THE ALADIN-MFSTEP SYSTEM AND ITS CONFIGURATION

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I) INTRODUCTION

The scope and working methods of the ALADIN project are described in the 46-4 issue of the WMO Bulletin (see Members of the ALADIN international team, 1997) but there exists no scientific publication encompassing all its aspects. Hence all the following, despite being written for the MFSTEP documentation, has been thought as an up-to-date reference document, with as much as possible mention of the original work that found its way into the ALADIN system's 'melting-pot'.

For the purpose of fulfilling the objectives of Work Package 10 of MFSTEP, a special configuration of the ALADIN NWP system will be run in dedicated mode on the SX6 computer of CHMI-Prague. The basic constraints of the TOP final set-up will be the following: (i) running a permanent ALADIN pseudo data assimilation cycle in full coupling with the 4D-Var long-cut-off cycle of the ARPEGE global NWP system of Météo-France in Toulouse (6 hour updating frequency in both cases, coupling every three hours, hourly output frequency for the atmosphere-ocean coupling data); (ii) once a week on Wednesday 00 UTC, launch of a 5 day ALADIN adaptation forecast coupled with a special run of ARPEGE based on the above-mentioned assimilation cycle (same conditions of coupling and production as above); (iii) an option will be considered in which SST results from the OGCM would enter the step 'i'.

The system will be run on a 589 x 309 domain with a mesh size of 9.508 km (5591 x 2928 km^2 hence). The projection will be a Lambert tangential one (reference point 46.47N-2.58E) and the centre of the domain will be at 41.95N-9.81E. There will be 37 vertical levels irregularly spaced in the so-called 'hybrid-eta' coordinate of Simmons and Burridge (1981), the top one being at 5hPa and the bottom one at about 17 meters above the surface. The elliptic spectral truncations will be E299/159 (linear-grid) for the forecasting model and E83/44 for the filtering part of the so-called blending procedure. The time-step will be of 400 seconds.

The post processing will be done on a lat/lon grid of 0.1 degree in each direction with limits at 19W, 37E, 30N and 48N (561 x 181 points hence).

II) DYNAMICAL PART

Generalities

Like for the whole project, there is no complete description of the ALADIN dynamics in the scientific literature, but its specificities with respect to IFS/ARPEGE can be well seen when reading Bubnova et al. (1995), Radnoti (1995) and Geleyn (1998), even if the specialised aspects of those papers are of more general scope.

Details

The ALADIN Hydrostatic Primitive Equations (HPE) dynamics is the transcription to the Limited Area Modelling (LAM) world of the IFS/ARPEGE global one, jointly developed by ECMWF and Météo-France. The jump from the spherical geometry to the tangential plane one is accomplished following the idea of Machenhauer and Haugen (1987) which allows to keep all the advantages of the spectral approach at minimum overhead costs (see Geleyn, 1998). The vertical discretisation is the one advocated by Simmons and Burridge (1981). The semi-implicit, semi-Lagrangian two-time-level time-marching scheme is quite close to the one described in Ritchie et al. (1995), Simmons and Temperton (1997), Ritchie and Tanguay (1996) and Hortal (2000), with two ARPEGE/ALADIN enhancements: the implicit treatment of the Coriolis term as proposed by Rochas (see Temperton, 1997) and an analytical (rather than interpolated) computation of the coordinates of the origin point of the trajectories. This scheme allows the use of the so-called 'linear grid' (see Côté and Staniforth, 1988), i.e. a reduction to its minimum of the spectral aliasing problem, as well as very efficient time steps (Courant numbers down to 23 m/s).

For the reasons explained in McDonald (1998), the orography (still of 'envelope' type for the time being, see below) is fitted like for a classical quadratic grid, but applying the method of Bouteloup (1995) spectacularly reduces the Gibbs effects over sea.

