LAM efforts at Estonian Meteorological Hydrological Institute

A. Männik, R. Rõõm
Estonian Meteorological Hydrological Institute,
University of Tartu

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.
The situation will change significantly after accession of EMHI to HIRLAM Consortium and Estonia will be able to use the model in operational work. This implies stronger constraints and demands from operational activities to the stability and quality of the environment.

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 2006). 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 scheme 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 6.4.0 with minor modifications. HIRLAM provides a wide range of options for modelling applications, but the following set has been chosen for current environment:
• 3DVAR 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
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.

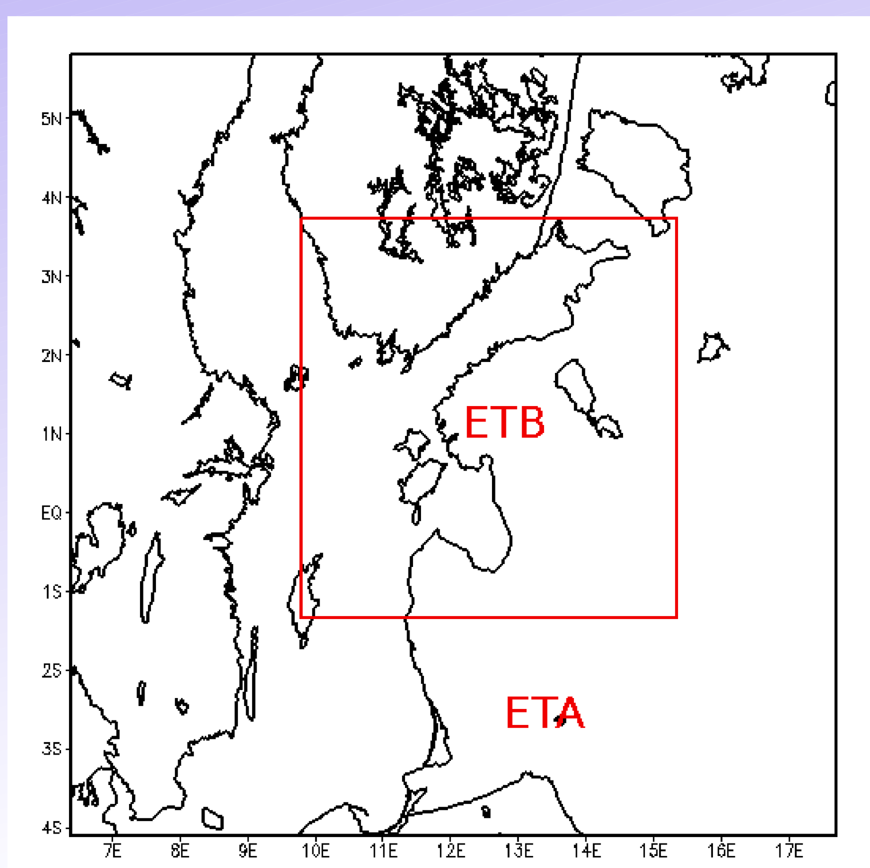

Figure 1. Modelling areas.

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.
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 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 twice per day with start at 00 and 06 GMT. ETB has its own analysis cycle similar to ETA. The time spent on computing of forecast is about two and a half hours.

