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The DMI-HIRLAM upgrade in November 2005

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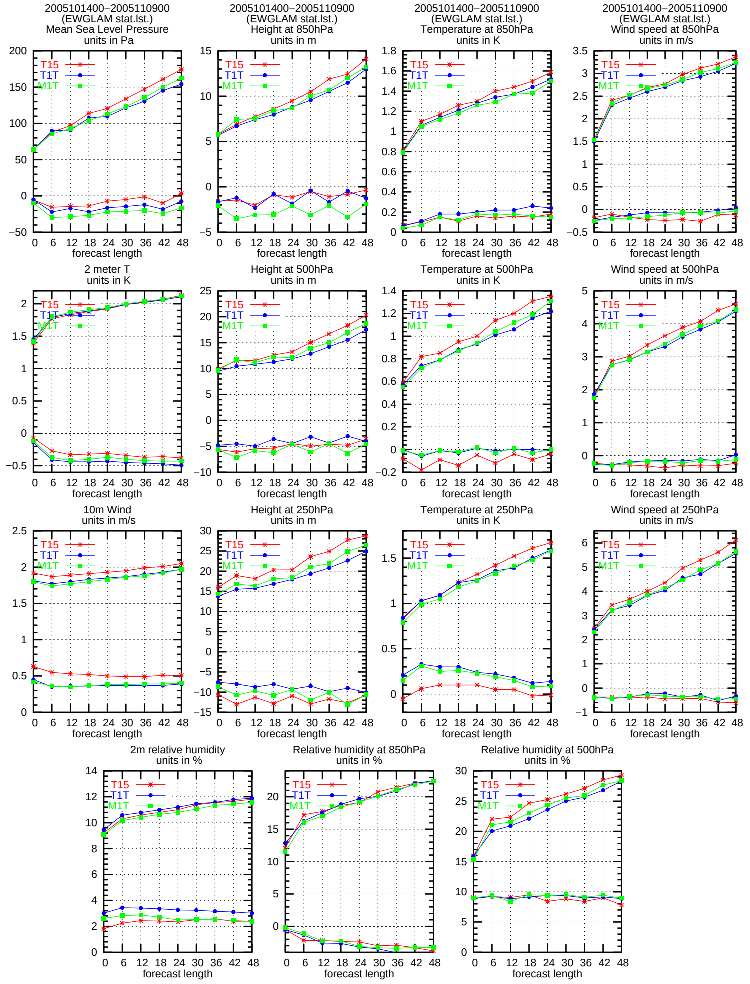

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Contents

Abstract

This report describes the November 2005 upgrade of DMI's operational forecast system DMI-HIRLAM and results of numerical experiments.

Resume

Denne rapport beskriver ændringerne i november 2005 opgraderingen af DMIs operationelle prognosesystem, DMI-HIRLAM, og viser resultater fra nogle numeriske tests lavet i forbindelse hermed.

Introduction

An upgrade to DMI's operational Numerical Weather Prediction (NWP) suite, DMI-HIRLAM, has recently been carried out and launched on Nov 9, 2005. This is the second major upgrade of the DMI-HIRLAM in 2005, following the previous one on May 31 (Yang et al., 2005).

The upgrade involves modifications to numerous components of DMI's operational HIRLAM forecast system. These modifications include a re-scheduling of the data assimilation cycling, hence a change of the assimilation interval from 3 h to 6 h, an explicit blending of large scale analyses with nested ones for prognostic quantities, an introduction of locally derived background error structure functions in the 3D-VAR analysis, a significantly increased usage of aircraft data, an implementation of the RTTOV8 (Radiative Transfer model for TOVS, release 8) package, a tuning of the physical parameterization in the turbulence and condensation schemes, and an increased time-stepping size in forecast integration.

In order to improve the efficiency of the procedure to validate the numerous changes proposed, involving various system modules, a model domain with reduced size compared to that of the operational T15, M15, has been introduced during the process. M15 contains only roughly half of T15's total number of grid-points, reducing significantly the computation needs in the validation process. The adequacy of using M15 for validation purpose has been positively verified by examining results from parallel experiments comparing M15 and T15.

The upgrade commenced following a series of extensive data assimilation experiments using the M15 suite, in which individual as well as combined new features have been evaluated. This is further supplemented by a real-time pre-operational test suite with DMI-HIRLAM T15 and S05, nearly one month prior to the final launch of the operational upgrade.

This report describes the main features of the upgrade and summaries main results validating individual components of the new suite. It is expected that the results of pre-operational parallel experiments will be reviewed separately in an accompanying report (in preparation).

Main features of the upgrade

Configuration of data assimilation cycling

Since autumn 1999, DMI-HIRLAM has employed a re-assimilation technique to utilize large scale analysis fields from ECMWF analyses directly in HIRLAM assimilation cycles. The purpose of such an exercise is to absorb the high quality, large scale analysis of the ECMWF global model due to its high quality analysis system and more extensive use of observation data. With a re-assimilation procedure, the quality of the first guess field in the HIRLAM data assimilation is improved. Previously, due to limitation in frequency of the ECMWF global analyses and forecasts (twice a day) and the lengthy delay in delivery, the re-assimilation in DMI-HIRLAM was launched only twice a day, starting from nominal time of 00 and 12 UTC with a subsequent 3 hour interval for the remaining times (Figure 1). Considering the current availability of the ECMWF Boundary Condition (BC) suite which is available 4 times a day with a delivery time within 6 hour on the nominal analysis time, it becomes feasible to re-arrange the DMI-HIRLAM cycling with a re-assimilation 4 times a day, at 6 hour intervals (Figure 2). This enables a more frequent and timely use of high quality ECMWF analyses in the HIRLAM re-assimilation cycles.

