The LMD Mars Global Circulation Model and Mars Climate Database

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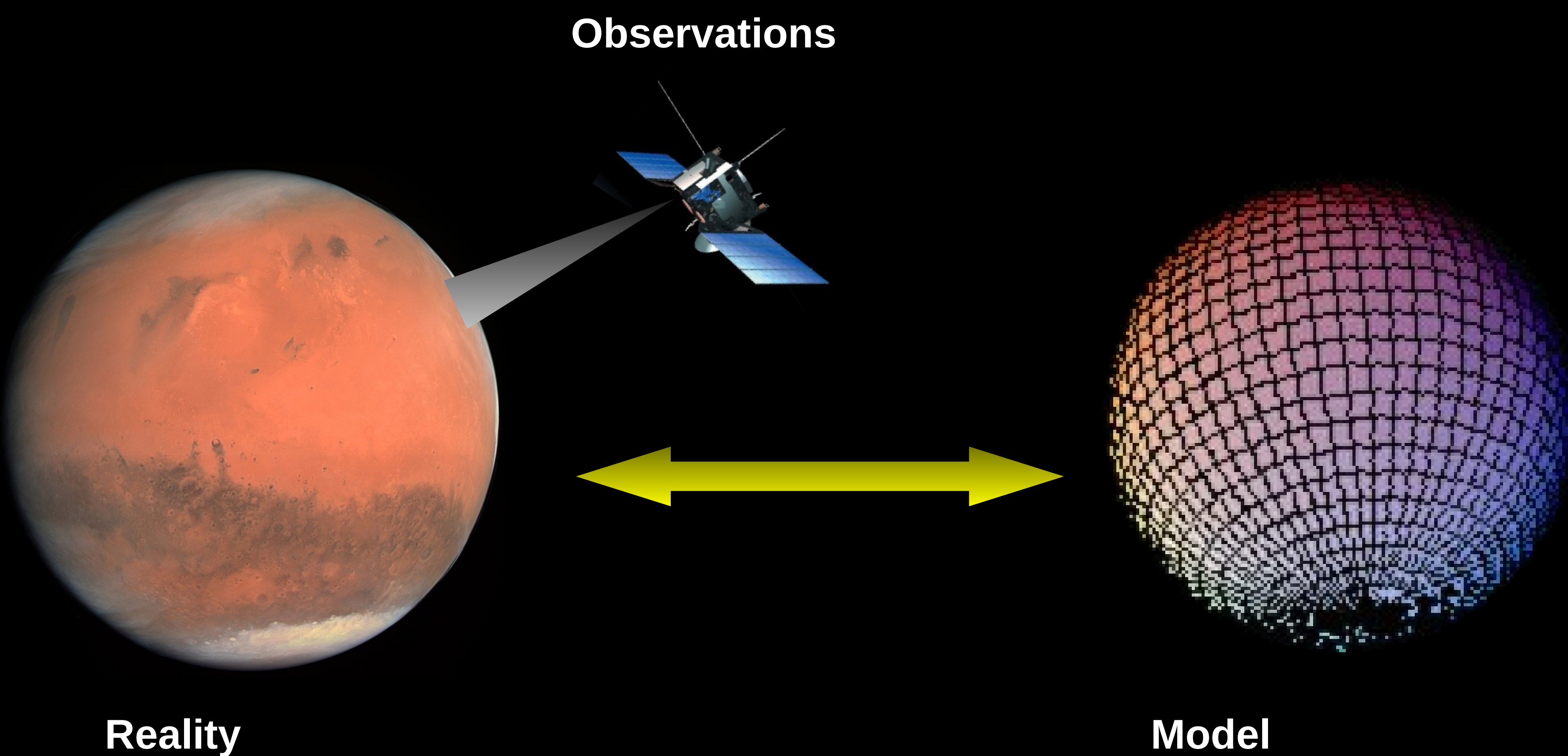
The LMD Global Circulation Models

a brief history of LMDZ

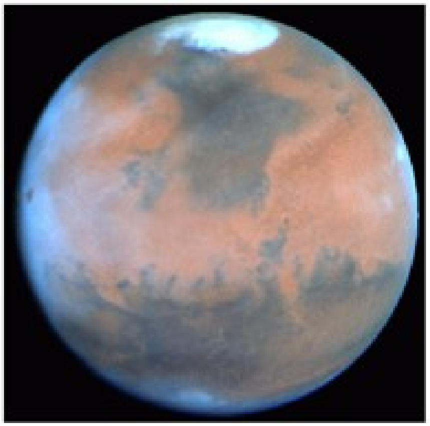
- The Pioneers : in the 1960s-70s : Robert Sadourny and Phu Le Van (Sadourny, 1975)
- The LMD5/LMD6 model : 1980-1985 (Laval, 1981)
- 1985 : Rewriting of the dynamical core : modularity and zoom (the previous version had been written over punch cards with a very small RAM memory).
- 1990 : versions for Mars, Titan, and a generic 20-parameter version (Frédéric Hourdin).
- 1992 : decision to develop the terrestrial model on the basis of this new dynamical core by adapting the physical package of LMD5/6
  => planetary and Earth versions of LMDZ grow in different directions
- 1990s-2000s : Development of Earth, Venus, Mars, Titan models
- 2008 : development of a « generic » GCM to study exoplanets (but also Early Mars, Early Earth, … and now the stratosphere of gas giants).
- 2011-now : start working on getting all versions to converge (use a common dynamical core) into a main framework to benefit from improvements in all directions (e.g. : parallelism of the code, new dynamical core).

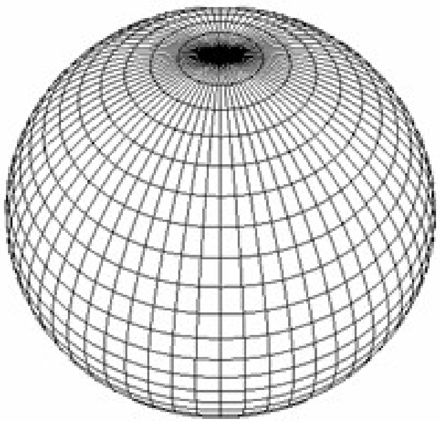
Building a “virtual” Mars

Objective : to accurately simulate the details of Mars meteorology based on physical equations



Overview of our General Circulation Model for Mars





1) Hydrodynamical code

⇒ ***to compute large scale atmospheric motions***

LMDZ **grid point model :**

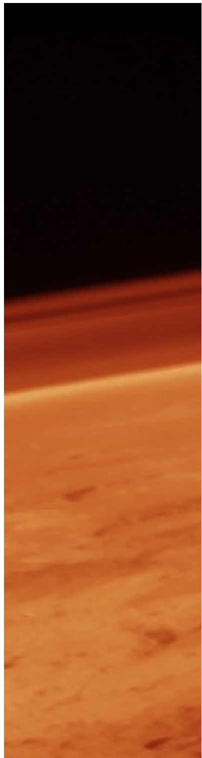
Typical horizontal resolution **64x48 (+possibility of zoom)**

2) Physical parameterizations

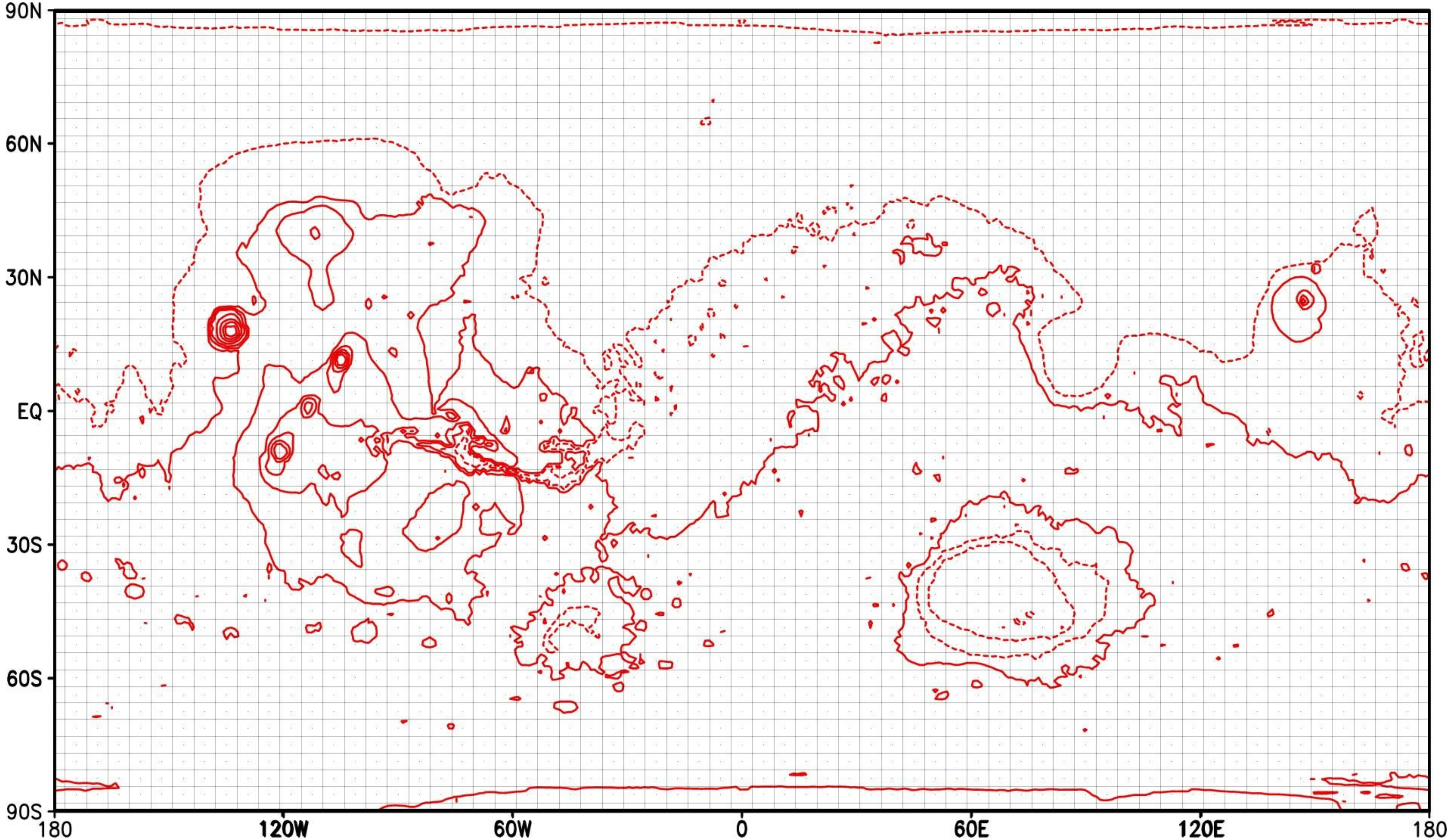
- ⇒ ***to force the dynamic***

⇒ ***to compute the details of the local climate***

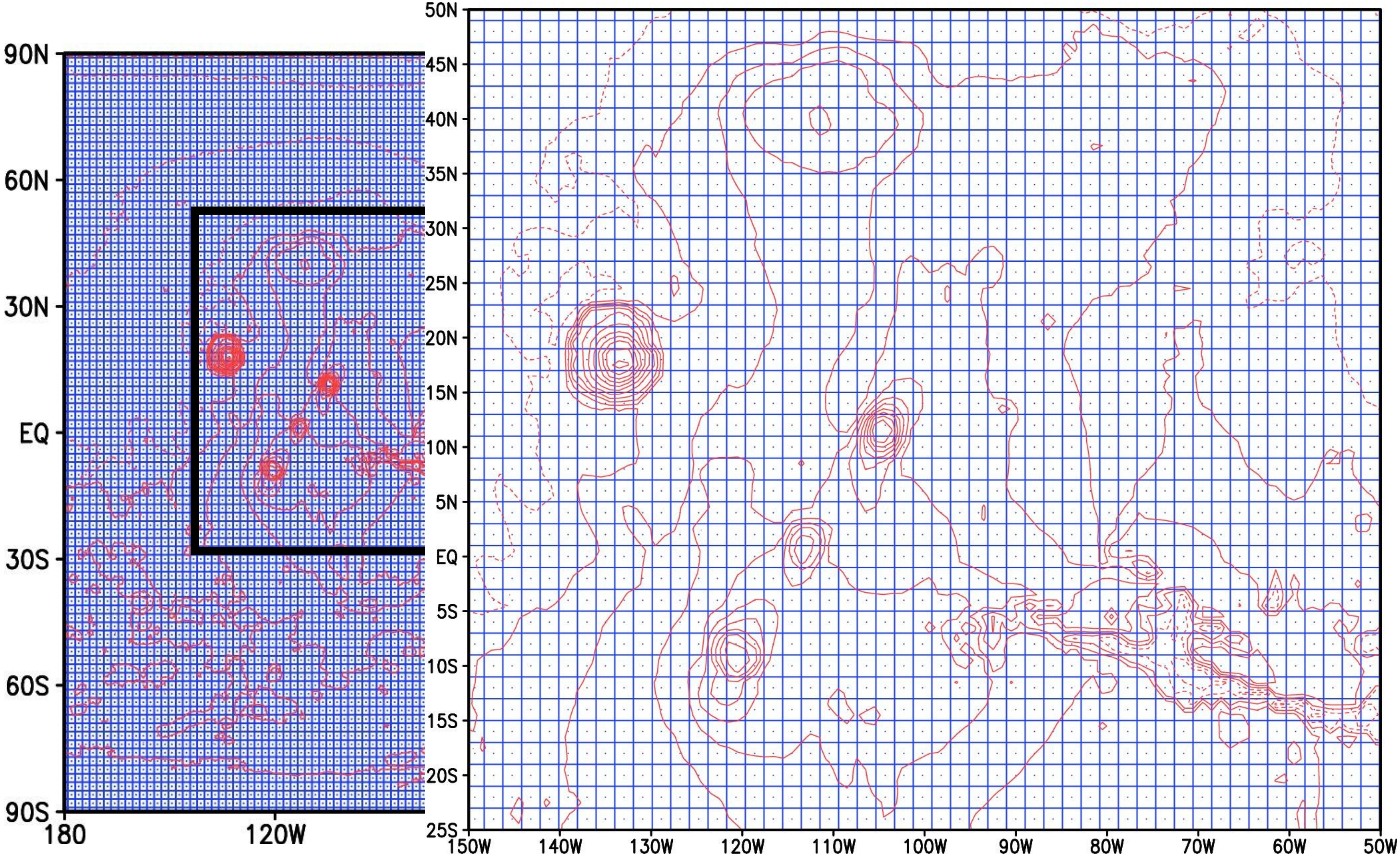
- **Radiative heating & cooling of the atmosphere (solar and thermal IR) by CO_2 and dust**
- **Surface thermal balance**
- **Subgrid scale atmospheric motions: Turbulence in the boundary layer, convection, orography drag, gravity wave drag**
- **Condensation of CO_2**
- **Water ice clouds and their radiative effect**
- **Chemistry, thermosphere, ...**



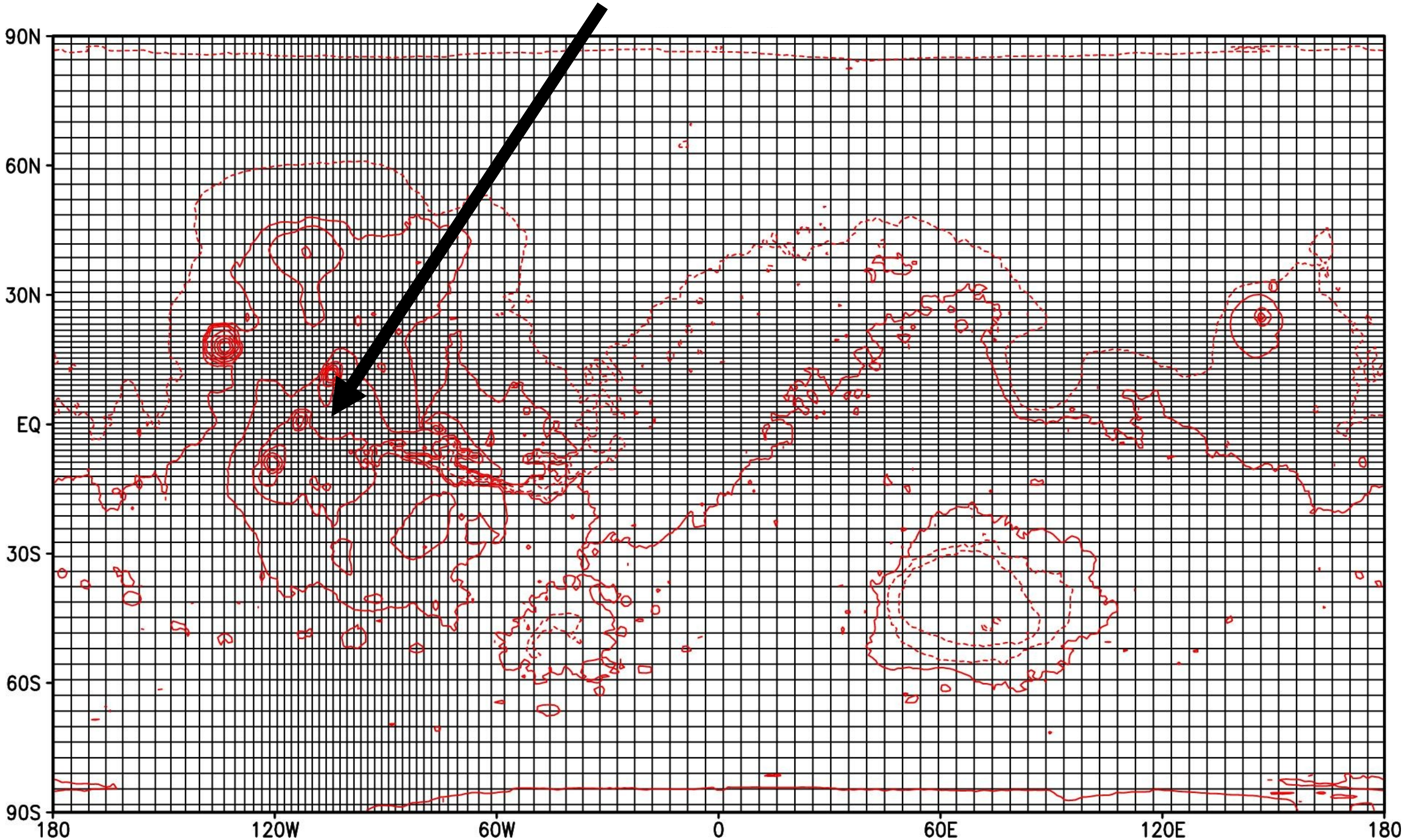
Horizontal grid of the LMD Mars GCM
the 64x48 “standard resolution” : 5.625°× 3.75°



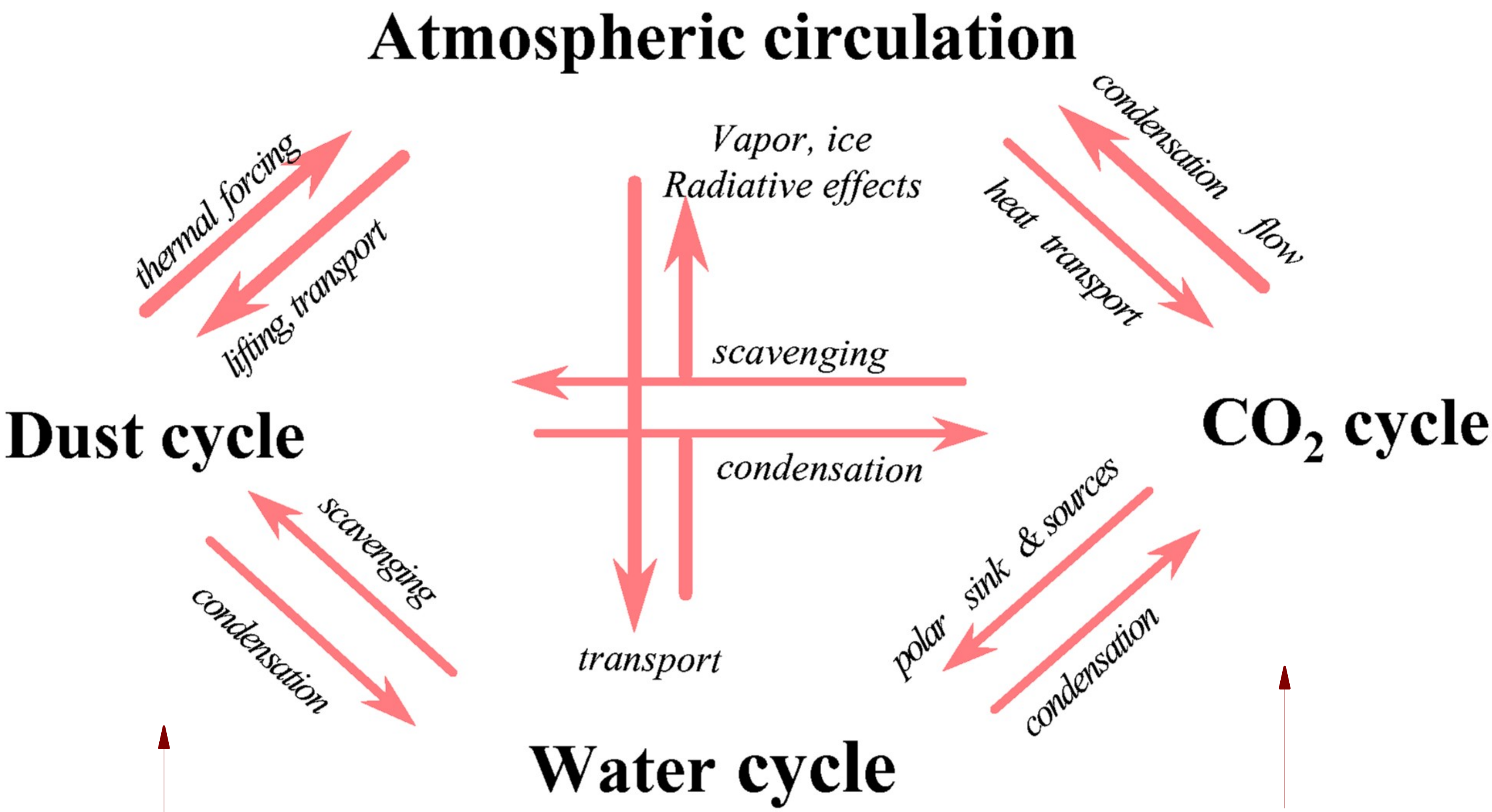
LMD Mars GCM at “high” resolution : 184x90
2°× 2°



