2.38	2.41	2.44	2.50	2.56	2.62	2.67	2.75

The mean bias of the 2-meter temperature is negtive and quite stable, between -0.75 and -0.90 ^oC, while the rmse is slowly increasing from about 2.4 ^oC for the analysis to about 2.8 ^oC for the +48 hours forecast.

Fig. 12 shows that the bias in the 4th quarter is close to zero, while the bias for 1st quarter is around -1.6 ^oC, which means that the DMI-HIRLAM-E 2-meter temperatures are too low. For the rmse the largest errors appear in the 2nd and 1st quarter respectively and the lowest errors appear in the 3rd quarter.

The relatively large errors in the analysis are explained by the fact that 2-meter temperature is not included in the analysis-system (and the verified "analysis" are in fact a +6 hour forecast)

4.1.3 10-meter wind velocity

10-meter wind. Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (m/s)	0.11	0.11	0.14	0.20	0.22	0.24	0.24	0.25	0.24
rmse (m/s)	2.04	2.03	2.09	2.14	2.20	2.25	2.30	2.34	2.40

The mean bias of the 10-meter wind velocity is small, but slightly increasing during the forecast-sequence, from about 0.1 m/s to about 0.25 m/s. The rmse increases slowly from about 2.0 m/s for the analysis to about 2.4 for the +48 hour forecast.

Fig. 13 shows the largest bias in 4th quarter, while the largest rmse are in the 1st and 4th quarter. As for 2-meter temperature the relatively large errors in the analysis are explained by the fact that 10-meter wind is not included in the analysis-system (and the verified "analysis" are in fact a +6 hour forecast).

4.2 Obs-verification of 850 hPa parameters

4.2.1 Height at 850 hPa

Height at 850 hPa. Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (m)	0.22	-2.59	-0.72	-1.27	-0.98	-2.66	-2.19	-2.16	-1.48
rmse (m)	4.84	8.87	10.03	12.82	14.32	17.36	18.77	22.09	23.55

The mean bias of the height of the 850 hPa pressure level is generally negative and relatively small during the forecast period, with the largest bias around -2.7 m. The negative bias means that DMI-HIRLAM-E generally is too cold between the surface and the 850 hPa level. The rmse increases during the forecast, from about 5 m for the analysis to about 24 m for the +48 hour forecast.

Fig. 14 shows that the largest rmse is in the 1st quarter and the smallest errors in the 3rd quarter. Generally the yearly variation is not as large as for the surface parameters

4.2.2 Temperature at 850 hPa

Temperature at 850 hPa. Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (^{o}C)	0.20	0.23	0.24	0.28	0.27	0.26	0.24	0.23	0.22
rmse (^{o}C)	1.12	1.32	1.38	1.50	1.56	1.68	1.73	1.87	1.94

The mean bias of the temperature at 850 hPa level is positive, between 0.2 and 0.3 ^{o}C. The rmse increases from about 1.1 ^{o}C for the analysis to 1.9 ^{o}C for the +48 hour forecast.

Fig. 15 shows that the bias is positive in all quarters, and only the 4th quarter shows a clearly increasing bias with forecast length. The largest rmse is for the 1st quarter and smallest errors for the 2nd quarter.

4.2.3 Wind velocity at 850 hPa

10-meter wind. Mean bias and rmse, 1998. DMI-HIRLAM-E15									
	+00	+06	+12	+18	+24	+30	+36	+42	+48
bias (m/s)	-0.29	-0.06	0.05	0.27	0.33	0.40	0.41	0.42	0.42
rmse (m/s)	2.04	2.86	3.01	3.29	3.45	3.74	3.86	4.11	4.23

For the 850 hPa wind velocity there is a clear increasing trend in the bias, with negative bias around -0.3 m/s for the analysis to 0.4 for the +48 hour forecast.

Fig. 16 shows that the smallest errors both for the bias and rmse are in the 3rd quarter. The largest errors are in the 1st quarter.

4.3 Comparison of G45, E15 and D05

Fig. 17 shows the verification results for mslp, 2-meter temperature and 10-meter wind, for the three different versions of DMI-HIRLAM, G45, E15 and D05. The comparison is based on data for Danish coastal and land stations, cf. Table 6.

For the mslp there is no significant difference between coastal and land stations. For both the bias and rmse there is essentially no difference between E15 and D05, and for the rmse there is only a small improvement going from G45 to E15/D05. For the bias G45 is slightly better than E15/D05.

For the 2-meter temperature at the coastal stations there is no significant difference between the models. For the land stations E15/D05 have smaller rmse than G45. The oscillation seen in the bias of G45 appears because the long (+48 hour) forecasts are only performed at 00 UTC and 12 UTC, cf. Table 1. This means that +12, +24, +36 and +48 hour forecasts are verified against observations at 00 UTC and 12 UTC, while the +18, +30 and +42 hour forecasts are verified against 06 UTC and 18 UTC observations. The oscillation can be generated by a diurnal variation in the bias or/and by large differences in the number of observations available at the time of the two set of analyses. Note that the G45 analysis and +6 hour forecast are verified against observations at all main observation times (00, 06, 12 and 18 UTC).

For the wind velocity there are only minor differences for the coastal stations. For the land stations, however, there is a significant improvement with higher resolution.

4.3.1 Precipitation

As mentioned in section 3 correct precipitation forecasts can be extremely important for the nuclear dispersion and deposition modelling, but unfortunately precipitation is both difficult to forecast correctly and to verify.

At DMI (c.f. Nielsen and Amstrup, 1999) the verification of precipitation forecast is based on data from 25 danish synoptic stations, including 20 stations from Table 6.

Table 7 below shows contingency tables of 12-hour precipitation for the forecast interval from +6 hour to +18 for DMI-HIRLAM-E15. From the table it is clear that E15 generally overpredicts precipitation as E15 has 40.2 % in class P1 (≤0.2 mm), while observations show 57.1 % in this class. Class P2 and P3 are overrepresented in the model with 26.2 and 24.9 respectively against 11.4 and 13.9 in the observations. For the large precipitation amounts (P4 and P5) model and observations are of the same order.

From the table it also appears that when E15 predicts "dry" weather (≤0.2 mm) it most probably also will be "dry" weather.

E15	**O1**	**O2**	**O3**	**O4**	**O5**	**sum**
F1 (<0.2mm)	38.3	1.2	0.5	0.1	0.0	40.2
F2 (0.2-1.0mm)	19.3	4.1	2.1	0.5	0.1	26.2
F3 (1-5.0mm)	8.7	5.3	7.9	2.2	0.8	24.9
F4 (5-10.0 mm)	0.7	0.6	2.3	1.8	0.9	6.3
F5 (≥ 10 mm)	0.1	0.2	0.6	0.7	0.8	2.4
sum	67.1	11.4	13.5	5.4	2.6	100
% FO	57.1	36.1	58.8	33.5	30.8	53.0

Table 3. Contingency tables (%) of 12-hour forecasted (F) and observed (O) precipitation. The precipitation classes (P) are given in the left column. FO is the percentage of the forecasted values in the same class as the observation class. The forecast is in the interval from +6 hour to +18 for the DMI-HIRLAM-G45. Data from 25 synoptic stations in Denmark from 1998.

In Table 7 and Table 8 the results are shown for D05 and G45. It appears that there is no significant difference between the models, but there are some minor differences; e.g. D05 has 4 % cases in F5, while G45 has 1.9 % in F5 - and observations showed 2.6 %.

4.4 Field verification results:

As discussed in section 3 the obs-verification has certain limitations (limited resolution in observation network compared with model resolution, data quality and data representativity). At DMI field-verification is performed for several parameters (Nielsen and Amstrup, 1999). Here is only showed one example, cf. fig. Fig. 20, showing the bias and standard deviation of mslp for the G45 +24 hour forecast for January, 1999. It appears that the largest errors are found in the Arctic, while the errors in Europe are relatively small for this month.