In connection with the above change, a 6 h assimilation interval instead of the nominal 3 h interval, has been adopted. Previously in DMI-HIRLAM a 3 h assimilation interval was employed in re-assimilation cycling, with the immediate purpose to utilize more observation data. The advantage

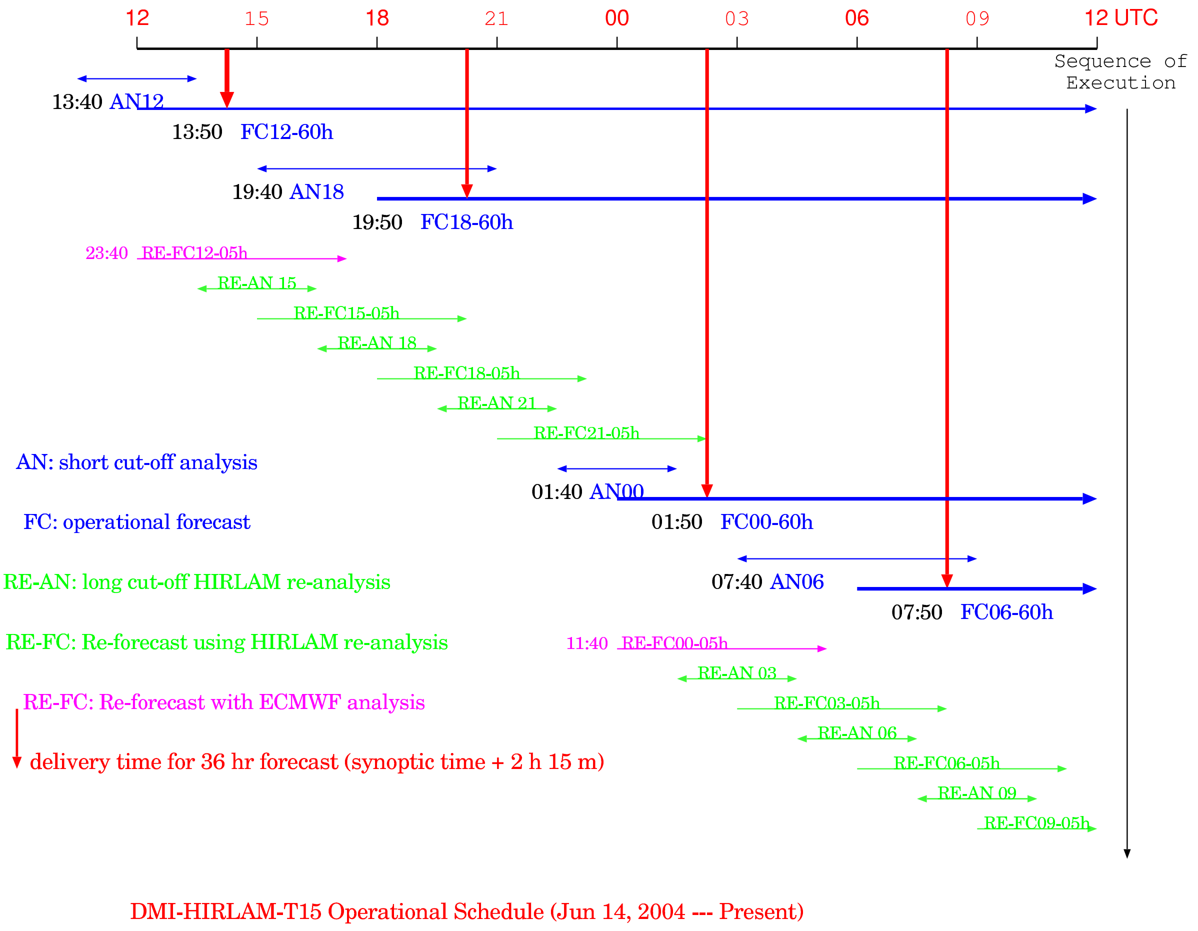

Figure 1: A diagram of the previous DMI-HIRLAM-T15 data assimilation cycle.

of such a frequent analysis update is not obvious, however, in view of the following two factors. First, the 3 h assimilation cycling here is only applied in re-assimilation cycle (i.e., solely for data assimilation purpose), it does not bring more frequent update of forecasts in real time as in the application of the Rapid Update Cycle (RUC); Second, although 3-h cycling, in comparison to 6-h cycling, may potentially utilize more non-synoptic data for the assimilation, presently not much (vertical) profile data are available for intermediate assimilation windows, thus the analysis results may potentially be dominated by the prescribed background error structure function, causing uneven data assimilation qualities between assimilation cycles. In addition, a more frequent model restart also requires equally frequent initialization, amplifying negative aspects of spin-up problems associated with the initialization procedure during forecast steps. Indeed, our earlier experiments using reference HIRLAM indicate noticeably worse results with a 3 h assimilation cycle compared to that with 6 h one (not shown here). In our current study, parallel experiments for summer and winter months have been made with M15 and using 3 h and 6 h cycling, respectively. The resulting observation verification indicates comparable scores.

Using 6 h cycling, the new schedule for T15 thus results in a reduction of the total wall-clock time for a full day data assimilation run of about 1 hour, utilizing the same computational resources.

