1: INTRODUCTION

- 1: Introduction
- 2: Discussion on numerical schemes
- 3: Reminders on Aladin, ARPEGE, IFS
- 4: Background and status of Aladin-NH
- 5: Adaptation to IFS ?
- 6: Conclusions

2: Discussion: CCSI vs. non-CCSI schemes

- SI schemes: linear partition of source terms
  → linear terms : implicit
  → non-linear terms: explicit

$$dX/dt = M(X) + L^{*}.(\overline{X}^{t} - X)$$

- Generally, the linear system L* is the T-L system of M around a given state X*

2: Discussion: CCSI vs. non-CCSI schemes

- Constant-coefficients SI (CCSI) schemes:

- The SI reference state X* is chosen:

  - stationary
  - horizontally homogeneous

→ L* is a constant-coefficient operator

2: Discussion: CCSI vs. non-CCSI schemes

- Non-Constant-coefficients SI (non-CCSI) schemes:

- The SI reference state X* is <u>NOT</u>:
  - stationary, and/or
  - horizontally homogeneous

- Typically: X*~X(t) , the current state

2: Discussion: CCSI vs. non-CCSI schemes

- Example : $dV/dt = R\,T\,\nabla q$, $q=\ln(p)$

CCSI: $T_{ref} = T^*$, $\nabla q_{ref} = 0$:

$$dV/dt = [R\,T'\,\nabla q]^0 + \overline{[R\,T^*\,\nabla q]}^t \ldots$$

non-CCSI: $T_{ref} = T^0$, $\nabla q_{ref} = 0$:

$$dV/dt = \overline{R\,T^0\,\nabla q}^t \ldots$$

2: Discussion: CCSI vs. non-CCSI schemes

- CCSI schemes result in simpler implicit problems, and cheaper solution (direct solvers)
- non-CCSI schemes allows smaller explicit residuals: more robust (but more expensive non-symmetric solvers)

2: Discussion: CCSI vs. non-CCSI schemes

- CCSI not robust enough for fine-scale EE
  (Ikawa 1988, Côté et al. 1993, Cullen 2000, Bénard et al. 2003, 2004)

- steep slopes (not represented in the linear system)
  $\Rightarrow$ large residuals
  $\Rightarrow$ instability

2: Discussion: CCSI vs. non-CCSI schemes

- Switching to non-CCSI schemes

  (Skamarock et al. 1997, UKMO, MC2, NCSU,…)

OR:

- Making CCSI schemes more implicit:

  $\rightarrow$ class of ICI schemes

  (GEM, Cullen 2000, Aladin-NH)

2: Discussion: CCSI vs. non-CCSI schemes

- ICI schemes: iterate the implicit problem using explicit terms as evaluated from the previous iterated implicit solution:

$$dX_{(k+1)} / dt = M(\overline{X}^{t}_{(k)}) + L^*(\overline{X}^{t}_{(k+1)} - X_{(k)})$$

- After convergence → trapezoidal scheme:

$$dX/ dt = M(\overline{X}^{t})$$

- Acts like a pre-conditioned fixed point algorithm for the trapezoidal scheme

2: Discussion: CCSI vs. non-CCSI schemes

- ICI schemes are robust for fine scale EE
- Fast convergence, if problem "well designed"
- Best suited than non-CCSI for spectral models

2: Discussion: CCSI vs. non-CCSI schemes

- Consistent choices:

- Grid-point model with non-CCSI : OK

  UKMO, MC2 (Thomas et al. 1998), Skamarock et al. 1997

- Grid-point model with CC-ICI : why not ?

  GEM

- Spectral model with CC-ICI : OK

  Aladin-NH

2: Discussion: CCSI vs. non-CCSI schemes

- How these robust schemes do blow-up ?

If Δt too big,

- non-CCSI: the iterative Helmholtz solver does not converge, and the models fails to be SI
- ICI: the iterative fixed-point algorithm does not converge, and the models fails to be trapezoidal

- Then the model is ready for blowing-up

3: Reminders on Aladin, ARPEGE, IFS

- ARPEGE and IFS = global HPE models,
- Aladin = LAM HPE and EE model

- ARPEGE and IFS cores similar except:
  - ARPEGE stretched grid and vertical FD
  - IFS regular grid and vertical FE

- All of them: CCSI SL spectral models (T*)

3: Reminders on Aladin, ARPEGE, IFS

- AROME = project for operational mesoscale (Δx=2.5km) model in 2008.