4.5 Profiles of wind and temperature

This section gives a summary of results from a sensitivity study of DMI-HIRLAM profiles of temperature and wind for the radiosonde station Jægersborg in Denmark, cf. e.g. *RODOS(WG2)-RP(97)10,-13,-14.*

It is emphasised that the study is based on older DMI-HIRLAM-data from 1994 to 1995, and that the model in the meantime has been further developed in many respects, especially regarding the boundary layer parametrisation (Nielsen et. al. 1999; Holtslag et. al., 1993; Cuxart et. al., 1995, Gollvik et. al., 1995) and physical parametrisation (Nielsen et. al.,1999; Sass et. al, 1999). Verification based on case-studies (Nielsen, personal communication) shows that the new parameterisation in general gives better results than the old parameterisation, and especially in convective conditions it gives more realistic profiles in the boundary layer.

In the previous operational version of DMI-HIRLAM the vertical diffusion scheme was based on a local approach (so-called K theory), i.e. the turbulent flux of the quantity is proportional to the local gradient of the quantity. Moreover, the proportionality factor (eddy diffusivity) depends on local gradients of mean wind and mean virtual temperature. This applies in the ABL under neutral and stable conditions, while the local approach is not appropriate under unstable and convective conditions, due to the nonlocal transport of the convective plumes.

Therefore, a nonlocal diffusion scheme has been developed according to Troen and Mahrt (1986) and Holtslag et al. (1993). In the nonlocal scheme, the eddy diffusivity is described by a profile on basis of diagnosed boundary layer height and a turbulent velocity scale.

Fig. 4 and Fig. 5 show two examples of vertical profiles of temperature, dew point temperature and wind observed at the radiosonde station Jægersborg and calculated by DMI-HIRLAM (analysis). On February 27 we had frontal precipitation and the observed temperature profile has a well-defined boundary layer up to about 600 meters, while the height of the boundary layer from the DMI-HIRLAM-profile is about 400 meters. Below 400 meters and above 1300 meters the agreement is fairly good. Note the fine agreement for the wind veering from easterly to westerly wind, though the wind velocity is too small in the lowest layers.

July 1, Fig. 4, the weather is dry with some sunshine and scattered cumulus clouds and northwesterly winds. The agreement between the observed and DMI-HIRLAM profiles is fairly good for temperature, wind direction and wind velocity, while the humidity is too high above the inversion. The estimated height of the boundary layer is more shallow than observed, but the difference is relatively smaller than in the previous figure.

The mean profiles for the temperatures at 00 and 12 UTC, for the period July to September, 1994, are shown in Fig. 6. Near the ground the HIRLAM temperature is too low during day, and too high during night, and above 400 meters the HIRLAM temperature is slightly too high, both during day and night.

Fig. 7 shows the mean error (ME) and mean absolute error (MAE) for the temperature profiles at 12 UTC for the period July to September, 1994, for the HIRLAM analysis (+00h) and the 24-hour forecast (+24h). The MAE is around 1.7°C near ground, decreasing to about 1.0 °C above 200 meters. The ME is around -0.8 °C near ground, becoming positive above 300 meters, indicating that the model profiles are too stable.

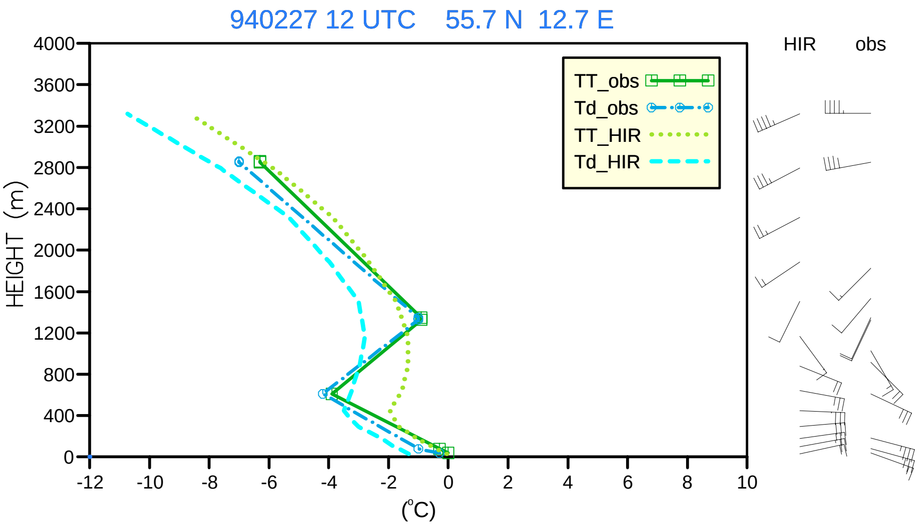

Fig. 4. Profile from February 27, 1994 12 UTC of temperature (TT), dew point temperature (Td) and wind (WMO-standard) observed at Jægersborg and calculated by DMI-HIRLAM.

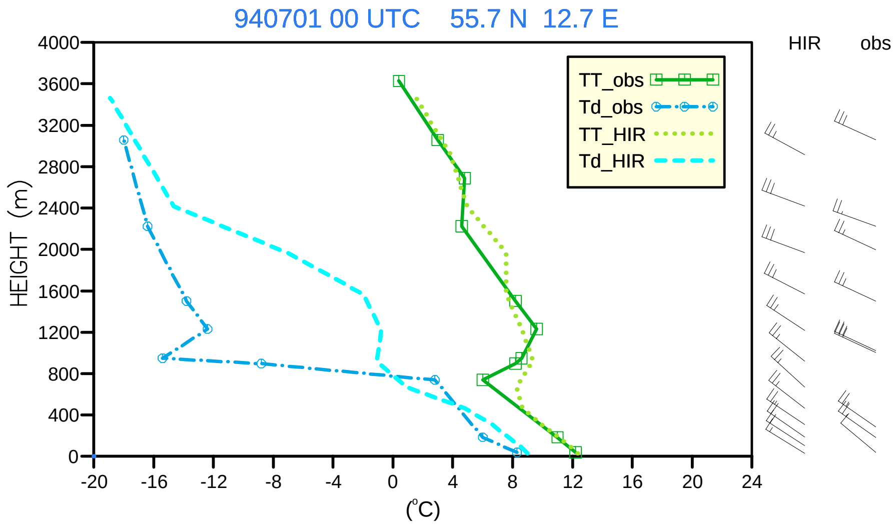

Fig. 5. As Fig. 4, but for July 01, 1994 00 UTC

The mean profiles of the wind velocity at 00 UTC and 12 UTC for the period July to September, 1994, are shown in Fig. 8, and the corresponding ME and MAE at 00 UTC are shown in Fig. 9. Generally the HIRLAM wind velocity is too high near ground, and the diurnal variations are not correctly described, so the gradient of the model wind velocity can be erroneous. This is especially important if one uses local gradients of, e.g., the Richardson number. The MAE is generally around 1.5 m/s for the analysis and 2 to 3 m/s for the 24-hour forecast, but in the case shown MAE is around 1.7 m/s both for the analysis and for the forecast.

Profiles for 1995 can be seen in the appendix, Fig. 18 and Fig. 19

Table 4 summarizes the ME and MAE of the temperature profiles at the 50-meter level for 1994 and 1995. The errors are generally largest for the day-time temperature during summer, with MAE around 2°C in 1994 and 1.5°C in 1995, but during the cold weather in the autumn of '95 the model gave too high temperatures, resulting in a positive bias of 2.4°C at night.