GCM : Zoomed grid (96x68) to locally reach higher resolution (1.8°× 0.6°) at reduced cost:



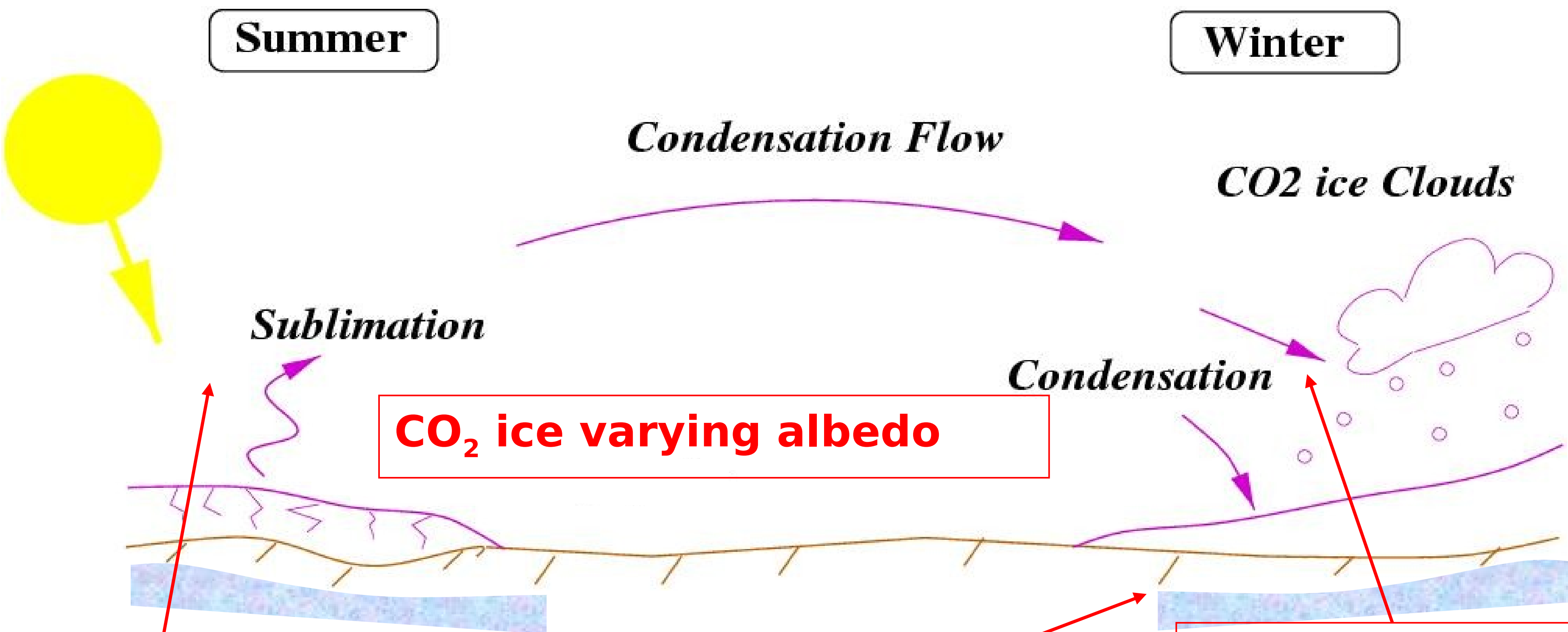
Mars climate : a complex system



Upper atmosphere processes and ionosphere

Photochemical cycle

Modeling the Martian CO_2 cycle



CO_2 ice varying albedo

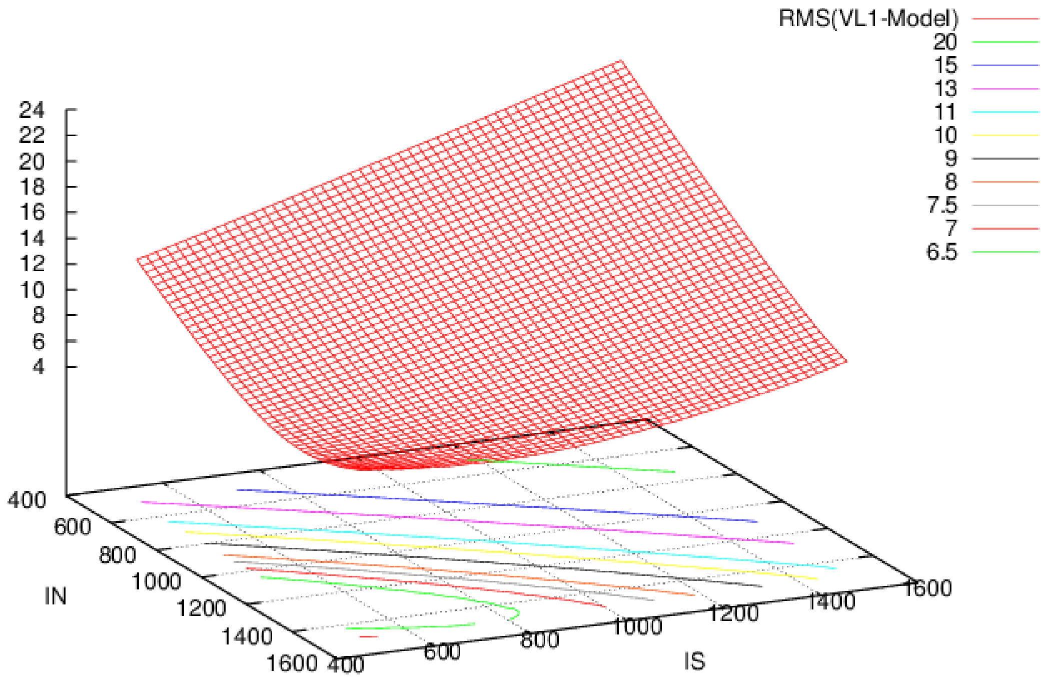
Non condensable gaz depletion

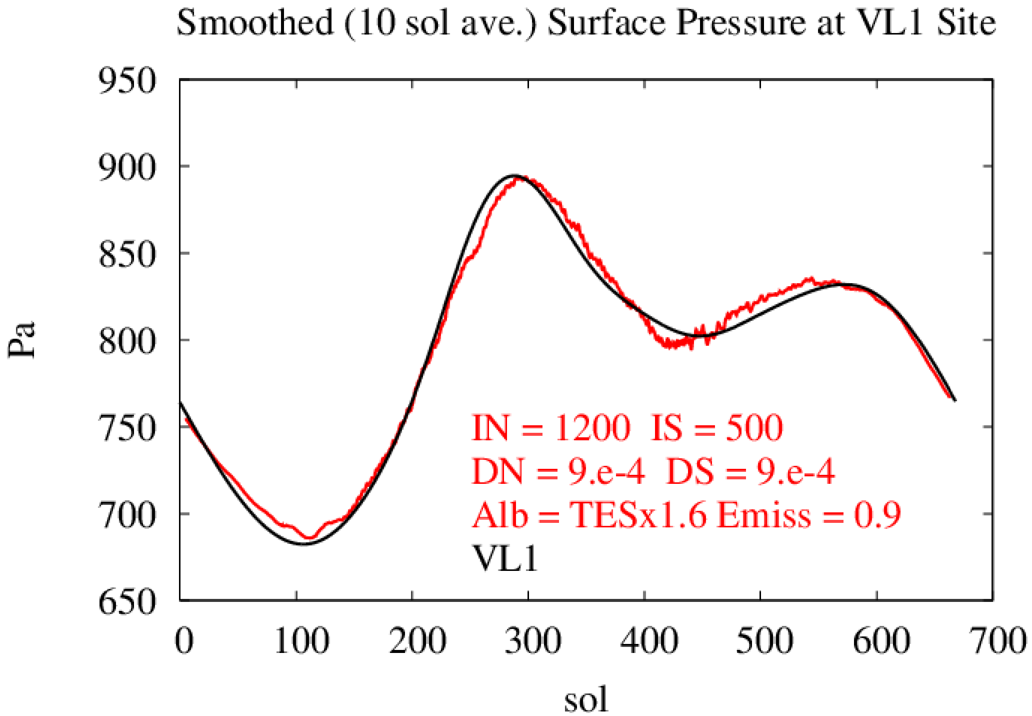
Storage of heat in subsurface water ice

Non condensable gaz enrichment and induced convection

Modeling the Martian CO_2 cycle

Goal: to obtain a good fit of the surface pressure as measured by Vicking Lander 1



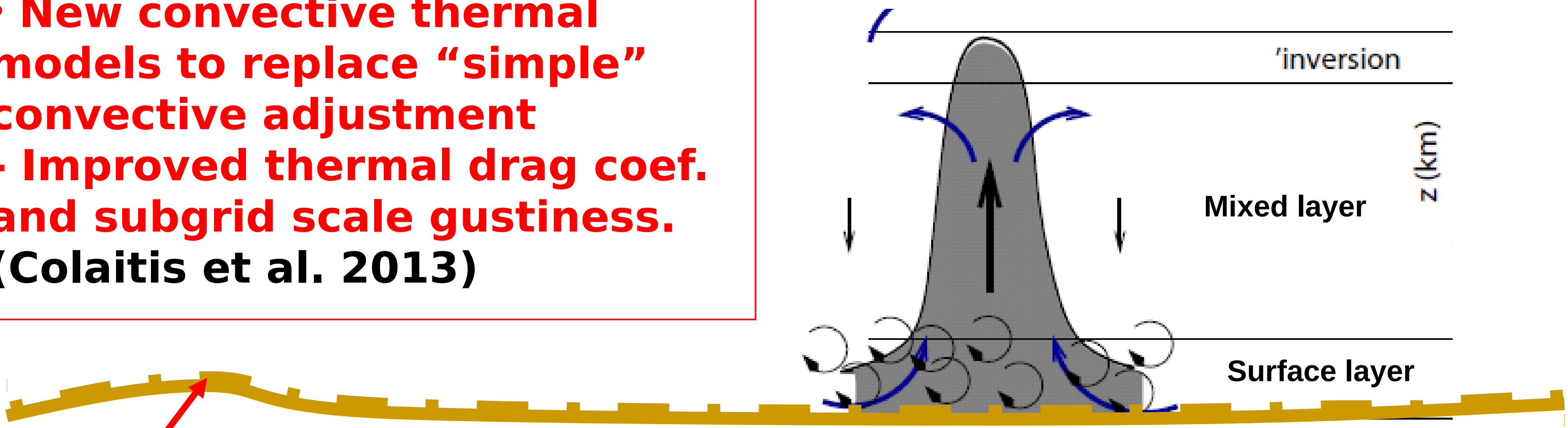


IN, **IS** : Thermal inertia of subsurface water ice tables

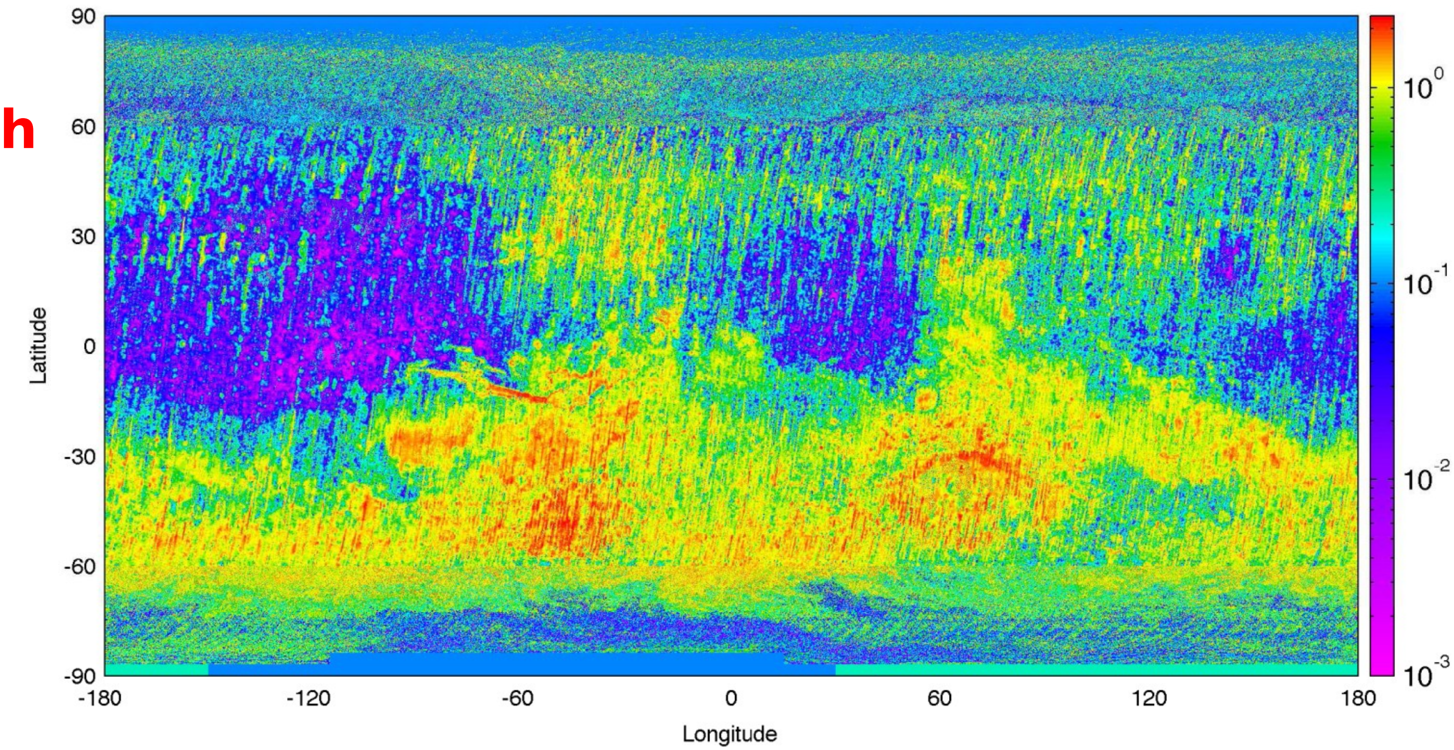
DN,**DN**: Ice table depth

Modeling subgrid processes, convection and turbulence

• **New convective thermal models to replace "simple" convective adjustment**
- Improved thermal drag coef. and subgrid scale gustiness.
(Colaitis et al. 2013)

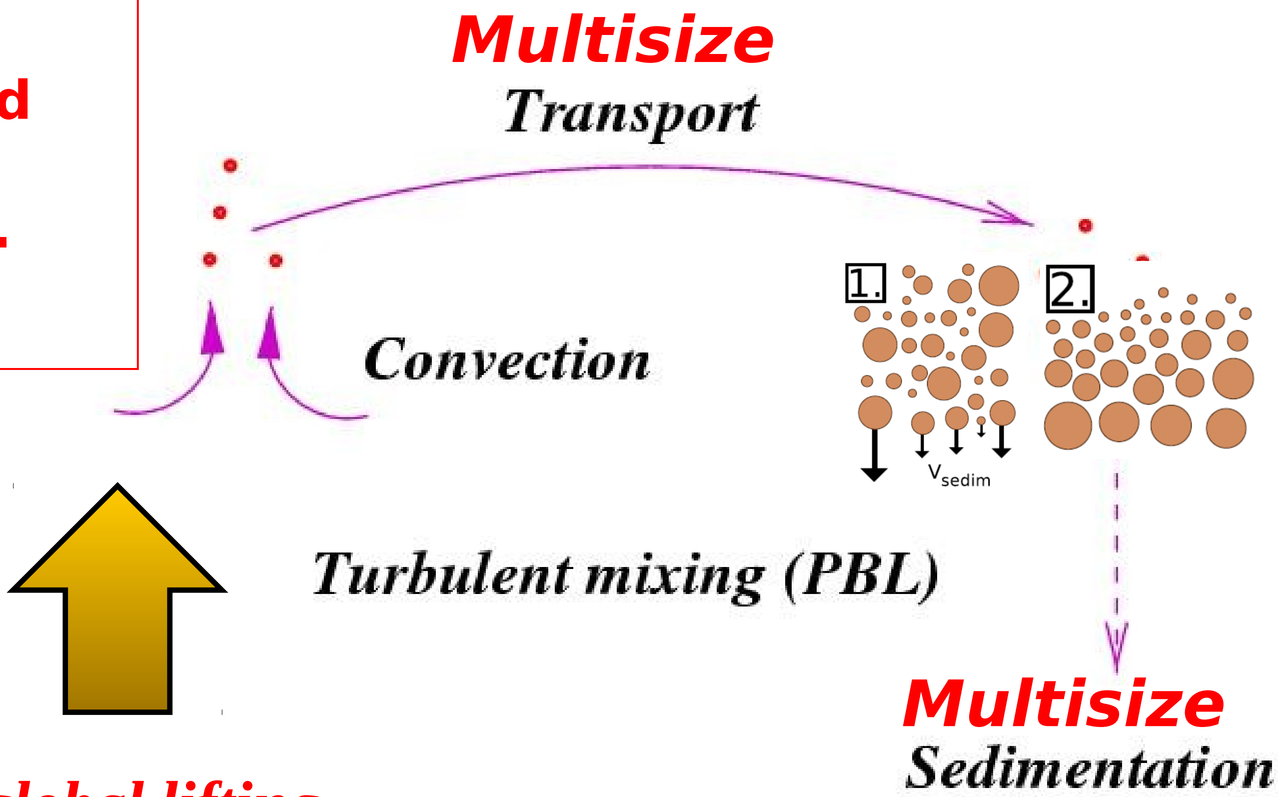


Roughness Length "z_0" Map derived from Extended Martian Rock Abundance Data
(Hebrard et al. 2011)



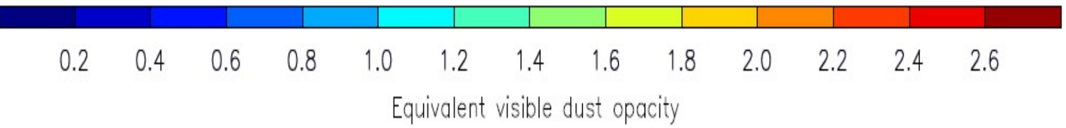
Modeling the dust cycle to simulate observed Martian years (MY24 – MY30)

Improved dust radiative transfer and properties (Wolff et al. 2009)



Constant global lifting

Column dust opacity is *normalized* using an input column dust scenario opacity



Zonal mean of reconstructed dust opacities for Martian years 24-30

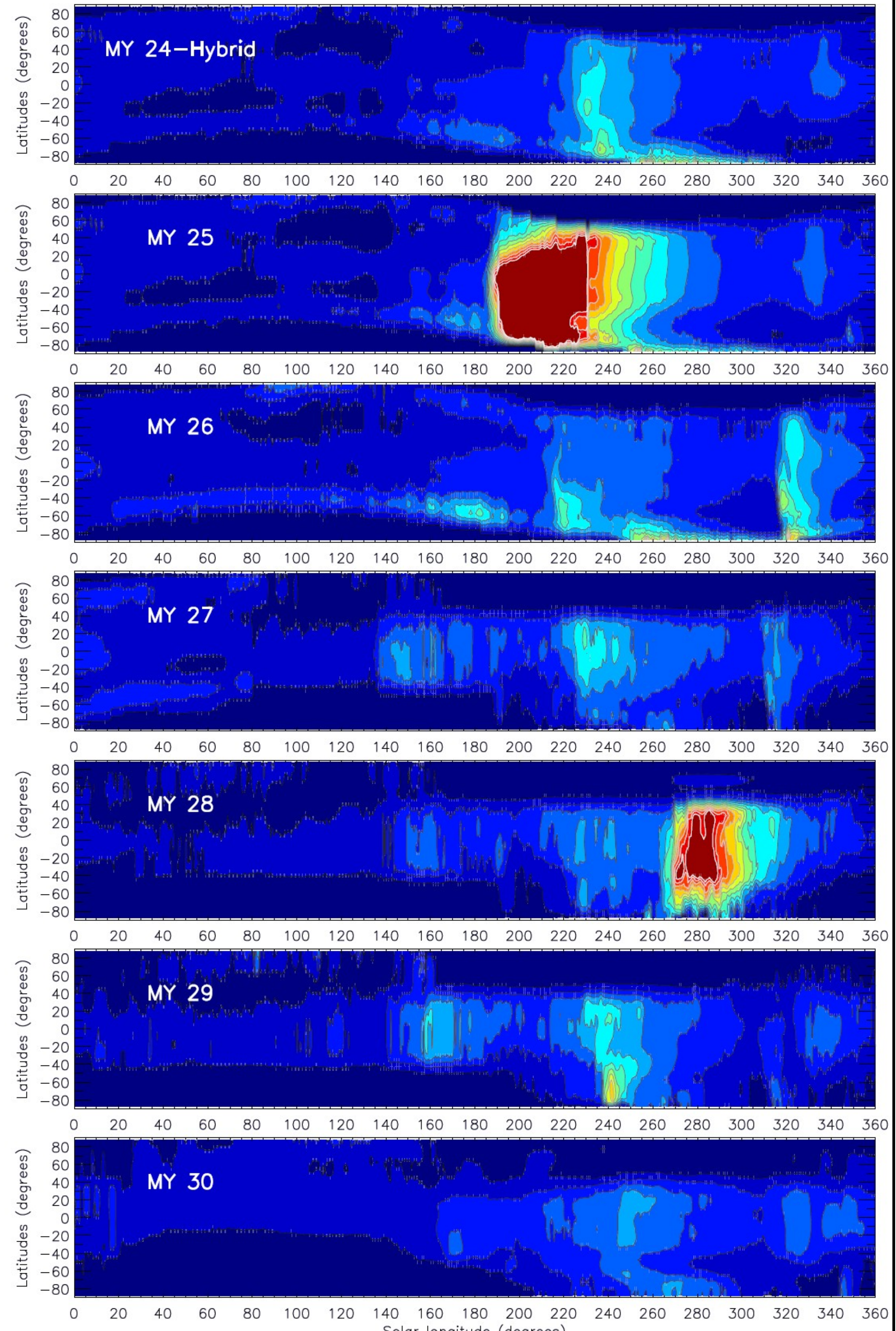
- We had to combine observations from **TES** (MY24-27), **THEMIS** (MY26-30), **MER**s (MY26-30) and **MCS** (MY28-30).

