Status about NH applications at M.-F.

P. Bénard, K. Yessad, Y. Seity, G. Hello, P. Brousseau,...et al.

Météo-France
CNRM/GMAP

5-6 December 2006 - Zagreb

Outline

- AROME status
- Arpege-NH and Aladin-NH status
- Toward more general spectral solver for implicit kernel

AROME status

MAIN TARGET :

AROME to become operational in 2008

still valid (... but 01/01 or 31/12 ?)

STATUS :

- Dynamical adaptation :

  quasi-routine in two moving small domains (1/4 FRANCE)

  240x240 pts, Dx=2.5km, Dt=60s, P24-30h

  moving to target domain Jan.07 (640x640 on new NEC SX8)

- Assimilation :

  prototype build with 3D-VAR RUC, 3h

  same data-types as Aladin (but higher resolution)

  forecast error statistics through ensemblist method

  quasi-routine in spring 2007 (on new NEC)

  assimilation of radar data in summer 2007 (?)

AROME status

the pressure is quite light (for time being)

- AROME does not come in replacement of something, but in addition.
- No score to be beaten absolutely
  well,... we would like AROME to beat ALADIN in some way !
  and would appreciate a score activated only when the coupling forecast is OK
  or compute scores for LAMs coupled with ANALYSES i.e. with a "perfect" coupling model.
- The AROME application is clearly considered as an early version of an evolutive and perfectible tool (domain, data, numerics, Phy/Dyn coupling, multi-phase equations...)
- However our "communication service" is sometimes a bit over-enthousiastic to our taste ! !
  (some good forecasts, but also some "brilliant" failures)

ARPEGE-ALADIN-NH status

status

- NH version of ARPEGE implemented in both uniform and stretched resolution (only for VFD, not VFE).
- test "neutrality" of NH switch at operational configurations (Δx, Δz, Δt) on test cases
- check analytical predictions through using variants around the optimal proposed scheme (NSITER, prog. var., etc.)

short-term

- design and implementation of a VFE scheme in the NH dynamical core (for/with M-F and ECMWF)
- LAM : inclusion of the map-factor variations in the (linear) implicit system for large LAM domains (for/with HIRLAM)
- LAM : finish the implementation of Rotated/Tilted/Mercator conformal projection (for/with HIRLAM).

Outline

- AROME status
- Arpege-NH and Aladin-NH status
- Toward more general spectral solver for the implicit kernel

Toward more general spectral solver for the implicit kernel

- VFE scheme more accurate
  Design of the VFE scheme for NH model (EE system) is not straightforward (several avenues examined)
  $\longrightarrow$ Implementation may require a more general spectral solver
- Investigating the effects of non-isothermal reference SI states $T^*(\eta)$ also needs a more general solver
  (although this functionality is not strictly needed currently)
- Introduction of map-factor variations $\mathbf{m}_*$ in the implicit system in case of global stretched, or large LAM domain
  This functionality might adversely combines with above more general solvers

Relaxing mathematical constraints in linear implicit problem

The horizontal eigenmodes are known (Fourier or spherical harmonics)
We solve the coupled implicit system for each horizontal eigenmode.

Several possible approaches :

- "no elimination" : huge amount of memory (and CPU) because one needs to store and solve the full linear problem for each harmonics. Advantageous for design, but costly.
- "total elimination" : less memory, less CPU, more efficient, but requires discrete properties for spatial operators to be fulfilled. Quite easy in VFD+unstretched, much less in VFE+stretched+etc.
- partial elimination : possible compromise for this dilemna