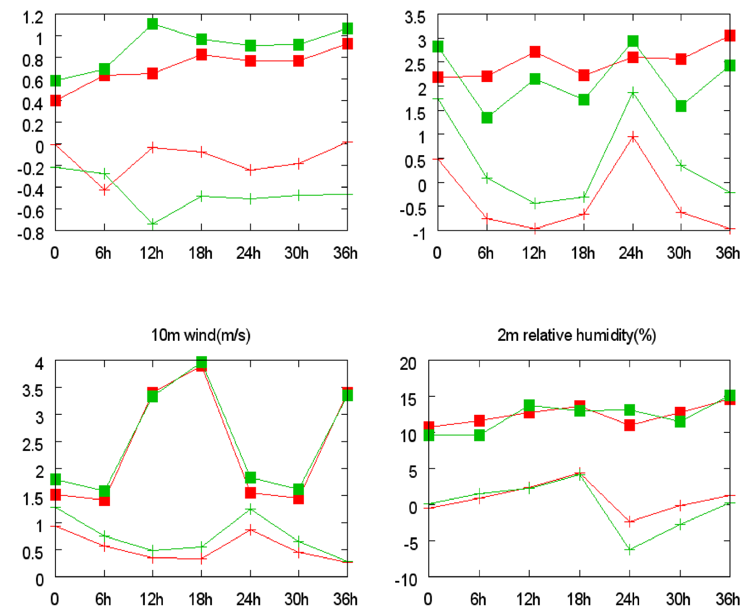

Figure 2. Biases (crosses) and RMS errors (rectangles) of surface parameters of HIRLAM ETA area (red) and ECMWF (green) in July 2006. 00 GMT forecasts are used to compute the statistics.

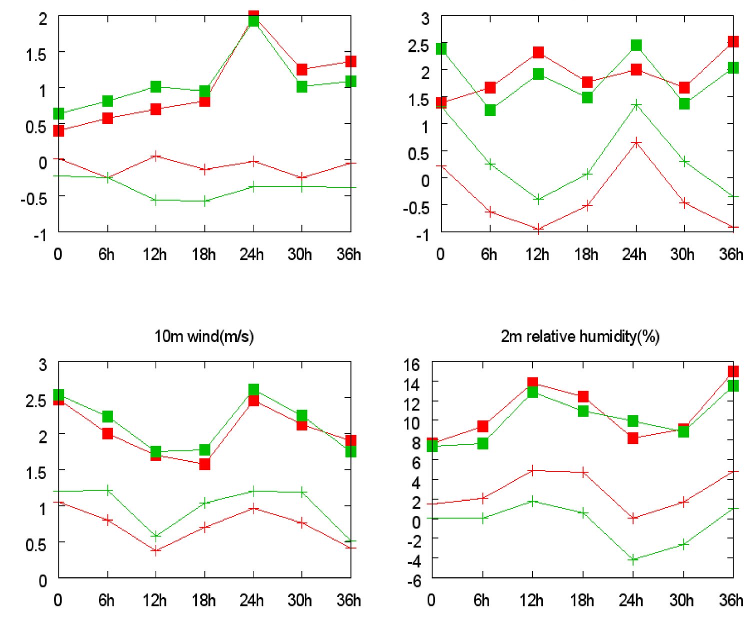

Figure 3. Biases (crosses) and RMS errors (rectangles) of surface parameters of HIRLAM ETA area (red) and ECMWF (green) in August 2006. 00 GMT forecasts are used to compute the statistics.

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.
Unfortunately the introduction of NH SISL model led also to problems with stability of ETB domain. The causes of instabilities have been investigated and linked to a deficiency in the models semi-implicit formalism. A fix has been proposed and installed to the NWP environment in September 2006. However, the period of operations is yet too short to draw final conclusions about the quality of the fix.
To evaluate the model performance, simple comparison with standard observations have been used so far. The set of stations common to both modelling domains is used to compute bias and root mean square error statistics.
As Estonia joined ECMWF in November 2005 it has become possible to compare the quality of NWP environment at EMHI to ECMWF forecasts. Sample results from July and August are presented in Figures 2 and 3. It is evident from the error statistics that the NWP environment at EMHI offers competitive quality to ECMWF forecasts over short range. In combination with earlier availability and more frequent updating of the forecasts the LAM approach proves to be viable solution to short range NWP at EMHI.
To compare the performance of ETB and ETA the following skill score is used

$$MSESS = 1 - \frac{MSE_{ETB}}{MSE_{ETA}}$$

Positive values of score indicate better performance of high resolution ETB area. Sample scores are presented for February 2006 (Figure 4) and June 2006 (Figure 5). It can be seen that ETB may offer skill in wind prediction while temperature forecasts are poor. The reason for poor temperature forecasts is not clear yet.

