DYNAMICO
Dynamical core on Icosahedral grid

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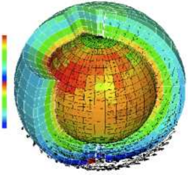
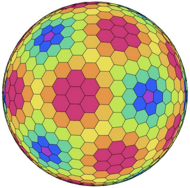




DYNAMICO fact sheet

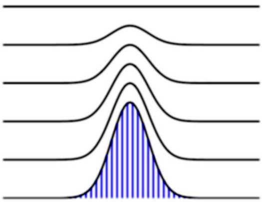
- hydrostatic, shallow-atmosphere
- icosahedral, hexagonal, C-grid, structured
- pressure-based hybrid terrain-following η coordinate
- Lorentz vertical staggering
- mass- and enstrophy-conserving FD (Sadourny, 1975 ; Ringler et al., 2010)
- explicit 4-th order dissipation
- Eulerian positive definite, slope-limited transport (Dubey et al., submitted)

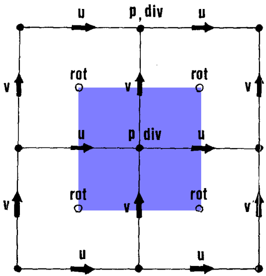
Planned 2012-2013

- quasi-hydrostatic, deep-atmosphere (M. Tort, PhD)
- energy conserving option
- coupling with LMD-Z physics package
- aquaplanet experiments

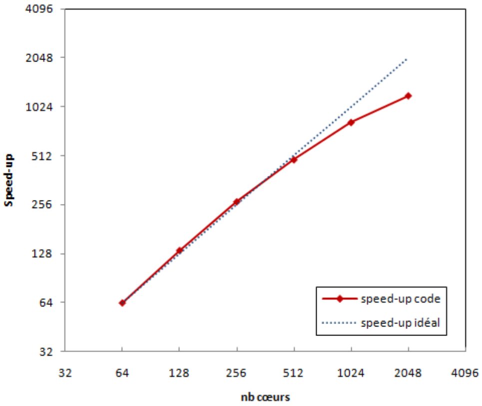
The LMD-Z core

- hydrostatic, shallow-atmosphere
- lat-lon, C-grid + polar filters
- grid-stretching
- pressure-based hybrid terrain-following η coordinate
- Lorentz vertical staggering
- mass- and enstrophy-conserving (Sadourny, 1975)
- explicit 4-th order dissipation
- Eulerian positive definite, slope-limited transport (Hourdin & Armengaud, 1999)
- used to model planetary atmospheres (Mars, Venus, Titan, ...)





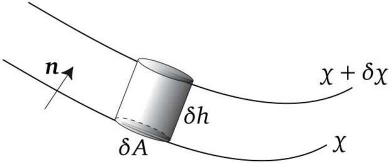
Scalability



Y. Meurdesoif (2010, 1/4 degree)

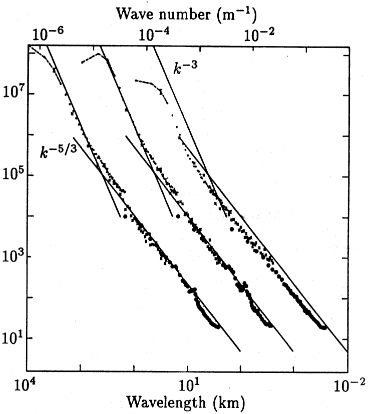
Potential vorticity and (potential) enstrophy

- Conservation of potential vorticity implies limits on the generation of vorticity

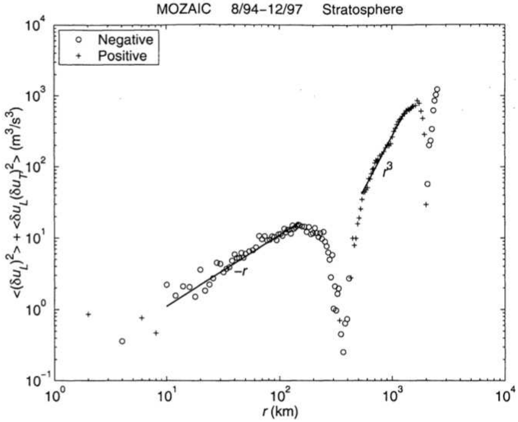


- At the discrete level, 3 levels of "vorticity conservation"
  1. Pressure gradient generates no vorticity
  2. Potential vorticity obeys an implied transport equation
  3. Potential enstrophy is conserved
- Conservation of energy and enstrophy tend to conflict with each other (Arakawa, 1966 ; Sadourny, 1975; Arakawa & Lamb, 1982 ; Ringler et al., 2010)

Enstrophy vs energy



Nastrom & Gage, 1985



Cho & Lindborg, 2001

The DYNAMICO project

Goals & principles

- Revive an interest in numerical methods at LMD/IPSL
- Break the scalability bottleneck by moving LMD-Z to a quasi-uniform-grid
- Hydrostatic core an important milestone suitable for short-term application to climate modelling
- Provide at least the properties already present in LMD-Z
- Extend LMD-Z to deep atmospheres
- Prefer simplicity & not reinvent the wheel !

