THE SPECTRAL LIMITED AREA MODEL ARPEGE/ALADIN

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Introduction

The recently developed model ARPEGE/ALADIN is the result of a cooperative project which was initiated in 1990 by METEO-FRANCE. The other National Meteorological Services involved in the project are those of Austria, Bulgaria, Croatia, the Czech Republic, Hungary, Morocco, Poland, Romania, Slovakia and Slovenia. The aim of the project was to develop the limited area counterpart of the global spectral model ARPEGE/IFS and to have a tool for dynamical adaptation at the limit of the hydrostatic assumption.

One of the crucial constraints kept in mind during the whole project was to remain as close as possible to the mother system ARPEGE-IFS and potentially to provide ALADIN as an element of that integrated system. This requirement itself predestinated the developer to the choice of spectral technique, but this decision was also attractive due to some other well known positive features, e.g.:

- more accurate horizontal derivative computations;
- simplified conservation properties through separation of vertical and horizontal discretizations;
- no systematic errors in advection;
- good description of phase and amplitude;
- easy and cheap solution of Helmholtz operator;
- possibility of spectral truncation,
- no problem with extension to all variational developments (3 and 4 dimensional variational analysis),

Since June, 1994 ALADIN has been quasi-operational: once a day from 00 UTC initial data it is launched for 36 hours over the Central-European region and the results are disseminated to some of the above mentioned countries via satellite. The integration domain with its fine-mesh can be seen on Figure 1.

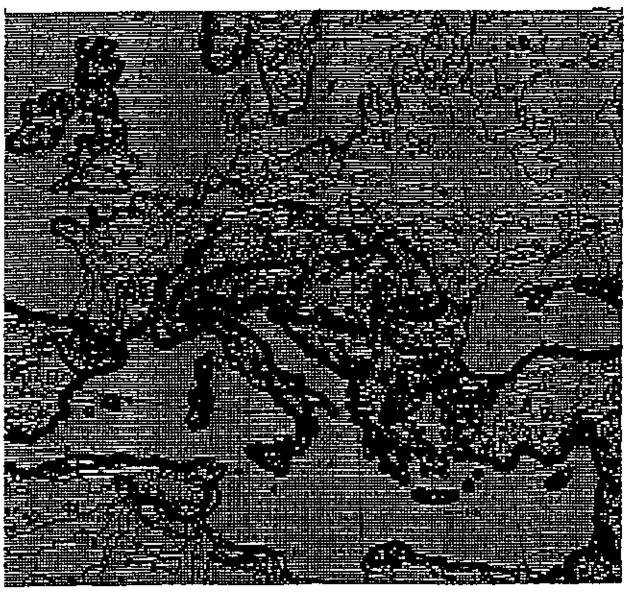

Figure 1: The quasi-operational integration domain with the fine-mesh grid.

The main characteristics of ALADIN, as far as the quasi-operational version is concerned, are as follows:

- It is a spectral model using Fourier spectral representation in both horizontal directions and therefore requiring double periodicity of the model fields;
- No assimilation cycle and analysis is applied: initial and lateral boundary conditions (LBC) are specified from global ARPEGE initial and forecast fields via interpolation;
- A regular grid is used on a Lambert or optionally on any conformal projection;
- For initialization a digital filter technique is applied;
- The model is coupled with global ARPEGE fields by a Davies Kallberg type relaxation scheme;
- A semi-implicit semi-Lagrangian scheme is applied, which enables the model to run with a longer time step. Currently the timestep is 432 sec for a 18.3 km mesh size on the collocation grid, i.e. the equivalent of a global T730 model;
- The vertical discretization (hybrid coordinates introduced by Simmons and Burridge, 1981) and the physical parameterization is taken from the global ARPEGE package without any modification.

Some of these characteristics and a few results will be discussed below.

Some basic model aspects

It has been emphasized in the introduction that ALADIN is just one member of a model system: the limited area version of the global system ARPEGE-IFS. Therefore most parts of the already existing global system were adopted without any or with just some slight modifications during the development. So both models have the same basic set of primitive equations, where the only task was to project the spherical equations onto a plane. This operation is mainly manifested in the curvature terms.