The horizontal diffusion is implicit linear and fourth-order with a divergence damping factor of five. The e-folding time of the smallest wave for vorticity, vertically scaled temperature and moisture is set proportional to the model mesh-size with a ratio of 12.3 m/s in the linear-grid case. This value is the one for the surface and the effect increases with height in inverse proportion to pressure.

The lateral coupling of the LAM is of the Davies (1976) type and its interaction with the semi-implicit procedure is performed at no additional cost thanks to the suggestion of Radnoti (1995).

Beside the HPE version, there exists a non-hydrostatic fully compressible version of ALADIN (Bubnova et al., 1995) following the suggestion of Laprise (1992) to keep the HPE continuity equation unchanged through the use of a hydrostatic-pressure-based vertical coordinate. However, this will not be used in the basic MFSTEP set-up, owing to its very small impact at 10 km of mesh-size.

III) PHYSICAL PARAMETRISATION PART

Generalities

The last widely published documentation of the parameterisation package described below is nine years old (Geleyn et al., 1994). It is still valid in a few aspects, especially those concerning the interfacing rules and/or thermodynamic constraints, the basis of the radiative calculations once the clouds are diagnosed, the stratiform precipitation scheme and the purely gravity wave part of the mountain drag. This however does not give a complete picture. The description below will be a rather homogeneous introduction (with references whenever available but without specific details) to the current situation with a few words about yet unused options and planned upgrades.

Radiation computations

The basic scheme is adapted from Geleyn and Hollingsworth (1979) and Ritter and Geleyn (1992) and simplified enough for being able to describe the interactions soil-radiation and clouds-radiation at each time step. The three main 'compromise' hypotheses for speeding-up the calculations are the following:

- only one spectral interval in the solar as well as in the thermal range, but consideration of all active gases as well as of the separation between liquid- and ice-cloud components;
- grey body assumption (i.e. linear monochromatic behaviour) for all effects except gaseous absorption (but multiple scattering is treated without approximation, even in the thermal domain, thanks to a delta-two-stream computation with a choice between random and maximum-random (unused) overlap hypothesis for cloud geometry);
- the interaction between line absorption of gases and two-stream 'adding' method as well as the saturation effects of the former are treated via the diagnostic estimation of a 'minimum' gaseous optical depth for all remaining effects, once (i) absorption of parallel solar radiation in the solar domain and (ii) so-called 'cooling to space' and 'exchange with surface' terms in the thermal domain have been treated exactly.

The diagnostic schemes for the 'radiative' clouds link the cloudiness to the production of stratiform and convective precipitations, and to the existence of inversions. The scheme is based on the following principles:

- cloudiness functionally depends (with different parameters for the stratiform and convective contributions to a single amount) on the diagnosed liquid- ore ice-water-content; the functional dependency is one of those proposed by Xu and Randall (1996);
- the contribution is obtained from the rate of generation of convective precipitation at the previous time step in one case;
- in the other case, one estimates the instantaneous super-saturation of the air properties averaged along a certain delta-theta thickness below, with respect to the local saturation state multiplied by a 'critical relative humidity' vertical profile (tuned with two parameters only);
- the partition between ice and liquid state depends only on temperature with a progressive transition below 0°C.

One is currently considering a new structure for the radiative computations in which the clear sky gaseous computations, the cloud/aerosol sub-model and the delta-two-stream solver would be considered as three independent parts, this allowing more flexibility and a different view of the 'radiative time stepping problem'. The benefits of this action will very likely be included in the MFSTEP pre-TOP phase, pending successful testing.

Turbulent vertical diffusion and PBL

The common scheme for the surface and upper-air exchanges is designed according to Louis (1979) and Louis et al. (1981), with the shallow convection incorporated according to Geleyn (1987) and recently modified to cure a tendency to an on/off behaviour in time and along the vertical. For the past four years a big effort (still on-going) has been made to improve the coefficients' dependency on the Richardson number in case of stable situations. Two (positive) critical Richardson numbers (each with a potentially modulated vertical profile) have been introduced. The first one deals with the enhancing effect on fluxes of sub-grid inhomogeneities and the second one with the difference in the effect of such inhomogeneities between the thermal and momentum parts of the calculation.

