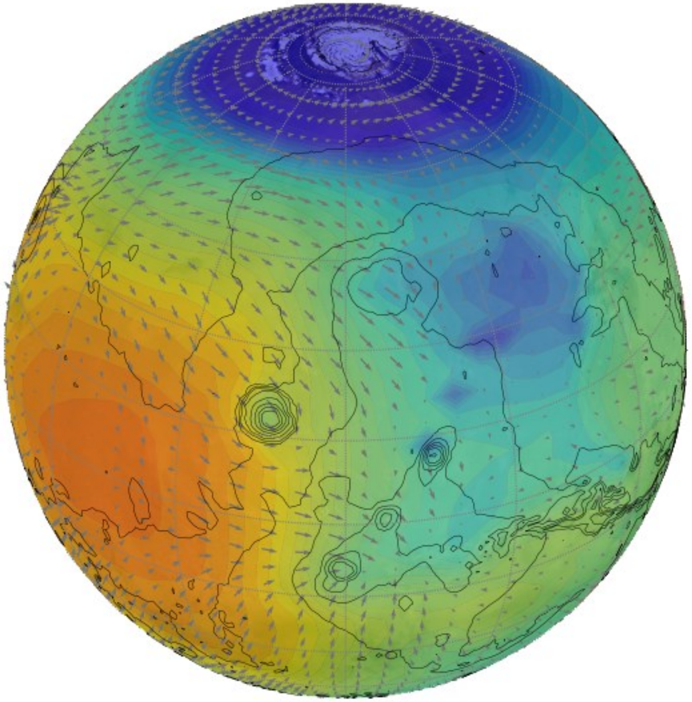
Mars Climate Database Training day May 26th 2016

Introduction: The Martian Environment: Observations and modelling



F. Forget, E. Millour and the MCD team

esa cnes LMD LATMOS Instituto de Astrofísica de Andalucía CSIC I·A·A The Open University University of Oxford

Mars Climate Database Training day May 26th 2016

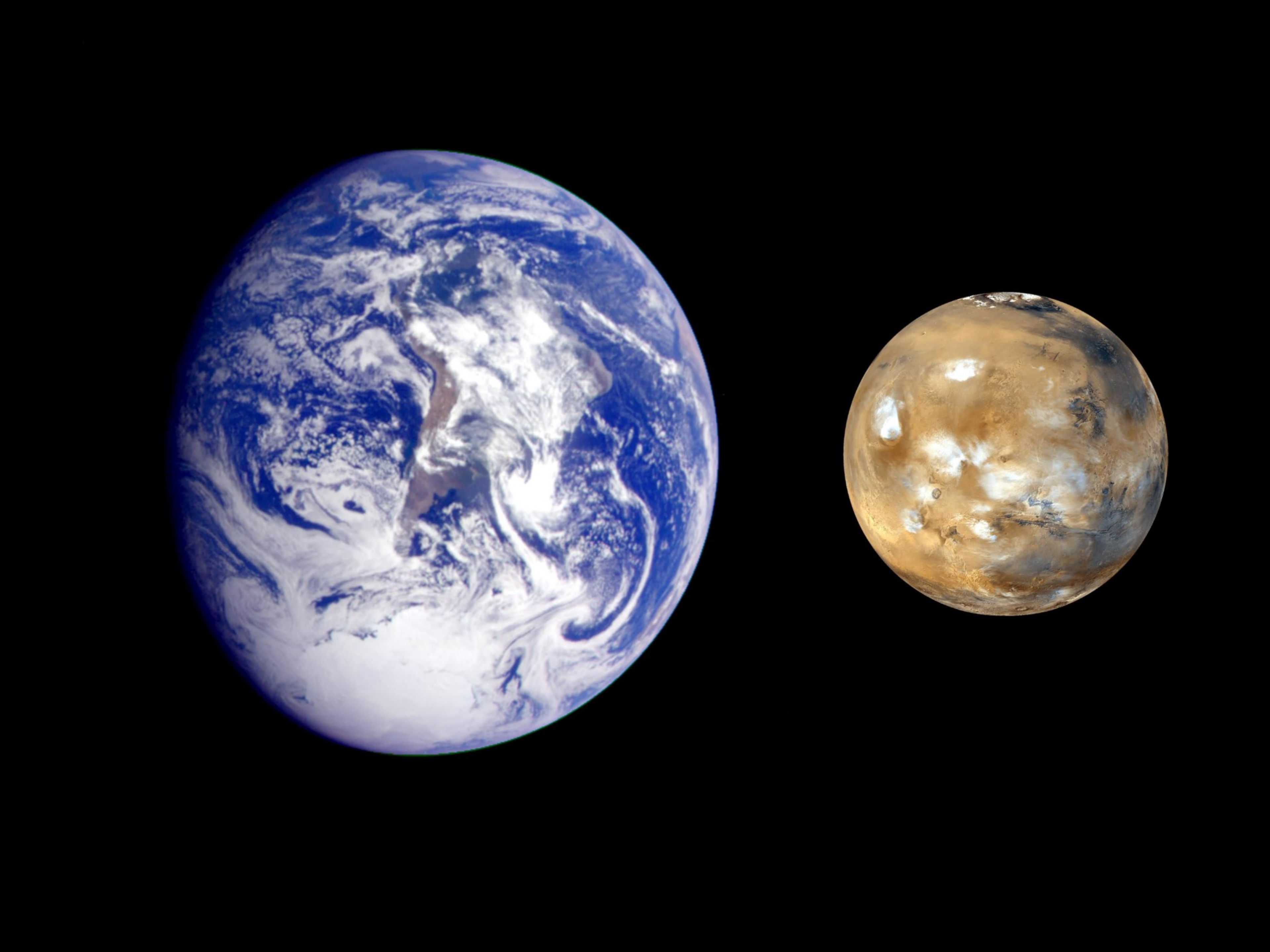
Agenda

Morning 9h30-12h30:

- Who'swho around the table ?
- The Martian Environment: Observations and modeling
- General description of the Mars Climate Database. + **break**
- MCD user presentations: (10' each)
  - S. Cardnell "A photochemical model of the dust-loaded ionosphere of Mars"
  - H. Gröller "Comparison of CO2 and O2 density and temperature profiles obtained by IUVS/MAVEN and SPICAM/MEX stellar occultations with MCD profiles"
  - L. Neary "The Cross-Drive project"

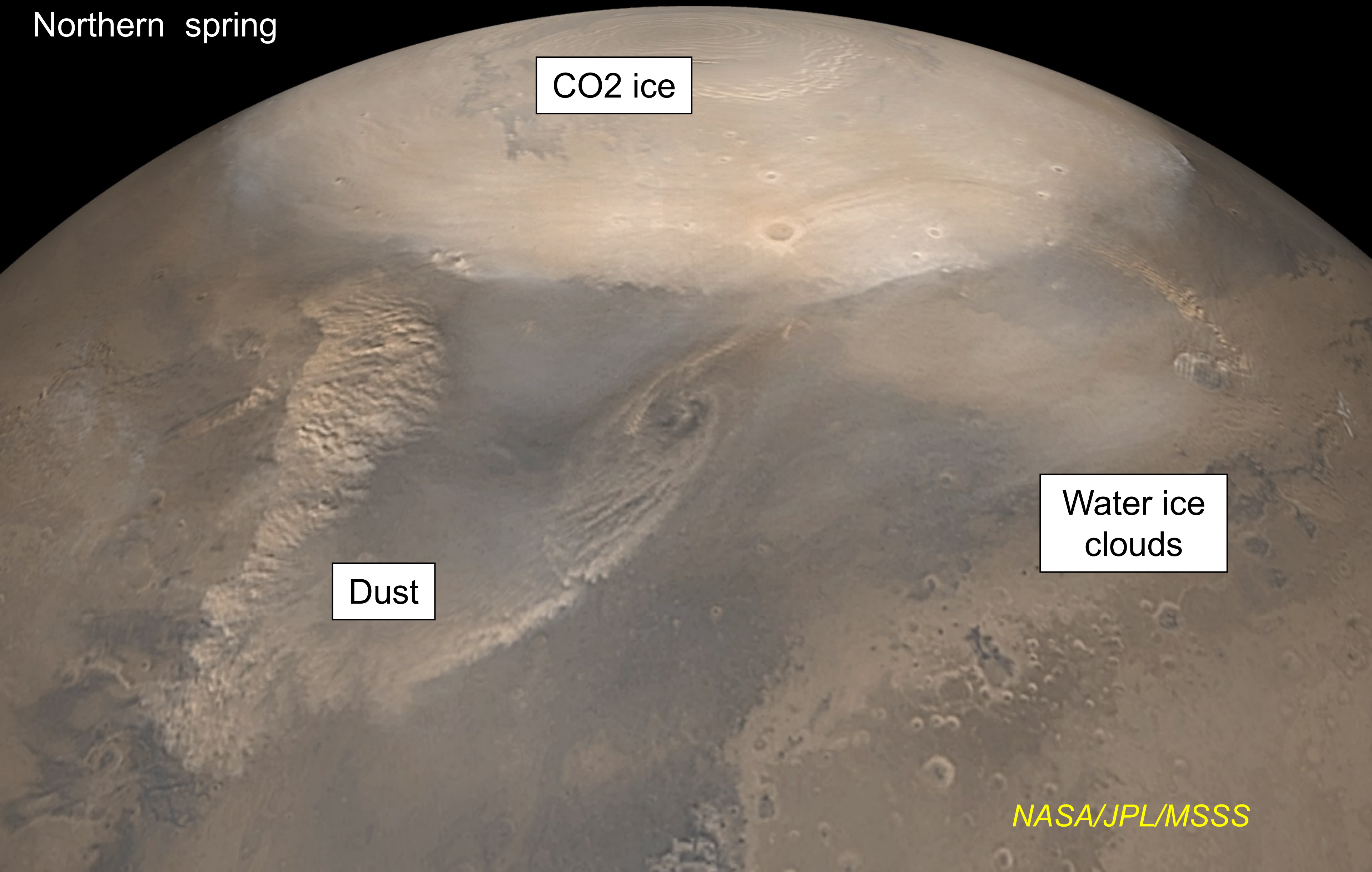
Afternoon: 13h30-17h00:

- The MCD full version
- MCD validation: where you should and should not trust the MCD
- Future MCD improvements.
- MCD user presentations: (10' each)
  - R. Lillis: "MCD: electron precipitation modeling for upcoming IR instruments"
  - G Parnaby "trajectory simulations"
  - J. Cuelho "Space Apps Challenge 2016: Mars Village"
- Discussion

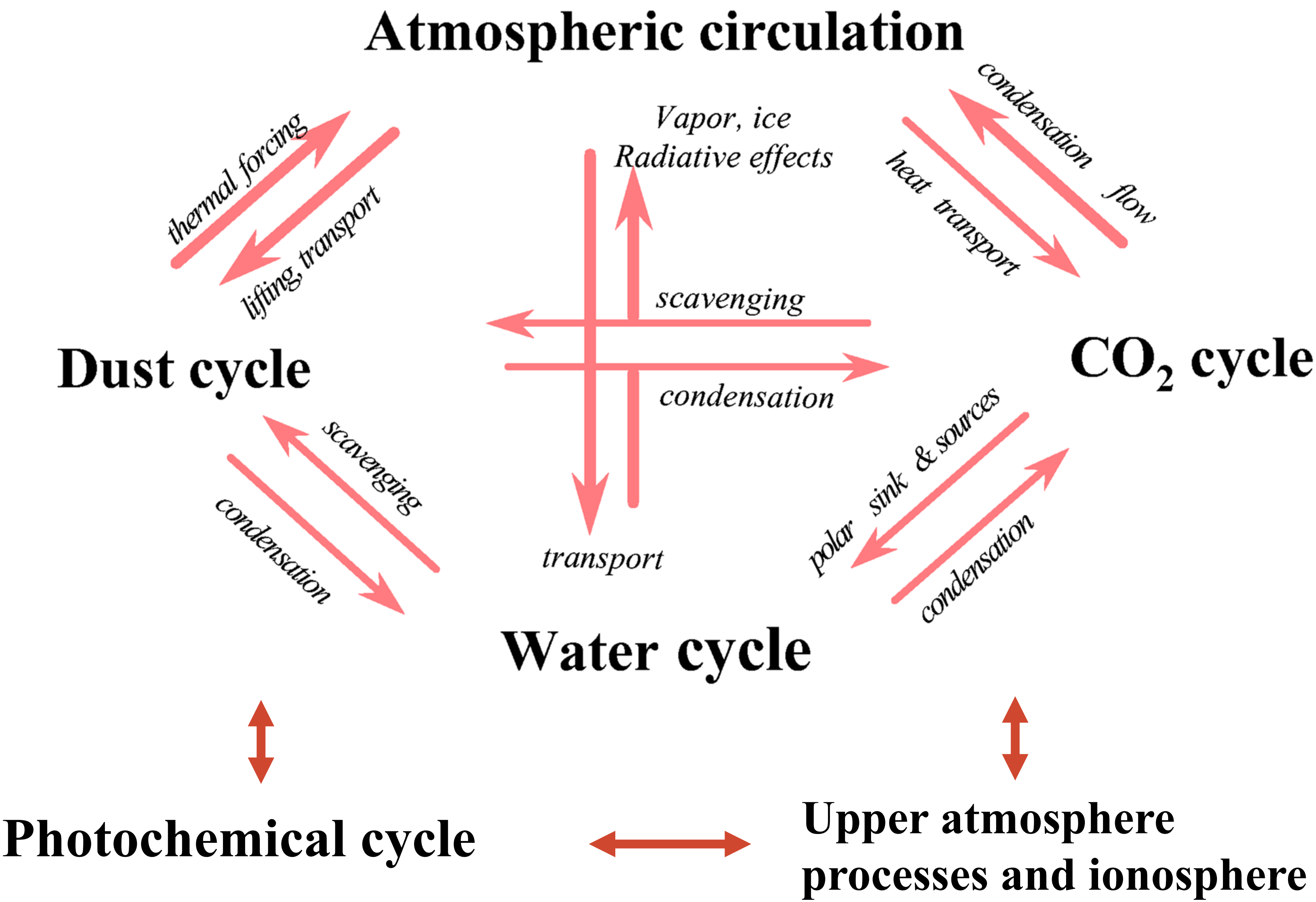


Mars climate now : atmospheric circulation, dust , CO_2 (and some water)

Northern spring



Mars climate : a complex system



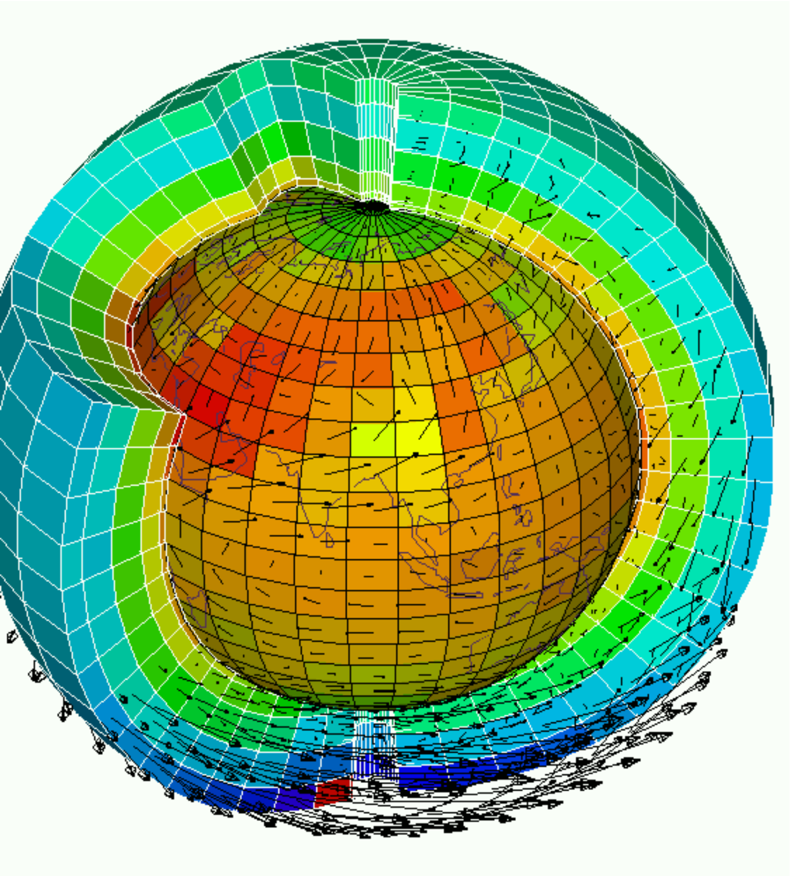
Key available observations of the Martian Environment (1/2)

- Temperatures (& densities) :
  - Below 70 km : full climatologies (sounder MGS/TES, Mxpress/PFS, MRO/MCS, Radio occultations)
  - Above 100 km: only a few profiles (~1000): SPICAM & IUVS Stellar occultations, Aerobraking Data, MAVEN NGIMS, etc.
- Surface pressure: Local in-situ measurements (Viking, Pathfinder, Phoenix, Curiosity)
- Winds: almost <u>nothing</u>
- Dust and clouds
  - Column climatology (MGS/TES, MRO: MCS, CRISM,Marci etc.)
  - Profile climatology (MCS; ~Spicam)

Key available observations of the Martian Environment (2/2)

- Water vapor :
  - Column climatologies (TES, Mars Express SPICAM, PFS, OMEGA)
  - Little information on vertical structure (~Spicam)
- Ozone (direct detection, or O2 fluorescence)
  - Column climatology: Spicam, MRO/Marci, Maven/IUVS, etc.
  - Stellar occultation profiles
- Long lived species (~Ar, N2, CO)
  - Column values: coarse climatology (Ar: Mars Odyssey GRS ; CO: MRO/Crism)
  - 3D structure above 120 km: in situ MAVEN/NGIMS
- Ionosphere: Electron density profiles and mapping (Radio Occultations; Radar MARSIS) + Ions in-situ (MAVEN/NGIMS)

General Circulation Models/ Global Climate models ⇨ GCMs



3D Numerical simulators of a planetary environment:

Résolution: ~100 km

Several models developped around the world:

- Since ~1980 : **NASA Ames** (USA) ⇨ ***Mars GRAM***
- Since ~1990:
  - **LMDZ GCM** (LMD with U. of Oxford & Open U. (UK), LATMOS (France) , IAA (Spain))
    ⇨ ***Mars Climate Database***
  - **GFDL** (USA, J. Wilson)
- Since ~2000:
  - **GEM Mars** (now IASB, Belgium, after start at York U., Canada…)
  - **Planet WRF (**Ashima research, USA)
  - **CPS** (Japan), **Dramatic** (Japan)
  - **Max Planck Inst** (MPS, Germany)
-

Basic characteristics of the LMD Mars Global Climate Model :

1) **LMDZ final Dynamical Core (Grid point Model)**

2) Radiative transfer:

- **TIR CO_2 wide band model (Hourdin 1991) + NLTE model (Lopez-Valverde 2011)**
- **NIR CO_2 (NLTE)**
- **EUV absorption**
- **Aerosols: Toon et al. 1989**

6) Dust transport and distribution : see below

3) **Subgrid scale dynamics**

- **Turbulence: Mellor and Yamada 2.5 Scheme**
- **Convection :**
- **Gravity waves (orographic) + low level drag:** Prametrisation of impact on the main flow

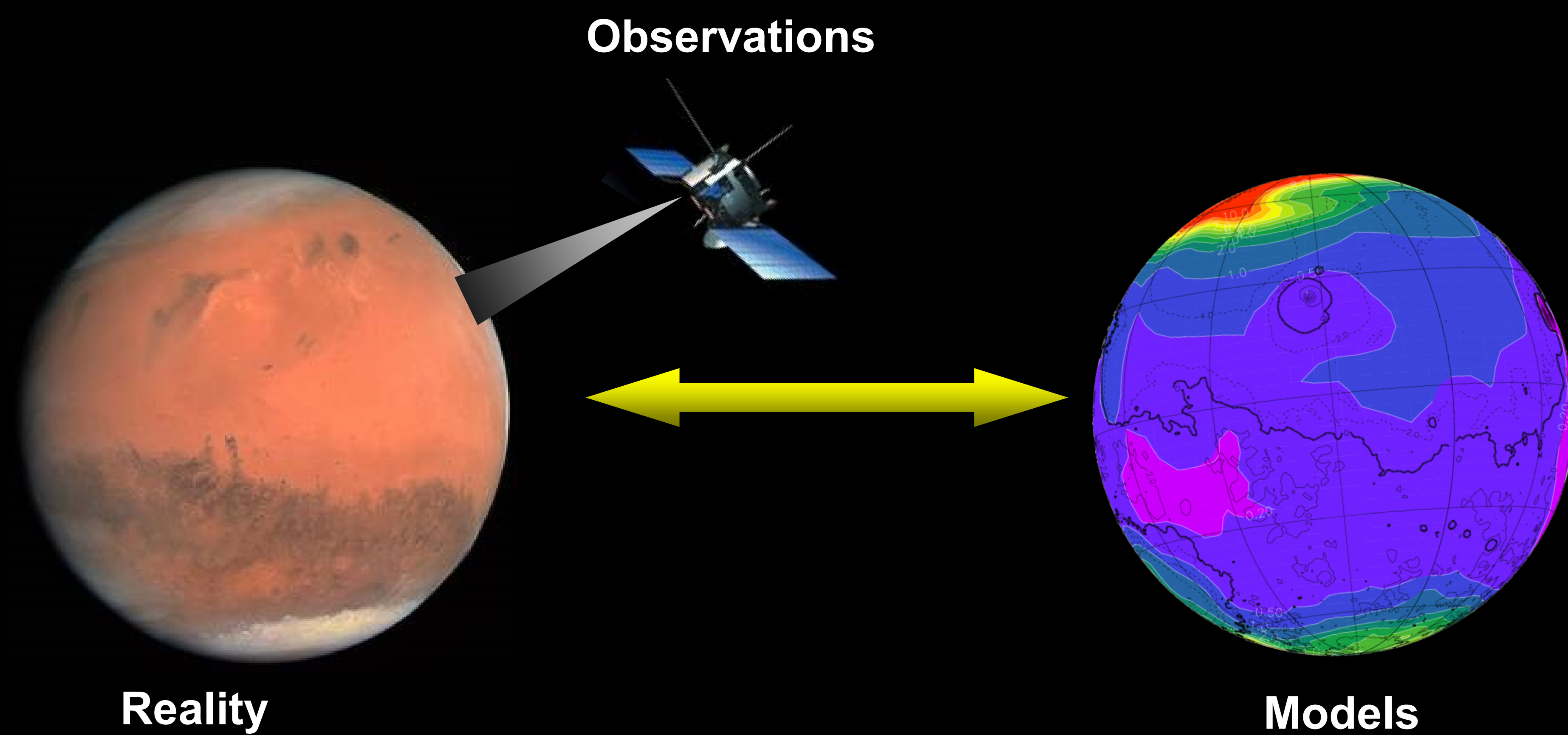
5) **Volatile:**

- **CO_2 cycle: see below**
- **H_2 O cycle: see below**

4) Surface and subsurface thermal balance

Forget and Lebonnois (2013) In

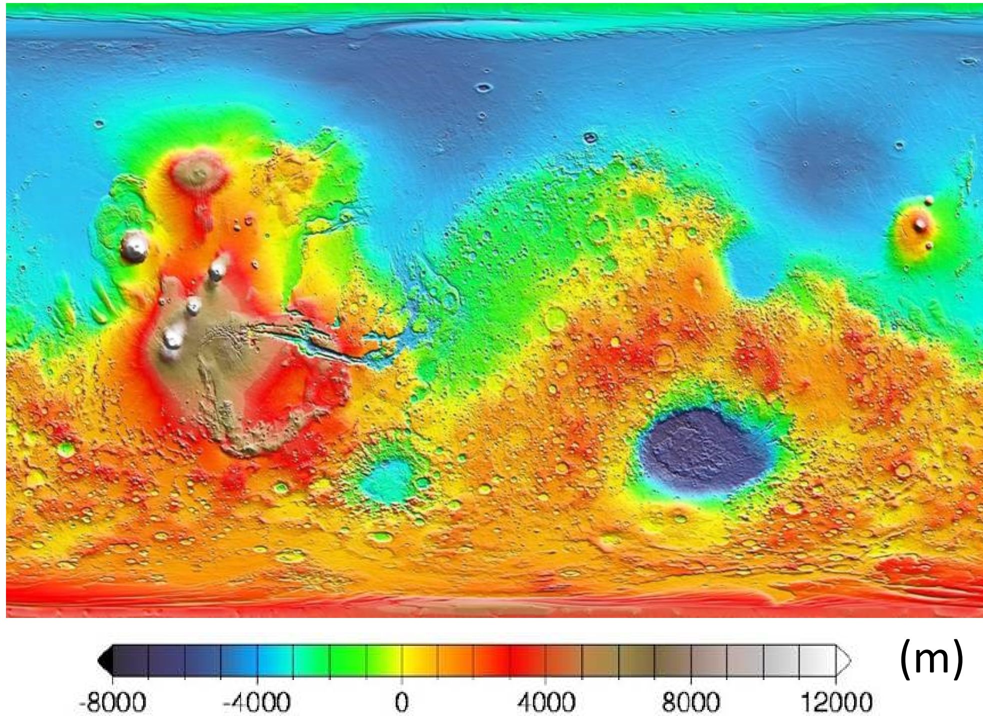
An ambitious goal : Building a “virtual” Mars behaving like the real one, on the basis of universal equations



Prescribed surface fields

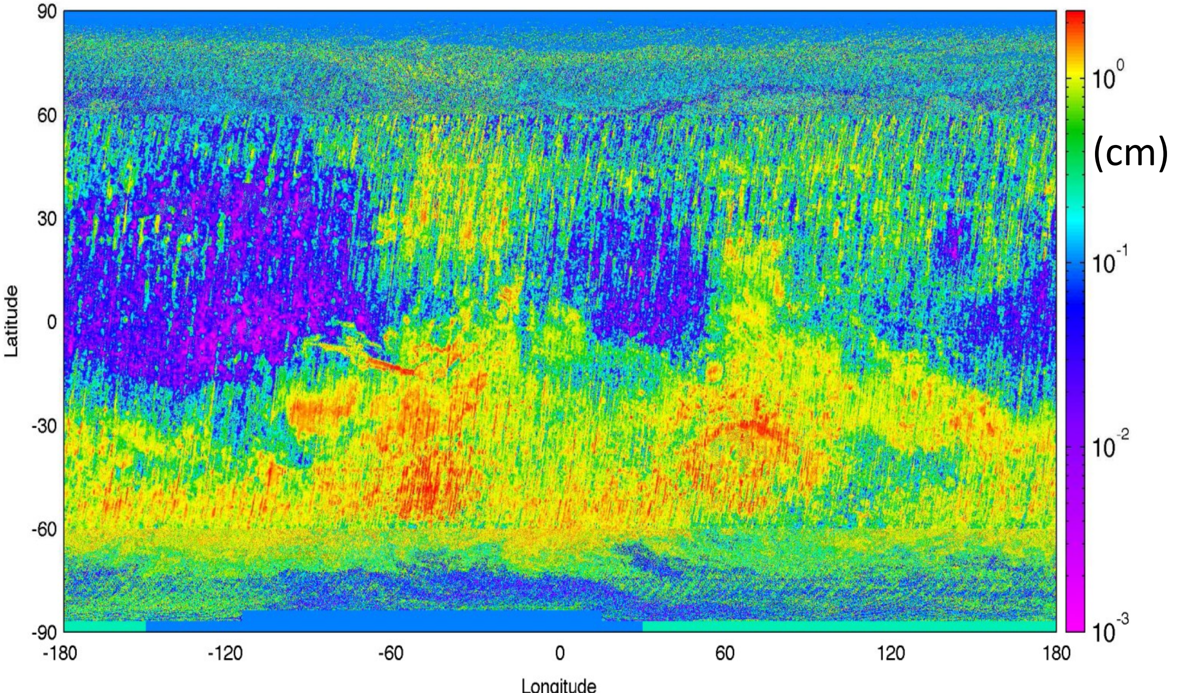
- Topography

(From MGS MOLA altimeter)



- Surface Roughness (cm)

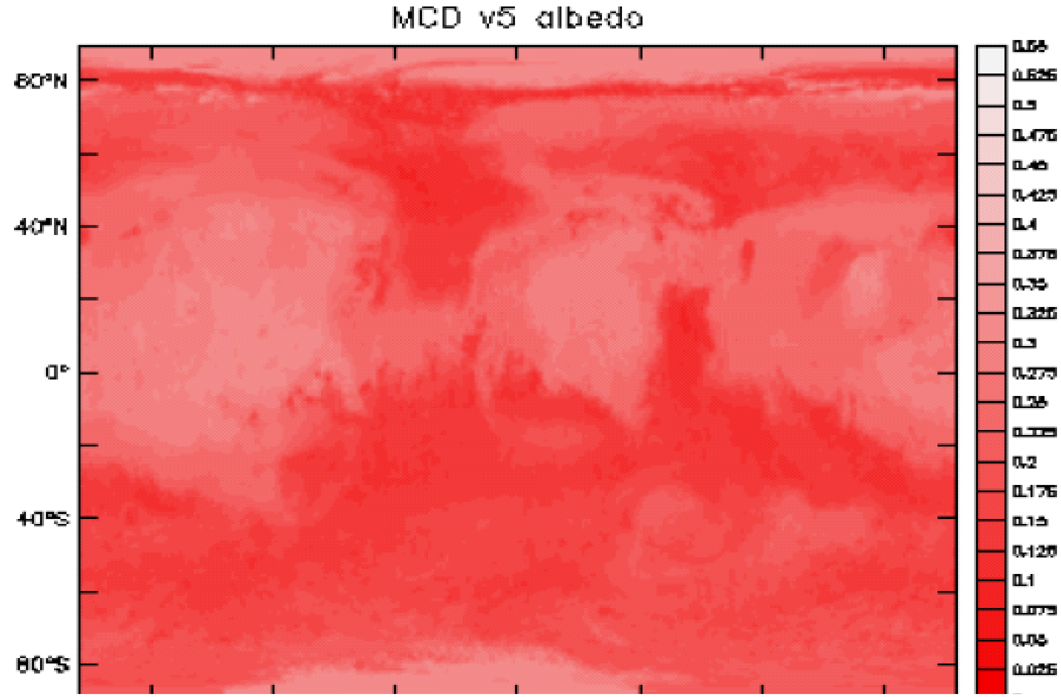
(Derived from TES Rock Abundance for the LMD GCM, *Hebrard et al. 2011*)



Prescribed surface fields

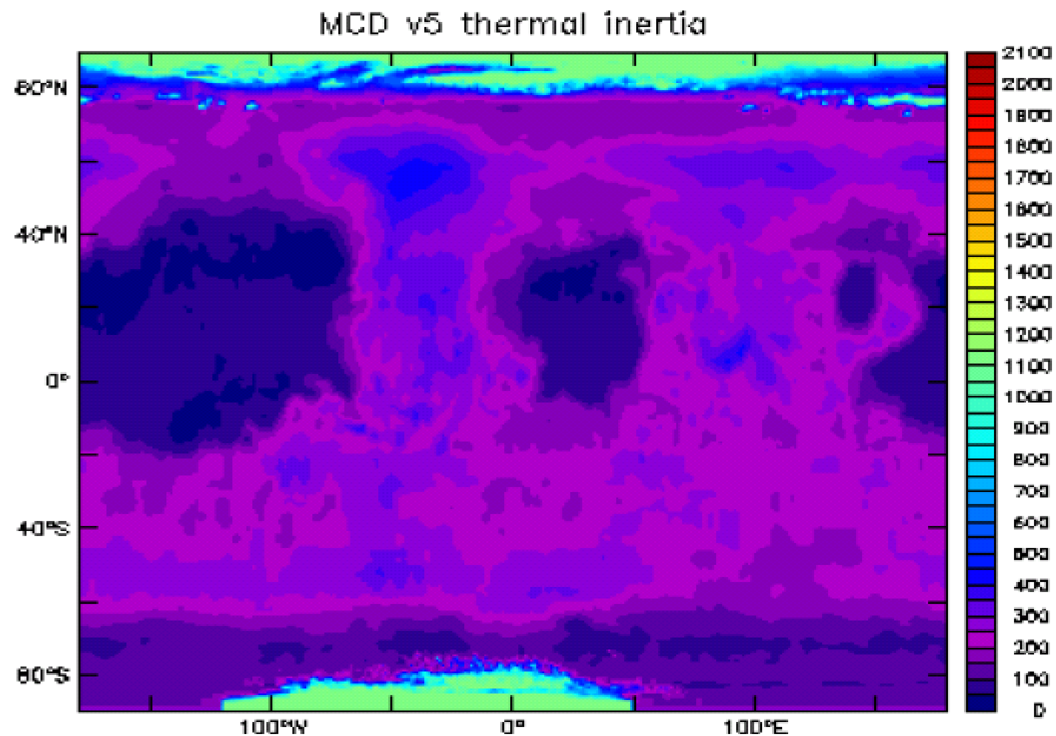
- Albedo

(From MGS TES solar channel)



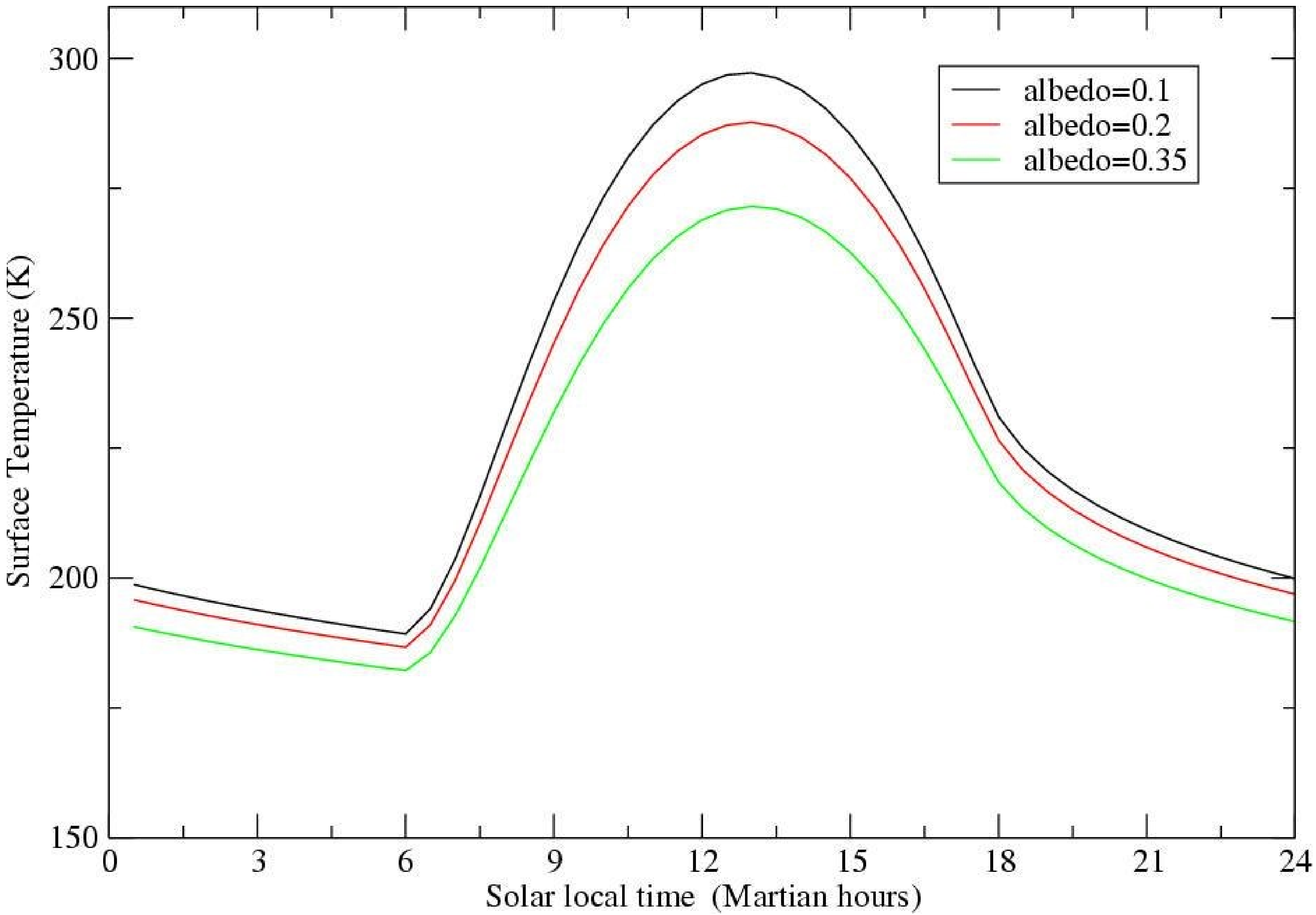
- Thermal inertia

(From MGS TES)