- We performed **gridding** of non-uniform observations on a regular grid (5°x5° lon-lat, 1 sol) using **weighted binning**

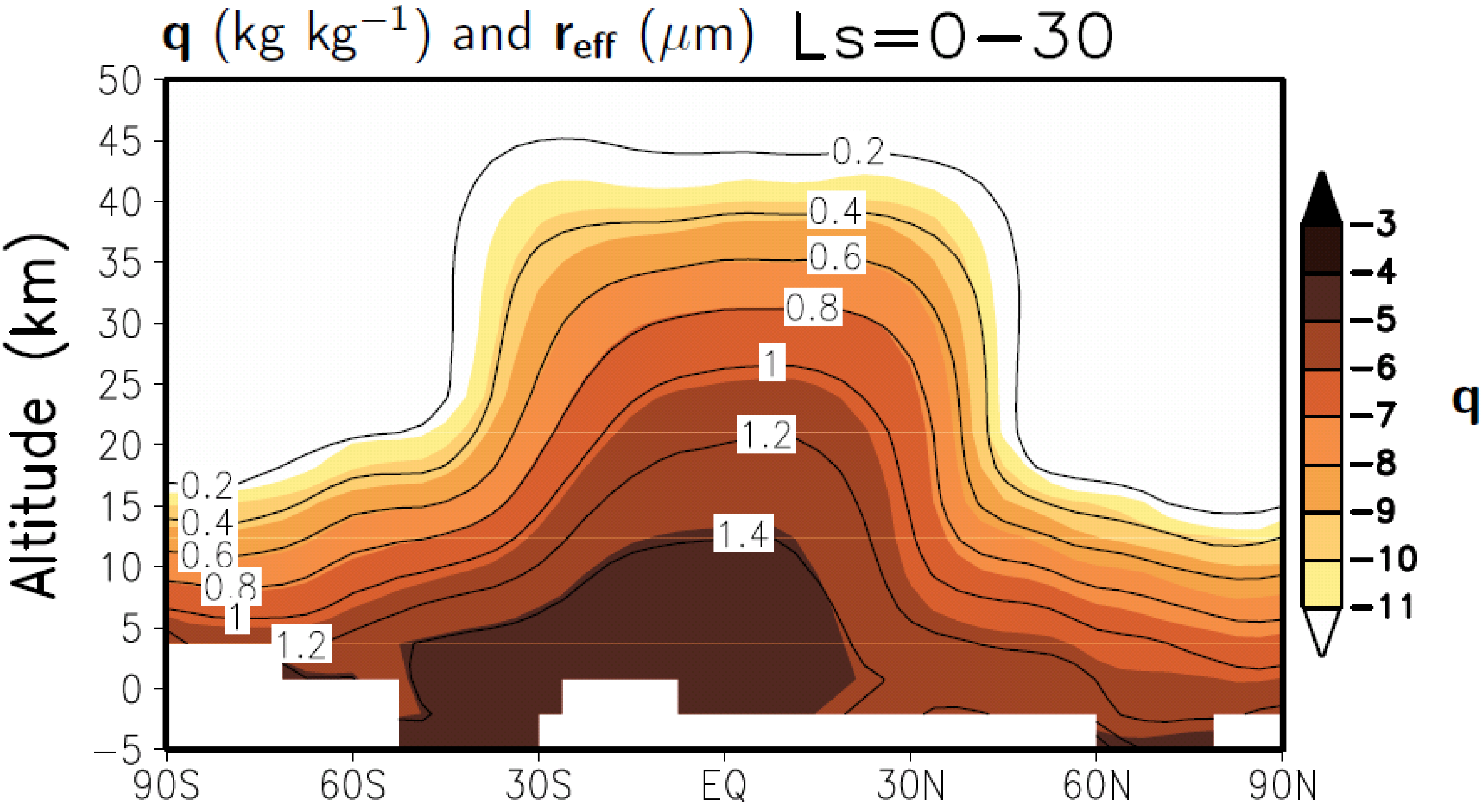
- We obtained more or less *incomplete maps* of total dust opacity, depending on the density of observations

- We **interpolated** the maps using **kriging**, and we finally obtained complete, daily maps of dust opacity on a regular grid.

Montabone et al. 2013, submitted



Transported dust mixing ratio and size distribution (2 moment scheme)



Madeleine et al. 2011

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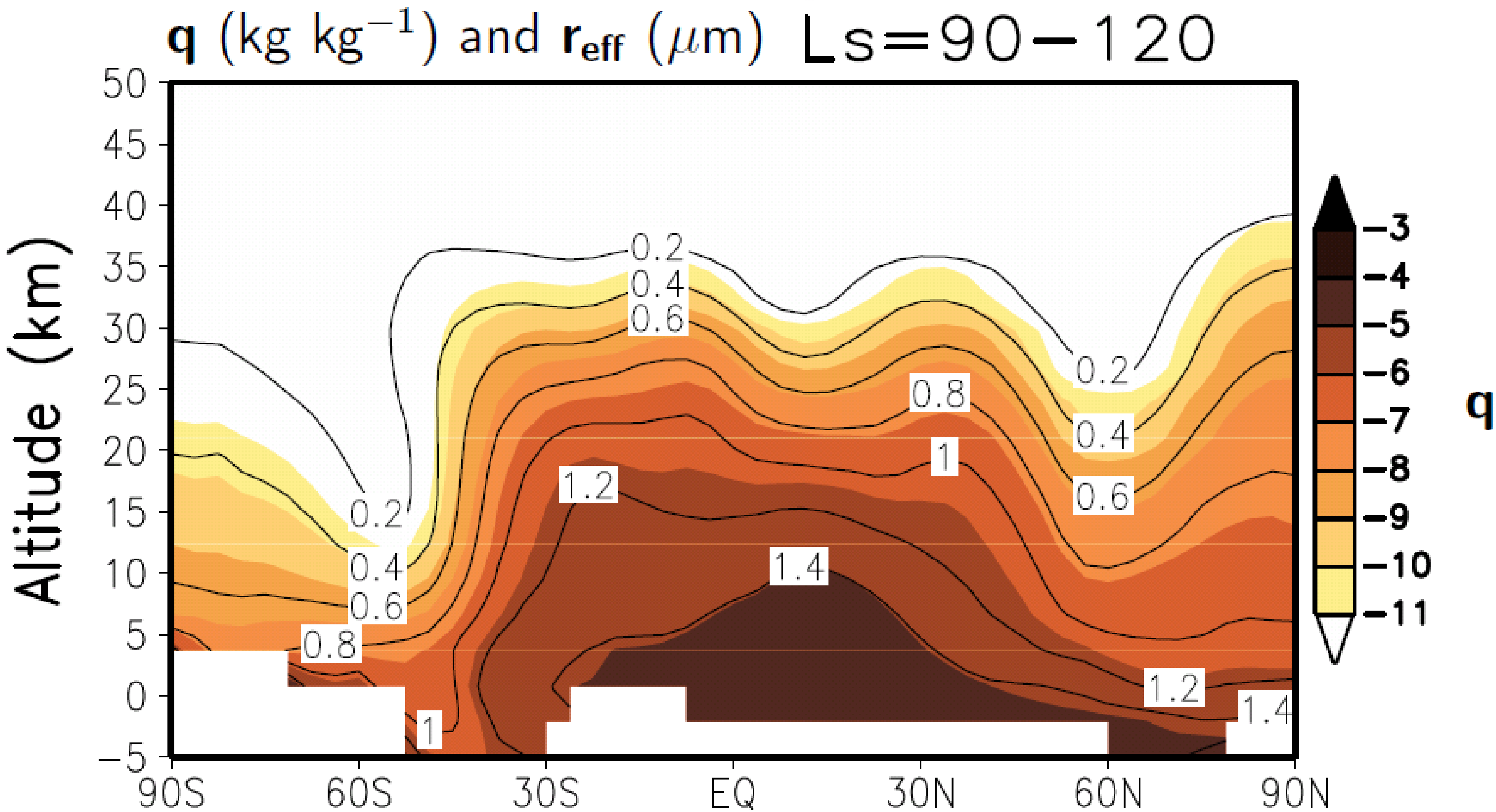

Madeleine et al. 2011

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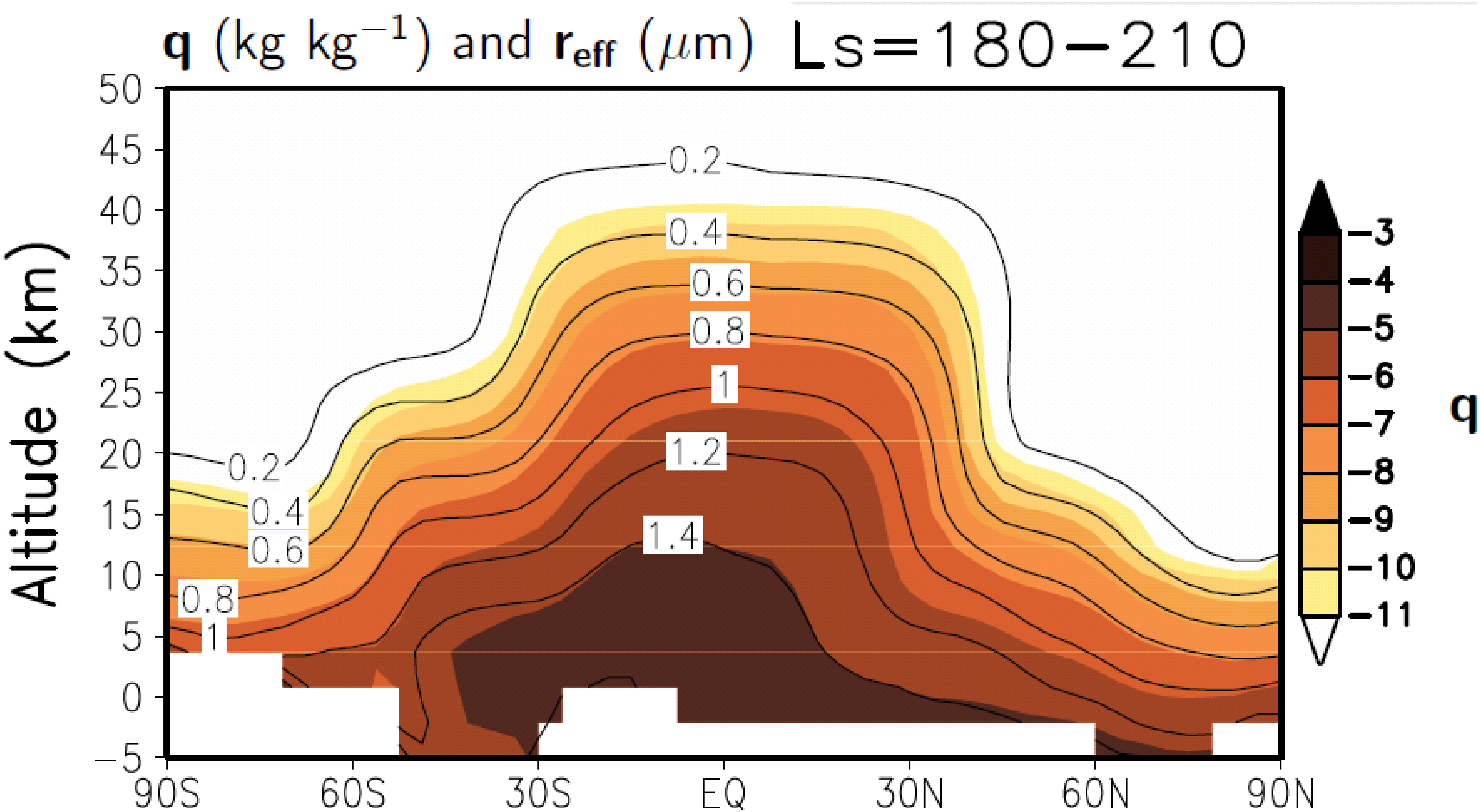
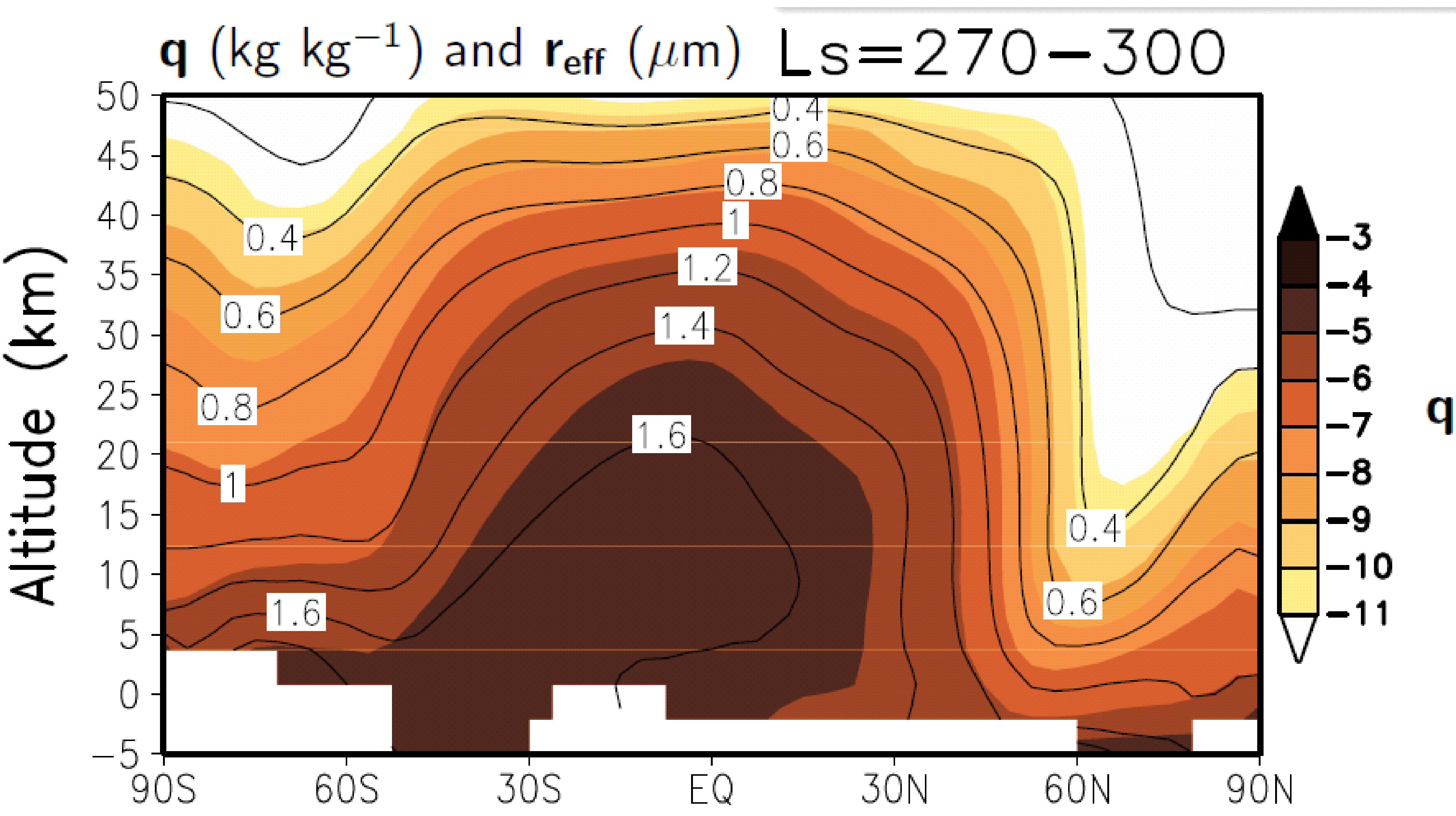
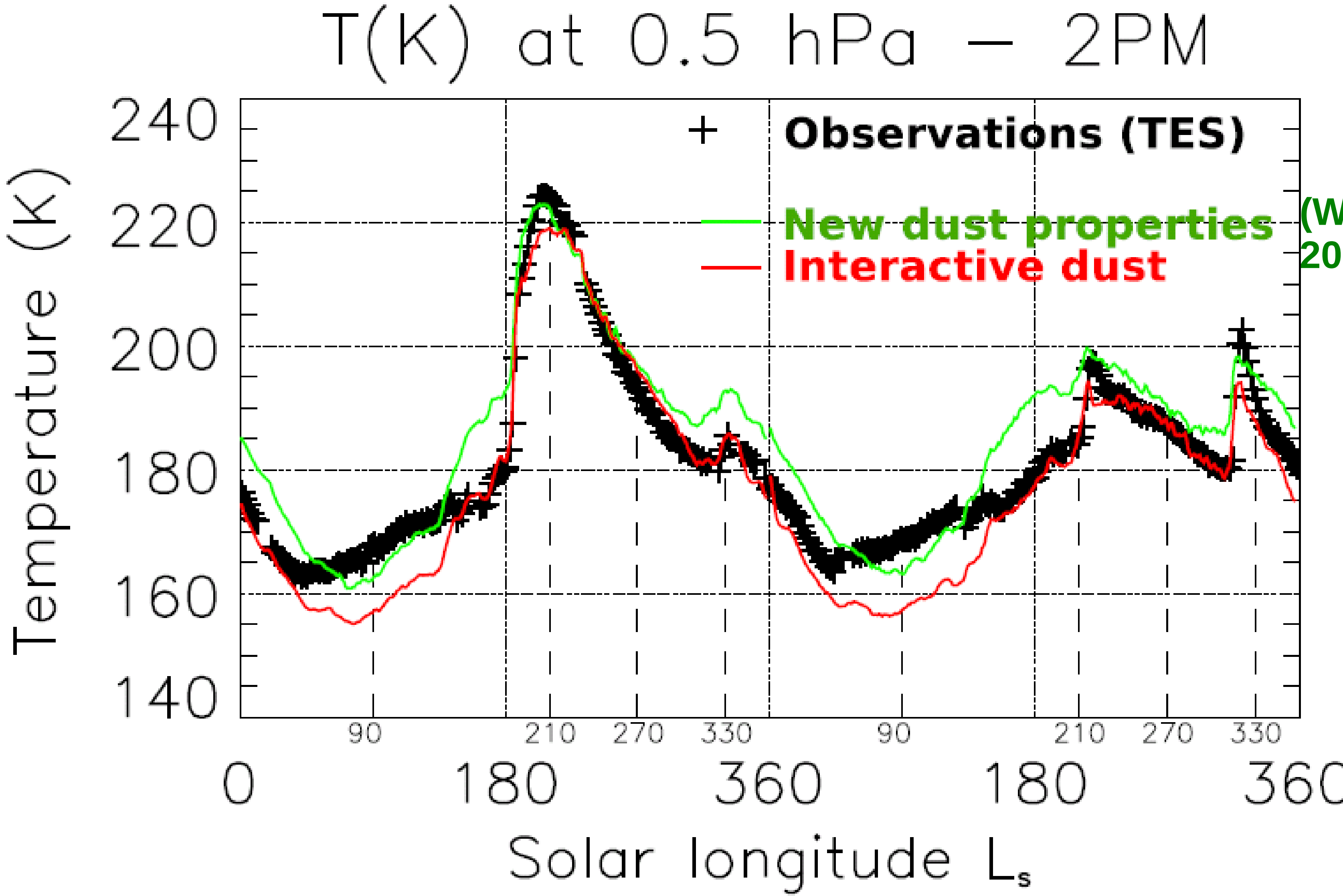


Madeleine et al. 2011

Transported dust mixing ratio and size distribution (2 moment scheme)

