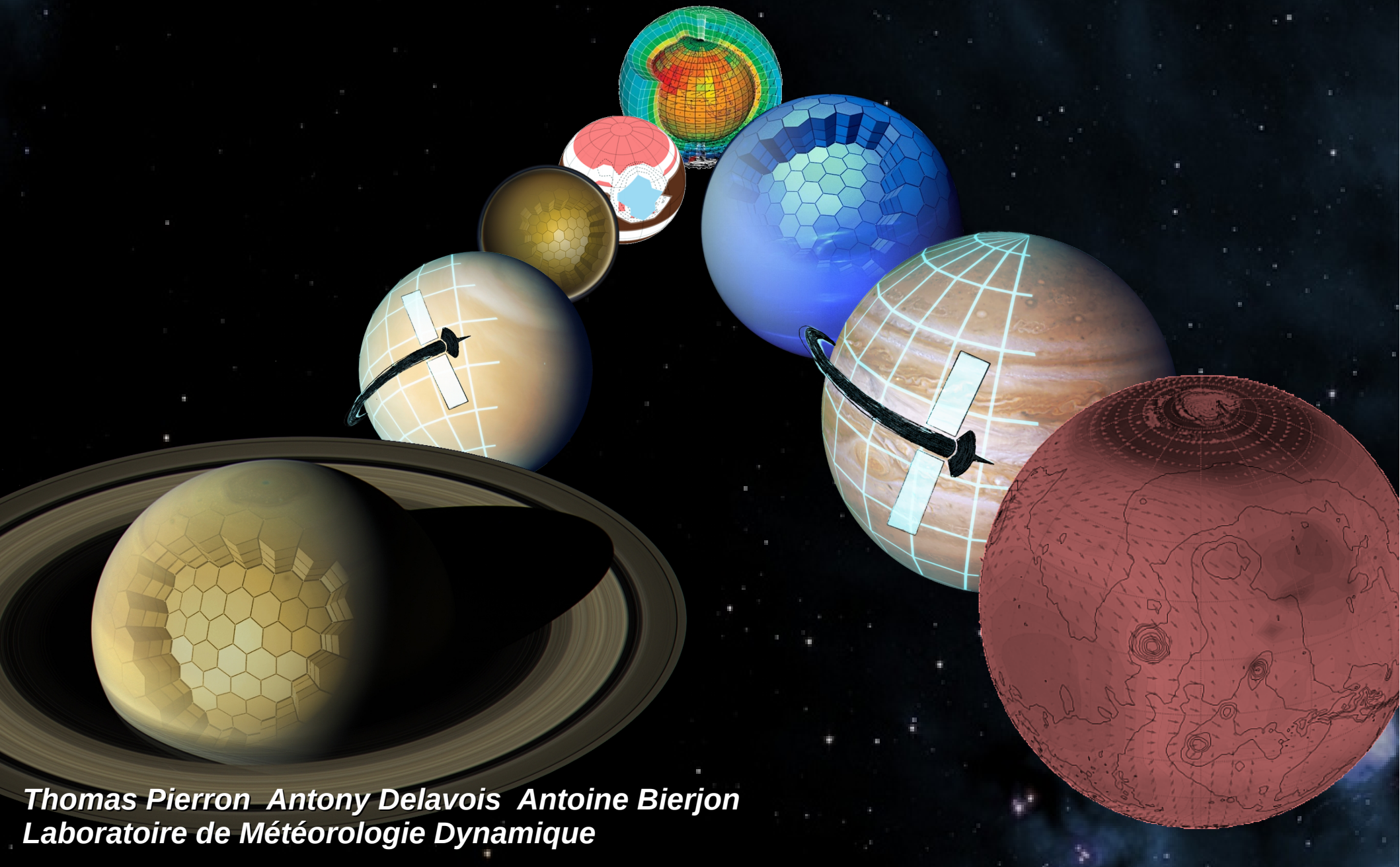
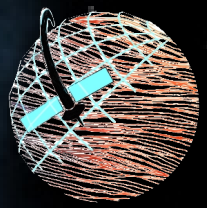
THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS



Thomas Pierron Antony Delavois Antoine Bierjon
Laboratoire de Météorologie Dynamique



THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS

What is a GCM ?

➡ A type of climate model : Mathematical description of the general circulation of a planetary atmosphere

Historical :

➡ 1956 : First climate model by the meteorologist Norman Phillips for the Earth troposphere (USA)

➡ 1970s : First GCM combining oceanic and atmospheric processes by NOAA (USA)

➡ 1975 : LMDZ for Earth by Laboratoire de météorologie dynamique (France)

➡ 1980s : Community Atmosphere Model (CAM) by the National Center for Atmospheric Research (USA)

➡ 1990s : Development of planetary GCMs at LMD

THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS

What does it do ?

