DYNAMICO

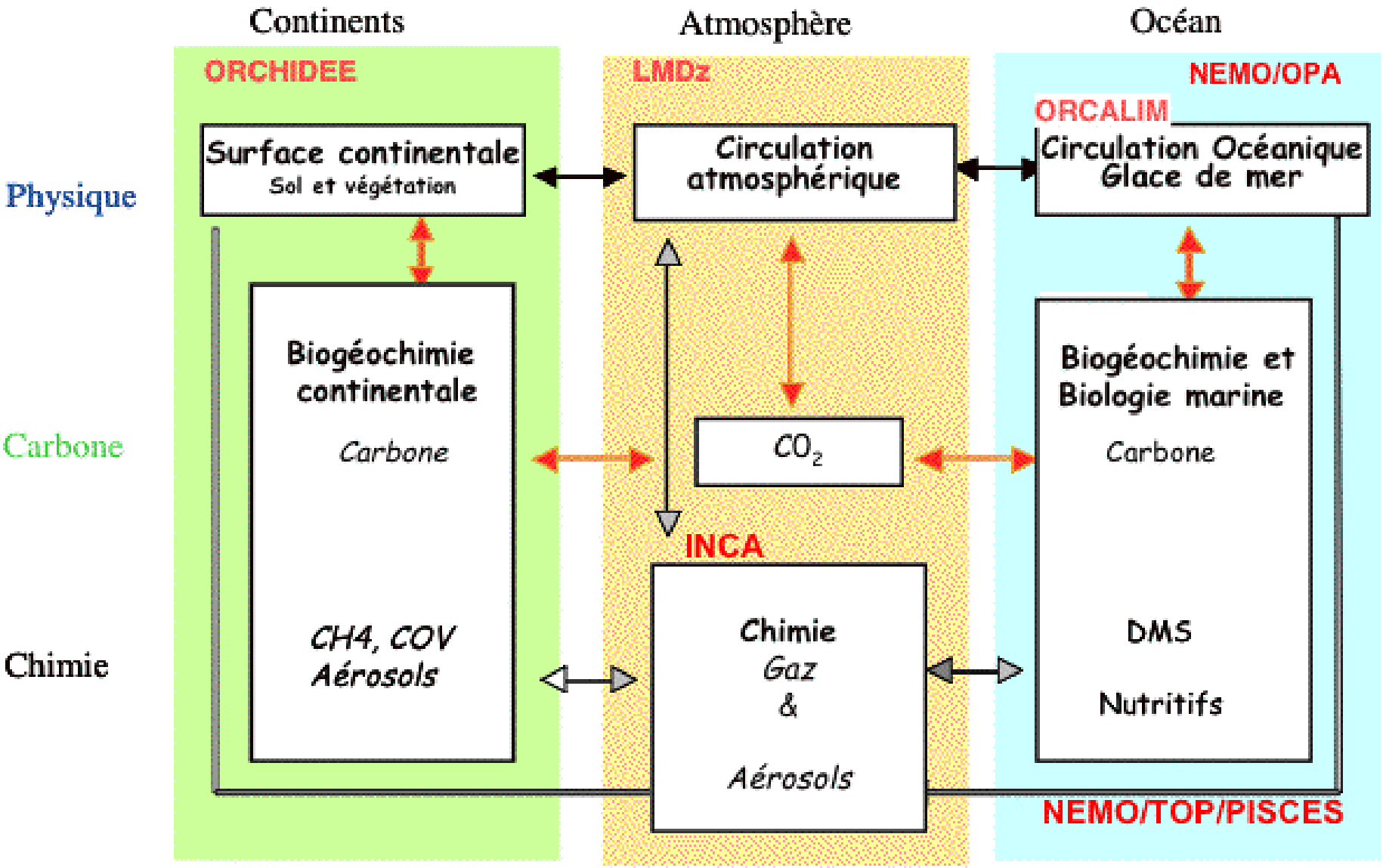
DYNamical core on ICOsahedral grid

Thomas Dubos,
LMD/IPSL, École Polytechnique
et al.

