HIRLAM
Recent activities and future plans in high resolution and numerics

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1 Introduction

The HIRLAM project is now in its fifth phase. The cooperation between the Nordic countries, Ireland, The Netherlands, Spain and Météo France has continued to be fruitful in terms of providing the member states weather services with a high quality NWP system and a high resolution research model. In the years to come the HIRLAM project will focus on the development of a 4D-var data assimilation system, a meso-scale (non-hydrostatic) model, improved coupling with dynamics and physics as well as proper treatment of the boundary conditions, together with improved parameterization of moist physics and surface processes. This note will briefly highlight some resent activities and future plans in high resolution modeling and numerics.

2 Non-hydrostatic modeling

HIRLAM aims for a non-hydrostatic model suitable on a 2 - 10 km scale. The activity in non-hydrostatic modeling will follow two complementary approaches. One approach will be based on the activity developed several years ago at the Tartu Observatory (Rõõm 1997). Their developments are are using the anelastic equations in a pressure based vertical coordinates but including non-hydrostatic effects and filtering sound waves. This model has been developed inside the HIRLAM Eulerian framework and will be developed further, both for parallellisation and later with semi-implicit and semi-Lagrangian schemes. A typical test, a flow over an idealized mountain, is shown in Fig. 1. A comparison with the reference HIRLAM shows in Fig. 2.

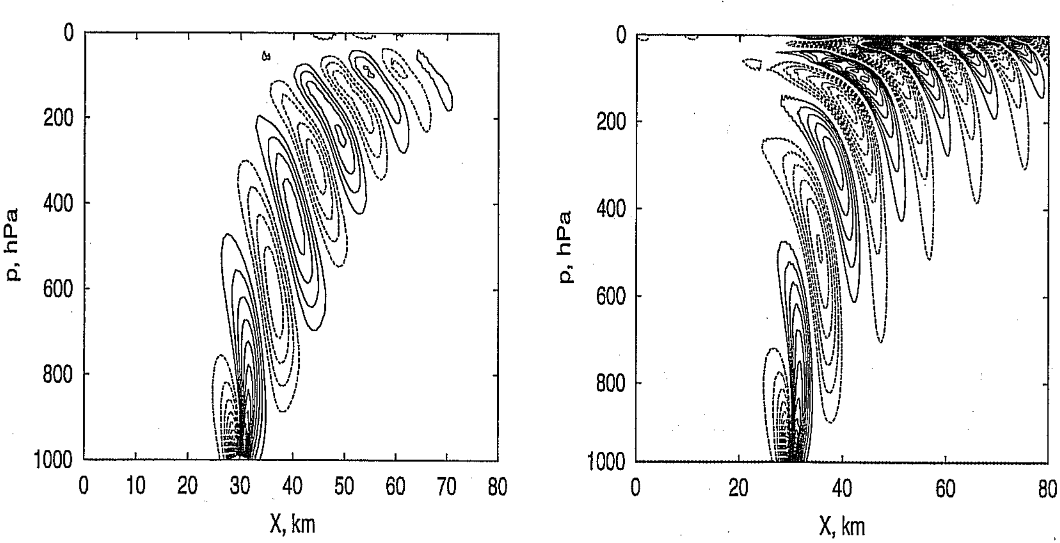

Figure 1: Vertical velocity waves at steady flow over one-dimensional orography. $a = 1km, h_0 = 200m, U = 15m/s, N = 0.01s^{-1}$. **Left: non-hydrostatic model, right: analytical model.**