➡ **Allows to make simulations of any planet atmosphere evolution during a chosen amount of time**

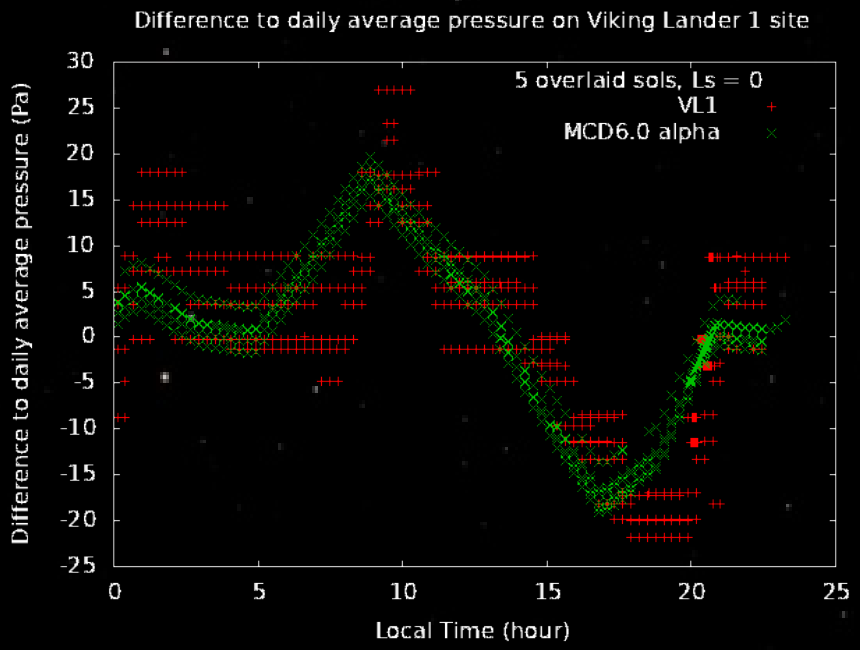
Output values : Surface pressure, temperature, wind velocity, mixing ratio of atmosphere components etc...

2D ➡ 4D fields

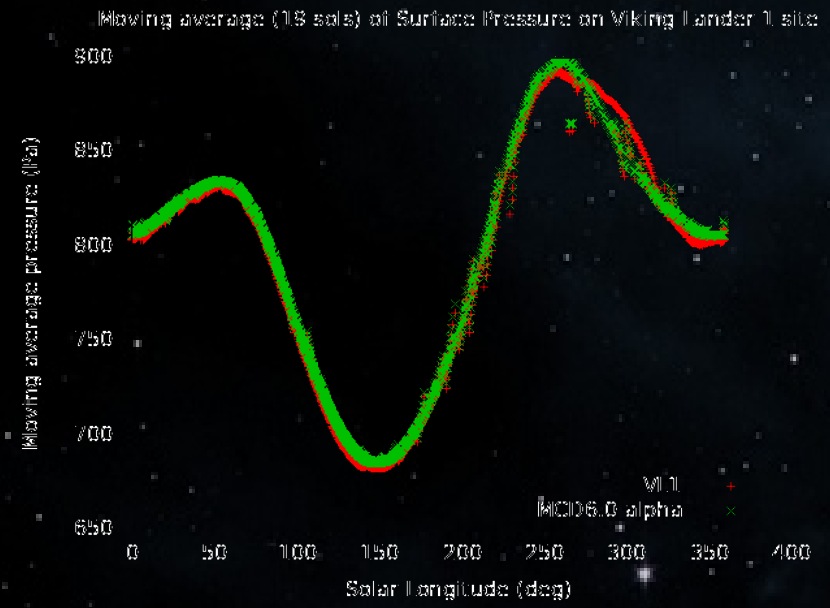
THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS

Two different kinds of studies :

Meteorology



Climatology



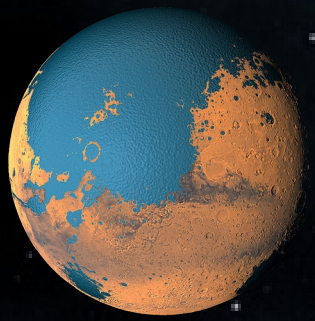
Climatology : statistical study of meteorology → Database : MCD, VCD...

THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS

What is it used for ?

➡ **Study of future and current evolution of climate :**

- Climate change on Earth
- Intensification of Jupiter’s storms
- Huge hurricanes on Saturne...



➡ **Study of planetary paleo climate :**

- Oceans on Mars
- Past habitability of Venus
- Planetary atmosphere formation…

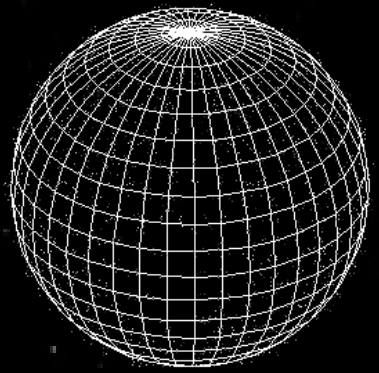
➡ **Spatial exploration of our solar system :**

- Orbiters : ExoMars TGO, EnVision (Venus), Cassini-Huygens (Saturne)...
- Landers : Phoenix (Mars), Venera (Venus), Cassini-Huygens (Titan)...

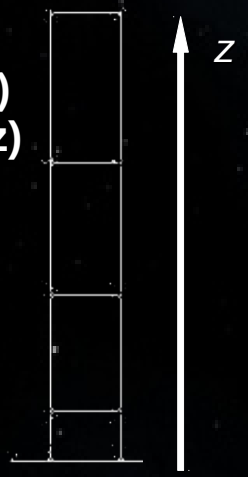
THE LMD GLOBAL CLIMATE MODELS : TOOLS FOR A BETTER UNDERSTANDING OF A PLANETARY PHYSICS

How does it work ?

Dynamics



Physics

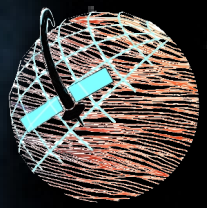


Tendencies due to :

- radiative transfer
- condensation
- subgrid dynamics
- ...

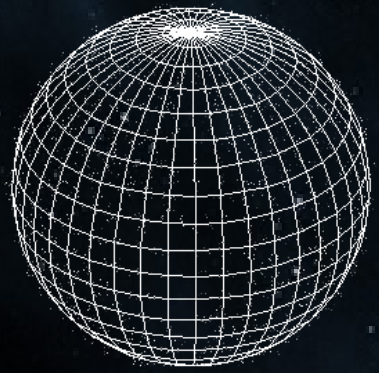
★ At each time step : call dynamics to calculate the tendency ➡ Integration

★ Every i_phys time step : call physics, calculates the evolution of physical variables and returns tendencies ➡ Integration



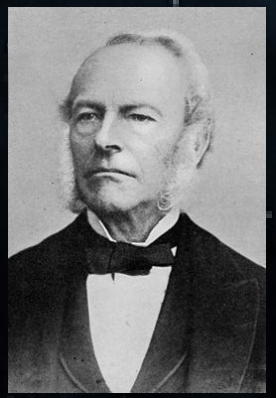
THEORETICAL BASES

Dynamics ?



- Large scale motion of a fluid in a rotating frame

- Based on Navier Stokes equations



➡ **Continuous equations with no analytical solution**

- 3D grid : welcome to the discretized world

➡ **Resolution, time step ?**
Numerical scheme, dissipation ?

THEORETICAL BASES

Dynamics : The Navier Stokes equations

Momentum Budget $\partial_t \mathbf{u} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho_0} \nabla p + \nu \nabla^2 \mathbf{u}$

Mass conservation $\nabla \cdot \mathbf{u} = 0$

+

Thermodynamics
Gravity
Coriolis
Tracer Advection (Van Leer I,1977)
...

