Progress of the AROME project

F. Bouttier, Y. Seity, S. Malardel, P. Riber, F. Duret, T. Montmerle[1]
Météo-France, CNRM

This paper presents a review of the latest developments and current plans for AROME in CNRM.

1. Introduction

The AROME (Applications of Research to Operations at MEsoscale) project has entered its main development phase at the beginning of 2003, with the arrival of substantial reinforcements to the AROME team. In summer 2003 the AROME dedicated staff was as follows in Toulouse :

- François Bouttier, project manager, *metview* and *Jb* developments;
- Pascale Riber, data assimilation script manager, development of the hybrid ALADIN/Méso-NH assimilation, introduction of mesoscale observations;
- Yann Seity, model software developments, implementation and testing of new physics from Méso-NH into the ALADIN code;
- Frédéric Duret, 2.5 km Méso-NH runs, assessment of spin-up and coupling problems;
- Sylvie Malardel, Méso-NH physics expert, definition of the physics/dynamics interface;
- Thibaut Montmerle, implementation of clear-sky Meteosat / MSG water-vapour radiance assimilation;
- Gwenaëlle Hello, ALADIN-10 km coordinator, NH dynamics development, feasibility study of the AROME-10 km system.

In autumn 2003, P. Riber will be replaced by Eric Wattrelot, and Ludovic Auger will join the team a nowcasting / mesoscale observations specialist. F. Bouttier will replace J.-F. Geleyn at the head of CNRM/GMAP.

This team is working in close relationship with the rest of the CNRM/GMAP group and a large part of the CNRM/GMME mesoscale research group. Namely, some substantial AROME-specific work has already been supplied by C. Fischer, V. Guidard, P. Bénard, R. Brozkova, J.-F. Geleyn at GMAP, and J. Stein, P. Jabouille, V. Masson, V. Ducrocq, M. Nuret, M. Tomassini, J.-P. Lafore, J. Payart, N. Asencio at GMME. More and more people are becoming involved in the project. There is growing interest in the research community for using the AROME 3d-var analysis (as an hybrid data assimilation with the Méso-NH model) for reanalyses of field experiments, notably in connection with flood forecasting in the Mediterranean basin, the MAP, ESCOMPTE and AMMA experiments, and urban pollution.

Without knowing it, most of the ALADIN community is already part of the AROME development effort, since much of the software and objectives are identical to the current ALADIN system. This is particularly true of the work on ALADIN-NH, ALADIN 3d-var, and validation studies. Indeed, AROME would probably not have been based on ALADIN software without the prospects of a substantial synergy with the ALADIN community. The main (and only ?) structural incompatibility between AROME and ALADIN is the choice of convection-resolving physics for the future AROME-2.5 km model, which is a radical change from the previous paradigm of small incremental physics developments on top of the "large-scale" ALADIN physics. This change may be somewhat frustrating with respect to the existing work on the large-scale physics. It is, however, regarded as the most efficient way of providing our NWP systems with cutting-edge physics for the convection-resolving scales, i.e. 1-3 km, that will bring unprecedented value in terms of quantitative precipitation forecasting and mesoscale storm forecasting. It also opens up exciting opportunities for collaboration with research institutes, on physics validation and improvement. By contrast, the

[1] working in GMAP thanks to an ALCATEL grant

AROME data assimilation system (basically, the ALADIN 3d-var with new observations and finer structure functions) will be structured so that it will be totally compatible with the ALADIN 3d-var.

There has been some debate on the need to develop a new model for 10-km resolutions. Would the AROME physics be of any use at these resolutions ? Why not keep the cheaper "old" physics which will keep improving in the ARPEGE model anyway ? Why burden the AROME project with the development of a 10-km resolution model if the ALADIN community is happy with the older model ? These questions have been discussed at a "special ALADIN-AROME workshop" in Prague on 11-12 April 2003, and the presentations (provided on the ALADIN website under item "*workshops*") can be regarded as an provisional documentation of the AROME project.