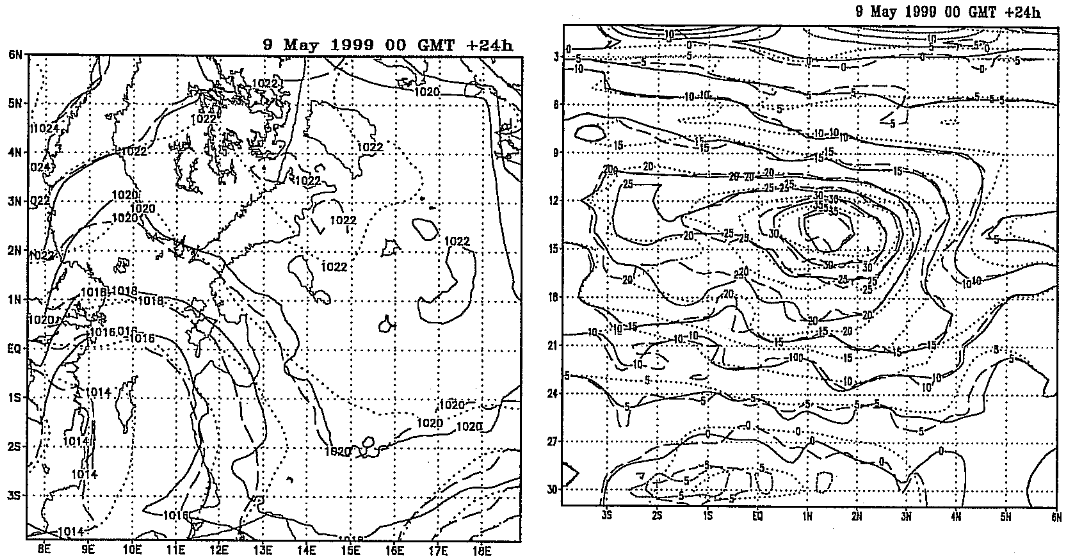

Figure 2: Surface pressure and vertical cross-section of u-wind along parallel 14E at the +24h forecast. Continuous lines - NH model; dashed lines HS semi implicit Eulerian scheme; dotted lines analysis. Grid 114x100x31; 11 km resolution; time step 60 s

Another approach will be based on a non-hydrostatic model already (pre)-operationally. This option should adapt an existing well-working semi-implicit and semi-Lagrangian model for implementation HIRLAM. The possible candidate model to start this work from are ALADIN, MM5 or GEM. There are a number of complex issues involved in the choices, but GEM is an operational model working well in 2 time level semi-Lagrangian and semi-implicit mode. It has a different discretization than HIRLAM, but the Laprise approach uses the same η -coordinate system as HIRLAM.

It is likely that adjoints will be very cumbersome to construct if an iterative 3-dimensional Helmholtz solver is used in the non-hydrostatic model. Therefore 4D-VAR is likely to remain incremental and hydrostatic in its inner loop. The non-hydrostatic model used in the outer loop of 4D-VAR needs to be consistent with the spectral HIRLAM used in the inner loop. The model in the inner loop should be regarded as a truncated version of the the full non-hydrostatic model and e.g. needs to use a consistent vertical discretisation and resolution.

3 Boundaries and filters

The current Davies (1976) scheme with a relaxation towards a specified value is a widespread approach for limited area models. However, some reasons for refinement on the boundary condition are evident.

- Flow relaxation may cause mass loss or gain
- External values are imposed even on outflow boundaries
- A geostrophic balance may be destroyed in the relaxation zone
- High resolution means small areas where the boundaries becomes more important

A possible solution to those problems would be to impose proper characteristics on the inflow boundary and let the outflow boundary be transparent, i.e. well-posed boundary conditions. Transparent boundary conditions, well-posed in the mathematical sense, have been developed both for hyperbolic and parabolic systems. These conditions are attractive because then our numerical scheme will approximate a well-posed problem. However, the theoretical conditions are such that they have to be approximated in order to get a useful numerical formulation. How one can do such approximations for NWP equations is not yet clear, but initial tests on simplified 1-D and 2-D systems have been performed by McDonald (2000). The continuation will be to develop exact transparent boundary conditions based on Engquist & Majda (1977) and on weak formulations for simplified systems of equations. Next step is to develop approximate transparent boundary conditions for the current HIRLAM model by using regularization procedures.

On the upper boundary HIRLAM is using a rigid lid condition which is not physical. Herzog (DWD) has developed a radiation boundary condition of Durran-Klemp type for η-coordinates. This has proved to work well there but not at Météo France. Some more research is needed before it it should be considerd for HIRLAM.

Digital filters have been found to be very effective for initialization of data for numerical weather prediction (Lynch & Huang 1992). The usual application of a filter requires a set of values of each variable arranged symmetrically about the initial time. These are generated by a backward (adiabatic) model integration, followed by a forward (diabatic) integration starting from a time half-way back through the span. Boundary filters can be applied to simplify the initialization problem. These filters are asymmetric: the output is valid at the start or end of the span, not at the center point. Thus, the input can be generated by a single, forward integration of the model over the filter span. This greatly simplifies the logistics of applying the filter in an operational context, and also reduces the computational overhead. The requirement for the output of a normalized low-pass filter to apply at the boundary of the span is achieved at the expense of boosting components with frequencies in the transition band. In order to avoid undesirable amplification of these components, the filter is applied incrementally: both the background field and the analyzed field are filtered, and the difference is added to the original background field, which may be assumed to be noise-free. This procedure has the desirable advantage that, if the analysis has made no change, the filter makes no change either.