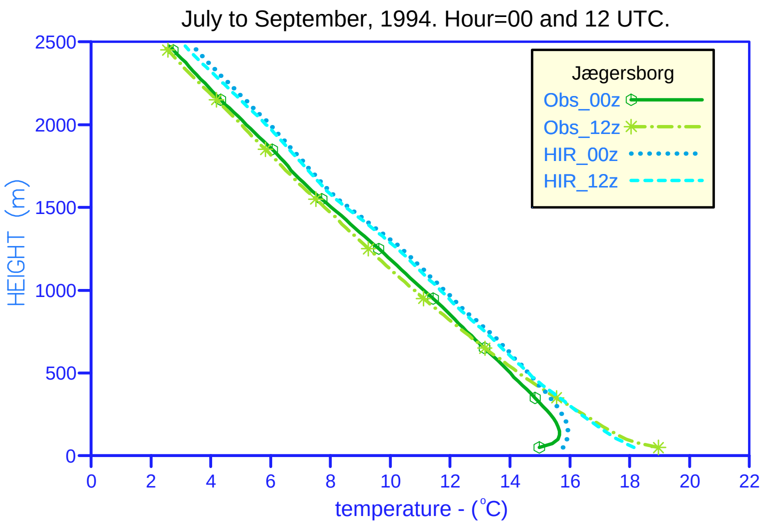

Fig. 6. The mean profiles of the temperature at 00 and 12 UTC for the period July to September 1994.

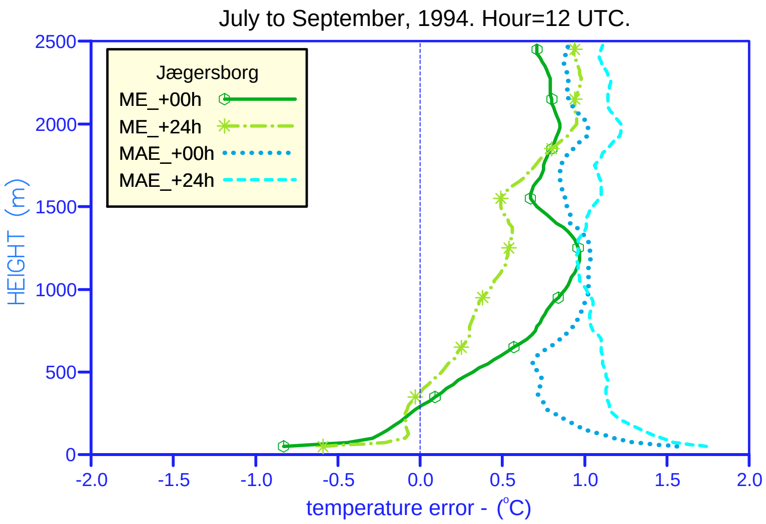

Fig. 7. Mean error (ME) and mean absolute error (MAE) for the temperature profiles at 00 UTC for the period January to March 1994 for the HIRLAM analysis (+00h) and the 24 hours forecast (+24h).

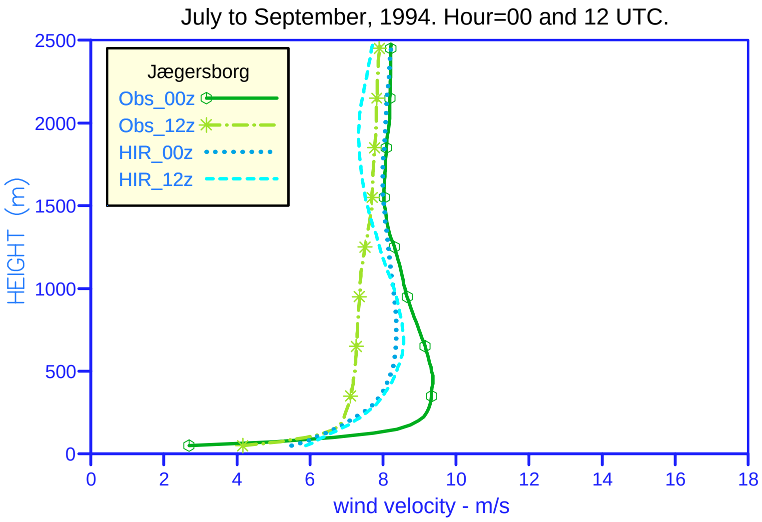

Fig. 8. The mean profiles of the wind-velocity at 00 and 12 UTC for the period July to September 1994.

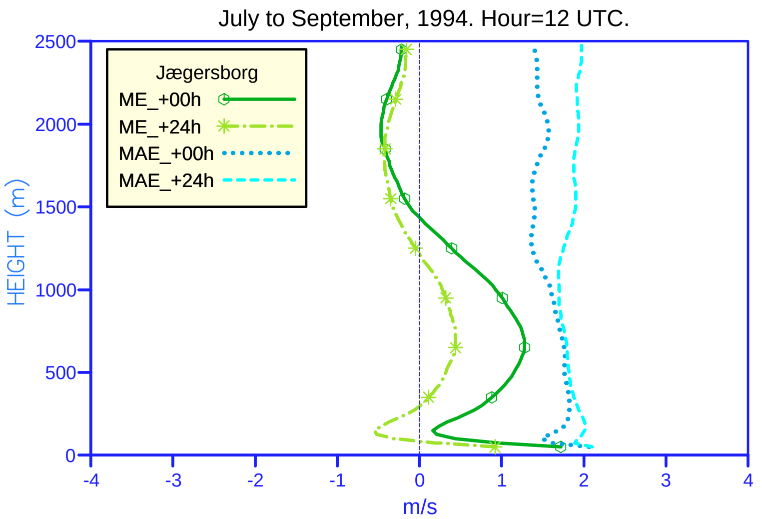

Fig. 9. Mean error (ME) and mean absolute error (MAE) for the velocity profiles at 12 UTC for the period July to September 1994 for the HIRLAM analysis (+00h) and the 24 hours forecast (+24h).

Period Error	ME 00 UTC	ME 12 UTC	MAE 00 UTC	MAE 12 UTC
Jan.-Mar., "94	0.4	-0.7	1.2	1.3
Apr.-June, "94	0.1	-2.1	1.4	2.4
July-Sept.,"94	1.1	-1.2	1.7	2.0
Okt.-Dec.,"94	1.7	0.3	1.8	1.0
Jan.-Mar., "95	0.4	-0.5	0.8	1.0
Apr.-June, "95	0.3	-1.1	1.4	1.7
July-Sept.,"95	0.9	-1.4	1.6	1.7
Okt.-Dec.,"95	2.4	0.6	2.5	1.5

Table 4. ME and MAE of the HIRLAM temperature profiles at about 50 meter height for Jægersborg 1994-95.

5 Conclusion

HIRLAM is a state-of-the-art analysis and forecast system for numerical weather prediction with a cooperation very active in a wide range of areas to improve the forecasting system in general, and - important for the nuclear emergency - with focus on improving forecast of precipitation, turbulence parameters and wind.

The standard routine verification of DMI-HIRLAM is based on guidelines from the European Working Group on Limited Area Modelling (EWGLAM) on the statistics of the modelled values and measured values ("obs-verification") or of the model field values and analysed field values ("field-verification"). The guidelines include recommendations on parameters, levels and a common list of radiosonde and synotic stations, so results can be intercompared.

For nuclear emergency purposes the design of an objective verification system of the meteorological input data should ideally be based on tracer experiments (as ETEX). From previous RODOS reports it appears that the results of the model simulations of the first ETEX experiment by the Danish Emergency Response Model of the Atmosphere (DERMA) utilising high-resolution data from the DMI-HIRLAM were very successful. The analysis showed that in general the use of DMI-HIRLAM data gave better results than the use of ECMWF data, in particular the use of DMI-HIRLAM data could explain some of the observed mesoscale features in the tracer gas measurements.

But as tracer experiments are difficult and expensive to accomplish, it is necessary to rely on traditional verification systems based both on obs-verification and field-verification. Concerning RODOS the LSMC (Local Scale Model Chain) needs estimates of local model wind compared with observed local wind, while the LRMC (Long Range Model Chain) rather needs verification of e.g. the wind over a large area, and therefore field-verification can be advantageous.

In this document some results of the standard verification performed at DMI and also results of a previous sensitivity study of vertical profiles of temperature and wind from DMI-HIRLAM are presented.

