STABILIZATION OF ARPEGE/IFS SEMI-LAGRANGIAN SCHEME FOR DIABATIC VARIABLE RESOLUTION PURPOSE AND OTHER PRE-OPERATIONAL PROBLEMS

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Summary: The various modifications (with respect to ECMWF formulation) necessary to allow an operational use of semi-Lagrangian scheme in METEO-FRANCE configuration of ARPEGE/IFS for NWP are examined. The specificity of the approach is related to the stretching transformation applied to the coordinate system in order to obtain high resolution in some areas.

It will be shown that the horizontal stretching has to be taken into account for the semi-implicit scheme, resulting in a specific "stretched" form of the Helmholtz equation. This equation is no longer diagonal in spectral space unlike its "not-stretched" counterpart, but can be solved at no significant extra-cost, due to a simple property of the stretching transformation in spectral space. The same methodology is used to design a more uniform horizontal diffusion operator which allows a proper control of small scale noise in the high resolution area. The spurious orographic resonance problem is solved by the first order decentering method, associated with divergence damping.

The stabilization of the scheme on the vertical requires a further treatment of the "fibrillation" problem which occurs in the vertical diffusion part when a specific criterion (involving Richardson number, vertical mesh and the time-step) is violated. The limitation of the time-step is finally due to this latter problem, and the vertical resolution at the bottom of the domain has to be slightly decreased in order to keep a good compromise between spatial and temporal errors.

Finally, some problems linked to operational implementation are examined; they concern the control of energetic spectra and the performance of the high resolution operational semi-lagrangian version.

1. INTRODUCTION

ECMWF and METEO-FRANCE jointly developed a unique NWP system (ARPEGE/IFS) for their operational application purposes. This system has been used at ECMWF in semi-Lagrangian (SL) mode since February 1993, but not sooner than October 1995 the switch towards SL mode has been possible at METEO-FRANCE. The profound reasons for this can be found in the specificity of the French Service approach for its operational forecast policy, which consists in achieving the highest possible resolution in some "interest areas" by mean of horizontally and vertically stretched coordinates (for the vertical part, the coordinate is also stretched in the ECMWF configuration, but to a lesser extent).

The choice of the horizontal transformation (*Schmidt*, 1977) was linked to the use of the spectral technique for the computation of horizontal derivatives. It has been shown that this transformation can work without problems with stretching factors uaround to $c = 3.5$. This implies resolutions varying by a factor 12.25 (i.e. $[1/c, c]$). On the vertical, the pressure resolution typically varies in the range from 1 to 10 or 15.

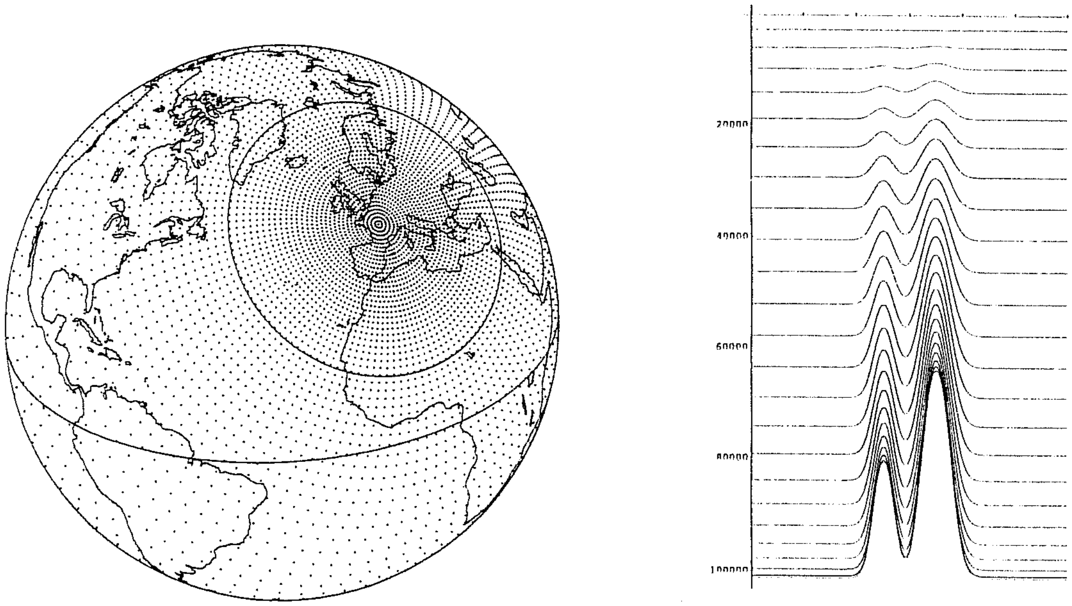

Fig. 1: T119 L24 ARPEGE horizontal (1 point over 9 plotted) and vertical grids

The horizontal and vertical grid for the former Eulerian operational version is shown on Fig. 1. One can note that the resolution smoothly varies thus avoiding the class of problems occuring in areas of strong resolution variation. Most of the problems discussed herefater are located in the high resolution areas.