4 Time integration methods

The HIRLAM semi-Lagrangian scheme has faced some serious problems in the past. The last known problem was a precision problem that only occurred on the VPP700 Fujitsu machine at ECMWF. Compared to integrations at other machines the one at VPP700 continuously lost mass. The change in surface pressure is a small number, compared to the pressure itself. HIRLAM, at present, only uses 32 bit on the VPP700 i.e. the pressure change is on the limit of accuracy. It happened so that the rounding consequently caused a loss of mass on the VPP700. The error was fixed by subtracting and adding a reference pressure in order to increase the accuracy.

The issue of the coupling between physics and dynamics has recently been approached from a semi-Lagrangian two-time-level perspective. Recent advances at ECMWF on semi-Lagrangian methods (Hortal 1999) and on physics- dynamics coupling (Wedi 1999) suggest methods which are the same time scientifically sound and specially developed for a semi-Lagrangian environment. The work by Wedi at ECMWF makes a distinction between those parameterizations seeking equilibrium with the current dynamics situation, e.g., vertical diffusion and gravity wave drag, and those responding to dynamics with longer time scale. Consequently, any type of smoothing or average can only be applied over those parameterizations responding slowly to dynamics, to be sure that equilibrium is not destroyed.

Also the performance of the semi-Lagrangian scheme advecting passive tracers will be studied and compared with other schemes. The aim would be to seek to improve conservation properties which are valuable for e.g., advection of liquid water content.

5 High resolution experiments

The heavy storms that hit northern Europe in December 1999 have provided us with excellent cases for test of the response to different model formulations. Experiences from the Danish Meteorological Institute (DMI) can be summarized as follows.

- It has been seen in a 0.5 deg. model resolution that the DMI-HIRLAM foreast model gives a very similar development as the corresponding ECMWF forecast starting from the analyses at 1999-12-02 12 UTC, 1999-12-03 00 UTC and 1999-12-03 12 UTC, respectively.
- Improved HIRLAM-forecasts have been achieved with increased model resolution. An improved result is achieved when the horizontal resolution is increased to 0.15 deg. (50 vertical levels). A small additional improvement is obtained in an experiment using a resolution of 0.075 deg.
- There is also a slight positive impact of using increased vertical resolution , e.g., 50 levels compared to 31 levels.

- When running in high resolution it is of some importance that the integration area is large enough to assure that the essential parts of the cyclone development take place inside the model domain.

Another example dominated by meso-scale enhancement is a case of meso scale snow bands that developed over the Baltic proper in December 1998, Fig. 3. The area around Gävle in north eastern part of Sweden was hit by a tremendous amount of snow. More than 1.5 meter of snow fell during three days. Since these storms are meso-scale phenomena and develop over sea where the density of standard observations is small, one has to rely on satellite and radar information to a large extent. These observations are not yet utilized in the data assimilation and the model has to develop the structures during the forecast.

The case was examined with three different horizontal resolutions: 55, 22 and 11 km. It is clear that the 55-km resolution is not enough to catch the meso-scale enhancement of the flow and precipitation. The higher resolutions are both capable of reproducing the amount of snow and the low level jet observed by the a radar near the coast. However, even the 22 km resolution is to coarse to develop the correct wind and precipitation pattern that develops in the Gulf of Finland and hits the South East coast of Sweden, Fig. 4, especially over Southern Baltic. A similar case was examined by Andersson & Gustafsson (1994) and the stressed the importance of the secondary circulations in the gulf of Finland and the geometry of the Baltic Sea. The current model results indicate that in order to simulate such severe events correct we indeed have to go down to 10 km horizontal resolution.