The spectral representation of model fields is another major point where the global and limited area solutions differ. In ALADIN, instead of the spherical harmonics used in ARPEGE-IFS, double Fourier series expansion is applied. The main advantage of this representation is the existence of very efficient algorithms for transforming real fields, the well known Fast Fourier Transforms. The relation between points and modes is chosen properly to avoid non-linear instability caused by non-linear terms (mainly by advection term): this provides similar constraints for ARPEGE and ALADIN, since in both cases the critical horizontal advection expressions are quadratic terms. To ensure isotropy and homogeneity in spectral space an elliptic truncation is applied in addition to the un-aliasing condition. The time integration of the model includes a semi-implicit correction for fast-propagating processes whether or not a semi-Lagrangian scheme is employed. It is a common feature in ARPEGE and ALADIN that all the preparatory steps of the semi-implicit correction are done in the gridpoint space and this part is identical for the two models. Then the solution of the Helmholtz equation is performed in spectral space. A 3-time level semi-Lagrangian scheme has been implemented for ALADIN, which can be characterized by second order of accuracy, 3 dimensional Lagrangian advection. Recently a 2-time level scheme has been tested for IFS and ARPEGE and it was validated for ALADIN as well. It will enter the quasi-operational version in due time.

Preparation of initial and lateral boundary fields

Integration of ALADIN is preceeded by a preparatory step in which the initial and lateral boundary fields are produced from global ARPEGE analysis and forecast fields by interpolation. This preparatory step requires a sequence of data transformations: global spectral fields are firstly transformed from spherical harmonics to the collocation grid, then the interpolation is accomplished in gridpoint space to the target geometry, starting with horizontal interpolation and continuing with biperiodicization. The last step on the target grid is the vertical interpolation which is followed by the direct Fourier transformations in both horizontal directions. Finally the initial and lateral boundary fields are fitted by spectral truncation. The order within the sequence of these operations was found crucial: Any other solution creates spurious noises. The horizontal interpolation is done with a possibility to use bilinear or "12-point" interpolation with cubic Lagrangian polynomials. During the interpolation optionally the land-sea-ice mask can be also taken into account by degenerating the order of the Lagrangian polynomials and there also exists an option (nearly always used) for interpolating only the departures from climate fields. In the vertical part of the interpolation procedure the displacement of the planetary boundary layer (PBL) is implemented. This requires the introduction of an intermediate vertical system, characterized by the same coefficients of the hybrid vertical coordinate and the same vertical levels as on input, but for which the surface pressure and orography are taken from the target grid. After this, the vertical interpolation is carried out in both systems and the results are combined by a weighting function varying between 0. and 1. in the PBL transition zone: results of the intermediate system are taken below and those of original one are taken above this zone and a smooth transition is forced by the coefficients inside the zone.

Initialization by a digital filter

Due to the finer orography used by ALADIN and the noise unavoidably introduced by the interpolation from global to limited area geometry, initialization of the prognostic fields is desirable even if the original information came from an initialized state. For this purpose, under the inspiration of the positive results achieved in the HIRLAM project (Lynch and Huang, 1992), the use of digital filters has been chosen. This method is a very simple and, as the tests proved, efficient tool for removing spurious high-frequency inertia-gravity wave oscillations and it has numerous advantages with respect to other methods, like non-linear normal mode initialization. Based on these results, the algorithm has been generalized so that it is available now for both the global and limited area version with numerous variants, such as recursive and non-recursive, adiabatic and diabatic, incremental and non-incremental filters.

Biperiodicization and coupling

As mentioned before, for the spectral representation of the model fields ALADIN uses double Fourier coefficients. This representation assumes periodic fields in both horizontal directions. The double periodicity of the fields is ensured by introducing an artificial zone, the so called extension zone, where a smooth transiton is provided between the Southern and Northern boundaries as well as between the Western and

Eastern boundaries of the physically meaningful domain. This method was originally introduced at the HIRLAM project (Machenhauer and Haugen, 1987) and in its ALADIN version the only significant difference is in the form of the biperiodicization operator: in ALADIN spline functions and transversal smoothing are used to ensure as much as possible regularity and isotropy of the generated "extension" fields.
Large scale effects are taken into account by the coupling procedure realized by a Davies-Kallberg relaxation scheme. Coupling and biperiodicization are carried out at the same step by using doubly periodic lateral boundary fields with a relaxation coefficient, which is identically 1.0 over the whole extension zone. Therefore, the biperiodicization does not cost much computing time during the model integration, since it is performed only during the preparation of the fields interpolated from ARPEGE. The organization of the horizontal domain with respect to coupling and biperiodicization can be seen on Figure 2.