Due to the horizontal stretching, a modification of spectral computations has been necessary, in order to take into account the variation of the local mapping factor. Both semi-implicit and horizontal diffusion schemes are concerned. The high resolution (and therefore sharp orography) obtained through the stretching also requires a special treatment of spurious orographic resonance (*Rivest et al.*, 1994). These points are examined in section 2. Section 3 focuses on vertical limitations, linked to the vertical diffusion scheme. Extra operational problems due to the variable mesh are discussed in section 4. Section 5 contains concluding remarks and the perspectives which could allow to avoid some of the problems listed in this paper.

2. HORIZONTAL STABILIZATION

2.1 Introduction of the mapping factor in the spectral computations

In the transformed spectral space, the expression for the local mapping factor M is given by

$$M(\lambda, \xi) = a + b\xi \tag{1}$$

where λ, ξ are respectively the longitude and the sinus of latitude on the transformed sphere, $a = (c^2+1)/2c$, and $b = (c^2-1)/2c$, c is the stretching coefficient.

The interesting property of Legendre polynomials in spectral space is:

$$\xi P_{(m,n)} = e_{(m,n)} P_{(m,n-1)} + e_{(m,n+1)} P_{(m,n+1)} \tag{2}$$

where n and m are respectively the total and zonal wave numbers ($|m| \leq n$), and $e_{(m,n)} = \sqrt{(n^2 - m^2)/(4n^2 - 1)}$.

Equation (2) remains formally valid for any horizontal field X spectral components:

$$\xi X_{(m,n)} = e_{(m,n)} X_{(m,n-1)} + e_{(m,n+1)} X_{(m,n+1)} \tag{3}$$

This yields the expression for the mapping factor multiplicative spectral operator:

$$[MX]_{(m,n)} = b e_{(m,n)} X_{(m,n-1)} + a X_{(m,n)} + b e_{(m,n+1)} X_{(m,n+1)} \tag{4}$$

and:

$$\begin{aligned} [M^2X]_{(m,n)} &= b^2 e_{(m,n)} e_{(m,n-1)} X_{(m,n-2)} + 2ab e_{(m,n)} X_{(m,n-1)} \\ &+ (a^2 + b^2(e^2_{(m,n)} + e^2_{(m,n+1)})) X_{(m,n)} \\ &+ 2ab e_{(m,n+1)} X_{(m,n+1)} + b^2 e_{(m,n+1)} e_{(m,n+2)} X_{(m,n+2)} \end{aligned} \tag{5}$$

Multiplications by M or M^2 of any horizontal spectral field can be performed by mean of the multiplication by a tridiagonal or 5-diagonal matrix for each of its zonal wave number column vector $X_{(m)}$. Since the matrix coefficients are "mathematical constants", this process can be very highly optimised and thus lead to a very small computational overcost.

This can be applied to the semi-implicit scheme for the stretched mode: The choice of a conformal geometrical transformation for the coordinate stretching leads to a very simple relationship between the first-order differential operator on the transformed coordinate (hereafter referred to as"rescaled") $\vec{\nabla}'$ and its true "geographical" counterpart $\vec{\nabla}$, i. e: $\vec{\nabla} = M\vec{\nabla}'$.

As the vorticity and divergence fields are obtained as second order derivatives of scalar fields (i.e. stream function ψ and velocity potential χ), the kinematic state variables of the model will be the "rescaled" vorticity and divergence: $\zeta' = \vec{\nabla}'^2\psi$,$D' = \vec{\nabla}'^2\chi$.

The semi-implicit (SI) temporal discretisation is designed as an explicit scheme with implicit correction. This means that the leap-frog time discretised form of the scheme can be written symbolically as

$$X_{t+\Delta t} = X_{t-\Delta t} + 2\Delta t \mathcal{M} X_t + 2\beta\Delta t \Lambda \left(\frac{X_{t+\Delta t} + X_{t-\Delta t}}{2} - X_t \right) \tag{6}$$

A linearised value $\overline{M}$ for the mapping factor in spectral space calculations can be used instead of the local value M for small timesteps. The chosen value ($\overline{M} = \text{Max}(M) = c$) insures a fully semi-implicit treatment of the waves at the stretching pole, yielding the following Helmholtz equation:

$$(1-\beta^2\Delta t^2\overline{M}^2 B\vec{\nabla}'^2)D'_{t+\Delta t} = \mathcal{D}'^* - \beta\Delta t\vec{\nabla}'^2(\gamma\mathcal{T}^* + \mu\mathcal{P}^*). \tag{7}$$

It can be seen that this Helhmoltz equation remains formally equivalent to the "classical" not stretched one (*Simmons and Burridge*, 1981). Due to the diagonality of the rescaled Laplacian in spectral space, the solution of the SI equation is equivalent to the inversion of a diagonal horizontal operator in spectral space, after a constant (i.e. pre-computed) vertical diagonalisation.