+

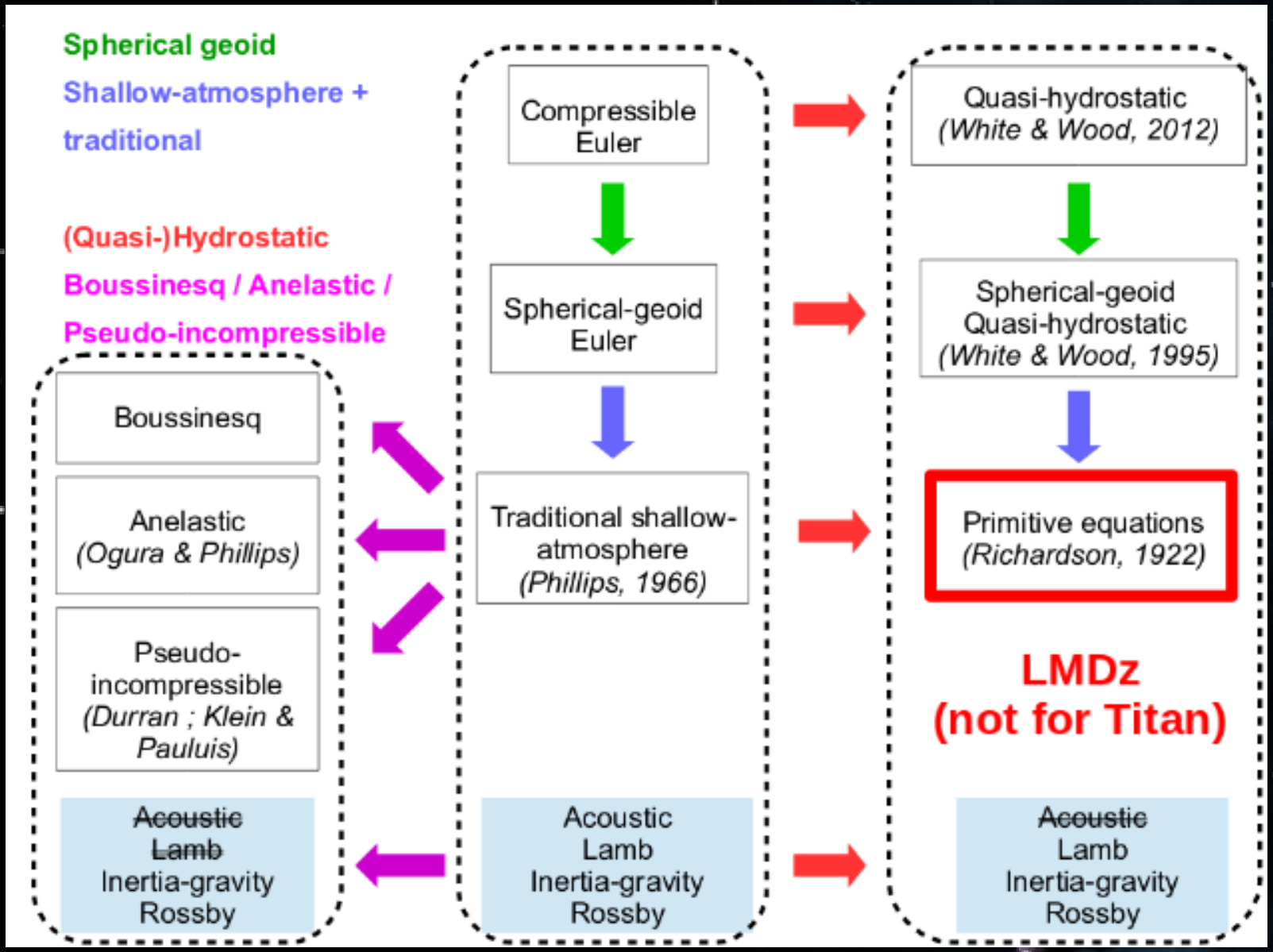
Hypotheses (next slide)

Primitive Equations of Meteorology

Not yet able to compute...