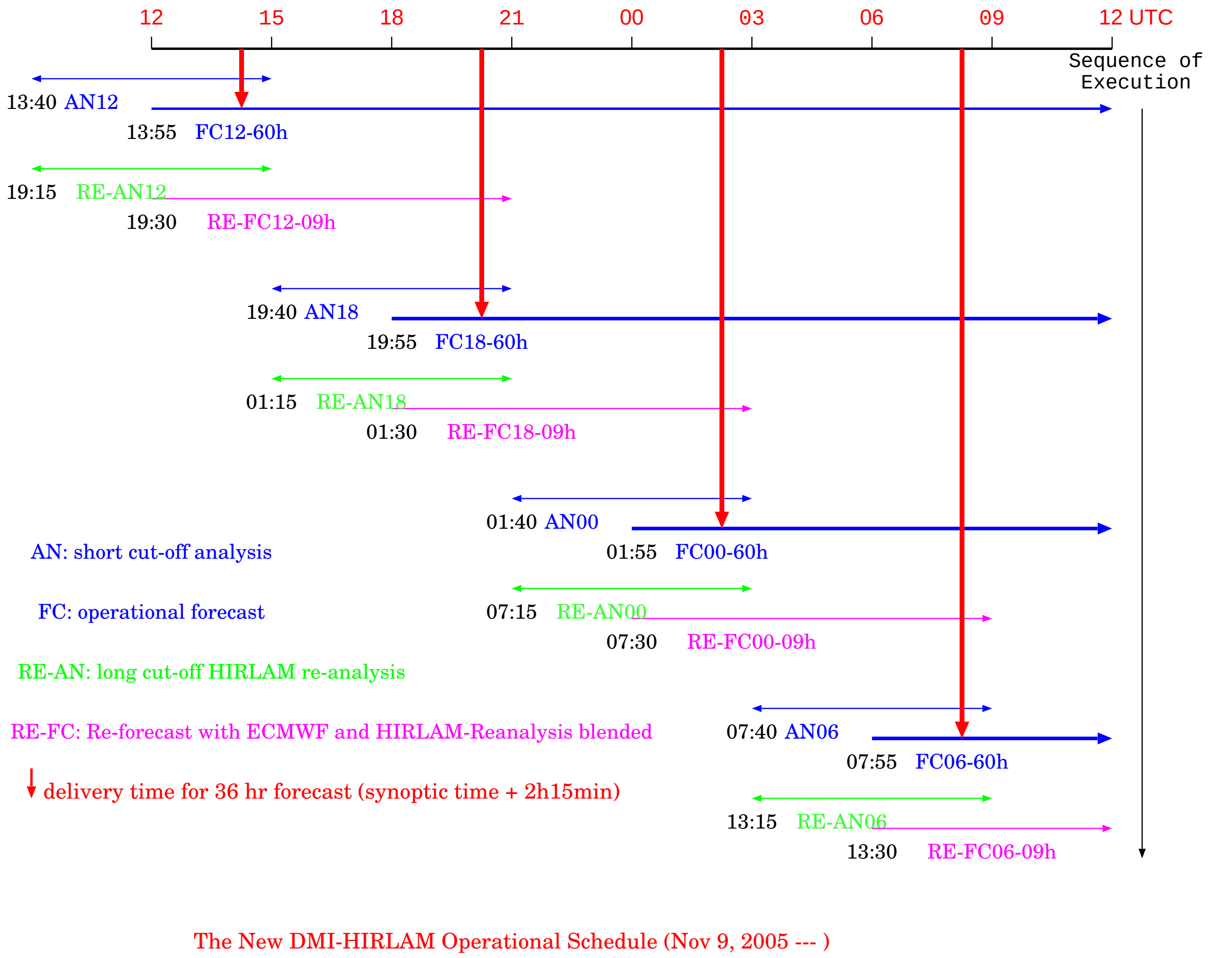

Figure 2: A diagram of the new DMI-HIRLAM-T15 data assimilation cycle.

Analysis coupling with incremental spatial filtering

Based on studies by Yang (2005), an analysis blending scheme has now been introduced into the re-assimilation cycle, in which the re-analysis of HIRLAM for the past cycle (6 hour earlier) is blended with the (late arriving) analysis from ECMWF, through an incremental spatial filter. This is designed so the HIRLAM forecast system can take advantage of the high quality, global large scale analysis in the latter, while retaining features with higher horizontal resolution in HIRLAM's own analysis. The purpose of such blending is to improve the quality of the short-range forecast, which is needed as a background state in the analysis cycle of the short cut-off long forecast. The new analysis blending is performed during the re-forecast step of T15 using the namelist option INCMOD set to 3, with locally modified source code in the HIRLAM forecast module.

Locally derived background error covariance matrix

The upper air analysis scheme, 3D-VAR, needs a priori information about the background error characteristics of the forecast model. Up to now a data set derived from SMHI's old operational archive has been used in DMI-HIRLAM's 3D-VAR analysis, and it is becoming increasingly inadequate due to the significantly different model features such as resolution, domain coverage, the forecast model itself. In this upgrade, the locally derived background error covariance statistics ("structure function"), using the so-called NMC-method and analytical balance approach, with the matching 12,h and 36 h forecasts of the archived operational T15 data, has been adopted. The upgrade enables an increased effective resolution in the 3D-VAR analysis. A preliminary scaling has

