Martian climates: from the past to the present

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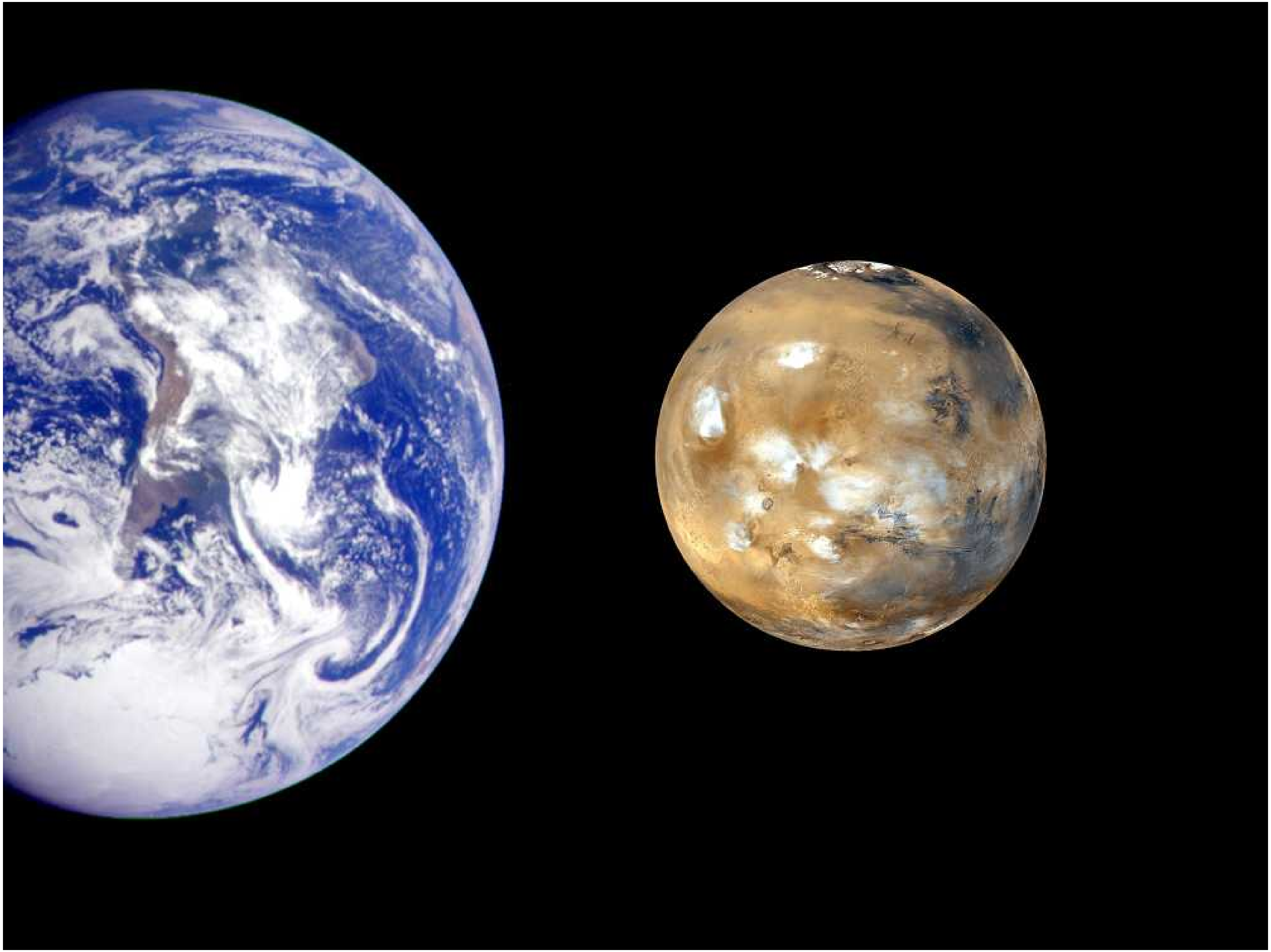
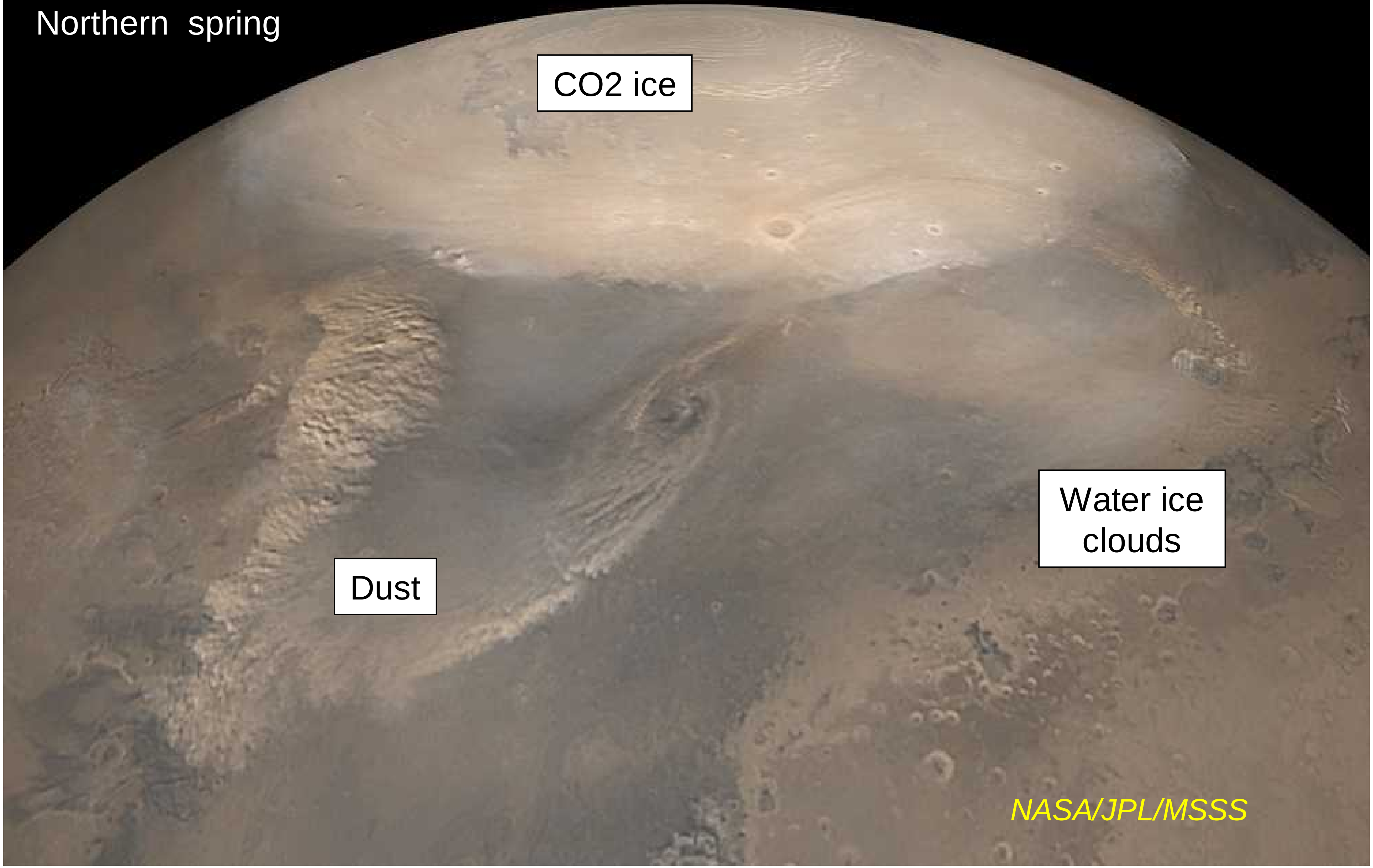
Outline

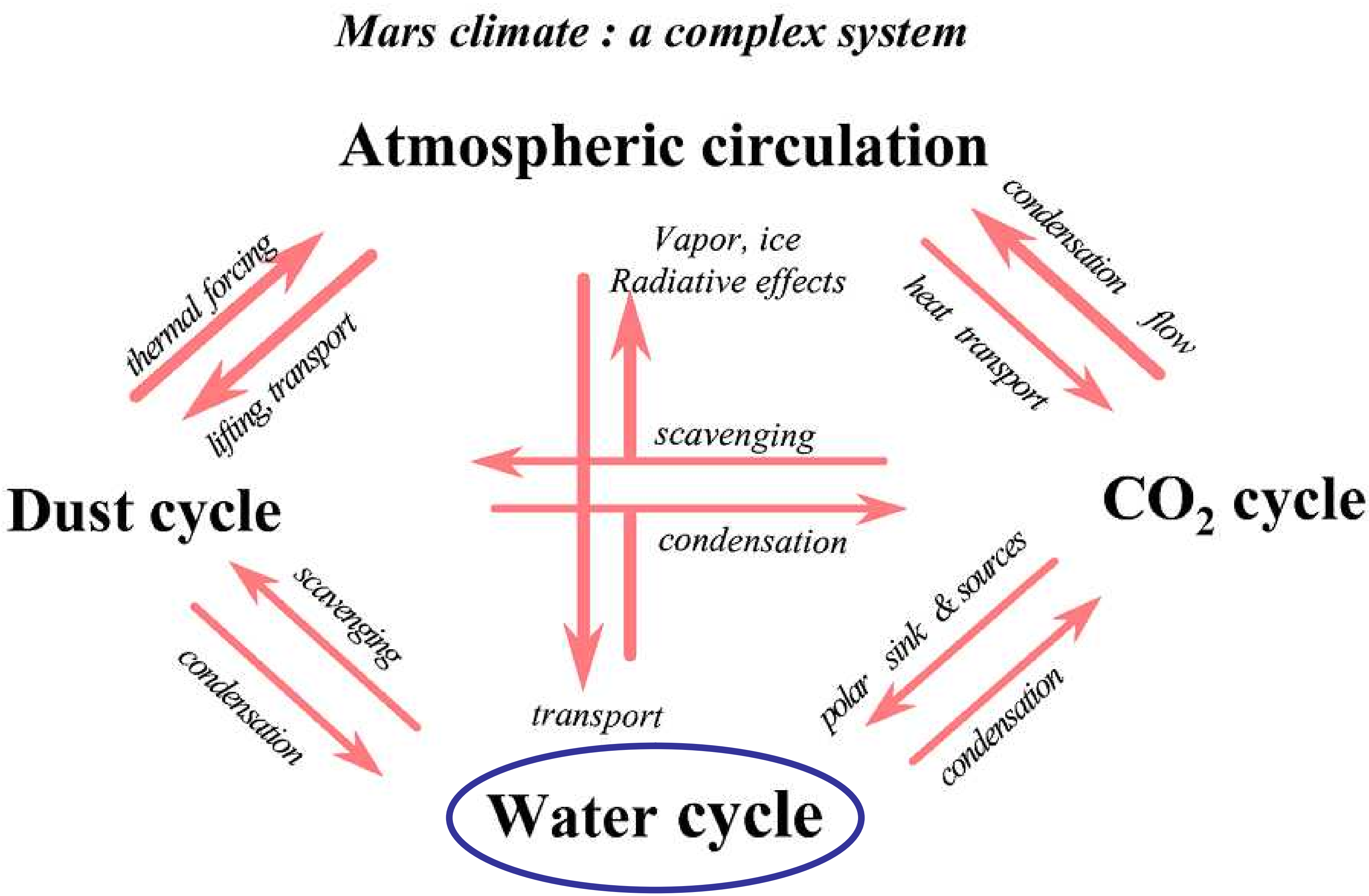
- Present-day Mars climate cycle : the water cycle
  - Observations of water, clouds and frost
  - Simulating the water cycle
- Recent climate variations
  - Observations of past climate icy landforms
  - Simulating and understanding past climate variations
- The early Mars climate
  - Geological evidences of different climates on early Mars
  - Simulating and understanding early Mars climates



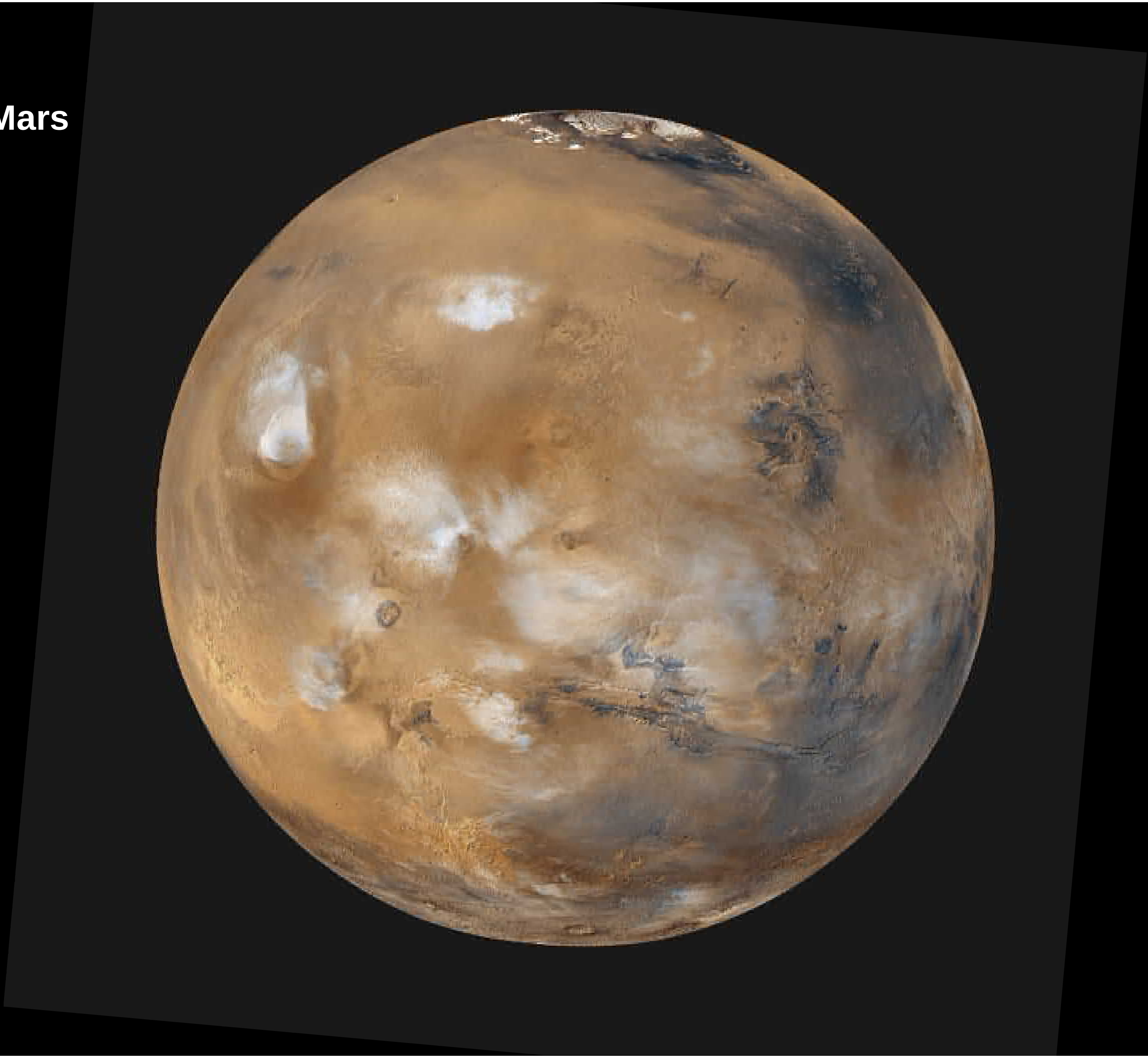
Mars climate now : atmospheric circulation, dust , CO_2 (and some water)

Northern spring

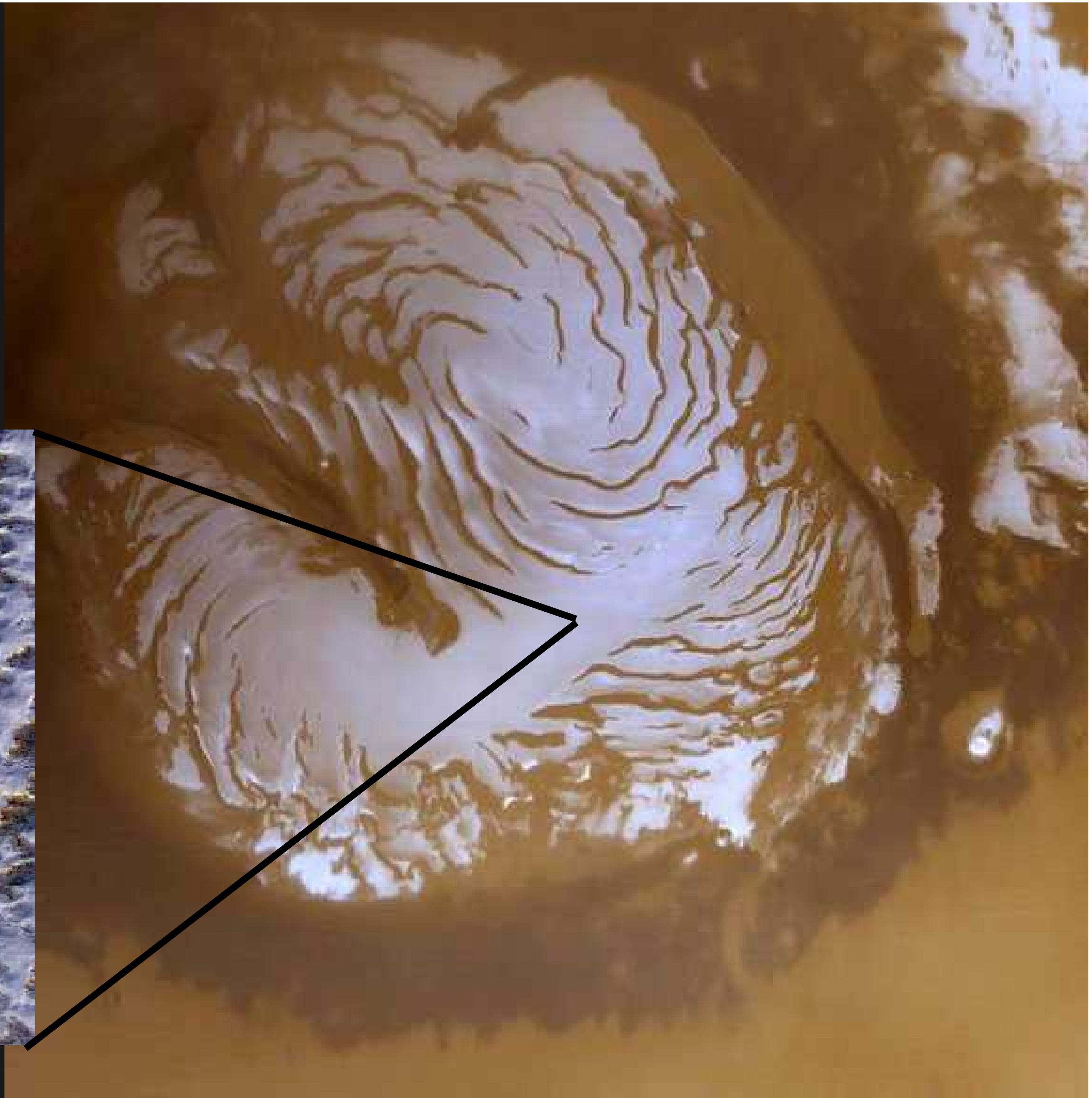



Mars climate : a complex system
Atmospheric circulation
thermal forcing
lifting, transport
Vapor, ice
Radiative effects
condensation flow
heat transport
scavenging
condensation
Dust cycle
CO2 cycle
scavenging
condensation
transport
polar sink & sources
condensation
Water cycle

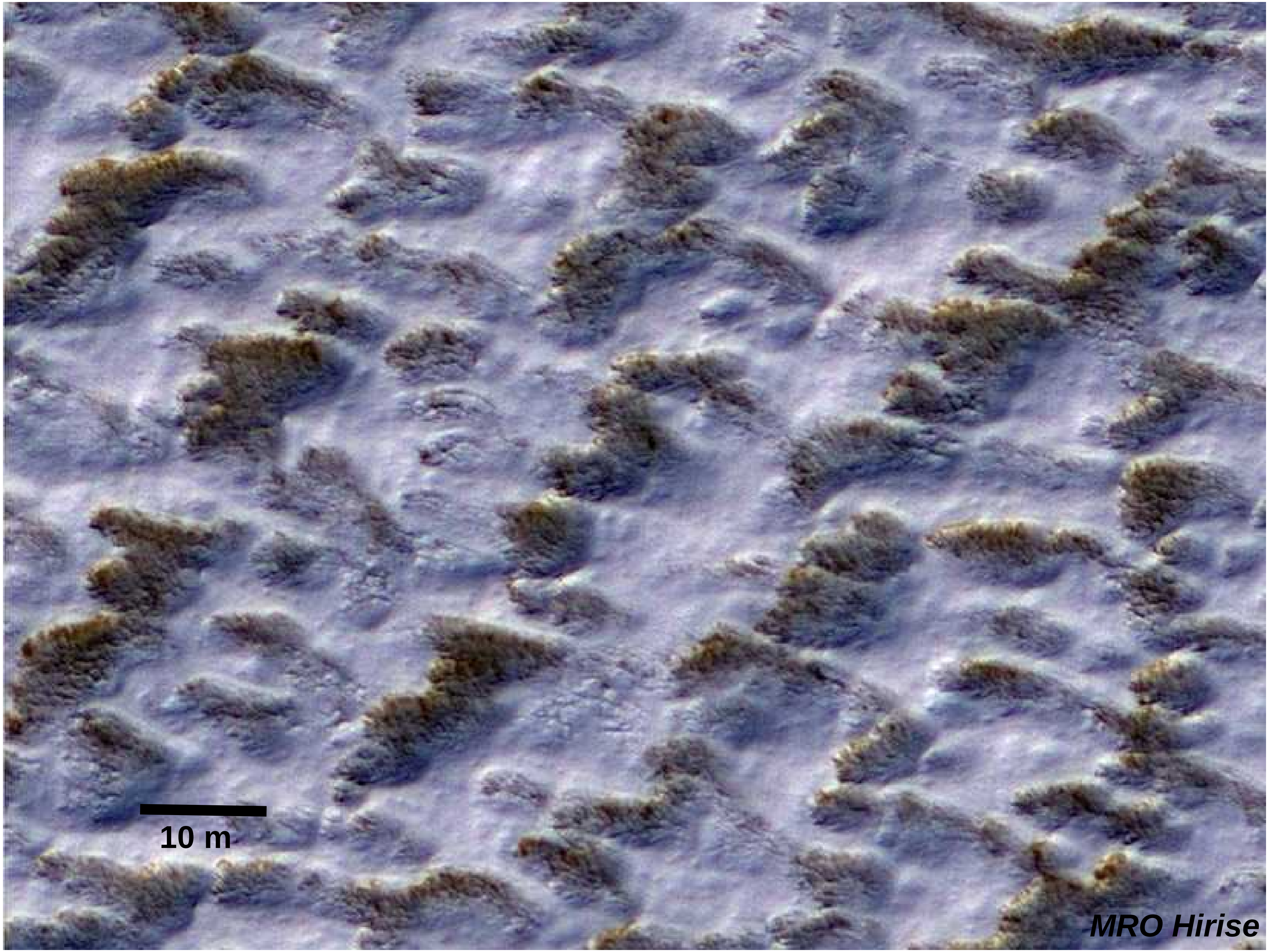
Water on Mars



Around North Pole : a relatively fresh and pure water ice layer interacting with the atmosphere (diameter : 1000 km)

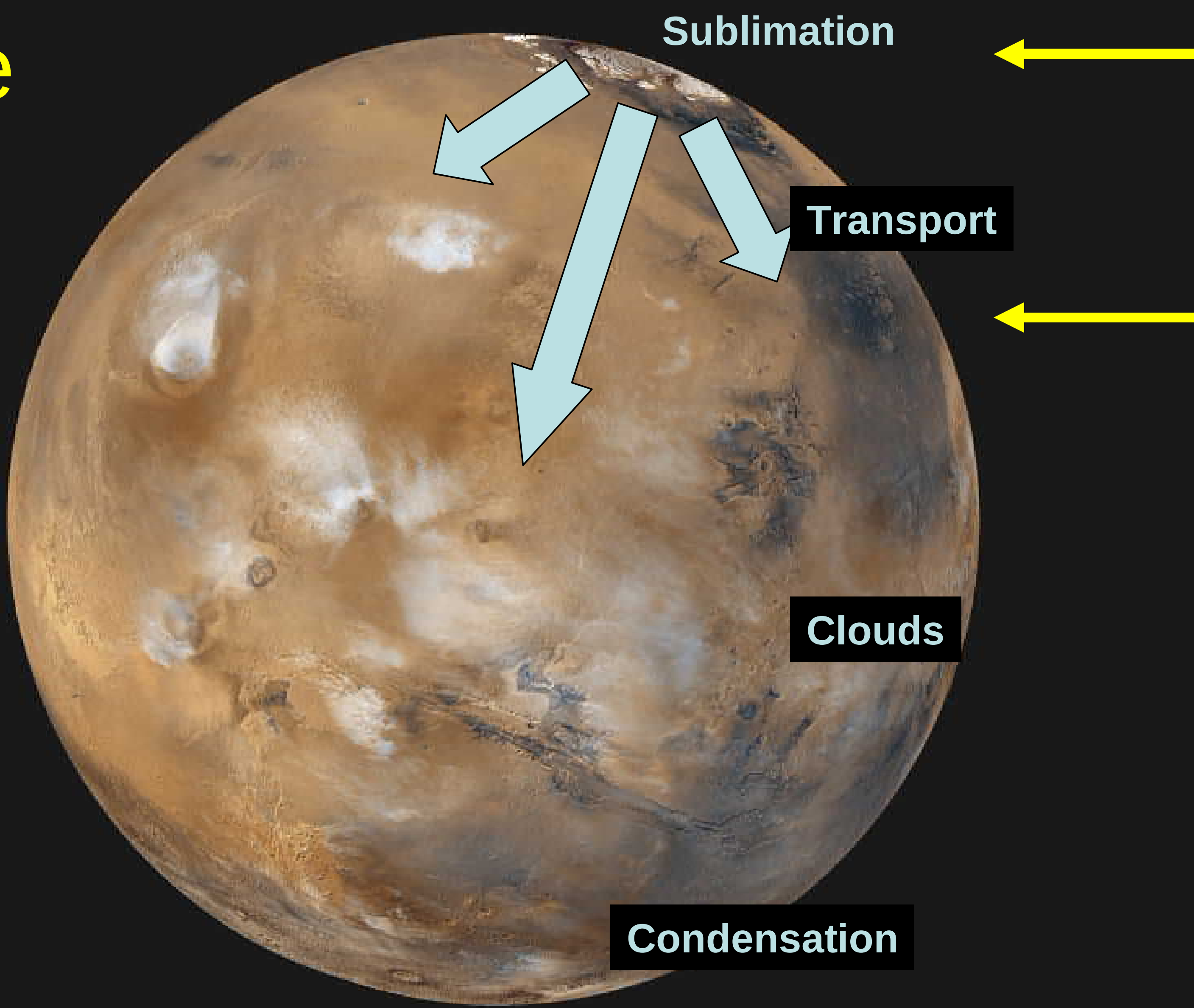


MRO Hirise


10 m
MRO Hirise

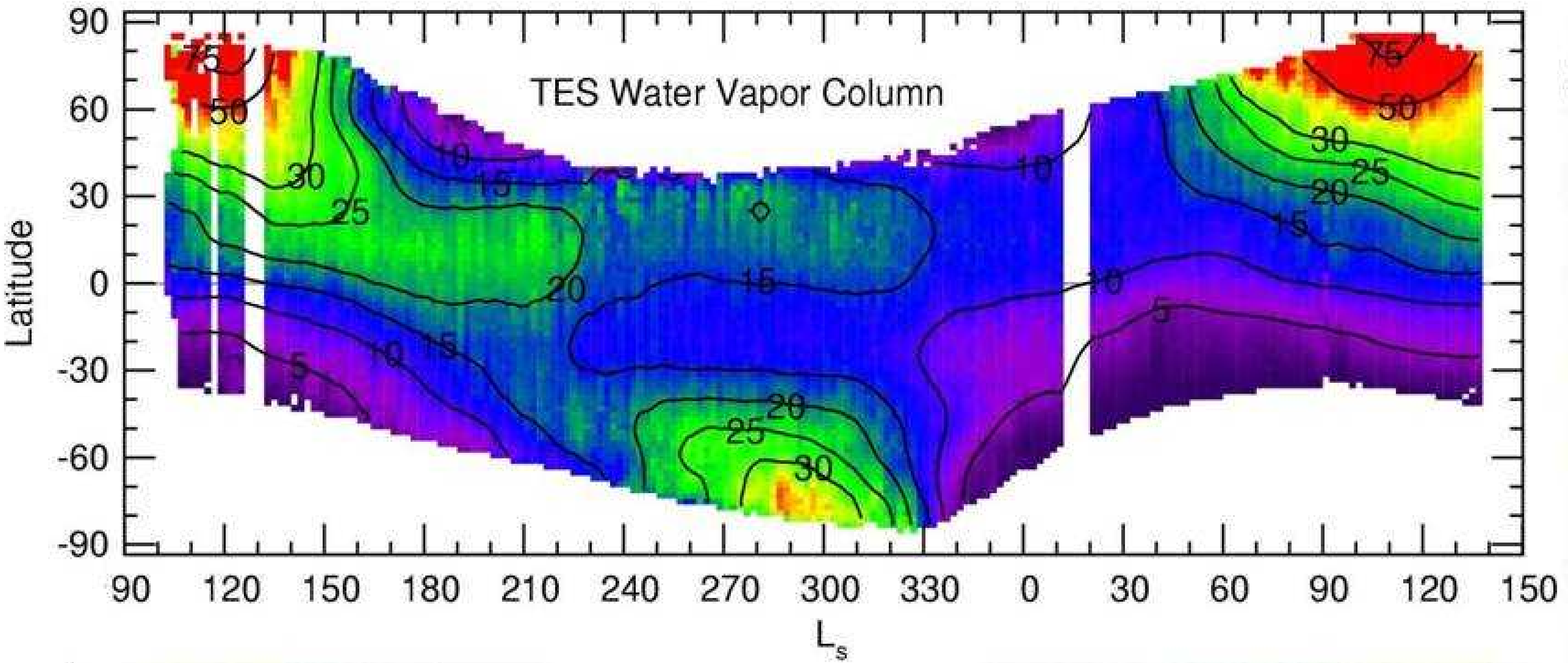
Mars water cycle

NORTHERN SUMMER

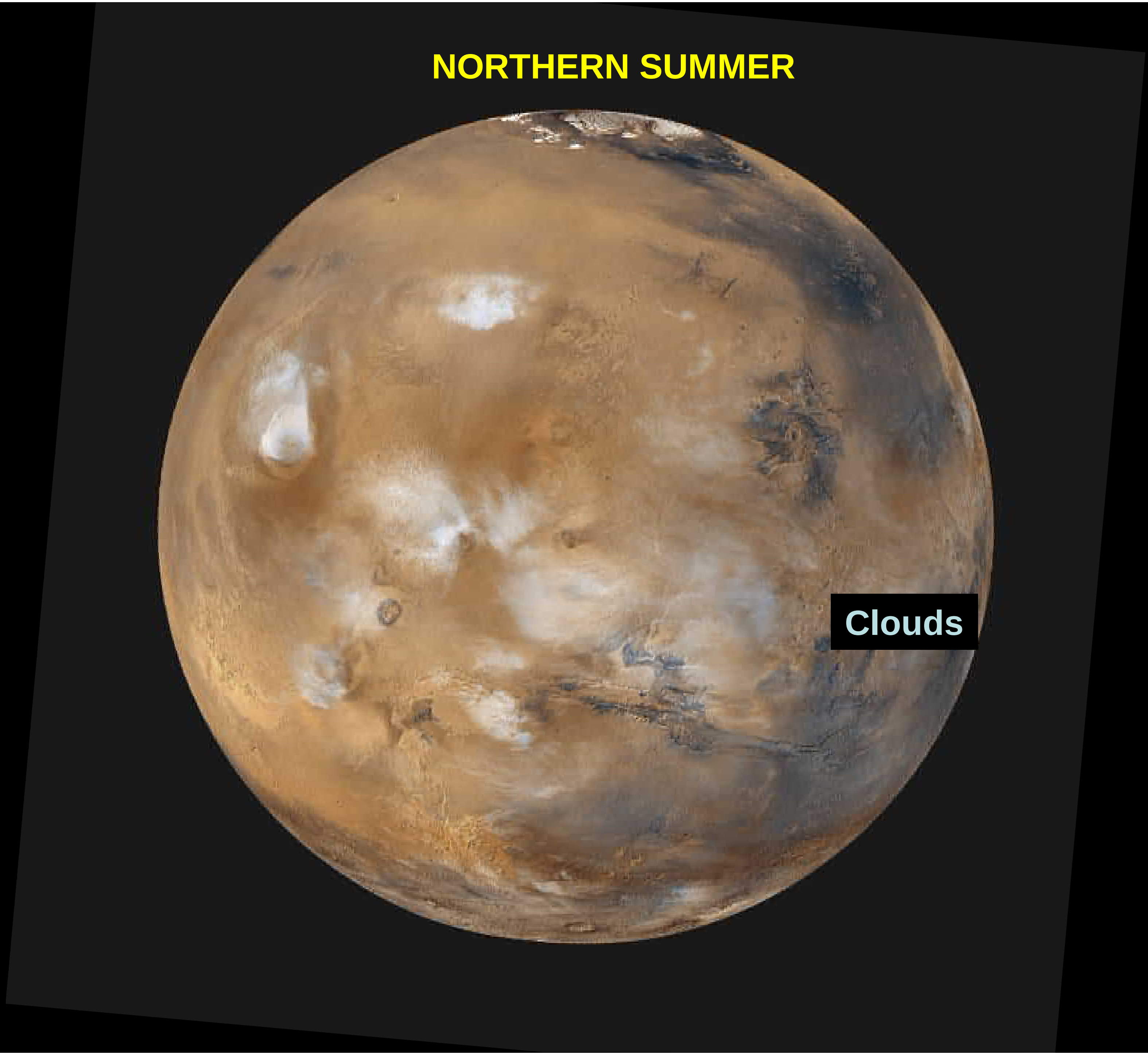


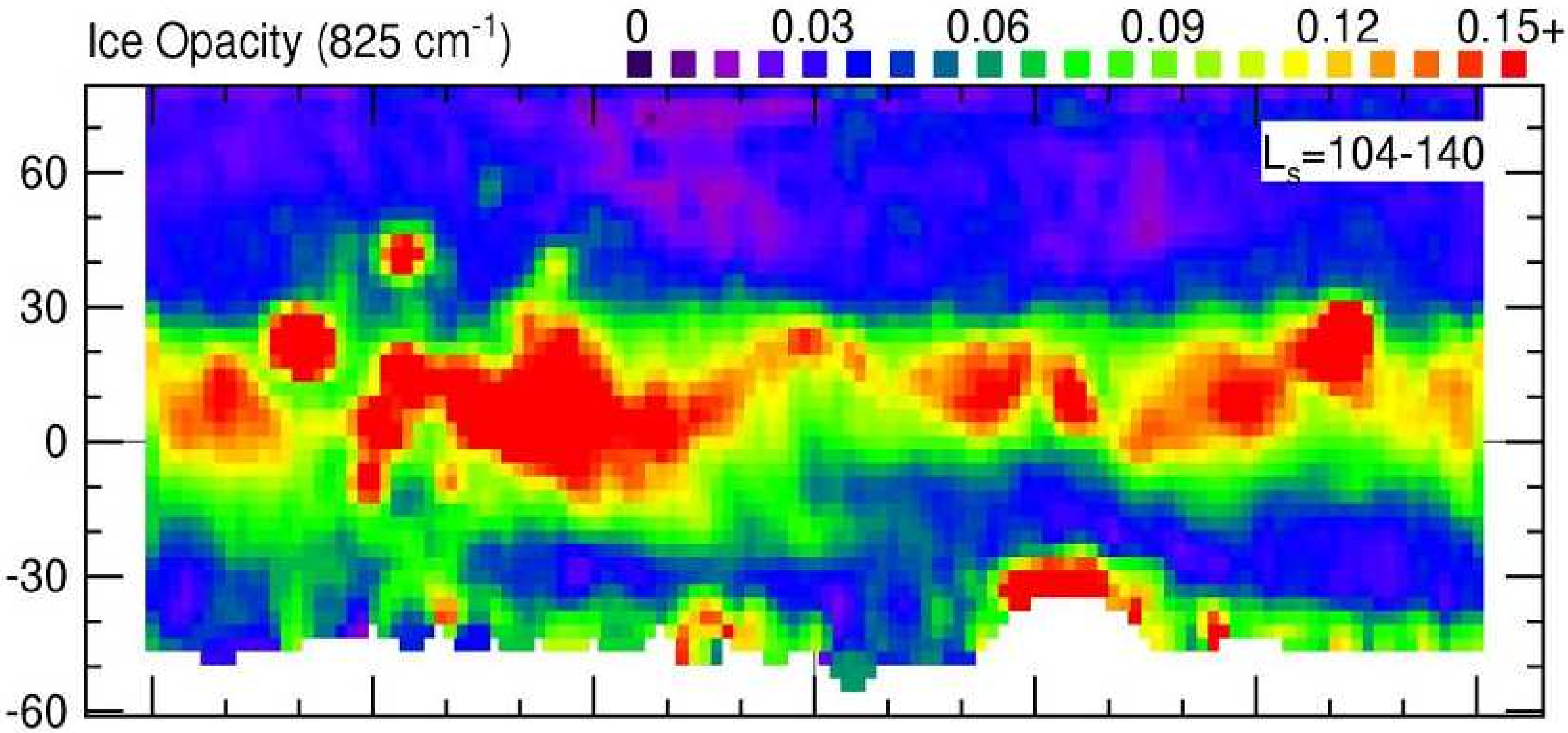
Mars water cycle

Atmospheric column of water vapor (précipitable microns)
(TES NASA Mars Global Surveyor data)



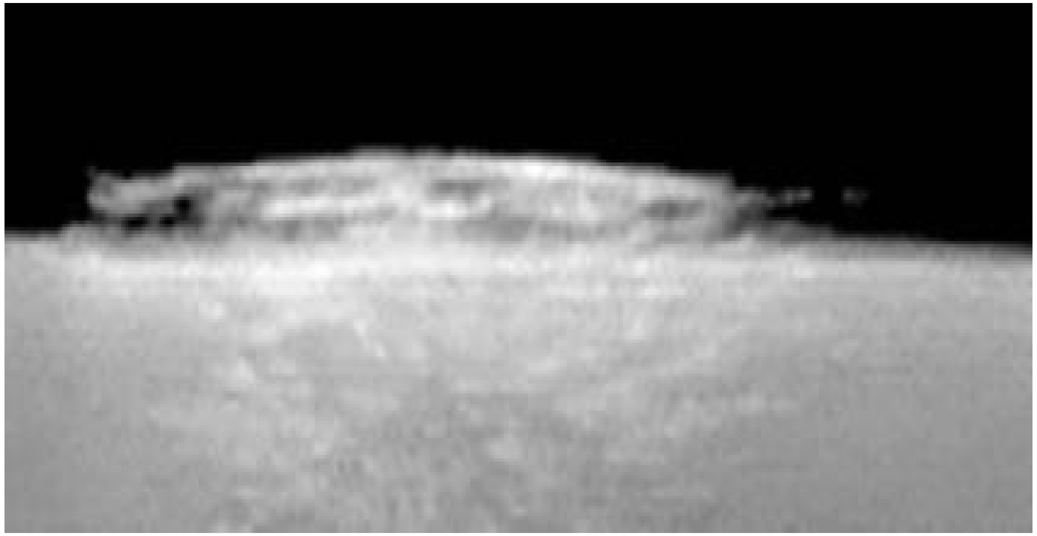
N Summer Fall Winter Spring Summer


NORTHERN SUMMER
Clouds

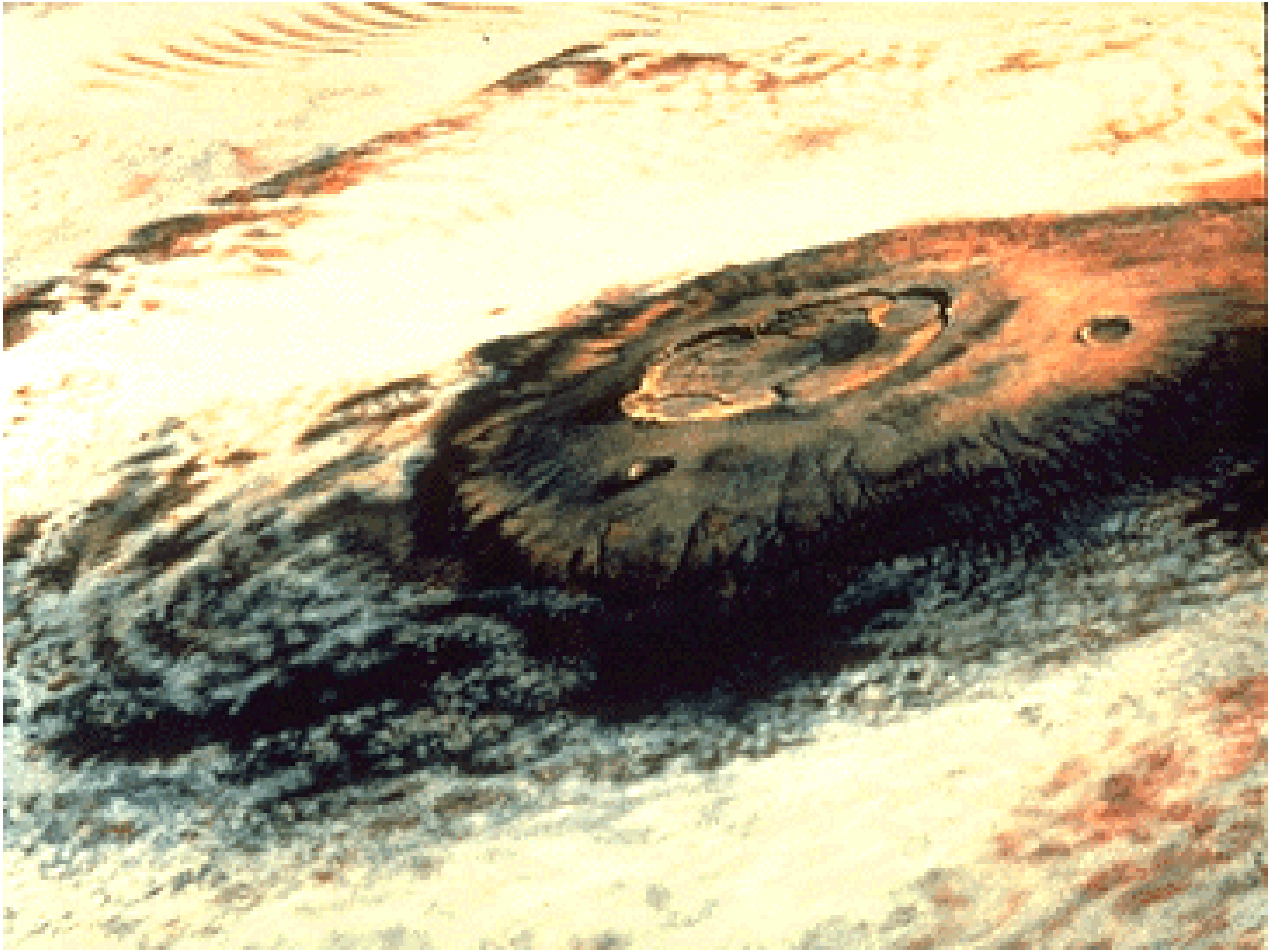


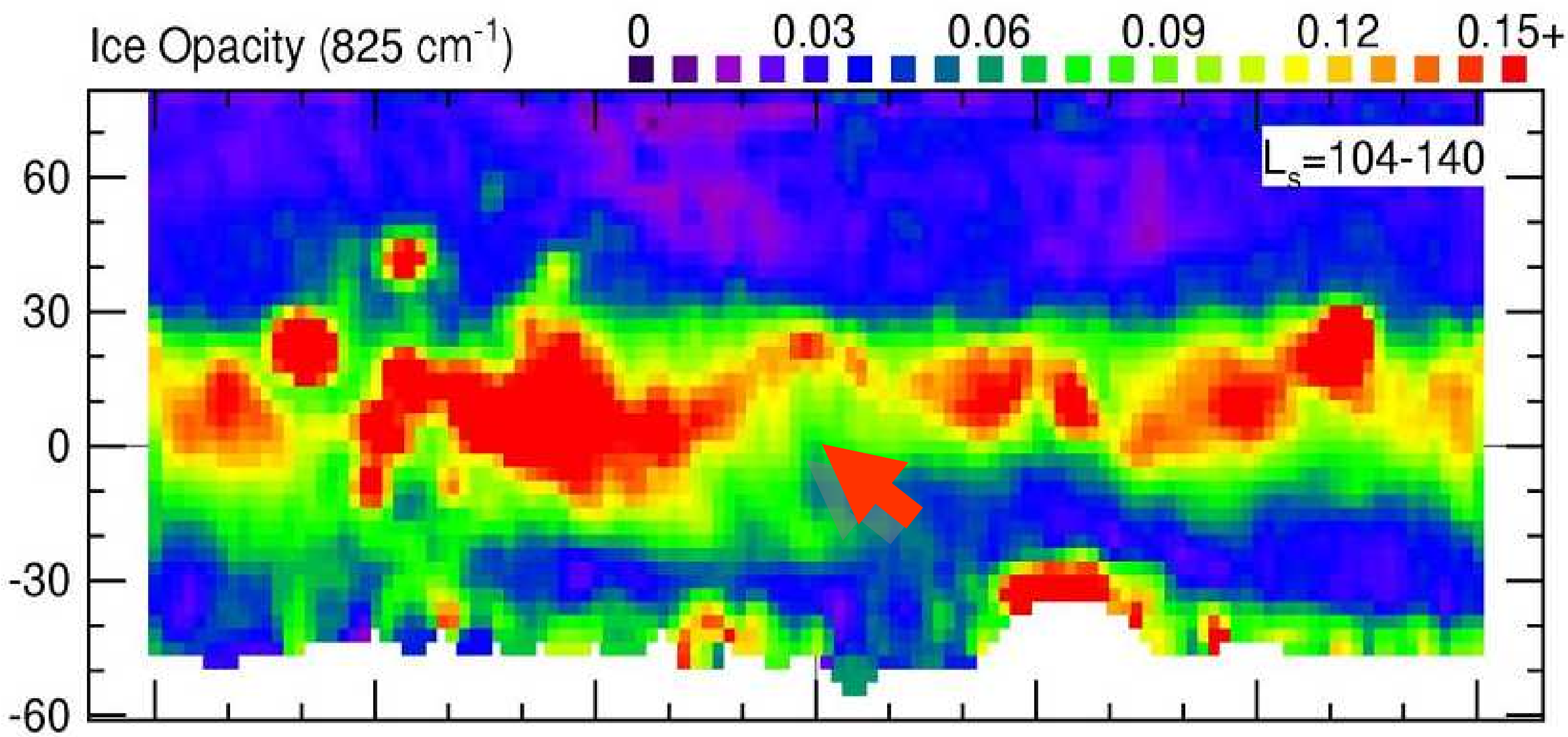
N. Summer Tropical Cloud belt

(TES thermal IR obs. Smith, 2001)

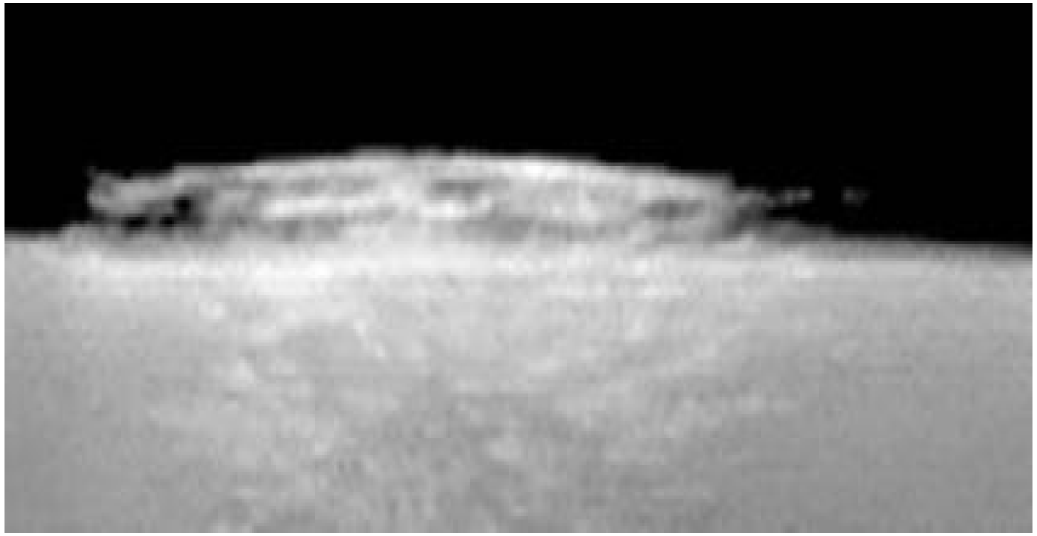


NASA/JPL/MSSS

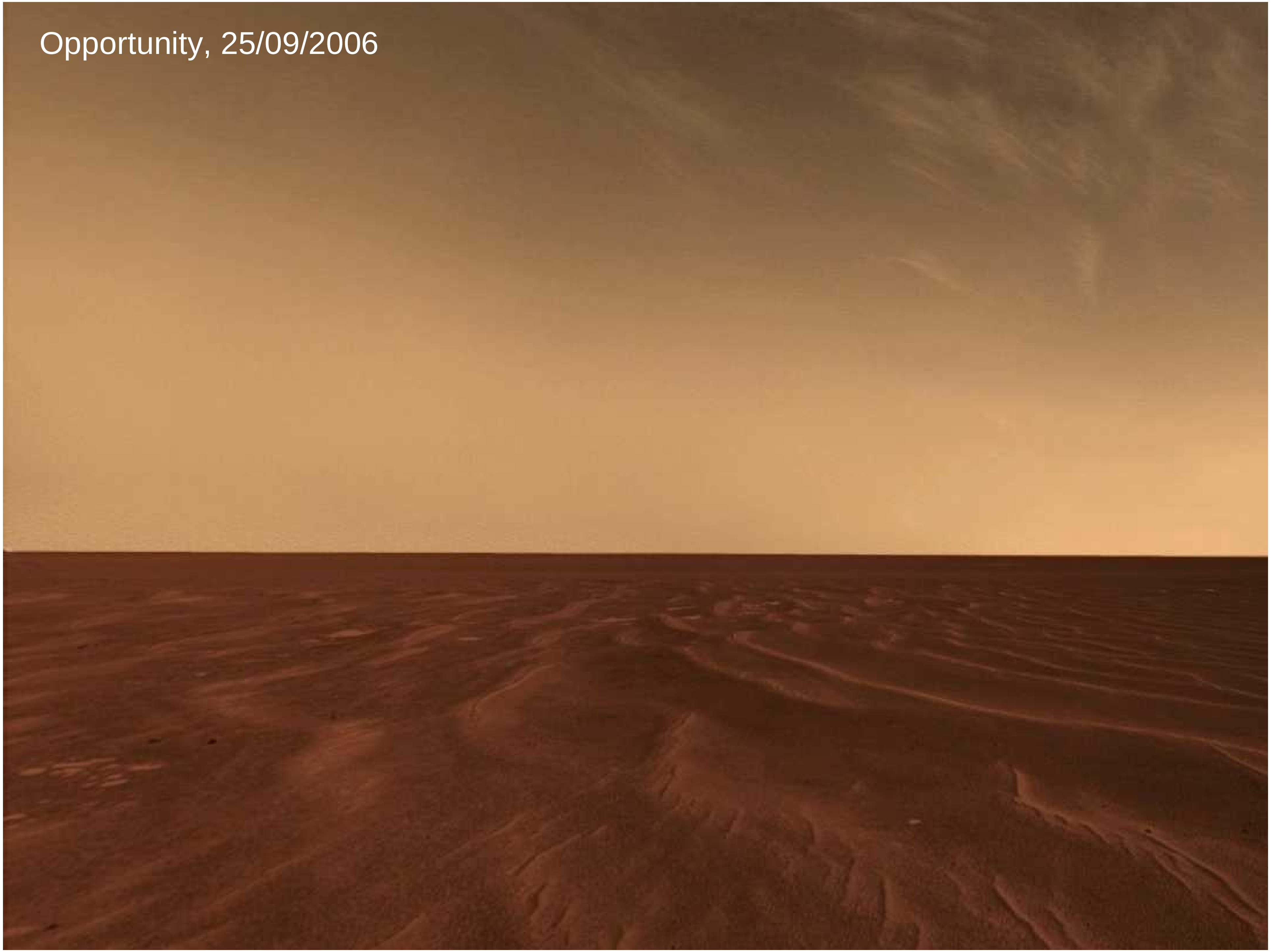




N. Summer Tropical Cloud belt



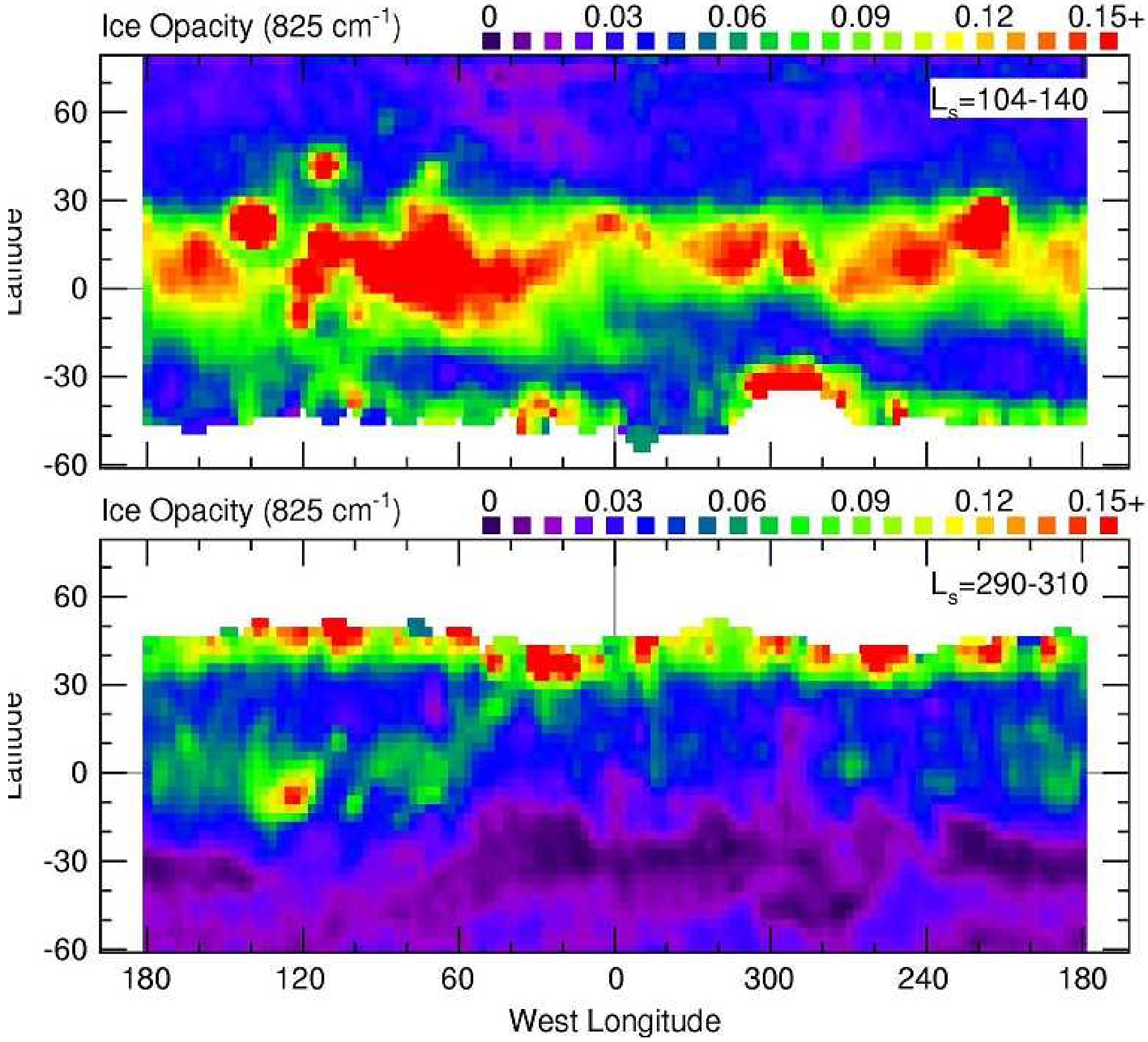
NASA/JPL/MSSS


Opportunity, 25/09/2006

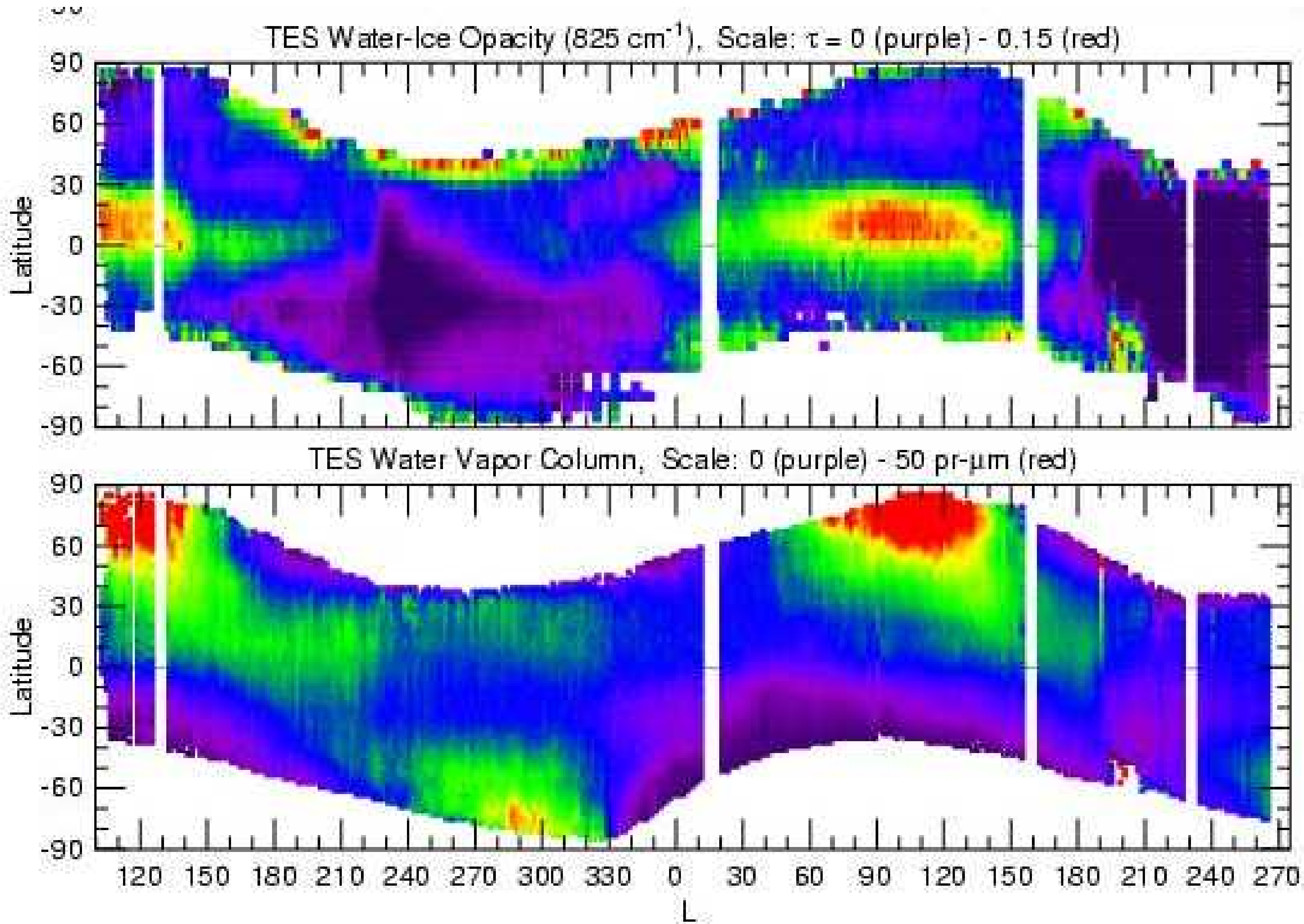
MAP of clouds:

N. Summer

N. Winter

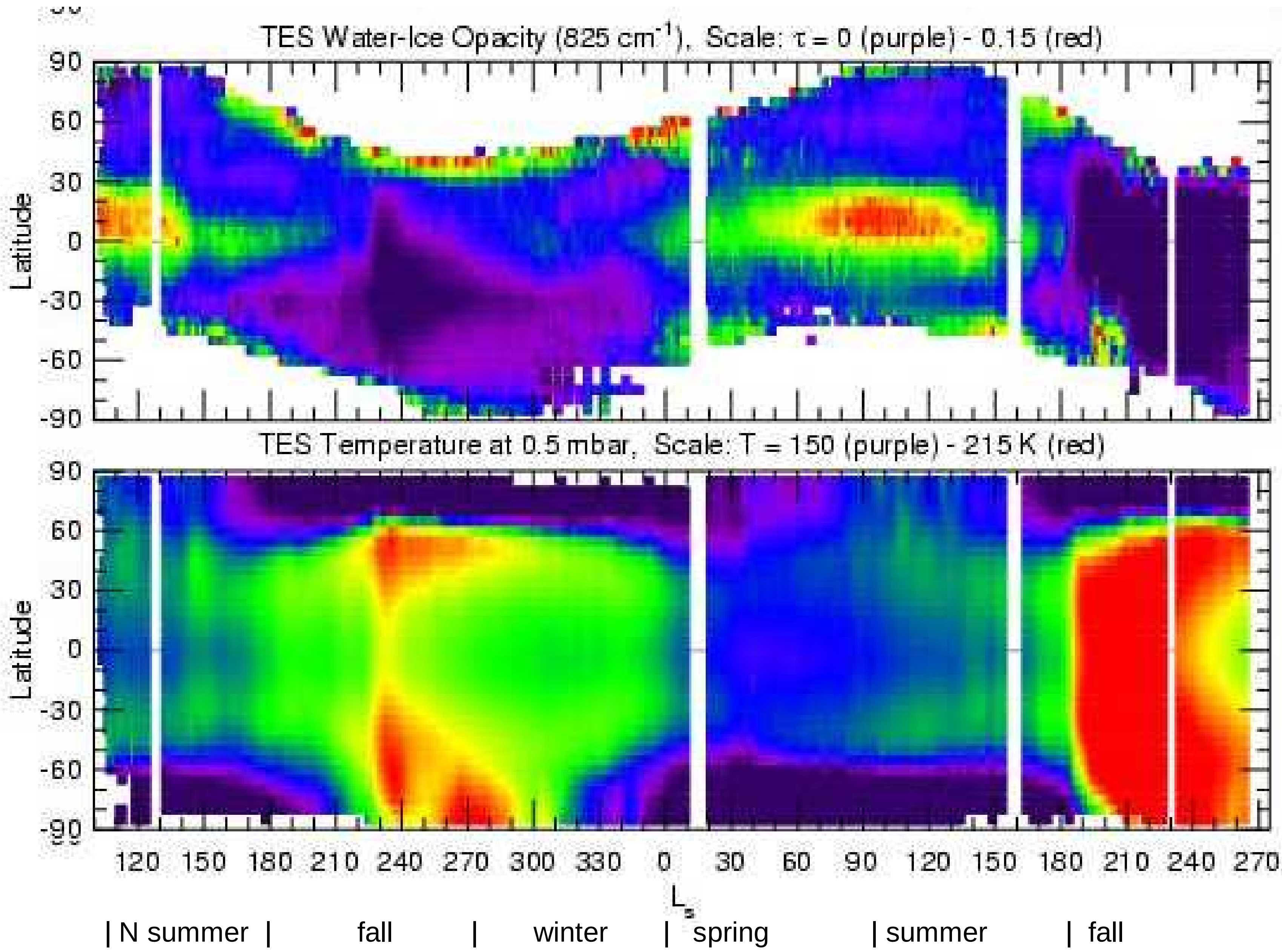


Remote sensing by TES (Mike Smith et al. , GSFC) at 2pm local time



| N summer | fall | winter | spring | summer | fall

Remote sensing by TES (Mike Smith et al. , GSFC) at 2pm local time



Other kind of clouds : Morning Haze

Remote sensing by TES (Mike Smith et al. , GSFC) at 2pm local time

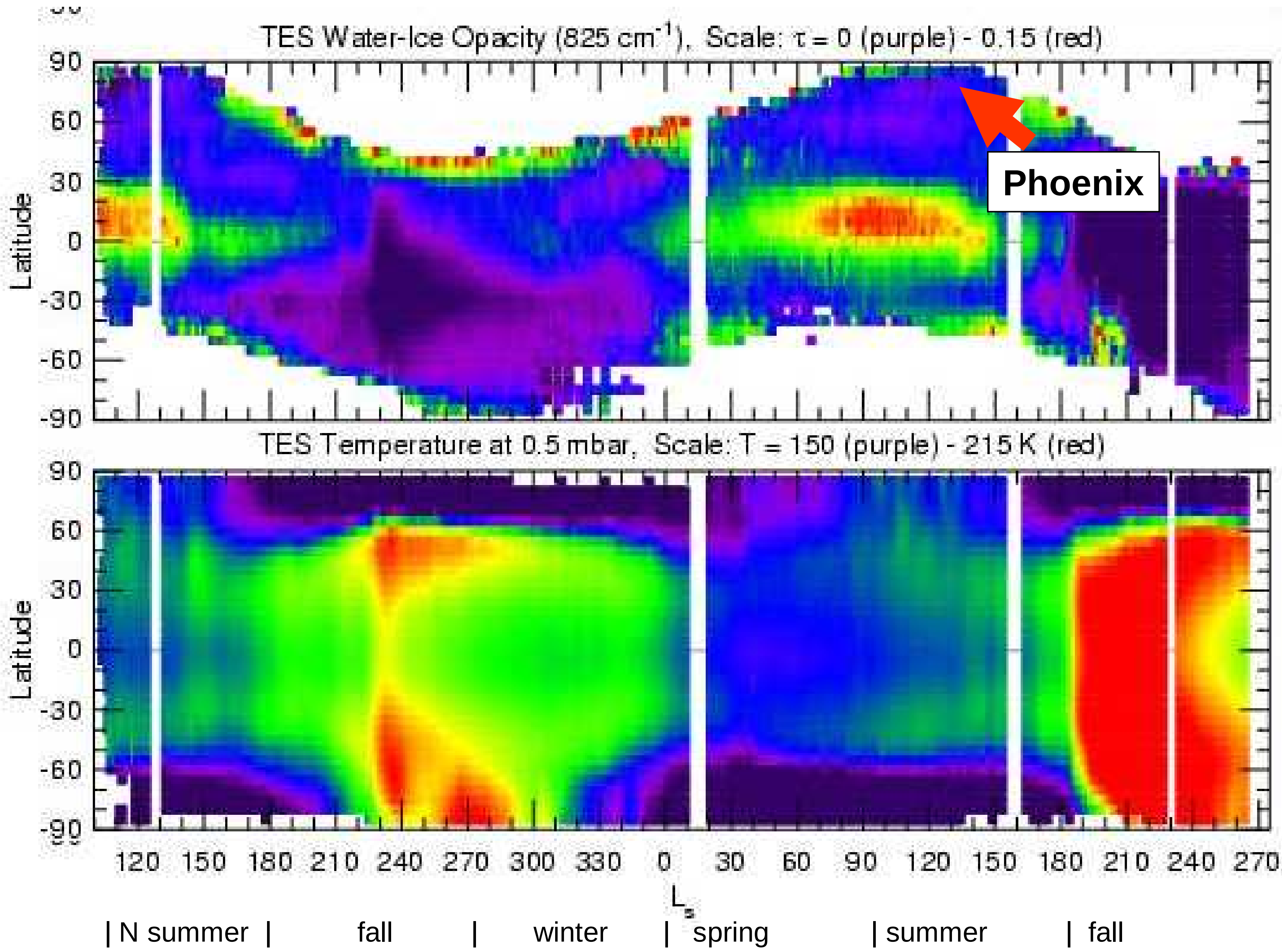
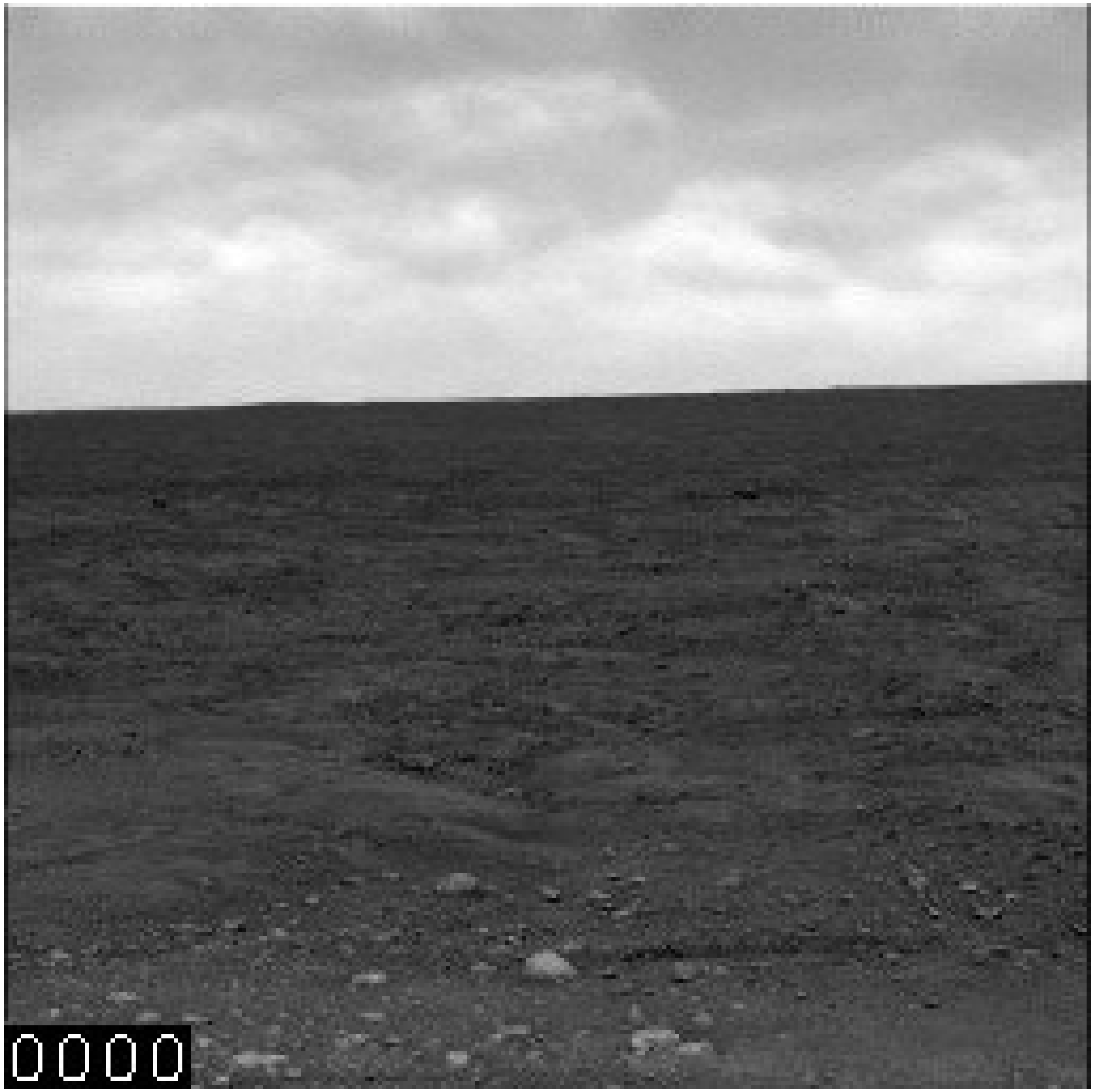
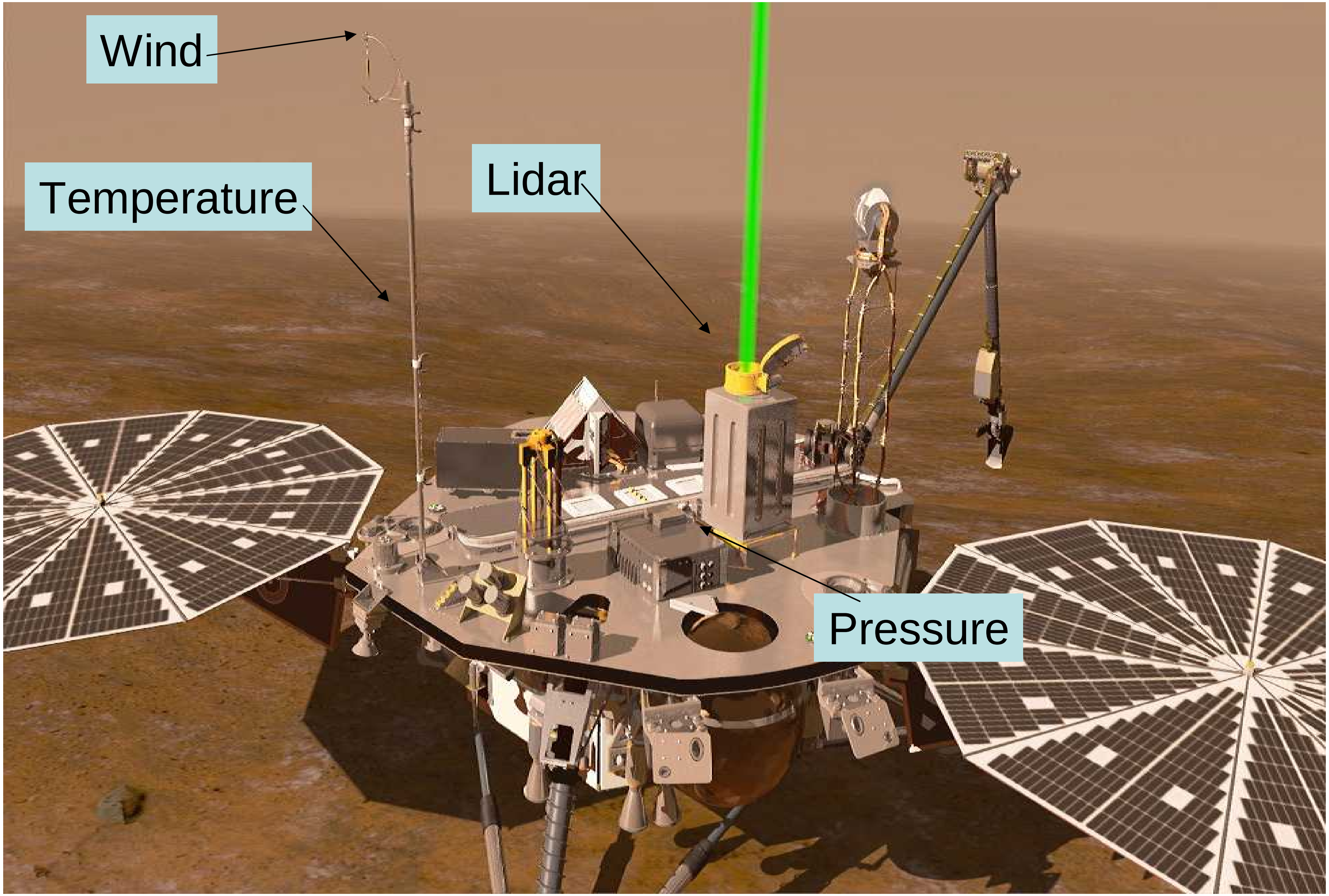


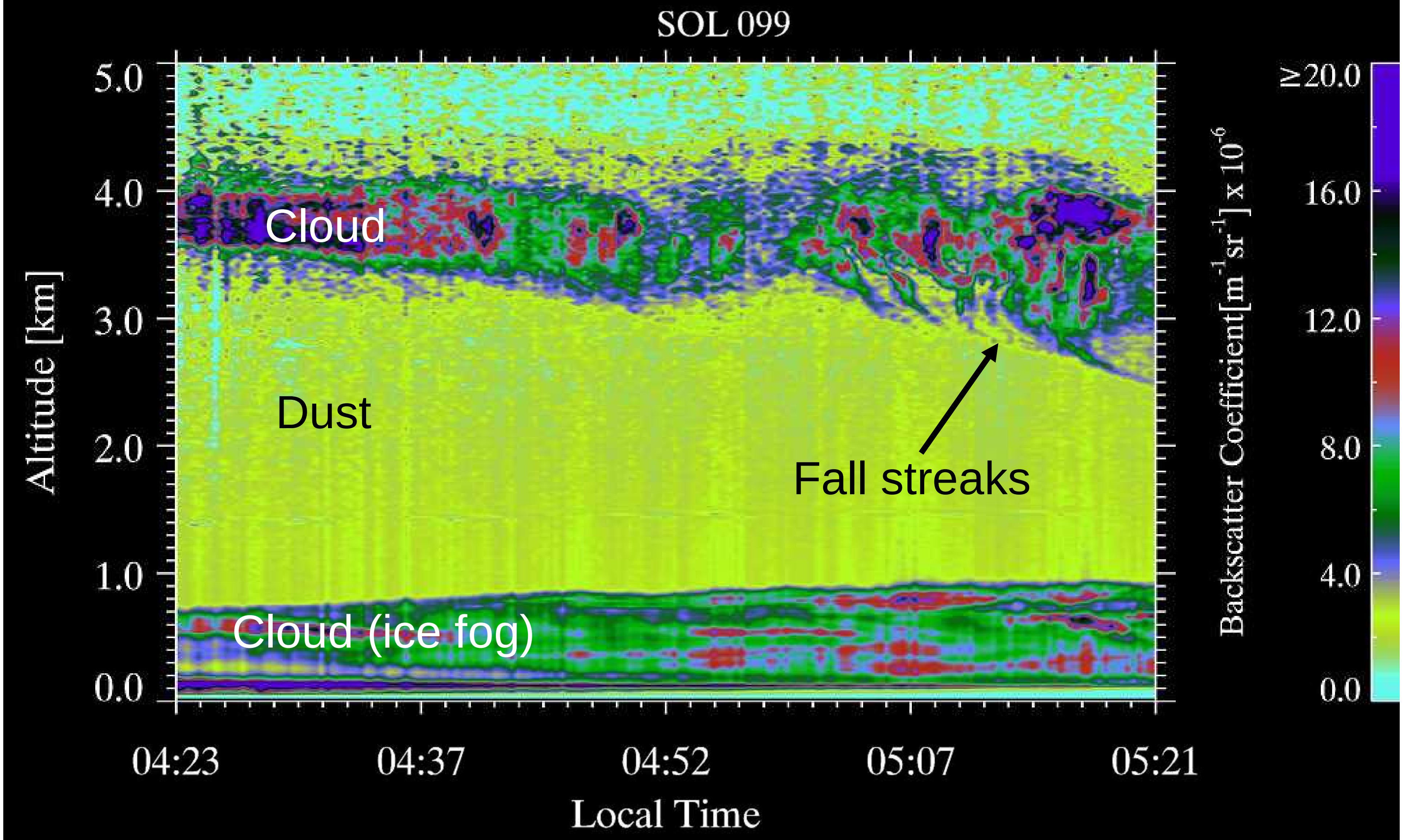
Image from Phoenix SSI camera



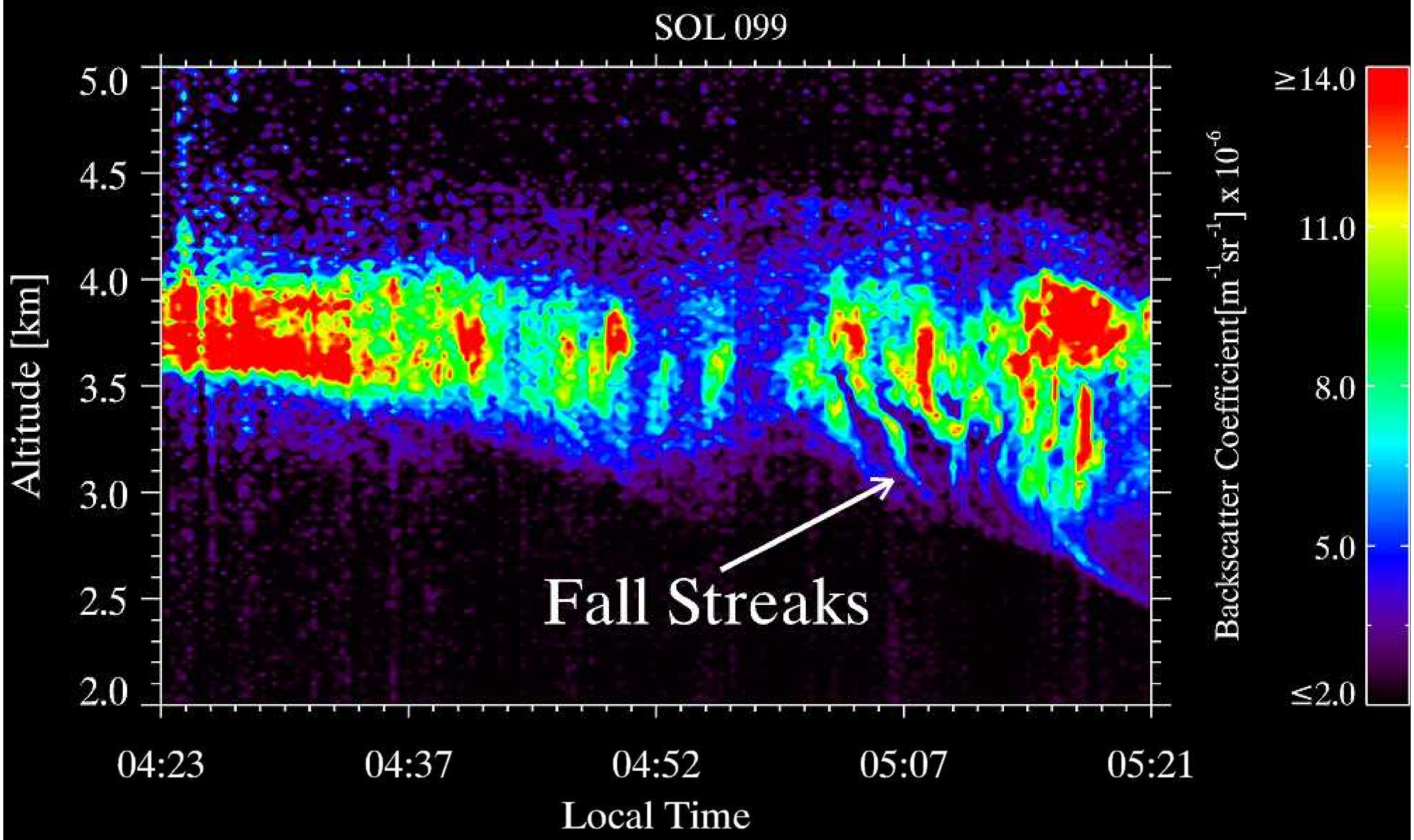
Phoenix Observations



Lidar Measurements of Dust and Clouds

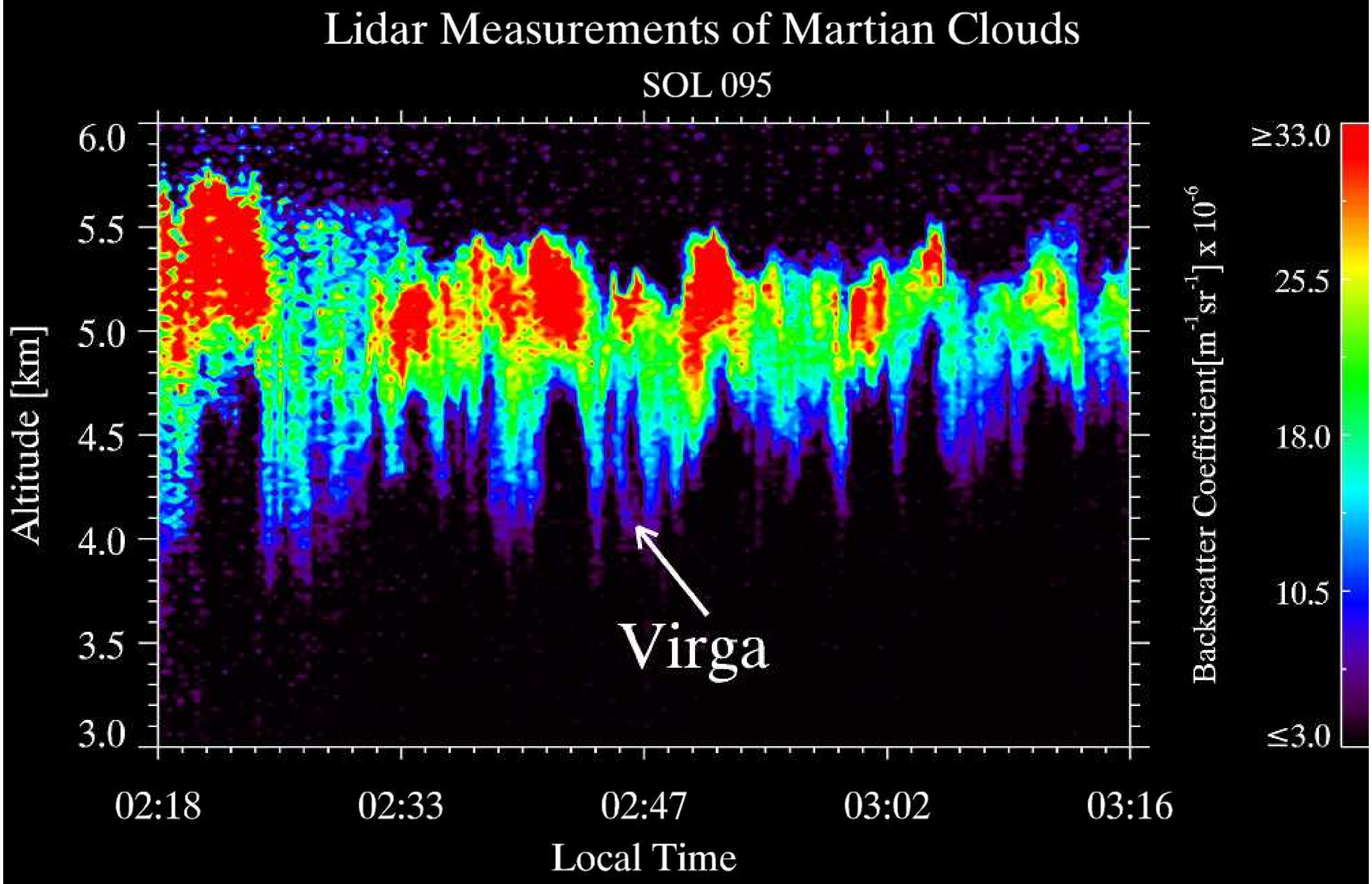


Whiteway et al. 2008



Whiteway et al. 2008

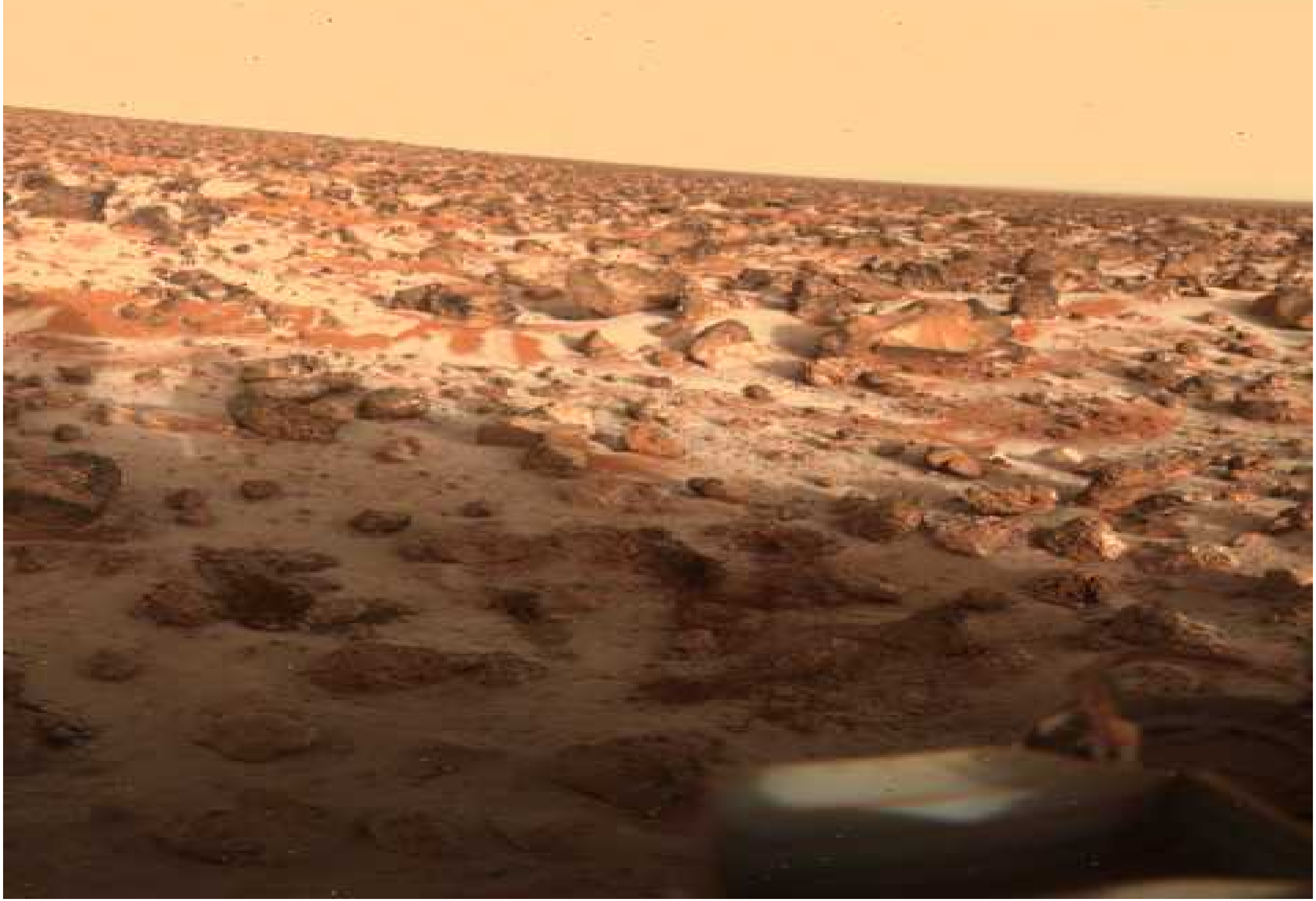

Fall Streaks
Whiteway et al. 2008
http://australiasevereweather.com/



Whiteway et al. 2008

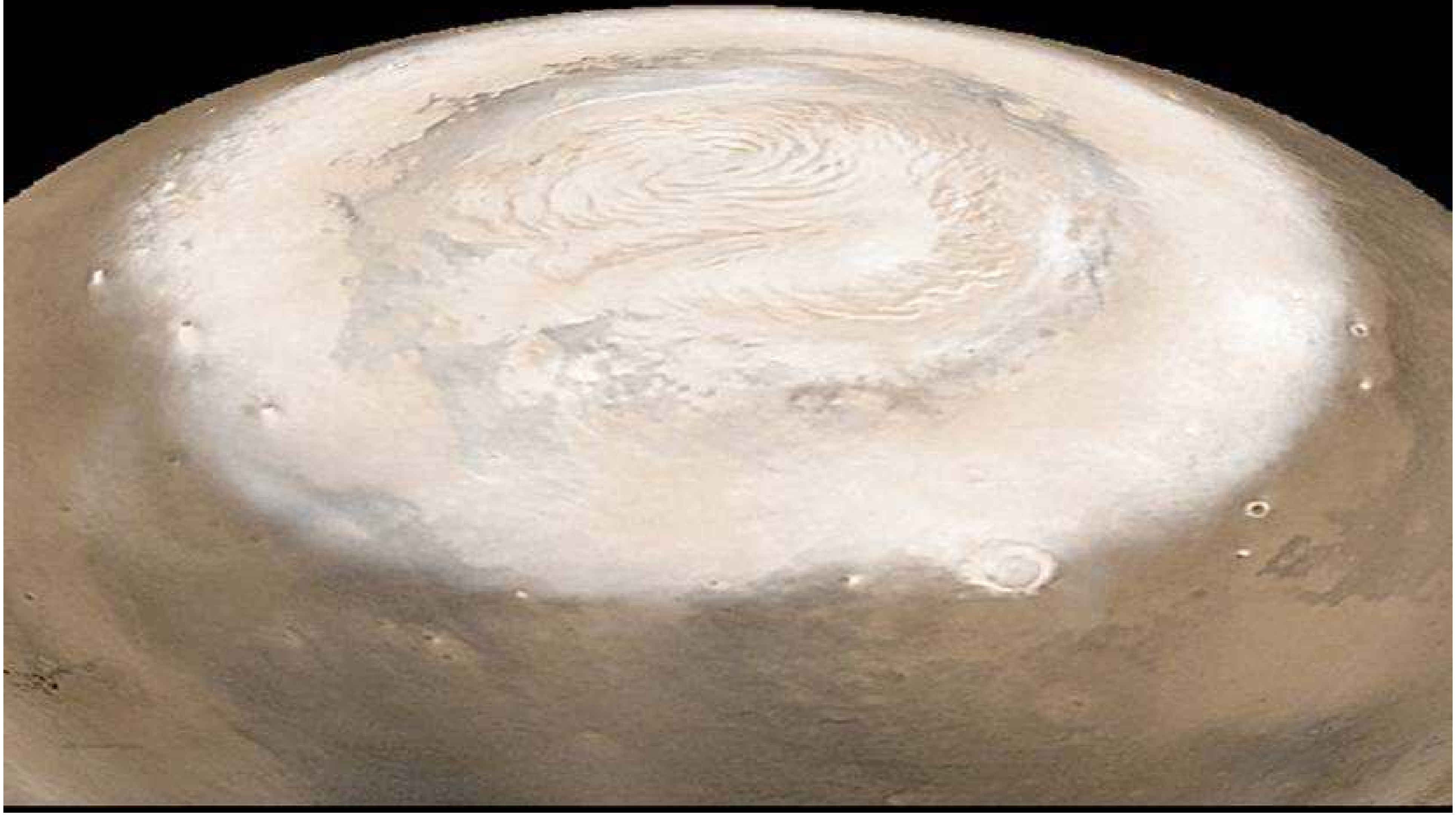

Virga

Surface frost, Viking Lander 2 (48 ° N) in winter



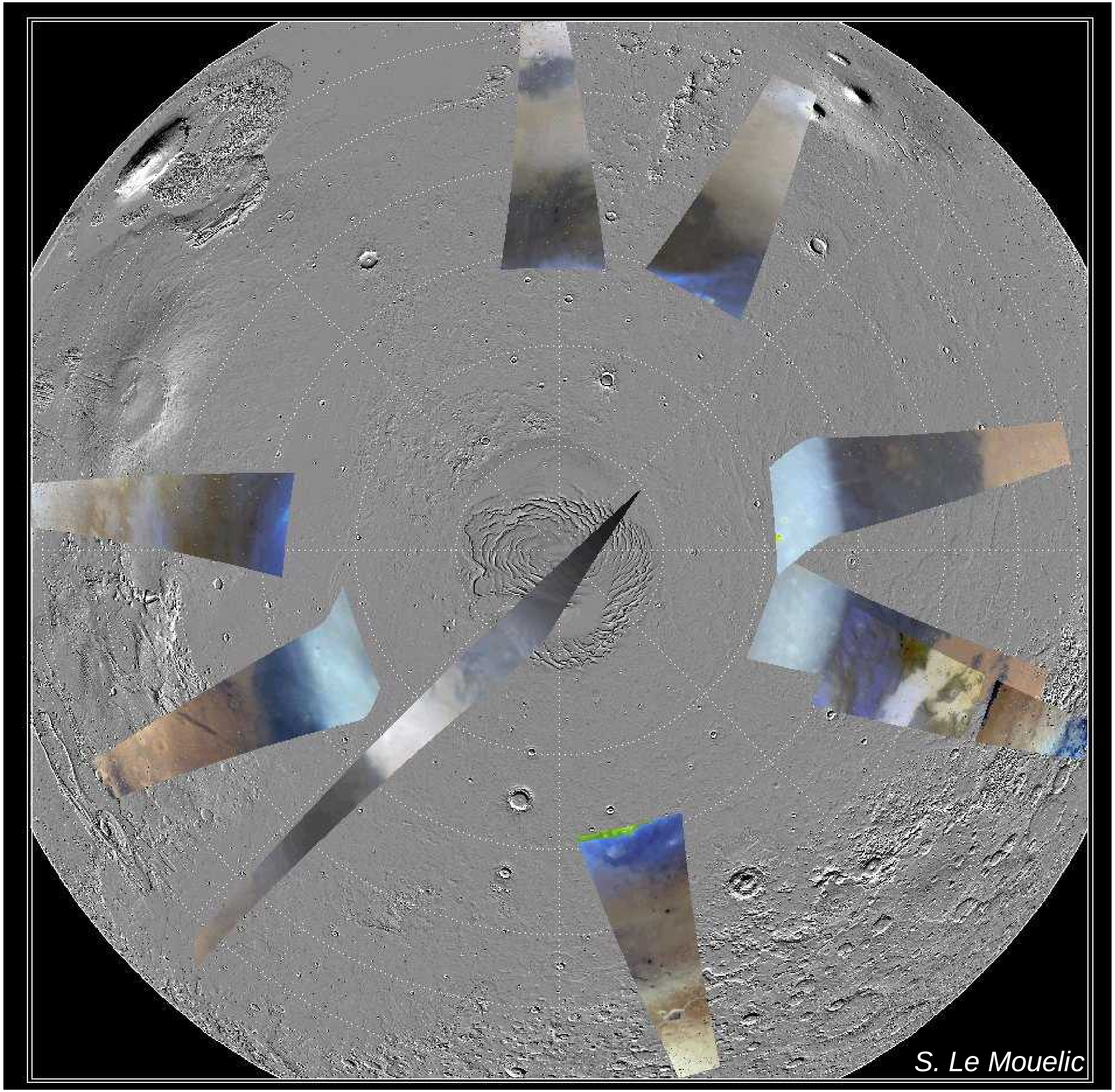
Seasonal ice cap in spring

(mosaic of the northern polar cap)



OMEGA data (visible)

S. Le mouelic



Ls=12-17 °

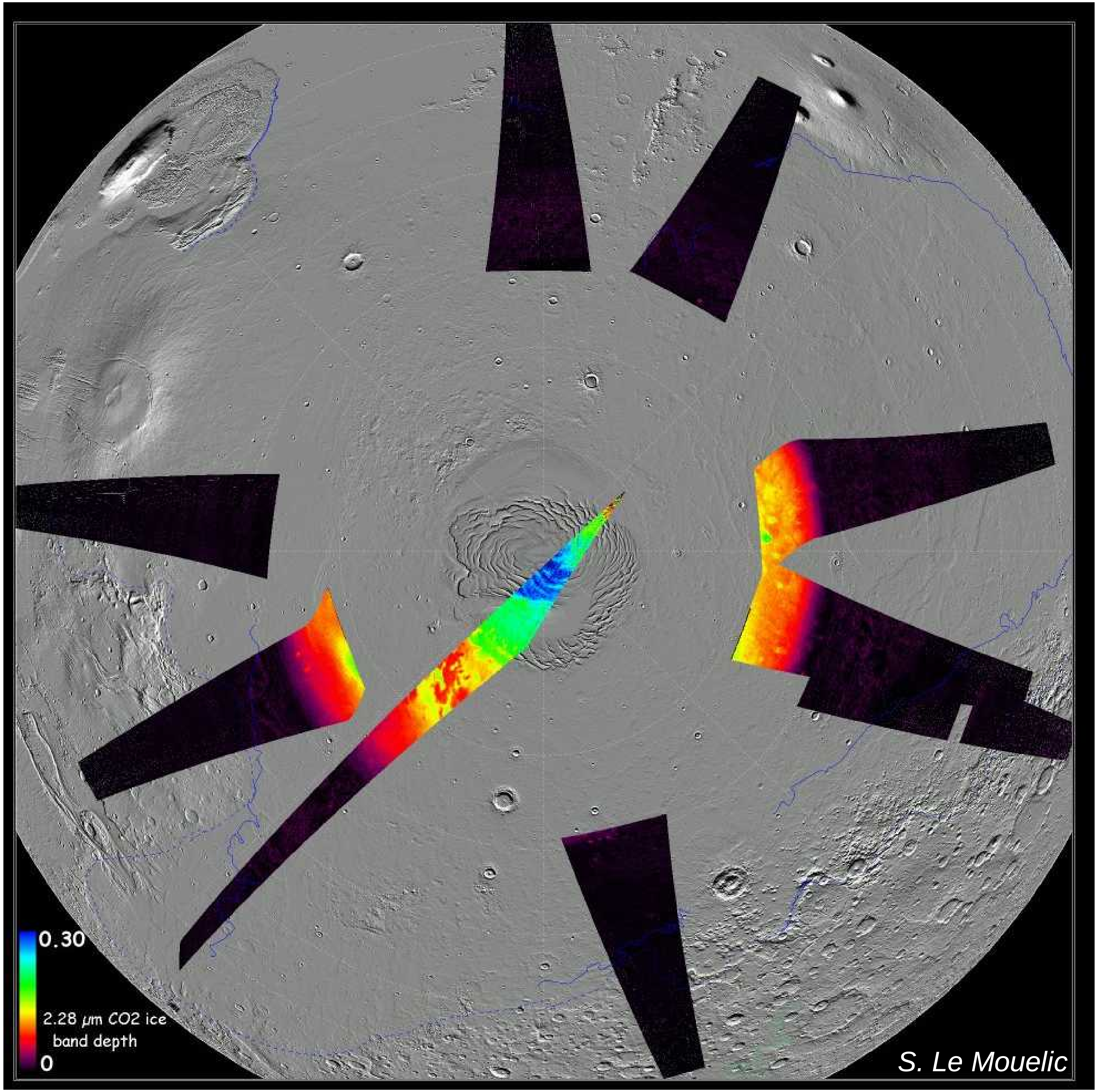
26 March – 9 April

CO_2 ice

S. Le mouelic

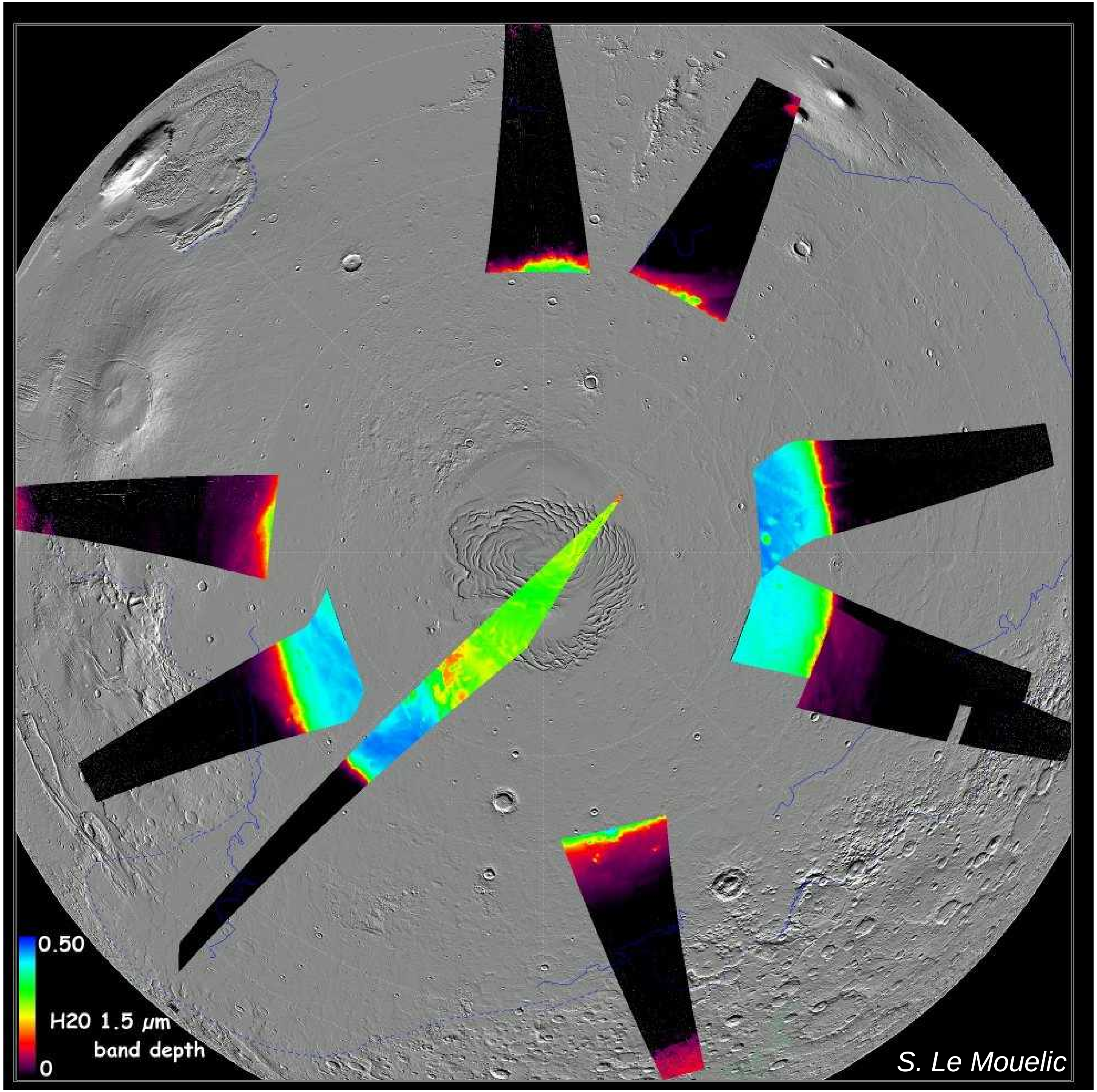
Ls=12-17 °

26 March
–
9 April



H_2O ice

S. Le mouelic



Ls=12-17 °

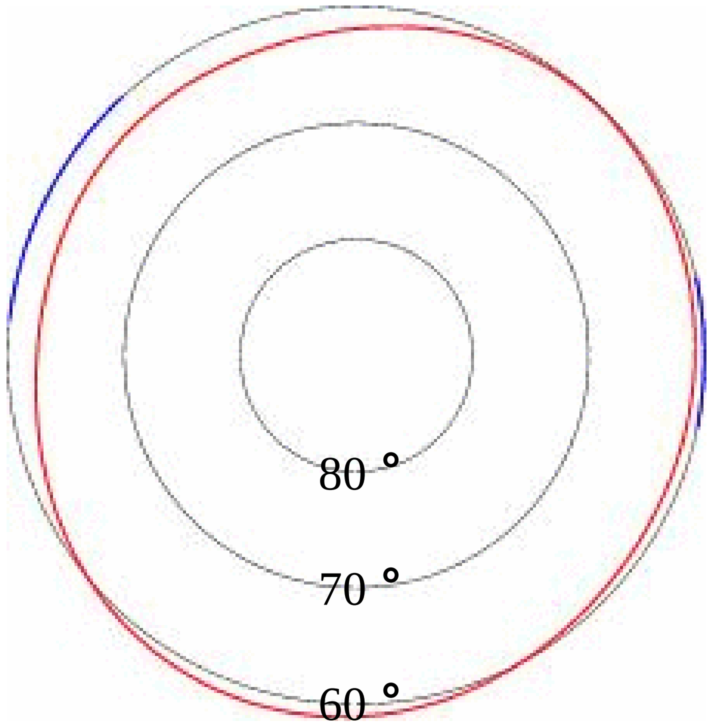
26 March
–
9 April

Recession of the Northern seasonal ice cap as seen by TES (*Titus et al. 2005*)

Ls = 0 – 90 °   (MGS year 3)

Blue : Albedo boundary (water frost)

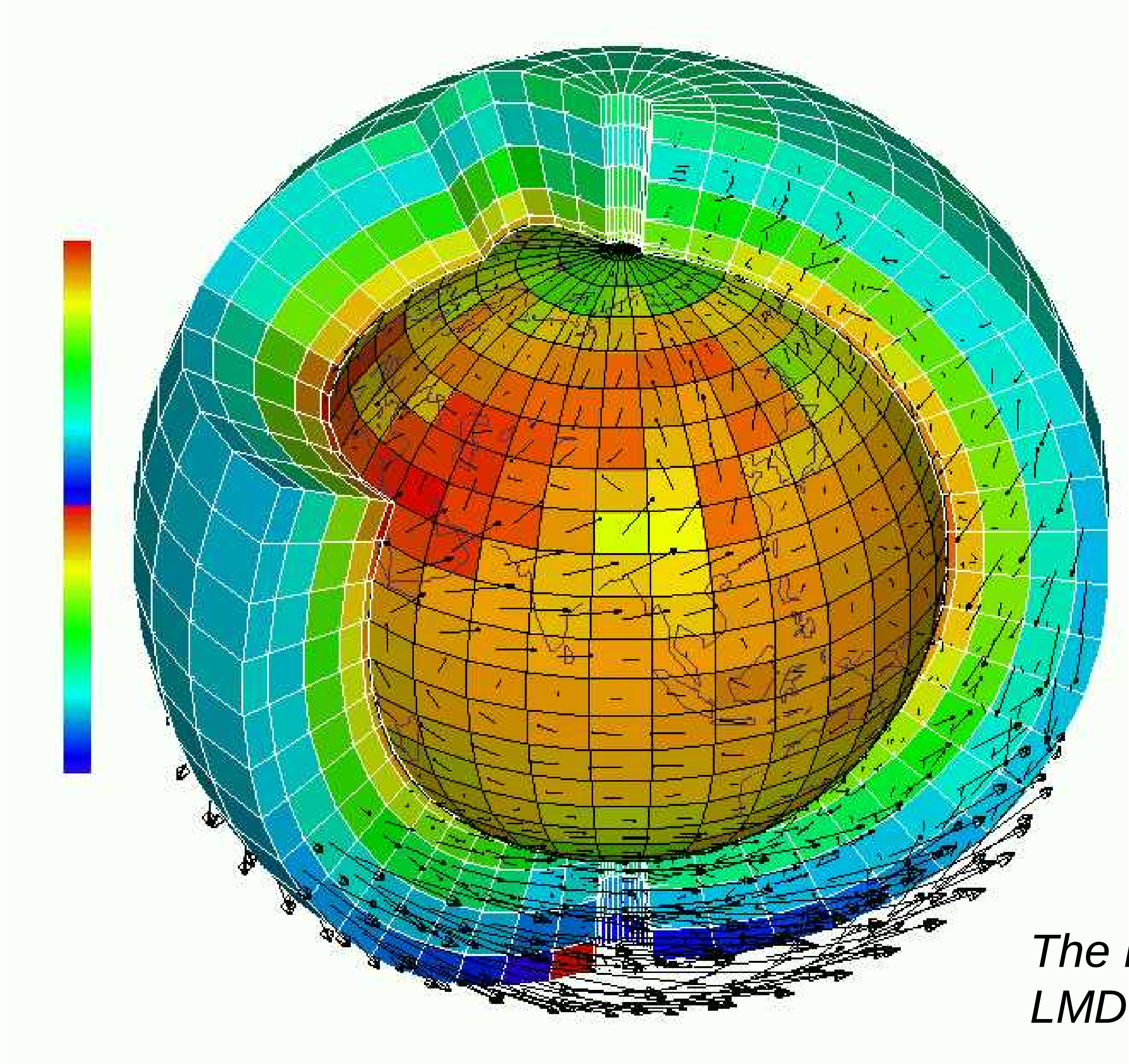
Red : Thermal boundary (CO_2 frost)



90 ° E

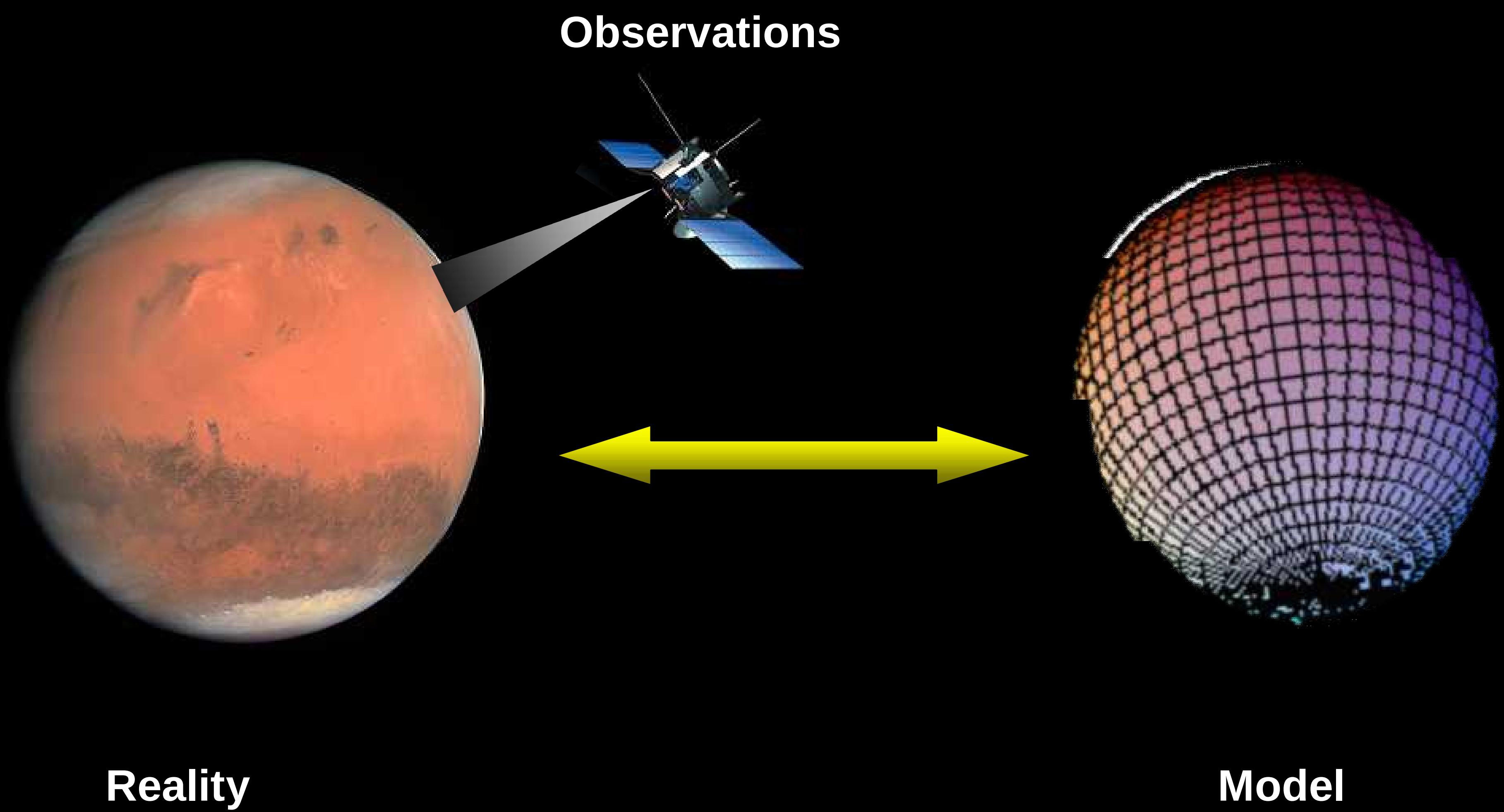
0 ° E

Modelling Mars water cycle with a Numerical Global Climate Model



The European GCM
LMD-AOPP-OU-IAA

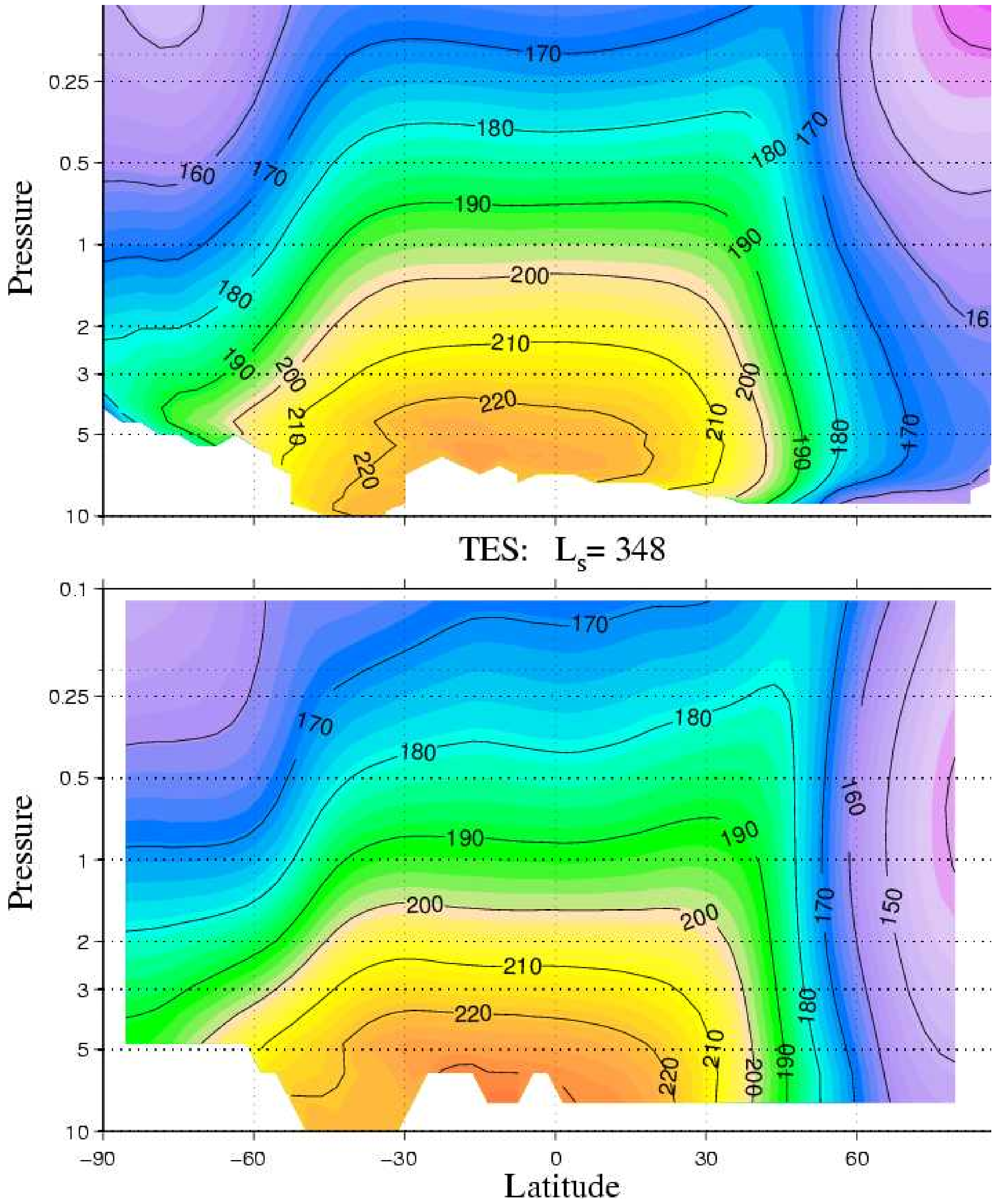
Simulation of planet Mars with a Global Climate Model (GCM)



Zonal mean temperature

Ls = 348 °

LMD GCM



TES Observations

Figures from John Wilson !

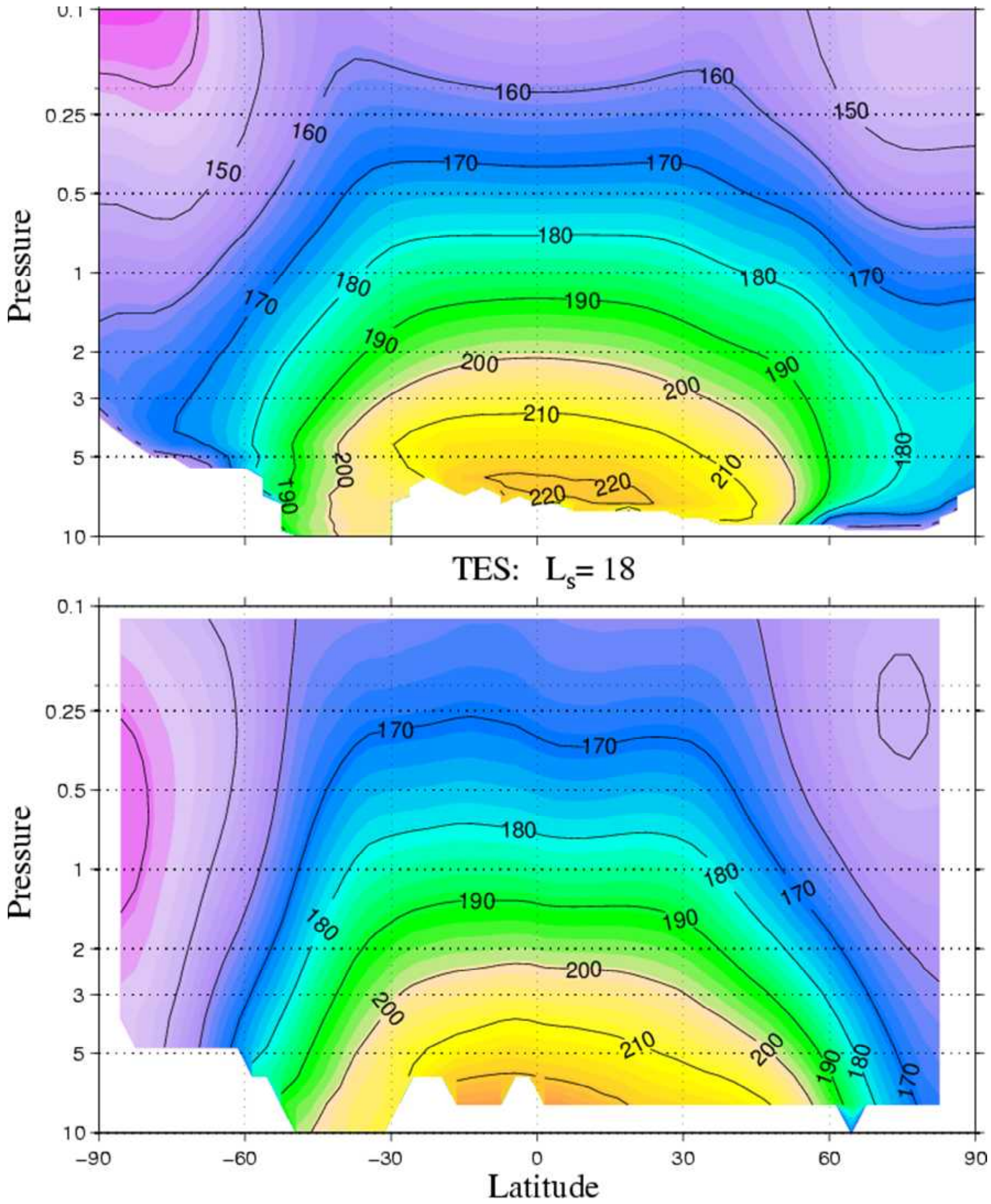
Zonal mean temperature

Ls = 18 °

LMD GCM

TES Observations

Figures from John Wilson !



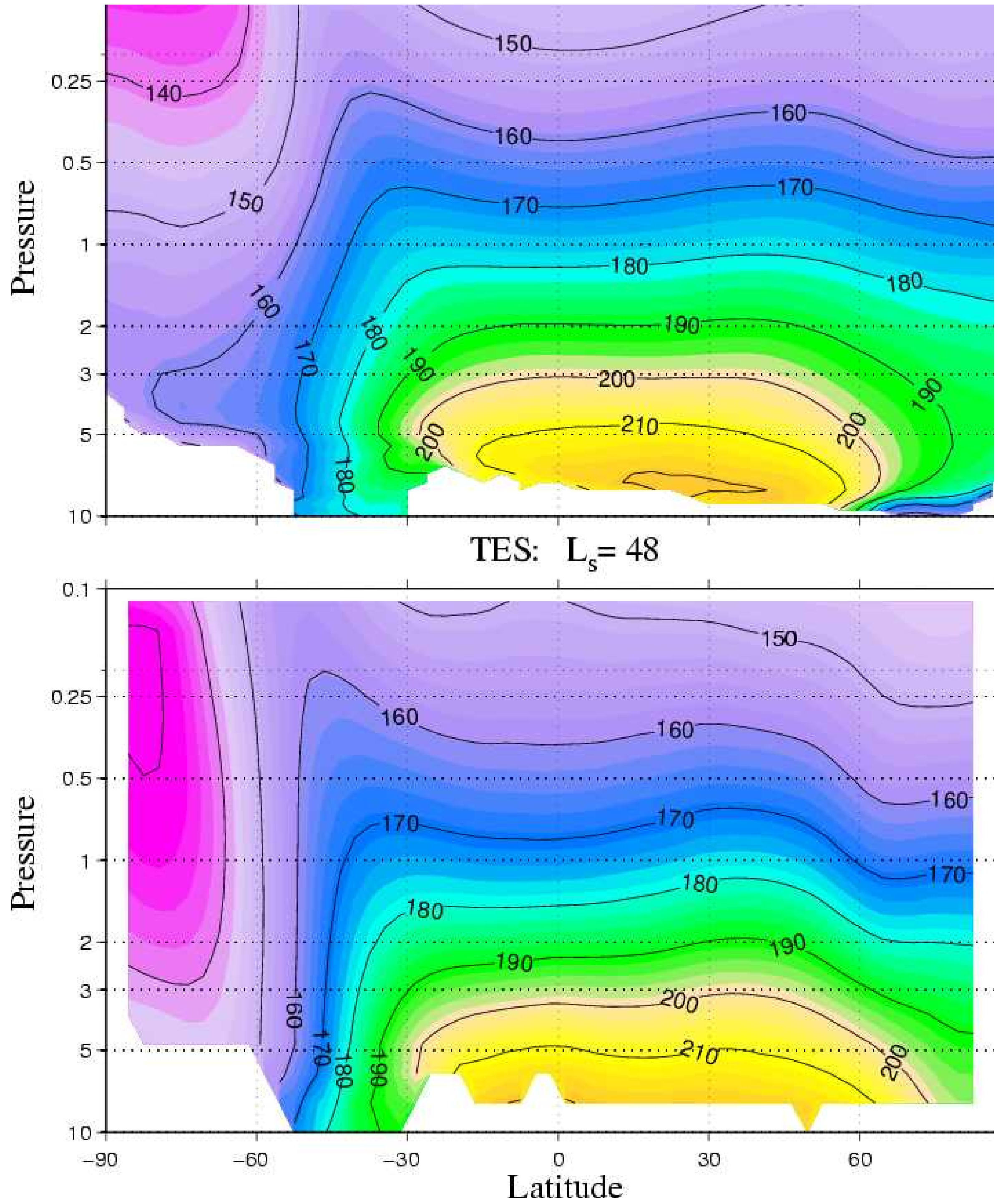
Zonal mean temperature

Ls = 48 °

LMD GCM

TES Observations

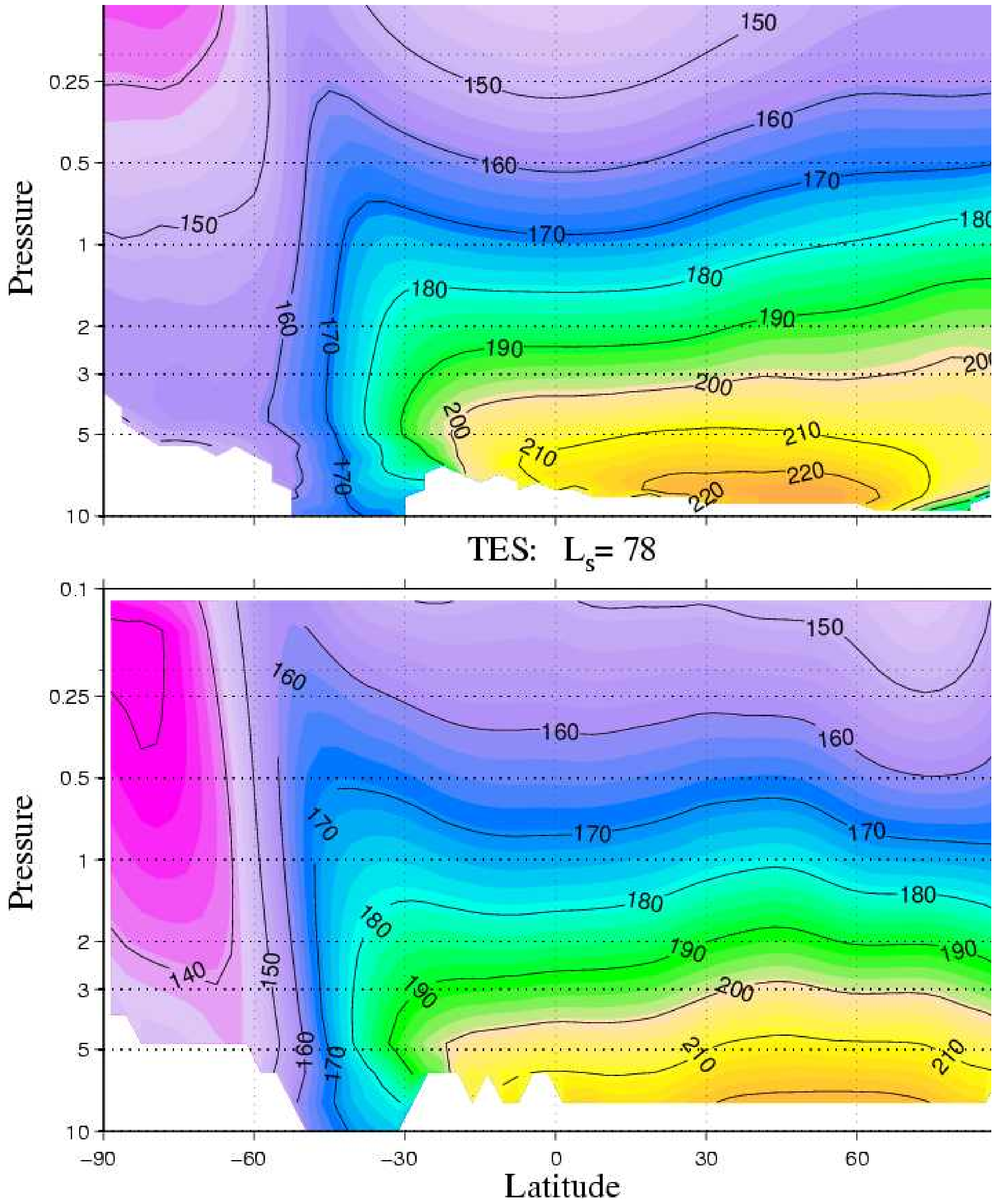
Figures from John Wilson !