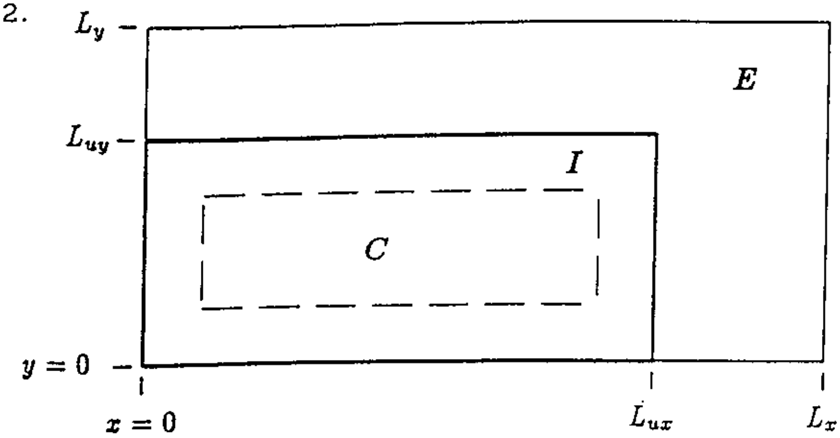

Figure 2: Organisation of the horizontal domain ofARPEGE/Aladin. The C zone is the inner domain, the domain of meteorological interest. The I zone is the region where the coupling is added. The E zone is the region needed for making the fields doubly periodic, for computing derivatives. Fields have a geographical meaning over the area C+I, extending over L_{ux} *and* L_{uy} *in the x and y directions, respectively. The periods are respectively* L_x *and* L_y*.*

Due to the fact that in the extension zone all prognostic fields are artificial and their values have nothing to do with the real atmosphere at any geographical location, in principle there is no need to carry out computations of physics and non-linear dynamics in this region. However, these expensive computations can be eliminated only if coupling is done after gridpoint computations just before the direct Fourier transformations. On the other hand this organization of the time stepping algorithm requires a special treatment of coupling fields because of the gridpoint part of the semi-implicit scheme. It means that the linear semi-implicit operator must be applied to the large scale fields in the same manner as it is done during the semi-implicit gridpoint computation within the C+I zone (Radnoti, 1995). This new method has several advantages:
- it highly reduces spurious noise near to lateral boundaries;
- it eliminates gridpoint computations in E-zone;
- it makes coupling of derivative fields unnecessary.

Verification results and validation

In the whole one year period of its quasi-operational stage ALADIN was regularly verified against SYNOP and TEMP observations and compared to the results of operational ARPEGE. It is difficult to have reliable conclusions because during this period the quasi-operational version of ALADIN was intensively modified and is still under development. However, one can notice that ALADIN usually gave slightly worse scores than ARPEGE when it was compared to SYNOP observations concerning wind and slightly better for temperature, a result also present, in a lesser extent, when comparing to TEMP observations for the lower part of the atmosphere; this surprising result has now been linked to an exaggerated amount of surface and upper air drag in ALADIN with respect to ARPEGE. Ways to cure it are tested to find the best balance between the several factors contributing to the low level drag of the model.
Detailed comparative investigations were done to decide whether a variable mesh global model with hyper-stretching or a high resolution limited area model can provide a better solution on the sub-synoptic scale (Caian and Geleyn, 1995). ALADIN and the stretched version of ARPEGE served as an ideal model environment for these studies since they have the same physics and some other common features. The results suggest that the stretching factor cannot be increased over a threshold limit and therefore that the limited area approach provides better results for "very high" resolutions.
The quality of ALADIN forecast was examined with a special attention in a situation when the enormous rain quantity caused floods in the southern part of France. The maximum precipitation was measured in Vaison la Romaine (over 300 mm within 24 hours), therefore the situation is often referred to as the "Vaison case". The precipitation forecast skills of several models with similar resolution were compared for this extreme case. With a proper tuning of horizontal diffusion ALADIN produced the closest amount to the observed one and could localize the area of maximum rainfall with a very good precision (Figure 3.).