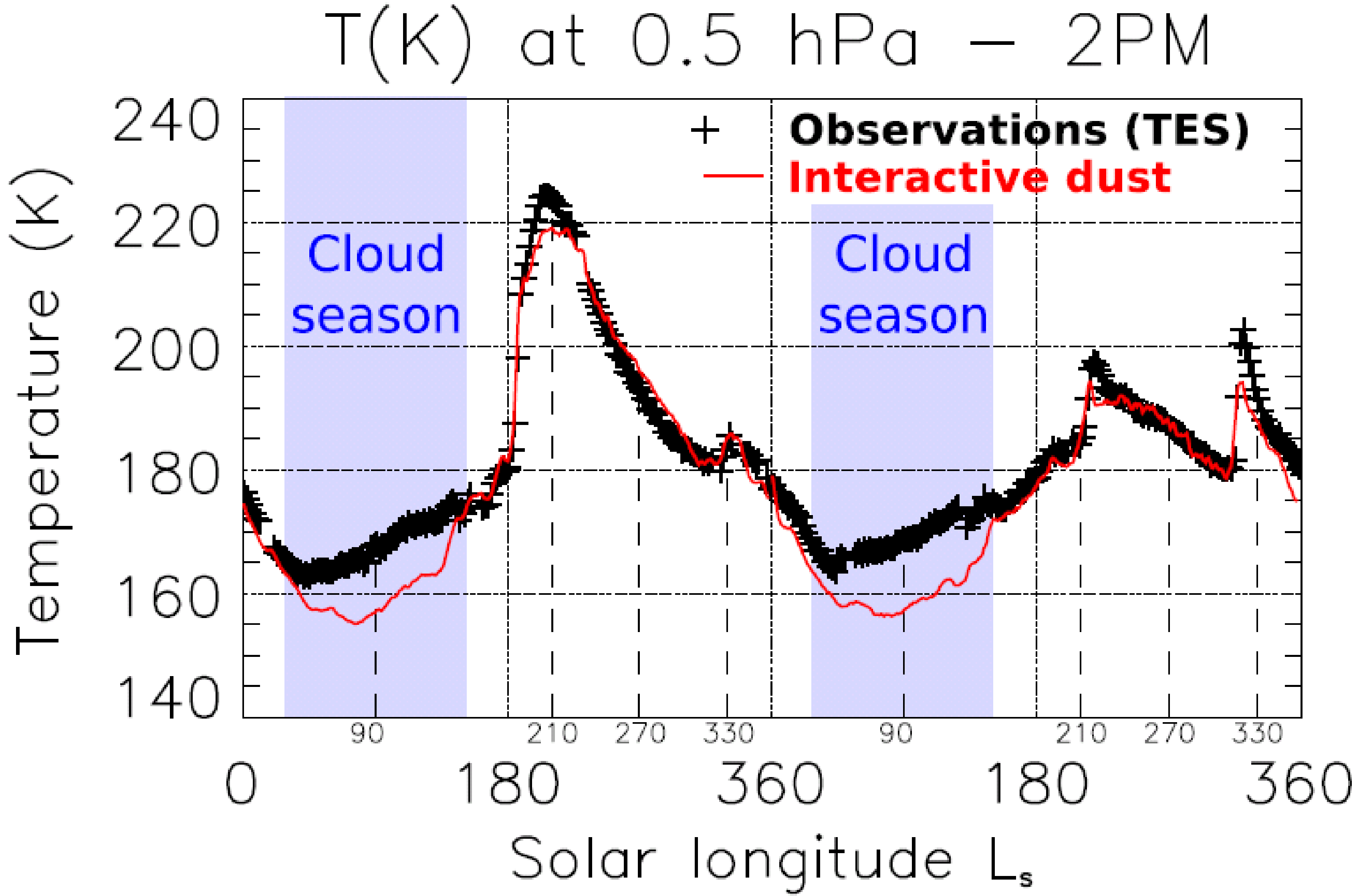


Madeleine et al. 2011



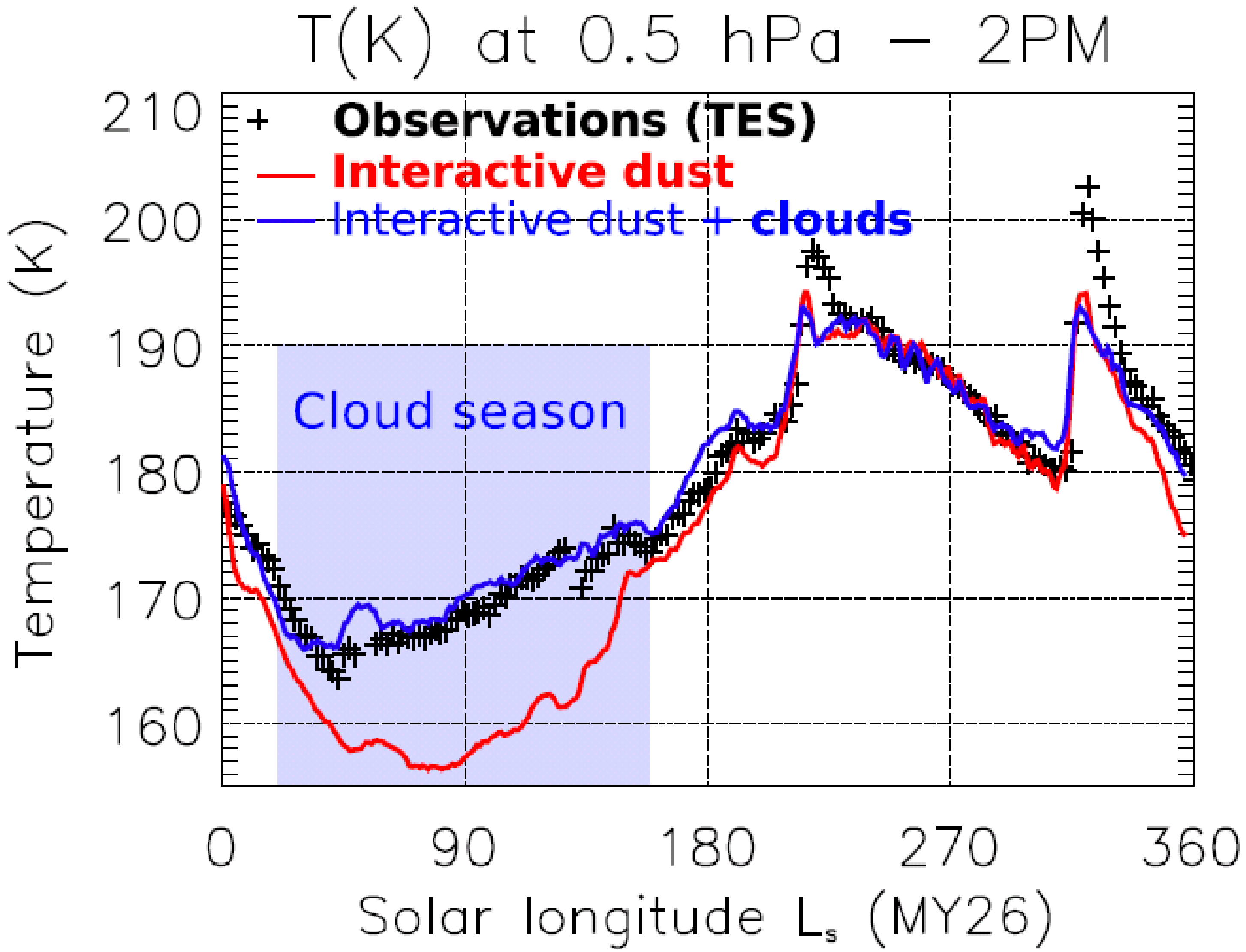
(Wolff et al. 2009)

Madeleine et al. 2011


T(K) at 0.5 hPa – 2PM
Temperature (K)
240
220
200
180
160
140
Observations (TES)
Interactive dust
Cloud season
Cloud season
90
210
270
330
90
210
270
330
0
180
360
180
360
Solar longitude L_s

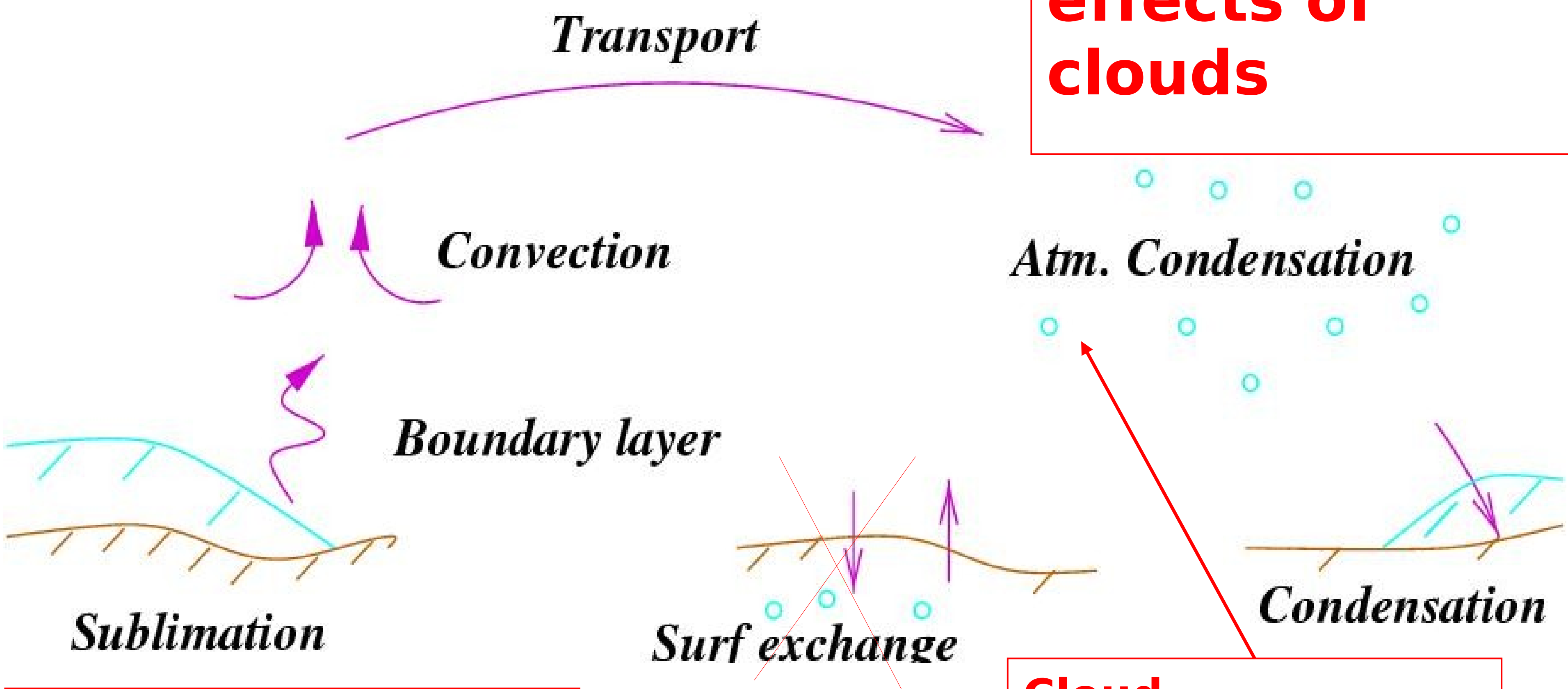
Impact of radiatively active clouds on temperature simulated in the LMD GCM

(Madeleine et al. 2011)



Modeling the Martian water cycle

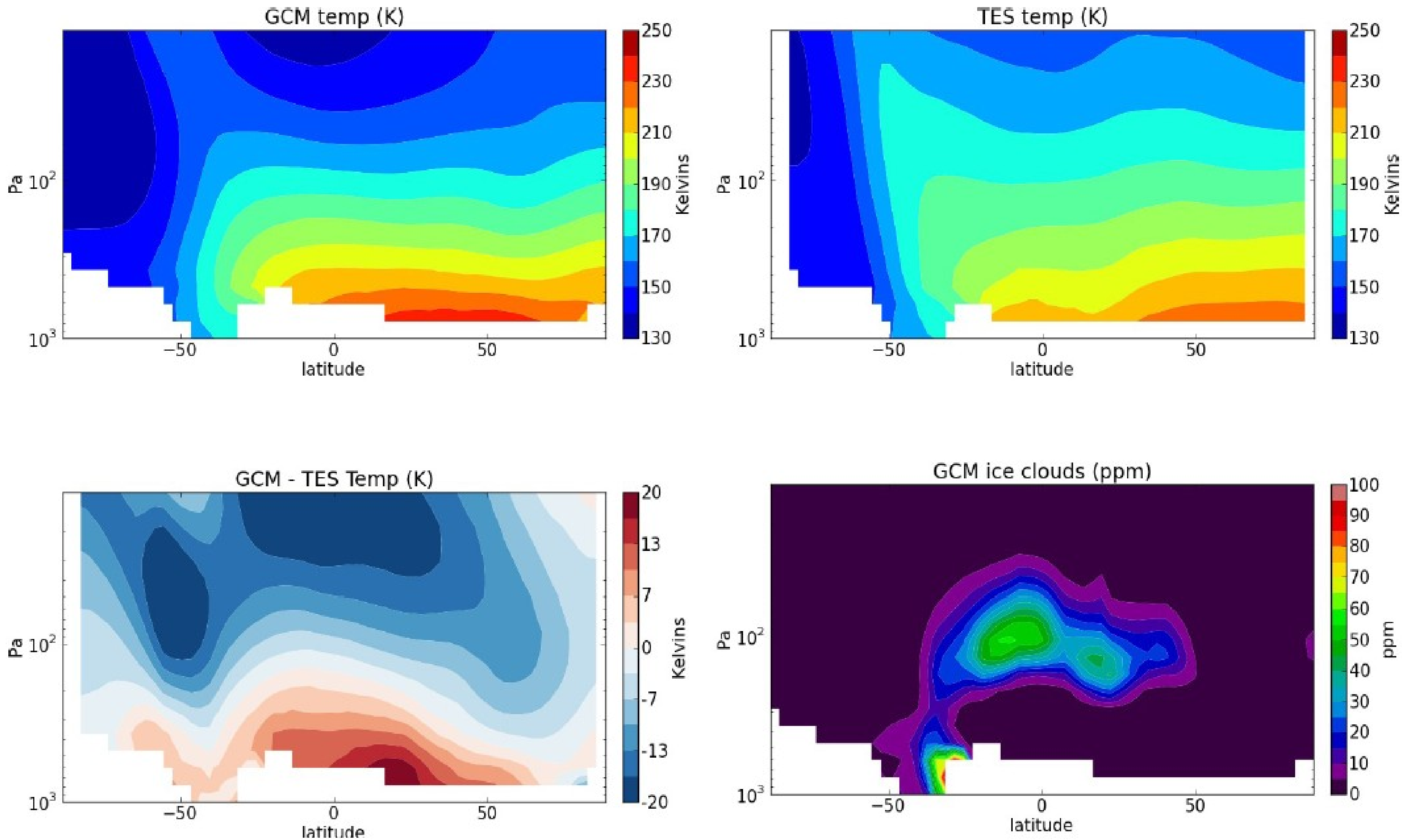
IR and solar walength radiative effects of clouds



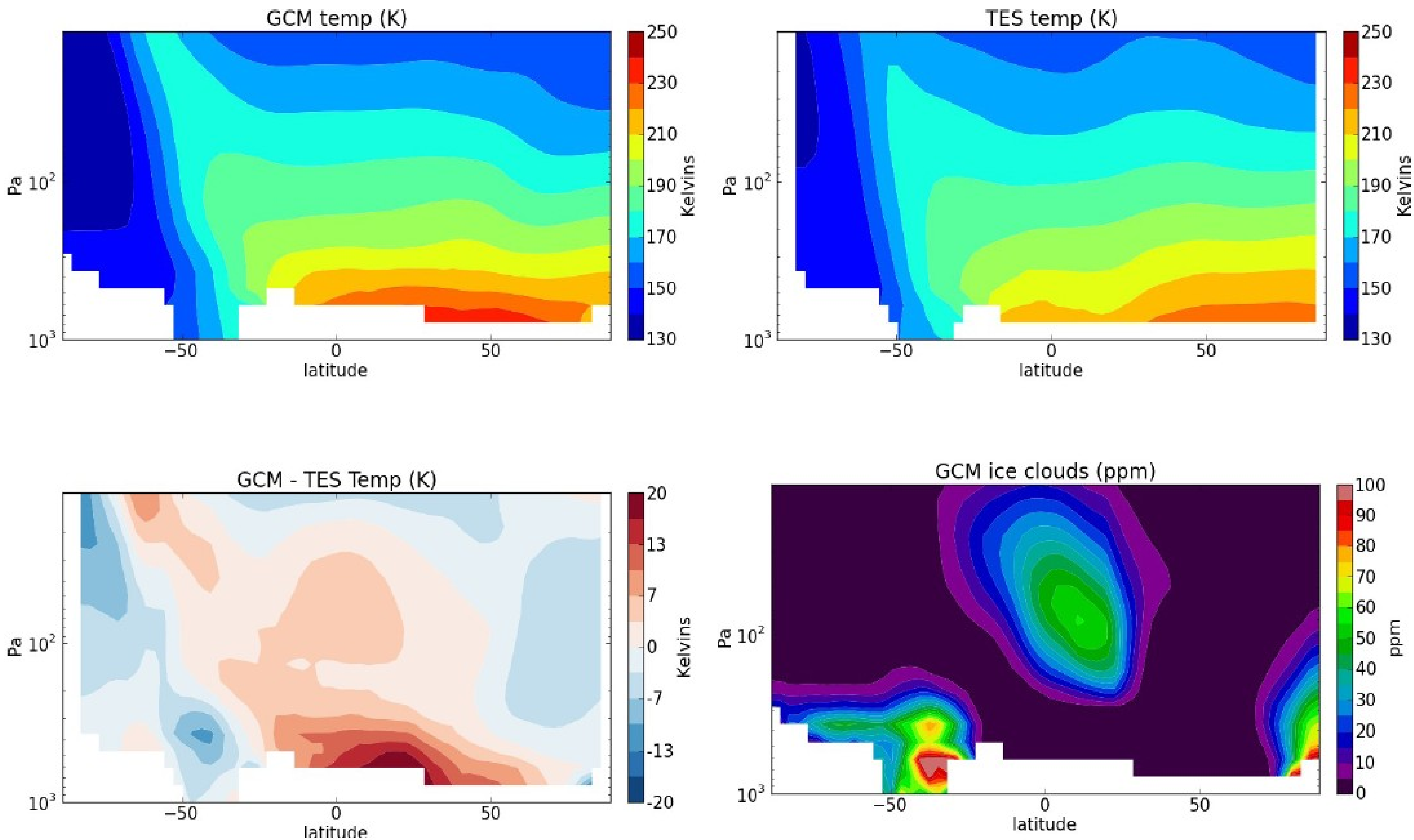
Representation of ice permanent reservoirs (outliers, albedo, thermal inertia…)

Cloud microphysics (nucleation, growth, dust scavenging)

Ls 90-120 MY26 – Inactive clouds



Ls 90-120 MY26 – Active clouds



Modeling the Martian Water Cycle

Work on a better modeling of the water cycle is in the core or the last 5 years of development… and it is not over...

Bottom line: Obtaining (tuning) a good water cycle is really tough…

...

