Intrdocution

Frédéric Hourdin

LMDZ : a general circulation model

1. General Circulation Models
2. LMDZ
3. Splitting/coupling and modularity
4. Operating modes

1. General Circulation Models

The world of numerical models

appearances

theories (physics, chemistry, biologie, economy)

mathematics

numerics

computers

Mathematics constitute a common language

Modeling concerns all the layers
Always try to make links with the upper layers
At same time, you must be aware of the layer in which you are working, or at which transition between layers.
Do not forget that your goal is to explain things in the first layer.

1. General Circulation Models

The « layers » in LMDZ :

Appearances :

→ Meteorology, climate, atmospheric composition

Theories :

→ Fluid mechanics
→ Gaz/radiation interaction
→ Phase changes/ Thermodynamics
→ Chemistry

Mathematics

→ Navier-Stokes (Primitive equations)
→ Thermodynamical laws
→ Radiative transfer

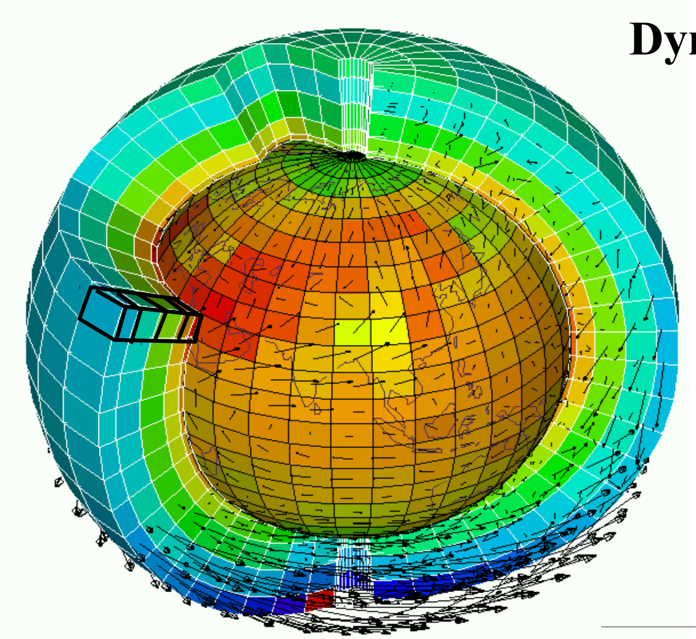
Numerics

→ Grid point discretisation
→ Finite volume and finite differences
→ Guaranty conservation of certain quantities, robustness, efficiency, rather than accuracy

Computers

→ Fortran / Linux
→ High Performance Computing
→ Modularity
→ Flexibility / Multi-configuration

1. General Circulation Models



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

  $D\rho/Dt + \rho \, \mathrm{div}\underline{U} = 0$
- Potential temperature conservation

  $D\theta / Dt = Q / Cp \ (p_0/p)^{\kappa}$
- Momentum conservation

  $D\underline{U}/Dt + (1/\rho)\ \underline{\mathrm{grad}p} - \underline{g} + 2\ \underline{\Omega} \wedge \underline{U} = \underline{F}$
- Secondary components conservation

  $Dq/Dt = Sq$

Primitive equations of meteorology

→ Thin layer approximation

→ Hydrostatic approximation (**valid down to 10-20 km**)

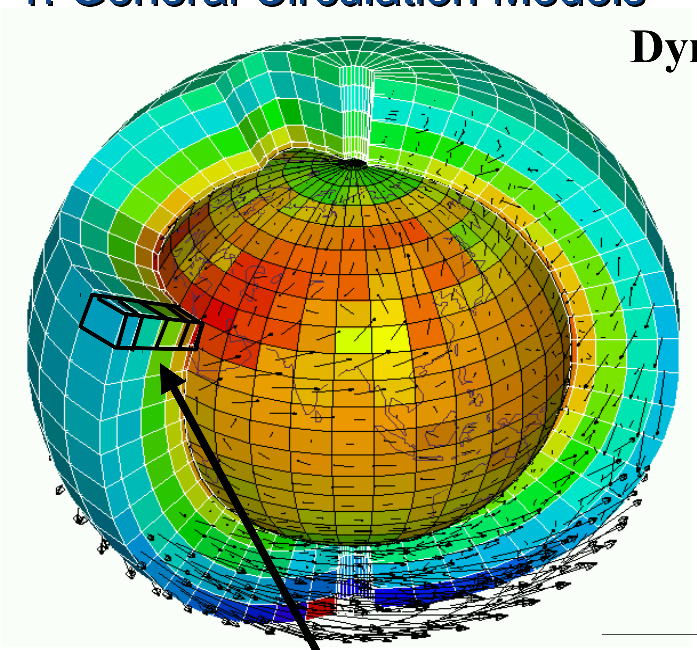
From physics to numerics :

→ Finite volume and finite differences

→ Explicit resolution down to 30-300 km depending of the configuration

→ Numerical conservation of important quantities (mass, water, enstrophy ...).

1. General Circulation Models



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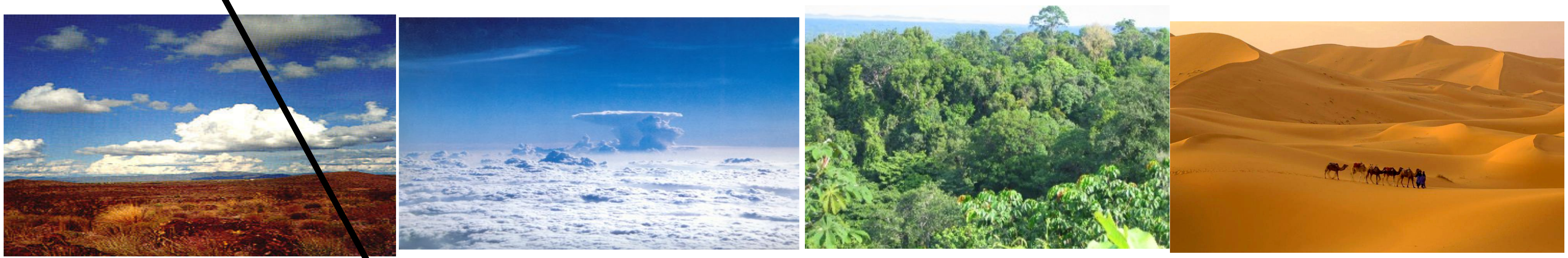

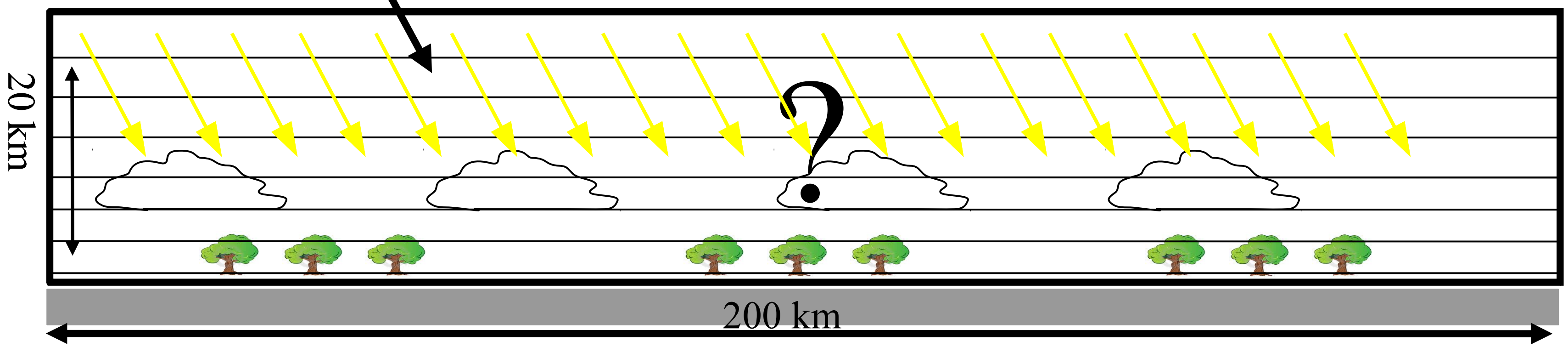

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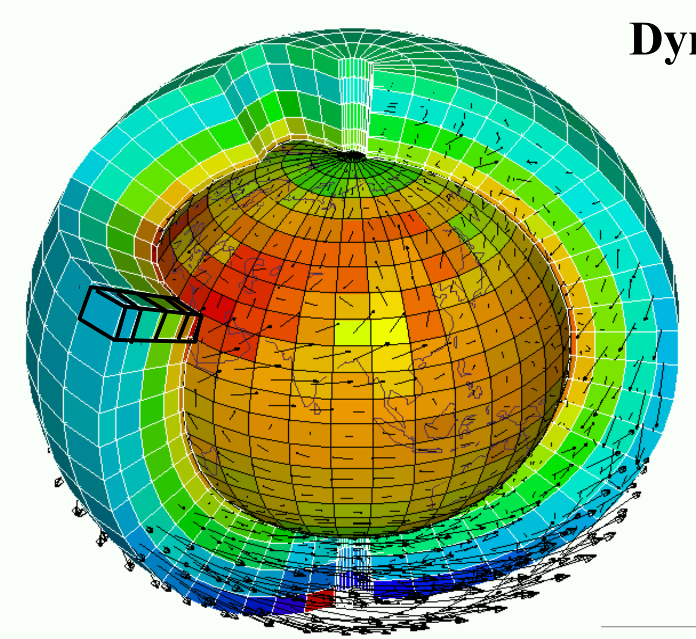

