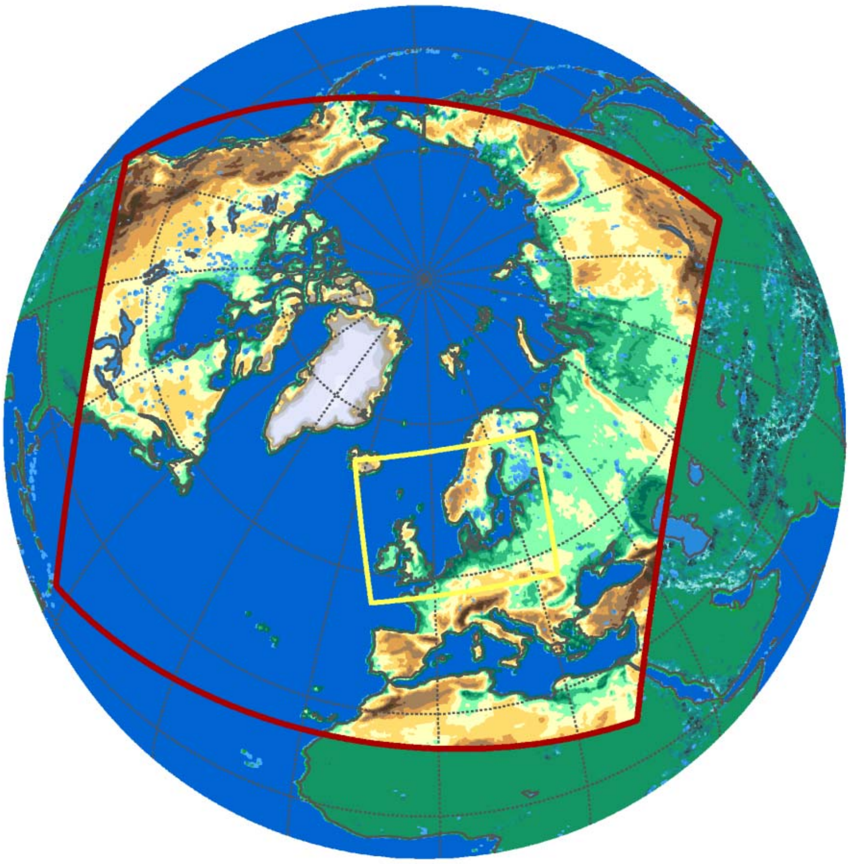
Danish Meteorological Institute
Ministry of Transport

Technical Report 05-13

Performance of DMI-HIRLAM-T15 and DMI-HIRLAM-S05 and the storm surge model in winter storms

Claus Petersen, Maryanne Kmit, Niels Woetmann Nielsen,
Bjarne Amstrup and Vibeke Huess



Colophone

Serial title:
Technical Report 05-13

Title:
Performance of DMI-HIRLAM-T15 and DMI-HIRLAM-S05 and the storm surge model in winter storms

Subtitle:

Authors:
Claus Petersen, Maryanne Kmit, Niels Woetmann Nielsen, Bjarne Amstrup and Vibeke Huess

Other Contributers:

Responsible Institution:
Danish Meteorological Institute

Language:
English

Keywords:
HIRLAM, storm surge, HIRLAM reference system, verification

Url:
www.dmi.dk/dmi/tr05-13

ISSN:
1399-1388

Version:

Link til hjemmeside:
www.dmi.dk

Dansk Resume

DMI's numeriske vejrprognosesystem, DMI-HIRLAM, er blevet udskiftet med en ny version af HIRLAM, der grundlæggende er en tilbagevenden til Reference HIRLAM. Den tidligere version af DMI-HIRLAM var baseret på en tidlig version af Reference HIRLAM, men havde inkluderet en del DMI-specifikke features. Disse havde både betydning for den tekniske afvikling af modellen og den meteorologiske ydeevne. I denne report er det godtgjort, at den meteorologiske ydeevne er forbedret en anelse i forhold til den foregående version. Dette er klargjort ved en standardverifikation for en vinterperiode og ved en subjektiv sammenligning mellem den nye og den gamle model af en række ekstreme stormsituationer.

Derudover testes DMI's stormflodsmodels evne til at forudsige vandstanden med forudsagte vinde fra den nye version af DMI-HIRLAM som input. Totalt set klarer den nye DMI-HIRLAM modelversion sig en anelse bedre.

Abstract

The former DMI-HIRLAM system has been replaced with a new DMI-HIRLAM which essentially is a return to the so-called Reference version of HIRLAM. The former version of DMI-HIRLAM was based on a early version of Reference HIRLAM but with many DMI specific features incorporated in the system. These had an effect on model performance with respect to the technical execution of the model and the meteorological performance. In this report it is shown that the meteorological performance of the new version of DMI-HIRLAM is slightly improved relative to the previous version. This is demonstrated by using standard verification of the model for a winter period and a subjective comparison between the new and old model version in some extreme storm cases. Finally the storm surge model's ability to predict the sea level height using forecasted wind from the new version of DMI-HIRLAM is tested. The overall conclusion is slightly in favor of the new DMI-HIRLAM model version.

Introduction

DMI-HIRLAM-T15 and DMI-HIRLAM-S05 comprise a nested system with DMI-HIRLAM-T15 as the outer domain and DMI-HIRLAM-S05 the inner domain. This model system replaced on 14 June 2004 the formerly operational DMI-HIRLAM-GEDN. The two different systems are depicted in Figures 1 and 2.

Besides the change in model domains, the DMI-HIRLAM-T15 and DMI-HIRLAM-S05 model system is in many ways very different from the DMI-HIRLAM-GEDN system. The coding structure has been completely revised. This has been done for optimal use of the NEC SX-6 supercomputer system at DMI. Operationally the required amount of computer resources has increased from 8 processors in the old system to 24 processors in the new system. The amount of I/O and memory in use have also increased substantially.

In this report there will be no focus on technical aspects of the change in the model system. These have been treated in an earlier DMI report [Ulrik Smith Korsholm and Claus Petersen, 2004]. The focus in this report will be on the meteorological performance of the DMI-HIRLAM-T15 and DMI-HIRLAM-S05 system compared to the previous DMI-HIRLAM-GEDN system. Essentially the upgrade of the code amounted to a return to the standard HIRLAM code, the so-called reference HIRLAM code, [Per Undén *et al.* 2002], and the most recent release from the HIRLAM community has been used as a starting point, presently version number 6.3. However major changes to this code have been made to improve both the meteorological and computational performance. This report describes what has been changed relative to DMI-HIRLAM-GEDN, [Bent Hansen Sass *et al.* 2002], as well as the changes relative to the HIRLAM reference code. A more comprehensive description of the changes in DMI's operational forecasting system relative to DMI-HIRLAM-GEDN and HIRLAM reference code has been published in a separate report [Xiaohua Yang *et al.* 2005].

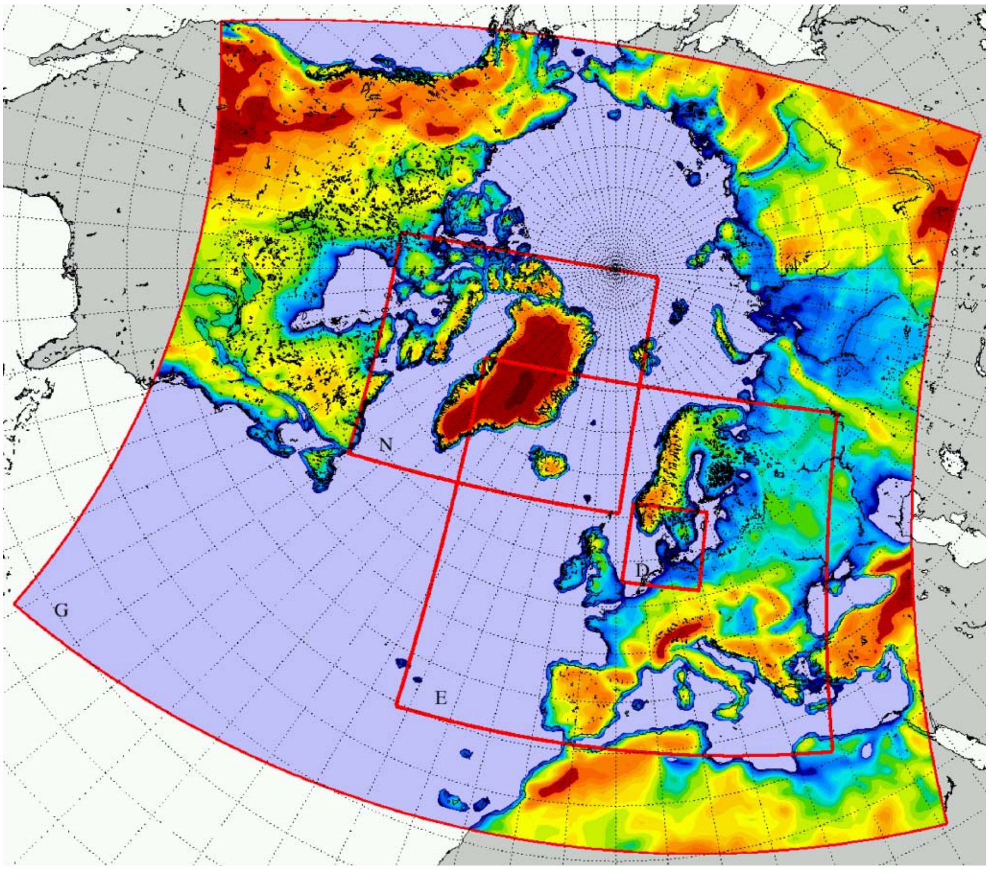


Figure 1: DMI-HIRLAM-GEDN nested model set-up, run operationally from October 1997 through mid June 2004. DMI-HIRLAM-G (marked in the lower left corner with 'G') is the outermost model area, run with 0.45°resolution. DMI-HIRLAM-E ('E' on figure) ran with 0.15°resolution, as well as DMI-HIRLAM-N ('N'), while DMI-HIRLAM-D ('D') was run with 0.05°resolution.

The report is a follow up on the previous report describing the meteorological performance of the last major upgrade of the DMI-HIRLAM system [Bjarne Amstrup *et al.* 2003].

In this report results from historical runs performed with the new DMI-HIRLAM-T15 and DMI-HIRLAM-S05 are compared to the DMI-HIRLAM-E. In addition, output from the DMI storm surge model, forced by DMI-HIRLAM-T15 and DMI-HIRLAM-S05, are compared to output from the DMI storm surge model forced by DMI-HIRLAM-E.

Historical runs of DMI-HIRLAM-T15 and DMI-HIRLAM-S05 in summer are planned and a DMI technical report describing the performance of the models, in particular precipitation forecasts, is expected to be published in the second half of 2005.

Modification of the DMI-HIRLAM system

The DMI-HIRLAM system consists of a forecast and an analysis module. Compared to the previous DMI-HIRLAM version, the analysis system has been expanded with a surface analysis module. The module is independent of the existing analysis module and is only used to initialize surface parameters for the surface scheme in the forecast model. No changes have been made to the HIRLAM 3-dimensional variational data assimilation system, 3D-VAR. The forecast model has been fundamentally changed in the coding structure as mentioned in the introduction. However the solution to the governing equations and the parameterization of the physical processes have in most cases remained unchanged. The three most important changes are

- a change from Eulerian to semi-Lagrangian advection,
- the change of the surface scheme which also includes a surface analysis system
- the initialization scheme, which has been changed from normal mode initialization to digital filtering [Per Undén *et al.* 2002].