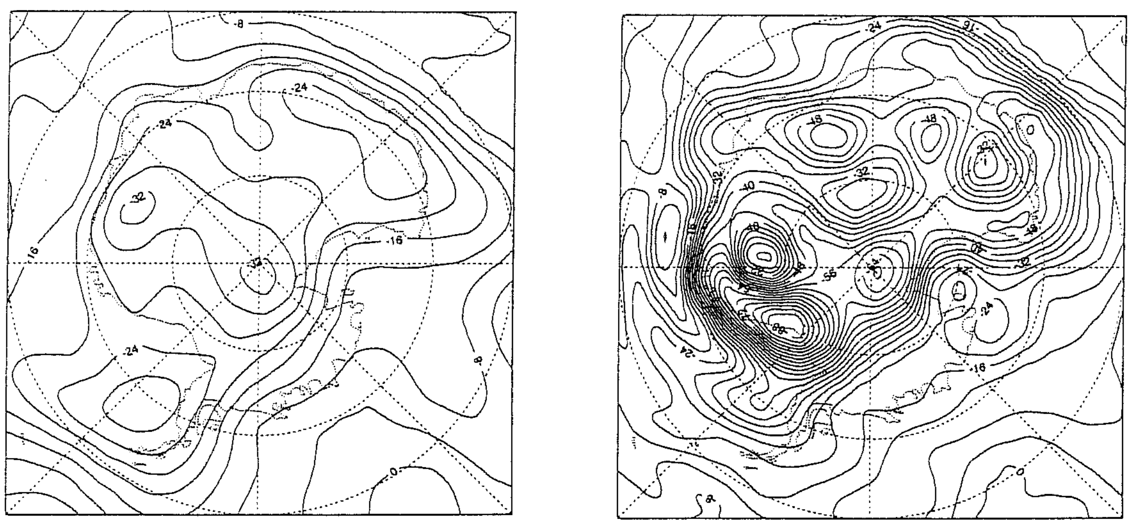

Fig. 2: 850 hPa temperature over Antarctic in T119 L24 c3.5 SL 72h forecasts from 15 July 1994 00 UTC. Δt =3 minutes (Fig. 2a) and Δt =15 minutes (Fig. 2b)

However, due to the linearisation around the $\overline{M}$ value, SI corrections are underestimated by a factor c^2 at the low-resolution pole, compared to their true value, resulting in instabilities in this area when large time-steps are used. Fig.2 shows 72h semi-Lagrangian T119 c3.5 forecasts of 850 hPa temperature over Antarctica (i. e. near the contraction pole), from 15 July 1994 00 UTC with a 3 minute (Fig. 2a) and a 15 minute (Fig. 2b) time-step. The unrealistic semi-implicit corrections in this area result in a spurious trend toward cold temperatures over Antarctica, leading to erroneous low temperatures (the maximum deviation from the reference analysis reaches -69 K).

This problem is solved by introducing the local mapping factor in the spectral part of the SI scheme. This yields the following Helmholtz equation:

$$(1-\beta^2\Delta t^2 B\vec{\nabla}'^2 M^2)D'_{t+\Delta t} = \mathcal{D}'^* - \beta\Delta t\vec{\nabla}'^2(\gamma\mathcal{T}^* + \mu\mathcal{P}^*) \tag{8}$$

(note the place of M with respect to $\vec{\nabla}'^2$ due to the non-commutativity of these two horizontal operators). The SI equation is no longer equivalent to the non-stretched one, because of the presence of the M^2 multiplicative operator. However, due to the property of this previously described operator, the vertically diagonalised version of this equation write as the inversion of a non-symmetrical 5-diagonal matrix for each zonal wave number m. The extra cost of this inversion is not significant since the operator is constant and can be pre-inverted at the beginning of the integration.

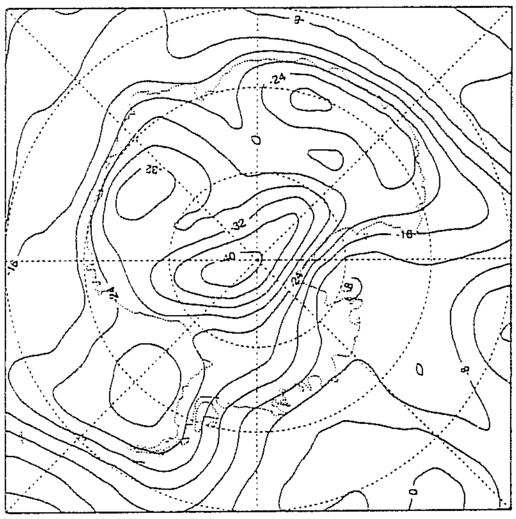

Fig. 3: Same as Fig. 2b, but with new SI scheme

The instability is completely removed with the new scheme, and no systematic trend can be detected through the forecast duration as can be seen on Fig. 3, which shows the 850 hPa temperature field (T850) after 72 h for the same semi-Lagrangian experiment as in figure 2*b*, except for the use of new semi-implicit scheme. The simple expression of the mapping factor in spectral space can also be used to improve the efficiency of the horizontal diffusion for the variable mesh version of ARPEGE with small extra cost.

In the regular mesh version of ARPEGE as classically in other spectral models, horizontal diffusion is performed by applying in spectral space a $\vec{\nabla}^r$ operator on prognostic variables (Sardeshmukh and Hoskins, 1984), where r is the order of horizontal diffusion. Such a scheme is convenient in spectral global models because of its low cost. Courtier and Geleyn (1988) had made the assumption that such a scheme could be still used in a variable-mesh spectral model, simply replacing the geographical derivative operator by the rescaled derivative operator.