A retuning of the ‘mixing length’ vertical profile was applied during this work and it is intended to make it dependent at some stage on the time- and space-dependent height of tropopause and PBL depth, the latter computed according to Ayotte et al. (1996).

The residual gusts when the wind is weak near the sea surface and the situation is unstable are treated via a stability-dependent enhancement of the result of the basic Charnock formula, in the spirit of the Miller et al. (1992) work. An enhancement to the moist convective case, inspired by the ideas of Redelsperger et al. (2000) is currently considered as well as the possibility to distinguish between roughness lengths for momentum and for heat over sea (as it is already the case over land). These improvements, if successfully tested, ought to find their ay in the pre-TOP or TOP phases of MFSTEP.

The ‘anti-fibrillation’ scheme of Bénard et al. (2000) is activated. Extending the idea of Girard and Delage (1990), it introduces an over-implicit treatment only when and where the linear local full stability analysis estimates it necessary in order to get a pre-chosen degree of ‘smoothness’ of the solution. In order to avoid getting ‘space-sliced’ patterns in place of time oscillations, a constraint of vertical monotonicity was recently imposed on the resulting over-implicit factor. Since this scheme, by construction, cannot handle the type of shallow convection parameterisation via turbulent exchange coefficients’ enhancement used in the package, the above-mentioned modification of the shallow convection scheme had to be introduced to harmonise the whole treatment.

Specific diagnostics for the boundary layer are (in a broad sense):

- interpolated values in the SBL (generally towards the measurement heights) according to Geleyn (1988);
- PBL height (up to now computed with a Richardson number offset, soon to be replaced by the above-mentioned adaptation of Ayotte’s method);
- maximum gust wind speed, either through a link with the dynamical roughness and the surface friction velocity or as the wind at the top of the PBL;
- CAPE and moisture convergence (several algorithmic options for each of them) computations for the instantaneous diagnostic of convective risk, especially in diagnostic mode with a frequent near-surface-analysis update.

Mountain drag scheme

It describes in a broad sense the influence of unresolved orography on the higher levels of the atmosphere in a way adapted from Boer et al. (1984) for the linear ‘gravity wave drag’ part (with full use of the Lindzen (1981) saturation criterion for applying the Eliassen-Palm theorem) and from Lott and Miller (1997) for the ‘form drag’ low level part. An optional (yet unused) parameterisation of the sub-grid scale so-called ‘lift’ effect exists, following Lott (1999). Some additional effects are taken into account for the following aspects:

- influence of the anisotropy of the sub-grid orography on the direction and intensity of the stress, according to Phillips (1984);
- use of averaged wind and stability low level conditions (and smooth return to the true profiles above the averaging depth) in order to get a surface stress as independent as possible of the model’s vertical discretisation;
- amplifying or destructive resonance effects parameterised according to the work of Peltier and Clark (1986), as well as dispersion effects in case of upper-air neutrality;
- the linear and non-linear potential instabilities of this complex scheme are preventively eliminated at the time of computation of the integrated effects (except for the ‘lift’ case that is currently an independent piece of parameterisation put in the scheme’s code only for convenience).

The whole scheme is currently under review with the aim to abandon the associated envelope orography and to replace its volume effect by a better tuned form drag and by the use of a revised version of the lift effect (that would then cease to be independent of the scheme’s backbone). This is very likely to be part of the standard set-up at the SVP stage of MFSTEP.

Deep convection

This parameterisation is surely the one that has received most attention in the evolution of the considered physics package. Contrary to the general tendency in other NWP groups, most of the attention has been paid to the formulation of the entrainment and to its consequences and not to the closure assumption, still of the Kuo-type, even if its practical implementation has also gone more complex than in the 80’s.