Zonal mean temperature

Ls = 78 °

LMD GCM



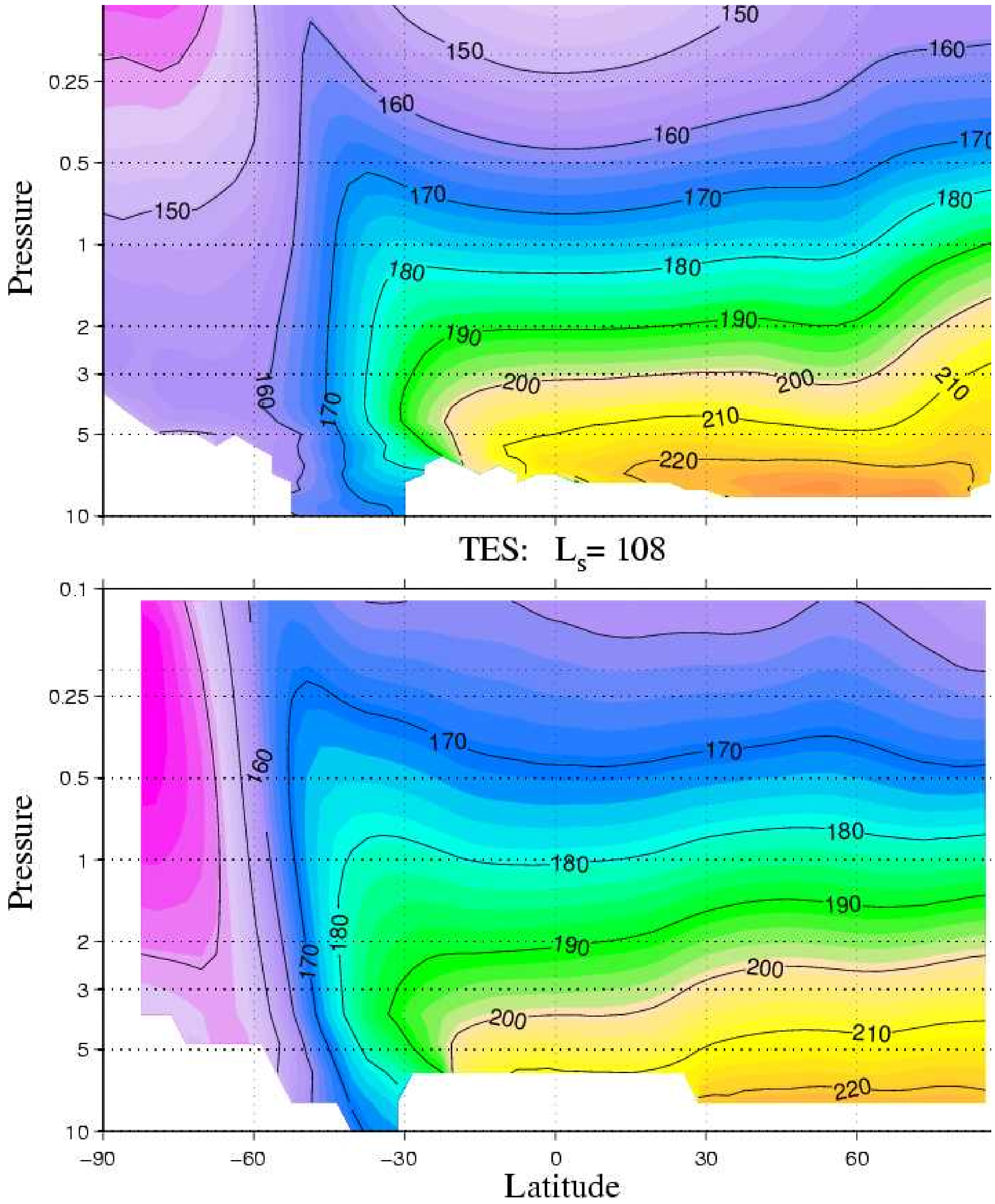
TES Observations

Figures from John Wilson !

Zonal mean temperature

Ls = 108 °

LMD GCM



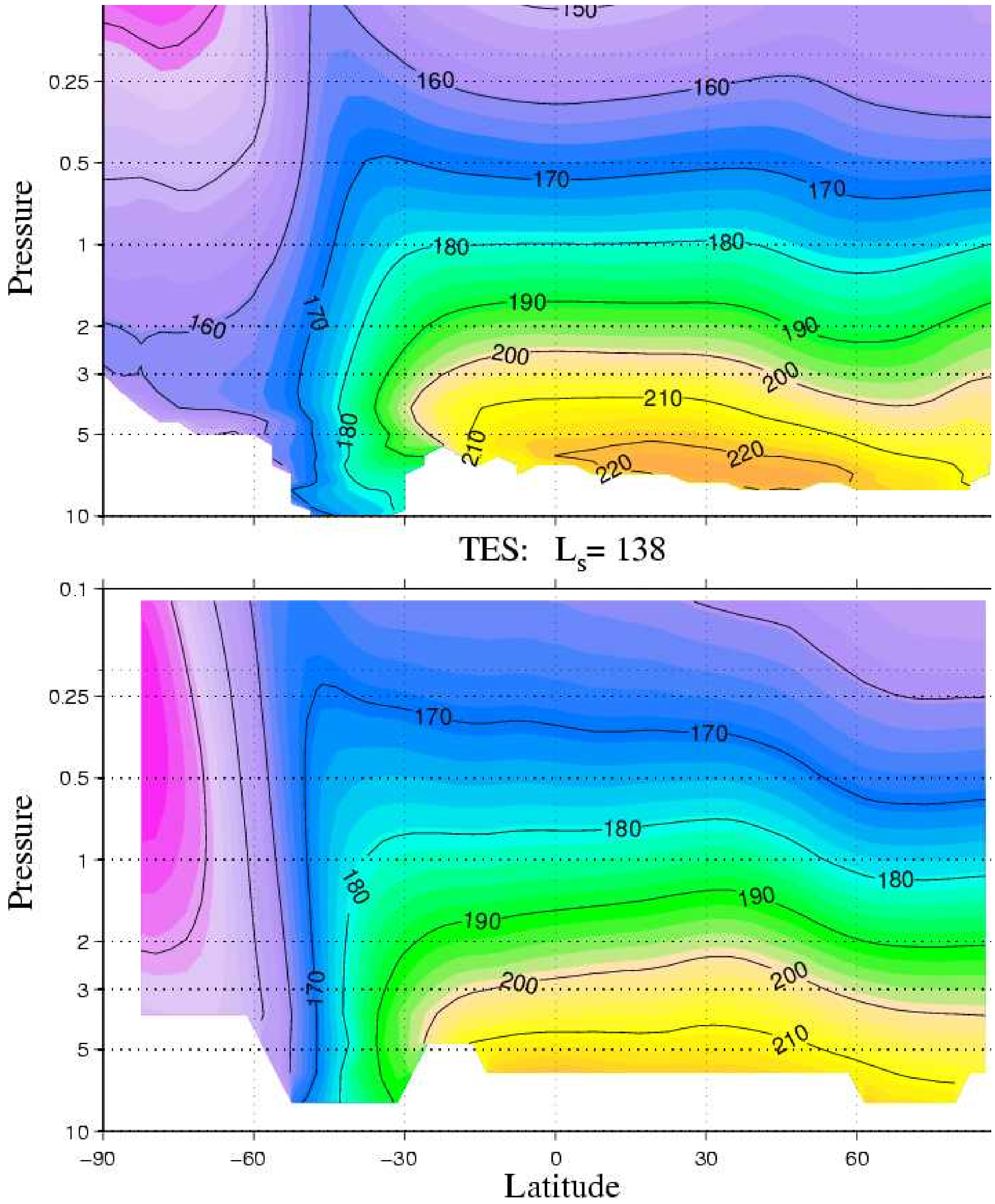
TES Observations

Figures from John Wilson !

Zonal mean temperature

Ls = 138 °

LMD GCM



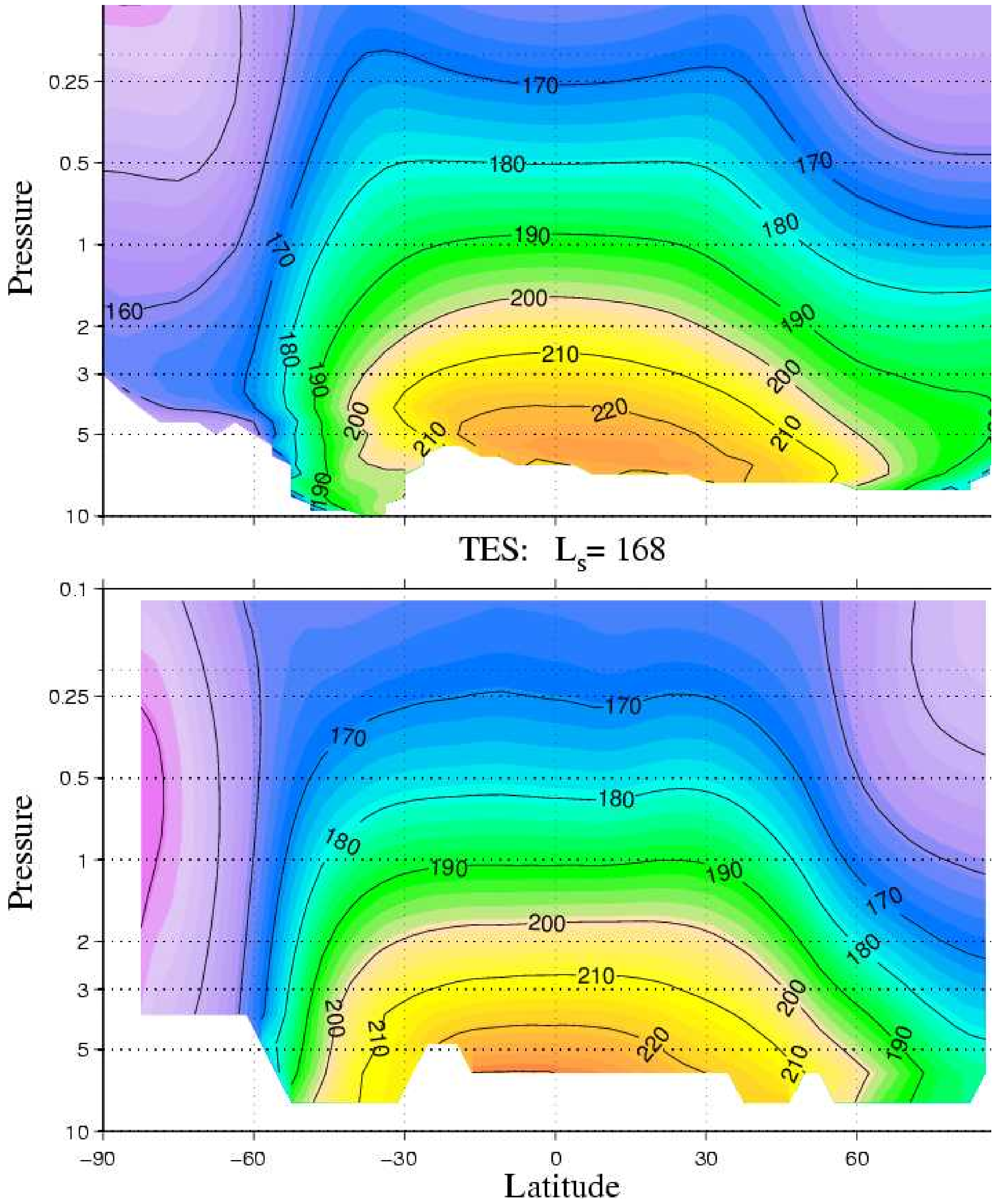
TES Observations

Figures from John Wilson !

Zonal mean temperature

Ls = 168 °

LMD GCM



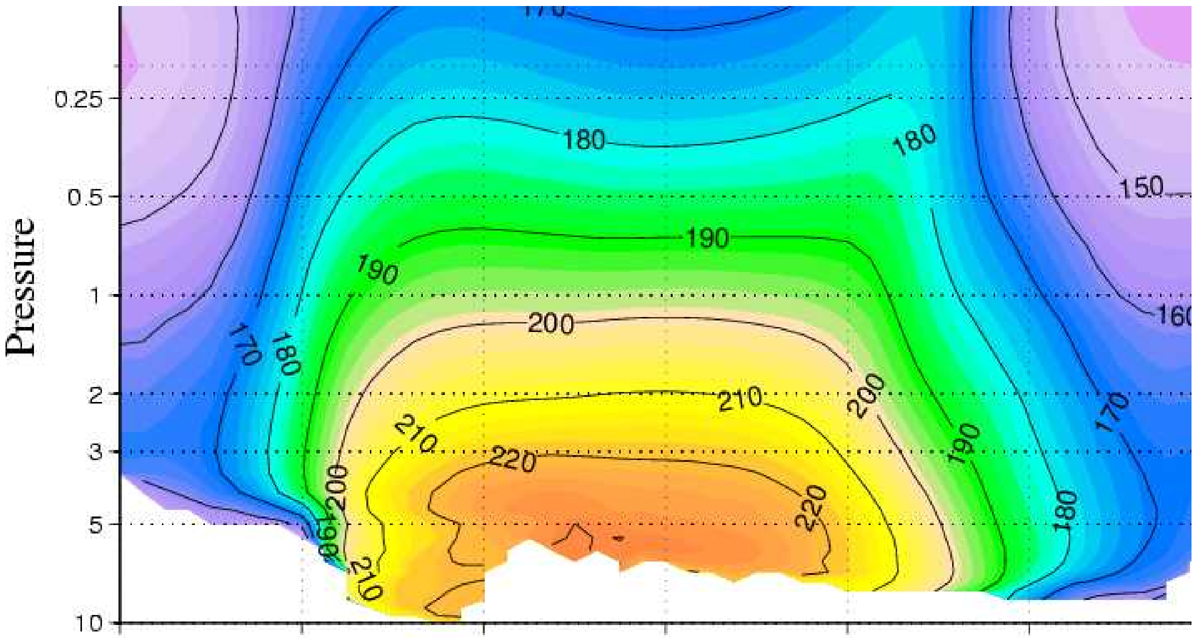
TES Observations

Figures from John Wilson !

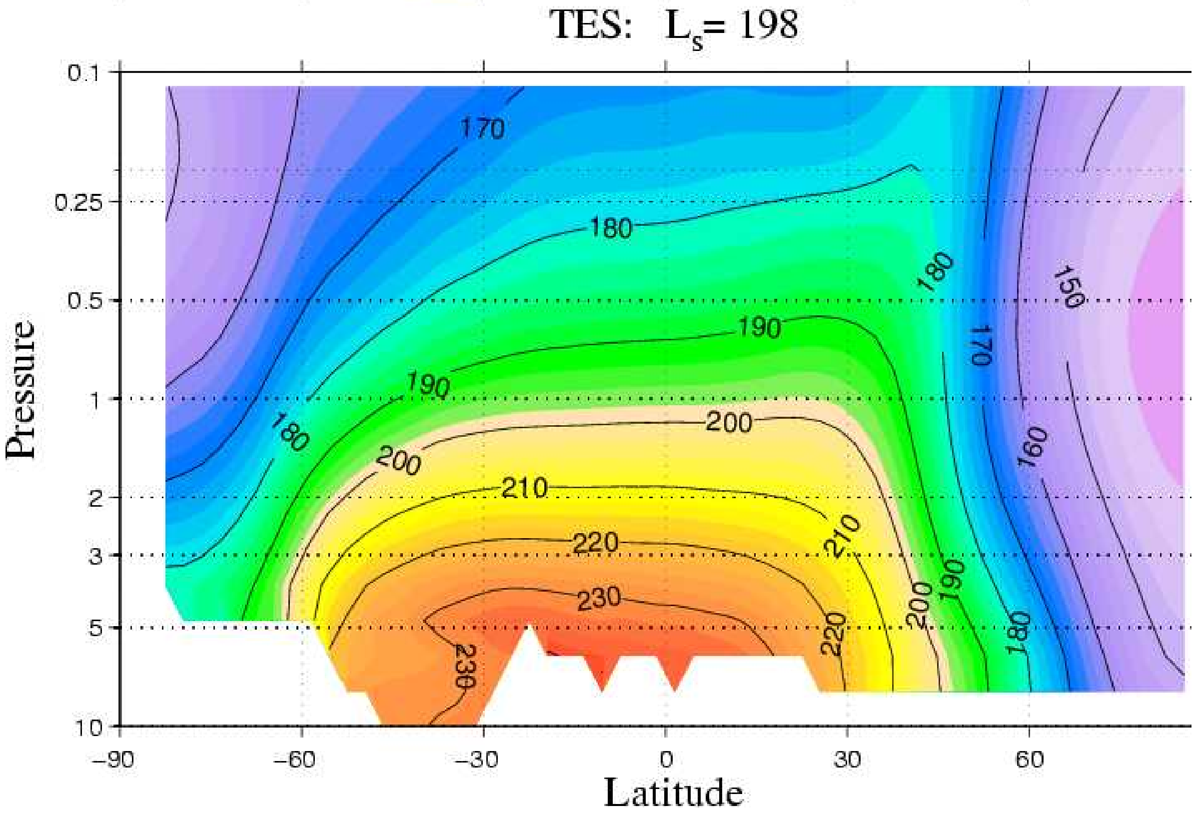
Zonal mean temperature

Ls = 198 °

LMD GCM



TES Observations



Figures from John Wilson !

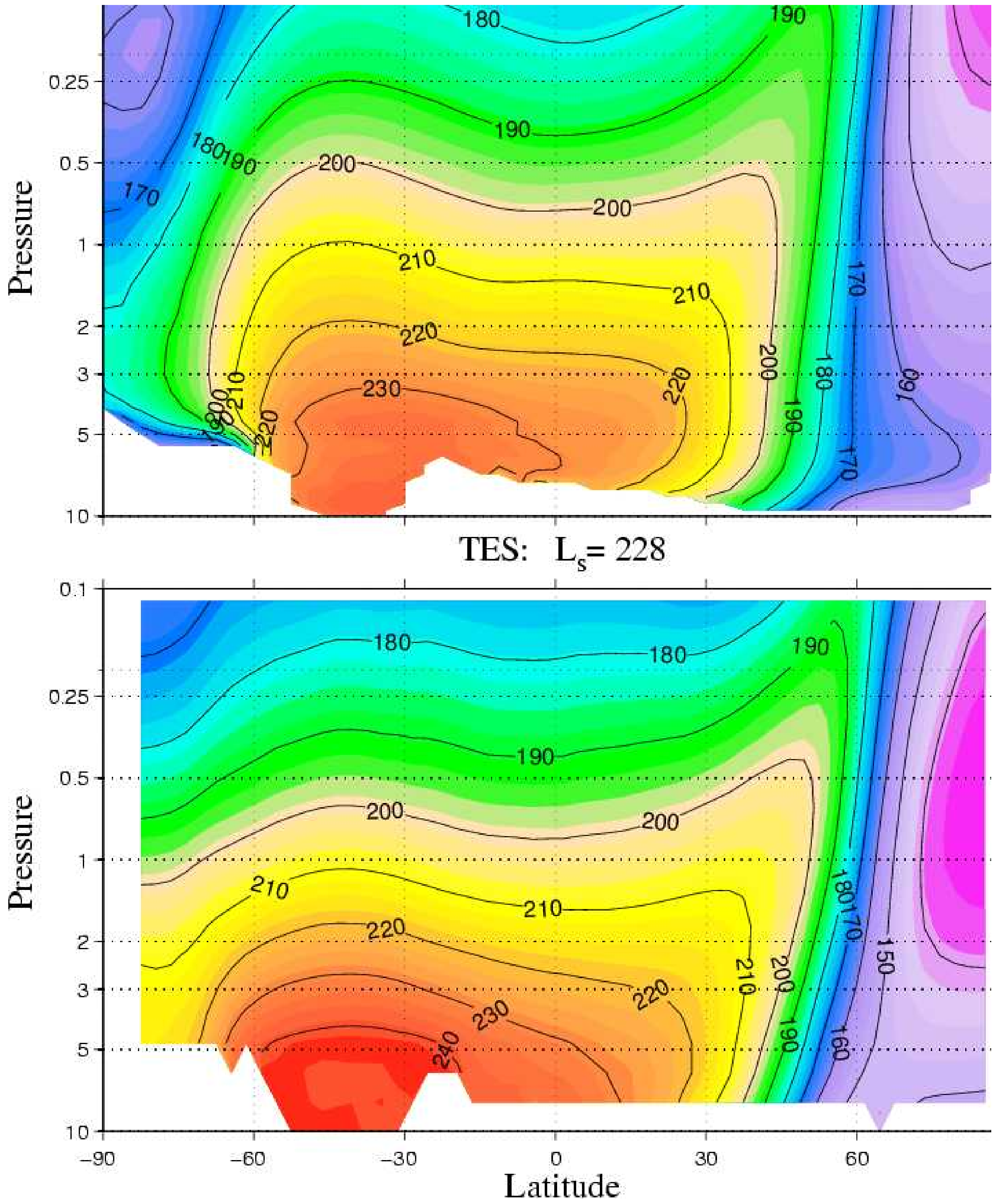
Zonal mean temperature

Ls = 228 °

LMD GCM

TES Observations

Figures from John Wilson !



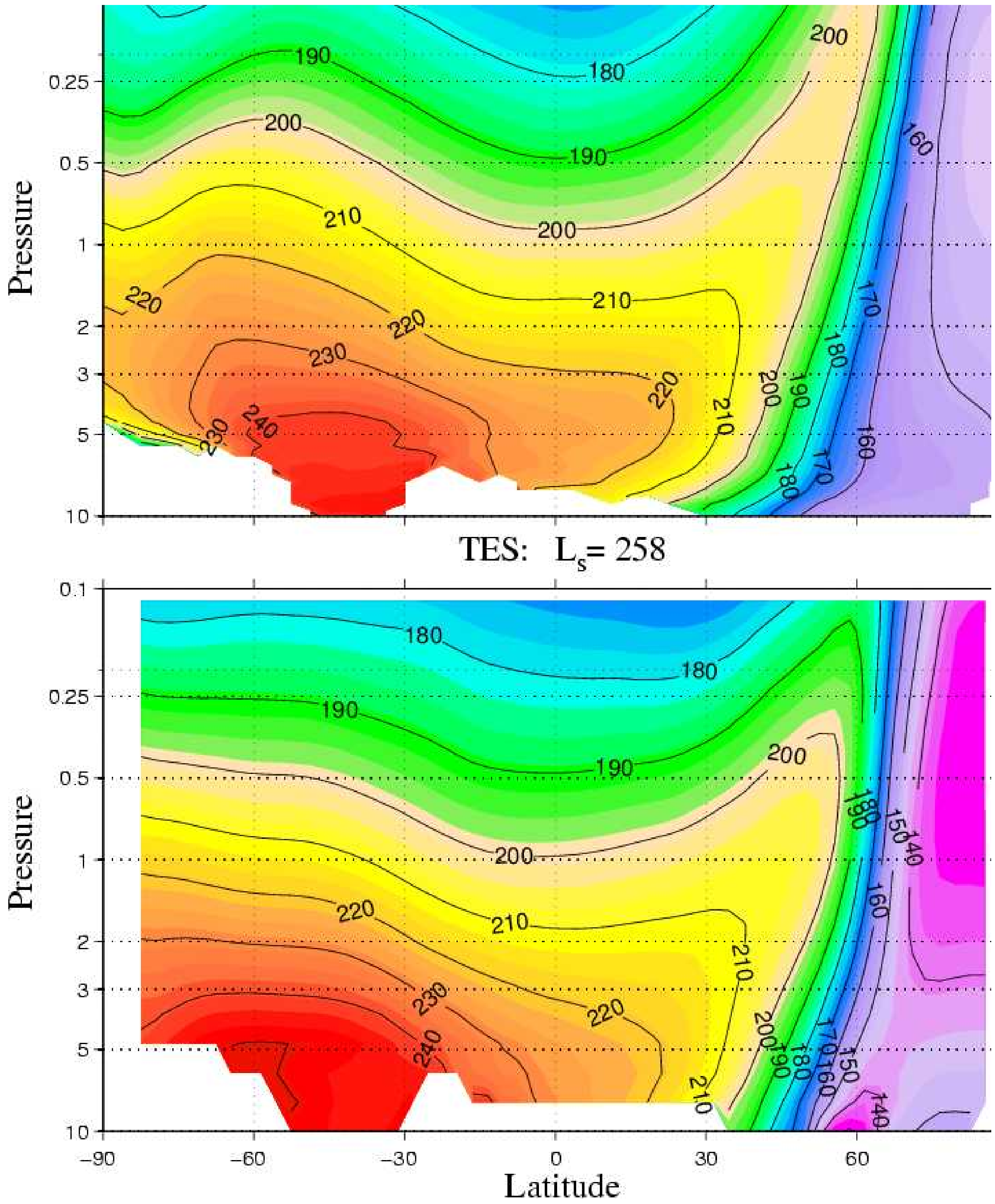
Zonal mean temperature

Ls = 258 °

LMD GCM

TES Observations

Figures from John Wilson !



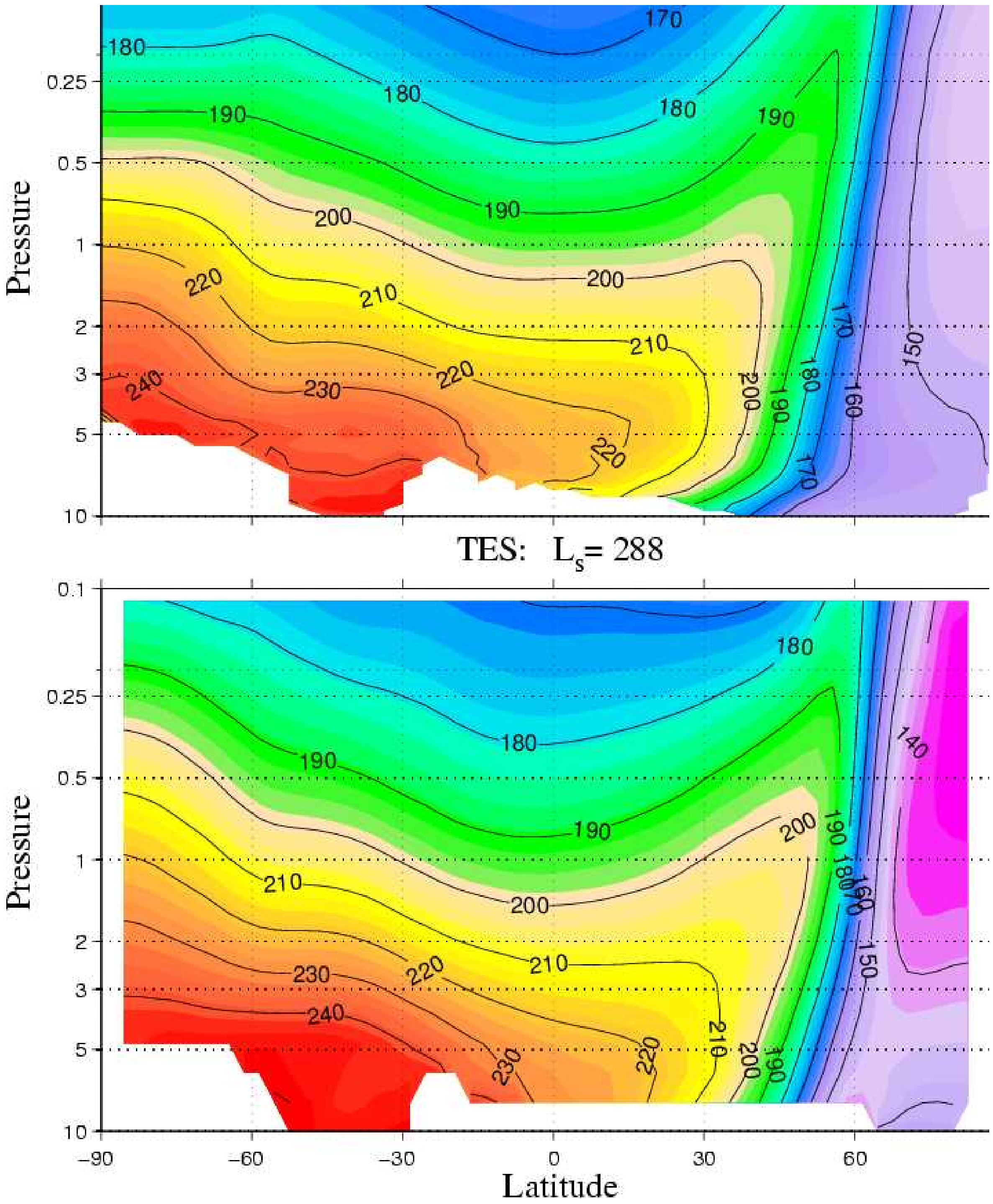
Zonal mean temperature

Ls = 288 °

LMD GCM

TES Observations

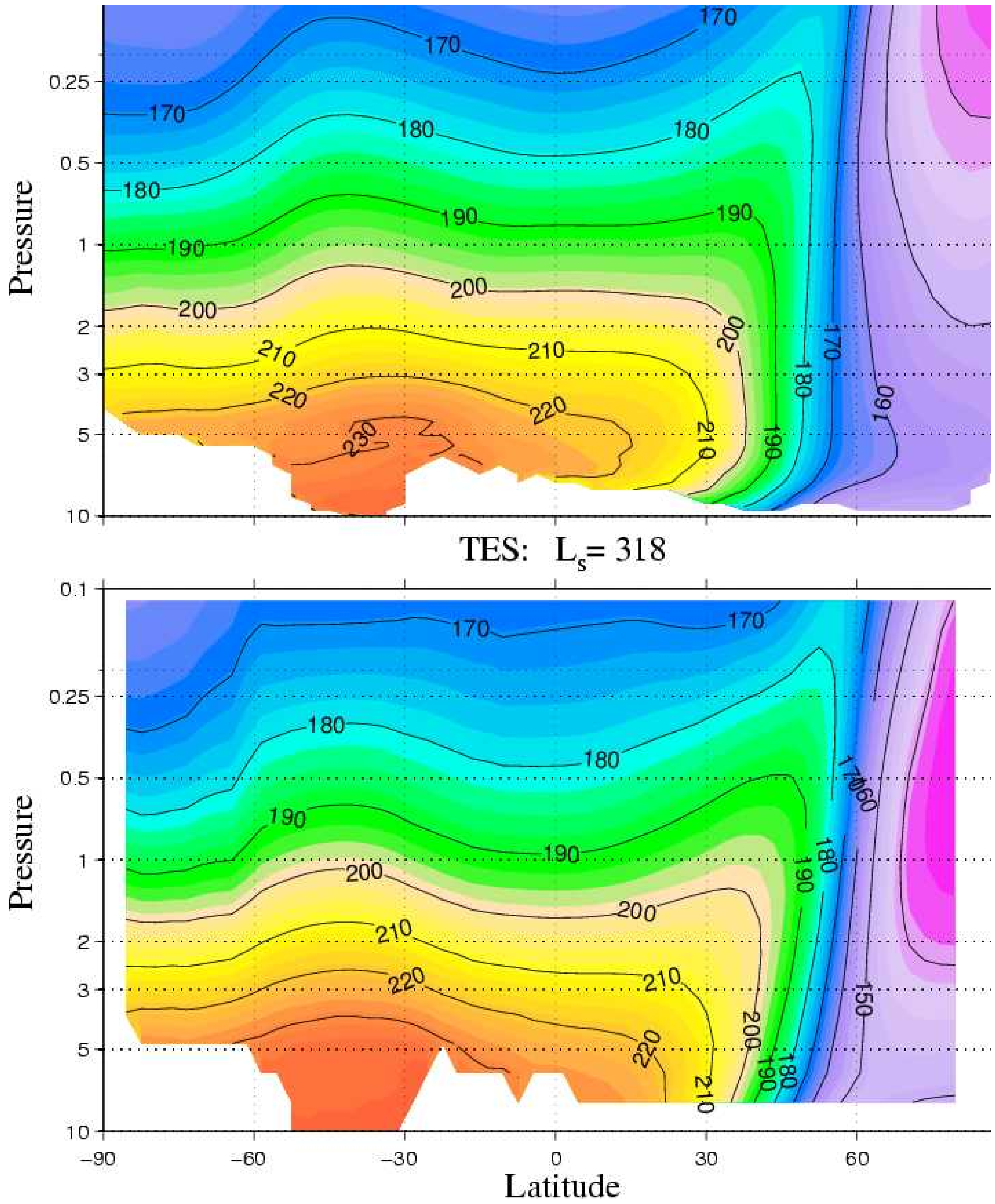
Figures from John Wilson !



Zonal mean temperature

Ls = 318 °

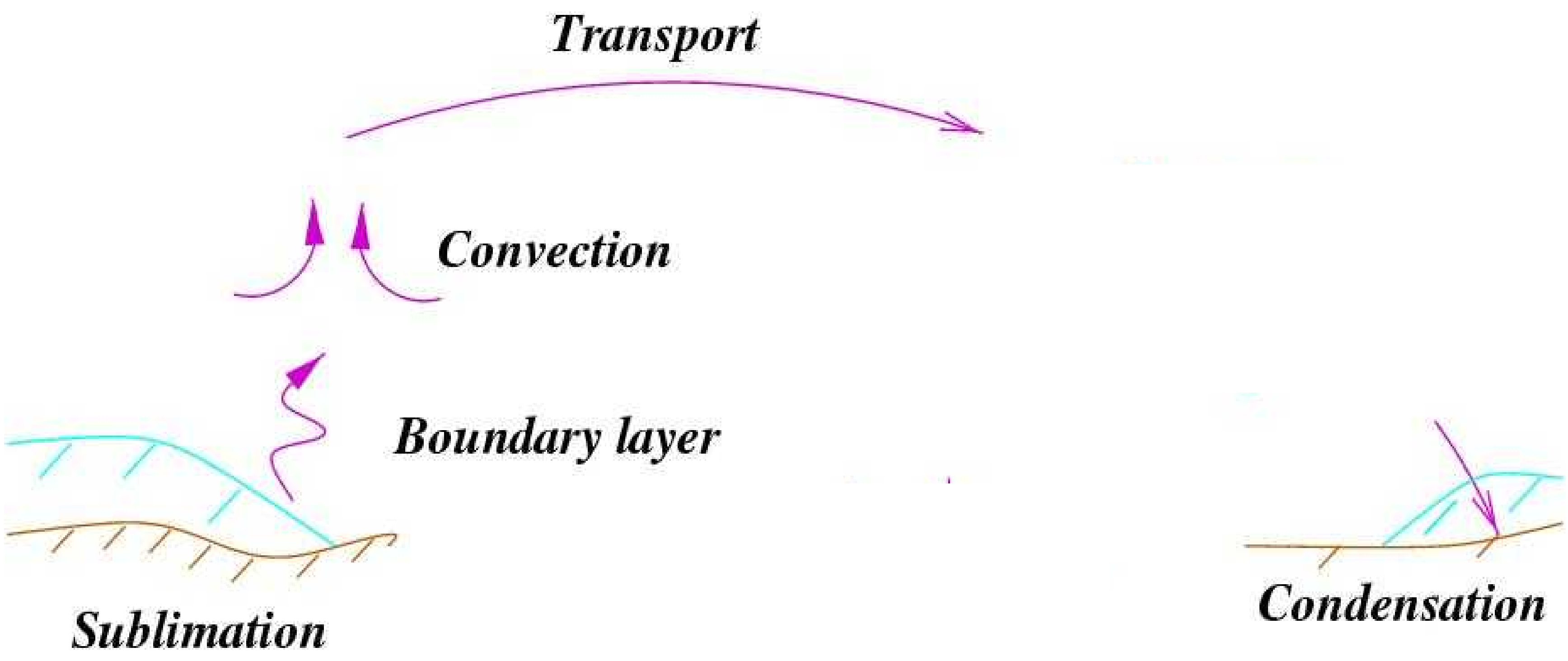
LMD GCM



TES Observations

Figures from John Wilson !

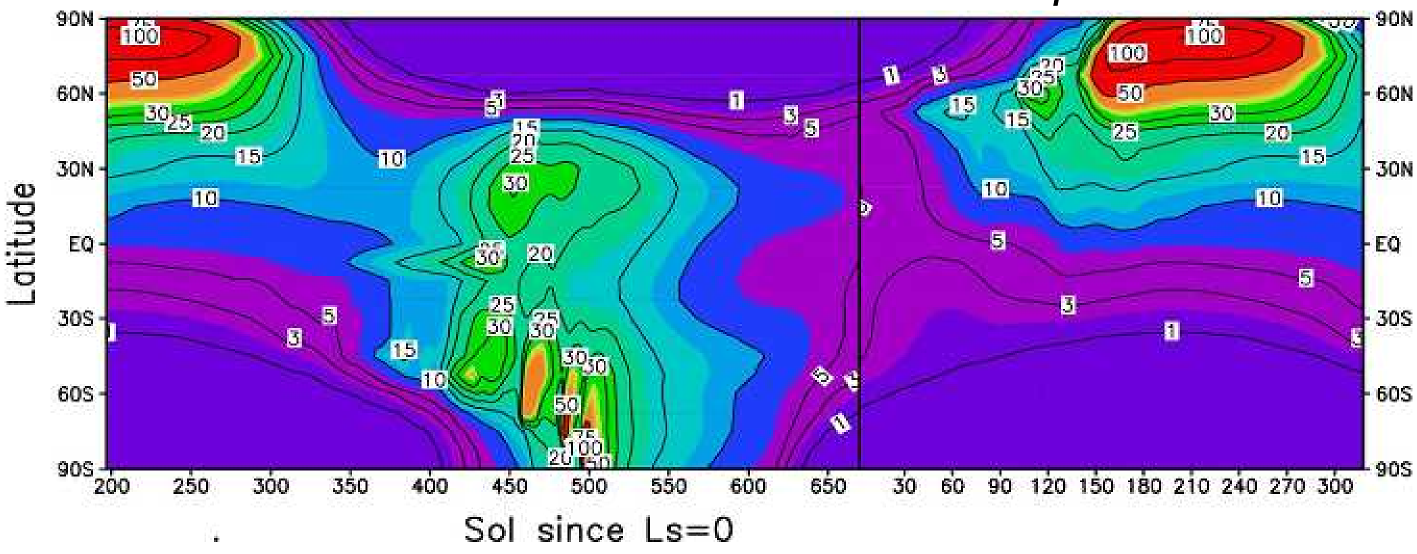
Modelling the water cycle



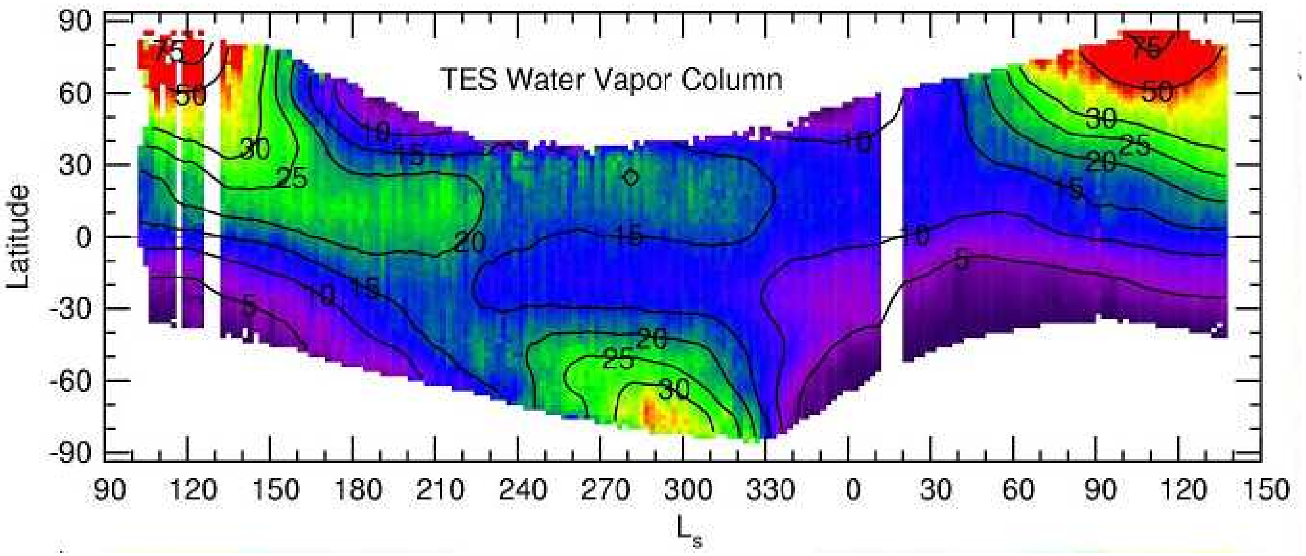
Seasonal cycle

Eté N. / Automne / Hiver / Printemps / Eté

Simple GCM Simulation

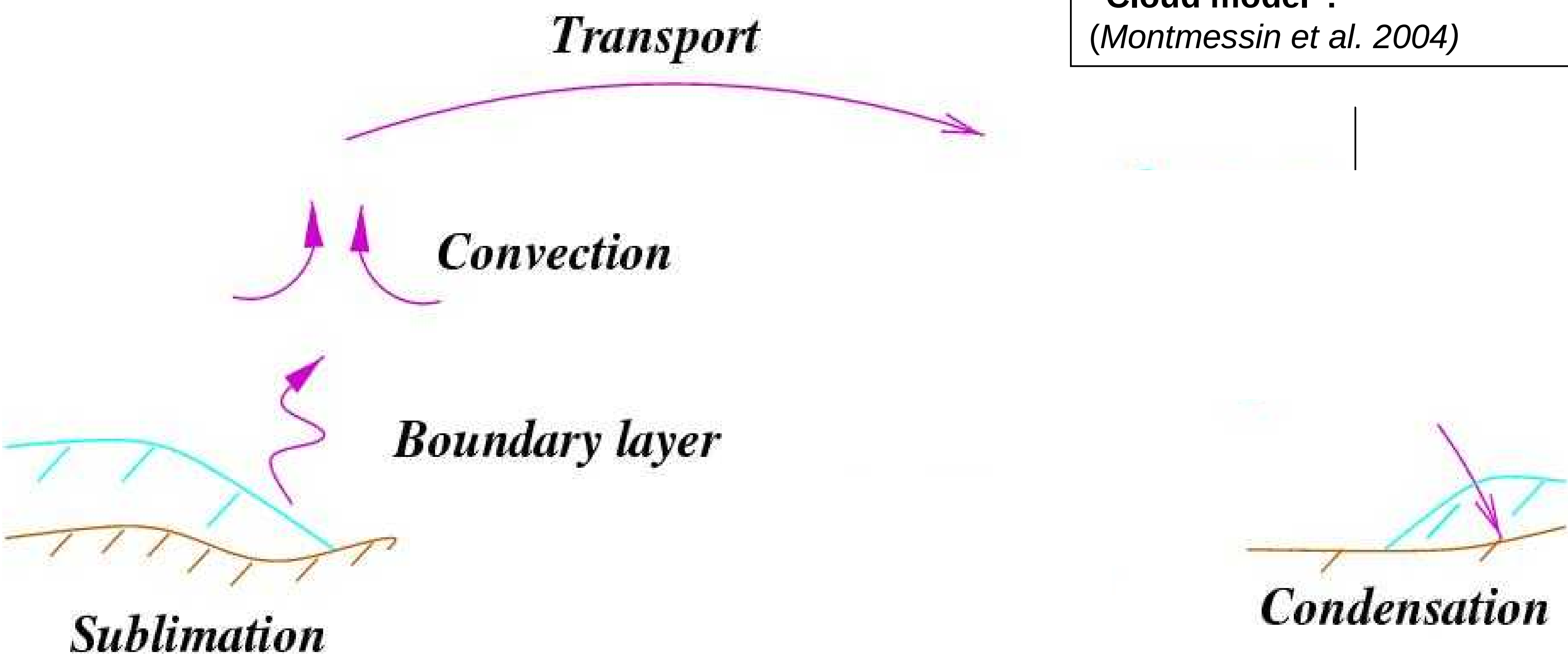


MGS TES Observations



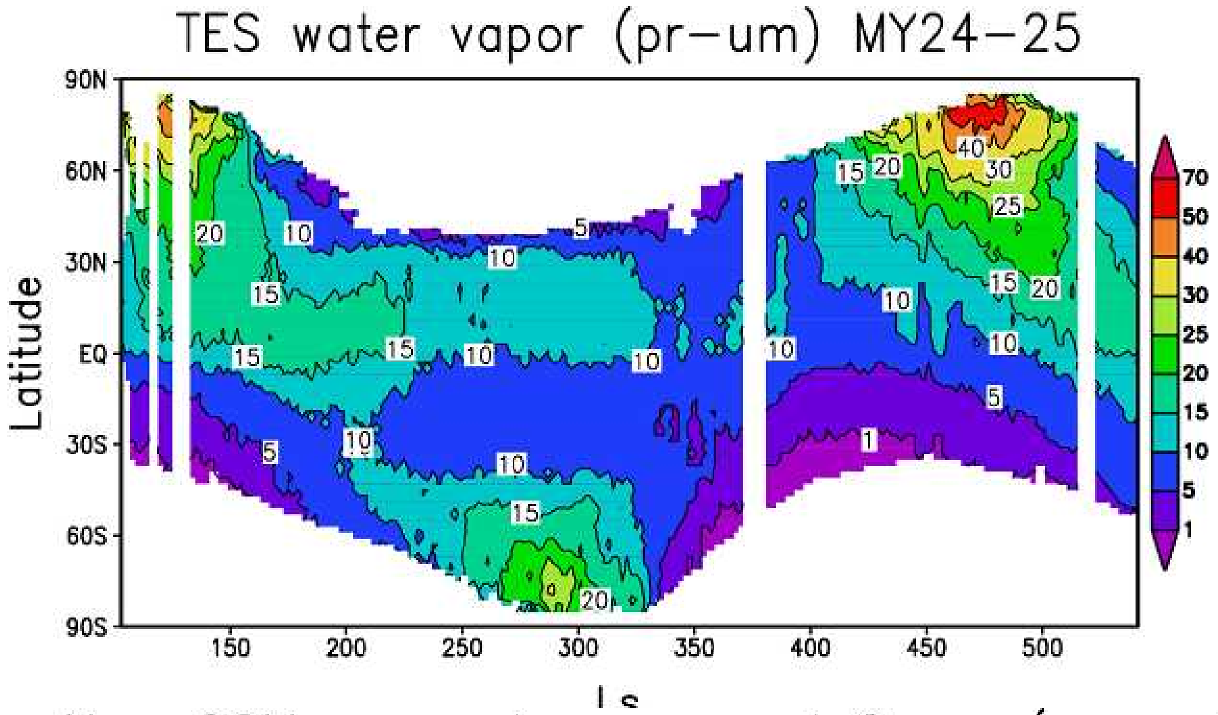
Modelling the water cycle

"Cloud model":
(*Montmessin et al. 2004)*

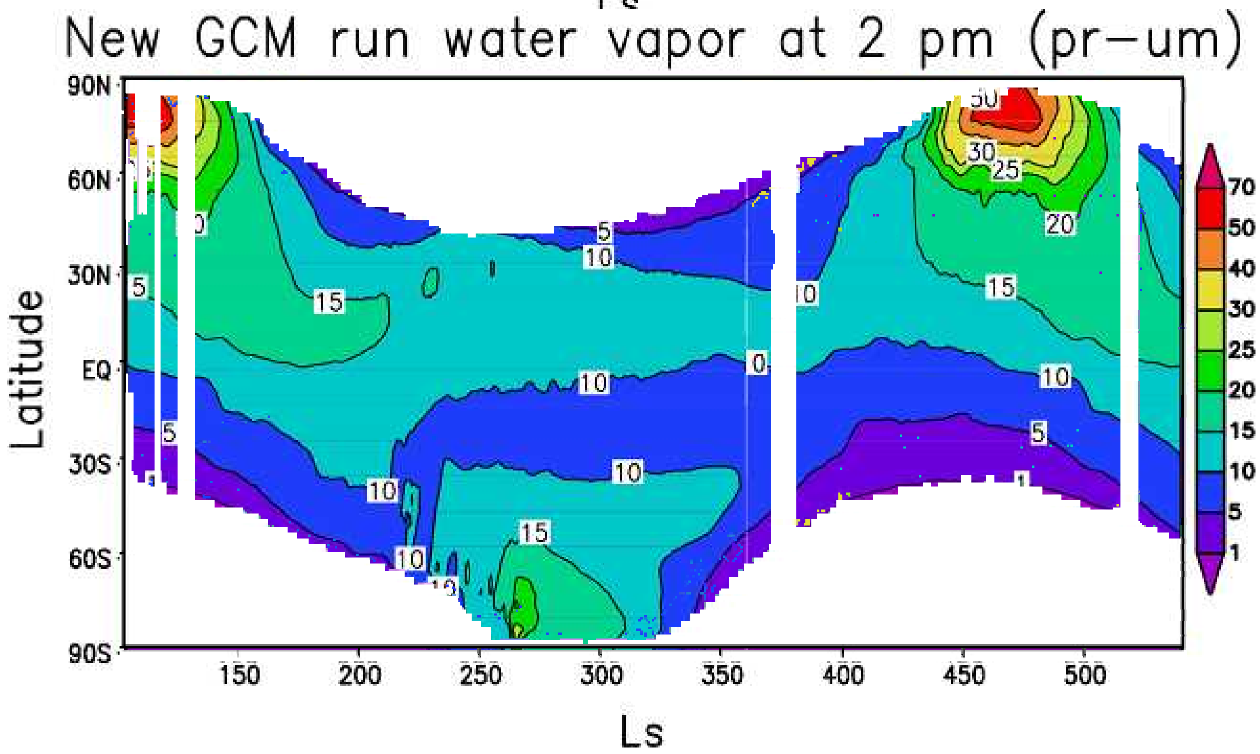


SEASONAL WATER CYCLE

OBSERVATION



MODEL



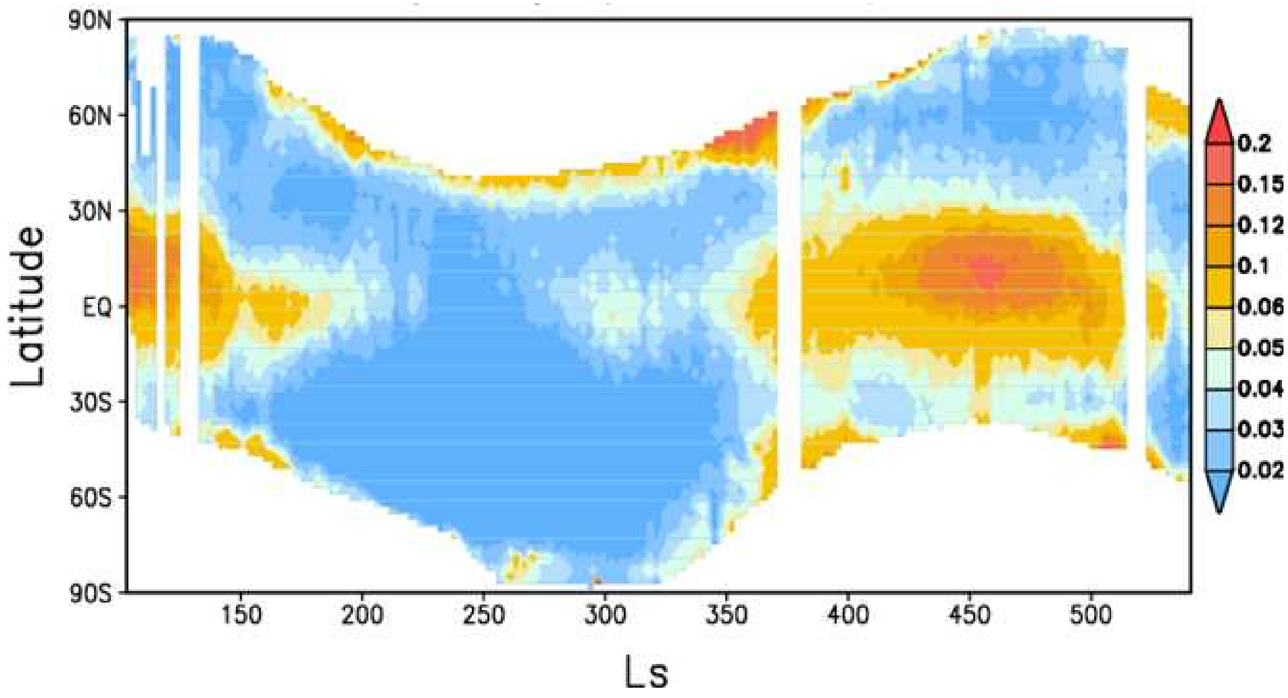
CLOUDS

TES ice absorption opacity

2pm

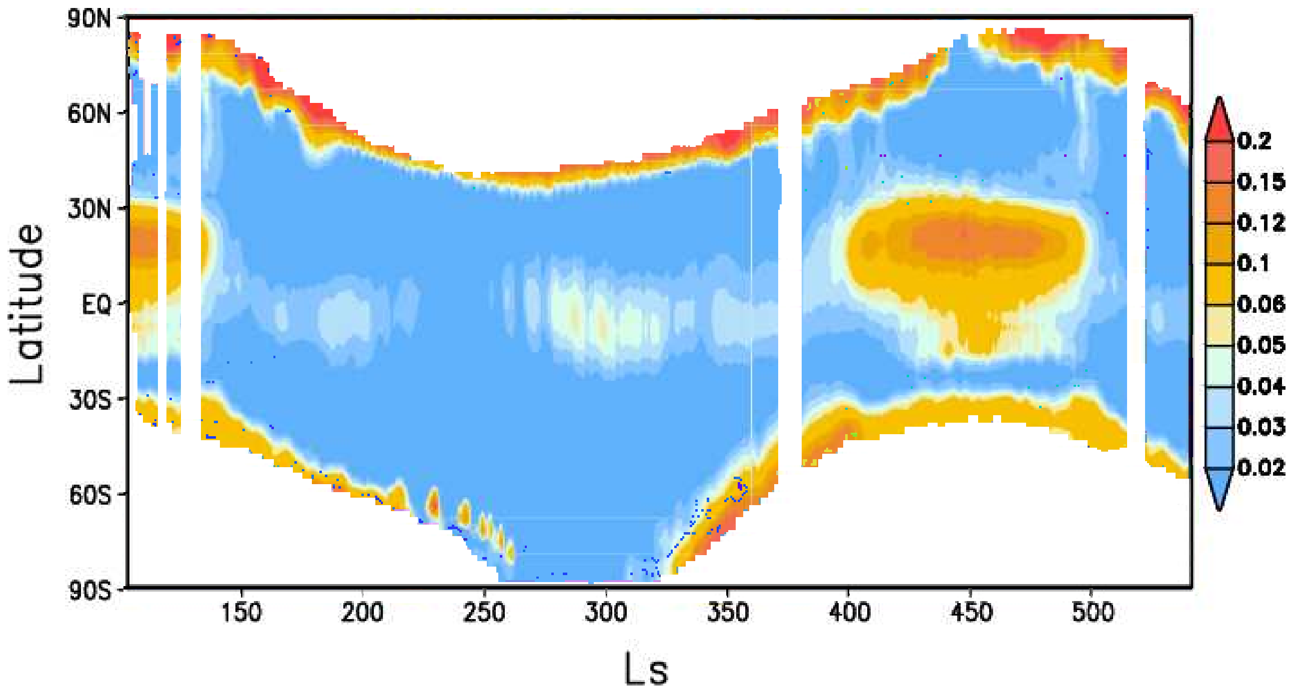
(825 cm-1)

MY24-25



GCM ice absorption opacity

2pm

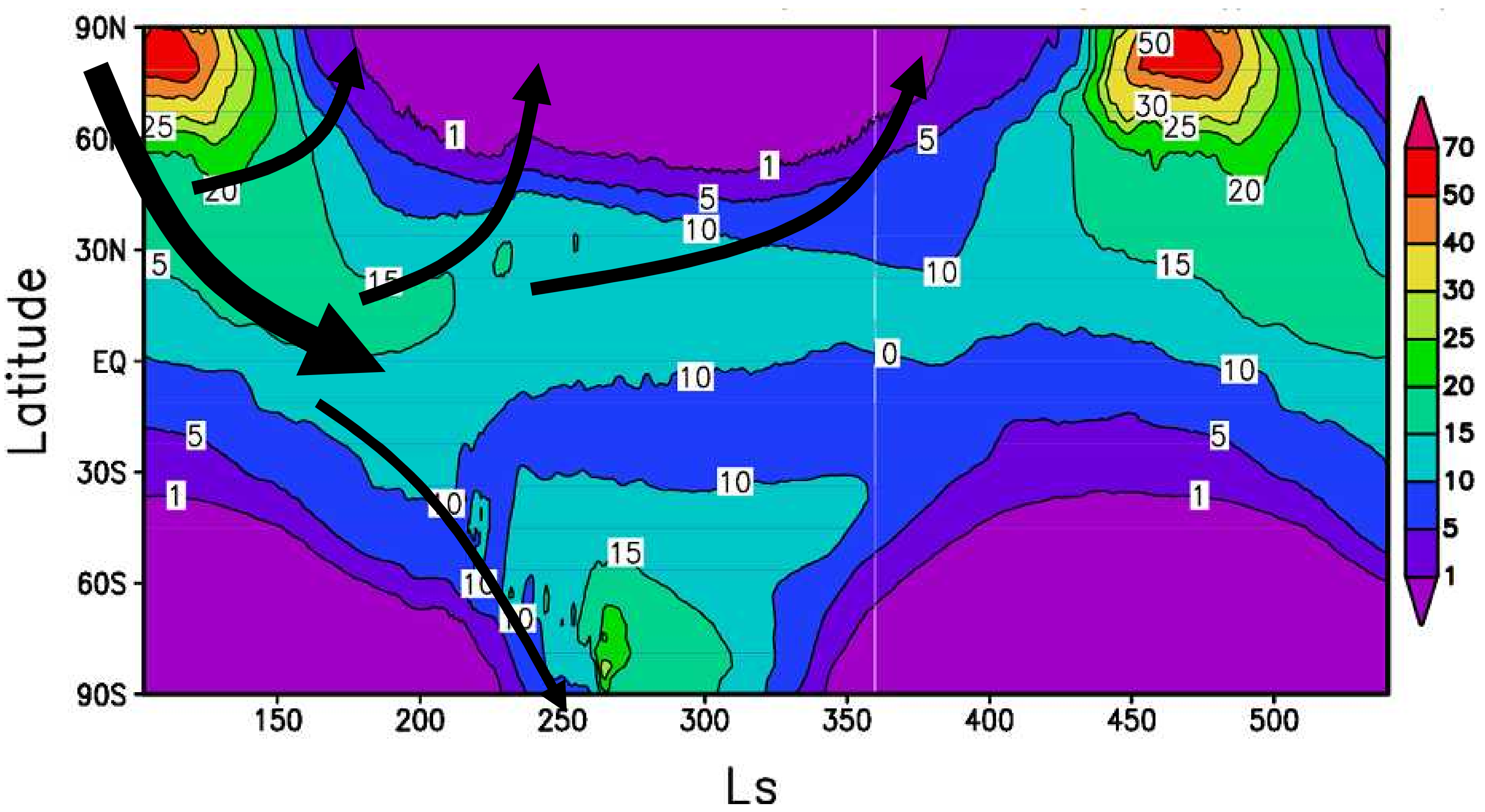


Basic facts learned from present-day GCM water cycle modelling :

1. A « closed » water cycle (almost !) (*Richardson and wilson 2002).*

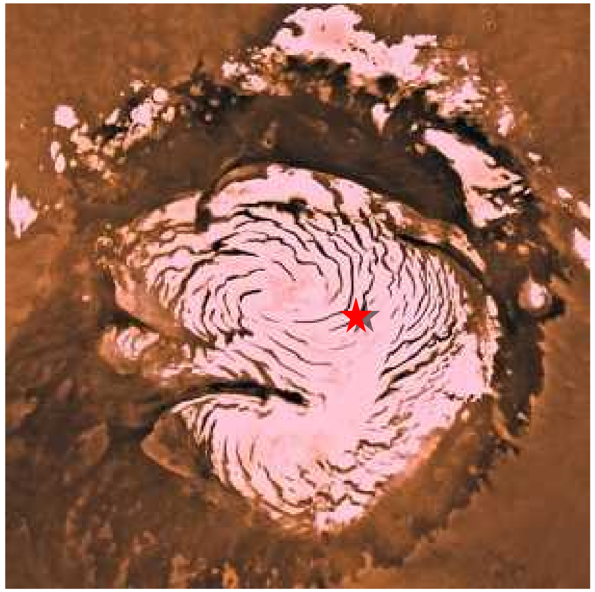
A closed seasonal cycle : most water released in summer goes back to North polar cap

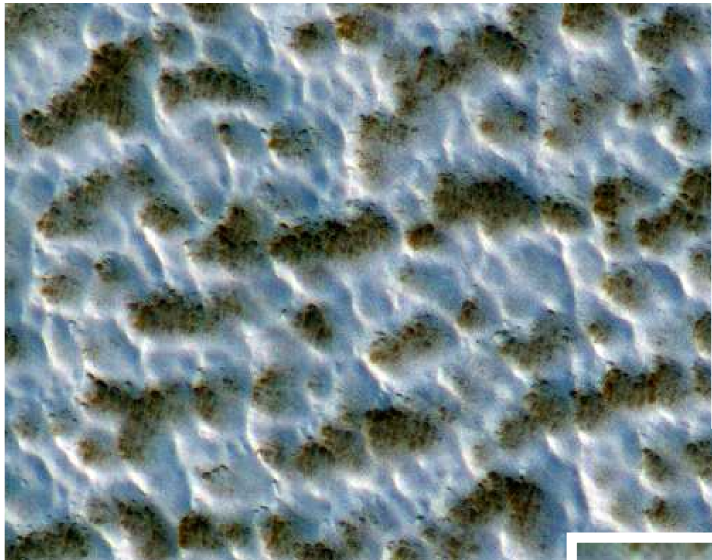
(the remnant get trap in the perrenial CO2 ice southern cap)

