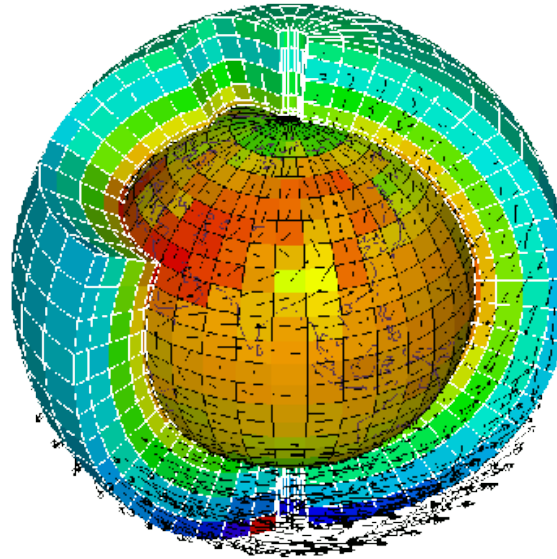
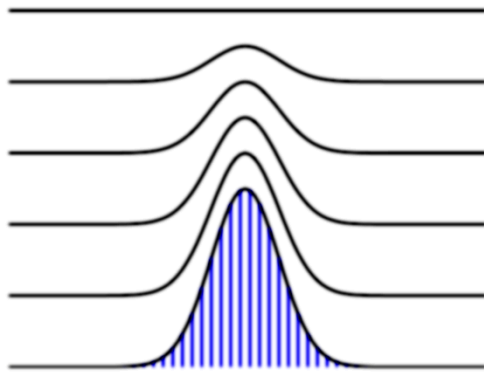


Nouvelle dynamique

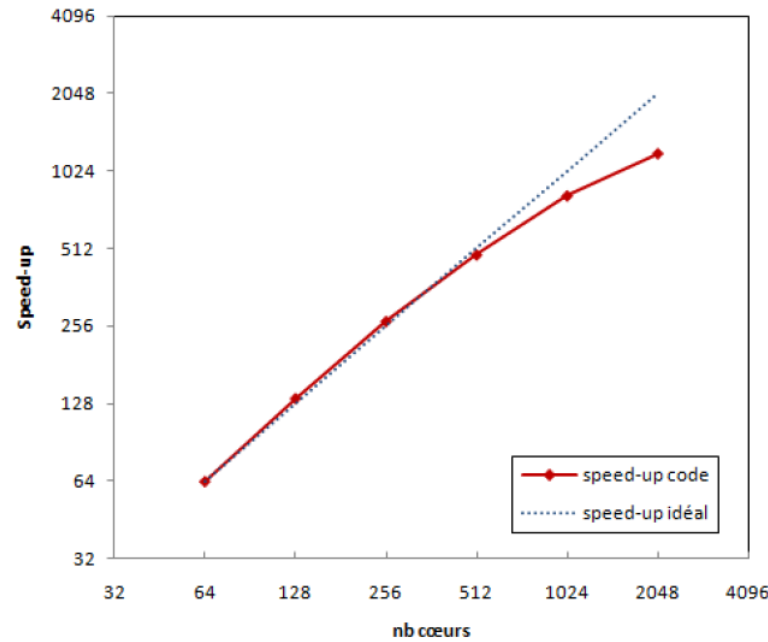
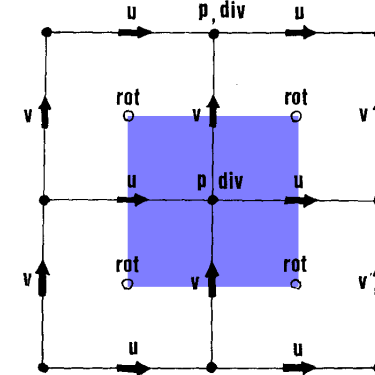
Présenté par T. Dubos

- Rappels : LMDz et scalabilité
- État des lieux
 - Cœur dynamique icosaédrique DYNAMICO
 - Validation
 - Performances
- Perspectives
 - Couplage dynamique/physique(s)
 - Intégration le modèle IPSL
 - Dynamique unifiée non-hydrostatique