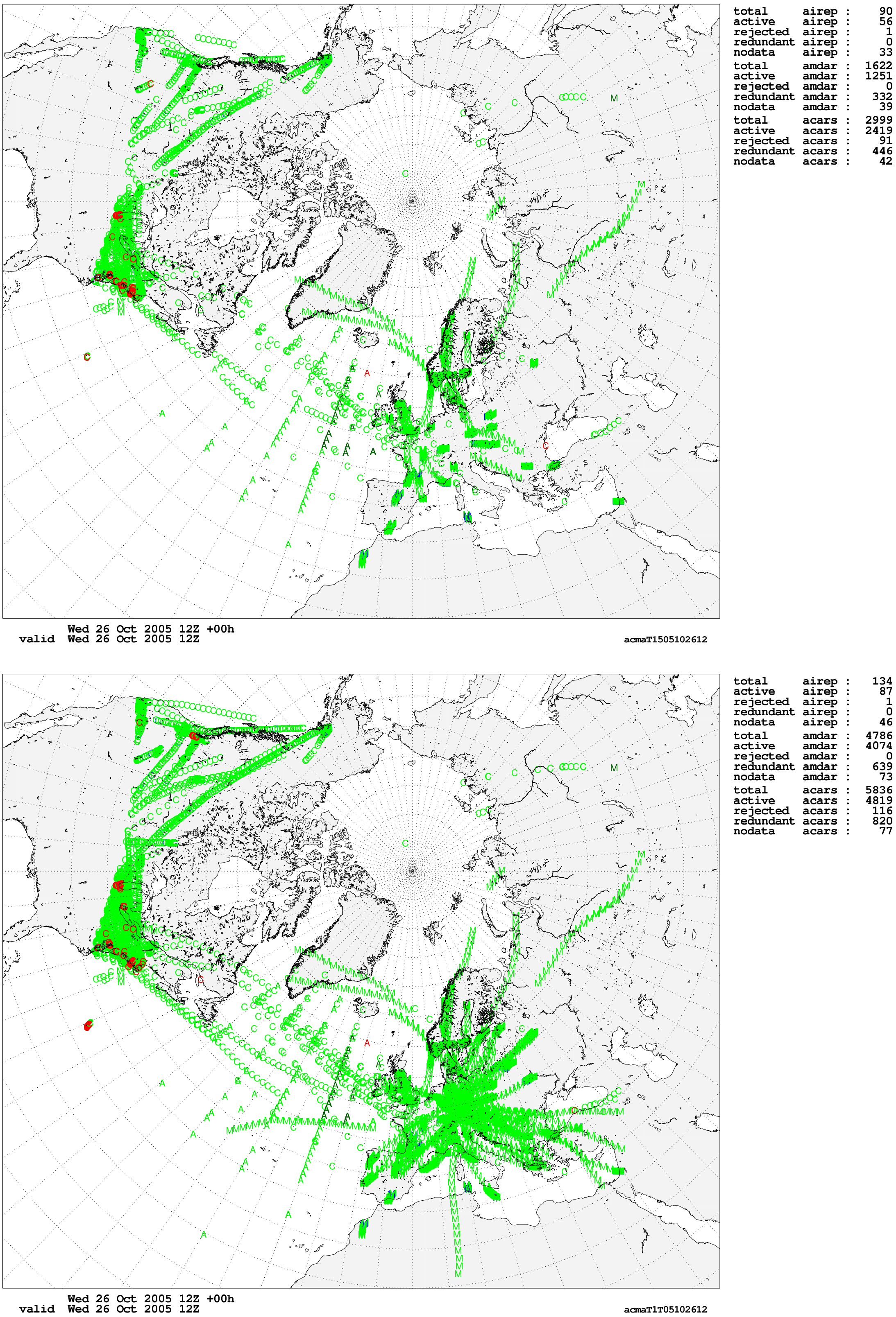

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Figure 3: Usage of AIREP (AIREP,ACARS,AMDAR) data in DMI-HIRLAM before and after the upgrade. The example is taken from a T15 cycle at 12 UTC comparing original and improved aircraft data use.

been made in connection with the new T15-structure function (ca. 0.4). It is anticipated that after a period of operational use, a further tuning of the scaling factor will be made.

Table 1: Contingency table showing impact of physics tuning for EWGLAM precipitation verification, 2005071506-2005081506

Control 18-30hr						Modified 18-30hr					
	O1	O2	O3	O4	O5		O1	O2	O3	O4	O5
F1	9358	371	193	56	46	F1	9544	425	210	53	45
F2	2133	444	350	88	52	F2	2023	463	365	88	53
F3	1311	579	803	267	183	F3	1243	512	775	278	184
F4	169	102	240	189	170	F4	175	100	213	171	137
F5	62	31	75	91	173	F5	58	27	98	101	200

Use of additional aircraft data in BUFR format

Technical changes in DMI's observation data reception have enabled DMI-HIRLAM to utilize a larger amount of aircraft data in the upper air data assimilation. These additional aircraft data have been available to DMI in the past but unused both because they were unknown to users and also due to inadequate assignment of data types for use in the HIRLAM observation pre-processing module OBSPROC. These data are mostly from European AMDAR (E-AMDAR) and packed in BUFR format, in contrast to the traditional GTS ASCII format. By assigning such data to proper data types (as normal E-AMDAR, sub-type 144) in the new DMI bufr-database, these data can be utilized by the upper-air analysis, resulting in an increase in the amount of aircraft data in T15 by a factor of 2 to 3, which may contribute positively to the quality of the data assimilation. The data were not made available in the old DMI bufr-database and first by a change to the new DMI bufrdatabase in this upgrade they were made available to DMI-HIRLAM.

Implementation of the RTTOV8 package

The updated software module for the radiative-transfer algorithm, RTTOV8, has been implemented on top of the HIRVDA software, replacing its predecessor, the RTTOV7 package. The RTTOV package, which is used to process AMSU-A data from NOAA 15/16 in HIRLAM, is made available through EUMETSAT's NWP-SAF. By upgrading the software package to RTTOV8, it potentially enables better use of the existing satellite data and secures future use of newer type of ATOVS data (Amstrup, 2005). Note that the use of RTTOV8 package has involved re-derivation of bias correction coefficients using forecast archives.

Tuning of physical parameterization

An adjustment has been made to the formulation of mixing length and thermal roughness for surface tiles with bare soil or low vegetation types. In addition, a minor code correction has been made in the condensation scheme STRACO. Early experience of using these modifications seem to indicate a reduction of positive surface wind bias, improved surface temperature and relative humidity scores. Table 1 demonstrates the positive impact of the physics tuning on the precipitation forecast for one month summer episode. However, the change also seems to be related to some degradation in the surface MSLP bias, presumably related to the reduced strength of Ekman pumping and hence the effective filling of lows. Further tuning is anticipated in the future.