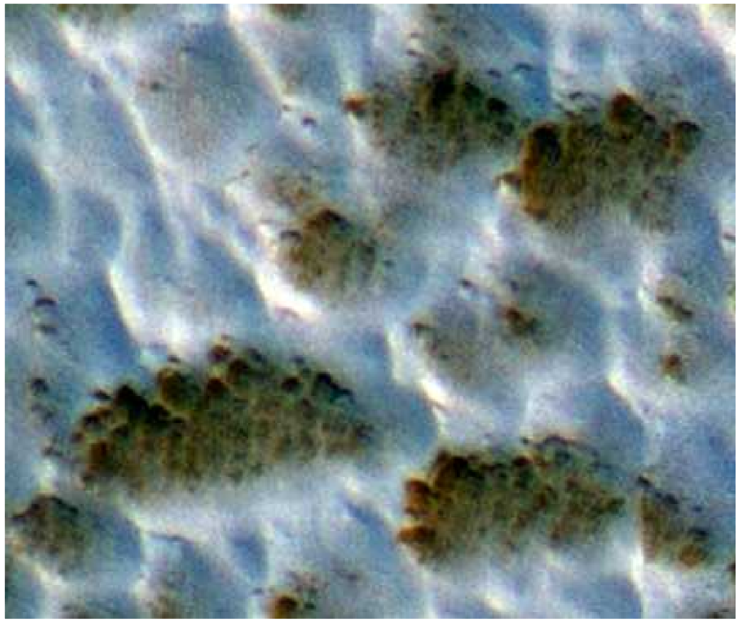


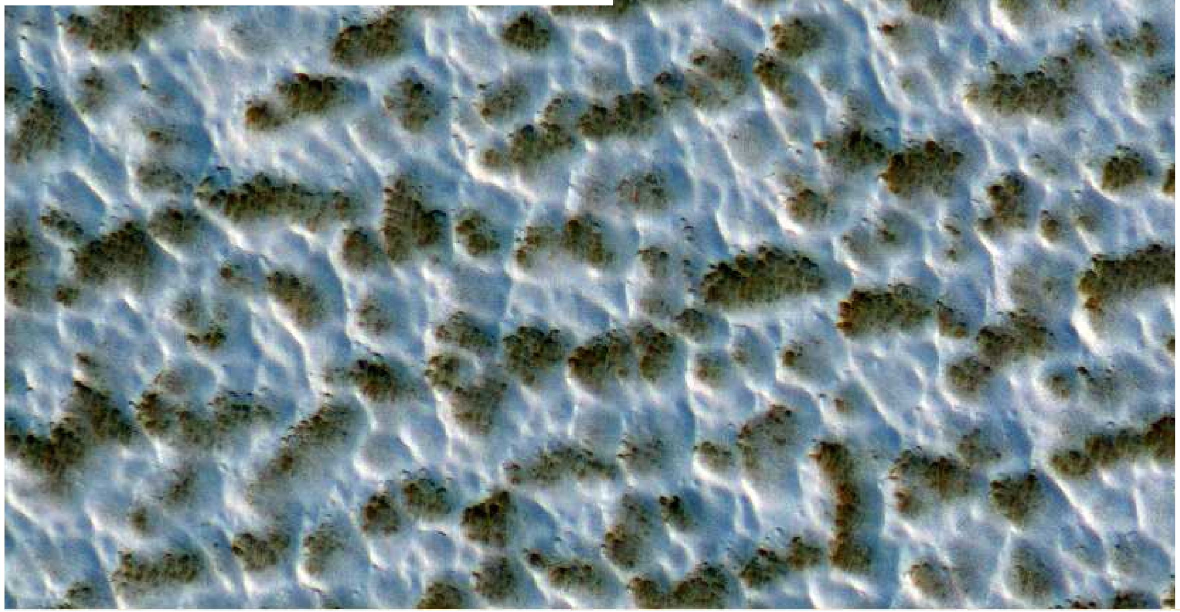
Northern Cap Texture

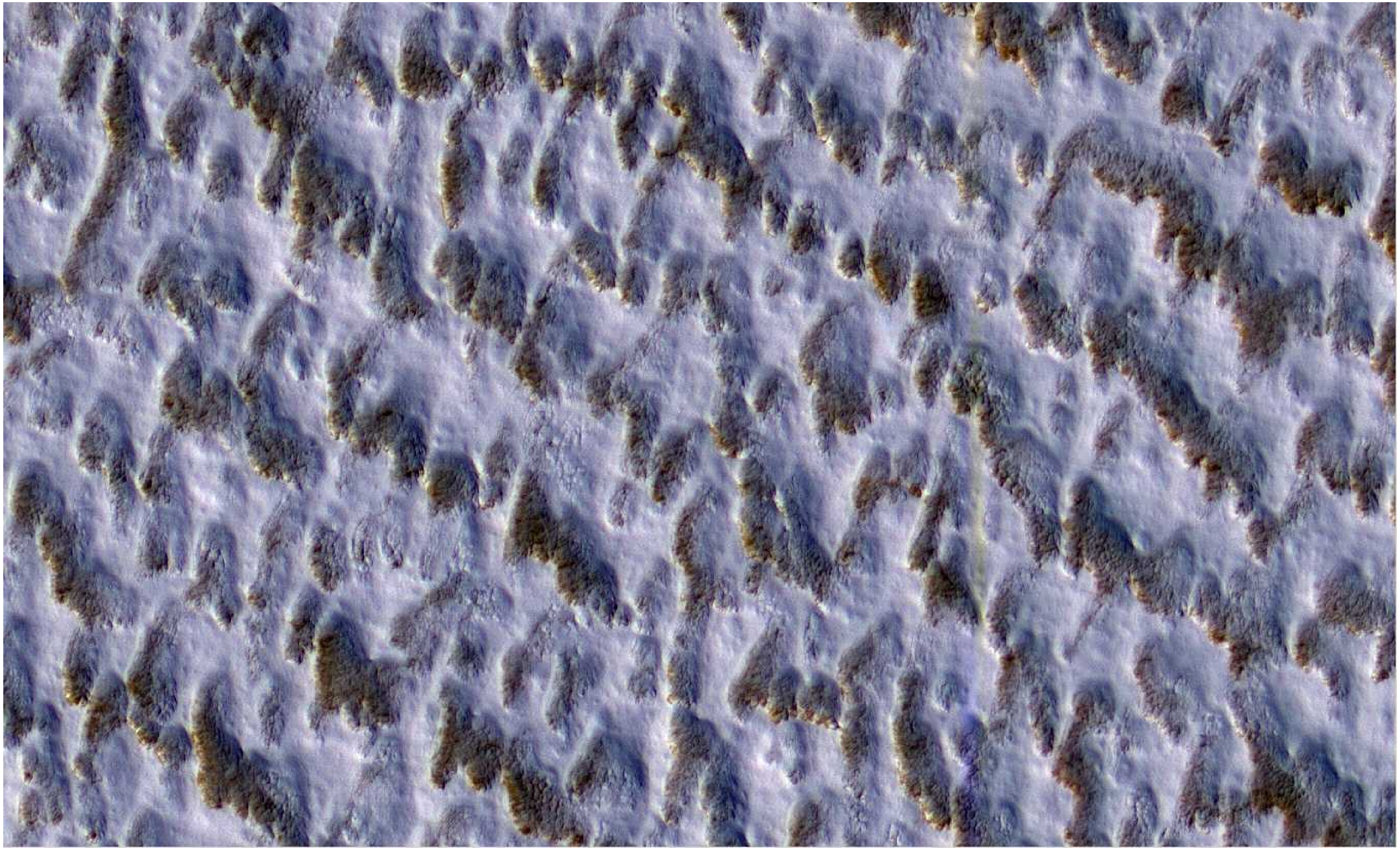
Byrne et al. 2008



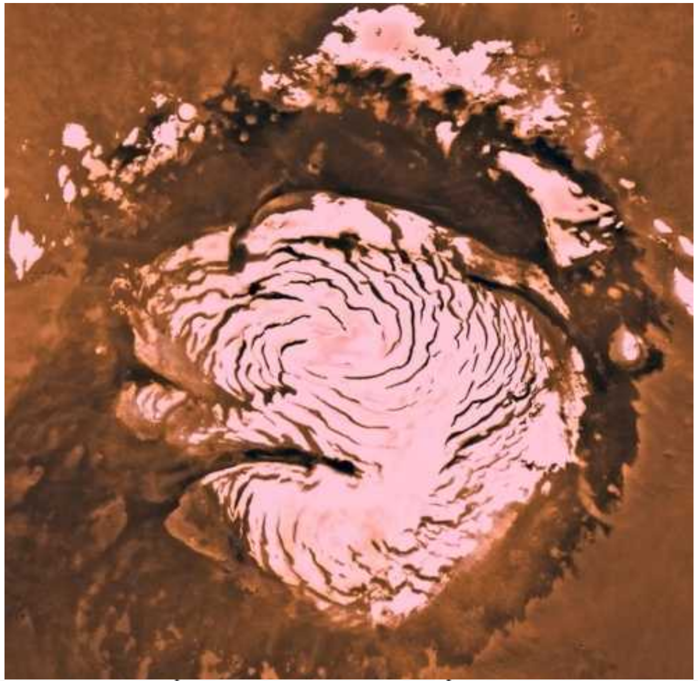








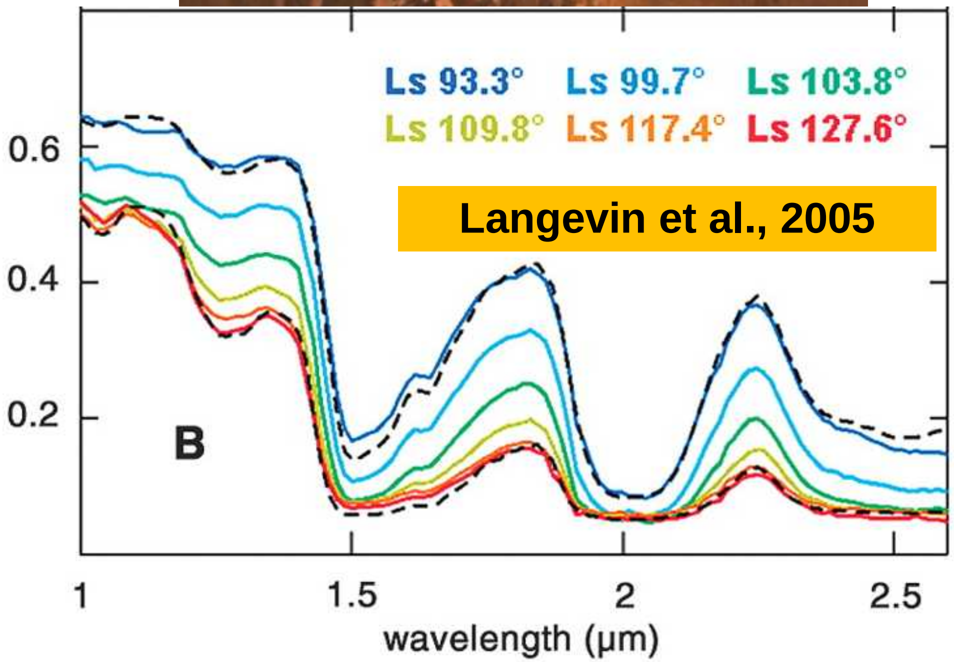
North Polar Residual Ice Cap



Byrne et al. 2008

- **Can we understand present accumulation/loss rates?**
  - **Dust-free ice must have accumulated recently**
  - **BUT: OMEGA grain-sizes indicates current net loss**
  - **N. Residual Cap has temporary variations in extent (~1%)**

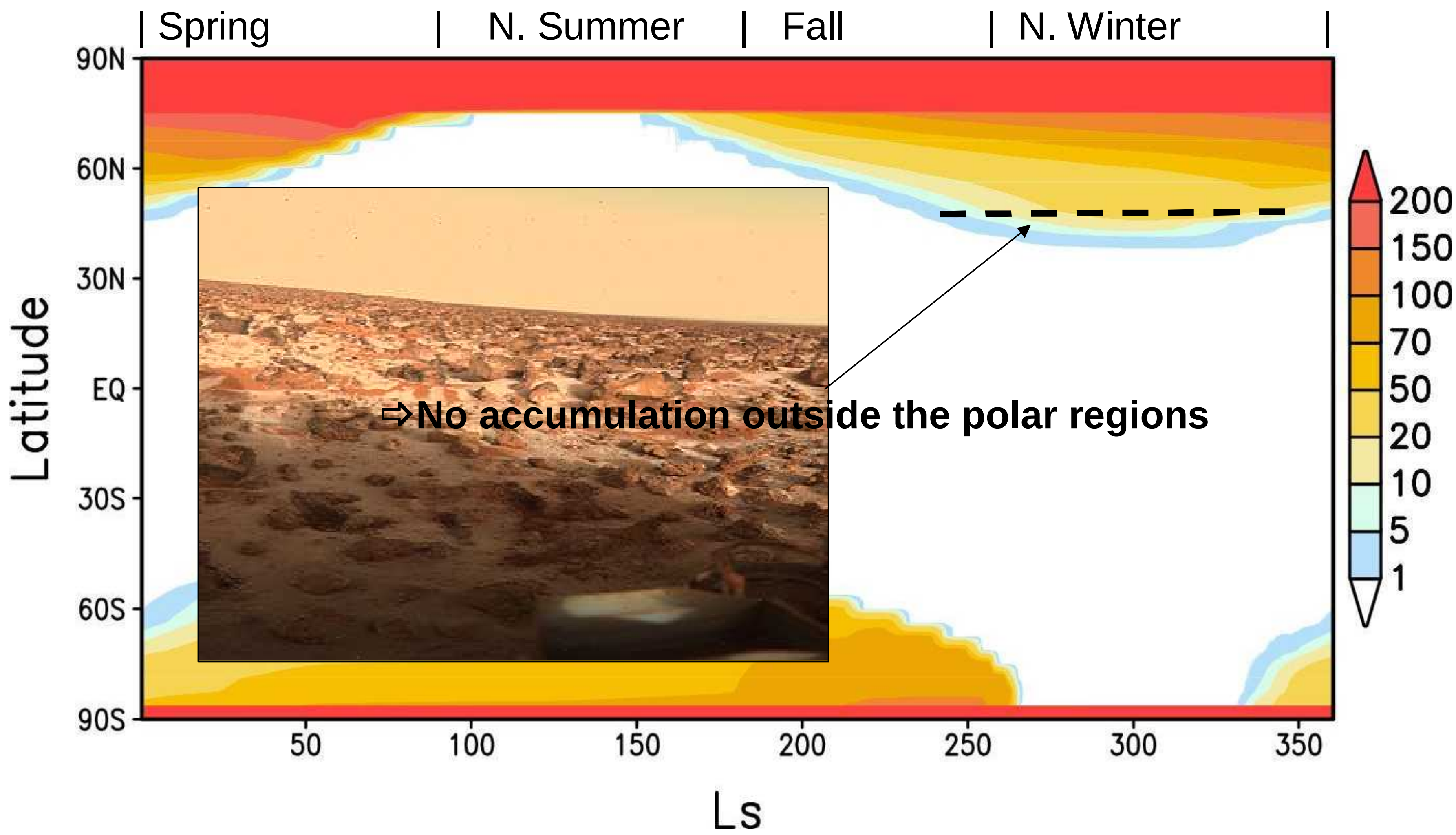
  - **i.e. it's not clear what's going on…**



Basic facts learned from present-day GCM water cycle modelling :

1. A « closed » water cycle
2. Surface water ice cannot accumulate outside the polar regions

GCM simulations of Zonal mean Surface water ice (µm):



Basic facts learned from present-day GCM water cycle modelling :

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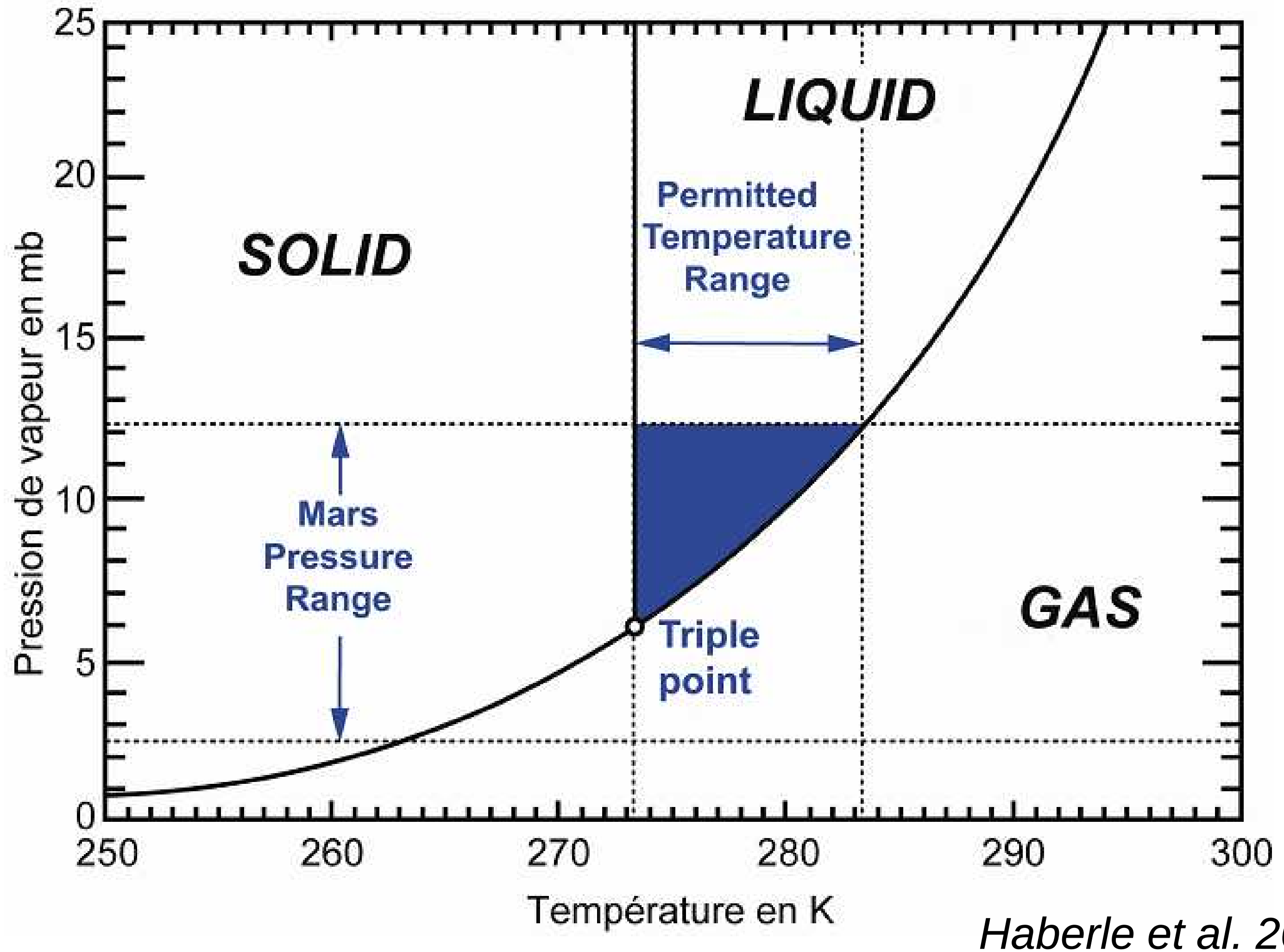
What about surface liquid water ?

Liquid water on Mars



Haberle et al. 2003

Liquid water on Mars ?

Pure water

Only if T >0 ° C and Ps > 610 Pa (triple point)

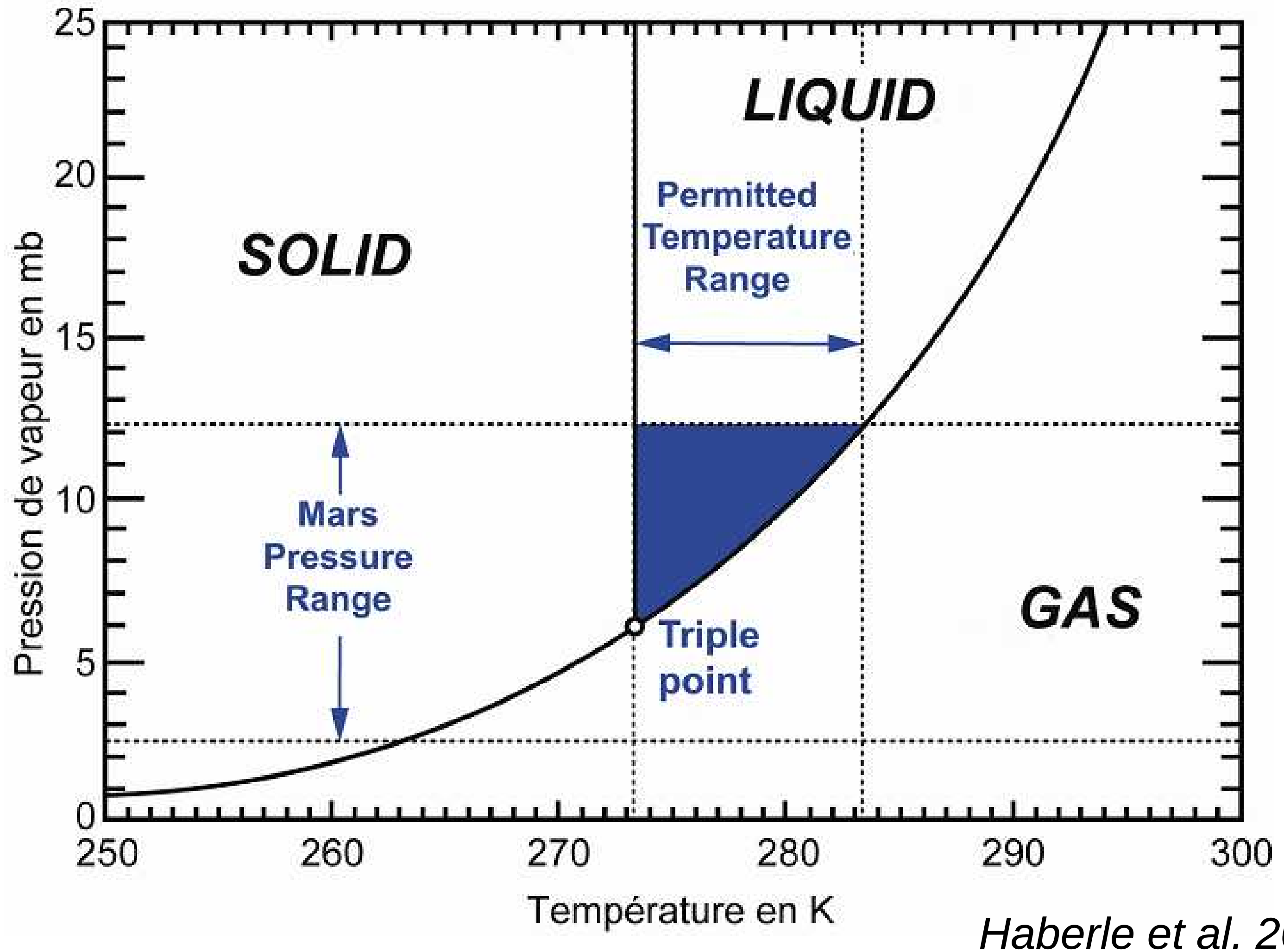
⇨ Reading phase diagram :

- Boiling : controlled by ABSOLUTE pressure (~atmospheric pressure)
- Evaporation : surface liquid water stability controlled by water vapor partial pressure in the air

(P_{H2O} = Pabs x [H_2O] << Pabs !

⇨ Pure Liquid water impossible except in lower plains (Ps> 6.1mb) where it is unstable

Liquid water on Mars



Haberle et al. 2003

- No pure liquid water ponds, but
  - Metastable water (Hecht, 2002.)
  - Role of « liquid » adsorbed water (Muehlman et al.)
  - Role of brines (with dissolved salts)
    - can be liquid at much lower P and T (as low as -70 ° C)
    - Example : Perchlorate detected by Phoenix MECA

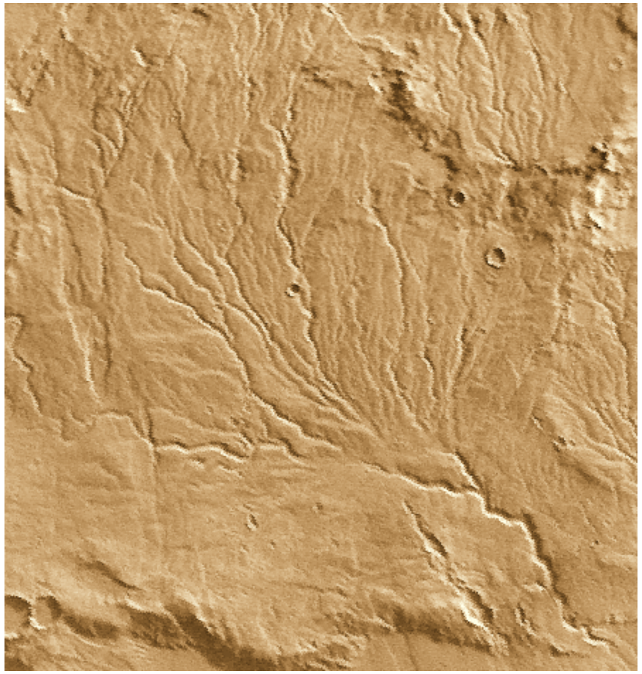
    ⇨Renno, et al., 2009 : evidence for « deliquescence » and liquid water at Phoenix site

On present-day Mars

- No accumulation of ice on the surface outside the polar regions.
- No surface liquid water

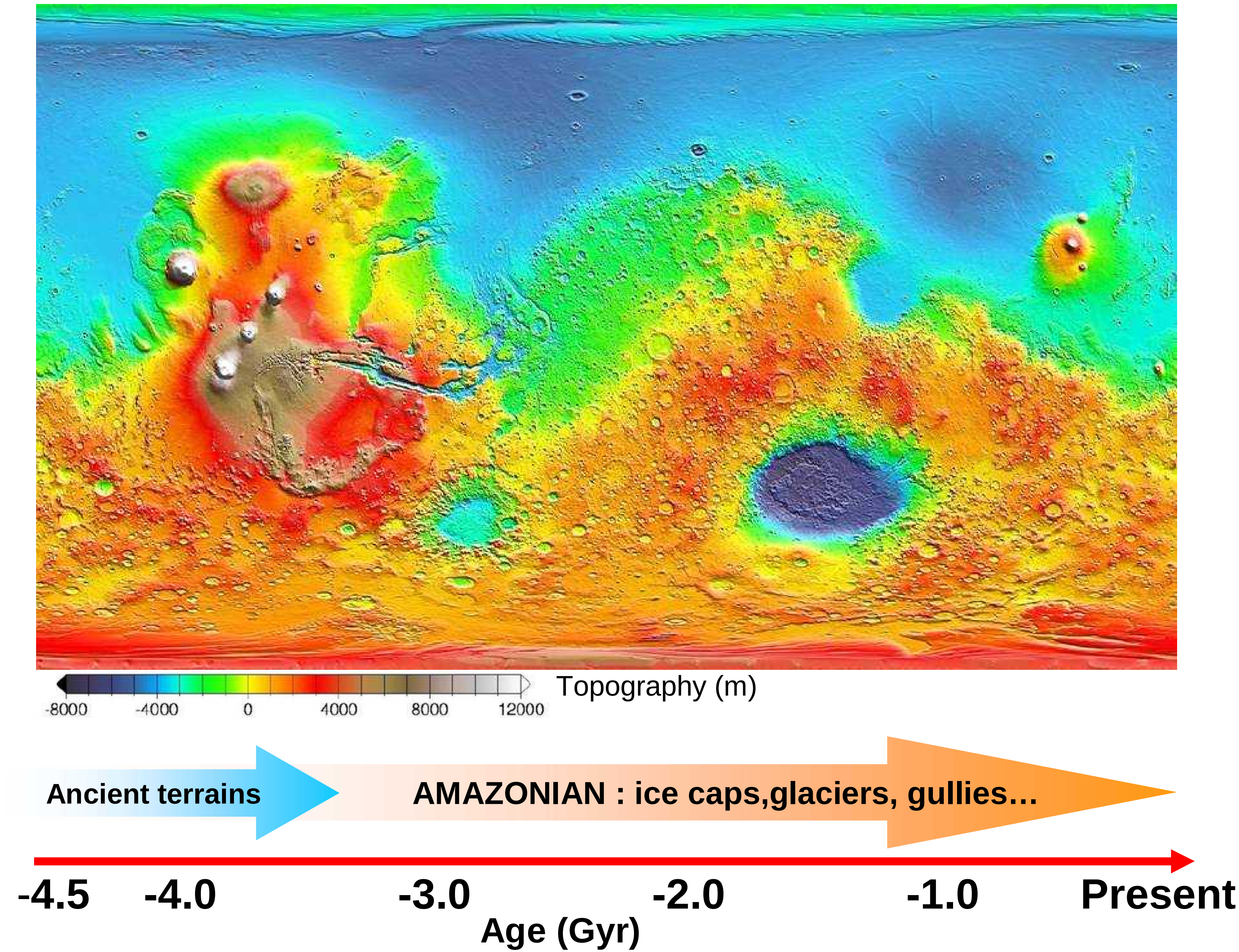
In the past ?

Very ancient terrains (>3.8 Ga)

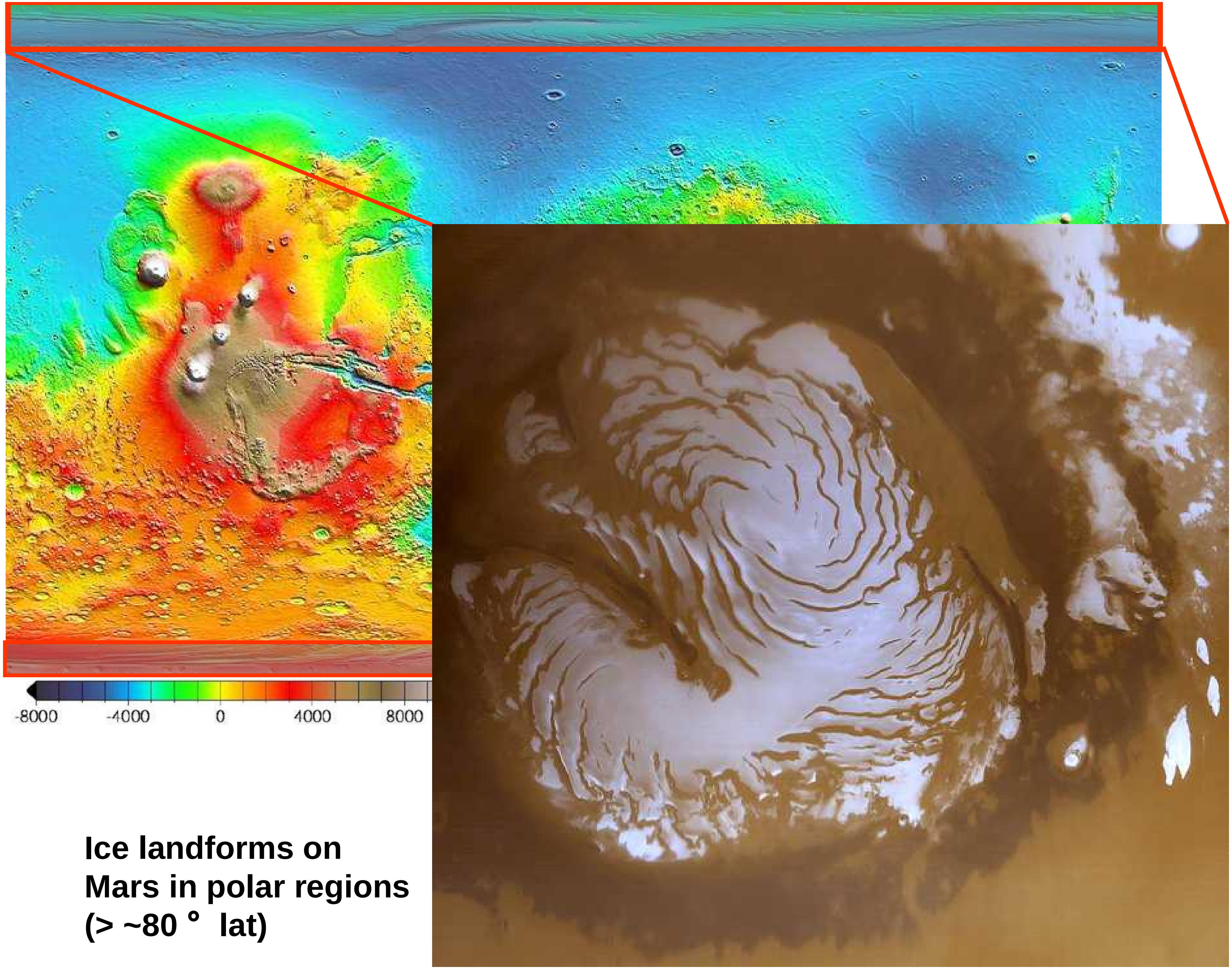


Recent terrain (-10^6 yr)

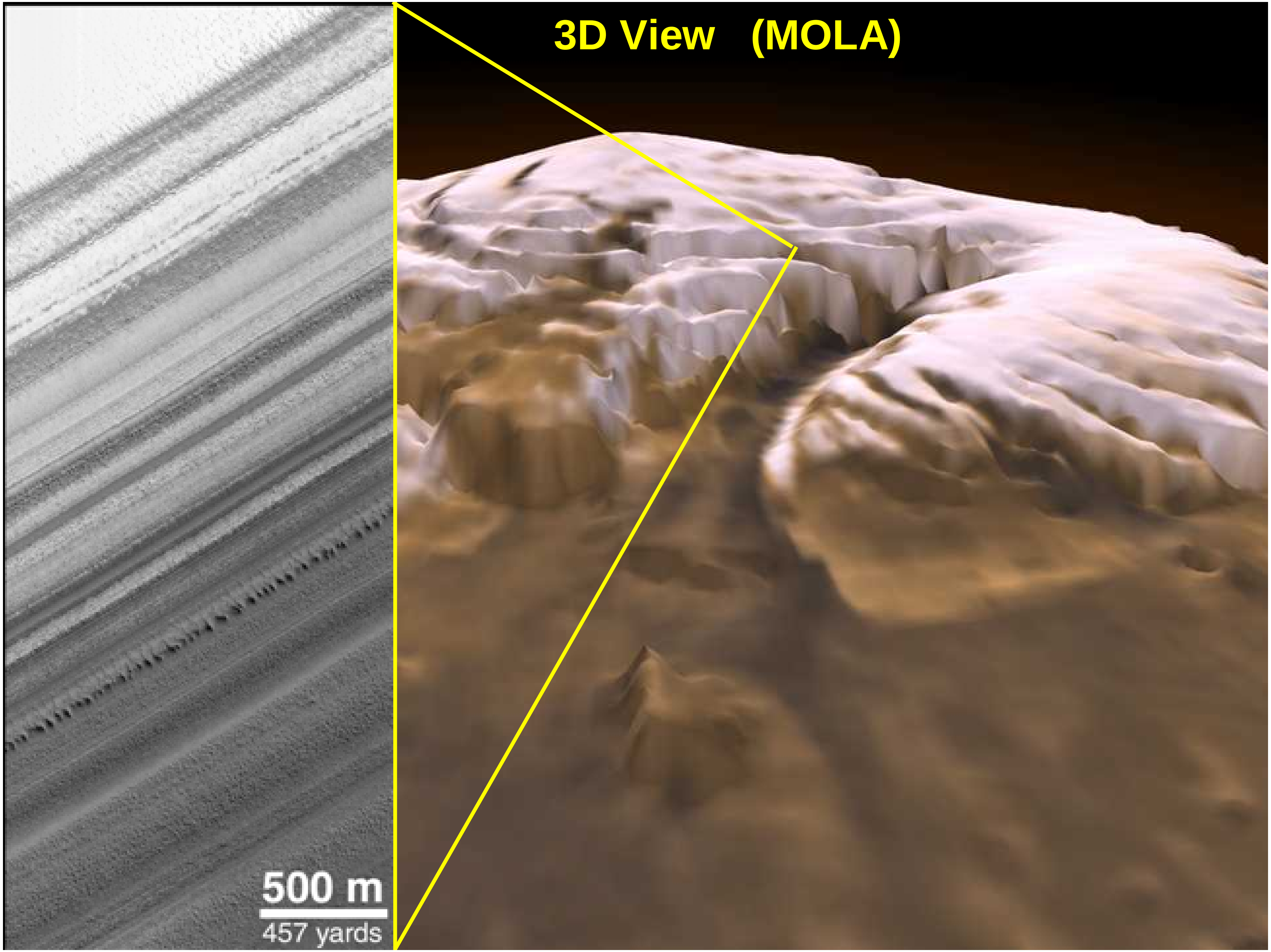
Recent terrain (-10^6 yr)



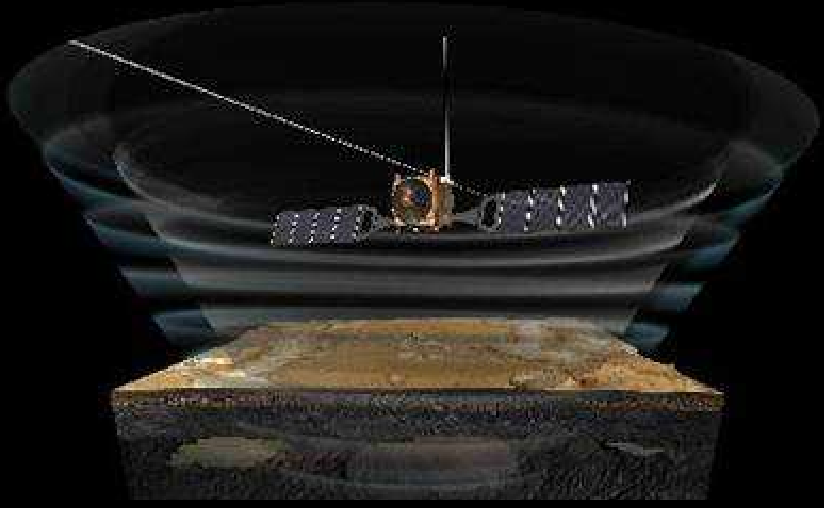
-8000
-4000
0
4000
8000
12000
Topography (m)
Ancient terrains
AMAZONIAN : ice caps,glaciers, gullies…
-4.5
-4.0
-3.0
-2.0
-1.0
Present
Age (Gyr)

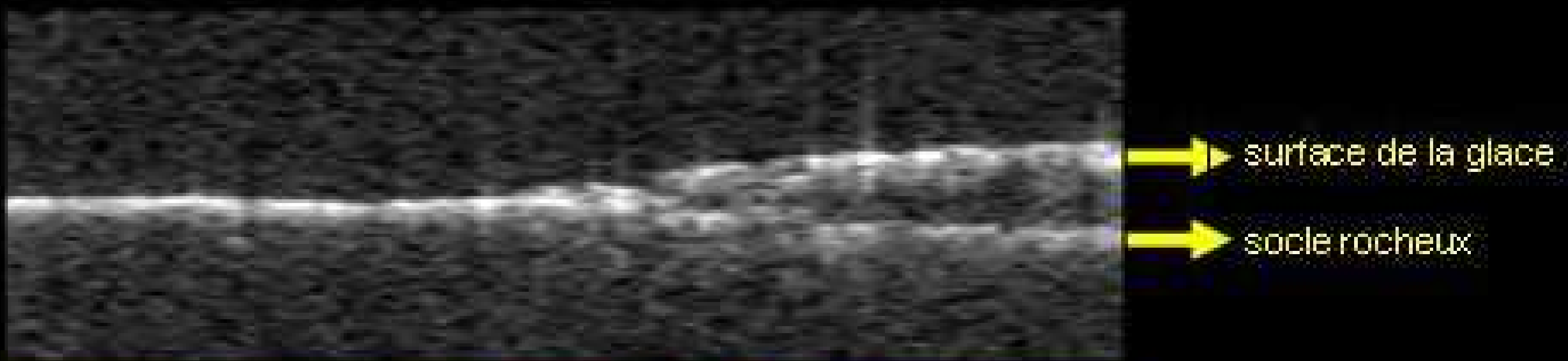


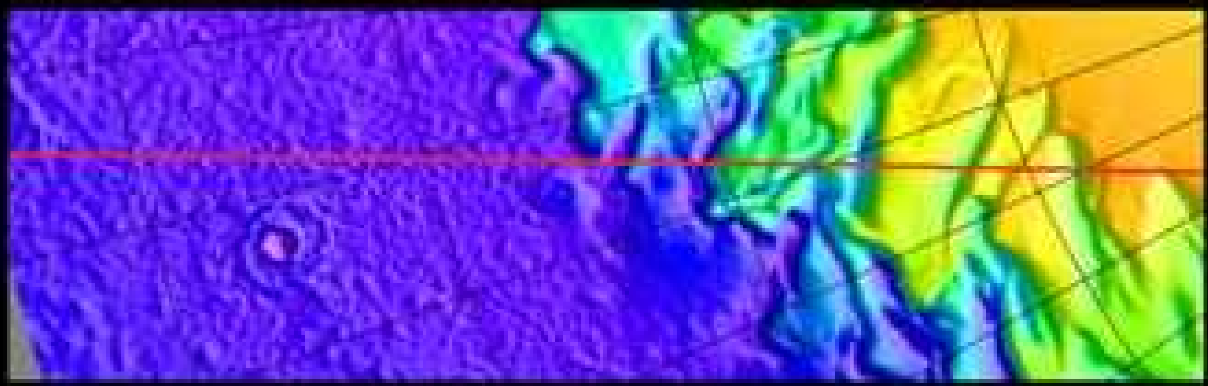
Ice landforms on Mars in polar regions (> ~80 ° lat)


3D View (MOLA)
500 m
457 yards

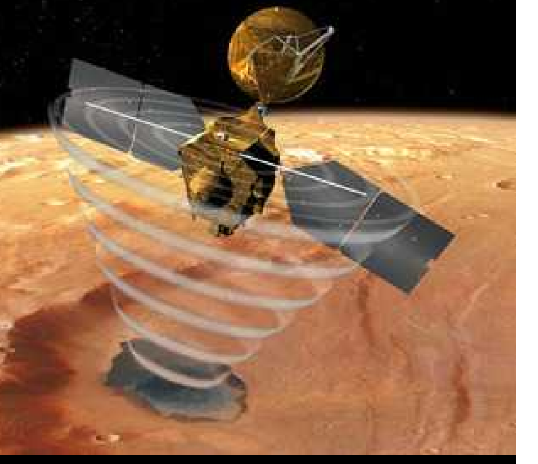
First Radar sounding with Mars Express MARSIS (december 2005) : 95% water ice

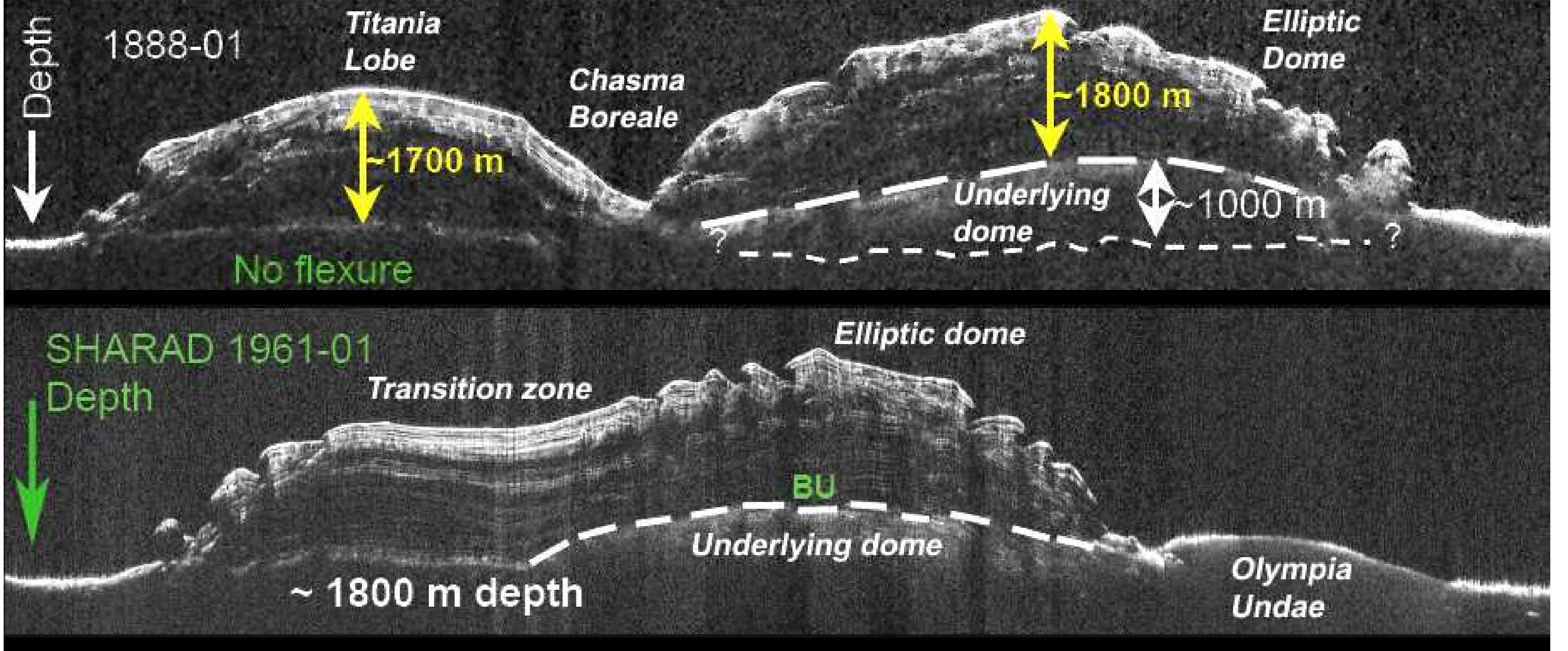


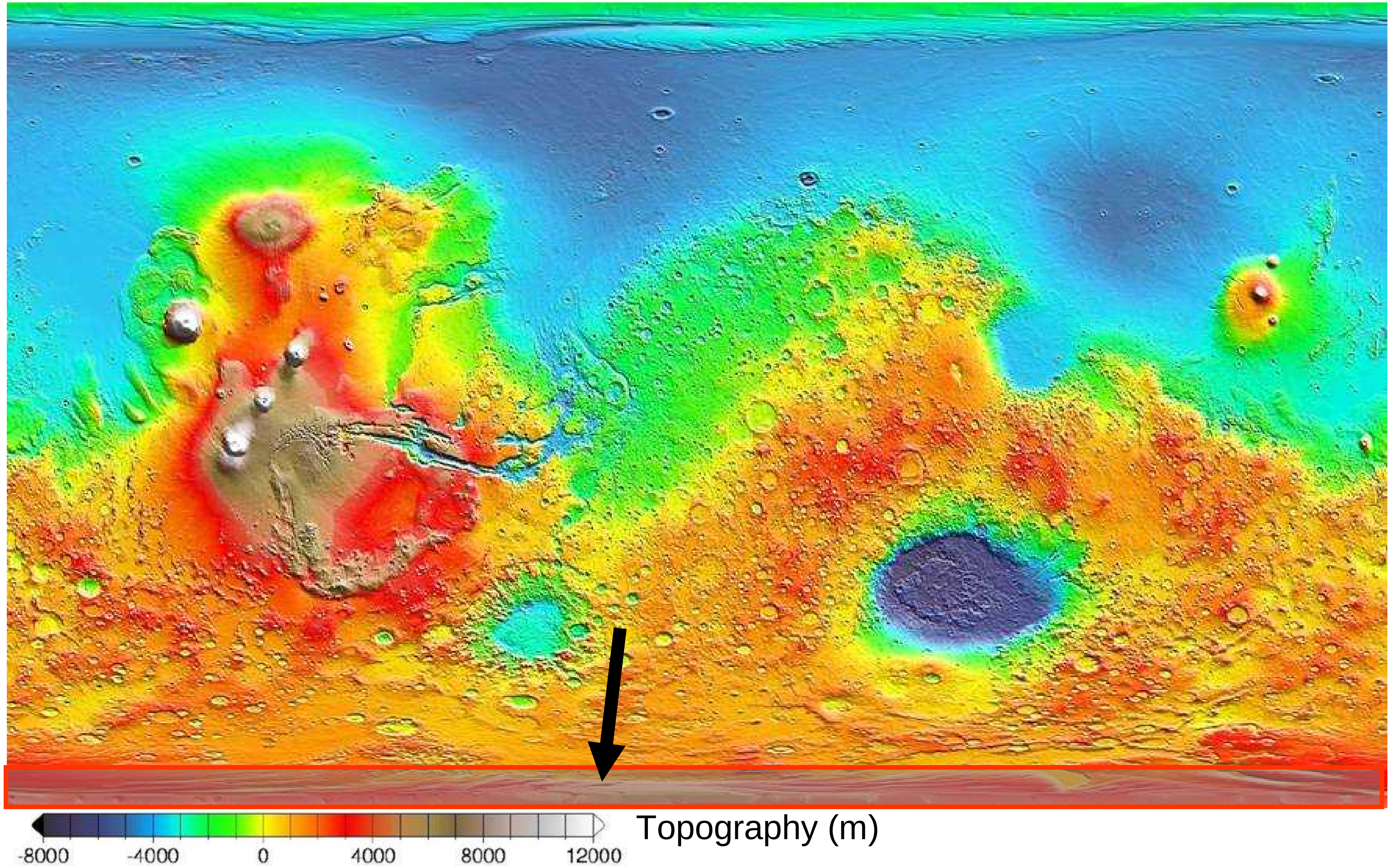




NPLD sounding with radar SHARAD on Mars Reconnaissance Orbiter

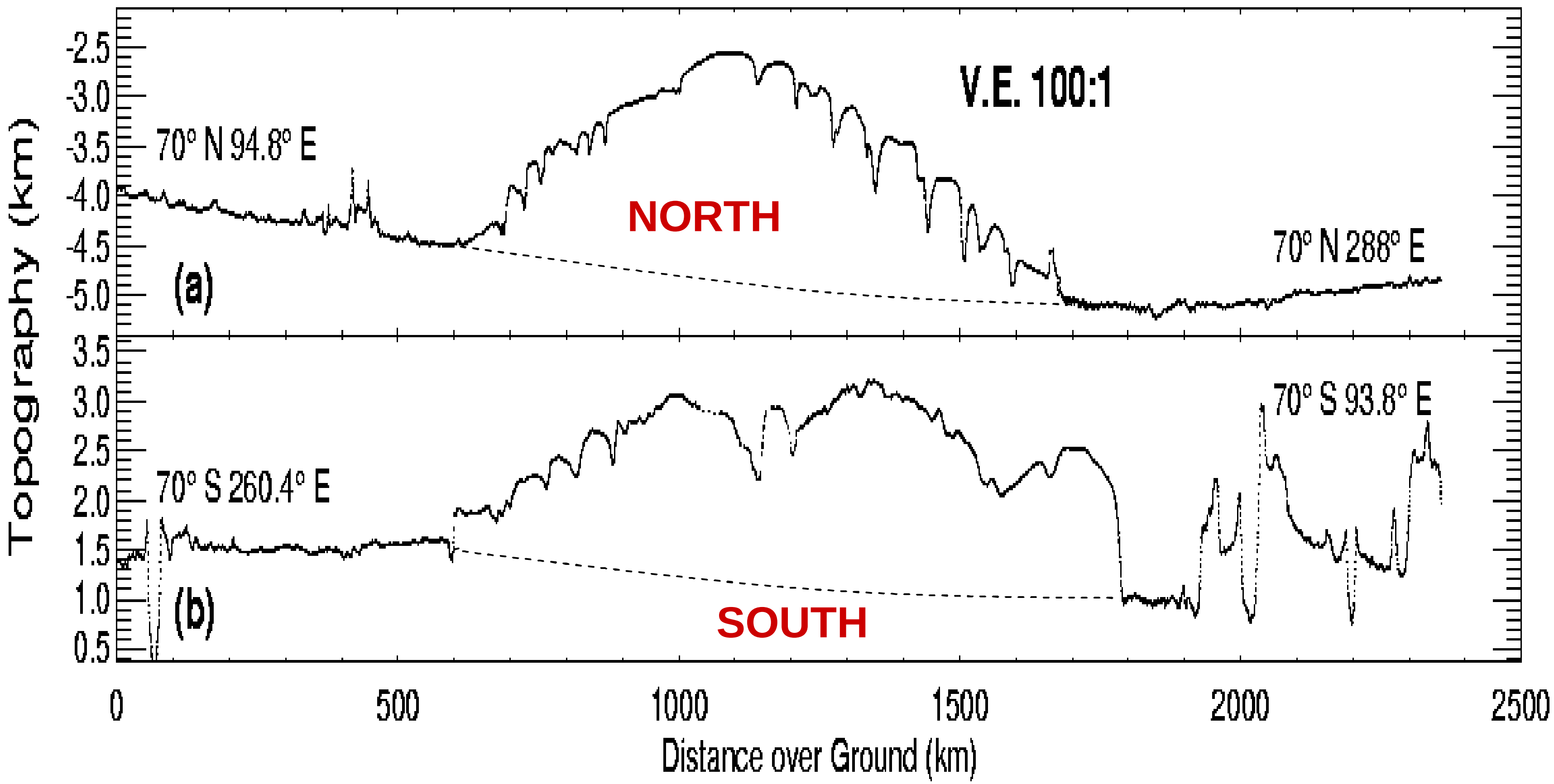




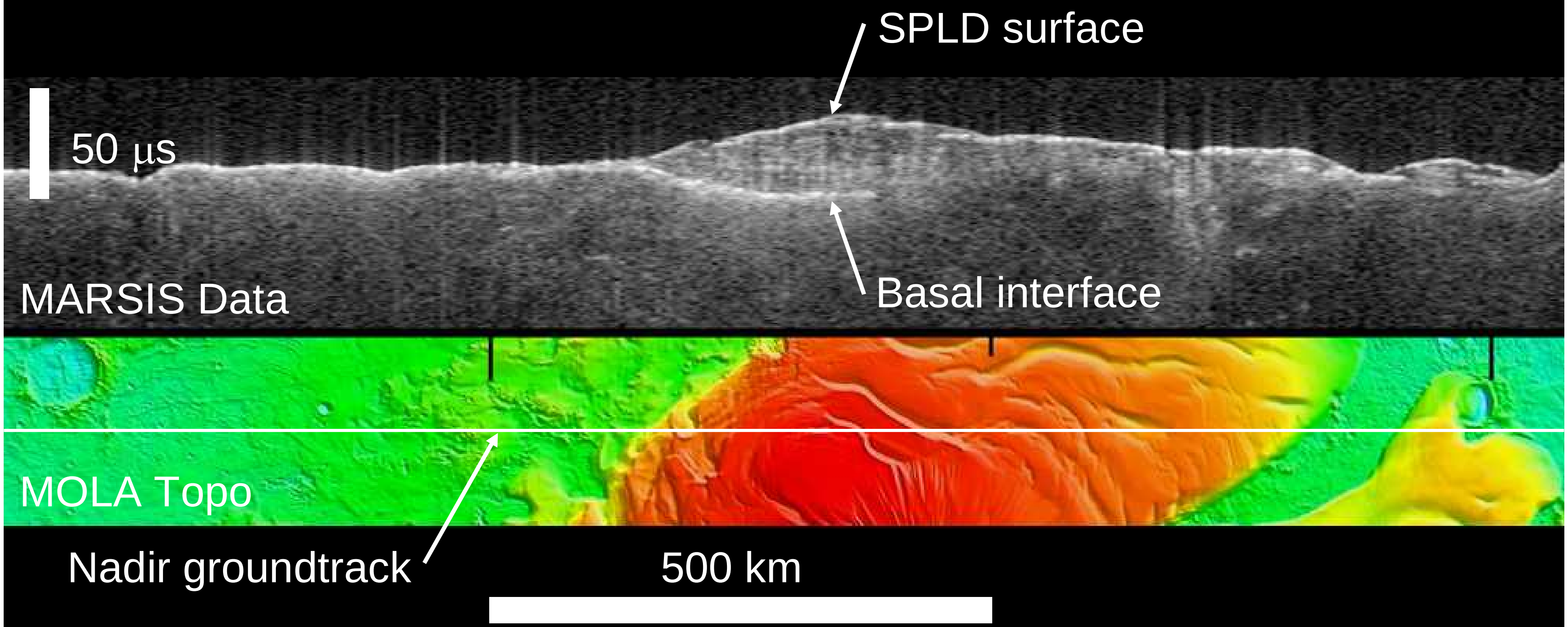


Ice landforms on Mars in polar regions (> ~80 ° lat)

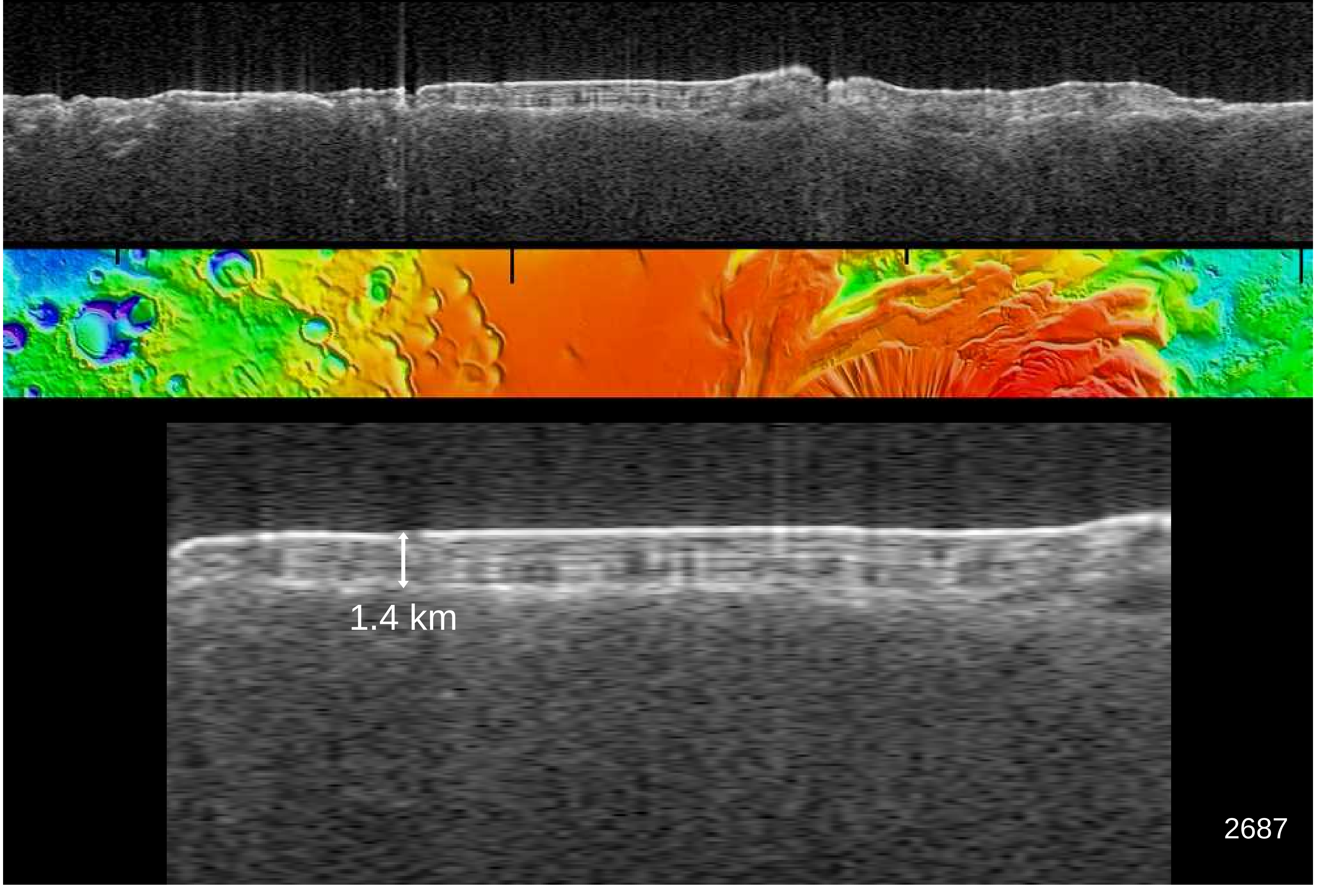
Topography of the polar regions

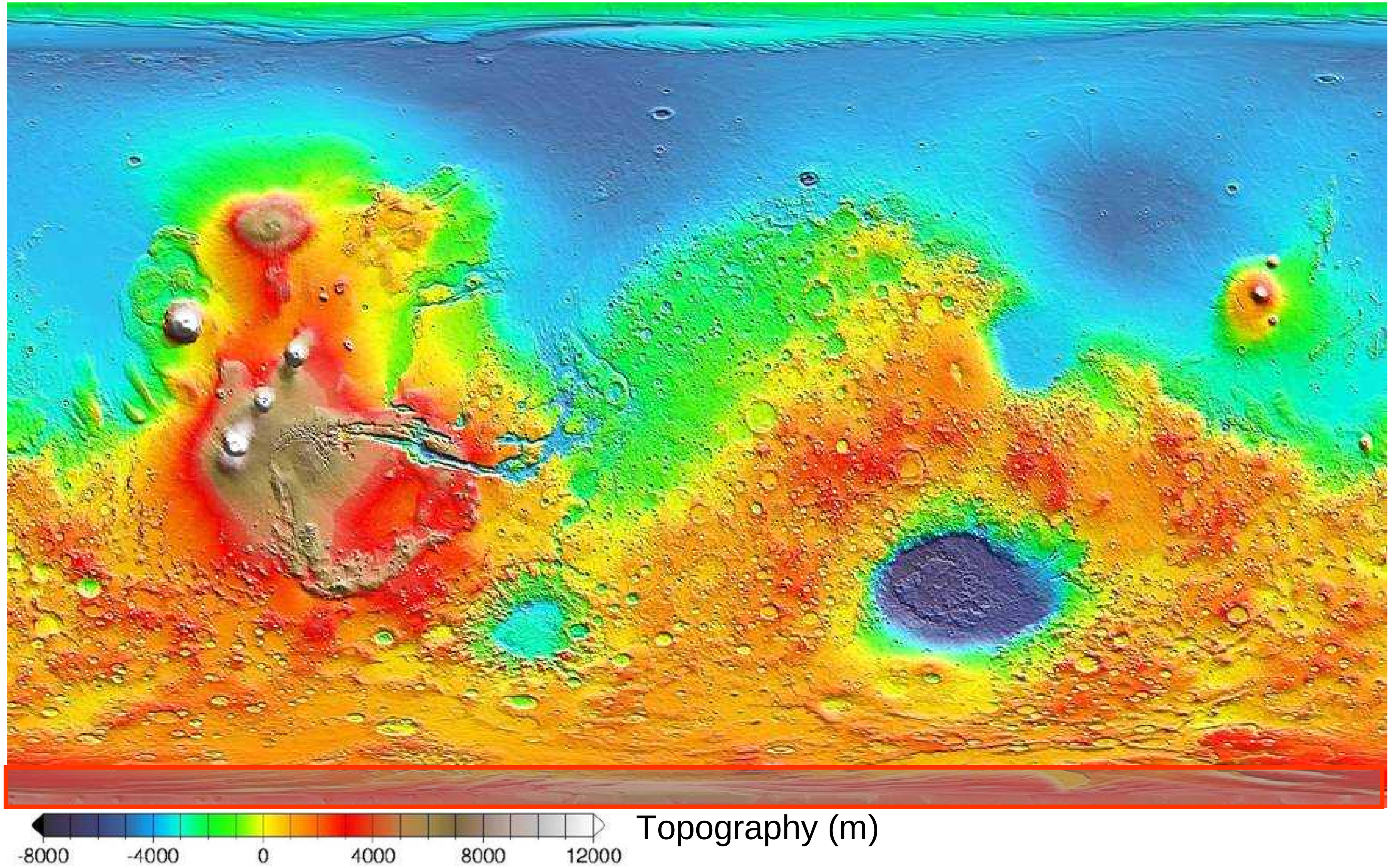


South Polar Layered Deposits seen by Mars Express Radar MARSIS- 3.3 km thick, almost pure ice !!