Brief history

- 2009 : started as Indian-French project
- 2010 : work on 2D transport scheme (S. Dubey)
- 2011 : shallow-water model (Ringler et al. , 2010)
- mid-2012 : dry 3D core (Y. Meurdesoif)

Old parts and new parts

$$\frac{\partial m}{\partial t} + \frac{\partial W}{\partial \eta} + \nabla_\eta \cdot \left(\overline{m}^h u\right) \quad m = -\frac{1}{g}\frac{\partial p}{\partial \eta}$$

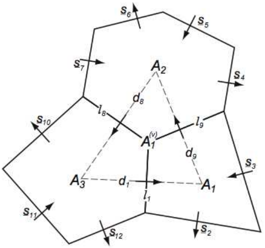
$$\frac{\partial mq}{\partial t} + \frac{\partial}{\partial \eta}\left(W\overline{q}^v\right) + \nabla_\eta \cdot \left(U\overline{q}^h\right) = S_q$$

$$\frac{\partial \Phi}{\partial \eta} + g\frac{m}{\overline{\rho}^v} = 0$$

$$\frac{\partial u}{\partial t} + \frac{\overline{\frac{\partial u}{\partial \eta}}^v \overline{W}^{vh}}{\overline{m}^h} + \overline{(f + \nabla_\eta \times u) \times u}^{TRiSK}$$

$$+\nabla_\eta \left(\overline{\frac{u^2}{2}}^h + e + \frac{p}{\rho} - \theta\pi + \Phi\right)$$

$$+\overline{\theta}^h \nabla_\eta \pi = S_u$$



Thuburn et al., 2009

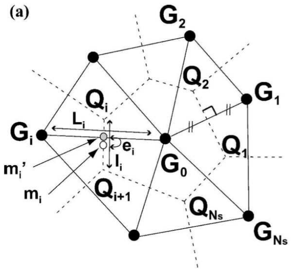
Miura (2007) ;

Dubey et al., submitted

Ringler et al., 2010 ; Dubos, PDEs on the Sphere 2012

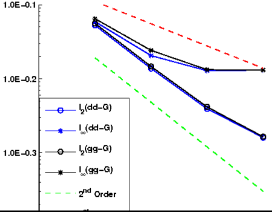
Gradient reconstruction for slope-limited finite-volume transport

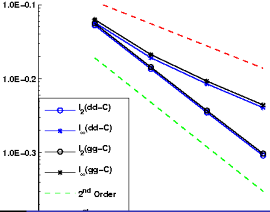
Miura & Kimoto, 2005



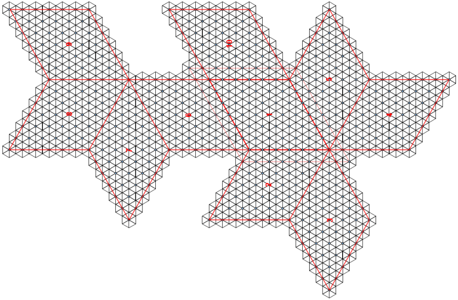
- Problem : first-order estimate of gradient given values around a given cell
- Explicit solution : Green-Gauss theorem
- Requires second-order accuracy estimate of point values

