Towards a Portable Model for All-scale Predictions

Accord All Staff Meeting

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A dynamical core for very-high resolution NWP applications

Objectives

- Improving stability over steep orography
- Maintaining scalability over massively parallel HPC-clusters

Current status of AROME perfomances

AROME and FVM dynamical cores - Summary

	AROME	FVM
Vertical coordinate	Mass-based	Height-based
Discretization	Spectral Transform (ST)	Finite Volumes (FV)
Linearization	Constant Coefficients	Non-constant Coef. (NC)
Implicit solver	Direct	Krylov Methods
Advection	Semi-Lagrangian (SL)	Eulerian (MPDATA)

PMAP - FVM dynamical core

Finite Volume Module (FVM)

- Eulerian non-oscillatory flux-form advection : MPDATA
- 2 time levels semi-implicit integration

  (implicit treatment of acoustic, buoyant modes and metric terms for orography)
- Height-based terrain-following coordinate

MPDATA - *Multi Dimensional Positive Definite Advection Transport Algorithm*

- Conservative transport scheme
- Conditional stability with $CFL < 0.5$ (implies small time steps)

Vertical coordinate

Mass-based

- \+ Hydrostatic part of the flow given by the coordinate
- \+ Reduced need for a top absorbing layer ($z \to \infty$)
- − Time dependency of metric terms ($\pi_s = \pi_s(x, y, t)$)
- − Integral vertical operators

Height-based

- \+ Metric terms (orography) independant for the time
- − Top absorbing layer required
- − Dependency to a prescribed hydrostatic ambient state

Solver : improving stability over steep orography

Inclusion of metric terms for orography in the implicit solver

AROME - Constant Coefficients

− Instabilities on steep slopes ($> 60°$)

- Direct Spectral solver
  + Exact solution in a single iteration
  − Non-constant coefficient computationnally intractable
- Iterative solver
  + Fixed number of iterations for the implicit solver
  + Near-constant weak scalability while increasing the resolution

FVM - Non-constant Coefficients - Iterative solver

+ Stable on steep slopes (up to 85°)

− Convergence rate depends on the prescribed ambient state

Zängl experiment with FVM

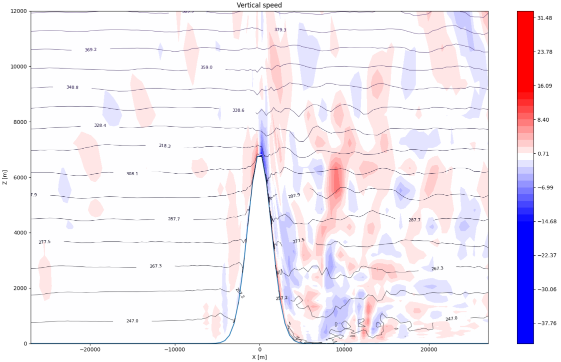

Figure 1: Zängl experiment with FVM : prescription of an uniform horizontal wind speed $u = 20\ m.s^{-1}$ and isothermal conditions on a gaussian shape. The maximum slope is 75°. Results after 6 hours with a time step $\delta t_{run} = 0.10\ s$.

Solver : improving numerical efficiency

Direct spectral solver

- **+** Exact solver (no iterations)
- **−** Global communications for Spectral Transform

Iterative Krylov solver

- **+** Near constant weak scalability
- **−** Convergence rate

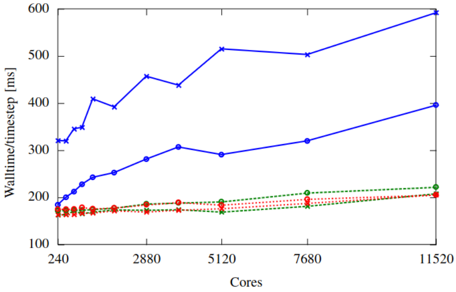

Figure 2: Weak scalability experiments on : spectral solver (solid blue), GCR(k) (dashed green), Richardson (short-dashed red)

Degrauwe D, Voitus F, Termonia Piet. A non-spectral Helmholtz solver for numerical weather prediction models with a mass-based vertical coordinate. QJR Meteorol. Soc. 2020; 1-15.

Transport scheme : Semi-Lagrangian vs. Eulerian MPDATA

MPDATA

- + Conservative scheme
- + Non-oscillatory
- − Conditionnally stable ($CFL < 0.5$)

Pointwise Semi-Lagrangian scheme

- + Unconditionnally stable
- + Performs well with CFL between 4 and 10
- − Non conservative under strong deformations

Transport scheme : Semi-Lagrangian vs. Eulerian MPDATA

Semi-Lagrangian Advection

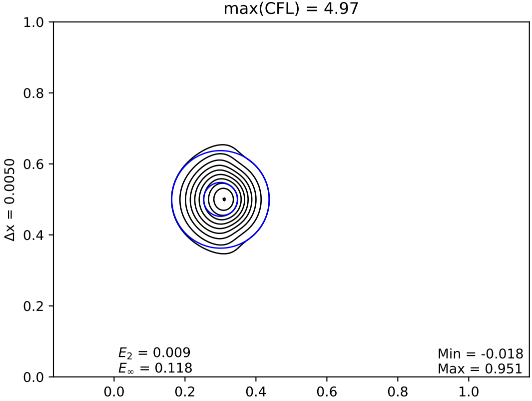

Figure 3: Durran and Blossey advection test with Semi-Lagrangian

Uniform flow over a steep orography on a vertical plane

Maximum slope	CFL_{max}	$Lipschitz$	Δt	Δz_{min}
15°	0.5		3	10
45°				10
75°				10

Lipschitz' condition for Semi-Lagrangian convergence

$L = max(\delta t|\frac{\partial u}{\partial x}|, \delta t|\frac{\partial v}{\partial y}|, \delta t|\frac{\partial w}{\partial z}|)$

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Physical processes for PMAP-FVM

Coupling ICE3 Microphysics scheme to FVM

- Translation of ICE3 to GT4Py
- Coupling of ICE3 and FVM with respect to small time steps options (Méso-NH)

Building on GT4Py + DaCe

GT4Py : GridTools for Python

- Domain System Language (DSL) for HPC code generation
- Portable accross CPU and GPU architectures
- Python code : readability and Object Oriented Programming

DaCe : Data Centric Parallel Programming

- Optimizing memory allocation for stencils
- DaCeML : Merging AI and Physics based models
  - Model inference using ONNX and integration with Pytorch
  - Automatic differenciation engine

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Building a demonstrator with PMAP

Development of a realistic model for Limited Area and LES

Physics packages on GT4Py

- Integration of GT4Py physics package to PMAP
  - ICE3 - Microphysics + Adjustments
  - ecRad (translated by ETHZ)
  - Turbulence scheme from COSMO
- Translation of packages
  - SURFEX
  - Shallow Convection