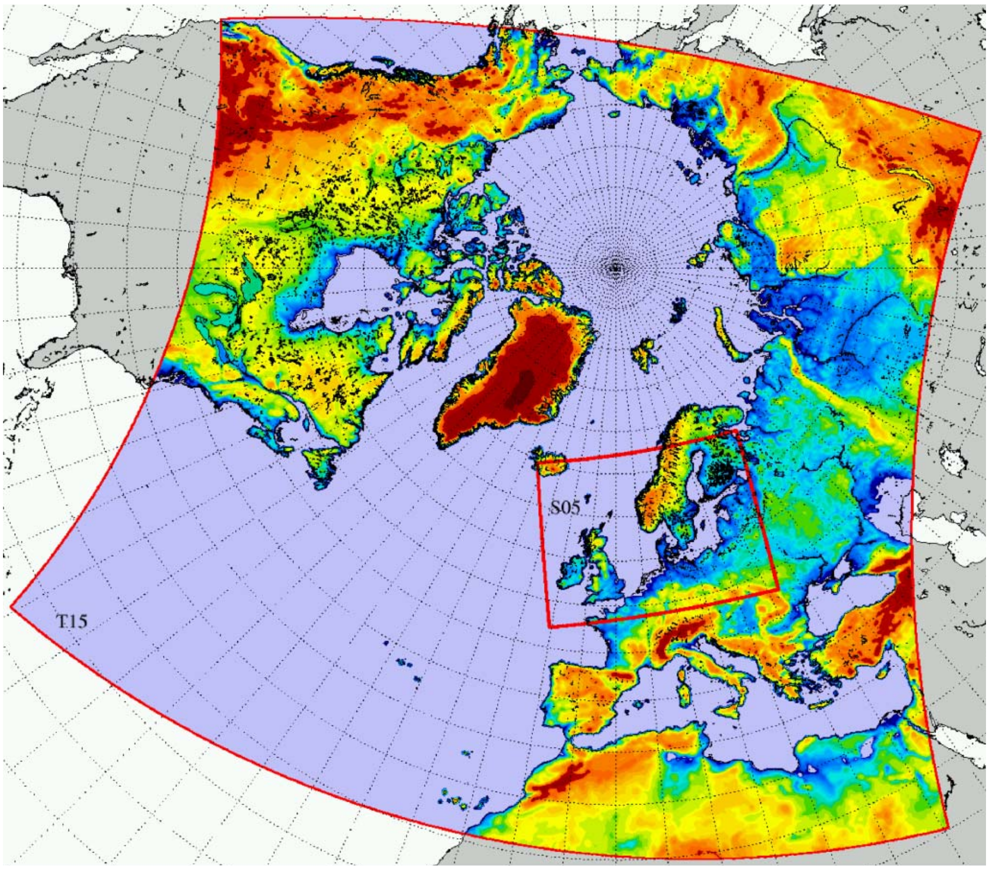


Figure 2: DMI-HIRLAM-T15 and DMI-HIRLAM-S05 nested model set-up, run operationally since mid June 2004. DMI-HIRLAM-T15 (marked in the lower left corner with 'T15') is the outermost model area, run with 0.15°resolution. DMI-HIRLAM-S05 ('S05' on figure) runs with 0.05°resolution.

Model domains and vertical structure

Table 1 and Figures 1 and 2 show the main characteristics of the model domains for DMI-HIRLAM-GEDN, DMI-HIRLAM-T15 and DMI-HIRLAM-S05, respectively. The DMI-HIRLAM-T15 and DMI-HIRLAM-G model domains are equivalent; the resolution in DMI-HIRLAM-T15 has been increased from 0.45°to 0.15°and the rotation of the grid has remained unchanged. DMI-HIRLAM-T15 has also replaced the two sub areas, DMI-HIRLAM-N and DMI-HIRLAM-E, and DMI-HIRLAM-T15 is now the main source for DMI applications needing meteorological data as input. DMI-HIRLAM-S05 replaces the former DMI-HIRLAM-D. The area of the model now also covers the Baltic Sea and the North Sea, an area of interest for the high resolution oceanographic models run at DMI, especially in connection with the storm surge model, Mike21. The resolution is unchanged (0.05°) but the rotation angle of the grid has been modified to get the optimal area. The vertical structure of DMI-HIRLAM-T15 and DMI-HIRLAM-S05 has been slightly modified but the number of levels is still 40.

Table 1: Model variables. For all operational models except for S05 the geographical coordinates $(\mathrm{polon}, \mathrm{polat})$ of the rotated south pole are: $(\mathrm{polon}, \mathrm{polat}) = (80^\circ, 0^\circ)$. For S05: $(\mathrm{polon}, \mathrm{polat}) = (10^\circ, -40^\circ)$.

Model Identification	G	N	E	D	T15	S05
grid points (mlon) grid points (mlat)	202 190	194 210	272 282	182 170	610 568	496 372
no. of vertical levels	40	40	40	40	40	40
horizontal resolution	0.45°	0.15°	0.15°	0.05°	0.15°	0.05°
hor. res. (assimilation)	0.45°	0.45°	0.45°	—	0.45°	—
time step (dynamics) time step (physics)	120 s 360 s	50 s 300 s	50 s 400 s	18 s 216 s	360 s 360 s	120 s 120 s
boundary age (in forec.)	6 h	0 h	0 h	0 h	6 h	0 h
boundary age (in ass.)	0 h-6 h	−3 h-0 h	−3 h-0 h	−3 h-0 h	0 h-6 h	0 h
host model	ECMWF	G	G	E	ECMWF	T15
boundary frequency	1/(3 h)	1/(1 h)	1/(1 h)	1/(1 h)	1/(3 h)	1/(1 h)
data assimilation cycle	3 h	3 h	3 h	3 h	3 h	3 h
forecast length (long)	60 h	36 h	54 h	36 h	60 h	54 h
long forecasts per day	4	2	4	4	4	4

Schedule and nesting

DMI-HIRLAM-T15 serves as the outermost model in the nested system. Compared to the previous DMI-HIRLAM-GEDN system, DMI-HIRLAM-T15 runs with the same schedule as DMI-HIRLAM-G with four 60 hour forecasts launched at 00, 06, 12 and 18 UTC respectively and two reassimilation cycles (00 and 12 UTC, indicated in Table 2 with T_E00 and T_E12, respectively) on a daily basis. Six hour old ECMWF frames are used as boundaries. In the two reassimilation runs, updated frames (0 hour old) are used. The number of vertical levels in ECMWF frames has been increased from 30 to 60, (roughly 47 of the 60 levels are interpolated to the 40 DMI-HIRLAM vertical levels, the remaining 13 are higher up in the atmosphere than the highest level in DMI-HIRLAM). These frames provide DMI-HIRLAM-T15 with updated boundaries every three hours. The first guess is obtained from the previous forecast and has an age of three or six hours. The first guess is used as input to the surface analysis. The surface scheme modifies surface quantities such as surface temperature and water content in the soil layer. The modified first guess from the surface analysis is used as a first guess in the 3D-VAR analysis system. The final analysis from 3D-VAR is used together with the modified first guess field from the surface analysis as initial conditions for the forecast model. DMI-HIRLAM-S05 is nested in the DMI-HIRLAM-T15 model and uses hourly updated boundaries from DMI-HIRLAM-T15. DMI-HIRLAM-S05 runs without 3D-VAR.

Table 2: Operational schedule, in which T_E denotes a restart from an ECMWF analysis; see the text for details.

UTC	DMI-HIRLAM-T15	DMI-HIRLAM-S05
1:37	T00+60h	
2:30		S00+54h
ECMWF 00 UTC		
7:37	T06+60h	
8:30		S06+54h
ECMWF 06 UTC		
11:45	T_E00+05h	
11:45	T03+05h	
11:45	T06+05h	
11:45	T09+05h	
13:37	T12+60h	
14:30		S12+54h
ECMWF 12 UTC		
19:37	T18+60h	
20:30		S18+54h
ECMWF 18 UTC		
23:50	T_E12+05h	
23:50	T15+05h	
23:50	T18+05h	
23:50	T21+05h	

Surface analysis

The surface analysis was designed with the surface scheme used in HIRLAM in mind. The primary data source for the surface analysis is conventional observations such as synop data. Additional analysis of sea surface temperature and ice cover from ECMWF is used as a first guess field to the sea surface analysis. From the observation data 2 meter temperature, 2 meter dew point temperature, sea surface temperature and snow depth are used to modify the surface quantities of the first guess field. A successive correction method is used where the first guess field is adjusted towards observed values. In order to make analysis of surface temperature and surface soil moisture, 2 meter temperature and 2 meter humidity increments are calculated and it is assumed that these increments are proportional to the surface increments. The adjusted parameters are sea surface temperature, fraction of ice cover, snow depth, surface temperature and surface soil moisture. In the previous version of DMI-HIRLAM there was a surface analysis of sea surface temperature and ice cover. However these were purely based on analysis from ECMWF. There was no analysis over land. The resolution of the ECMWF SST fields, previously used in the DMI-HIRLAM forecast model and now in the surface analysis, has increased from 1.0°to 0.5°

Analysis system

The analysis from the free atmosphere is still based on 3D-VAR. The only analysis system changes relative to that described in [Bent Hansen Sass *et al.* 2002] are new data sources, (e.g., use of NOAA16 AMSU-A ATOVS data, NOAA17 ATOVS AMSU-A data; NOAA17 was replaced by NOAA15 in October 2003. There are no changes relative to DMI-HIRLAM-GEDN.

Incremental digital filter initialization and blending

The initialization of DMI-HIRLAM has been changed from normal mode initialization to digital filter initialization, DFI, [Xiang-Yu Huang and Xiaohua Yang, 2002]. Incremental digital filter initialization, IDFI, is used to combine the tasks of initialization and blending initial conditions, [Xiaohua Yang, 2004]. IDFI can be used for a single model, in which case the analysis and first guess of the same model are used when calculating the initial model state. This is done for DMI-HIRLAM-T15 four times a day for each 60 hour forecast. IDFI is also used for every DMI-HIRLAM-S05 run and two times daily for DMI-HIRLAM-T15, for blending the host model analysis and the nested model first guess. This method makes it possible to run the model without the data assimilation module but still retain small scale features from the first guess field. Interpolated analyses or interpolated initialized analyses from an outer nested model are used as input. It is assumed that the resolution of the outer host model is lower and thus on a larger scale. In the incremental digital filter these larger scales are retained and blended with small scale features from the first guess field, which is the output of the surface analysis, its input being a forecast from the previous run of the inner, nested model. DMI-HIRLAM-S05 uses an interpolated initialized analysis from DMI-HIRLAM-T15 as input. This is done for every forecast. DMI-HIRLAM-T15 uses an interpolated initialized analysis from ECMWF two times daily as input to the first run in the reassimilation cycle. It is believed that ECMWF can provide better large scale analyses than the HIRLAM analysis system. This can be justified from the fact that ECMWF's long cut off allows for the use of more data, that more data types are used and that ECMWF run data assimilation two times daily using the more advanced 4-dimensional variational data assimilation system. DMI-HIRLAM-GEDN also used increments in a similar way to that just described. However the method was not based on digital filter methods but rather on a locally adopted, undocumented method.

Advection scheme

Eulerian advection has been replaced by semi-Lagrangian advection. The semi-Lagrangian advection scheme has made it possible to increase the time step significantly but it is also computationally more expensive per time step. The physics package also uses the same time step as the Lagrangian advection scheme. In DMI-HIRLAM-GEDN the physics package ran with a longer time step than the Eulerian advection. This option is not available in the new reference HIRLAM model set-up. It is noteworthy that the Lagrangian advection and its interaction with the model physics has been numerically very stable. This was not always the case with the interaction of Eulerian advection and the model physics which could especially become numerically unstable in certain convective situations.

Surface scheme

The surface scheme has been replaced by an entirely new scheme. The old scheme made distinctions between sea, ice and land. The new scheme has in addition three grid tile types for land which are bare soil, forest and low vegetation. For the three grid tile types, each grid tile being assigned one of the types, the ISBA (Interaction between Soil, Biosphere and Atmosphere) formulation is used. The solution of the equations for the surface and soil layers is based on an entirely different approach. The old scheme basically solved the heat equation for the soil layers using fluxes from the atmosphere as input to the energy budget at the surface, and climate values as lower boundary conditions. The new surface scheme uses a force restore approach and a more complicated parameterization of the soil processes such as vegetation and different types of soil. The calculation of surface fluxes and diagnostic quantities such as 2 meter temperature and 10 meter wind are based on a different approach in the new set-up. In order to reduce the 10 meter wind bias, the vegetation roughness has been increased by a factor of three.