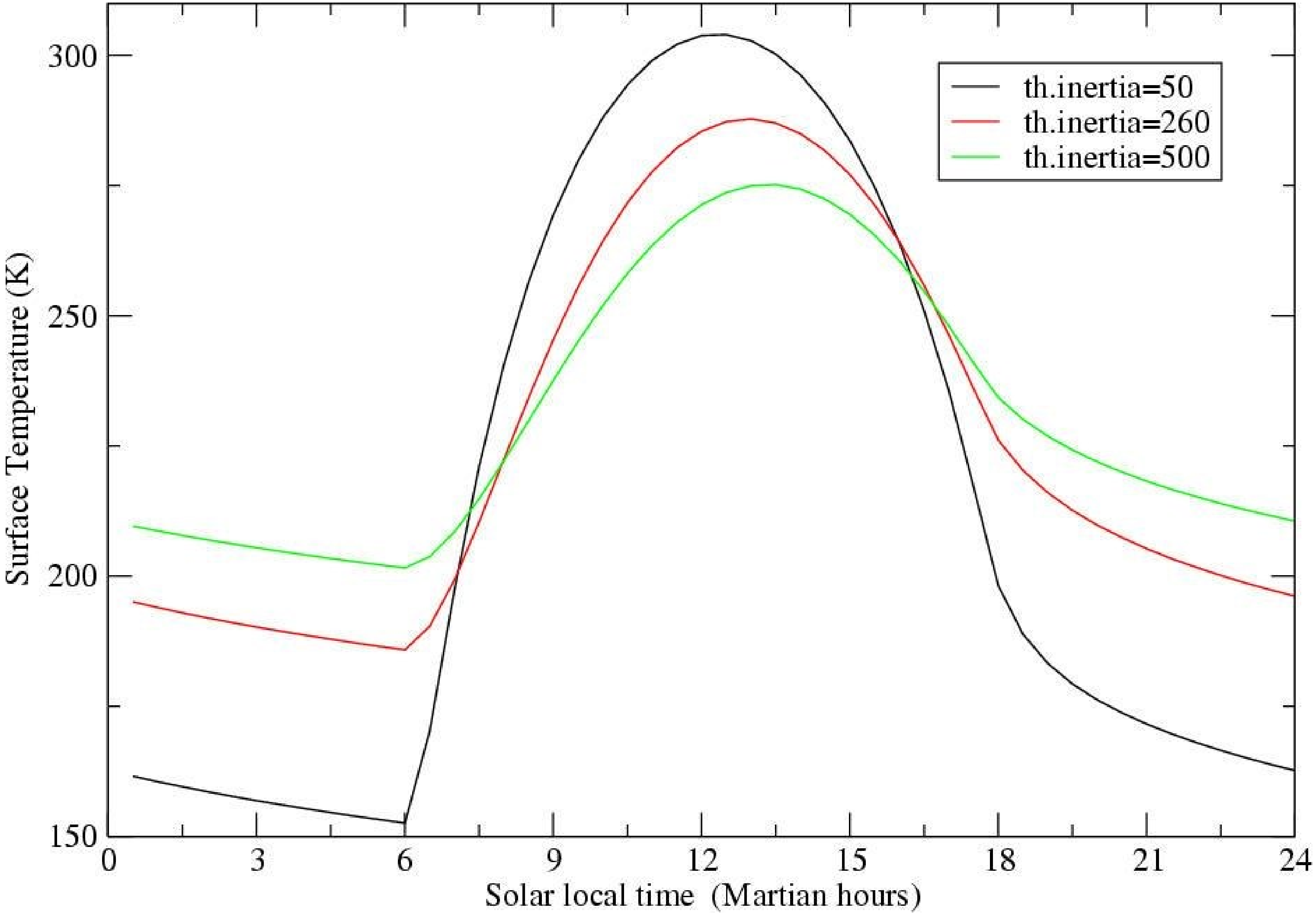
Influence of Albedo on Surface temperature

(Exemple: lat =0°, Ls=344°)



Influence of Thermal Inertia on Surface temperature

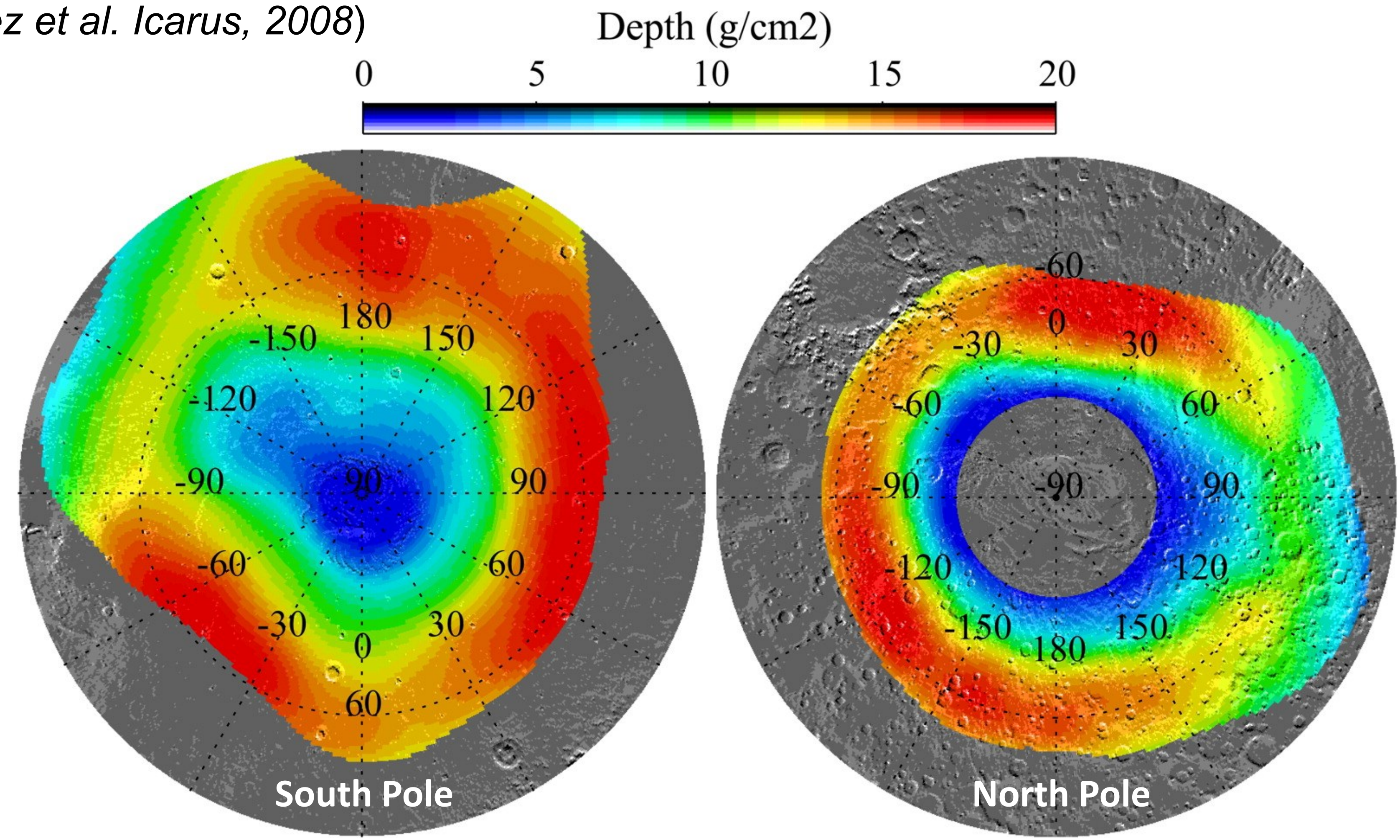
(Exemple: lat =0°, Ls=344°)



Taking into account subsurface Ice thermal inertia

(Ice depth taken from Mars Oddyssey Neutron spectrometer data)

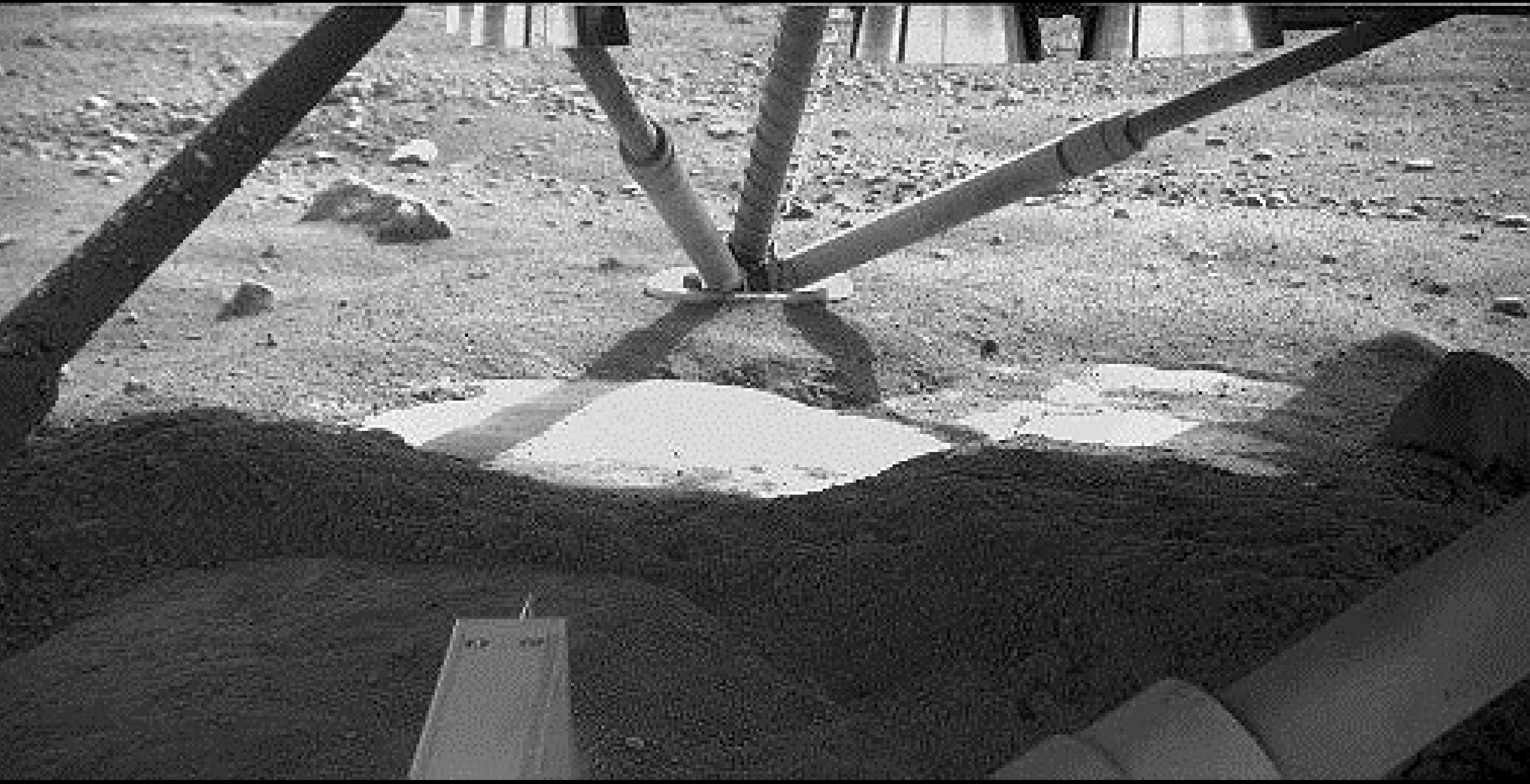
(*Diez et al. Icarus, 2008*)

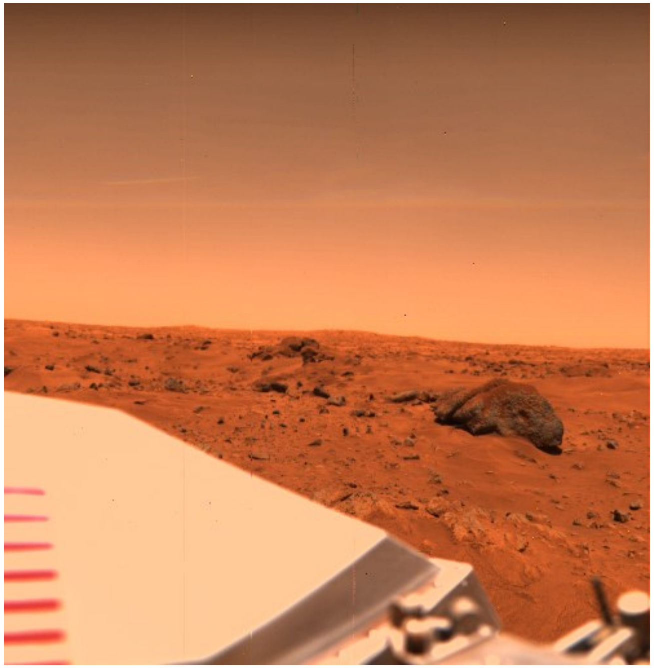


Depth sensitive to dry soil layer density and composition

⇨ **Tunable parameter**

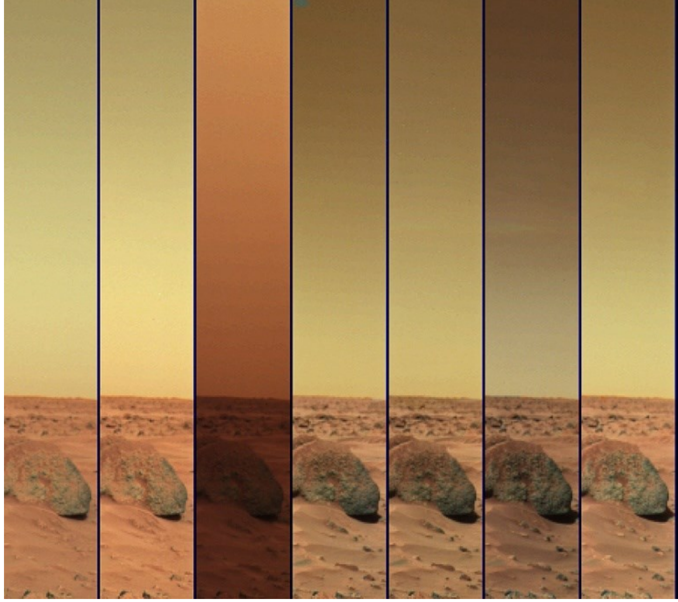
Below Phoenix Lander at 68°N : ice exposed by landing thrusters

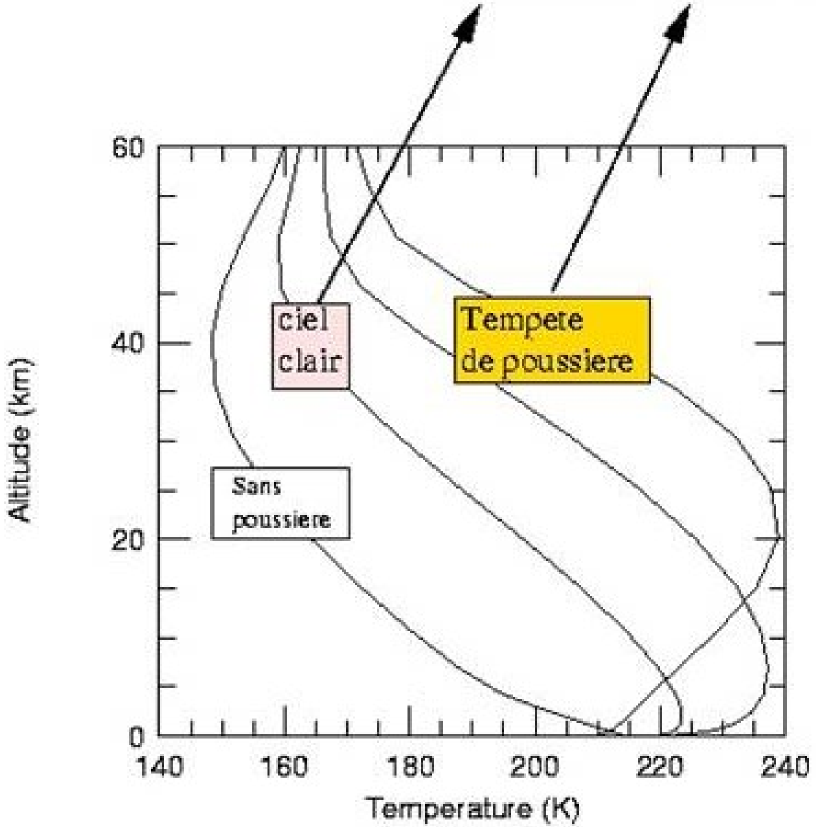




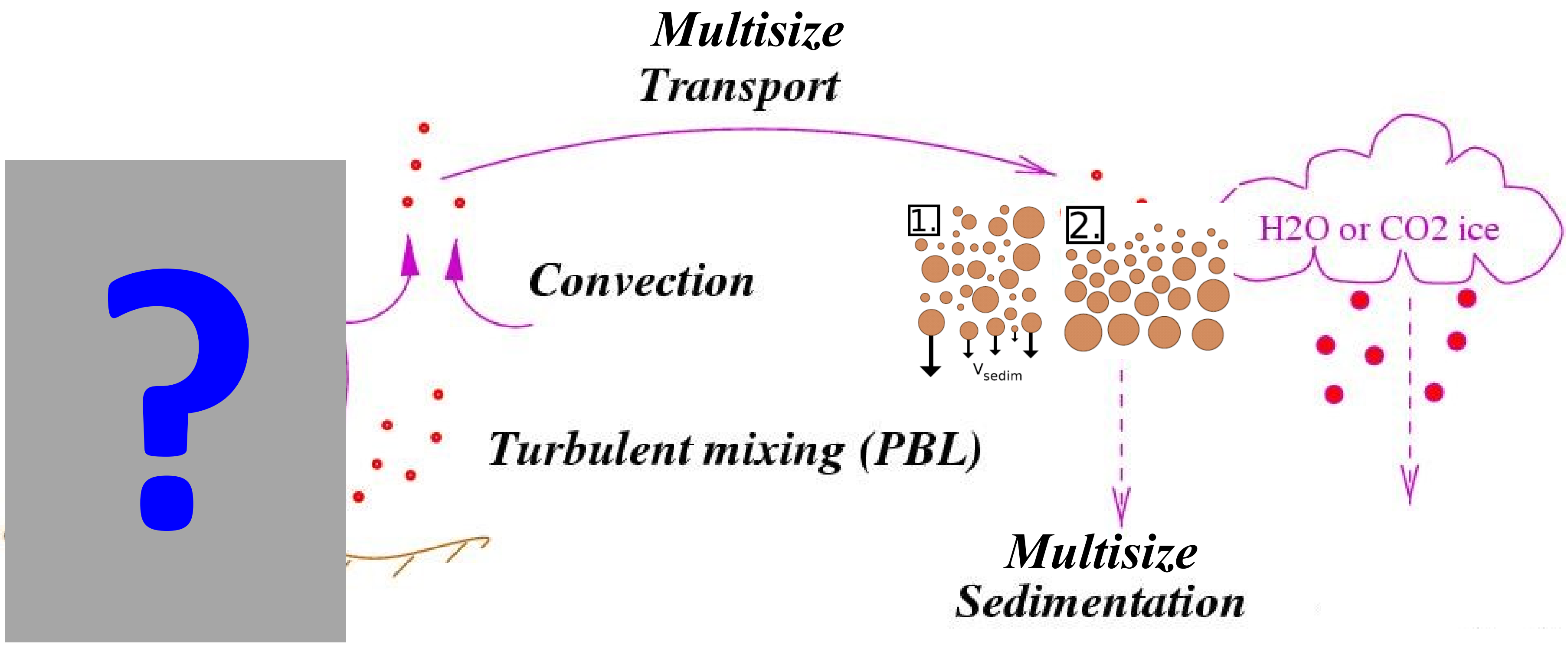
Viking Lander 1

Impact of dust on atmospheric temperatures

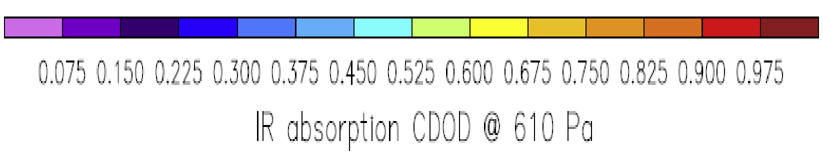




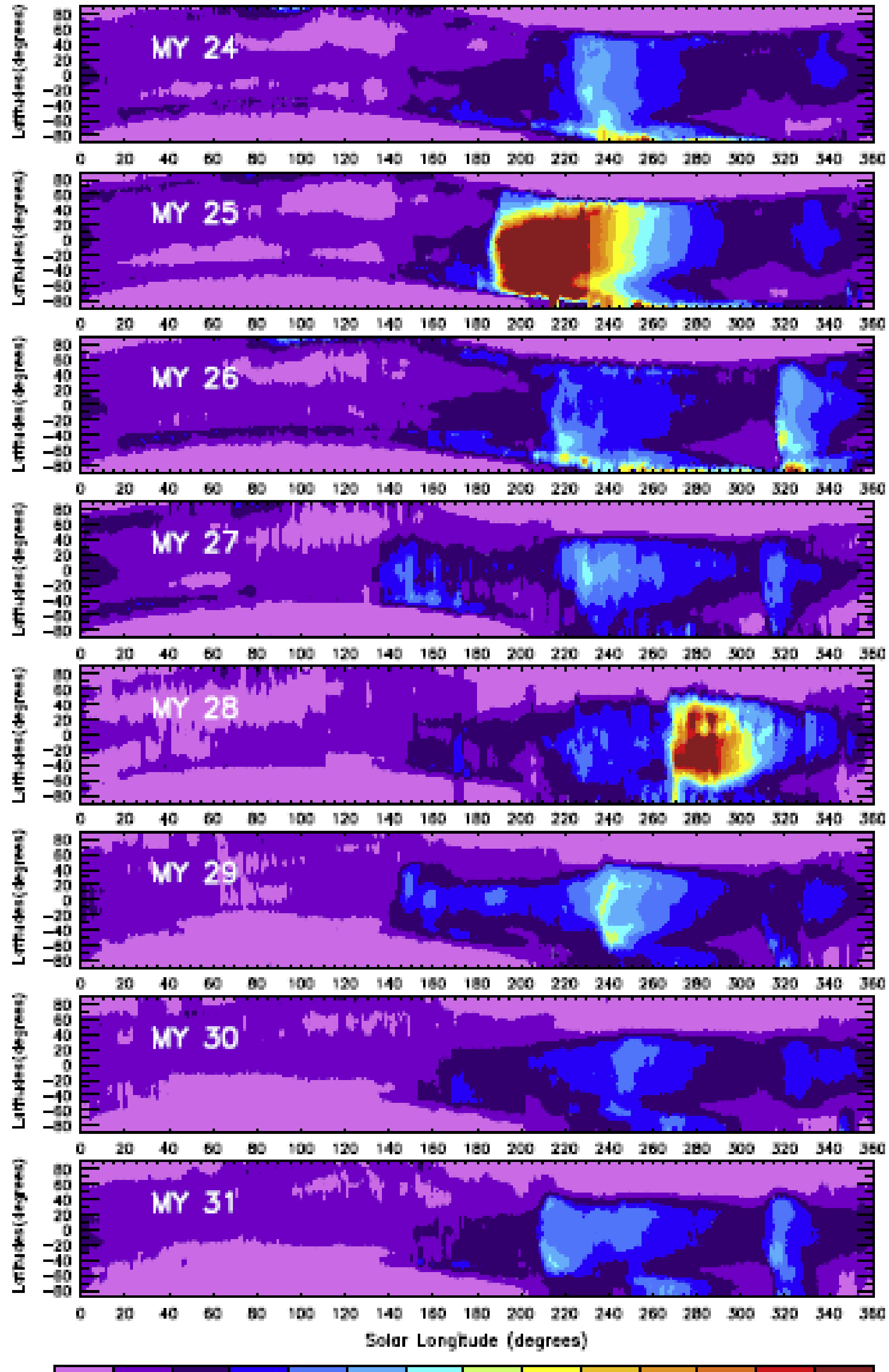
Dust cycle model in the LMD GCM



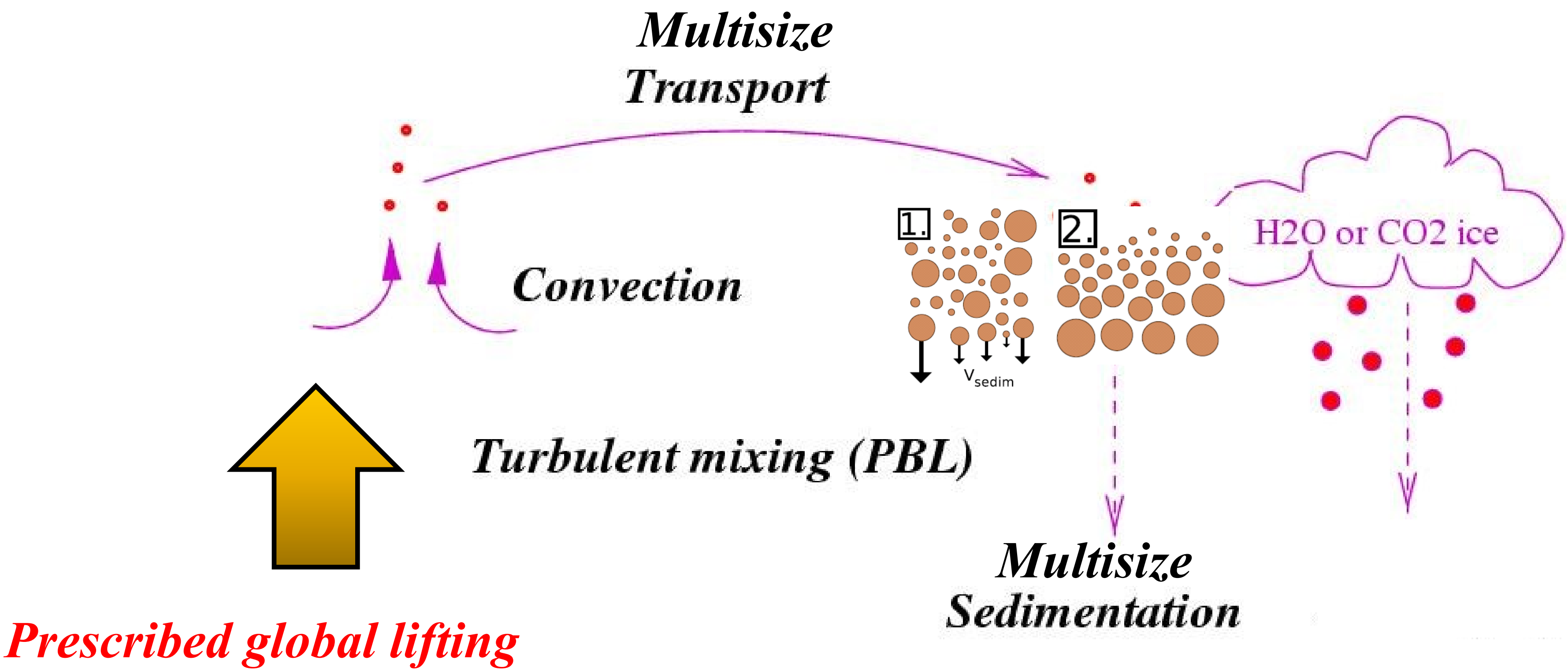
DUST SCENARIOS
Zonal mean of reconstructed column dust opacities for martian year 24-31



Montabone et al. 2015 (Icarus)

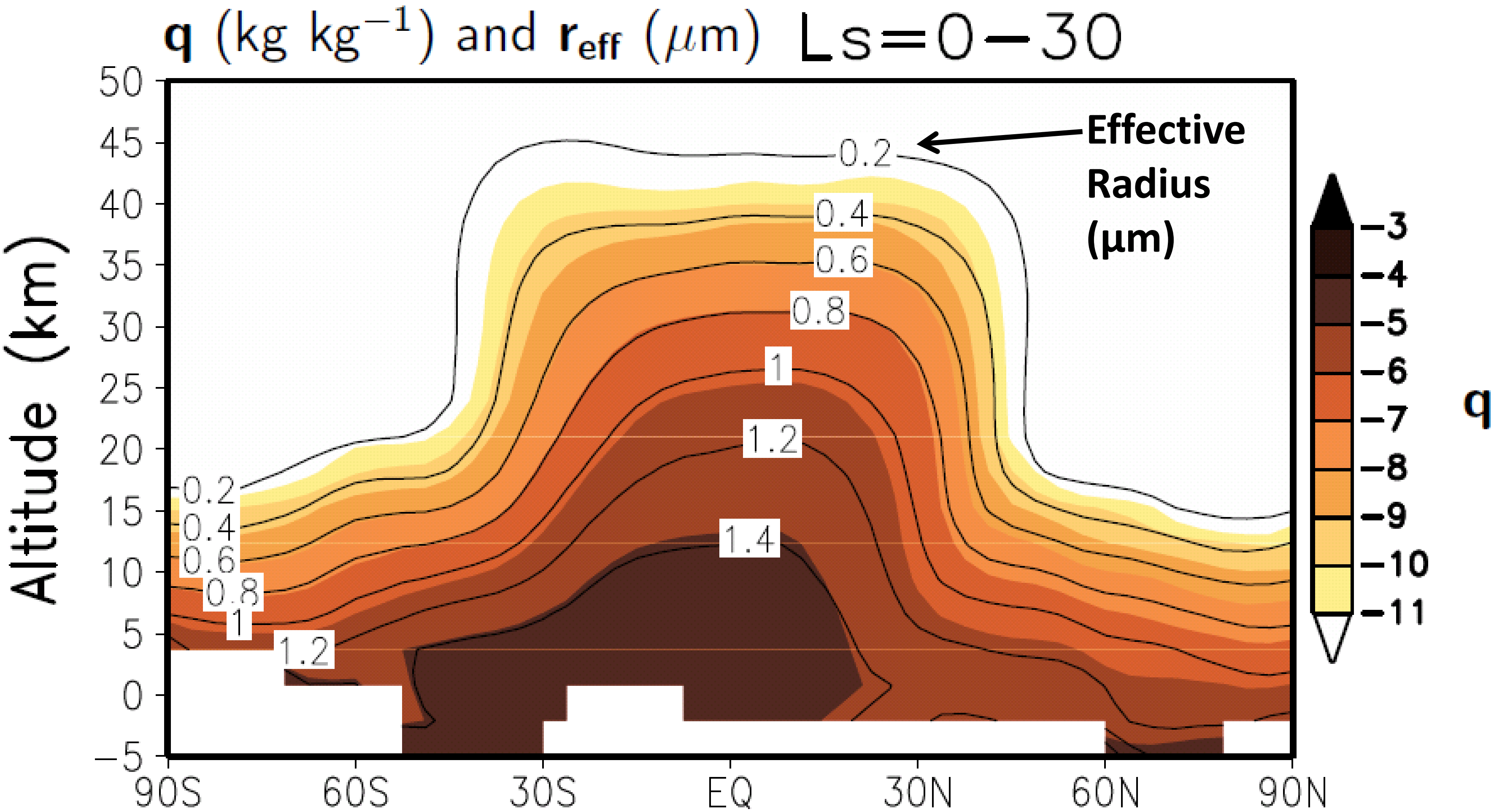


“dust cycle model” to simulate observed Martian years (MY24 – MY32)



(Madeleine et al. 2011)

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



Madeleine et al. 2011

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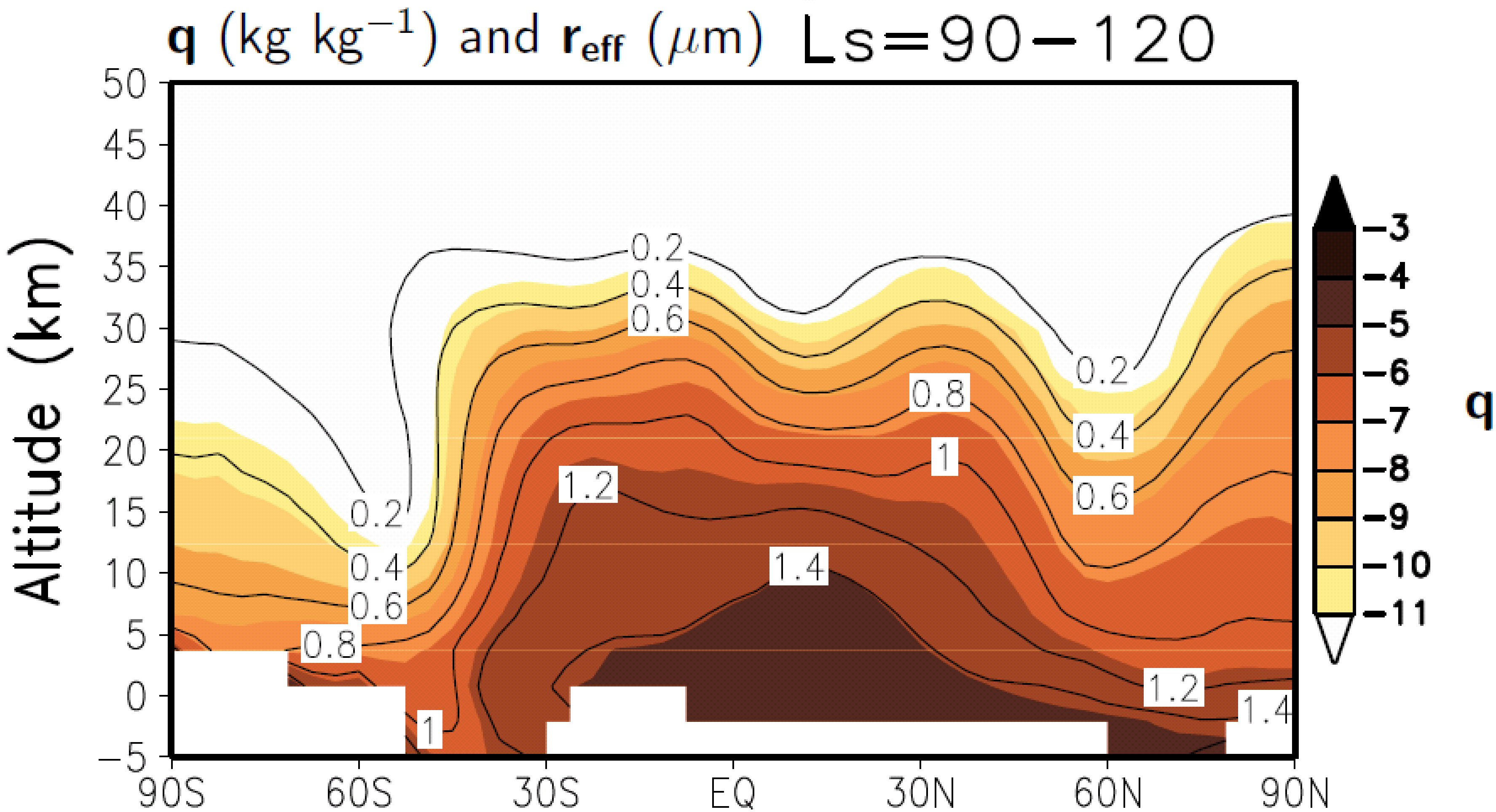