This kind of horizontal diffusion scheme is equivalent, in the grid point space, to the following formulation:

$$\frac{\partial X}{\partial t} = -\frac{K_X}{M^r}\vec{\nabla}^r X \tag{9}$$

where K_X is the diffusion coefficient for the variable X, and $\vec{\nabla}$ is the first order horizontal derivative operator in the geographical space. The horizontal diffusion effect is thus weaker near the high resolution pole (where $M > 1$) than near the other one. The asymmetry between the two poles increases with the stretching coefficient, but also with the order of the horizontal diffusion derivative operator, and can become very large. For example, with a derivative order $r = 5$ and a stretching coefficient $c = 3.5$, M^r (and thus the intensity of diffusion) varies from 1/525 to 525. Therefore, such a formulation is no longer satisfactory in a variable-mesh spectral model when the stretching coefficient becomes significantly larger than 1, especially when using high selective horizontal diffusion orders.

The homogeneous diffusion operator can be written in terms of the rescaled derivative operator as:

$$\frac{\partial X}{\partial t} = -K_X M^r \vec{\nabla}'^r X. \tag{10}$$

The implicit temporal discretisation of this equation results in the inversion of a banded matrix with $2r + 1$ non-zero diagonals for each zonal wave number m. This problem could practically be solved in a similar way as presented in section 3 by mean of "LU" factorisations. However, for the typical values of r needed to obtain a sufficiently selective diffusion operator ($r \simeq 5$), this method would require excessive computational and storage costs (the problem would be 11-diagonal).

The idea used to reduce the size of the problem is to replace the function M^r in equation (10) by an approximated form $\widehat{M^r}(\xi)$ written as a low degree polynomial of ξ as proposed by Déqué (personal communication). For our purpose, a second degree polynomial in ξ approximation has been chosen, and appears to be satisfactory for approximating the M^r function up to $r \simeq 5$, in a sense that the violation of homogenity of horizontal mixing due to this approximation remains weak. Expression of $\widehat{M^r}(\xi)$ is:

$$\widehat{M^r}(\xi) = a_0 + a_1\xi + a_2\xi^2 \tag{11}$$

where the constants a_0, a_1 and a_2 are chosen in order to minimise the squared difference between M^r and $\widehat{M^r}$

Figure 4a shows meridional variations of the exact (solid line) and approximated (non-solid lines, same convention as in RHS of the figure) mapping factor obtained by this method: in the approximate formulation, the exact mapping factor is generally over-estimated in the contracted hemisphere and near the equator of the computational sphere, and under-estimated near the high-resolution pole. Figures 4b to 4e show the variations of the ratio $1/[M(\xi)]^r$ and $\widehat{M^r}(\xi)/[M(\xi)]^r$, which represent the ratio of the original and of the new diffusion scheme intensities compared to the intensity of the true geographical diffusion (i.e. intensity of true geographical diffusion should lie on the horizontal axis). Near the high resolution pole, the new scheme is closer to homogeneous diffusion for low orders than for high orders, and remains better than the original scheme for the four values presented. However, it can be seen in figure 5e that the diffusion at the contraction pole becomes comparable for the original and the new scheme when $r = 6$. This second degree approximation should thus not be used with orders larger than 5.

The practical implementation of the diffusion for the stretched version of ARPEGE then consists in superimposing the two schemes in a unique formulation (termed hereafter "unified" scheme of diffusion)