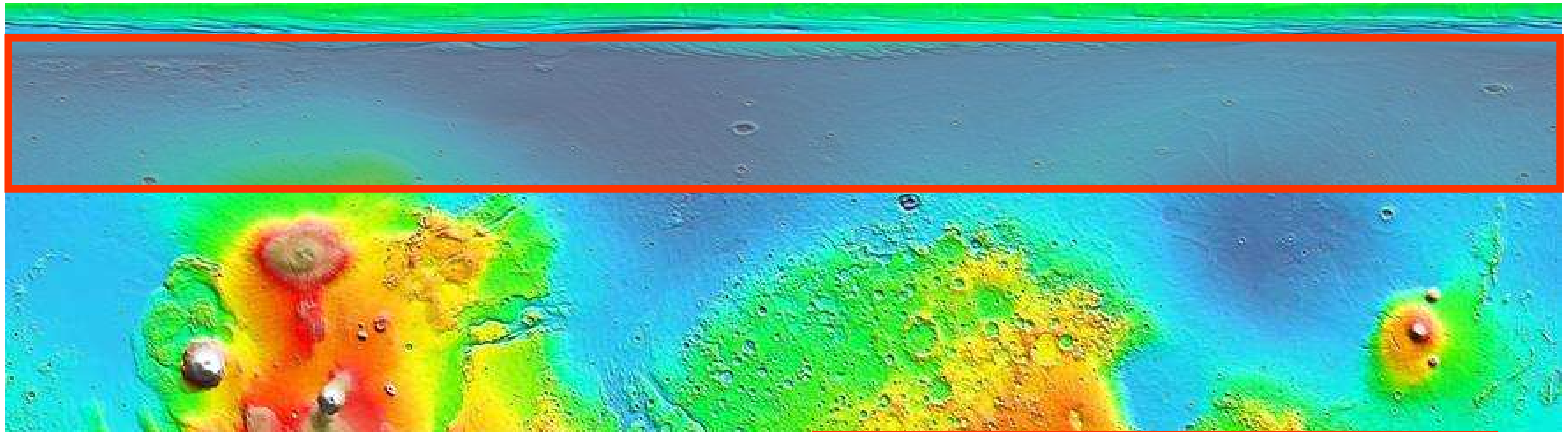


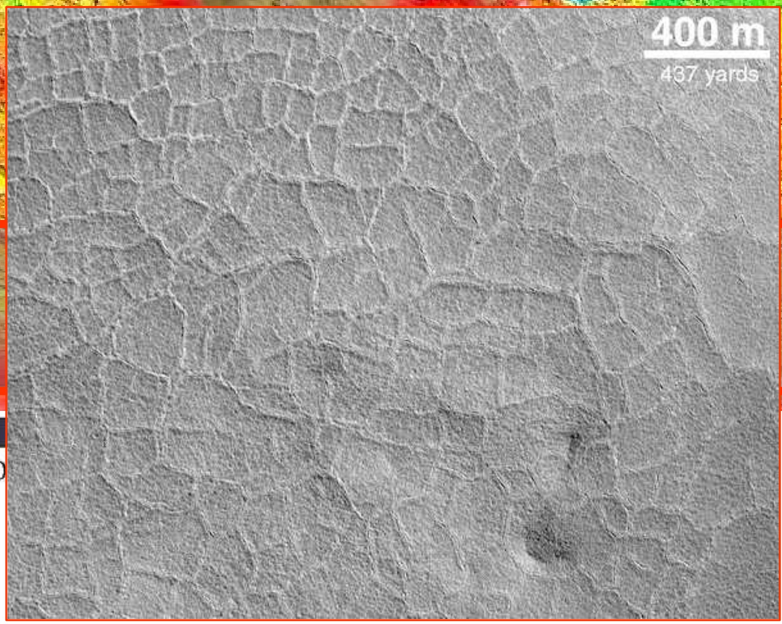
Internal Layering in the south polar layered deposits (MARSIS)

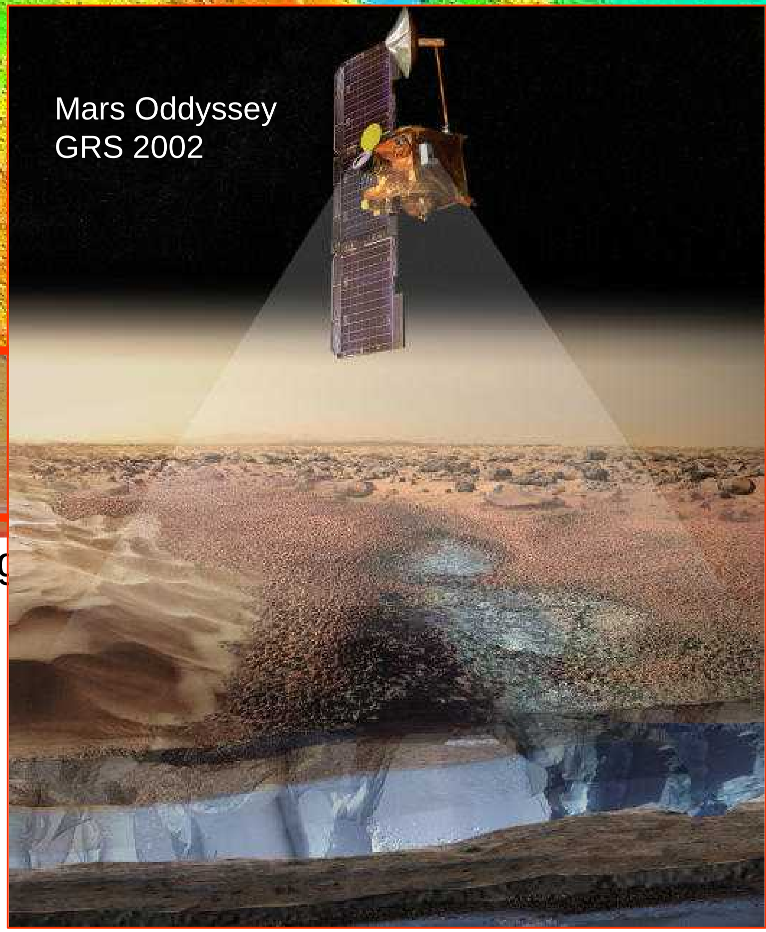




Ice landforms on Mars in polar regions (> ~80 ° lat)

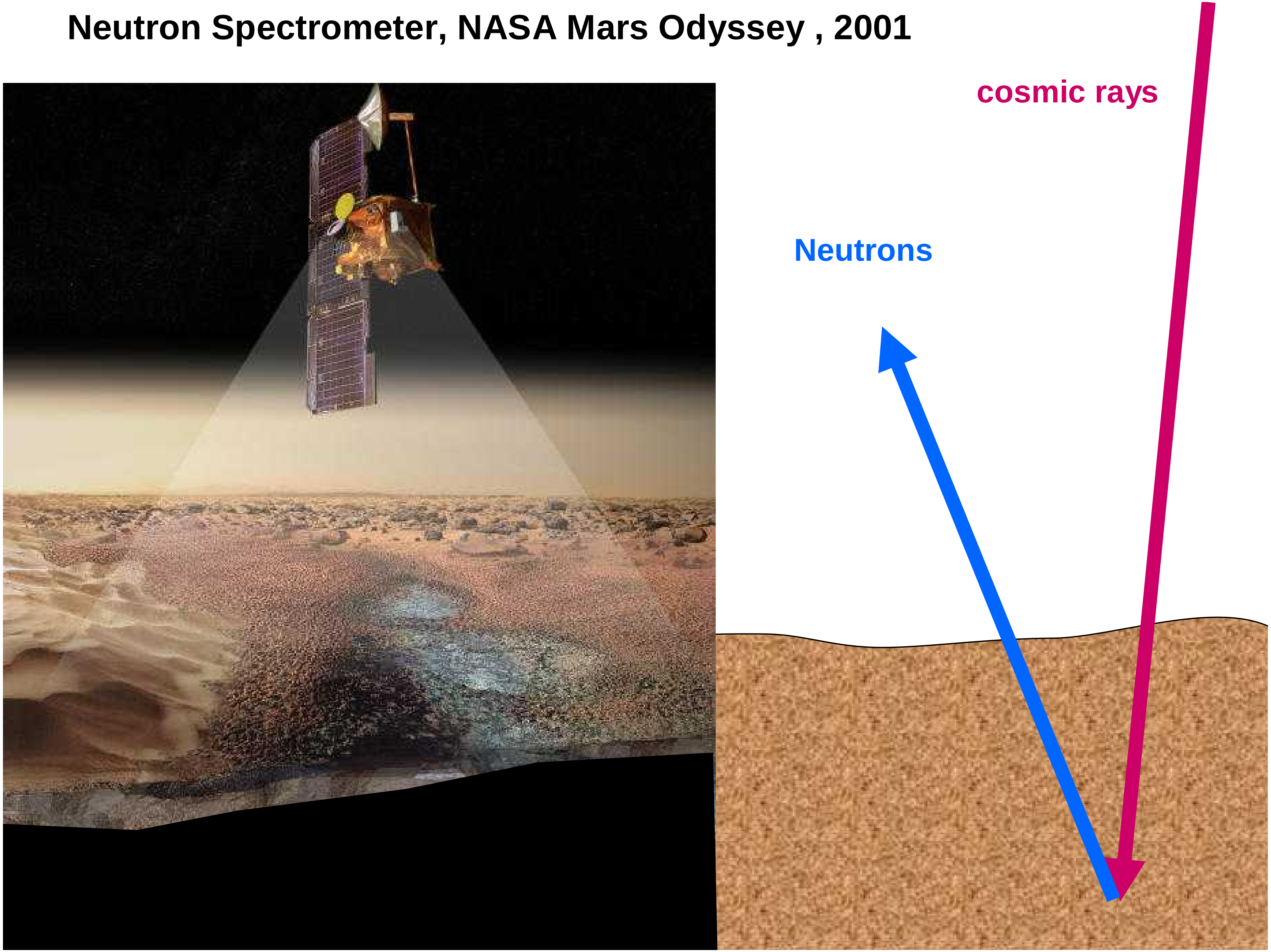




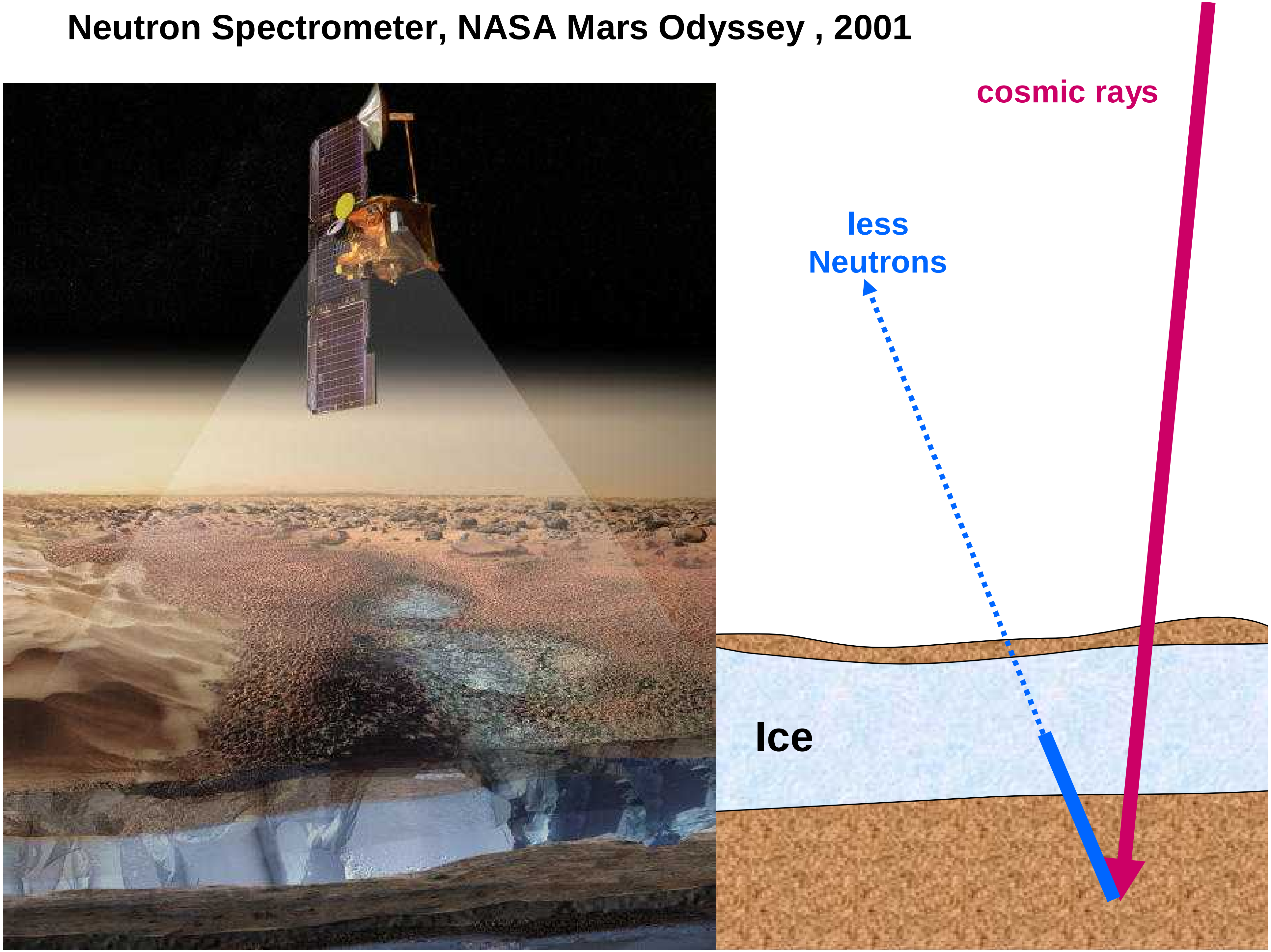


Ice landforms on Mars at high latitudes > 60 °

Neutron Spectrometer, NASA Mars Odyssey , 2001

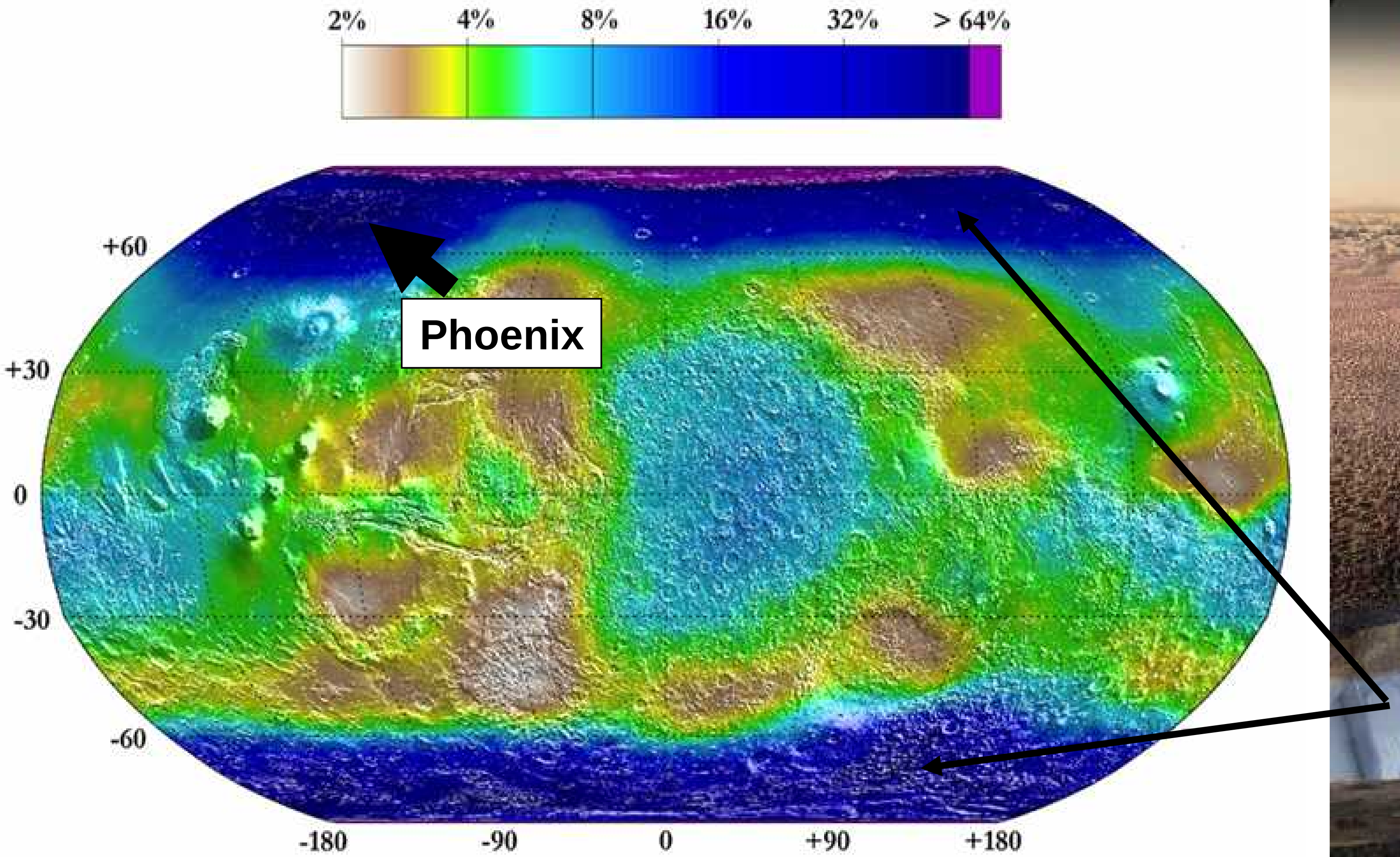


Neutron Spectrometer, NASA Mars Odyssey , 2001

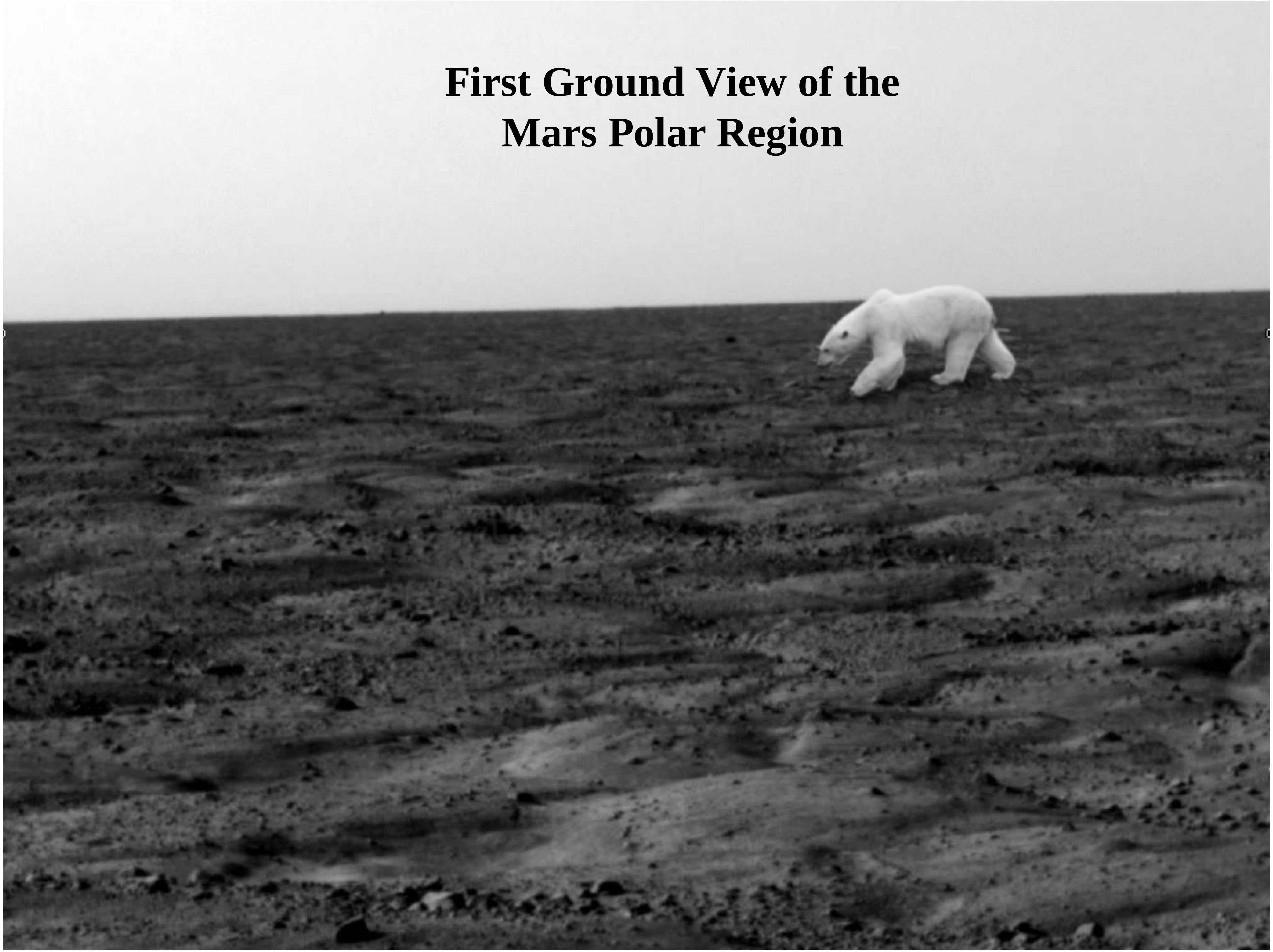


An ice-rich layer discovered by Mars Oddyssey below a few cm of dry sediments

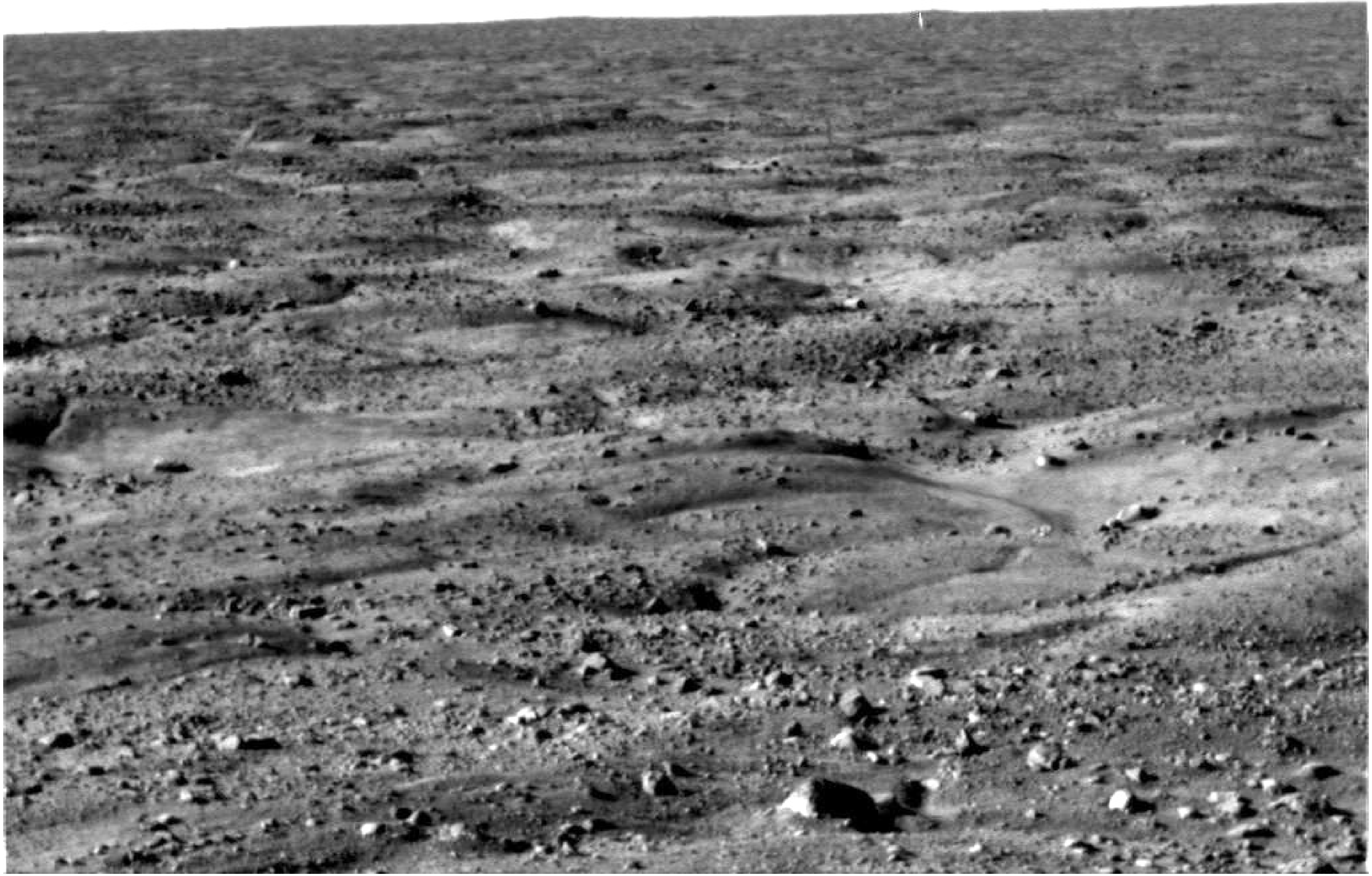
Minimum water equivalent hydrogen abundance (weight percent) deduced from Neutron flux
(Boynton et al. 2002 , Feldman et al. 2004)



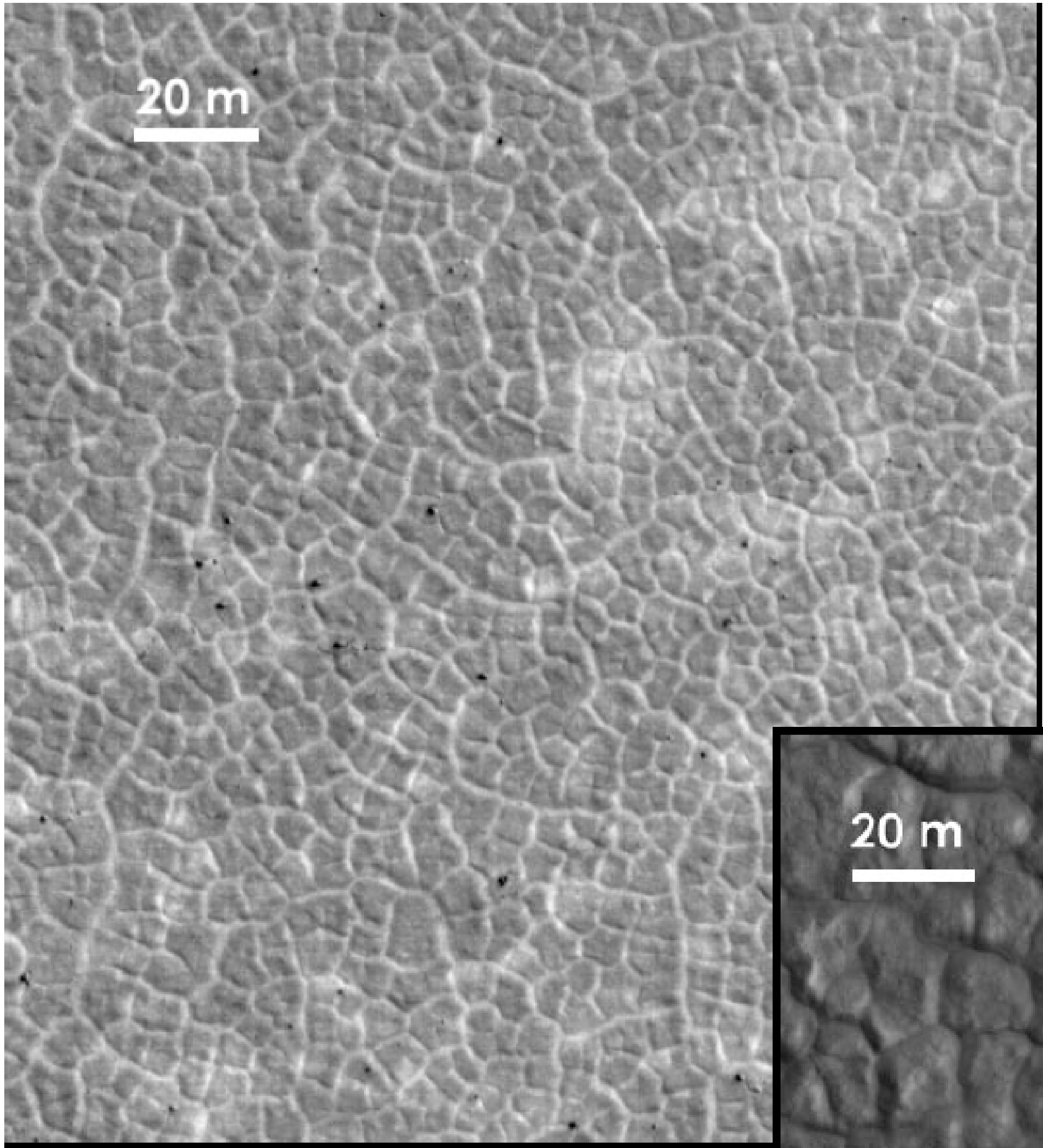
Phoenix: May 25, 2008   68°N


First Ground View of the
Mars Polar Region

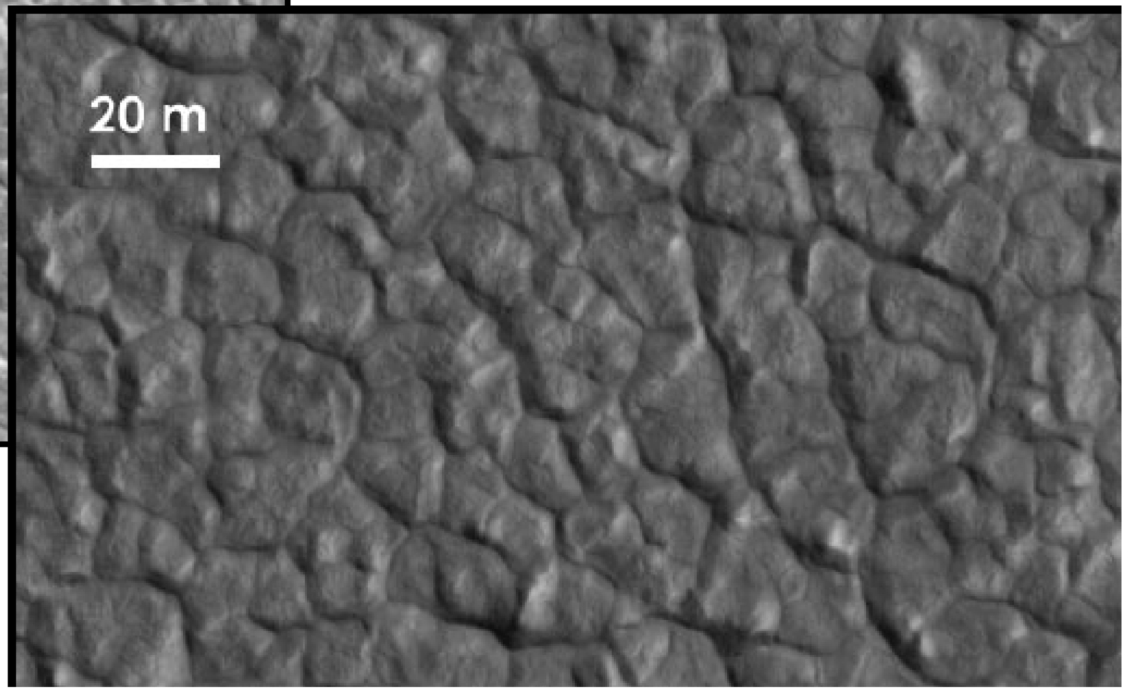
1st image Phoenix, may 2008




Antarctique



High Martian latitude surface shaped by subsurface ice layer (60°-90° latitude)

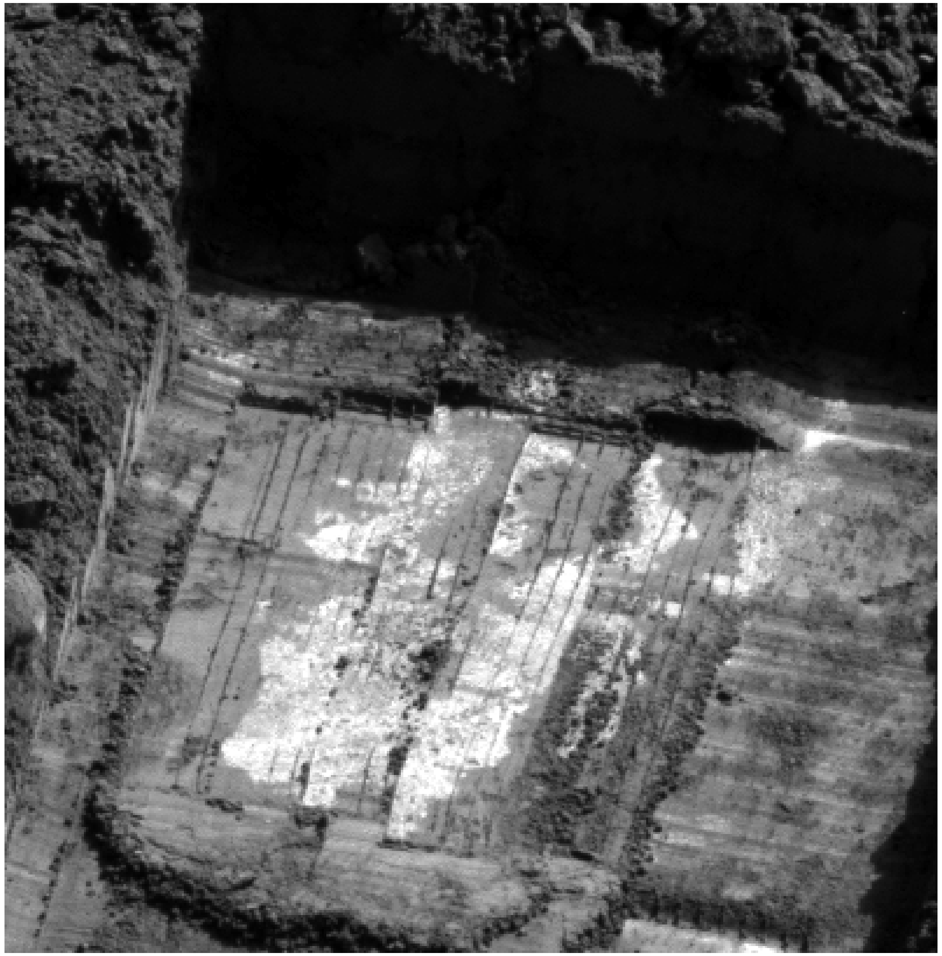


Below Phoenix : ice exposed by landing thrusters

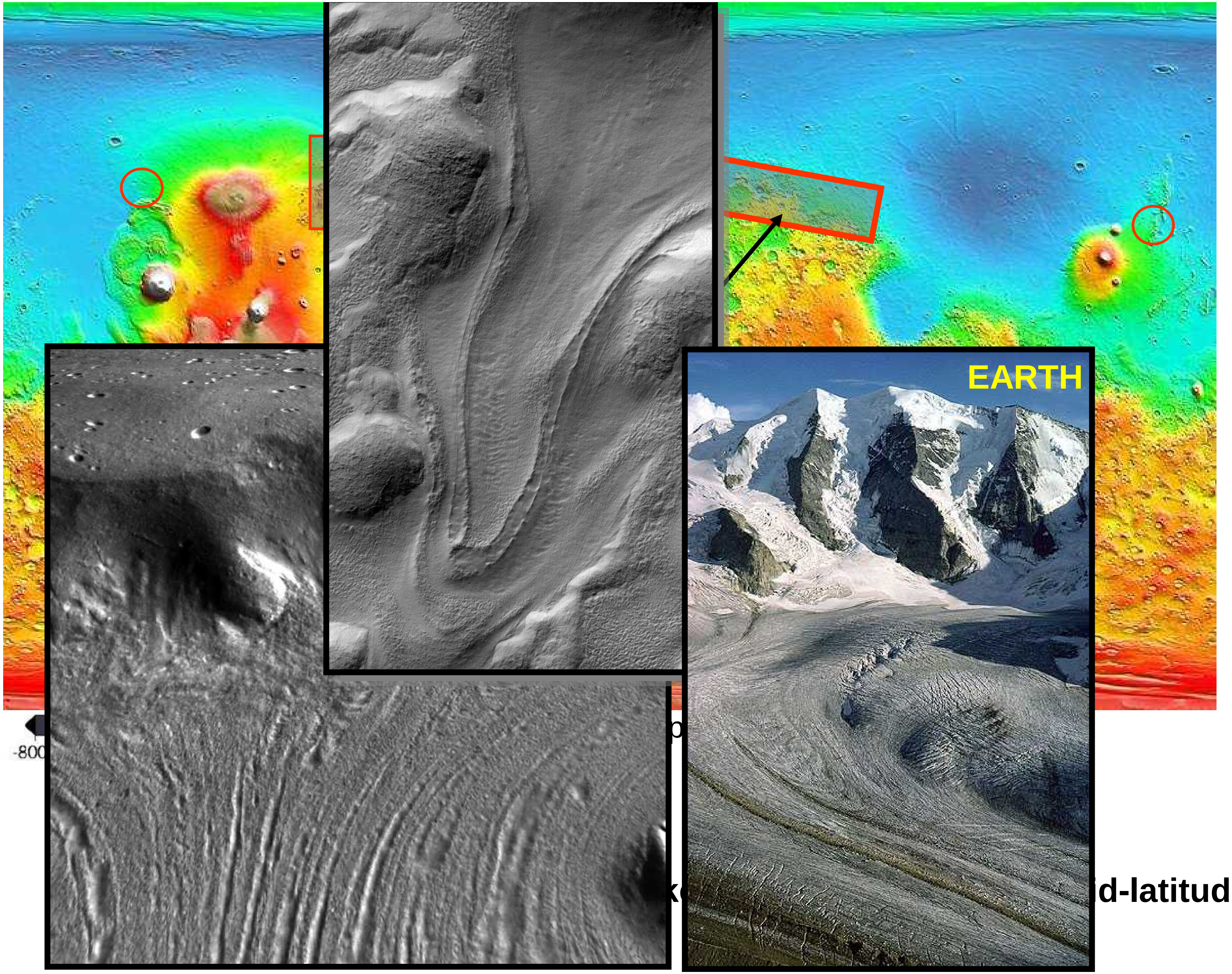
Below Phoenix : ice exposed by landing thrusters

Phoenix Ice-Bottomed Trenches

Dodo-Goldilocks

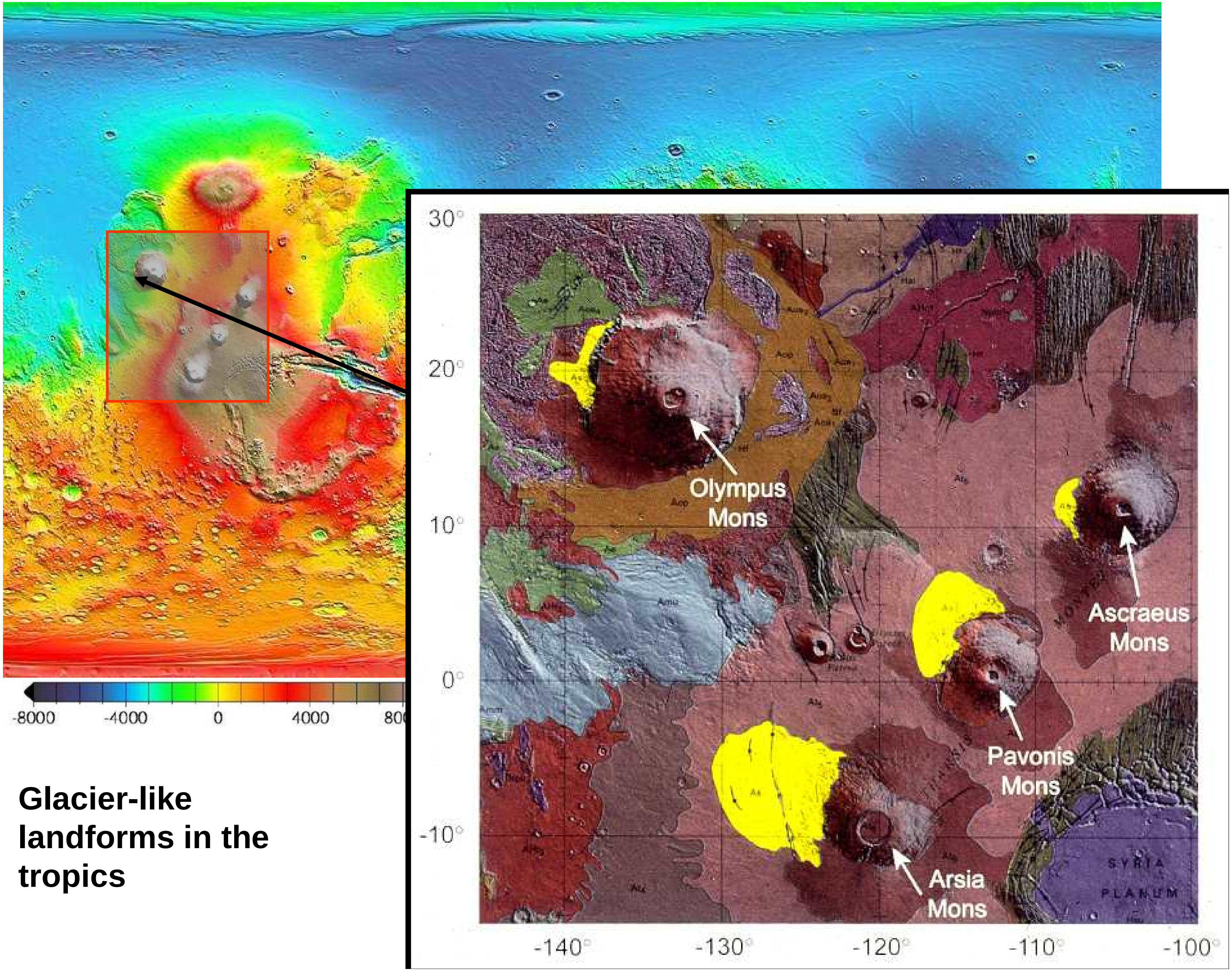


Snow White



-800

id-latitudes



Glacier-like landforms in the tropics

- Ice mantling and glaciers :

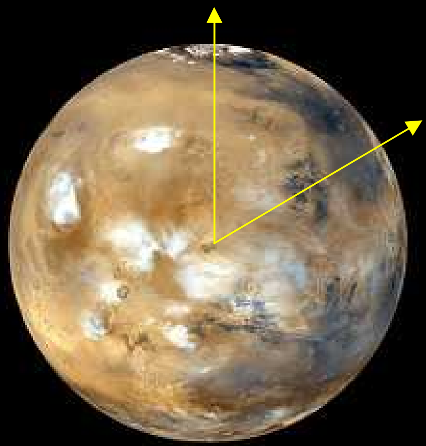
What happened ?

  - Diffusion of water vapor in the subsurface pores ? (e.g. *Mellon and Jakosky, 1993.*)
  - Role of hydrothermalism ? (e.g. *Neukum et al.)*
  - Atmospheric Ice precipitation ? *(e.g. Forget et al., 2006, Mishna et al., 2003)*

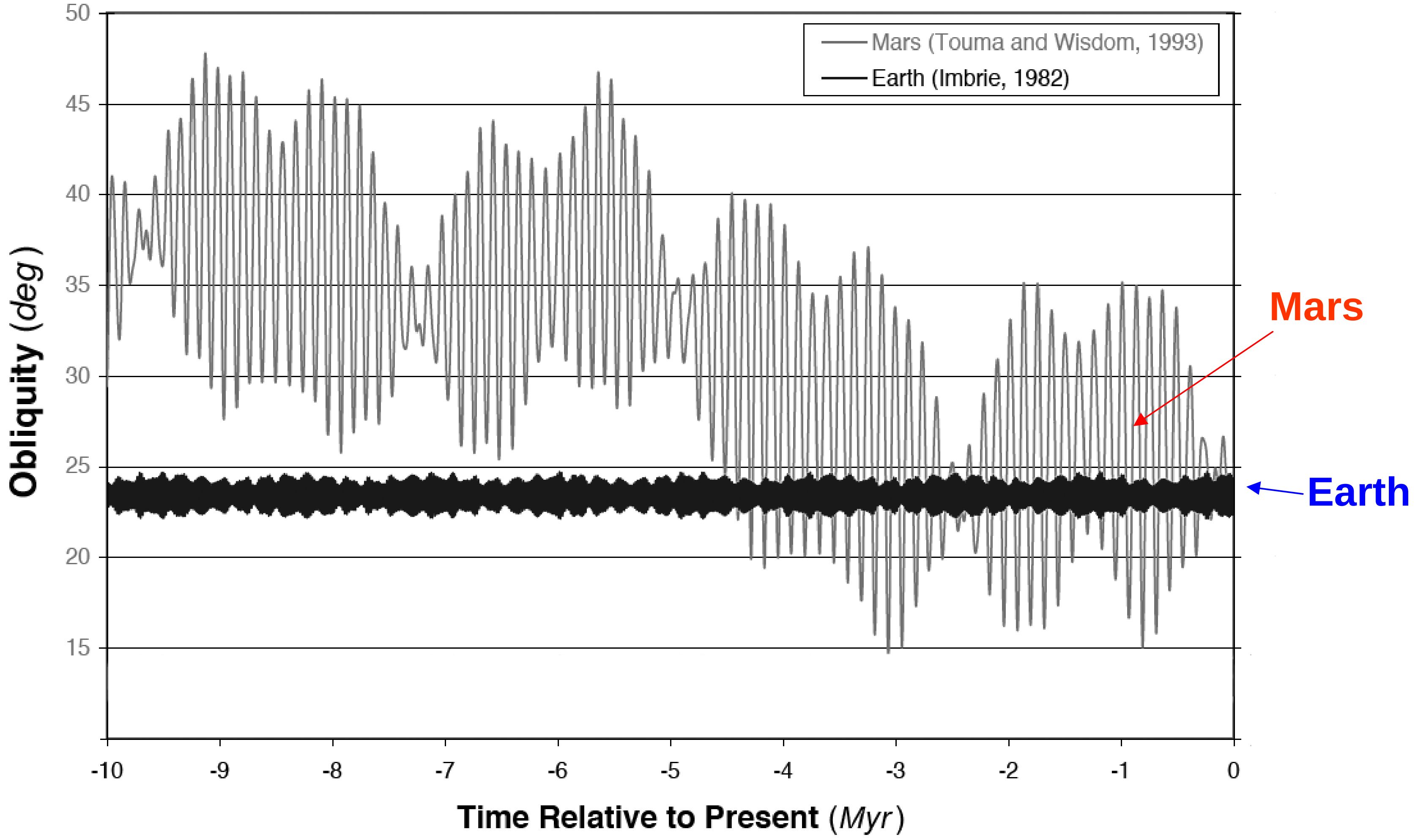
Climate changes resulting from obliquity variations

Earth obliquity: variations ± 1.3°

Mars: variations
between 0° et >60° !



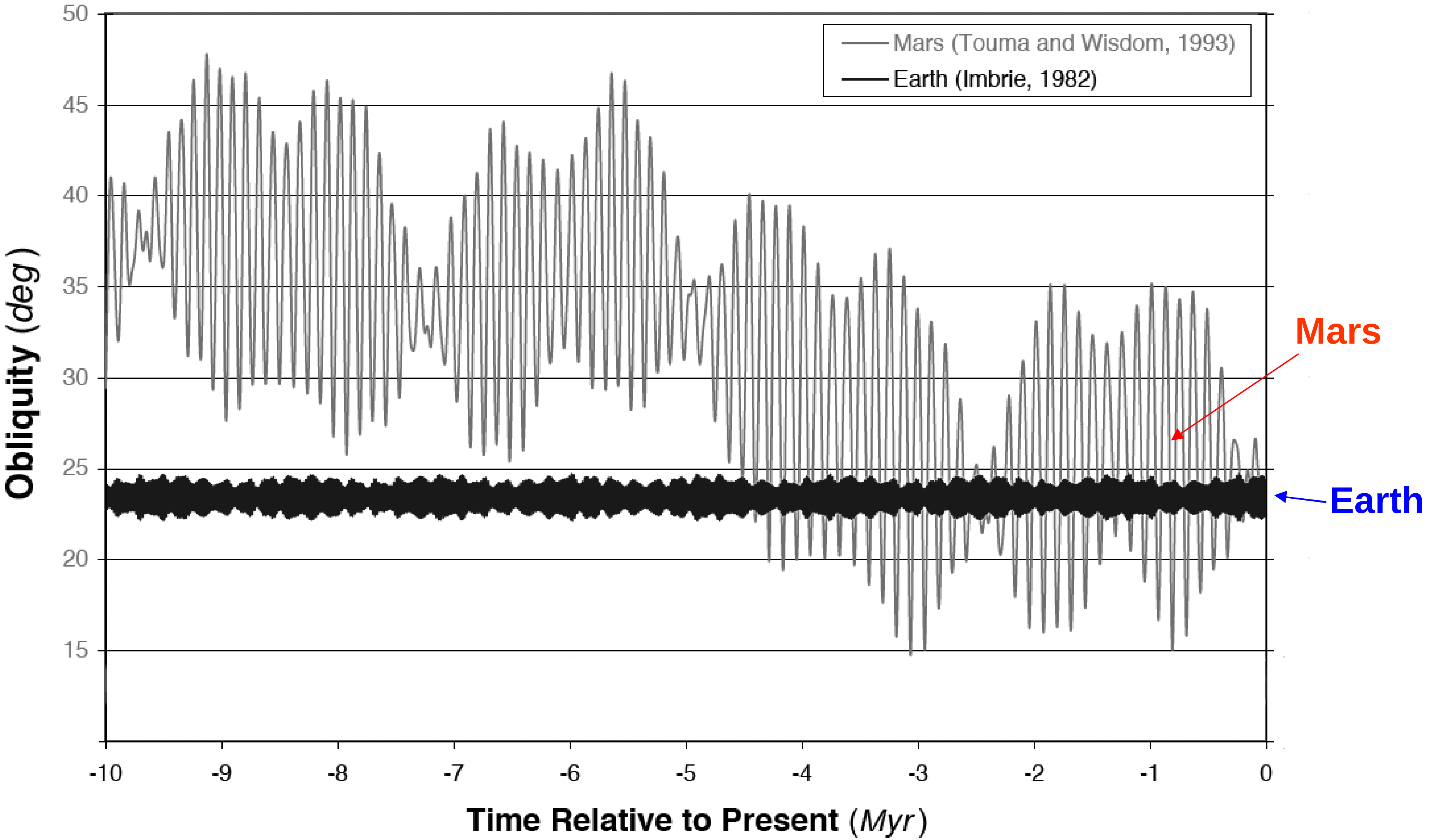
Laskar et al. 2004
Laskar and Robutel 1993
Touma and Wisdom 1993



During Mars History, most likely obliquity: 41.8 ° (Laskar et al. 2004)

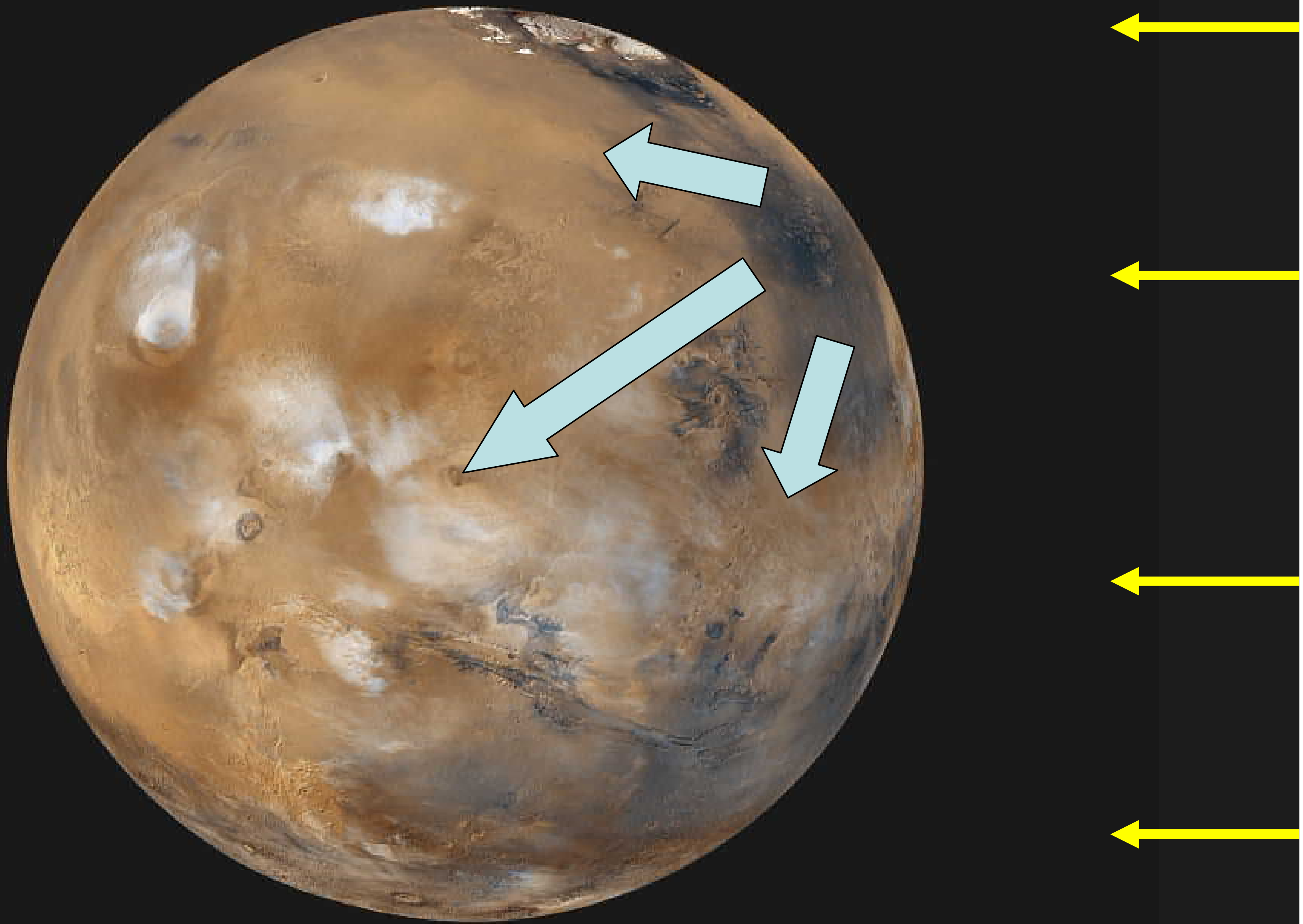
Laskar et al. 2004
Laskar and Robutel 1993
Touma and Wisdom 1993

Mars and Earth obliquity in the past 10 Myr



Before ?? => During Mars History, most likely obliquity: 41.8 ° (Laskar et al. 2004)

Mars water cycle at high obliquity



LMD GCM Simulations:

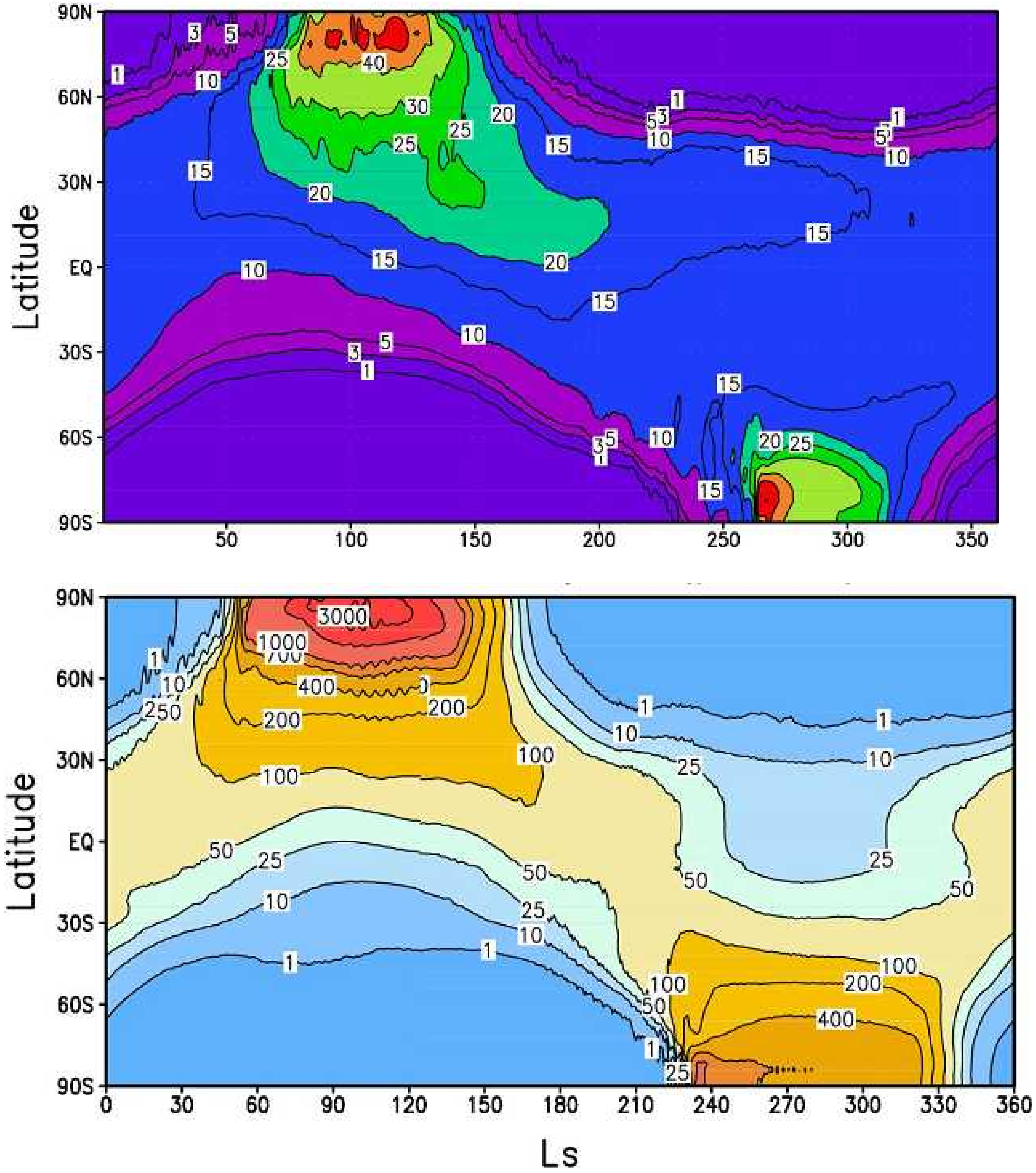
Water vapor column

(*precipitable –microns*)

On present-day Mars :

Same, but 45 ° Obliquity

(Circular orbit)

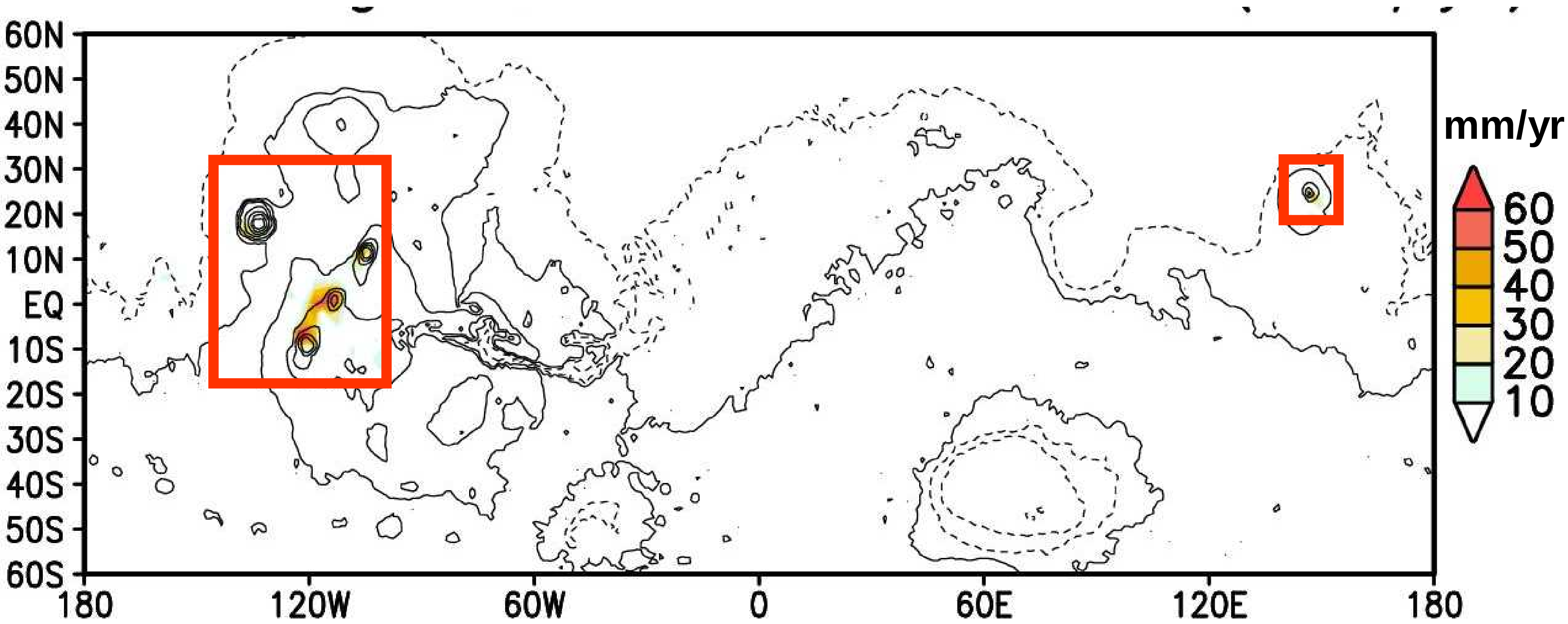


Ice accumulation rate (mm/yr)

high resolution simulation (2 ° x2 °)

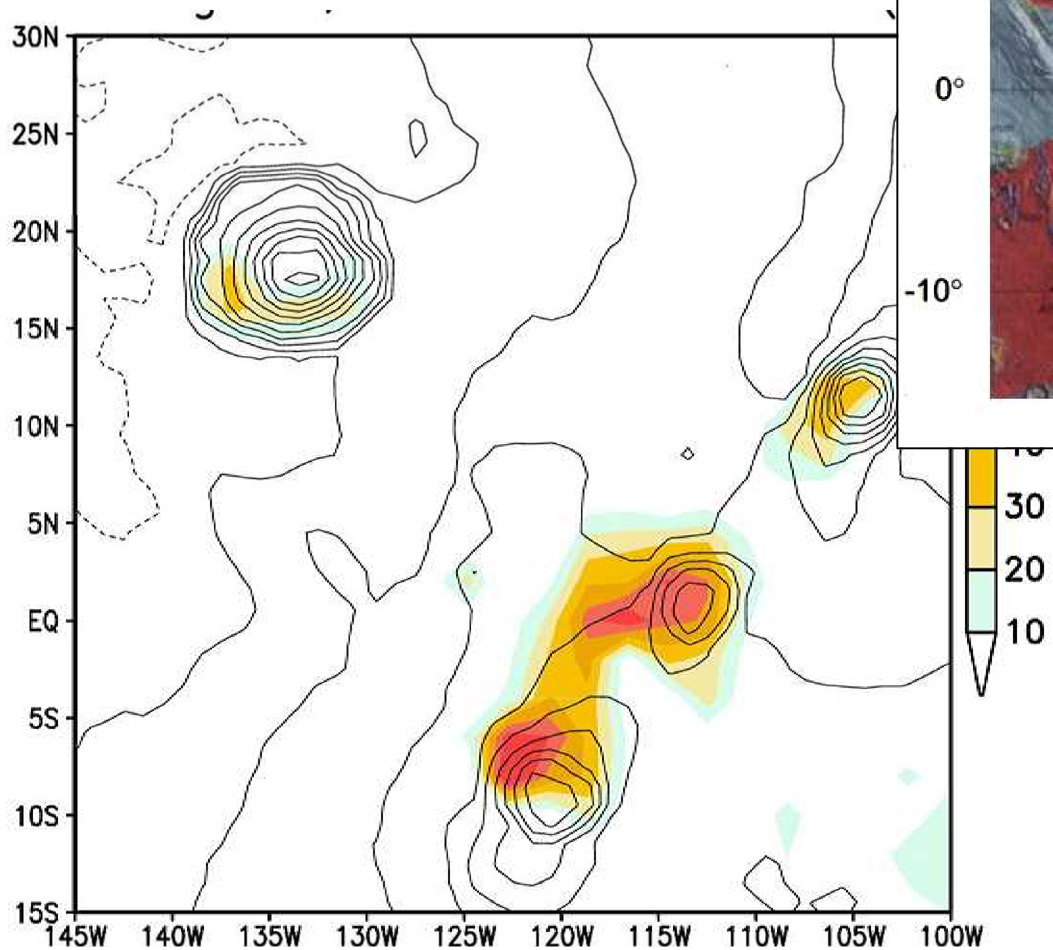
Obliquity = 45 ° , Excentricity = 0, Dust Opacity =0.2

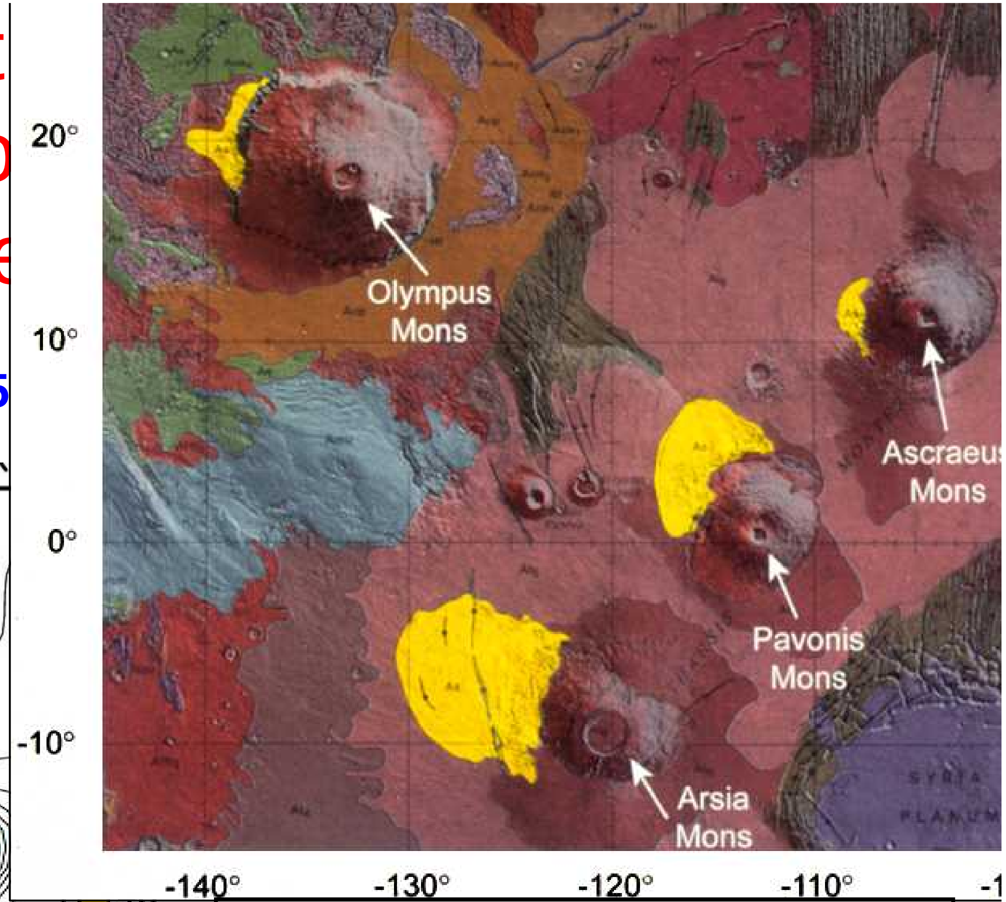
Forget et al. Science 311, p368, 2006



The format
accumulatio
very high re

Forget et al. 2006: Obliquity = 45



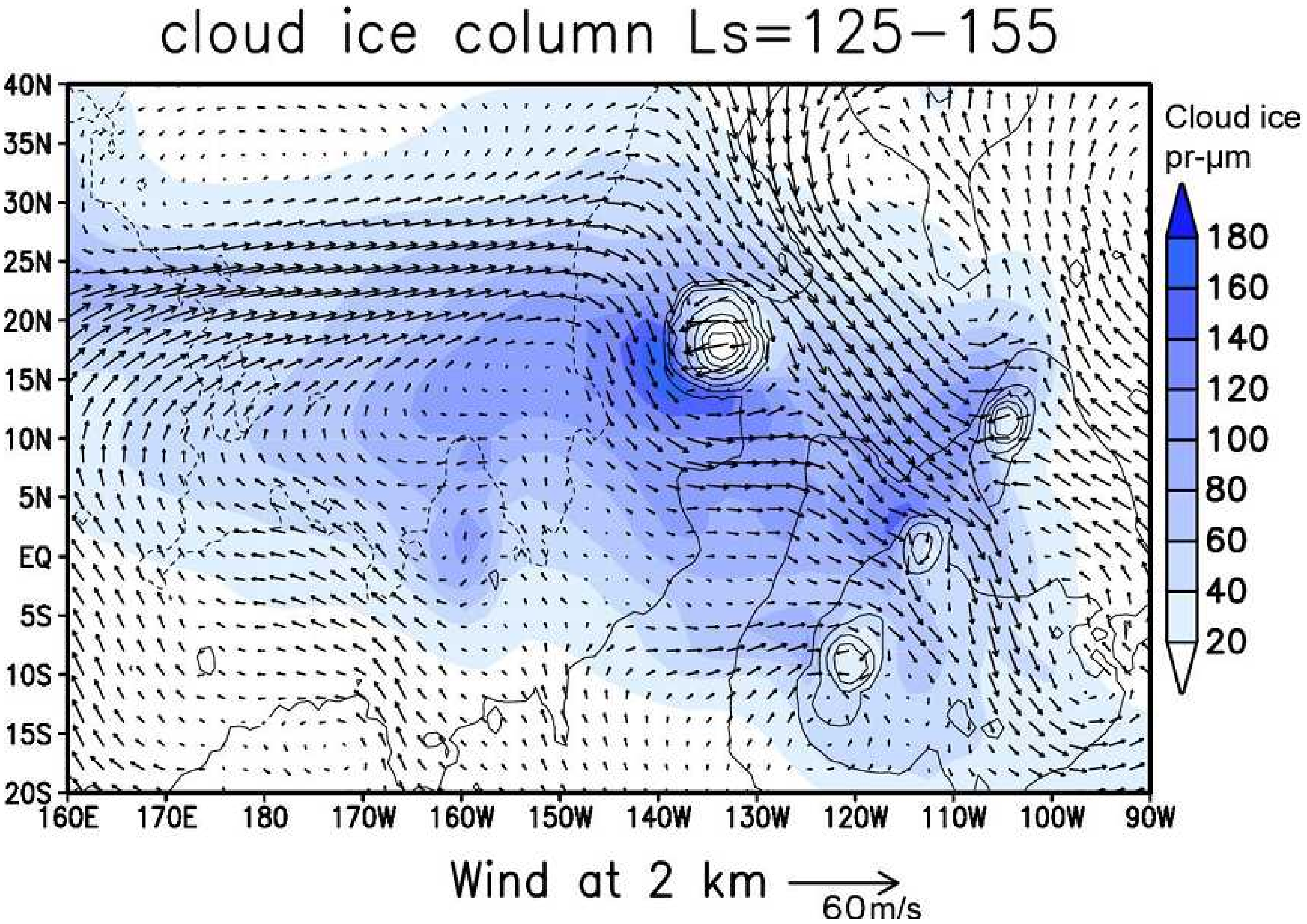


•Fan shaped deposits, drop moraines characteristic of cold based glaciers.