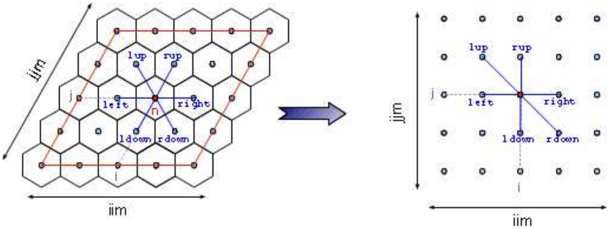
⇒ must use centroids of control volumes



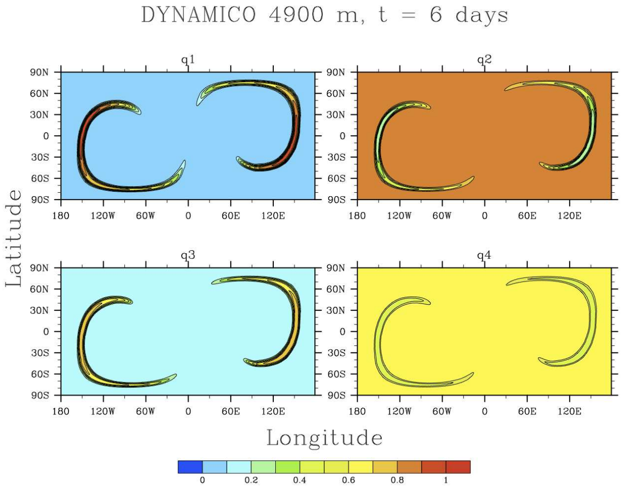


The icosahedral grid is structured

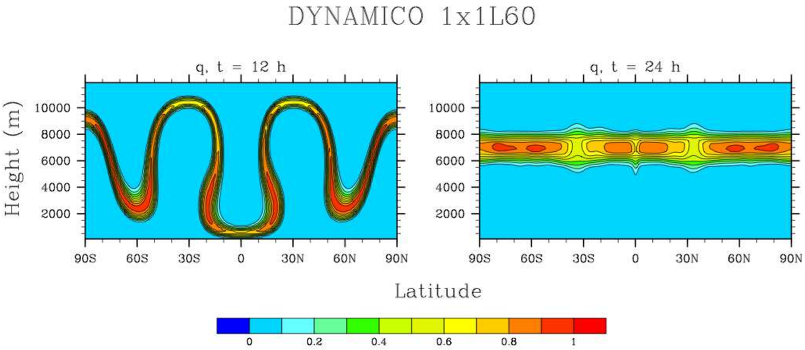




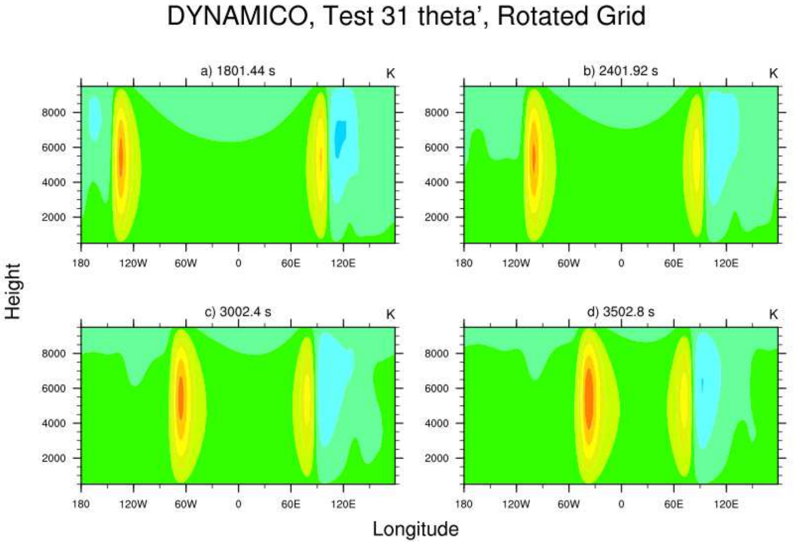
3D transport



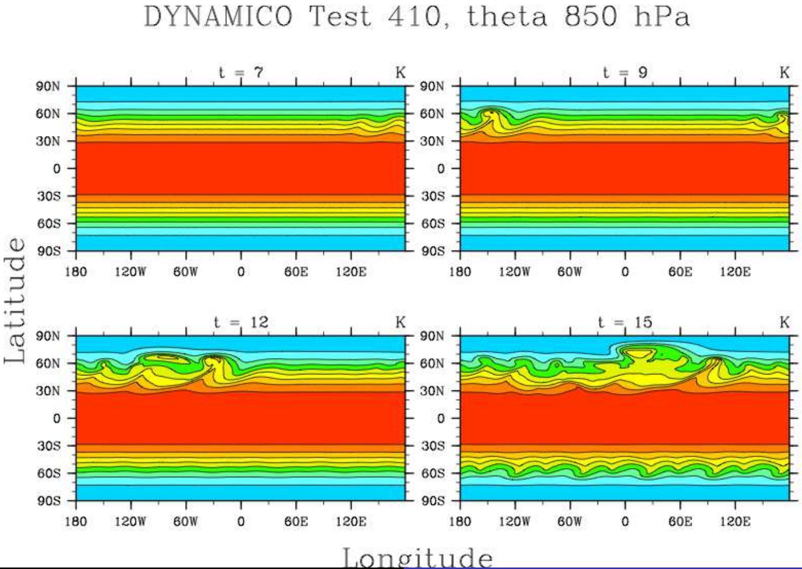
3D transport



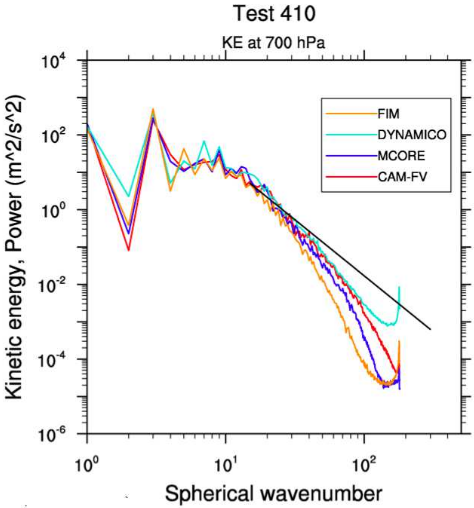
Gravity wave



Baroclinic wave (Jablonowski & Williamson)



Baroclinic wave (Jablonowski & Williamson)



(C. Jablonowski, PDEs on the Sphere 2012)

Ongoing work

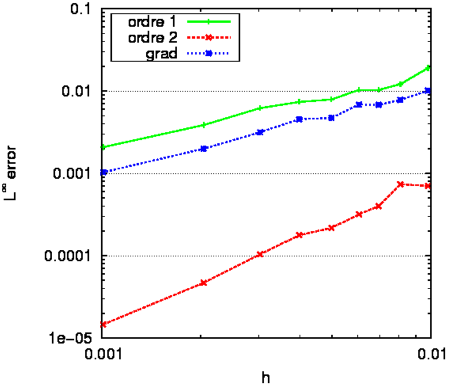
Planned features

- Parallel I/O (XIOS, Y. Meurdesoif)
- On-the-fly parallel post-processing (with J. Thuburn, U. Exeter) starting with conservative regridding (E. Kritsikis)
- Deep-atmosphere dynamics (M. Tort)
- Grid stretching

Potentially desirable features

- Non-orthogonal C-grid
- Conservative grid nesting (N. Kevlahan, M. Aechtner U. McMaster)
- Other aproaches :
  - well-balanced finite volumes (F. Bouchut)