Inactive Clouds

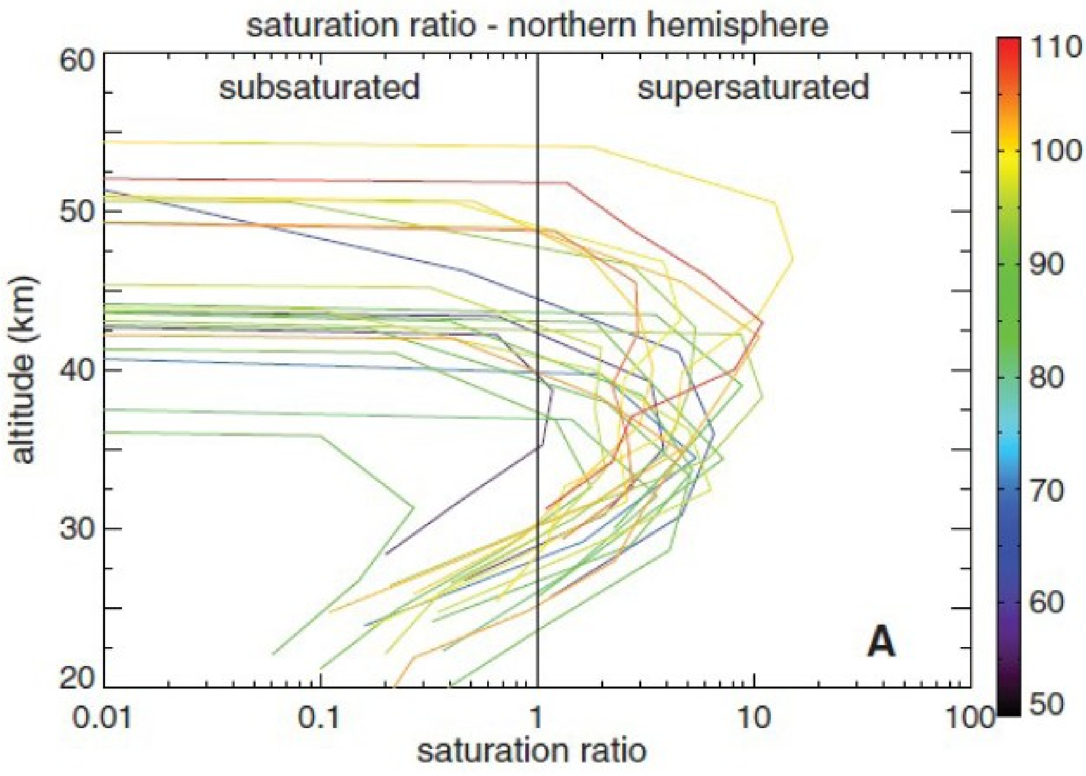
Active Clouds

Illustration off the difficulties ; concept slide from Thomas Navarro

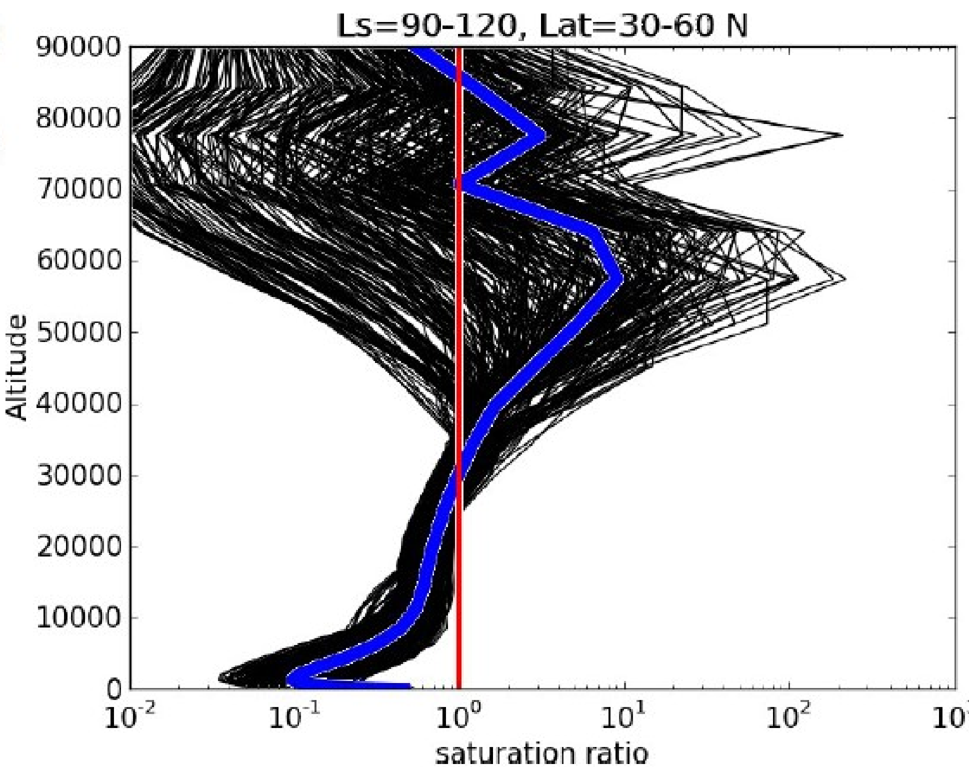
Modeling the Martian Water Cycle

Among the things that work:

Water vapor profiles with improved microphysics: comparison with SPICAM solar occultation data of H2O supersaturation



Maltagliati et al. 2011, Science

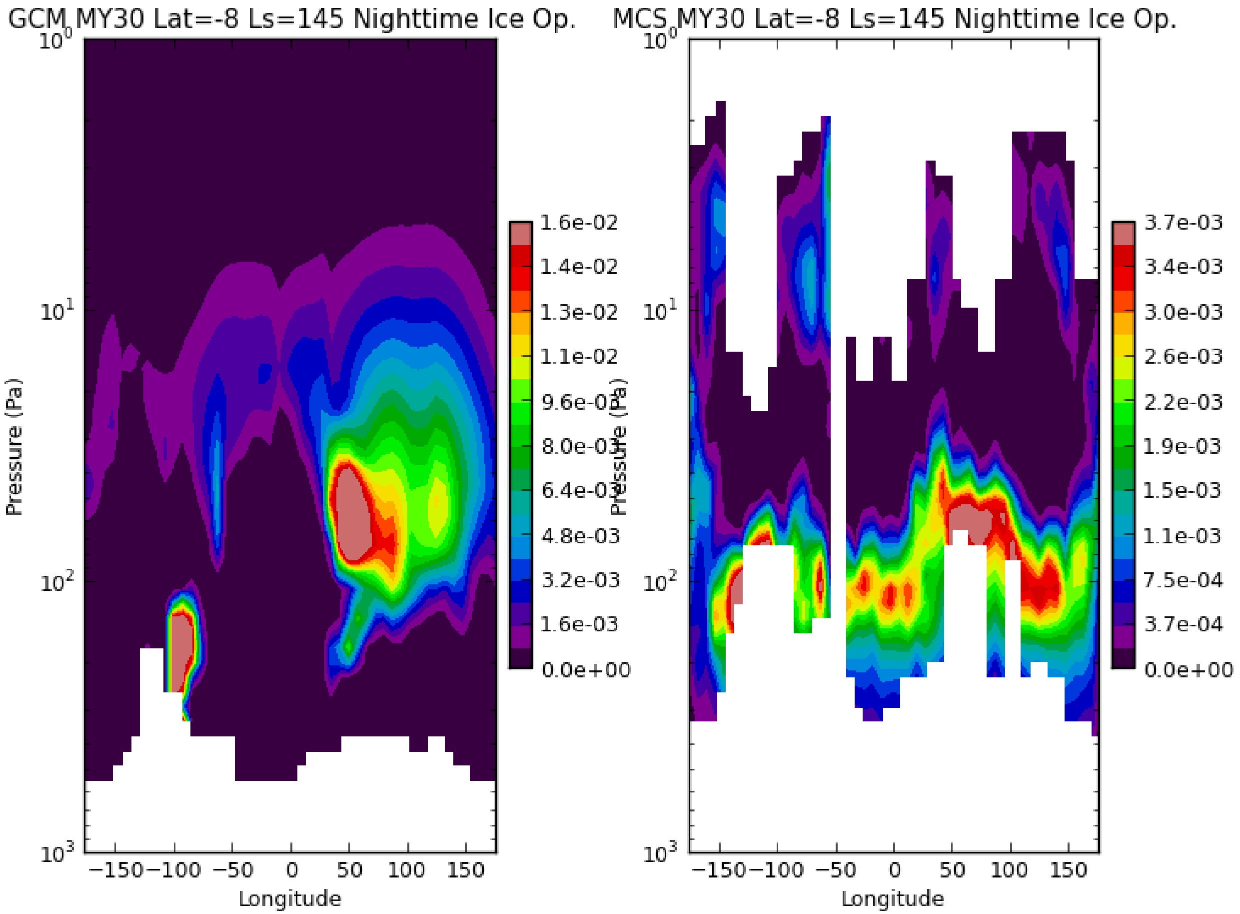


LMD GCM

Modeling the Martian Water Cycle

Among the things that do not work:

LMD GCM and MCS observations comparison
Nighttime Ice Opacity, MY30, lat=-8, Ls=145



- Quite different clouds; in thickness (10 times more in the GCM than seen by MCS) and location…

Inclusion of chemistry and upper atmosphere (mesosphere/thermosphere) proceses in the LMD GCM

F. Gonzalez Galindo / M.A. Lopez-Valverde (IAA, Spain)
J.-Y. Chaufray (LATMOS)

Main improvements over the last ~5 years

- Better representation of the chemistry and photochemistry reactions (F. Lefèvre, LATMOS)

- Improved CO_2 NLTE cooling (latest M.A. Lopez-Valverde scheme, using actual CO_2 levels and bands, and taking into account the variations of atomic O).

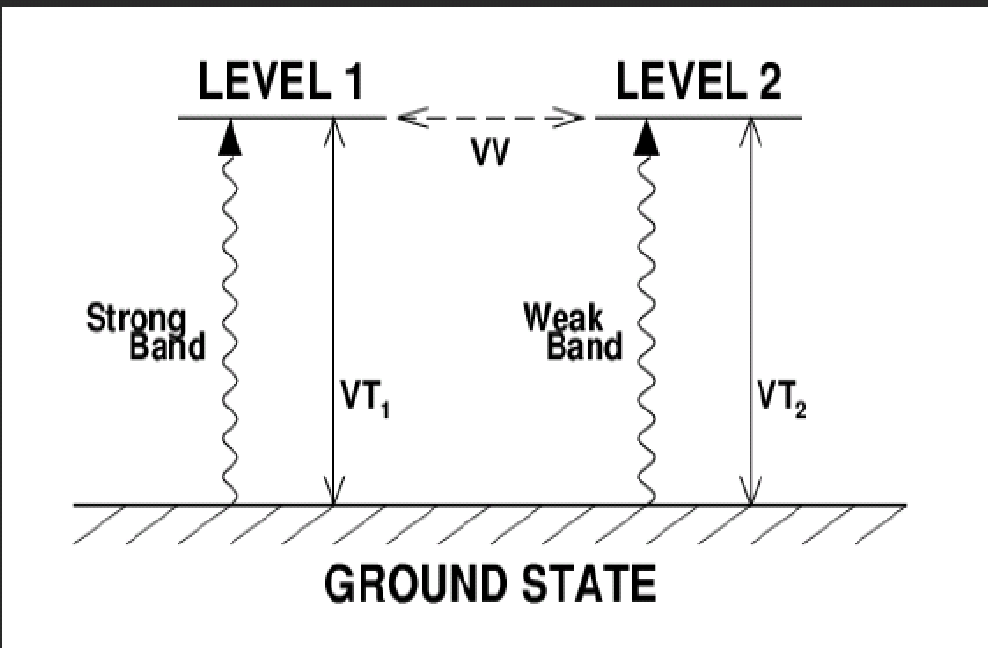
- Improved representation of molecular diffusion

- Complete neutral-ion interaction Ionospheric Model in the GCM

- Creation of a fully dynamic Ionospheric model (side project by J.-Y. Chauffray, not in the standard GCM)

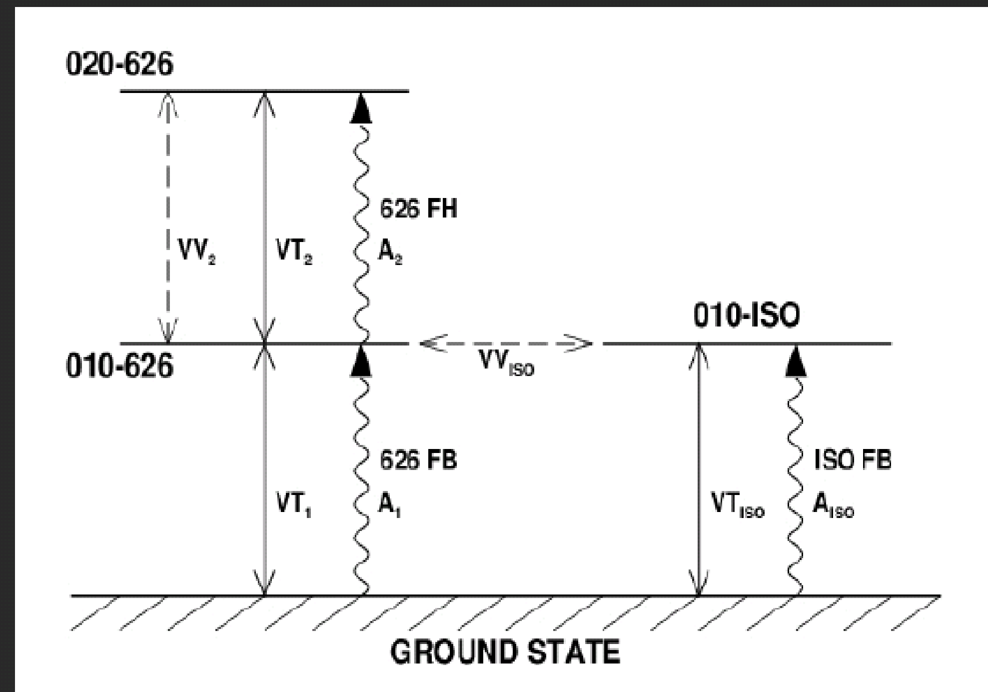
New NLTE 15 µm cooling param.

Old scheme (López-Valverde & López-Puertas, IRS 2000)



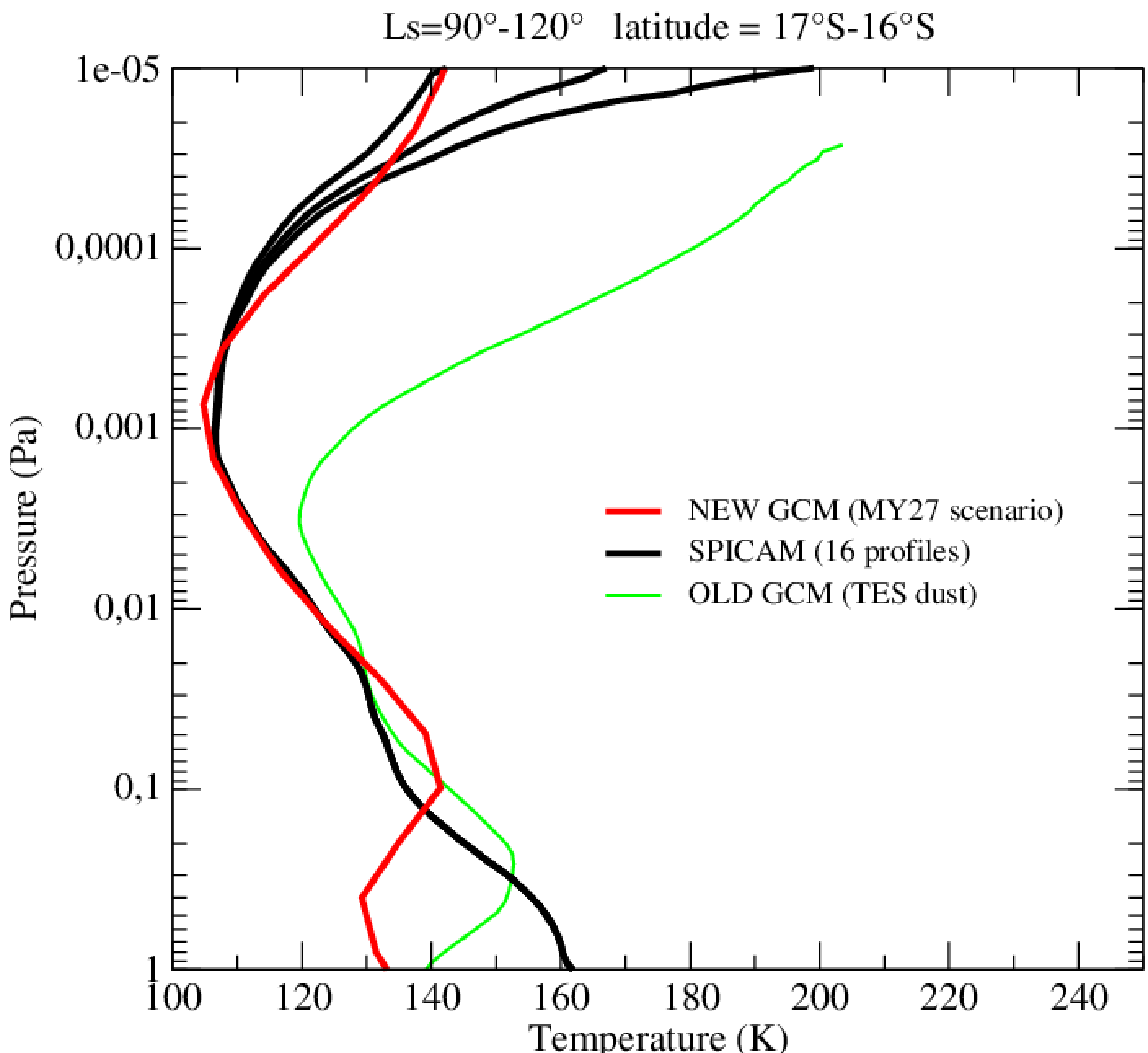
- Virtual levels and bands
- Cool to space approx.
- Fixed O
- Computationally fast

New scheme (López-Valverde et al., in prep.)

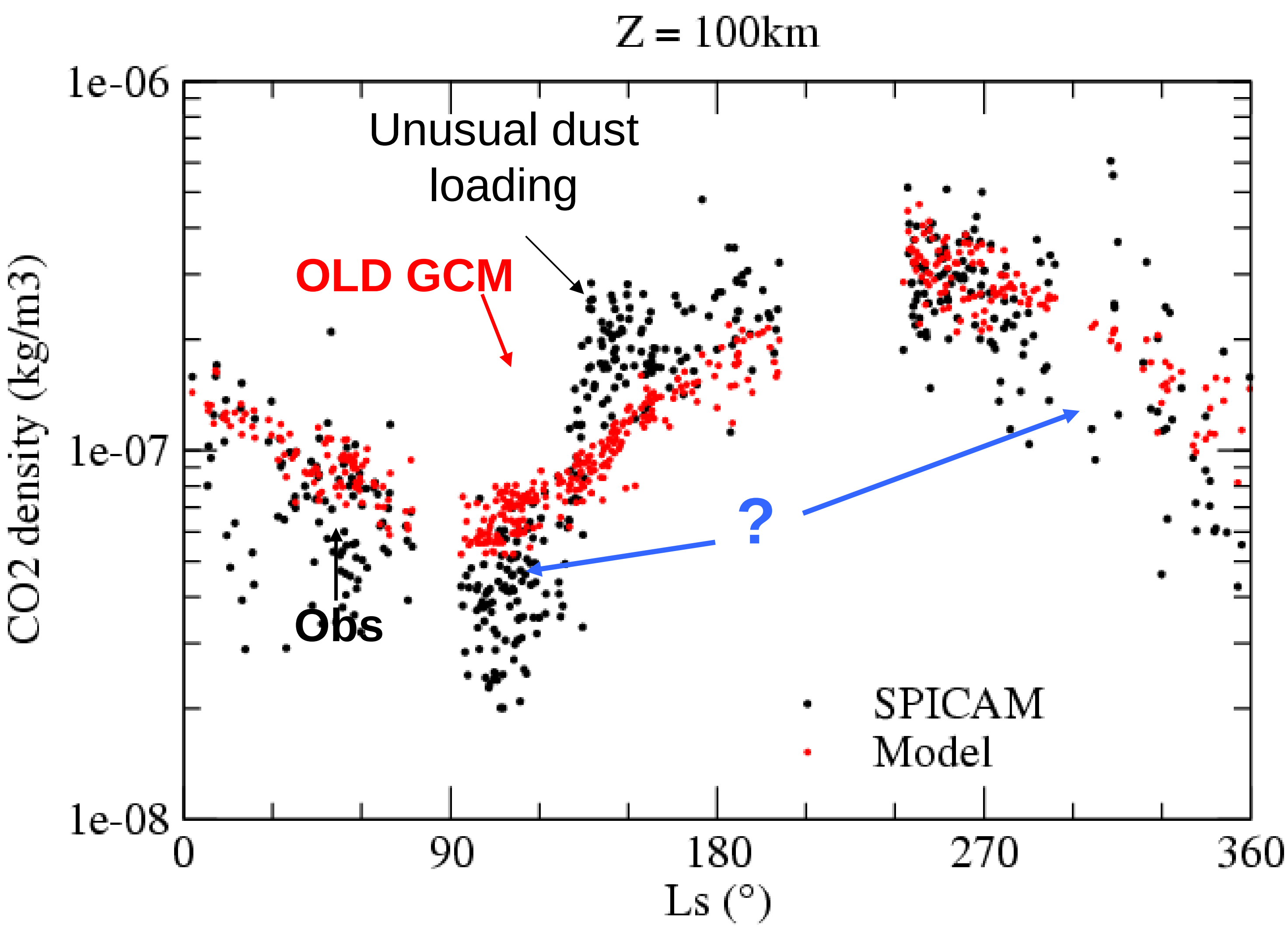


- Actual CO2 levels and bands
- Full exchange between layers
- Variable O
- More CPU expensive

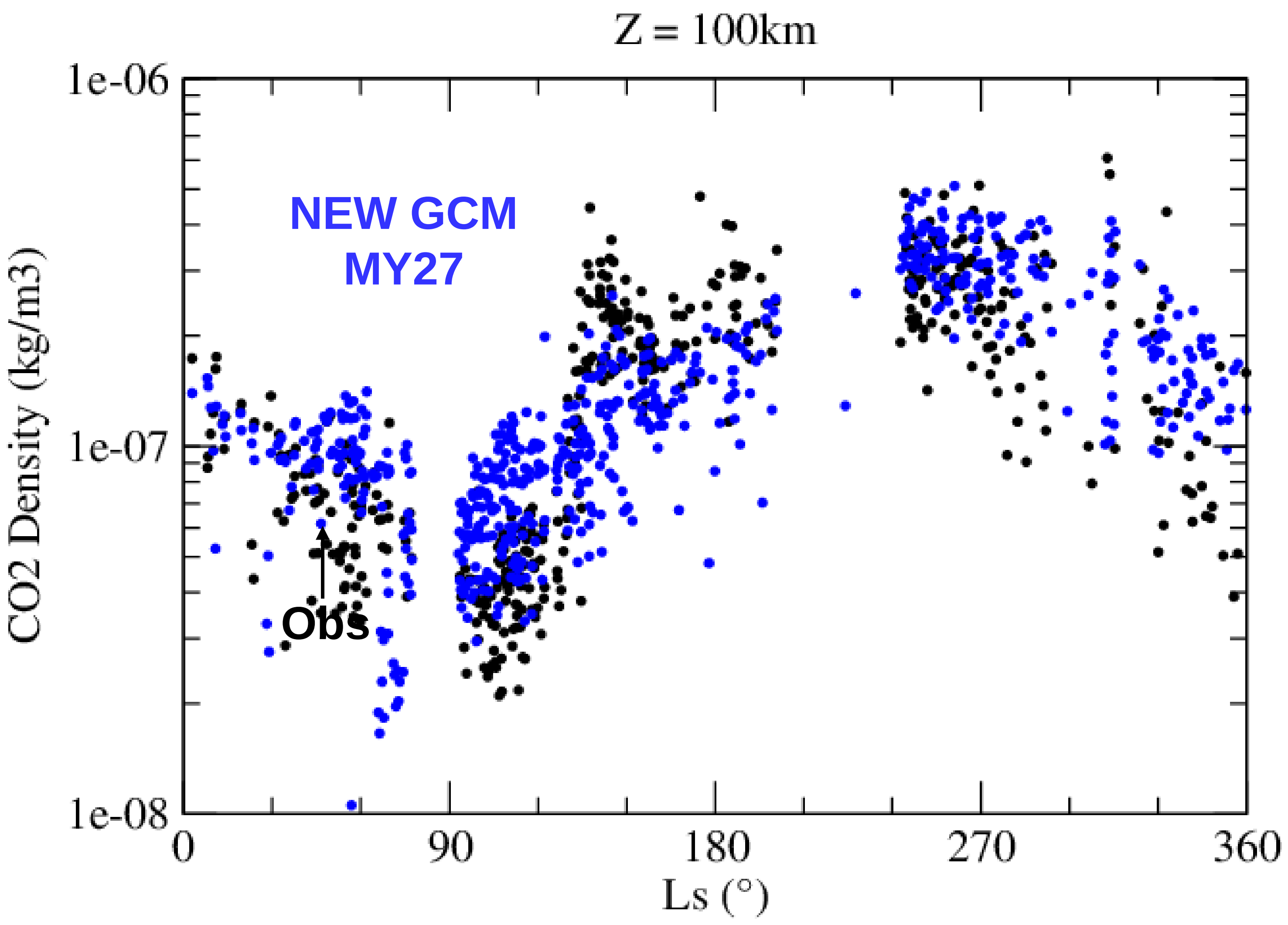
Comparison with SPICAM data :
Impact of new NLTE 15 µm cooling parametrisation:



