Strategy discussion by the HIRLAM-5 Advisory Committee 2001.

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February 15, 2002

1 Introduction

At the HAC meeting No 3 in Helsinki, May 2001, the strategic issues of the future role and development of HIRLAM was discussed. It was based on a discussion paper from Thor Erik Nordeng, where an overview of the planned resolutions and data assimilation methods of the different centres was given. Also the role of limited area models and the influence of boundaries versus initial conditions was discussed in this paper and by the HAC at the meeting.

Furthermore, a note from Per Kållberg was presented, describing the need for advanced and very frequent data assimilation for very short range forecasting.

This paper builds on the discussion at (and minutes from) that HAC meeting with some further considerations and comments added. Furthermore, the discussion is extended to some other areas of importance for the strategy for high resolution limited area modelling as well.

2 Meso-scale model and its initialisation

The first issue in the discussion was the case of data assimilation for a model of very high resolution over a small area. It is clear that the data assimilation in this case is important mainly for the very short range of the forecast and that the boundary forcing relatively soon will dominate the evolution.

It was concluded that it is still the case that advanced data assimilation with all the latest non-conventional data is needed in order to provide a very good very short range forecast, i.e., from e.g. +3h to +12h. This is crucial for severe weather, strong winds or heavy precipitation. The accuracy in this short range needs to be very high, and this is the range where current NWP do not yet provide enough skill or usefulness compared to the achievements of NWP for ranges beyond 12 h. This is due to various spin-up effects and inadequate analysis or even lack of observations (that can be used for NWP). It must be the case that the very short range forecasts are always reliable and more reliable than the older forecasts valid for the same time (convergence of the NWP system).

To achieve this purpose one needs a good physical initialisation of the model and that all observations that are available for nowcasting enter the NWP system. Even though 4D-VAR has the best available mechanism for introducing non-conventional observations and for physical initialisation, it is not clear that it can be run efficiently enough at that very high resolution with timeliness short enough for nowcasting. The repeated way of running 4D-VAR with incrementally more observations as they arrive (Quasi-continuous variational data assimilation, Järvinen, 1996, QJ 122, 515) is projected to be a more economic way for short range forecasting. As an alternative one may also envisage that 3D-VAR could be used for some of the now-casting NWP models. It would though probably have to be confined for the very latest update from observations, as the physical initialisation and time optimality is missing from the 3D-VAR method.

Also the very high resolution meso-scale aspects of the statistical analysis method needs to be explored. The multi-variate statistical coupling between variables brakes down or changes with increased resolution and also the patterns become more an-isotropic as e.g. physiographic details become more prominent.

Nudging is a way of bypassing some of the difficulties, and particularly the efficiency penalty, of 4D-VAR. Such an analysis is however sub-optimal and the control of the spreading of information is ad-hoc and not very well following the physics of the atmosphere. Implicitly the forecast model is used for adjustments during its forward integration and it is well-known that this process is dispersive and results in loss of information. In the case of very dense and uniform observing systems, this is less of an issue, providing no quality control is needed in the analysis (this is a serious reservation, though, especially as more advanced flow-dependent and cross-observation interactive quality control develops). Thus, one can see a number of objections against nudging, as least as a long term strategy.

There may still be observations that are hard to assimilate directly, physically, e.g. cloud information presently. Some centers have developed pseudo-observation techniques for introducing such data as e.g. radiosonde profiles. (E.g. MOPS at the Met Office, but also through MESAN (SMHI), MetClock (KNMI) and new developments at DMI). Such data may be introduced through direct insertion or with a nudging technique. (The success of these methods at SMHI and KNMI have so far been quite limited). This is a measure that may be used also in the future, judicially, where one cannot benefit from using the data directly in the more optimal or mathematically correct ways.

3 Coupling between Synoptic scales and Meso scales

It emerged very clearly that the coupling issue is a very serious one and crucial for the meso-scale model. Deficiencies in the lateral boundary conditions will usually spread very quickly through the whole domain during the forecast time. Apart from the numerical formulation of the LBC themselves (which Hirlam is working on), it is crucial to have very tight coupling in time and with a compatible physics. Probably a coupling every time step (or at least several times per hour) and with the same or very similar vertical resolution in both models will become necessary. For this to be realised in practice, Hirlam must also support and develop the synoptic scale system in parallel to the meso-scale one, unless another very compatible coupling model can be employed locally or closely coupled communication wise.

The quest for transparent LBC will continue and will become more important. Although the problems of the Davie's type relaxation have not been demonstrated to be very large, it is not likely that they will remain satisfactory when the boundary zone is in close proximity to the area of interest and when developing systems need to be accurately advected into the area.

The method of variable resolution grids can be an alternative to LBC. There are two ways of doing this, the first as is done for GEM with a global coarse grid with a gradual refinement over the area of interest. (Also Hirlam has a variable resolution version, although still a LAM with LBCs). The other way is to have stepwise increase of resolution with adapted model equations in the interfaces built on conservation principles.

4 Synoptic scales

The other issue for Hirlam is the synoptic scale model, covering a relatively large part of the Hemisphere and providing forecasts up to about 2 days. This is the conventional range where both 3D- and 4D-VAR methods as well as physical parameterisation have been well developed. It is clear that on this scale and for the forecast range from +12 to +48h, 4D-VAR is the best data assimilation method. Also use of non-conventional data will be important and even crucial, both for the data sparse areas, but also in general to provide a better physical initialisation of the model.

The question in the Hirlam community is whether we need such a synoptic scale system? One might direct all the resources towards only developing the very high resolution system and rely on ECMWF boundaries from a slightly older global forecast. The major motivation for the Synoptic system is the coupling issue as described above. Another reason is of course that at least some countries will want to maintain the production, and certainly the possibility, of synoptic NWP for readiness or defense reasons as well as for any other responsibilities over wider areas.