  - geometric schemes (F. Gay-Balmaz)
  - mixed finite elements (S. Christiansen, U. Oslo)

Second-order conservative regridding



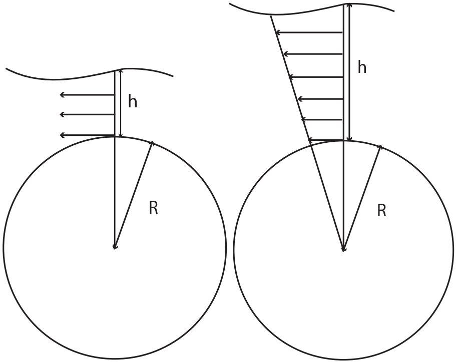
Deep-atmosphere dynamics

Deep quasi-hydrostatic equations in a general vertical coordinate

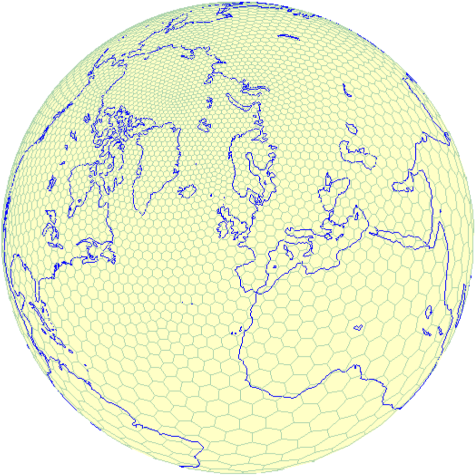
- have time-dependent metric terms
- and a full Coriolis force

PV/Energy Conserving formulation

Incorporate metric and entrainment velocity into prognostic variable for velocity
$\Rightarrow$ vector-invariant form



Grid stretching (Schmidt transform)



Summary

- DYNAMICO is now a (prototype) icosahedral-hexagonal hydrostatic core
- Low-order approach based on
  - variational principles ⇒ discrete conservation,
  - simplicity
  - reuse of suitable existing parts from IPSL or elsewhere
- Much validation / optimization still needed
- Goal is to put it to effective use as soon as possible on Earth and planets
- We expect to also improve the legacy lat-lon LMD-Z which will not disappear any time soon