1: INTRODUCTION

• 1: Introduction
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2: Discussion: CCSI vs. non-CCSI schemes

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

\[
d\mathbf{X}/dt = \mathbf{M}(\mathbf{X}) + \mathbf{L}^*(\mathbf{X}^t - \mathbf{X})
\]

- Generally, the linear system \( \mathbf{L}^* \) is the T-L system of \( \mathbf{M} \) around a given state \( \mathbf{X}^* \)
2: Discussion: CCSI vs. non-CCSI schemes

- Constant-coefficients SI (CCSI) schemes:

- The SI reference state $X^*$ is chosen:
  - stationary
  - horizontally homogeneous

$\rightarrow L^*$ 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 NOT:
  - stationary, and/or
  - horizontally homogeneous

• Typically: $X^* \sim X(t)$, the current state
2: Discussion: CCSI vs. non-CCSI schemes

• Example: \( \frac{dV}{dt} = R \ T \ \nabla q \), \( q = \ln(p) \)

**CCSI:** \( T_{\text{ref}} = T^*, \ \nabla q_{\text{ref}} = 0 : \)
\[
\frac{dV}{dt} = [R \ T' \ \nabla q]^0 + [R \ T^* \ \nabla q] \ ...
\]

**non-CCSI:** \( T_{\text{ref}} = T^0, \ \nabla q_{\text{ref}} = 0 : \)
\[
\frac{dV}{dt} = R \ T^0 \ \nabla q^t \ ...
\]
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

• 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:
  → 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:

\[ \frac{dX_{(k+1)}}{dt} = M(\bar{X}^t_{(k)}) + L^*(\bar{X}^t_{(k+1)} - X_{(k)}) \]

- After convergence \( \Rightarrow \) trapezoidal scheme:

\[ \frac{dX}{dt} = M(\bar{X}^t) \]

- 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 $\Delta t$ 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 \((\Delta x=2.5\text{km})\) model in 2008.

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

• For dynamical purposes here, AROME\(\equiv\)Aladin
4: Background & status of Aladin - NH

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

$$P_0 = \frac{(p - \pi)}{\pi^*}$$

$$d_0 = -\frac{\partial w}{\partial z^*}$$

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)

\[ P = \frac{(p - \pi)}{\pi} \]
\[ d_3 = - \frac{\partial w}{\partial z} \]

• Flat: SI stable with SL \( \Delta t \)
• Steep slope: SI unstable \( \Rightarrow \) further studies
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

- Comfortable Δt:
  - For Δx=10km, 2-TL SI → Δt ≈ 200s
  - For Δx=2.5km, 2-TL ICI (1 iter) → Δt ≈ 60s
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
• Costs:

**MésoNH (Eulerian, Anelastic, Explicit)**
  – $\Delta t = 4s$, CPU = 24h 20

**AROME (SL, EE, ICI with 1 iteration)**
  – $\Delta t = 15s$, CPU = 9h
  – $\Delta t = 45s$, CPU = 3h 23
  – $\Delta t = 60s$, 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)

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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 → 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.