6.01 NONHYDROSTATIC HIRLAM WITH SEMI-LAGRANGIAN SEMI-IMPLICIT DYNAMIC CORE IN HIGH RESOLUTION NWP ENVIRONMENT

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1. INTRODUCTION

Starting from the end of the year 2003, a very high resolution nonhydrostatic NWP system is running in a near-operational regime at Estonian Meteorological Hydrological Institute (EMHI). This is a collaboration effort between University of Tartu (UT), EMHI and Finnish Meteorological Institute (FMI). EMHI hosts the environment, provides communication and computing facilities. EMHI helps also to define the requirements and societal demand to the project. FMI provides boundary and observational data to the forecast model. FMI delivers also its long-lasting limited area modelling and operational forecasting know-how. The role of UT is to maintain the environment, to develop nonhydrostatic core model together with high resolution physics package and ensure its scientific and operational quality.

The project aims for high-precision presentation of local effects and improvement in short range forecasting. The advances are expected mostly in precipitation event or local wind modelling and in increase of severe weather forecasting precision. In addition, it is hoped that the high resolution NWP data is beneficial to wide range of practical and scientific applications like air pollution modelling or coastal research. Thus, the project should benefit and facilitate the scientific research by providing numerical output and research problems to scientific community. The project helps hopefully to improve the quality of short range forecasts and to develop a new range of services of local high precision forecasts.

It should be noted that since its inception, the NWP environment has been considered rather an experimental than a full-featured operational production ready system. It should be viewed as a prototype system to identify the advances or shortcomings of the very high resolution NWP system and to assess the feasibility of the approach. The development team is aware that the environment may contain significant design problems and a lot of issues are expected to rise during everyday operations. However, the main idea was to start with and use what is available now and solve the problems step by step as they occur and technical side allows.

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2. MODEL DESCRIPTION

The NWP system is based on the NWP model of HIRLAM Consortium and also on its nonhydrostatic (NH) extension, developed at UT. In February 2005, the semi-implicit semi-Lagrangian (SISL) nonhydrostatic dynamic core was introduced into the NWP environment. The basis for dynamics are the semi-anelastic pressure-coordinate equations of motion and thermodynamics in Lagrangian form (Rõõm, Männik and Luhamaa 2005). The pressure-coordinate model is essentially the White model (White 1989) which has been successfully employed in HIRLAM framework before, using Eulerian representation (Männik, Rõõm and Luhamaa 2003, Rõõm and Männik 2002, Männik and Rõõm 2001)

The main properties of the NH SISL HIRLAM schema are:

- It uses height dependent reference temperature profile which results in enhanced stability rates as the nonlinear residuals are minimized in vertical development equations
- The model is semi-anelastic which means that internal acoustic waves are filtered out with the assumption of incompressibility in pressure space.
- NH SISL tries to be as close as possible to the parent hydrostatic HIRLAM SISL scheme (McDonald 1995, McDonald and Haugen 1992). The existing routines of trajectory calculations and interpolations as well as the interface to physical packages are maintained.
- To evaluate baric (includes nonhydrostatic component) geopotential, an elliptic equation is solved using FFT algorithms. The Earth curvature is assumed to be small perturbation to flat geometry.

It must be noted that the NH SISL scheme is only an adiabatic core. A substantial problem to the application of the NH SISL HIRLAM grows out from the lack in parent model of suitable physical package for very high resolution modelling. NH SISL uses physics routines as they are in HIRLAM without modification, as developed for lower resolution synoptic scale modelling purposes. It is possible to adapt current routines of physics to very high resolution

and some modifications of that kind are available from newer official versions of HIRLAM. However, the fine tuning and possible critical revision of the schemes might require considerable effort in the future.
The biggest advantage of NH SISL is that it allows to use remarkably longer time-step and to increase modelling domain at NH resolutions compared to Eulerian implementations. The switch from previous NH SI Eulerian system to NH SISL allowed to increase the modelling area three times (ca 1.7 times in respective horizontal direction) and decreased computational time by factor of two.