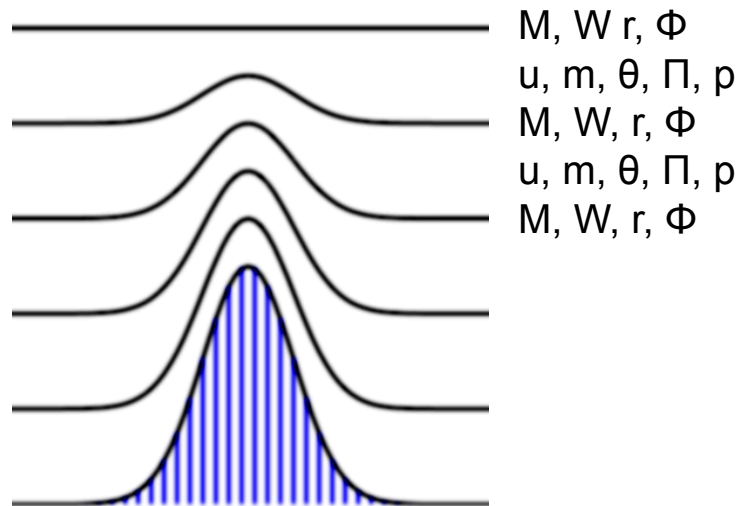
Coordonnée pression



Grilles décalées
Conservation de l'énergie /
entropie (Sadourny, 1975)



Y. Meurdesoif (2010, 1/4 degree)



Discrétisation verticale conservant l'énergie
 (Tort et al., Dubos et al., en prép.)

Transport défini positif
 (Dubey et al., soumis)

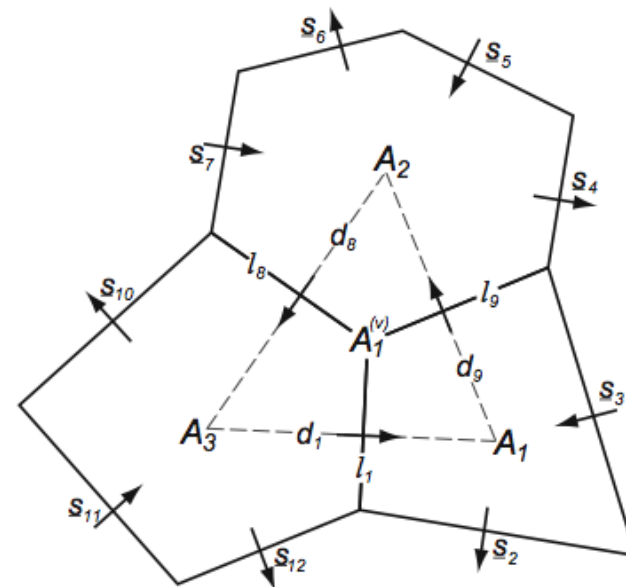
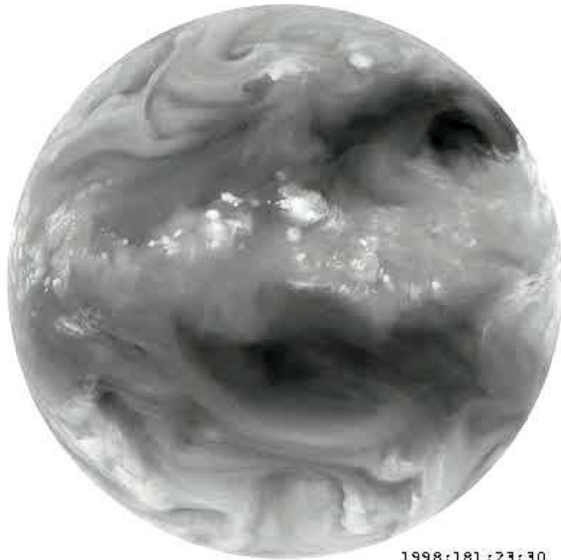


Schéma de type « Sadourny » généralisé aux maillages non-structurés
 (Thuburn et al., 2010)

hydrostatic
dynamical core



1998:181:23:30

$$\begin{aligned}\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot (\rho \mathbf{u}) &= 0 \\ \frac{\partial \Theta}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot (\theta \rho \mathbf{u}) &= 0 \\ \frac{\partial \mathbf{u}}{\partial t} + \frac{1}{\rho} \left(\mathbf{f} + \frac{\partial}{\partial \mathbf{x}} \times \mathbf{u} \right) \times \rho \mathbf{u} \\ + \frac{\partial}{\partial \mathbf{x}} \left(\frac{\mathbf{u}^2}{2} + \Phi \right) + \theta \frac{\partial}{\partial \mathbf{x}} \pi &= 0 \\ \frac{\partial p}{\partial \eta} + \rho g &= 0\end{aligned}$$

Potential temperature

$$v = \frac{\partial z / \partial \eta}{\rho}, \quad \theta = \frac{\Theta}{\rho}$$

$$H[\rho, \mathbf{u}, \Theta, z] = \int \rho \left[\frac{\mathbf{u}^2}{2} + e(v, \theta) + gz \right] dx dy d\eta$$