The results of the obs-verification for the EWGLAM stations (91 radiosonde stations and 371 synoptic stations) show that the resemblance between measurements and the DMI-HIRLAM analyses and forecasts in general is quite good. For the DMI-HIRLAM-E15 the root mean square error (rmse) of the 2 m-temperature is around 2.5 ^{o}C; for the 850 hPa temperature the rmse is about 1 ^{o}C for the analysis increasing to about 2 ^{o}C for a 48 hour forecast. For the 10 m-wind velocity the rmse is around 2 m/s; for the 850 hPa wind velocity the rmse is around 2 m/s for the analysis increasing to about 4 m/s for a 48 hour forecast.

Comparison of the different model versions, G45, E15 and D05, shows no significant difference between E15 and D05 for most parameters, but for the 2-meter temperature and especially the 10-meter wind there is a significant improvement with higher resolution.

Precipitation verification based on data from 25 Danish synoptic stations shows that for E15 around 53% of the precipitation forecasts are in the correct class. The main reason for the errors is a general overprediction of small amount of precipitation by DMI-HIRLAM. The results for G45 are slightly better, and the results from D05 slightly worse.

The results of the sensitivity study of vertical profiles of temperature and wind from DMI-HIRLAM from 1994-95 shows that the resemblance between measurements and the DMI-HIRLAM profiles at Jægersborg is quite good, but especially in unstable and convective conditions errors in the temperature profiles can be caused by a too weak development of the boundary layer.

Also the diurnal variation of the DMI-HIRLAM temperature near ground is too small; and the diurnal variation of the DMI-HIRLAM velocity is too small, especially DMI-HIRLAM does not reproduce well the nocturnal jet.

However, a new boundary layer parameterization, implemented in the DMI-HIRLAM together with a new physical package, seems to result in significant improvements, producing more realistic profiles and deeper unstable boundary layers.

6 References

6.1 Relevant RODOS reports:

RODOS (WG2)-RP(97)10: *Quality Validation of Analyzed and Forecast Vertical Profiles of Wind and Temperature from the DMI-HIRLAM Model in Comparison with Radiosoundings,* by Alix Rasmussen and Jens Havskov Sørensen. Published in: Proceedings of the Sixth Topical Meeting on Emergency Preparedness and Response, American Nuclear Society, San Francisco, California, April 22-25, 1997. pp 31-34.

RODOS (WG2)-RP(97)11: *Comparison of Measured and Modelled Mixing Heights during the Borex"95 Experiment,* By T. Mikkelsen, P. Astrup, H. E. Jørgensen, S. Ott, J. H. Sørensen, P. Løfstrøm. In: The Determination of the Mixing Height - Current Progress and Problems. EURASAP Workshop Proceedings, Oct. 1-3, 1997, Risø National Laboratory, pp 109-112. Risø-R-997(EN) ISBN 87-550-2325-8, ISSN 0106-2840,

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RODOS (WG2)-RP(97)14: *Validation of Mixing Height Determined from Vertical Profiles of Wind and Temperature from the DMI-HIRLAM* NWP Model in Comparison with Radiosoundings, by A. Rasmussen, J.H. Sørensen and N.W. Nielsen. In: The Determination of the Mixing Height - Current Progress and Problems. EURASAP Workshop Proceedings, 1-3 October, 1997, Risø National Laboratory, Eds: S.-E. Gryning, F. Beyrich and E. Batchvarova, Risø-R-997(EN) ISBN 87-550-2325-8, ISSN 0106-2840, pp. 101-104

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RODOS (WG2)-RP(97)19: *Method for Calculation of Atmospheric Boundary-Layer Height used in ETEX Dispersion Modeling*, by J. H. Sørensen and A. Rasmussen.. In: Proceedings of the Sixth Topical Meeting on Emergency Preparedness and Response, April 22-25, 1997, San Francisco, California, pp. 503-506, ISBN 0-89448-623-3.

RODOS(WG2)-TN(99)10: *User's manual for the Atmospheric Dispersion Module: MET-RODOS*, by Torben Mikkelsen, Søren Thykier-Nielsen, Poul Astrup, Sandor Deme, Jens Havskov Sørensen, Alix Rasmussen, Jürgen Päsler-Sauer, Thomas Schichtel, Wolfgang Raskob and Reinhard Martens.

RODOS(WG2)-TN(99)11: *Description of the Numerical Weather Prediction Database HIRLAM*, by Jens Havskov Sørensen, Alix Rasmussen, Torben Mikkelsen , Søren Thykier-Nielsen , Poul Astrup and Sandor Deme.

6.2 Other References:

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7 Appendix -Table 5 - Table 8

SINGLE-LEVEL FIELDS	
• surface geopotential	• surface pressure
• sea surface temperature	• surface temperature
• 2-meter temperature	• 2-meter specific humidity
• 10-meter *u* wind component	• 10-meter *v* wind component
• fraction of ice	• fraction of land
• albedo	• dynamic (sea) surface roughness
• climatological surface roughness	• surface sensible heat flux
• surface latent heat flux	• accumulated stratiform precipitation
• surface momentum flux	• atmospheric boundary layer height
• accumulated convective precipitation	
MULTI-LEVEL FIELDS	
• *u* wind component	• *v* wind component
• temperature	• specific humidity

Table 5. Fields delivered by DMI for RODOS partners during the project

Land Stations	Coastal stations
WMO-no station name	WMO-no station name
06030 Ålborg	06041 Skagen
06034 Sindal Airp.	06052 Thyborøn
06048 Hadsundbroen	06058 Hvide Sande
06060 Karup	06071 Fornæs Fyr
06070 Tirstrup	06079 Anholt Havn
06104 Billund	06081 Blåvandshuk Fyr
06110 Skrydstrup	06096 Rømø
06120 Odense Airp.	06119 Kegnæs Fyr
06143 Lolland-Falster Airp.	06142 Albuen
06153 Tyvelse	06149 Gedser Odde
06160 Værløse	06151 Omø Fyr
06170 & Roskilde Airp	06165 Hesselø

Table 6. Danish land and coastal station list. (The stations 06034, 06048, 06143 and 06153 have stopped operation after 1998).

D05	**O1**	**O2**	**O3**	**O4**	**O5**	**sum**
F1 (<0.2mm)	37.8	1.6	0.7	0.1	0.0	40.3
F2 (0.2-1.0mm)	18.8	3.3	2.0	0.5	0.1	24.6
F3 (1-5.0mm)	9.8	5.2	6.9	2.0	0.7	24.6
F4 (5-10.0 mm)	0.8	0.7	2.4	1.9	0.6	6.5
F5 (≥ 10 mm)	0.4	0.4	1.2	1.0	1.0	4.0
sum	67.6	11.3	13.2	5.4	2.6	100
% FO	55.9	29.0	52.4	34.5	40.8	50.9

Table 7. Contingency tables (%) of 12-hour forecasted (F) and observed (O) precipitation. The precipitation classes are given in the left column. FO is the percentage of the forecasted values in the same class as the observation class. The forecast is in the interval from +6 hour to +18 for the DMI-HIRLAM-D05. Data from 25 synoptic stations in Denmark from 1998.

G45	**O1**	**O2**	**O3**	**O4**	**O5**	**sum**
F1 (<0.2mm)	40.8	1.5	0.8	0.1	0.1	43.3
F2 (0.2-1.0mm)	19.0	4.4	3.0	0.9	0.4	27.7
F3 (1-5.0mm)	6.8	4.8	7.2	2.3	0.9	21.9
F4 (5-10.0 mm)	0.4	0.5	1.9	1.5	0.8	5.2
F5 (≥ 10 mm)	0.1	0.1	0.6	0.6	0.5	1.9
sum	67.2	11.3	13.5	5.5	2.6	100
% FO	60.8	38.8	53.5	27.7	18.4	54.4

Table 8. Contingency tables (%) of 12-hour forecasted (F) and observed (O) precipitation. The precipitation classes are given in the left column. FO is the percentage of the forecasted values in the same class as the observation class. The forecast is in the interval from +6 hour to +18 for the DMI-HIRLAM-G45. Data from 25 synoptic stations in Denmark from 1998.