Madeleine et al. 2011

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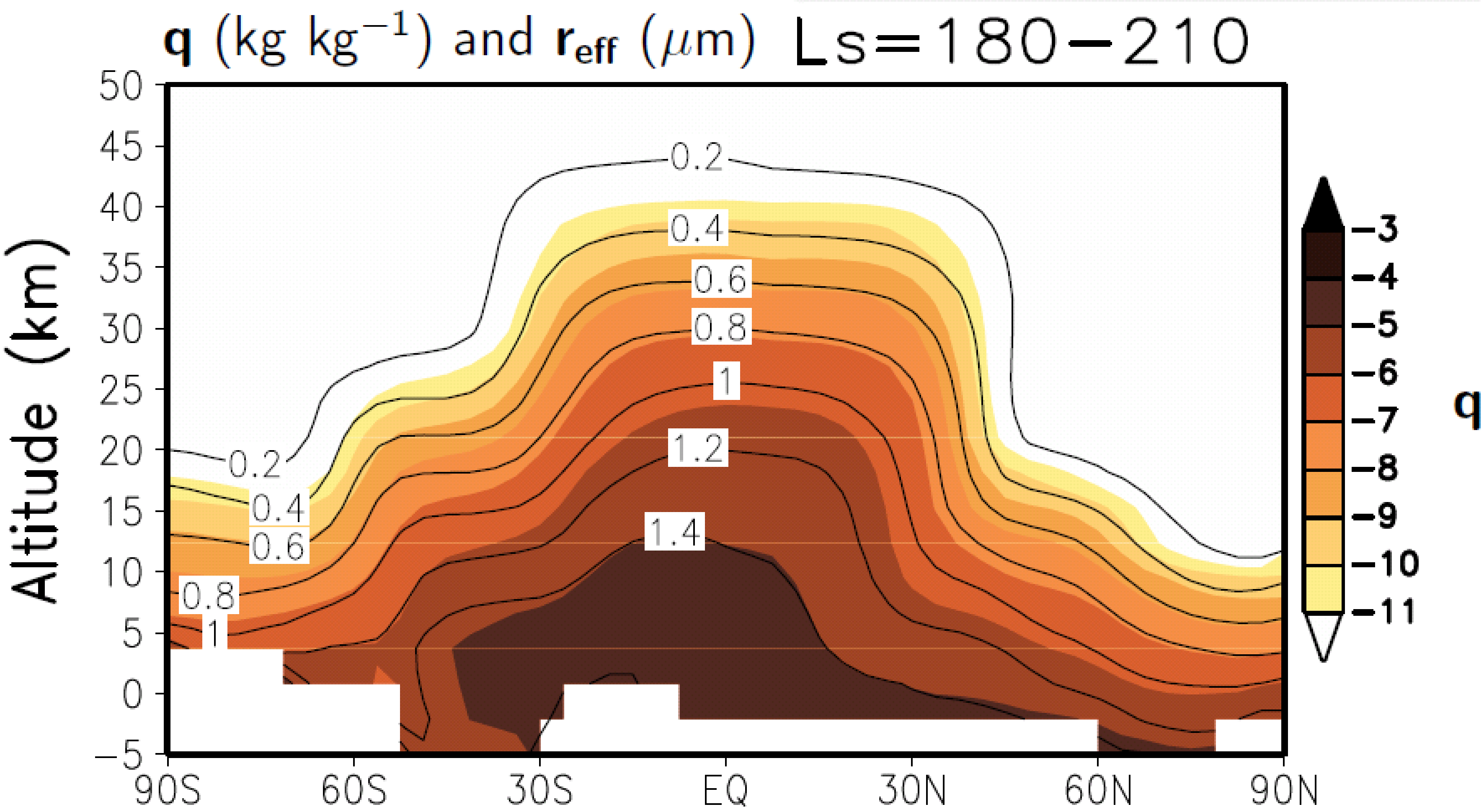

Madeleine et al. 2011

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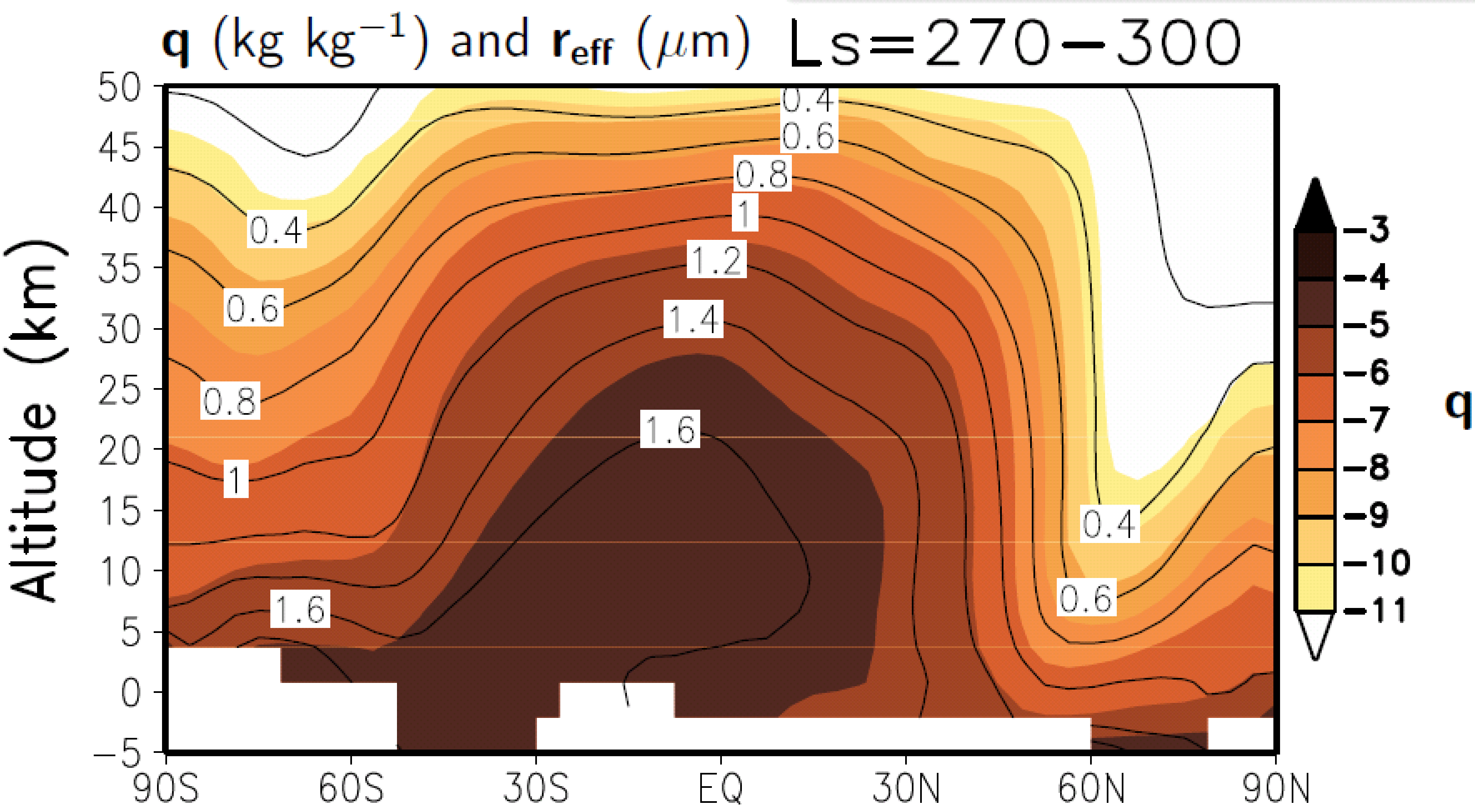
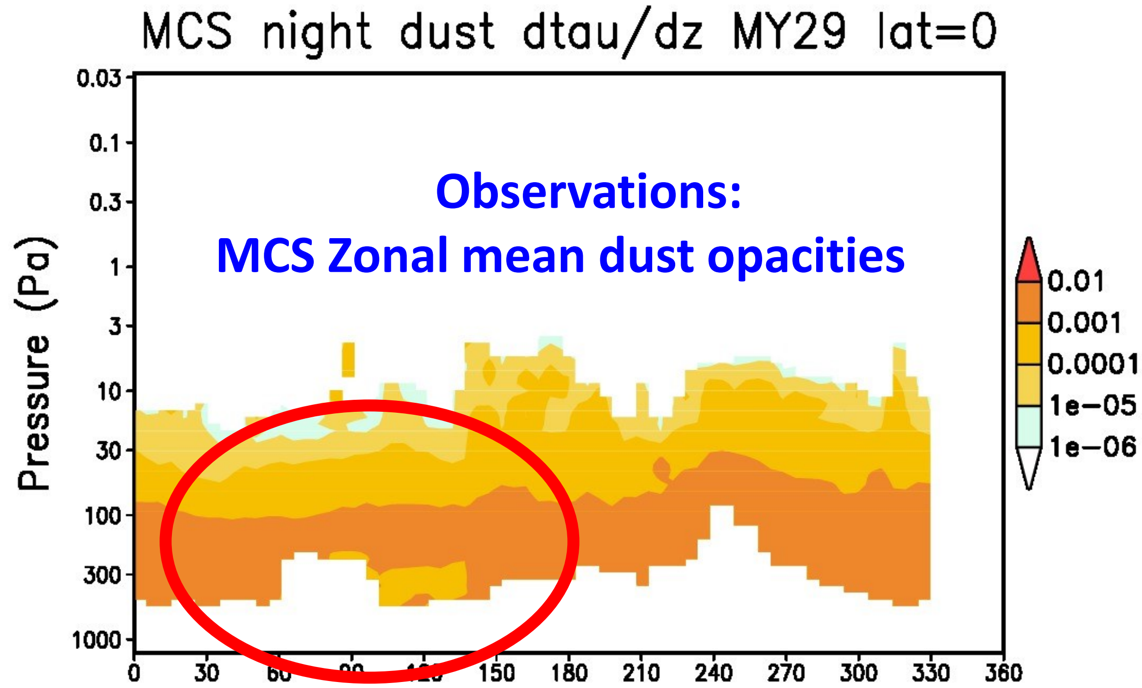


Madeleine et al. 2011


MCS night dust dtau/dz MY29 lat=0
Observations:
MCS Zonal mean dust opacities
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
0
30
150
180
210
240
270
300
330
360
0.01
0.001
0.0001
1e−05
1e−06

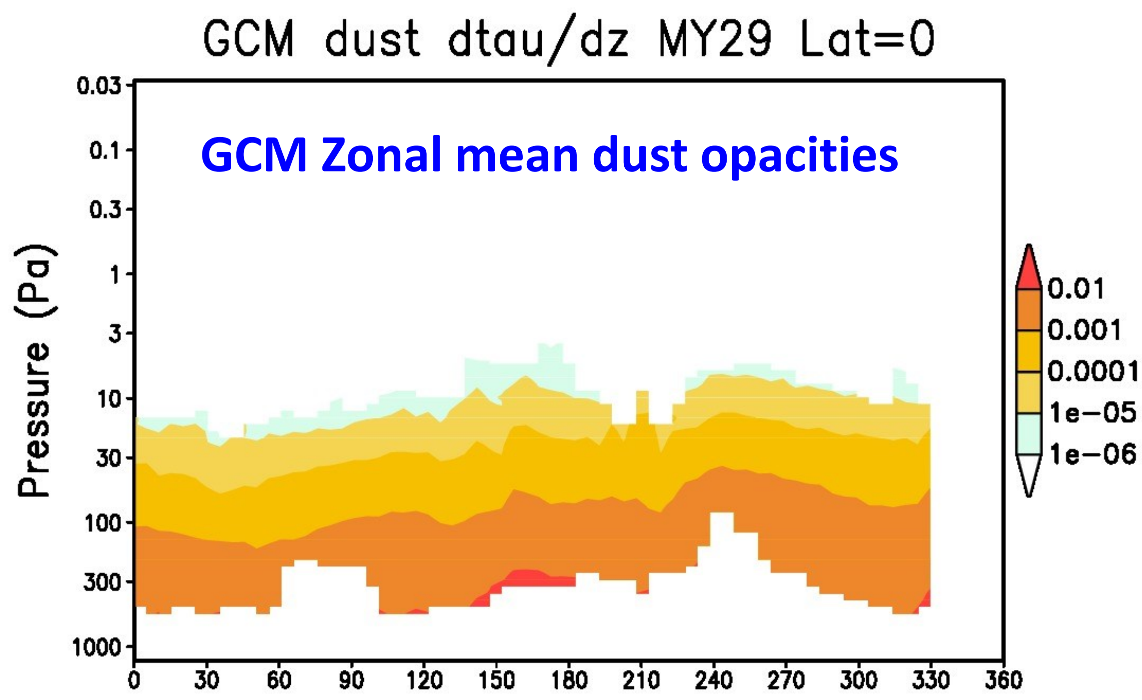
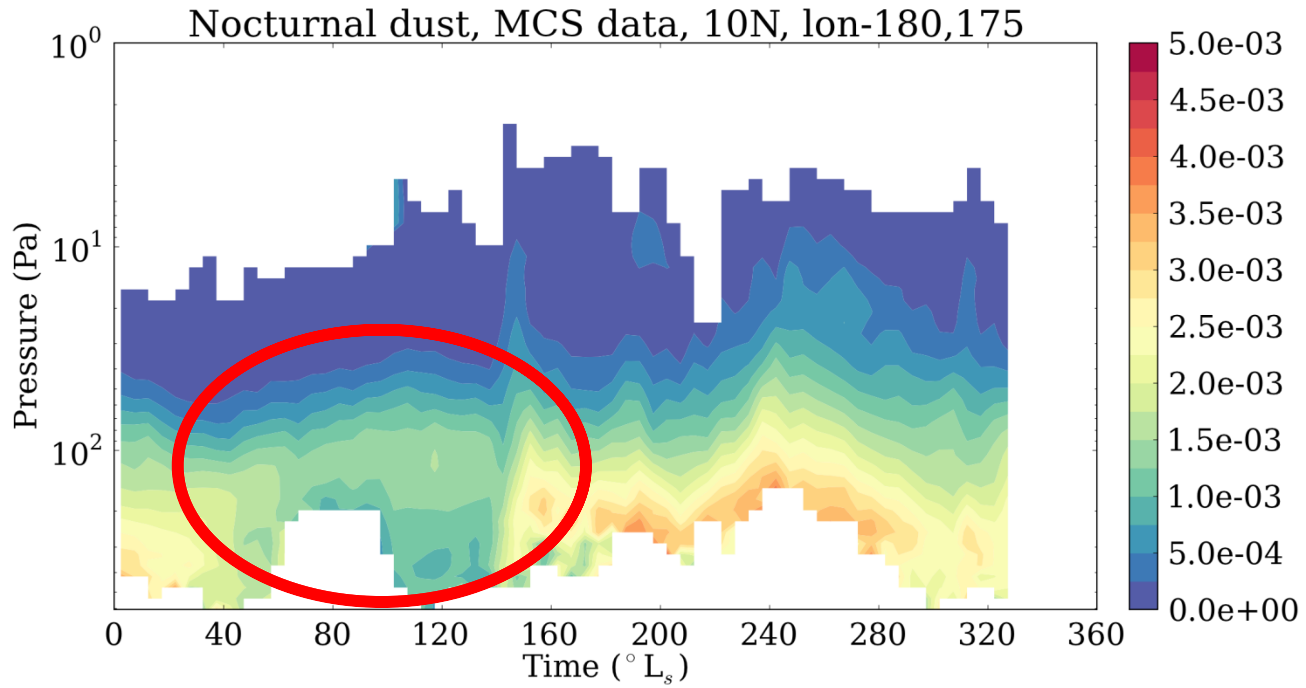

GCM dust dtau/dz MY29 Lat=0
GCM Zonal mean dust opacities
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
0
30
60
90
120
150
180
210
240
270
300
330
360
0.01
0.001
0.0001
1e−05
1e−06

Figure from Alizee Pottier

Nightime dust at 10°N

MCS observations



LMD GCM Model

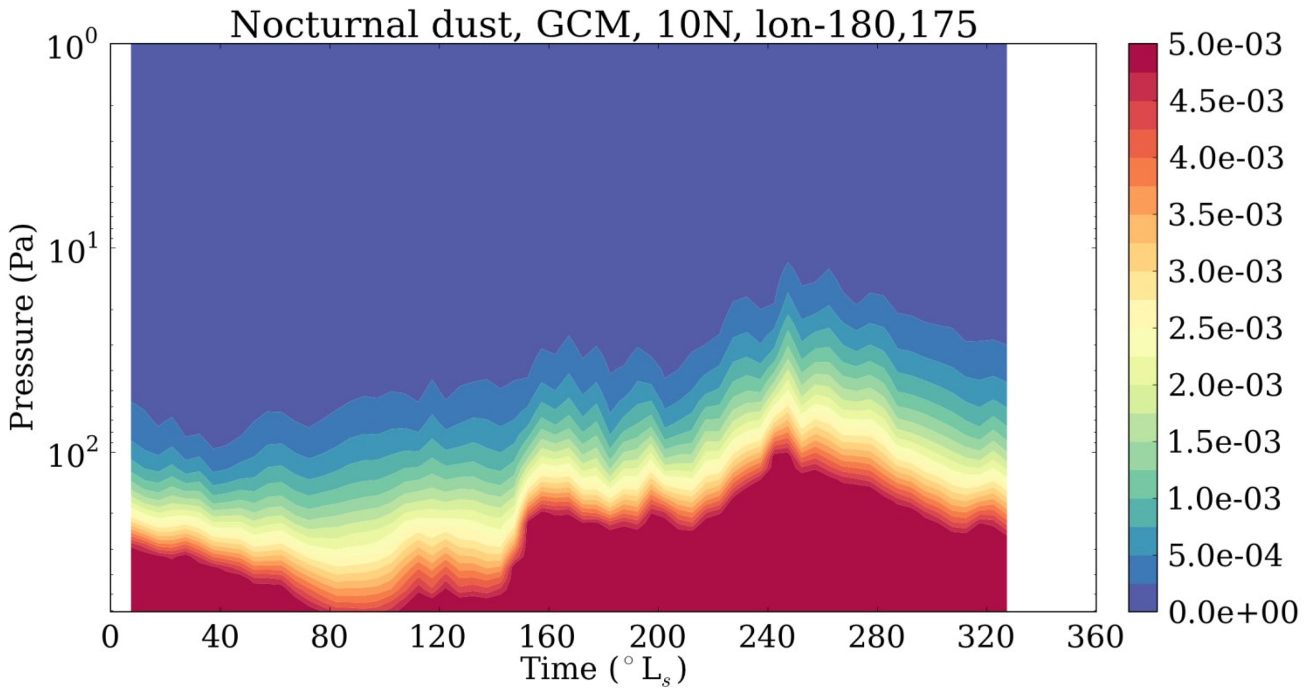
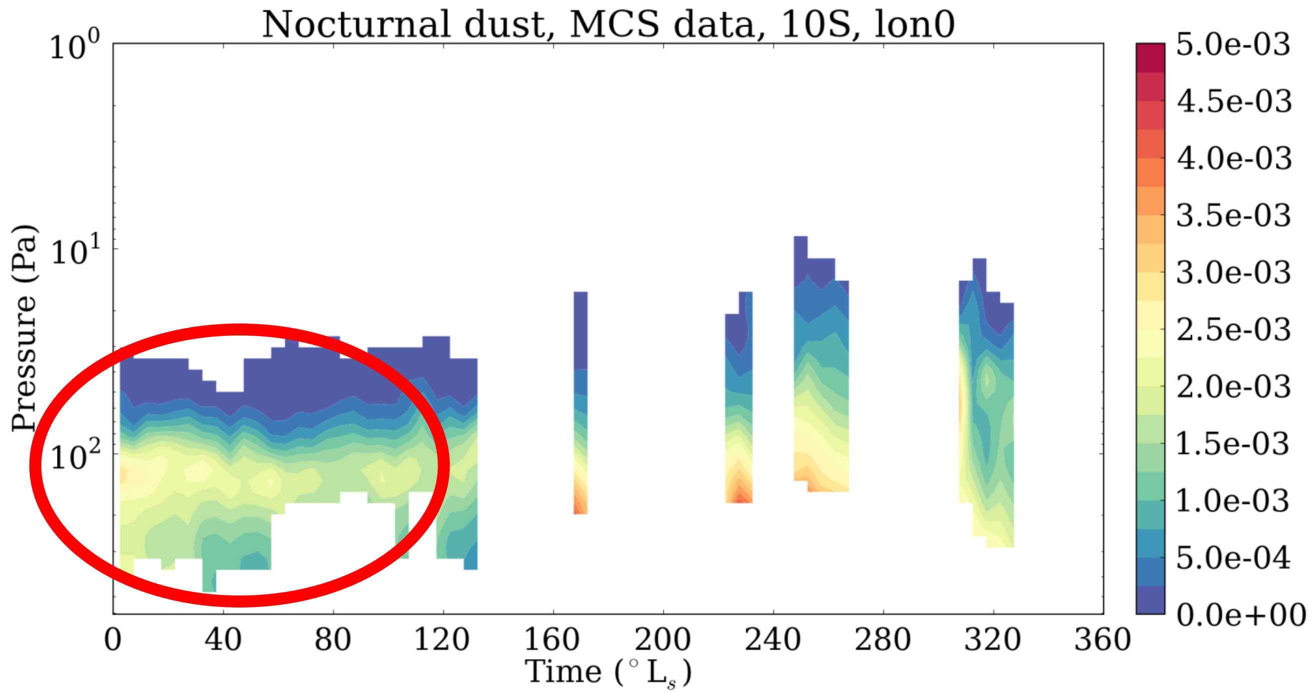


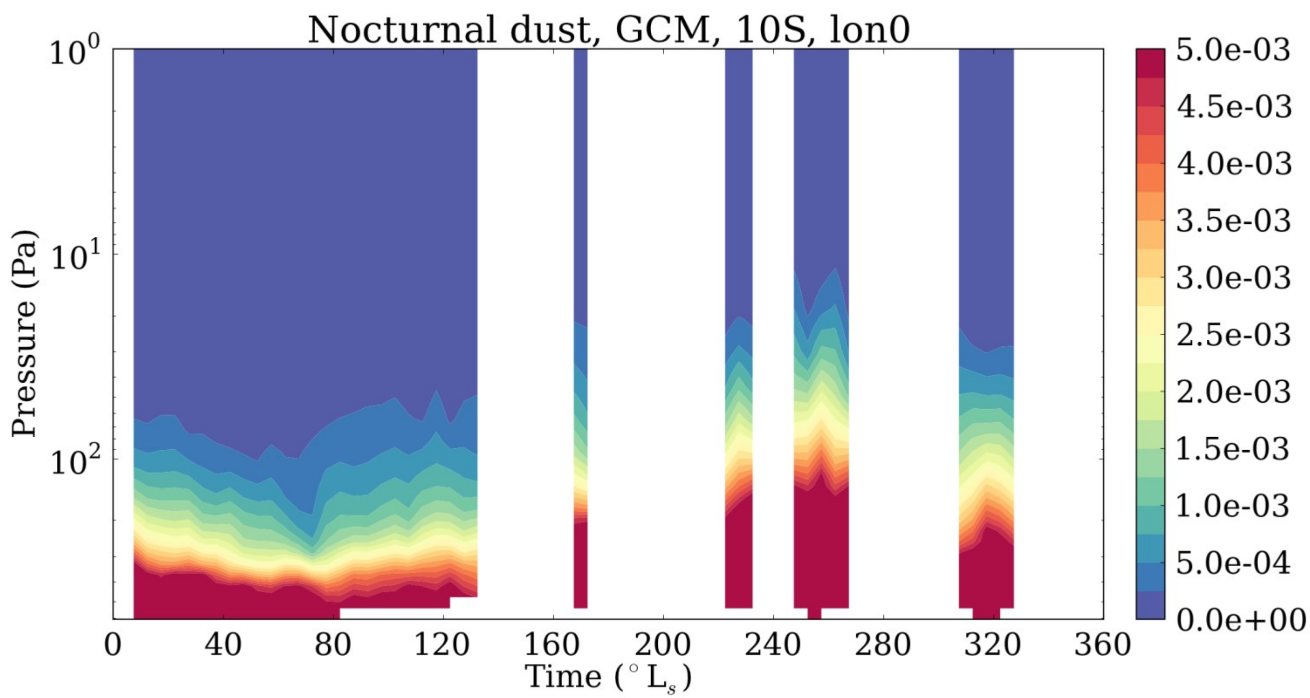
Figure from Alizee Pottier

Local Nightime dust at 10°N 0°E

MCS observations



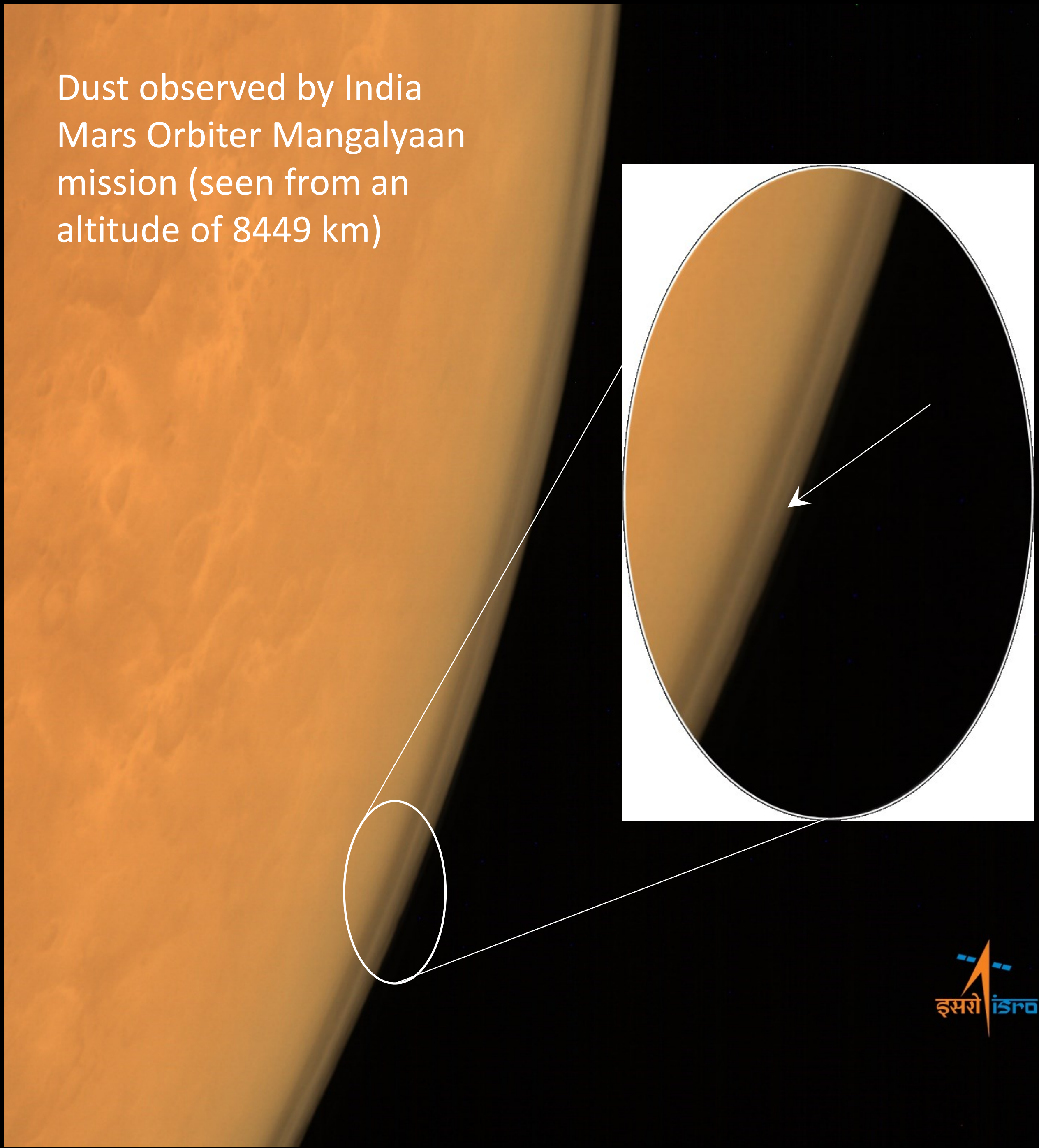
LMD GCM Model



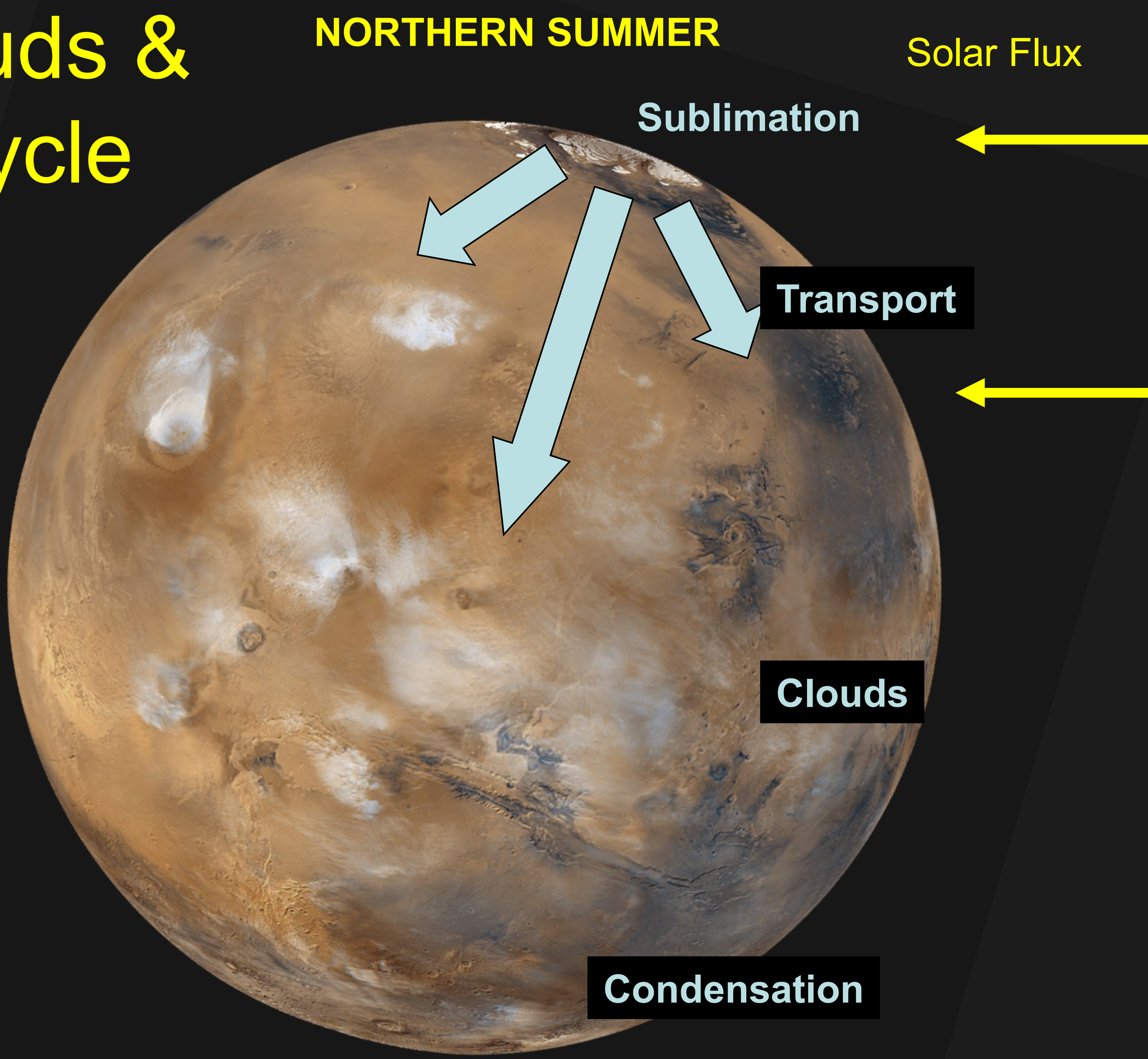
Dust aerosols

Key problems remains:

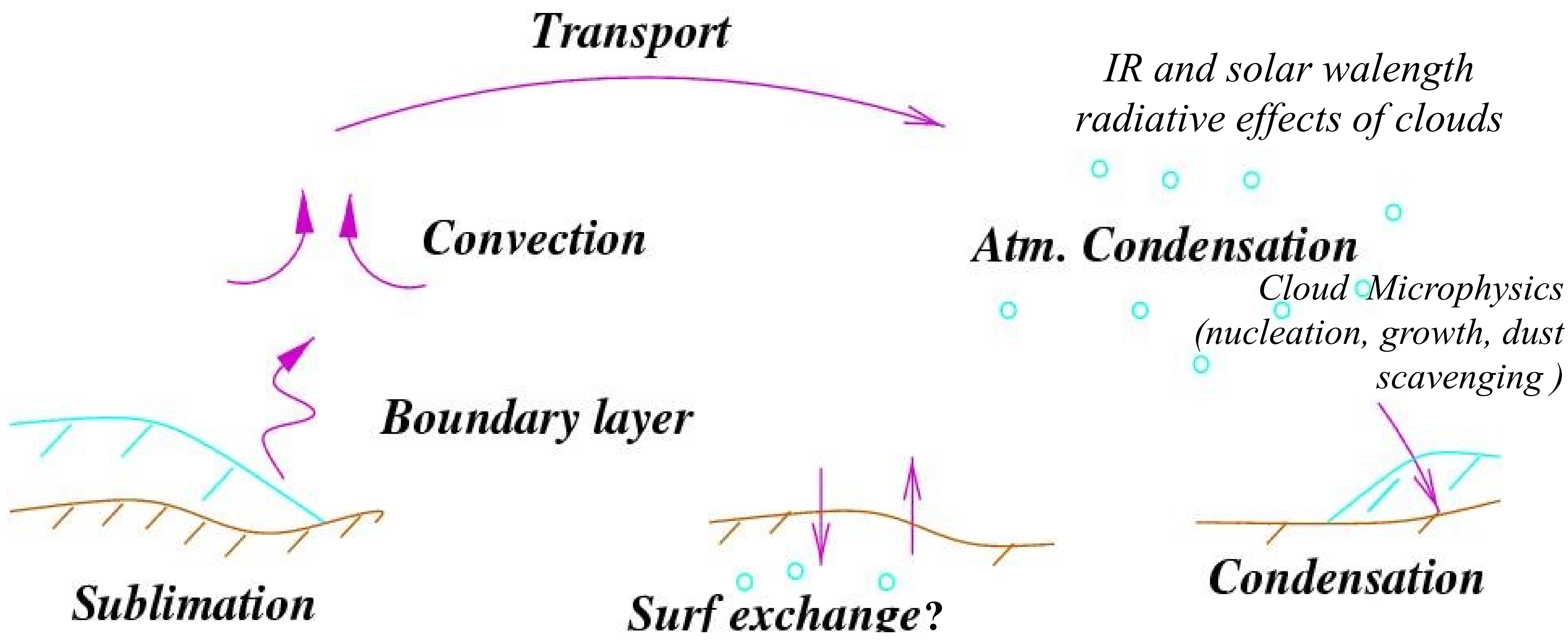
- Dust vertical structure (detached dust layers !) remains to be properly modeled
- Dust lifting and storms difficult to predict


Dust observed by India
Mars Orbiter Mangalyaan
mission (seen from an
altitude of 8449 km)