Other modifications

Increase of time step sizes

With the introduction of more stable advection schemes in HIRLAM-T15 such as the Ritch-Tanguay

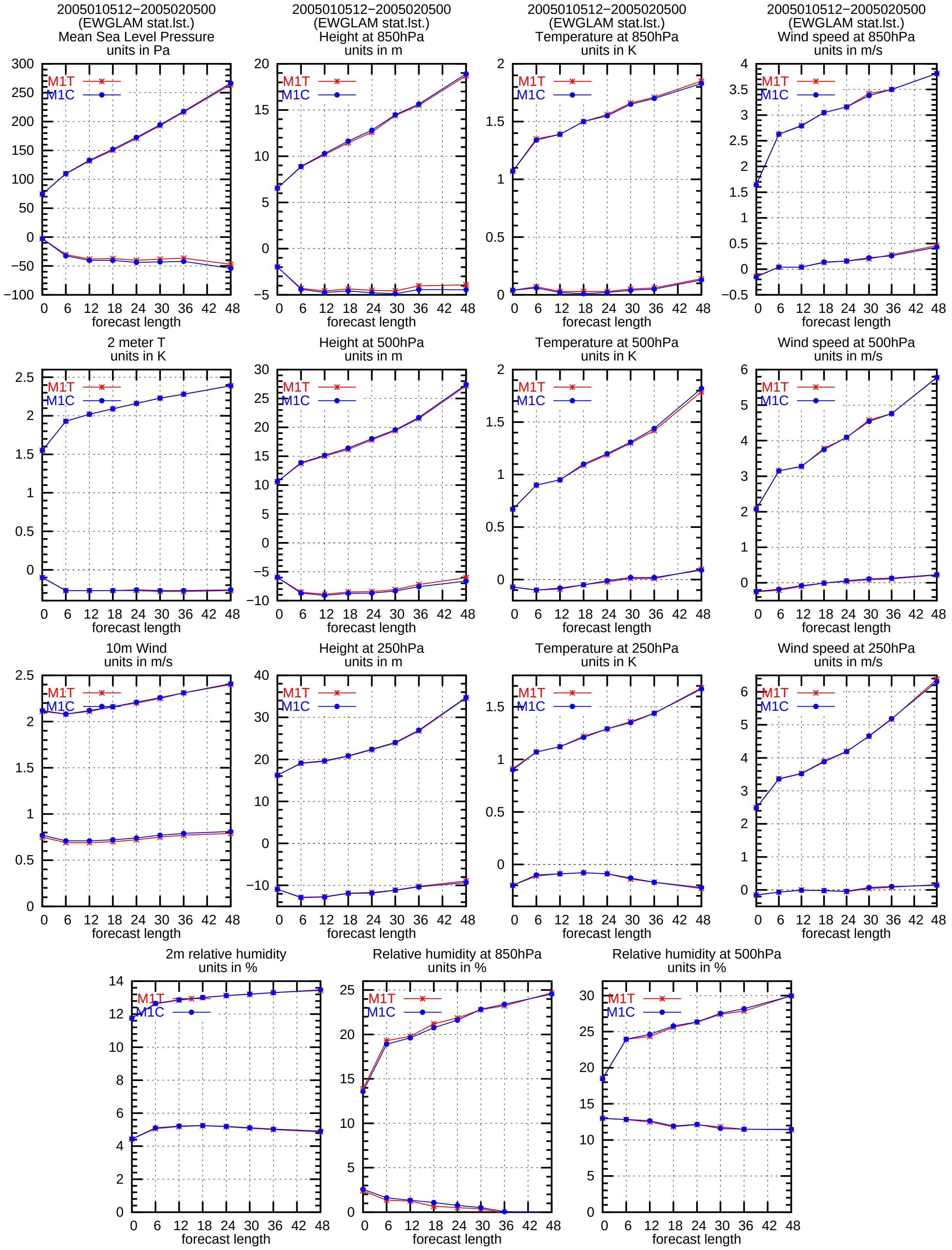

Figure 4: EWGLAM observation verification scores of key parameters averaged for forecasting using time-stepping of 6 min (M1T, in red) and 7.5 min (MIC, in blue). The experiment period is January 5 to February 5, 2005.