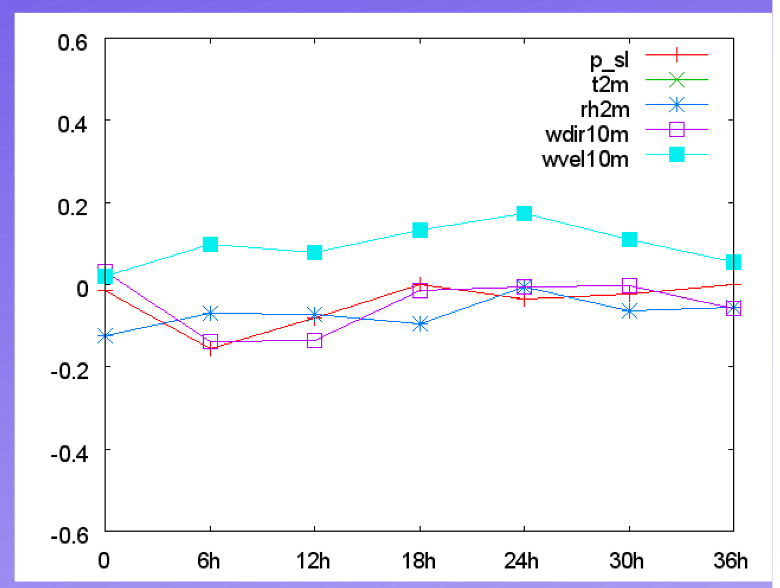

Figure 4. Skill of ETB over ETA surface variables in February 2006

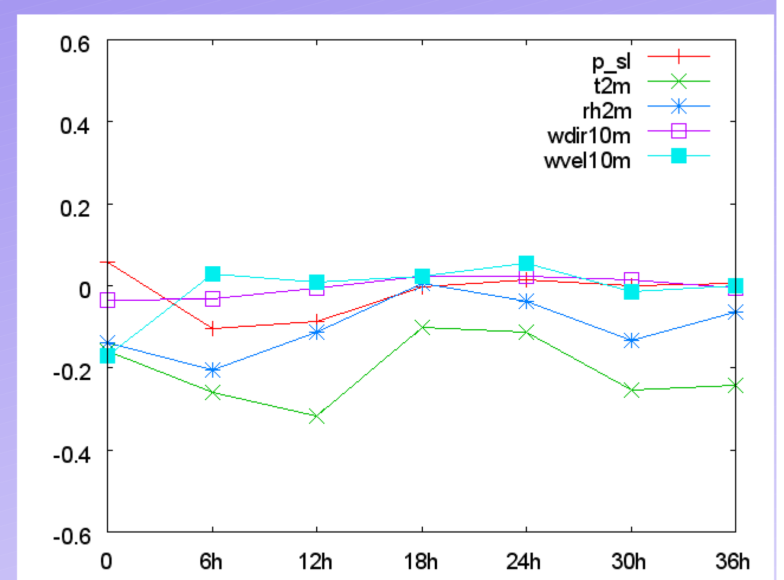

Figure 5. Skill of ETB over ETA surface variables in June 2006

It is of course hard to evaluate the high resolution model on the basis of standard verification scores as features can be easily missed and phase errors can produce double penalties.
To evaluate precipitation characteristics of both models a semi-automatic system is in development in EMHI. The difference of integrated precipitation fields is plotted after every forecast and if significant differences are found further analysis of forecast quality is possible. Figure 6 shows HS and NH model 36h integrated precipitation forecast differences. The start time of forecast is 00 GMT on 2 October 2006. The Figure 6 shows remarkable difference in precipitation. Unfortunately, the situation can not be linked to ground station measurements yet, but high resolution model seems to strongly overestimate the precipitation amounts.
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.