Mars clouds & water cycle

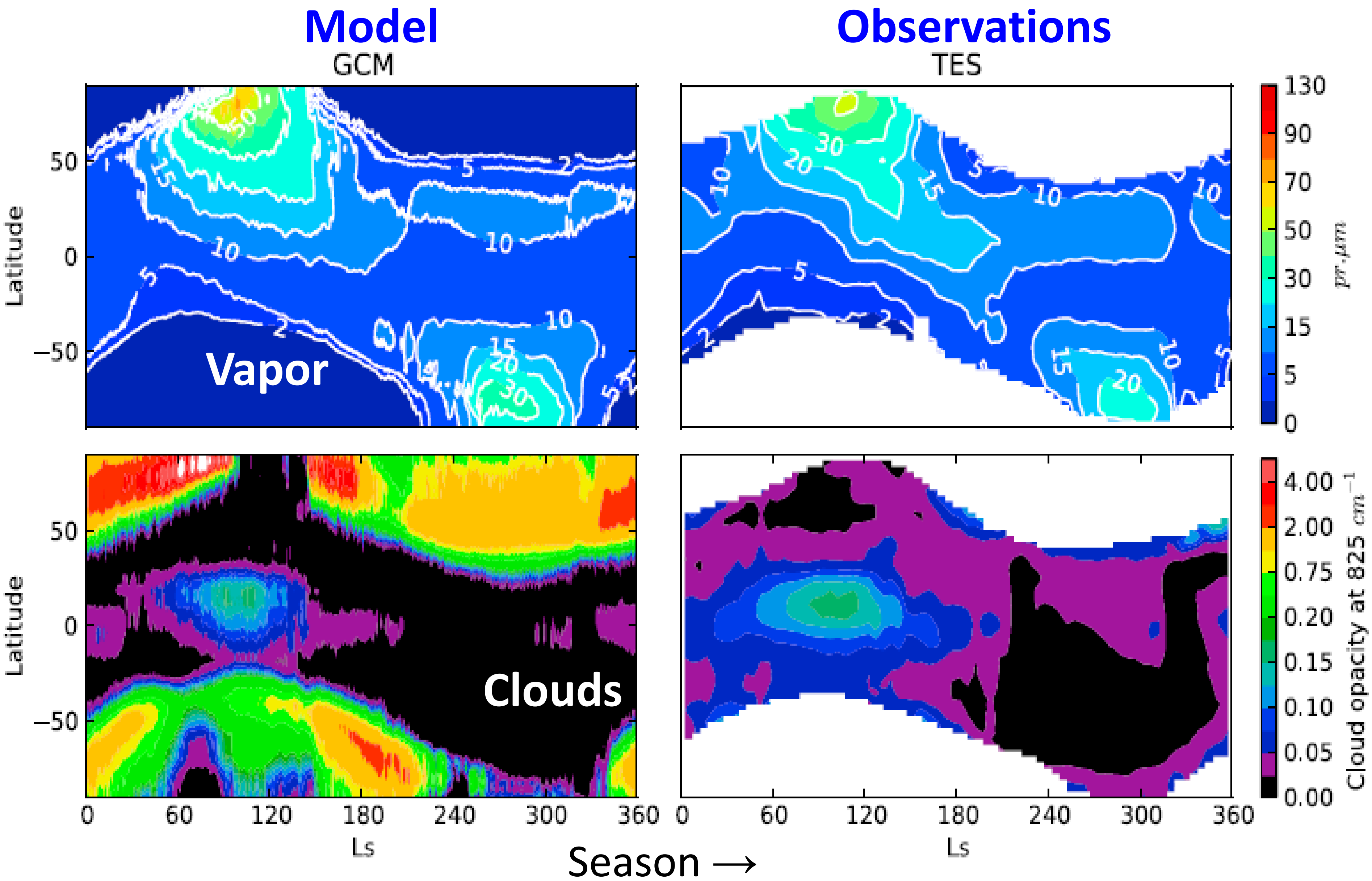


Modelling Water cycle and clouds



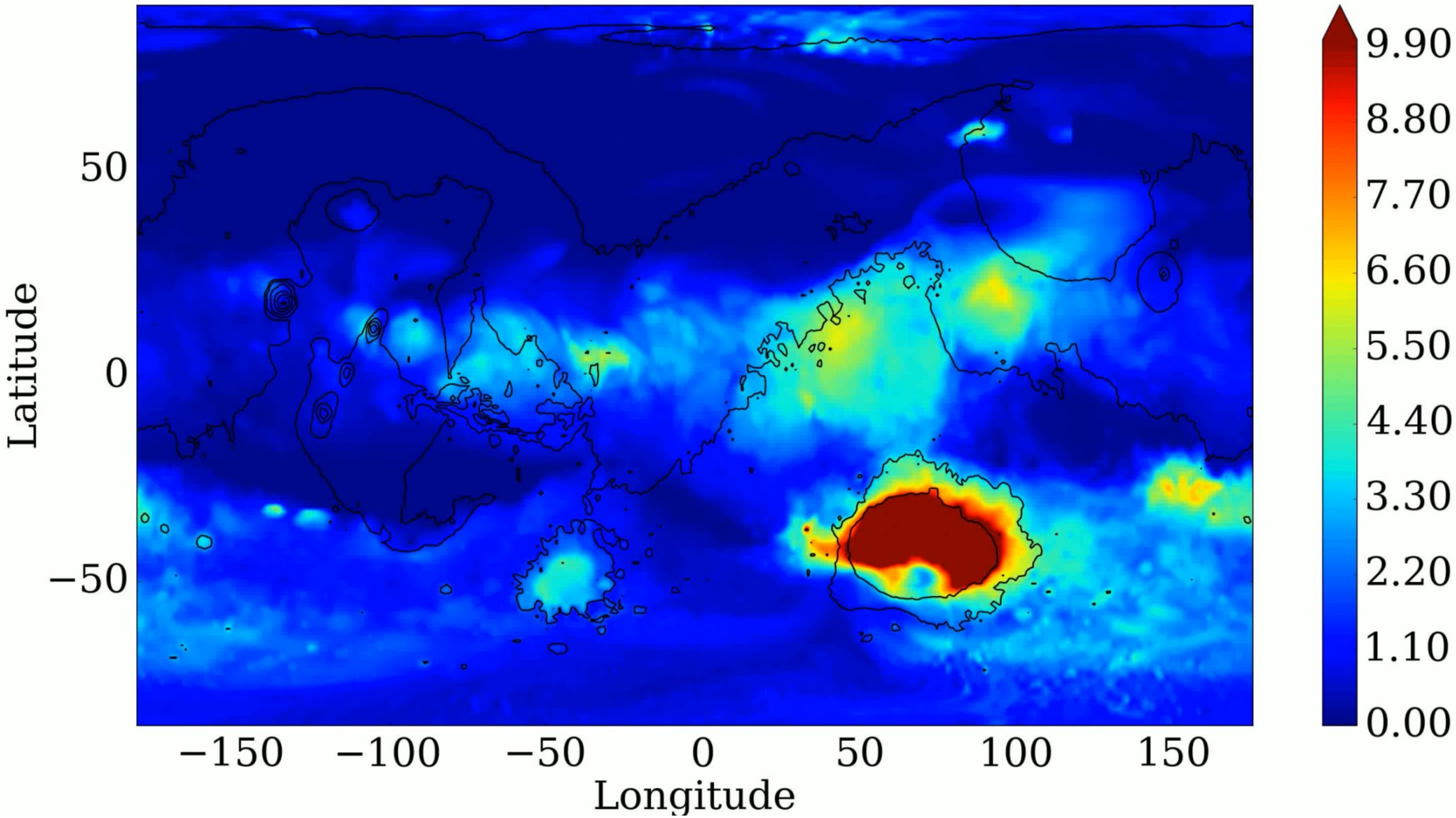
Water cycle in GCM version 5.2

(Navarro et al. 2015)



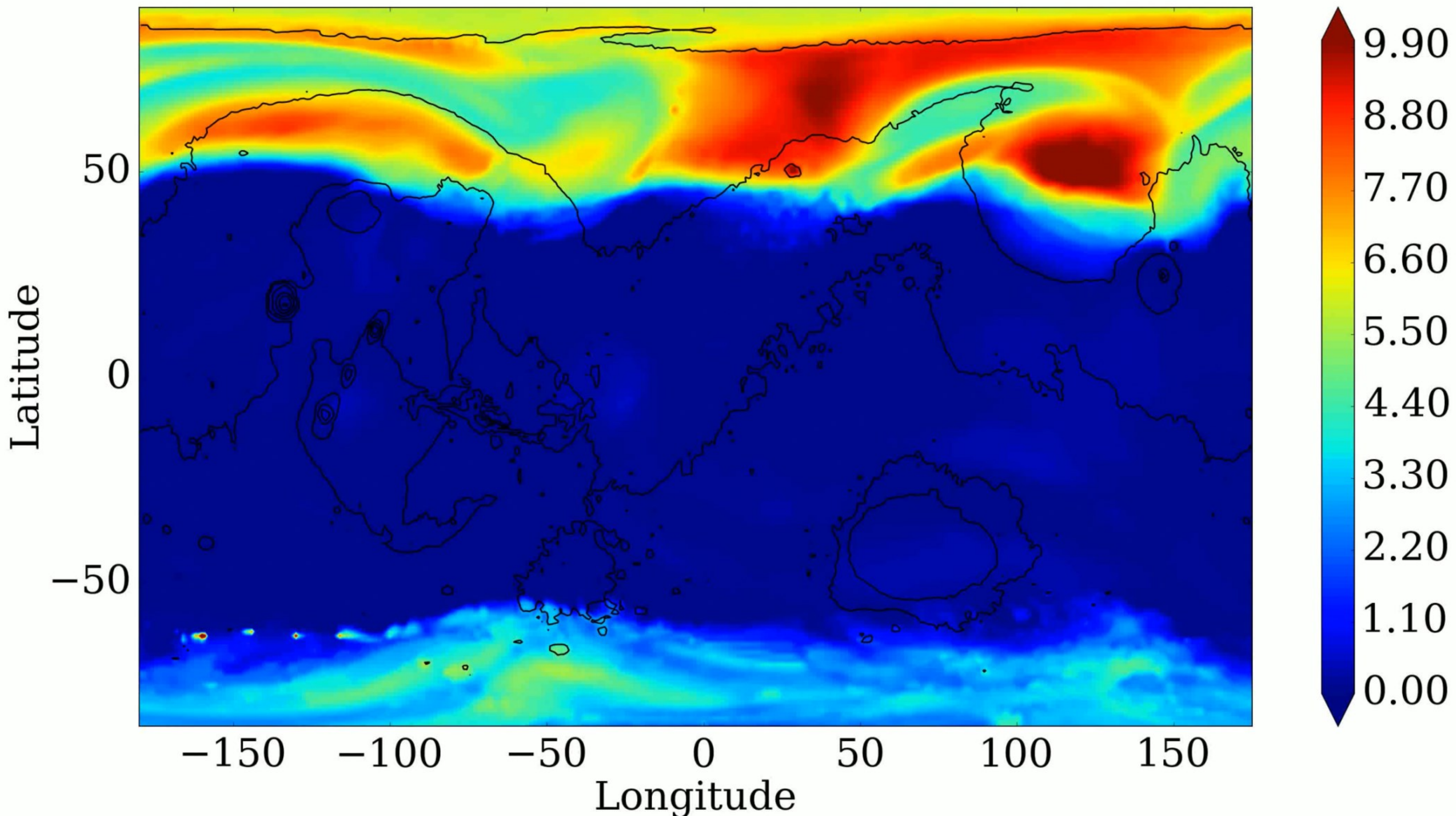
H2O ice clouds (pr-µm) Ls=120°

LMD GCM 1°x1°

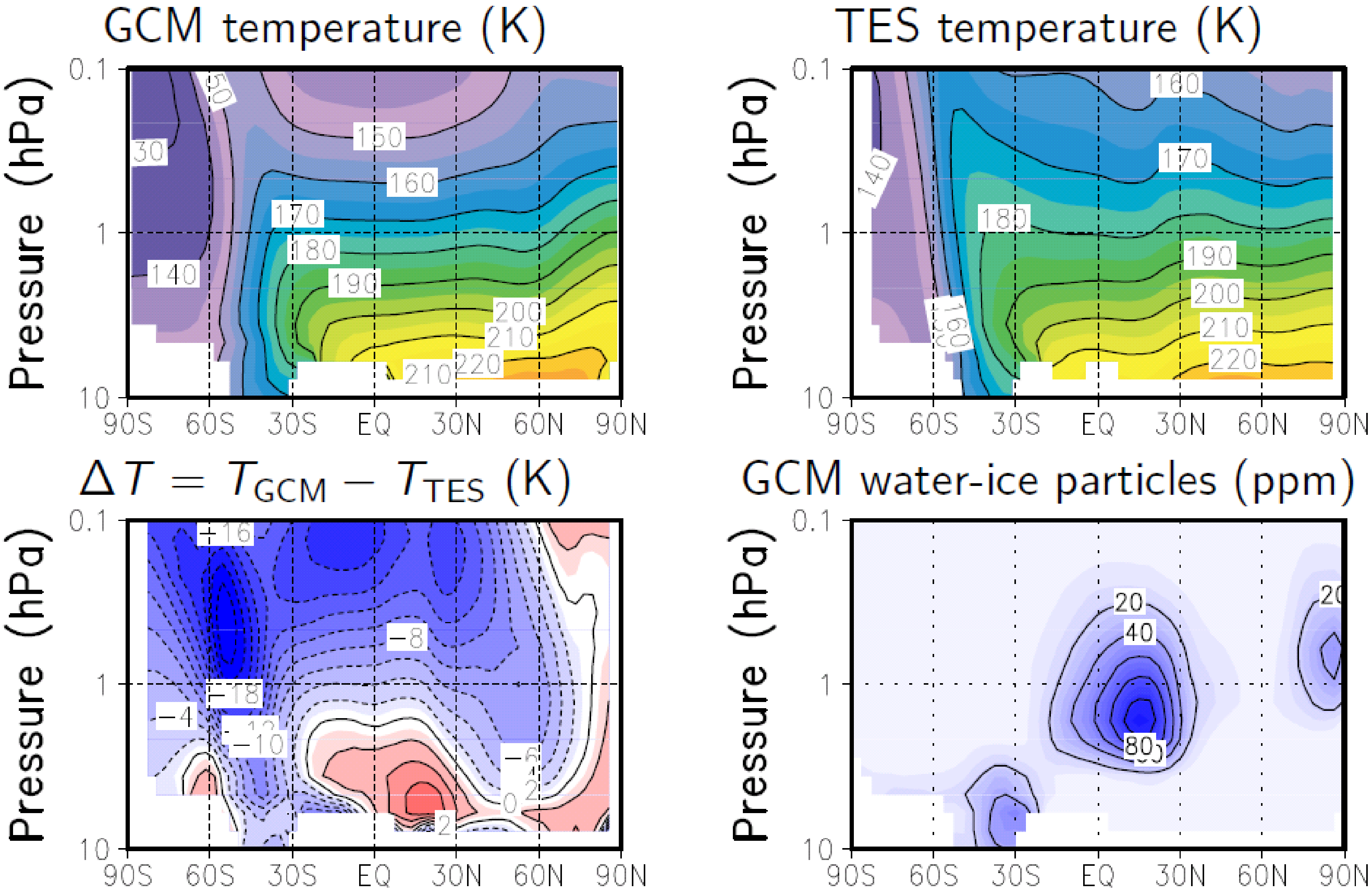


H2O ice clouds (pr-µm) Ls=210°

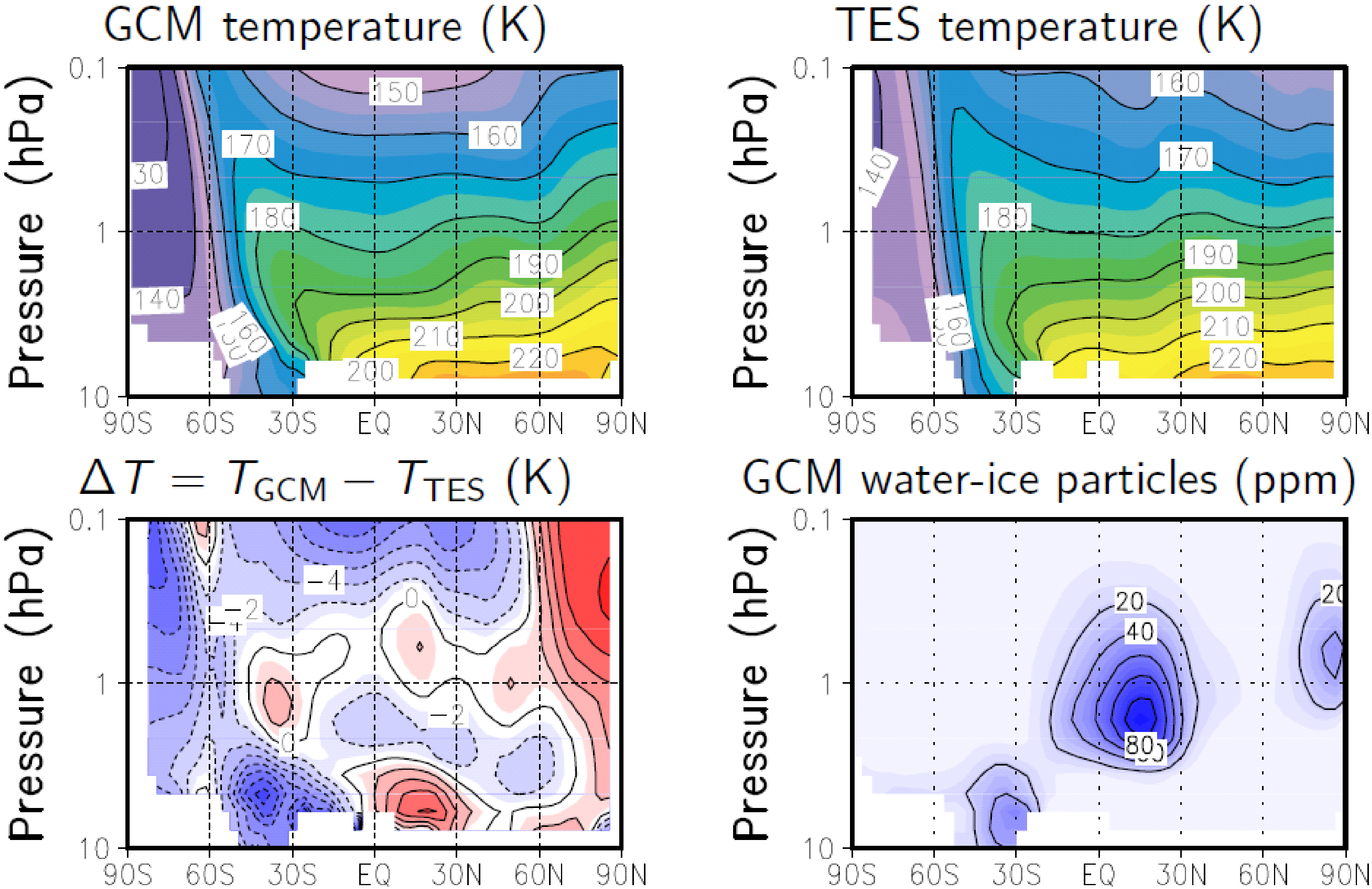
1°x1° GCM



Temperature without active clouds $(L_s = 90°)$



Temperature when clouds are active ($L_s = 90°$)



Radiatively active Water ice clouds in a GCM

Temperatures → **Water vapor** → **Water ice clouds** → **Temperatures**

Destabilizing feedback

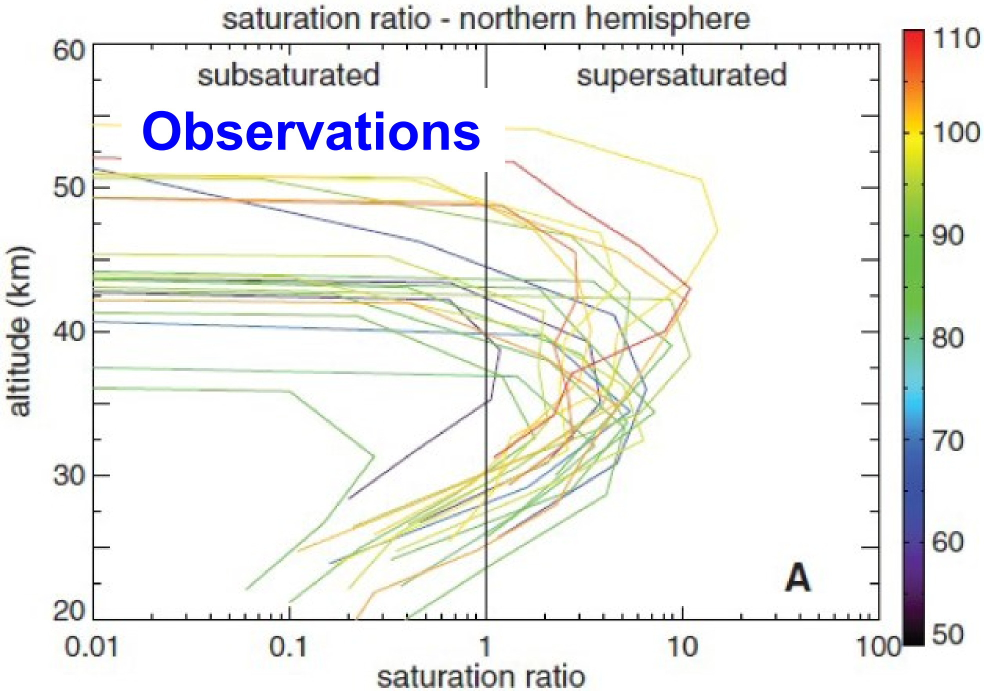
...

Inactive Clouds

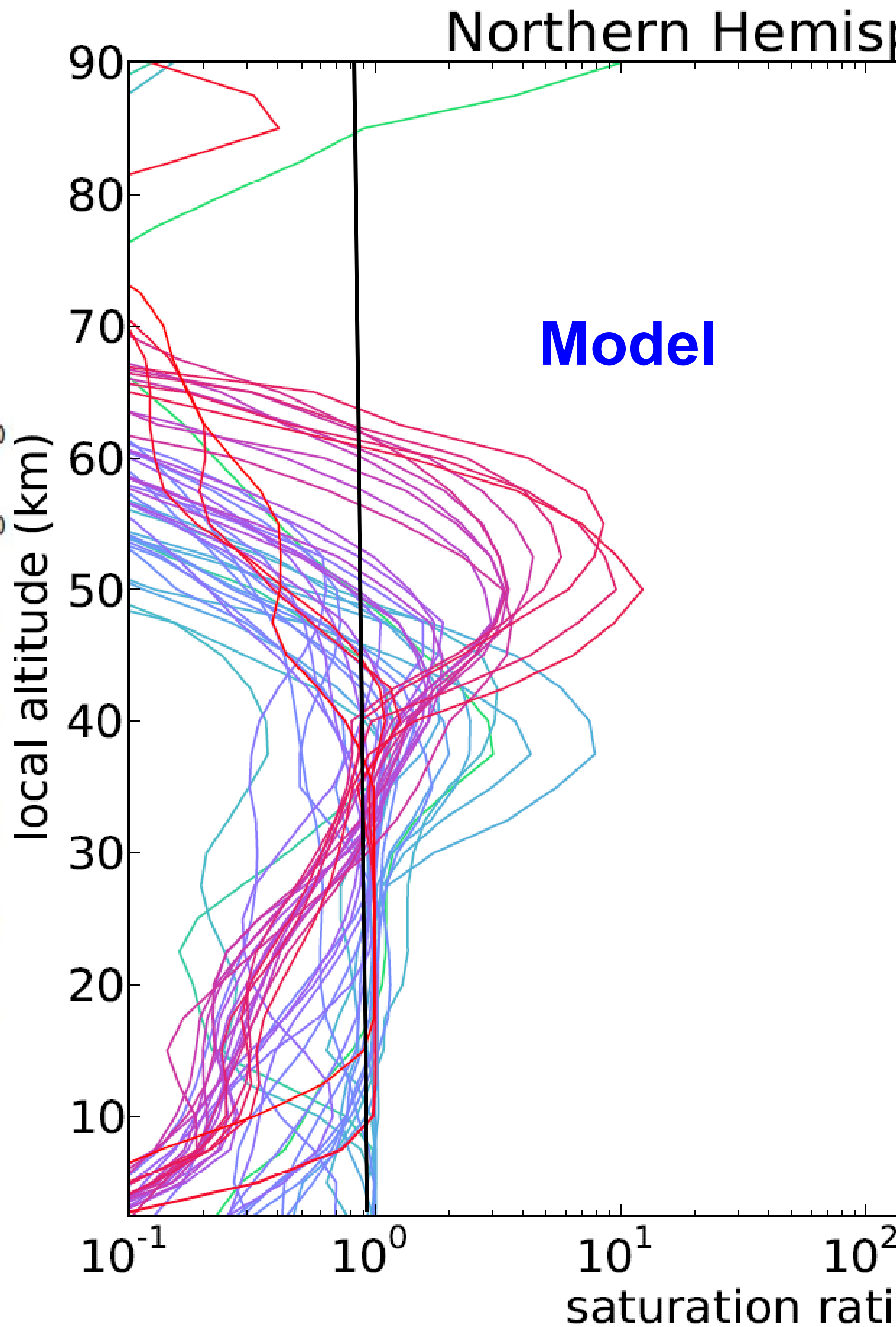
Active Clouds

Illustration off the difficulties ; fromThomas Navarro

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

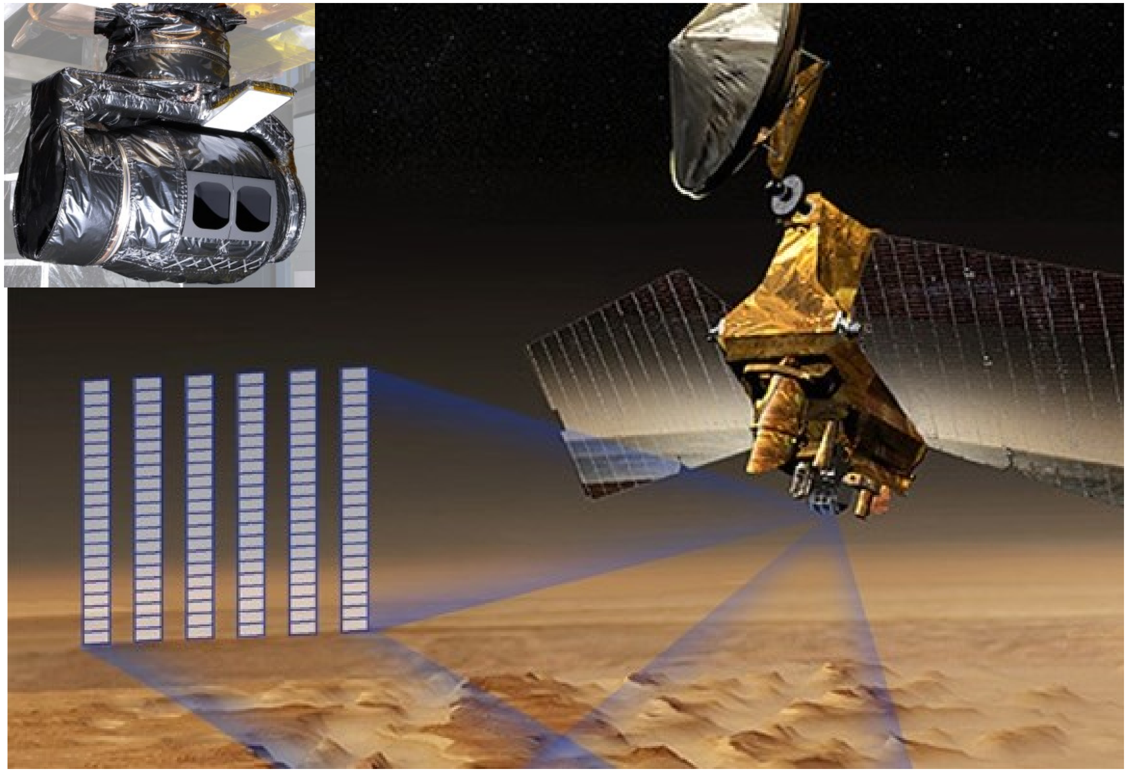


Maltagliati et al. 2011, Science



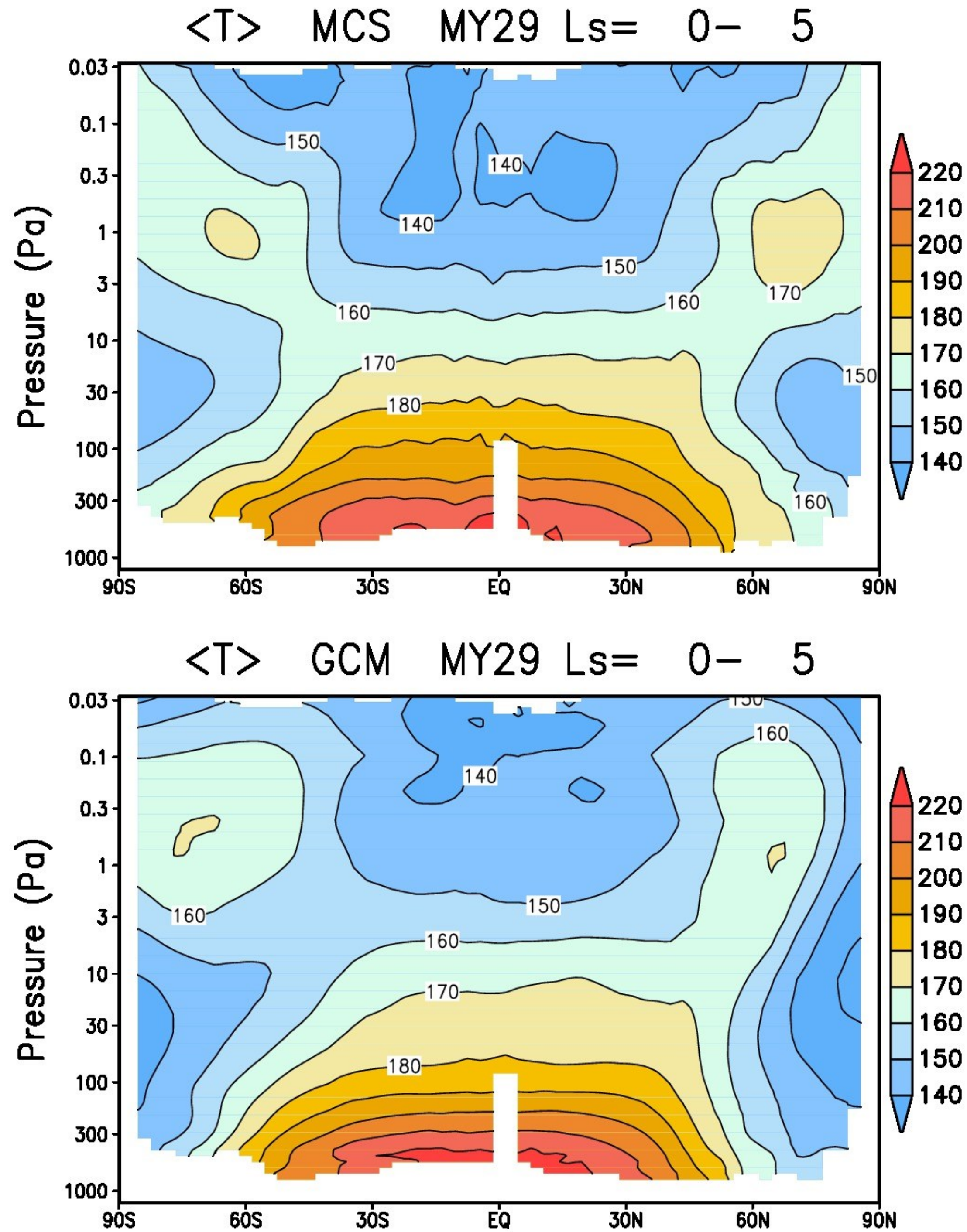
Comparison with Mars Climate Sounder

- Comparison with Binned Mars Climate Sounder data (*Luca Montabone*)
- Bin sizes: Ls: 5° lat: 3° lon 7.5°
- Today : Martian Year 29



Zonal mean temperatures

$\frac{1}{2}$ (Tday + Tnight)



<T> MCS MY29 Ls= 0- 5
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
150
140
140
150
160
160
170
160
170
180
150
160
220
210
200
190
180
170
160
150
140
<T> GCM MY29 Ls= 0- 5
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
160
140
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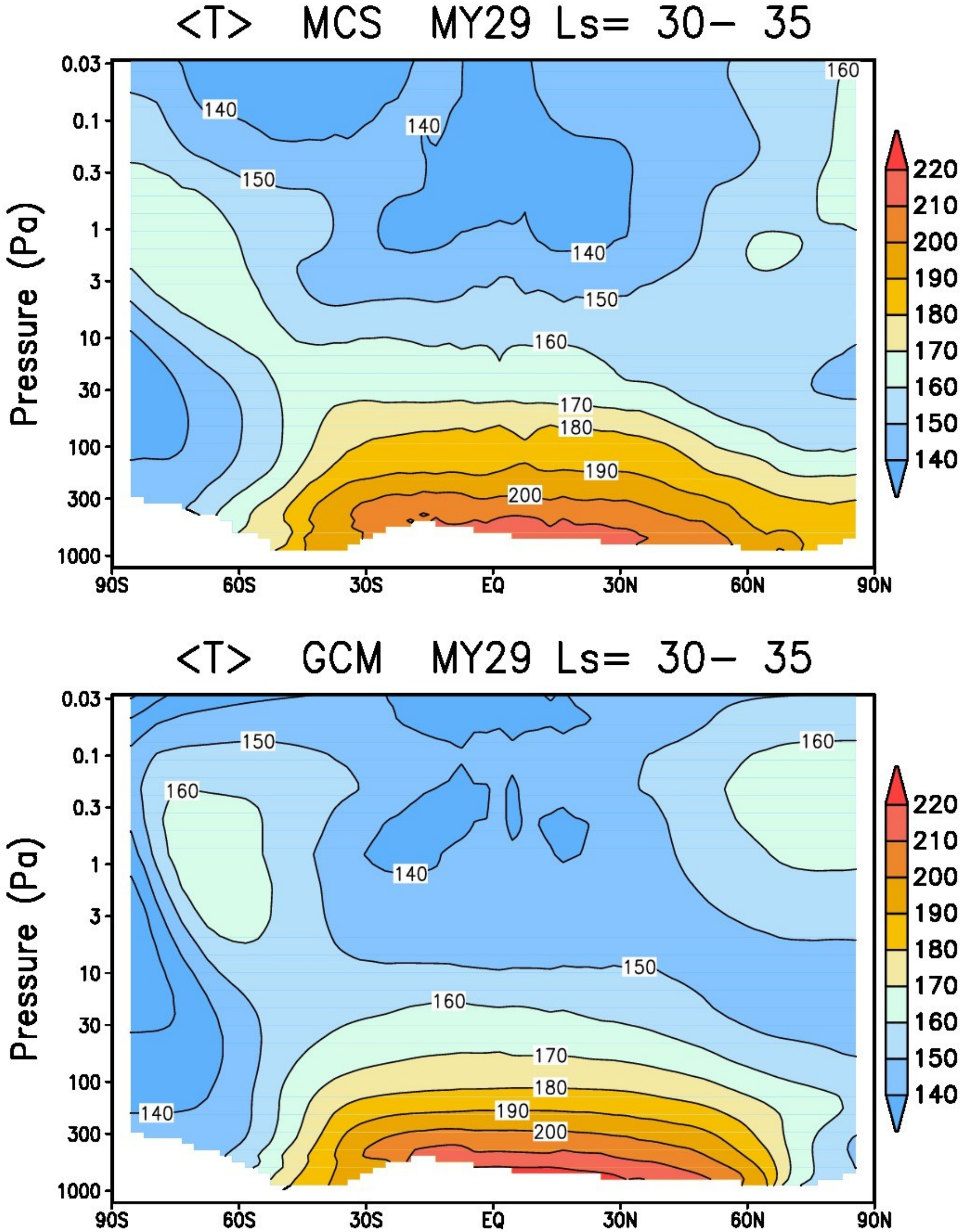
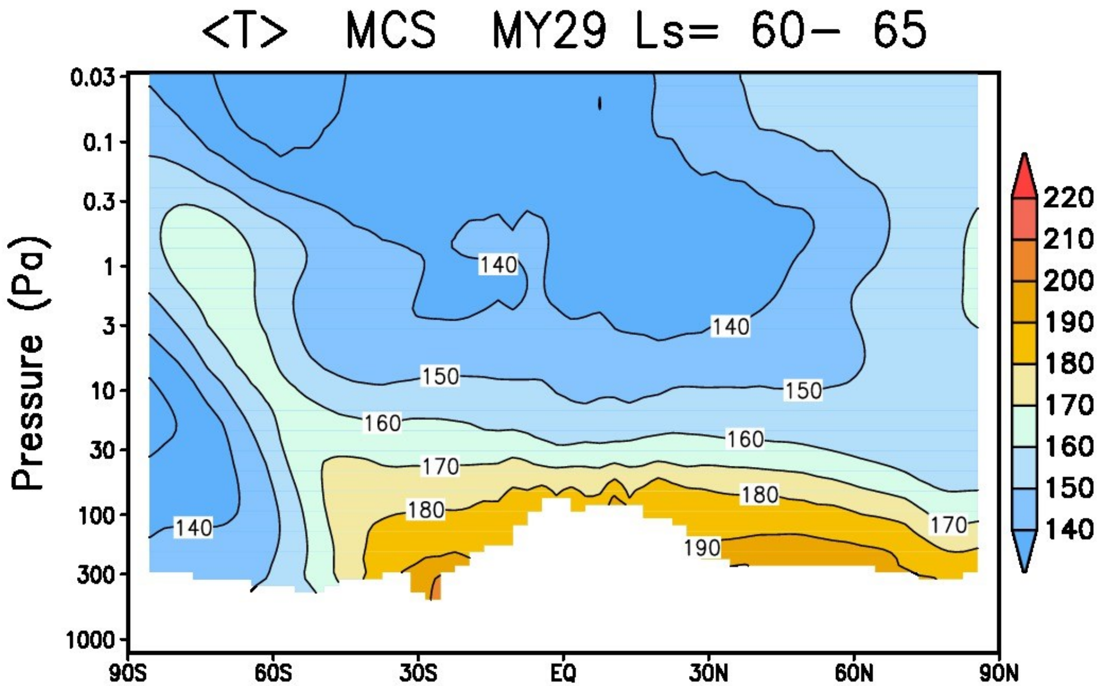
180
170
160
150
140