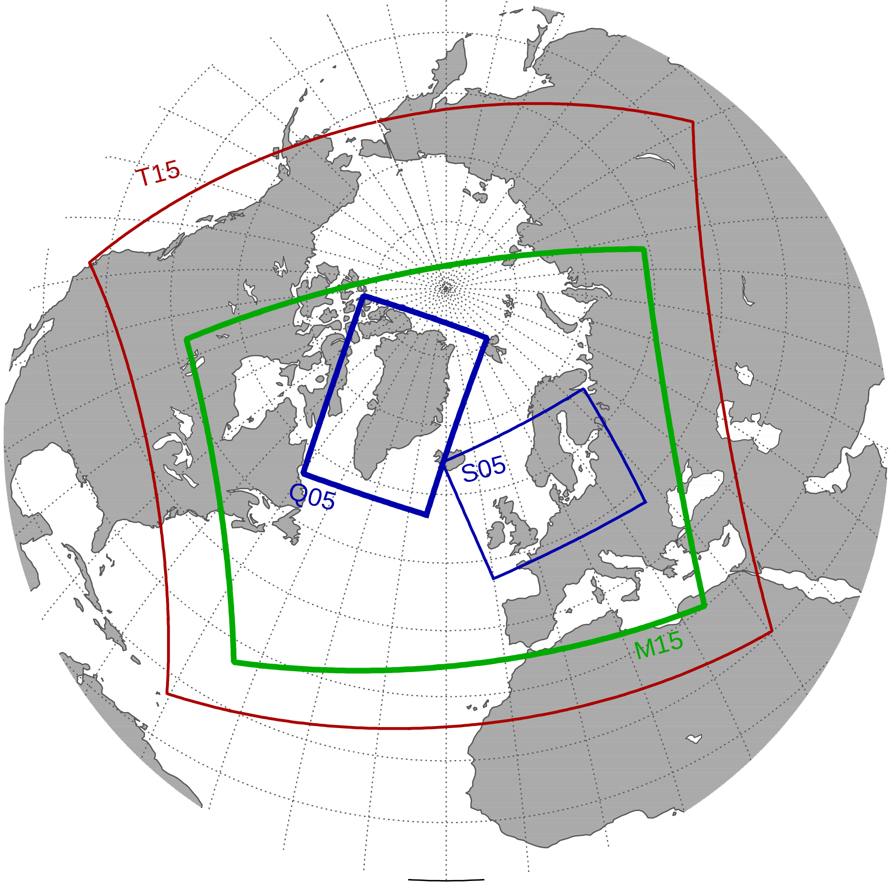

Figure 5: Domain coverage of various DMI-HIRLAM model set-ups including the new suite M15.

temperature correction in areas with high orography (early 2005), and the SETTLS advection scheme in May 2005, it has become possible to explore increasing time-stepping size used in the forecast integration. Two month-long data assimilation runs for winter and summer episodes have been performed comparing the impact of the size of time step on the forecast quality. Figure 4 shows, e.g., the comparison of key forecast scores between the two. Based on these results it was concluded to be appropriate to increase the time step size in the forecast suite for T15 and S05, from 360 s and 120 s to 450 s and 150 s.

Initialization scheme

In the initialization scheme, a correction has been made to the cut-off time scale of DFI (Digital Filter Initialization) filtering. With the Twice DFI scheme (TDFI) using a Dolph Chebychef filter, the filter span is 2 hours with a cut-off time scale of 3 hour. In the earlier implementation, a mistake was made so that the effective cut-off time scale was 6 hour. Furthermore, in the Incremental DFI scheme, a modification has been implemented to ensure non-negative specific humidity, cloud water and turbulent kinetic energy following the filtering. No major difference has been observed in parallel test results associated with these code changes.

M15, a model suite with reduced domain

The DMI-HIRLAM model upgrade as described above involves system elements changes in various modules, requiring extensive and careful evaluation and tuning through numerical experiments. For the operational suite on the T15 domain, this implies especially heavy test work. In order to improve