3. NWP ENVIRONMENT

The NWP model, which is employed in the environment, is HIRLAM version 6.1.0 with minor modifications. HIRLAM provides a wide range of options for modeling applications, but the following set has been chosen for current environment:

- Optimum interpolation for data analysis
- Implicit normal mode initialization as initialization scheme
- Semi-implicit semi-Lagrangian scheme
- ISBA scheme for surface parameterization
- The STRACO scheme for large scale and convective condensation
- Savijärvi radiation scheme
- CBR-turbulence scheme

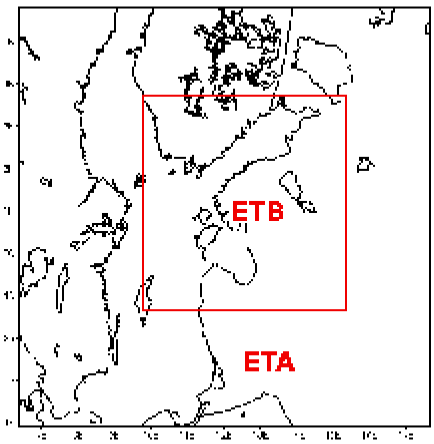

Figure 1. Modelling areas.

The integration areas are presented in Figure 1. Lower resolution area named ETA has horizontal resolution 11 km and hydrostatic SISL scheme with 400 s time-step is applied in the forecast model. The grid is 114x100 points in horizontal directions and 40 levels. The ETB area has 3.3 km horizontal resolution and applies NH SISL with 150 s time-step. The grid is 186x170 points in horizontal and 40 levels.
ETA area is introduced for several purposes. The computing power at EMHI is insufficient to cover the whole area of interest with 3.3 km resolution model. Thus, intermediate solution had to be found to satisfy all involved parties. The area is also useful to soften the transition from 22 km area directly to 3.3 km which could create interpolation problems in boundary zone. ETA area can serve as a reference model for comparison. It has not been used yet in that purpose routinely and, as discussed later, several difficulties may arise, but in principle such a background data are necessary for model evaluation.
Boundary fields to ETA are provided by FMI. They are cut out from forecasts of FMI operational model which has horizontal resolution 22 km. The fields are provided four times a day with forecasting start-point at 00, 06, 12 and 18 GMT. As FMI requires the time to prepare the analysis and calculate the forecast, the fields arrive 4.5 h hours later. The time frequency of boundary fields for ETA is 3h. The time frequency of boundary fields for ETB area is 3h as well. However, the frequency can be increased up to 1h. The environment utilizes the boundary relaxation scheme from HIRLAM 6.1.2 version, which is similar to MC2 model.
Twice a day 36h forecasts are produced in ETA area. Start-points for forecast are 00 and 06 GMT. Due to the time spent on obtaining boundaries and computing, plus time zone difference, forecast products are delivered to users at 8.15 and 14.15 local time. Computation of analysis and forecast takes approximately 15 minutes. To maintain analysis cycle, additional two 6h forecasts are produced by ETA with start at 12 and 18 GMT
The ETB area uses forecasts of ETA area as lateral boundaries. 36h forecasts are produced once per day with start at 00 GMT ETB has its own analysis with interval of 24h. The time spent on computing of forecast is about one and a half hours.

4. EXPERIENCE

The very high resolution NWP system has been in work since autumn 2003. The system has been in continuous development improving gradually. Starting from February NH SISL model was introduced to the environment which resulted in increased domain and smaller time consumption rates which means shorter delay from observations to forecast. The current cut-off time is 7.5 hours. This is still too high for a system which should produce frequent short forecasts. Thus, the methods to shorten the delay must be considered in future. The increase of domain was necessary also because the whole country was not covered by older system. Though this is rather political aspect, it was important for the local scientific community as well. At the same time, the increased domain demands better archiving capabilities and when