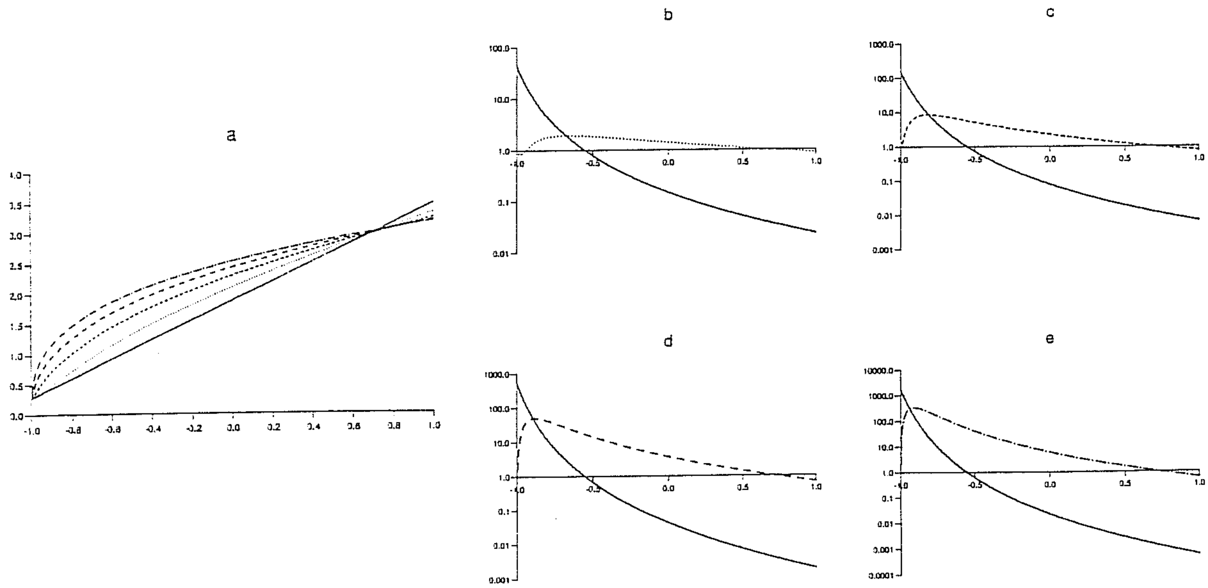

Fig. 4: a: Comparison of M and $\left(\widehat{M^r}\right)^{(1/r)}$ for r =3, 4, 5, 6. Comparison of $\widehat{M^r}/M^r$ and $1/M^r$ for r =3 (b), 4 (c), 5 (d), 6 (e). The horizontal axis represents ξ. Line convention is the same in LHS and RHS of the figure.

by denoting respectively by r and u the orders of the two schemes (u can be different from r), then solving an implicit discretisation of

$$\left(\frac{\partial X}{\partial t}\right)_{\mathrm{u}} = -(K_X \vec{\nabla}'^{r} + K_{\mathrm{u}X}\widehat{M^u}\vec{\nabla}'^{u})X \tag{12}$$

Due to the fact that M^u is approximated by a second degree polynomial of ξ, the solution of equation (12) is equivalent to the inversion of a 5-diagonal matrix for each zonal wave number m. The same method previously used in the semi-implicit scheme remains valid here to solve the implicit operator.

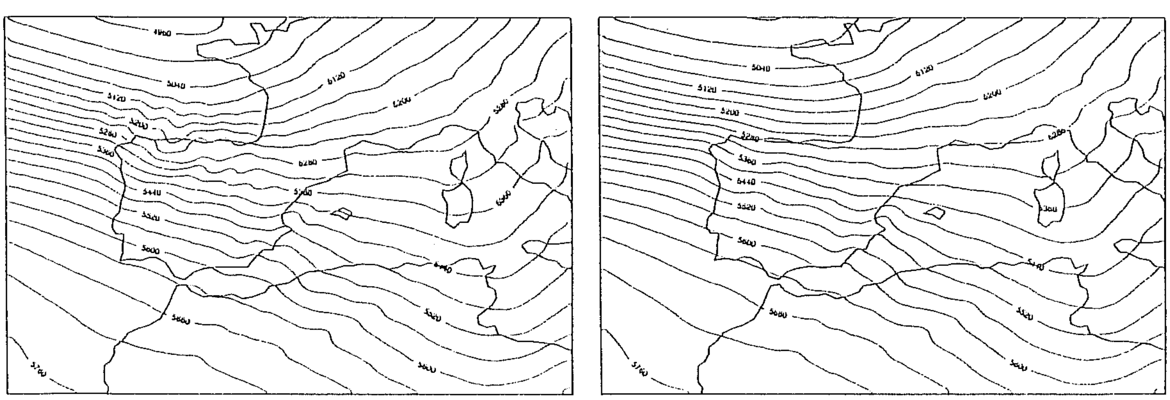

Fig. 5: 12 h SL forecast of Z500 from the analysis of 25 February 1989 00 UTC a: original diffusion scheme; b: unified diffusion scheme.

The weakness of the original diffusion scheme is its inefficiency in damping small-scale structures arising in the vicinity of the stretching pole. Figure 5 shows a 12 hour semi-Lagrangian forecast of Z500 from the analysis of 25 February 1989 00 UTC over Europe, a situation which exhibits a strong jet over the Iberian Peninsula. The original (resp. unified) diffusion scheme simulation is showm on Fig. 5*a* (resp. Fig. 5*b*). The flow is affected by strong oscillations if only the original diffusion is used. The unified diffusion allows to damp the magnitude of the oscillations to a more reasonable value.

Another advantage of the unified diffusion scheme is to allow a better control of energetic spectra since wave damping can be selectively enhanced in each hemisphere. This last point is examined in section 4.

2.2 Solution to spurious orographic resonance problem

The problem of spurious response of semi-lagrangian schemes to orographically forced flows has been addressed by applying the first order solution proposed by *Rivest et al.* (1994), combined with a 9-fold enhancement of horizontal diffusion magnitude for the divergence field. With a decentering value $\epsilon = 0.2$ the flow response to orography is very close to the Eulerian one without noticeable impact on the global characteristics of the circulation and scores. The recent proposal by Ritchie and Tanguay (see e.g. in this volume) about the "Eulerian-like" treatment of orography has also been implemented and submitted to preliminary tests. It manages to effectively reduce the resonance problem even with smaller decentering factors. However it was found that it did not bring any advantage when used with those versions of semi-lagrangian schemes which perform interpolations for time t at the medium point of the trajectories: for this class of schemes, the resonance with $\epsilon = 0.2$ is greater or equal when the Eulerian treatment of orography is introduced than in the classical version. On the other hand, this scheme allows a better conservation of mass in all classes of semi-lagrangian schemes. Nevertheless, this problem is more a problem of resolution than a stretching one, and no specific work in ARPEGE was necessary for its solution.