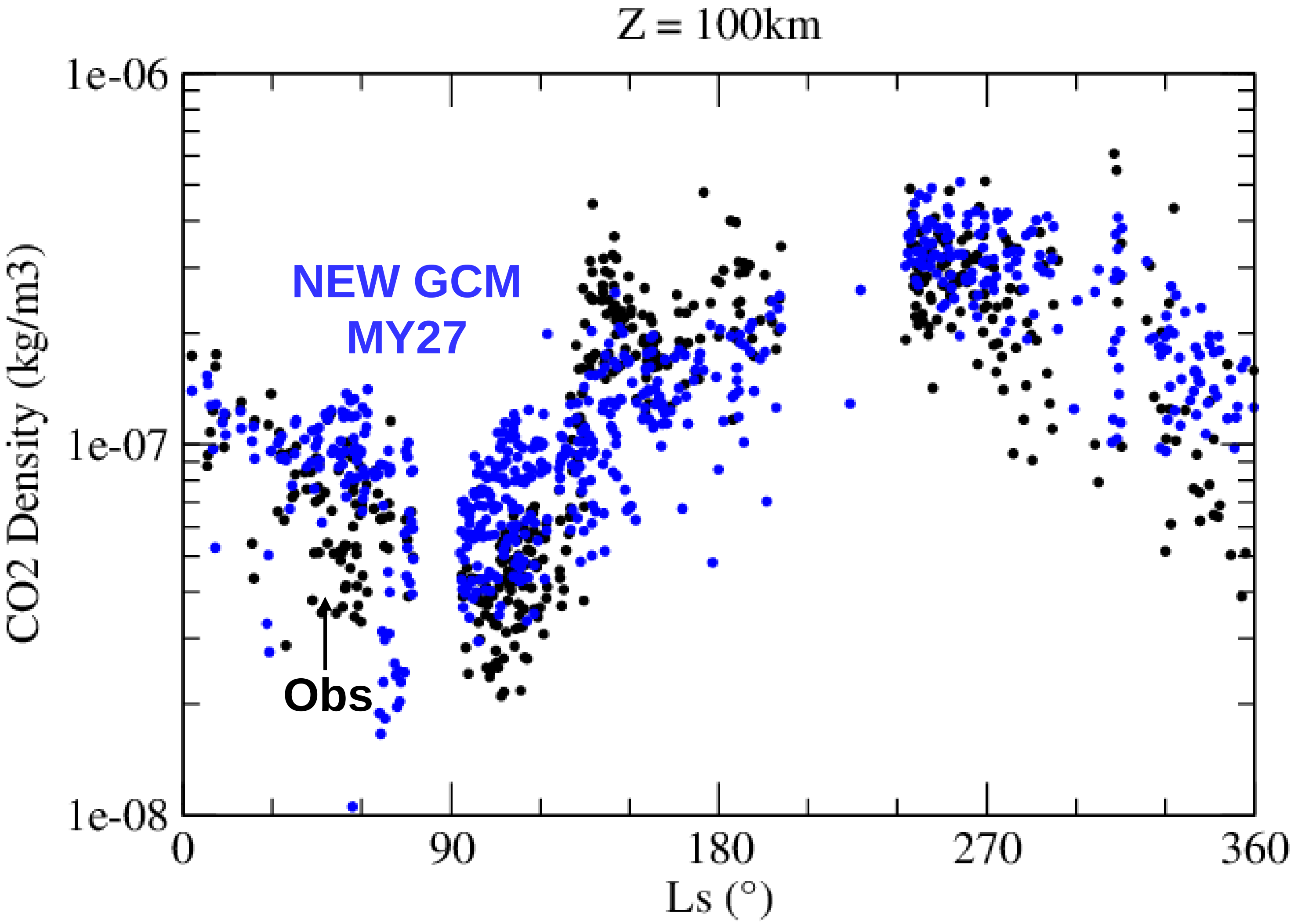
Seasonal evolution
SPICAM vs GCM density z = 100km



Seasonal evolution
SPICAM vs GCM density   z = 100km



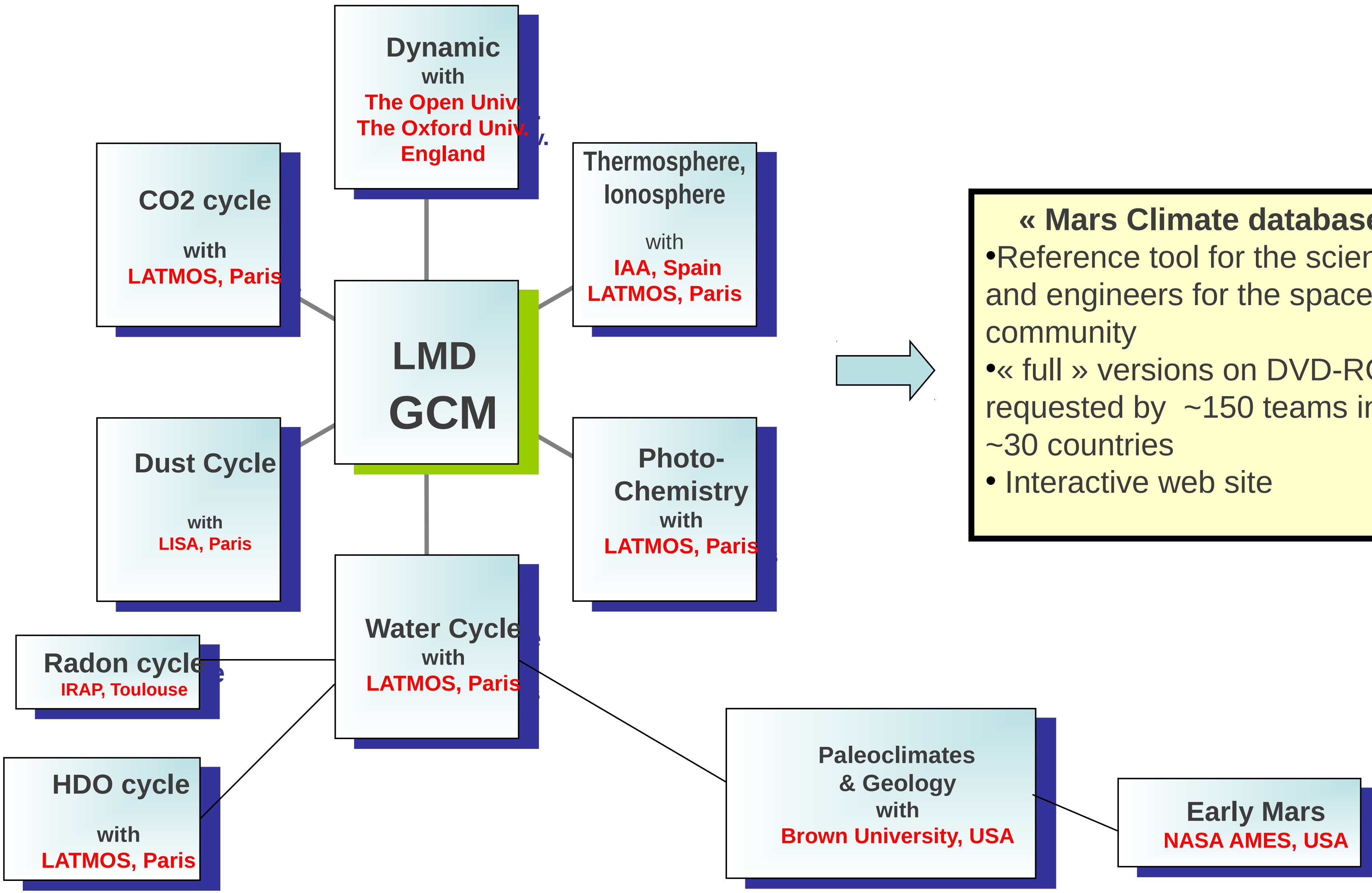
SPICAM vs GCM density z = 100km



Variability : GCM results vary from day to day (here: a 5 days window)

Synthesis : application of the LMD GCM

Strong Collaboration with LATMOS (IPSL, France),
The Open University and the University of Oxford (UK) , IAA (Granada, Spain)



« Mars Climate database »

- Reference tool for the scientific and engineers for the space community
- « full » versions on DVD-ROM requested by ~150 teams in ~30 countries
- Interactive web site

The Mars Climate Database

a brief history of the MCD project

- 1995: **ESA** (European Space Agency) and **CNES** (French Space Agency) identify the need for a better comprehension of the Martian environment for future missions to Mars.
- 1995: The LMD and AOPP (Oxford University) groups (later joined by the IAA, Spain, group) team up, and funded by ESA and CNES , improve their GCMs to provide outputs (the MCD) to the Space agencies and the scientific community.
- 2001: MCDv3.0 (and then MCDv3.1) is released (the first to be really distributed, with a large number of users).
- 2005 : MCDv4.0 and MCDv4.1 released.
- 2006 : MCDv4.2 released.
- 2008 : MCDv4.3 released.
- 2012: MCDv5.0 released (there will probably be an MCDv5.1 in 2013)

What is the Mars Climate Database ?

- The Mars Climate Database (MCD) is a database **derived from Global Climate Model** (GCM) **simulations**.
- The MCD is intended to be useful for engineering applications (e.g. Entry Descent & Landing studies) and scientific work which require accurate knowledge of the Martian atmosphere (e.g. Analysis of observations).
- The MCD is freely available, either via an online access (http://www-mars.lmd.jussieu.fr) for moderate needs, or a more complete version which includes advanced post-processing software.
- Over the years, the MCD has been distributed to more than 150 teams around the world.

MCD contents & main features

- The MCD provides mean values and statistics of main meteorological variables: **pressure**, **atmospheric density**, **temperature**, **winds,** along with their variability and means to reconstruct realistic perturbed states of the atmosphere.
- Example of variables included in the MCD:

- Surface temperature and pressure

- Thermal and solar radiative fluxes

- CO_2 ice cover

- Dust column opacity and mass mixing ratio

- [H_2O] vapour and [H_2O] ice columns and mixing ratio

- [CO], [O], [O_2], [N_2], [CO_2], [H_2], [O_3], ... volume mixing ratios

- Air specific heat capacity, viscosity and reduced gas constant r

- Height of the PBL (Planetary Boundary Layer), friction velocity

- Maximum updraft and downdraft vertical winds in the PBL

MCD contents & main features

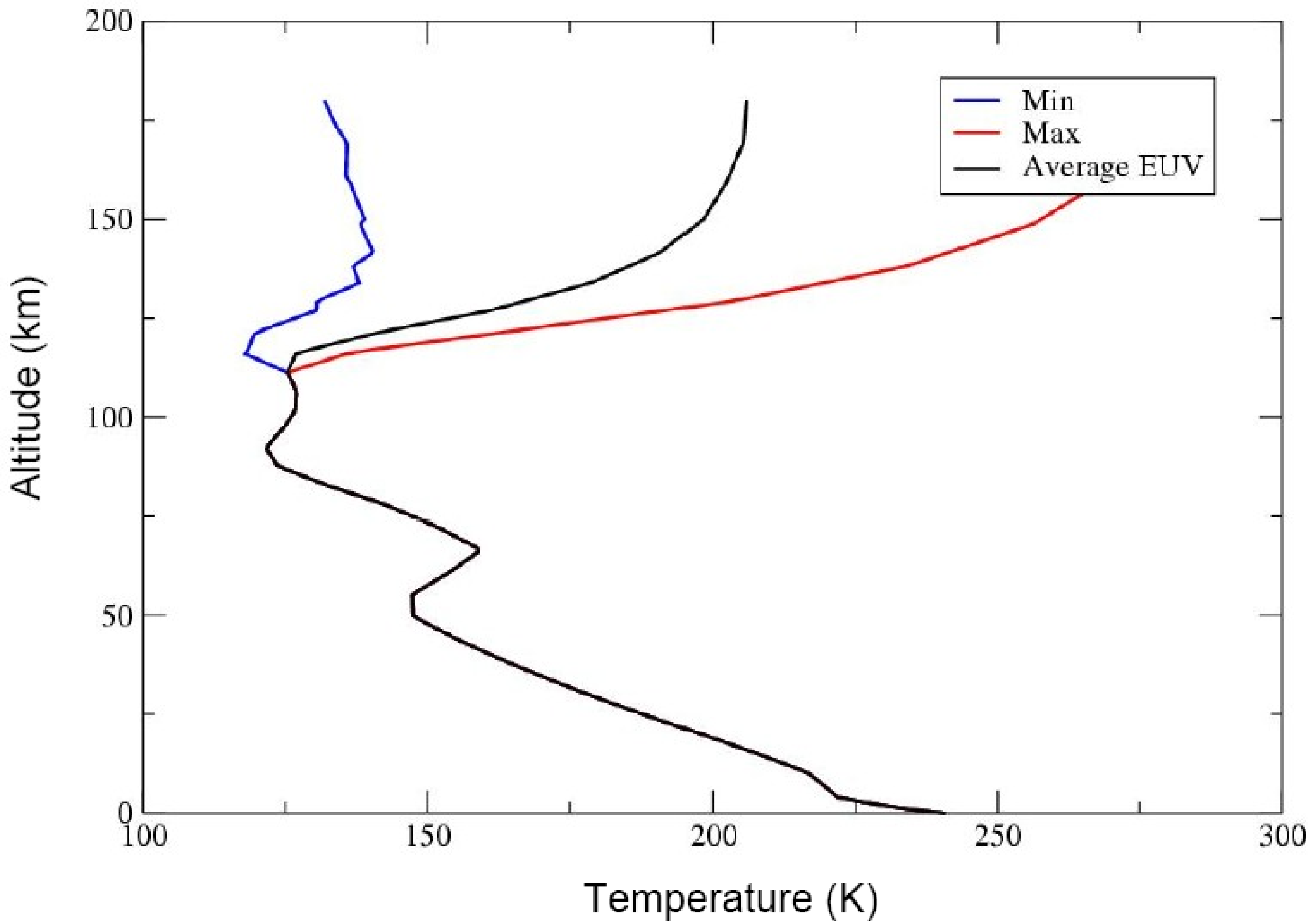
- The MCD provides a set of dust scenarios (topped with EUV upper atmosphere solar max, ave or min conditions) designed to “bracket reality”.

MCD contents & main features

- The MCD extends **up to the thermosphere** (overall up to ~350 to ~500 km) where the influence of **Extreme Ultra Violet** (EUV) input from the Sun is significant.

<u>3 EUV scenarios</u>:

- Minimum
- Average
- Maximum



MCD v5 dust scenarios

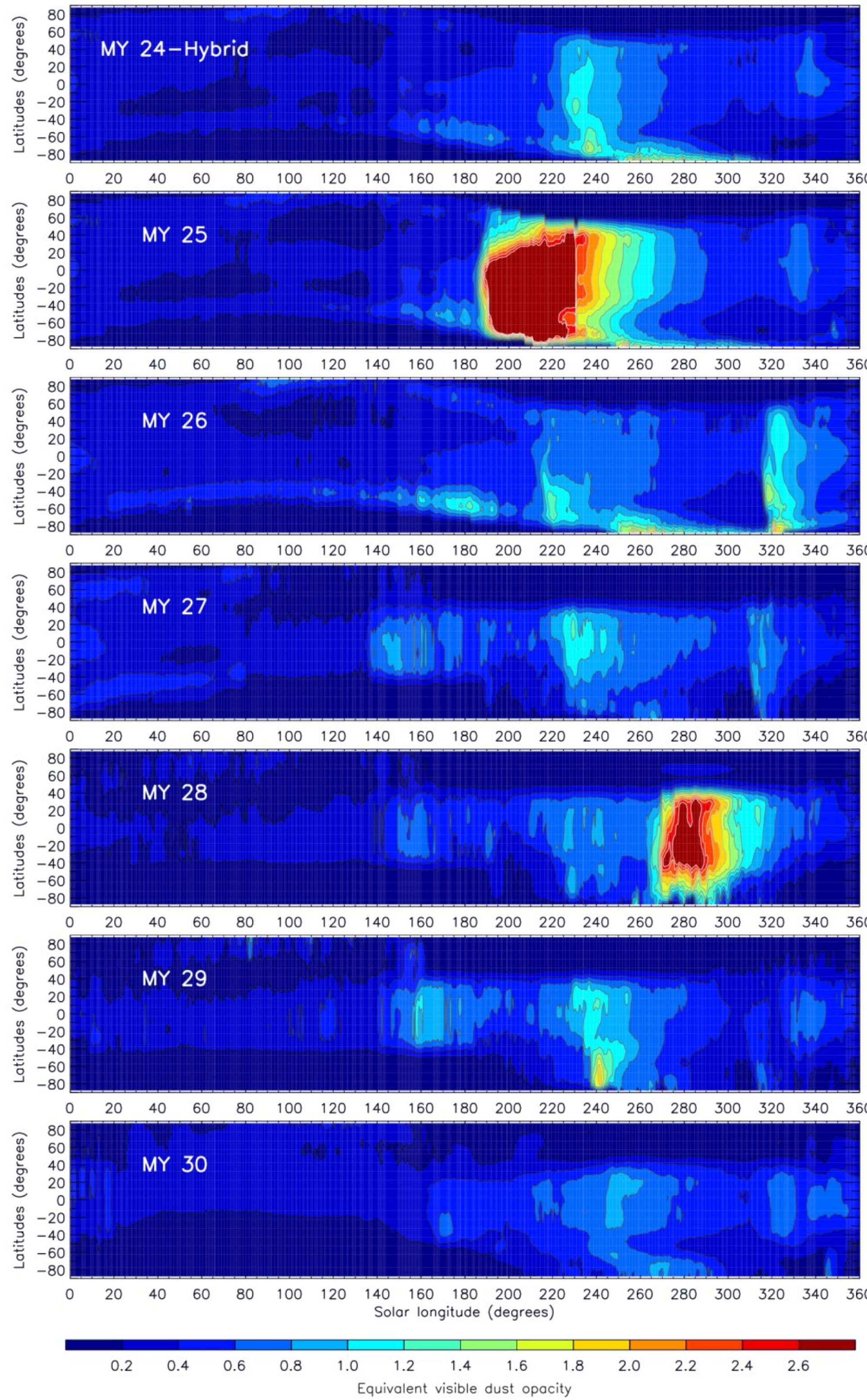
- The MCD provides a set of dust scenarios (topped with EUV upper atmosphere solar max, ave or min conditions) designed to "bracket reality".

- A **"Climatology" dust scenario**: derived from the combination of runs from individual years, in order to provide a mean climatology for years without global dust storms
- A "**cold**" (low dust) scenario
- A "**warm**" (high dust) scenario
- A "**dust storm**" scenario: with fixed high opacity (tau=5) and using Ockert-Bell (dark) dust properties.