further increase of domain becomes available, the archiving strategy must be reconsidered as well.
To evaluate the model performance, simple comparison with standard observations have been used so far. Larger ETA model uses standard HIRLAM package where forecast is compared against the set of standard observations. With the former smaller ETB area the number of observations was so small that statistical averaging over stations was not reasonable. The statistical averaging over upper-air data was even not possible, as in the area existed only one sounding station.
Thus, to evaluate the ETB forecasts, time series of observations were compared against forecasts at few selected stations. The example is presented on Figures 2 and 3. Figure 2 presents monthly average of comparison of ETA, ETB and FMI forecasts against sounding station at Harku in April 2005. This was the only station which all three models shared in the former system. As sounding profiles were obtained once a day at 00 GMT, only the 24h forecasts can be verified. Figure 3 presents monthly average of verifications of forecasts of different length for ETA and ETB models against standard observations at Tõravere meteostation in April 2005.
The verification method presented here were useful only to certain extent. It helped to uncover problems and gave hints about the quality of the very high resolution model. However, this method was regarded only as a “first aid kit”. It is problematic to assess the overall quality of the very high resolution model based on observations in few stations. Thus, more sophisticated methods have to be used or developed for such a system in the future.
With the increased ETB modelling domain the standard statistical approach becomes feasible again. The verification system has to be reconsidered according to newer domain. However, many important questions still require answering. Figure 4 and 5 show standard verification scores of HS ETA model, HS ETB model and NH ETB model. The statistics is gathered in a model comparison experiment over two week period in January 2005. Although small differences do exist in verification scores which could be used for speculation, in essence, the differences vary significantly depending on how many or which days are included in calculations. In general, it is only possible to conclude that different models have comparable quality, which is of course a weak argument for spending resources on very high resolution NWP models. The picture is slightly different when forecasts are compared against each other. Figure 6 shows HS and NH model 36h integrated precipitation forecast differences. The start time of forecast is 06 GMT on 3rd January 2005. The Figure 6 shows remarkable difference in precipitation. Unfortunately, the situation can not be linked to ground station measurements in this case. However, the method itself can potentially be applied in high resolution NWP model quality assessment. It requires significant human intervention and monitoring, but is simple and accessible.
This experiment shows that standard verification scores which are obtained routinely can only hint for potential problems and the problems should be clearly manifested for serious consideration. The verification statistics is barely usable for model comparison, if the models are approximately of the same quality. Strong dependence of verification statistics on data selection indicates that the usage of verification statistics is highly questionable if heterogeneous systems like ETA and ETB are compared. This means that efforts to homogenize the ways of running ETA and ETB models have to be taken in future. Homogenization could also bring effectively out the model comparison potential of the two area system. In general, we can conclude that high resolution forecasts verification is quite problematic from 2D ground-based observational data, without entrainment of additional 3D data.

5. CONCLUSIONS

NH SISL HIRLAM is successfully applied in very high resolution NWP environment at EMHI. The scheme allows remarkable efficiency compared to older set-up. The quality is comparable with lower resolution HS system.
The problem of validation of the high resolution forecast is largely unsolved. Application of standard verification scores is not satisfactory measure and can only be used as a starting point for the future development.
The high resolution forecast should be compared to a reference model to find out whether remarkable differences exist. The differences should be evaluated against observations where available. The method can be applied on selected cases and requires human intervention.
The extra value of high resolution forecasting is not clear. More effort should be put on the development of products or enhancement of operating conditions of high resolution NWP model which could make possible benefits explicit.

6. FUTURE DEVELOPMENTS

In near future the NH SISL HIRLAM and very high resolution NWP environment at EMHI will focus on the following goals:

- The system should be ported over latest official version of HIRLAM (6.4.0). This change is expected to introduce better support for very high resolution modelling (climate files, stability) and increased computational performance.

- As HIRLAM 6.4.0 does not support OI analysis any more, the 3DVAR analysis scheme will be introduced to the environment.
- Physical package of HIRLAM needs critical revision at 3.3 km resolution. The interaction with nonhydrostatic adiabatic core should be investigated as well. It is planned to use explicit representation for deep convection and the parameterization of shallow convection.
- As standard RMS statistics offer very little ground for quality assessment of very high resolution models, it is necessary to seek for methods which evaluate comparative differences with reference forecast on case by case basis, if remarkable differences exist.
- Increase of vertical resolution, if additional computing power will be available.