- DYNAMICO started in 2009 as a working group
- Now involves 10-15 persons but only few full-time
- Mixes work towards
  - Development of a *hydrostatic* dynamical core to be included in LMD-Z and IPSL-CM
  - Development of original numerical methods which may (or not) end up in a dynamical core
- Icosahedral grid adopted for both scientific and sentimental reasons
- Funded through IPSL, French-Indian IFCPAR and G8 (ICOMEX)

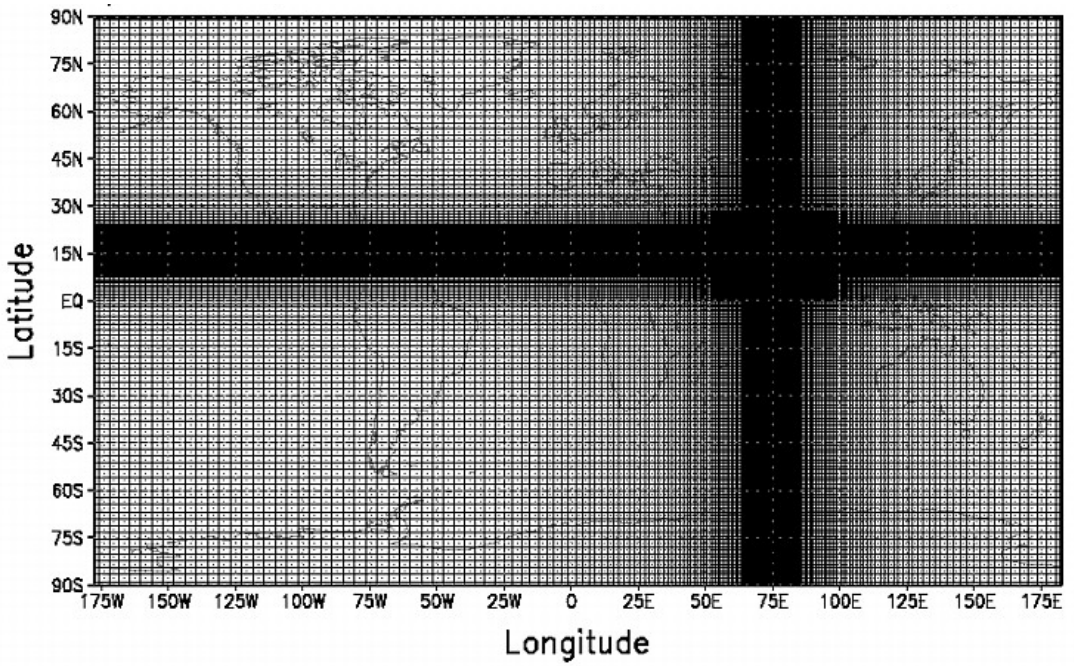
- Environment (IPSL-CM) and history (LMD-Z)
- Status and ongoing work