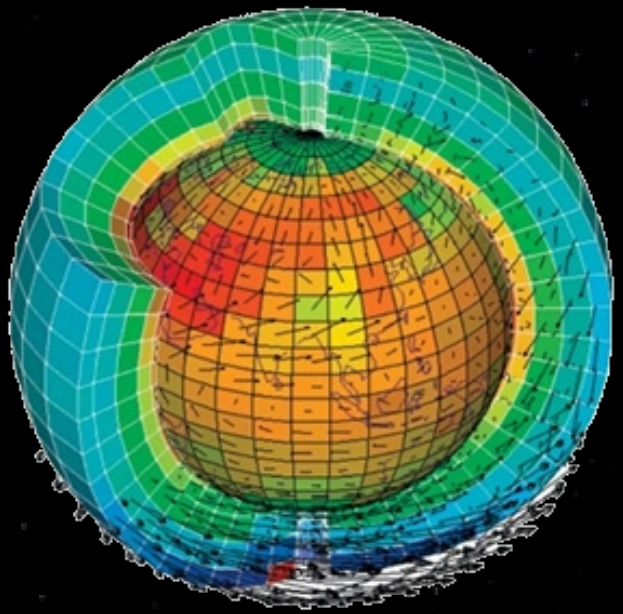
Discretisation needed

HYPOTHESES



Courtesy of T.Dubos, LMD

THE DIGITAL DYNAMICAL PART

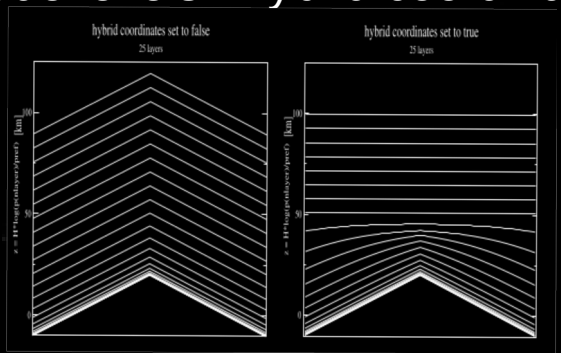


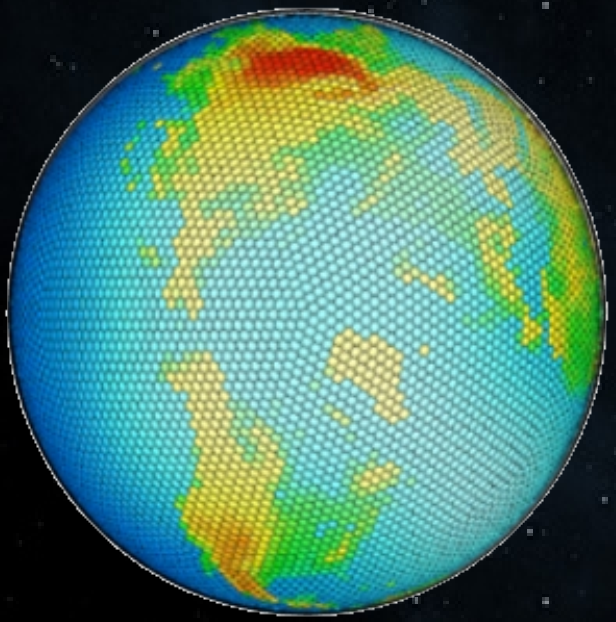
LMDz :

Longitude / Latitude 3D grid

Resolution : 64x48x73 : Mars

Altitude levels : hybrid coordinates





Dynamico :

A new dynamical core

Based on icosahedral meshing

Massively parallel computation

Saturn, Jupiter, Venus and soon Mars !

Resolution: 0.5° = 500 km Saturn

THE DIGITAL DYNAMICAL PART

Dynamics : Numerical schemes

- **Finite Differences (Leapfrog-Matsuno) for dynamics**
- **Finite volumes for tracers advection**
- **Time step depends on resolution : stability**

Variables :

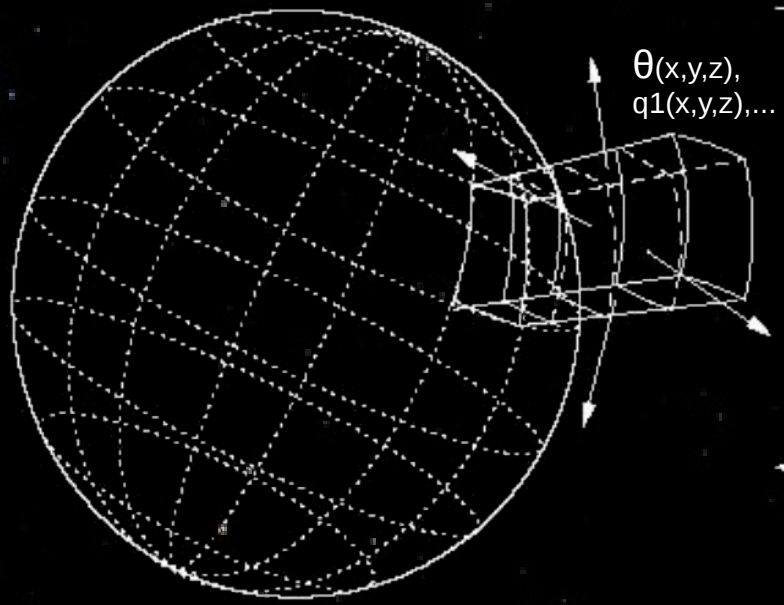
winds, T°, ps ,tracers

Computed at grid points

Mean values

How are represented sub-scale processes ? **Physics !!!**

PHYSICAL PARAMETRIZATIONS



θ(x,y,z),
q1(x,y,z),...