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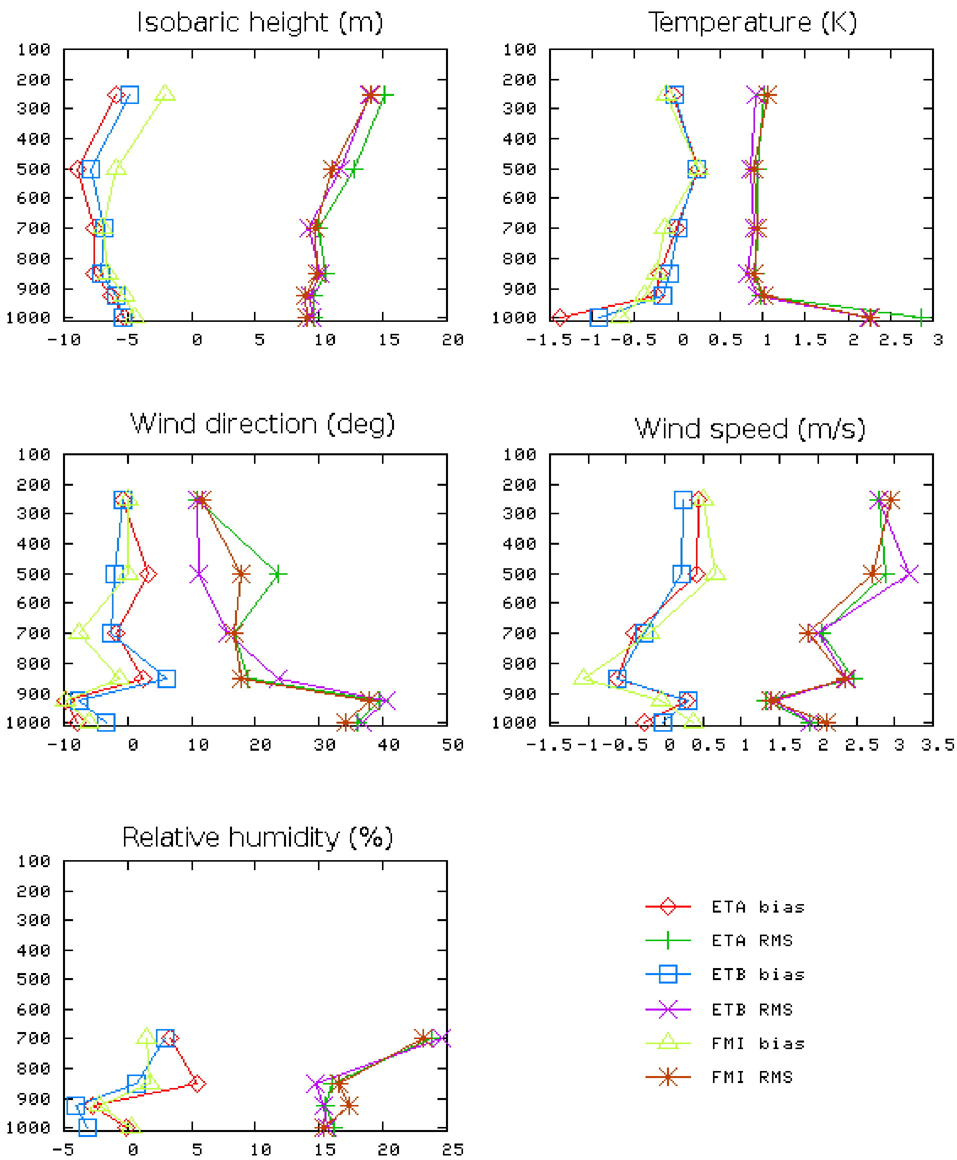

Figure 2. Verification statistics of three models against Harku sounding station in April 2005.