<T> MCS MY29 Ls= 30- 35
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
150
160
170
180
190
200
210
220
<T> GCM MY29 Ls= 30- 35


<T> MCS MY29 Ls= 60- 65
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
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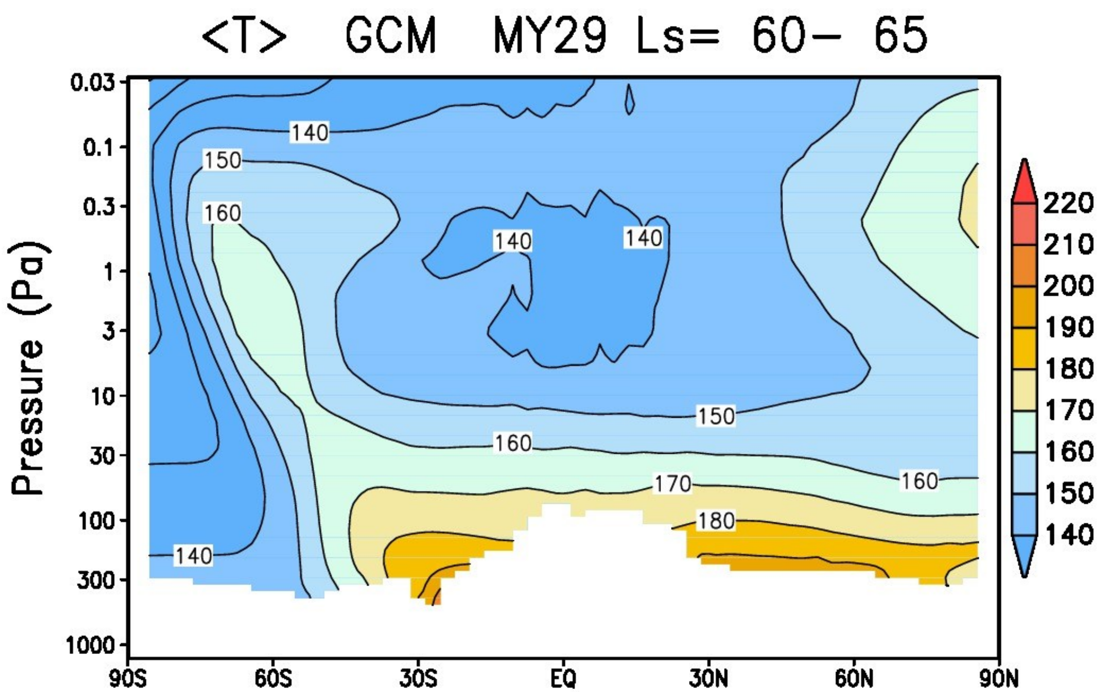
170
160
150
140


<T> GCM MY29 Ls= 60- 65
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
150
160
170
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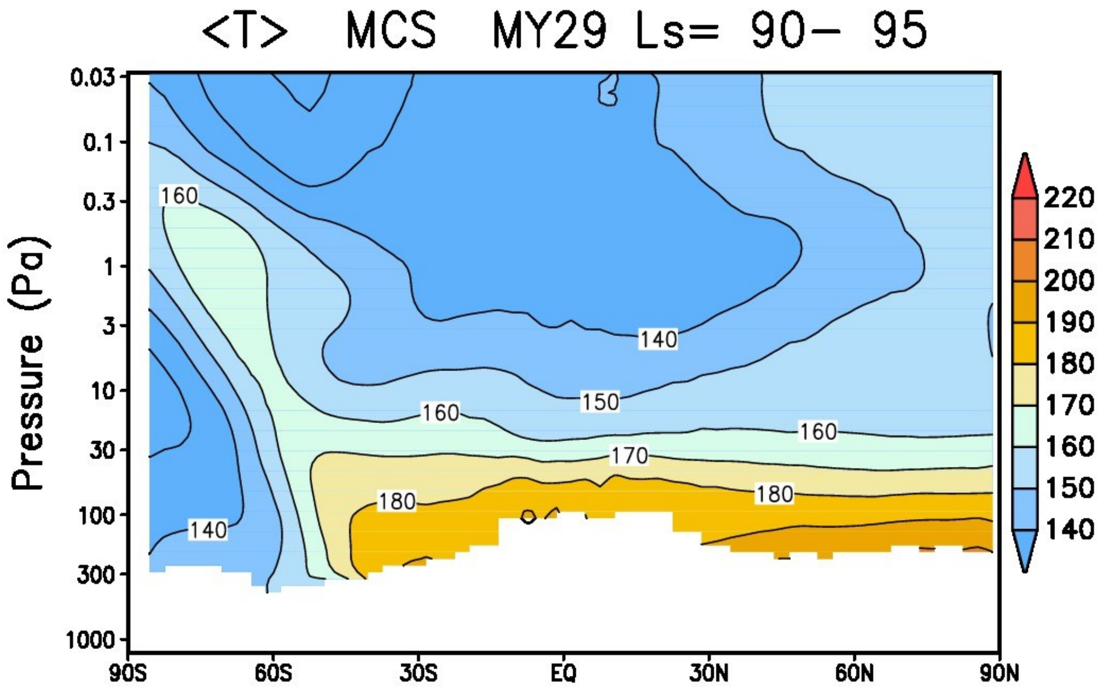
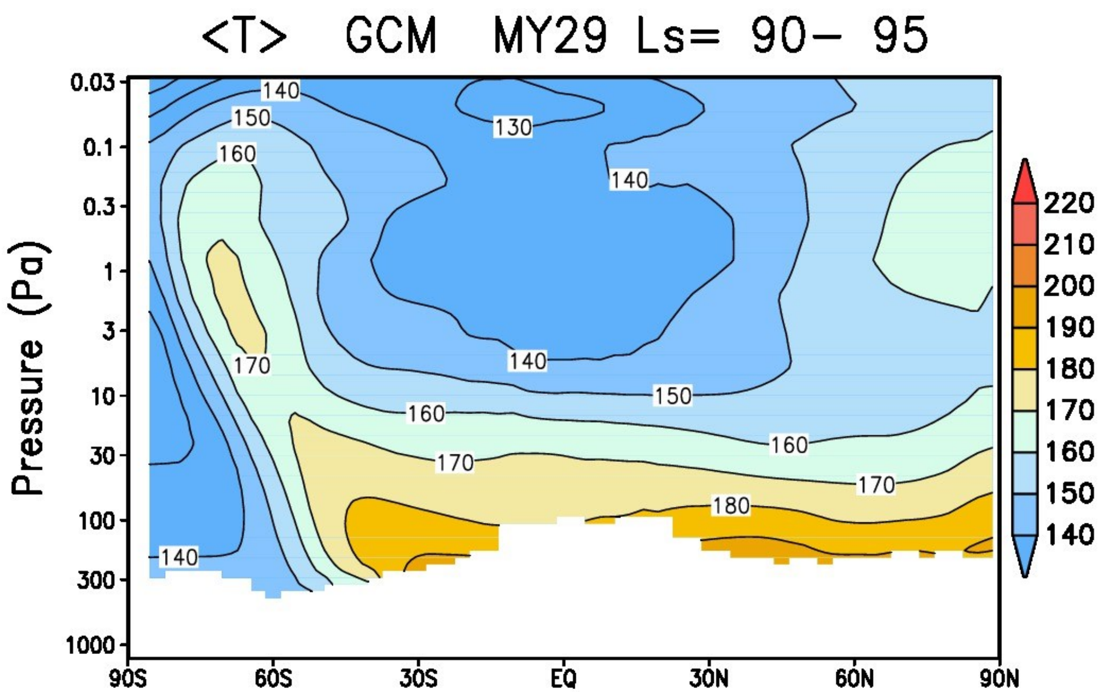
220
210
200
190
180
170
160
150
140


<T> MCS MY29 Ls= 90- 95
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
160
140
150
160
170
180
160
180
140
220
210
200
190
180
170
160
150
140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Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
150
160
130
140
170
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160
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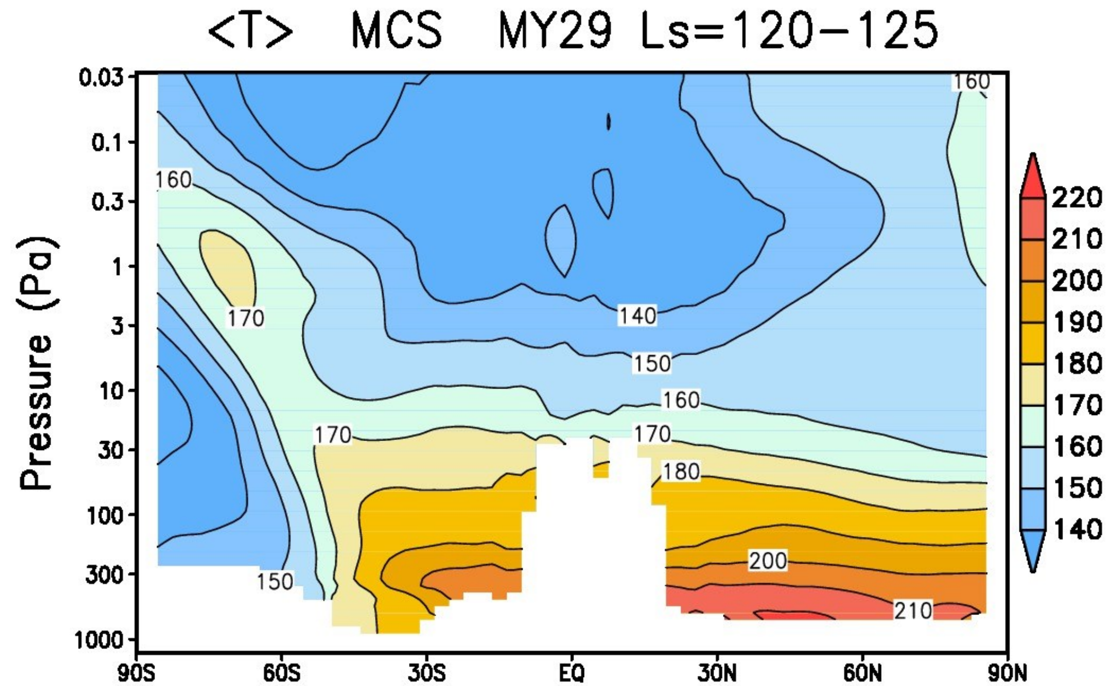
180
170
140
220
210
200
190
180
170
160
150
140


<T> MCS MY29 Ls=120-125
Pressure (Pa)
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1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
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150
220
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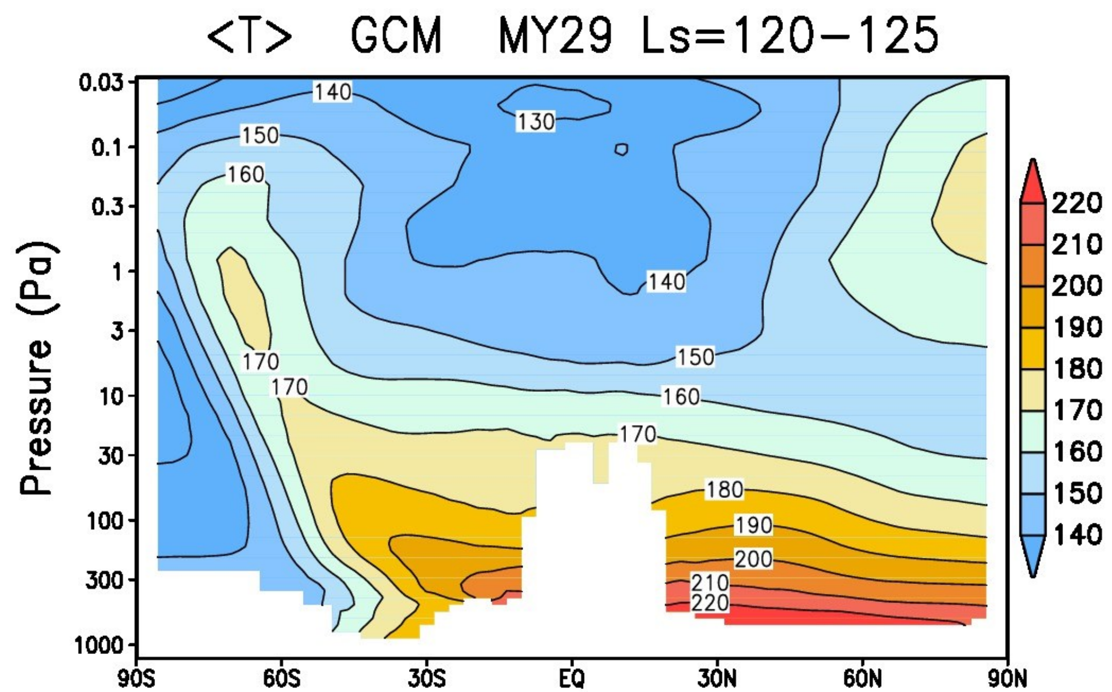
<T> GCM MY29 Ls=120-125
Pressure (Pa)
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0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
130
150
160
140
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150
160
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180
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200
210
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200
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180
170
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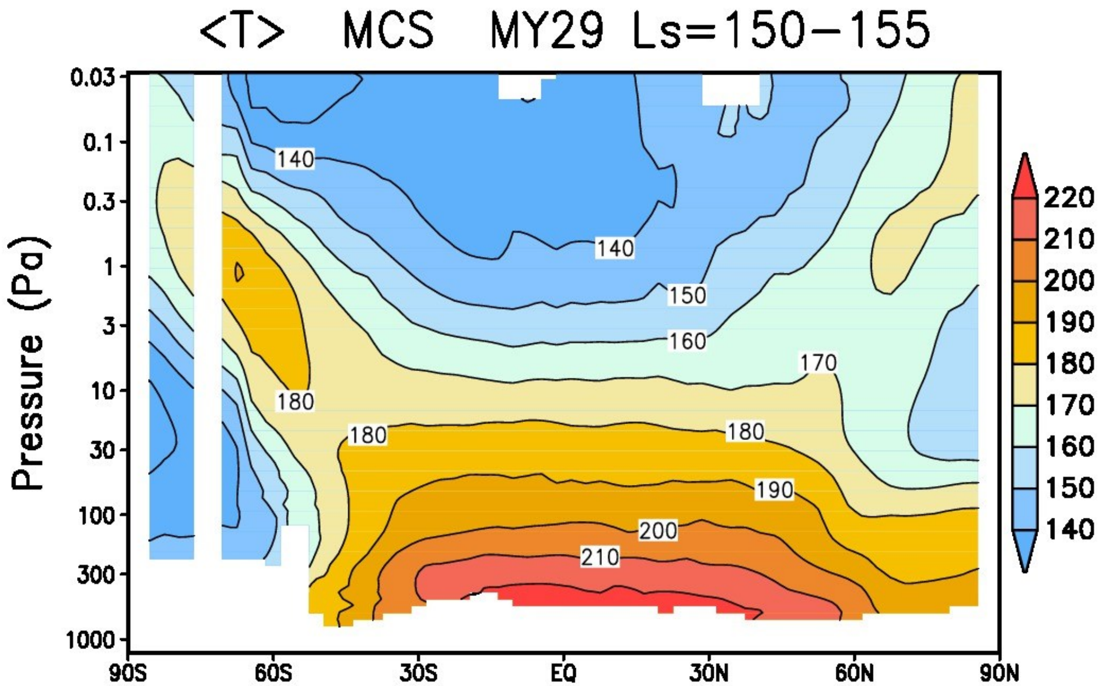
150
140


<T> MCS MY29 Ls=150−155
Pressure (Pa)
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0.3
1
3
10
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100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
140
150
160
170
180
180
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200
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200
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180
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150
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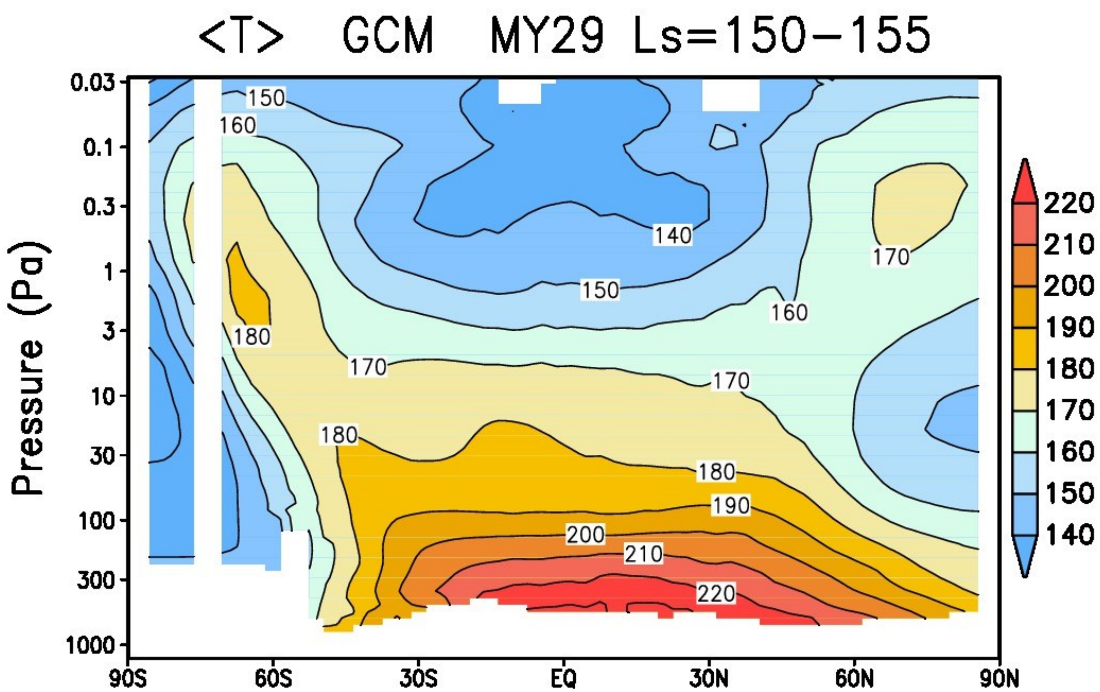
<T> GCM MY29 Ls=150−155
Pressure (Pa)
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0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
150
160
140
170
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180
170
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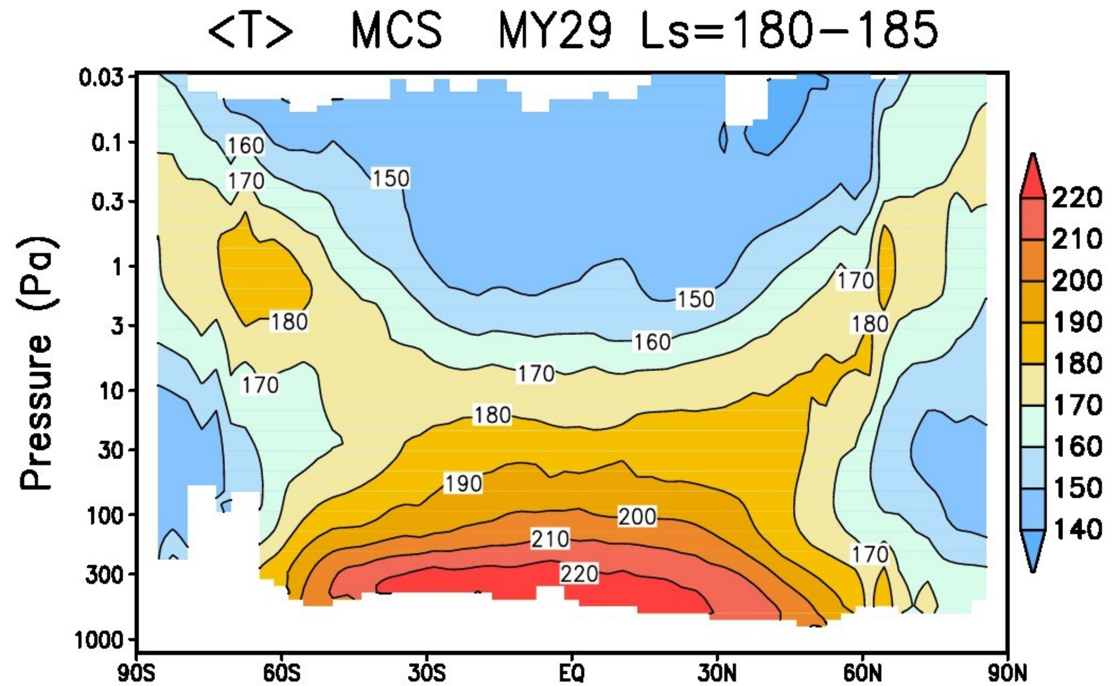
150
140



<T> MCS MY29 Ls=180-185
Pressure (Pa)
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0.1
0.3
1
3
10
30
100
300
1000
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150
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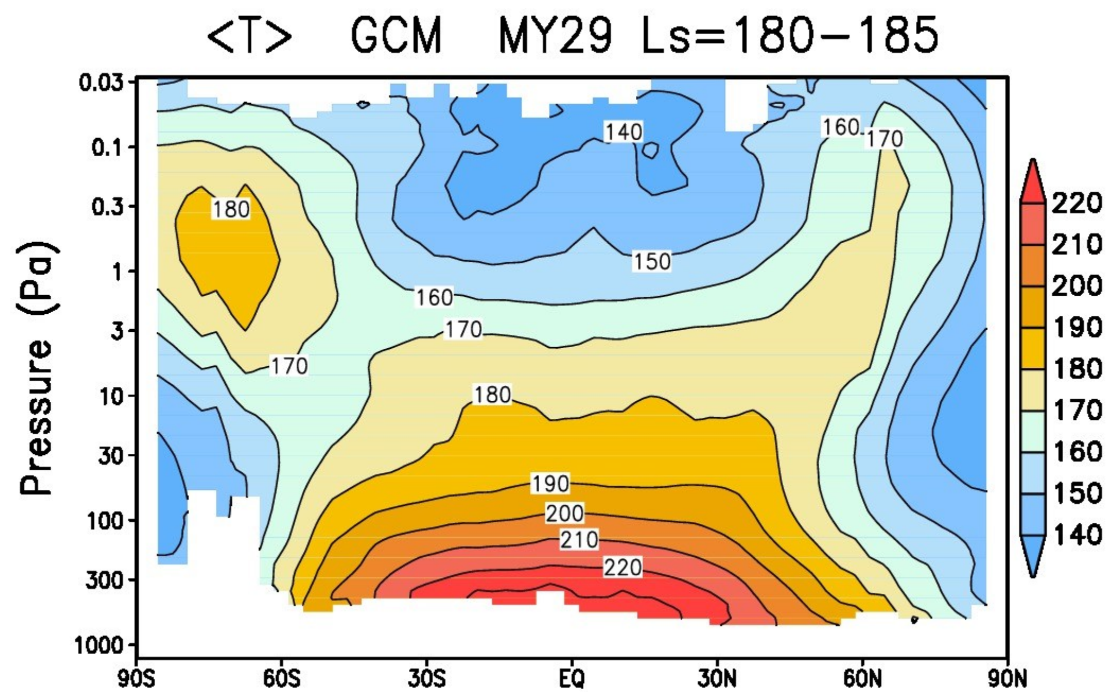

<T> GCM MY29 Ls=180-185
Pressure (Pa)
0.03
0.1
0.3
1
3
10
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100
300
1000
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30S
EQ
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150
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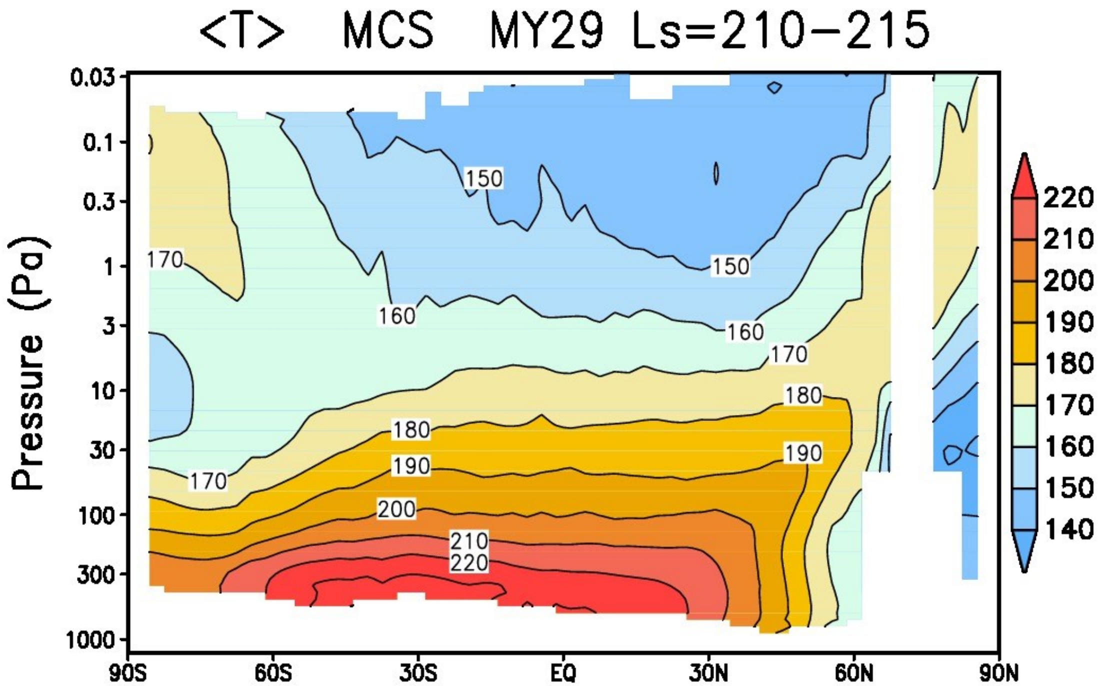
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Pressure (Pa)
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1
3
10
30
100
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1000
90S
60S
30S
EQ
30N
60N
90N
150
160
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180
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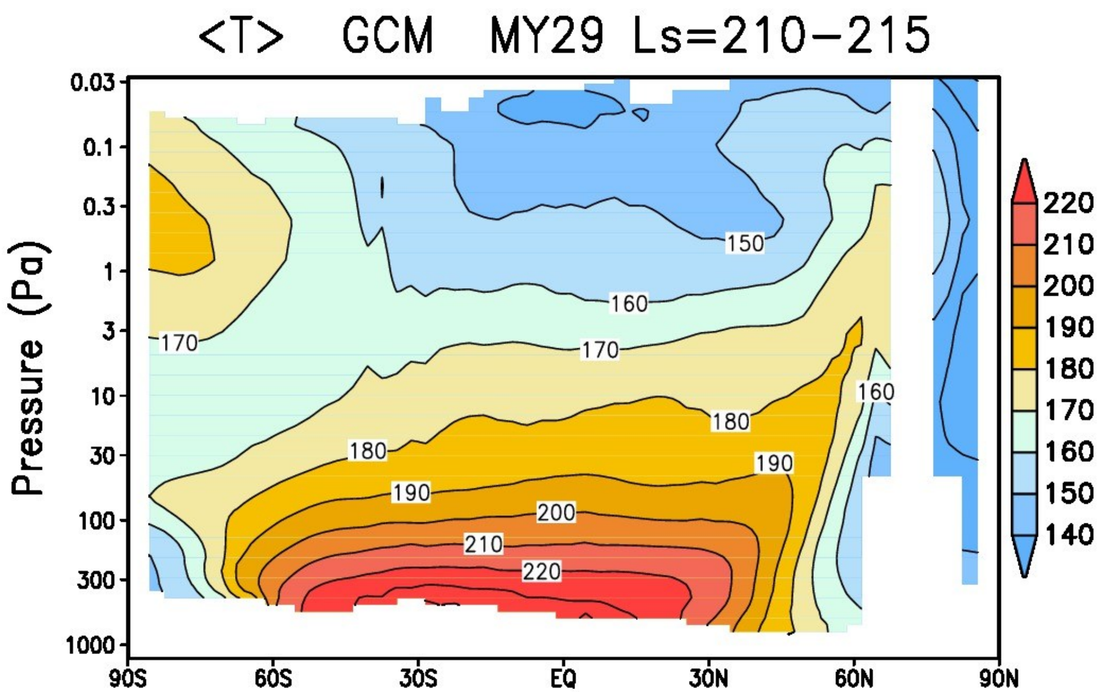
<T> GCM MY29 Ls=210-215
Pressure (Pa)
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0.3
1
3
10
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100
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1000
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200
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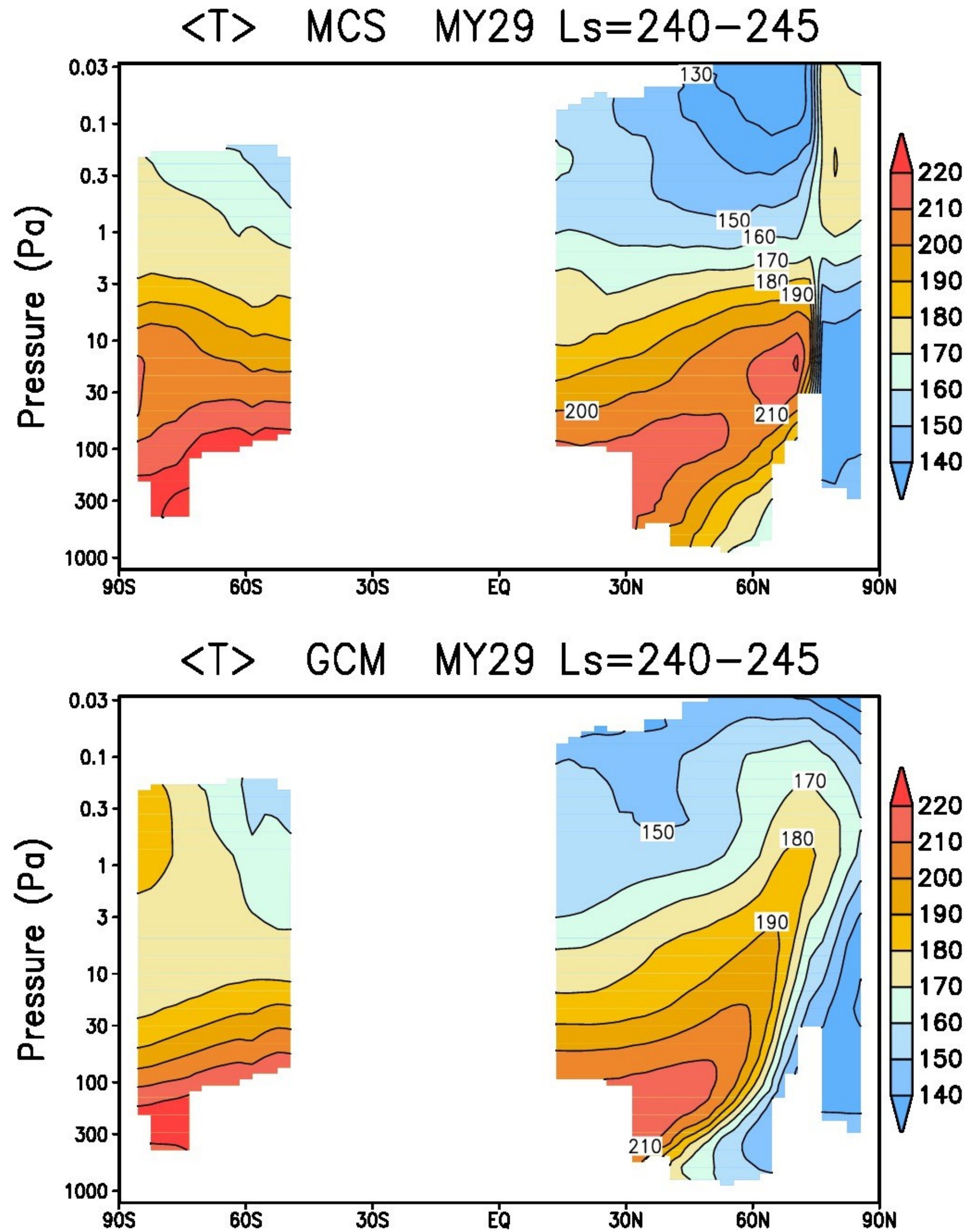
220
140


<T> MCS MY29 Ls=240-245
Pressure (Pa)
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0.3
1
3
10
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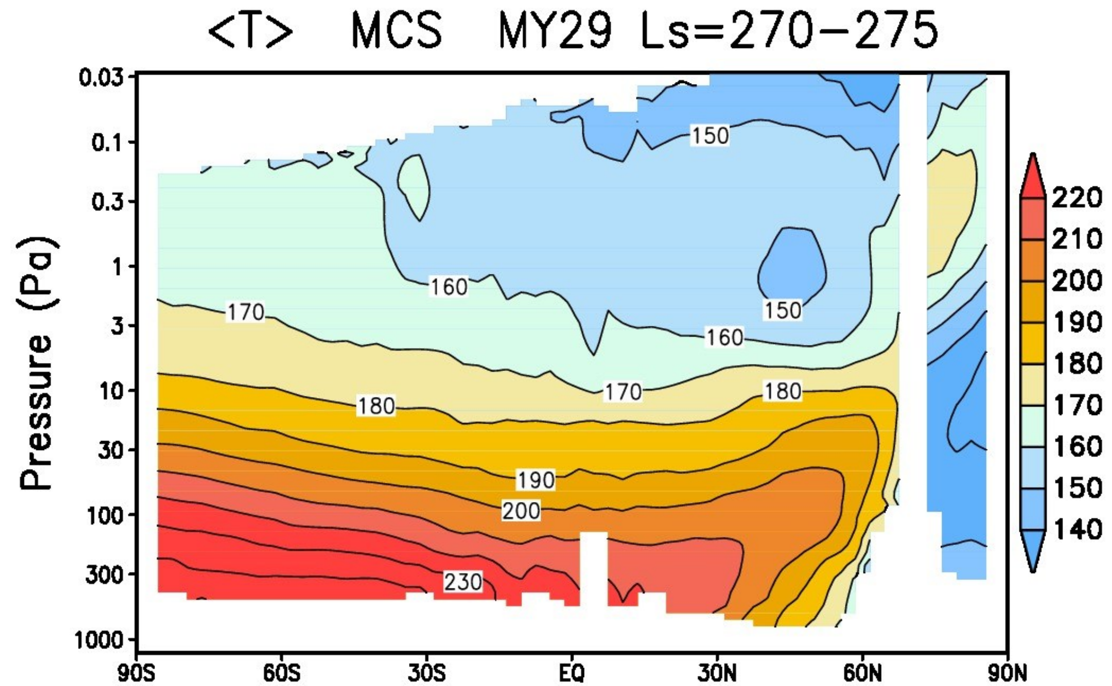
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
130
150
160
170
180
190
200
210
220
140
<T> GCM MY29 Ls=240-245
Pressure (Pa)
150
170
180
190
210