2. Model development

The AROME model is essentially ALADIN-NH with new physics, since it has been demonstrated by intercomparison studies (see the last ALADIN Newsletter) that ALADIN-NH dynamics has the right level of physical realism and numerical efficiency, and its development is close to completion. Hence, the dynamics and numerics are entirely based on the latest versions of ALADIN-NH with the new semi-implicit solver that give hope that time-steps of the order of 1 minute are feasible at 2.5 km resolution. The truncation with be rectangular (not elliptic) in order to remove any spectral effects on the physics computations (local microphysics adjustments in particular), which has been satisfactorily validated in model runs, but implies some adjustments to the 3d-var *Jb* code. Nevertheless the discretisation constraints will imply, as in any mesoscale model, that the effective size of the smallest resolved phenomenon (say, a cloud) will be of the order of 10 km in the free atmosphere, the full resolution being achieved near the surface thanks to the physiographic forcing. Further smoothing may be necessary in the vicinity of the coupling zone in order to mitigate the effect of inconsistencies with the large-scale model : this will be the subject of future studies. The use of a spectral rectangular linear discretisation also seems to imply that the biperiodisation (so-called extension) zone can be rather thin and that cheap, simple techniques could be used for biperiodisation : this also needs to be studied. The new 3d fields to be implemented for the AROME physics (cloud and precipitation variables, TKE) will never go into spectral space. Eventually, the model's historical files may not need to be spectral at all, which would make model files more user-friendly.

The dynamics/physics coupling requires some very serious attention, as this will have serious implications on the cost and accuracy of the future AROME model. The ALADIN-NH team has developed a new predictor-corrector scheme, which should provide good overall stability. Accuracy is regarded as essential for two reasons : (a) the behaviour of the AROME physics must be devoid of numerical artefacts that would harm the interaction with the scientific community, and (b) most of the expected predictability at meso-beta-scale being generated by small structures (convective cells, rain bands, surface features, ...), the view of a model that only needs to provide the right synoptic-scale tendencies to get the right forecast is probably not valid for AROME. Extreme care shall be devoted to find the right efficiency versus accuracy compromise in all aspects of the physics/dynamics interface. Although the core of the Meso-NH physical parameterisation software should remain untouched, the following aspects need a fresh view :

- What are the local conservation laws in the model, i.e. what is the definition of a model air parcel in the presence of microphysical processes ? This question is still unsolved in both ALADIN-NH and Meso-NH models. It is being investigated at CNRM and a firm answer is needed in order to finalize the AROME physics/dynamics interface software. Both models are currently based on hypotheses that may be meteorologically unsatisfactory in very strong convective systems (thunderstorms and tropical cyclones) : at kilometric scales, precipitation should not fall instantaneously in the model, and this involves mass changes that are not negligible compared to the gaseous mass.

- How do we plug together the semi-Lagrangian advection scheme, the time-stepping and the physical parameterisations ?
- What is the correct time-step for physical computations ? Actual physical processes rarely act on the same time-scales as the dynamics time-step. The relatively short AROME time-step may allow a simple explicit treatment of surface processes, but microphysical adjustment is still much faster, whereas radiation being very expensive and slowly-evolving should probably not be recomputed at every time-step.

Most of these statements may sound iconoclastic in terms of the previous ALADIN philosophy. In reality, most of the older principles still apply, but their implementation needs adaptation in accordance with the AROME space- and time-scales, which are very different from large-scale models, with different governing physical mechanisms. Perhaps the most frustrating aspect is that we need to adapt to existing parameterisations, instead of re-inventing our own. This is the price to pay for collaborating with the research communities, but in return it will grant us access to world-class specialists on physics development and validation, and we will have arguments to convince them of the importance of tailoring parameterisations in order to get the right efficiency, accuracy and robustness for NWP applications.

The AROME physics development in 2003 is entirely directed toward probing the limits of a (voluntarily naively) straightforward "plug-in" approach, whereby the relevant Meso-NH physical parameterisation software is directly interfaced with the ARPEGE/ALADIN dynamics. Since a stable 3d ALADIN-NH version is not yet available (mainly because the 3d array management is being rewritten in ARPEGE/IFS, which will facilitate a lot the implementation of the AROME microphysical and TKE fields), all the work has been carried out in the 1d column version of ARPEGE/ALADIN. The physics have been rigorously compared with 1d column Meso-NH tests with the same forcings, checking that the results are the same within tiny differences in discretisation.