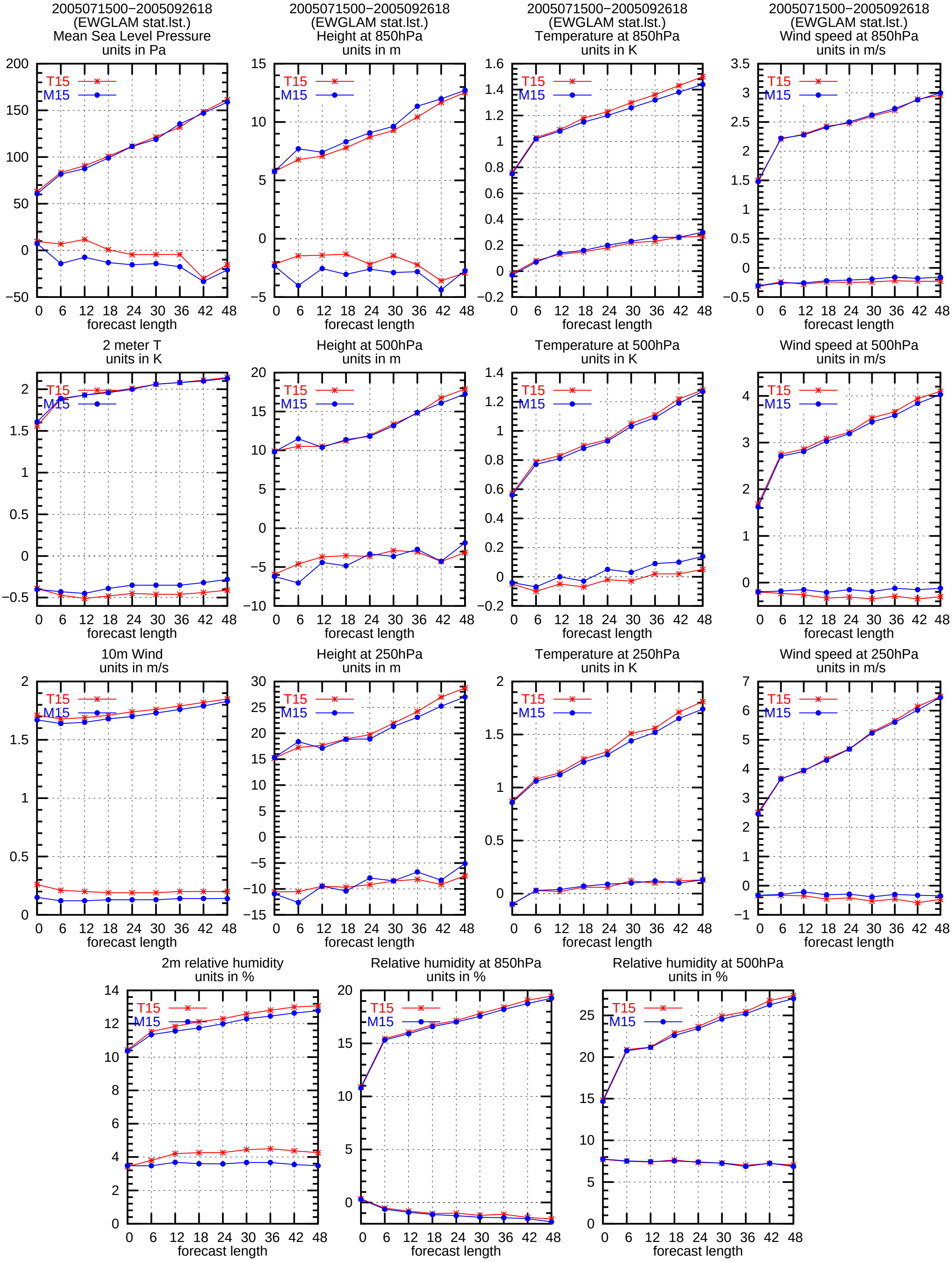

Figure 6: EWGLAM observation verification scores of key parameters averaged for forecasting comparing operational T15 suite with that of M15. The experiment period is July 15 to September 26, 2005.

the efficiency of the validation procedure associated with the model upgrade, M15, a model domain with reduced size compared to that of the operational T15, has been introduced (Figure 5).

Compared to T15 with a grid mesh of 610x568x40, M15, with a grid mesh of 366x490x40 but with the same spatial resolution, contains only about half of T15's total number of grid points, thus reducing significantly the computation needs in the validation process. In Figure 5, the domain coverage of M15 is compared also to other of DMI's operational ones: T15, S05 and Q05.

As is shown in the Figure 5, with roughly half of the grid points compared to T15, the M15 domain is still capable to provide a reasonably good coverage for DMI's key forecast service area, i.e, Denmark with surrounding countries, Faroe Islands as well as Greenland. The reduced computational needs with M15, meanwhile, enable model run on a single NEC-SX6 node with a similar delivery time as that for the corresponding T15 when running on 3 nodes.

A two and half month parallel M15 suite has been run from middle July to late September 2005. Figure 6 shows observation verification scores for the period. Note that in the M15 suite there has been some preliminary modification of the turbulence scheme regarding the mixing length, which is assumed to account for some of the score differences for surface parameters. In general one can see that the two suites have a comparable performance for key parameters. Interestingly, M15 tends to produce slightly better scores for day 2, probably due to the influence of ECMWF forecast. The results seem to confirm it being appropriate to use M15 for pre-operational meteorological evaluation on most features in preparation for a future operational upgrade.

Meteorological evaluation for historical and real-time runs

Using primarily M15, a large number of numerical experiments have been conducted examining individual or combined new model components.

After the preliminary and positive evaluation of the model upgrade using M15, two month-long evaluation tests of historical episodes for winter (Jan 2005) and summer (mid-July to mid-August 2005) have been performed comparing the operational and new upgrade suites for the T15 domain. Finally, in addition to the evaluation of the historical episodes, the new update suites were put into a pre-operational parallel run for the operational T15/S05 suites. Figure 7 shows the forecast scores comparing the operational and the pre-operational suites (for both T15 and M15 domains) for the period Oct 14 to Nov 9, 2005, demonstrating a rather positive improvement with the new upgrade.

To summarize, results of these parallel and/or real-time parallel numerical experiments are generally in favor of the upgrade. In particular, the new suite has been found to feature
— a reduced surface wind RMS and reduced positive surface wind bias
— a reduced summer time T2m RMS and negative T2m bias
— a reduced RMS in RH2m and reduced positive bias
— little change in RMS for MSLP but a slightly increased negative bias
— an improvement in the precipitation verification scores, mainly for the small precipitation class.

Summary

The Nov 2005 upgrade of DMI-HIRLAM consists of several major changes to the operational suite, covering various components of the HIRLAM forecast system. In the new suite, the configuration of the data assimilation cycling has been changed aiming for a more frequent and timely use of high quality ECMWF global analyses and forecasts, and to have a simpler structure of the re-assimilation setup. Experimental results also support the change of the data assimilation interval from the previous 3 h to 6 h, which in addition results in a significantly reduced total computation time. In this upgrade, a blending scheme to combine large scale features from the ECMWF global analysis with that of HIRLAM's analysis for remaining scales is implemented in re-assimilation cycles, using the