<T> MCS MY29 Ls=270-275
Pressure (Pa)
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0.3
1
3
10
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100
300
1000
90S
60S
30S
EQ
30N
60N
90N
150
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170
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150
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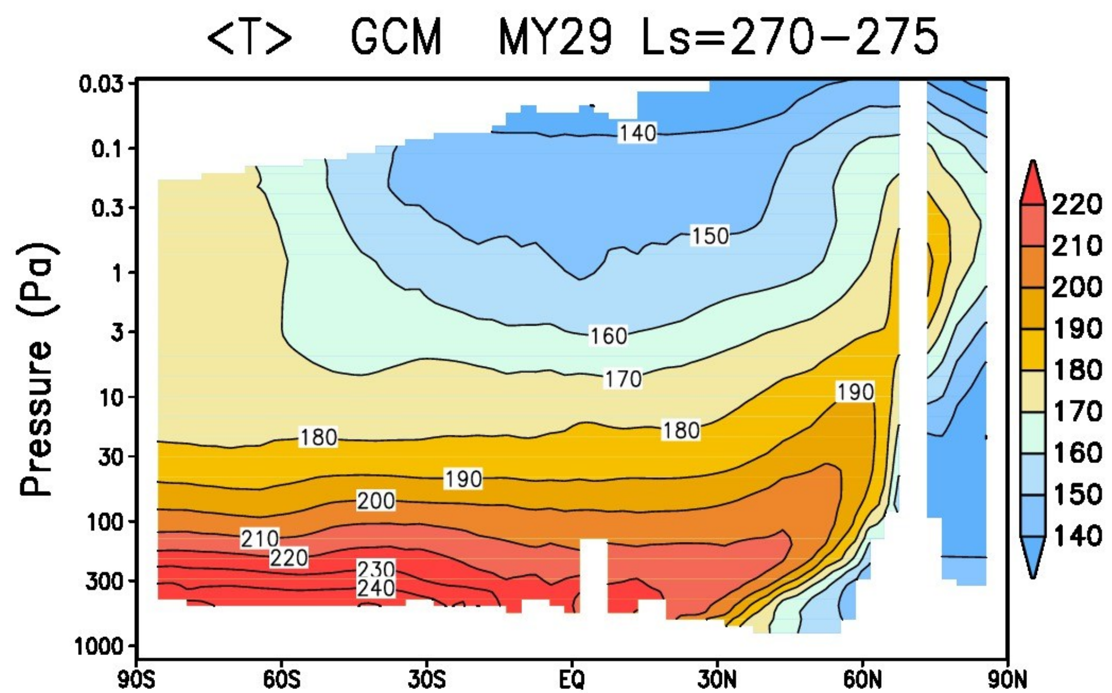
<T> GCM MY29 Ls=270-275
Pressure (Pa)
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0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
140
150
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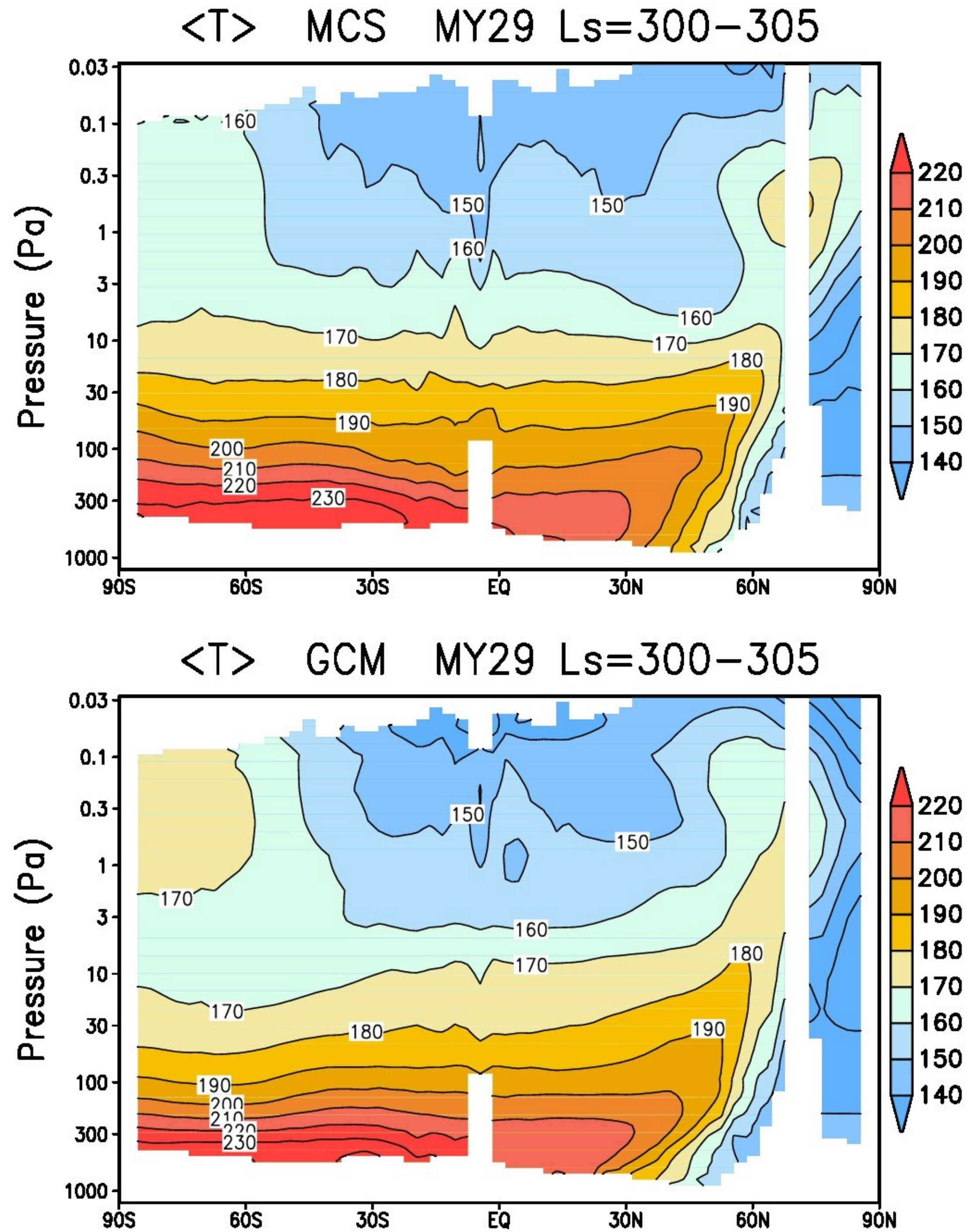
180
170
160
150
140


<T> MCS MY29 Ls=300-305
Pressure (Pa)
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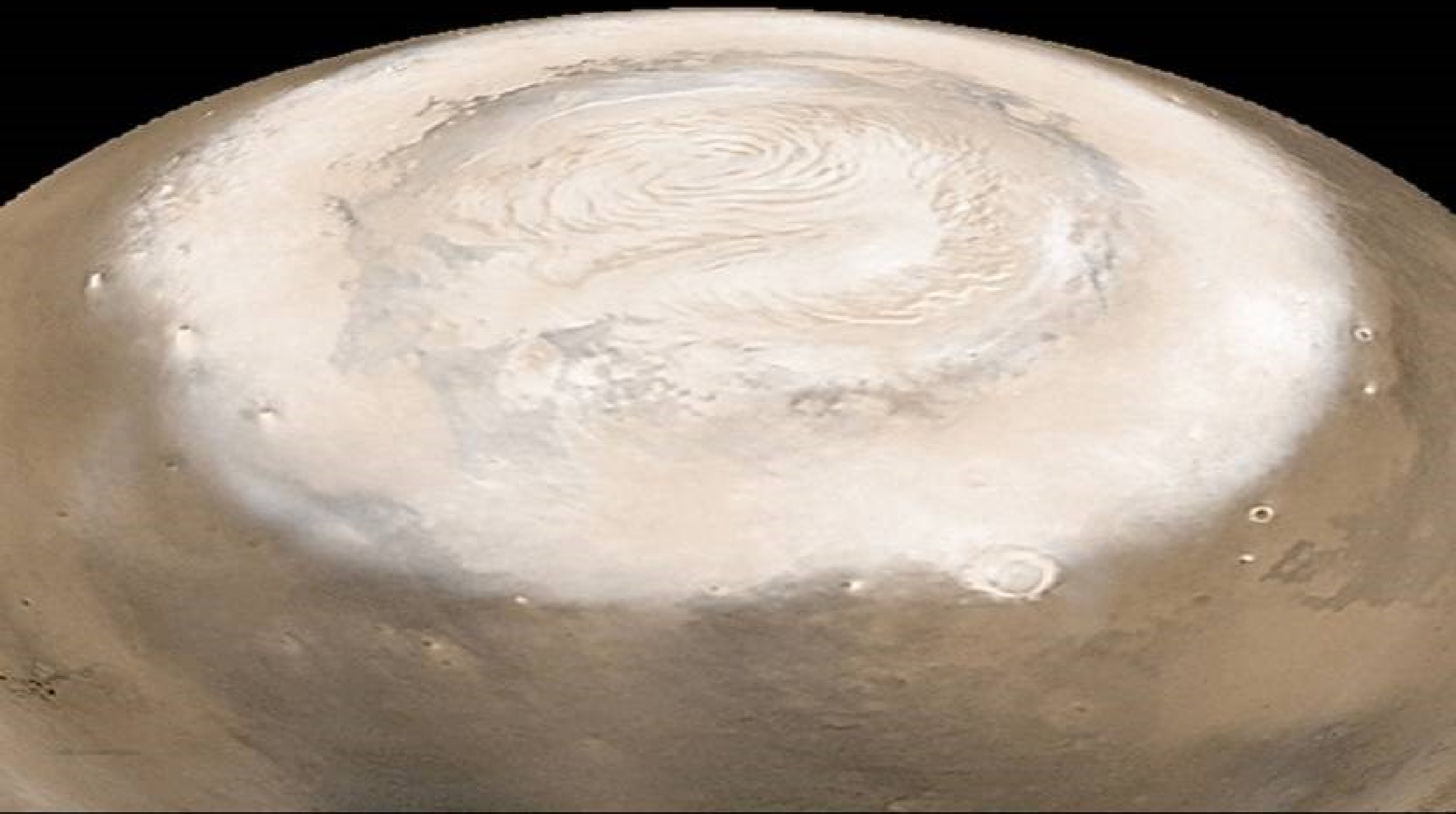
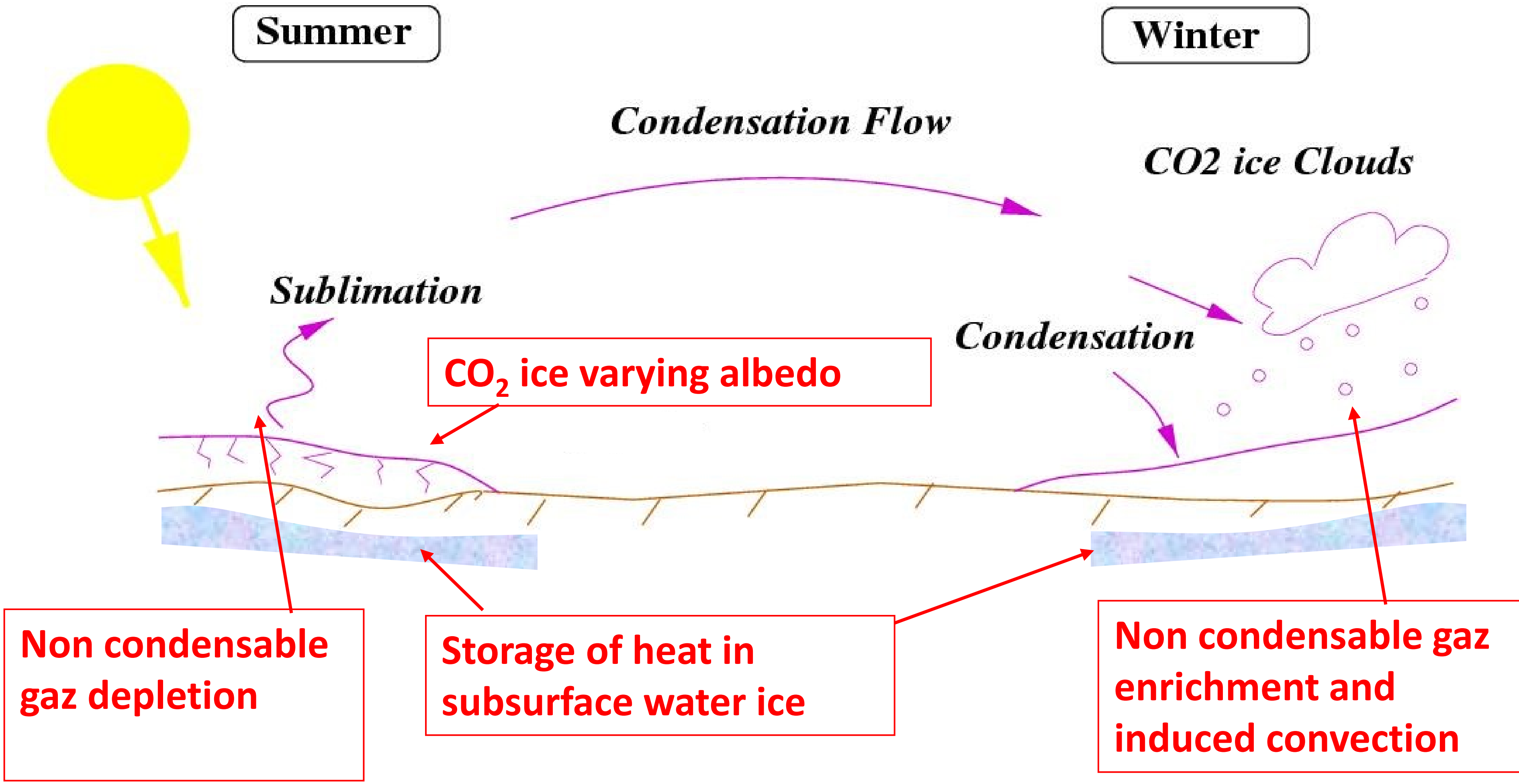
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
160
150
150
160
160
170
170
180
180
190
190
200
210
220
230
220
210
200
190
180
170
160
150
140
<T> GCM MY29 Ls=300-305
Pressure (Pa)
0.03
0.1
0.3
1
3
10
30
100
300
1000
90S
60S
30S
EQ
30N
60N
90N
150
150
170
160
170
180
170
180
190
190
200
210
230
220
210
200
190
180
170
160
150
140

CO_2 cycle

Seasonal CO2 ice cap in spring (mosaic)

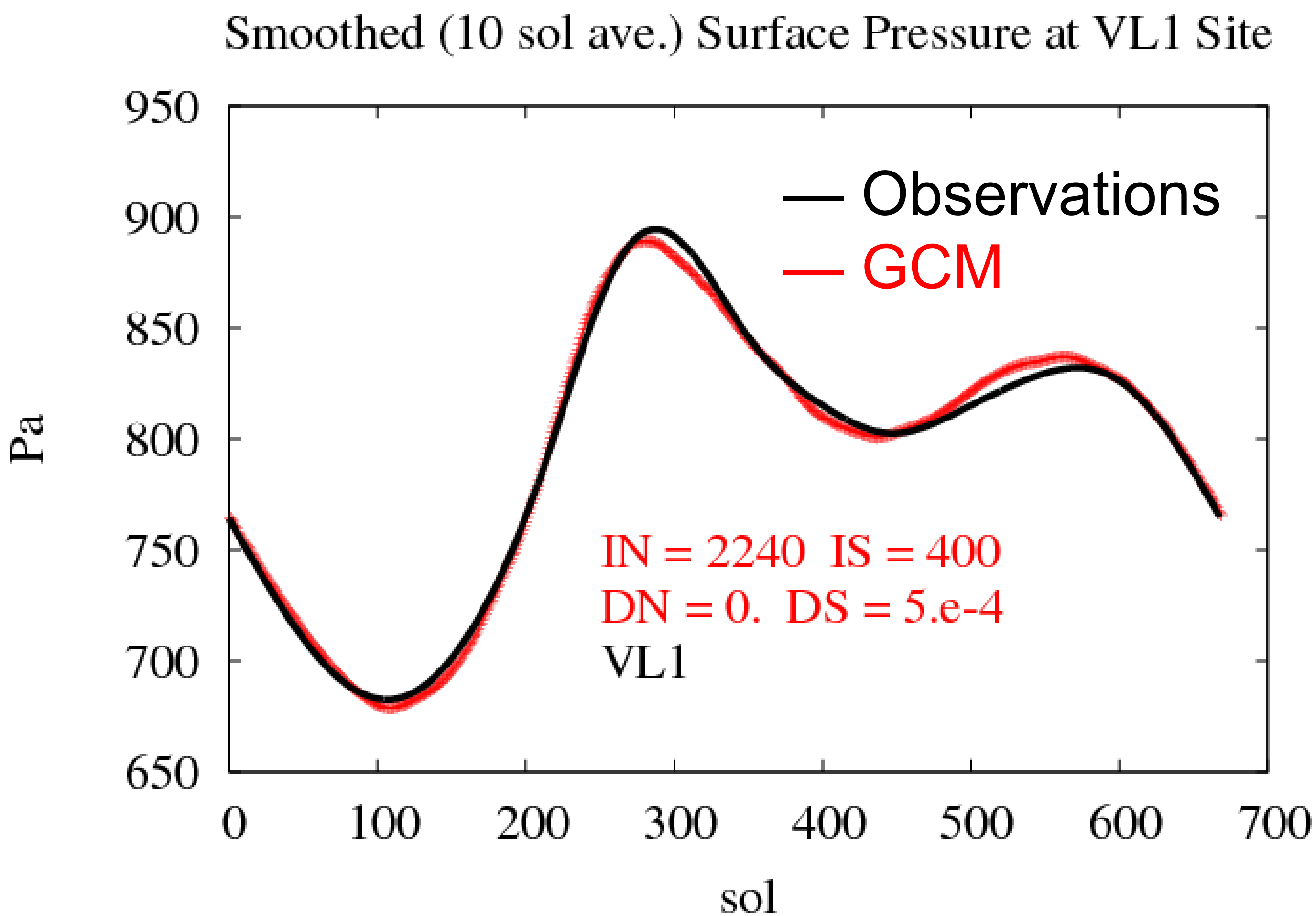


CO_2 cycle in the LMD GCM

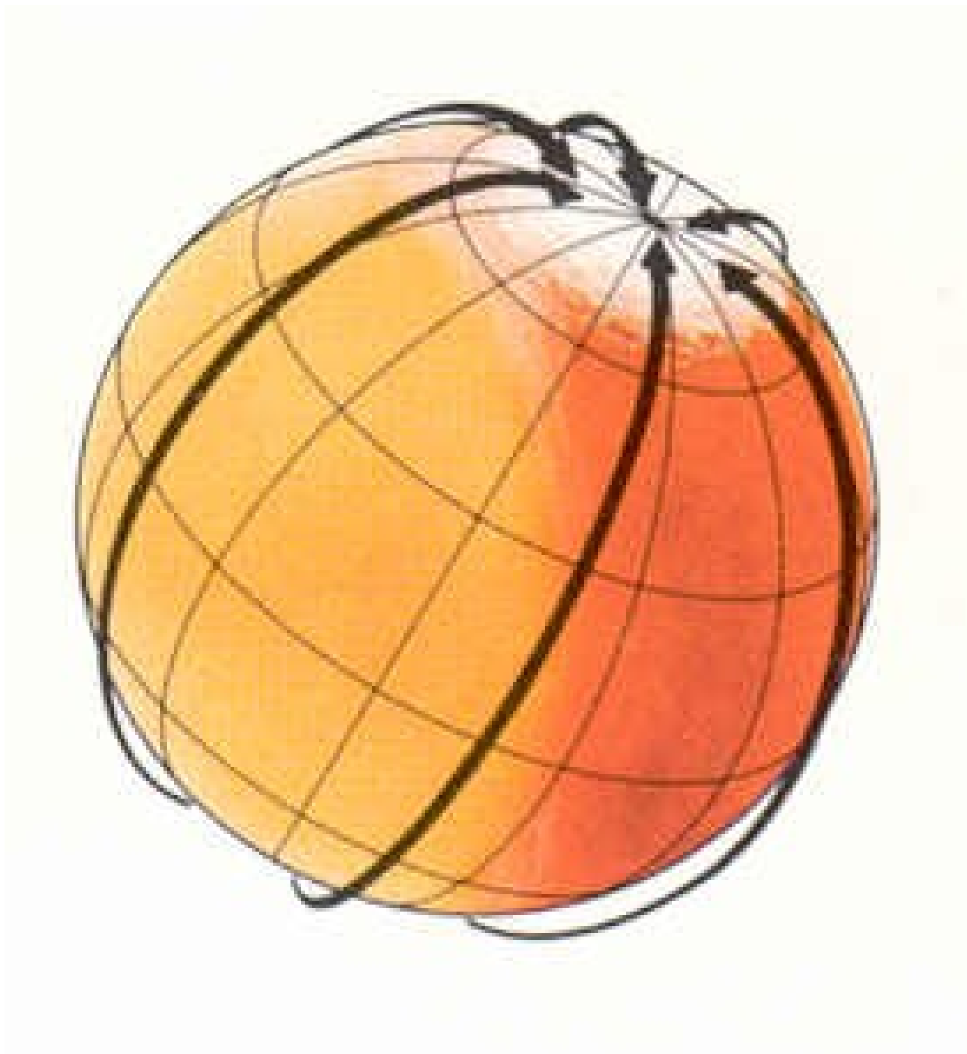


Modelling Surface pressure variations (GCM v5)

Fitting Viking Lander 1 pressure measurements
with subsurface ice depth driven by Mars Odyssey Neutron Spectrometer ice depth measurements
(adjusting dry layer properties and subsurface ice thermal inertia)

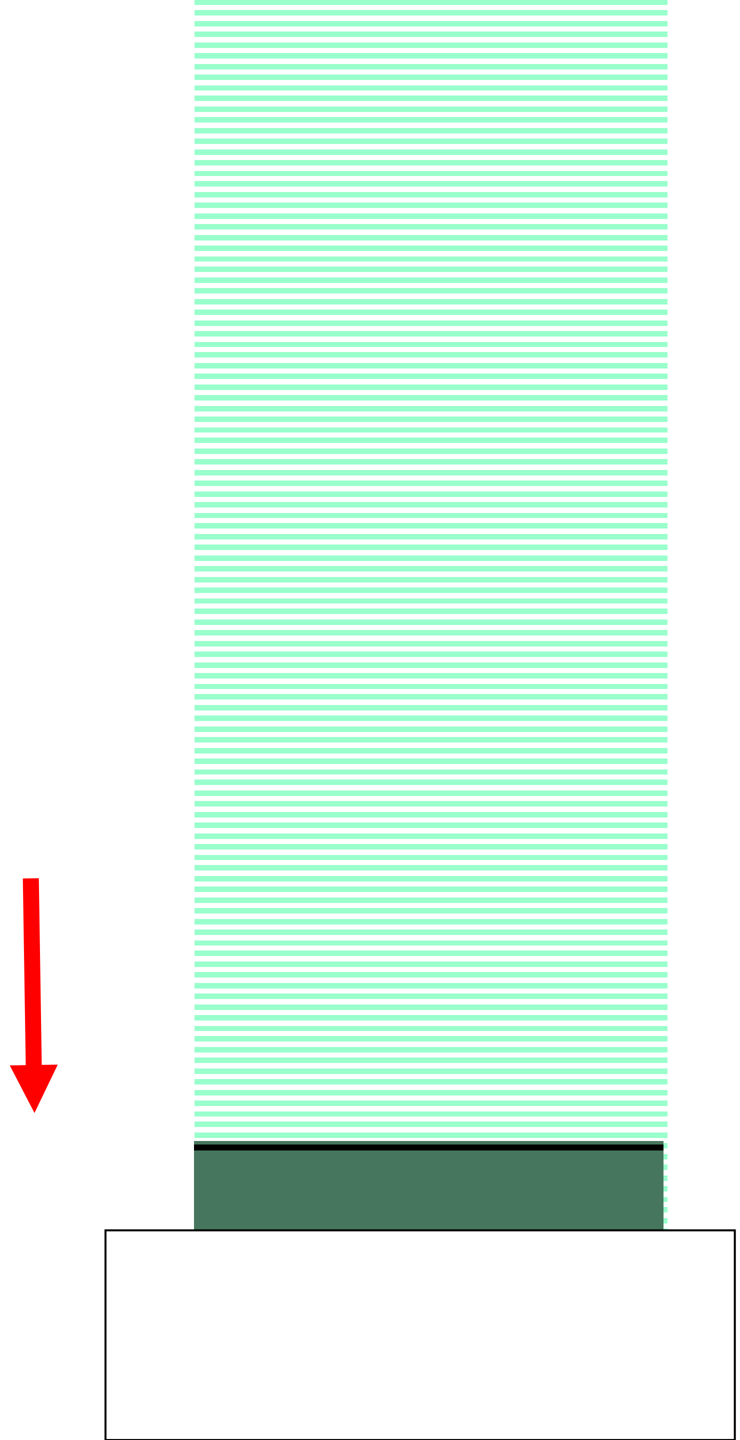


Condensation flow induced by CO2 cycle

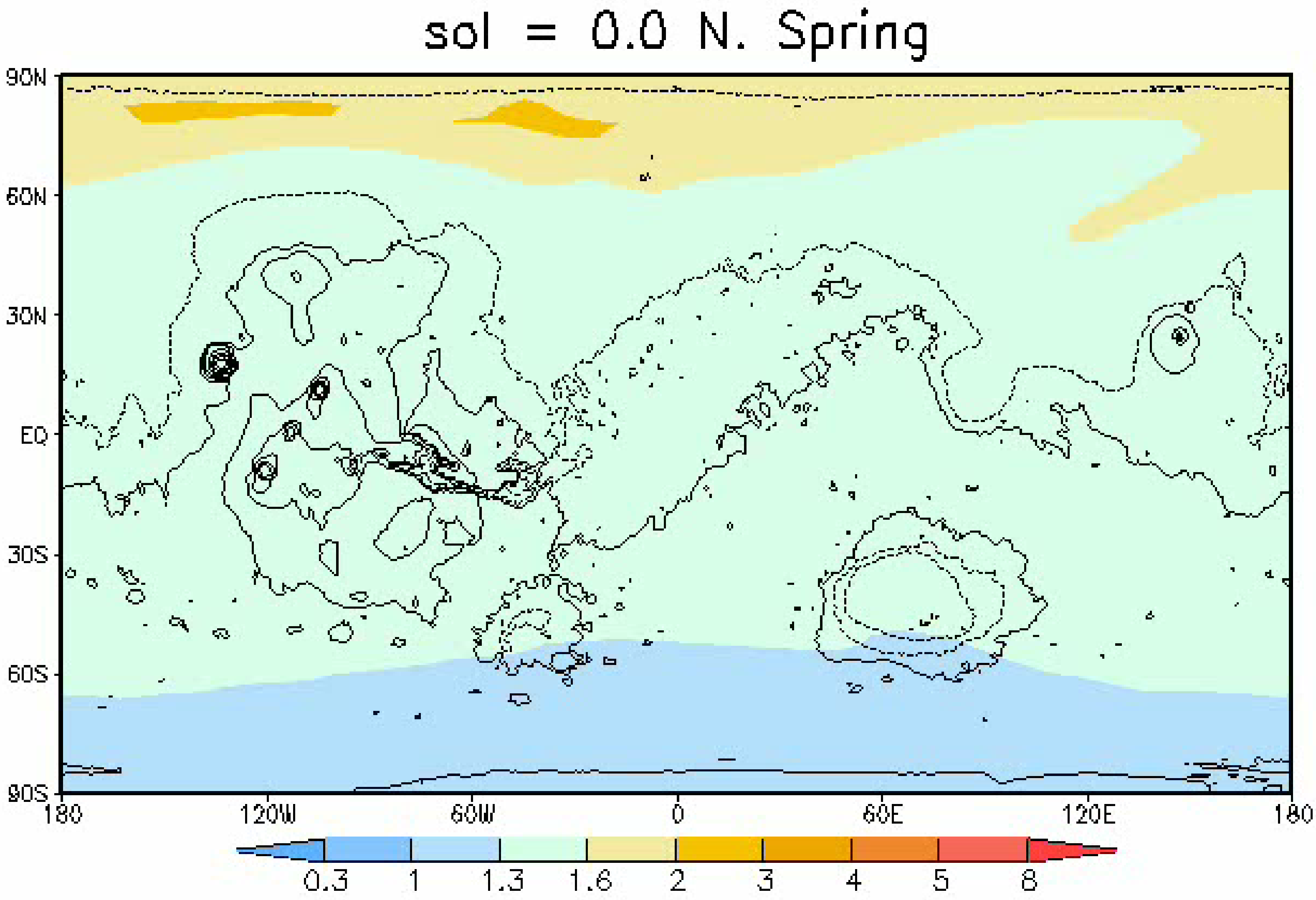


Surface condensation of CO_2

Near Surface enrichment of other gases

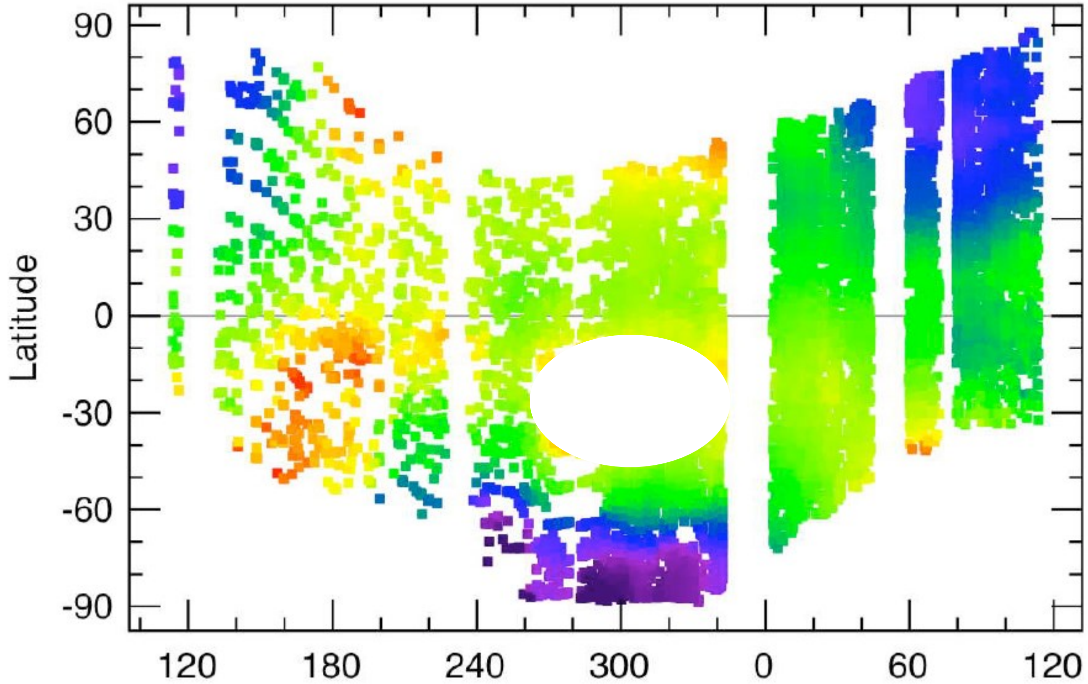


Argon column averaged mixing ratio (%)

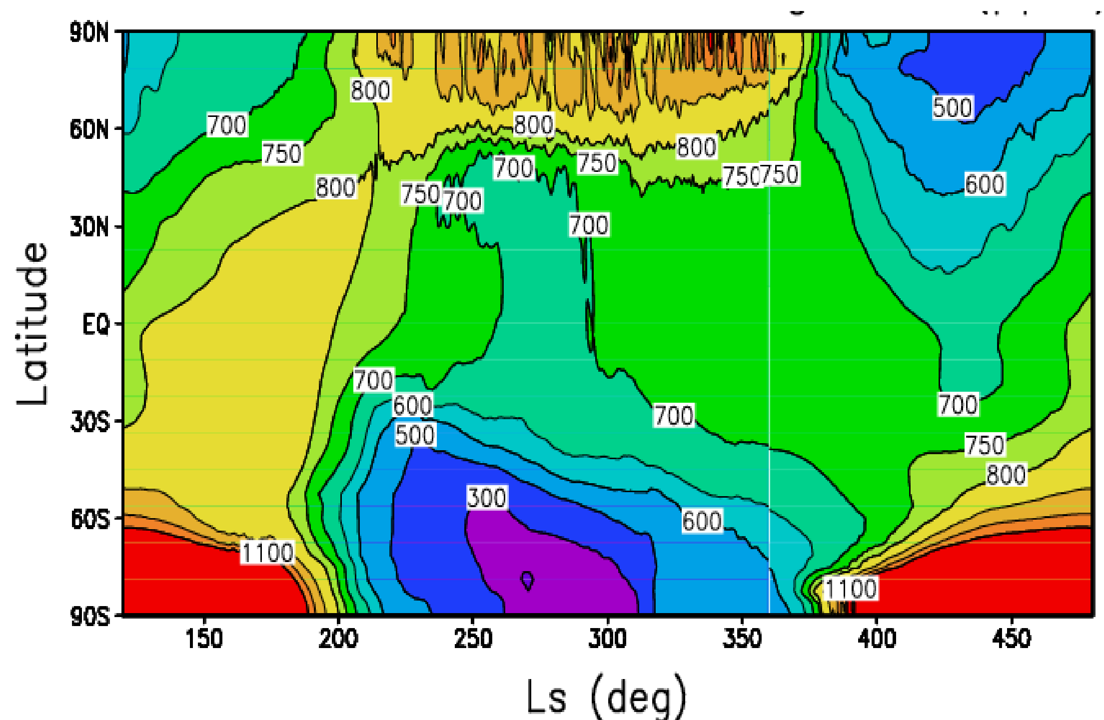


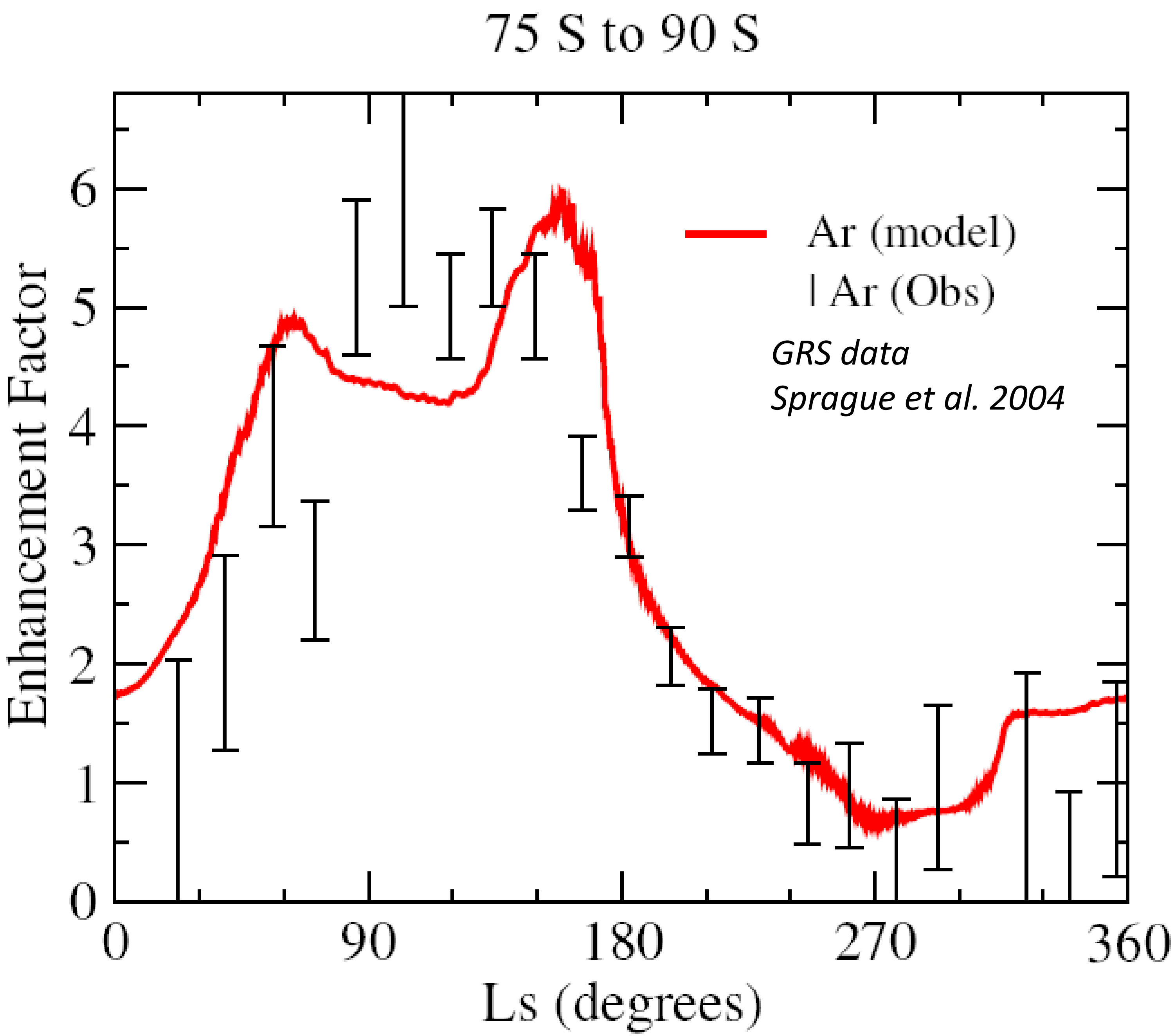
Observation of CO by CRISM (ppm)
(Mike Smith 2008)