8 Appendix - Fig. 10 - Fig. 19

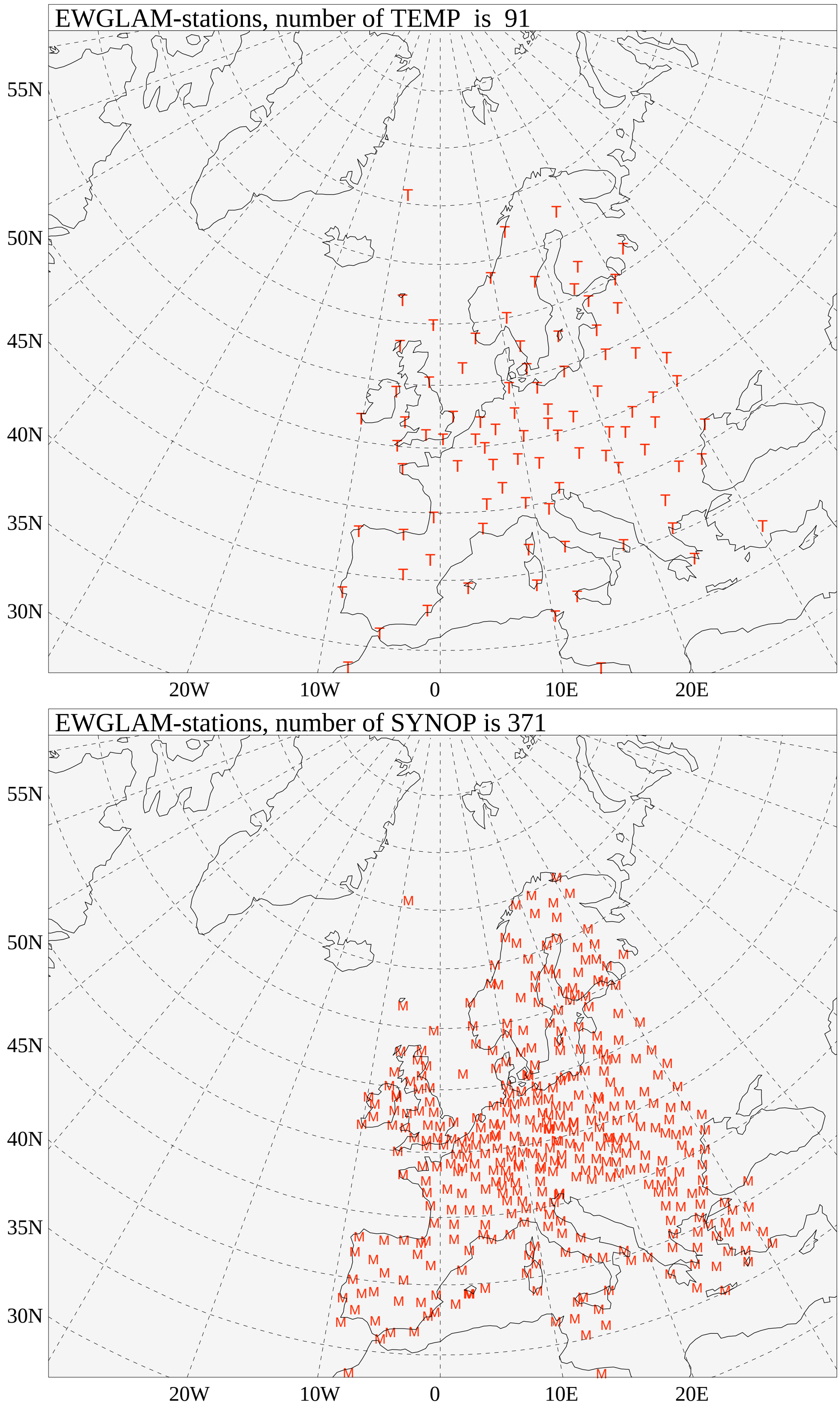

Fig. 10.a-b EWGLAM stationlist for the objective verification, Radiosondes (upper) and synoptic stations (lower).

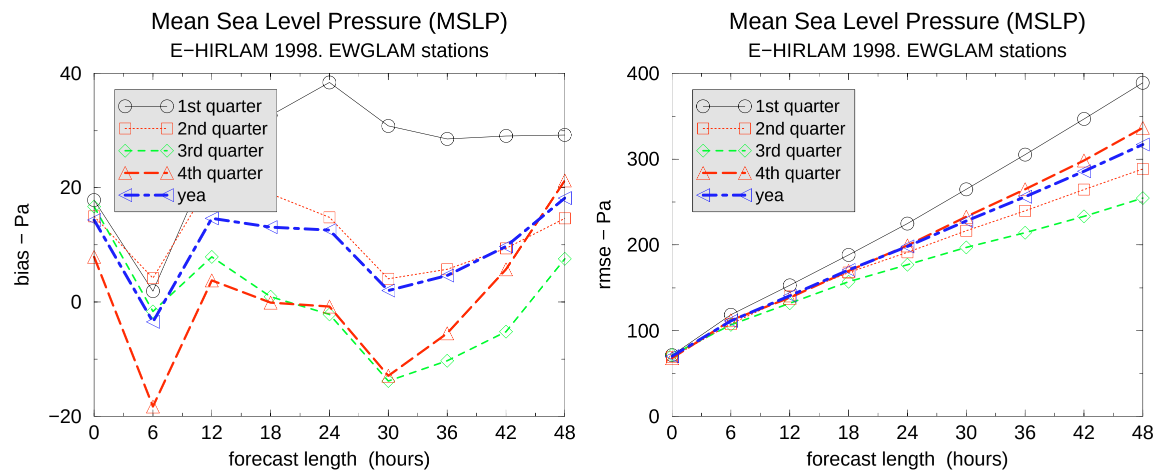

Fig. 11. Bias (left) and rmse of MSLP for E-HIRLAM. EWGLAM-stations, 1998.

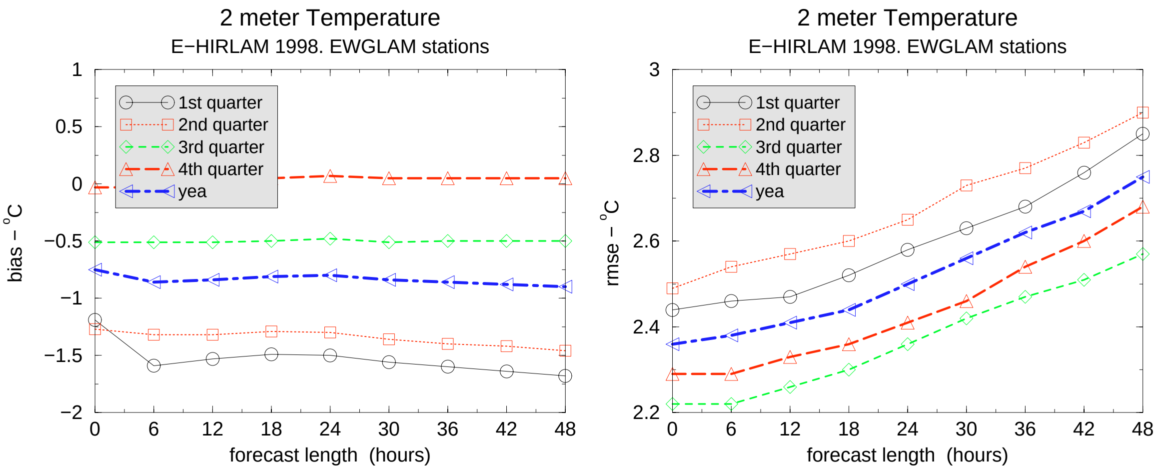

Fig. 12. Bias (left)and rmse of 2-meter temperature for E-HIRLAM. EWGLAM-stations, 1998.