The linear implicit system

coupled system :

$$
\begin{aligned}
\underline{D'} - \delta t \nabla'^2 \left[RT^* \left(\mathbf{G}^* - 1 \right) \underline{\mathcal{P}} - R\mathbf{G}^* \underline{T} - RT^* \underline{q} \right] &= \underline{\widetilde{D}} \\
\underline{\mathrm{d}} - \delta t \left(-\frac{g}{rH_*} \mathbf{L}_v^* \underline{\mathcal{P}} \right) &= \underline{\widetilde{\mathrm{d}}} \\
\underline{\mathcal{P}} - \delta t \left[\left(\mathbf{S}^* - \frac{C_p}{C_v} \right) \mathbf{m}_*^2 \underline{D'} - \frac{C_p}{C_v} \underline{\mathrm{d}} \right] &= \underline{\widetilde{\mathcal{P}}} \\
\underline{T} - \delta t \left(-\frac{RT^*}{C_v} \mathbf{m}_*^2 \underline{D'} - \frac{RT^*}{C_v} \underline{\mathrm{d}} \right) &= \underline{\widetilde{T}} \\
\underline{q} - \delta t \left(-\mathbf{N}^* \mathbf{m}_*^2 \underline{D'} \right) &= \underline{\widetilde{q}}
\end{aligned}
$$

where : $\underline{D'}$, $\underline{\mathrm{d}}$, $\underline{\mathcal{P}}$, $\underline{T}$ and $\underline{q} = \ln(\pi_s)$ prognostic var. vector
$\mathbf{G}^*$, $\mathbf{S}^*$, $\mathbf{N}^*$ integral vertical discretized operators
$\mathbf{L}_v^*$: vertical discretized Laplacian operator
$\mathbf{m}_*^2$: linearized map-factor (uniform or non-uniform)
∇'^2 : horizontal Laplacian operator (in spectral geometry)

Classical : full elimination

$\mathbf{m}_*^2$ and ∇'^2 operators always commute with vertical operators

The classical way is to perform a full algebraic elimination of variables.

$$
\begin{array}{rcl}
\left[1-\delta t^2 c_*^2 \nabla'^2 (\mathbf{I}+\mathbf{A}_1^*)\mathbf{m}_*^2\right] \underline{D'} - \delta t^2 \nabla'^2 \left(-RT^*\mathbf{G}^* + c_*^2\right) \underline{\mathrm{d}} & = & \underline{D}^\bullet \\
-\delta t^2 \dfrac{\mathbf{L}_v^*}{rH_*^2} \left(-RT^*\mathbf{S}^* + c_*^2\right) \mathbf{m}_*^2 \underline{D'} + \left(1-\delta t^2 c_*^2 \dfrac{\mathbf{L}_v^*}{rH_*^2}\right) \underline{\mathrm{d}} & = & \underline{\mathrm{d}}^\bullet
\end{array}
$$

In EE system, this requires a mathematical property to be fulfilled.
(C1) : $\quad \mathbf{A}_1^* \equiv \mathbf{G}^*.\mathbf{S}^* - \mathbf{G}^* - \mathbf{S}^* + \mathbf{N}^* = 0$

Then, $(\mathbf{I}+\mathbf{A}_1^*)$ commutes with everything, and the elimination can be pursued to obtain a single equation valid for only one state-variable vector $\underline{\mathrm{d}}$.

Classical : full elimination

$$\Rightarrow \left[1 - \delta t^2 c_*^2 \left(\mathbf{m}_*^2 \Delta' + \frac{\mathbf{L}_v^*}{rH_*^2} \right) - \delta t^4 \frac{N_*^2 c_*^2}{r} \mathbf{T}^* \mathbf{m}_*^2 \Delta' \right] \underline{\mathrm{d}} = \underline{\mathrm{d}}^{\bullet\bullet}$$

$$\Leftrightarrow \left[1 - \delta t^2 \mathbf{m}_*^2 \mathbf{B}^* \Delta' \right] \underline{\mathrm{d}} = \underline{\mathrm{d}}^{\bullet\bullet}$$

Easy to solve by direct (inversion) method in space of vertical eigenmodes

Classical : full elimination

However : not always possible to make the constraint (C1) fulfilled :

- For VFE discretisation no solution found **so far**
- For non-isothermal linear reference states $T^*(\eta)$