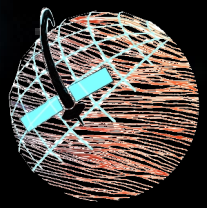
Dynamical state variables

Physical fields
(surface and subsurface variables, integrated column variables, some 3D tracers...)

Tendencies due to :
- radiative transfer
- condensation
- subgrid dynamics
- ...

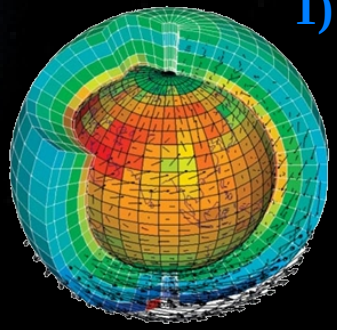
Dynamical grid

Physical « grid »



PHYSICAL PARAMETRIZATIONS

1) Dynamical Tendencies

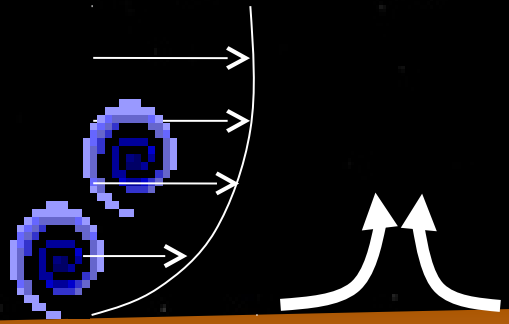


2) Radiative transfer:

- High Atmosphere EUV absorption
- VIS & NIR absorption
- Thermal IR absorption/emission
- (Non) Local Thermodynamic Equilibrium
- Aerosols
- Rings shadowing

3) Subgrid scale dynamics

- **Turbulence, Boundary Layer**
- **Convection :** “Thermals” + “Convective Adjustement”
- **Gravity waves (orographic + low level drag + non-orographic)**



4) Surface and subsurface thermal balance

5) Volatiles:

CO2, H2O, Sulfur, CH4, …
cycles & microphysics

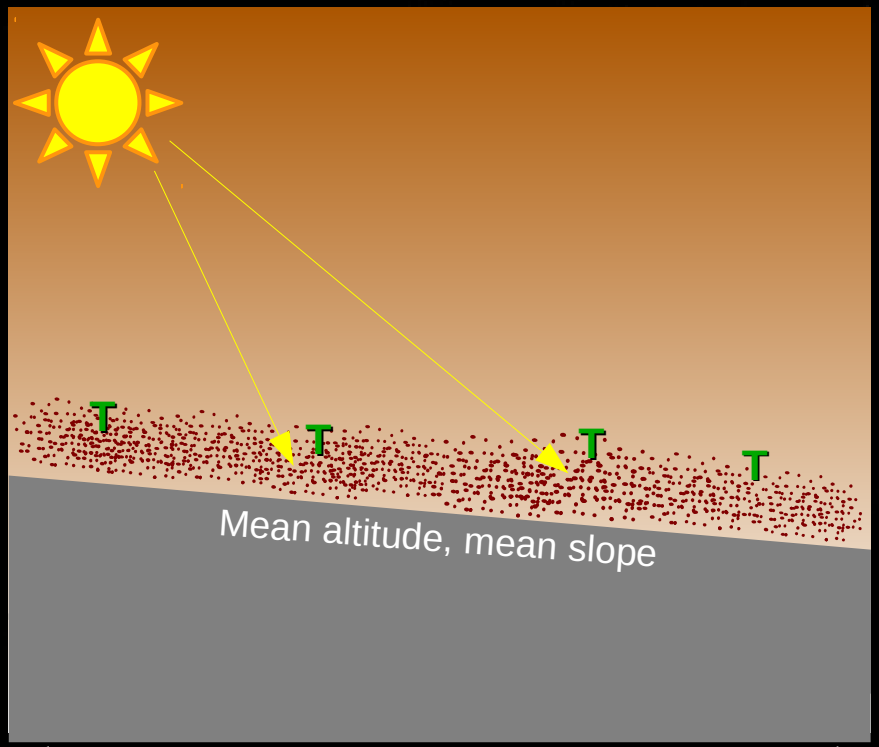
6) Aerosol transport and distribution

AND A LOT MORE !

Forget and Lebonnois (2013), “Comparative Climatology of Terrestrial Planets” book, Univ of Arizona press 2013.