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Parameterizations purpose : account for the effect of processes non resolved by the dynamical core
→ **Traditional « source » terms in the equations**

- *Q* : Heating by radiative exchanges, thermal conduction (neglected), condensation, sublimation, **subgrid-scale motions (turbulence, clouds, convection)**
- *F* : Molecular viscosity (neglected), **subgrid-scale motions (turbulence, clouds, convection)**
- *Sq* : condensation/sublimation (q= water vapor or condensed), chemical reactions, photo-dissociation (ozone, chemical species), micro physics and scavenging (pollution aerosols, dust, ...), **subgrid-scale motions (turbulence, clouds, convection)**

Parameterizations : principles




- Compute the **average effect of unresolved processes on the global model state variables** ($\underline{U}$, θ, q)

- **Based on a description of the approximate collective behavior** of processes

- Involve additional **parameterization internal variables** (cloud characteristics, standard deviation of the sub-grid scale distribution of a variable, …)

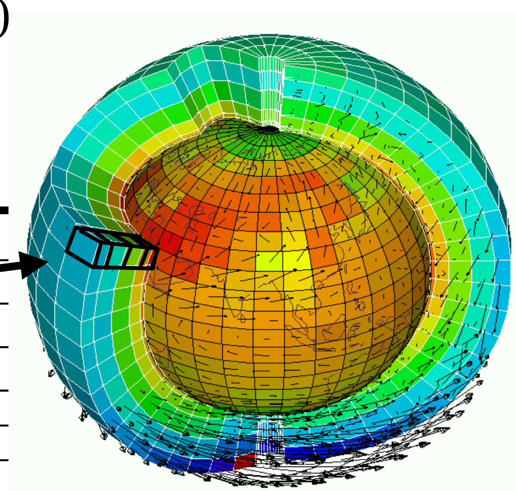
- Derive **equations** relating internal variables to the state variables

  $\underline{U}$, θ, q at time t → **internal variables** → $\underline{F}$, Q, Sq → $\underline{U}$, θ, q at t+δt

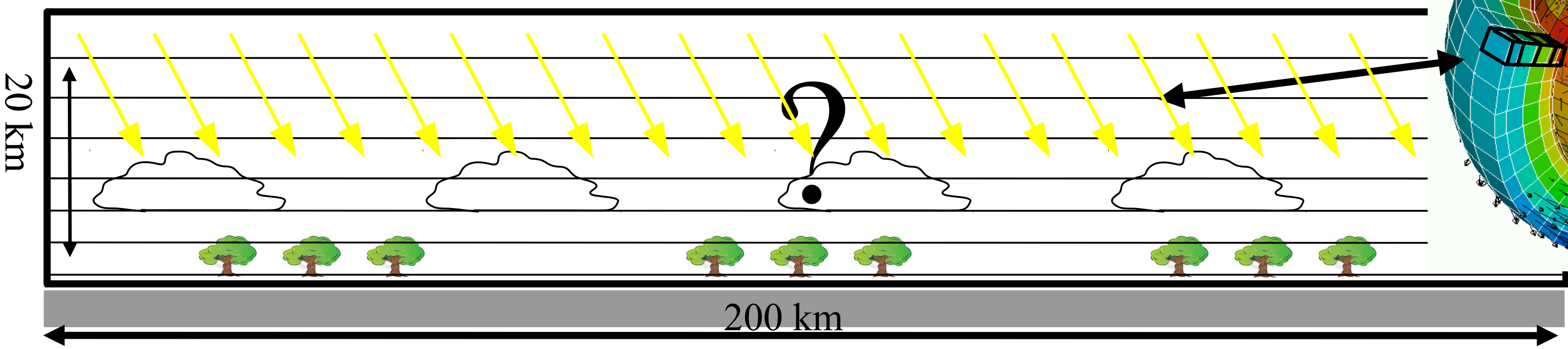
- **Homogeneity hypothesis** (statistical) on the horizontal of the targeted processes (like in the plane-parallel approximation of radiative transfer)

  → 1-dimensional equations in z (vertical exchanges only)

  → Independent atmospheric column



Inside an « atmospheric column » ...



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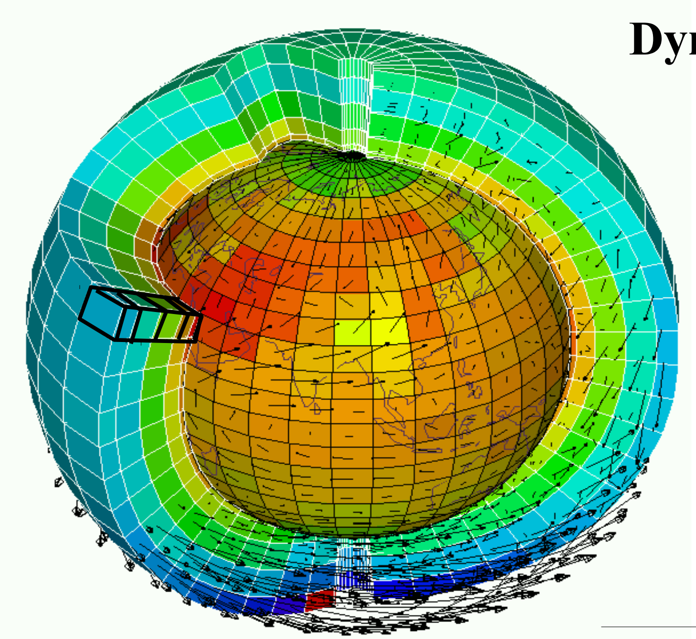
   1. General Circulation Models
   2. **LMDZ**
   3. Splitting/coupling and modularity
   4. Operating modes

2. LMDZ



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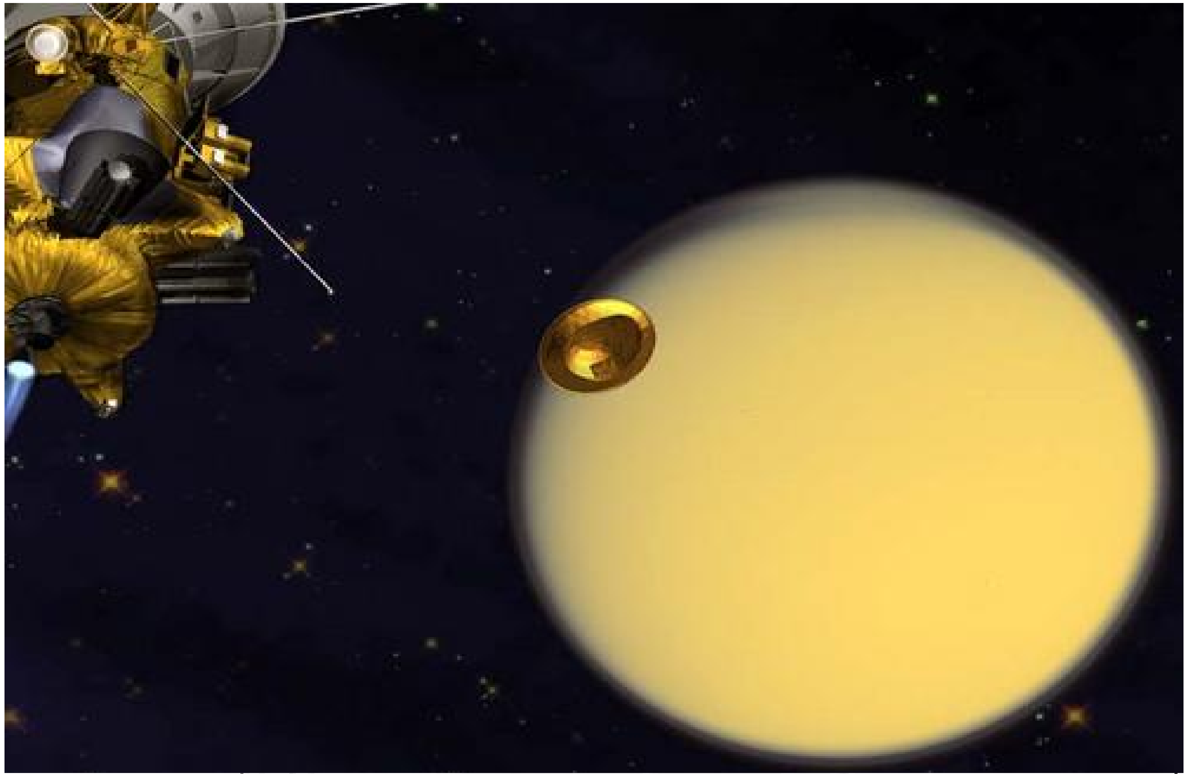
The LMDZ dynamical core :

