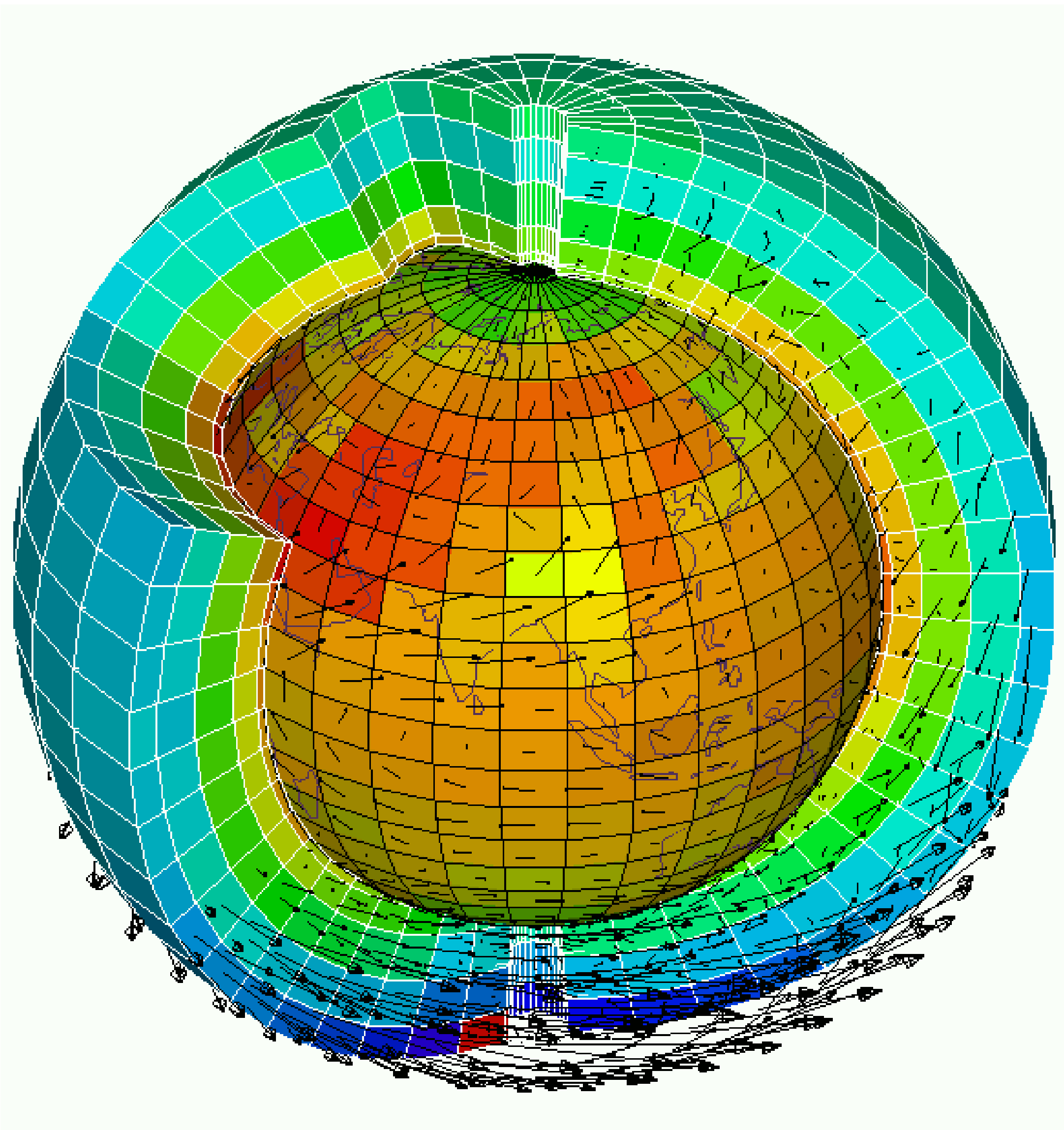
MODELING THE MARTIAN ATMOSPHERE WITH THE LMD GLOBAL CLIMATE MODEL

F. Forget[1], E. Millour[1], F. González-Galindo[1] J.B. Madeleine[1], F. Lefèvre[4] , A. Spiga[1] P-Y. Meslin[1] S. Lebonnois[1], F. Hourdin[1], S.R. Lewis[2] , L. Montabone[1,2] , P.L. Read[3] ,, F. Montmessin[4], , M.A. López-Valverde[5]

Laboratoire de Météorologie Dynamique, IPSL, Université Pierre & Marie Curie, BP99, 4 place Jussieu, 75252 Paris, Cedex 05, France, [2]The Open University, Milton Keynes, UK, [3] AOPP, University of Oxford, UK, [4]Service d'Aéronomie, IPSL, Université Pierre & Marie Curie, BP102, Paris, France, [5]Instituto de Astrofísica de Andalucía, Granada, Spain,

General Circulation Models/ Global Climate models

⇒ GCMs

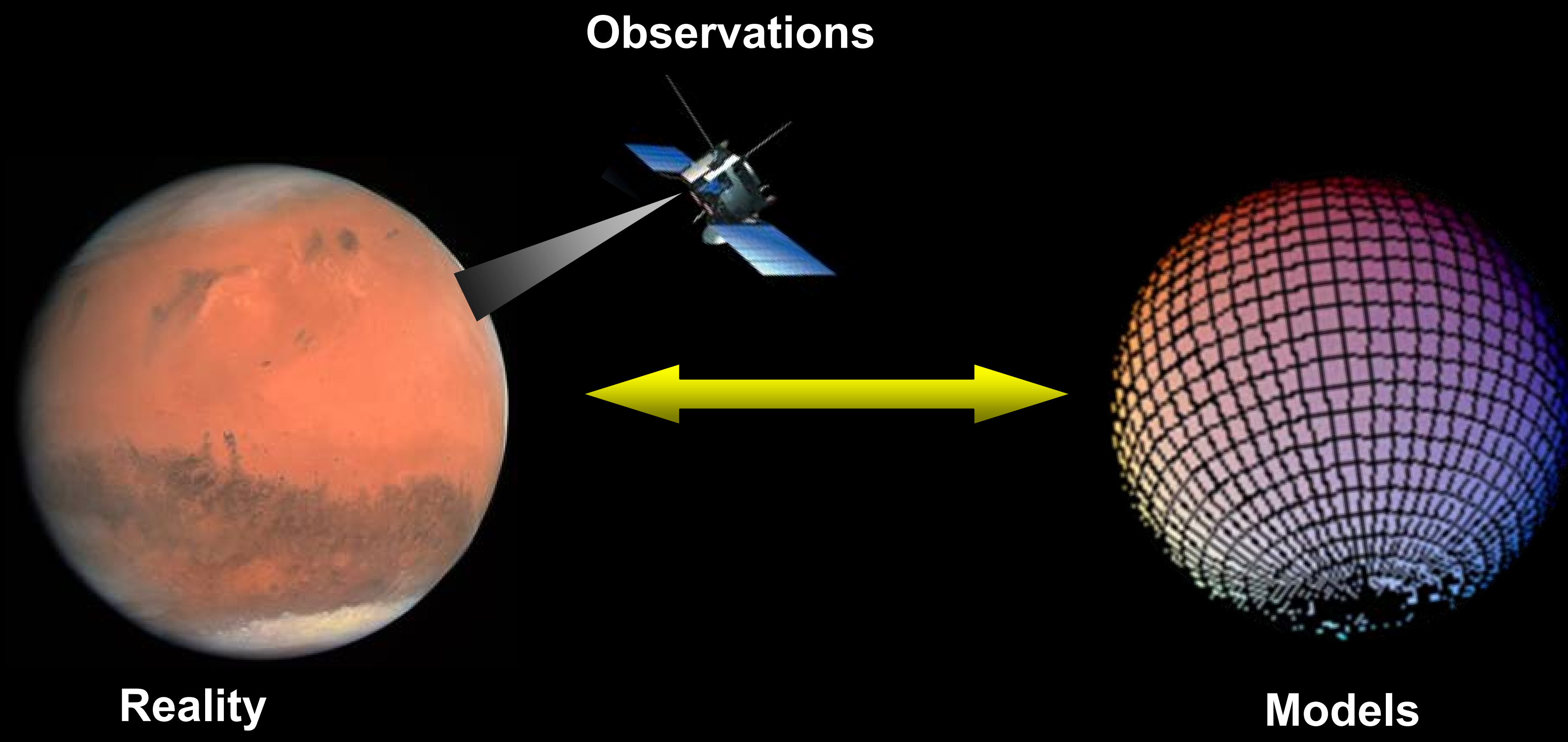


3D Numerical simulators of a planetary environment: designed to simulate the « entire reality »

Several GCMs

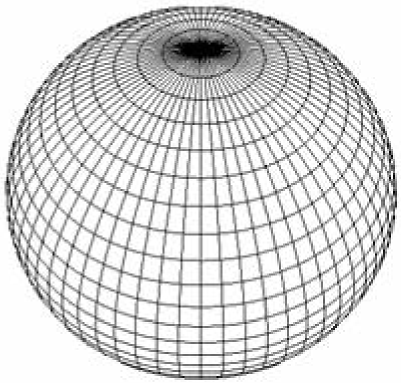
-NASA Ames, GFDL
-LMD, AOPP,
-Caltech
-MPS,
-Japan,
-York U.
- …

An ambitious goal : Building virtual planets behaving like the real ones, on the basis of universal equations



How GCMs work ? :

The minimum General Circulation Model for Mars



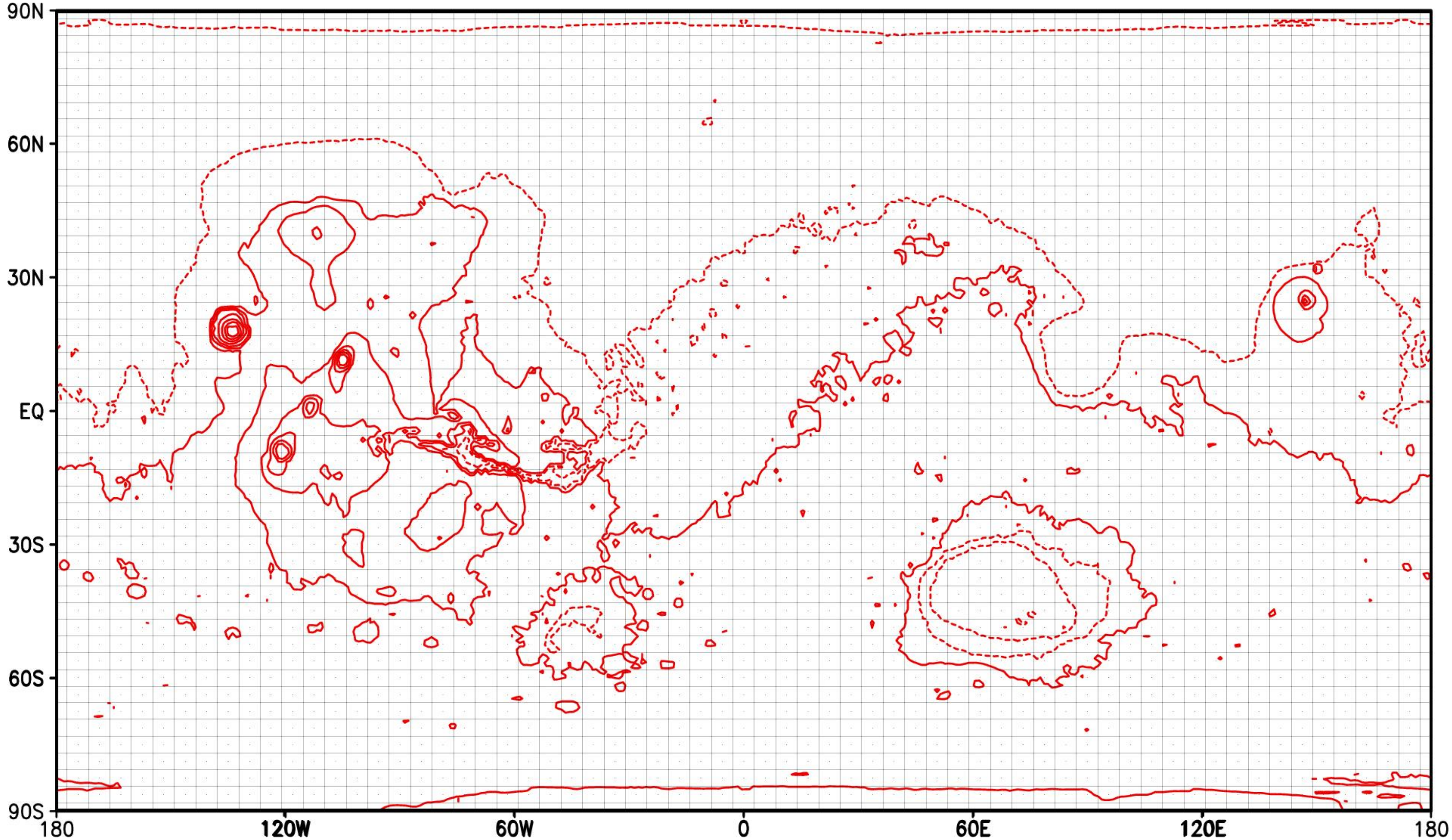
1) Hydrodynamical code

$\Rightarrow$ ***to compute large scale atmospheric motions***

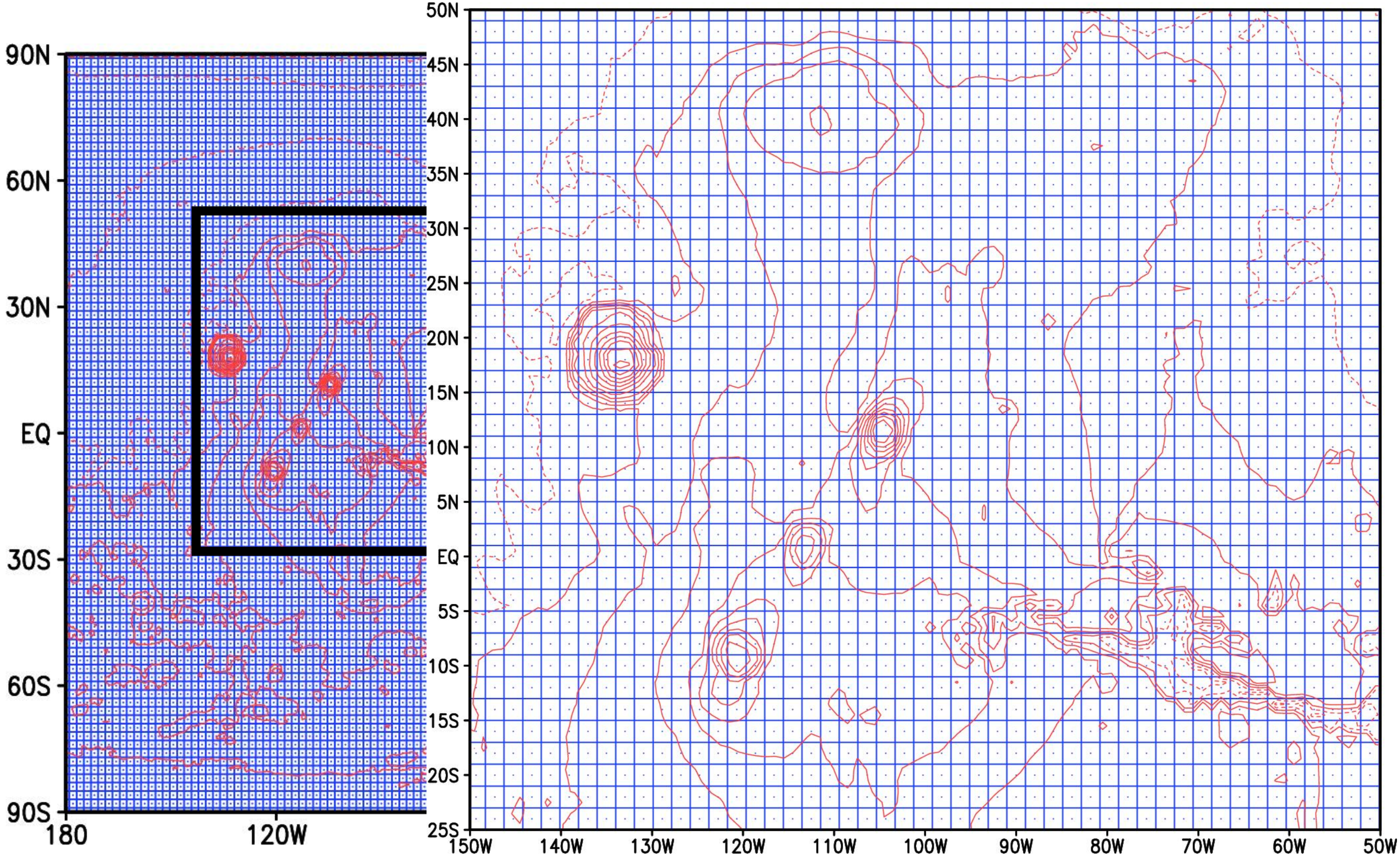
LMD : grid point model :