(a) (b)

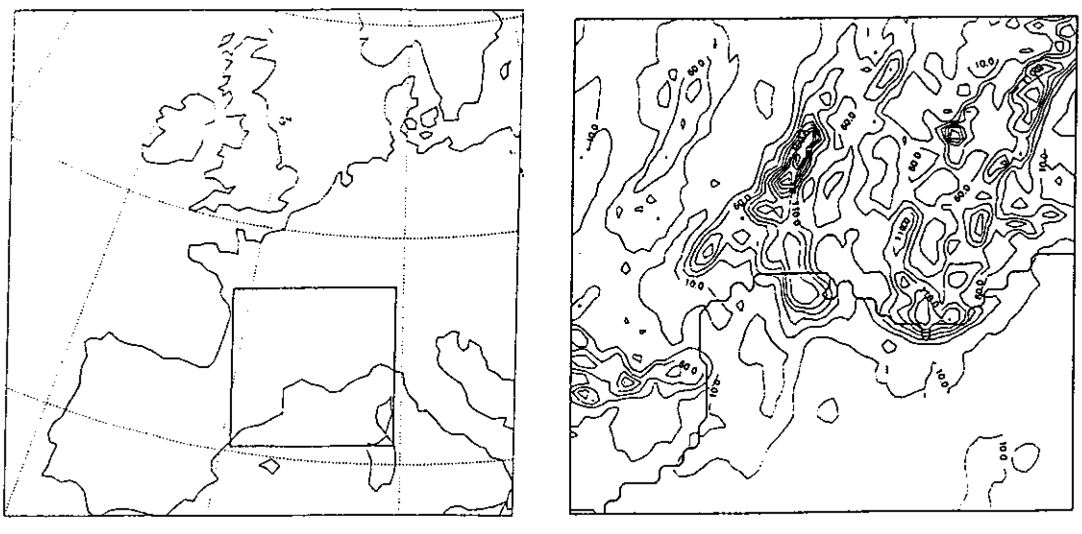

Figure 3: The integration area with the zooming (a) and the 24 hour accumulated precipitation forecast obtained by ALADIN over the zoomed area (b). The plotting interval is 25 mm. The wider solid line is the Mediterranian coast line (Fig. taken from Bubnova et al., 1995).

ALADIN was also validated with very high resolution (10 km in horizontal and 41 vertical levels) on initial data coming from the T213, 31 level ECMWF reassimilation. The comparison of the results with observations made during the PYREX field experiment shows that the local wind systems are captured reasonably well by the model. The results prove the capability of the model to simulate the local flow influenced by steep orography.

ALADIN as a research tool, plans for future developments

Besides the need to create an operational high-resolution limited area model, ALADIN was also considered as a tool for research from the beginning. In several PhD studies, ALADIN was applied for the corresponding research developments and experiments.
The non-hydrostatic version of ALADIN was developed within this framework (Bubnova et al.,1995). This development was carried out based on the idea of introducing the hydrostatic pressure as the vertical coordinate (Laprise, 1992). This made it possible to transform the hydrostatic model into a non-hydrostatic one without deeply changing its basic structure.
Another research topic to be mentioned here is the sensitivity studies being carried out on frontal waves by the use of the adjoint version of ALADIN (Horanyi and Joly, 1994).
The objective analysis scheme using the optimum interpolation technique has been implemented and currently it is in a pre-operational phase. According to the longer term plans we intend to implement a variational assimilation scheme. This will rather be a 4-dimensional than a 3-dimensional variational assimilation. The problem occuring at the LBC-s during the adjoint integration can be solved by the use of a spectral coupling. Such a scale selective coupling technique has been tested in ALADIN and the results showed that although it is not a proper solution for longer integrations, on the typical time range of the relevant adjoint integrations it gives good results.
The climate version of the model is also under development and we intend to take part in some climate research projects with running ALADIN in "climate" mode, i.e. coupled with observed or GCM-produced long series of LBC-s.

ACKNOWLEDGMENTS:

We would like to thank every participant of the project and all those collegues from METEO FRANCE who helped us in the development of the model. We are particularly grateful to our project leader Jean-Francois Geleyn and the earlier French participant Veronique Ducrocq. The support from Emmanuel Legrand is also acknowledged. It also has to be mentioned here that our work could not have been carried out without the ARPEGE/IFS code, which was partly developed by ECMWF.
The project was funded by the MICECO program of the French Government, by the PECO program of the European Community, by the French Ministere de l'Enseignement Superieur et de la Recherche and by several bilateral programs between France and Hungary, Morocco, Slovenia and Romania.

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