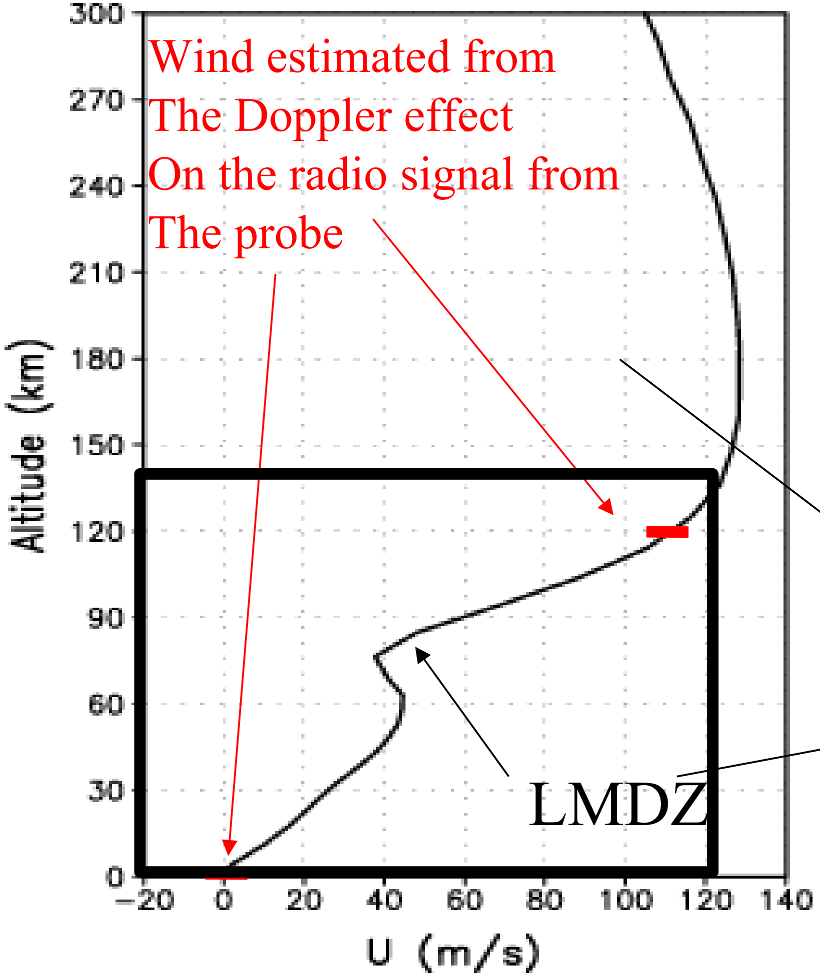
→ Global longitude-latitude grid
→ Zoom capability (« Z » of « LMDZ »)
→ Finite difference / finite volume numerical schemes
→ Conservation of air mass, enstrophy, partly angular momentum and energy
→ Positive/monotonic/conservative Van Leer schemes for tracer advection
→ Horizontal dissipation (stability + scale interaction) : iterated Laplacian
→ Sponge layer (dumping winds and wave in the upper layers)

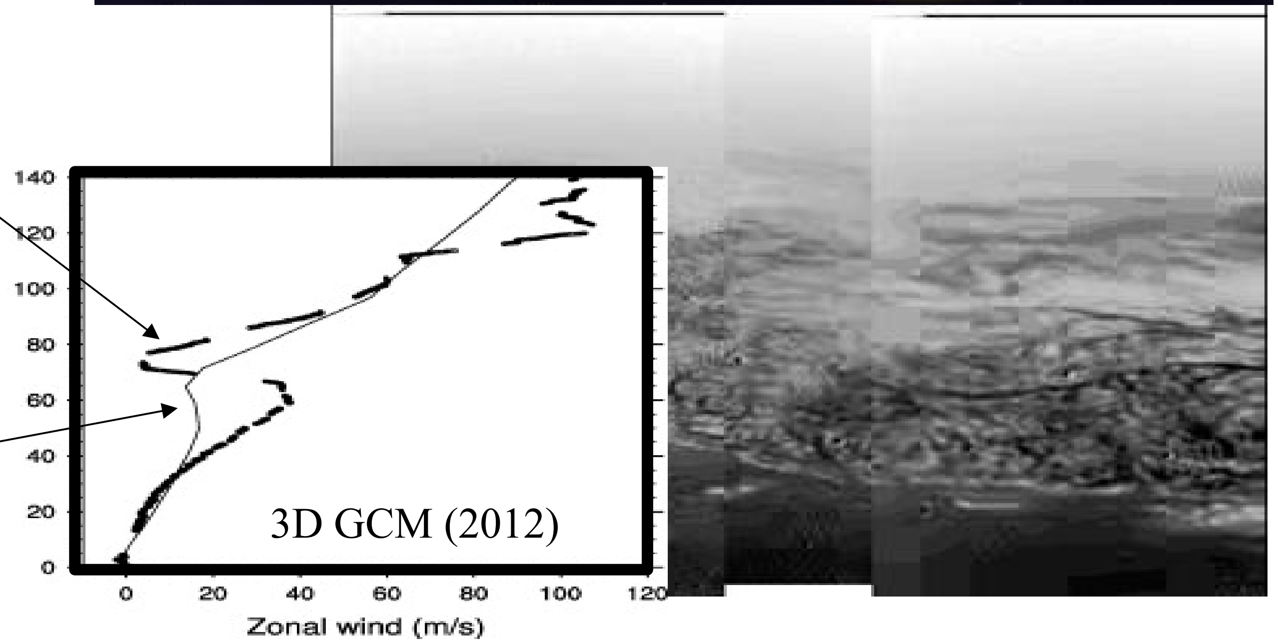
2. LMDZ

Planetary atmospheres
Mars, Titan, Venus, Triton, ...

Prediction of Titan atmospheric super-rotation
with the LMDZ Titan GCM (1995, 2005)
An a posteriori comparison with
The Huygens entry profile

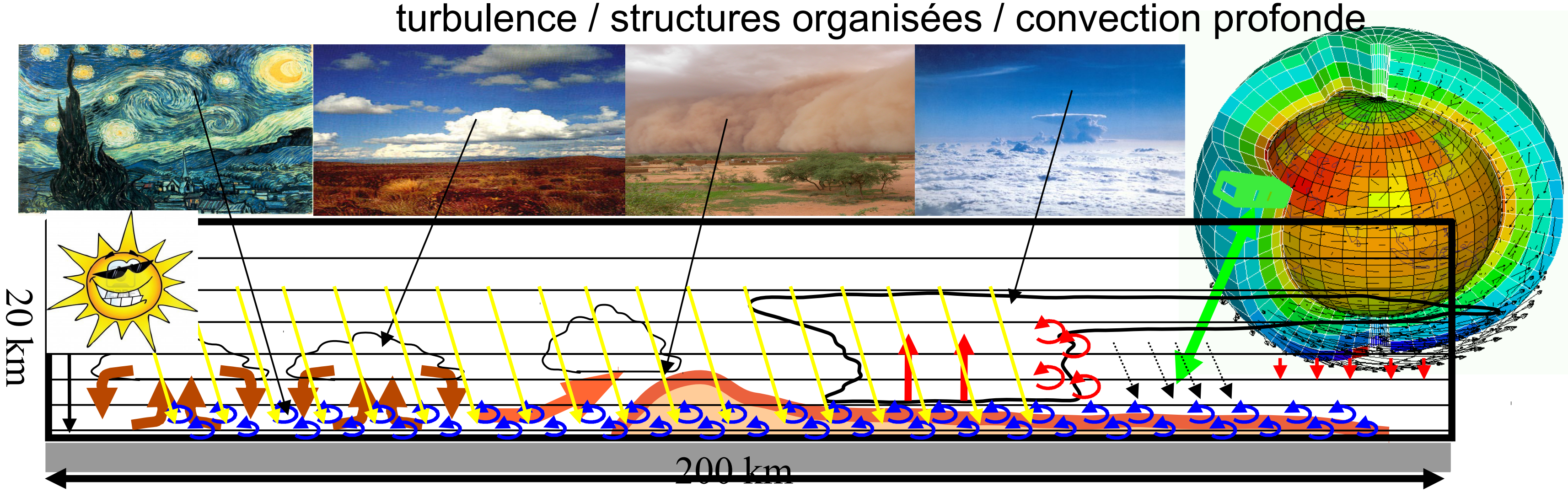






2. LMDZ

« Physique terrestre »
Un nouveau cadre de travail et développement des paramétrisations
Choix de séparer trois échelles pour le transport vertical :
turbulence / structures organisées / convection profonde



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→ Rio, C., F. Hourdin, F. Couvreux, and A. Jam, **2010**, Resolved Versus Parametrized Boundary-Layer Plumes. Part II: Continuous Formulations of Mixing Rates for Mass-Flux Schemes, Boundary-layer Meteorol., 135, 469–483, 2010.
→ Rio et al., **2012** : closure revisited

LMDZ – a brief history

Pioneers : years 60-70. Robert Sadourny and Phu Le Van (Sadourny, 1975)