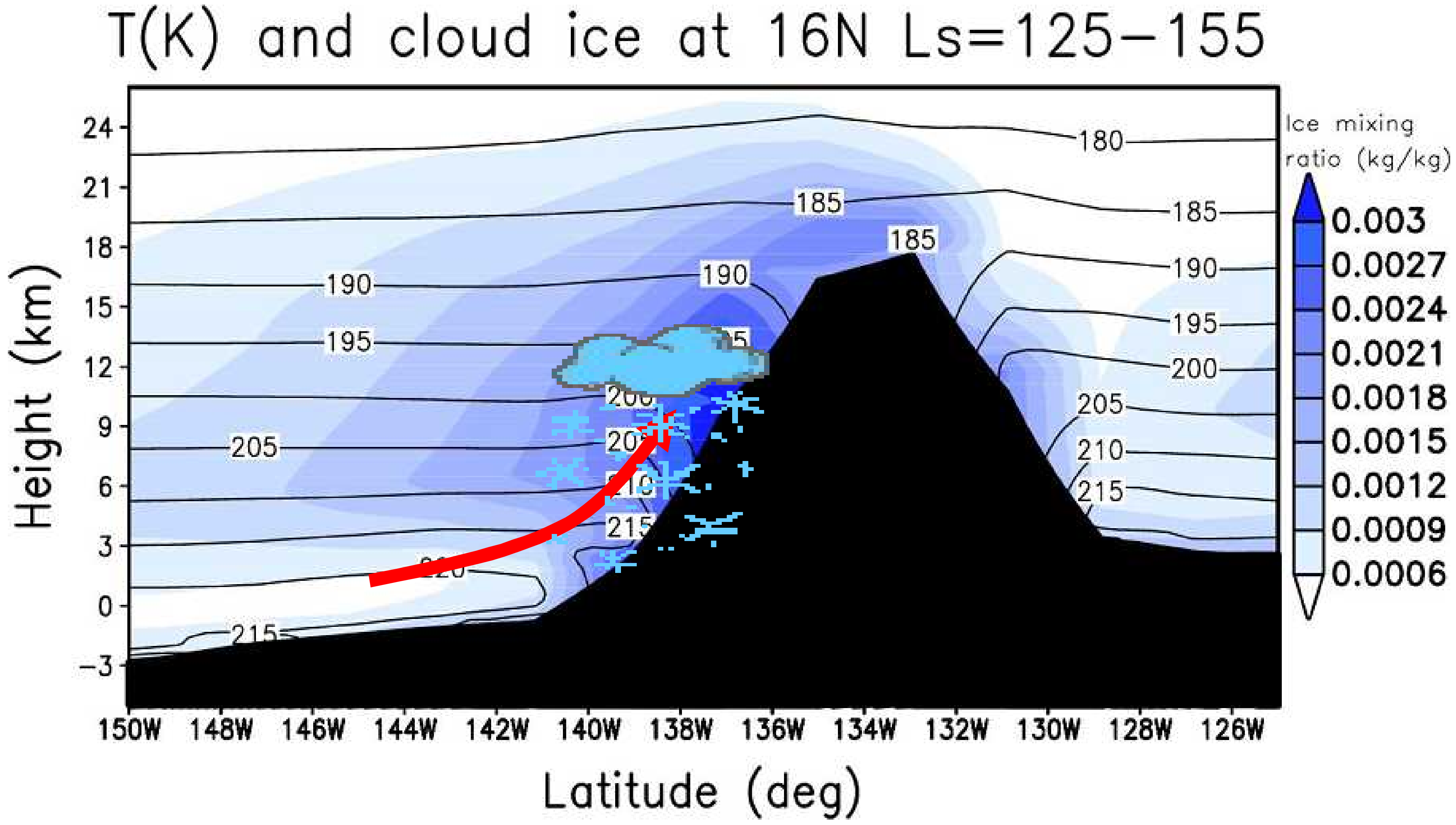
•Rock glaciers

Head et al. 2003, Shean et al. 2005, Head et al. 2005 Lucchitta 1981

At high obliquity: Ice accumulation by ice precipitation on windward slope

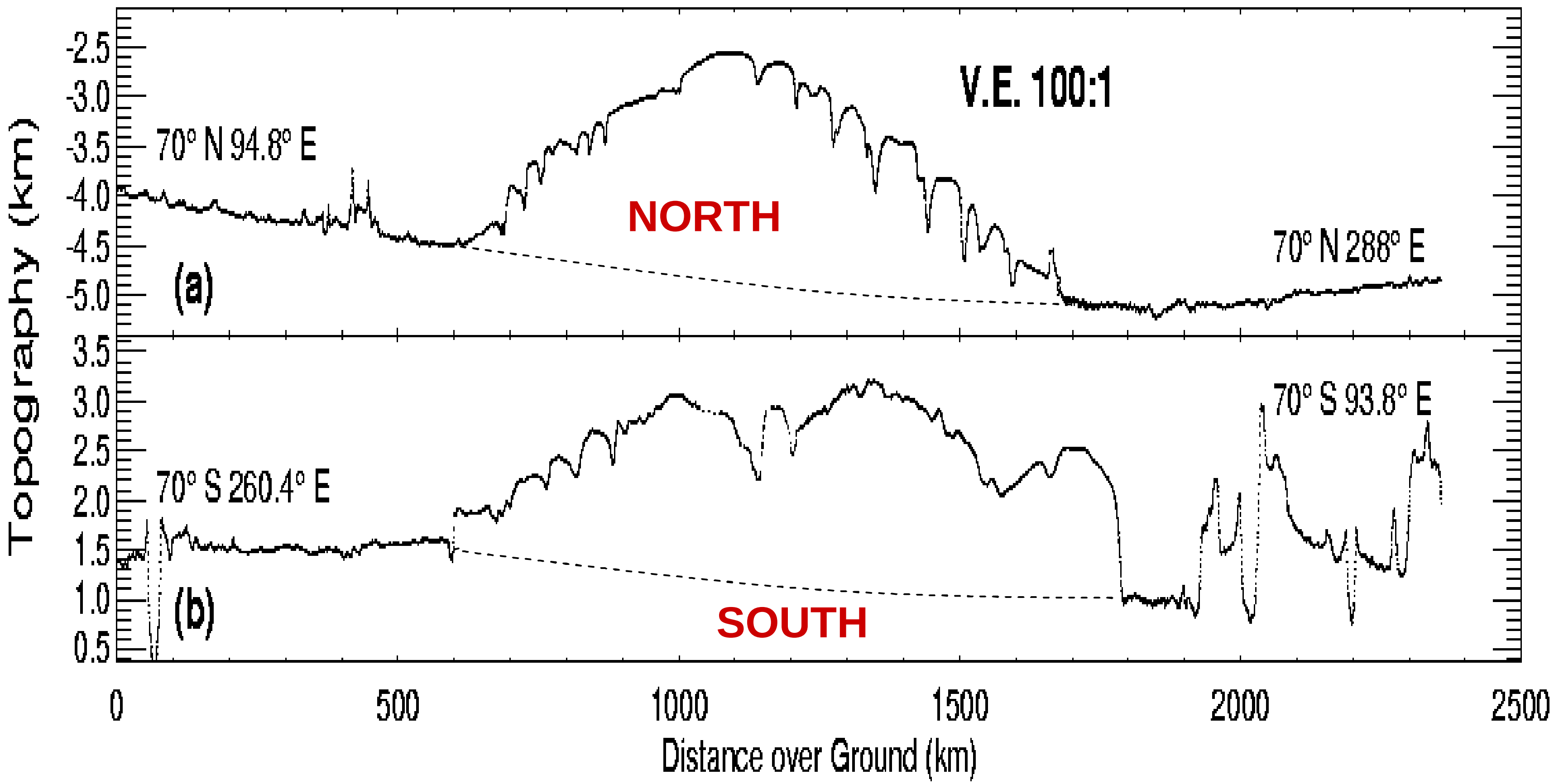


At high obliquity: Ice accumulation by ice precipitation on windward slope

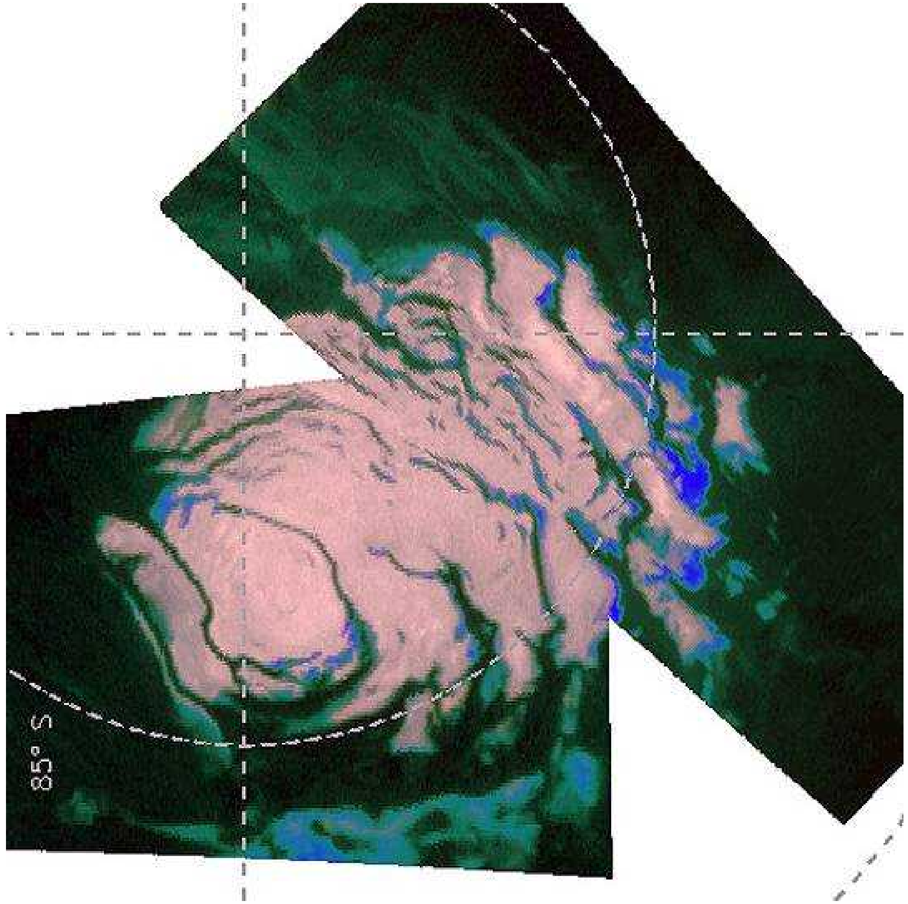


What if water ice is also available **at the south pole ?**

Topography of the polar regions

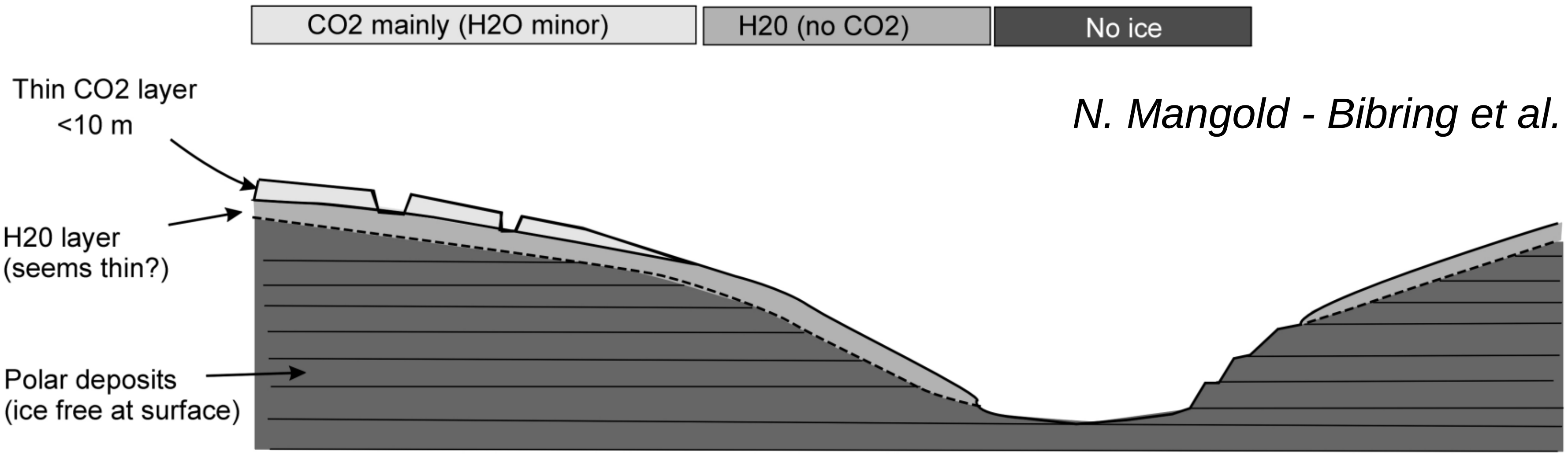


Near the south pole: permanent surface WATER ICE seen by Mars Express OMEGA



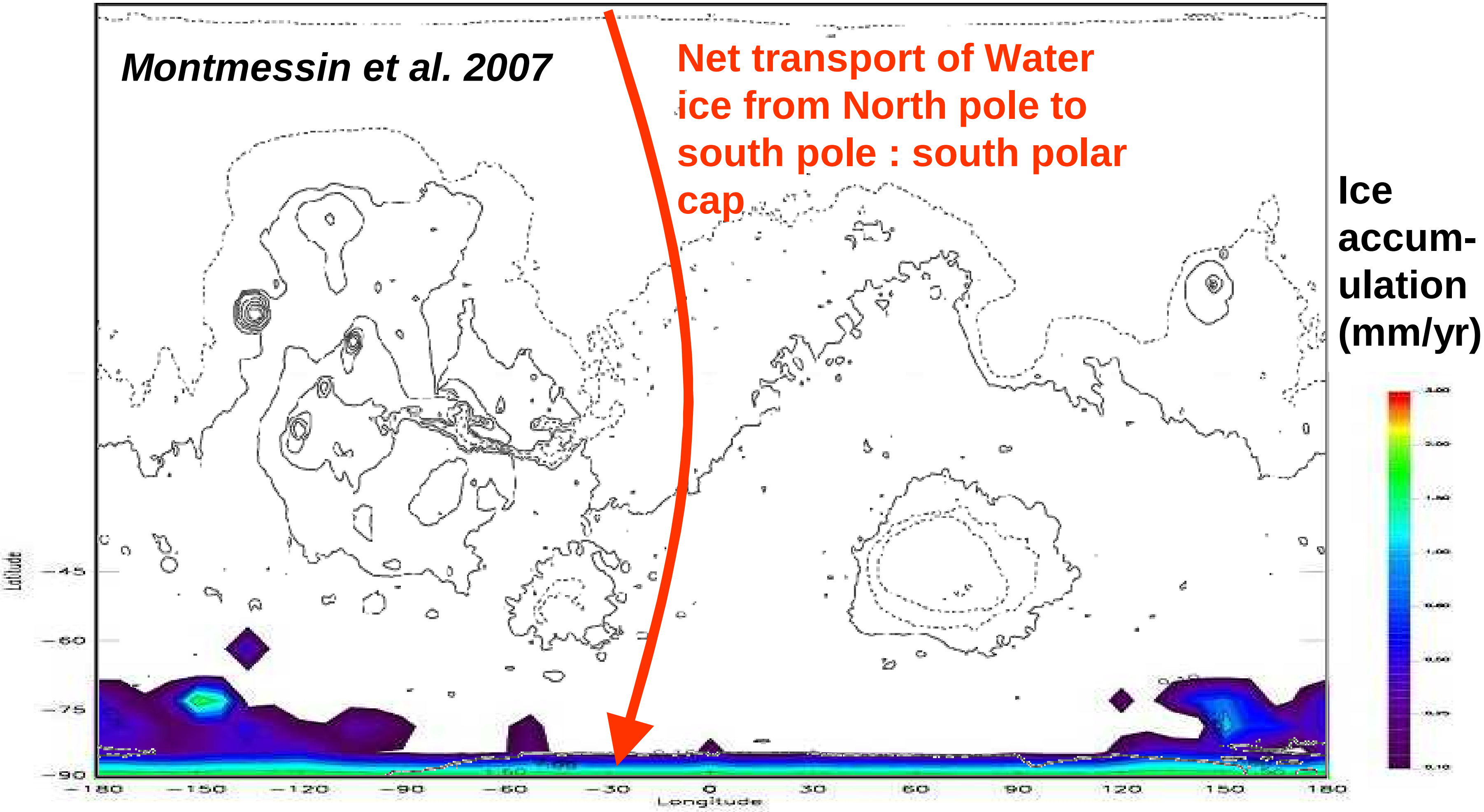
Blue: H_2O ice
White CO2 ice

Bibring et al. 2004



N. Mangold - Bibring et al. 2004

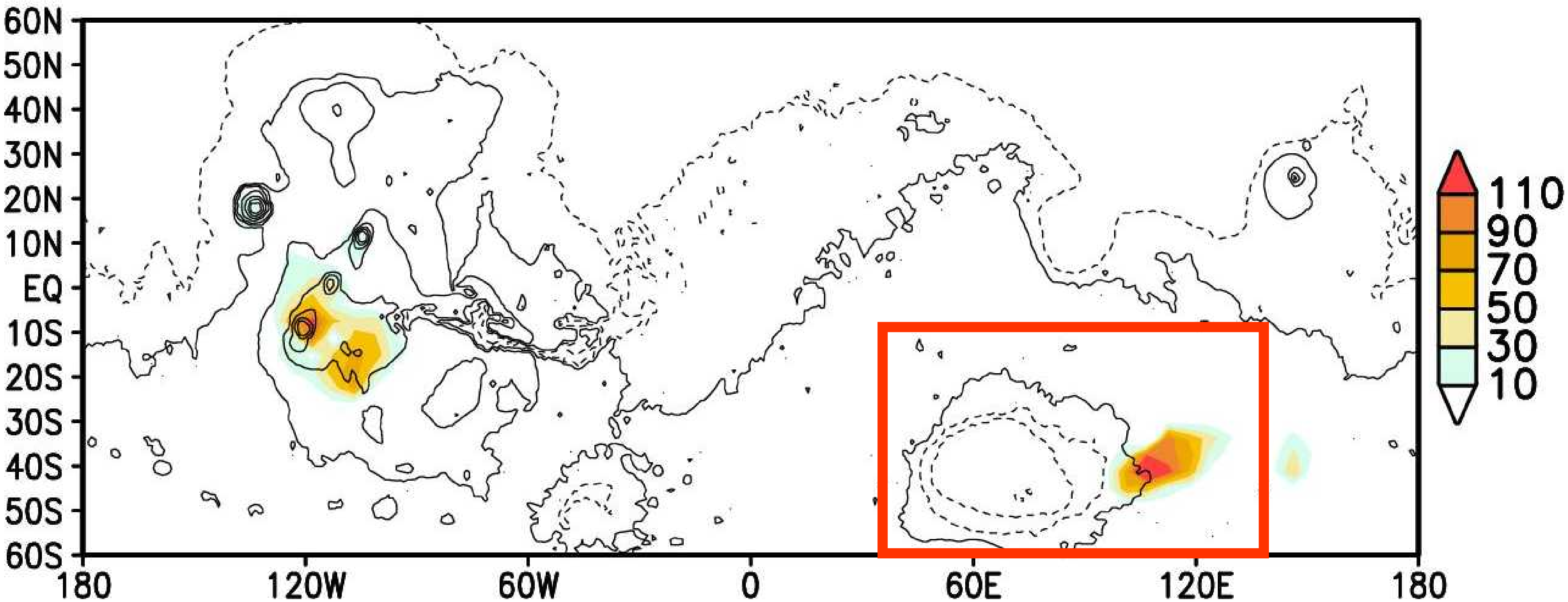
Ice accumulation -75000 years ago
Perihelion = Northern summer (≠ today)

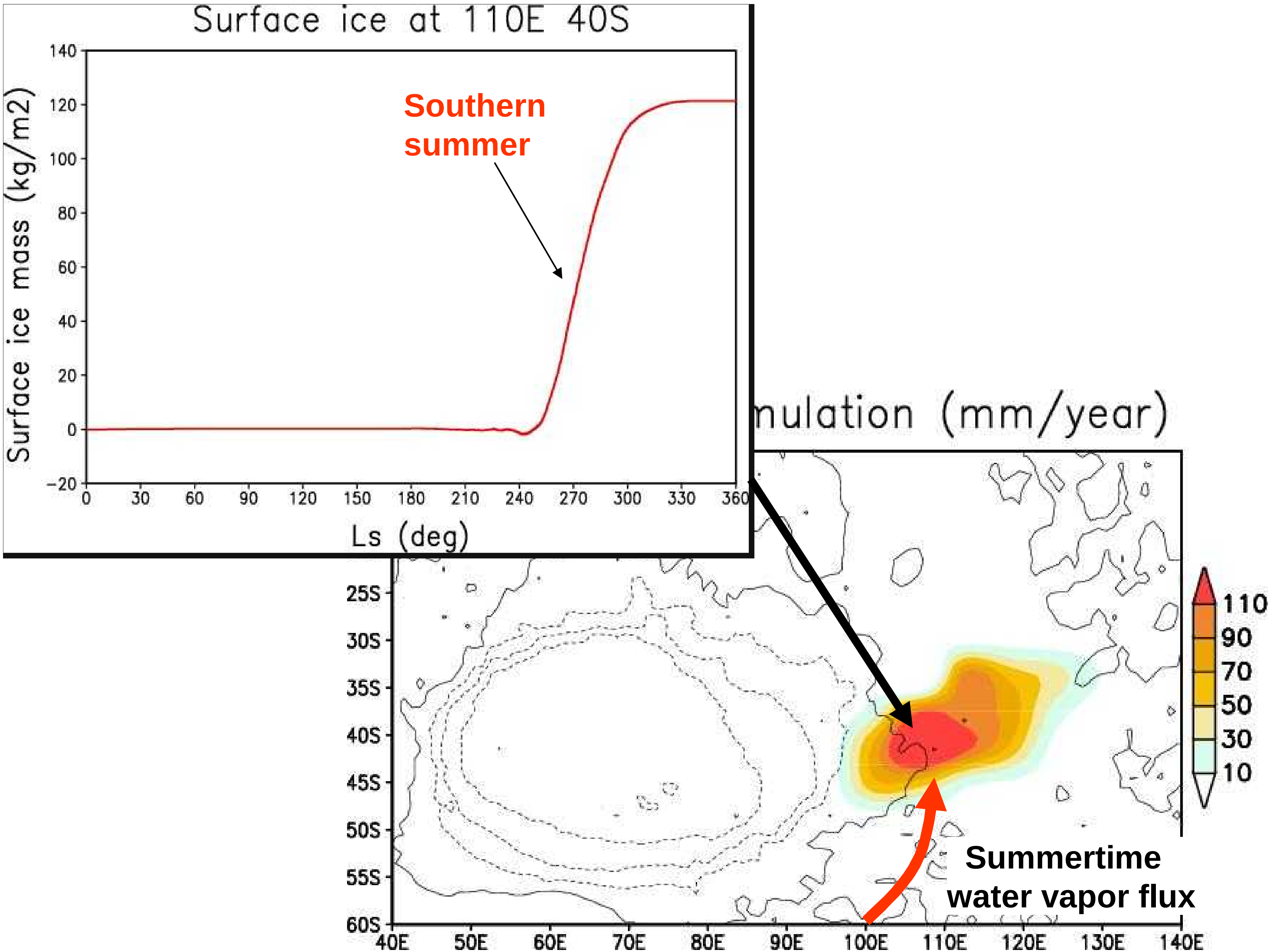


High Obliquity Simulation with a water ice cap **at the south pole**

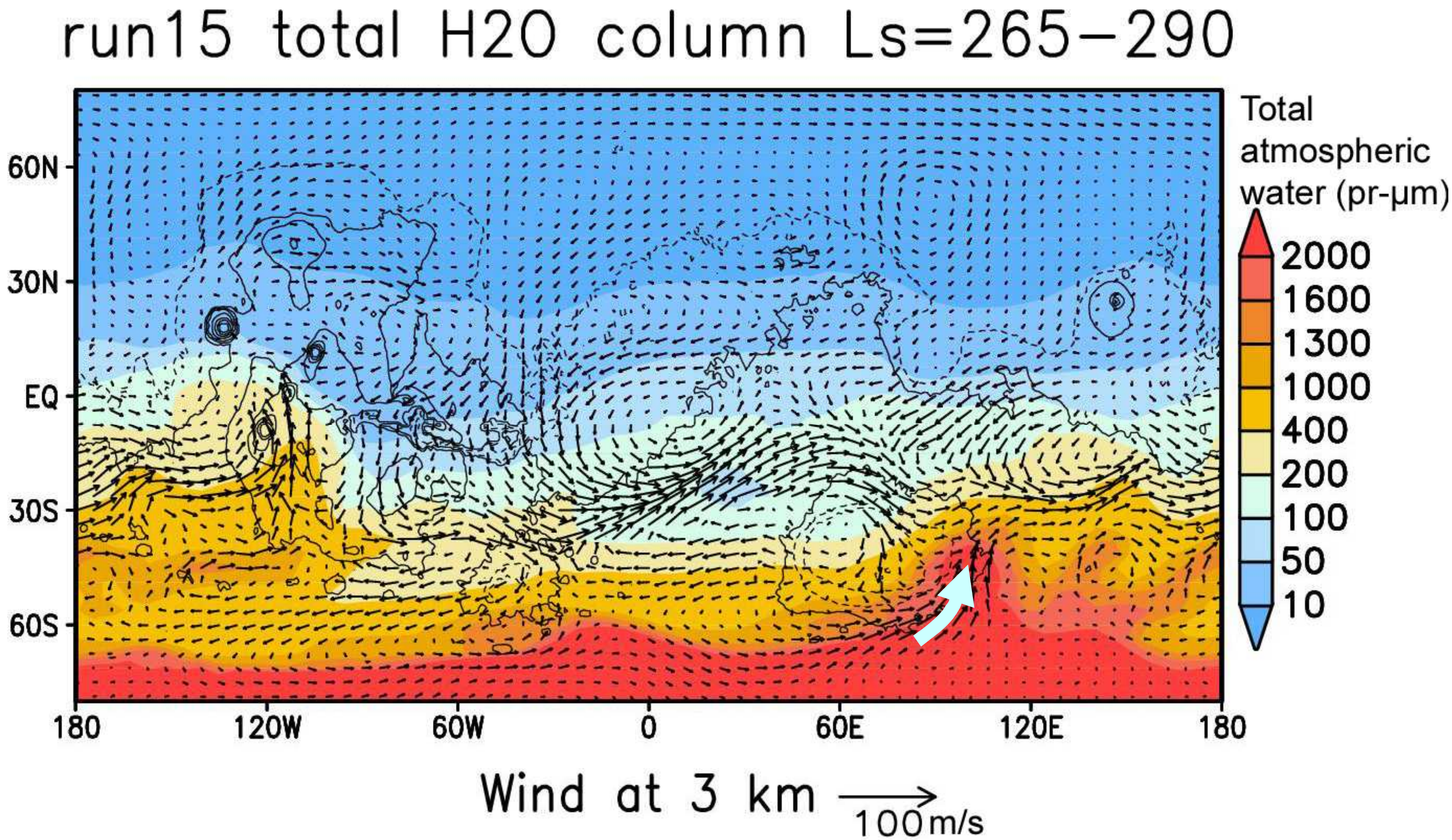
(Forget et al. 2005)

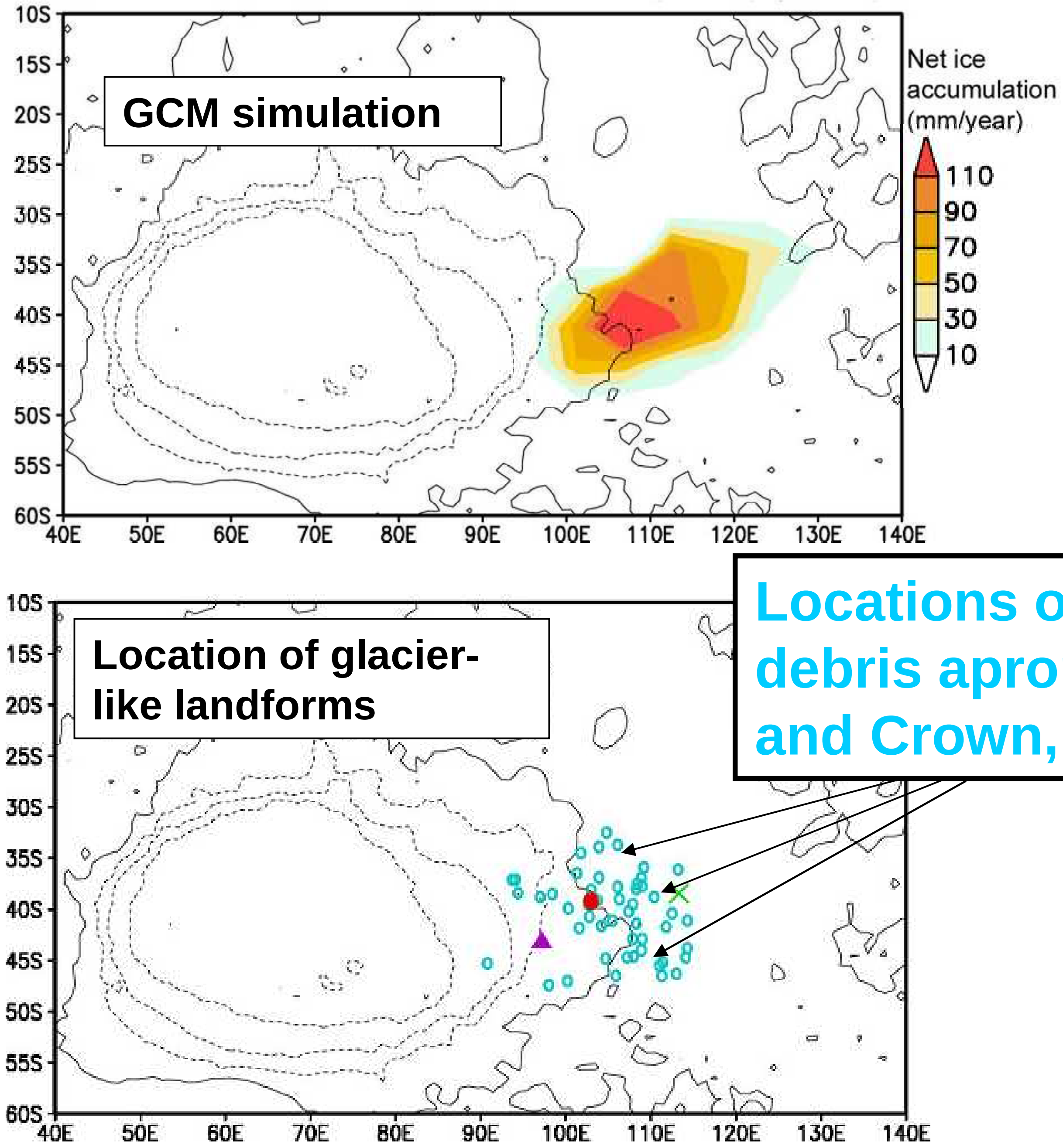
Yearly accumulation rate (mm/year) (1Oth year simulation)



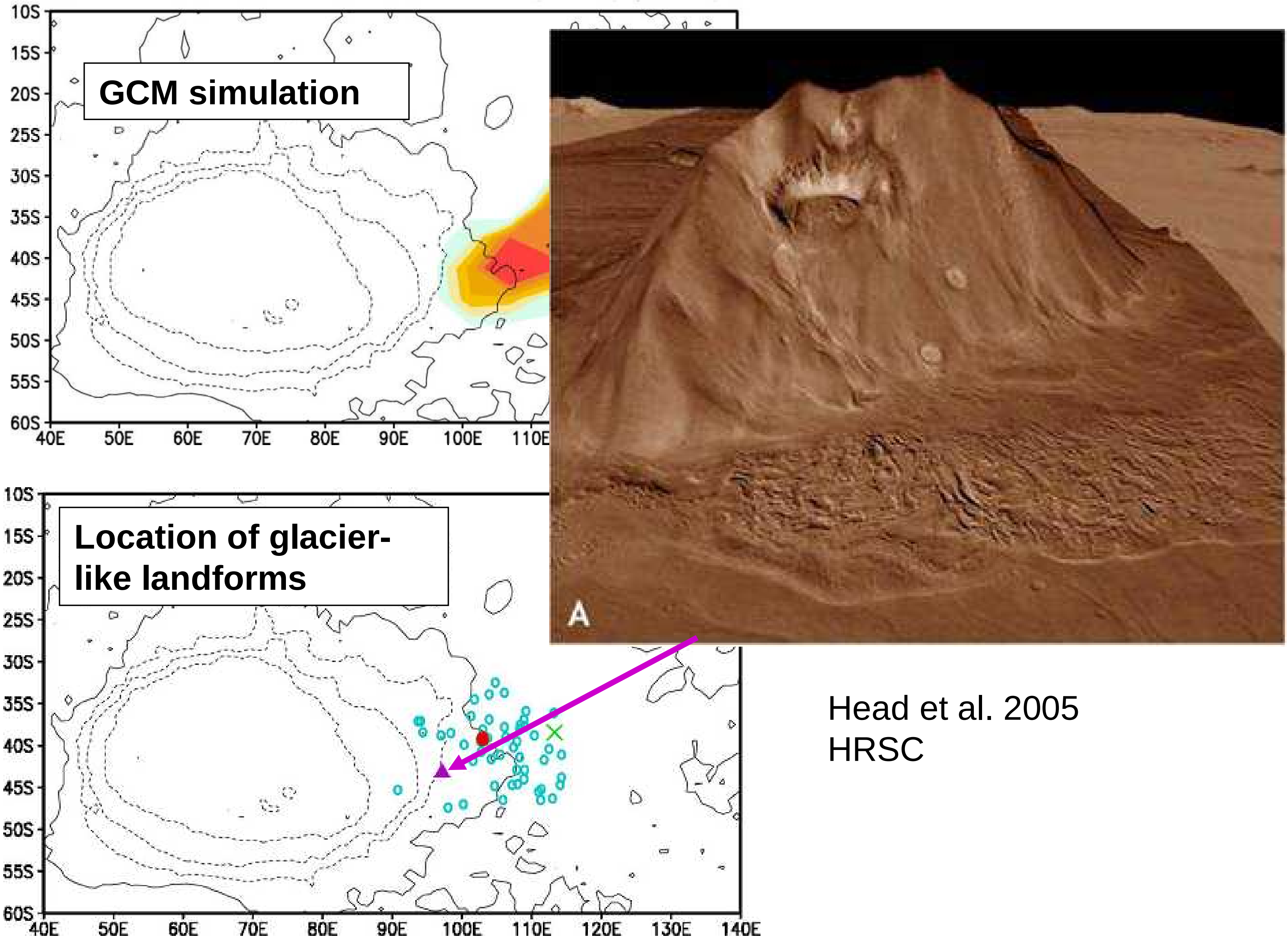


Surface ice at 110E 40S
Surface ice mass (kg/m2)
Ls (deg)
Southern summer
mulation (mm/year)
Summertime water vapor flux

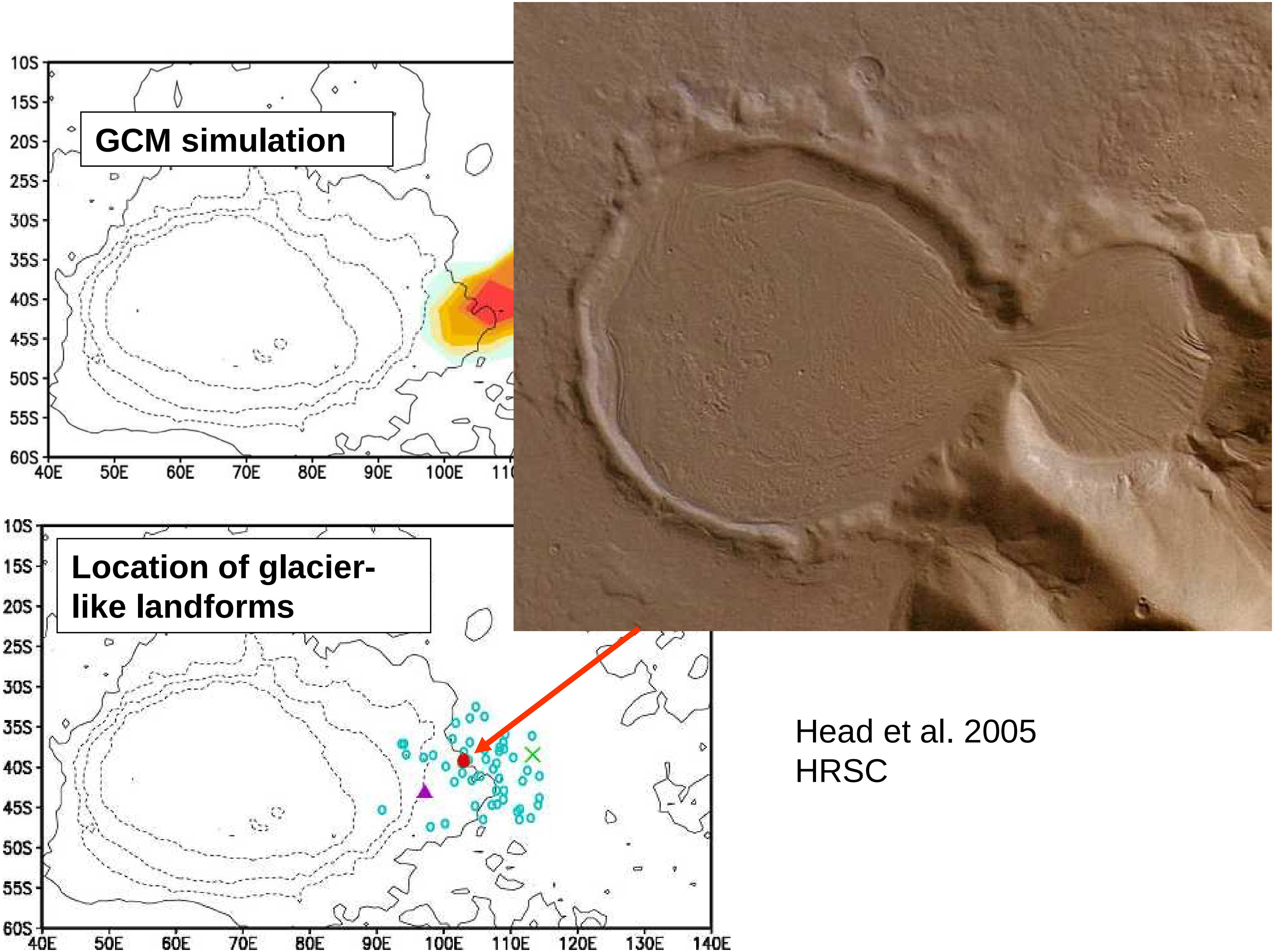

run15 total H2O column Ls=265-290
Total atmospheric water (pr-μm)
2000
1600
1300
1000
400
200
100
50
10
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E
180
Wind at 3 km
100m/s



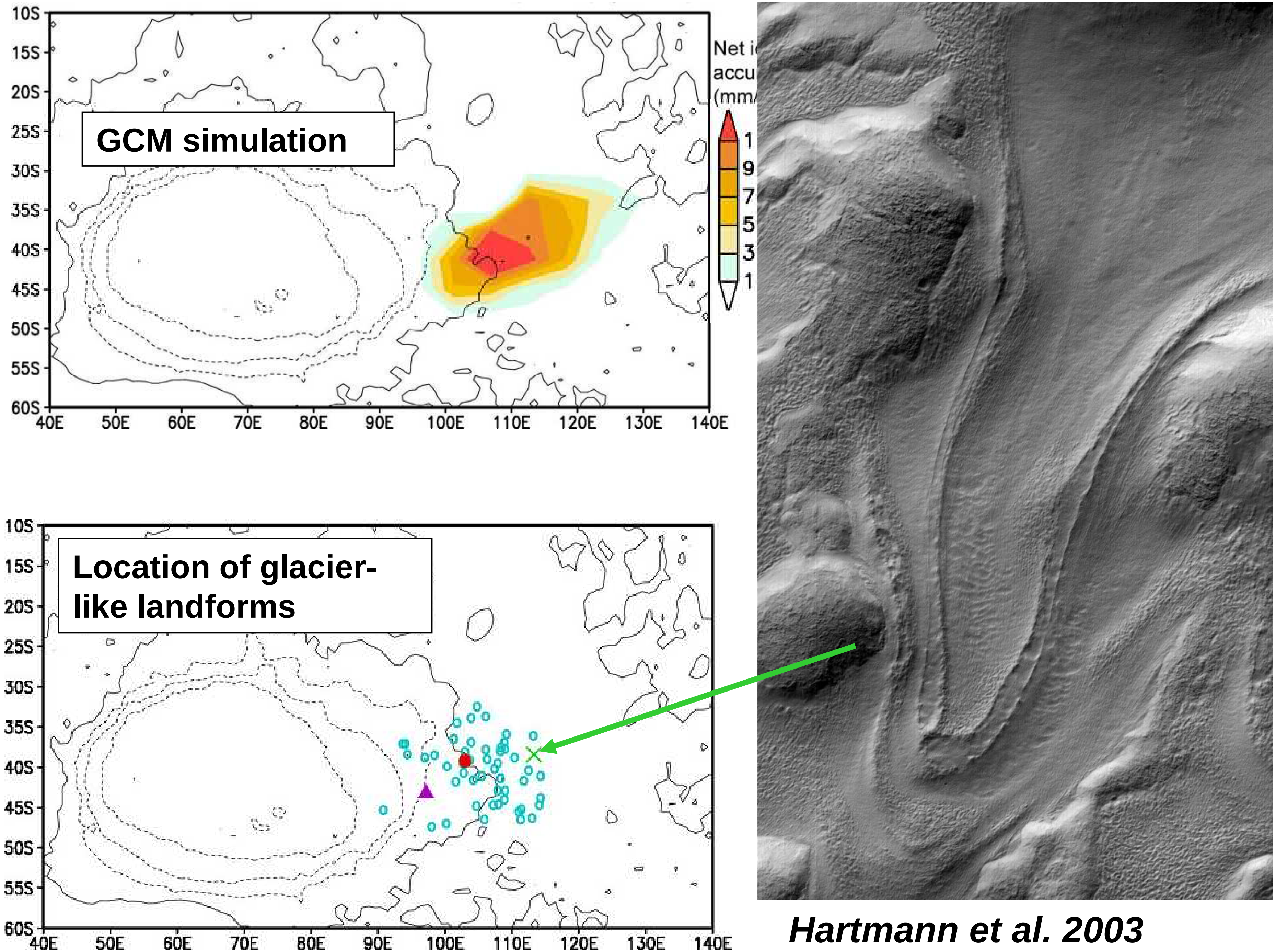
Locations of the 54 ice-rich debris apron mapped by Pierce and Crown, Icarus 2003



Head et al. 2005
HRSC



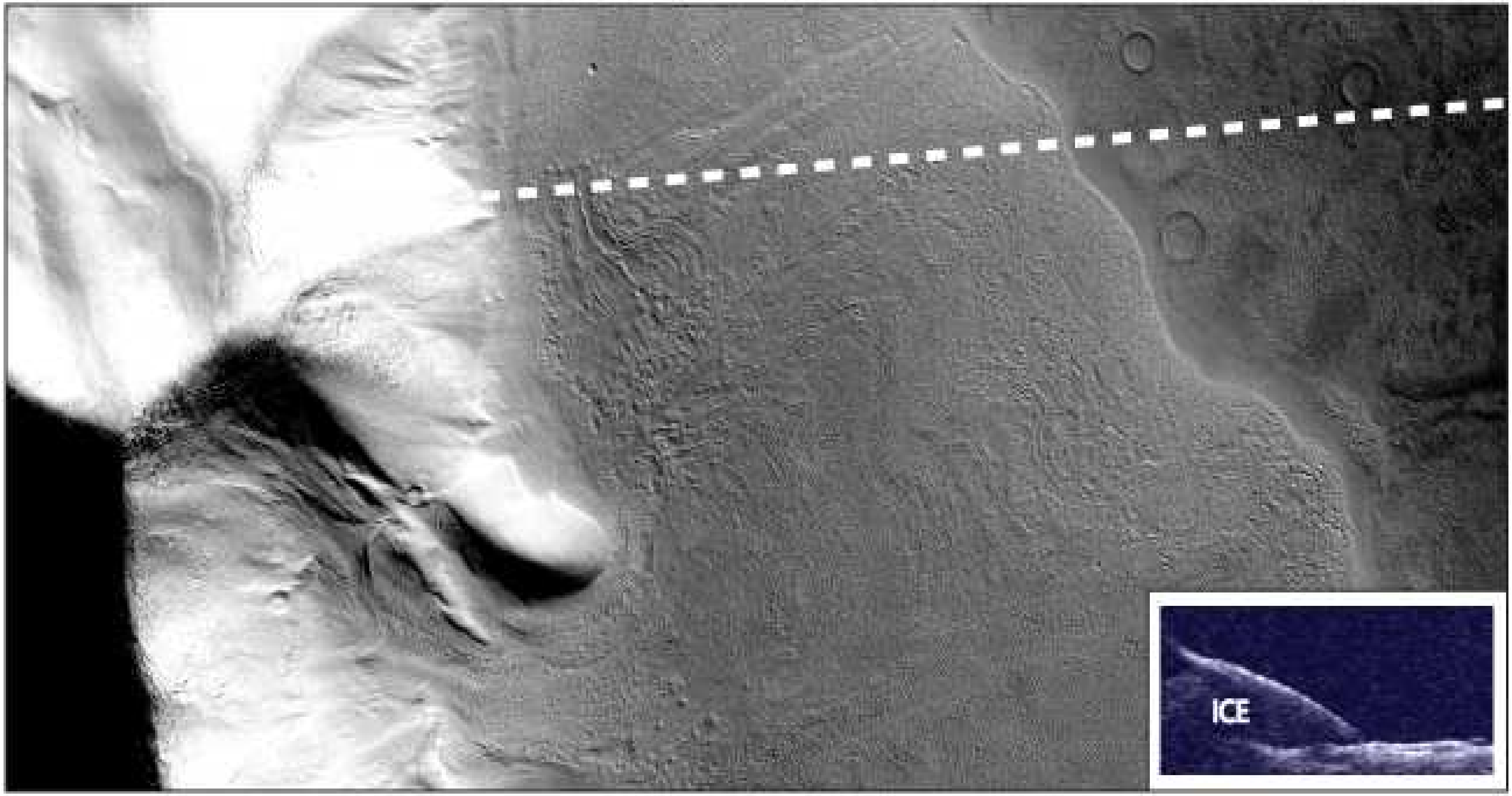
Head et al. 2005
HRSC



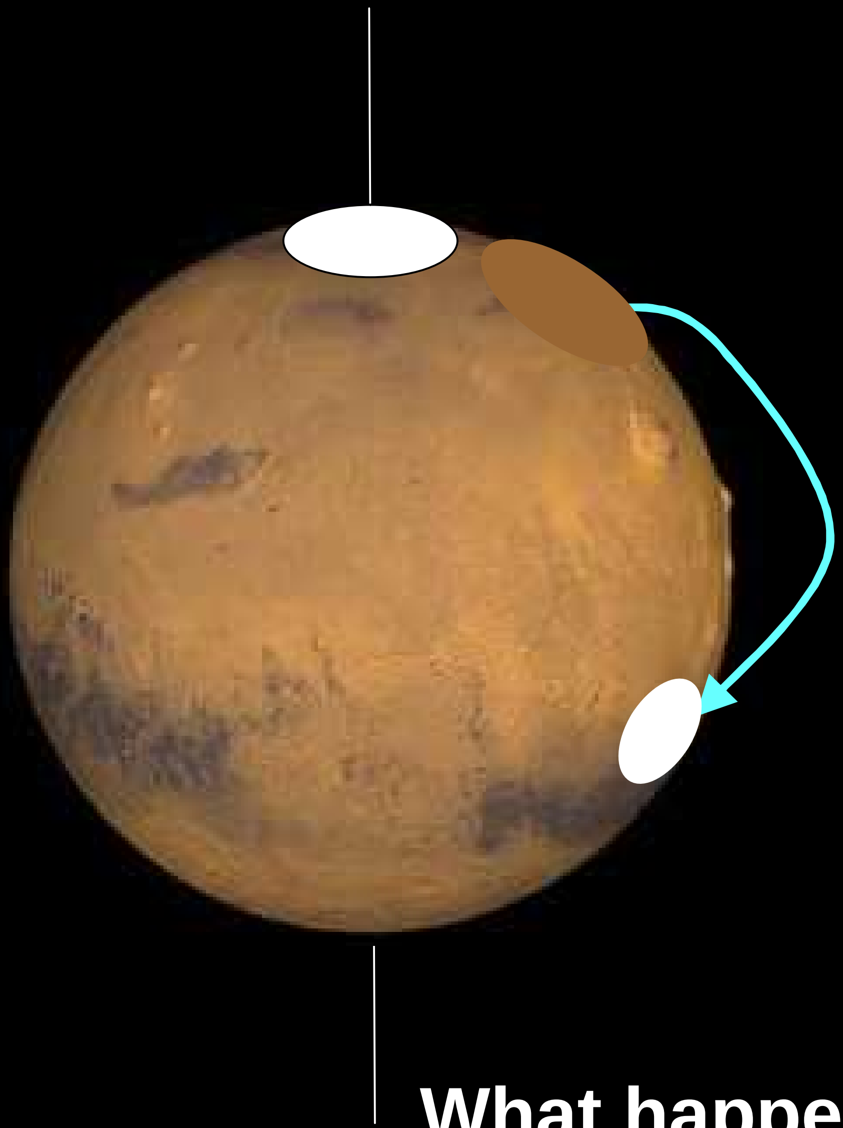
Hartmann et al. 2003


Lobate debris aprons
(Image stereo Mars Express HRSC)
10 km (6.4 mi.)

MARSIS Radar sounding of lobate debris aprons : debris covered glacier !

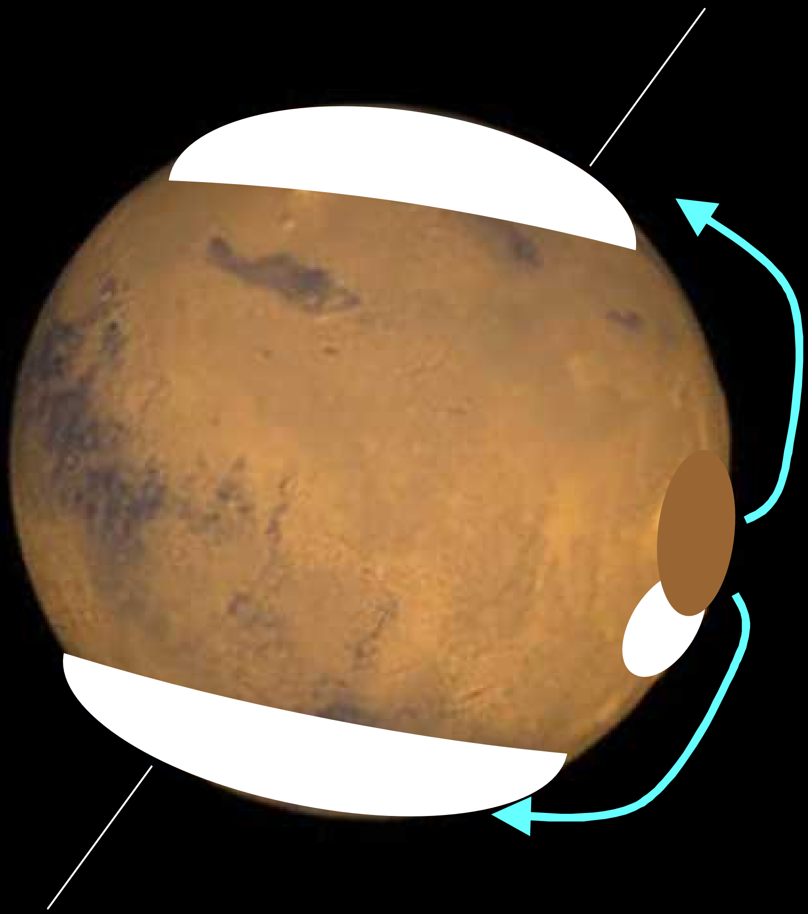


GCM simulation of high obliquity

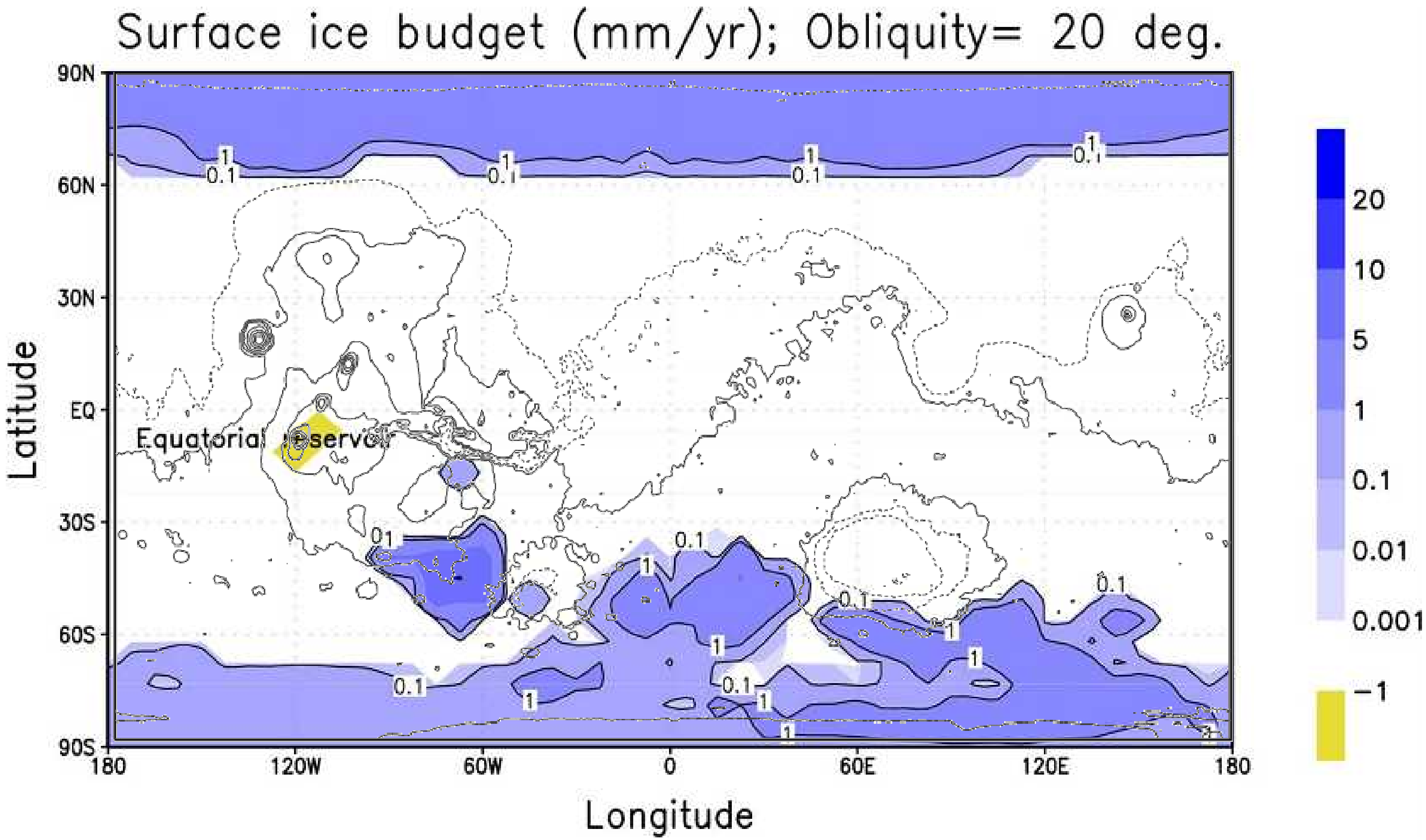


What happened next ?