Horizontal kinetic
energy

Internal energy

Potential energy

energetically consistent,
hydrostatic
dynamical core



1998:181:23:30

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \frac{\delta H}{\delta \mathbf{m}} &= 0 \\ \frac{\partial \Theta}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \left(\theta \frac{\delta H}{\delta \mathbf{m}} \right) &= 0 \\ \frac{\partial \mathbf{m}}{\partial t} + \frac{1}{\rho} \left(\frac{\partial}{\partial \mathbf{x}} \times \mathbf{m} \right) \times \frac{\delta H}{\delta \mathbf{m}} \\ + \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \rho} + \theta \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \Theta} &= 0 \\ \frac{\delta H}{\delta z} &= 0 \end{aligned}$$

Tort & Dubos, JAS 2014
Dubos & Tort, MWR 2014

Planetary velocity

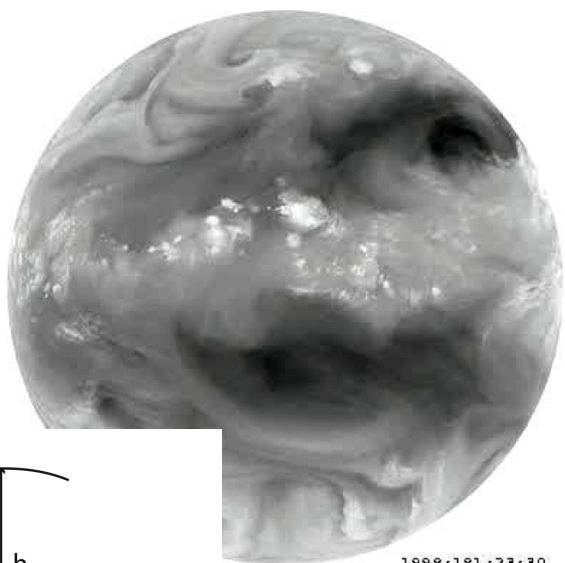
Absolute velocity

$$\mathbf{m} = \mathbf{u} + a\mathbf{R}$$

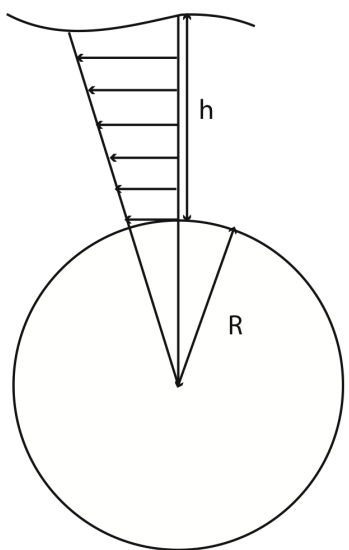
$$H[\rho, \mathbf{m}, \Theta, z] = \int \rho \left[\frac{(\mathbf{m} - a\mathbf{R})^2}{2} + e(v, \theta) + gz \right] dx dy d\eta$$

Horizontal kinetic
energy

energetically consistent,
hydrostatic, deep-atmosphere
dynamical core



1998:181:23:30



Atmosphère profonde
→ Coriolis complet

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \frac{\delta H}{\delta \mathbf{m}} &= 0 \\ \frac{\partial \Theta}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \left(\theta \frac{\delta H}{\delta \mathbf{m}} \right) &= 0 \\ \frac{\partial \mathbf{m}}{\partial t} + \frac{1}{\rho} \left(\frac{\partial}{\partial \mathbf{x}} \times \mathbf{m} \right) \times \frac{\delta H}{\delta \mathbf{m}} \\ + \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \rho} + \theta \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \Theta} &= 0 \\ \frac{\delta H}{\delta z} &= 0 \end{aligned}$$