The LMD5/LMD6 model : 90-95 (Laval, 1981)

1985 : Rewriting of the dynamical core : modularity and zoom (the previous version had been written over punch cards with a very small RAM memory)

1990 : versions for Mars, Titan, and a generic 20-parameter version

1992 : decision to develop the terrestrial model on the basis of this new dynamical core, by adapting the physical package of LMD5/6

1995-1999 : transport of trace species

2005 : First participation to CMIP exercise with LMDZ

2007 : rising organization around LMDZ (web, regular meetings,Svn, training, …)

2011 : “New Physics” version (result of a 10-year research) and participation to CMIP5

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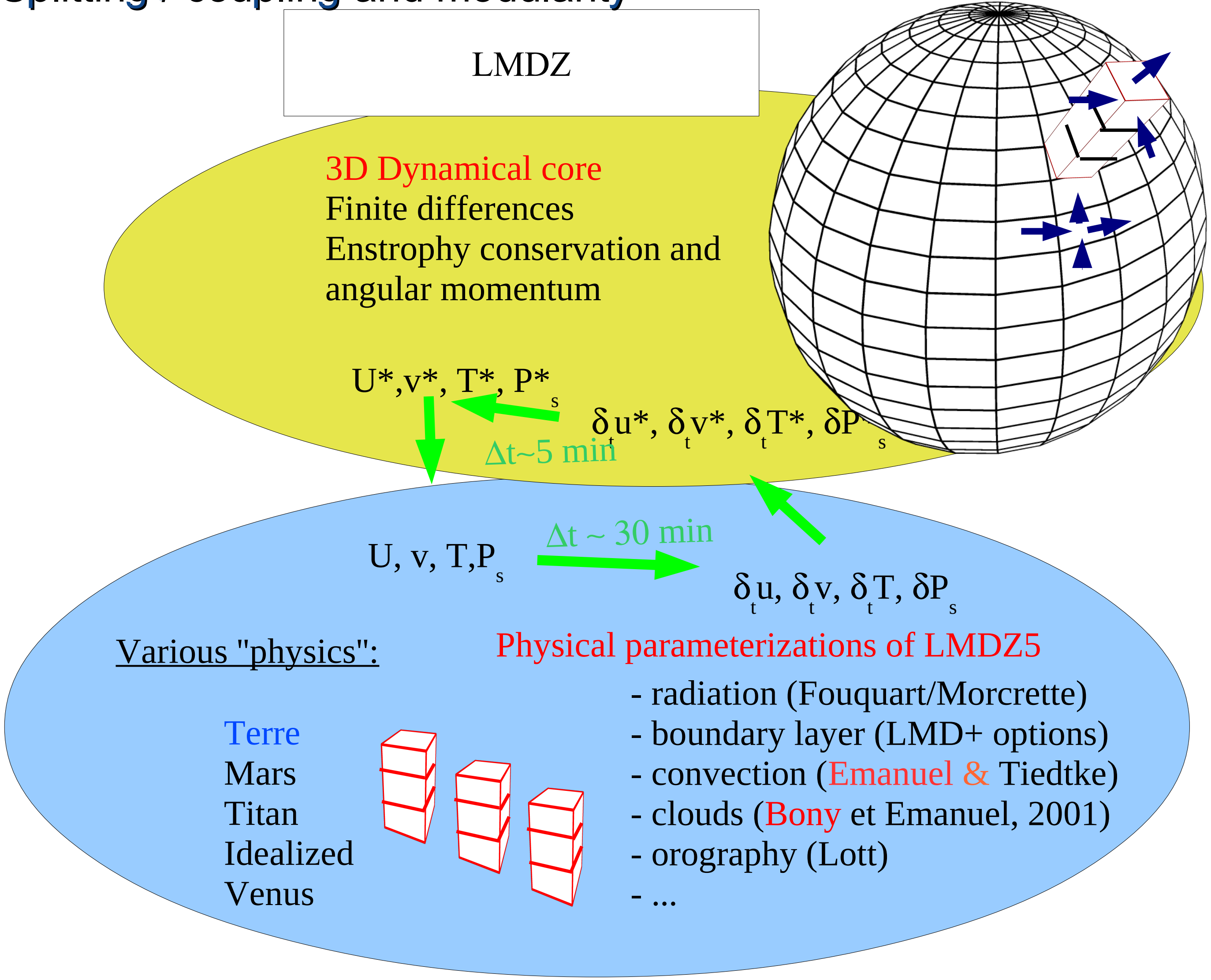
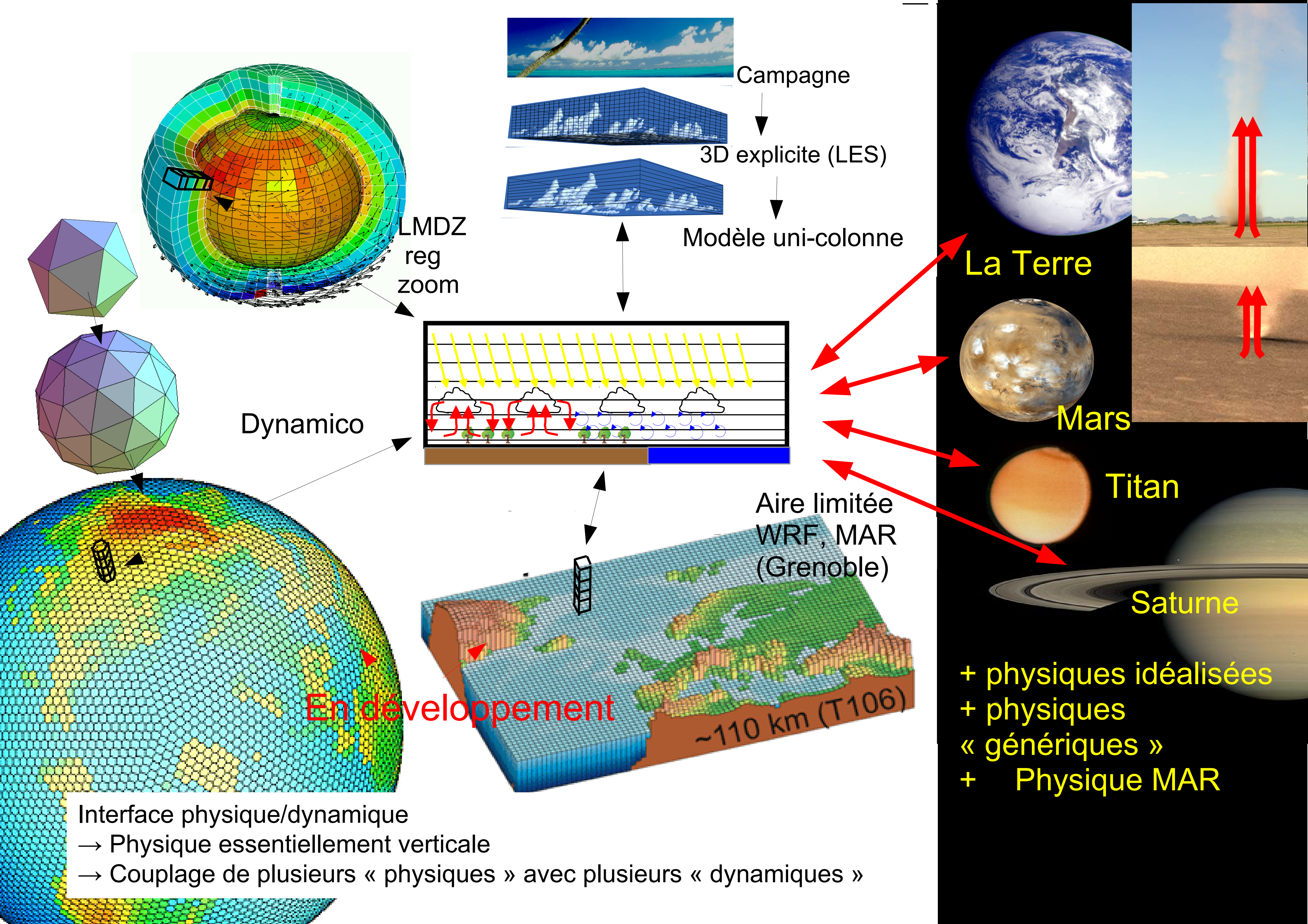
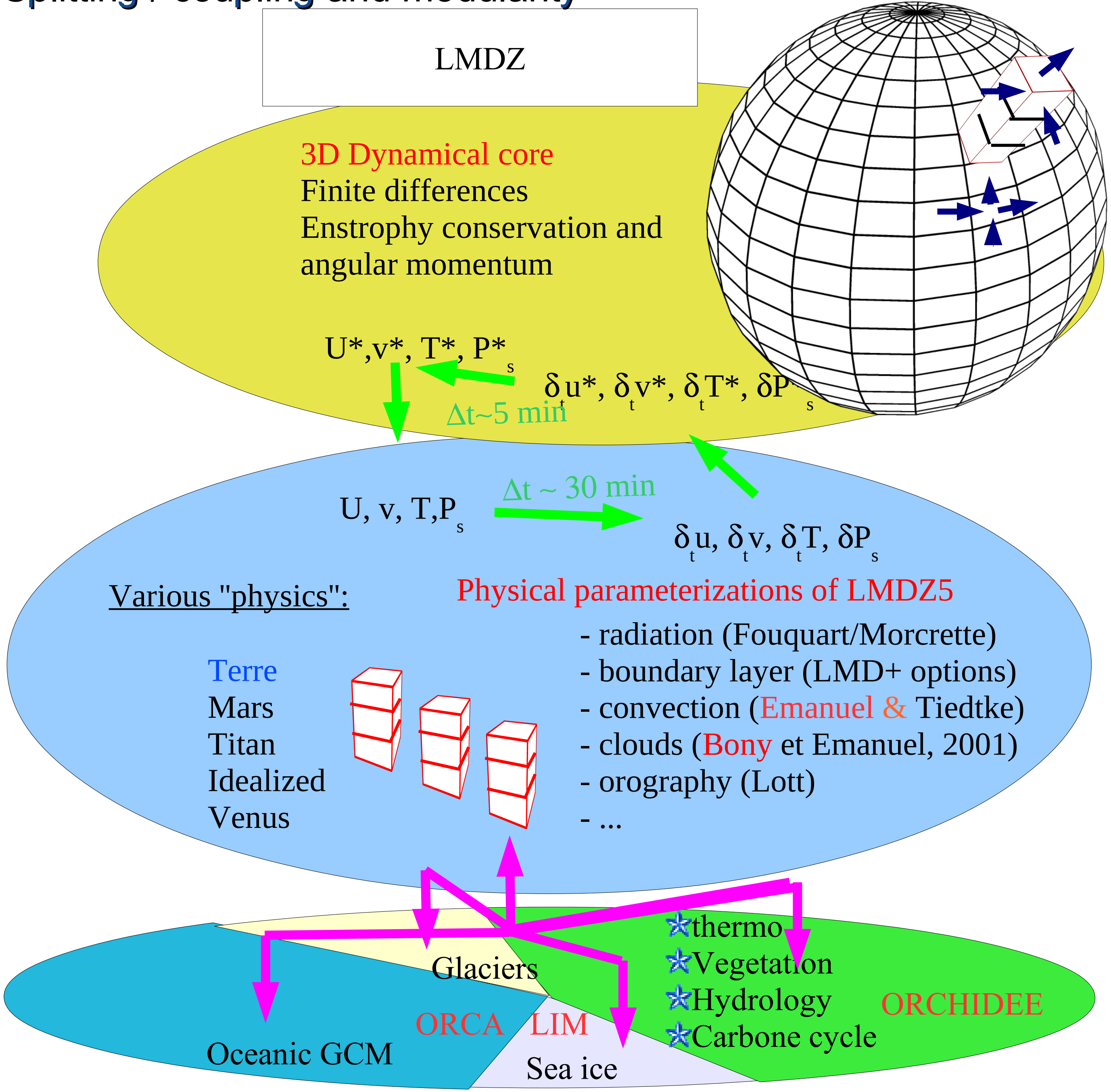
3. Splitting / coupling and modularity