Typical resolution **64x48 , possibility of zoom**

LMD GCM : standard resolution : 5.625°× 3.75°

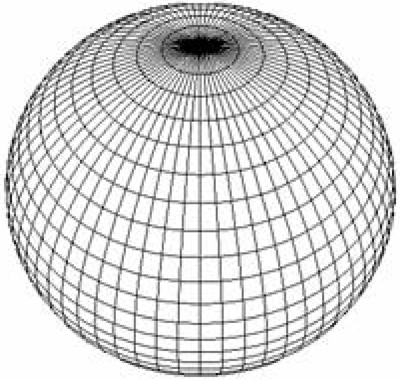


LMD GCM : high resolution : 2°× 2°



How GCMs work ? :

The minimum General Circulation Model for Mars

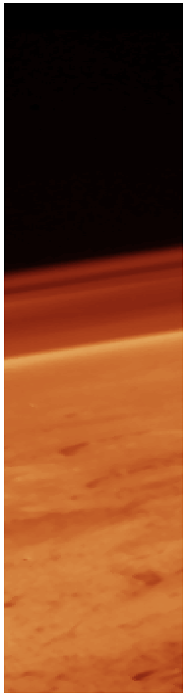


1) Hydrodynamical code

⇒ *to compute large scale atmospheric motions*

LMD : grid point model :

Typical 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 CO2 and dust
- Surface thermal balance
- Subgrid scale atmospheric motions :

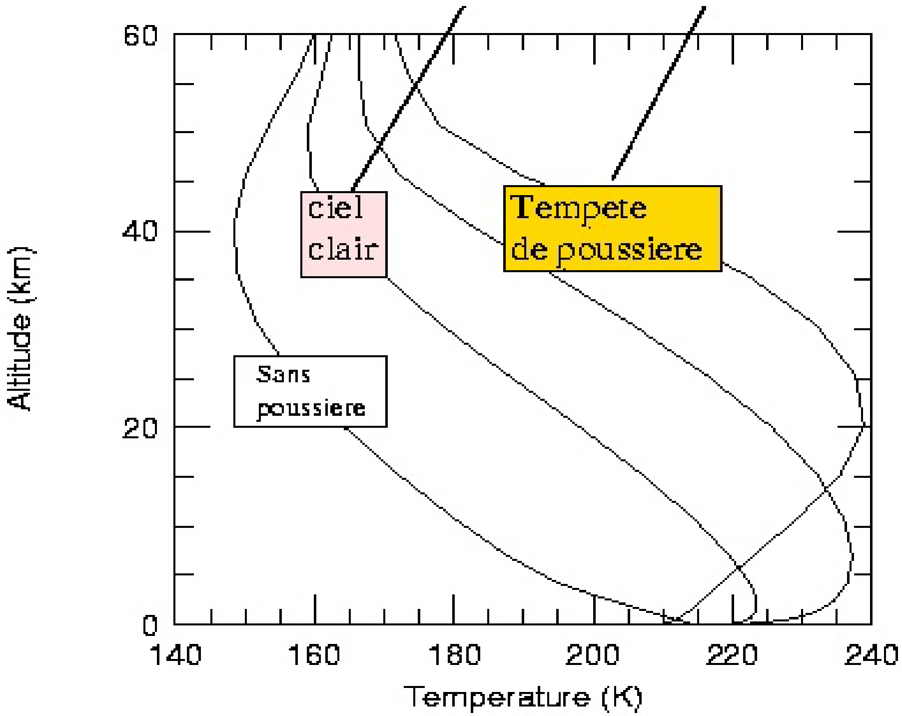
● Turbulence in the boundary layer ● Convection *•Relief drag* *•Gravity wave drag*

- CO2 condensation :

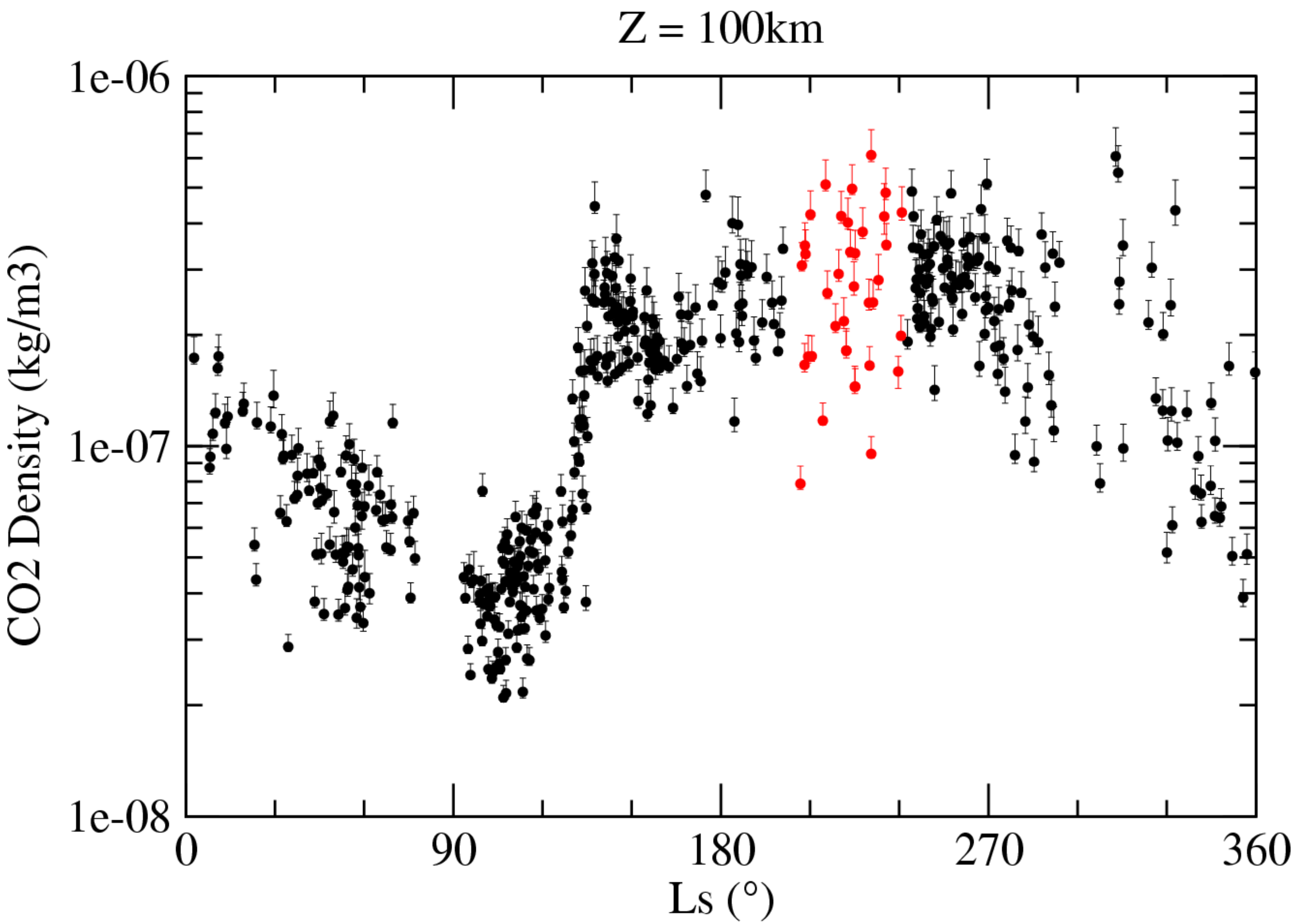
DUST : so important for Atmospheric dynamics and thermal structure

- Problem : below 50 km : the thermal structure is sensitive to the dust distribution

$\Rightarrow$

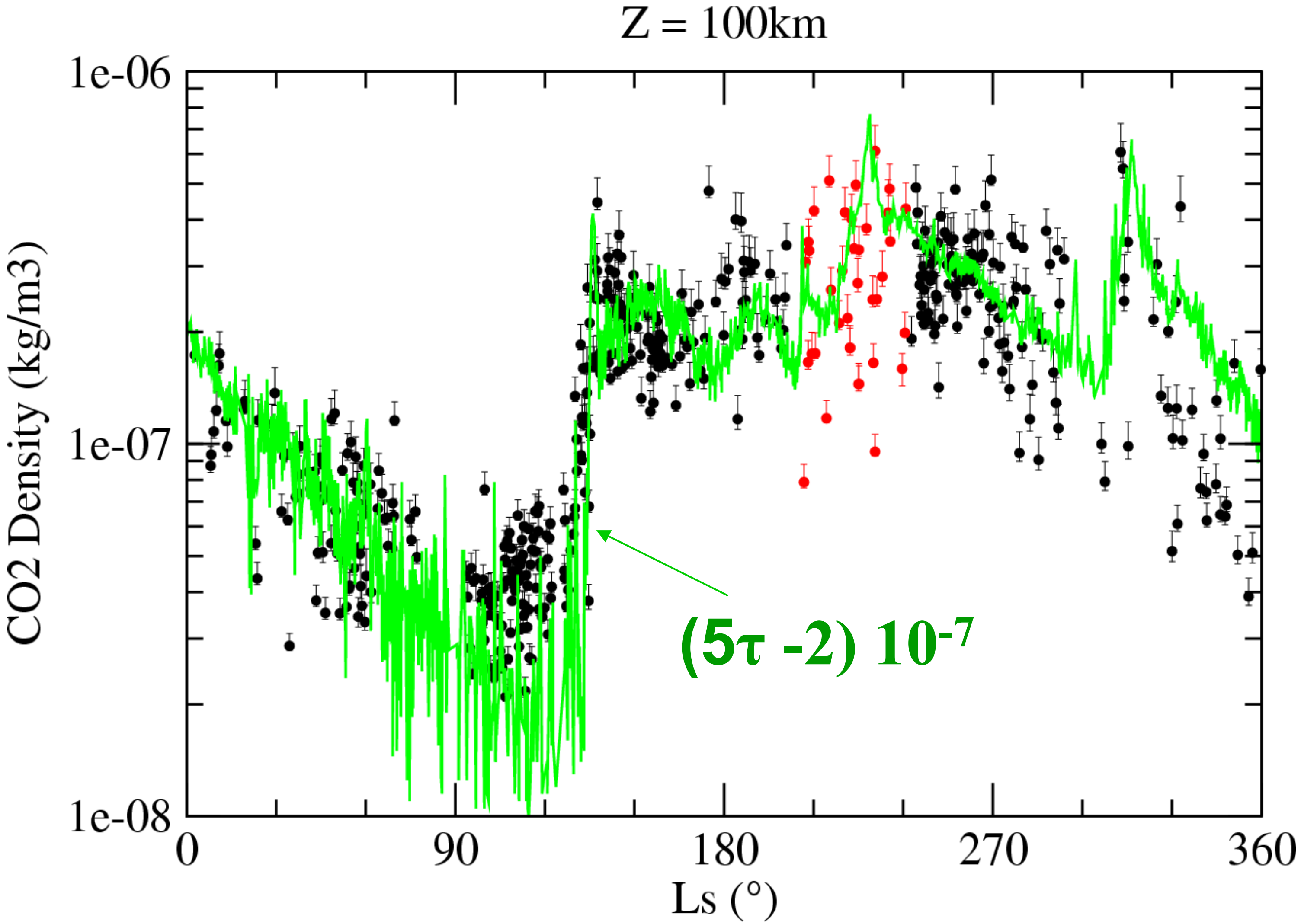


Comparison of SPICAM CO2 density at 100 km with opportunity surface dust opacities



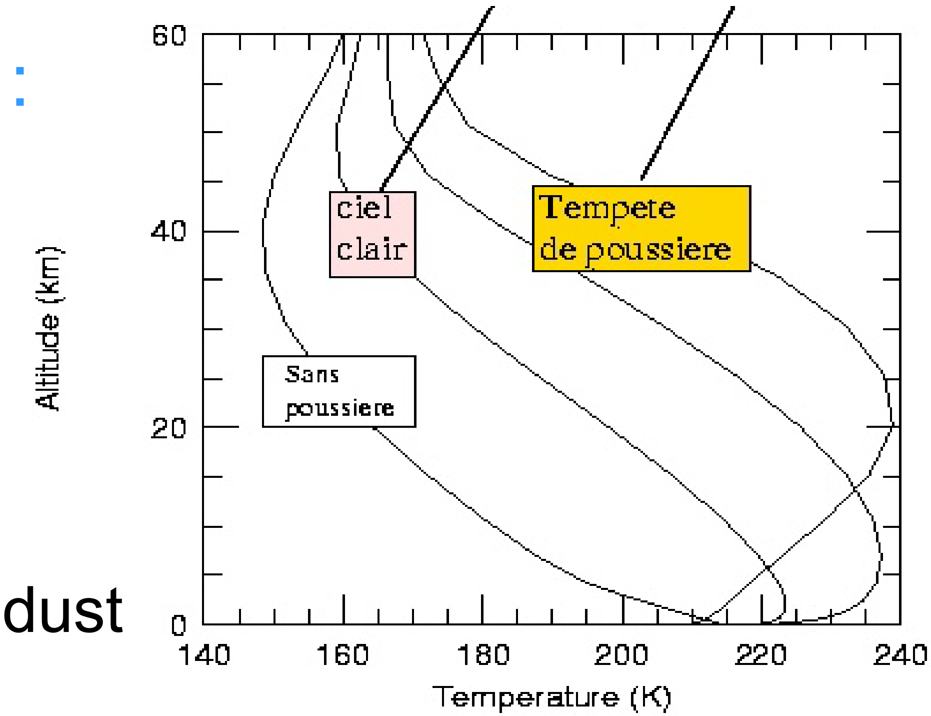
Forget et al. (2009)

Comparison with opportunity dust opacities « τ »



DUST : so important for Atmospheric dynamics and thermal structure

- Problem : below 50 km : the thermal structure is sensitive to the dust distribution



⇒ Require to prescribe a “dust distribution”

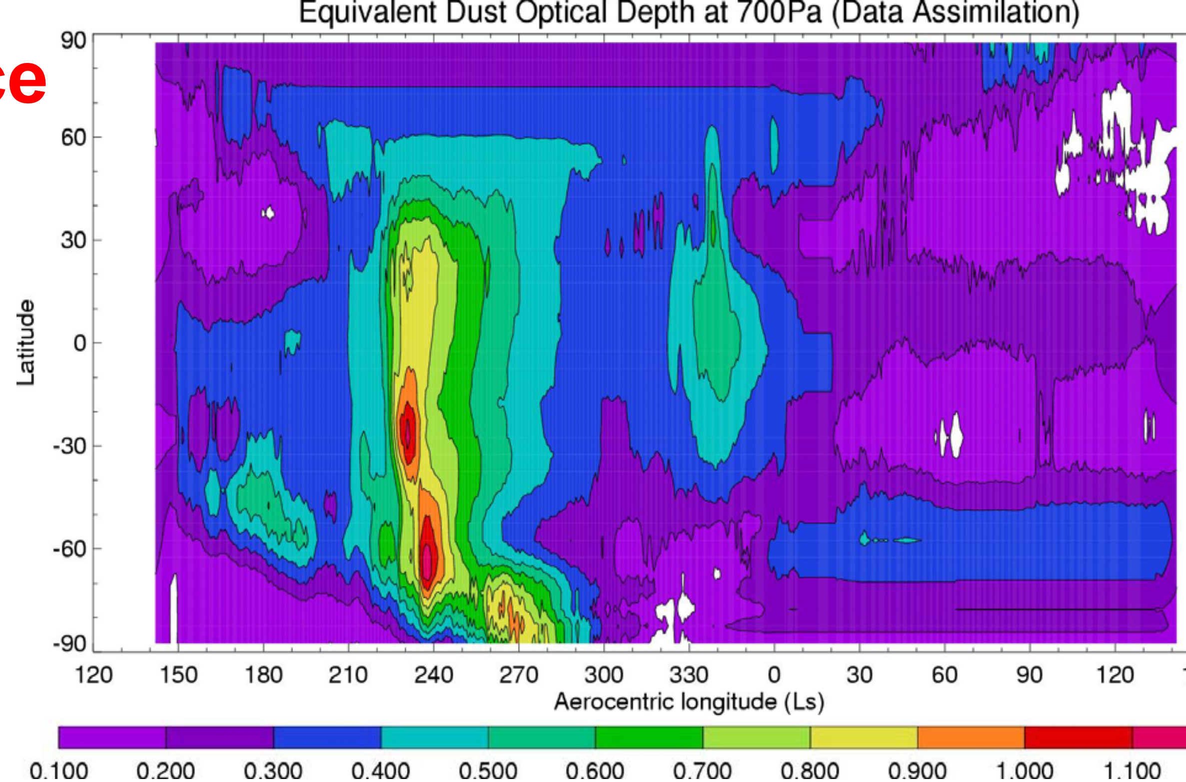
problem analogous to Sea Surface Temperature forcing in Earth climate