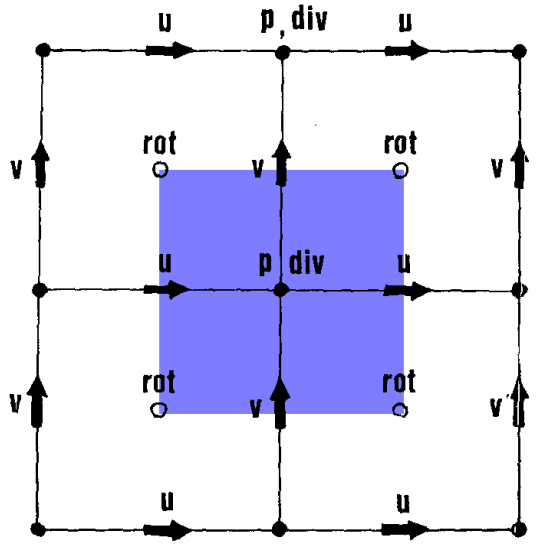
IPSL Earth System Model



LMD-Z AGCM

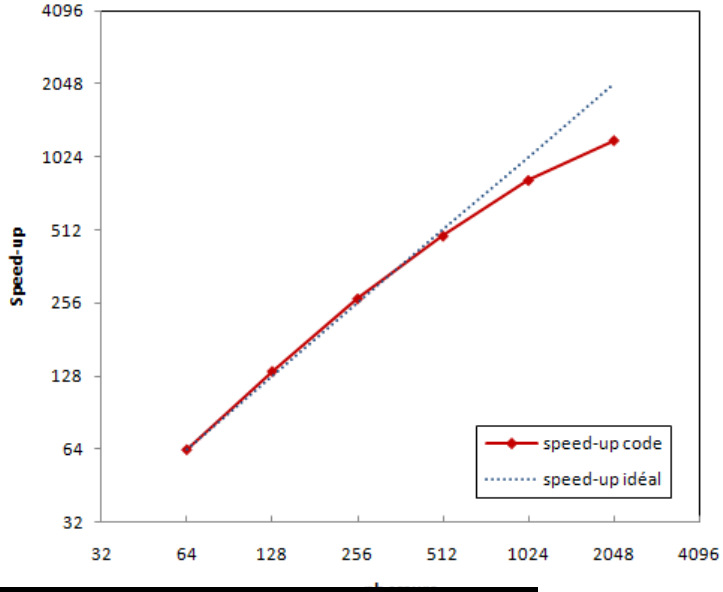
- Grid : lat-lon + terrain-following pressure-based coordinate
- Hydrostatic dynamics : C-grid, potential-vorticity conserving finite-differences + polar filters (Sadourny, 1975)
- Transport : van Leer slope-limited positive definite finite volumes (Hourdin & Armengaud, 1999)
- Physics package : Mellor & Yamada, Hourdin et al, 2002, Rio et al, 2008 et Pergaud et al 2009 …
- Stretched grid capability for regional climate (Zoom)
- « Universal » model : used for planetary atmospheres with adapted physics package (Mars, Venus, Titan, ...)