Campagne
3D explicite (LES)
Modèle uni-colonne
LMDZ
reg
zoom
Dynamico
La Terre
Mars
Titan
Saturne
Aire limitée
WRF, MAR
(Grenoble)
En développement
~110 km (T106)
+ physiques idéalisées
+ physiques
« génériques »
+ Physique MAR
Interface physique/dynamique
→ Physique essentiellement verticale
→ Couplage de plusieurs « physiques » avec plusieurs « dynamiques »

3. Splitting / coupling and modularity



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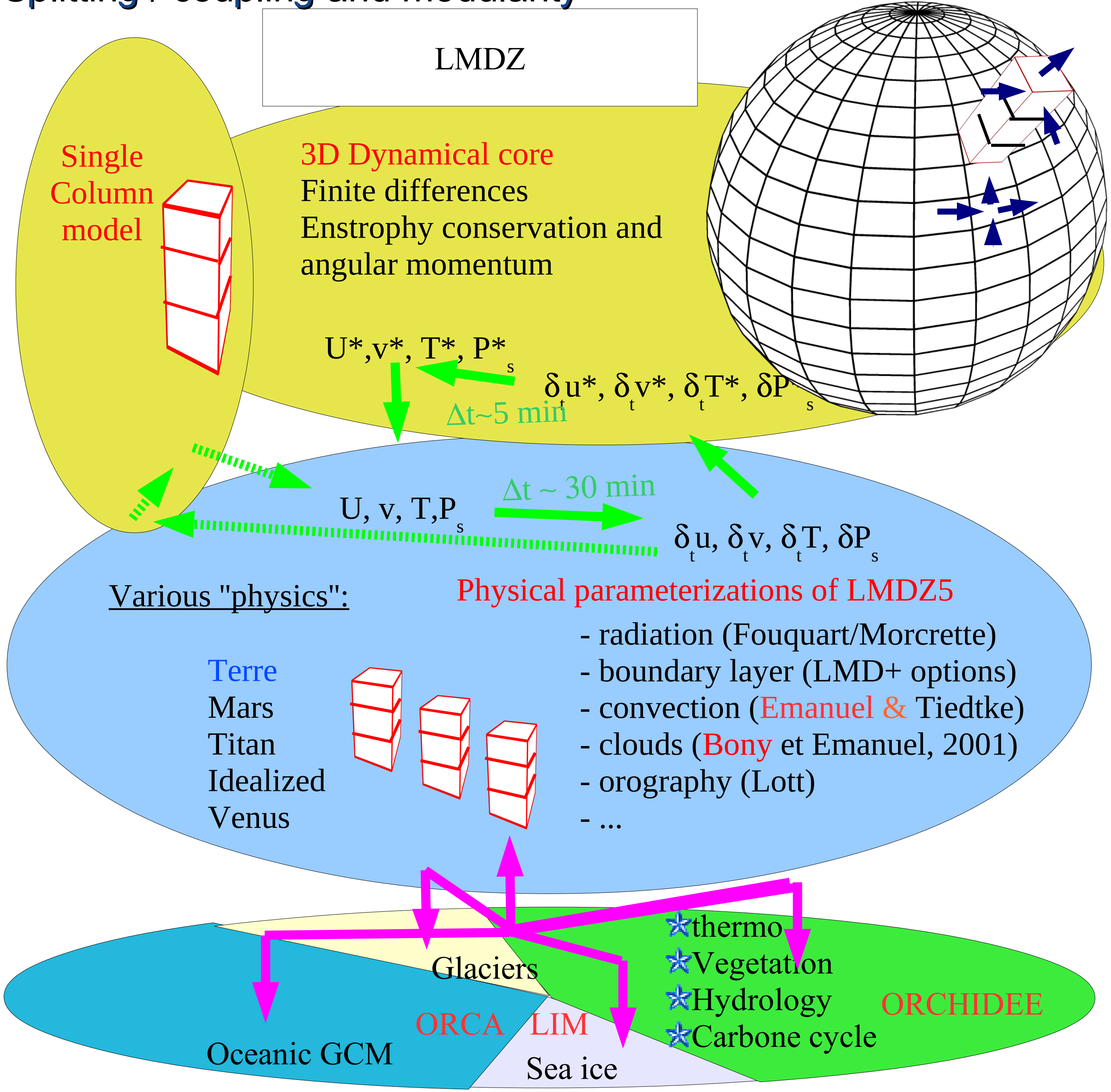