- Aladin-NH EE dynamical core
- Improved mesoscale physics
- 4D-VAR analysis
- Mesoscale data assimilated …

- For dynamical purposes here, AROME≡Aladin

4: Background & status of Aladin - NH

- First version (1995): Eulerian SI with P_0, d_0

$$P_0 = (p - \pi) / \pi^*$$

$$d_0 = - \partial w / \partial z^*$$

Unstable with Eulerian $\Delta t \Rightarrow$ iterate cross-term (Bubnova et al. , 1995)

Unstable with SL $\Delta t \Rightarrow$ further studies needed

4: Background & status of Aladin - NH

- 2000: the structure of NL residuals strongly depends on the choice of prognostic variables

(Bénard 2003, Bénard et al. 2004a)

$$P = (p - \pi) / \pi$$

$$d_3 = - \partial w / \partial z$$

- Flat: SI stable with SL Δt
- Steep slope: SI unstable $\Rightarrow$ further studies

4: Background & status of Aladin - NH

- 2001: with slope, stability is very sensitive to NL residuals in elastic term D_3 (Bénard et al. 2005?)

$$d_4 = D_3 - D$$

- Moderate slopes: SI quite stable
- Steep slopes SI: quite unstable

- Steep slopes ICI with one iteration: stable

4: Background & status of Aladin - NH

- Problem of large instability of 2-TL EE schemes in presence of NL thermal residuals ($T^* \neq T$)
  (Semazzi et al. 1995, Quian et al, 1998)

- 2003: Source of problem identified and solved for mass-based coordinates (Bénard, 2004b).

- Needs two reference temperatures : T^*, T_e^*
- The linear system is no longer a TL system

4: Background & status of Aladin - NH

- Robustness is considered OK
- Accuracy: Consistency problem encountered in the SL version (artifacts in the stationary solution as in Klemp, Skamarock and Fuhrer 2003).

- Identified and solved by modifying the Bottom BC for SL version consistently with SL scheme

4: Background & status of Aladin - NH

- Status of Aladin-NH dynamical core:

  - Mass coordinate (Laprise, 1992)
  - Still shallow atmosphere approximation
    (see Wood and Staniforth 2003 for extension to deep atm.)
  - Set of new prognostic variables
  - Consistent Lower BC for SL scheme
  - Different T* and T_e*
  - Implemented: 3-TL SI, 2-TL SI, 2-TL ICI

4: Background & status of Aladin - NH

- Most probable target for operational use:

  - Prognostic variables: P, d4
  - T^* and T_e^* for 2-TL scheme
  - ICI (1 iteration) for steep slopes

- Confortable Δt:

  - For Δx=10km, 2-TL SI $\rightarrow \Delta t \approx 200$s
  - For Δx=2.5km, 2-TL ICI (1 iter) $\rightarrow \Delta t \approx 60$s

4: Background & status of Aladin - NH

- Real case simulation with physics

(Thanks to Yann Seity, Sylvie Malardel):

- "Gard 2002" fast flood in September 2002

- Full Meso-NH (research model) physics

(Redelsperger, Lafore, Bougeault,…)

- Aladin-NH Dynamics

(ICI scheme with 1 iteration)

4: Background & status of Aladin - NH

- Gard September 2002 flood case:

- Basis : oper anal Aladin 08 Sept 2002 - 12 Z
- Coupling Aladin every 3h
- 12 hours forecast
- Mesh 2.5 km, 180*180 points
- 41 levels

4: Background & status of Aladin - NH

- Costs:

MésoNH (Eulerian, Anelastic, Explicit)

- Δt = 4s , CPU = 24h 20

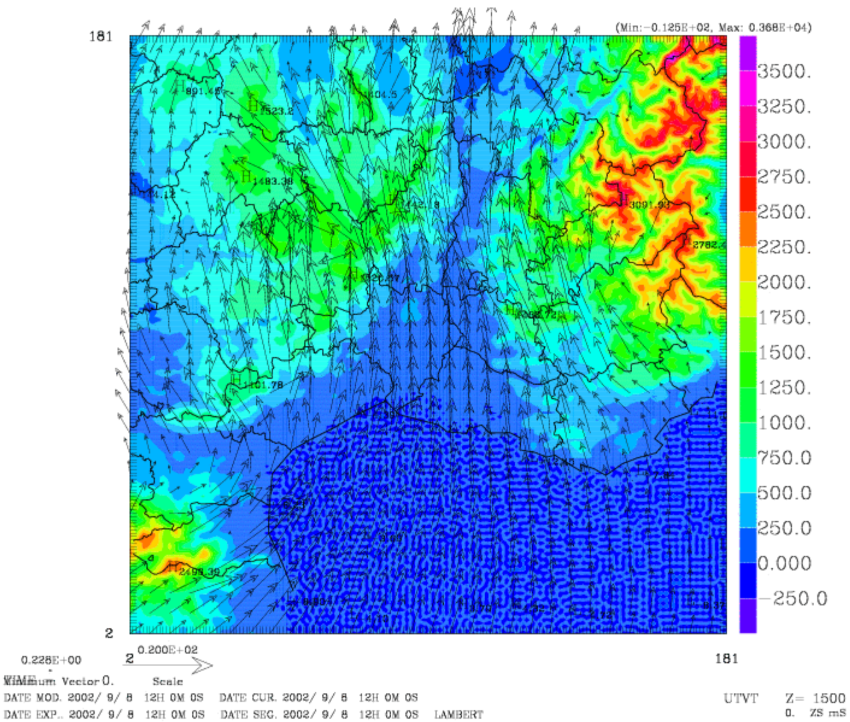
AROME (SL, EE, ICI with 1 iteration)