Tort & Dubos, JAS 2014
Dubos & Tort, MWR 2014

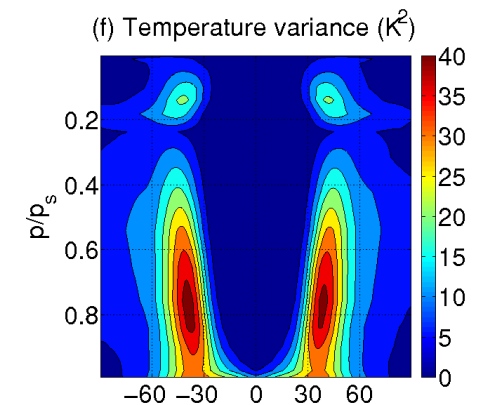
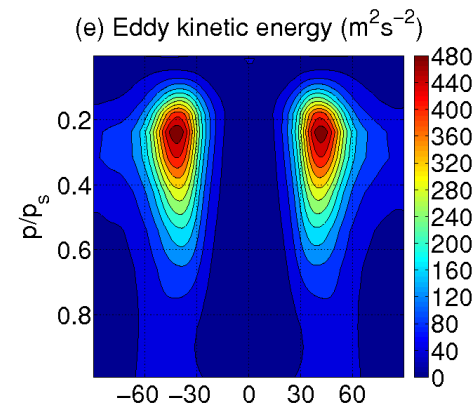
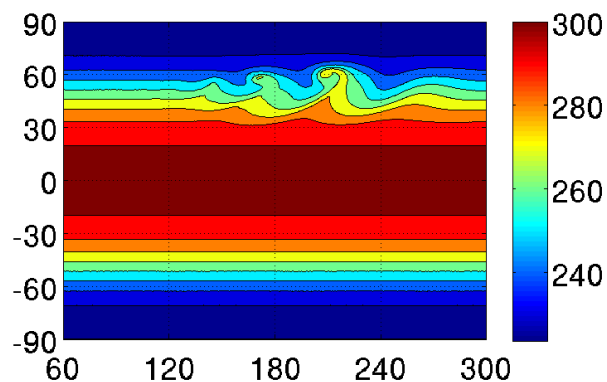
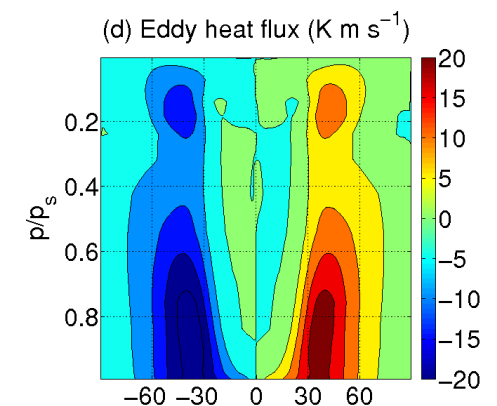
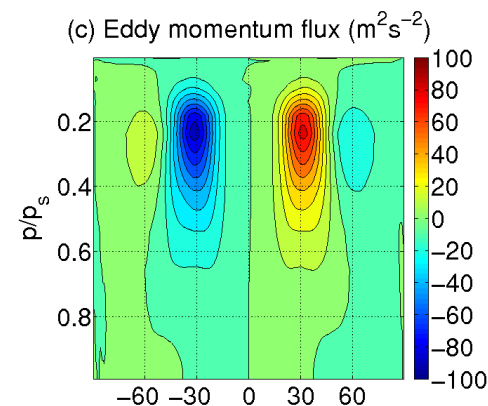
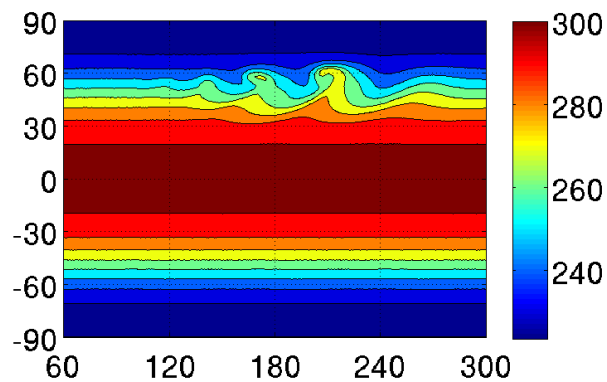
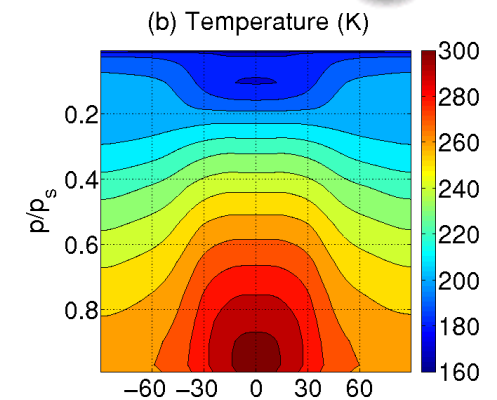
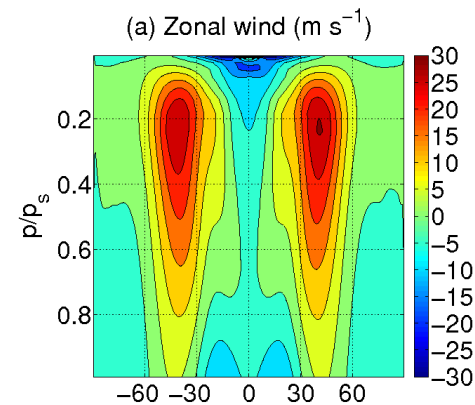
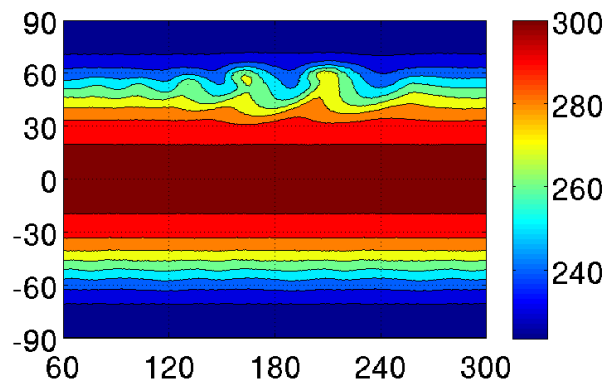
Vitesse planétaire