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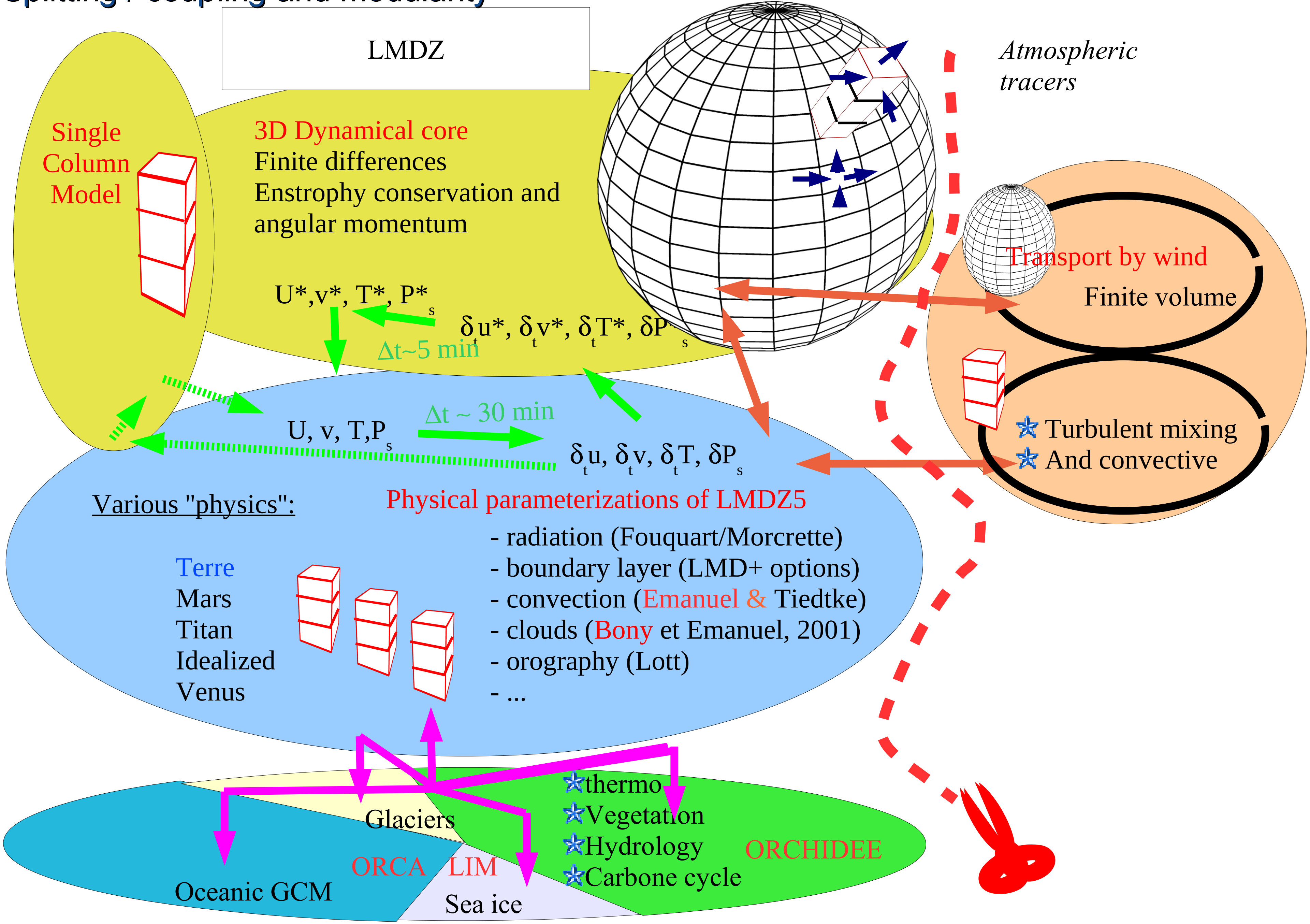

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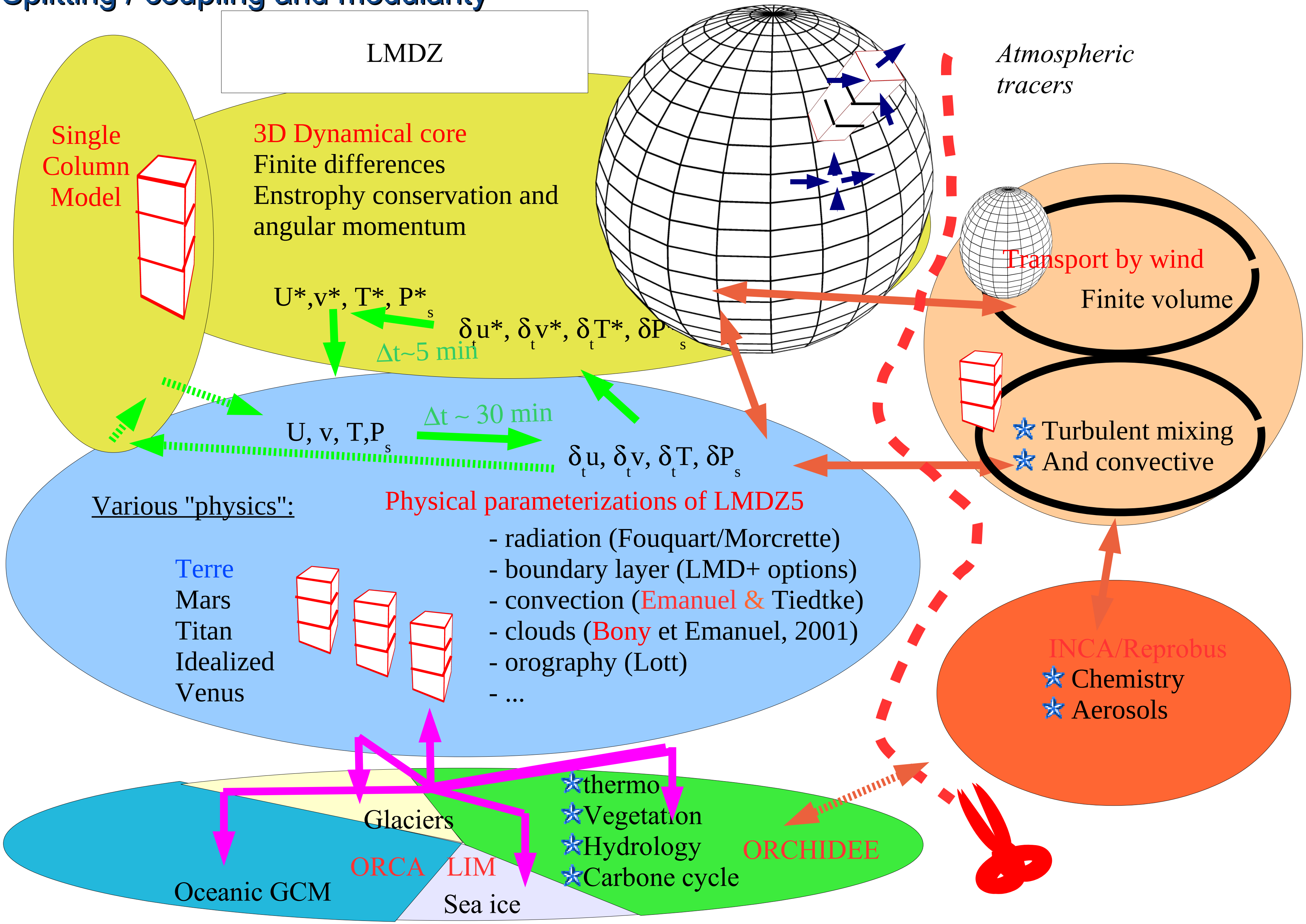

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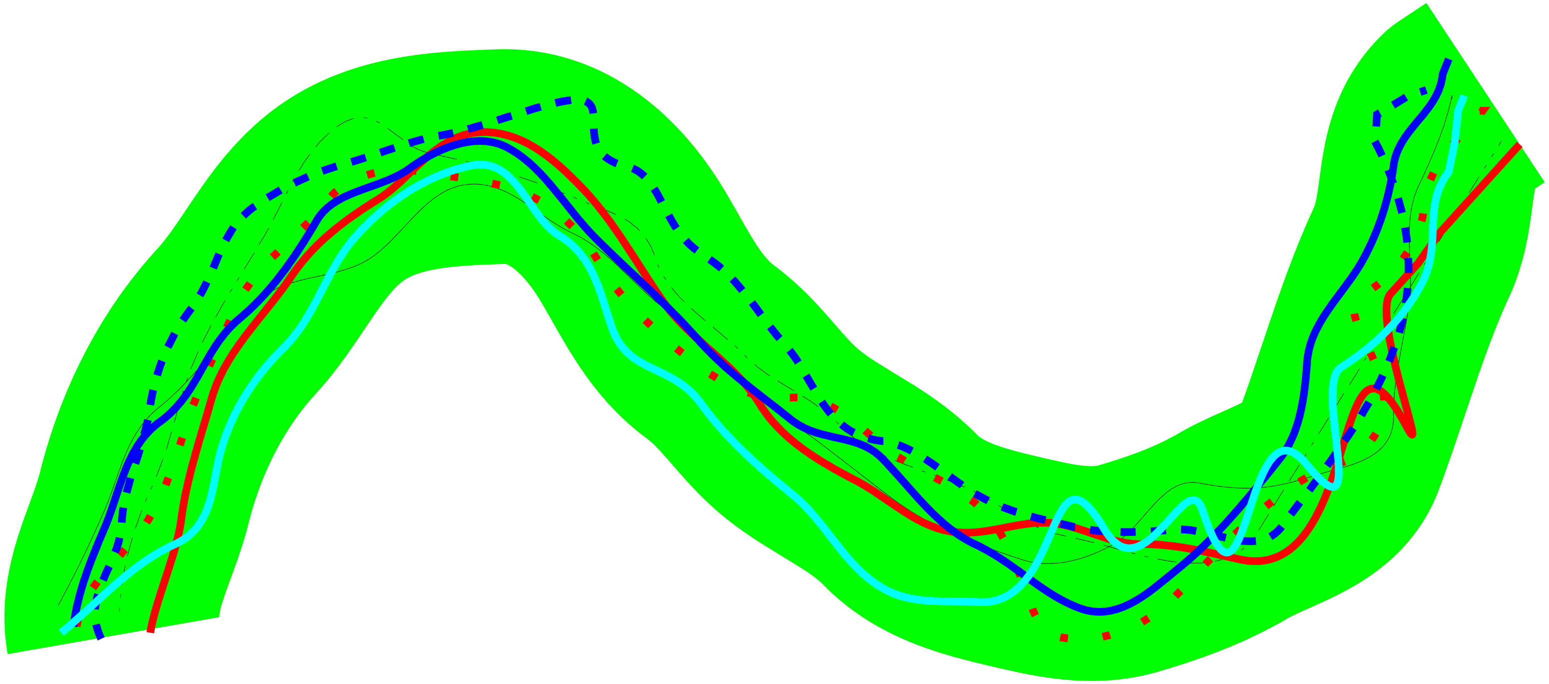
   4. **Operating modes**