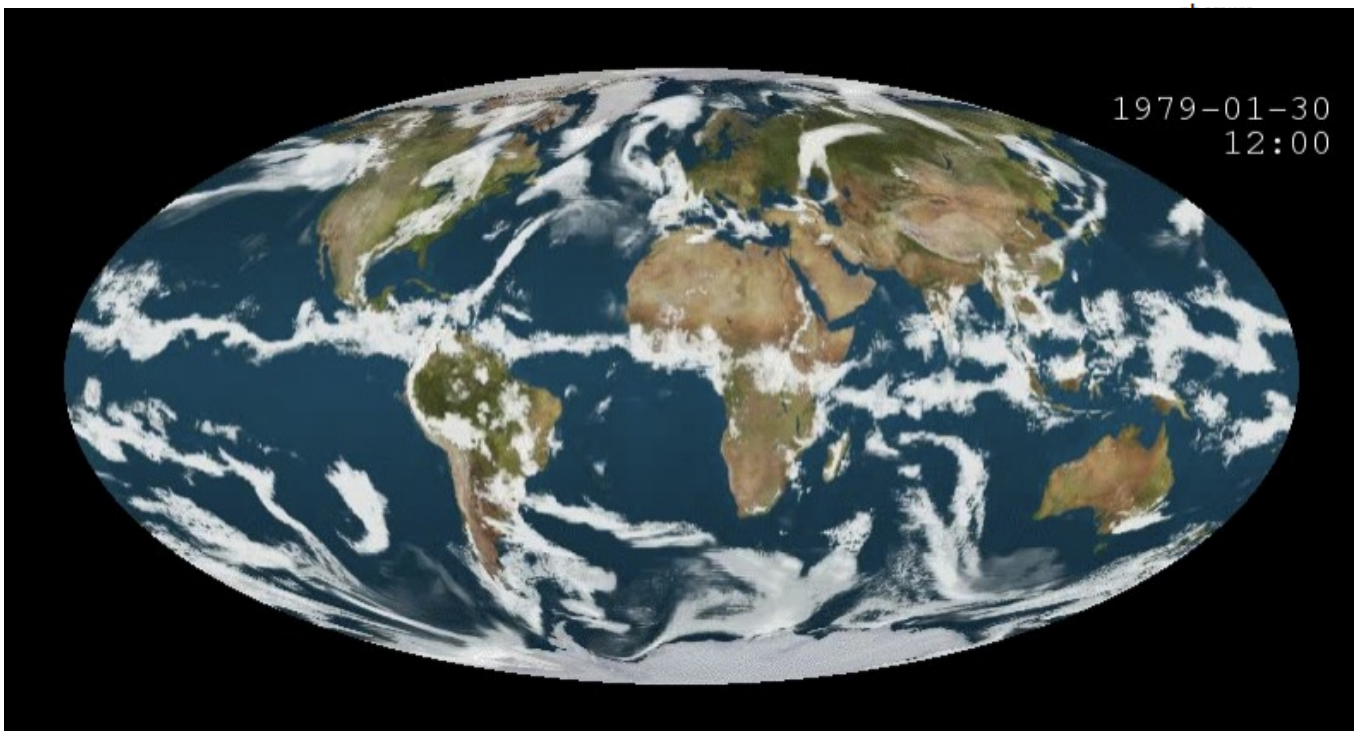




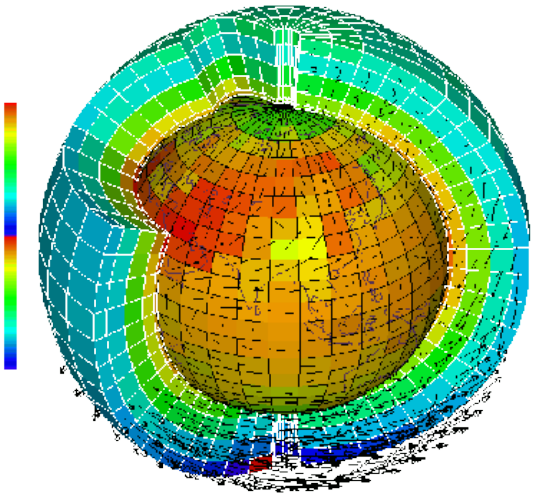
LMD-Z : scalability limits

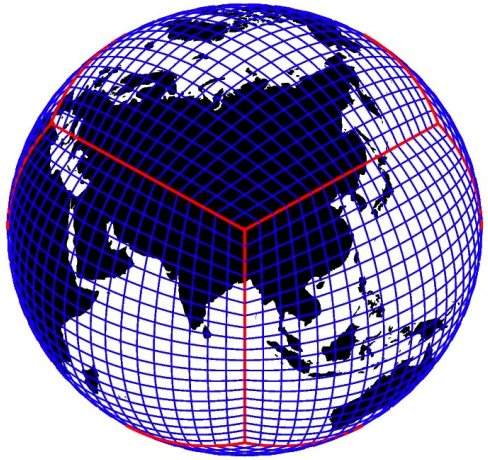
- Polar filter is needed for stability but globally zonal operation => scalability bottleneck
- Scales up to ~2000 cores (MPI+OpenMP) at 1/3 degree (768x767x39)
- 20 years of fully coupled simulation (OPA at ¼ degree) in 35 days





From lat-lon to quasi-uniform grids





Sadourny, 1972

Current plans are on icosahedral grid

- best homogeneity
- has orthogonal primal/dual meshes
- was Sadourny's favourite

Sadourny et al., 1968

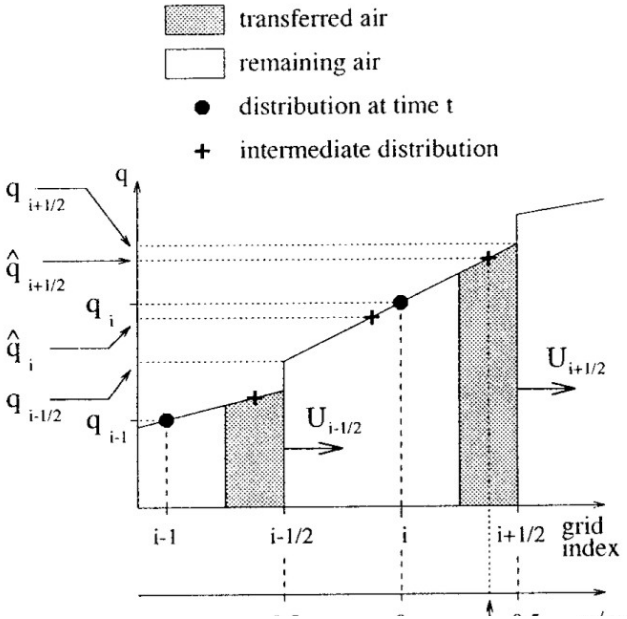
- Transport : positive definite slope-limited transport
- Dynamics : C-grid PV-conserving finite differences
- Also exploring well-balanced finite volume schemes (A-grid)