Fig. 6 shows the Z500 24 hour forecast from 1989/02/25, without (a) and with (b) the "Eulerian" treatment of orography, for a SL scheme with t terms computed as an average between origin and arrival points on trajectories. The resonance magnitude is clearly controlled and the contour oscillations have the same amplitude as for the Eulerian version.

3. VERTICAL STABILIZATION

For horizontal resolutions close to operational ones, the 3-time levels SL scheme can be used practically with Courant numbers of about 6 in the adiabatic version (e.g 20 mn in T119 c3.5). However, when physical parameterizations set is introduced, instabilities can occur with long time steps, due to the presence of non-linear physical terms (*Girard and Delage*, 1990). In our configuration of ARPEGE, with high vertical resolution near the surface, such an instability appears in the vertical diffusion scheme. This instability results in so called "fibrillations" (strong high-frequency oscillations) for low-level fields (particularly in areas of high orography near the high resolution pole) as shown in Fig. 7*a*.

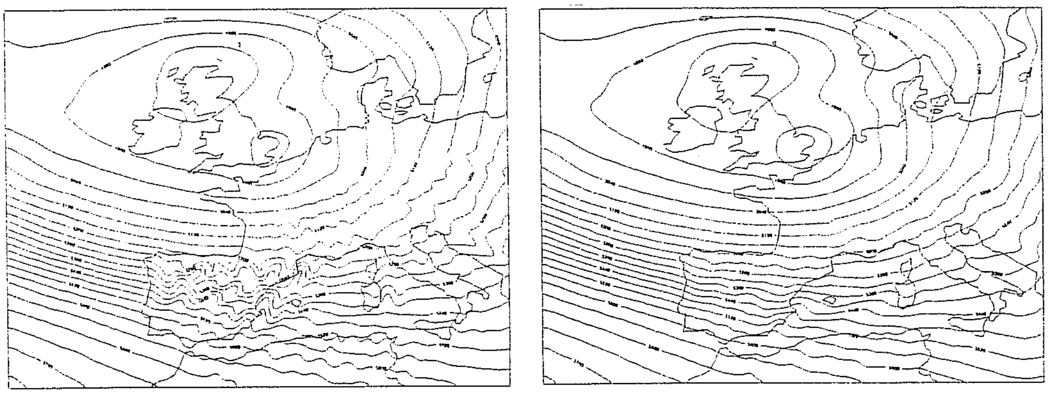

Fig. 6: 24 h SL (Dt=15 mn) forecast of Z500 from the analysis of 25 February 1989 00 UTC a: without "Eulerian" scheme; b: with "Eulerian" scheme for orography.

For an exchange coefficient type formulation of the vertical diffusion, the scheme can be written

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial z}\left(K(Ri)\frac{\partial X}{\partial z}\right) = F(K).X \tag{13}$$

where K is the exchange coefficient, X the diffused variable, and Ri the Richardson number. The implicit discretization of the latter scheme is formally equivalent to:

$$\frac{X^{+} - X}{\Delta t} = F(K).X + \beta \Delta t \frac{\partial}{\partial t}\left(F(K).X\right) \tag{14}$$

where β is the implicitness coefficient. With $\beta = 1$ the scheme is fully implicit since the RHS of (14) is then evaluated at $t + \Delta t$.

The numerical stability condition can be written:

$$\frac{\Delta t}{\Delta z^2} \leq f(Ri, \beta) \tag{15}$$

where f is a function which depends on the chosen expression for K. With realistic dependency of K with respect to Ri, the scheme is found to be conditionally unstable for stable temperature profiles. However, the presence of β in the dependency function of the criterion make it possible to locally and dynamically increase β in order to keep the flow in the stability domain. This is of course done at the expense of the accuracy, but it should be noted that this loss of accuracy only occurs when and where it is absolutely necessary, thus minimizing the impact of the correction. Some preliminary tests with values of β uniformly greater than one showed that the forecast quality is effectively degraded, particularly for the low-level winds (not shown). Since it was not desirable to make this "anti-fibrillation" scheme being activated too frequently, the stability domain was increased by choosing a slighlty (i.e. $\approx 10\%$) coarser vertical mesh in the lower part of the domain.

Fig. 7 shows the typical impact of these two features on the time evolution of $\omega_{\max}$ for the 72 h ARPEGE forecast starting from 1994/10/31, 00 UTC.