MCD v5 dust scenarios

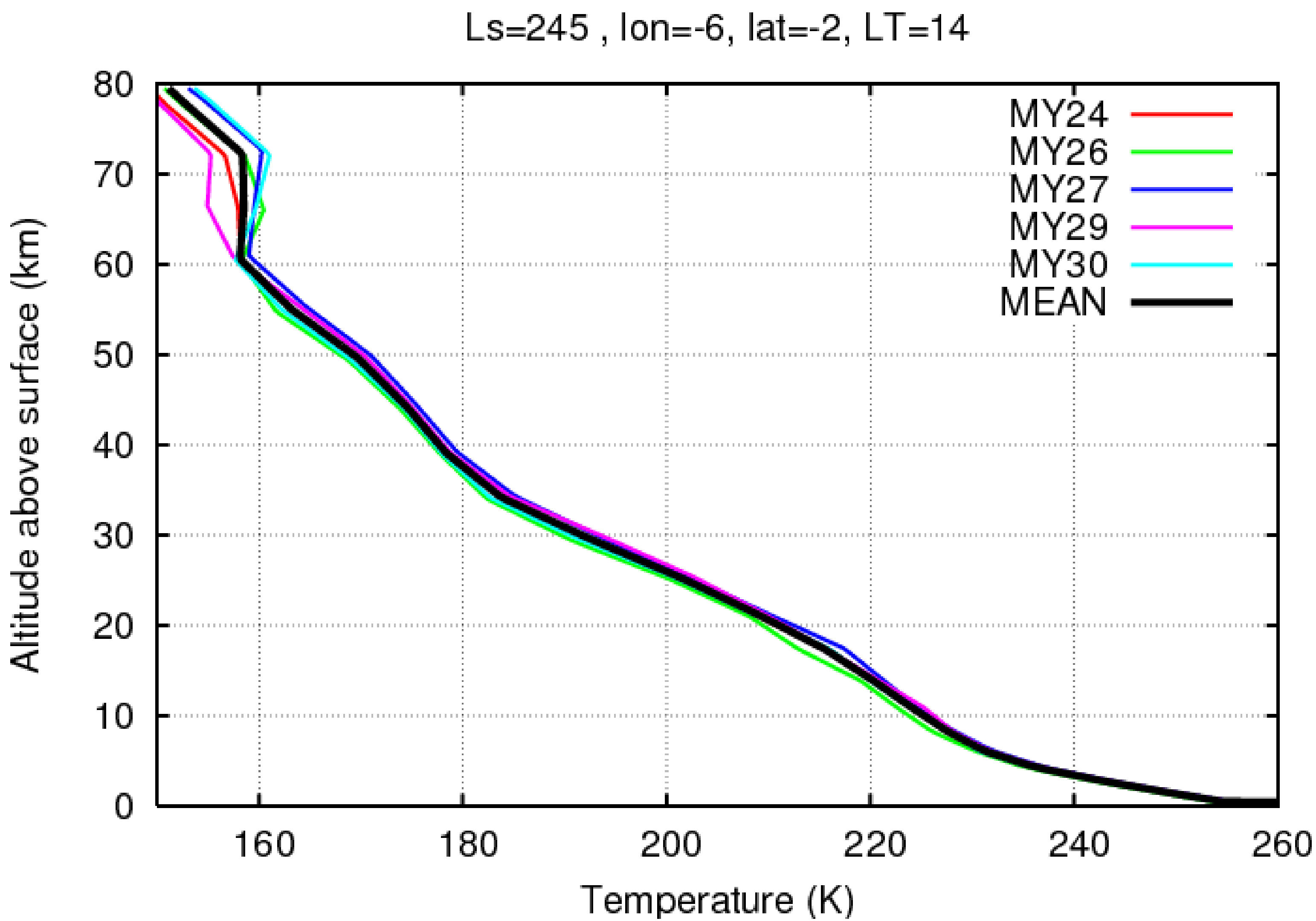
- **Combining** the outputs of runs from all 5 “non-global dust storm” years (MY 24, 26, 27, 29, 30), we generate the **mean Mars year climatology**.

- In addition, the variability encompassed in all these simulations is included in the MCDv5 **improved large-scale perturbation scheme.**



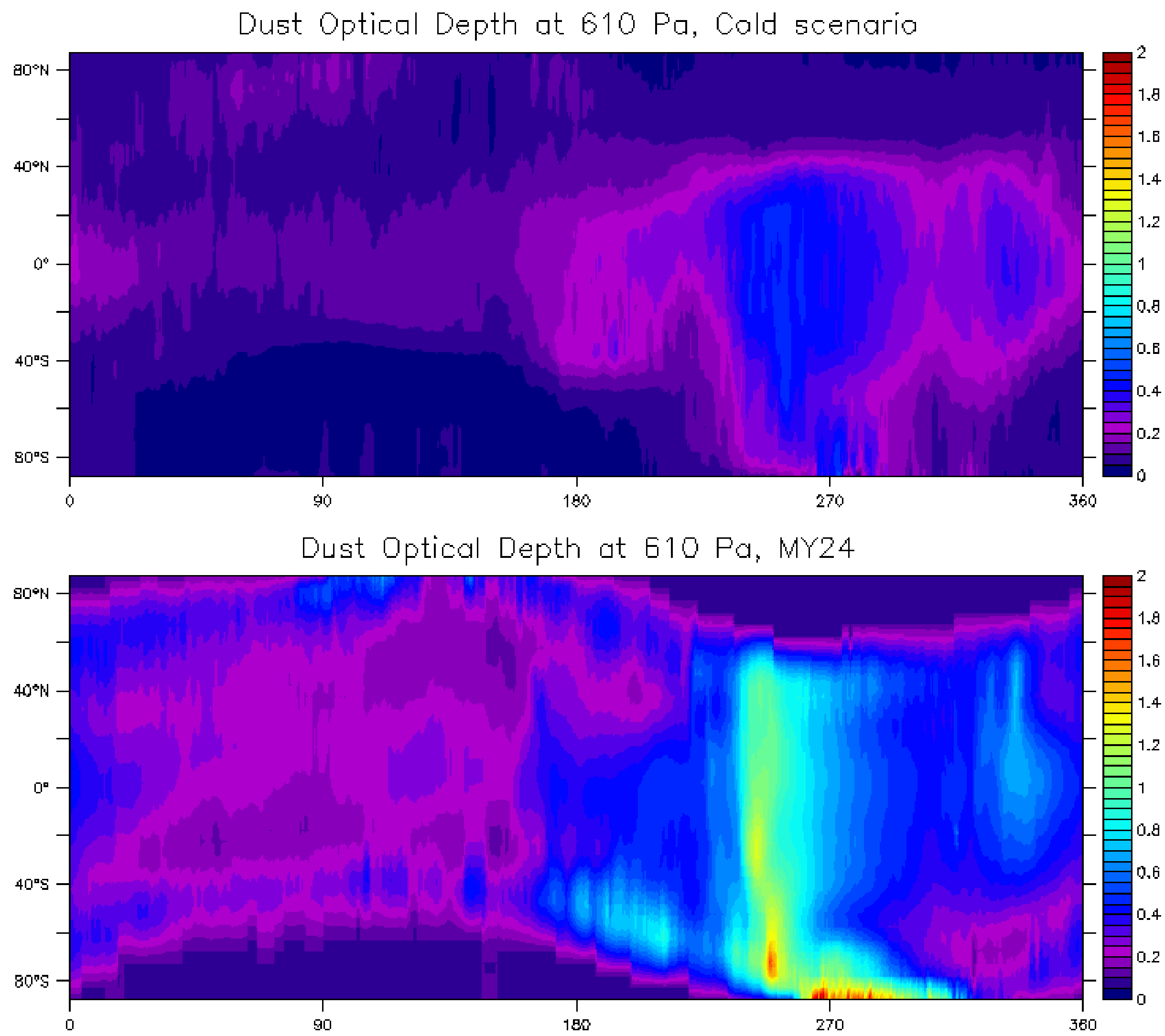
The Mean Year Dust Scenario

- The "climatology scenario" is simply compiled as an ensemble average of the five separate MY runs.



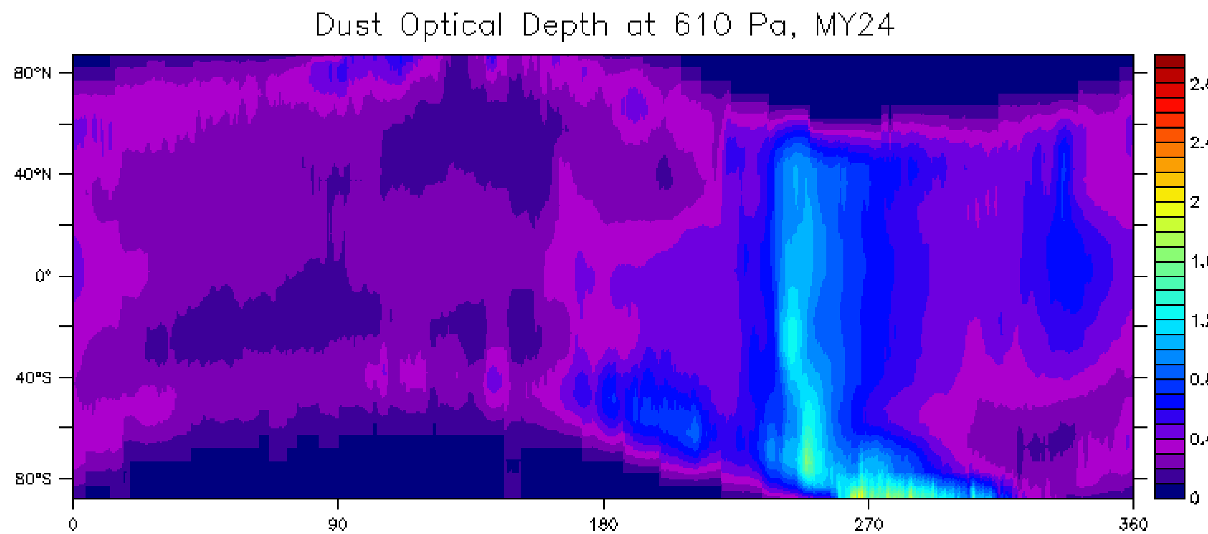
MCD v5 dust scenarios

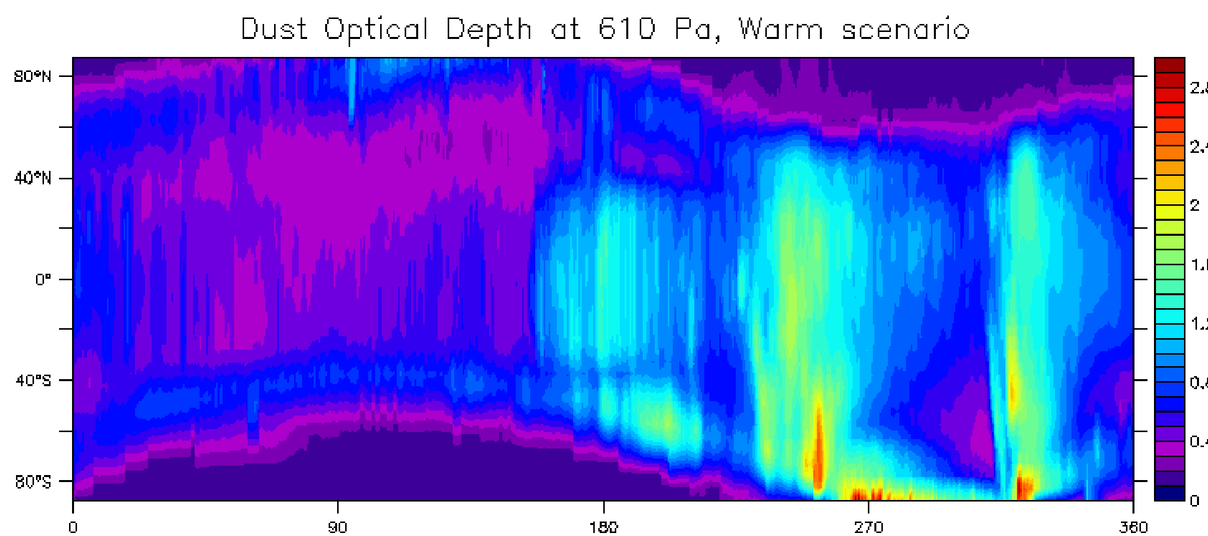
- The **cold scenario**: Very low amount of airborne dust. Dust opacity at a given season and location is taken as the minimum over the 7 Martian years MY24-MY30 dust scenarios, moreover decreased by 30%.



MCD v5 dust scenarios

• The **warm scenario**: Very high amount of airborne dust (but not a planet encircling dust storm event). Dust opacity at given season and location is taken as the maximum over the 7 Martian years (excluding the global dust storm periods during MY25 and MY28), moreover increased by 30%.

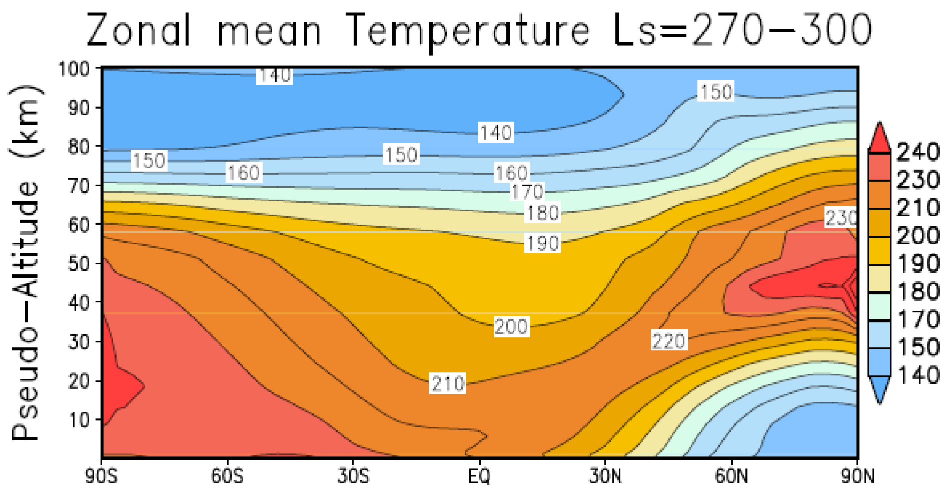


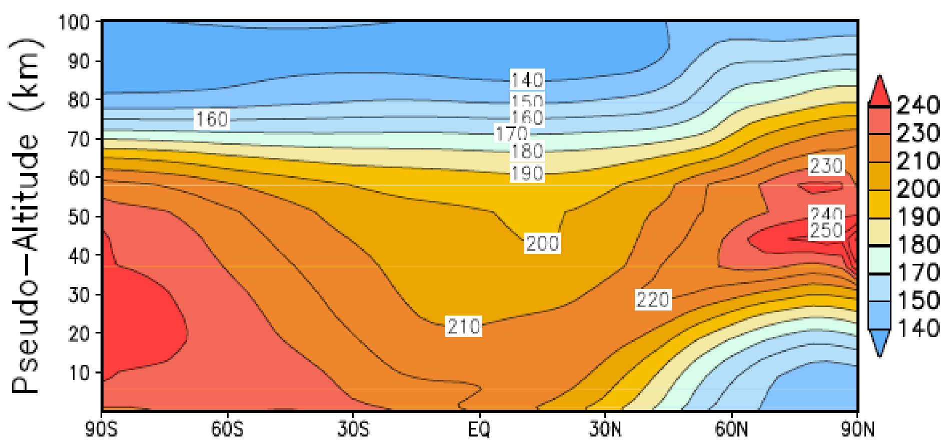


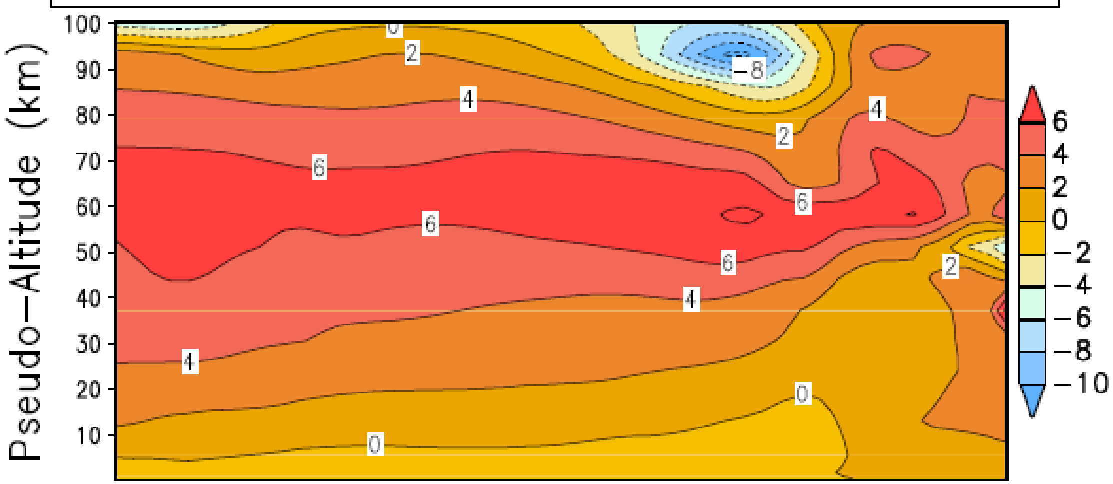
MCD v5 dust scenarios

- The **dust storm scenario**: An extreme case of fixed high opacity (tau=5) combined with “darker dust” properties (ie: using Ockert-Bell dust properties instead of Wolff et al. properties).

Upper right: Ockert Bell dust
Lower right: Wolff et al. dust
Lower left: Temperature difference between darker and nominal dust: warming around 60km.



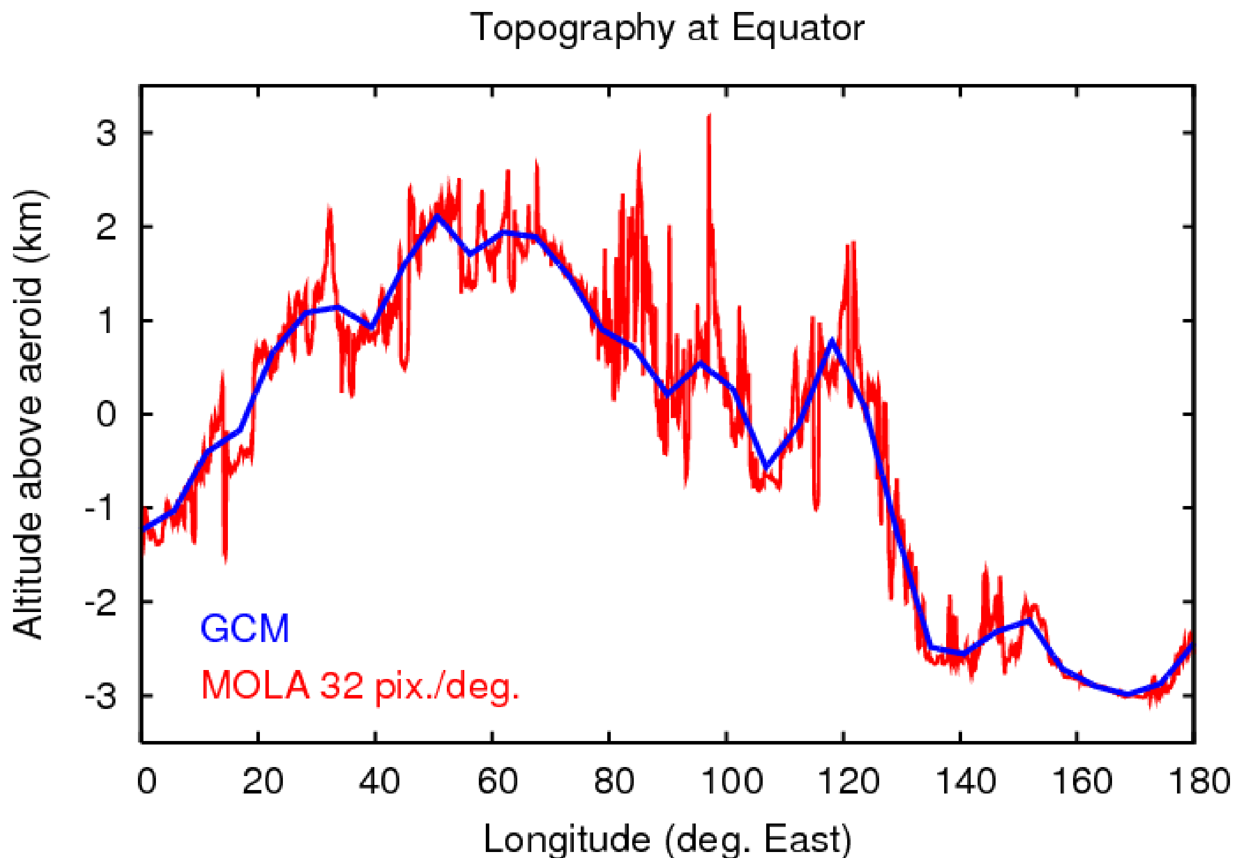




MCD high resolution outputs

- The GCM from which the MCD is derived is run at 5.625° x 3.75° resolution in longitude x latitude.
- The MCD post-processing software includes a high resolution mode based on 32 pix./deg. MOLA topography

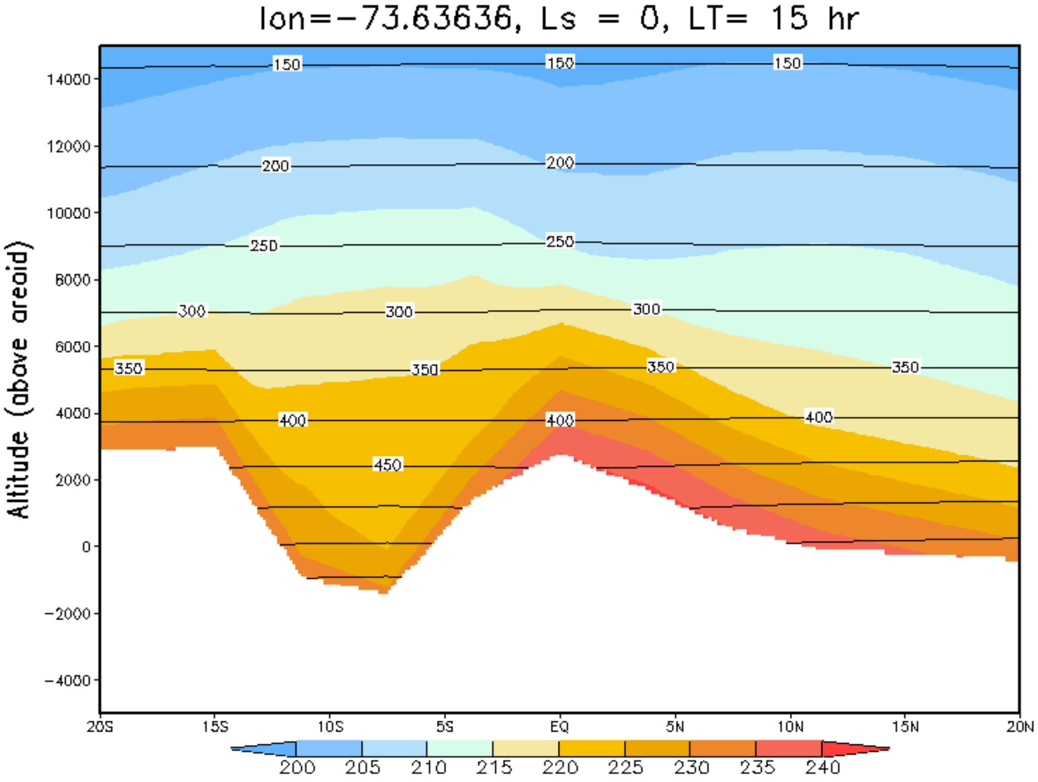
High resolution surface pressure is obtained by combining MCD surface pressure, MOLA topography and VL1 pressure records (procedure validated by Spiga et al. 2007)