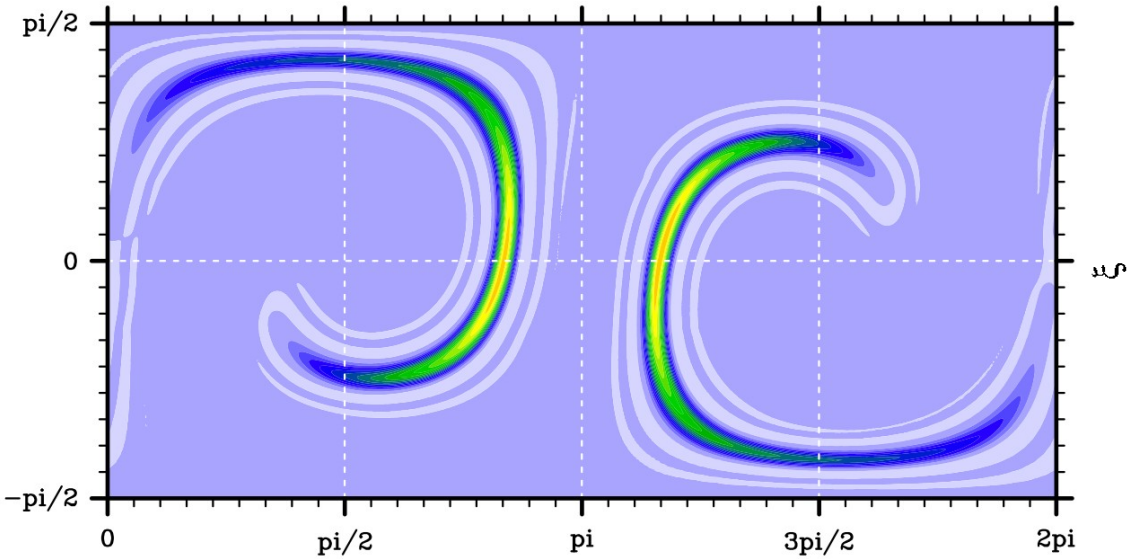
Positive definite finite-volume transport

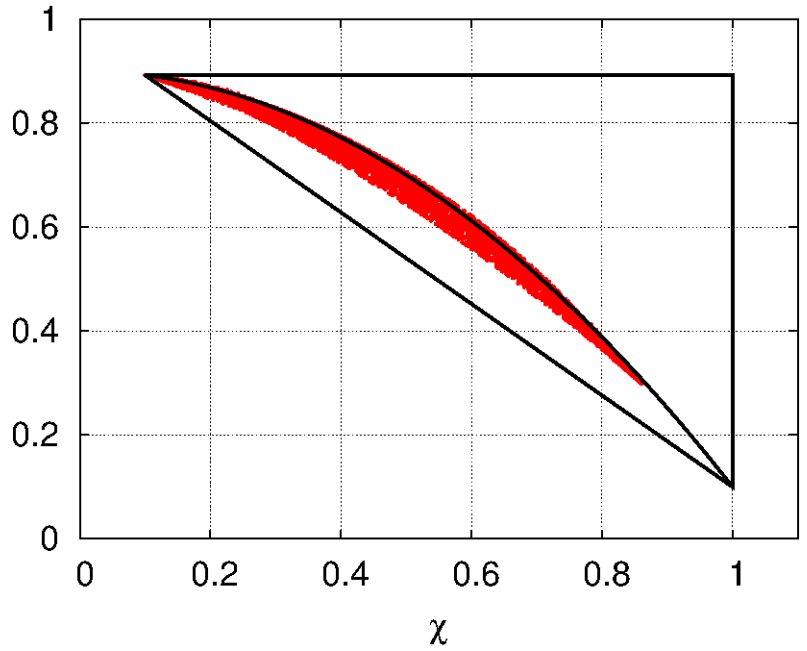
Multidimensional extension of van Leer approach

Lauritzen et al. (submitted ?)