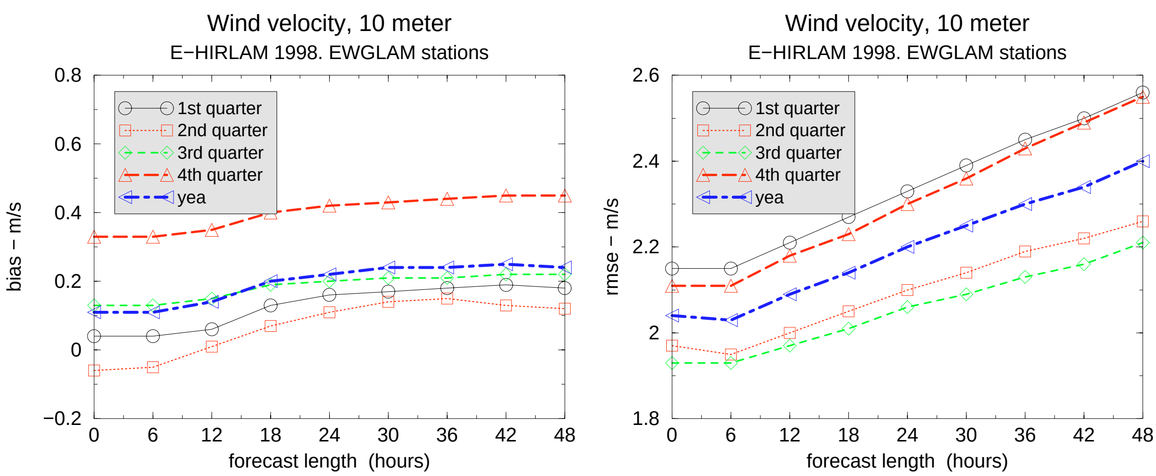

Fig. 13. Bias (left)and rmse of 10-meter wind velocity for E-HIRLAM. EWGLAM-stations, 1998.

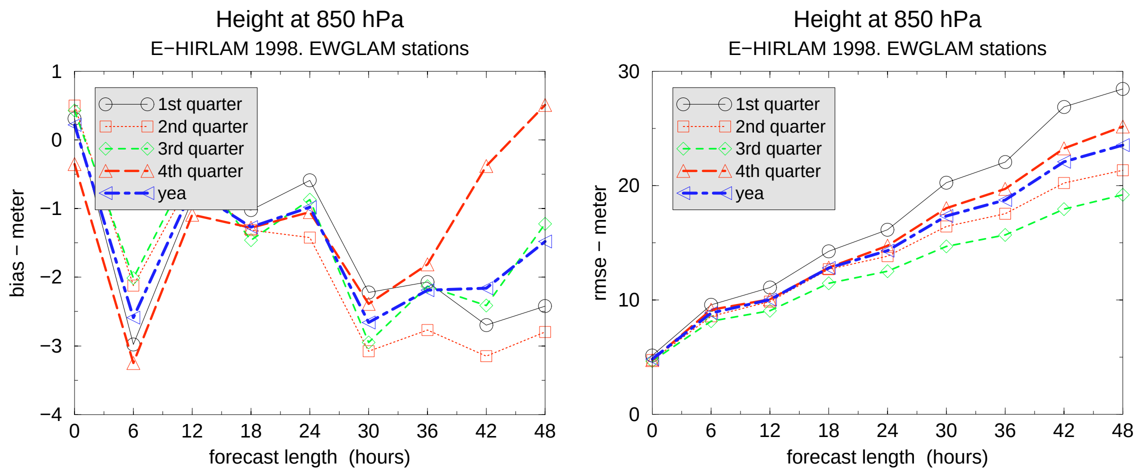

Fig. 14. Bias (left) and rmse of height at 850 hPa for E-HIRLAM. EWGLAM-stations, 1998.

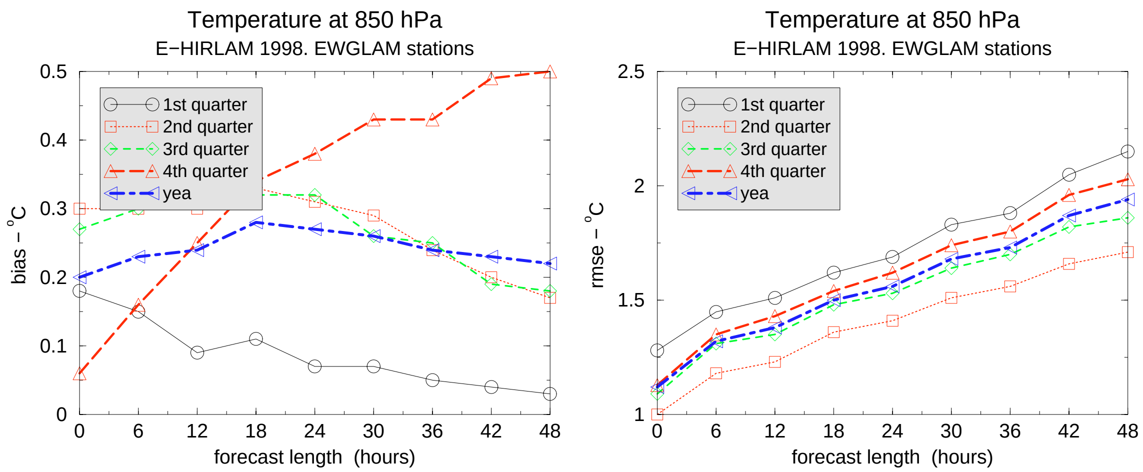

Fig. 15. Bias (left) and rmse of 850 hPa temperature for E-HIRLAM. EWGLAM-stations, 1998.

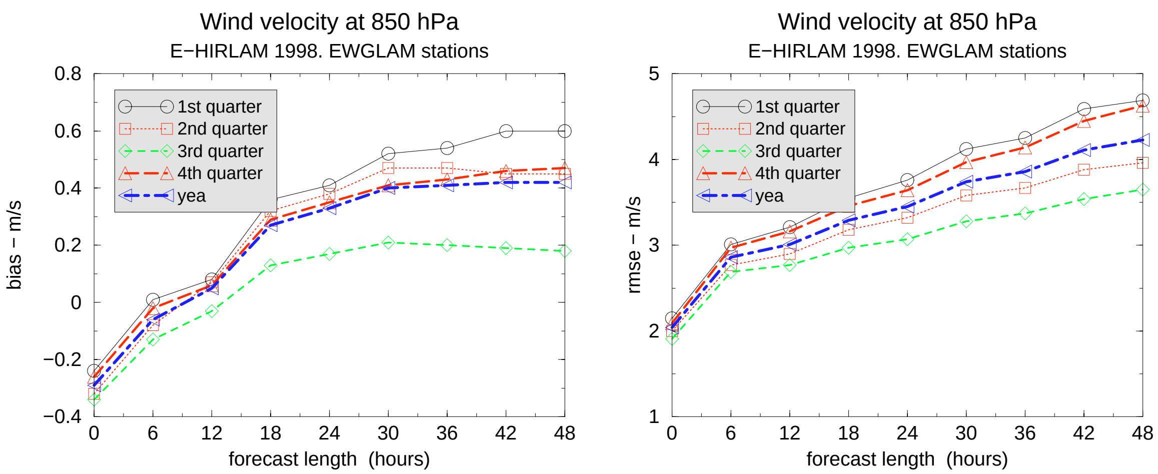

Fig. 16. Bias (left) and rmse of wind velocity at 850 hPa for E-HIRLAM. EWGLAM-stations, 1998.