- cloud ICE3 microphysics : successfully tested as stand-alone for a convective cloud, and in conjunction with the other schemes for a stratiform cloud (BOMEX case; Fig. 1).
- 1d prognostic turbulence scheme (a 3d turbulence scheme is under preparation by the Meso-NH community, but will not be available in the short term) : successfully tested, except the effects of sloping terrain which cannot be investigated in a 1d framework.
- radiation (a version of ECMWF's Fouquart-Morcrette scheme) : successfully tested on a radiation-sensitive stratiform cloud case. The software must be updated with respect to the latest ECMWF developments (RRTM scheme). A proposal for a more efficient, modular and more general scheme has been put forward by J.-F. Geleyn and it will be investigated if the required manpower can be found.
- surface ISBA scheme : the technical externalisation of the scheme (I/O and physiography) is not complete, but the parameterisation itself has successfully been tested. It is anticipated that the future AROME ISBA scheme will involve distinct file formats for the atmospheric and surface variables, and that the physiography will be derived from the Meso-NH software (with some developments to cater for biperiodisation and spectral properties of the orography)

The top priority for the last quarter of 2003 is the setting up of a working 3d prototype of AROME to demonstrate the viability of the concept by running some well-documented convective storm cases at resolution 2.5 km, involving a comparison with Meso-NH and a first assessment of the numerical cost of the future AROME model.

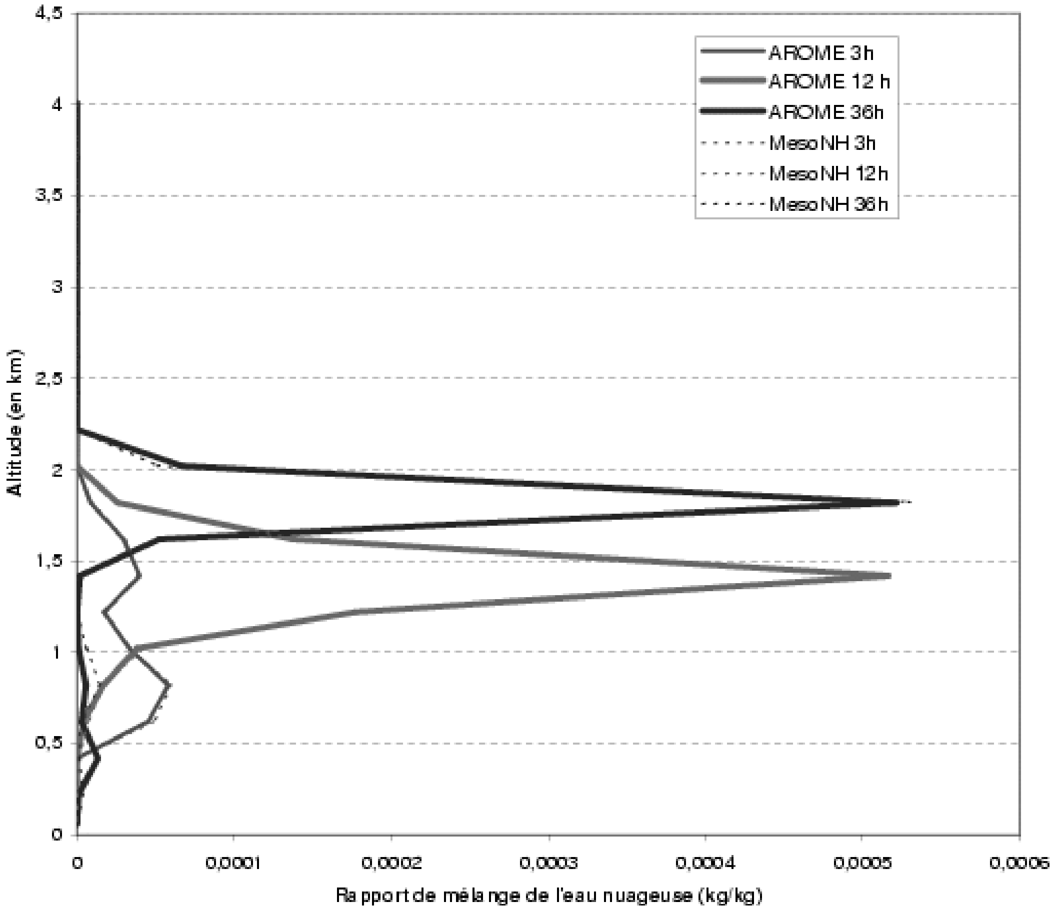

Figure 1 : Validation of the (microphysics, 1d turbulence, radiation) AROME parameterisations package in the single column ALADIN model, on a BOMEX stratiform cloud case. The plot shows vertical profiles of cloud variables for three forecast ranges on the same day, and compares ALADIN (full lines) and Meso-NH (dotted lines) with the same original parameterisations and large-scale forcing. Only tiny inconsistencies are found within the discretisation errors, which validates the correctness of the migration of physical packages between the two models on this particular test-case. (experiment performed by S. Malardel and Y. Seity)

In parallel, the work on a 10-km version of AROME is due to commence soon with an upgrading of the existing Kain-Fritsch-Bechtold subgrid convection scheme (used by Meso-NH and already interfaced as an option in ARPEGE). The need for a gravity wave drag scheme will be investigated in the framework of the prototype of AROME-10 km, sometime in 2004, probably through ALADIN collaborations.