The original scheme is the mass-flux-type one from Bougeault (1985), modified for the numerical stability according to the Appendix of Geleyn et al. (1982). In its current version it encompasses the following refinements:

- the Kuo-type closure has been made dependent on the horizontal resolution according to the ideas of Bougeault and Geleyn (1989) since the dynamical part of the moisture convergence is here modulated by a factor depending on the mesh size and that goes to zero for a vanishing one;
- a very simple microphysics to avoid 'deep convection' from too shallow clouds; this follows the proposal formulated in the Appendix of Arakawa and Schubert (1974);
- it is forbidden to have deep convection when absolute dry convection is active;
- a comprehensive treatment of the vertical transport of horizontal momentum that includes the recirculation by the mass-flux in the Schneider and Lindzen (1976) sense, the effect of lateral entrainment and the effects of pressure difference between the cloud and its environment following the proposal of Gregory et al. (1997); the 'non-hydrostatic' part of the moist adiabat ascent/descent computations are treated in conformity with Gregory's underlying hypotheses;
- a provision for cancelling the computations when the potential for convective rain at the surface makes it unlikely for the ascent to reach the lifting condensation level;
- a vertically varying detrainment rate with a constant component plus a dependency on the buoyancy decrease in the upper part of the cloud;
- an entrainment rate that (i) varies from higher values at the bottom to lower ones at the top alike the proposal of Gregory and Rowntree (1990), (ii) is dependent on a first estimate of the integrated buoyancy and (iii) encompasses the 'ensembling entrainment' concept (i.e. the clouds inside a grid-box that survive at a given height have a higher buoyancy than the averaged one below, because they entrained less in their lower part) in its consequences on the profiles;
- parameterisation of downdrafts via quasi-symmetric computations for the ascending and descending motions (Ducrocq and Bougeault, 1995); the additional differences are a geometric modulation of the mass flux to avoid its convergence in the sole lowest model level and constant entrainment/detrainment rates along the vertical, contrary to the description in the last two bullets, valid only for updrafts;
- in the closure assumption for the downdraft part, precipitation fluxes' creation replaces moisture convergence but Bougeault's main closure coefficient (ratio of mass flux to buoyancy) has been constrained to remain smaller for downdrafts than for updrafts in order to avoid a runaway feedback when a shallow moist unstable layer caps a deep dry and well-mixed PBL; to alleviate the consequences of this 'security' in terms of surface fluxes a compensating 'unorganised' sub-cloud evaporation term is incorporated following the relaxation method of Geleyn (1985).

Stratiform precipitation scheme

There is neither storage of the liquid and solid phases in the clouds, nor consideration of partial cloudiness, but a revised Kessler (1969) method is used for computing precipitation evaporation, melting and freezing. A ratio of the falling speed for the two types of precipitation allows distinguishing two aspects in the liquid/ice partition:

- formation that follows the same partition as the one used in the radiative diagnostic cloud scheme;
- evolution for the falling parts that takes into account the past 'history' of the falling fluxes, even if those are diagnosed under a (time-step by time-step updated) stationarity assumption.

Quite sophisticated parameterisations of the soil processes

This is based on the ISBA scheme described by Noilhan and Planton (1989) and by Giard and Bazile (2000). Some modifications have been added to the scheme for taking into account the freezing-melting effects of the soil water at different levels. The research version of the same scheme is well known through the participation to the various international inter-comparisons (PILPS, SNOWMIP, …).

IV) 'PSEUDO DATA ASSIMILATION' PART

Generalities

The pseudo data assimilation scheme in ALADIN-MFSTEP will be the most original part of the whole procedure, with respect to similar atmosphere-ocean forcing exercises in the past, owing to its 'anti-spin-up' character that should help getting as smooth as possible a transition in the forcing between each 6h leg of the continuous assimilation cycles. It is based on the so-called 'blending method' according to Brozkova et al. (2001), which preserves both the result of the ARPEGE global model analysis for the large scales and the orography-linked details of the previous ALADIN forecast for the smaller scales. This method can be seen as a special application of the multi-incremental approach (Courtier et al., 1994) within a data analysis/assimilation procedure encompassing both coupling and coupled models, the assimilation of the latter being done in this case ‘without observations’.