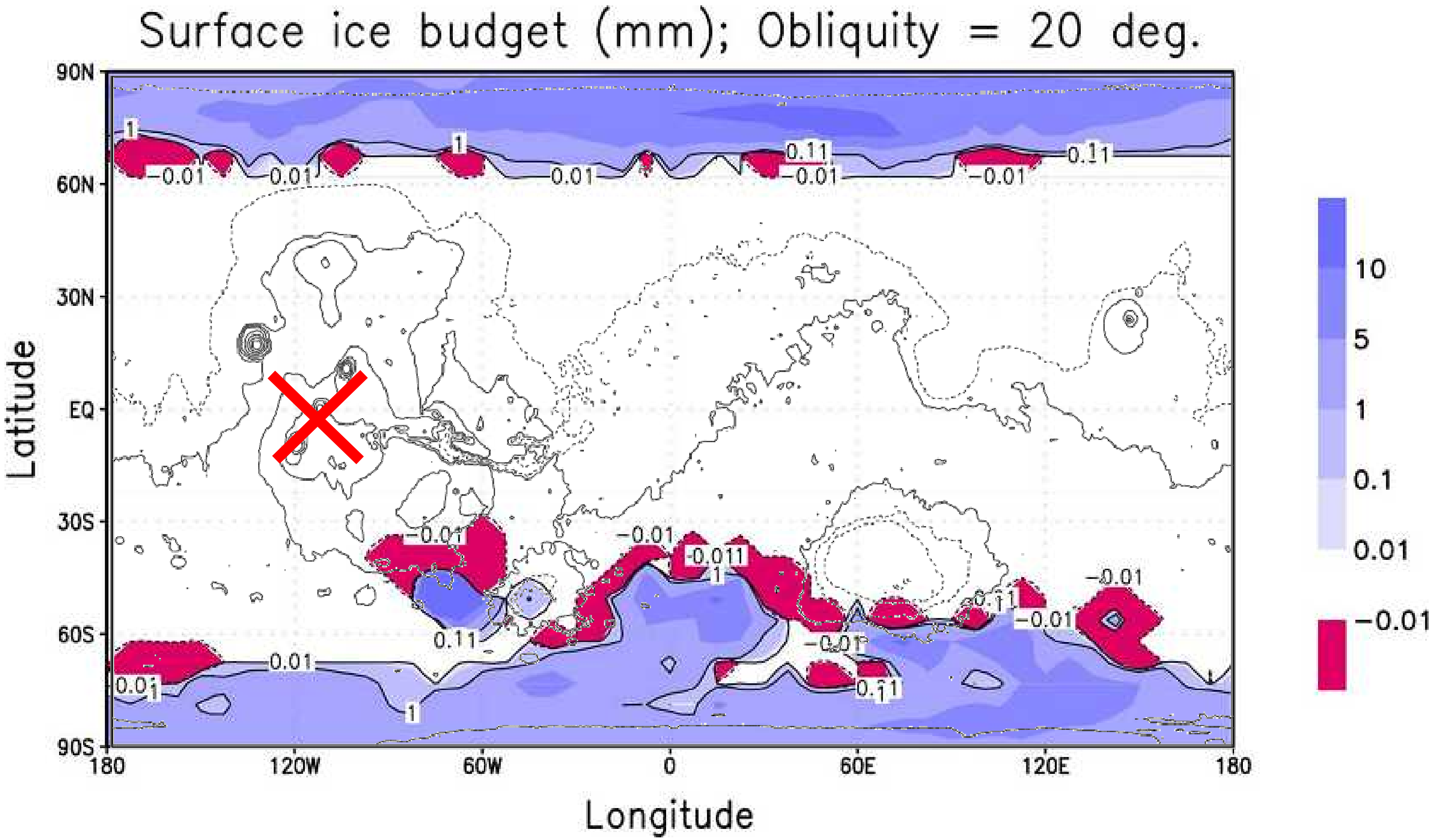
Back from high obliquity to low obliquity



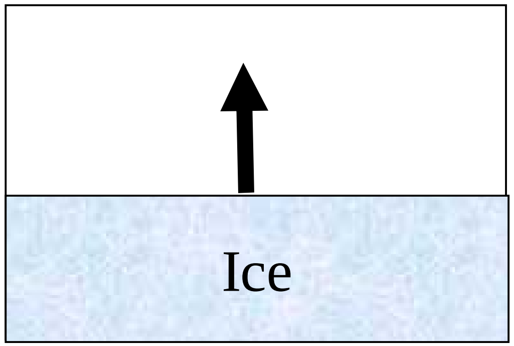
•Levrard, B., Forget, F., Montmessin, F. and Laskar, J. Recent ice-rich deposits formed at high latitudes on Mars by sublimation of unstable equatorial ice during low obliquity *Nature*, 431, 1072-1075 (2004)

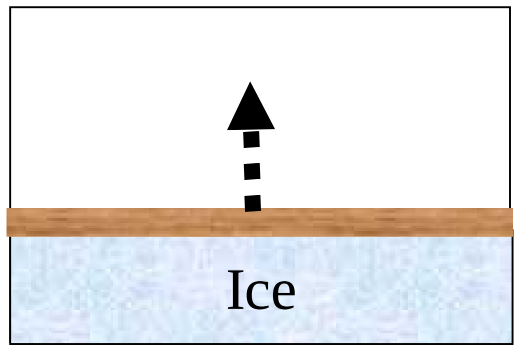


Surface ice budget (mm/yr); Obliquity= 20 deg.
Latitude
Longitude
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
Equatorial reservoir
20
10
5
1
0.1
0.01
0.001
−1

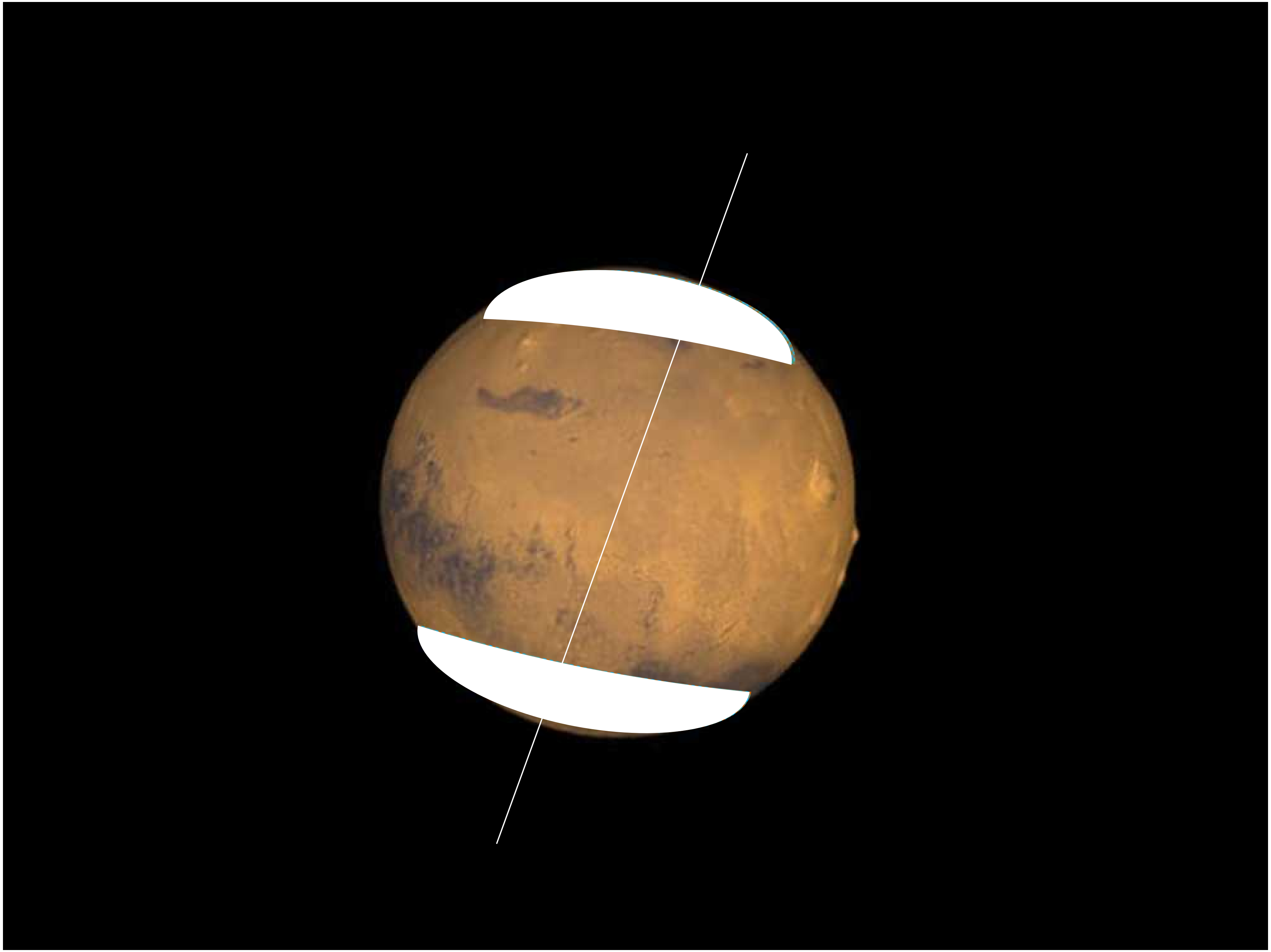


Surface ice budget (mm); Obliquity = 20 deg.
Latitude
Longitude
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
10
5
1
0.1
0.01
−0.01


Ice



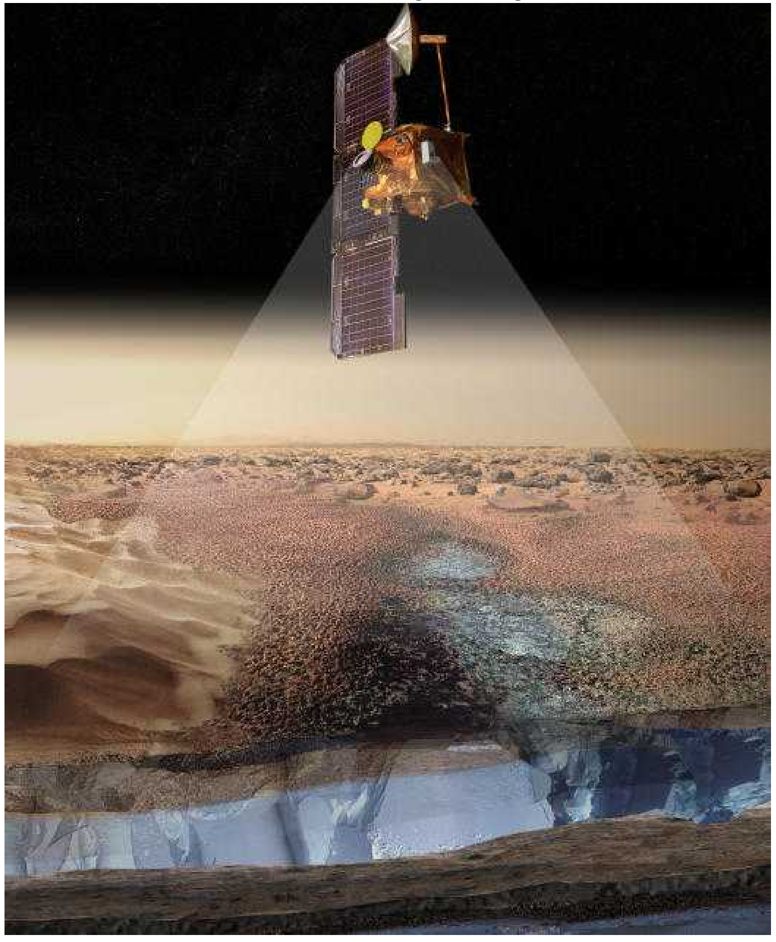
Mischna et al. 2003

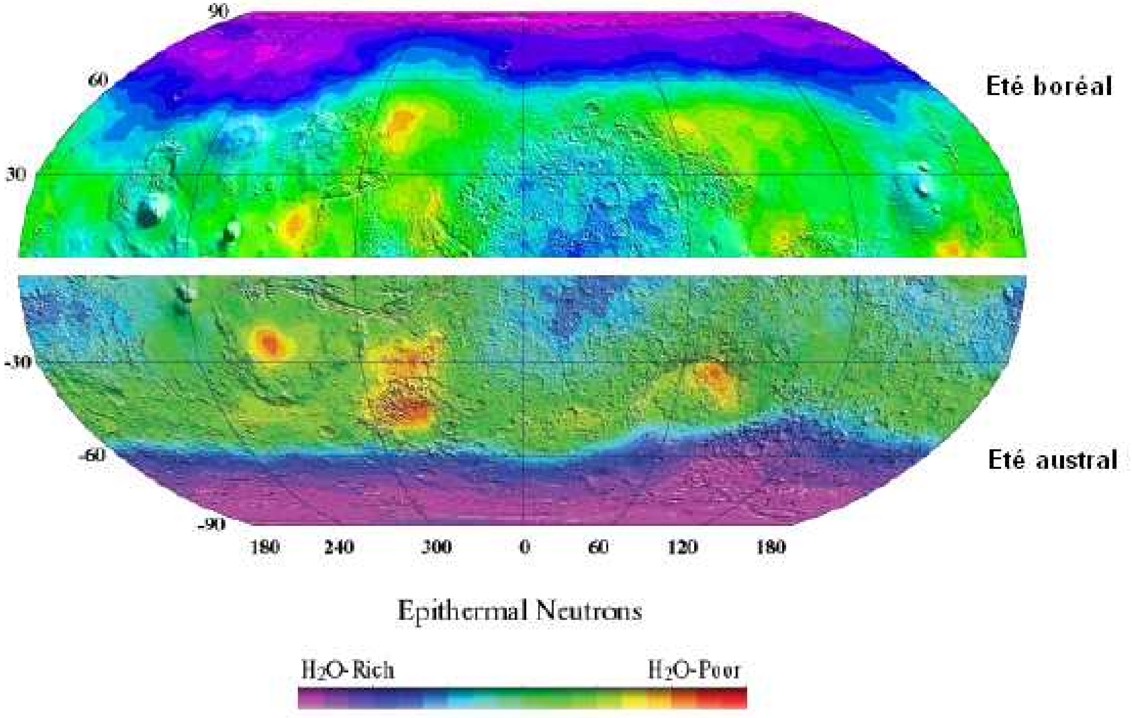


Near surface ice detected by Mars Odyssey GRS

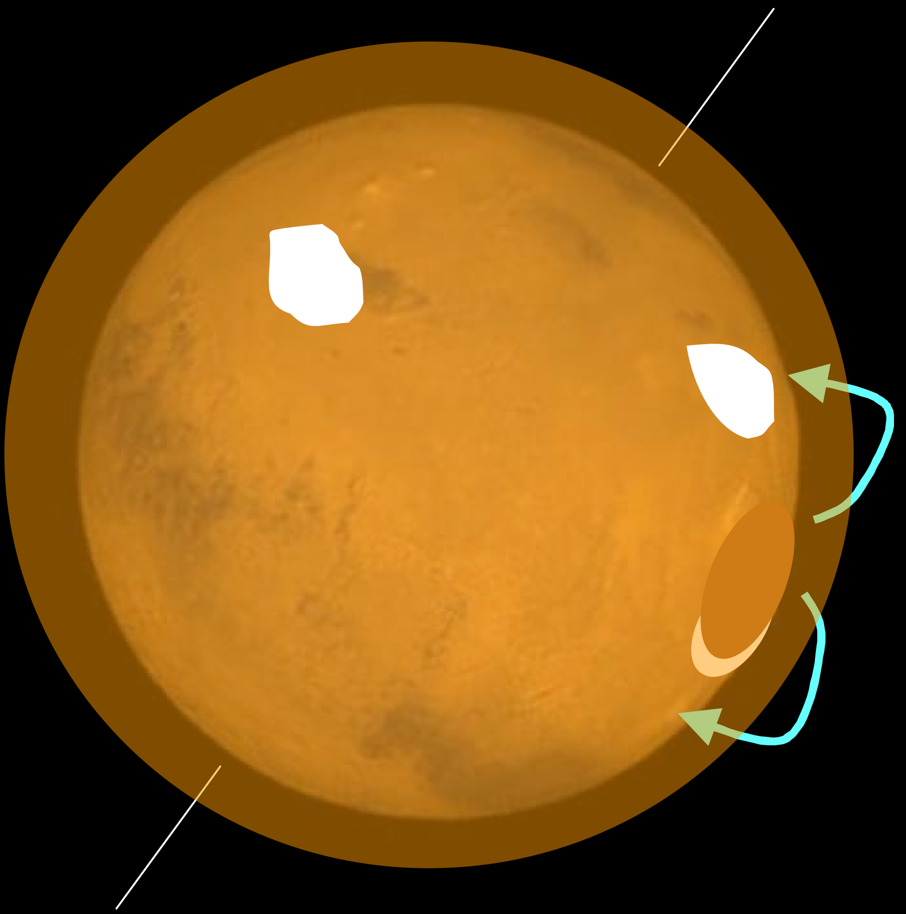
(Boynton et al., Feldman et al., Mitrovanov et al., 2002…)

NASA Mars Odyssey



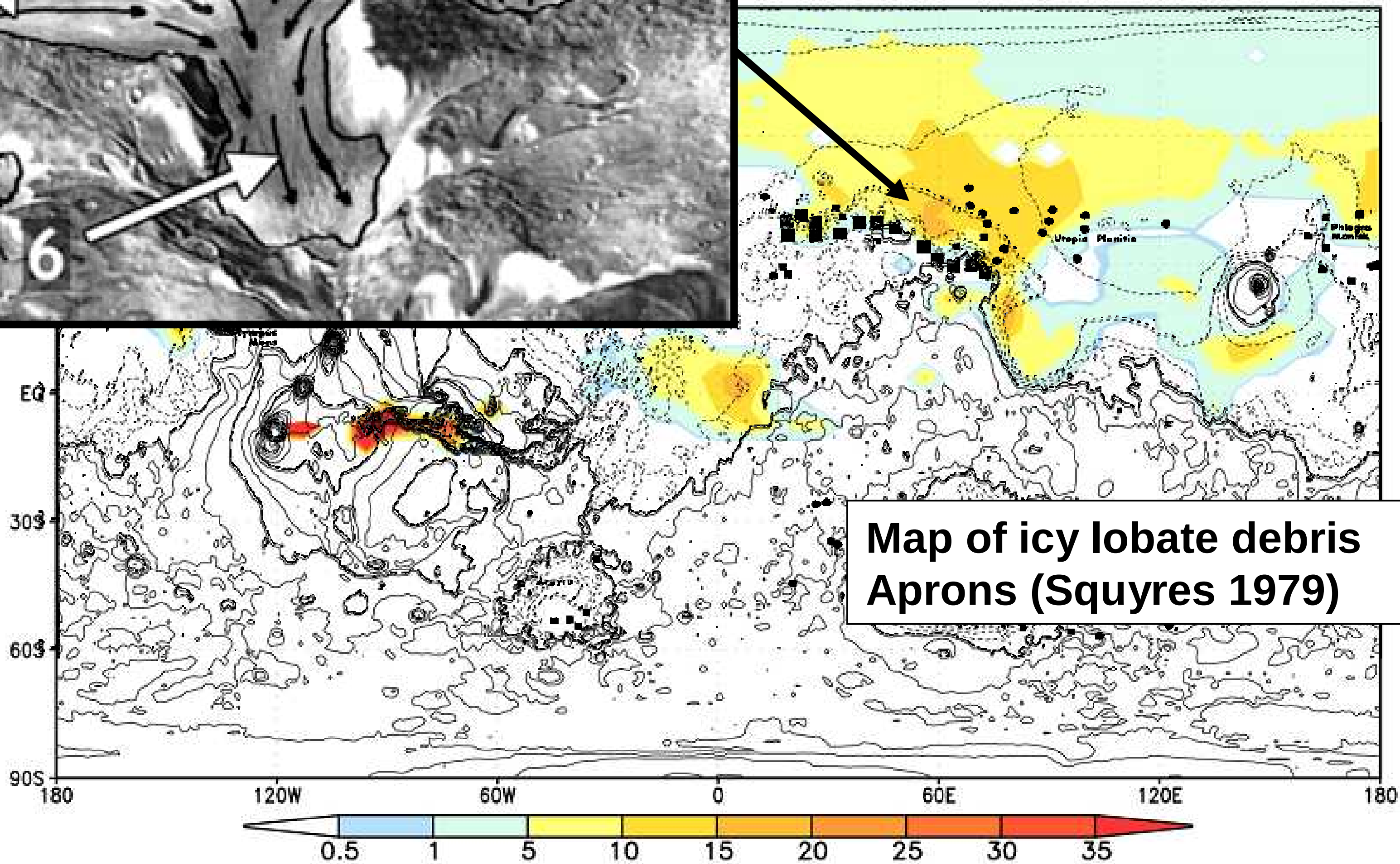


Back from high obliquity to low obliquity
WITH HIGH ATMOSPHERIC DUST OPACITY
(J-B Madeleine et al., 2009)



Obliquity = 35 °

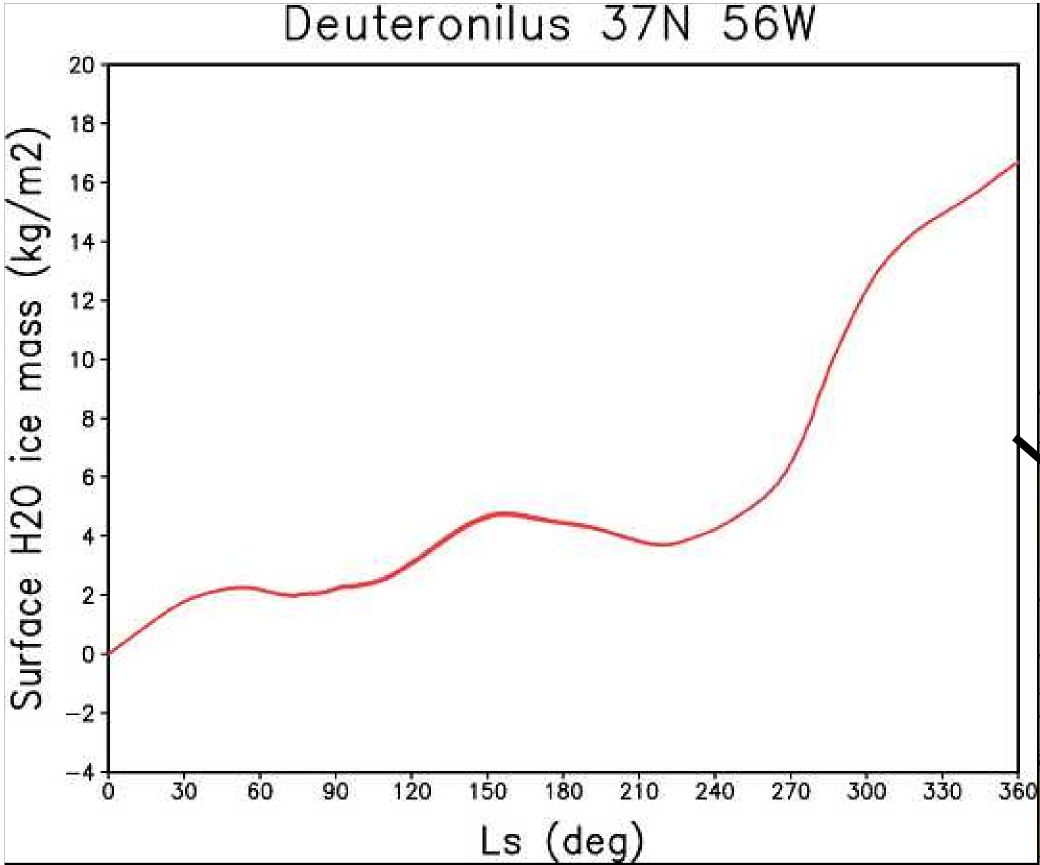
…arsis Glaciers

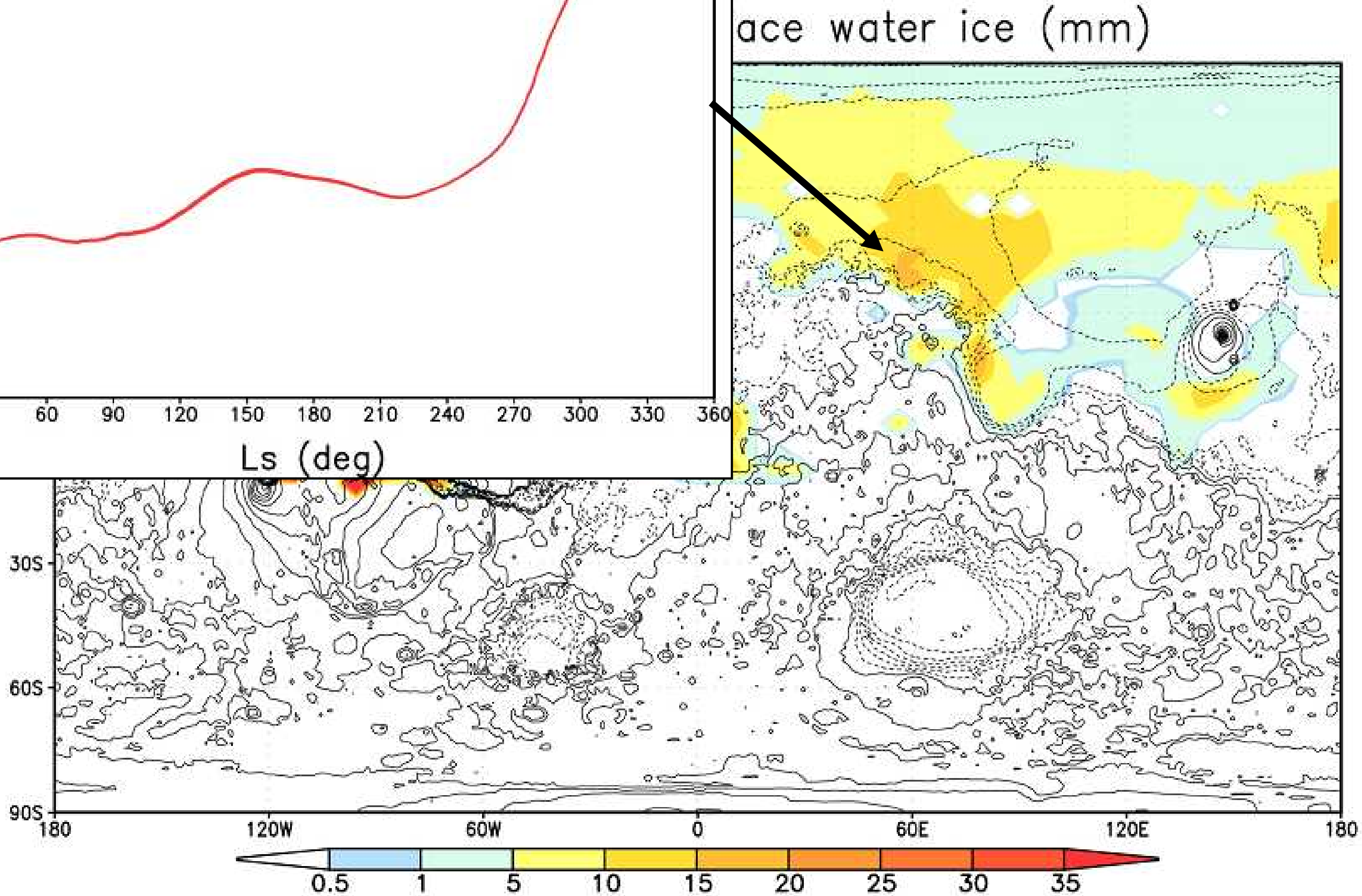


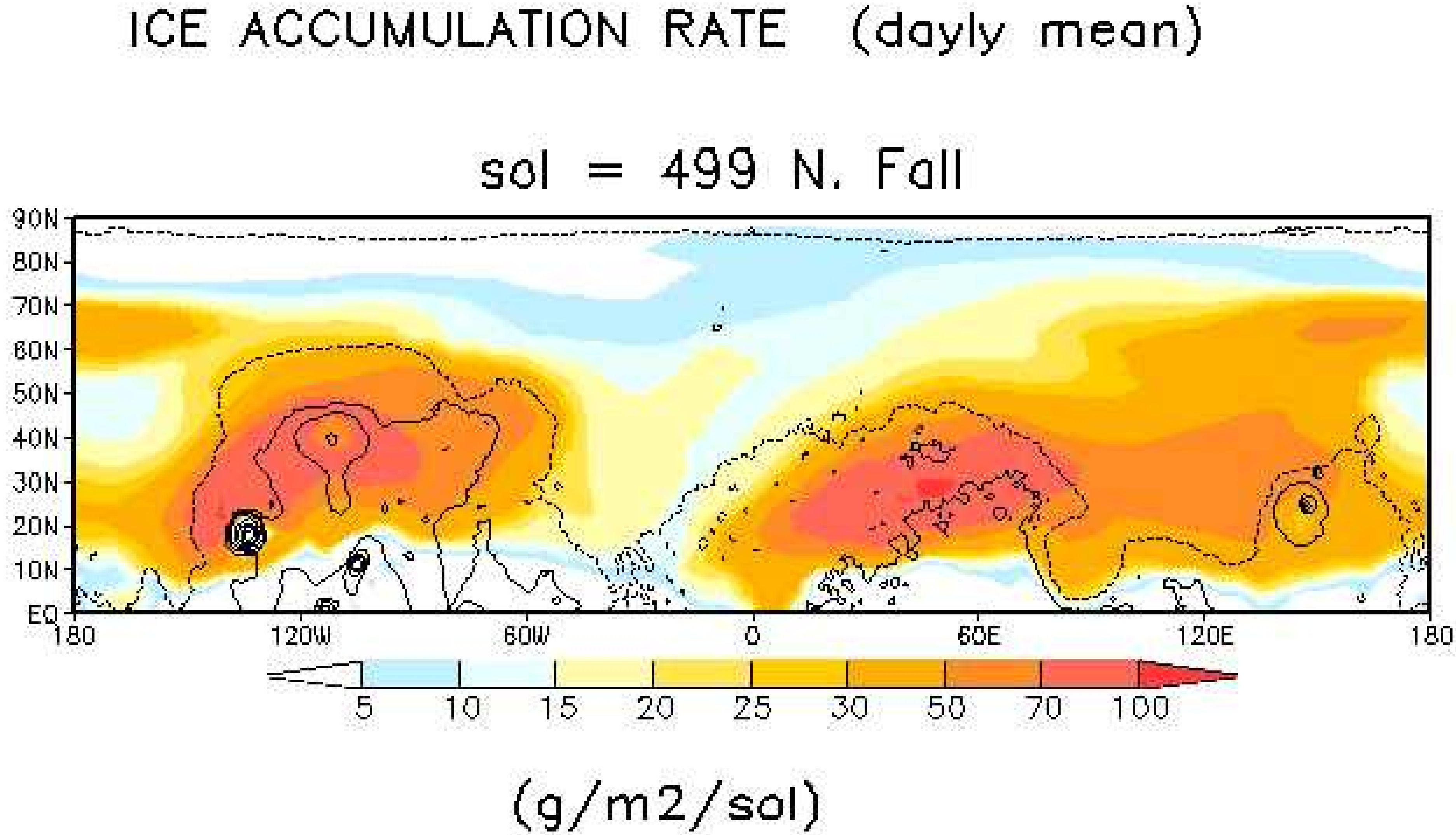
Map of icy lobate debris Aprons (Squyres 1979)

Obliquity = 35 °

arsis Glaciers

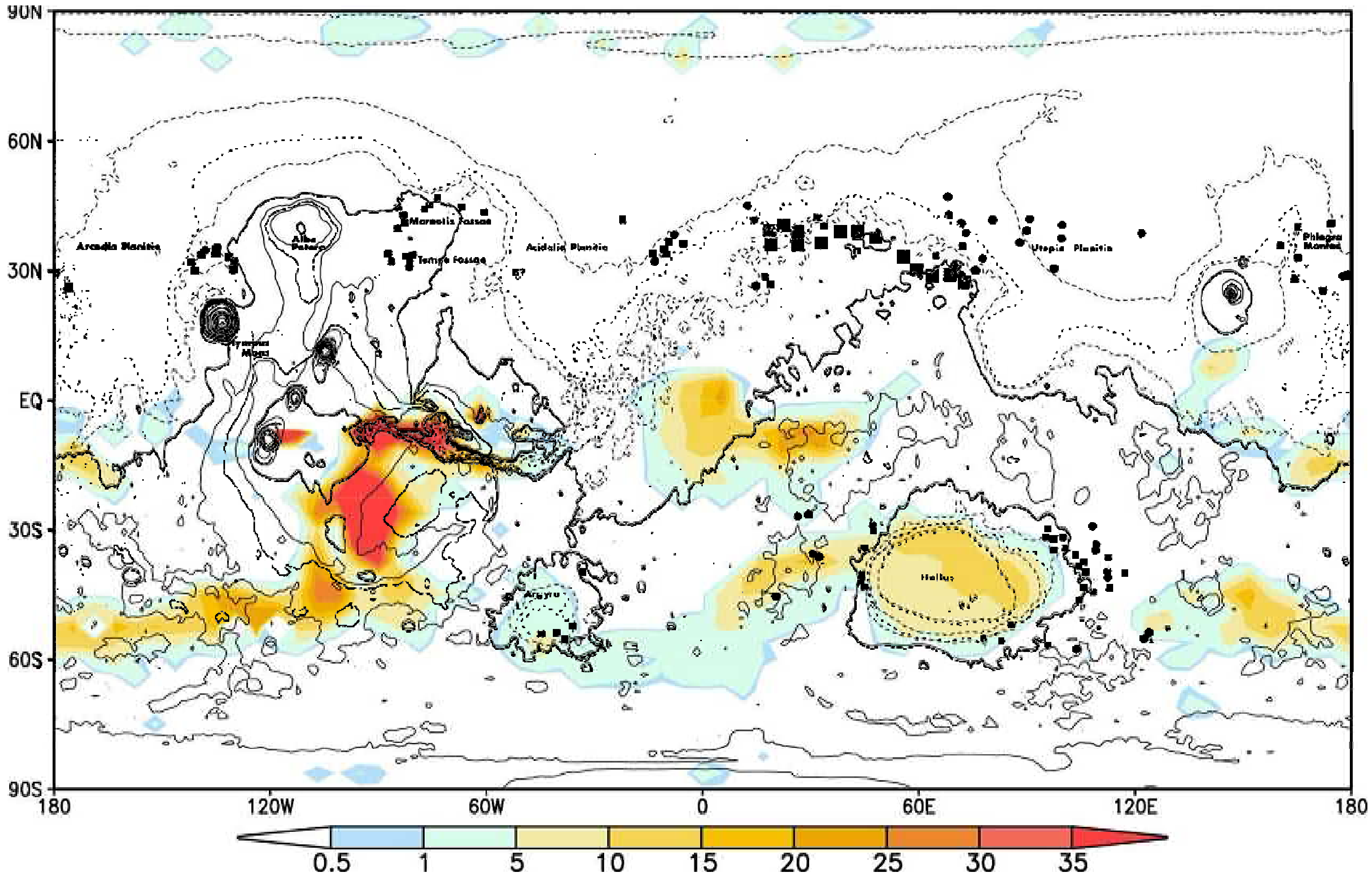


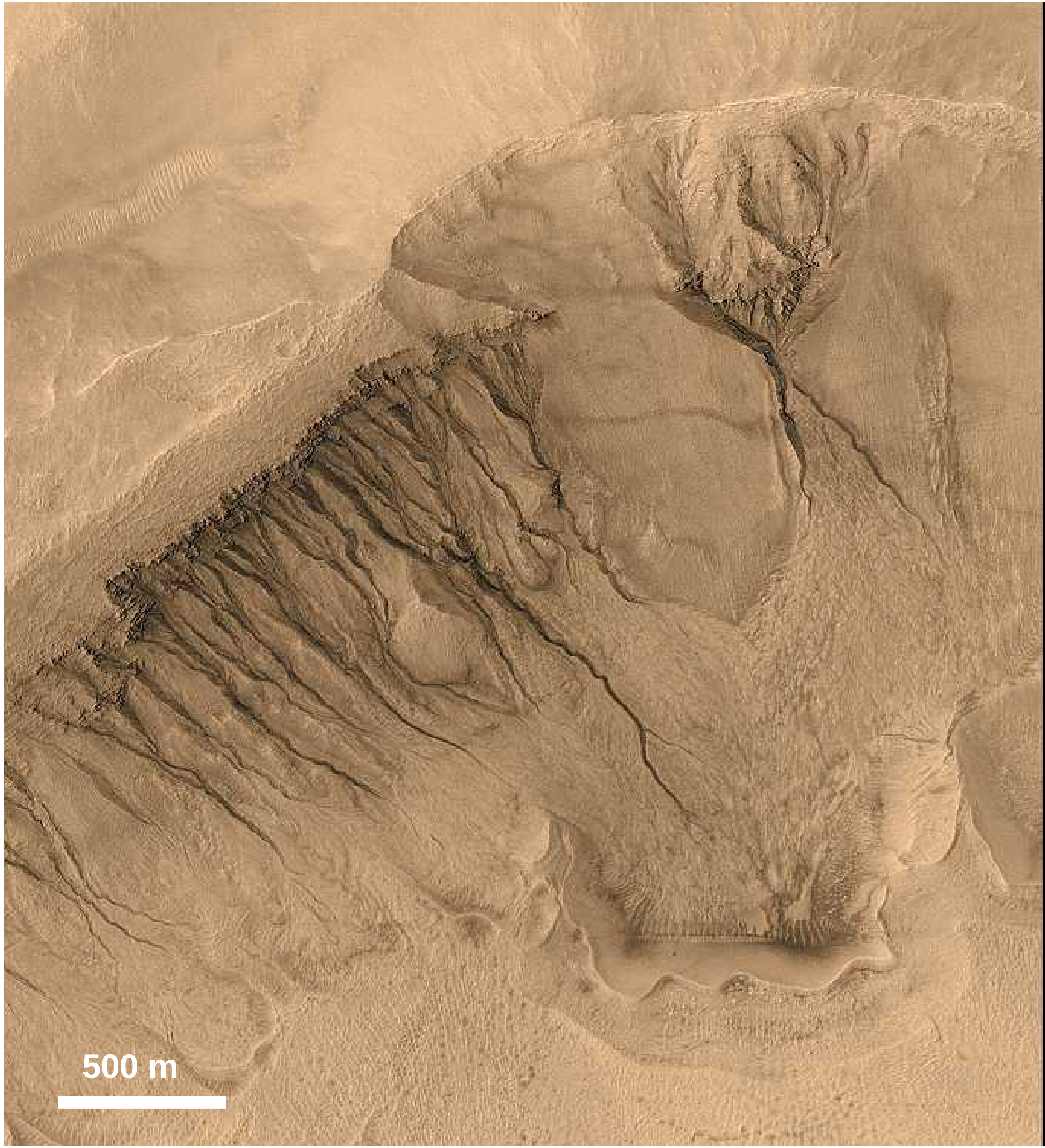



ICE ACCUMULATION RATE (dayly mean)
sol = 499 N. Fall
90N
80N
70N
60N
50N
40N
30N
20N
10N
EQ
180
120W
60W
0
60E
120E
180
5
10
15
20
25
30
50
70
100
(g/m2/sol)

Dust opacity = 2.5 **Obliquity = 35 °** **Ls(perihelion)=90 °**

Water source = Tharsis Glaciers





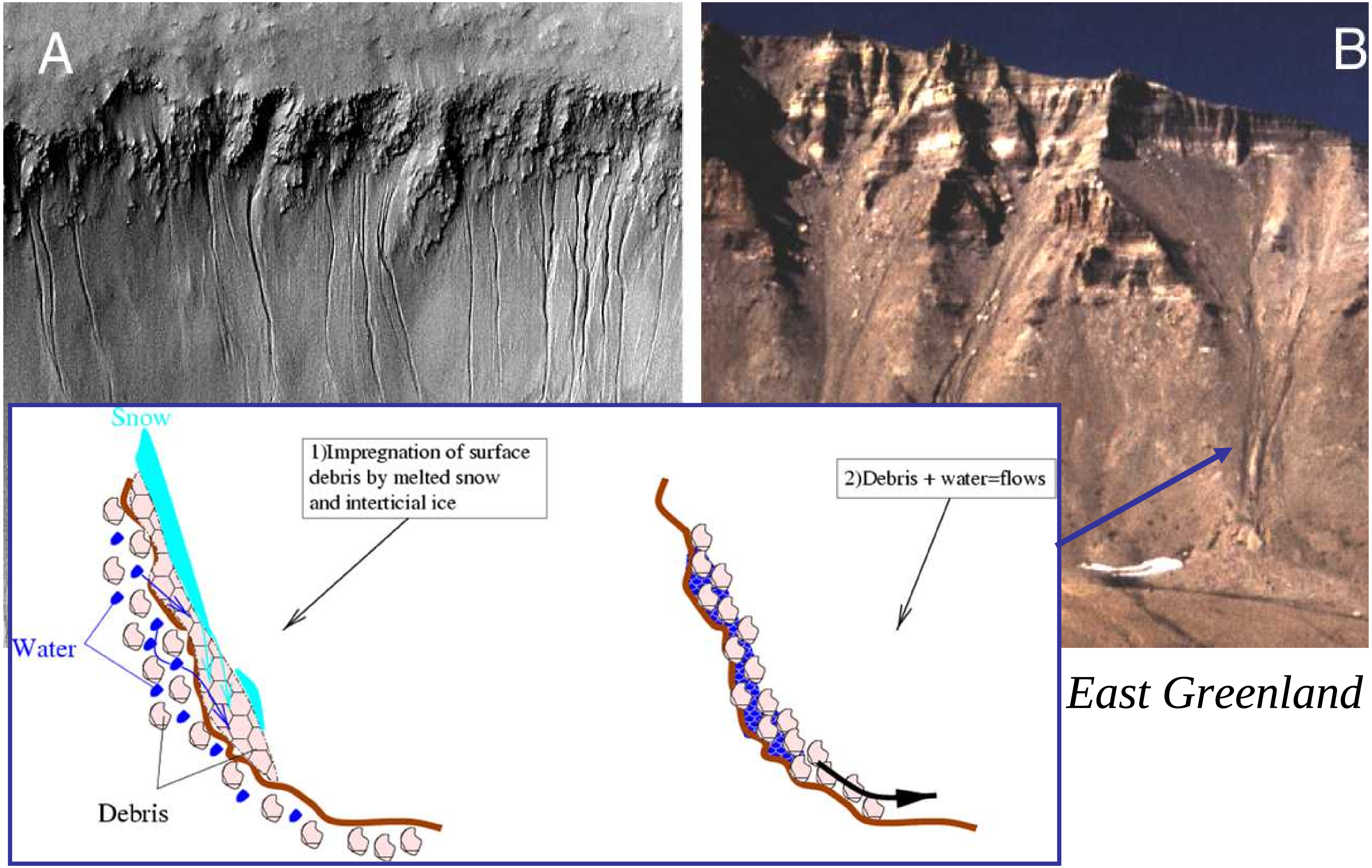
Gullies "recently" formed by liquid water

• subsurface aquifer ?
(Malin and Edgett. , Mellon et al. , Heldmann and Mellon, 2004, Heldmann, et al., 2007.)

• Melted ice at high obliquity
(Costard et al., Forget et al. , Williams et al., 2008)

Malin and Edgett, 2000

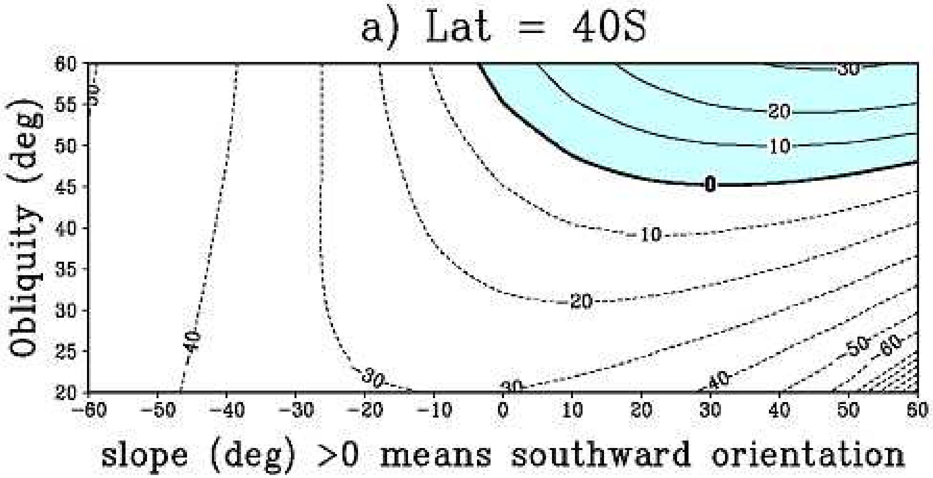
Mars Gullies Earth analogs: *(Costard et al. 2002)*

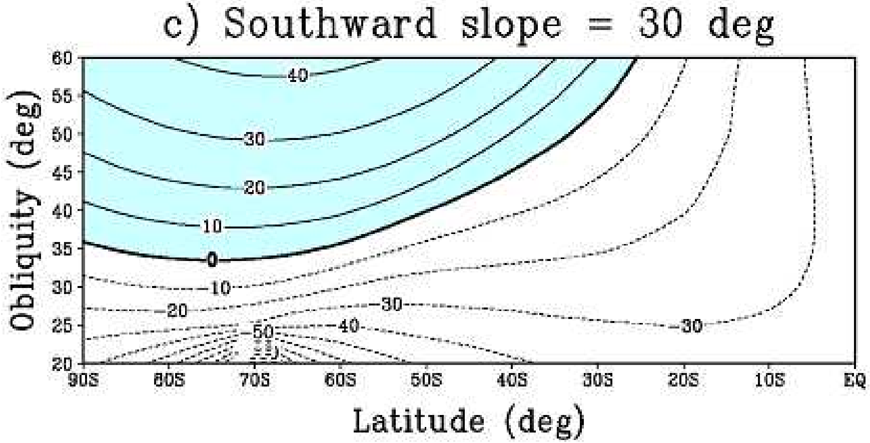


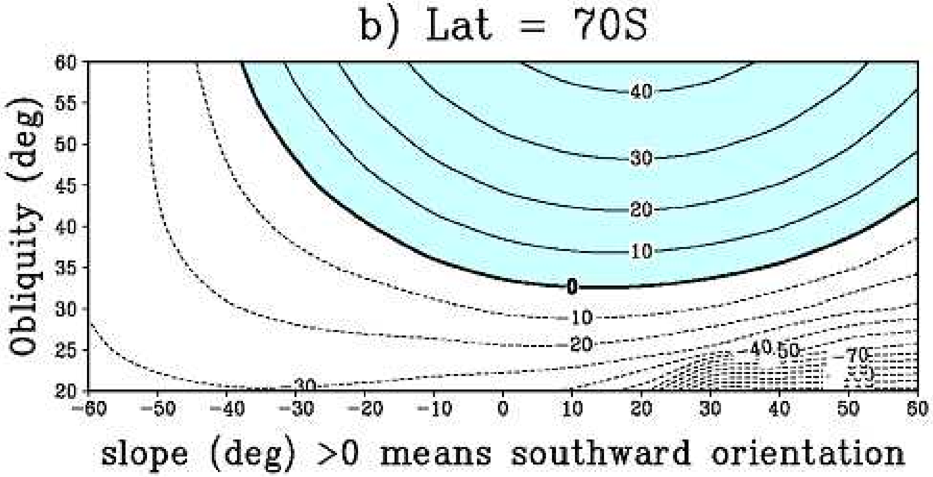
East Greenland

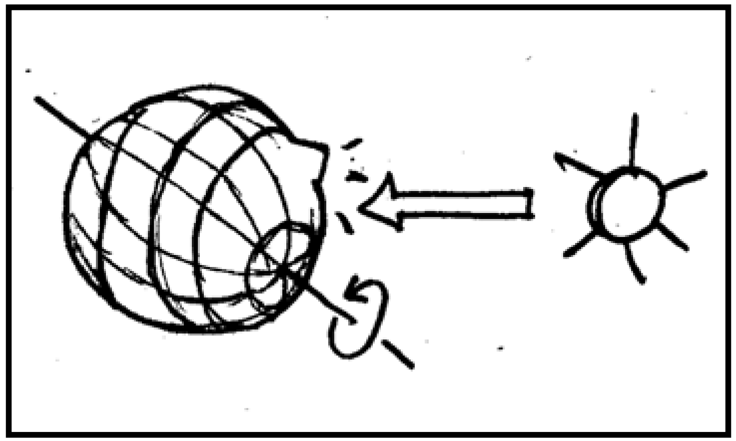
Simulated diurnal mean surface temperature at various obliquity

(max temperature = near summer solstice)









(Costard, Forget, Mangold and Peulvast, Science 2002)

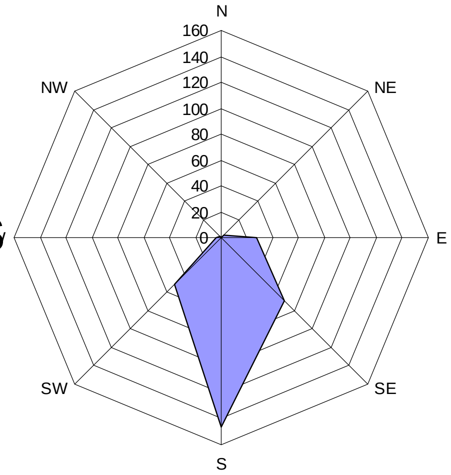
Orientation of 746 slopes with gullies observed by MOC

(*Balme, et al., 2006.*)

(all the gullies in data archives M01 to -E18)

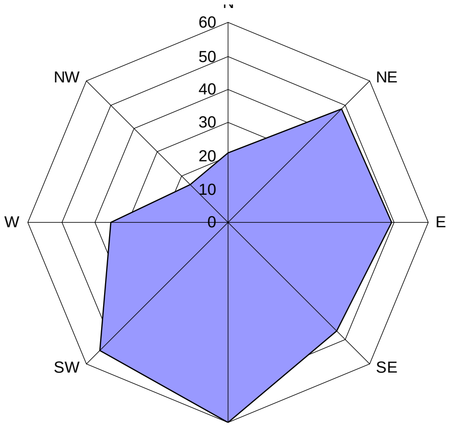
27 ° S – 40 ° S

(301 slopes)



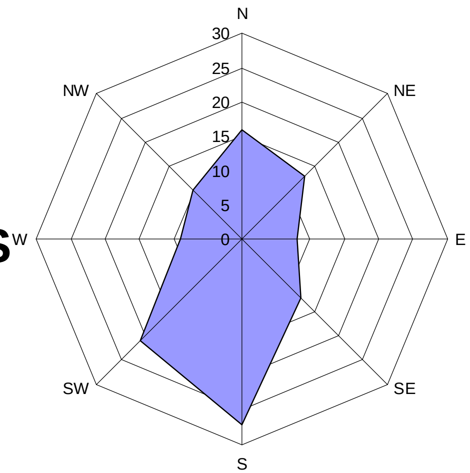
40 ° S- 60 ° S

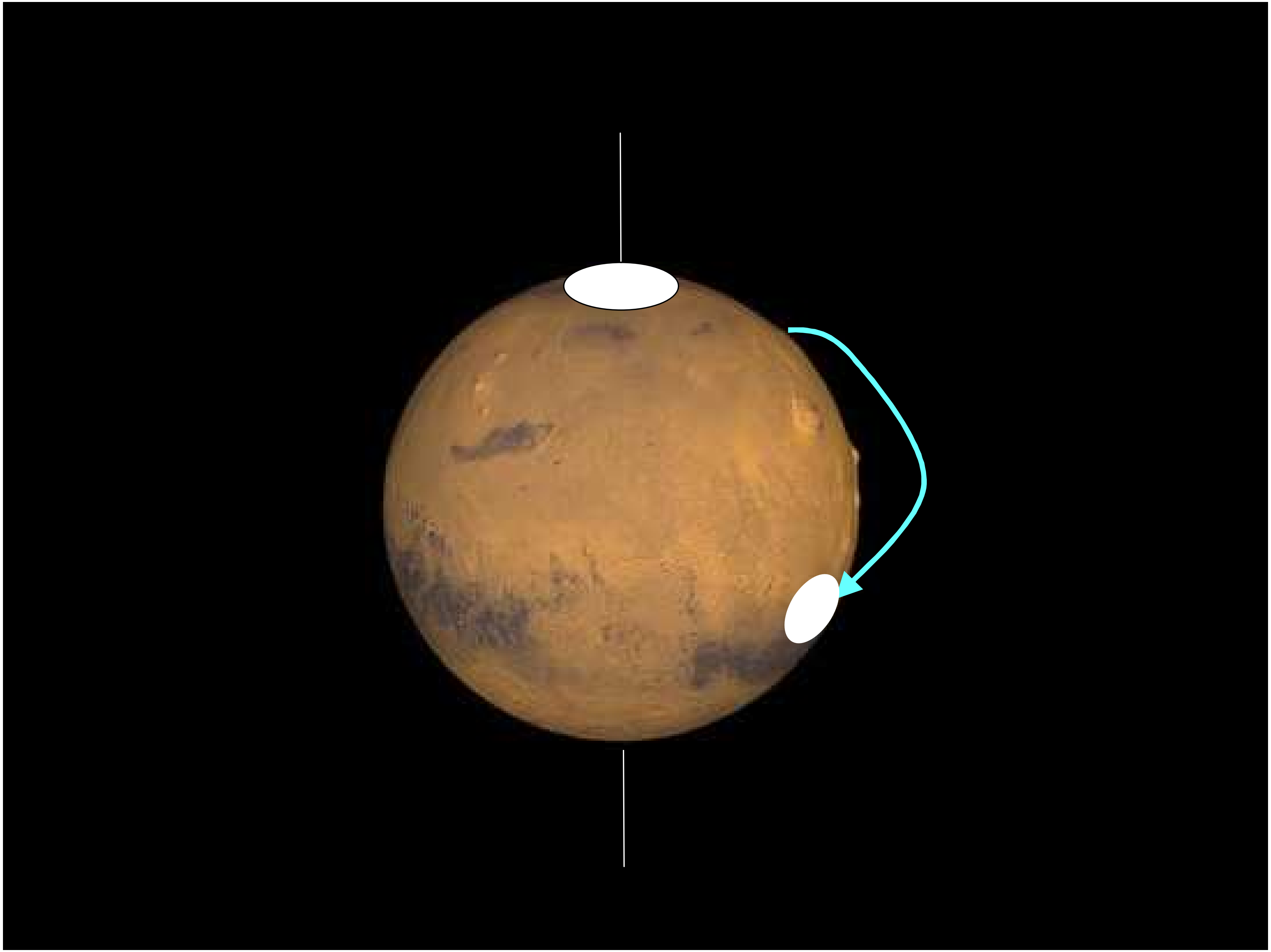
(329 slopes)

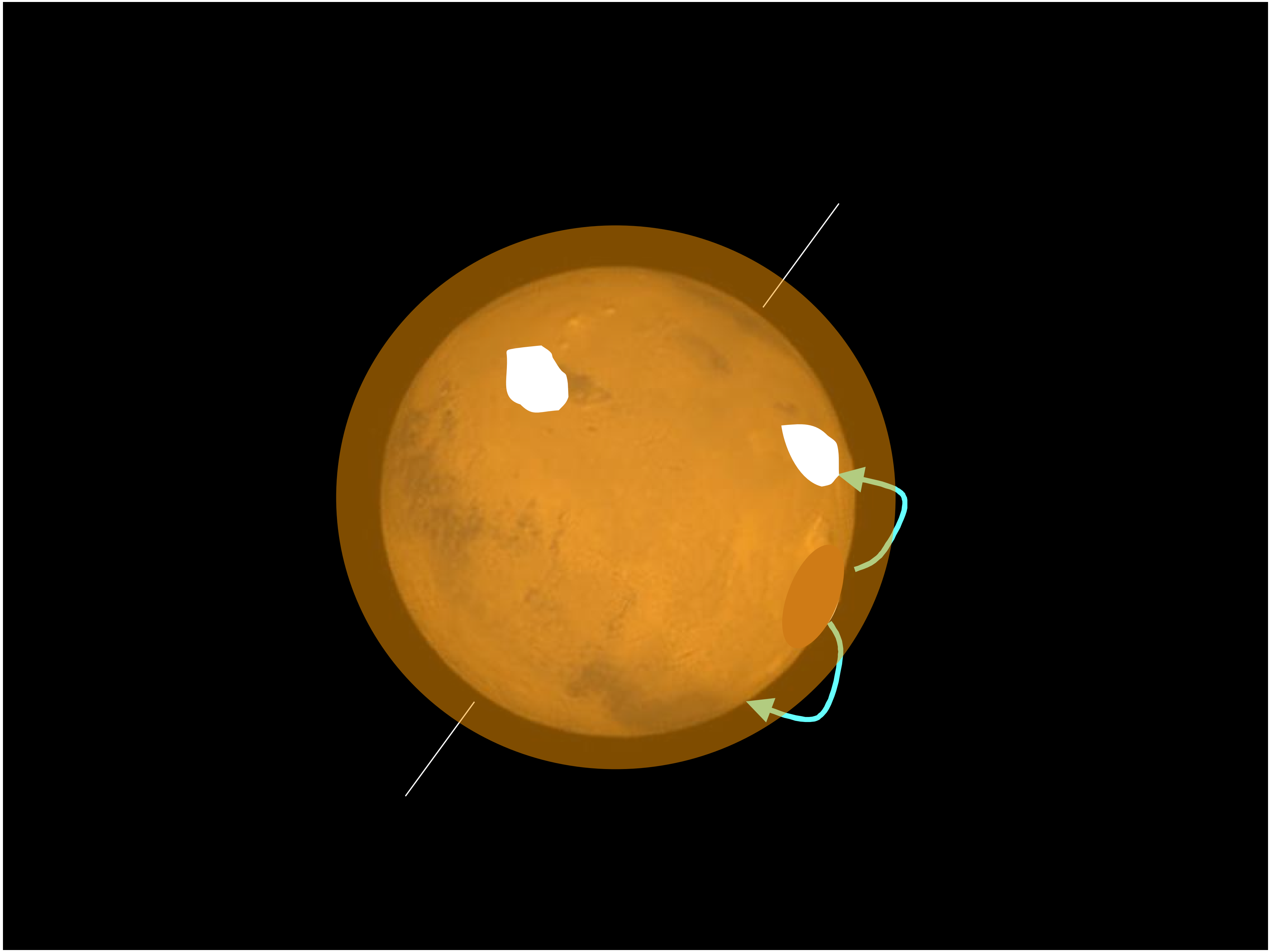


60 ° S- 82 ° S

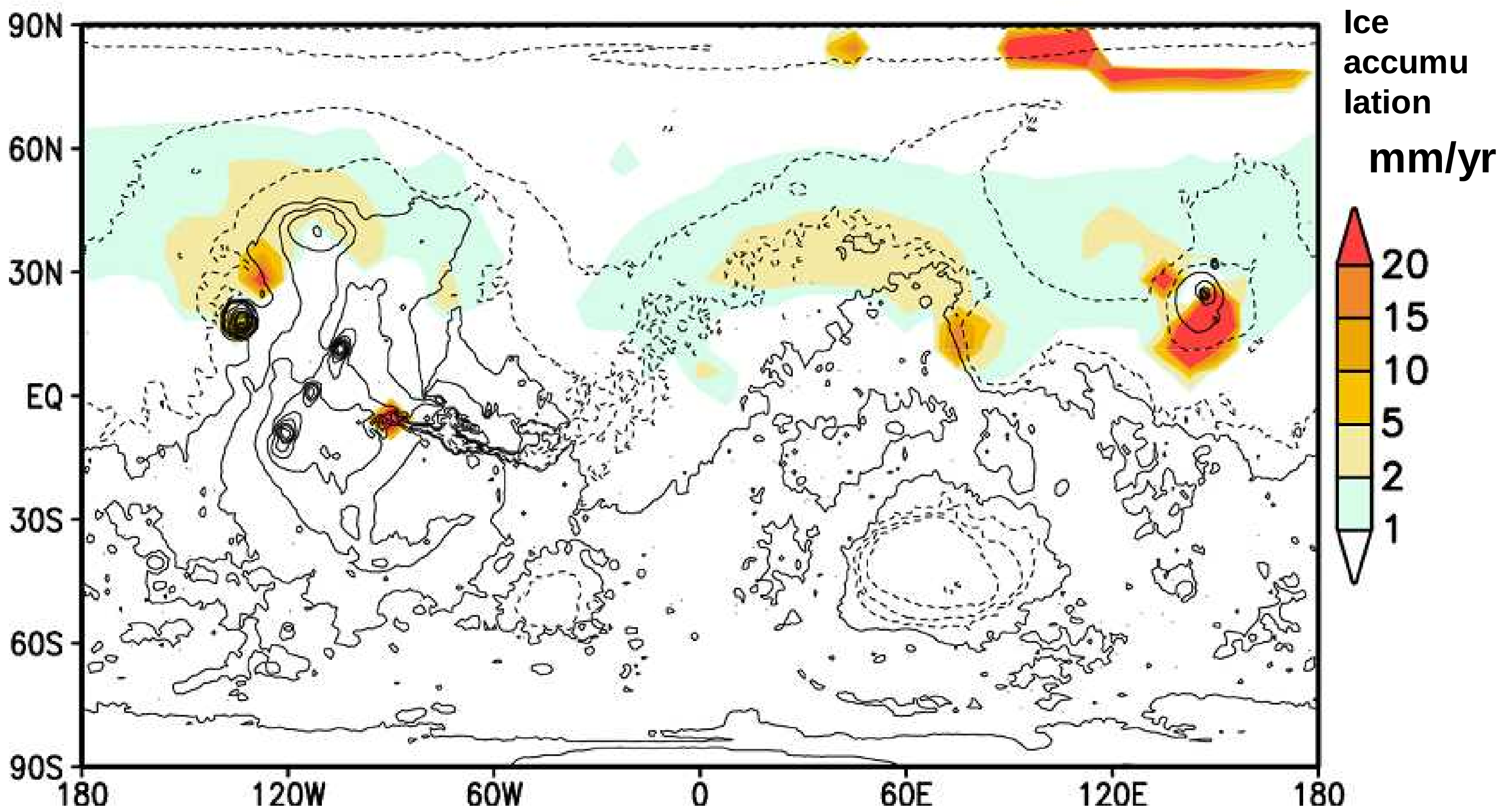
116 slopes)

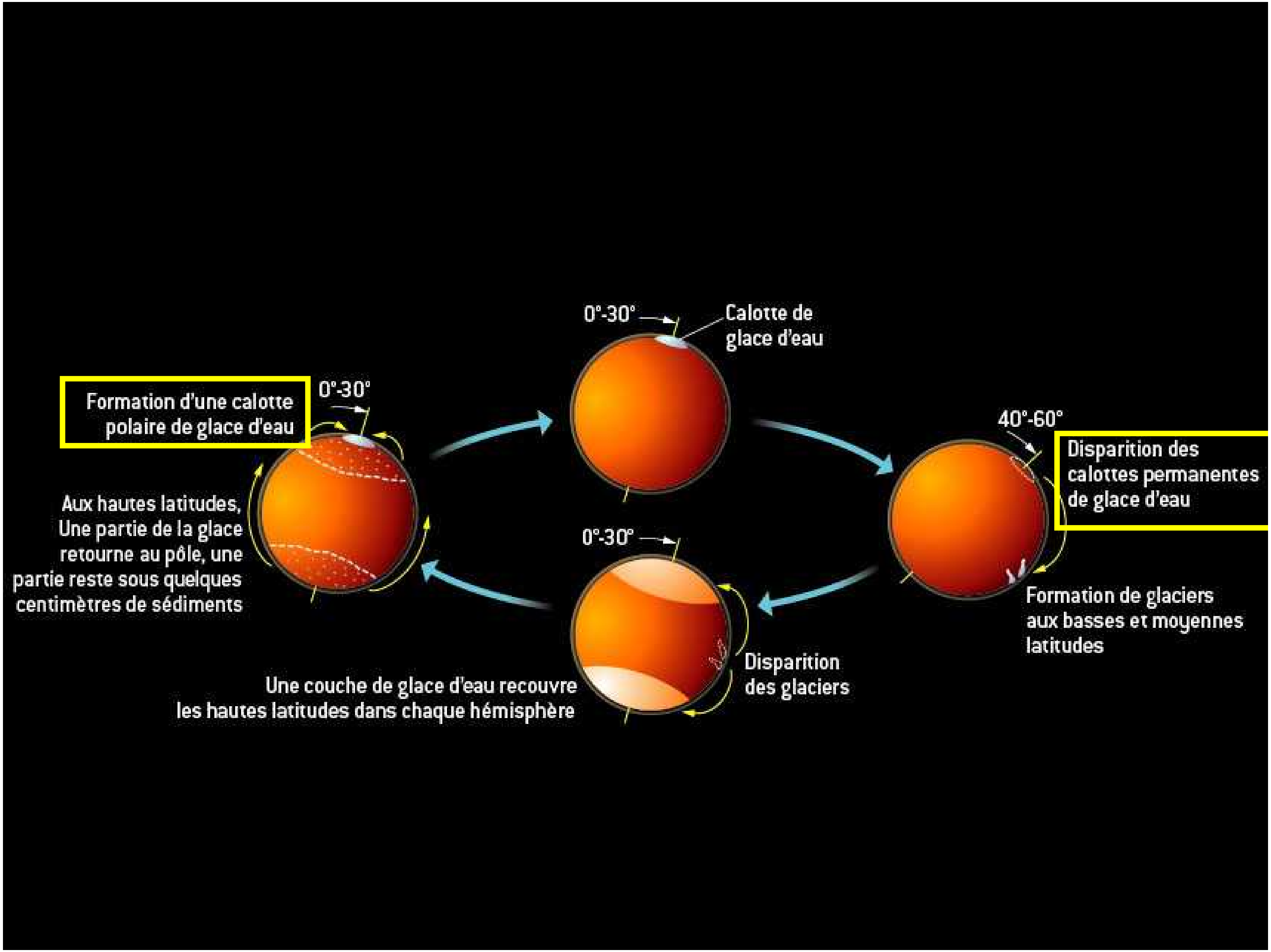




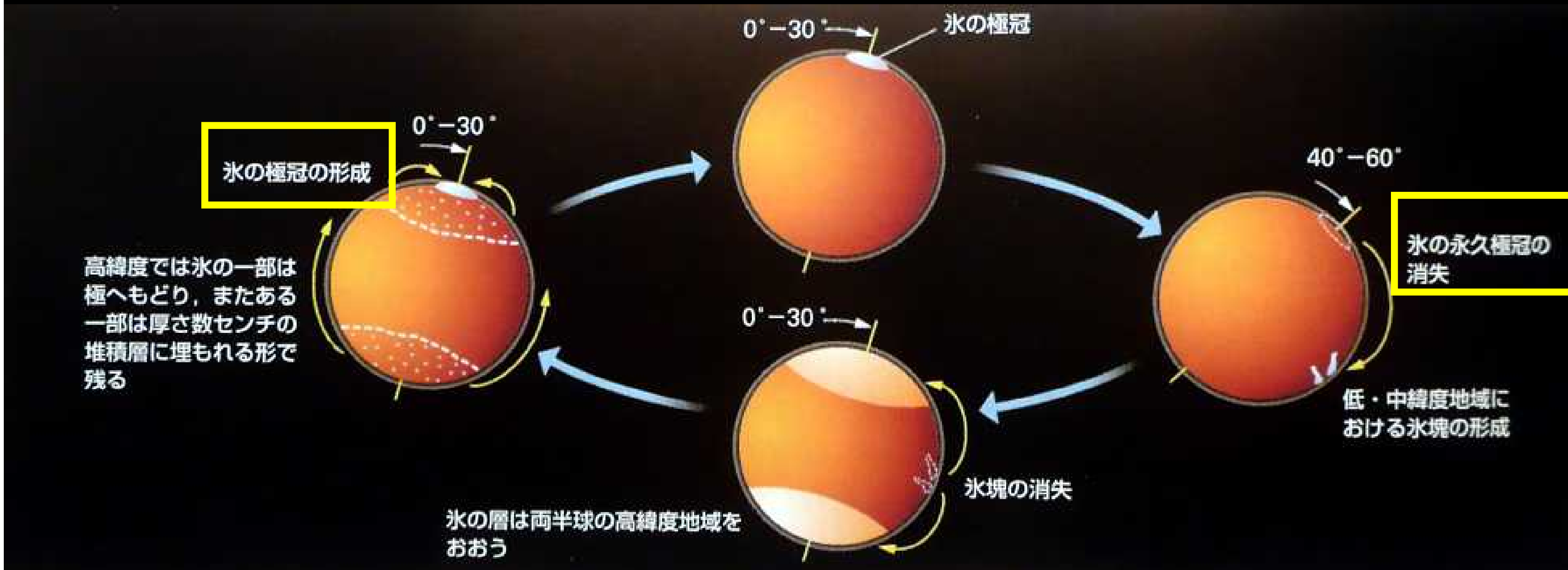


- **Source : N. polar cap Obliquity = 45 ° Ls(perihelie)=270 °**
- **Varying dust opacity :**
    - Ls = 0 ° -180 ° : tau = 0.2
    - Ls = 180 ° -360 ° : tau = 2.5