3. Data assimilation developments

The AROME assimilation development is giving priority to projects that are fully compatible with both ALADIN and ARPEGE systems. The short-term preoccupations of AROME are :

- assimilation of MSG data for cloud and humidity initialization, at full image resolution (of the order of 4 km every 30 minutes),
- generation of acceptable high-resolution structure functions for 3d-var,
- interfacing of 3d-var with Meso-NH model runs,
- efficient use of existing datastreams at enhanced resolution (mesoscale automated stations, aircraft and ATOVS radiances),
- a decision on the need for dynamical initialization for AROME,

- coupling with the large-scale data assimilation system,
- assimilation of radar data for cloud and precipitation initialization.

All these actions have started, except for the last one which is more complex. It is in its definition phase and awaits new manpower. This has lead to the preparation of a standard set of scripts and visualization tools in CNRM for running "hybrid" data assimilation experiments at 2.5 km resolution where ALADIN 3d-var provides the analyses and Meso-NH provides 6-hour forecast cycles. Meso-NH forecasts are converted to ALADIN first-guess files on the same horizontal domain; the main approximation involved is the re-interpolation in the vertical. Screening and 3d-var are run as in conventional ALADIN experiments, and the resulting ALADIN increment is converted into a Meso-NH increment, which ensures that Meso-NH features not represented in the ALADIN discretisation are not corrupted in the process.

The hybrid-system forecast cycle will soon be reduced to a few hours. On current machines, the hybrid data assimilation experiments can be run on (typically) 200 x 200 km domains in research mode. The use of Meso-NH has three advantages at this stage : (1) to allow research on fine-scale data assimilation, i.e. to start now without waiting for the availability of an AROME prototype, (2) to facilitate the take-up of the new system by the Meso-NH mesoscale research groups, (3) to give instant access to numerous Meso-NH diagnostic facilities for investigating model behaviour at very fine scales. The data assimilation scripts have grown from existing ALADIN/ARPEGE experimental scripts and there will be a user support team at CNRM/GMAP. The intention is to integrate them within the OLIVE[2] experiment-management environment, which should eventually be accessible for remote users. Scientists who are interested in using the hybrid system early may contact CNRM in 2004 (when the system has been properly validated), and seek training on the Meso-NH model.

In-depth evaluation of the Meteosat and MSG radiance information content in ALADIN 3d-var has shown that the data should primarily be used as clear-sky water vapour radiances, which gives information with low vertical resolution on humidity in the middle and upper troposphere. The spatial and temporal resolution is potentially very large, so a positive impact is expected on the assimilation of convective clouds. Unfortunately, very little MSG data is available so far and we have only been able to demonstrate that real MSG data does have an impact on the humidity analysis, which makes the model state more consistent with the observations. Frequent MSG data is expected late in 2003, which will be used to assess the data impact more precisely over several data assimilation cycles. Some complementary 1d-var studies have been made to demonstrate the potential advantage of having better radiometric resolution in future geostationary satellites.

Clear-sky water vapour radiances have the obvious drawback of not being useful in cloudy situations. It is planned to test the use of radiances on cloudy scenes, which should help in the initialization of cloud tops, using the latest RTTOV radiative transfer software version. Some testing has started on the initialization of the clouds themselves, based on statistical cloud classification products which use multispectral information, and can be used to invent bogus cloud profiles that are assimilated as pseudo radio-soundings. This very empirical approach has already been developed for the Meso-NH model with interesting results, so it was decided to adapt it to the ALADIN 3d-var, which required little development. The meteorological aspects of the technique are under investigation by the CNRM mesoscale group (M. Nuret), with the intention to apply them to the AMMA (African Monsoon) field experiment programme.