Implicit horizontal diffusion

The horizontal diffusion is still based on the same implicit horizontal diffusion scheme, the so-called Raymond filter. The order of the diffusion scheme has been increased from fourth order in DMI-HIRLAM-GEDN to sixth order in DMI-HIRLAM-T15 and DMI-HIRLAM-S05.

Vertical diffusion

DMI-HIRLAM still utilizes the CBR scheme. Some modifications to the CBR scheme have been necessary in order to get correct surface winds and filling of lows. These aspects can to some degree be seen as a tuning of the CBR scheme and especially a tuning of the boundary condition at the surface. The most important update of the CBR scheme has been a new parameterization of the surface stress [Niels W. Nielsen and Bent Hansen Sass 2004]. In the old set-up it was assumed that the surface stress and the surface wind were parallel. However it can be justified that the direction of the surface wind and the surface stress are not necessarily parallel. The rotation of the surface stress relative to the surface wind will increase the cross isobaric wind and lead to a more correct filling of lows. The rotation angle is dependent on the stability of the atmosphere. The CBR scheme used in DMI-HIRLAM-GEDN is based on an older version of the CBR scheme. Nevertheless, aside from the turning of surface stress there are few differences between the two versions.

Table 3: Standard periods run. Both the first and the last days in each period are included. The boundary files are for DMI-HIRLAM-T15 (see text) and the frequency is how often the boundary files are available.

Period	start day	end day	#days	Boundary files	freq.
Jan./Feb. 2002	20020123	20020225	37	Rotated FRAME forecasts	3 h
Dec. 1999+	19991129	19991203	5	Regular $1.5°$ analyses and 6 h forecasts	6 h

Experimental set-up of DMI-HIRLAM-T15 and DMI-HIRLAM-S05

Essentially the operational DMI-HIRLAM-T15 and DMI-HIRLAM-S05 suite as of November 2004 has been used for running these tests. The periods 20 January to 25 February 2002 and 29 November 1999 to 3 December 1999 were chosen and the first period is identical to one of the test periods DMI-HIRLAM-GEDN was tested on as described in [Bjarne Amstrup *et al.* 2003]. The results from these tests are in this report compared to the new results from the DMI-HIRLAM-T15 and DMI-HIRLAM-S05 tests for the same periods. The periods and the boundary data used can be seen in Table 3. The schedule for DMI-HIRLAM-T15 is identical to the schedule used in DMI-HIRLAM-GE. DMI-HIRLAM-S05 follows the same schedule as DMI-HIRLAM-D except that for DMI-HIRLAM-S05 only four daily runs are made and the reassimilation cycles have been omitted, see Table 2. This means that the first guess field is always six hours old, originating from the previous forecast. In DMI-HIRLAM-D the reassimilation twice a day meant that the first guess field for the runs at 00 and 12 UTC was 3 hours old. Observations and boundary data from ECMWF are identical in both experiments. It should be clear that the boundary data from ECMWF only have 30 levels in these experiments and not 60 levels as in the present operational set-up. The benefit of 60 levels in the boundary data is not an issue in this report.

Case studies

Two 'old' cases, C1 and C2, and one more recent case, C3, have been selected for inter-comparison. C1 is about the December 1999 storm in Denmark and C2 is about a less severe storm on 28 January 2002, affecting the North Sea and Denmark. The third, more recent case, deals with the severe storm over Southern Scandinavia on 8 January 2005. In all the cases storms let to storm surge conditions at the Danish North Sea coast.

The inter-comparison for the December 1999 storm is between DMI-HIRLAM-E and DMI-HIRLAM-T15. The former was operational prior to 14 June 2004 and the latter has been operational since then.

Case C2 also includes an inter-comparison between DMI-HIRLAM-T15 (T1X) and DMI-HIRLAM-S05 (S0X). In the case studies included here, DMI-HIRLAM-T15 and -T1X refer to essentially the same model system. DMI-HIRLAM-T1X is used for situations for which this model system version was a test version. DMI-HIRLAM-T15 is used to describe the operational model system version.

DMI-HIRLAM-S05 is nested in DMI-HIRLAM-T15 (see Figure 2) and has a horizontal resolution of approximately 5 km. In the figures presented below DMI-HIRLAM-E and DMI-HIRLAM-T15 are referenced as D1C and T1X, respectively. Note that T1X refers to the historical runs described here and which were made using the operational set-up from 16 November 2004.

Case C1

Figures 3 and 4 show forecasts of mean sea level pressure (mslp) and near-surface wind (at 10 m height). Figure 3 shows results for D1C and Figure 4 shows corresponding results for T1X. The forecasts of the storm evolution are fairly good in both model versions. A tendency for a slightly deeper low with a more easterly position is seen in T1X, particularly in the longer forecasts (Figure 4, upper row). The predicted location of the near-surface wind maximum over the southeastern North Sea in the 30 and 24 hour forecasts is shifted a little northeastward in T1X relative to D1C. The northeastward shift seems to agree better with observations (not shown) and the analyses (Figure 3 and Figure 4, bottom row, right). The predicted maximum near-surface wind speed is highest in D1C, except for the 18 hour forecast.

Case C2

Figures 5, 6 and 7 show forecasts and analyses of mslp and near-surface wind for C2. Left and right columns depict results for D1C and T1X, respectively. The analyses at 6 hour intervals from 12 UTC on 28 January 2002 (Figure 5, bottom row) until 00 UTC on 29 January 2002 (Figure 7) show an initial relatively sharp surface trough with counterclockwise rotation moving eastward and weakening. The surface trough tends to be sharper and the near-surface winds on the downstream side of the trough are consistently higher in T1X. Note that the same holds for the analyses. Here the near-surface winds are not analyzed and therefore markedly influenced by the first guess.

Figures 8 to 10 show that the differences in near-surface wind speed between T1X and S0X generally are smaller then the corresponding differences between T1X and D1C. S0X is identical with T1X, but run on a smaller domain and with a higher horizontal resolution (about 5 km instead of about 15 km in T1X and with analyses based on increments from T1X). T1X analyses and forecasts provide boundary values for S0X with an update frequency of 1 hour.

Case C3

The selected cases C1 and C2 are relatively old. A more recent storm case, C3, from 8 January 2005 has also been investigated, including an inter- comparison with forecasts from the old operational system prior to the upgrade on 14 June 2004. Predictions by T15 from four different initial times are shown in Figure 11. This figure shows good consistency between the predicted near-surface wind at different initial times. The storm surge models forced by winds from S0X gave remarkably good predictions of sea levels along the Danish wadden sea coast. A record high sea level was predicted for Limfjorden and a record high sea level occurred.

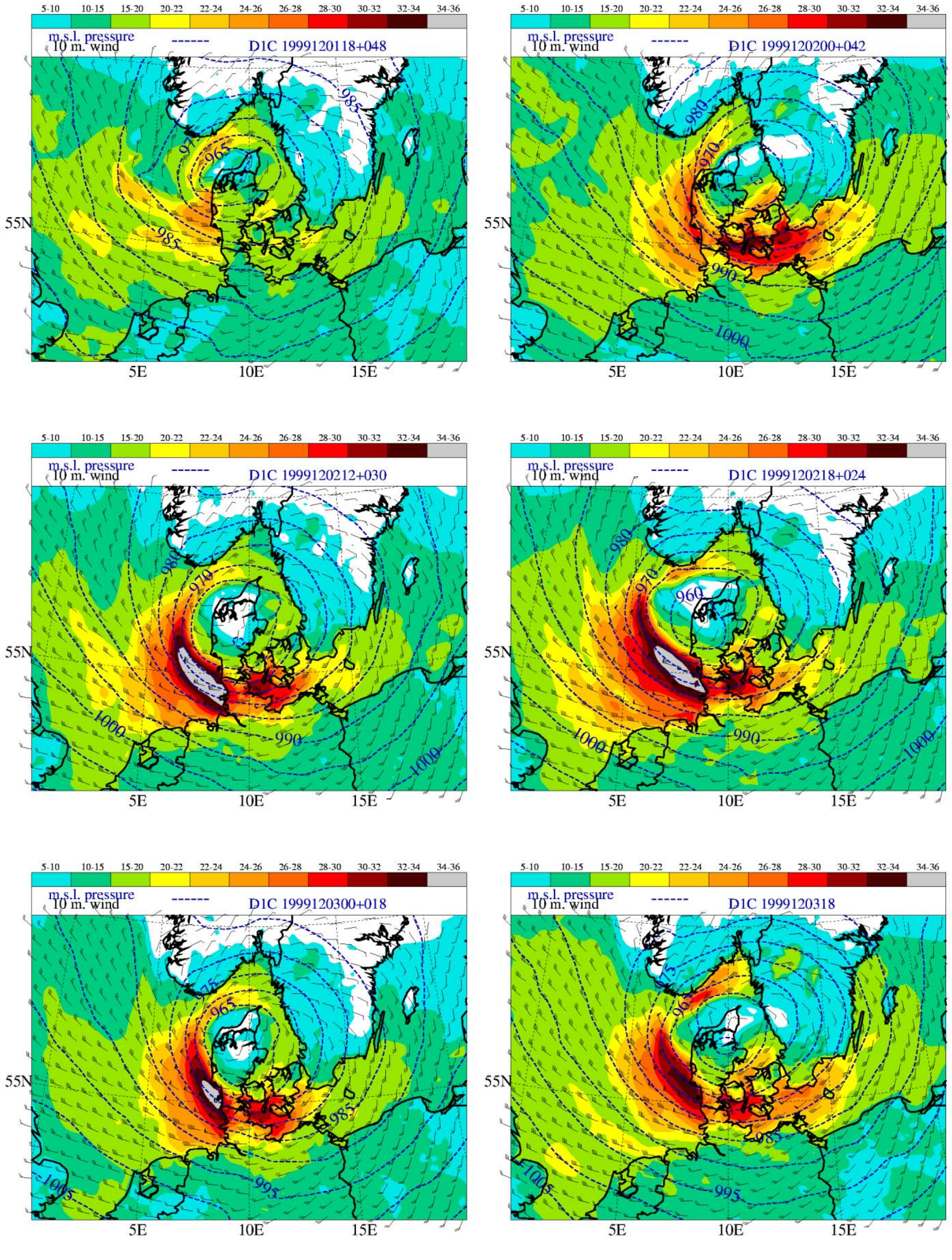


Figure 3: DMI-HIRLAM-E forecasts from different initial times of mean sea level pressure (dashed contours, interval 5 hPa) and wind at 10 m height (color scale in $\mathrm{m\,s^{-1}}$, wind barbs WMO standard) and analysis valid at 18 UTC on 3 December 1999.