- Δt = 15s, CPU = 9h
- Δt = 45s, CPU = 3h 23
- Δt = 60s, CPU = 2h 30

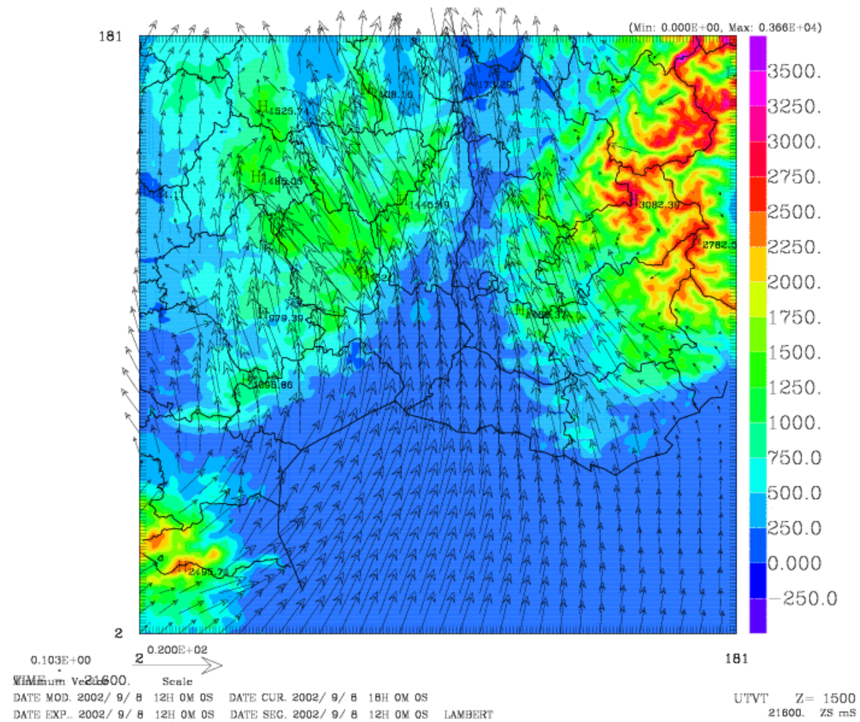
Real case (Gard fast-flood 2002)

1500m wind at 18 Z

AROME (60s)



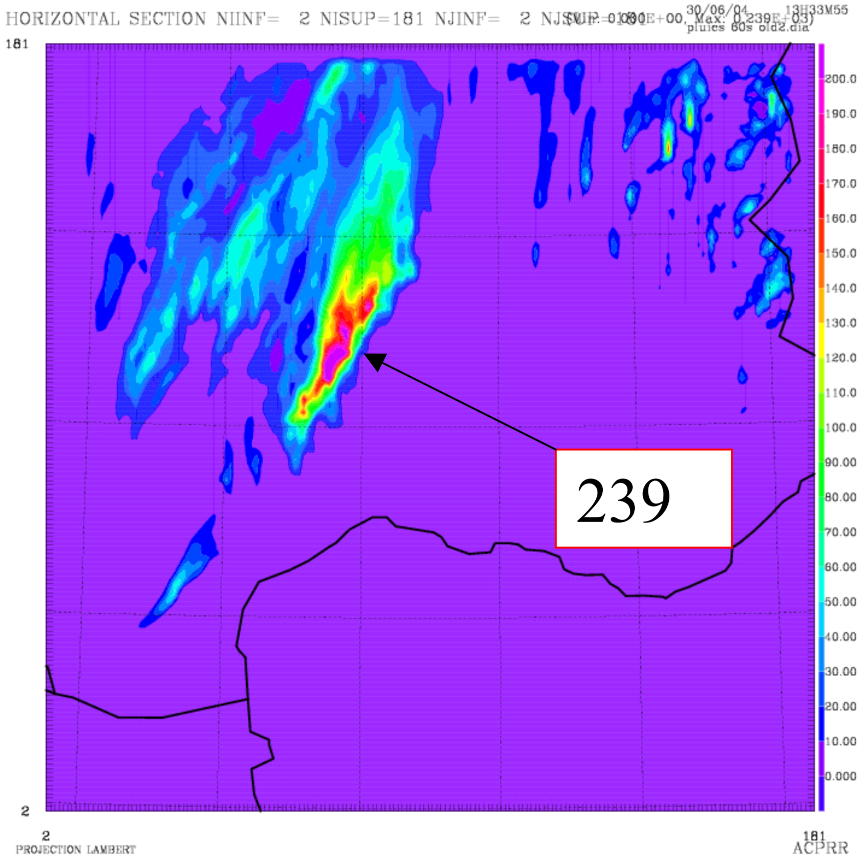
Meso-NH (4s)