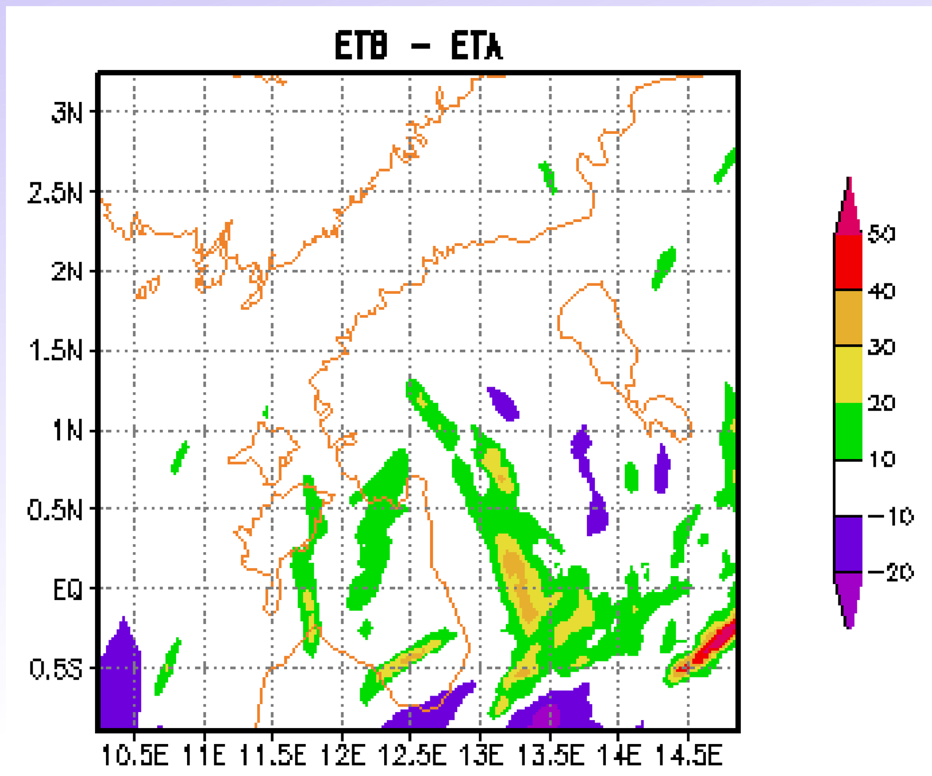

Figure 6. 36h integrated precipitation difference of NH ETB and HS ETA forecasts.

6. FUTURE DEVELOPMENTS

In near future the NH SISL HIRLAM and very high resolution NWP environment at EMHI will focus on the following goals:
• **Estonia will join HIRLAM Consortium in 01.01.2007**
• The computing system will be upgraded this autumn.
• Increase of vertical resolution, area increase of ETA to include the whole Balic Sea.
• Forecasts will be provided 4 times a day.
• Usage of boundary conditions from ECMWF is being considered.
• 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. The explicit representation is in development.
• 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.

REFERENCES

McDonald, A., 1995: The HIRLAM two time level, three dimensional semi-Lagrangian semi-implicit limited area, gridpoint model of the primitive equations. *HIRLAM Technical Report,* **17,** 25p.
McDonald, A., and J. E. Haugen, 1992: A two-time-level, three-dimensional semi-lagrangian semi-implicit, limited-area gridpoint model of the primitive equations. *Mon. Wea. Rev.,* **120,** 2603 – 2621.
Männik A., R. Rõõm, A. Luhamaa, 2003: Nonhydrostatic generalization of pressure-coordinate based hydrostatic model with implementation in HIRLAM: Validation of adiabatic core. *Tellus A,* **55,** 219 – 231.
Männik, A., R. Rõõm, 2001: Nonhydrostatic adiabatic kernel for HIRLAM. Part II. Anelastic, hybrid-coordinate, explicit-Eulerian model. *HIRLAM Technical Report,* **49,** 53p.
Rõõm, R., A. Männik, A. Luhamaa, 2006: Nonhydrostatic adiabatic kernel for HIRLAM. Part IV. Semi-implicit semi-Lagrangian scheme. HIRLAM Technical Report, **65,** 46p.
Rõõm, R., A. Männik, 2002: Nonhydrostatic adiabatic kernel for HIRLAM. Part III. Semi-implicit Eulerian scheme. *HIRLAM Technical Report,* **55,** 29p.
White, A. A., 1989: An extended version of nonhydrostatic pressure coordinate model. *Q. J. R. Meteorol. Soc.,* **115,** 1243 – 1251.