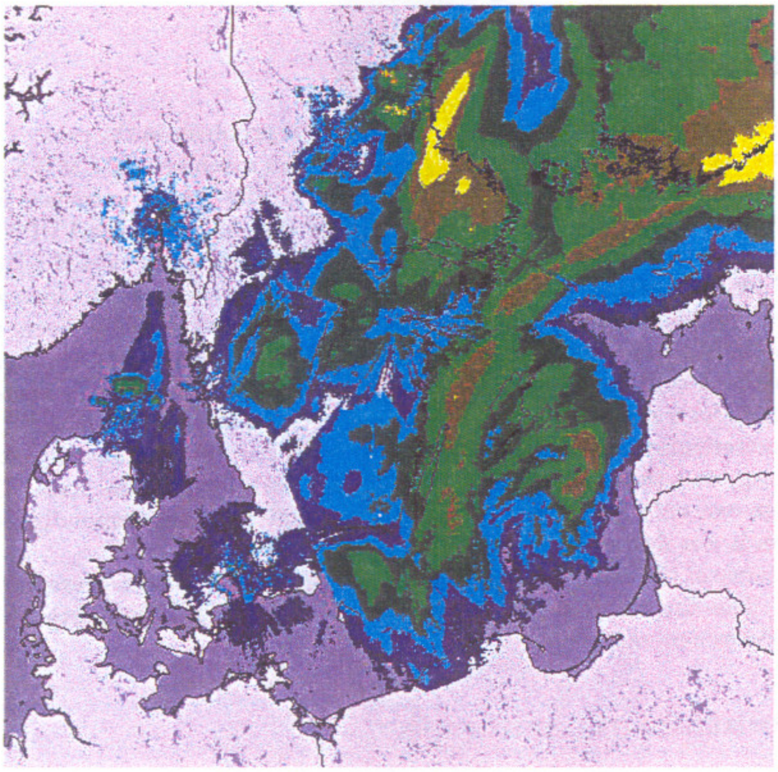

Figure 3: Composite radar picture over 24h accumulated precipitation from 7th of December 1998.

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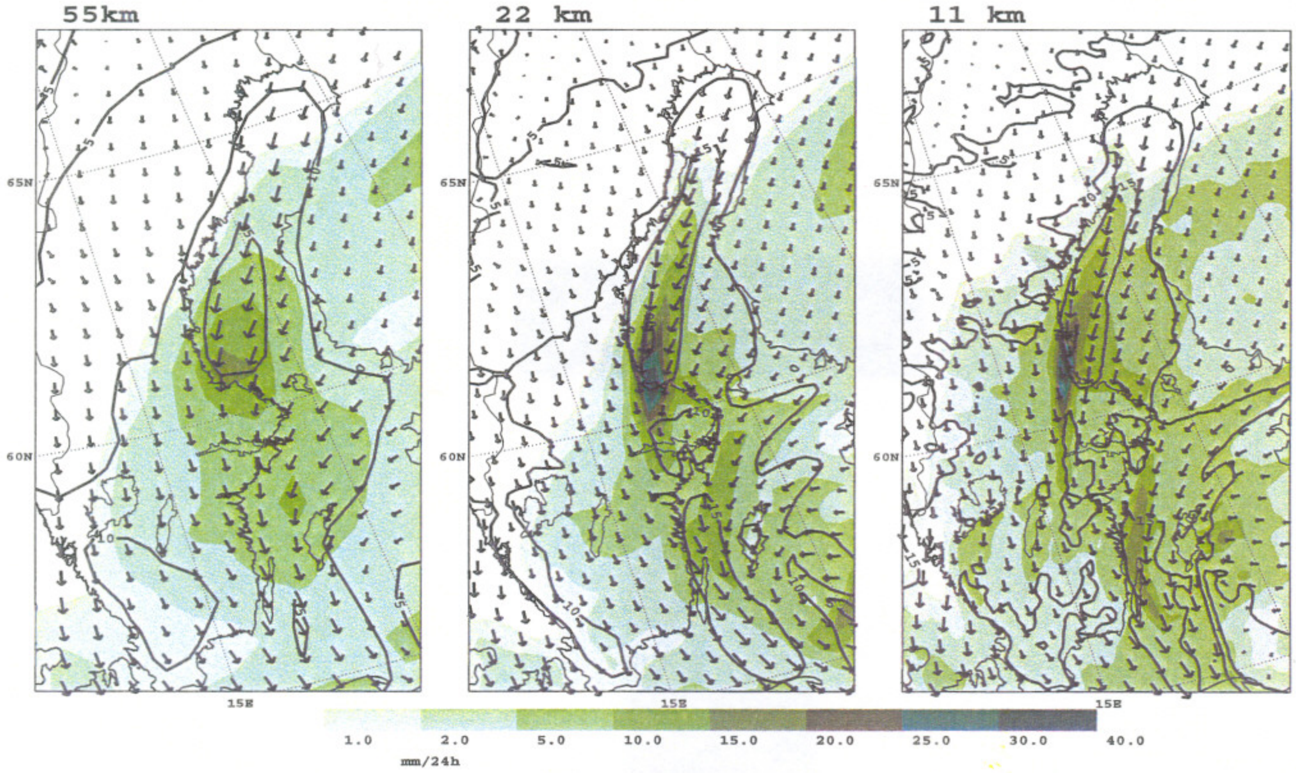

Figure 4: Wind at lowest level (31) and 24h accumulated precipitation valid at 06 UTC 7th of December 1998. The different horizontal resolutions are from left to right: 55, 22 and 11 km.

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