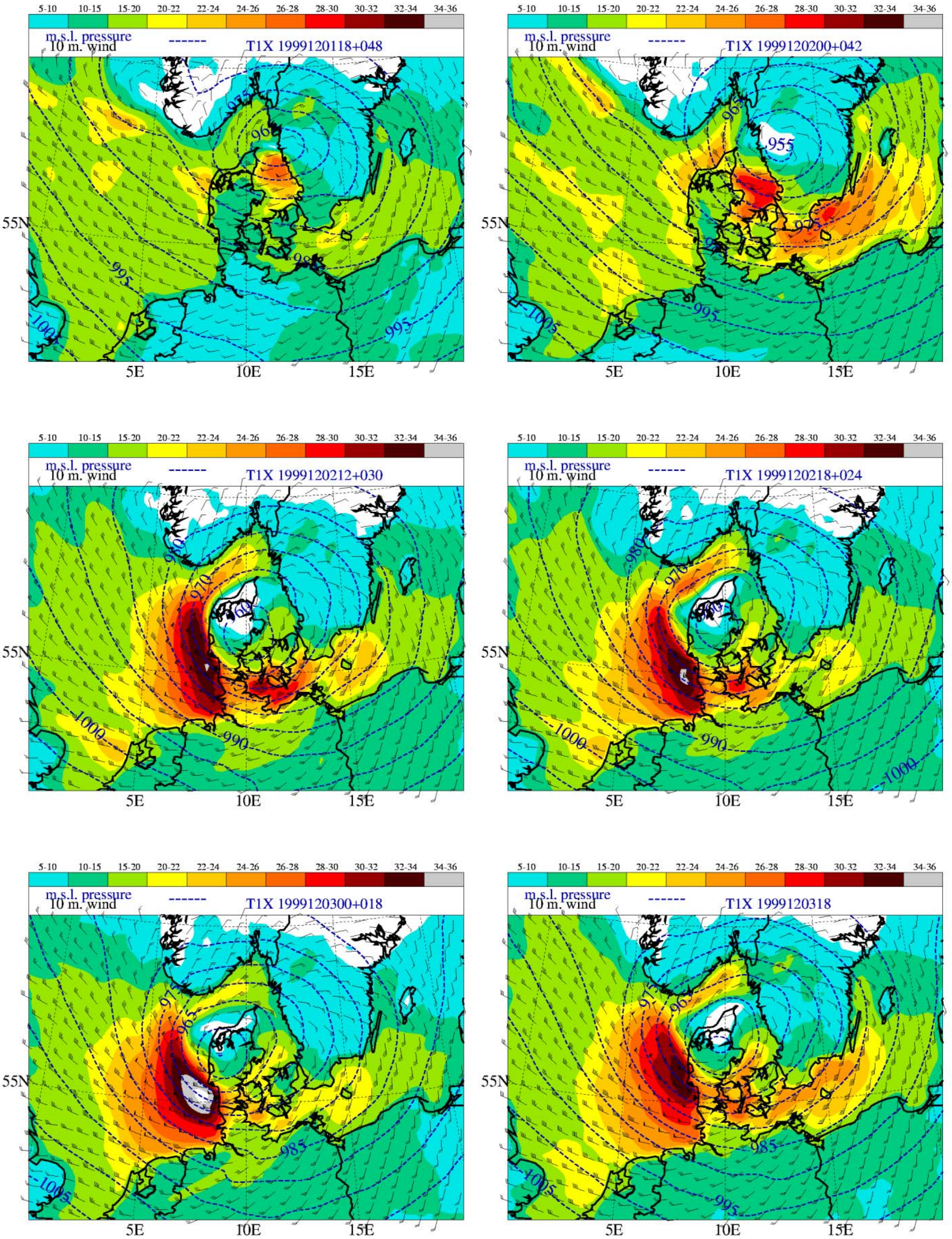


Figure 4: Same as Figure 3, but for DMI-HIRLAM-T15 forecasts and verifying analysis.

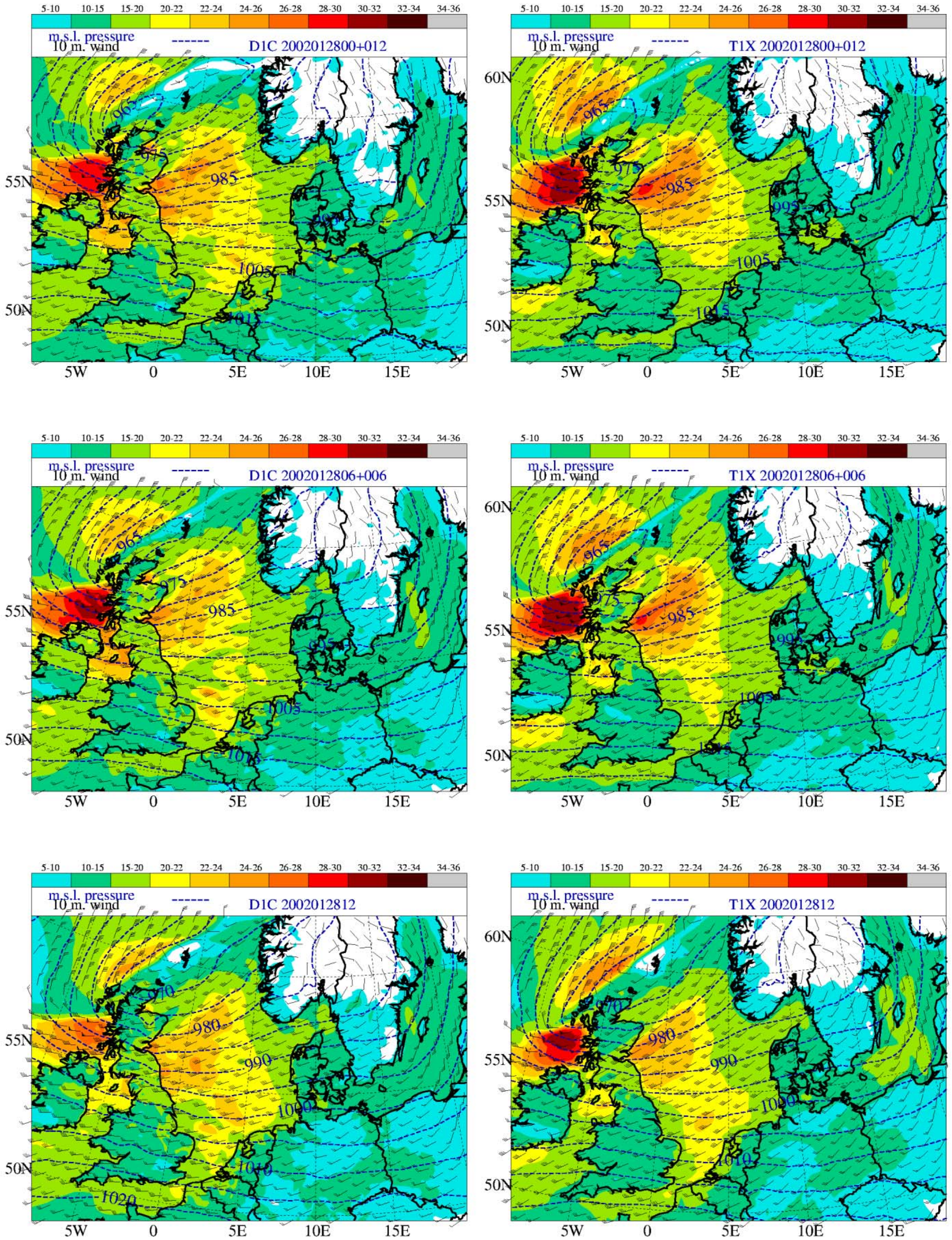


Figure 5: DMI-HIRLAM-E (left column) and DMI-HIRLAM-T15 (right column) forecasts from two different initial times and verifying analyses of mean sea level pressure (dashed contours, interval 5 hPa) and wind at 10 m height (color scale in $\mathrm{m\,s^{-1}}$, wind barbs WMO standard) valid at 12 UTC on 28 January 2002.

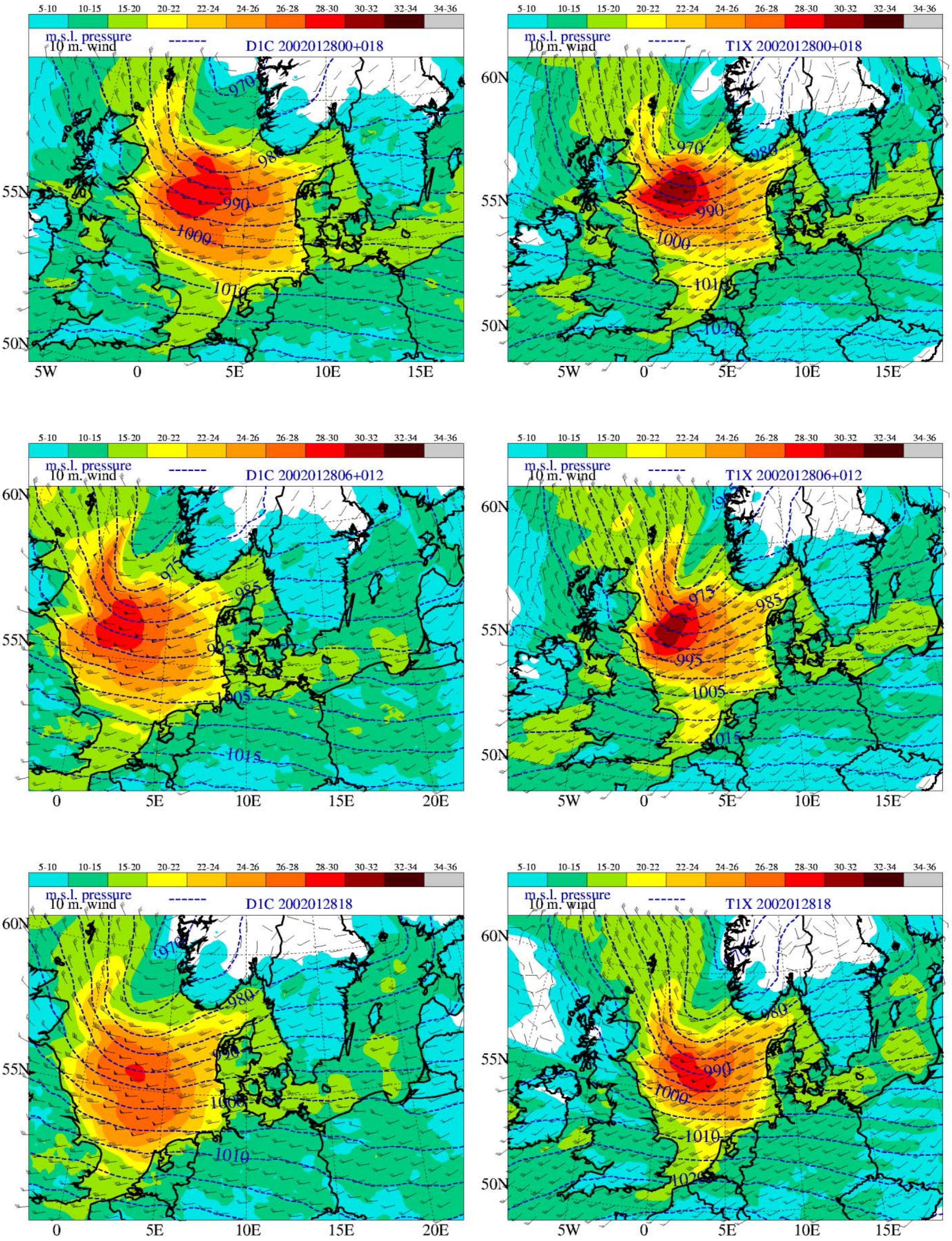


Figure 6: Same as Figure 5 , but for valid time 18 UTC on 28 January 2002. Note that the map areas in the D1C and T1X plots differ.