Another reason is that the scientist and developers need to have some experience and knowledge of also the synoptic scales over large enough an area to fully simulate e.g. baroclinic developments. Both 4D-VAR data assimilation and forecast models need to be tested and made to behave in a reasonable manner also on the synoptic scales. This should not divert too much effort from the main mission of the meso-scale forecasting system, though. It is still valuable and necessary to evaluate and compare models on the synoptic scales, where e.g. the same areas may be covered by several centres. It is felt to be unsatisfactory to only, or mainly, be confined to dynamical adaptation from large scale boundary forcing.

5 Development of Physics

The current and immediately projected physical parameterisation in Hirlam is developed for the fairly moderately high resolutions of around 20 km and may be used for the 8-10 km range, but certainly not well adapted to resolutions af a few km. This is in common with most other models in Europe or elsewhere in the world. Several models have been run successfully at very high resolutions of a few km but with explicit convection, resolved by the model. This seems to be possible at 2-3 km resolution but not at coarser resolutions. At least current convection parameterisations need to be switched off, implicitly or explicitly, at those resolutions. Still, there are certainly important effects not yet resolved at the km scale, like entrainment/detrainment and downdraughts. One likely development is that the turbulence scheme should take over more and more the role of representing unresolved processes of the convection.

The turbulence scheme itself will need to become 3-dimensional at some stage as the resolution gets higher and the interaction between neighbouring model boxes cannot be ignored (or almost ignored). Also, as the convection scheme switches off, the turbulence scheme needs to be formulated in terms of moist conservative variables.

In general, the assumption of almost separate isolated processing in neighbouring boxes will have to be relaxed in several aspects. One of these is for snow fall, where the time scales of advection and fall are such that the snow fall at ground level is quite decoupled from the production at cloud levels.

The radiation scheme will need to cater for the slope of the surfaces, as steep slopes are resolved and will be heated quite differently at low solar elevations. Also the cloud interaction will can become much more sophisticated.

The surface scheme will resolve more and more details, and it is actually conceivable that the tiling scheme may become less crucial as resolutions improve to the km scale. Still, there are scales in nature of smaller extent, that still could be represented as fractions. (E.g. snow cover and forest as opposed to open land.)

The analysis of surface fields will need to be enhanced. Vegetation and evaporative properties need to be estimated on a real time basis. Surface and sea temperatures will or are quite well catered for with current surface and satellite observing systems. Snow cover can be enhanced from satellite estimations and furthermore its albedo. Lakes are difficult but the ice/snow cover and surface temperatures need to be estimated and possibly modelled.

6 Dynamics

Even though Hirlam can be run at high resolutions, the non-hydrostatic effects tend to become noticeable at resolutions of some km and it is better to include those in the model. Even though is is hard to demonstrate the direct forecasting benefits yet, it is likely to lead to less problems having a more complete set of equations included.

Hirlam has a non-hydrostatic core available, as developed by the Tartu group, and this is a working but approximated non-hydrostatic model. It is probably quite sufficient to use this an-elastic system, including first order terms, for a number of years to come, for resolutions of a few km and even down to some hundred m, at least as presented by the authors. At a later stage, however, it will probably be desirable to treat the full un-approximated set of Navier-Stoke's equations. Note however that exact solutions to the model equations are not possible with any approach as most methods end up with a full 3-dimensional Poisson equation to solve iteratively for the divergence or mass variable. (The Laprise vertical coordinate used e.g. for ALADIN allows separation).

Recent results as e.g. presented at the SRNWP workshop in Bad Orb show clearly that numerical methods again are becoming much more important in the meso-scale, as the deficiencies af the numerics become much more visible. It is likely that continued attention and development is needed for advection and integration schemes to minimise systematic errors in the smallest scales in the models.

The choice of vertical coordinate is becoming more of an issue, both from the point of the non-hydrostatic models, and from the point of the inadequacy of terrain-following coordinates at very high resolution, when the quasi-horizontal surfaces have considerably large slopes. As a first measure, horizontal diffusion becomes incorrect and is best to switch off. There are some moves of going towards pure height coordinates, whereas others maintain the need for terrain following coordinates. The argument is if there is enough vertical resolution to resolve the boundary layer at different terrain heights.

7 Summary

Some strategic issues have been discussed here, based on the initial discussions by the HAC in May 2001. It is clear that the main mission for Hirlam is to provide a very accurate high resolution very short range forecast. To achieve this it is both necessary to assimilate all the available non-conventional data and to use a tight and accurate coupling with a synoptic scale model.

The data assimilation methods for very short range forecasting are not completely obvious, as the timeliness is crucial. Developments of 4D-VAR may be combined with a late update with 3D-VAR. Nudging methods cannot be excluded, at least for some types of data that are difficult to insert directly. The non-optimality of these methods brings however several reservations against the method in general.

The synoptic model should preferably also be in the area of interest of Hirlam mainly for the coupling aspects, but also for providing some larger scale forecasts and maintaining the necessary skills of scientists and of the scientific algorithms.

A number of issues in the physical parameterisation will need to change as the resolutions improve to the scales of a few km. It involves mainly explicit convection, 3-dimensional effects in turbulence and precipitation as well as in radiation. Furthermore the surface schemes may start to resolve "tiles" but the intitial specifications become even more important.

The forecast model needs to be non-hydrostatic and the numerical schemes need a lot of attention at those very high resolutions. Also the vertical coordinate systems and the degree of terrain following are serious issues, as the terrain following ones have severe problems associated.