Dubey, Dubos & Hourdin (soon)



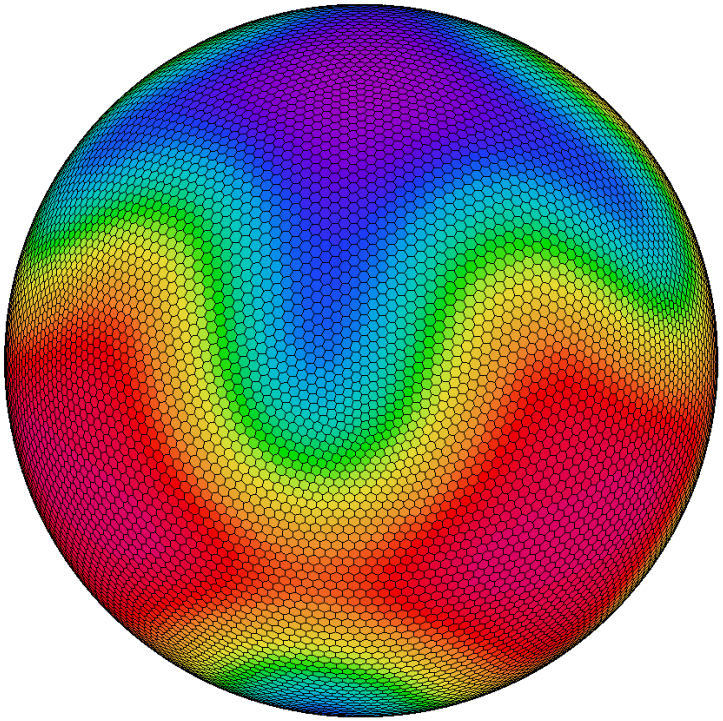




Potential-vorticity-conserving hexagonal C-grid scheme

Generalization of Sadourny's ideas to arbitrary grids

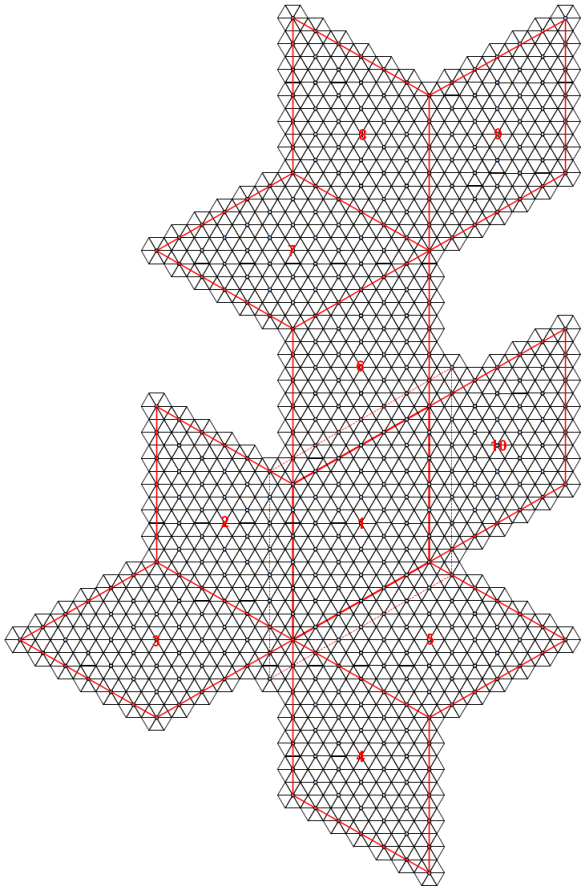
- Bonaventura & Ringler, 2005 (ICON project)
- Thuburn et al., 2009 (MPAS)