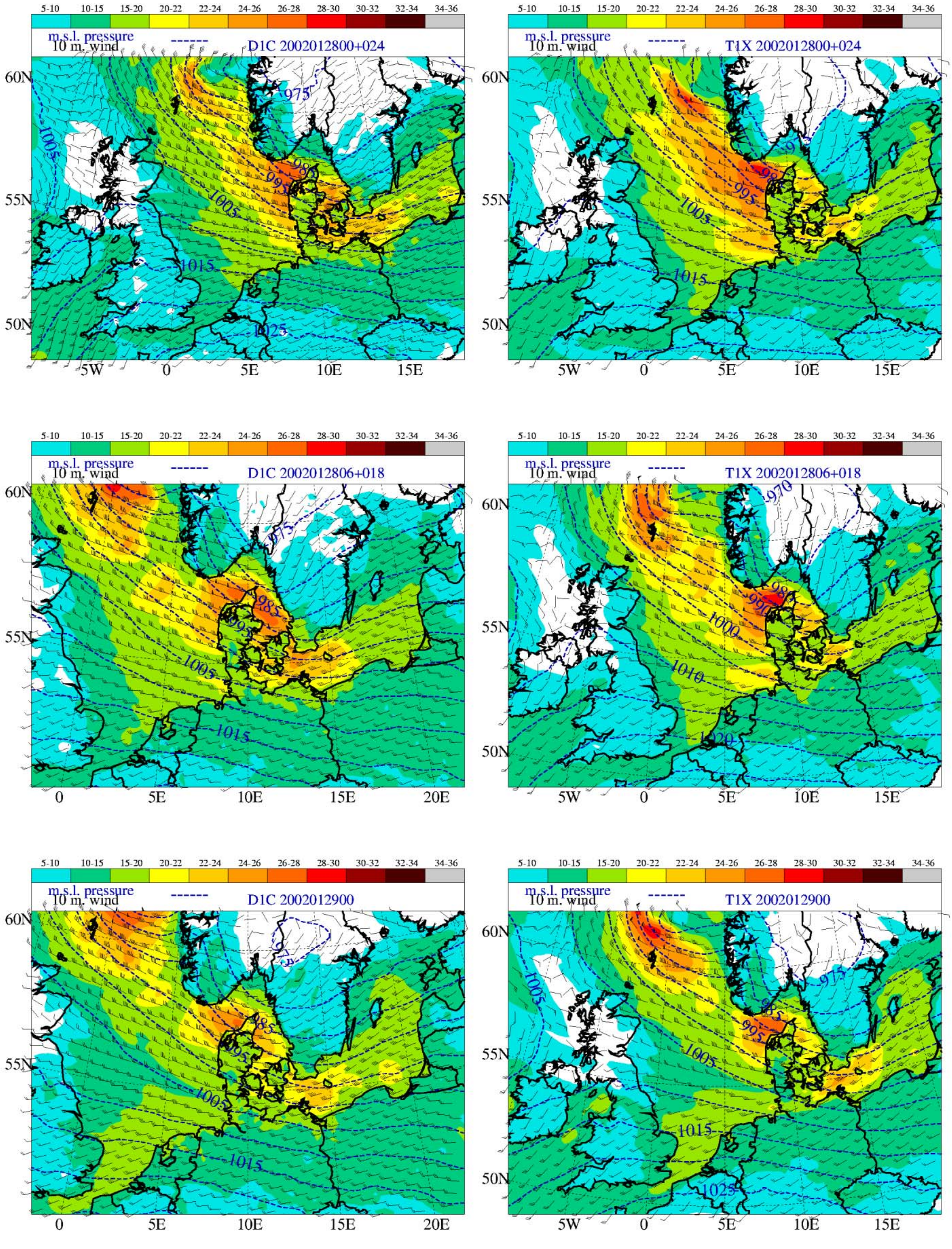


Figure 7: Same as Figure 6, but for valid time 00 UTC on 29 January 2002. Note that the map areas in the D1C and T1X plots differ.

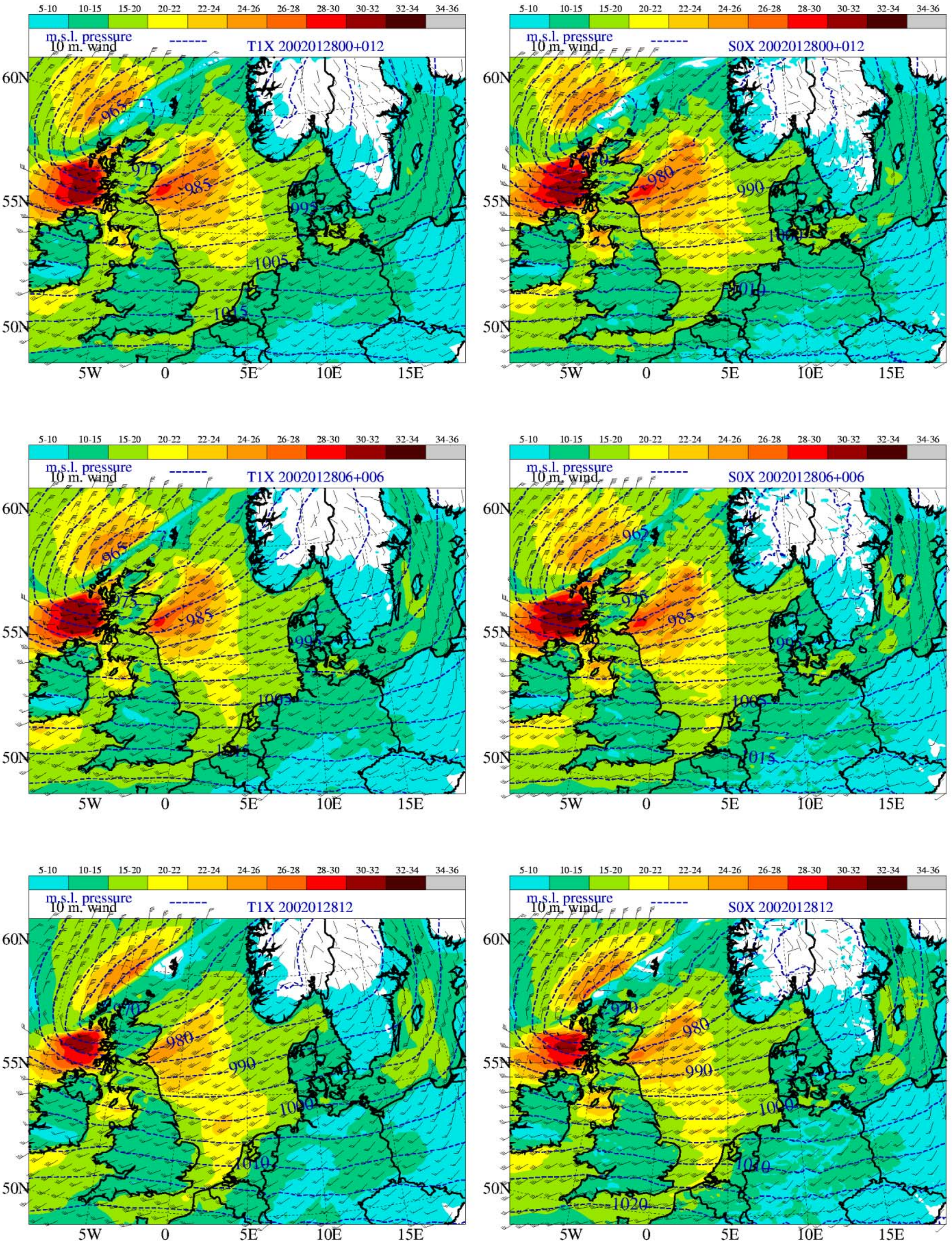


Figure 8: DMI-HIRLAM-T15 (left column) and DMI-HIRLAM-S (right column) forecasts from two different initial times and verifying analyses of mean sea level pressure (dashed contours, interval 5 hPa) and wind at 10 m height (color scale in $\mathrm{m\,s^{-1}}$, wind barbs WMO standard) valid at 12 UTC on 28 January 2002.

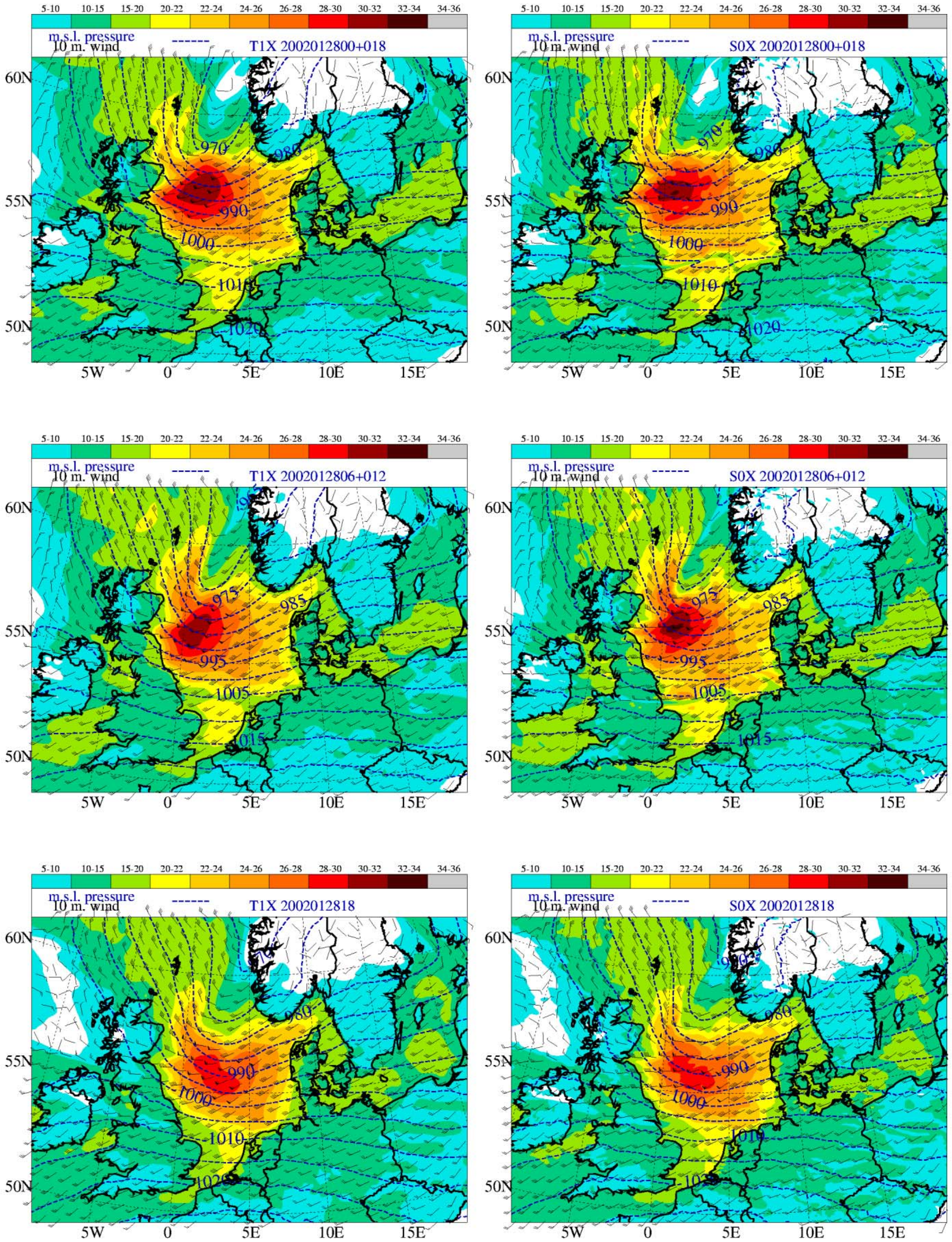


Figure 9: Same as Figure 8, but for valid time 18 UTC on 28 January 2002.