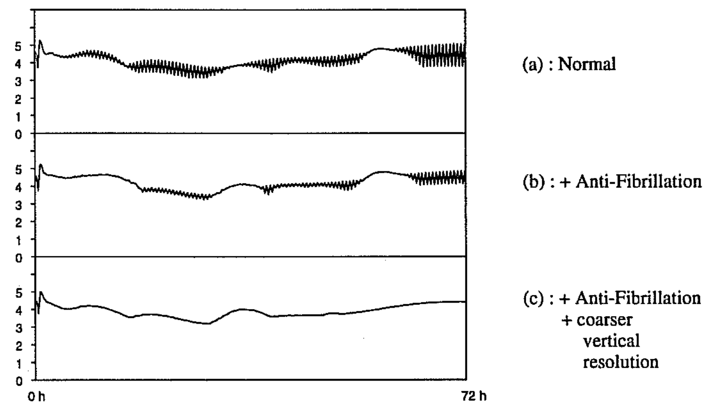

Fig. 7: Temporal evolution of $\omega_{\max}$ between 0 and 72 h from 1994/10/31, 00 UTC, for the SL T119 L24 c3.5 ARPEGE version, with $\Delta t = 9$ mn.

In addition, the time step of the model has finally been set to a shorter value than allowed in adiabatic case, in order to avoid stability problems. Safe values for the time step were found to be $\approx$ 10 mn in T119 L24 c3.5 and $\approx$ 8 mn in T149 L27 c3.5.

4. PRE-OPERATIONAL PROBLEMS

4.1 Horizontal diffusion and spectra

Another point specific to the stretched geometry is the problem of horizontal diffusion and spectrum control. Spectra diagnoses are traditionally used to evaluate the impact of horizontal diffusion schemes. But this cannot be done in a straightforward manner in the case of a variable resolution, because spectra obtained in the stretched geometry are physically meaningless since different scales are mixed through the geometrical transformation. The actual impact of the diffusion scheme in our case can only be evaluated via "geographical" spectra (i.e. in the not-stretched geometry), and in domains sufficiently small to ensure a weak variation of the resolution over their whole area. An accurate comparison with the exact Laplacian based operator of ALADIN limited area model is then possible.

Fig. 8 shows such spectra presented together with those obtained with ALADIN forecasts in a domain 3400 $\times$ 3400 km wide, centered on the high resolution pole of ARPEGE (ALADIN uses the same equations as ARPEGE, but in Lambert projection, resulting in a quasi-constant mesh over this domain). The corresponding ARPEGE spectra in this geometry are obtained via interpolation followed by a Fourier decomposition in each horizontal direction. The double Fourier decomposition is limited to an elliptic truncation and spectra are computed with respect to total horizontal wave numbers. The wave number 1

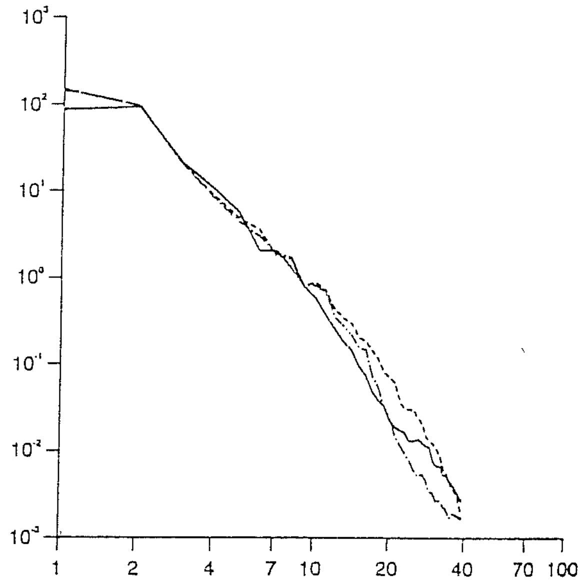

Fig. 8: ARPEGE and ALADIN kinetic energy spectra from 1995/01/06, 00 UTC after 36 hours. (solid: Aladin; dashed: original diffusion scheme; dot-dashed: unified diffusion scheme)

thus represents wave lengths of 3400 km, and the smallest ARPEGE wave is represented by the wave number 39. The spectra are obtained from a 36 hour forecast starting on 06 January 1995 00 UTC. The diffusion scheme in ALADIN uses a fifth-order operator, and reasonably reproduces the natural slope of the energy spectrum in the forecast flow. For ARPEGE, the original diffusion scheme and the unified scheme with a fifth-order pseudo-geographical diffusion are shown on a model level close to 500 hPa.

For the ARPEGE experiment with the original diffusion scheme (dashed curve) the amount of energy is larger than in the reference ALADIN spectra, because of insufficient damping in this area. In the experiment with numerical and geographical components of the unified scheme (dashed-dotted curves), the energy is clearly reduced for wave numbers above 10.

The unified diffusion scheme thus allows a better control of the energetic spectra in the case of stretched geometry. But in counterpart, the tuning of horizontal diffusion operators is more difficult, not to say critical: There are now two independent operators, the effect of which can only be checked on constant-resolution areas. This point can be considered as a handicap for the variable resolution approach, since the tuning of horizontal diffusion has to be done for each resolution or stretching change.