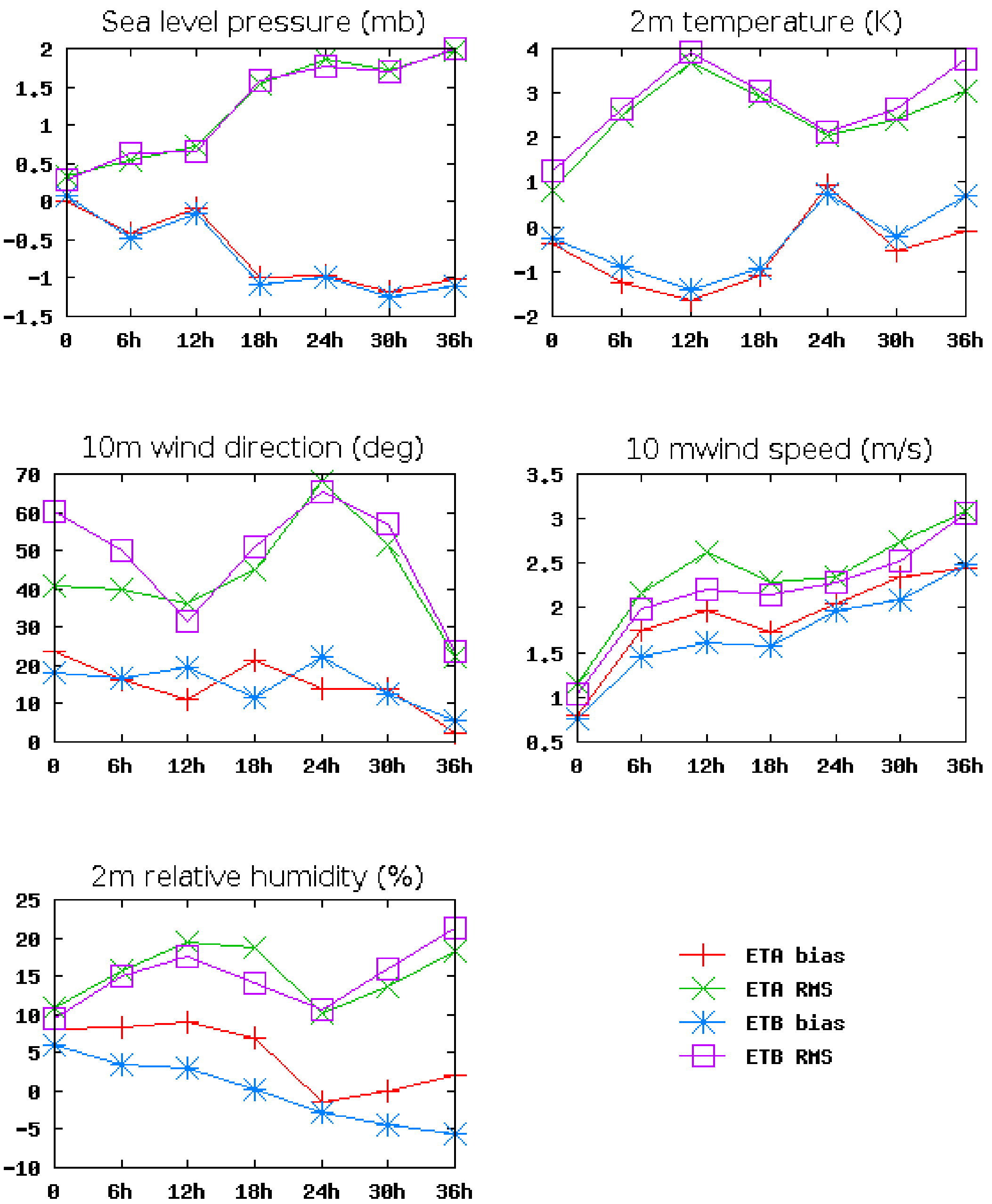

Figure 3. Verification statistics of ETA and ETB model forecasts against observations in Tõravere meteostation in April 2005