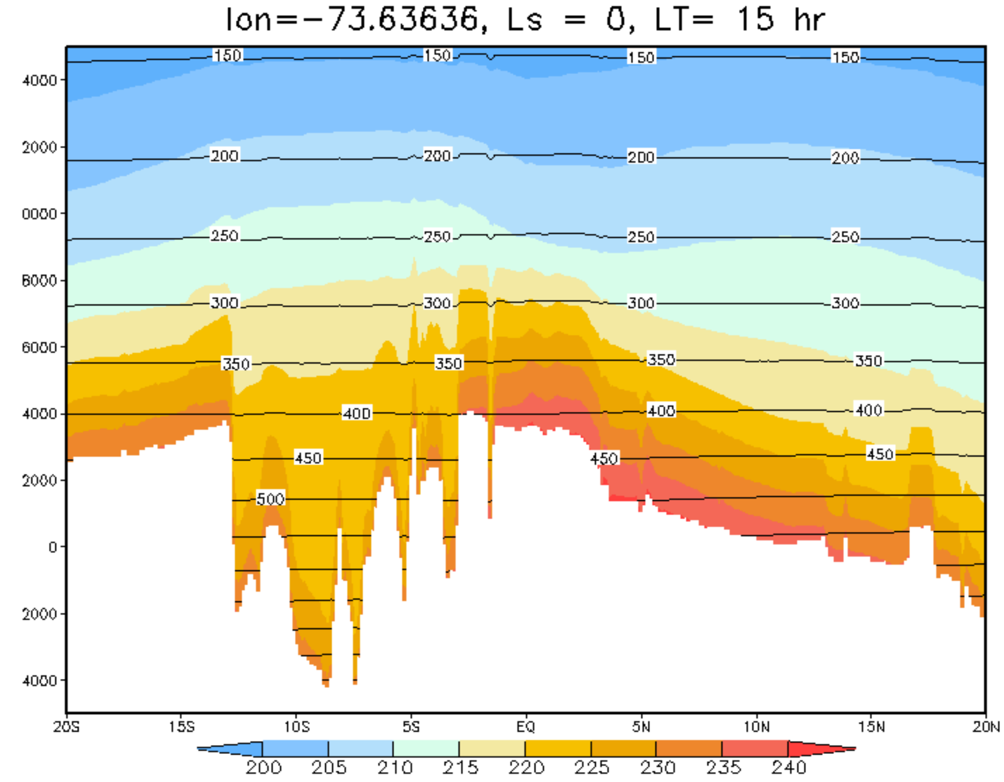


MCD high resolution outputs

- The high resolution scheme extends to the reconstruction of atmospheric variables (empirical scheme validated using high resolution GCM runs).

Example: temperatures above Valles Marineris





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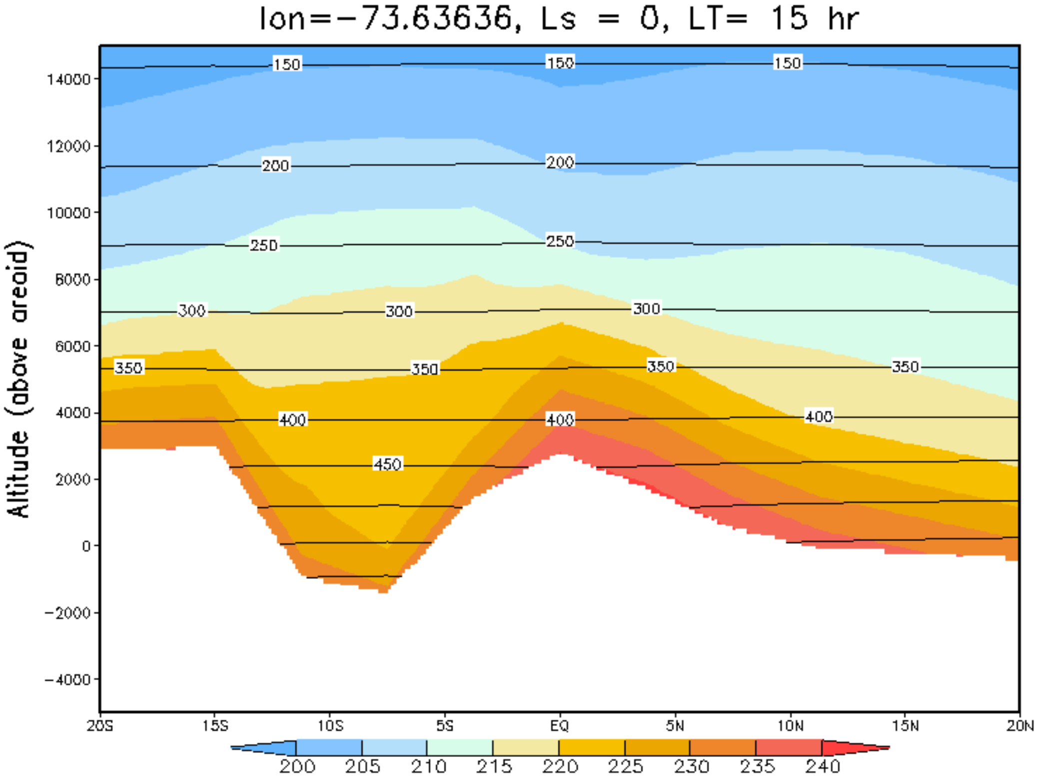
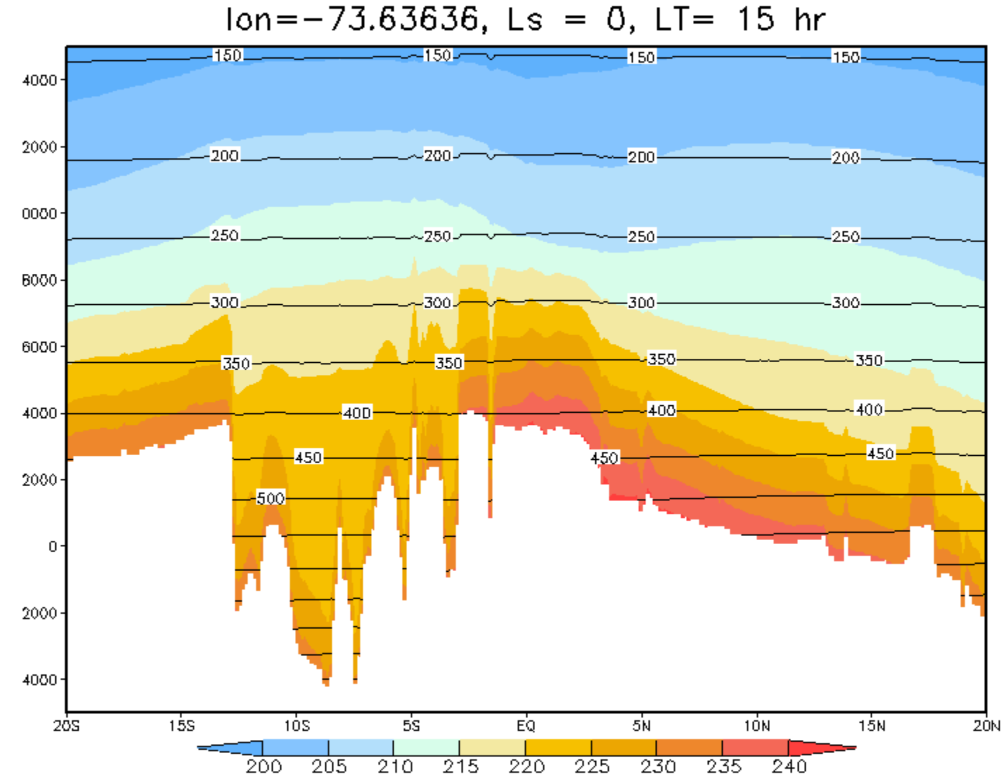
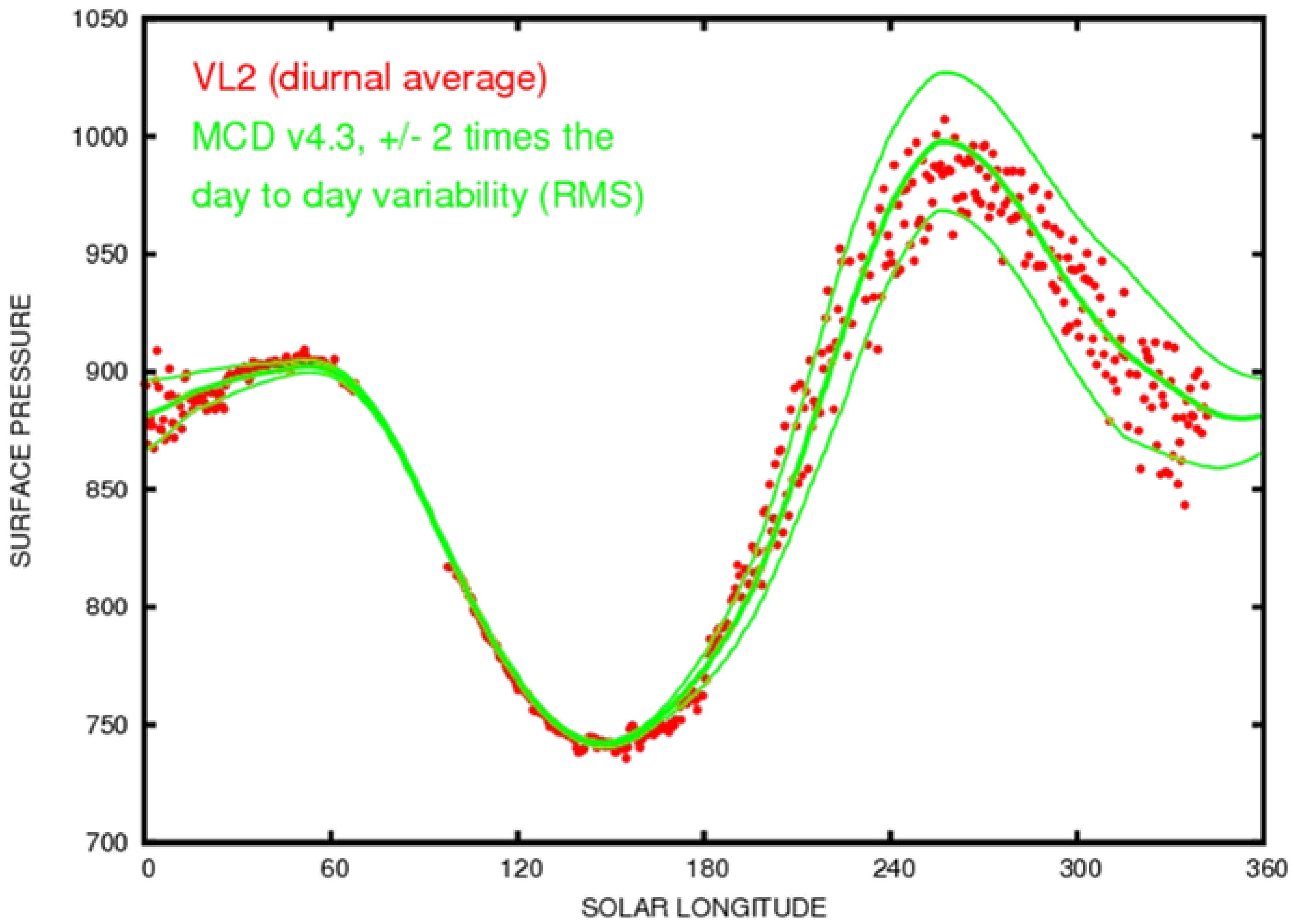




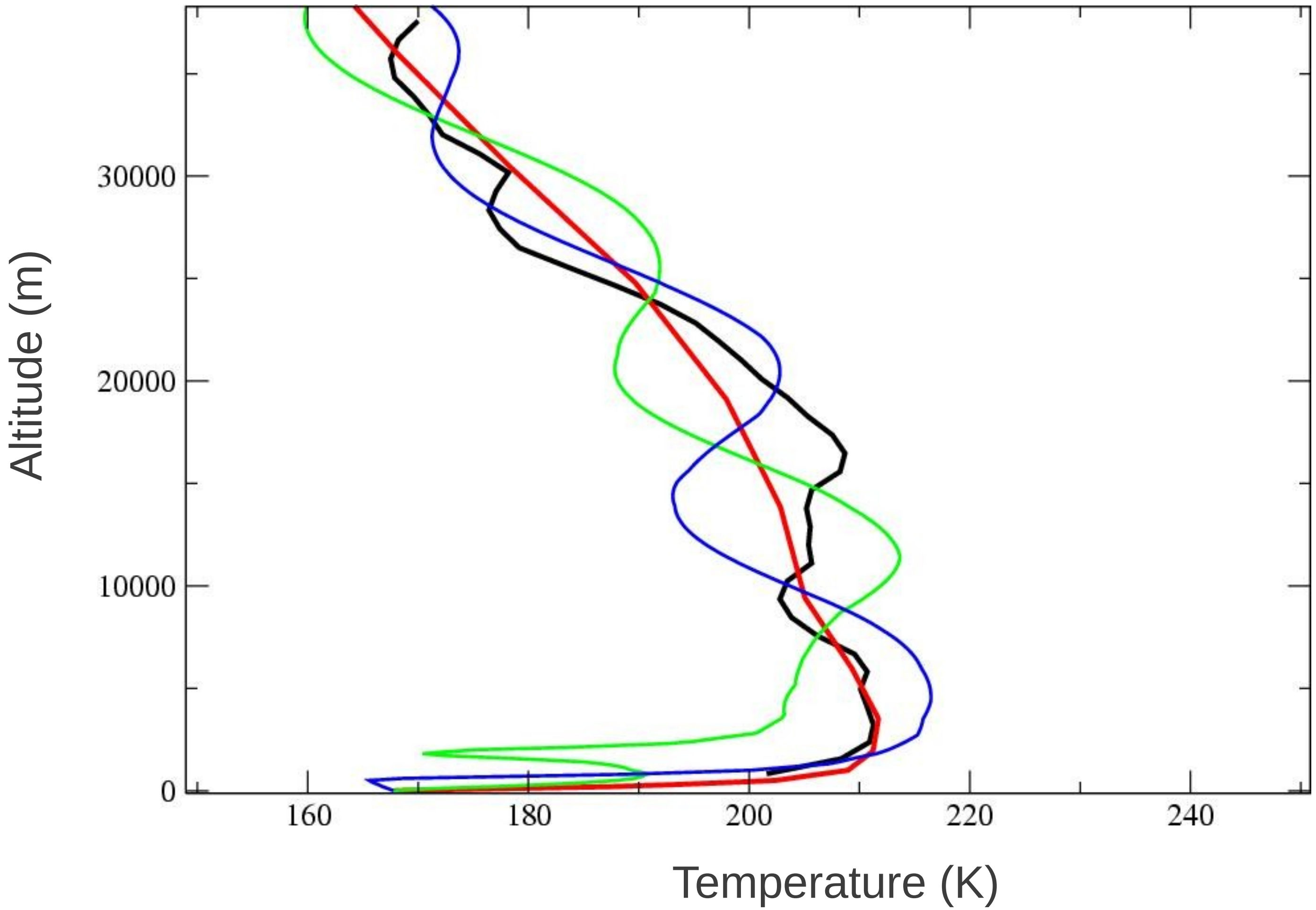
MCD variability models

- In addition to the mean climatological values, the MCD includes the **day-to-day variability** (RMS) of main meteorological variables (density, temperature, winds, pressure, ...)
- <u>Example</u>: surface pressure at VL2 site:



MCD variability models

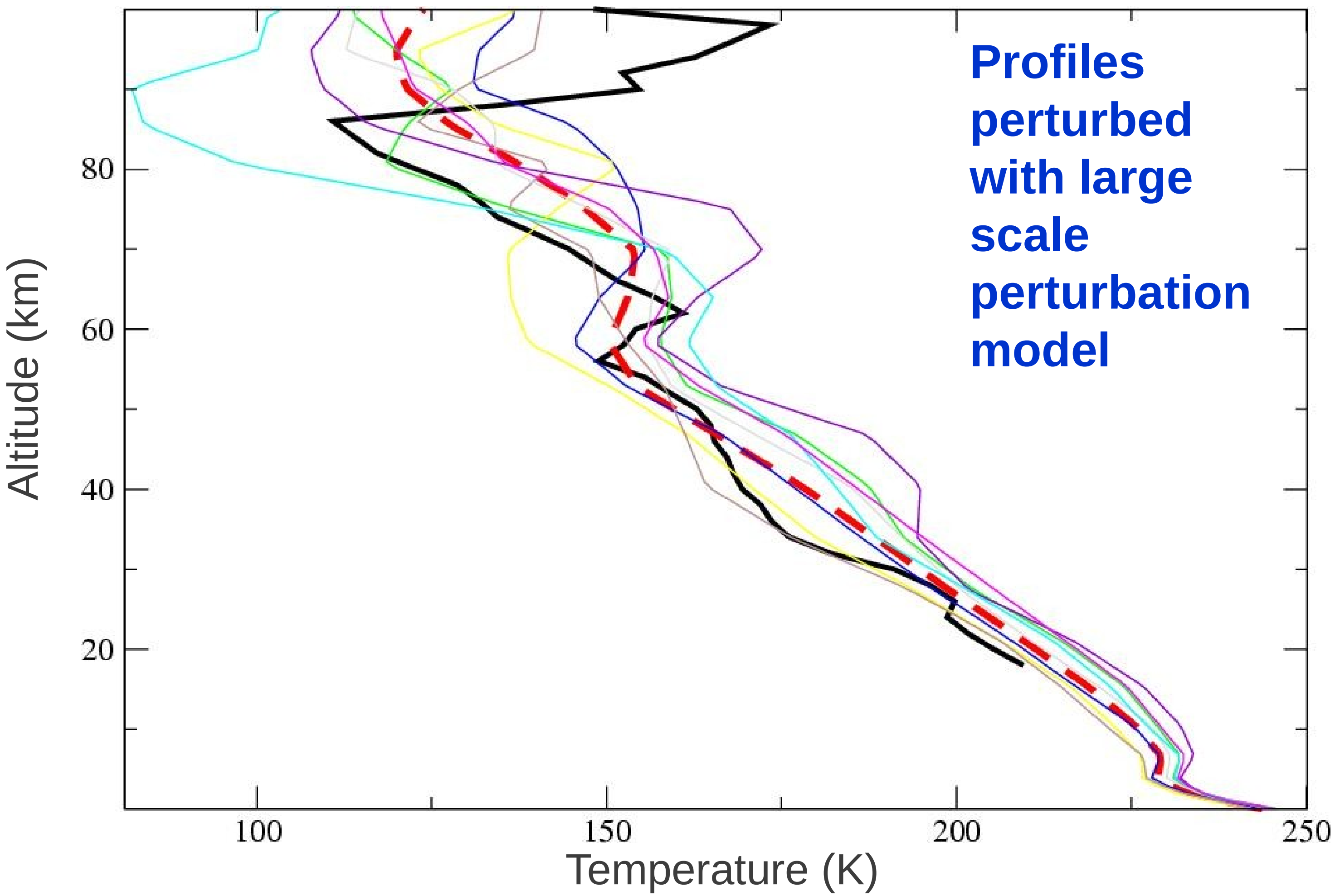
- Users may reconstruct variability by adding perturbations to the mean climatological values, as **small scale perturbations** (gravity waves)
- <u>Example</u>: MGS Radio Occultation and MCD predictions with random gravity waves.



- Gravity waves are not represented in the GCM simulations (sub-grid parameterization)
- Source & intensity depends on low-level wind and sub-grid scale topography
- Tunable vertical wavelength (2 to 30 km; default : 16 km)
- Constant amplitude above 100 km

MCD variability models

- Users may reconstruct variability by adding perturbations to the mean climatological values, as **large scale perturbations** (reconstructed from EOFs derived from GCM runs).
- <u>Example</u>: Opportunity entry profile



Mars Climate Database, summary

- The Mars Climate Database (MCD) is a database **derived from Global Climate Model** (GCM) **simulations**.
- The MCD is intended to be useful for engineering applications (e.g. Entry Descent & Landing studies) and scientific work which require accurate knowledge of the Martian atmosphere (e.g. Analysis of observations).
- With the MCD, one may explore the climatology of Mars, but also its variability.
- The MCD is freely available, to obtain a copy, just ask us!
- One can also access a limited online version of the MCD:

  http://www-mars.lmd.jussieu.fr/mcd_python

  (python interface by A. Spiga, currently for MCDv4.3; MCDv5.0 under beta testing)