The reconfiguration of ALADIN 3d-var to 2.5 km domain has so far involved no ALADIN software change. It proved quite easy to use high-resolution networks such as RADOME (French automatic SYNOPs, spaced every 30 km or so). The next step will be the modification of the screening strategy for aircraft, SATOB and ATOVS data. A Eumetsat fellow (previously N. Fourrié) is expected at CNRM/GMAP, to work on the mesoscale use of radiances. The main investment on 3d-

[2] for informations on OLIVE, contact Eric Sevault at GMAP

var was the adaptation of the *Jb* statistics in order to produce satisfactory structure functions. Existing NMC-lagged statistics produce typically 60-km wide increments when applied to 200 x 200 km 2.5 km-resolution domains, which is too smooth for the phenomena we want to analyse (typically, 20-km circulations). As these phenomena are highly intermittent in space and time, NMC-type "brute force" statistical calibrations are probably not relevant for our targets, and more targeted *Jb* calibration techniques need to be invented, probably based on some ensemble techniques. In order to get first results quickly, a very pragmatic approach has been adopted whereby the 10-km ALADIN NMC-lagged statistics are extended by adding empirical small-scale error-variance spectra. This must be done rather carefully so as not to create spurious interlevel correlations through the non-separable covariance model. To make a long story short, a very satisfactory downscaling algorithm is obtained by which the "standard" 10-km ALADIN *Jb* statistics are adapted to any 2.5 km domain, with compactly supported structure functions that are about 30 km wide, which seems like a safe choice for first testing, and a much reduced amount of geostrophic balance at small scales. This has been implemented as a new external program, the further evolution of which will be a key strategic element in future improvements of the AROME analysis system.

Following experience with ARPEGE and ALADIN there was much concern on the creation of convective-scale spin-up problems by a high-resolution analysis system. Tests with Meso-NH have shown that there is some spin-up in the microphysics, but it settles down after a few minutes of forecasting. No spurious gravity-wave activity can be detected in situations with well-developed convective cells (which themselves generate substantial gravity waves). Gravity waves quickly radiate out of a 200 x 200 km simulation domain anyway (in less than 30 minutes), so they are not concerning for preliminary assimilation experiment. The initialization problem will need reassessment when we can afford running with larger domains (the AROME target is a 2000 x 2000 km) and a microphysics analysis facility is implemented, probably using radar data.

The assimilation of radar data is a daunting development project, which is starting to take shape. It will involve one permanent staff at CNRM/GMAP (primarily for technical integration), at least one ALADIN collaborator (on observation definition and observation operator technicalities), and the nowcasting research team in CNRM/GMME (V. Ducrocq's team) where a Ph.D student will work on the scientific aspects of the radar observation operator in connection with the radar technology specialists in several French and foreign institutes. The DWD Radar Simulation Modell software has been requested for study. Radar data assimilation raises several challenges, which are detailed in a separate paper. The emphasis is on radar reflectivity assimilation, since the (easier to assimilate) Doppler wind are not yet available on sufficiently well developed operational networks. Our plans for assimilating radar data are regarded as very ambitious by the international community and we hope they will be a prominent element in the success of the AROME project.

4. Conclusion : what next ?

Now the data assimilation aspects are in good hands, the top priority is the development of the AROME prototype. First demonstration runs at 2.5 km resolution are expected by the end of 2003. In 2004, the great challenges will be :

- to optimize and stabilize the AROME-2.5 km software, with a cleaning of the physics/dynamics interface and a decision on how the survival of the "old" ALADIN physics will be ensured during the 2004-2010 transition period from ALADIN to AROME physics,
- to provide a 10-km resolution version of the prototype, and to test whether its added-cost/new-benefits ratio is acceptable with respect to the older ALADIN model, for all ALADIN partners,

- to structure the scientific work of the willing ALADIN partners in the AROME/ALADIN-2 system, notably regarding numerical techniques, the physics and the interfacing with the Meso-NH scientific community,
- to start real cooperative work on developing new observation operators, namely for reflectivities, line-of-sight wind components, GPS information and low-resolution averaging kernels in 3d,
- to investigate mesoscale predictability issues, mainly in connection with the large-scale data assimilation and ensemble forecasting systems,
- to demonstrate the added value of the AROME concept in future NWP systems, which will be required to justify the cost of the new model.

This will no doubt be the subject of many interactions within the ALADIN community, in order to ensure that cooperation on AROME yields demonstrable benefits for everyone.