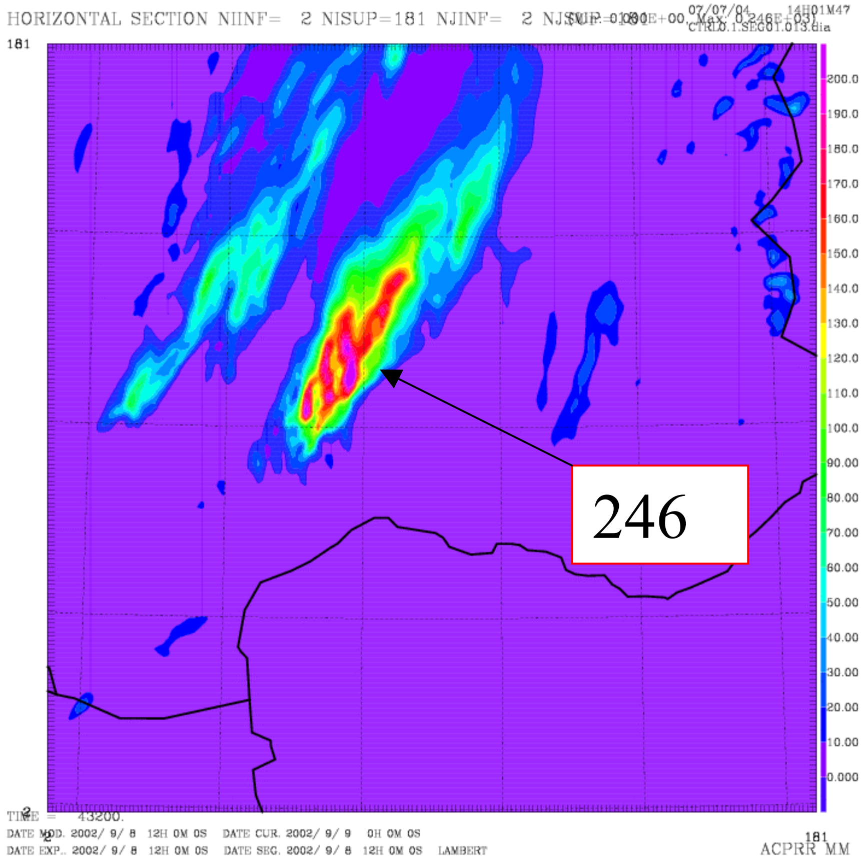
Real case (Gard fast-flood 2002)

Cumulated precipitations over 12h

AROME (60s, d4)



MESO-NH (4s)



4: Background & status of Aladin - NH

- With various tests such as the one presented previously, the dynamical core of Aladin-NH has been evaluated as suitable for the target use considering stability and accuracy aspects.

- Real 3D cases
- Semi-academic 2D cases (with physics)
- Academic cases (dry physics or adiabatic)

5: Adaptation to IFS ?

- In principle EE easier in IFS than in Aladin or AROME, due to poorer resolution

(smoother slopes, smoother fields,…)

→ no theoretical problem to be foreseen for applicability

5: Adaptation to IFS ?

- Scientific work needed:

Finite differences $\rightarrow$ Finite elements

- EE have vertical derivatives whilst HPE have only integrals
- detailed inspection of the numerics (pressure, SI elimination…)

- Technical work needed:

- Clean unretained research options
- Replace LAM specific routines by general ones
- Unified SI solver for LAM, global stretched, global

6: Conclusions

- After deep study, the quite unstable early version of Aladin was made robust enough for NWP purposes.
- The spectral CC SI (or ICI) seems still viable for this target purpose.
- The deep changes involved make the dynamics of Aladin-NH a new one (prognostic variables, linearization procedure, time scheme…).

6: Conclusions

- There seems to be no substantial advantage to either height- or mass-based coordinates for EEs

- The very relevant differences are more in the choice between:

  - Spectral $\Rightarrow$ CCSI or CCICI
  - Non-spectral (FD or FE) $\Rightarrow$ non-CCSI or non-CCICI

- Non-spectral + CCICI seems a less natural choice.

6: Perspectives

- Extensive testing to choose the time-scheme.
- Cooperation with HIRLAM for dynamical core of mesoscale NWP application.
  → Inclusion of rotated Mercator geometry (for large domains including poles)
- Possible cooperation with ECMWF for inclusion of global stretched geometry.
- Inclusion of deep atmosphere capability.