$$r = a + z, \quad \rho = \frac{r^2 \partial r / \partial \eta}{v}, \quad \mathbf{m} = r(\mathbf{u} + r\mathbf{R})$$

$$H[\rho, \mathbf{m}, \theta, z] = \int \rho \left[\frac{(\mathbf{v} - r^2 \mathbf{R})^2}{2r^2} + e(v, \rho) + \Phi(r) \right] dx dy d\eta$$

Géométrie sphérique

Gravité variable



Instabilité barocline
(Jablonowski & Williamson, 2006)
résolutions $\sim 3^\circ$, 1.5° , 0.75°

Validation sur cas idéalisé climatique (Held & Suarez 1994) :
circulation forcée par rappel vers une structure thermique
prescrite (ici 1000j à $\sim 1^\circ$)



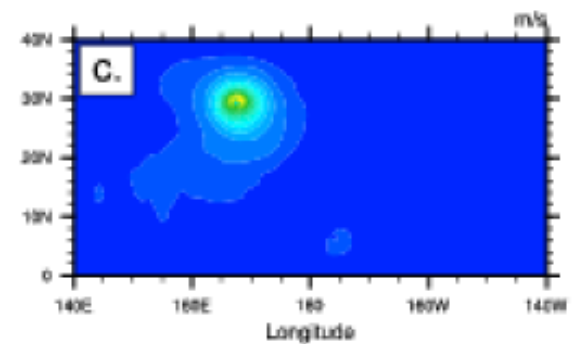
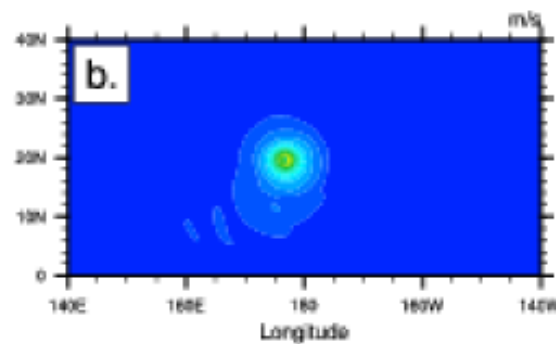
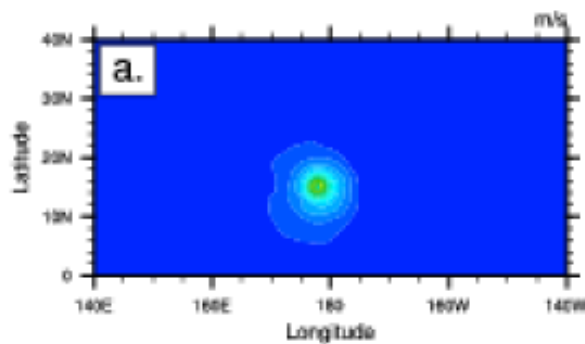
Validation sur cas idéalisé **climatique** (*Held & Suarez 1994*) :
circulation forcée par rappel vers une structure thermique prescrite (ici 1000j à $\sim 1^\circ$)