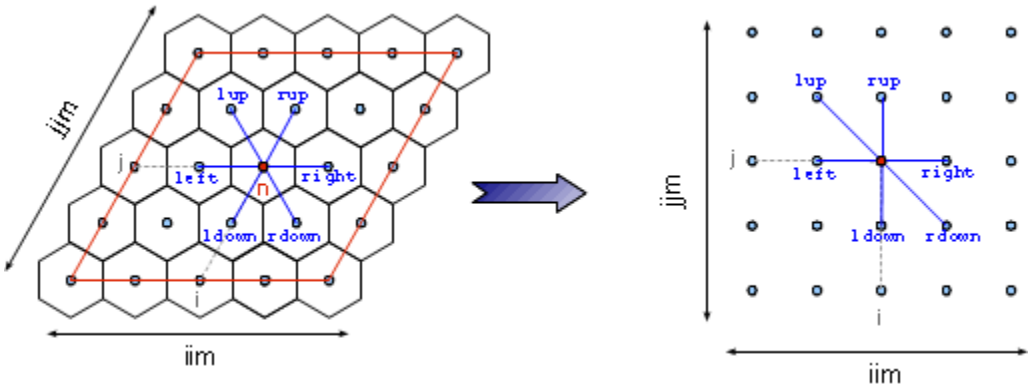
Imbalanced numbers of triangles, edges and hexagons
=> numerical mode either in
- Divergence (mass on triangle)
- Vorticity (mass on hexagons)

Vortical numerical modes seem less severe => put mass on hexagons.

- Shallow water-model currently running (same as Skamarock et al., 2009)
- 3D primitive equations currently under work, expected Q1 2012 ; should be very similar to hydrostatic MPAS.
- Zoom capability probably based on grid stretching a la NICAM (2012?)

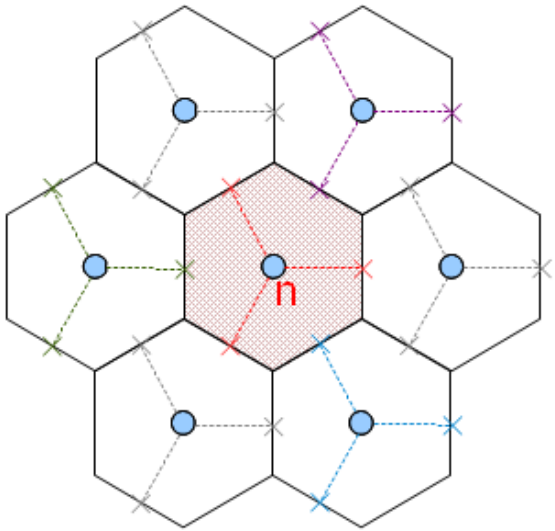


Quasi-structured data layout (Y. Meurdesoif)



- Data stored in rectangular arrays
- Direct access to neighbours via constant offsets
- No special case for pentagons (handled by metrics)

```
DO j=jj_begin,jj_end
  DO i=ii_begin,ii_end
    n=(j-1)*iim+i
    dhi(n)=-1./Ai(n)*(ne(n,right)*ue(n+u_right)*le(n+u_right)  + &
                      ne(n,rup)*ue(n+u_rup)*le(n+u_rup)  +       &
                      ne(n,lup)*ue(n+u_lup)*le(n+u_lup)  +       &
                      ne(n,left)*ue(n+u_left)*le(n+u_left)  +    &
                      ne(n,ldown)*ue(n+u_ldown)*le(n+u_ldown)  + &
                      ne(n,rdown)*ue(n+u_rdown)*le(n+u_rdown))
  ENDDO
ENDDO
```



Deep-atmosphere equations

M. Tort, T. Dubos, F. Hourdin, V. Zeitlin

- on Earth atmosphere is shallow compared to planetary radius
- not true for all planets : on Titan 500km vs 2500 km !