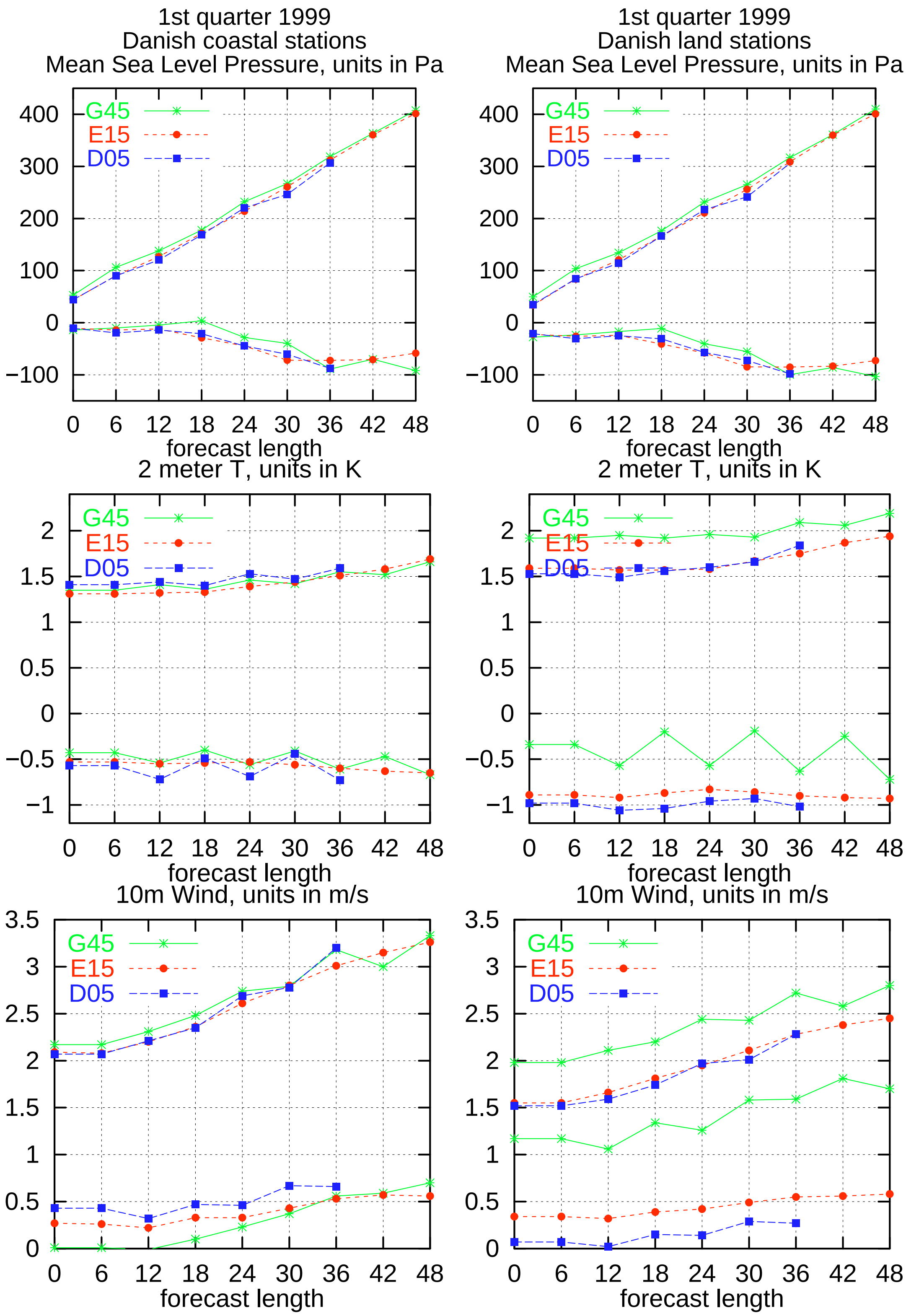

Fig. 17. Verification results for the 12 coastal stations (left) and 12 land stations (stations) of mean sea level pressure (mslp), 2-meter temperature and 10-meter wind velocity for G45, E15 and D05. Data from 1st quarter of 1999.

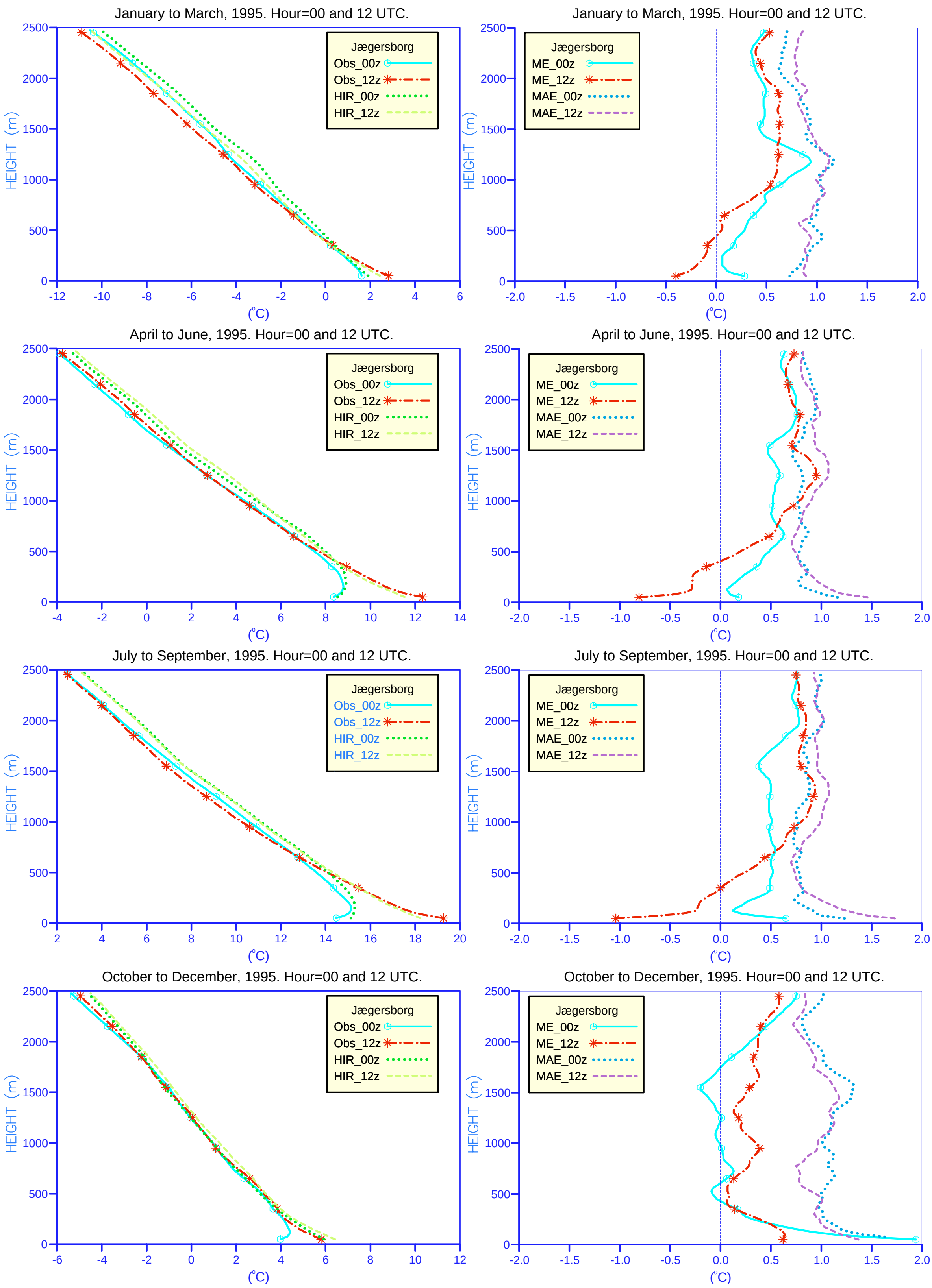

Fig. 18. The mean profiles(left) of the temperature at 00 and 12 UTC for 1995. The corresponding mean error (ME) and mean absolute error (MAE) to the right.