Day 3

Day 5

Day 10

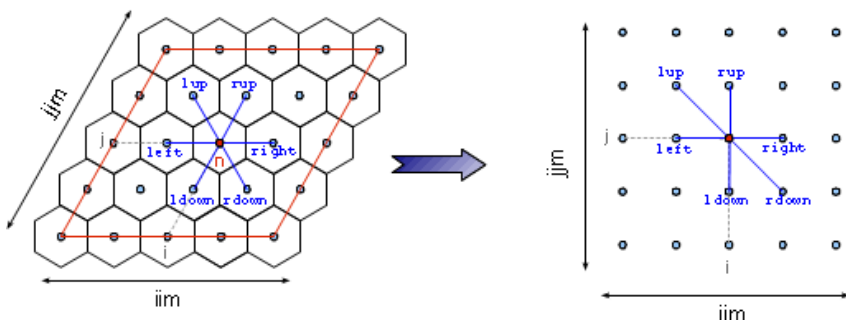
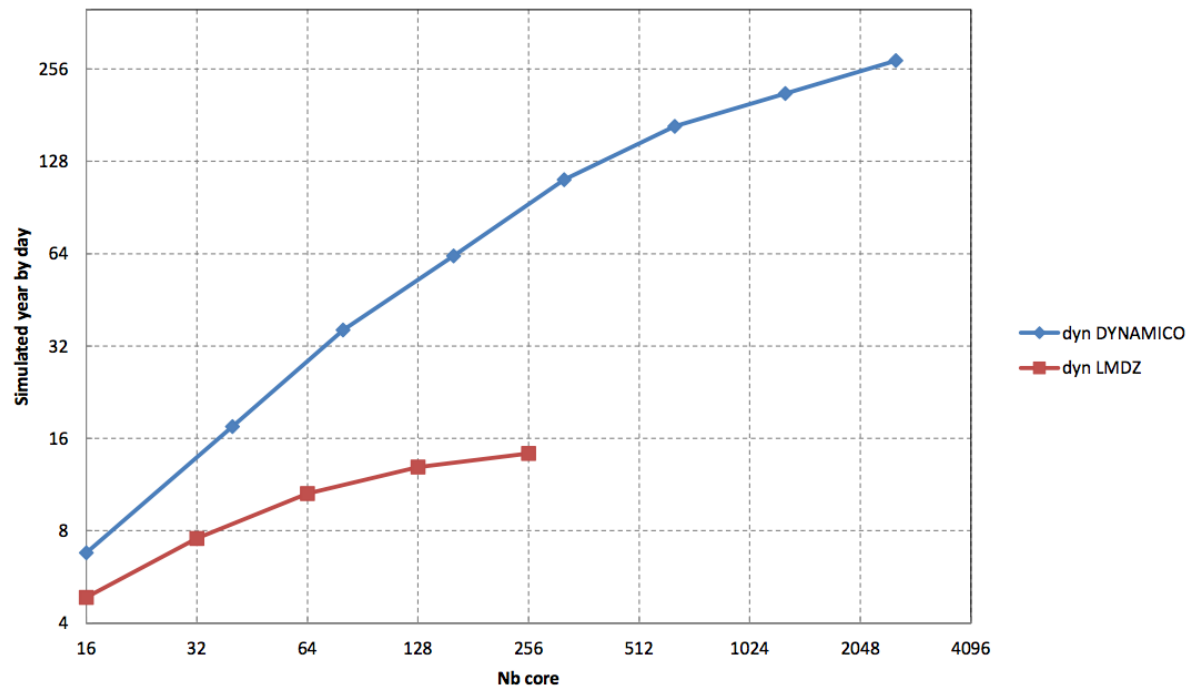
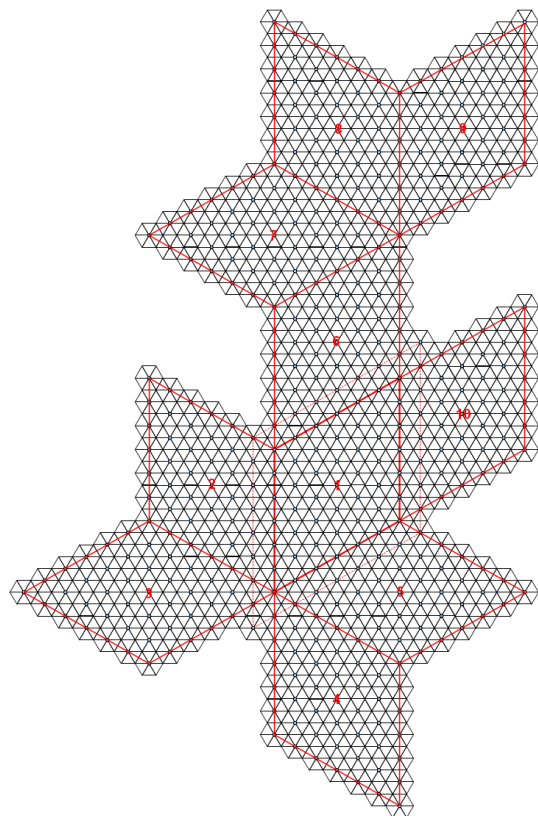


Cyclone tropical idéalisé : couplage dynamique / physique simplifiée
(Reed & Jablonowski, 2011), ici résolution 1/2 degré