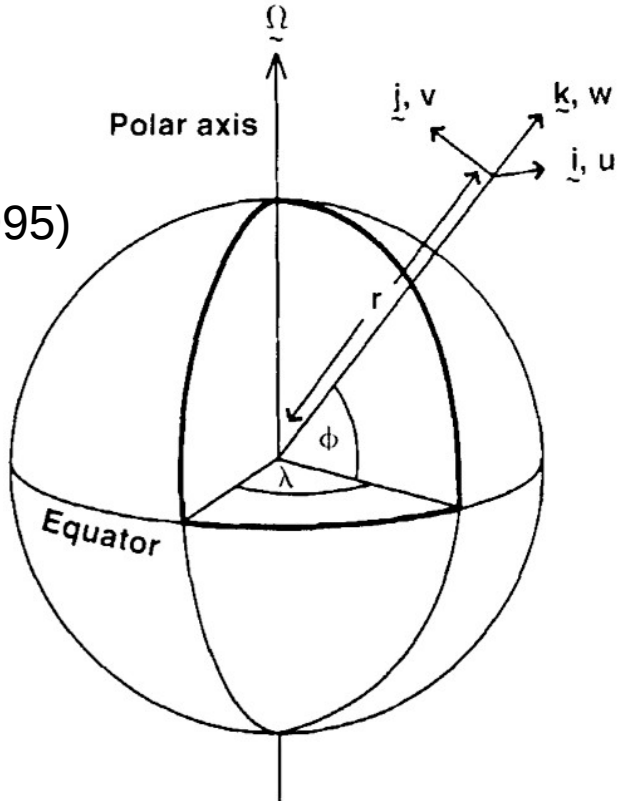
=> remove shallow atmosphere approximation

=> must also include complete Coriolis force (White & Bromley, 1995)

$$\frac{Du}{Dt} - \left(2\Omega + \frac{u}{r\cos\phi}\right)(v\sin\phi - w\cos\phi) + \frac{1}{\rho r\cos\phi}\frac{\partial p}{\partial\lambda} = F_\lambda$$

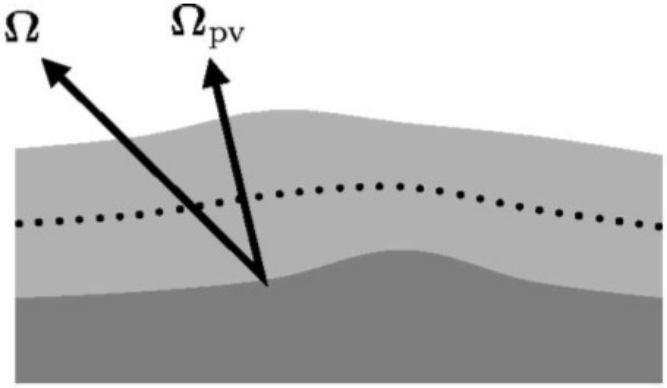
$$\frac{Dv}{Dt} + \left(2\Omega + \frac{u}{r\cos\phi}\right)u\sin\phi + \frac{vw}{r} + \frac{1}{\rho r}\frac{\partial p}{\partial\phi} = F_\phi$$

$$-\left(2\Omega + \frac{u}{r\cos\phi}\right)u\cos\phi - \frac{v^2}{r} + g + \frac{1}{\rho}\frac{\partial p}{\partial r} = 0$$



PhD starting sept. 2011

- Effect of non-standard terms on idealized dynamics (Dellar & Salmon, 2005)
- PV-conserving discretization of deep hydrostatic equations
- Improve modelled general circulation of Titan (with S. Lebonnois, LMD)



Well-balanced finite volume schemes

F. Bouchut, V. Zeitlin

- Based on shock-resolving finite volumes for shallow-water equations, initially developed for hydraulic applications (dam break)
- Riemann solver handles dry areas (zero-mass layers) => terrain-intersecting coordinates
- Handles rough orography while maintaining the state of rest (well-balanced)
- Well-balanced treatment of Coriolis force (apparent orography)

Recent/ongoing advances

- Multilayer extension working around the loss of hyperbolicity (Bouchut & Zeitlin, 2010)
- Spherical extension under work