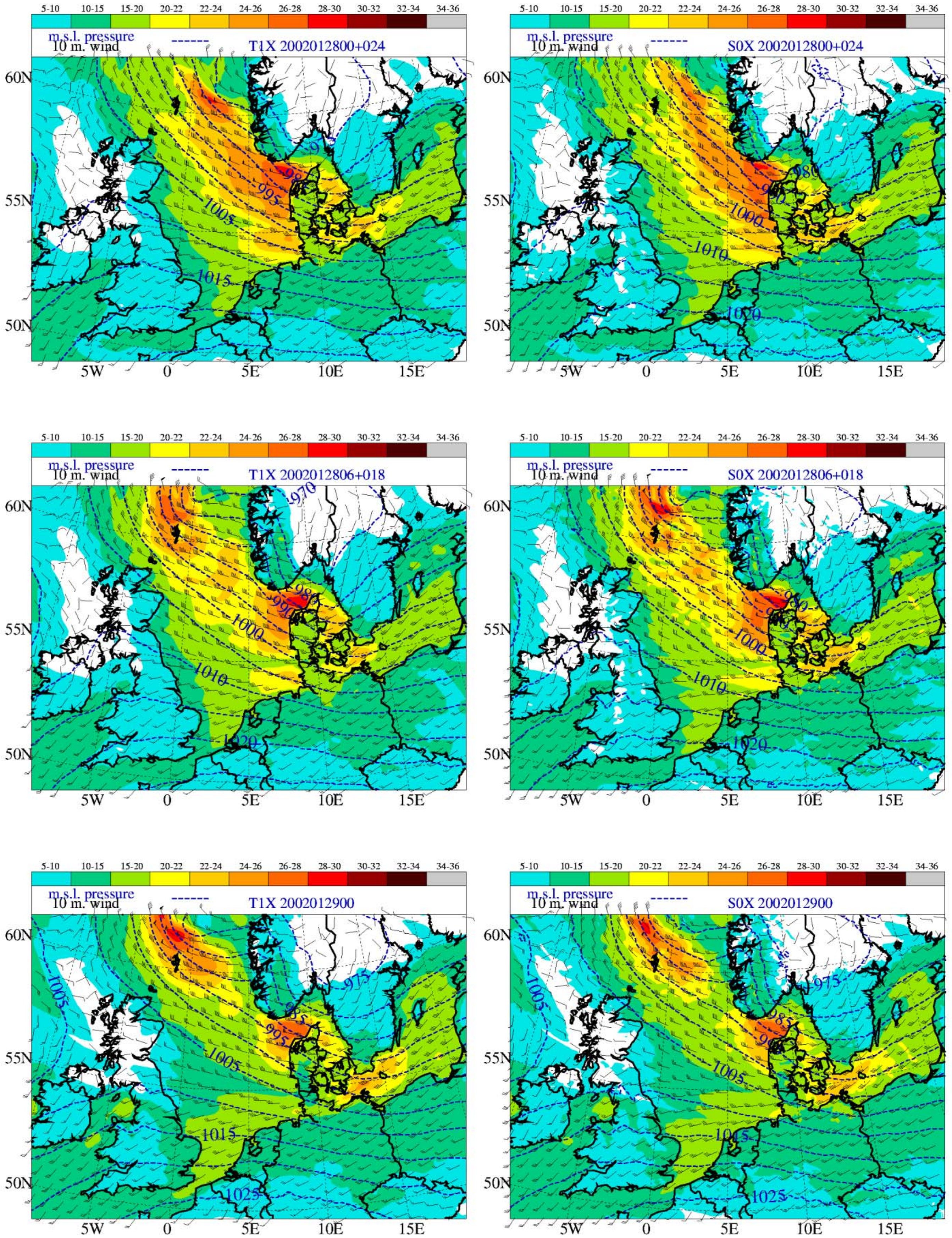


Figure 10: Same as Figure 9, but for valid time 00 UTC on 29 January 2002.

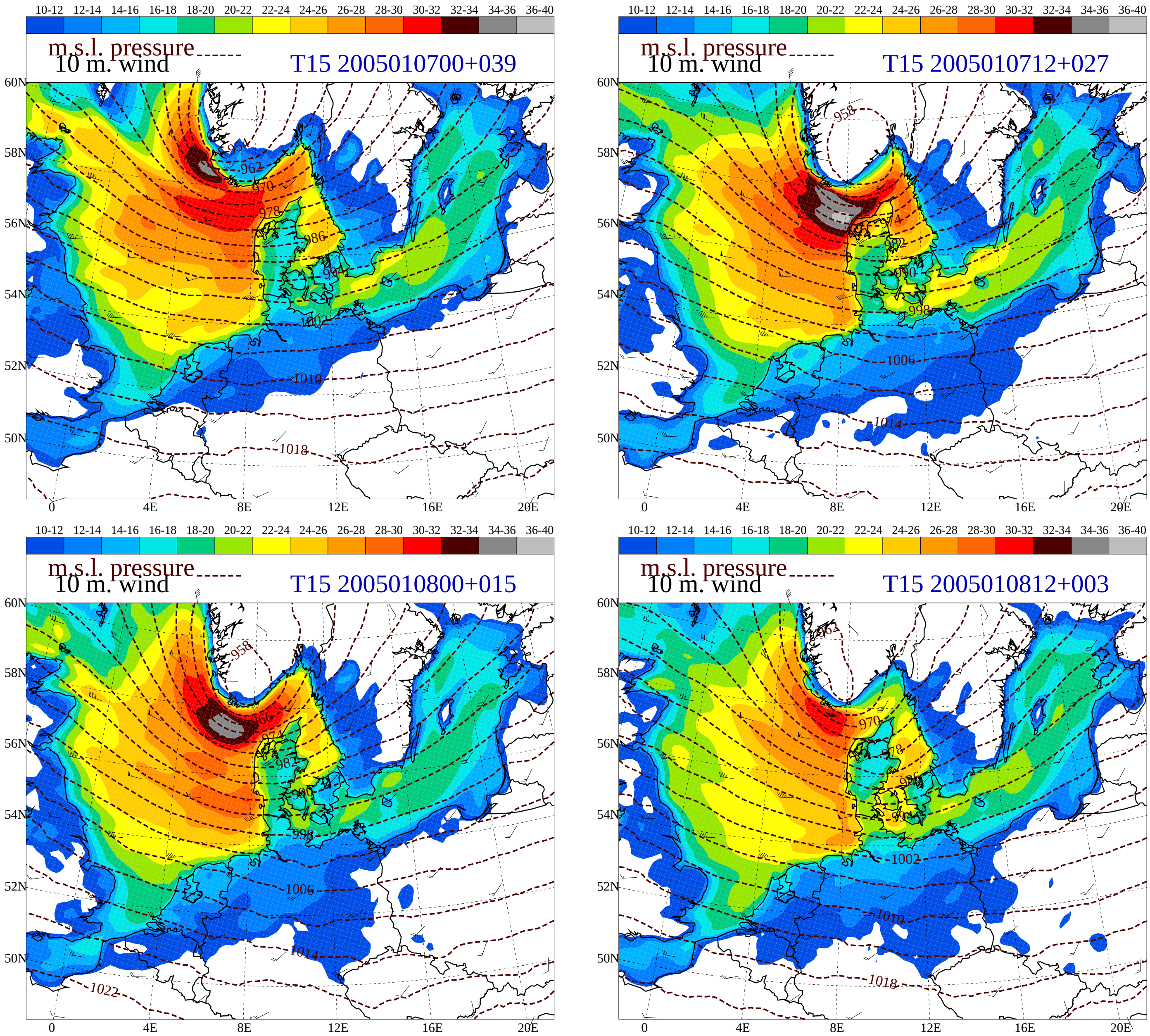


Figure 11: DMI-HIRLAM-T15 forecasts from different initial times of mean sea level pressure (dashed contours, interval 5 hPa) and wind at 10 m height (color scale in $\mathrm{m\,s^{-1}}$, wind barbs WMO standard) valid at 15 UTC on 8 January 2005.

Verification

The results are compared in different ways. Partly by case studies described earlier and by a standard observation verification where forecast results are compared to standard SYNOP and radiosonde observations using an EWGLAM[1] station list and also for some surface variables against a Danish station list. We have not included any precipitation verification scores here. Figure 12 shows bias scores (forecast value minus observed value) and root mean square (rms) for the surface variables 10 m wind, mslp (mean sea level pressure) and 2 m temperature; for the upper level variables temperature, wind speed and geopotential height at 850 hPa, 500 hPa and 250 hPa; and for relative humidity at 850 hPa and 500 hPa as function of forecast length using the EWGLAM station list for the old model (D1C) and the new model (T1X). Figure 13 shows bias-scores and rms-scores for the surface variables 10 m wind, mslp and 2 m temperature using the Danish station list for the old model (D1C) and the new models (S0X and T1X). For the EWGLAM station list the new model in general has better or similar scores than the old model for the temperature and wind at the given levels; one exception being the 10 m wind speed bias. For mslp the old model has slightly better rms-scores for medium forecast length and a somewhat better bias-score. For 850 hPa and 500 hPa geopotential height the old model has slightly better rms-scores and better bias-scores. For 250 hPa geopotential height and 850 hPa relative humidity, the new model has clearly better scores. For the Danish station list the new models has much better 2 m temperature scores in the period studied here and marginal better 10 m wind speed scores. For mslp the old model has better bias-scores as also seen for the EWGLAM station list.

[1] European Working Group on Limited Area Model

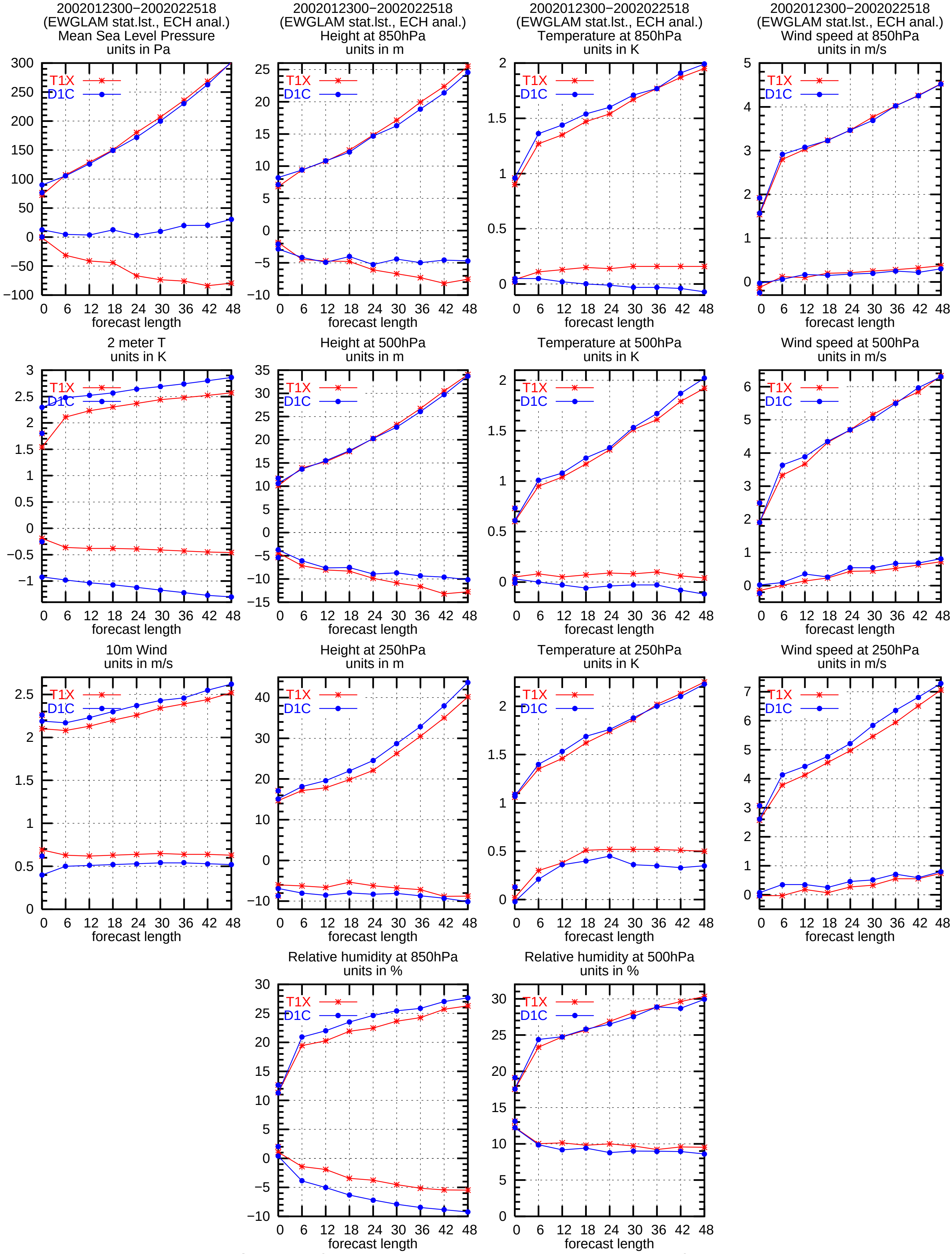


Figure 12: Obs-verification of old model (D1C) and new model (T1X) for the January/February 2002 period. EWGLAM station list.