Performance parallèle

Y. Meurdesoif, 2013

Dynamico : 32x32x10x39lvl Vs LMDZ 96x95x39



degrees	cores	year/day	Mh/100yr
3	320	110	0,0077
1	1280	20	0,15
1	5120	55	0,22
1/2	5120	10	1,2
1/2	11520	18	1,5
1/2	20480	28	1,8
1/4	20480	5	10
1/4	46080	8	14

Measured
Extrapolated

Perspectives

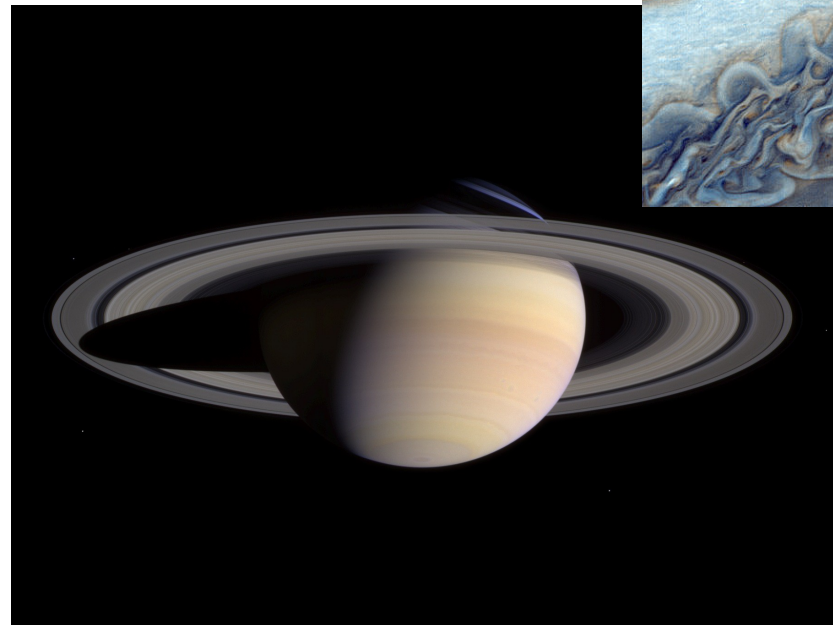
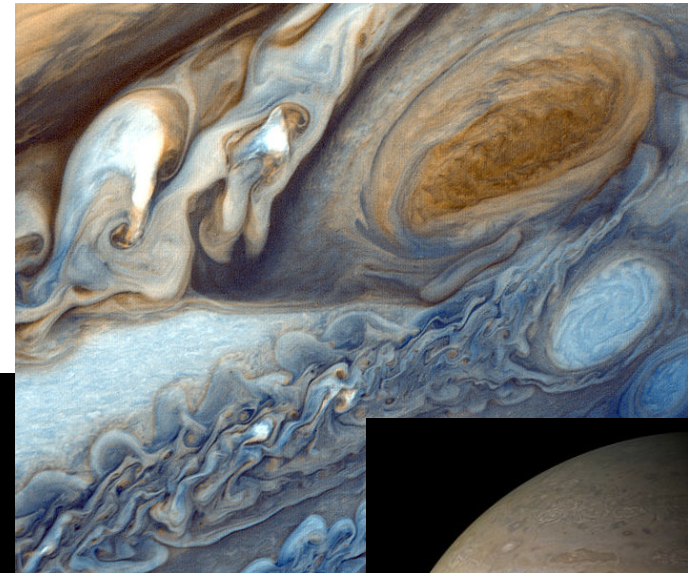
*Projet ANR HEAT Highly Efficient Atmospheric Modelling
(verdict mi-juillet 2014)*

LMD – LSCE – LAGA – CNRM/GAME – INRIA/MOISE - CERFACS

- Couplage dynamique/physique(s)
- Intégration au modèle IPSL
- Dynamique unifiée non-hydrostatique