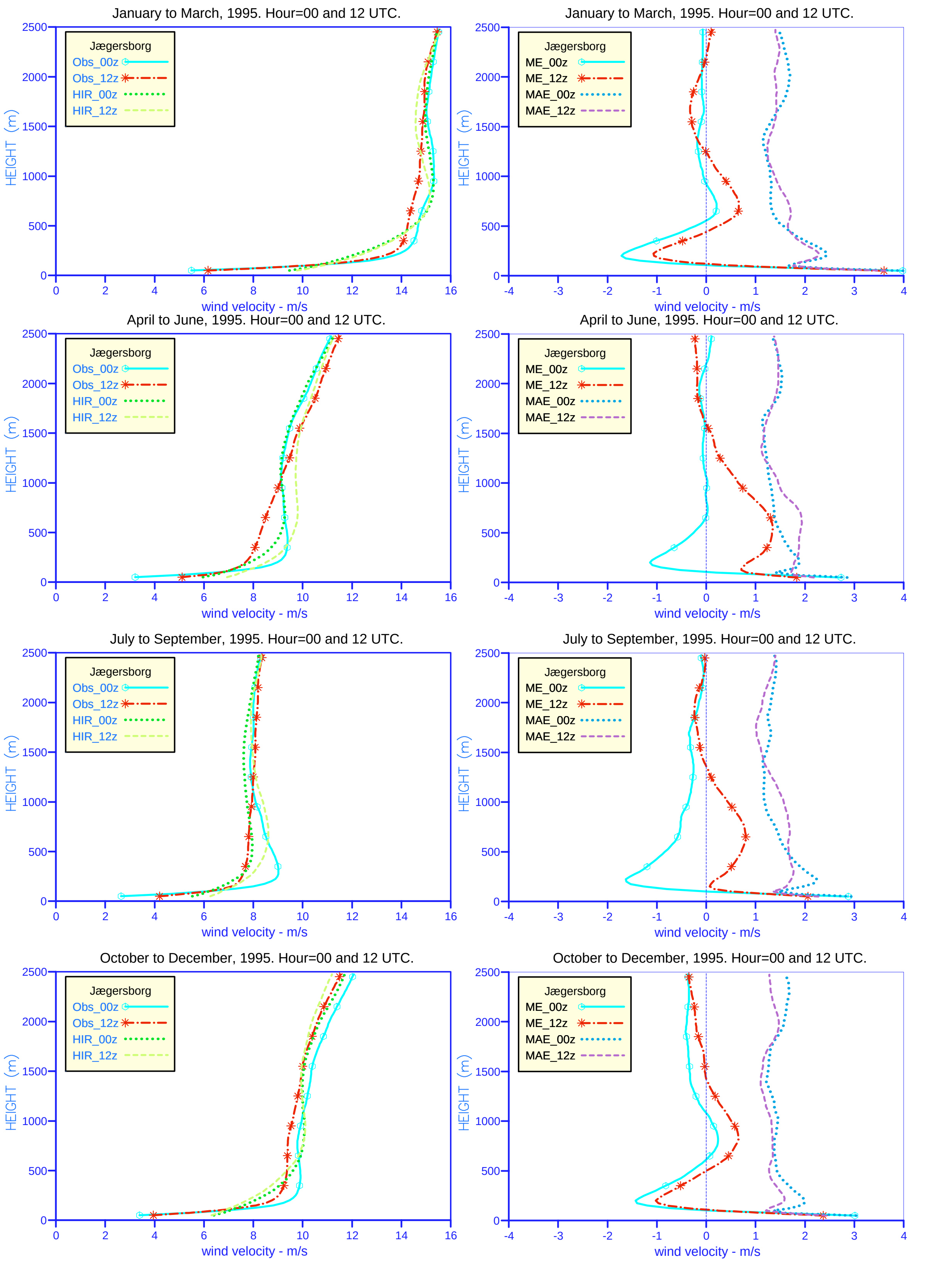

Fig. 19. The mean profiles (left) of the wind-velocity at 00 and 12 UTC for 1995. The corresponding mean error (ME) and mean absolute error (MAE) to the right.

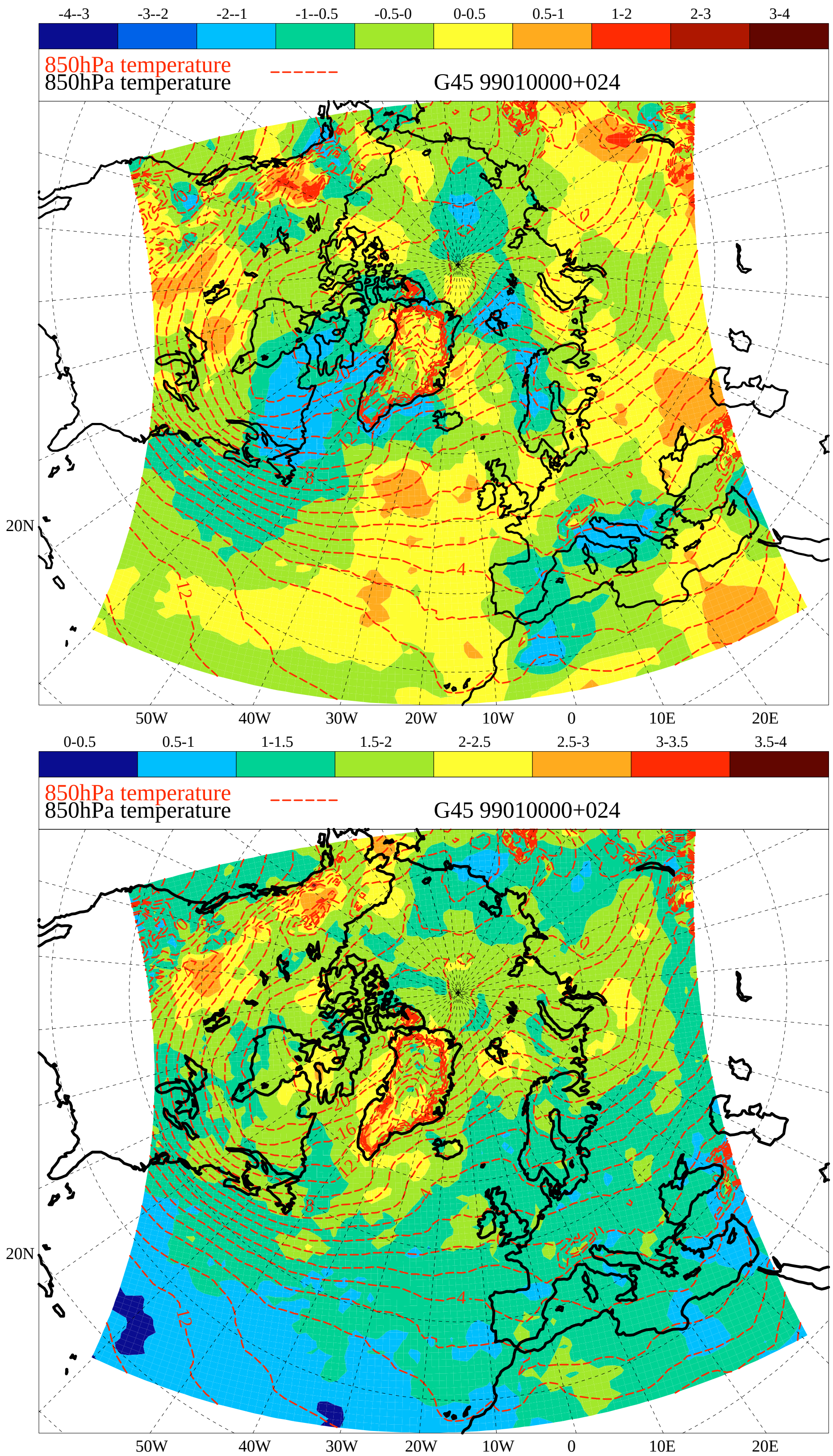

Fig. 20.a-b. Standard deviation (lower) and bias (upper) of 850 hPa level temperature for G45, January 1999.

9 Document History

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