Partial elimination

In case (C1) not fulfilled (i.e. $\mathbf{A}_1^* \neq 0$), we can stop just after the substitution of $(\underline{\mathcal{P}}, \underline{T}, \underline{q})$ in $\underline{D'}$, $\underline{\mathrm{d}}$ equations.
This does not require any mathematical constraint to be fulfilled.

$$
\begin{aligned}
\left[1 - \delta t^2 c_*^2 \nabla'^2 (\mathbf{I} + \mathbf{A}_1^*) \mathbf{m}_*^2\right] \underline{D'} - \delta t^2 \nabla'^2 \left(-RT^* \mathbf{G}^* + c_*^2\right) \underline{\mathrm{d}} &= \underline{D}^\bullet \\
-\delta t^2 \frac{\mathbf{L}_v^*}{rH_*^2} \left(-RT^* \mathbf{S}^* + c_*^2\right) \mathbf{m}_*^2 \underline{D'} + \left(1 - \delta t^2 c_*^2 \frac{\mathbf{L}_v^*}{rH_*^2}\right) \underline{\mathrm{d}} &= \underline{\mathrm{d}}^\bullet
\end{aligned}
$$

$$
\begin{aligned}
\left[1 - \delta t^2 \nabla'^2 (\mathbf{B}_1 + \mathbf{C}_1) \mathbf{m}_*^2\right] \underline{D'} - \delta t^2 \nabla'^2 \mathbf{B}_2 \underline{\mathrm{d}} &= \underline{D}^\bullet \\
-\delta t^2 \mathbf{B}_3 \mathbf{m}_*^2 \underline{D'} + \left(1 - \delta t^2 \mathbf{B}_4\right) \underline{\mathrm{d}} &= \underline{\mathrm{d}}^\bullet
\end{aligned}
$$

$$
\left[\mathbf{I} - \delta t^2 \mathbf{M}_{\mathrm{lap}} . \mathbf{B} . \mathbf{M}_{\mathrm{map}}\right] . \underline{Z} = \underline{Z}^\bullet \quad \text{where } \underline{Z} = (\underline{D'}, \underline{\mathrm{d}})
$$

Partial elimination

$$\left[\mathbf{I} - \delta t^2 \mathbf{M}_{\mathrm{lap}}.\mathbf{B}.\mathbf{M}_{\mathrm{map}}\right].\underline{Z} = \underline{Z}^{\bullet}$$

In original scheme, efficient solution in vertical normal-modes space :

$$\mathbf{B} = \left[\mathbf{Q}_{\mathbf{B}}^{-1}.\Delta_{\mathbf{B}}.\mathbf{Q}_{\mathbf{B}}\right]$$

This is no longer straightforward ($\mathbf{M}_{\mathrm{lap}}$, $\mathbf{M}_{\mathrm{map}}$ and $\mathbf{Q}_{\mathbf{B}}$ do not commute).

This is because

$$\mathbf{M}_{\mathrm{lap}} = \begin{pmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \nabla'^2 \end{pmatrix}$$

$$\mathbf{M}_{\mathrm{map}} = \begin{pmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{m}_*^2 \end{pmatrix}$$

are no longer scalar matrices for a given spectral component

Partial elimination

- Solve the complete system for each horizontal wavenumber (but very memory-demanding)

- Iterative solution in the space of vertical eigenmodes of the system obtained when (C1) fulfilled.
- This system then acts a preconditionner for the iterative algorithm.
- Convergence speed $\approx ||\mathbf{C}_1|| / (1 + ||\mathbf{B}||)$
- The spectral solver would cease to be a direct (non-iterative solver).

Conclusions

- Current dynamical kernel OK for current applications
- Extension to large domains/map-factors and VFE discretisation is wished and is in progress
- This require more general linear system to be solved
- Either try to maintain the feasability of the **direct** "$L \times L$" solution
- or implement a more general solver (an **iterative** one)