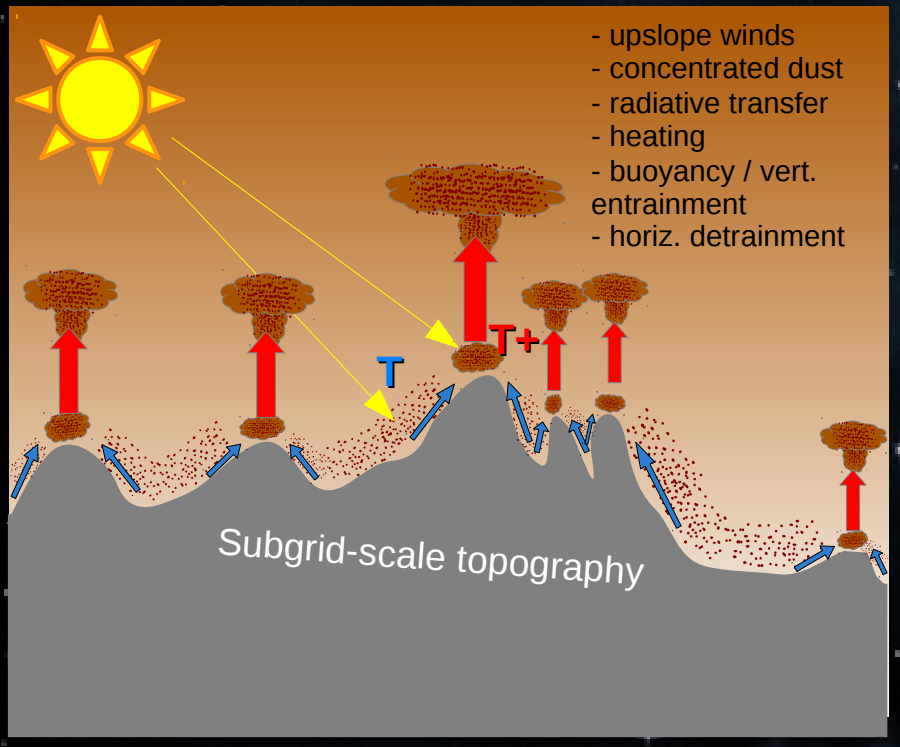
PHYSICAL PARAMETRIZATIONS :
Example of subgrid-scale dust entrainment by slope winds

