Keynotes on Dynamics aspects

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Current status of ALADIN/HIRLAM dynamics

- **Horizontal** :
  - Structured collocation Z-Grid Spectral (SP) bi-Fourier discretization.
  - Highly accurate derivative evaluation.
  - Trivial recovering of the horizontal wind components from horizontal divergence and vorticity.
- **Coupling** :
  - One-way time-dependent lateral bounday conditions.
  - variant of Relaxation scheme.
- **Vertical** :
  - Lorenz vertical grid with FD/FE discretization.
  - Time-dependent pressure-based hybrid terrain-following coordinate.

Current status of ALADIN/HIRLAM dynamics

- **Equations** :
  - Fully compressible (EE) and Hydrostatic (HPE) systems both coexist through a simple switch.
  - Prognostic equations of motion in vector-from.
- **Time discretization** :
  - Constant-coefficient Semi-implicit (SI) and Iterative Centred Implicit (ICI) schemes.
  - Reduction to a single 3D Helmholtz-type equation.
  - Spectral technique is used as a direct solver.
- **Transport scheme** :
  - non mass-conserving Semi-Lagrangian (SL) treatment of advection.

Motivation for changes

Despite its successful use for NWP applications, the efficiency of SI-SL-Spectral technique might be jeopardized if strong scalability property is demanded on future massively parallel HPC infrastructures :

1. SL : Increase amount of mpi-communications for large advective CFL.
2. SI : Direct solvers (Spectral or not) for 3D Elliptic problem do not scale well. It is a non-local problem whose radius of action (range) is as large as the maximun wave CFL.
3. SP : leads to unavoidable global communications in order to perform (X-Y) transpositions.

The natural strategy is to promote more "local" methods, which imply compact stencil space discretization and nearest neighbour communications.

Horizontal grid structure

The actual collocation grid structure of the existing code should be maintained, but Z-grid should be discarded in favor of A-grid.

Essential or desirable mimetic properties of the local discretization :

- Computational modes should be absent or well controlled,
- Mass conservation,
- Pressure gradient forces should produce no unphysical source of vorticity,
- Terms involving the pressure and Coriolis should be energy conserving.

Corollary : An efficient Filter must be designed to control spurious computational modes, which in turn advocates for high-order local space discretization.

Horizontal discretization

- Structured A-grid mesh: corresponds to the “minimal change” option. Use of ”high-order” FD or FE discretization in replacement of spectrally computed derivatives.
  Finite Volume (FV) discretization is better-suited for conservation property than FD/FE, but this represents a bigger change in the model.

- The degree of similarity between Global and LAM codes should be kept maximal.
- There is currently no reason to consider two-way nesting in NWP.
- Could we benefit from a flexible and parallel data structure framework from Atlas project of ECMWF for Global NWP ?

Vertical : Potential issues

This is our less explored topic :

- Lorenz vs Charney-Philips grid ?
- Stability and accuracy over steep-slopes ?

For the time being we still manage to run the model at 100 m horizontal resolution, but in the future we believe that the problem should be tackled.

Equations

The fully compressible system EE as a dynamical core at sub-kilometric resolution.

- Local higher-order FD/FE discretizations seem to perform better (in term of conservation properties) on equations of horizontal motion cast in vector-invariant form (instead of the current vector-form).
- FV approach would require to recast the EE in flux-form. Of common use with terrain-following z-based vertical coordinate. But, Is it compatible with time-dependent pressure-based coordinate ?

Strong interest and effort in designing thermodynamically consistent set of EE equations at MF.

Time discretisation :

1. Maintaining SI time-scheme technique together with local space discretized method to guarantee the use of comfortable time-steps.
   - Use of preconditioned iterative Krylov solver approach (i.e, GCR, GMRES, BiCGSTAB) to invert the 3D linear system. Multi-grid or Direct spectral constant-coefficient (or subtle combinaison of both) could be used as preconditioner.

   Ability to relax somewhat the constant-coefficient constraint of the SI linear sytem for better robustness of the scheme.

2. If such a 3D solver fails to be scalable, a fallback solution could be to apply "Horizontally Explicit Vertically Implicit" (HEVI) time schemes. $\Rightarrow$ Time-critical approach.

Transport scheme

- SL treatment can still be kept provided that the size of the Halo is controled by using moderate advective CFL numbers. However, an inherently mass-conserving SL approach should be considered.

- Is Eulerian approach still viable for NWP applications ?

Summary

- At GMAP, we are currently working on :
  - Exploring high-order local discretizations while keeping the current grid-structure
  - Exploring alternative approaches : HEVI time-schemes.
- Through ESCAPE and HEAT projects :
  - visibility on IFS FVM (PantaRhei) scheme,
  - Visibility on DYNAMICO (FD/FE) *conserving*-scheme.
- Topics for wider collaborating exploration :
  - 3D Elliptic solvers in pressure-coordinate.
  - re-design data flow to enable plugging in alternate dynamical cores.