4. Operating modes

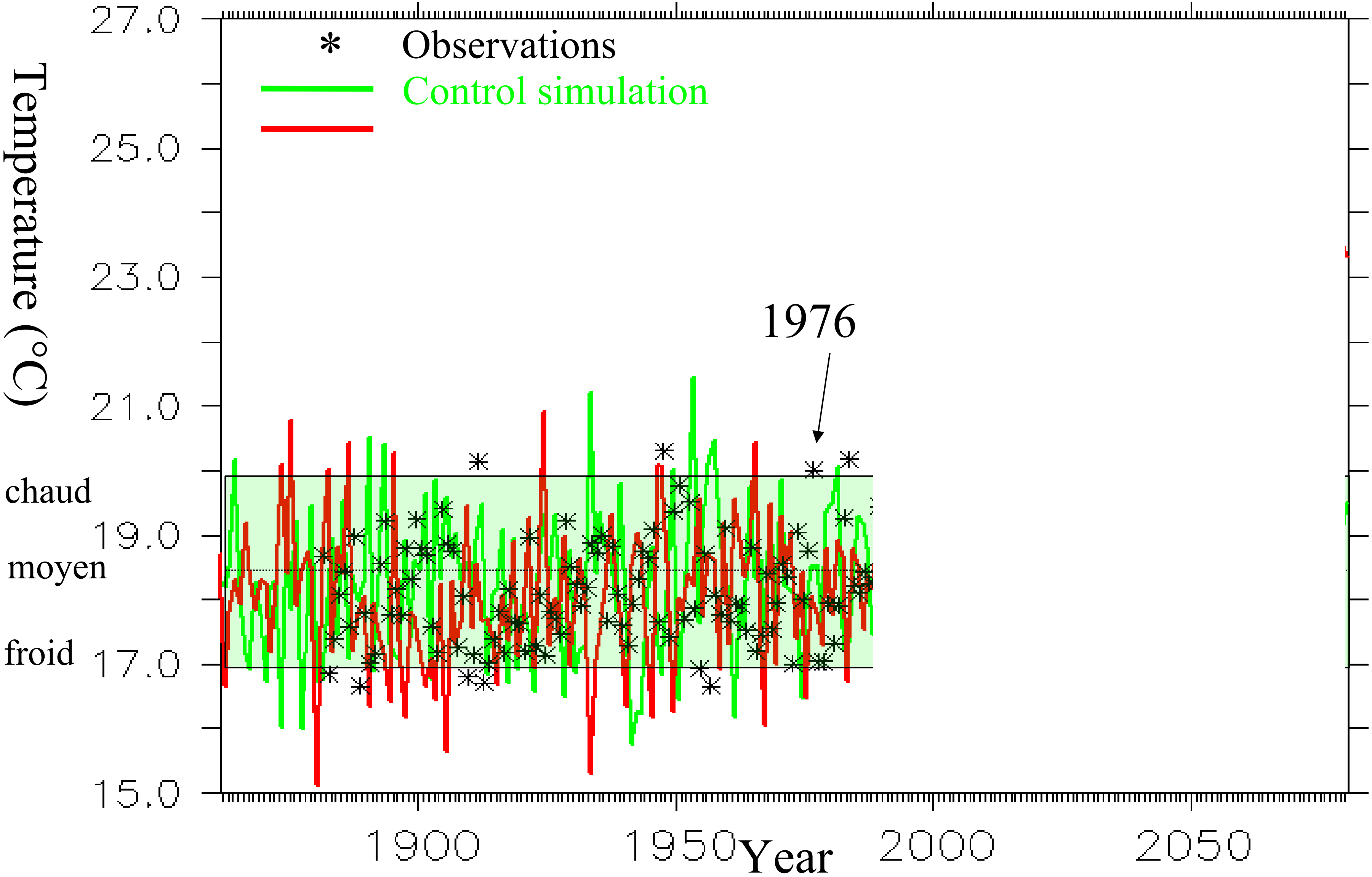
Climate modeling / numerical weather forecast

- **Models** : identical.
- **Duration** : several decades or centuries / 15 days (seasonal forecast in between)
- **Initial state** : any (existence of an attractor : the climate) / “analysis” obtained through an assimilation procedure of observations into the model.
- **Forecast** : statistical (ex : inter-annual variability, intensity of storms ...) / deterministic (the weather of tomorrow).



4. Operating modes

Time evolution of the average summer temperature (°c) over France between 1860 and 2080



(IPCC Scenario SRESA2, IPSL coupled model)

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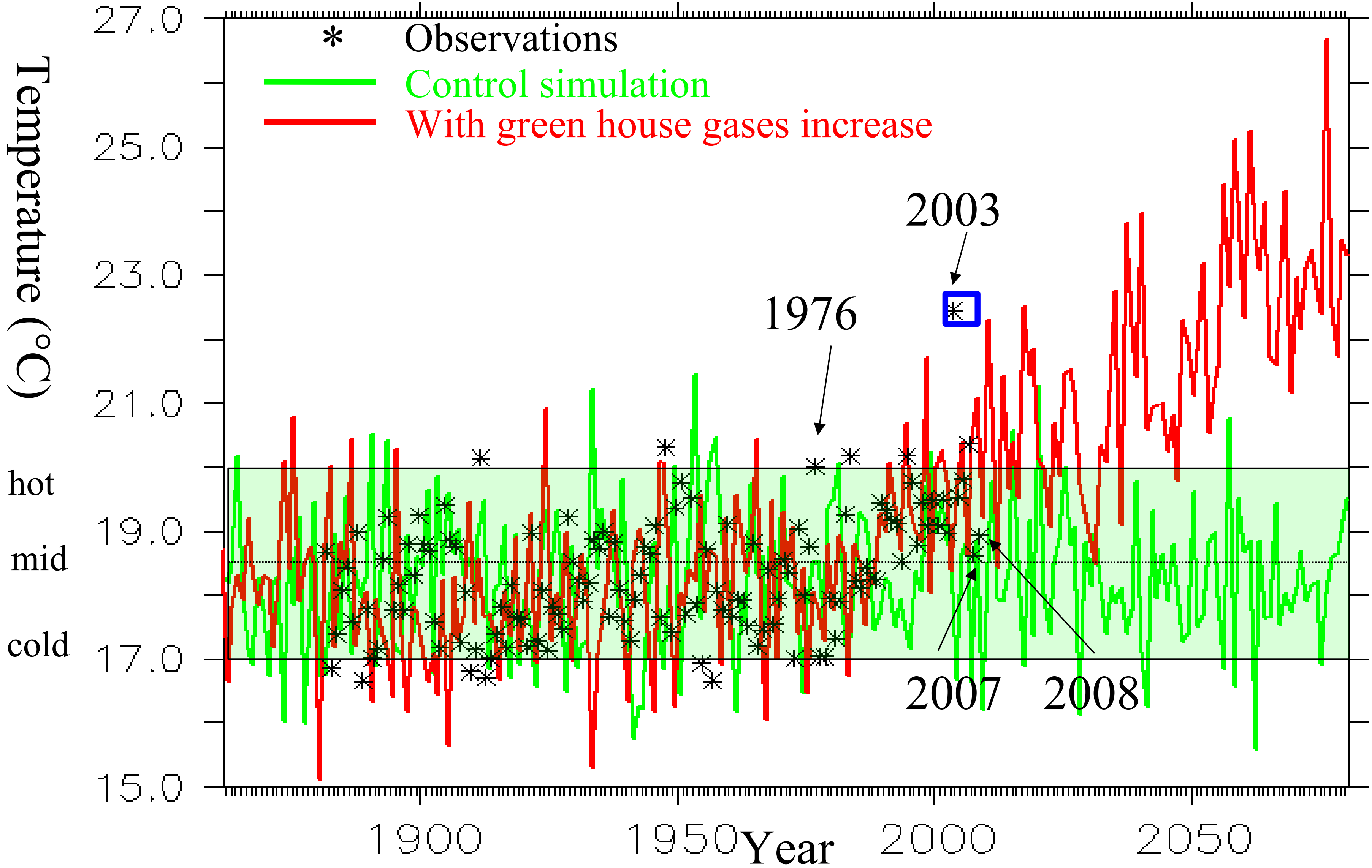