Prescribed reference "Martian year 24" dust scenario"

Prescribed dust opacity at 700 Pa :

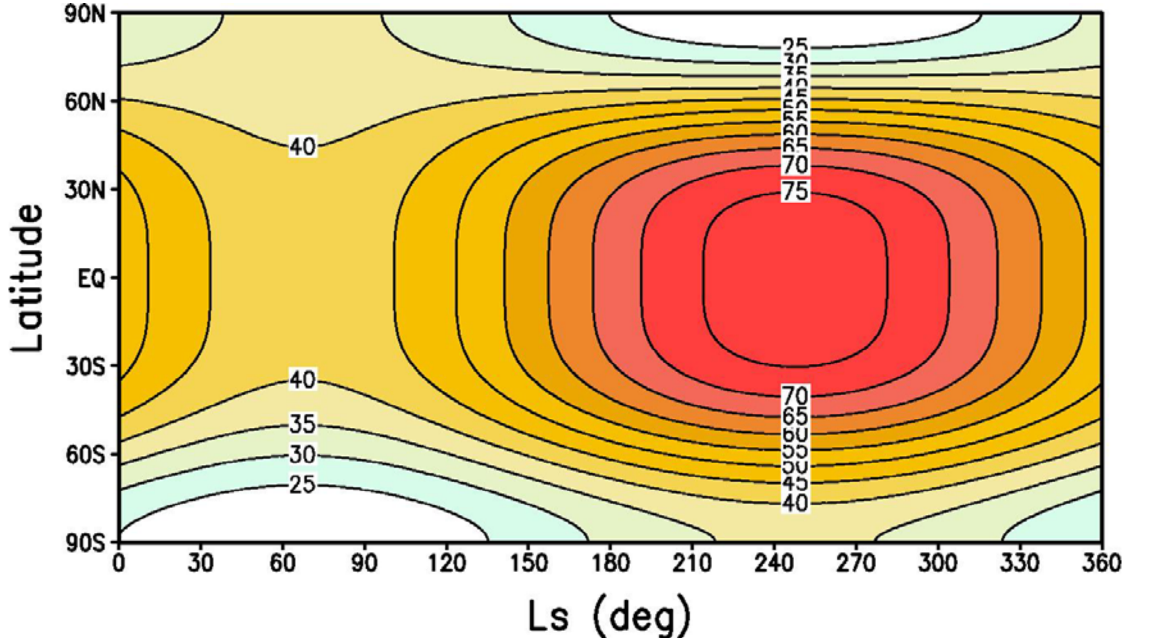
⇒Varies as a function of Latitude, Longitude and time

Based on 1999-2001 TES data assimilation (Montabone and Lewis) : "Martian Year 24"

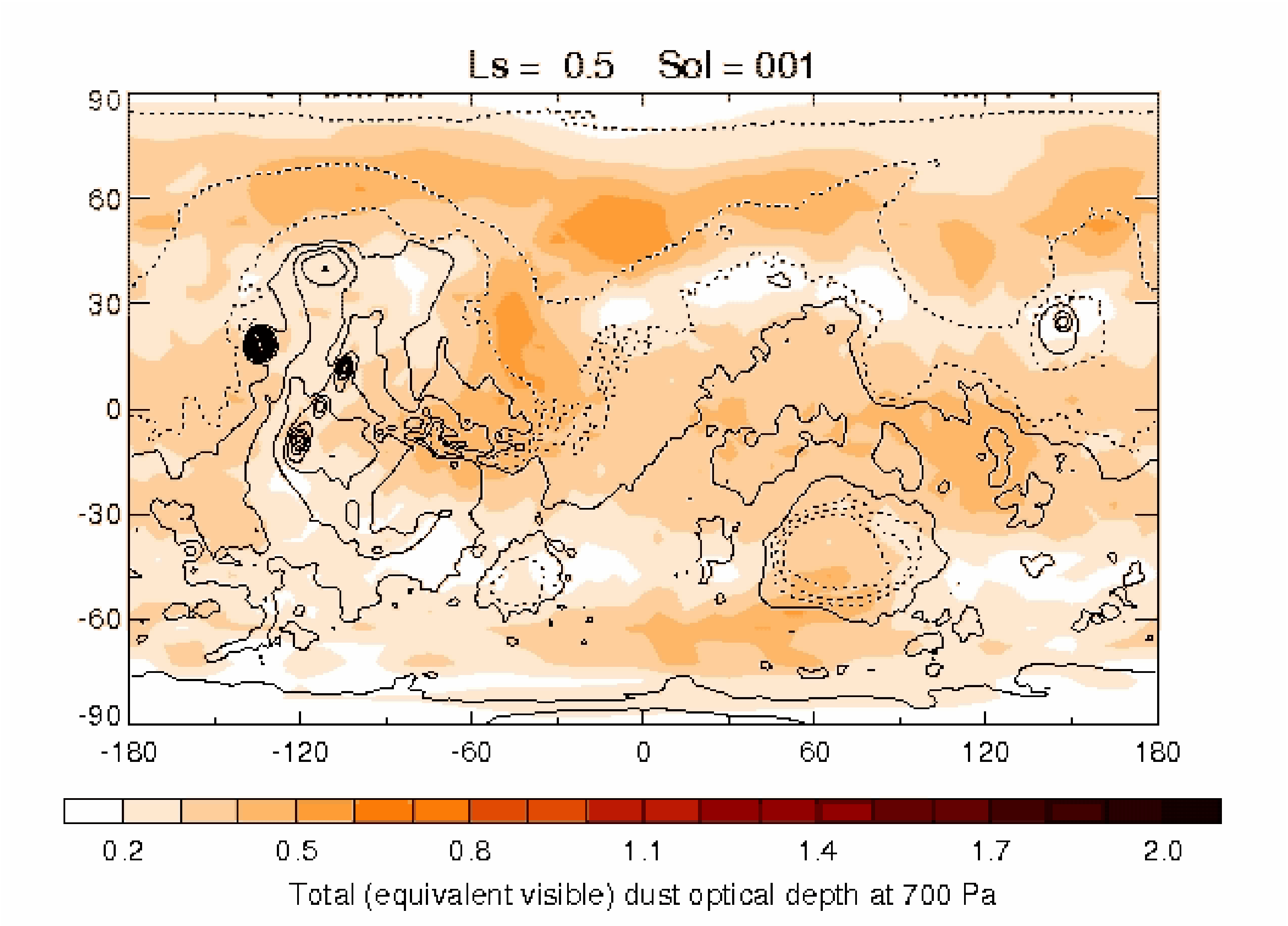


Top of the dust layer (km):

(based on Viking and Mariner 9 limb observations)



MY 24 GCM reference dust scenario



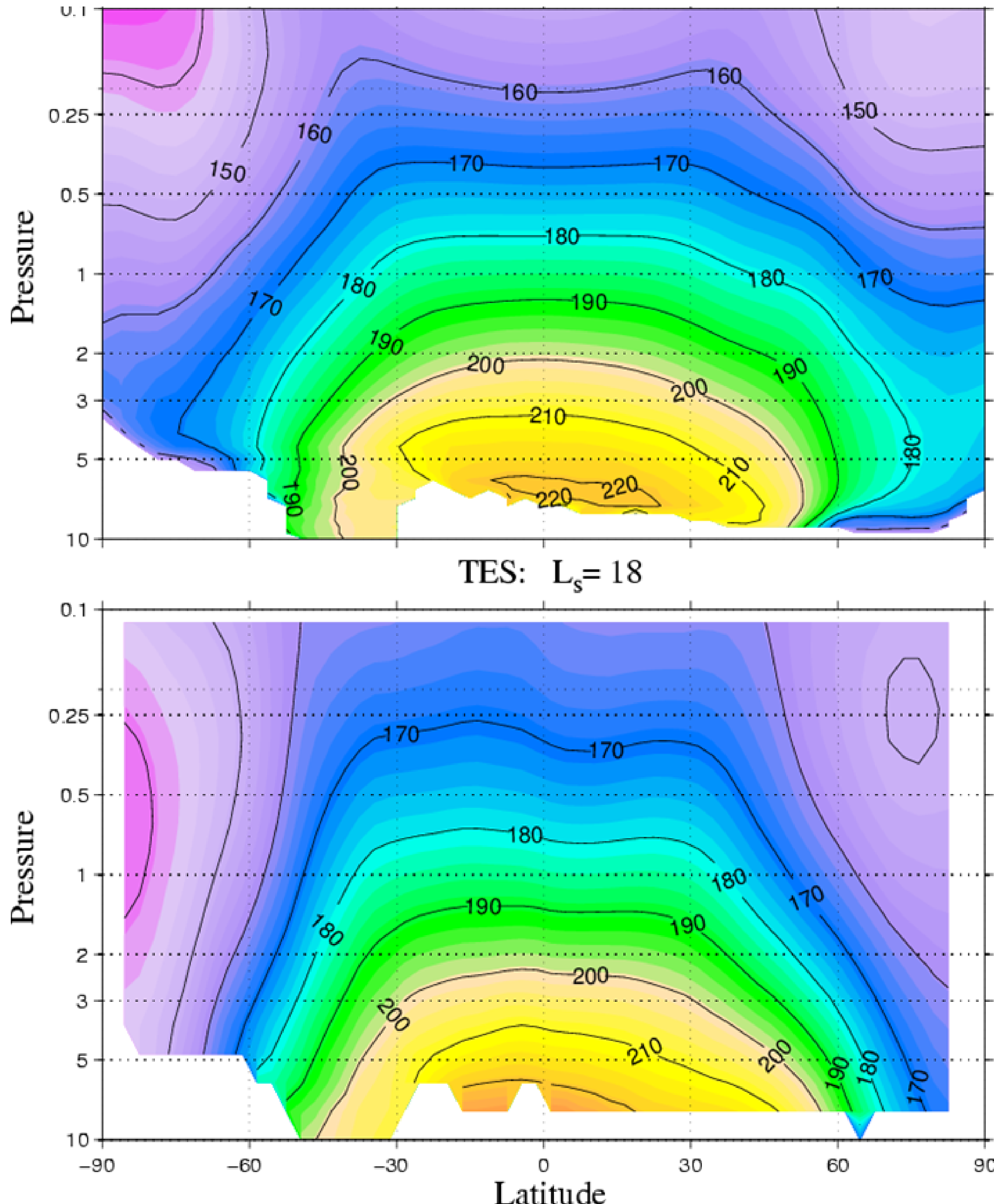
Courtesy Steve Lewis
(TES dust assimilation)

Zonal mean temperature

Ls = 18°

LMD GCM

TES Observations



Figures from John Wilson !

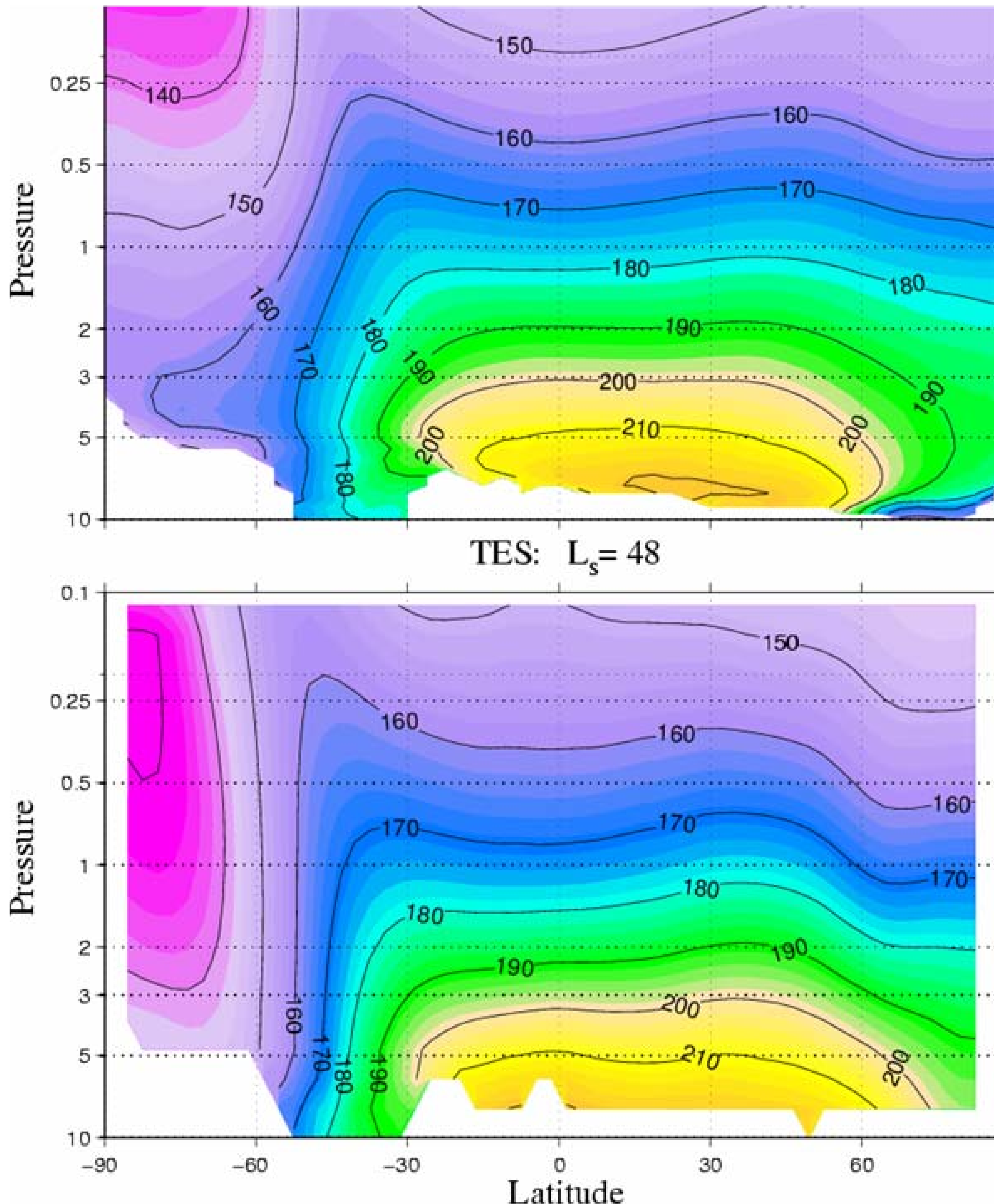
Zonal mean temperature

Ls = 48°

LMD GCM

TES Observations

Figures from John Wilson !