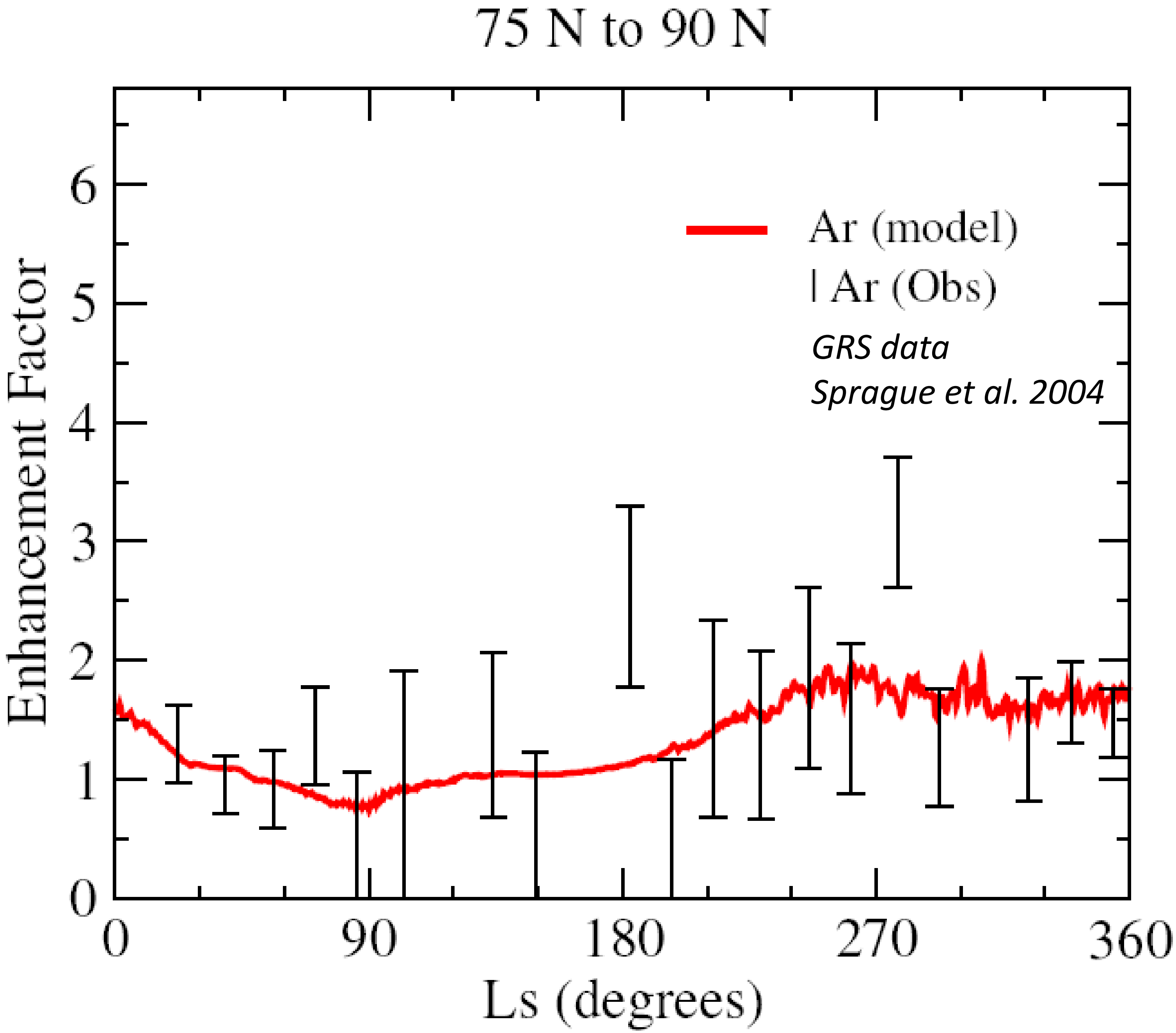
Observations



Model

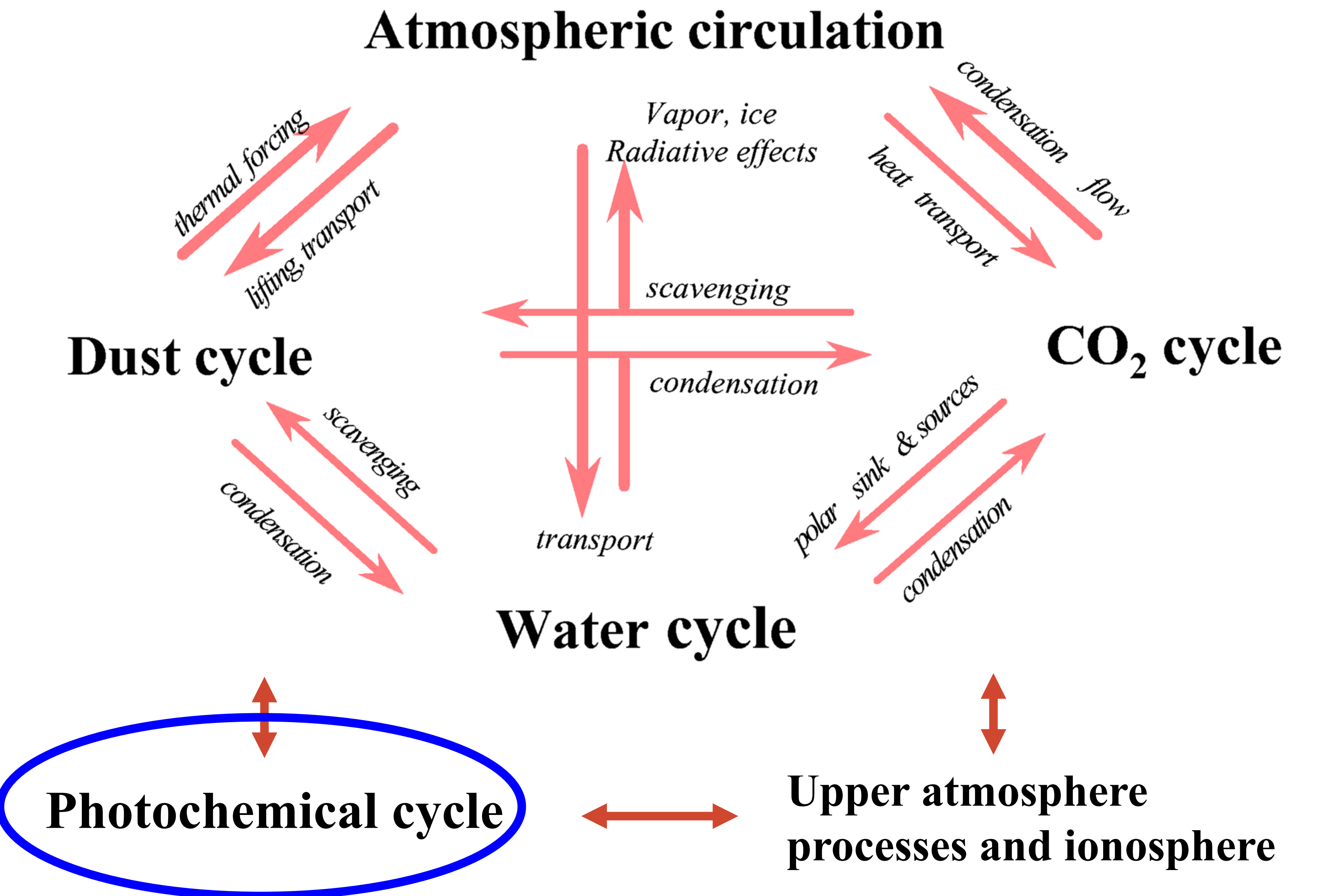



75 S to 90 S
Ar (model)
| Ar (Obs)
GRS data
Sprague et al. 2004
Enhancement Factor
0
1
2
3
4
5
6
0
90
180
270
360
Ls (degrees)

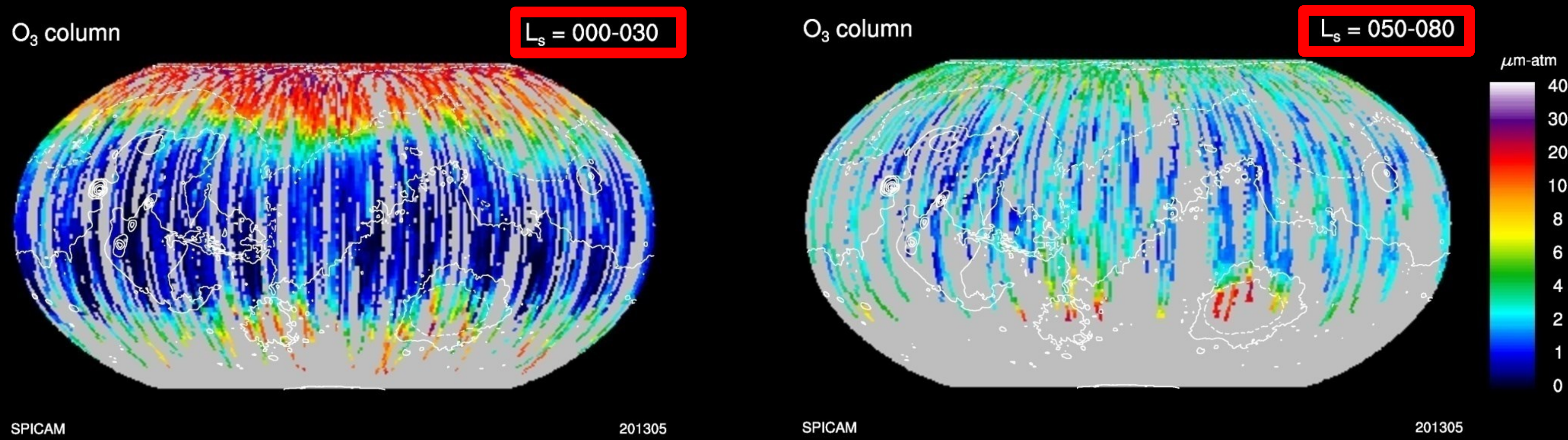


75 N to 90 N
Ar (model)
| Ar (Obs)
GRS data
Sprague et al. 2004
Enhancement Factor
0
1
2
3
4
5
6
0
90
180
270
360
Ls (degrees)

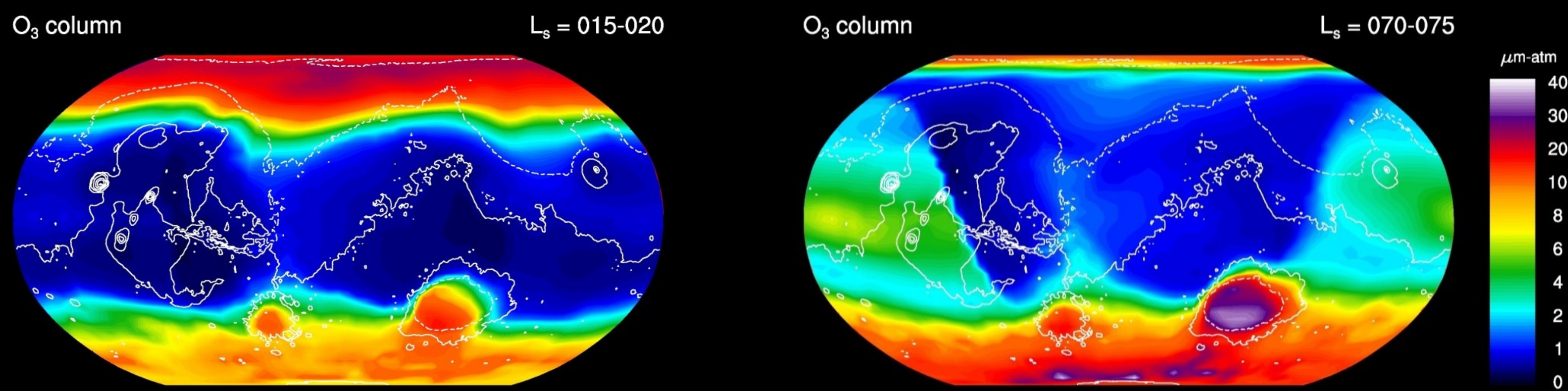
Mars climate : a complex system



Observations O_3 SPICAM 2004-2011

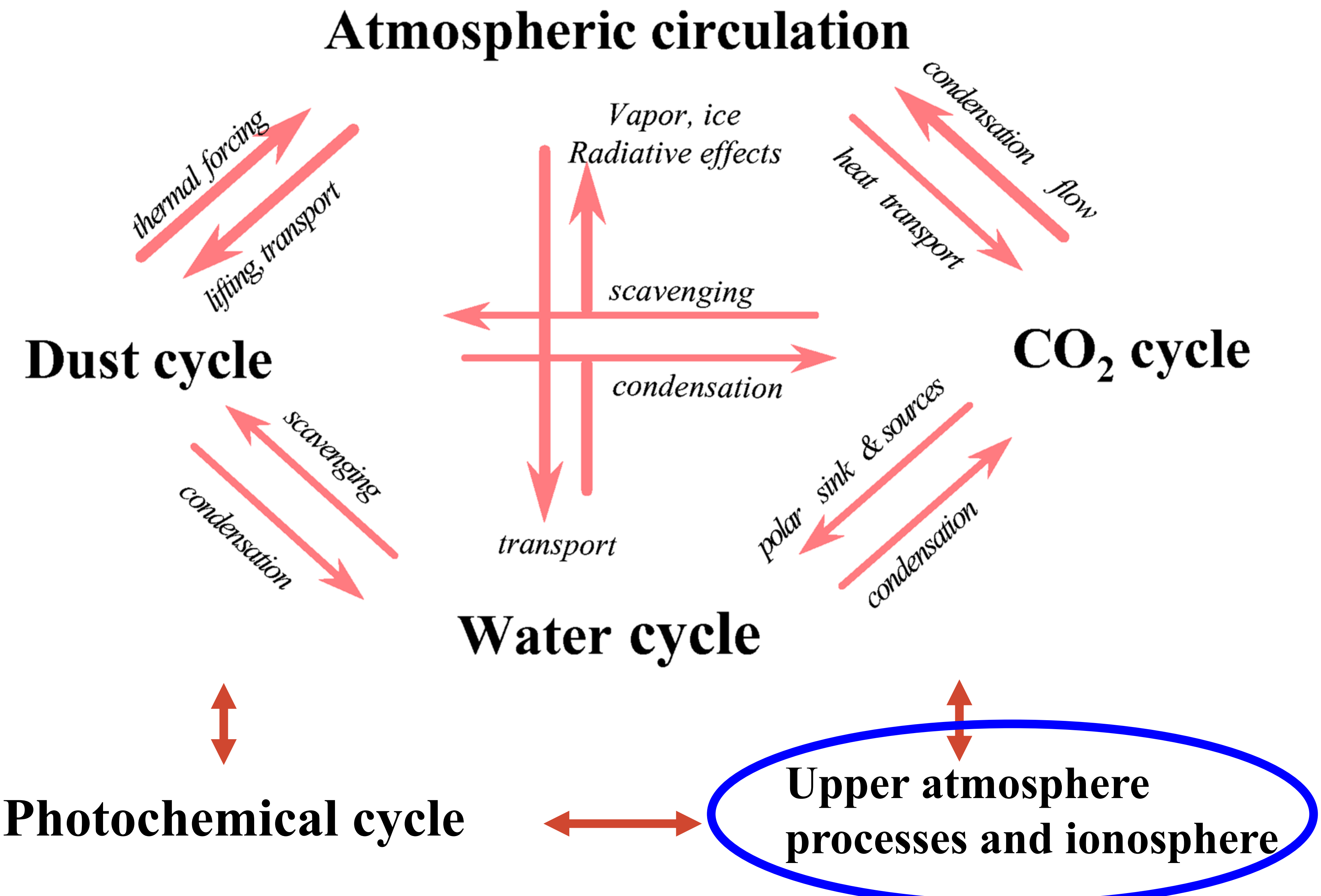


Model : LMD GCM



Franck Lefevre et al. (2004, 2008, 2014)

Mars climate : a complex system



Toward the upper martian atmosphere

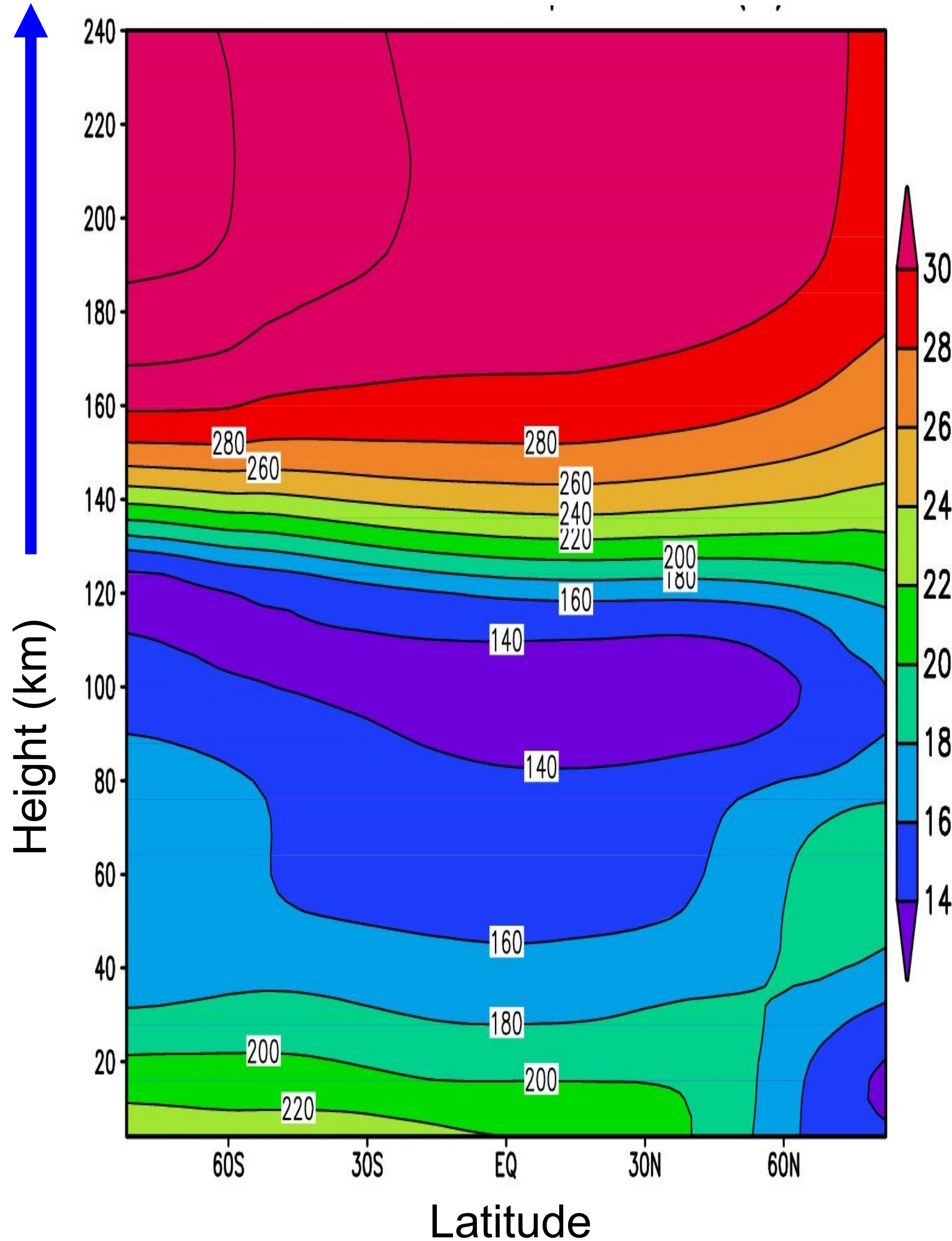
- UV and EUV Heating
- Thermal conduction
- NLTE CO_2 cooling
- Non homogeneous atmosphere :
  - Molecular diffusion
  - Molecular viscosity
  - Photochemistry

Angelats I Coll 2005

Gonzalez-Galindo et al. 2005, 2007, 2009

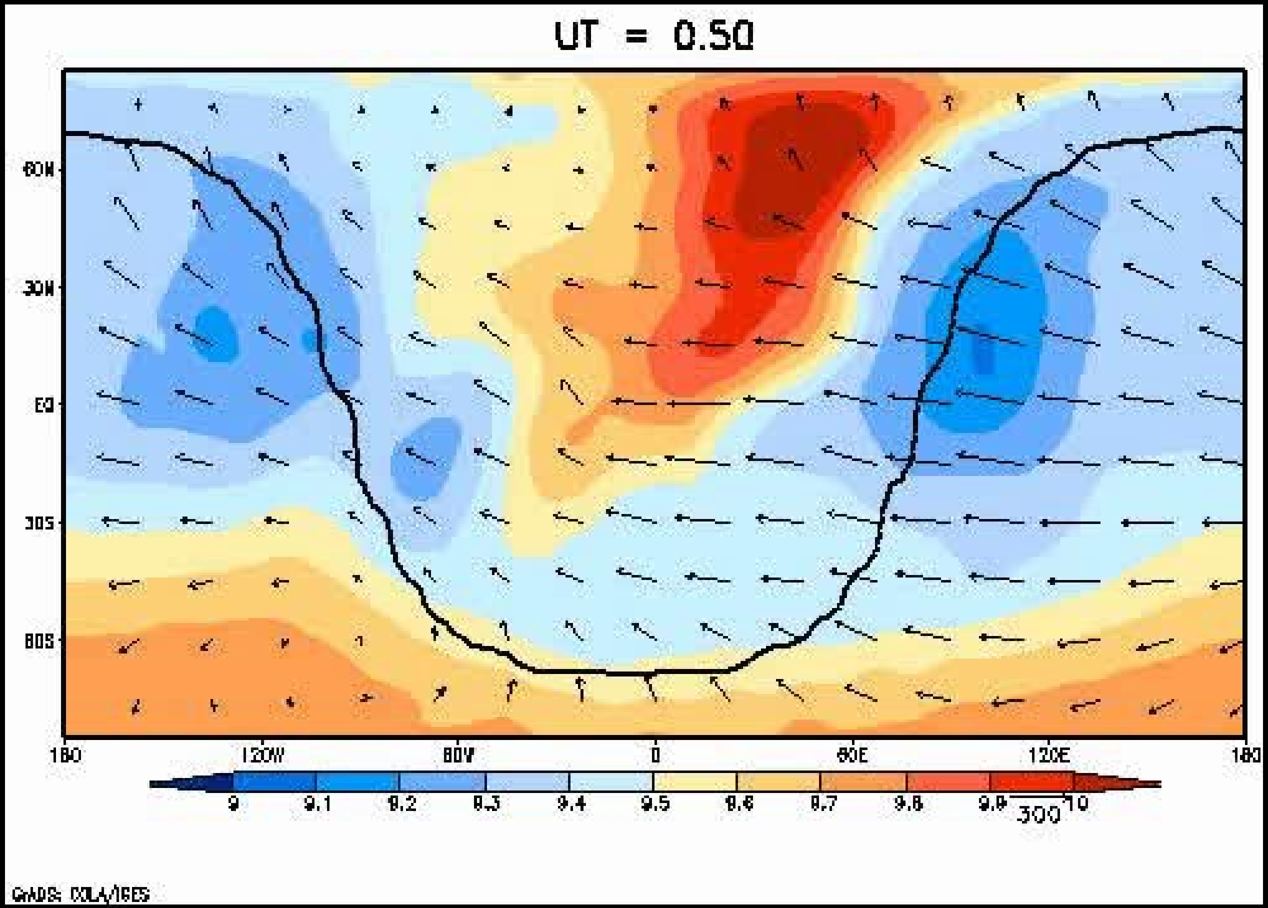
- Ionospheric processes

Zonal Mean temperature
Northern winter solstice

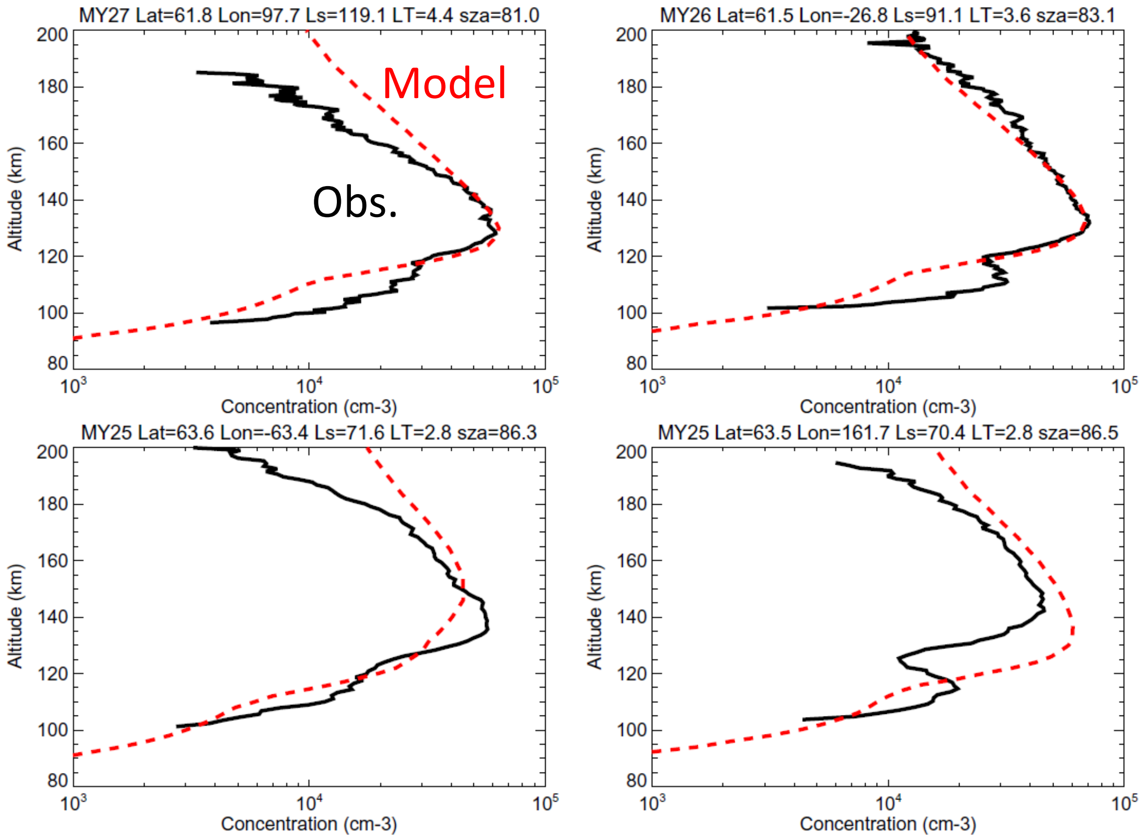


Example of results of the extended model

O and wind at Z = 200 km Ls = 300°



Ionosphere



Profils de densité électronique mesurés par radio-occultation

Gonzalez Galindo et al., 2013

Source of variability in the upper atmosphere

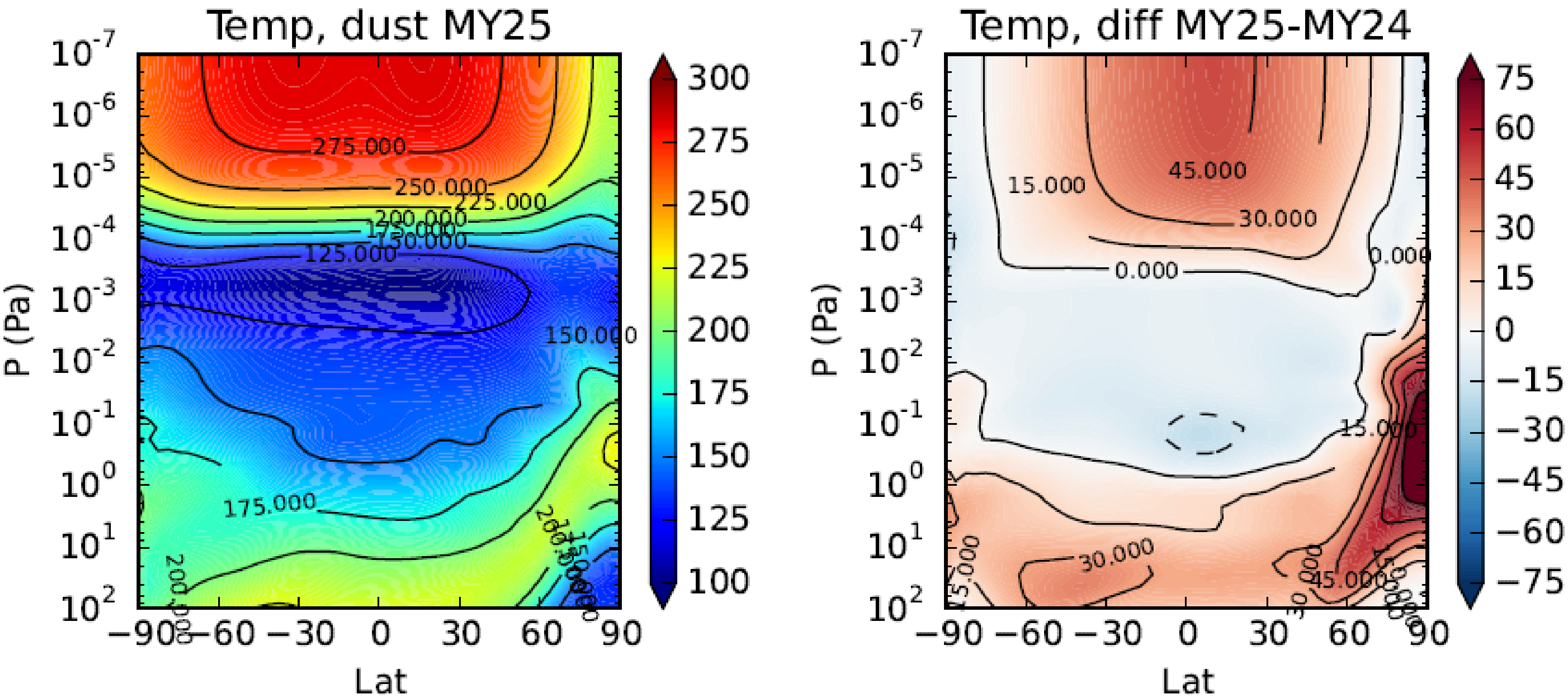
- Dust storm in the lower atmosphere

  (impact temperature between 0 and ~60km, and thus density above)

- Solar EUV variability
- Atmospheric waves
  - Thermal tides (migrating and non migrating)
  - Transient waves
  - Gravity waves

Impact of dust on atm. Temperatures

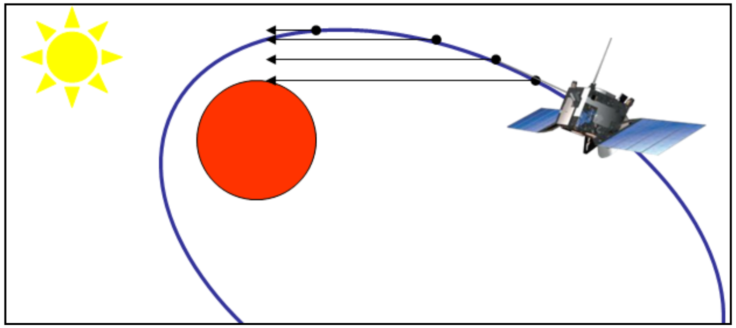
Change of temperatures at Ls=201° due to MY25 global dust storm

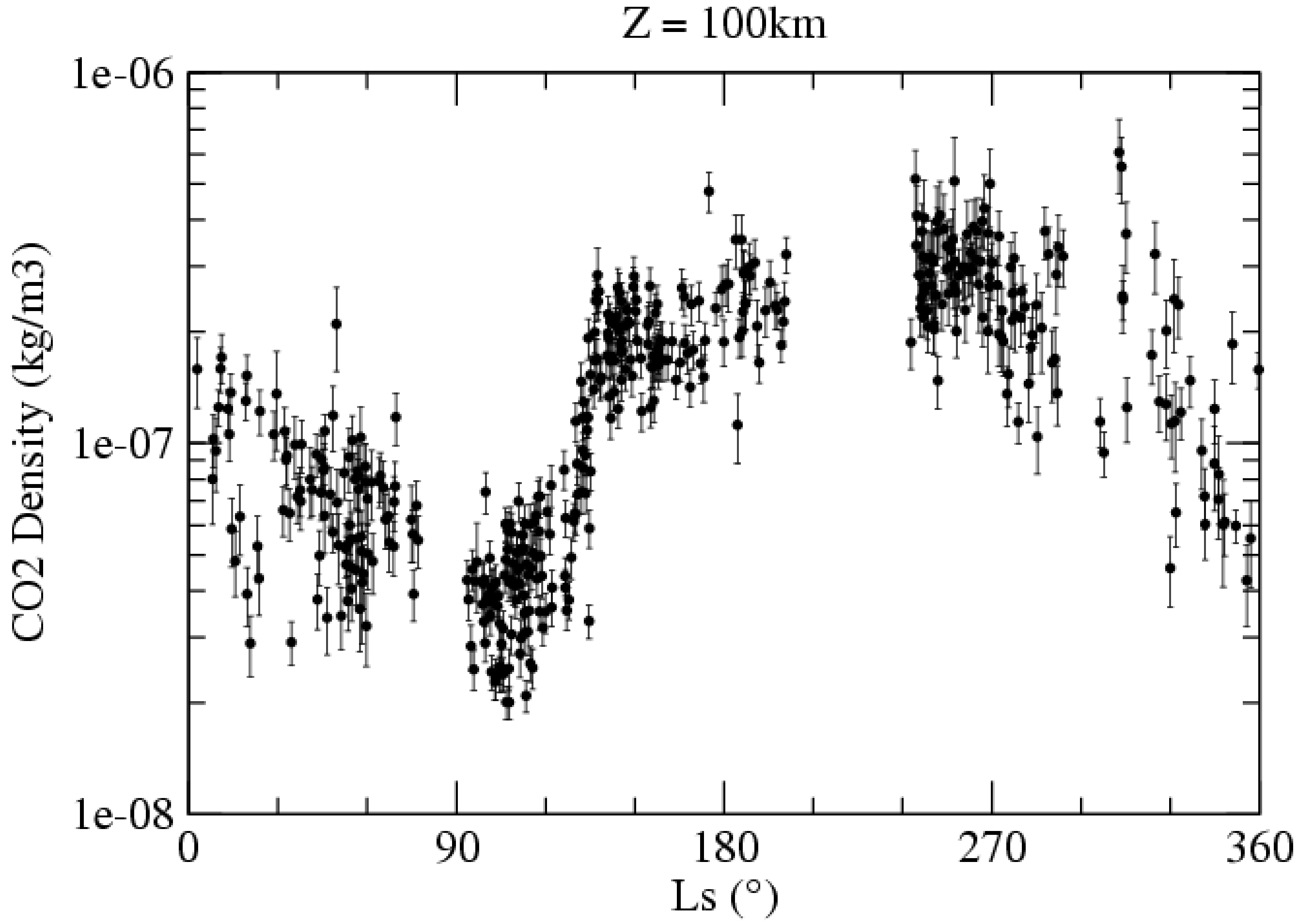


Gonzalez-Galindo et al. (2015)