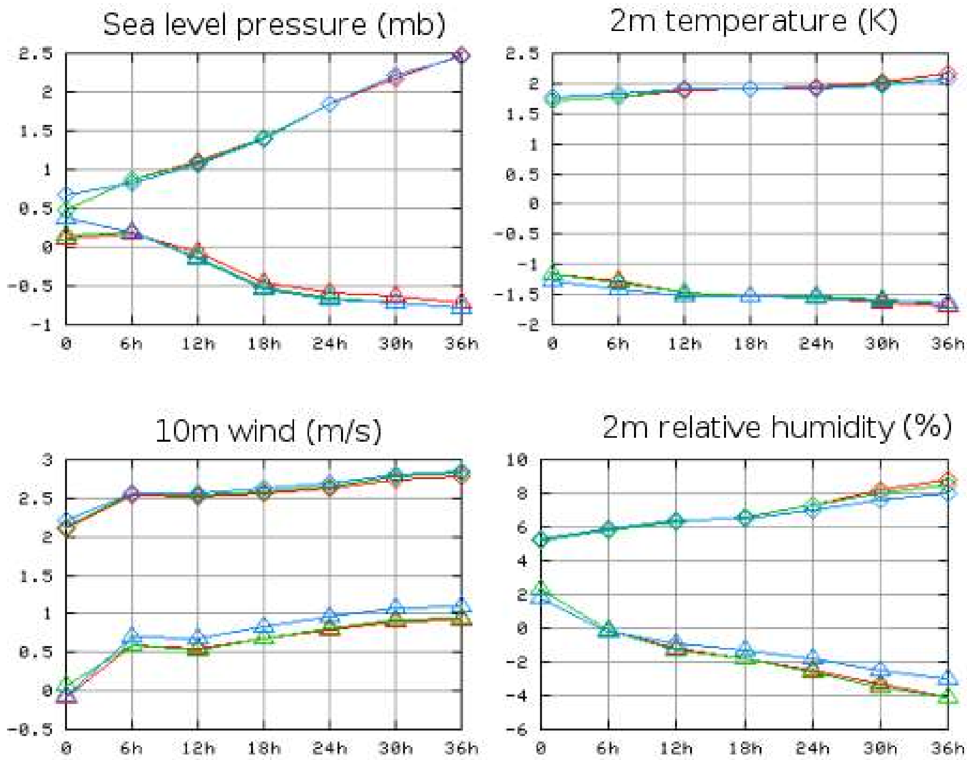

Figure 4. RMS errors (rhomb) and biases (triangle) for sea-level pressure, 2 m temperature, 10 m wind and 2 m relative humidity at different forecast lengths. Red line marks HS SISL with 3.3 km resolution, green line NH SISL at 3.3 km resolution and blue line HS SISL with 11 km resolution.

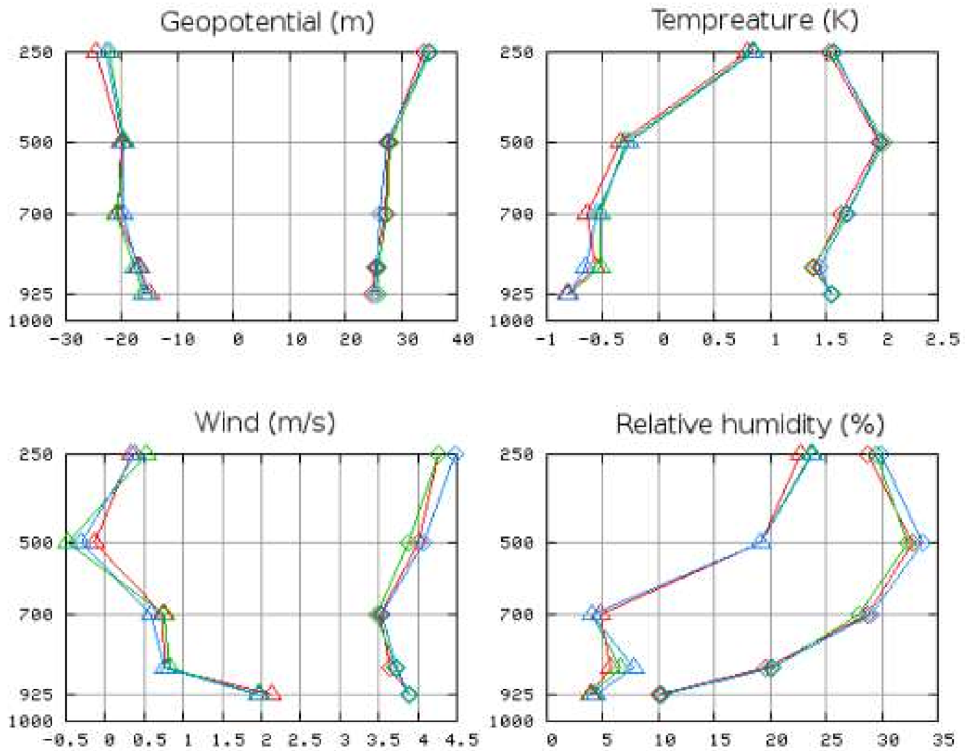

Figure 5. RMS errors (rhomb) and biases (triangle) for geopotential height, temperature, wind and relative humidity of 36 h forecast at different pressure levels. Red line marks HS SISL with 3.3 km resolution, green line NH SISL at 3.3 km resolution and blue line HS SISL with 11 km resolution.