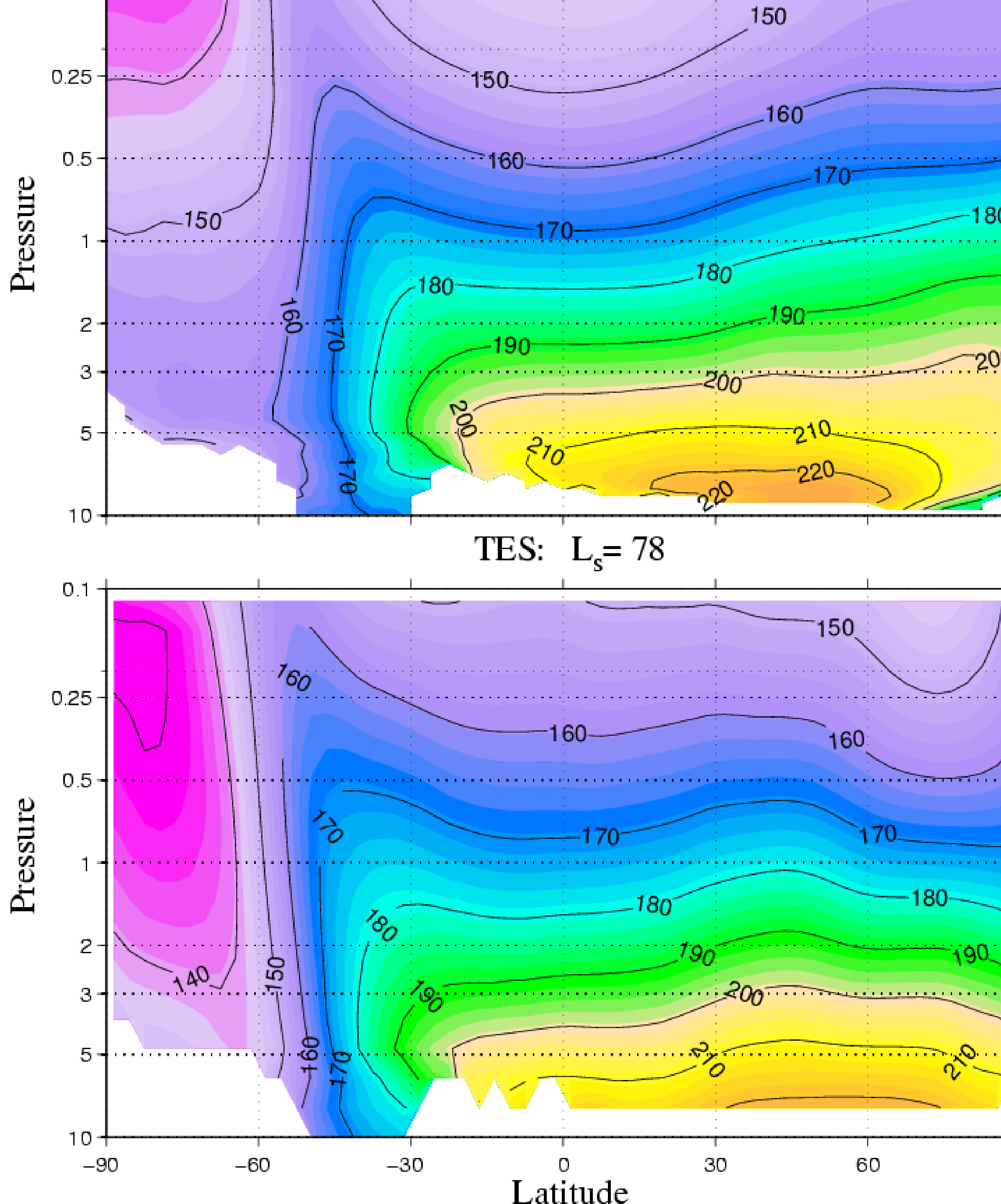
Zonal mean temperature

Ls = 78°

LMD GCM

TES Observations

Figures from John Wilson !



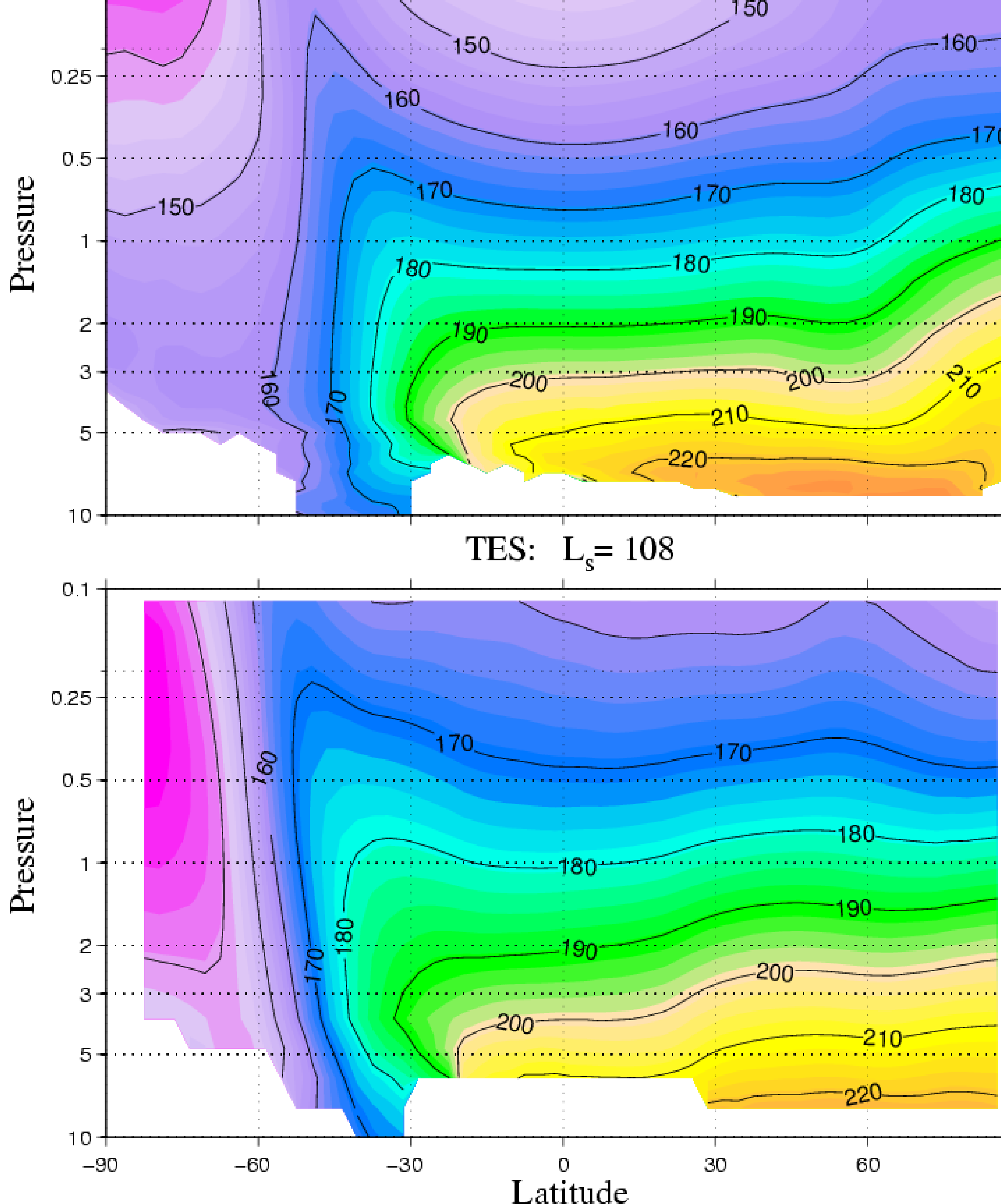
Zonal mean temperature

Ls = 108°

LMD GCM

TES Observations

Figures from John Wilson !

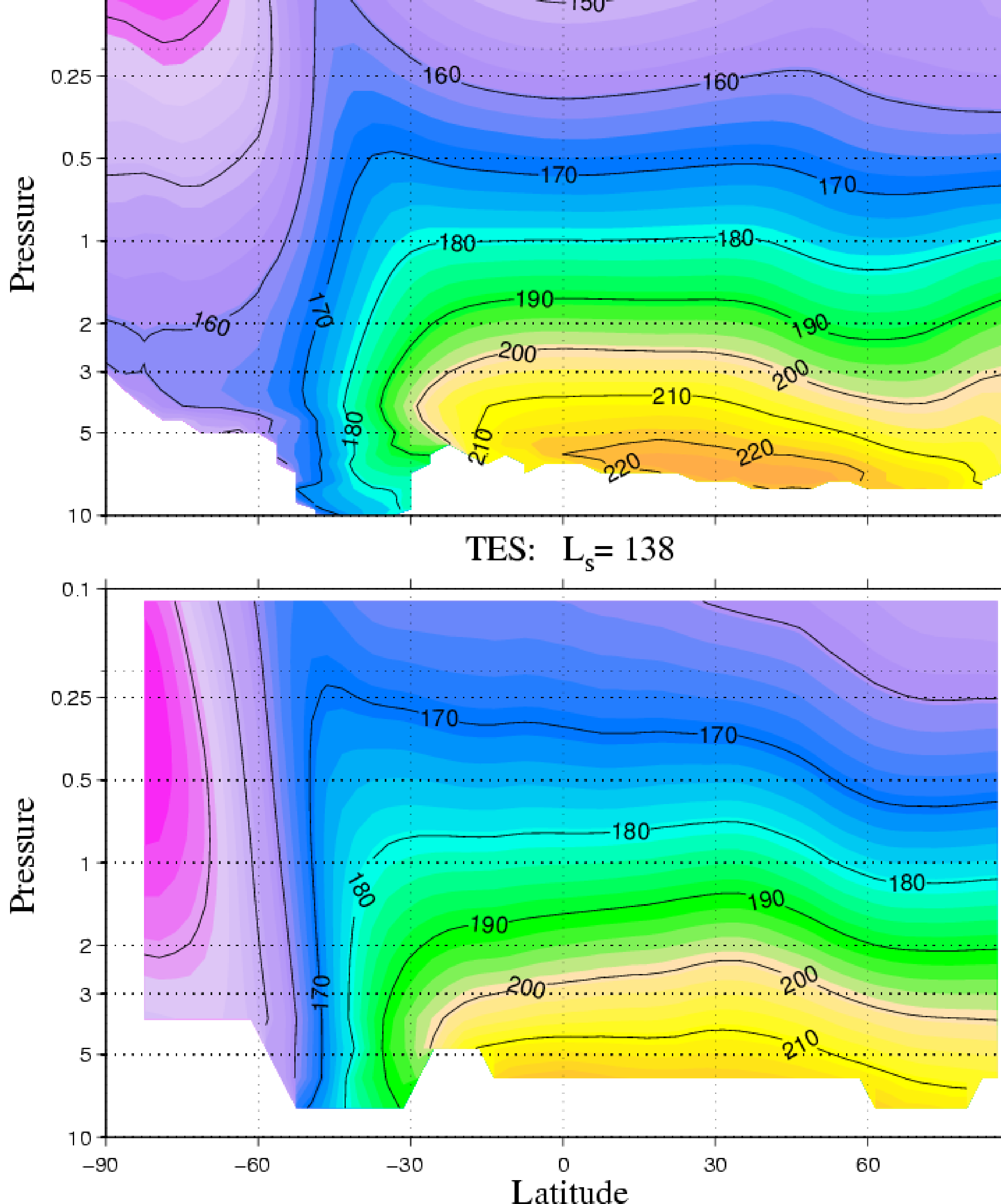


Zonal mean temperature

Ls = 138°

LMD GCM

TES Observations

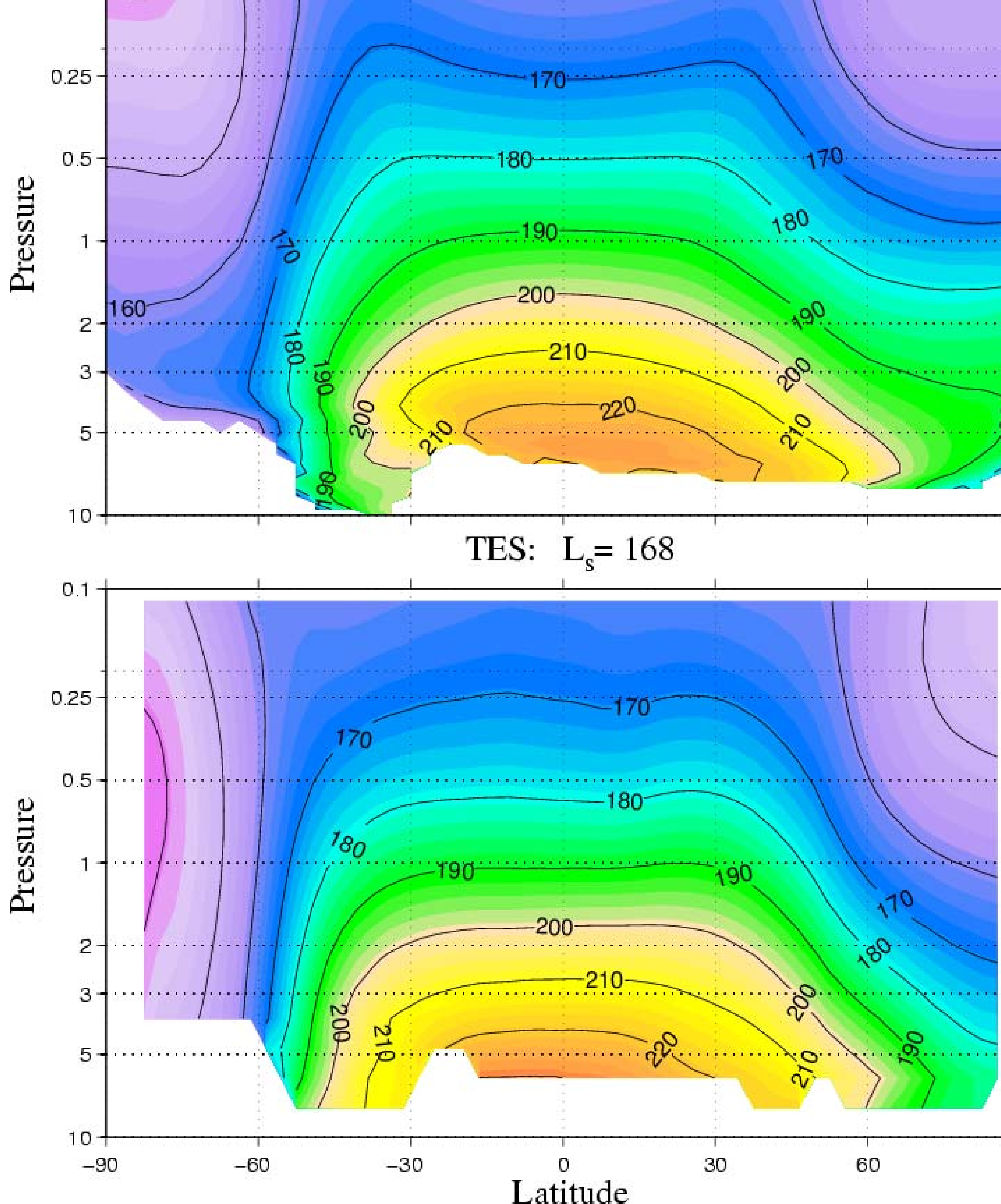


Figures from John Wilson !

Zonal mean temperature

Ls = 168°

LMD GCM



TES Observations

Figures from John Wilson !