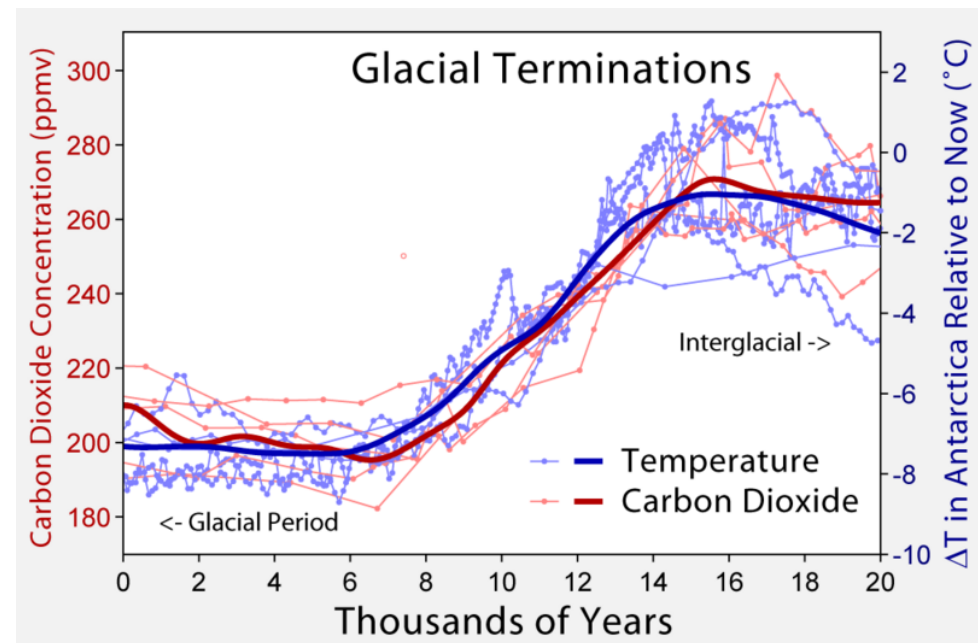
Atmospheric dynamics of Giant Planets

- Coupling with Saturn/Jupiter physics (Guerlet et al., 2014)
- High-resolution simulations ($1/4 - 1/8$)

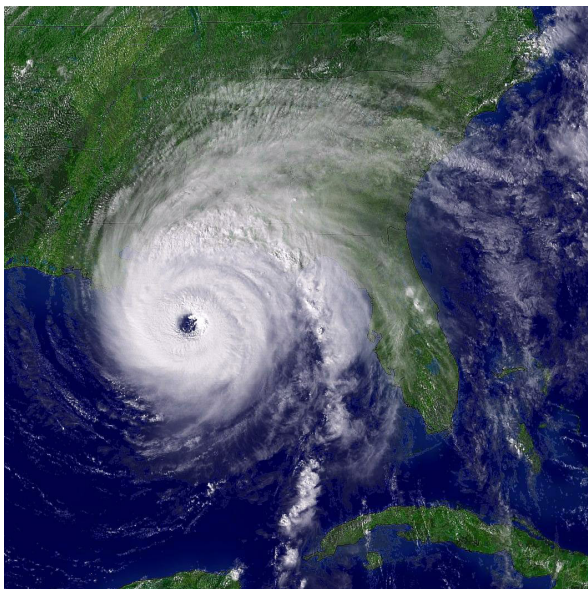


Towards multi-millennial scale Earth System simulations

- Coupling with LMD-Z physics
- Aquaplanet simulations
- Land surface (ORCHIDEE)
- Atmosphere-ocean coupling
- Chemistry (INCA)



Towards an energetically consistent, hydrostatic / non-hydrostatic unified core



$$\begin{aligned} \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \frac{\delta H}{\delta \mathbf{m}} &= 0 \\ \frac{\partial \Theta}{\partial t} + \frac{\partial}{\partial \mathbf{x}} \cdot \left(\theta \frac{\delta H}{\delta \mathbf{m}} \right) &= 0 \\ \frac{\partial \mathbf{m}}{\partial t} + \frac{1}{\rho} \left(\frac{\partial}{\partial \mathbf{x}} \times \mathbf{m} \right) \times \frac{\delta H}{\delta \mathbf{m}} \\ + \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \rho} + \theta \frac{\partial}{\partial \mathbf{x}} \frac{\delta H}{\delta \Theta} &= 0 \\ \frac{\partial W}{\partial t} + \frac{\delta H}{\delta z} &= 0 \\ \frac{\partial z}{\partial t} - \frac{\delta H}{\delta W} &= 0 \end{aligned}$$

Vertical momentum

Absolute covariant velocity

$$W = \rho w, \quad \mathbf{m} = \mathbf{u} + a\mathbf{R} + w \frac{\partial z}{\partial \mathbf{x}}$$

$$H[\rho, \mathbf{m}, \Theta, z, W] = \int \rho \left[\frac{W^2}{2\rho^2} + \frac{\left(\mathbf{m} - w \frac{\partial z}{\partial \mathbf{x}} - \mathbf{R} \right)^2}{2} + e(v, \theta) + gz \right] dx dy d\eta$$

Vertical kinetic energy

Horizontal kinetic energy

- Existant
 - Cœur dynamique icosaédrique DYNAMICO
 - Validé court terme / long terme
 - Parallèle
- Perspectives
 - Couplage dynamique/physique(s)
 - Intégration au modèle IPSL
 - Dynamique unifiée non-hydrostatique