4.2 Semi-Lagrangian scores

The operational implementation of the semi-Lagrangian scheme required some score evaluation. This has been done in a test assimilation suite in parallel to the Eulerian operational one. Each version is compared to its verifying analyses to compute scores. Not surprisingly, the SL T149 L27 version exhibits better scores than Eul T119 L24 one on low resolution areas (South of 20S and tropics) due to the resolution increase. However, on the high resolution area (Europe domain), the impact of SL is more mixed: Fig. 9 shows the score differences between the two suites with respect to the forecast range and vertical level. The shaded areas represent better scores for Eulerian version. It can be seen that wind scores are degraded while temperature scores are quite neutral, and geopotential scores are better for SL version. However, it has been shown that the score degradation for the wind is due to the increase of resolution more than to a semi-Lagrangian or stretching problem *per se*: this problem was not observed for a SL T119 L24 suite, but was also observed in ALADIN. It is likely to come from frictional process representation. Nevertheless, this indicates that running ARPEGE or ALADIN at high resolutions allowed by the semi-Lagrangian scheme requires a complete retuning of physical processes; this will be done in next future.

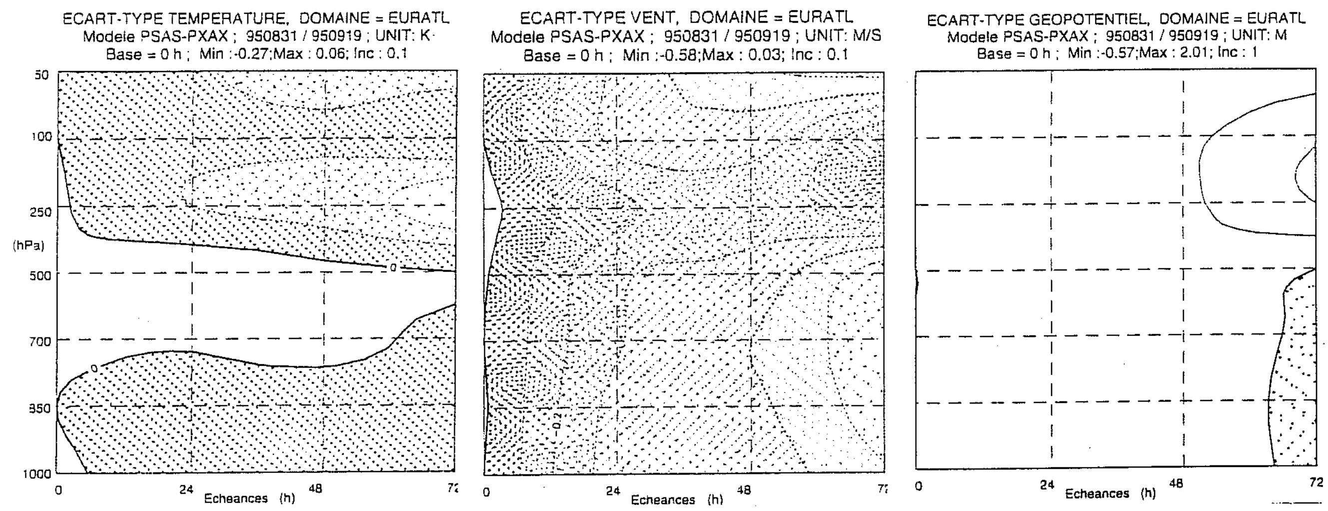

Fig. 9: Differences (Eul - SL) ARPEGE scores in "Europe Domain". (explanation in figures; dashed areas represent negative values) a: temperature, b: vent, c: geopotential.

5 . CONCLUSION

Some adaptations of numerical scheme formulations in ARPEGE to long time steps has allowed the semi-lagrangian version to become operational in October 1995 at METEO-FRANCE. These improvement concern the spectral semi-implicit and horizontal diffusion computations, the control of the orographic resonance and of the vertical diffusion fibrillations problems. The version implemented is a 3-time level fully interpolating scheme. The time step has been chosen according to vertical constraints rather than horizontal ones.

The perspectives of METEO-FRANCE are now to improve the efficiency of the scheme without degradation of scores: the possibilities of 2-time levels schemes are currently examined as well as the opportunity to reduce the grid density for a given spectral truncation (linear grid). The first item gave encouraging preliminary results for a double time step: the score degradation is however about 2.5 % due to the implicit treatment of Coriolis term.

The Eulerian treatment of orography allows a smaller decentering factor to address the orographic resonance problem: the question of the interest of using a second-order decentering thus remains open since this feature is memory consuming.

The comparison of SL T149 L27 and Eul T119 L24 scores has shown that a complete revision of physical package tuning has become necessary in ARPEGE, a task that will be carried out in 1996.

A global remark concerning the variable mesh technique is the difficulty to properly handle the numerical diffusion in order to control energetic spectra. The addition of a second operator made possible the spectrum control by increasing the number of degrees of freedom of the problem, the counterpart of which has been automatically the increased complexity of a satisfactory tuning. This could be seen as a motivation to examinate the possibility of performing at least a part of the horizontal diffusion through the grid-point interpolation process in the semi-lagrangian scheme. The use of interpolators with *ad hoc* properties could take in charge the part of diffusion which have a dependency in resolution, in order to avoid the treatment in spectral space.

Finally, the plans at METEO-FRANCE concern the implementation of the semi-lagrangian scheme in the non-hydrostatic version of ALADIN at the beginning of 1996.

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