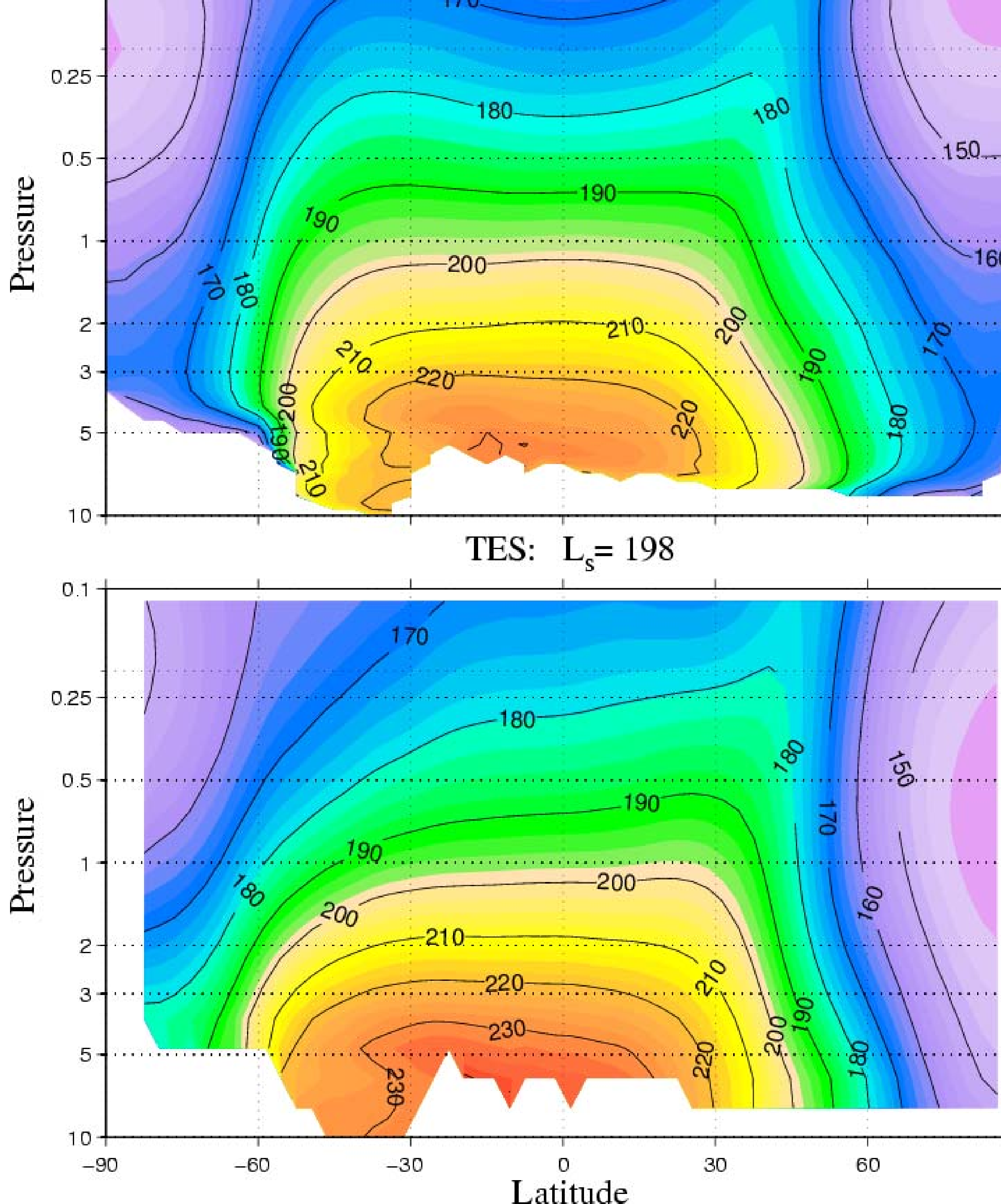
Zonal mean temperature

Ls = 198°

LMD GCM

TES Observations

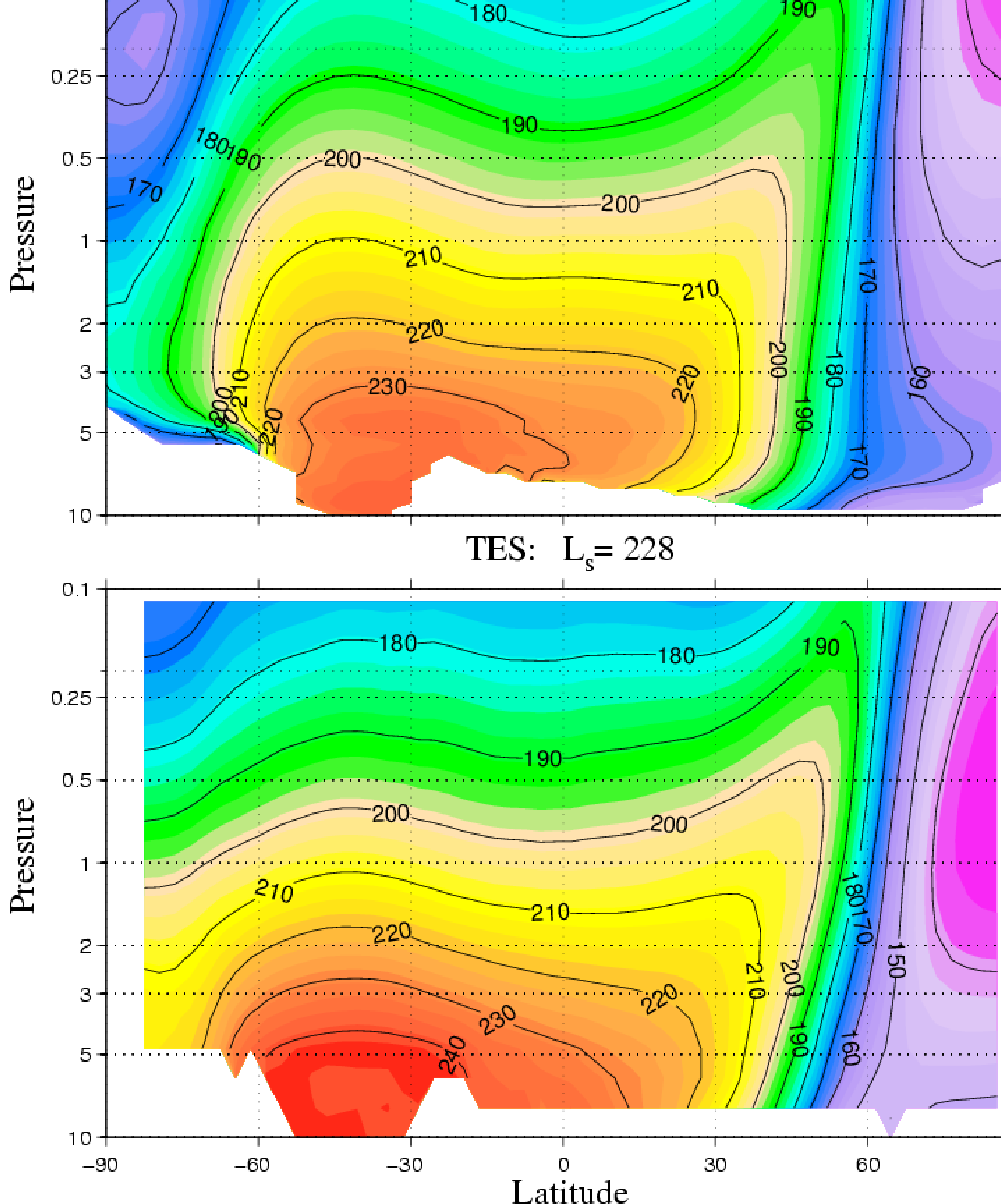
Figures from John Wilson !



Zonal mean temperature

Ls = 228°

LMD GCM



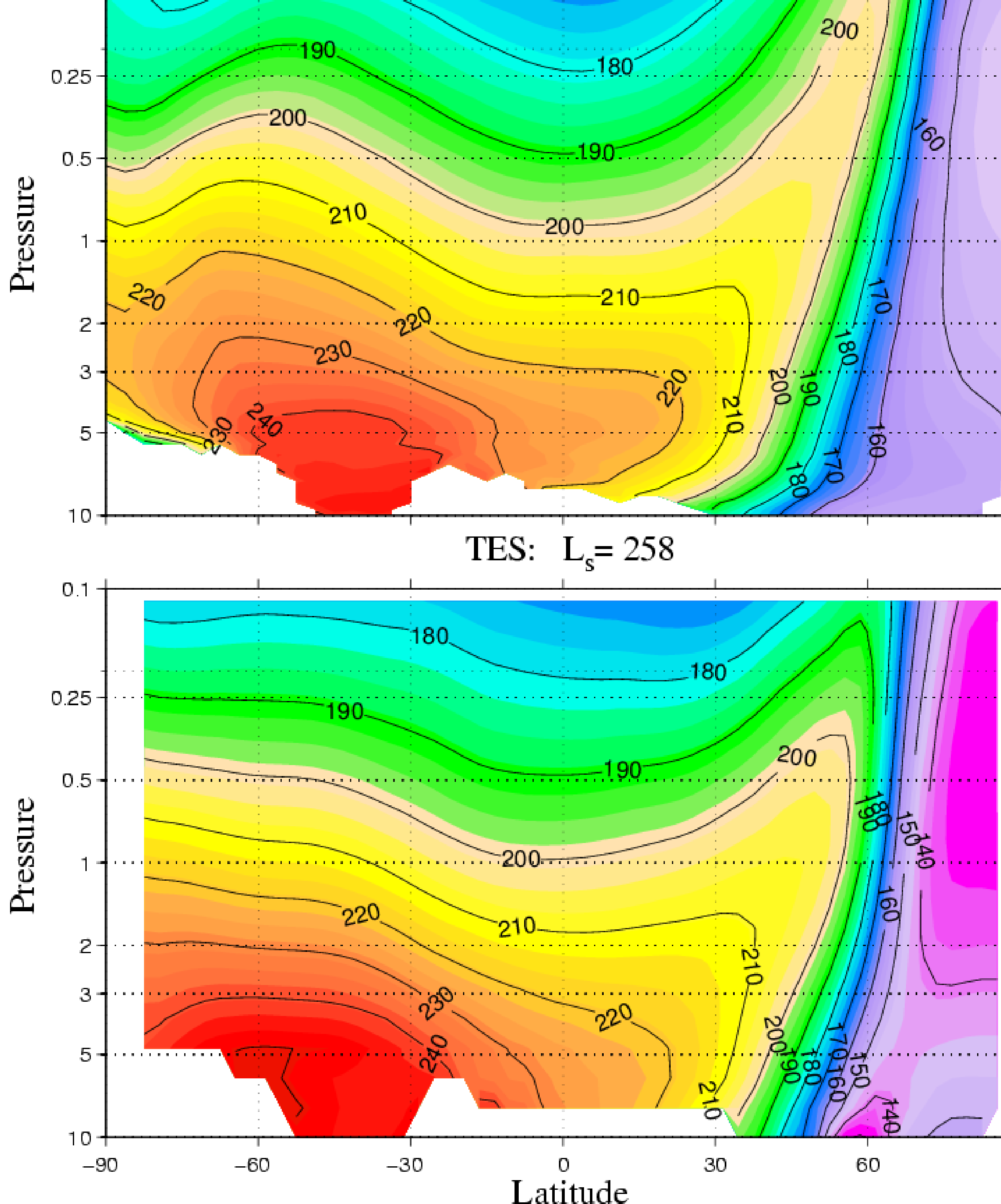
TES Observations

Figures from John Wilson !

Zonal mean temperature

Ls = 258°

LMD GCM



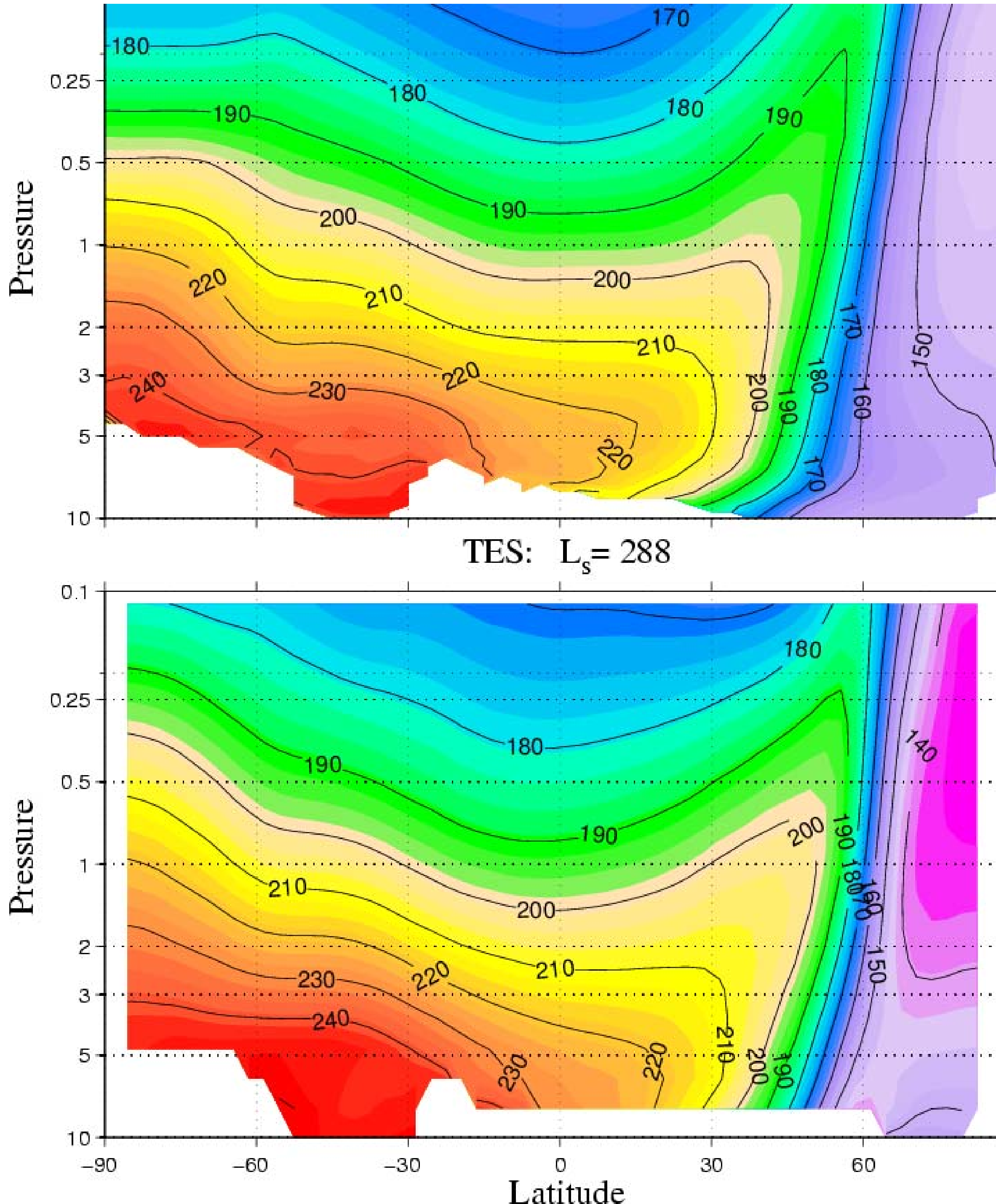
TES Observations

Figures from John Wilson !

Zonal mean temperature

Ls = 288°

LMD GCM



TES Observations

Figures from John Wilson !