Grid scale



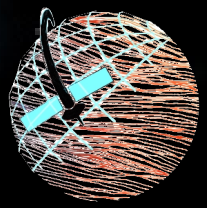
One cell
~300x200km²

Subgrid scale



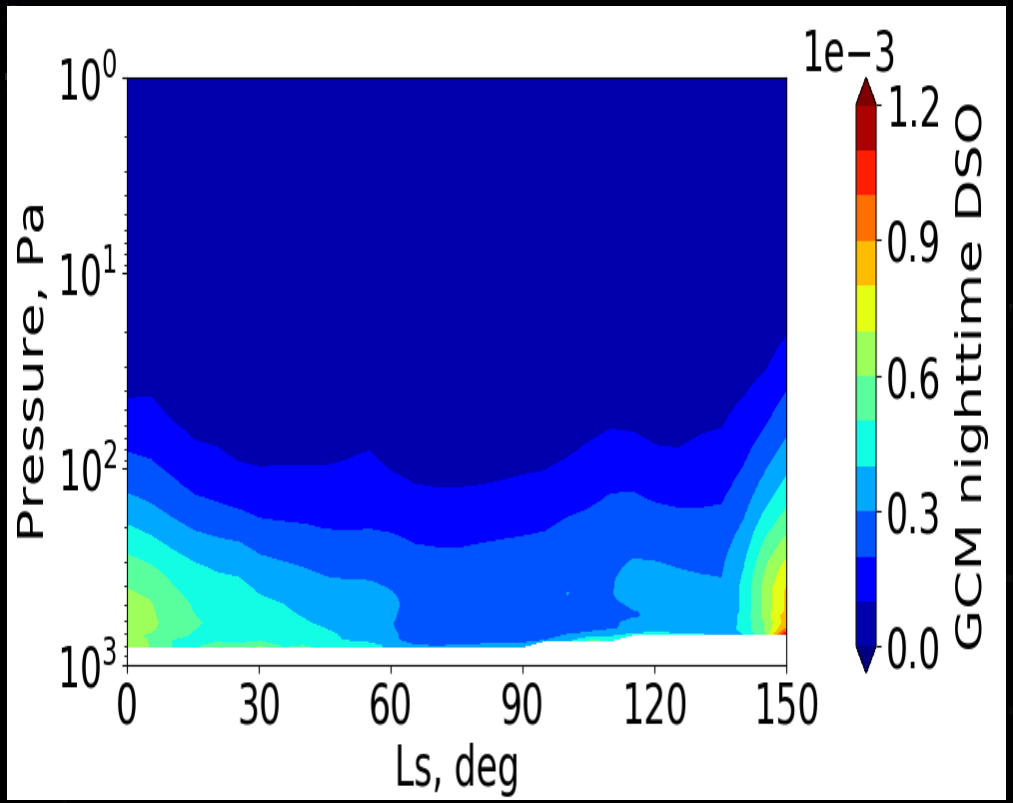
One cell
~300x200km²

Margaux VALS (2019), "Modélisation Numérique des Cycles de l'Eau et des Poussières de la Planète Mars et de leurs Couplages." thesis, Sorbonne Universités.

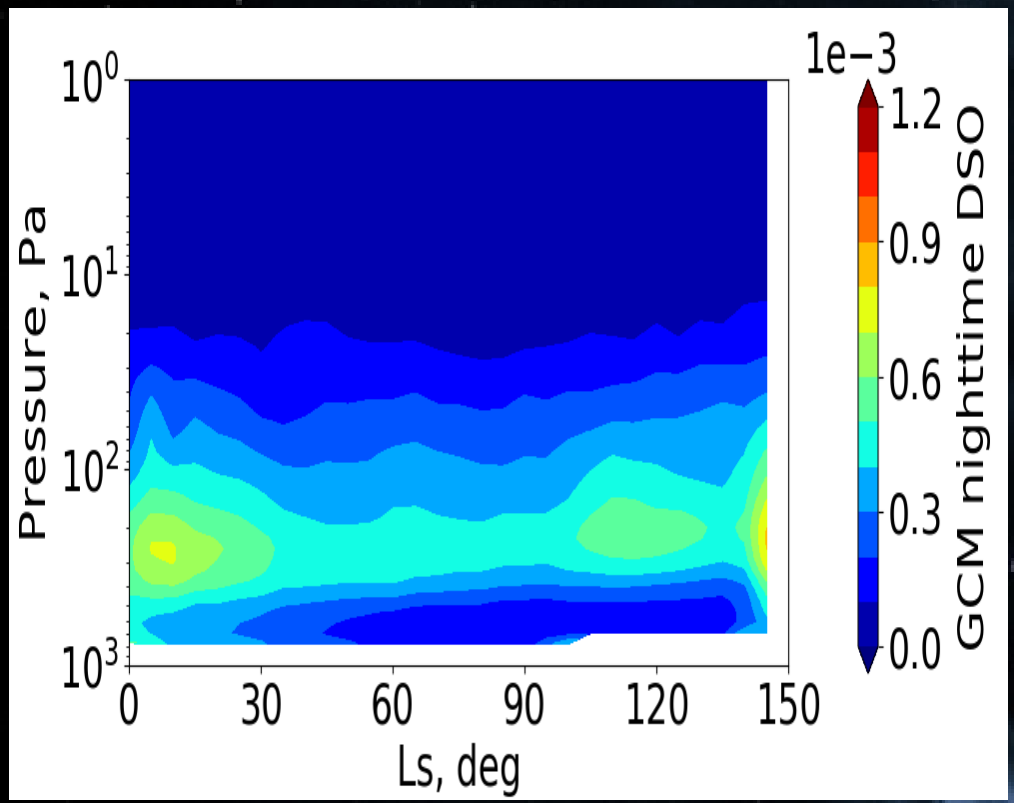


PHYSICAL PARAMETRIZATIONS :
Example of subgrid-scale dust entrainment by slope winds (2)

GCM dust
without the parametrization



GCM dust
with the parametrization



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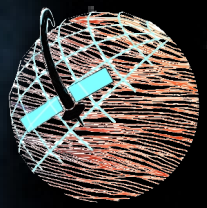

CONCLUSION

➡ **GCM : Mathematical and numerical climate model**

- Exists since 1970s in climatology and meteorology
- Used for solar system exploration and climate studies
- Composed of two distinct parts but related :

➡ **Dynamics :**

- Common to all planetary body
- Based on Navier-Stokes Equations
- 3D grid (LMDZ, Dynamico…)

⇒ **Ensures the horizontal transport from adjacent cells**

Physics coupled with the dynamics

➡ **Physics :**

- Specific to each planetary body
- Depends on the interactions that take place (radiative transfer, chemistry, gravity waves...)

⇒ **Juxtaposition of independent vertical 1D columns**