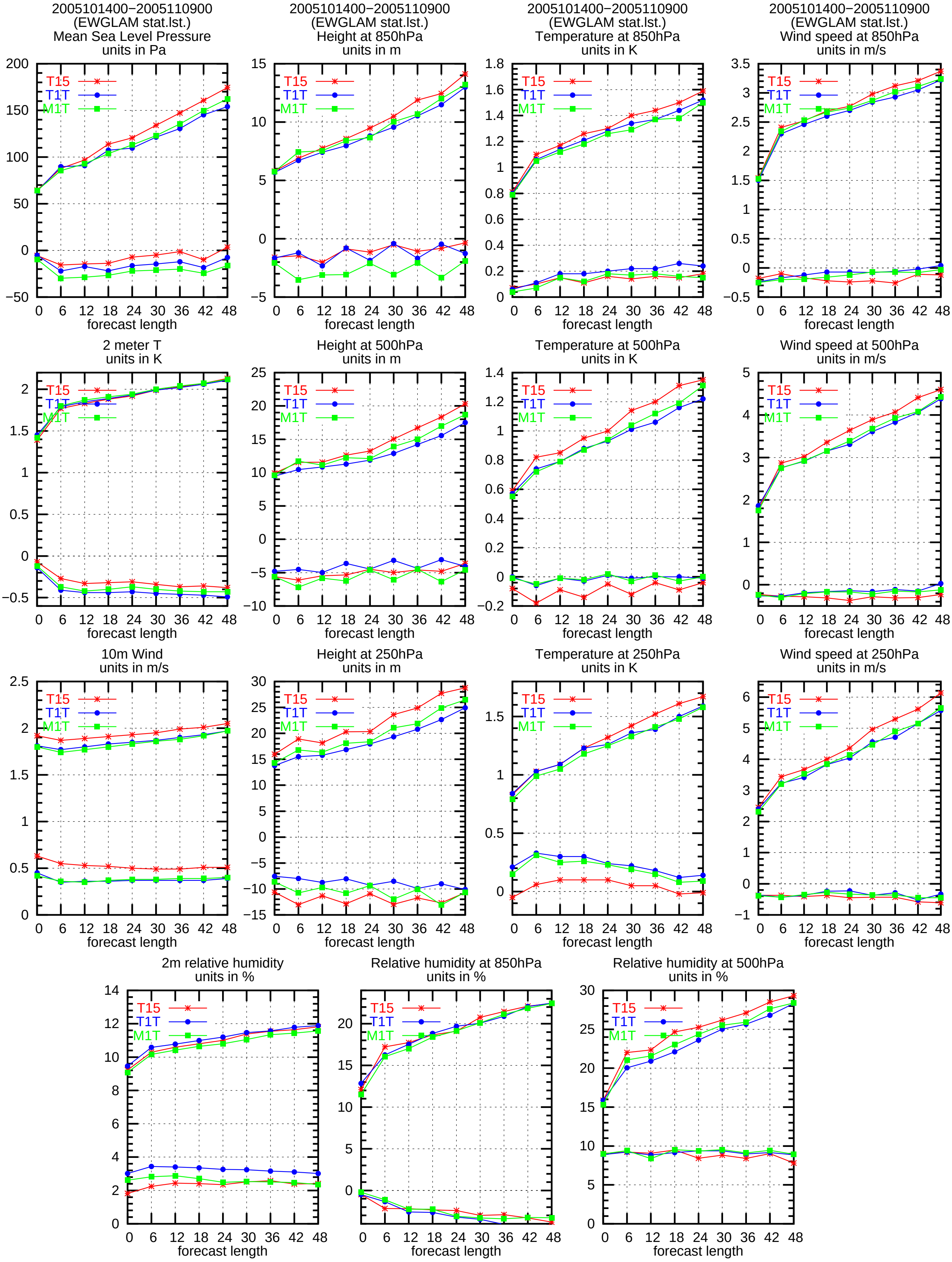

Figure 7: EWGLAM observation verification scores of key parameters averaged for forecasting comparing operational T15 suite with that of parallel suite on the T15 and M15 domains, T1T and M1T. The experiment period is October 14 to November 9, 2005.

algorithm proposed in Yang (2005). The T15 analysis now uses locally derived background error structure functions in 3D-VAR. This also enables an increased effective resolution in the 3D-VAR analysis. The new DMI-HIRLAM is now using a significantly larger number of aircraft data, available in BUFR format. Implementation of the new software package RTTOV8 for AMSU-A data is now included, enabling a potentially better use of the existing satellite radiance data and future use of newer types of satellite radiance data. For the physical parameterization in the forecast model, adjustments have been made to the formulation of the mixing length and thermal roughness for surface tiles of bare soil or low vegetation types. In addition, there is a minor code correction in the condensation scheme STRACO. Finally, based on the evaluation of several month-long data assimilation experiments, an increase of the time step sizes for the T15 model, from the current 360s to 450s, is adopted. The time steps for the 0.05 degree resolution runs, S05 and Q05, have also been increased, from 120s to 150s, respectively.

An innovative feature during the preparation of this upgrade is the introduction of a smaller model domain, M15, used for validation studies evaluating meteorological performance of new upgrades. In this connection, a real-time model suite of M15 has been established in order to accumulate experience with its relative performance in comparison to the correspondingly larger T15 domain. The feasibility of using M15 for validation purposes has been demonstrated through multi-month parallel tests. The M15 has been proved to be useful to enable an inclusion of a large number of new features in the current upgrade, most of them have been tested extensively either individually or combined.

From multi-month evaluation tests of historical episodes for winter (Jan 2005) and summer (mid-July to mid-August 2005), as well as the real-time pre-operational test during October 14 to November 9, 2005, the conclusion is that the new operational upgrade results in a substantial improvement in the forecast of several key verification parameters, such as a reduced rms and reduced positive bias in surface winds, a reduced summer time rms and negative bias for T2m, a reduced rms and reduced positive bias in RH2m, an improved std in MSLP albeit with a somewhat increased negative bias. Finally, the upgrade also results in an improvement in precipitation scores, mainly for the small precipitation class.

It should be mentioned that several components and the evaluation procedure adopted in the pre-operational tests for this upgrade have been motivated by technical requirements enabling easier introduction of further upgrades in the near future, namely an increase of the model resolution in both the horizontal and the vertical, and an upgrade in the assimilation method to 4D-VAR.

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Appendix A: Operational schedule

Table 2: Operational schedule of DMI-HIRLAM which consists of runs with T15, S05 and Q05. T_R in the table denotes a re-assimilation featuring blending of HIRLAM's re-analysis and the ECMWF analyses.

Launch Time (UTC)	T15 Cycle	S05 Cycle	G05 Cycle
01:00	T_R18 +09 h		
01:37	T00 +60 h		
02:20		S00 +54 h	
02:55			G00 +36 h
07:00	T_R00 +09 h		
07:37	T06 +60 h		
08:20		S06 +54 h	
08:55			G06 +36 h
13:00	T_R06 +09 h		
13:37	T12 +60 h		
14:20		S12 +54 h	
14:55			G12 +36 h
19:00	T_R12 +09 h		
19:37	T18 +60 h		
20:20		S18 +54 h	
20:55		G18 +36 h	

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