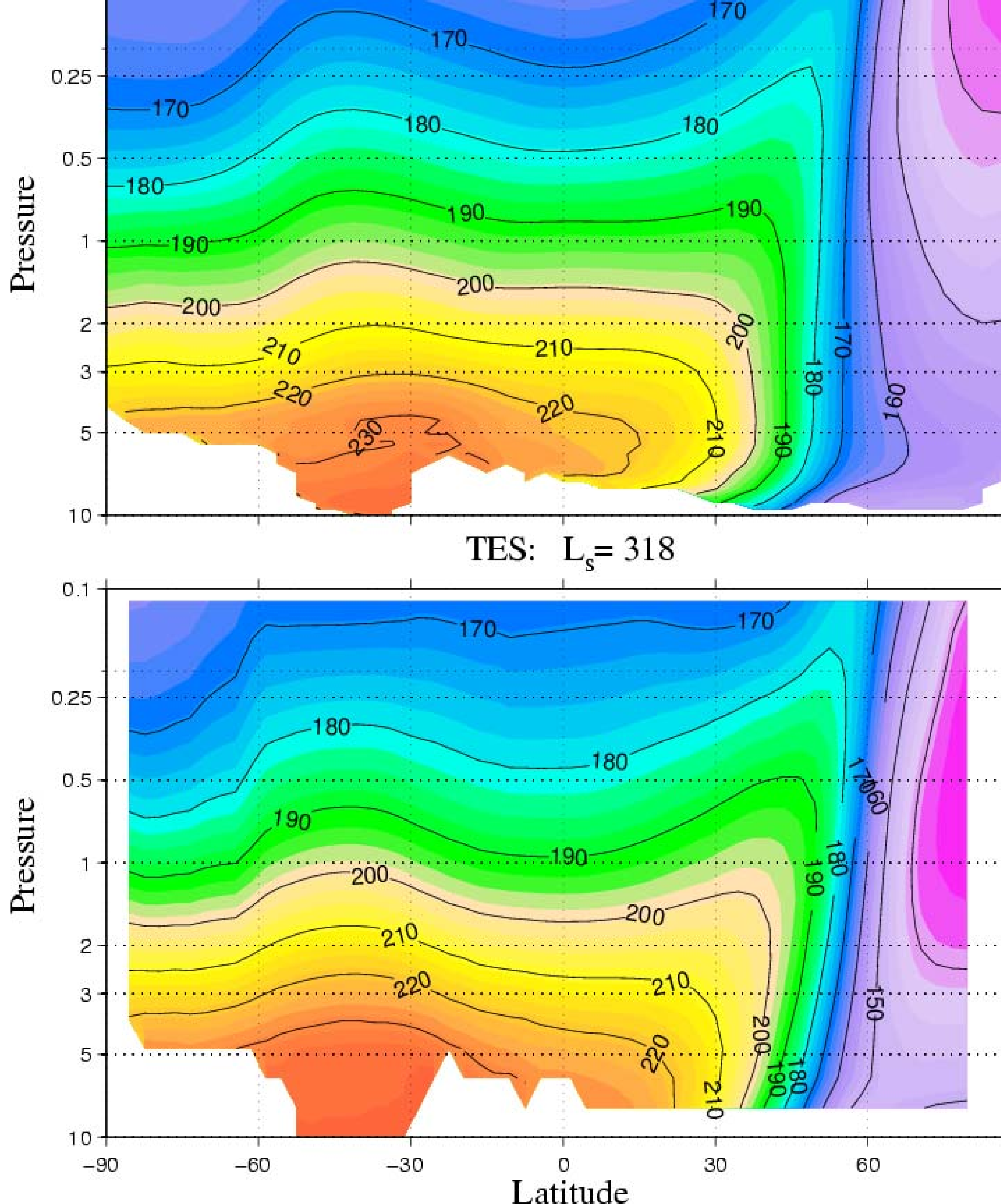
Zonal mean temperature

Ls = 318°

LMD GCM

TES Observations

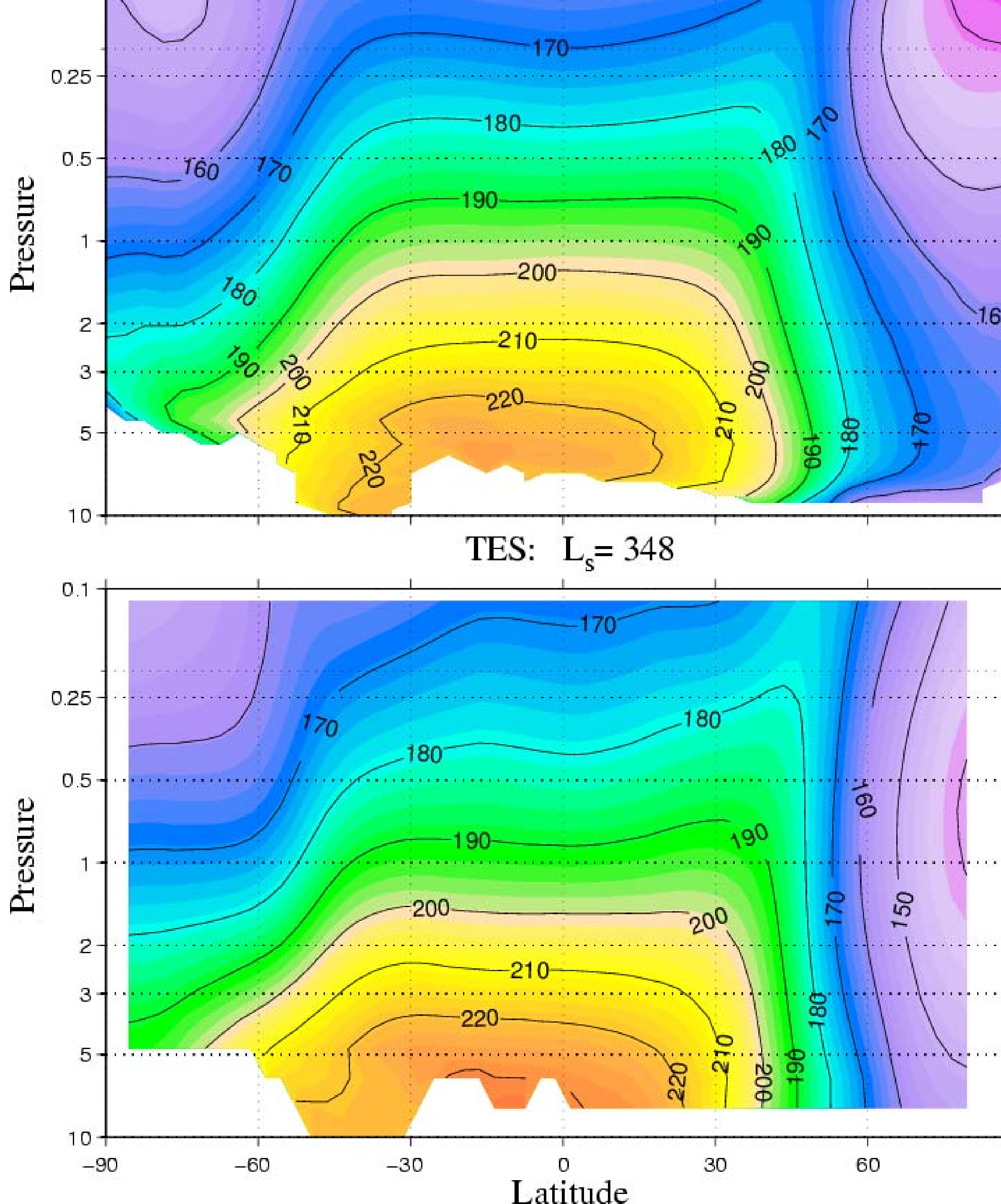
Figures from John Wilson !



Zonal mean temperature

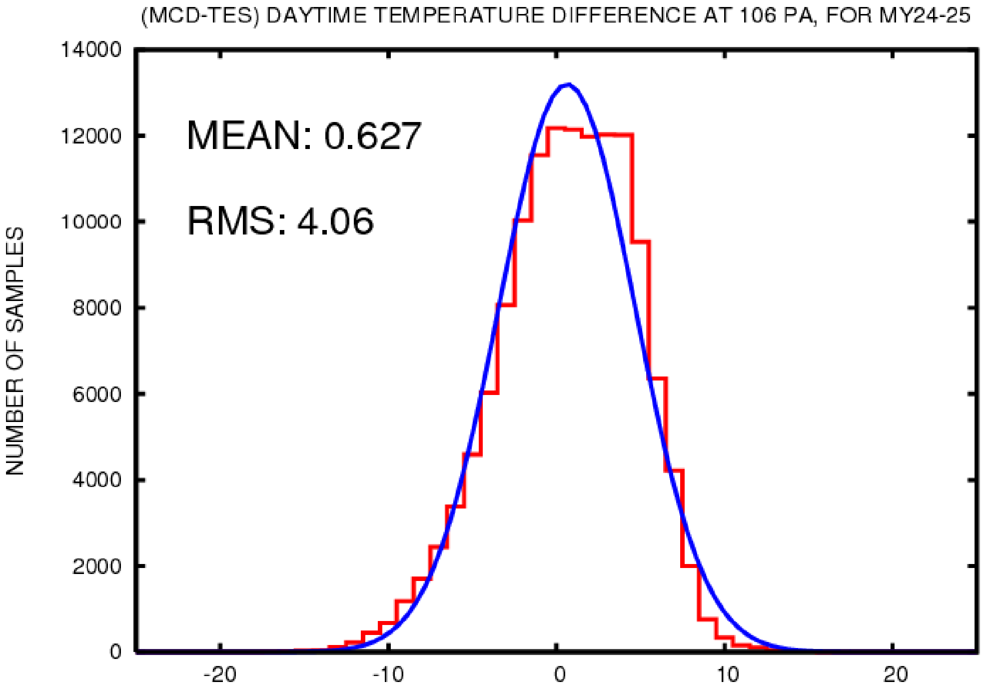
Ls = 348°

LMD GCM

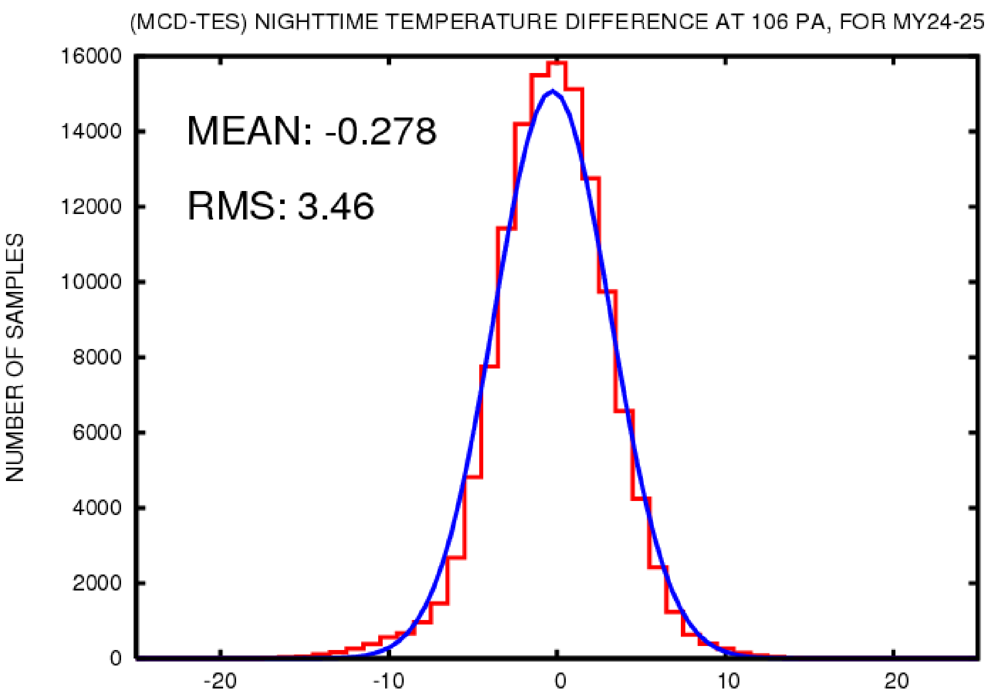


TES Observations

Figures from John Wilson !

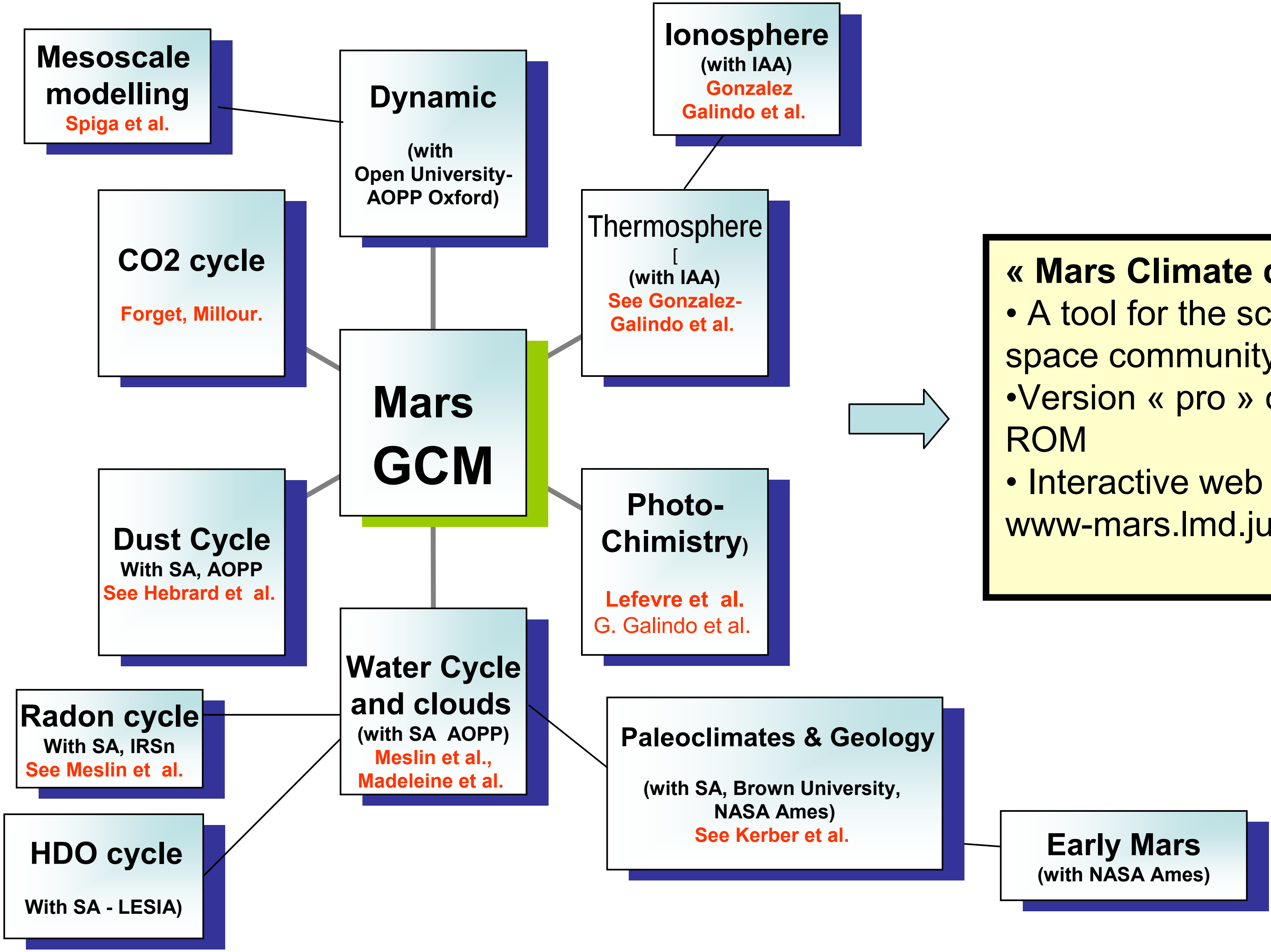


Distributions of atmospheric temperature difference, at 106 Pa, between the baseline LMD GCM (MCDv4.2 high res.) and TES



- Statistics computed for:
  - Pressure: 106 Pa
  - MY24: 102.5 < Ls < 360
  - MY25: 0 < Ls < 180
  - -50 < latitude < 50
  - Bins of 1K

Recent Applications of the LMD GCM



« Mars Climate database »

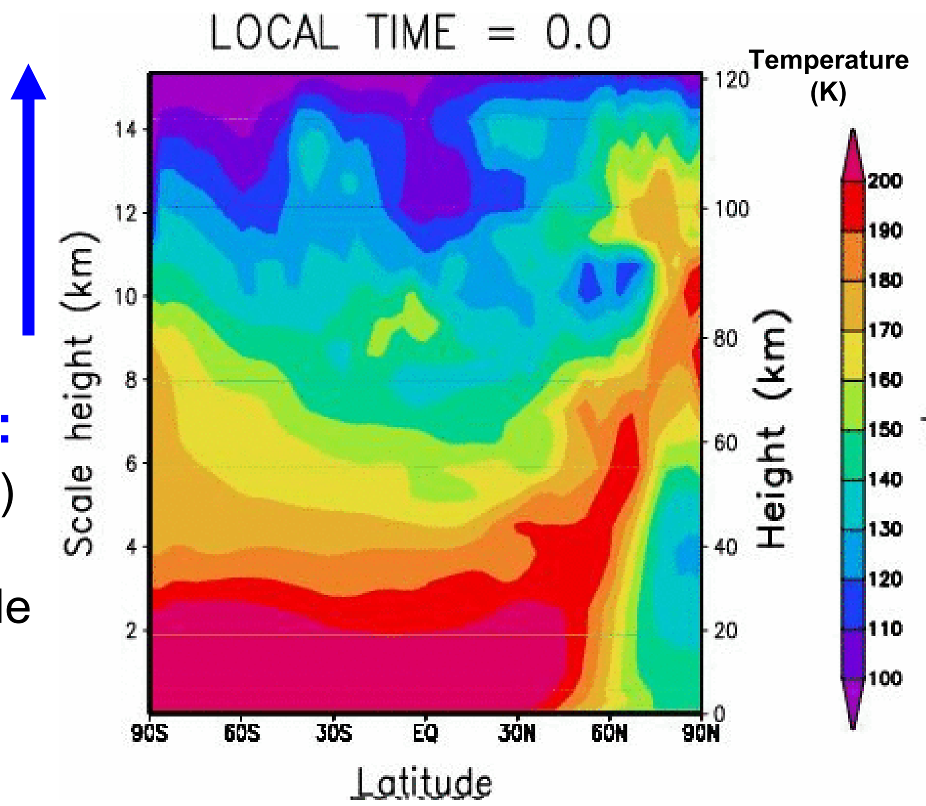
- A tool for the scientific and space community
- Version « pro » on DVD-ROM
- Interactive web site: www-mars.lmd.jussieu.fr

Toward the upper martian atmosphere

- **Motivation :**
  - Very active dynamics, coupled to lower atmosphere.
  - Need for information for spacecraft design
  - Preparation of Mars Express SPICAM (PI: J-L. Bertaux)

- **Extension #1: From 80 to 120 km :**
  - The “local thermal equilibrium” (LTE) assumption is no longer valid

  ⇨ Collaboration with M. Lopez-Valverde (IAA, spain) to develop a new fast “Non LTE” radiative transfer model

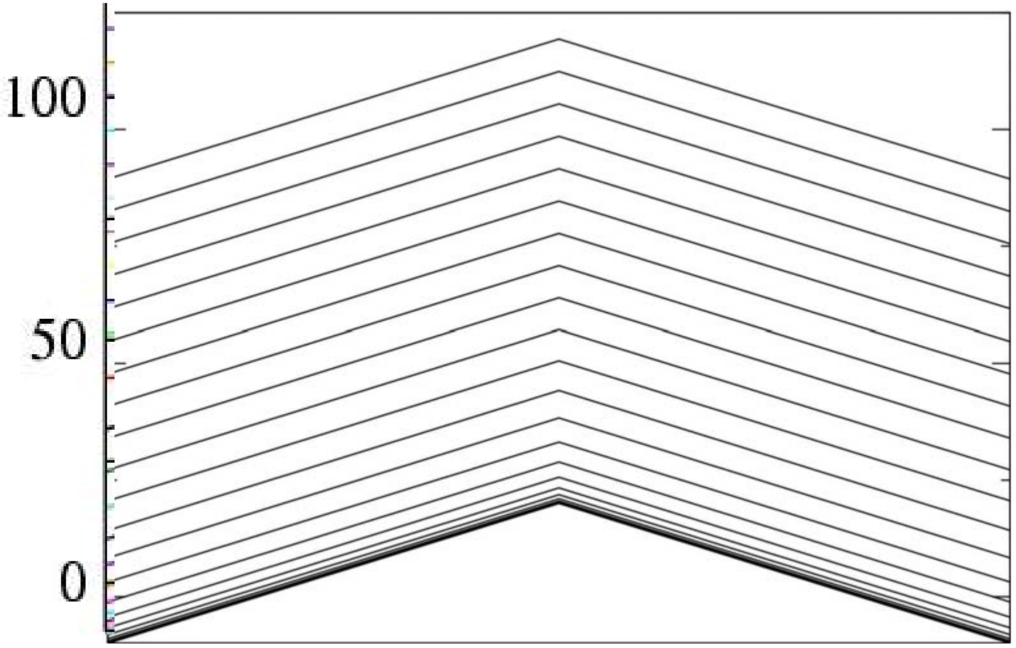


Vertical discretization :