Upper air blending

The initial conditions for a Limited Area Model (LAM) may basically be obtained either by interpolating the initial conditions of the driving model to the LAM grid (dynamical adaptation mode) or by an independent data analysis/assimilation procedure in the LAM (data assimilation mode). The smaller the size of the LAM domain is, the more the dynamical adaptation mode is appropriate since the analysis of larger scales over a small domain becomes more and more questionable (Berre, 2000). If one wants to avoid the dilemma between the two above-mentioned basic solutions, an appropriate treatment of the larger scales may be achieved by applying a so-called blending technique where the fields of the driving model and of the LAM are selectively combined in function of the scales resolved by each model. This technique is used in ALADIN in order to keep the 4DVar ARPEGE results for the long waves, well resolved by the global model, and to combine them with the short-range meso-scale ALADIN forecast. The meso-scale part of the ALADIN solution (itself denoted as ‘guess’), unresolved by ARPEGE, should thus be kept in the initial conditions. In other words the blending is a meso-scale analysis without observations, where the long-wave part of the spectra is analysed by ARPEGE and where the short-wave part of the spectra relies on its own ALADIN guess. The hypothesis is that the short-wave guess is more realistic and closer to the truth (thanks to the balance with the fine-mesh surface forcing) than the short-wave result obtained simply by interpolating the ARPEGE analysis.

The determination of the smallest scales still well captured by the analysis of ARPEGE is based on the resolution of the ARPEGE analysis increments and also on the resolution of its deterministic forecast. This scale limit, together with the size and resolution of the ALADIN domain provides a first estimate of the ‘blending truncation’ (see Part ‘I’ above) within the ALADIN spectra. A smooth transition between the ARPEGE and ALADIN spectra, around the blending truncation, is implicitly obtained by the Digital Filter Initialisation (DFI) method (Lynch et al., 1997). The digital filter is applied on both ARPEGE and ALADIN fields at the low spectral resolution of the blending truncation in order to obtain a filtered large-scale decrement, to be then added to the high resolution guess. The blending truncation and DFI settings are the tuning parameters of the system. The tuning criteria is to keep realistically active structures both in the initial and +6h forecasts states, together with realistic physical fluxes in the early hours of the forecast (thus taking care of the spin-up poblem). Beside the smooth transition between the spectra, the digital filter offers the advantage to balance the final blending increment when adding the meso-scale ALADIN information to the large-scale part. This is ensured by the properties of the digital filter incremental initialisation, gently creating a good balance of mass and wind fields in the initial condition blended state. Any use of an external initialisation can thus be avoided.

Surface blending

DFI blending of the upper-air dynamical variables can be completed by a blending of soil variables, where the interpolation procedure transports the surface analysis increments instead of the surface analysis itself. The initial values of the surface variables in ALADIN are obtained by adding the interpolated ARPEGE surface analysis increments to the ALADIN guess. To avoid a divergence of the cycle, a weak relaxation toward the ARPEGE analysis is applied. The surface blending may easily separate the treatment of the soil and sea surfaces (a useful property in the MFSTEP case) and it can be combined with an independent surface analysis scheme (solution currently in testing phase).

Perspectives

While the blending method improves mainly the treatment of surface forcing in a meso-scale LAM, the next step is to analyse meso-scale structures that the fine-mesh LAM is in principle able to describe. Since we cannot obtain a correct sampling over the LAM domain to estimate the error structure functions for long waves, it is preferable not to re-analyse these long waves and to rely on the global model analysis. For this, DFI blending is an ideal tool. The blended state, containing the corrected large-scales from the global analysis, is a logical first guess for the meso-scale analysis using the so-called ‘lagged’ background error statistics (Siroka et al., 2003). It is however unlikely that such an evolution will be ready for a safe use in the TOP phase of MFSTEP.

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