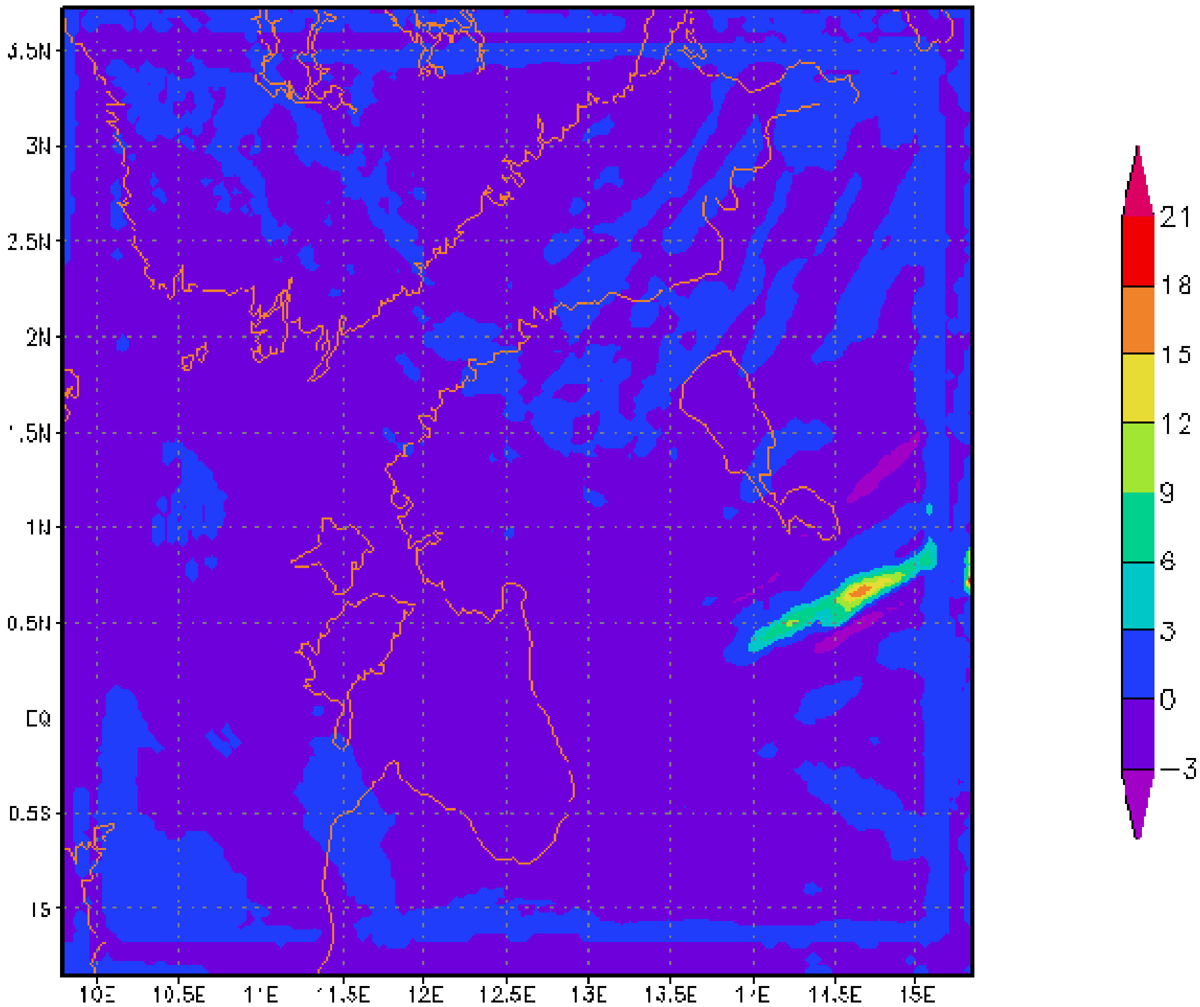

Figure 6. 36h integrated precipitation difference of NH ETB and HS ETB forecasts.