Density vs season   z = 100km

(Mars Express SPICAM Stellar occultation, Forget et al. 2009)

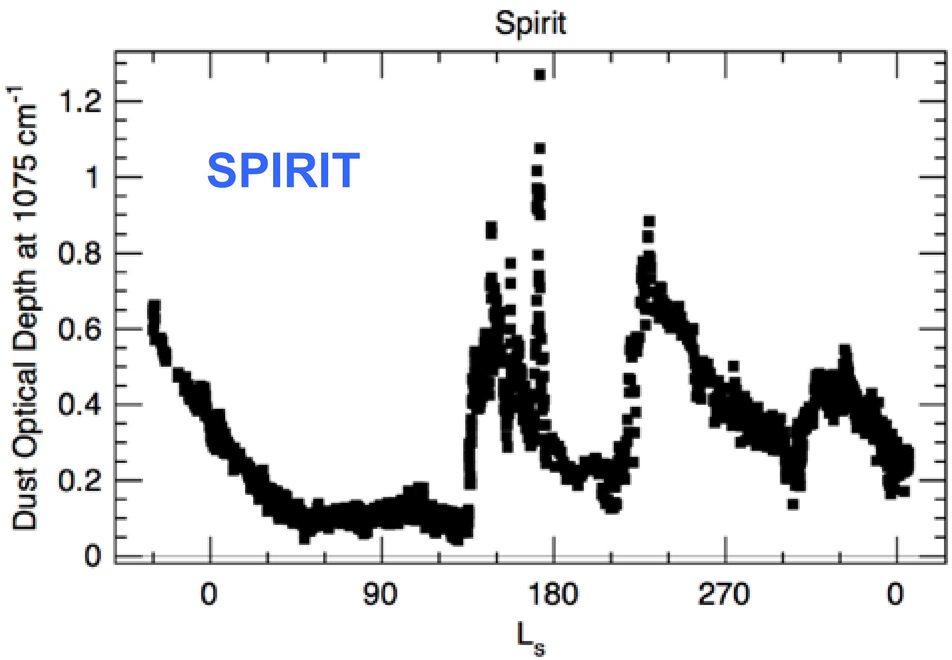


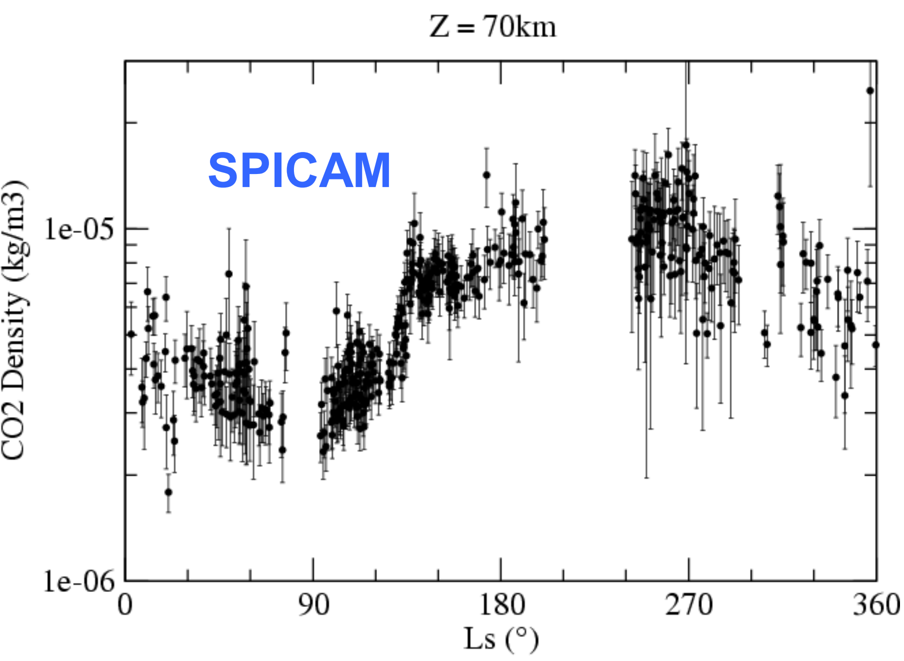


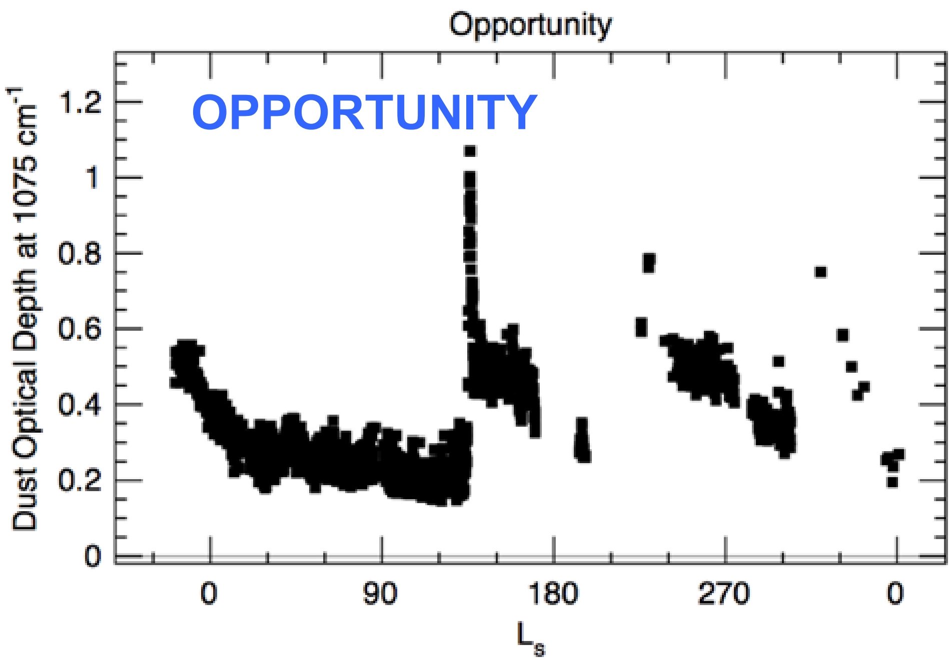
Comparison with miniTES dust measurements from the Mars Exploration Rover

Smith et al. 2006

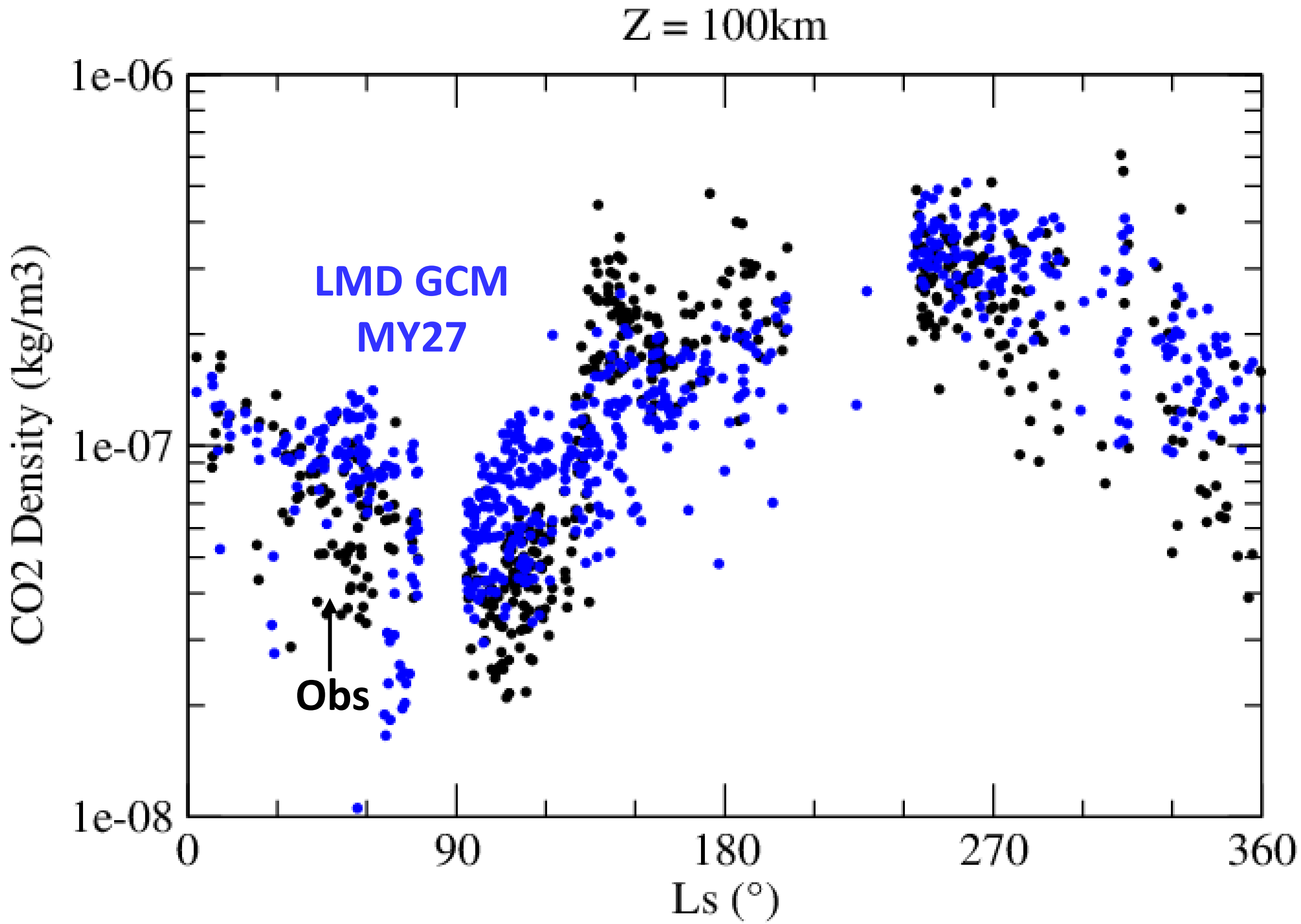
Unusual dust loading event around Ls=130°



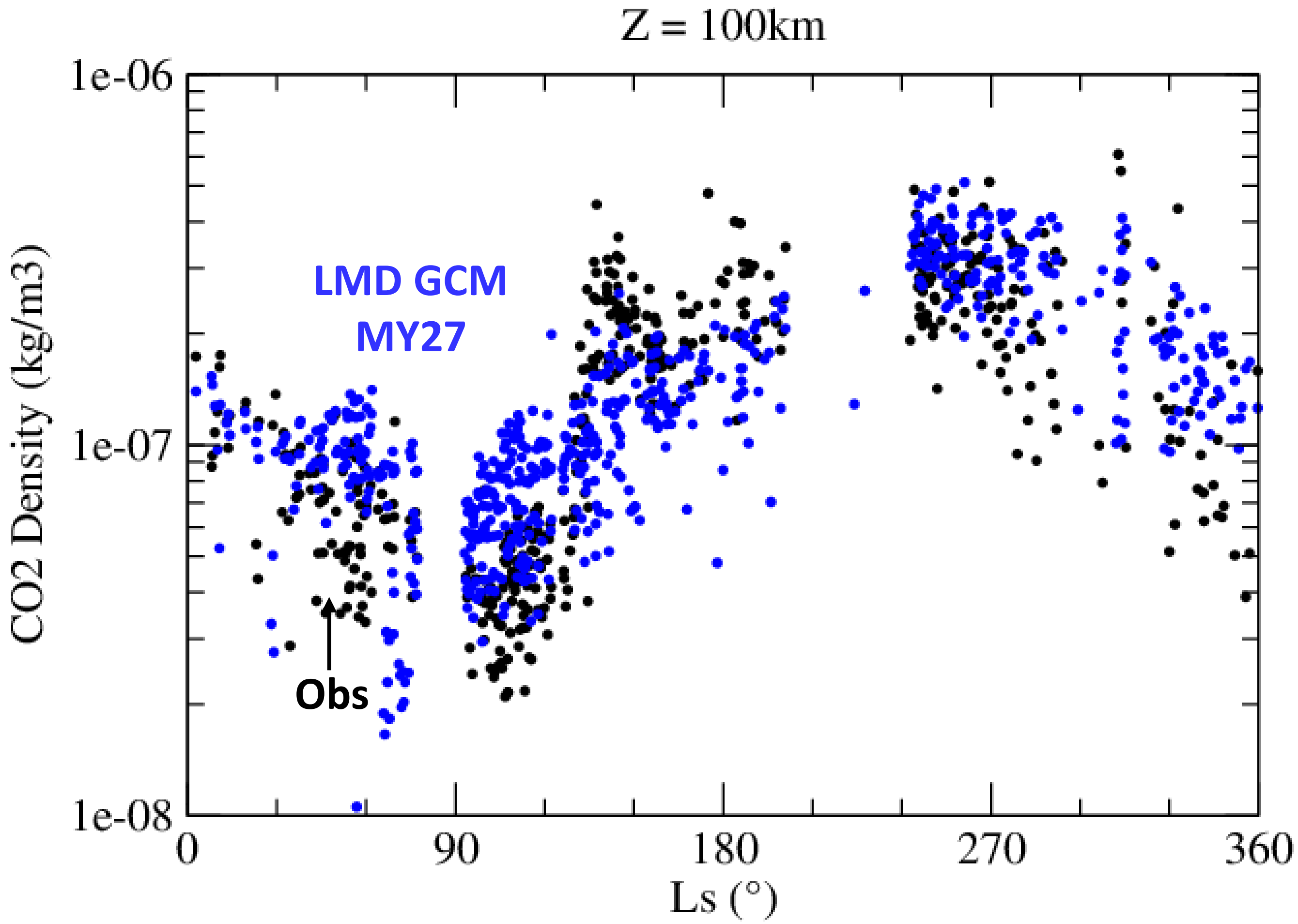




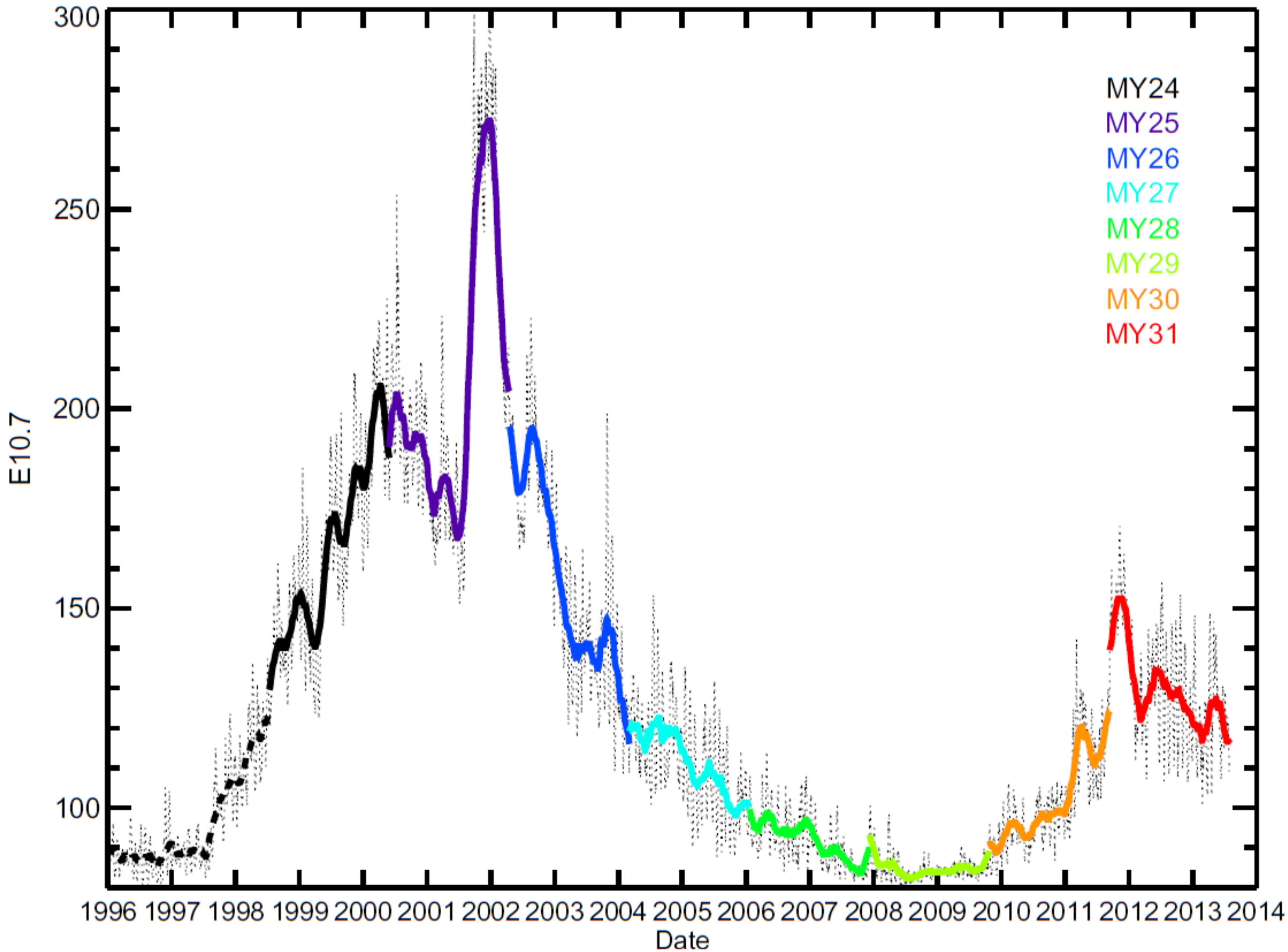
SPICAM vs GCM density z = 100km



SPICAM vs GCM density z = 100km

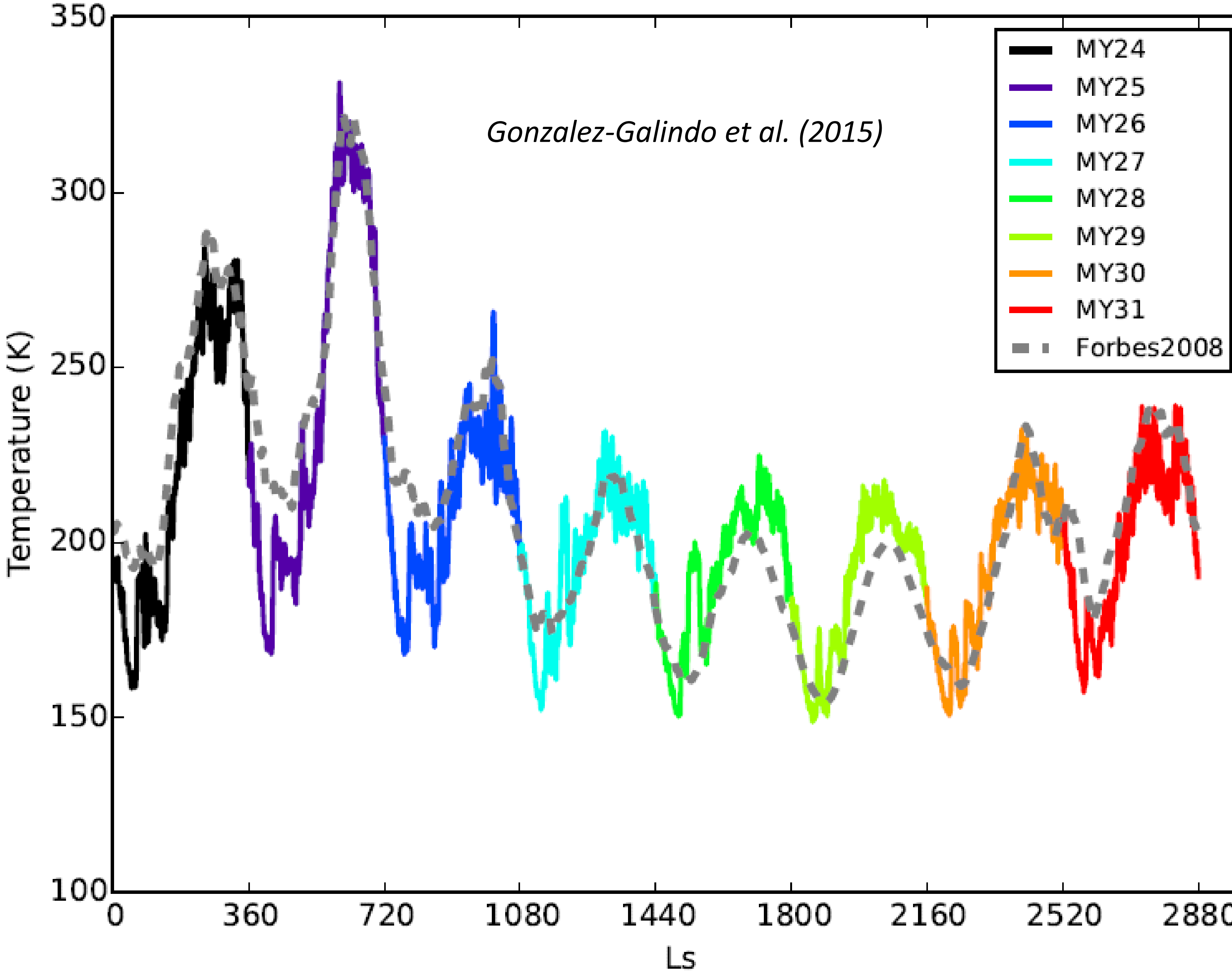


EUV forcing : E10.7 proxy

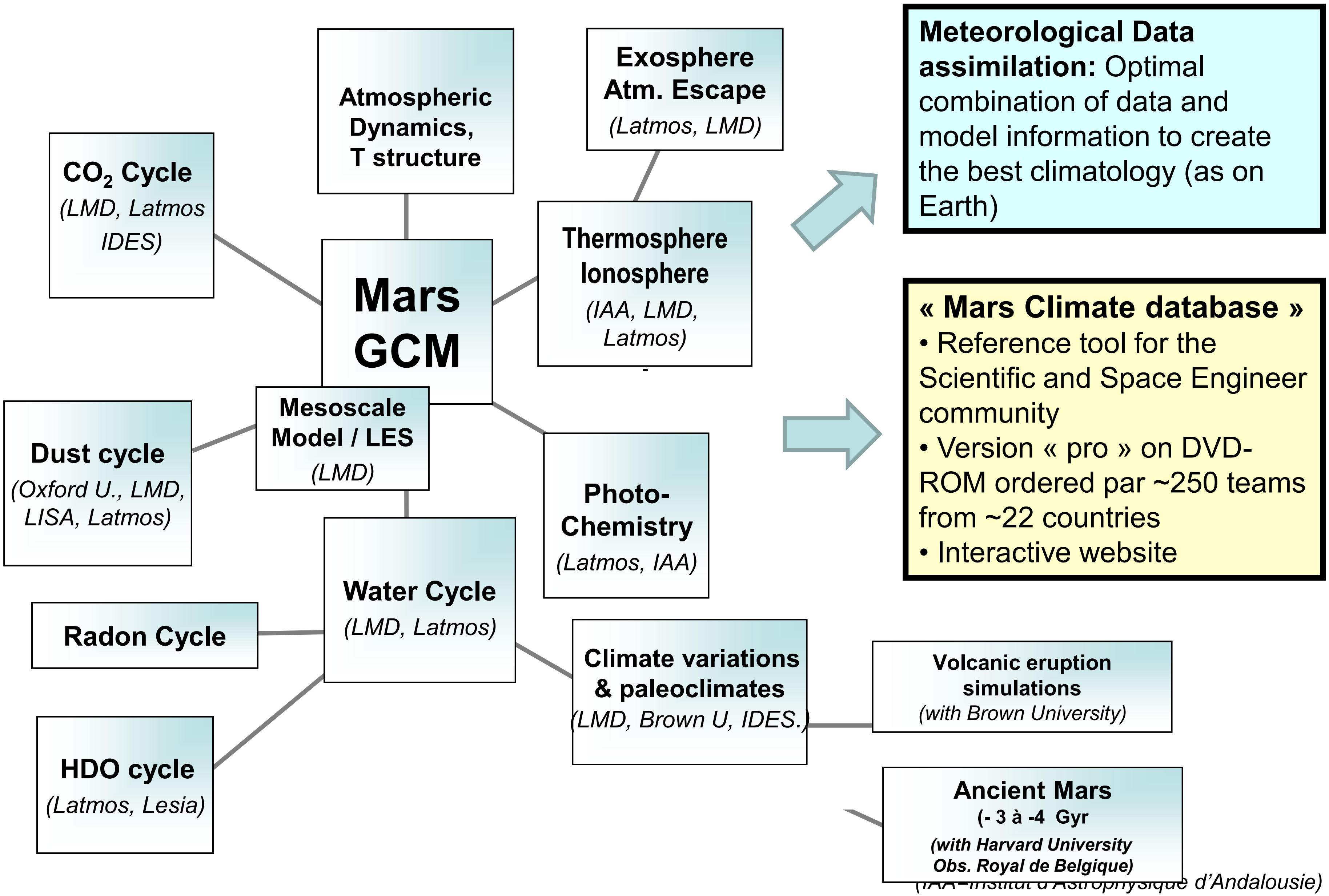


Gonzalez-Galindo et al. (2015)

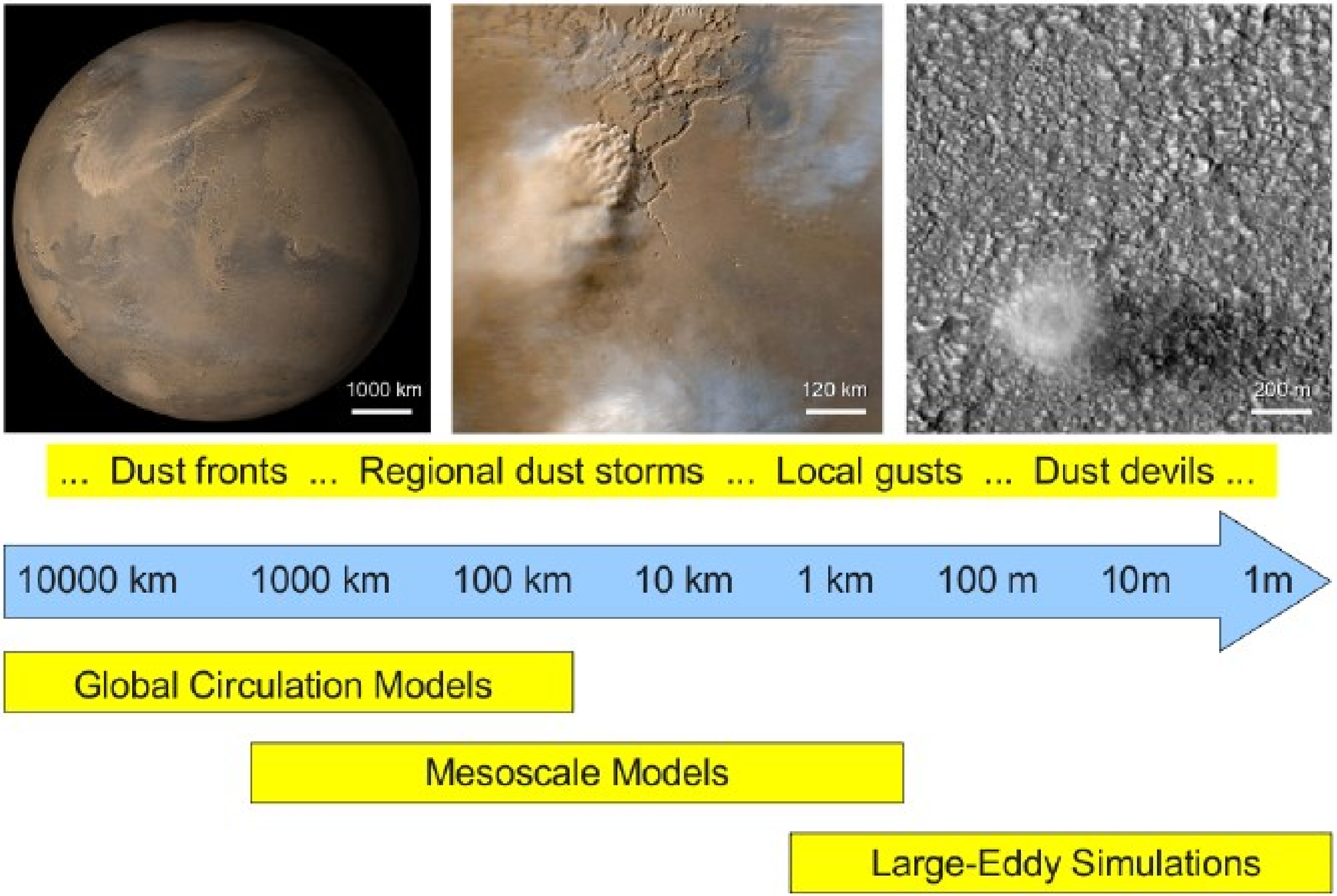
LMD GCM Zonal mean exobase temperatures at noon and lat=50S



The LMD/IPSL « Mars system simulator »



Scales and Models



[Spiga and Lewis, Mars Journal 2010]

Meso-scale Model

Simulate regional Mars meteorology in a limited area with a resolution of ~ 10 km. The LMD mesoscale model:

WRF dynamical core

integration of conservation laws for momentum, mass, energy, tracers

LMD Mars physics

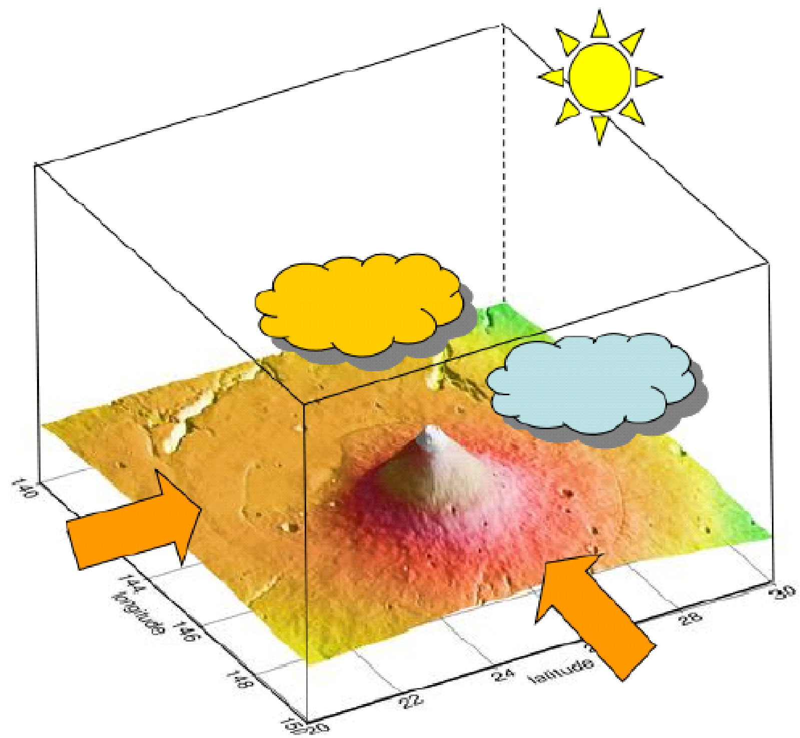
radiative transfer (dust and CO_2), soil model, vertical mixing, microphysics (H_2O and CO_2), lifting/sedimentation, chemistry

LMD Mars GCM fields

initial and boundary conditions

MGS hi-res dataset

topography, albedo, thermal inertia
specific dust scenarios

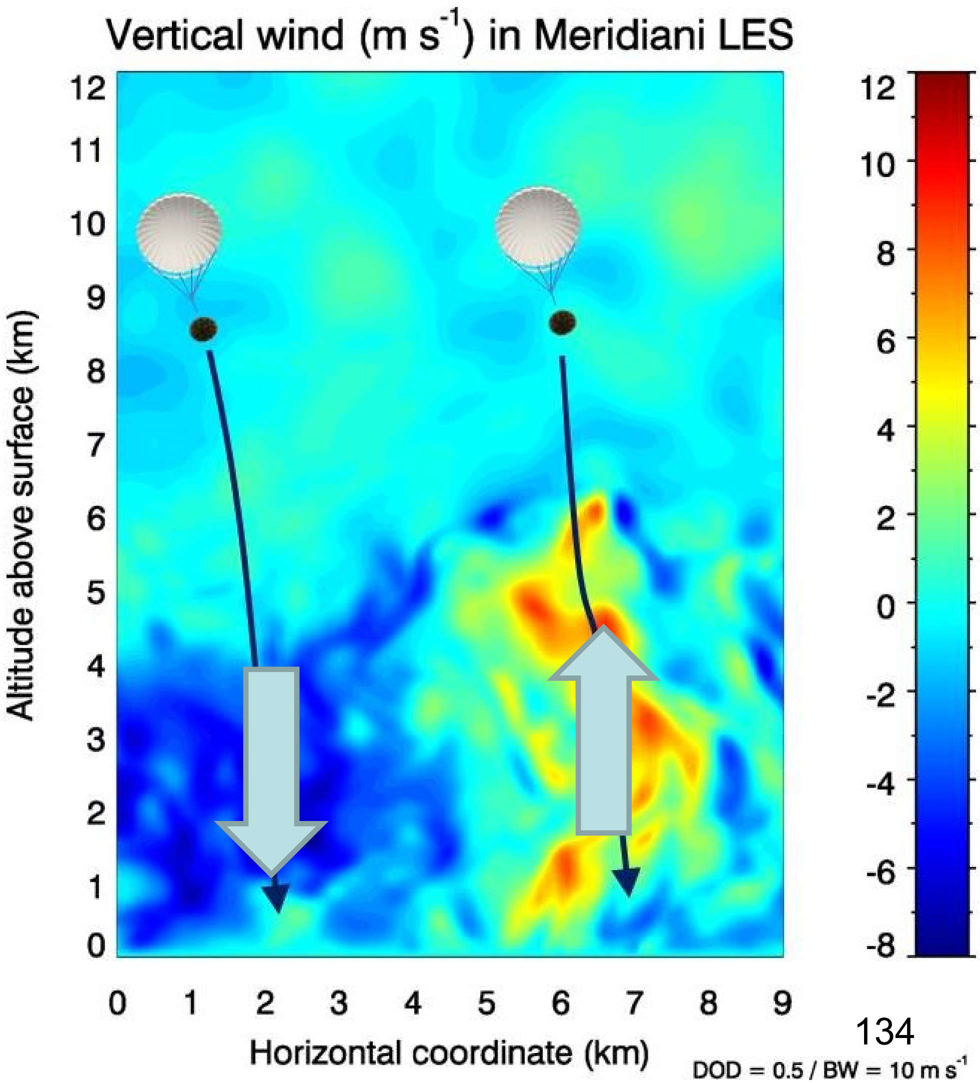


[Spiga and Forget, JGR, 2009]

Microscale Model "*Large Eddy Simulation model*" (LES) for the convective Boundary layer

Daytime convective motions can creates strong updraft and down draft.
This can now be simulated using a "Large Eddy Simulation Models"

- "Non hydrostatic fluid dynamical core"
- **Resolution : 10 to 50 meters** to resolve convective cells
- Full Physical parametrizations package



Boundary Layer models in the extremely unstable Martian conditions

« Large Eddy Simulation » of the daytime convection .

(*Spiga and Forget 2009*)

Ideal Tracer Transport by Convective vertical Motions

10 km

5 km

0 km

5 Kind of tools developped to simulate the Martian environment developped at LMD

1. **Global Climate Model** (“GCM”).
   Résolution: ~200 km
2. **Mars Climate Database** (“MCD”) : dérived from GCM simulations.
3. **Meso-scale model** (“MM”): Local circulation:
   Résolution:~10 km
4. **Large Eddy Simulation Model** (“LES”): simulation of the boundary layer (convection). Résolution: ~20 m
5. **1D engineering model** (“LMD1D”). Radiative and thermal environment to design surface hardware

6. **Surface Illumination Tool** (Monte Carlo model)