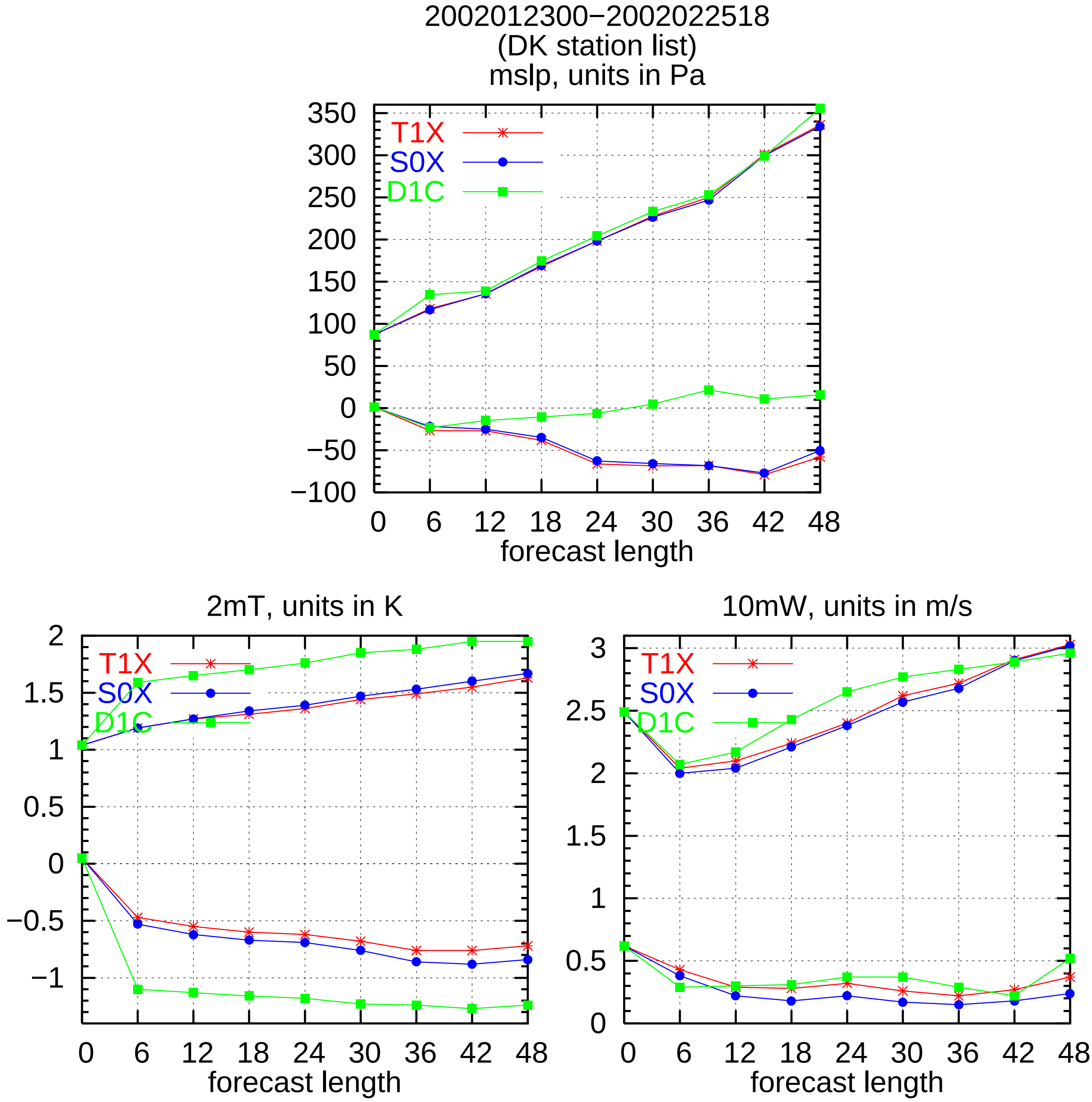


Figure 13: Obs-verification of old model (D1C) and new models (T1X and S0X) for the January/February 2002 period. Danish station list.

Storm surge model test

Any major upgrade of the DMI-HIRLAM system has to be scrutinized by tests with DMI's operational storm surge model. A storm surge model is highly sensitive to the meteorological forcing fields (10 m winds), and benchmark tests have been performed to ensure that the quality of DMI's storm surge warning system is at the very least maintained after a DMI-HIRLAM upgrade.

DMI's operational storm surge model, Mike21, is a barotropic model, forced with DMI-HIRLAM surface level pressure, and "stressed" 10 m wind fields (i.e. 10 m winds that give the HIRLAM surface stress using the Mike21 wind drag formula). The Mike21 tests are run with 48 hour forecasts for a number of test periods. A new run is made every six hours corresponding to a new HIRLAM analysis and forecast. No analysis takes place in Mike21.

The initial value of the sea level for the first run in a benchmark test period is taken from a 'hot file,' i.e., a 6 hour forecast from the operational set-up, valid at the beginning of the test period. Subsequent Mike21 runs in a test period are initiated from the new fields produced by the test run.

Four benchmark periods have been chosen for the Mike21-HIRLAM tests:

Case I	3 December 1999 hurricane with flooding in the Wadden Sea.
Case II	28 January 2002 flooding in the Wadden Sea.
Case III	21 February 2002 high water in the western Baltic.
Case IV	8 January 2005 flooding in the Wadden Sea.

The first three cases are "old benchmark periods", whereas case IV is a new, recent storm surge situation, included here to demonstrate the quality of the storm surge system after the June 2004 upgrade of the DMI-HIRLAM system.

The following DMI-HIRLAM models have been compared in the Mike21 benchmark tests:

D1C	the operational 15 km model before the June 2004 upgrade.
T1X	the new 15 km grid model.
S0X	the new 5 km grid model (in CaseIV called S05 to indicate the change from test to operational version).

Storm surge model test results

Time series for the predicted sea level at pilot stations calculated with Mike21 forced with fields from the three different DMI-HIRLAM versions D1C, T1X and S0X are compared with observed water level from tide gauges, and shown for selected stations and forecast lengths in Figure 15 to Figure 17 for the Cases I-III.

For each of the three old benchmark cases examples are shown from three stations. For the two situations with westerly winds (Case I and Case II) we select Ribe, Esbjerg (in the Wadden Sea) and Thyboroen (at the North Sea coast). For Case III with high water in the Western Baltic we select Fredericia, Aabenraa and Korsoer (see Figure 14).

The model calculated time series shown in the Figures are composed of 6 hours time slides with the same forecast length (i.e. the 0-6 hours forecast time series consist of the first 6 hours time series from all the model runs). The time series shown do therefore consist of a discontinuity each 6 hour (at 00Z, 06Z, 12Z and 18Z), and the large jump seen in the time series, especially for the long forecast lengths, are caused by large differences between the different model runs.

Figure 14: Location of the six sea level stations shown in this report.

For the recent storm surge situation, Case IV, the Mike21 water level forecasts calculated with fields from the old operational, D1C, and the new operational high resolution model, S05, are shown in Figure 18 for the stations Esbjerg at the Wadden sea and Thyboroen at the entrance to the Limfjord. Only the 0-6 hour forecast lengths are shown.

Case I:
For the hurricane case the predicted sea level forecasts from both the new DMI-HIRLAM models improve the maximum sea level compared to the old D1C model. A large improvement is seen for forecast lengths of up to 24 hours ahead for a large number of the pilot stations; see Esbjerg and Ribe (please note that the tide gauge in Ribe broke down during the storm). In some areas the new models overestimate the sea level, e.g., Thyboroen forecast lengths of 0-6 hours. But in general improvements are seen with the new models for the majority of the validated stations around Denmark.

Case II:
For the January western storm the pattern is more unclear. For some stations and some of the forecast lengths, the new models overestimate the sea level relative to the old model version (see Esbjerg 6-12 hours forecast), whereas for other stations and forecast lengths there are improvements.

Case III:
For the high water situation in the western Baltic, no large differences in the peak values are seen between the model versions. The new models for some stations seem to improve the water level forecasts before the maximum values; see Fredericia.

Case IV:
The new model overestimates the sea level before the peak in the water level at Esbjerg, but improves the maximum water level. At Thyboroen at the entrance to the Limfjord an improvement is seen.

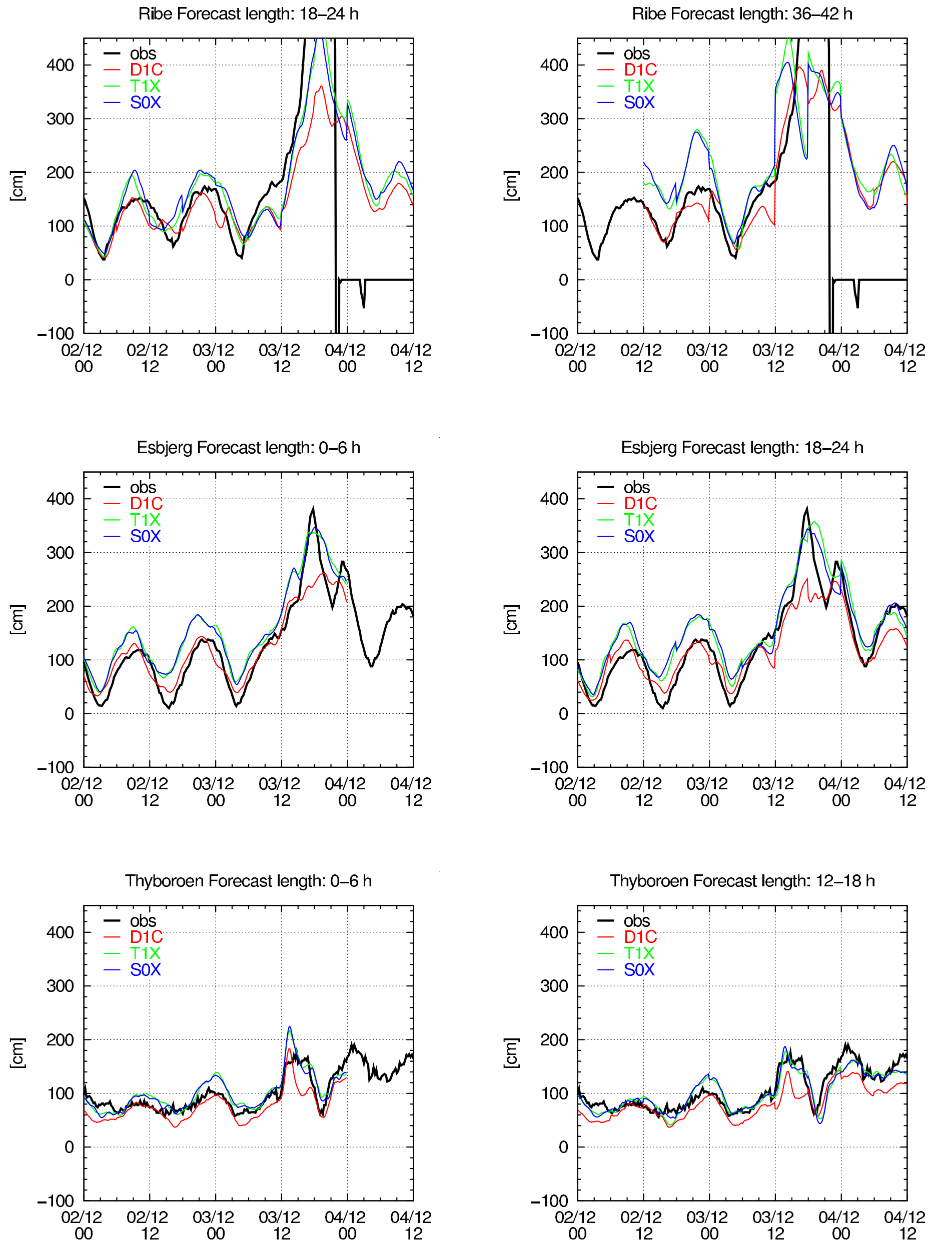


Figure 15: Case I: forecasted and observed water level for selected forecast length for Ribe, Esbjerg and Thyboroen. The black curve is observations. The red, green and blue lines are time series composed of 6 hours time slides with the indicated forecast length from the D1C, T1X and S0X models, respectively.