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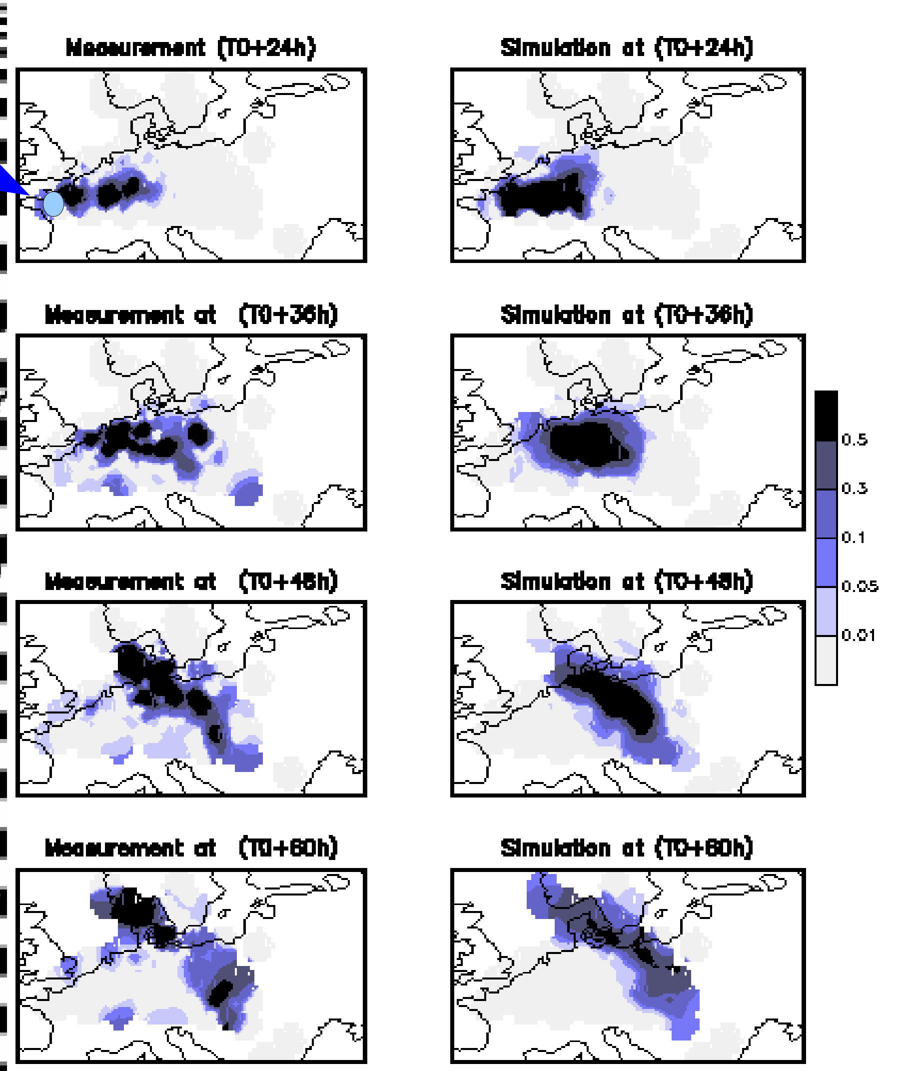
Numerical simulation with LMDZ
Chemical tracer (PMCH) emitted in French Britany (ETEX)



Nudging

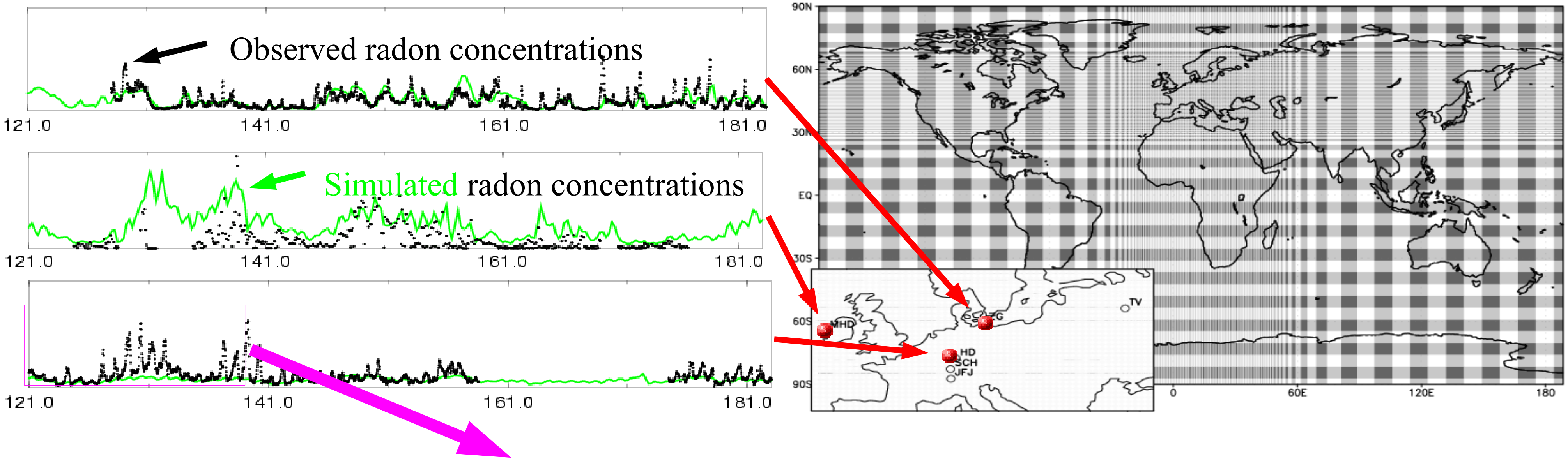
$$\frac{\partial u}{\partial t} = \left.\frac{\partial u}{\partial t}\right|_{GCM} + \frac{u_{analysis} - u}{\tau}$$

$$\frac{\partial v}{\partial t} = \left.\frac{\partial v}{\partial t}\right|_{GCM} + \frac{v_{analysis} - v}{\tau}$$

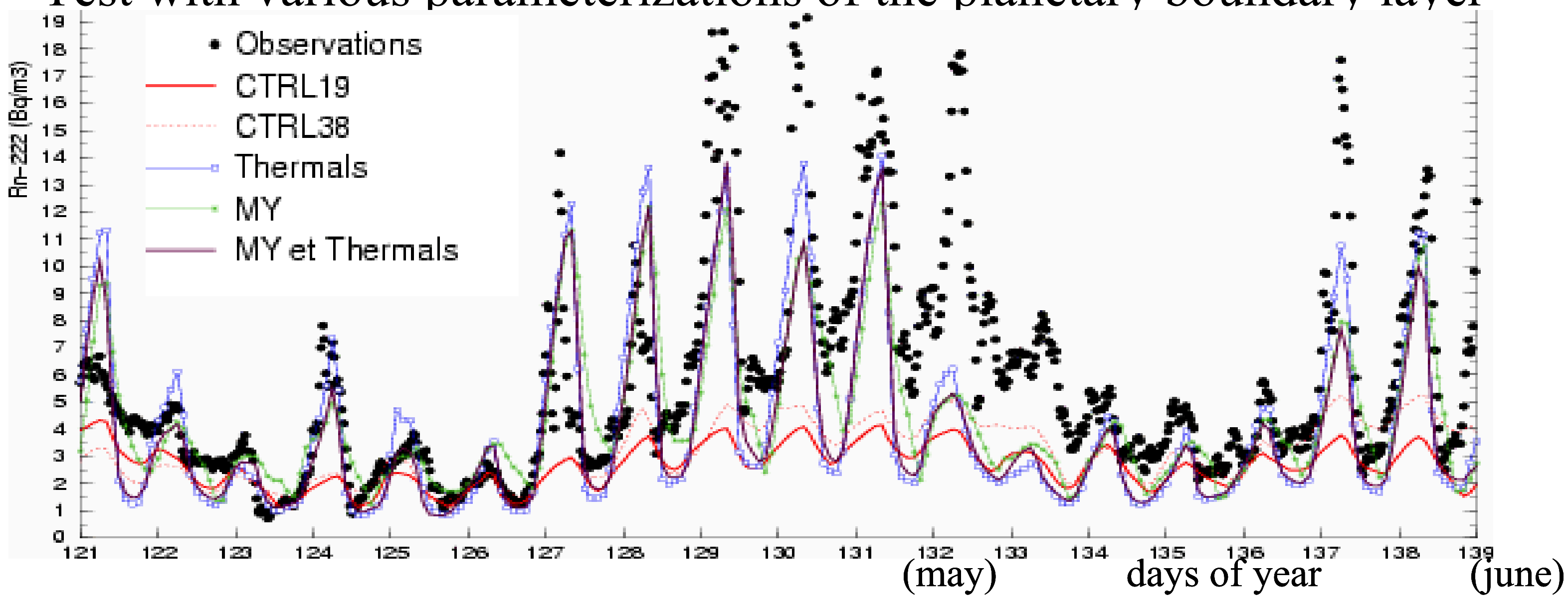
τ Time constant for the relaxation of the model wind toward analyses

$u_{analysis}$ $v_{analysis}$

Simulation of the surface concentration of radon* with LMDZ, nudged by ECMWF winds, with a refined grid over Europe (40x40 km2)



Test with various parameterizations of the planetary boundary layer



* Radon is a tracer of continental air masses, emitted almost uniformly by continents only. Life time of about 4 days.