Evolution from Terrain following "sigma" ($\sigma = p/ps$) coordinates to σ-p «hybrid» coordinates

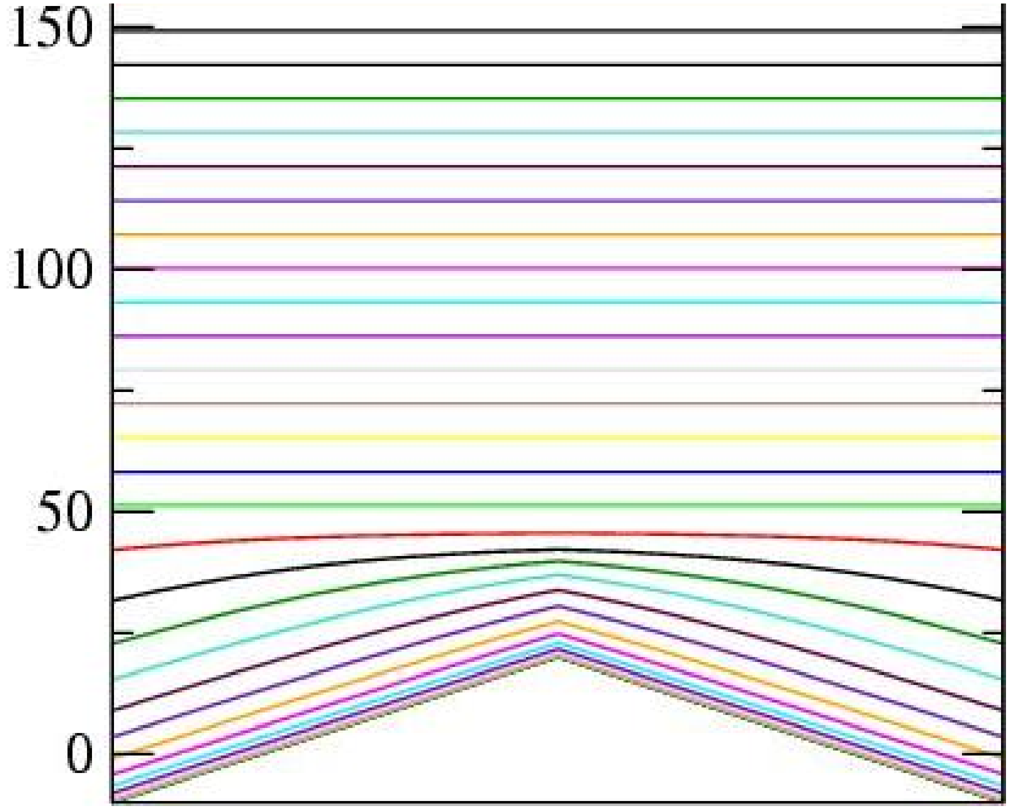
25 layers

σ coordinates



Vertical discretization :

Evolution from Terrain following “sigma” (σ= p/ps) coordinates to σ-p «hybrid» coordinates

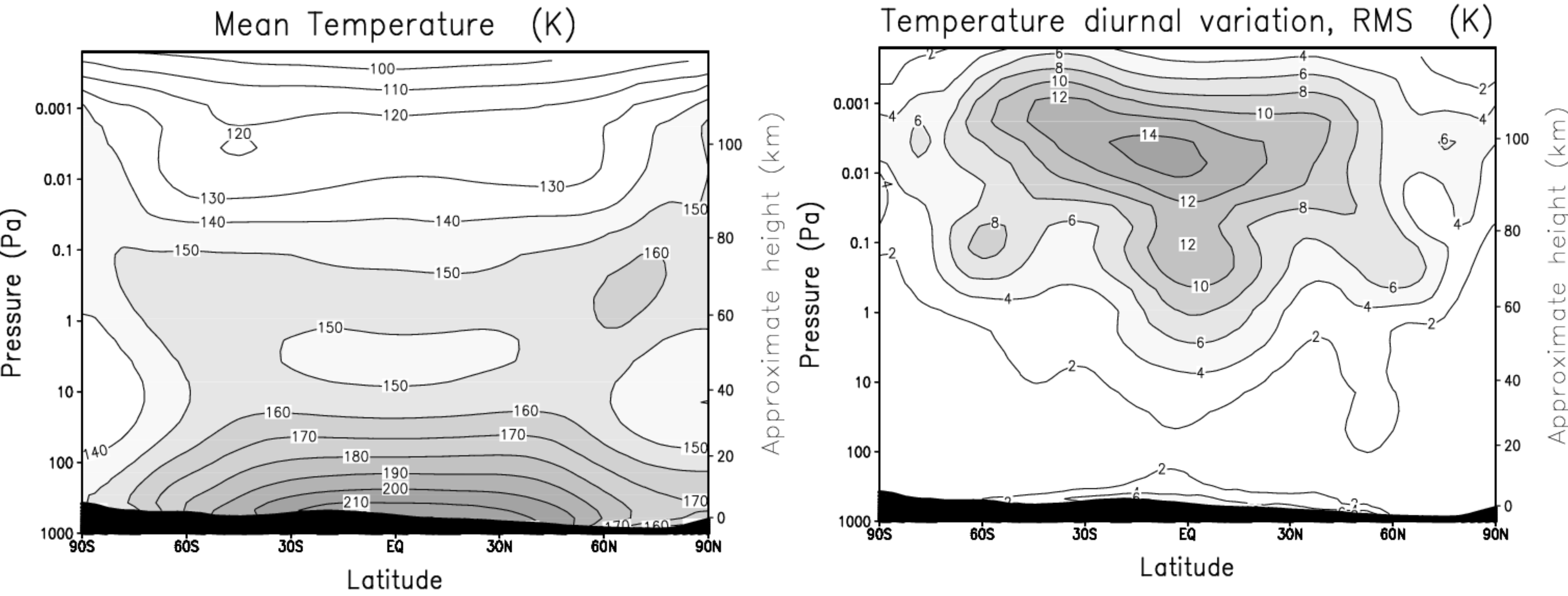


32 layers

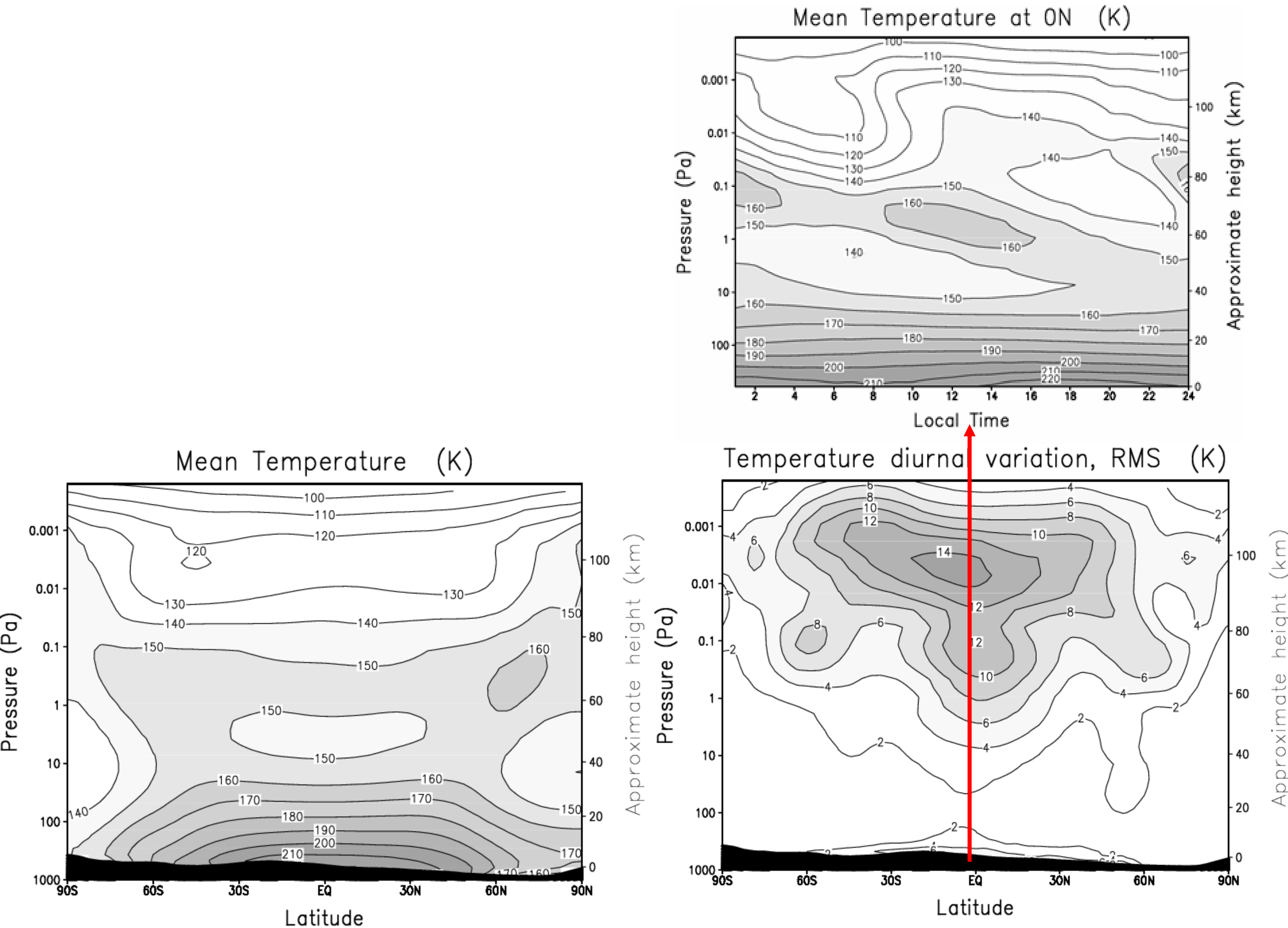
hybrid coordinates

General Circulation 0-120 km

Example : N. Spring Equinox Ls=0°-30°
Mean temperature



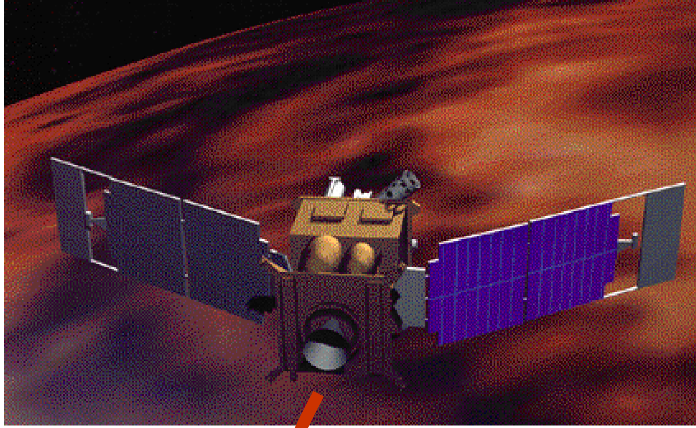
LMD

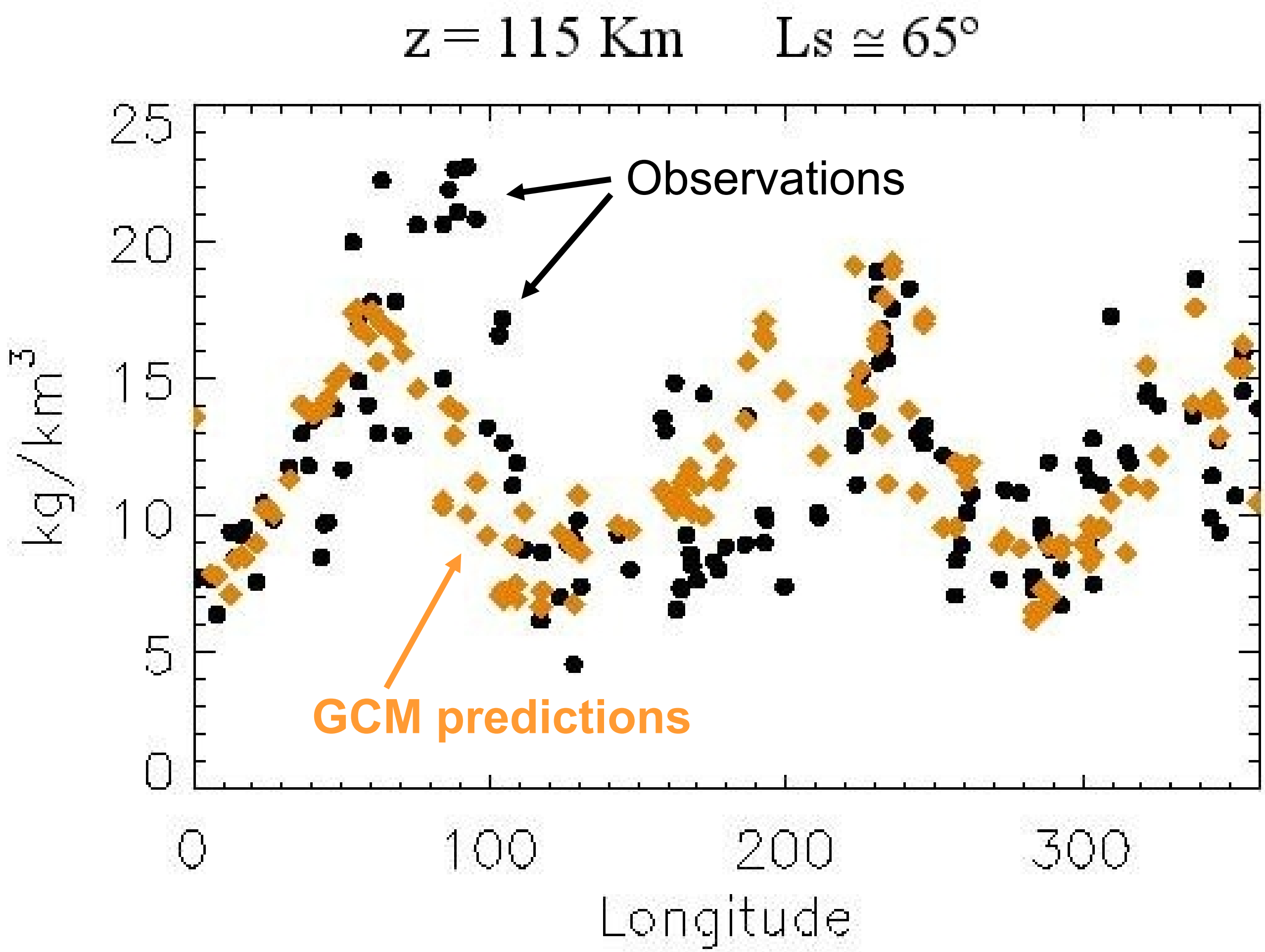

Mean Temperature at 0N (K)
Pressure (Pa)
Approximate height (km)
Local Time
Mean Temperature (K)
Pressure (Pa)
Approximate height (km)
Latitude
Temperature diurnal variation, RMS (K)
Pressure (Pa)
Approximate height (km)
Latitude
90S
60S
30S
EQ
30N
60N
90N