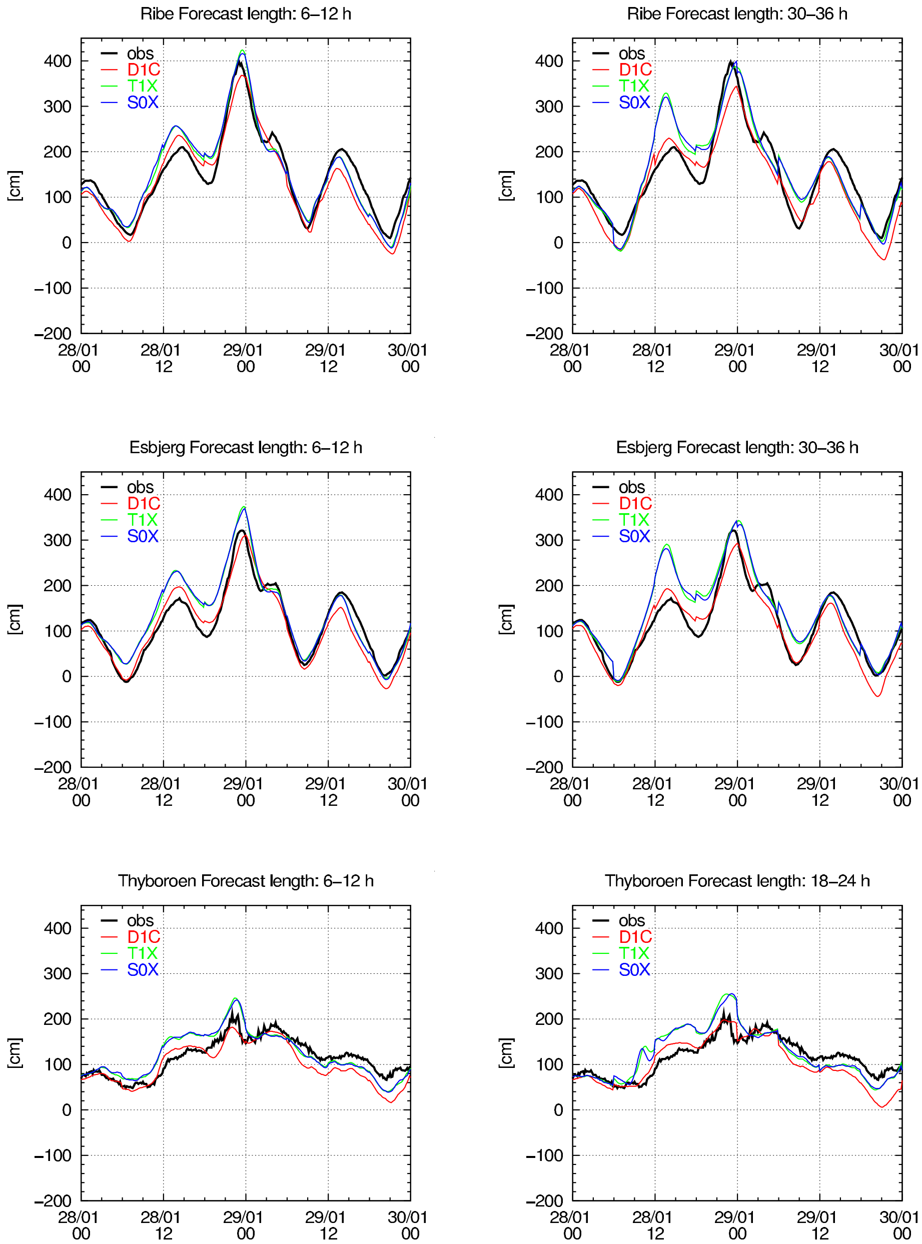


Figure 16: Case II: forecasted and observed water level for selected forecast lengths for Ribe, Esbjerg and Thyboroen. The black curve is observations. The red, green and blue lines are time series composed of 6 hours time slides with the indicated forecast length from the D1C, T1X and S0X models, respectively.

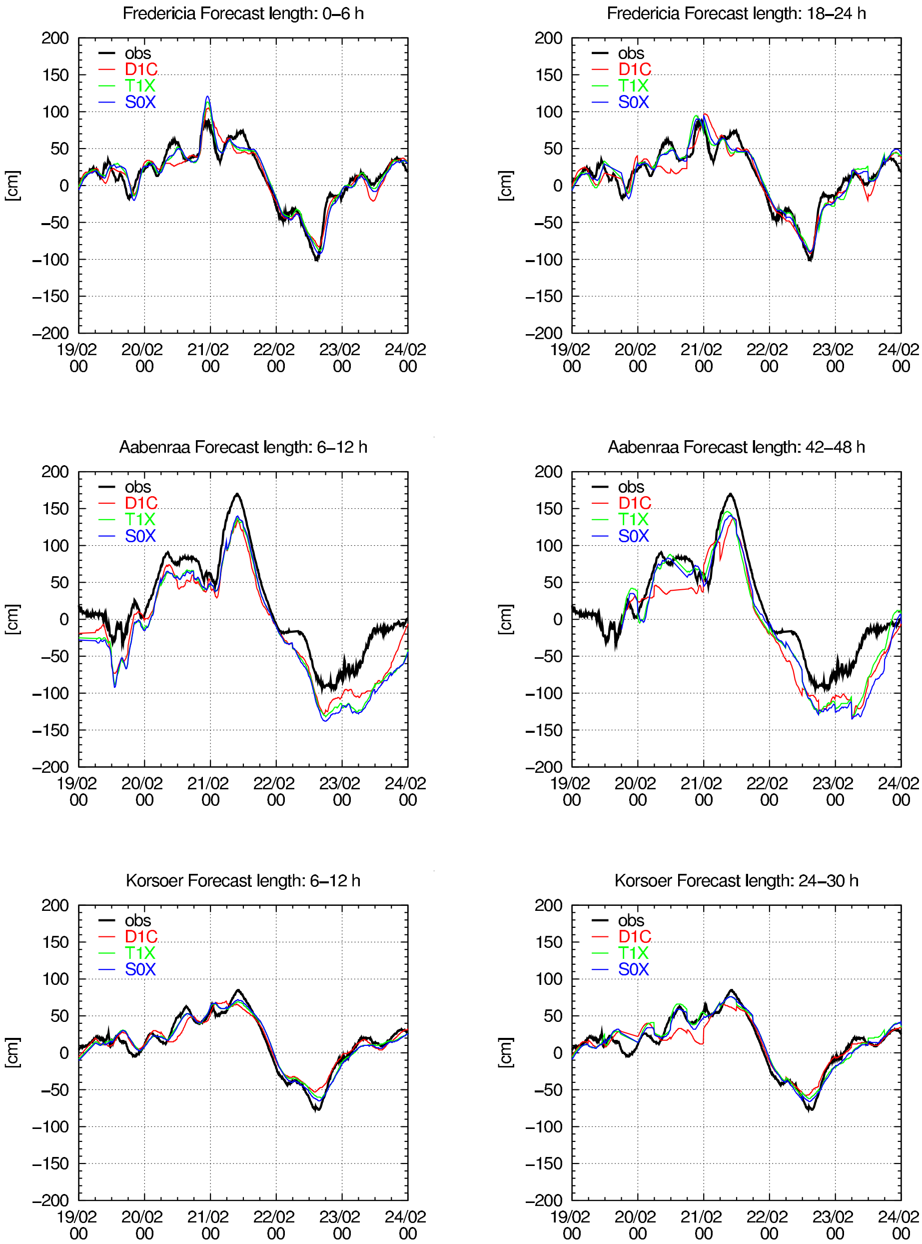


Figure 17: Case III: forecasted and observed water level for Fredericia. The black curve is observations. The red, green and blue lines are time series composed of 6 hours time slides with the indicated forecast length from the D1C, T1X and S0X models, respectively.

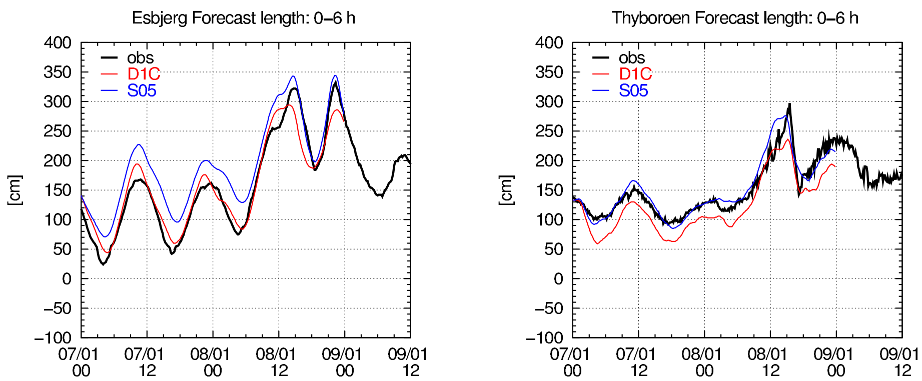


Figure 18: Case IV: forecasted and observed water level for Esbjerg and Thyboroen. The black curve is observations. The red and blue lines are time series composed of 6 hours time slides with the indicated forecast length from the D1C and S05 models, respectively.

Conclusion

It has been particularly important to verify that the DMI-HIRLAM-TS system performs well in winter situations with severe weather and especially cases with extreme weather conditions with a potential risk for storm surge situations. The DMI-HIRLAM-TS system has been validated by three different approaches and compared to the previously DMI-HIRLAM system. A standard verification using SYNOP and radiosonde observations has shown that DMI-HIRLAM-TS for the period 23 January 2002 to 25 February 2002 gave reasonably good results compared to the previous version of DMI-HIRLAM. For most quantities, the new set-up performed slightly better but the improvement is not very significant. For the application of the Storm Surge Model, the verification of 10 m wind is comparable with the previous version of DMI-HIRLAM however with a slightly higher positive bias. Case studies of three different situations with high water and severe weather have been subjectively verified. Two extreme weather events 3 December 1999 and 8 January 2005 were well forecasted with the new DMI-HIRLAM-TS system. The 3 December 1999 storm was well forecasted by both the new and old DMI-HIRLAM system. In the case of the 8 January 2005 storm, DMI-HIRLAM-TS predicted this extreme event with high precision and the storm surge model was also able to produce a very accurate prediction of the sea level in both time and space. It is worthwhile to note that the event already is well forecasted in the 39 hour forecast and that the following forecasts all are consistent with this early forecast. A third case with high water also gave the same impression of the model performance. The storm surge model was tested on four different cases with flooding or high water levels in the Danish waters. Although the improvement cannot be seen in all cases and depends of the location of the observed sea level height and the individual cases, the overall conclusion from a subjective point of view is that the combined system of DMI-HIRLAM-TS and the storm surge model has slightly improved the forecasted height of the sea level.

References

[Bjarne Amstrup *et al.* 2003] Results from DMI-HIRLAM pre-operational tests prior to the upgrade in December 2002. DMI Technical Report 03-20.

[Xiang-Yu Huang and Xiaohua Yang, 2002] A new implementation of digital filtering initialization schemes for HIRLAM. Norrköping, March 2002. HIRLAM Technical Report, pp.33.

[Ulrik Smith Korsholm and Claus Petersen, 2004] Reference Hirlam on NEC SX-6, Part 1. DMI Technical Report 04-23.

[Niels W. Nielsen and Bent Hansen Sass 2004] Rotation of the surface stress as a tool in parameterization of atmospheric turbulence. DMI Scientific Report 04-07.

[Bent Hansen Sass *et al.* 2002] The operational DMI-HIRLAM system - 2002-version. DMI Technical Report 02-05.

[Per Undén *et al.* 2002] HIRLAM-5 Scientific Documentation.

[Xiaohua Yang, 2004] Adaptation of the Reference HIRLAM in DMI's operational suite. April 2004. HIRLAM Newsletter, 45, 81-91.

[Xiaohua Yang *et al.* 2005] The DMI-HIRLAM upgrade in June 2004. DMI Technical Report 05-09.

Previous reports

Previous reports from the Danish Meteorological Institute can be found at:
http://www.dmi.dk/dmi/dmi-publikationer.htm