LMD

Mars Global Surveyor aerobraking data analysis

In situ measurement of atmospheric density at 115 km

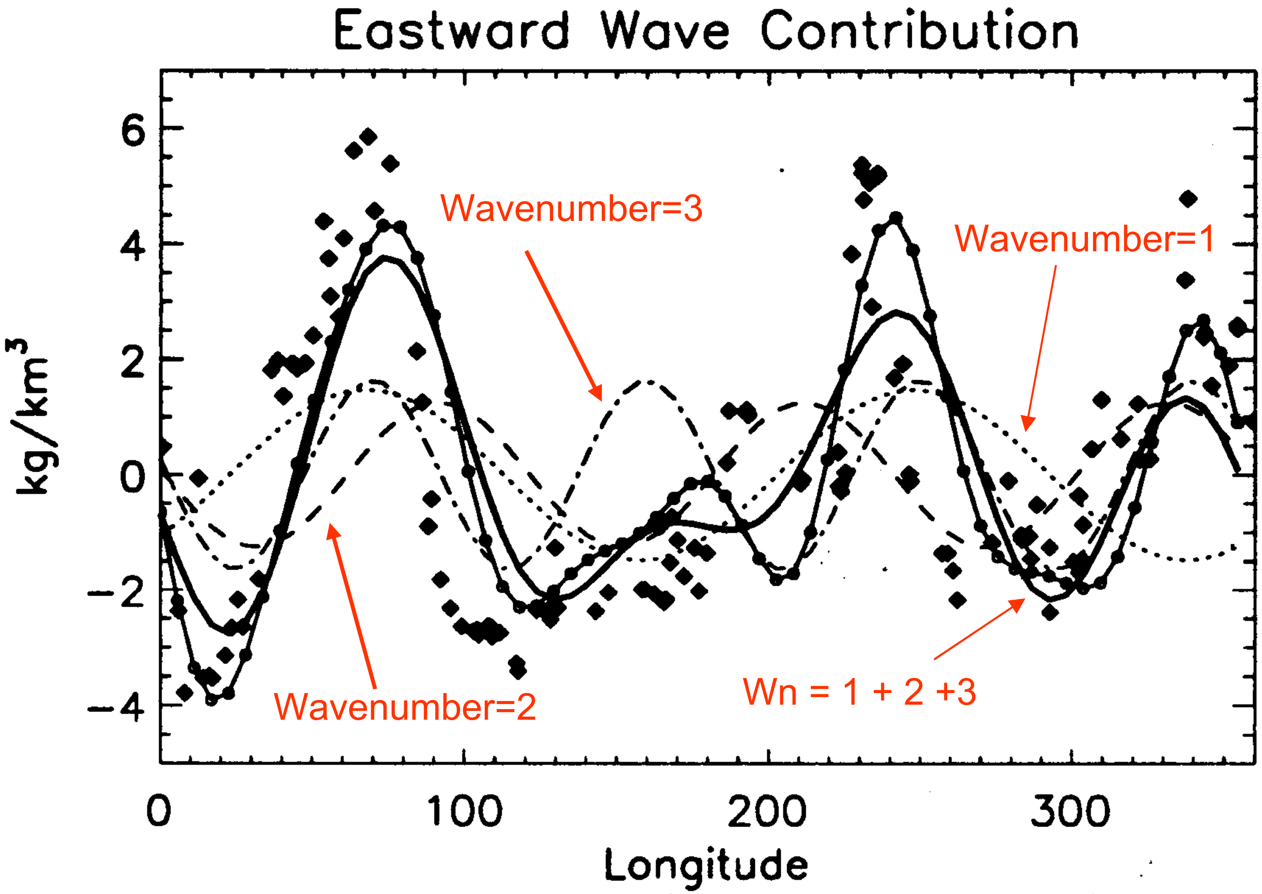




Angelats I Coll (2004)

Mars Global Surveyor aerobraking data analysis

Superposition of eastward tidal waves at 115 km



Angelats I Coll (2004)

Toward the upper martian atmosphere

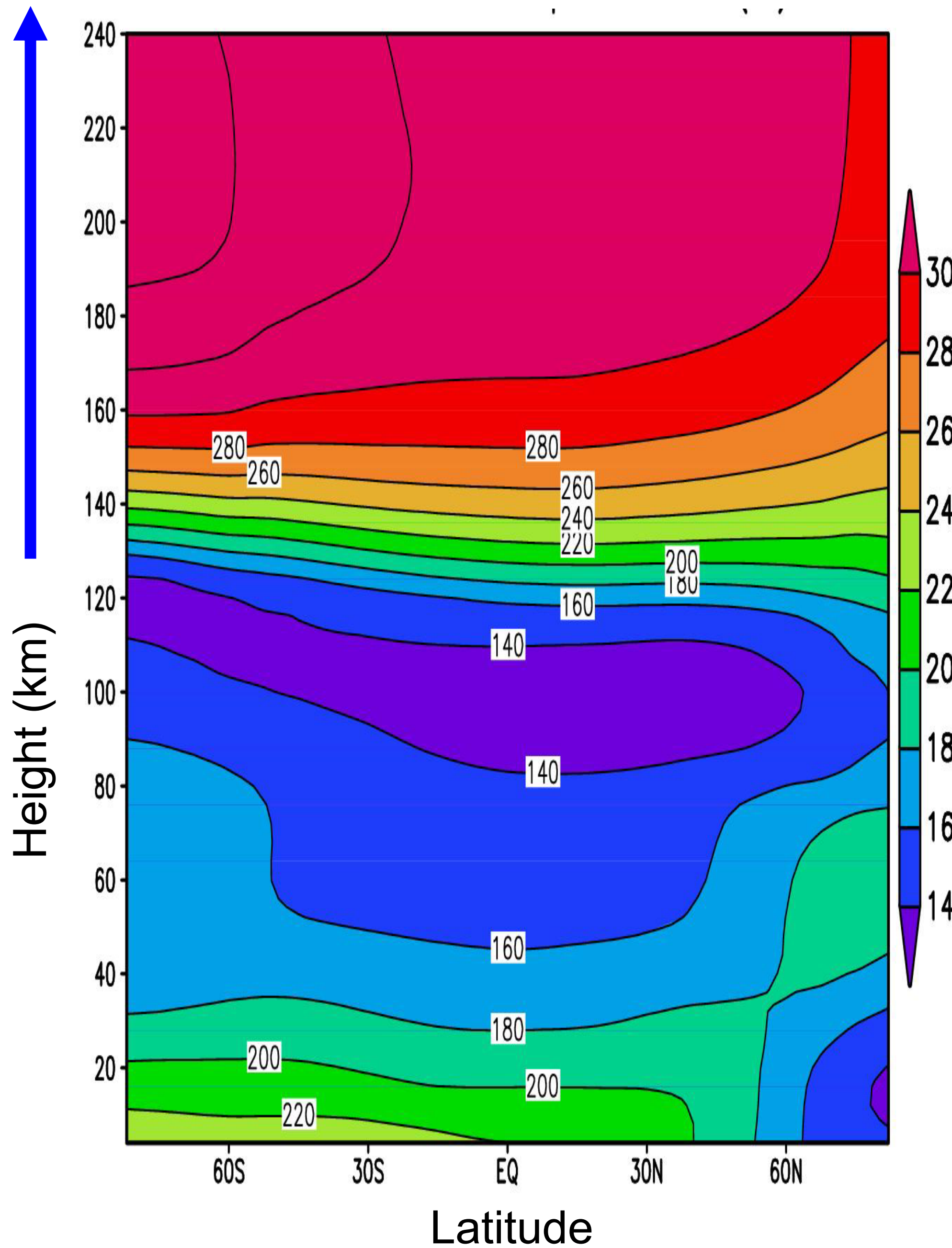
- **Extension # 2 : From 120 km to above 250 km : Thermosphere**

- UV and EUV Heating
- Thermal conduction
- NLTE CO_2 cooling
- Non homogeneous atmosphere :
  - Molecular diffusion
  - Photochemistry

Angelats I Coll 2005

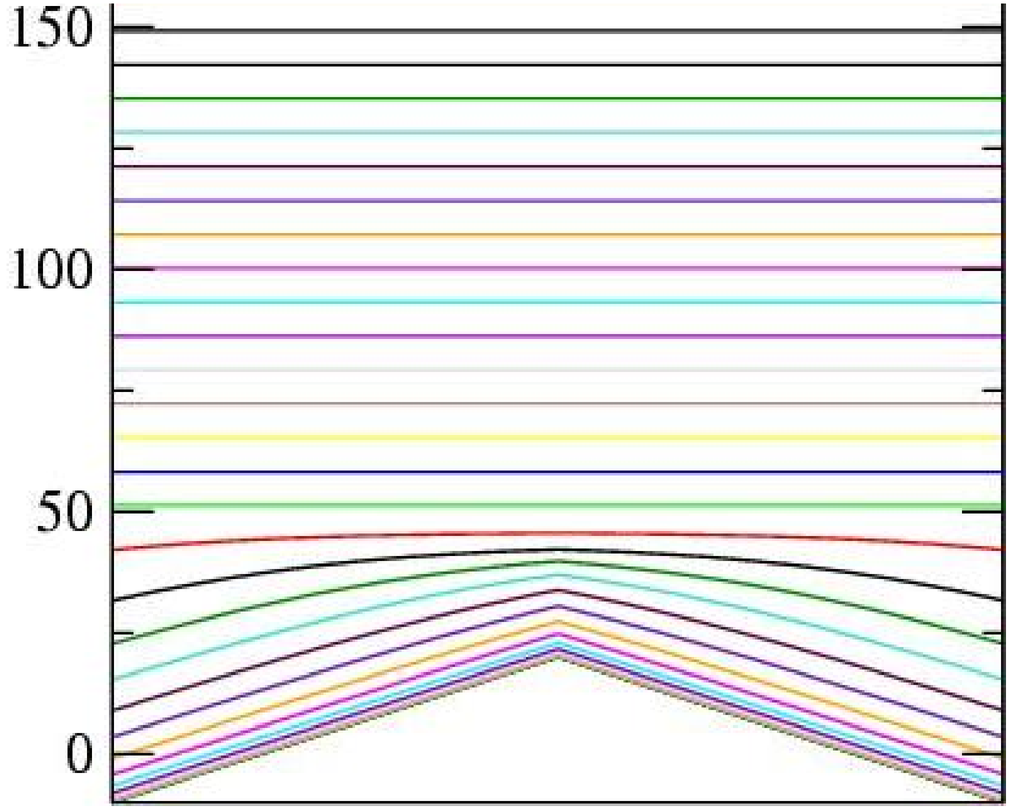
Gonzalez-Galindo et al. 2005, 2007, 2009

Zonal Mean temperature
Northern winter solstice



Vertical discretization :

Evolution from Terrain following "sigma" (σ= p/ps) coordinates to σ-p «hybrid» coordinates

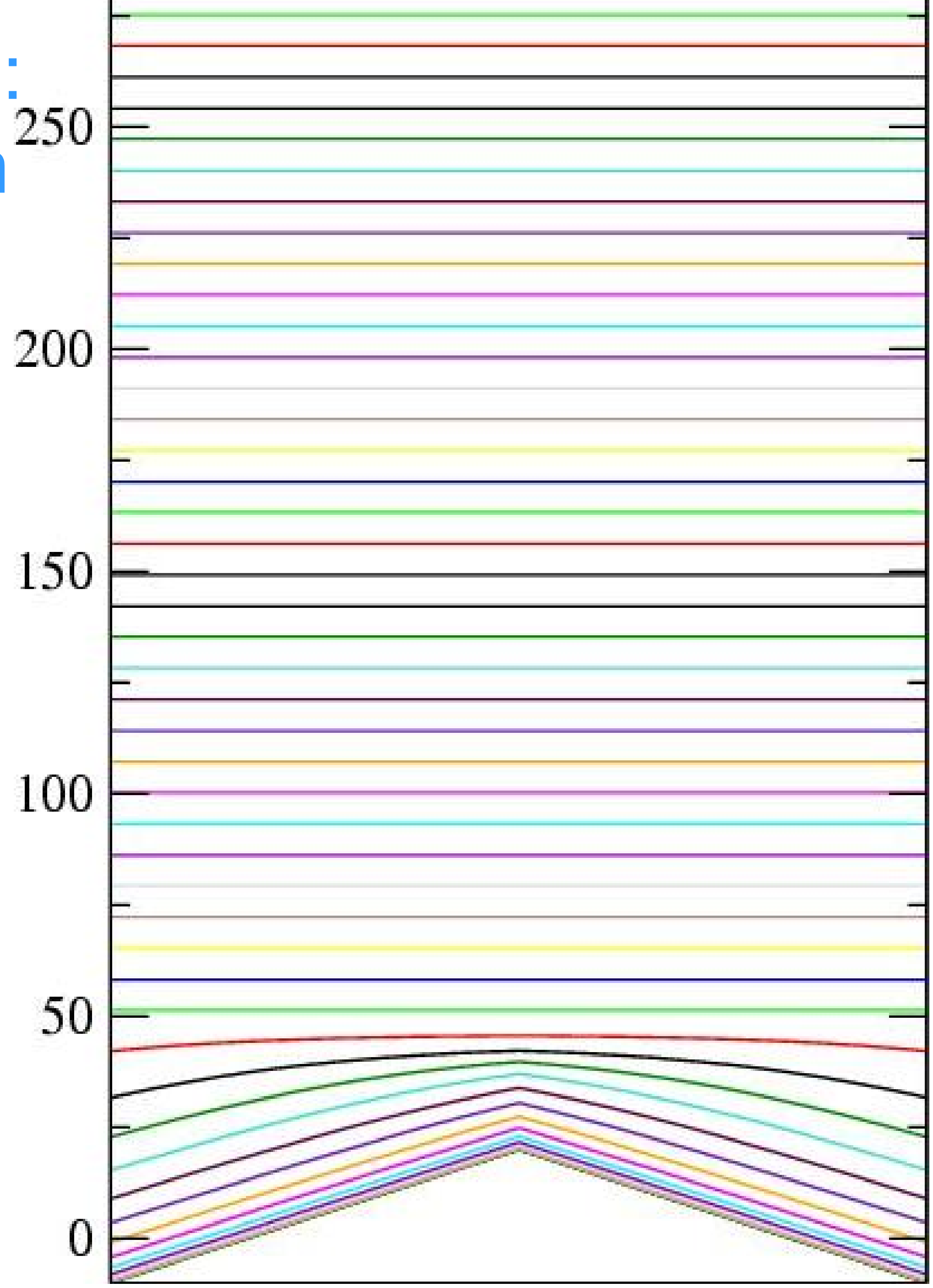


32 layers

hybrid coordinates

Vertical discretization :

Evolution from Terrain following "sigma" (σ= p/ps) coordinates to σ-p «hybrid» coordinates



50 layers

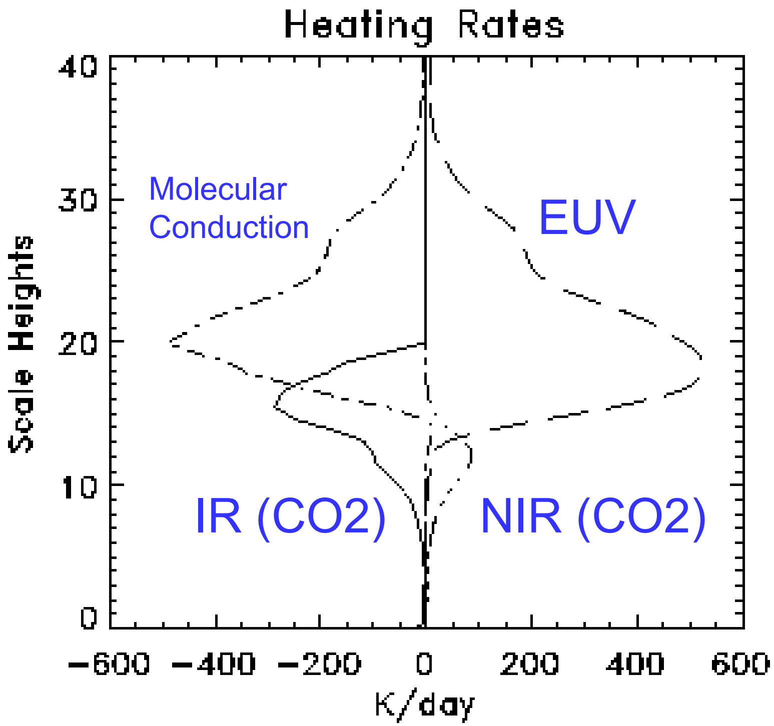
hybrid coordinates

GCM simulation of the atmosphere thermosphere 0 – 300 km …

.

(F. Gonzalez-Galindo , M. Angelats I Coll, F. Forget, LMD)

(see Gonzalez-Galindo et al., JGR, 2009)



- **New parametrisation**

Heating and cooling :

- EUV heating NLTE cooling
- Molecular conduction

Non Homogeneous atmosphere

- Molecular diffusion
- Photochemistry (21 reactions)

- **Species :**
  - CO_2, CO, O_2,, H_2 , $O(^3P)$, $O(^1D)$,, OH, H, HO_2, H_2O, H_2O_2, O_3 , *N_2, Ar*

Zonal mean Heating rates

Ls=270° (N. winter solstice)