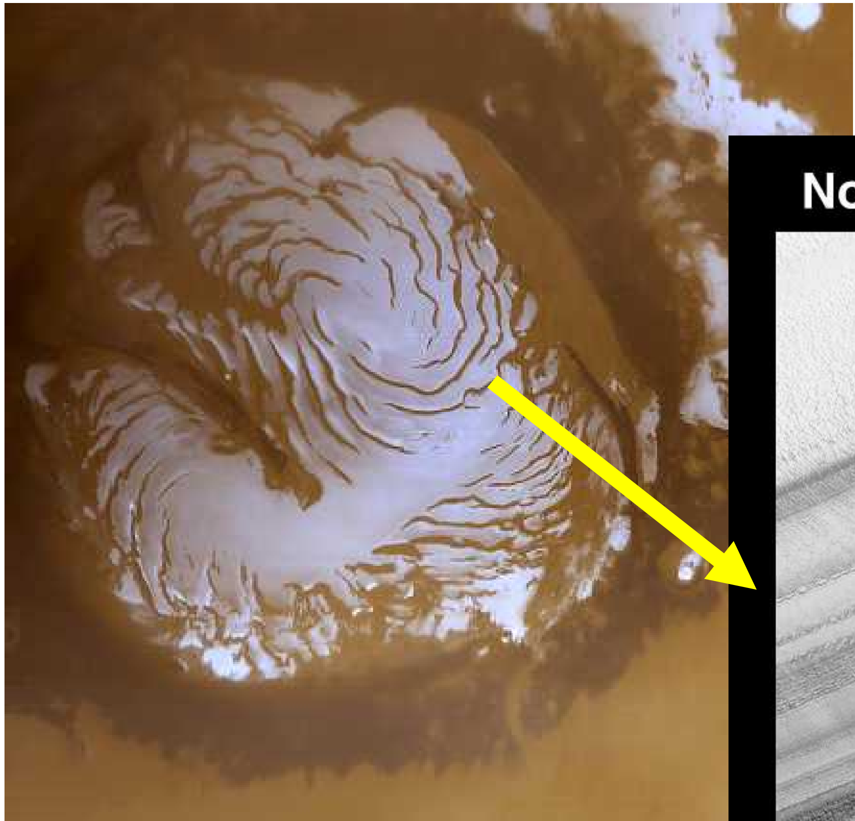


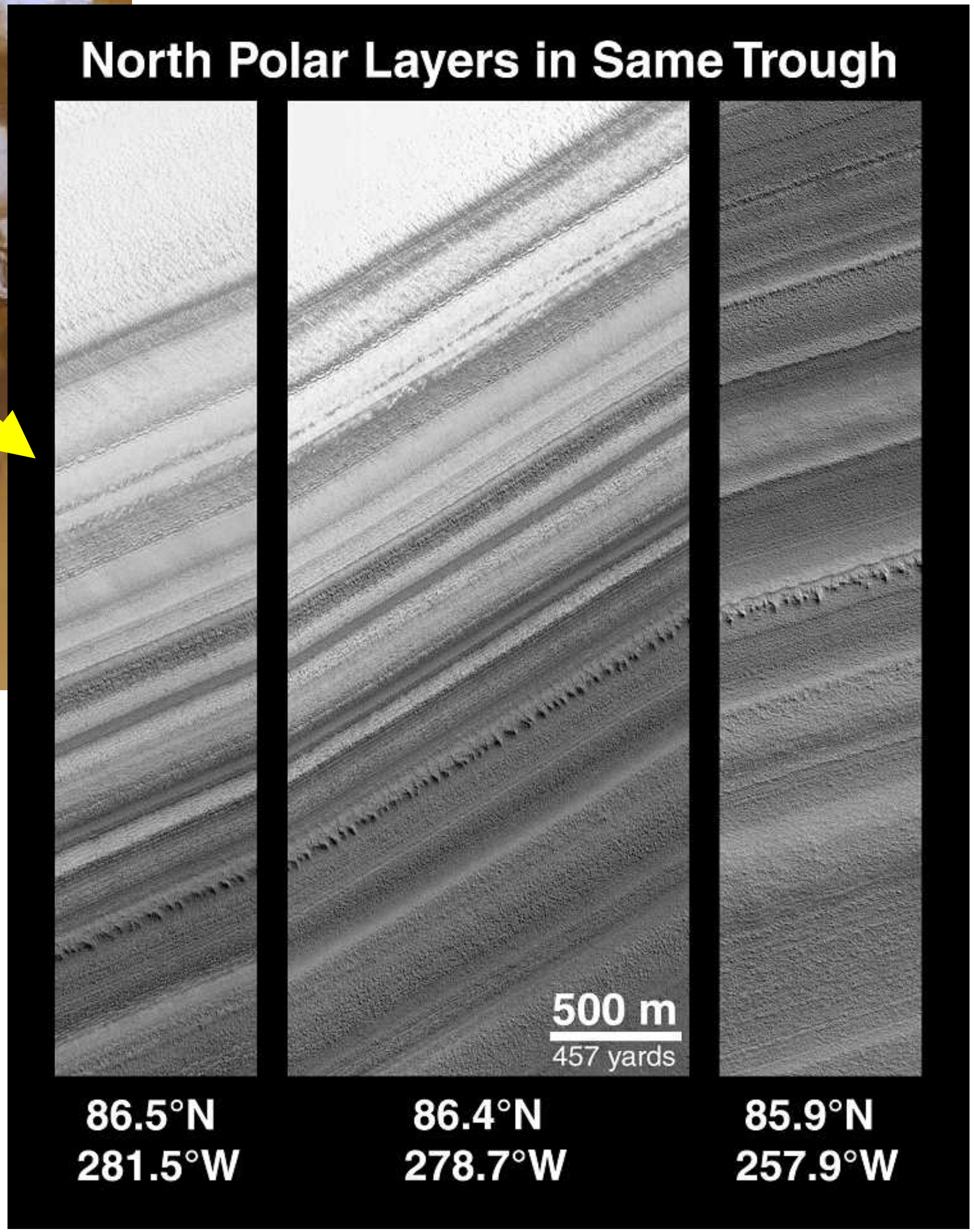


0°-30°
Calotte de glace d'eau
Formation d'une calotte polaire de glace d'eau
0°-30°
40°-60°
Disparition des calottes permanentes de glace d'eau
Aux hautes latitudes, Une partie de la glace retourne au pôle, une partie reste sous quelques centimètres de sédiments
0°-30°
Formation de glaciers aux basses et moyennes latitudes
Disparition des glaciers
Une couche de glace d'eau recouvre les hautes latitudes dans chaque hémisphère

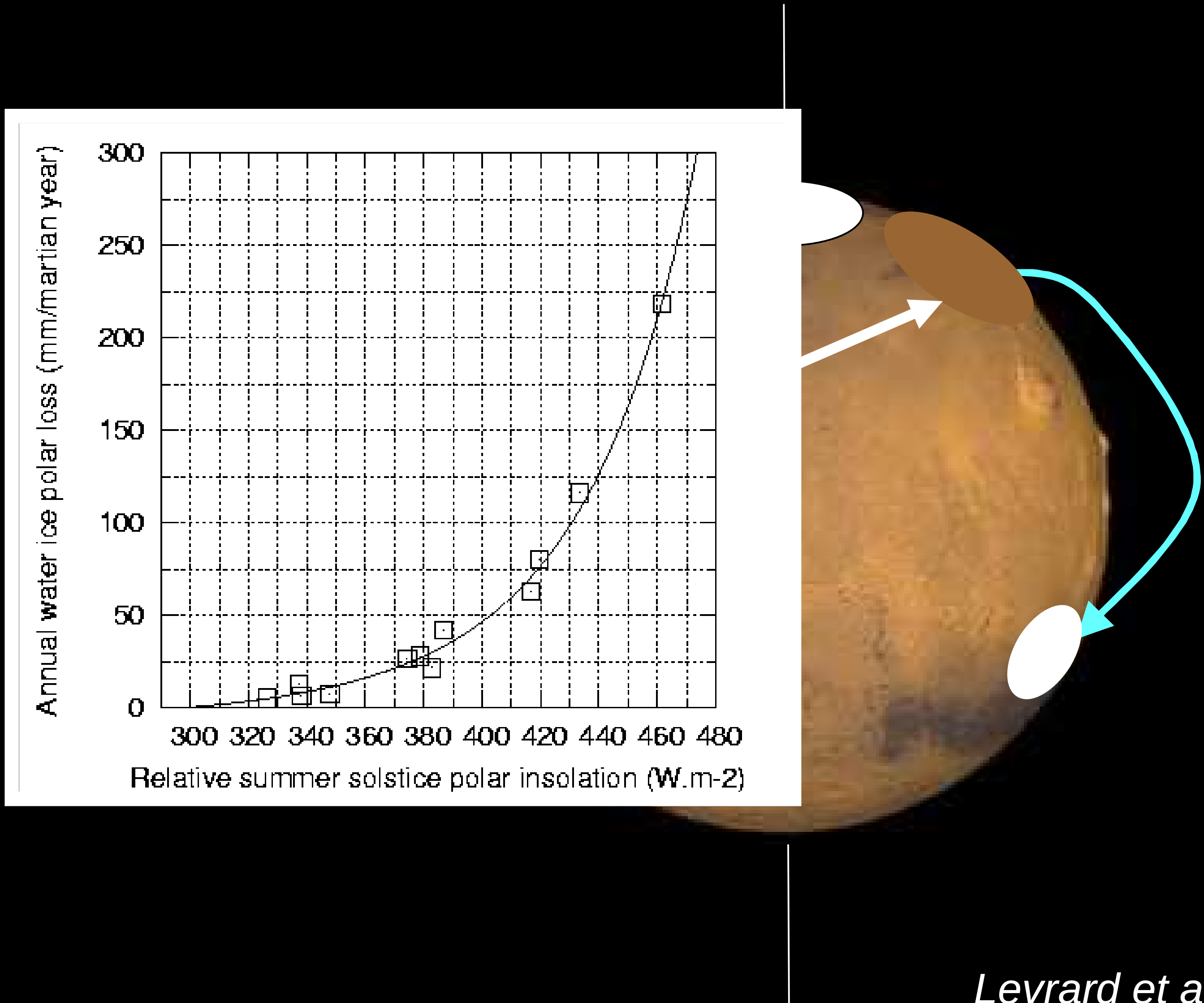

0°−30°
氷の極冠
氷の極冠の形成
0°−30°
高緯度では氷の一部は極へもどり，またある一部は厚さ数センチの堆積層に埋もれる形で残る
40°−60°
氷の永久極冠の消失
低・中緯度地域における氷塊の形成
0°−30°
氷塊の消失
氷の層は両半球の高緯度地域をおおう

- **Can we use the modeled past climates to reconstruct the north polar layered deposits history ?**
- ⇨ *Levrard et al.*, **JGR**, june 2007
-

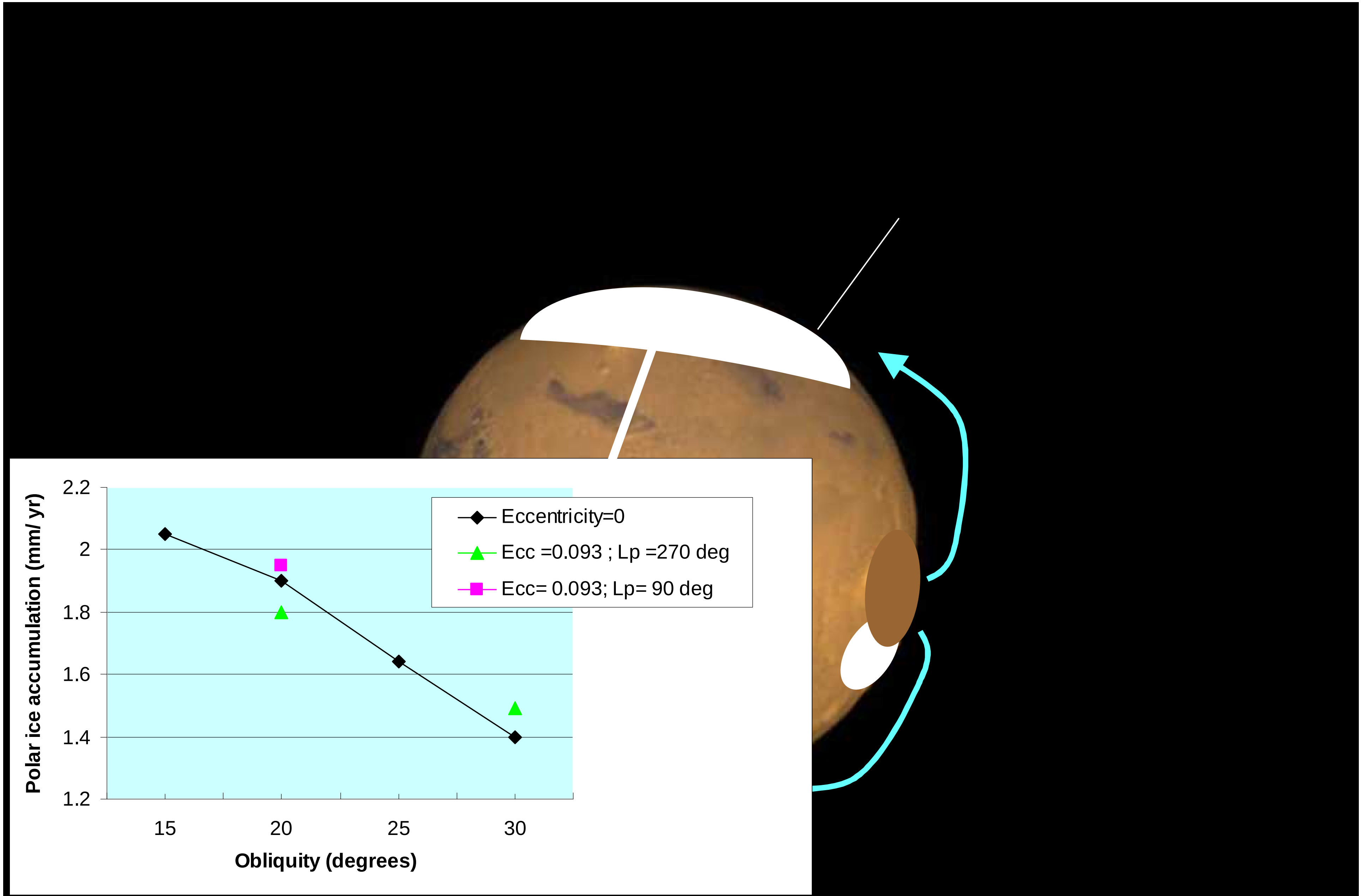




Record of climate variations in the polar layered terrain?



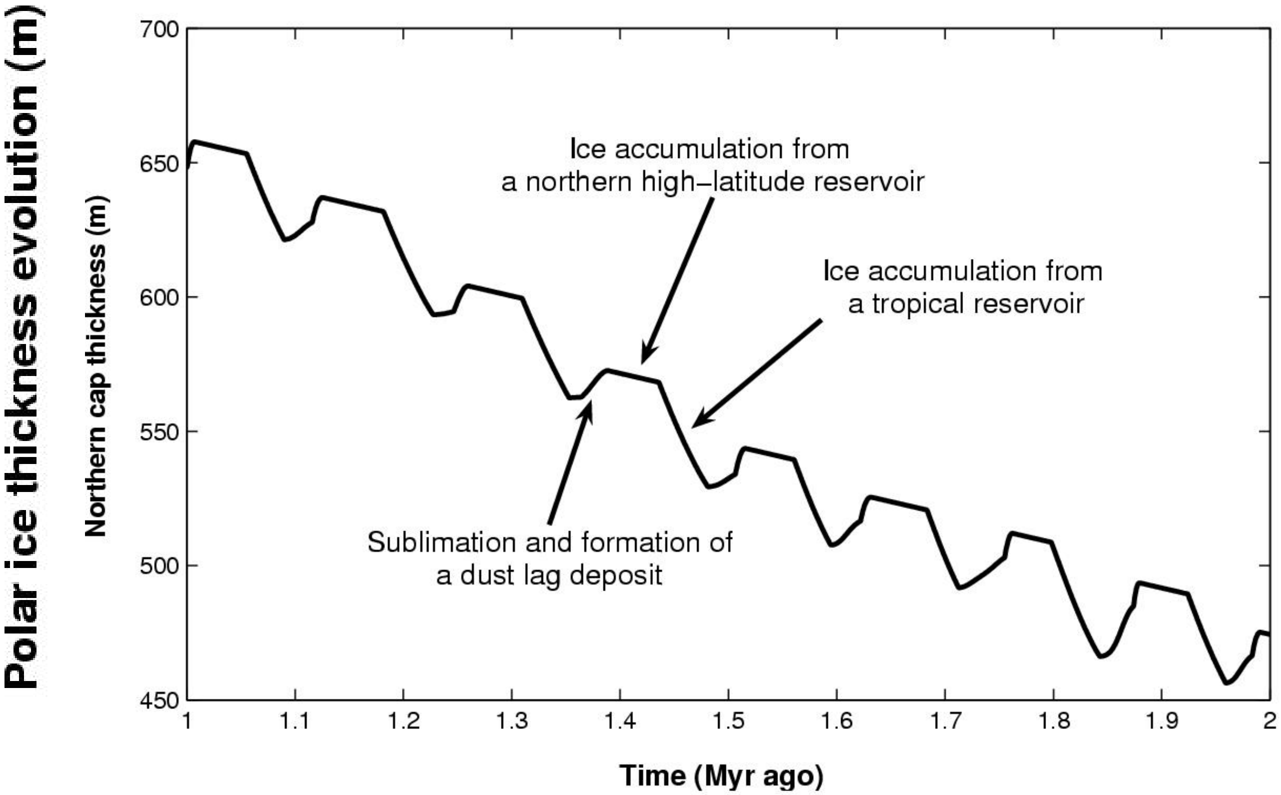
Levrard et al. 2007

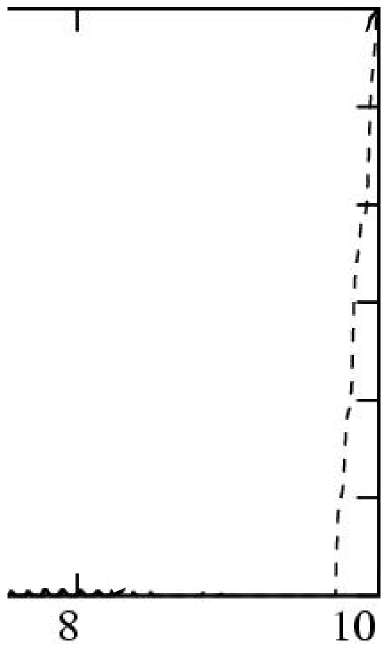


Levrard et al. 2007

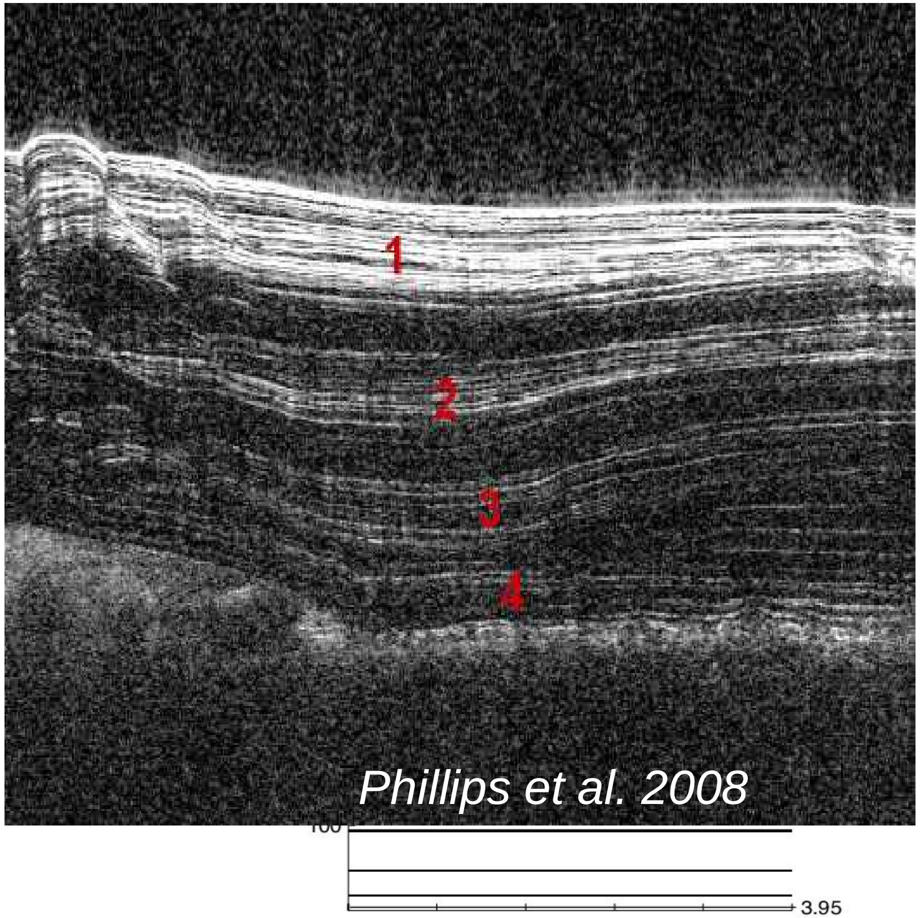
Simulation of the Northern polar deposits based on LMD GCM simulations

(*Levrard et al., JGR, in press, 2007*)

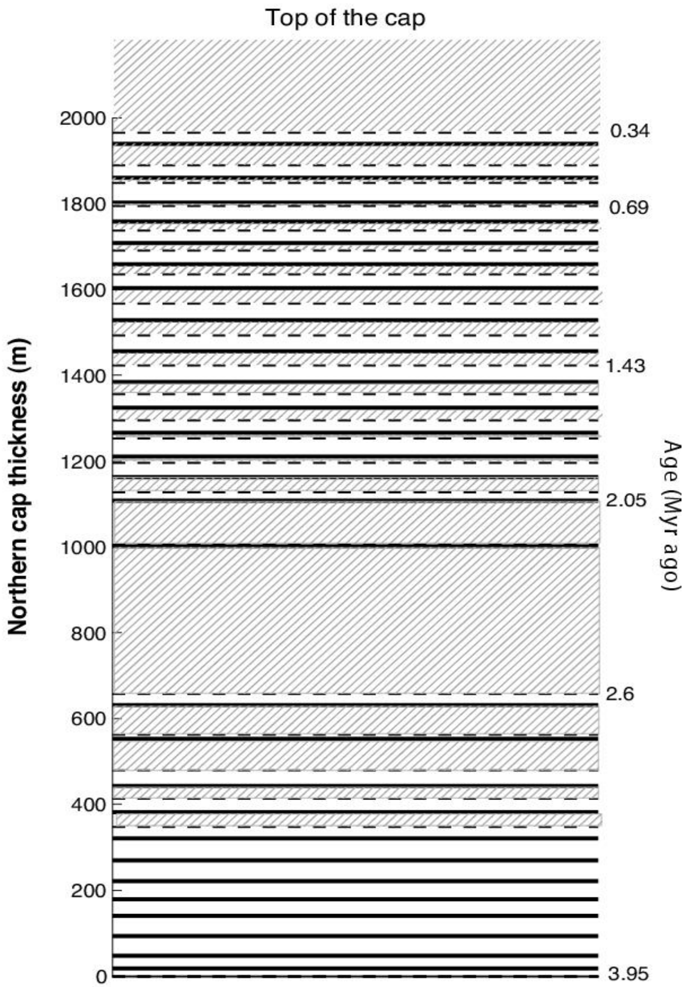




Structure of the modeled present day polar cap with a 3 reservoirs system :nnNorthern cap ; Tropics ; mid-latitudes



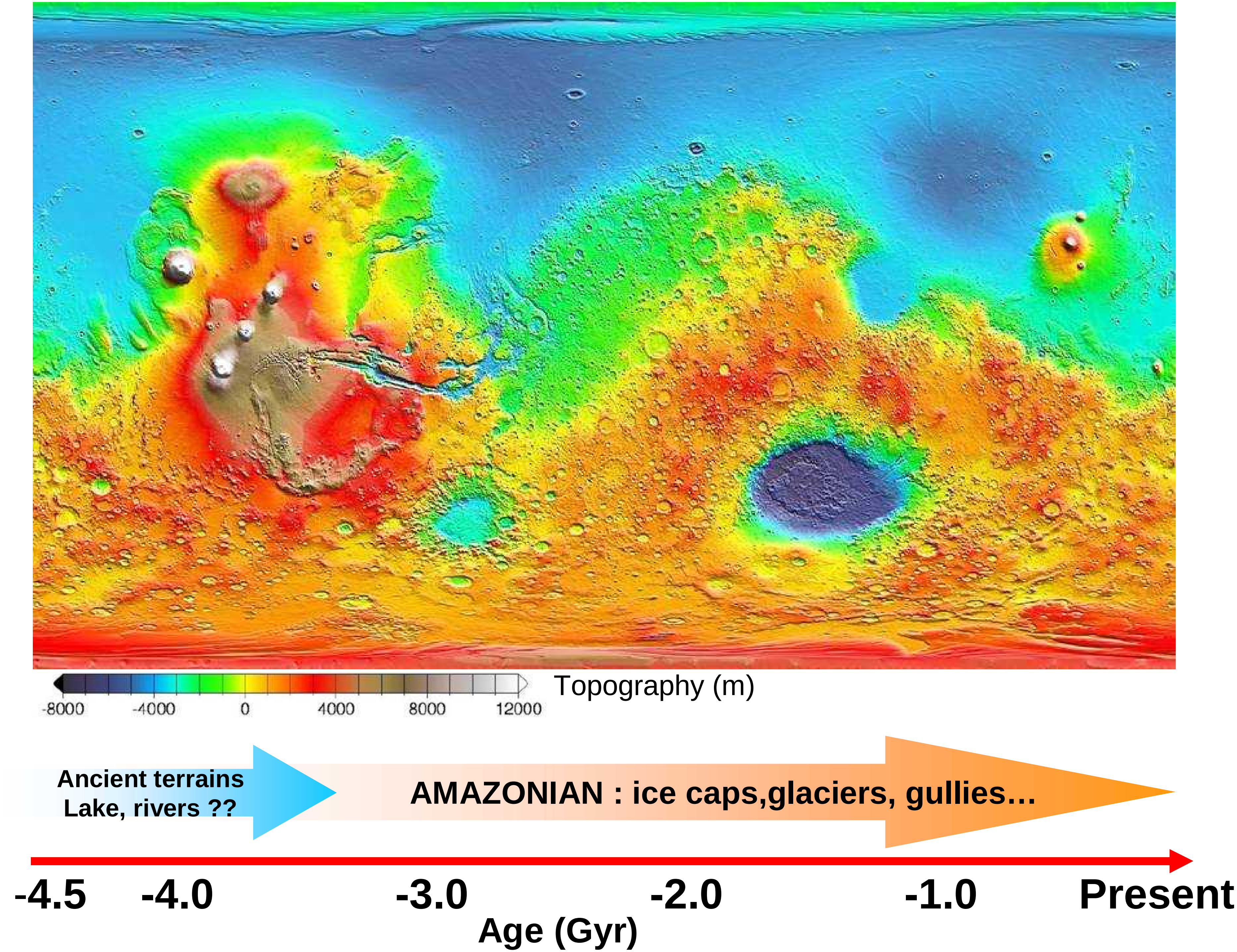
Case 1 : slow accumulation from mid-lat reservoirs : 0.17 mm/yr



Case 2 : fast accumulation from mid-lat reservoirs : 1.7 mm/yr

Some conclusions about « recent » climate

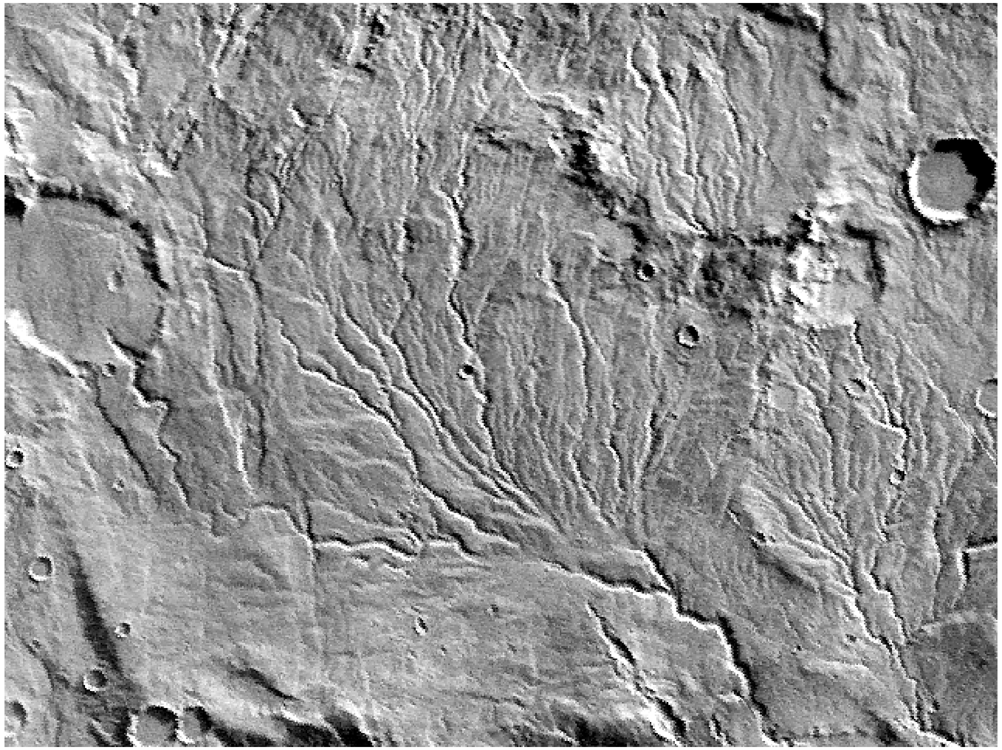
- Due to the variations of Mars orbital / rotational parameters, the **current** Mars climate system have mobilized large amount of water to form glaciers, ice caps until recently and in the future.
- Several **robust** mechanisms have been simulated by the Global Climate Model.
- Lots of issues remain in the model (radiative effect of ice and vapor, role of regolith and dust lag, dust cycle, dust-ice interaction, etc…) and to understand the relatives ages of the icy landforms
- **Could we also simulate Mars climate ~4 billions years ago ?**


-8000
-4000
0
4000
8000
12000
Topography (m)
Ancient terrains
Lake, rivers ??
AMAZONIAN : ice caps,glaciers, gullies…
-4.5
-4.0
-3.0
-2.0
-1.0
Present
Age (Gyr)

More and more observations suggesting that « early Mars » was different, with flowing liquid water, possibly precipitation:

Only in ancient terrains:

- Valley networks
- High Erosion rate in very ancient terrains
- Layers, « Lacustrine » deposits, deltas
- Mineralogy related to water alteration

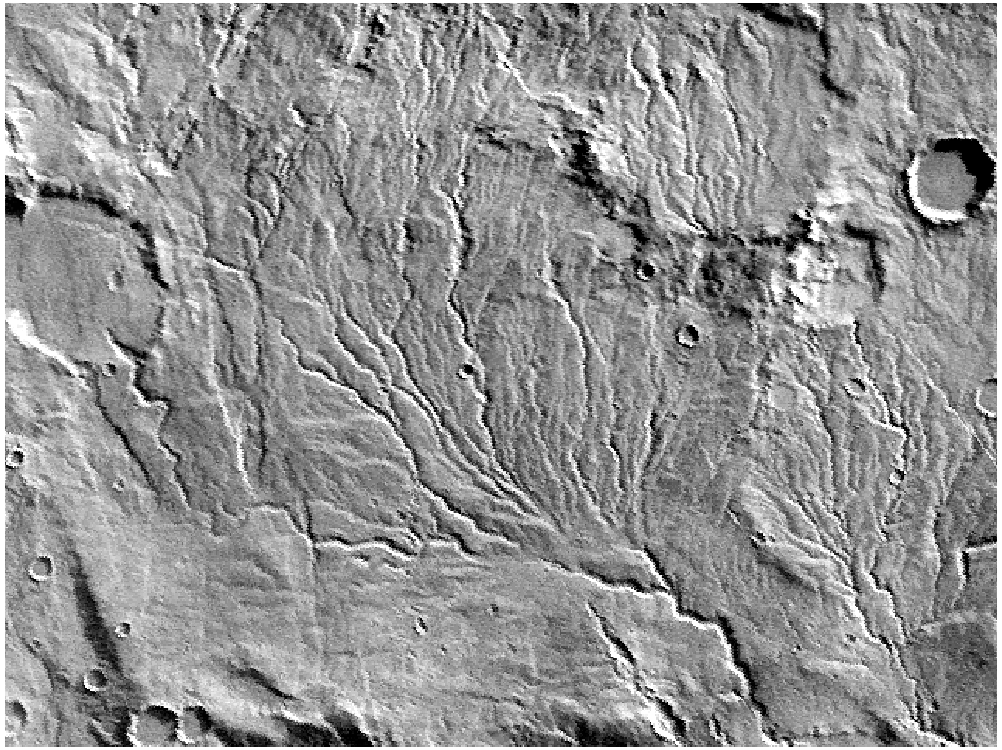


MARS : Warrego Vallis

150 km

EARTH

(Yemen ; same scale)



MARS : Warrego Vallis

150 km

Ansan and Mangold 2006 :
large drainage densities revealed by Themis ⇨ Precipitation

More and more observations suggesting that « early Mars » was different, with flowing liquid water, possibly precipitation:

Only in ancient terrains:

- **Valley networks**
- **High Erosion rate in very ancient terrains**
- **Layers, « Lacustrine » deposits, deltas**
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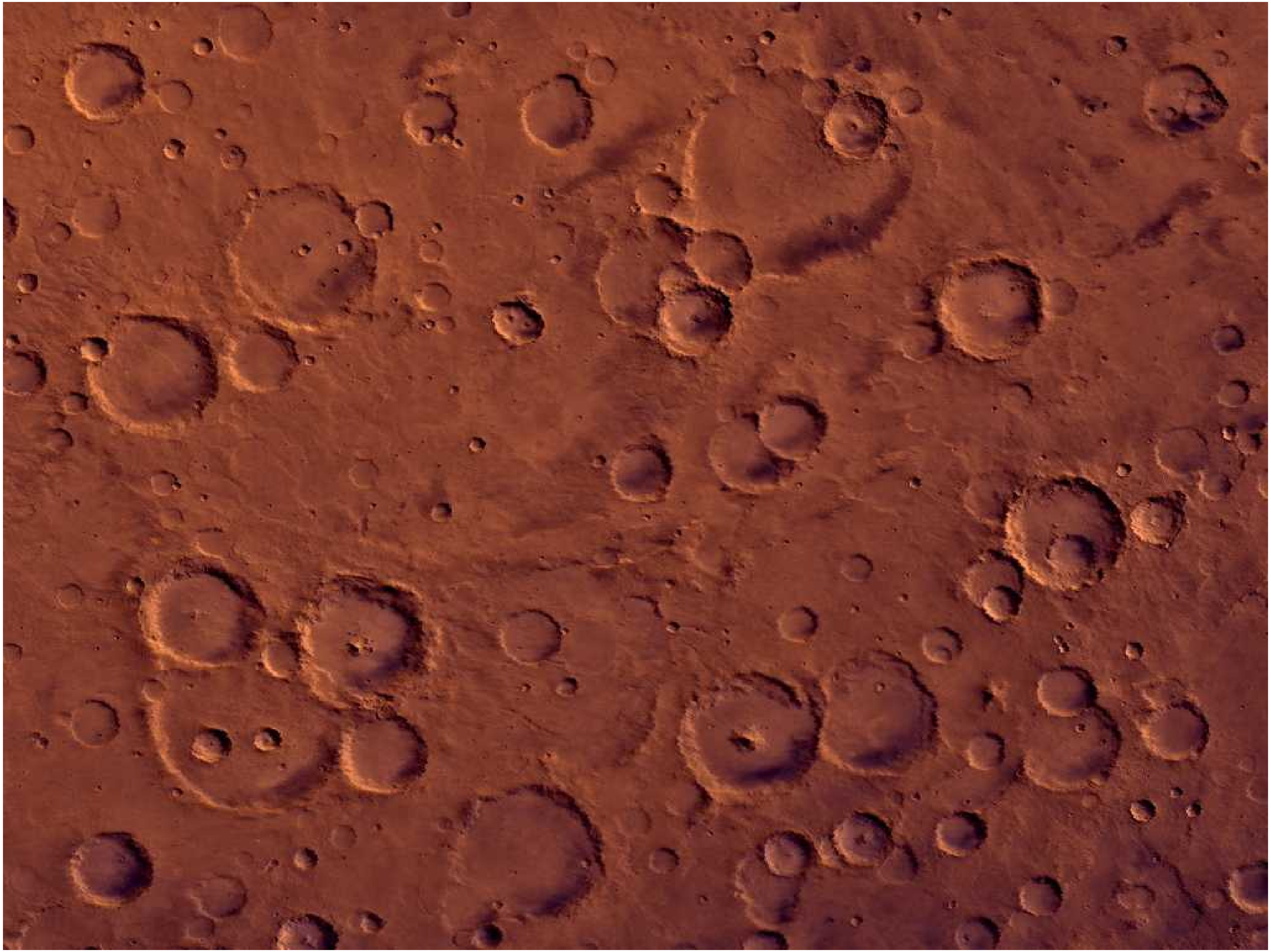
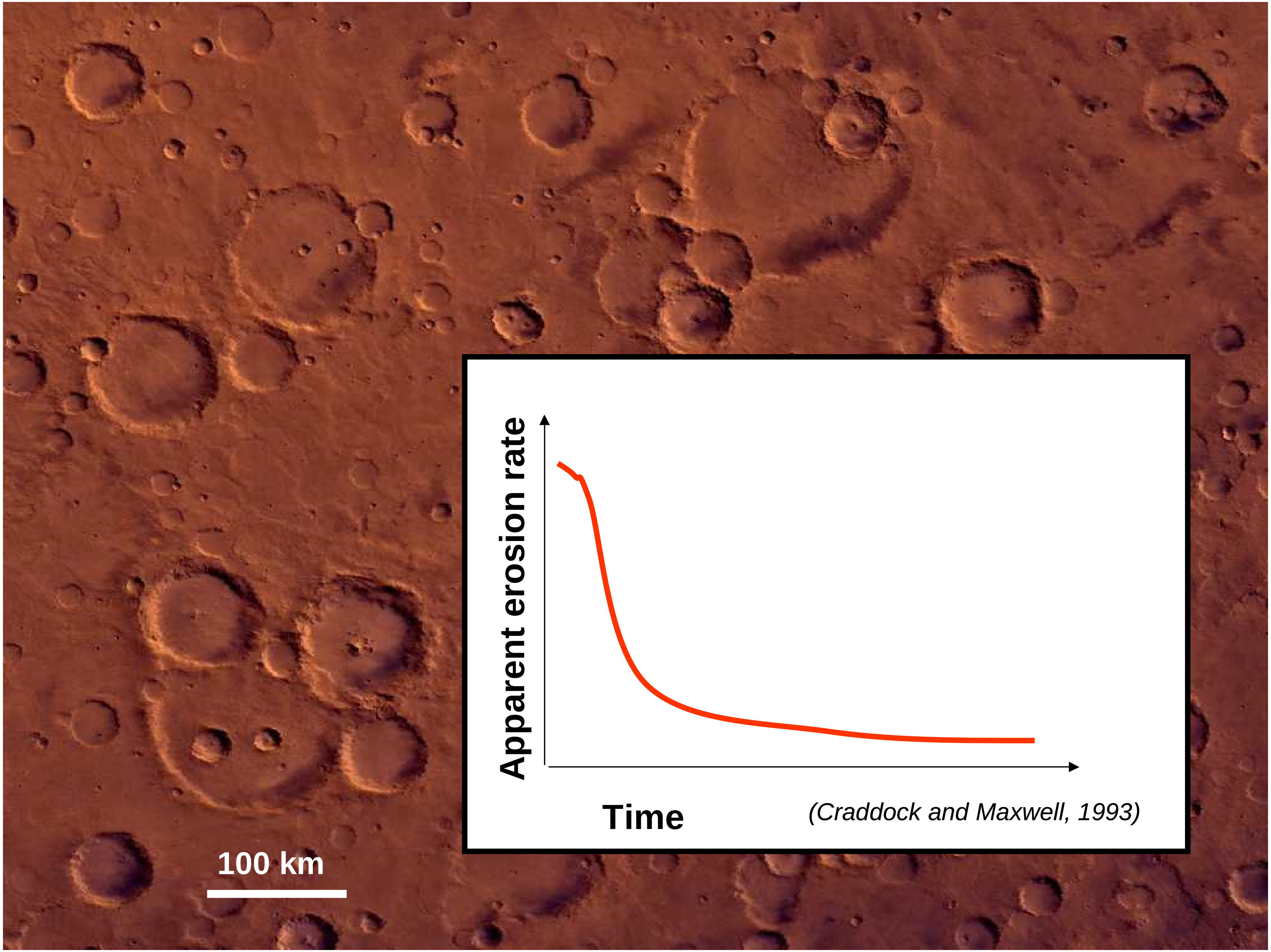


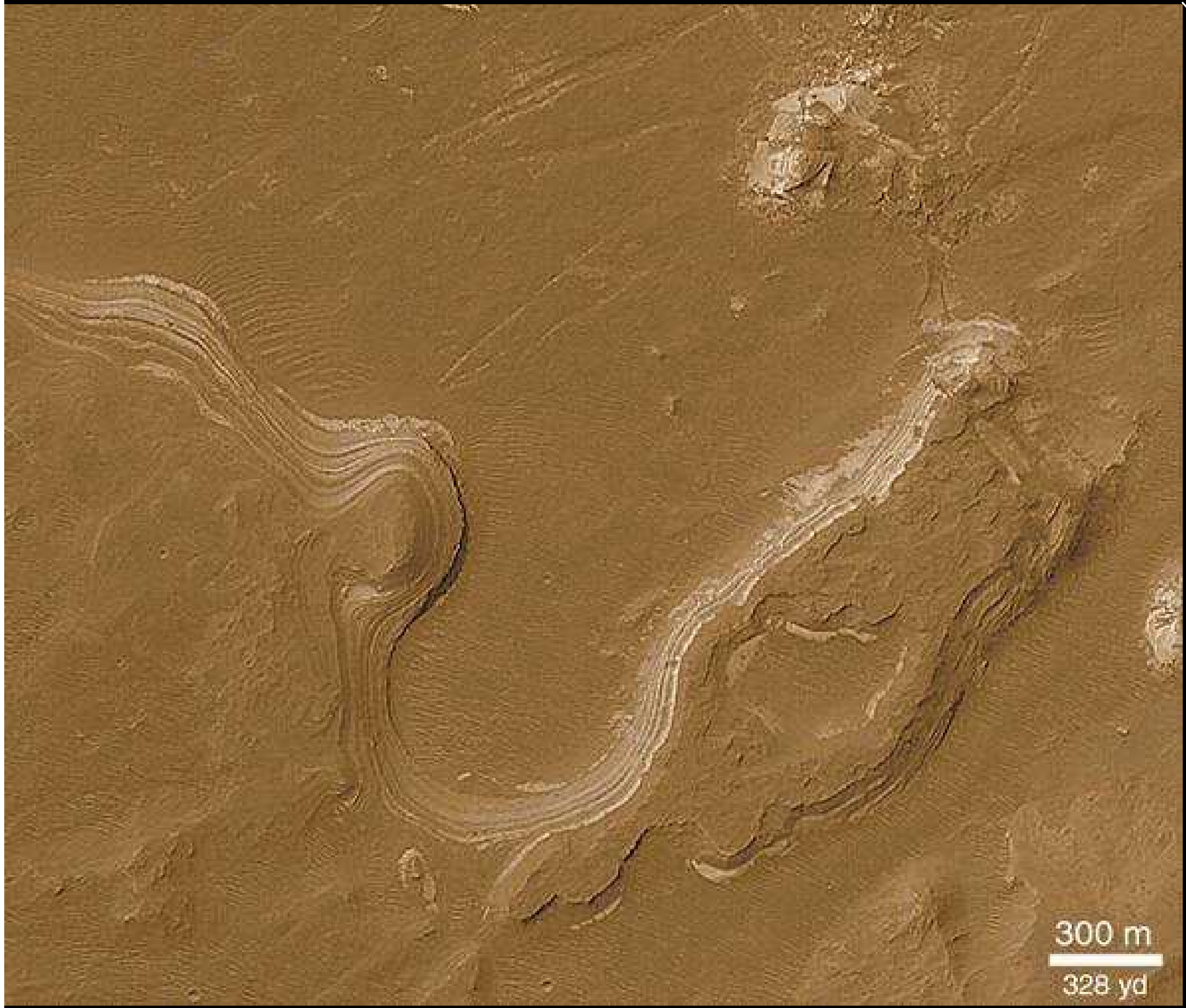

Apparent erosion rate
Time
(Craddock and Maxwell, 1993)
100 km

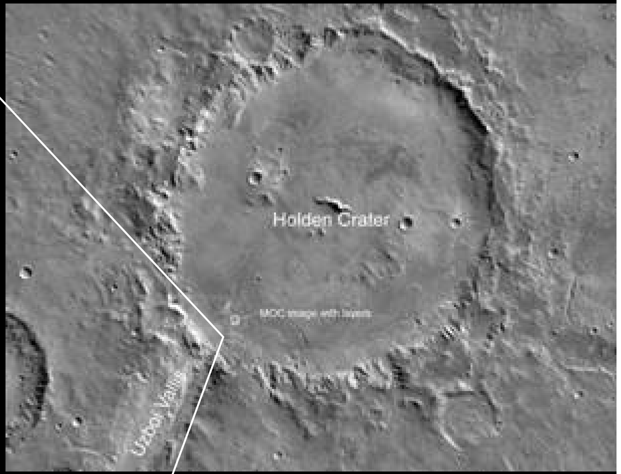
More and more observations suggesting that « early Mars » was different, with flowing liquid water, possibly precipitation:

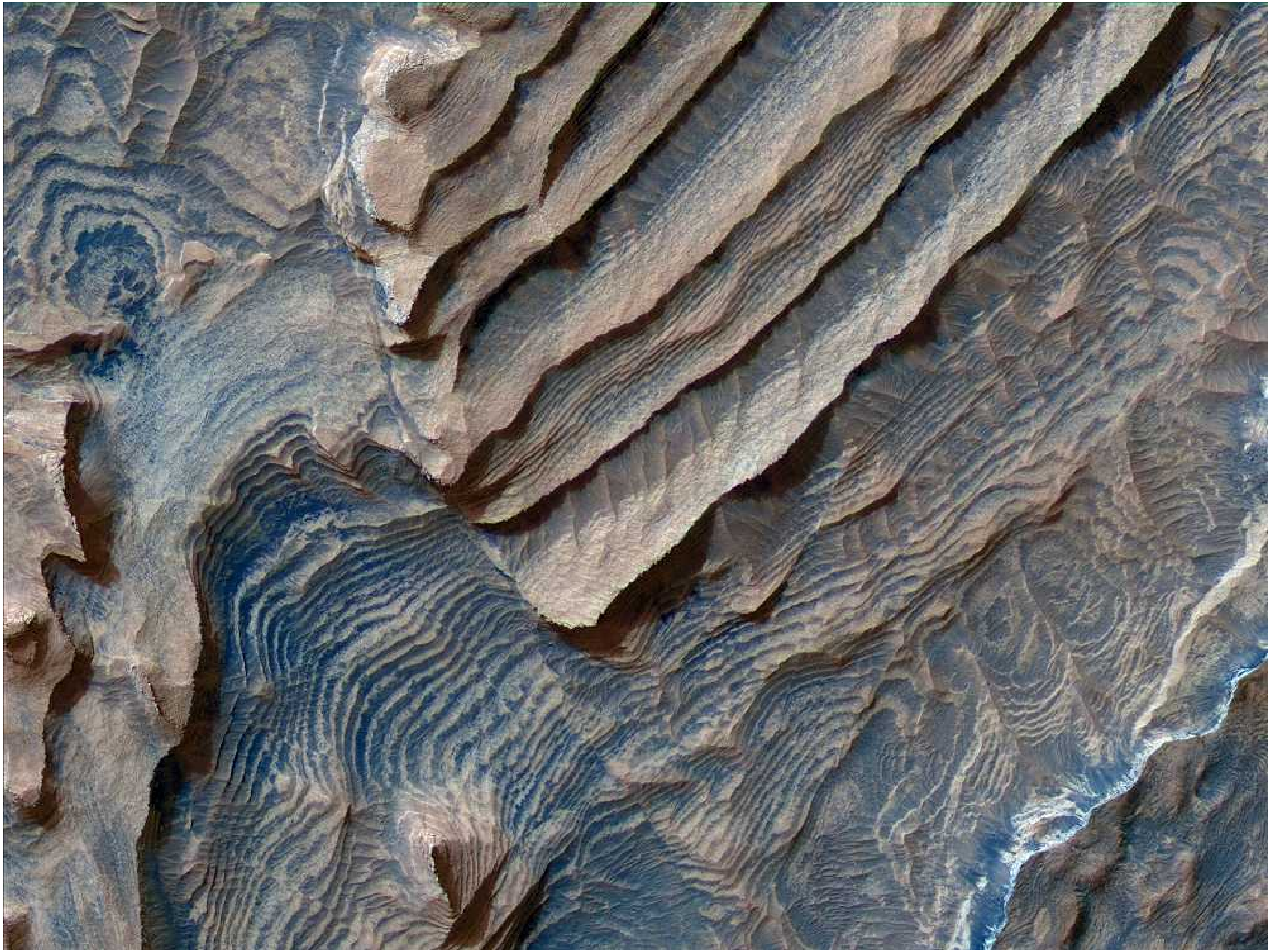
Only in ancient terrains:

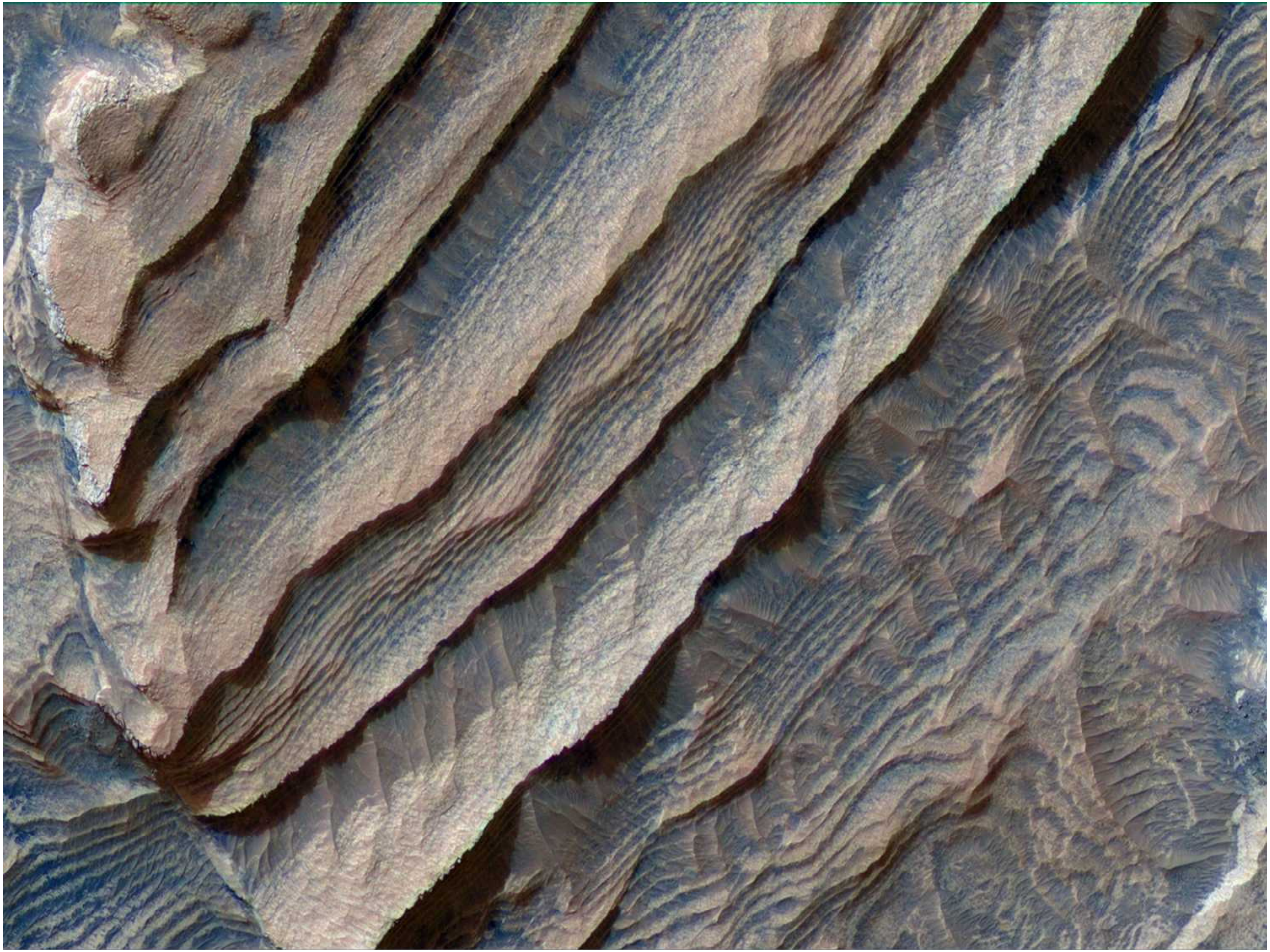
- **Valley networks**
- **High Erosion rate in very ancient terrains**
- **Layers, « Lacustrine » deposits, deltas**
- **Mineralogy related to water alteration**

Shores of ancient lakes ?










Malin and Edget 2003
Moore et al. 2003
See also Mangold and Ansan 2006

More and more observations suggesting that « early Mars » was different, with flowing liquid water, possibly precipitation:

Only in ancient terrains:

- **Valley networks**
- **High Erosion rate in very ancient terrains**
- **Layers, « Lacustrine » deposits, deltas**
- **Mineralogy related to water alteration :**
- **Clays** ***(****detected by Mars Express Omega): in very ancient terrains*
- **Sulfate** ***(****detected by Omega & MER): less ancient terrains*
- Hematite ***(****detected by MGS TES)*
- Silica (Opal) *(Spirit)*

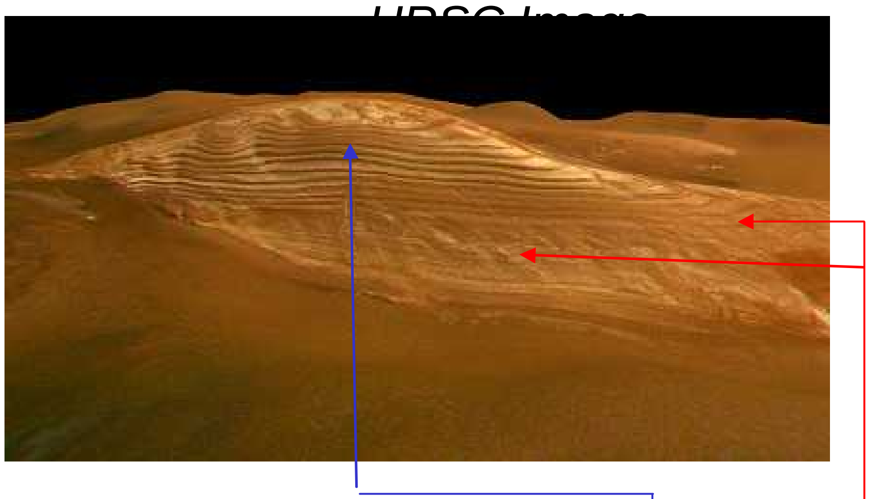
Sulfate

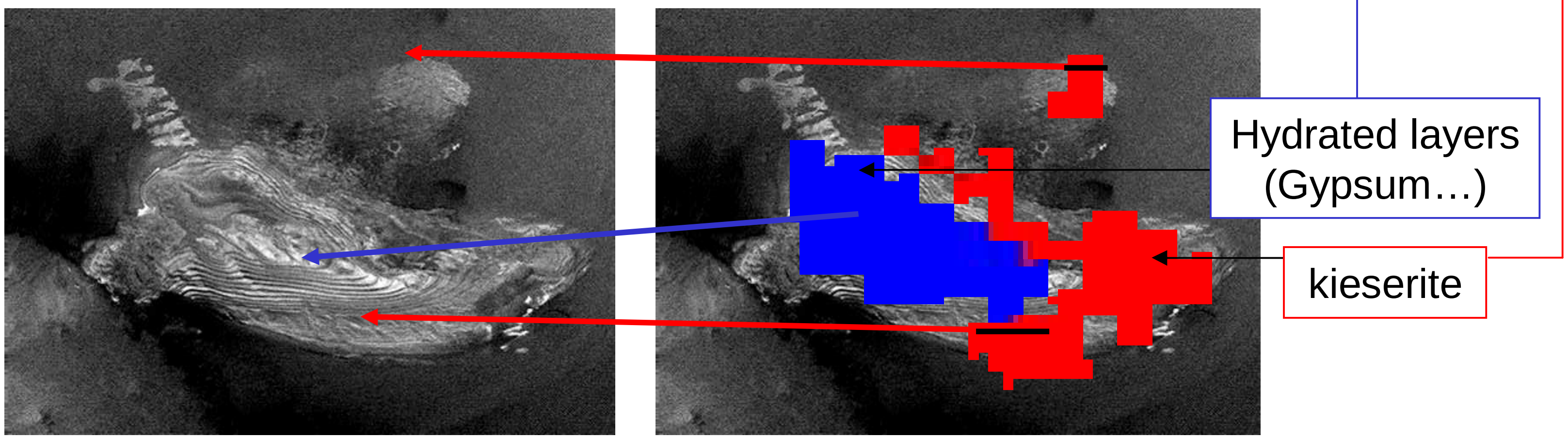
(Kieserite , Gypsum, etc…

in three types of terrains (*younger than clay!)*

- within layered deposits in Valles Marineris
- in the Terra Meridiani area
- within the dark dunes of the North polar cap

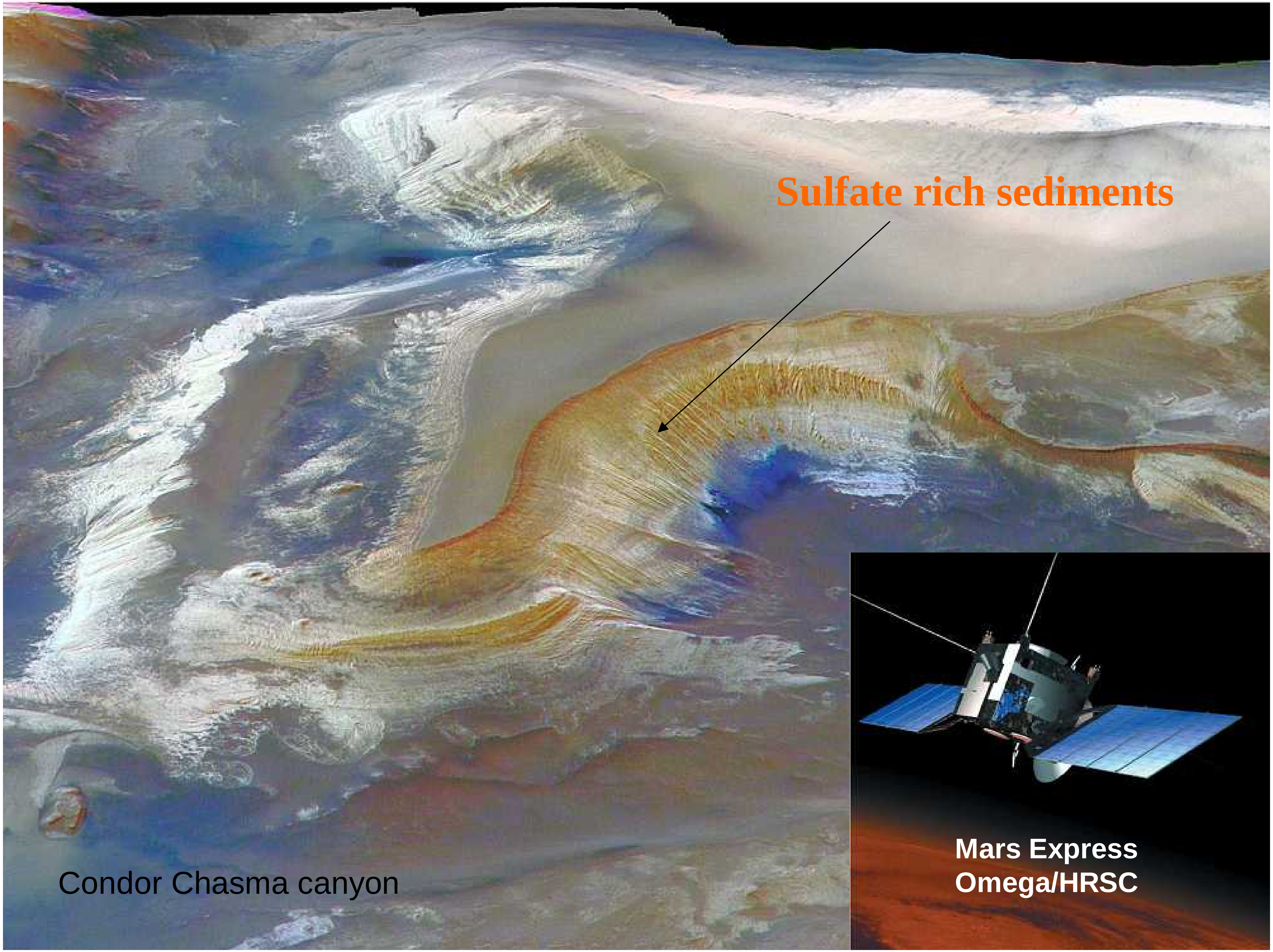
Sulfates can be formed as salts, tracing evaporation processes. Other "exotic" processes without surface liquid water could also be possible

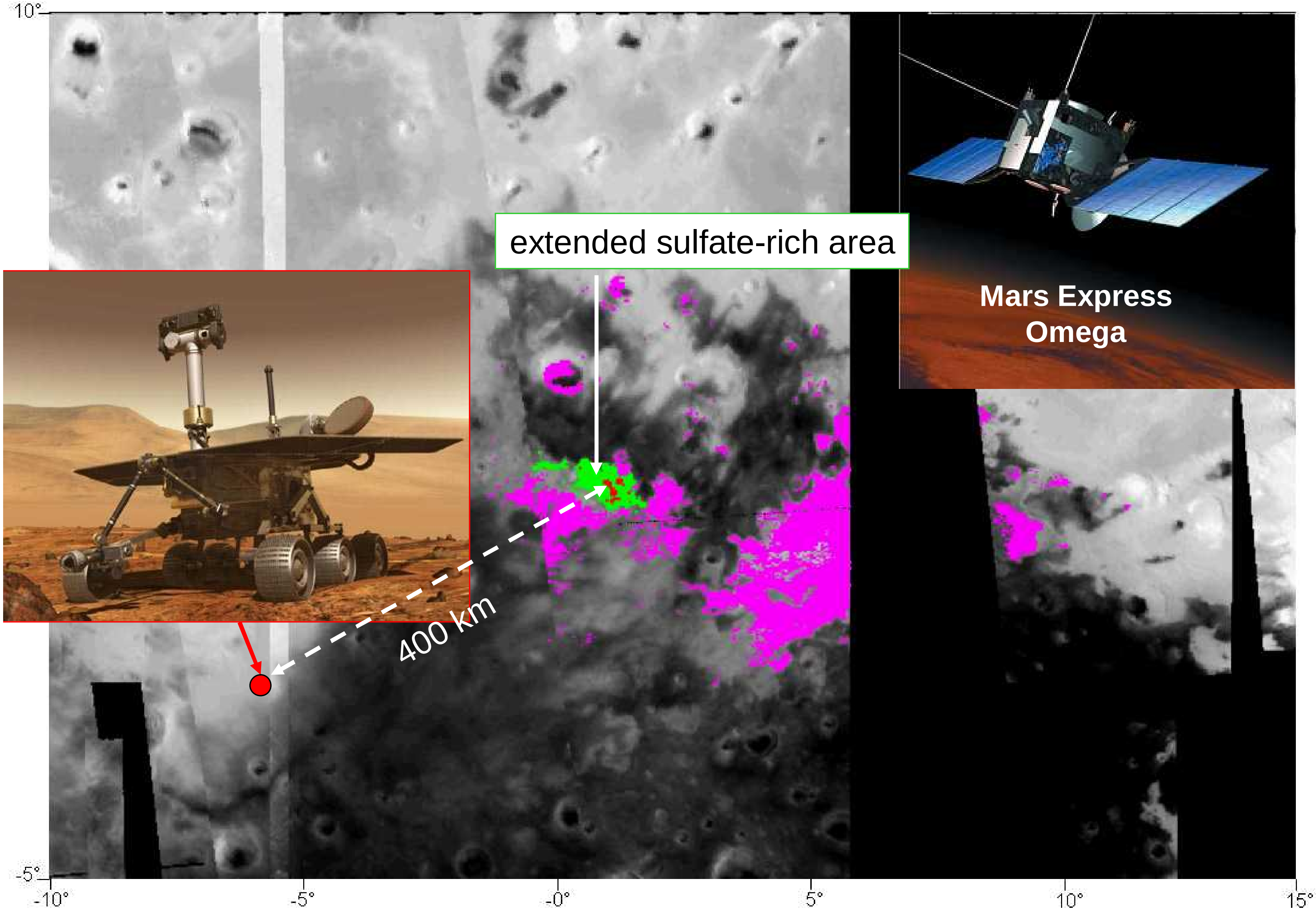




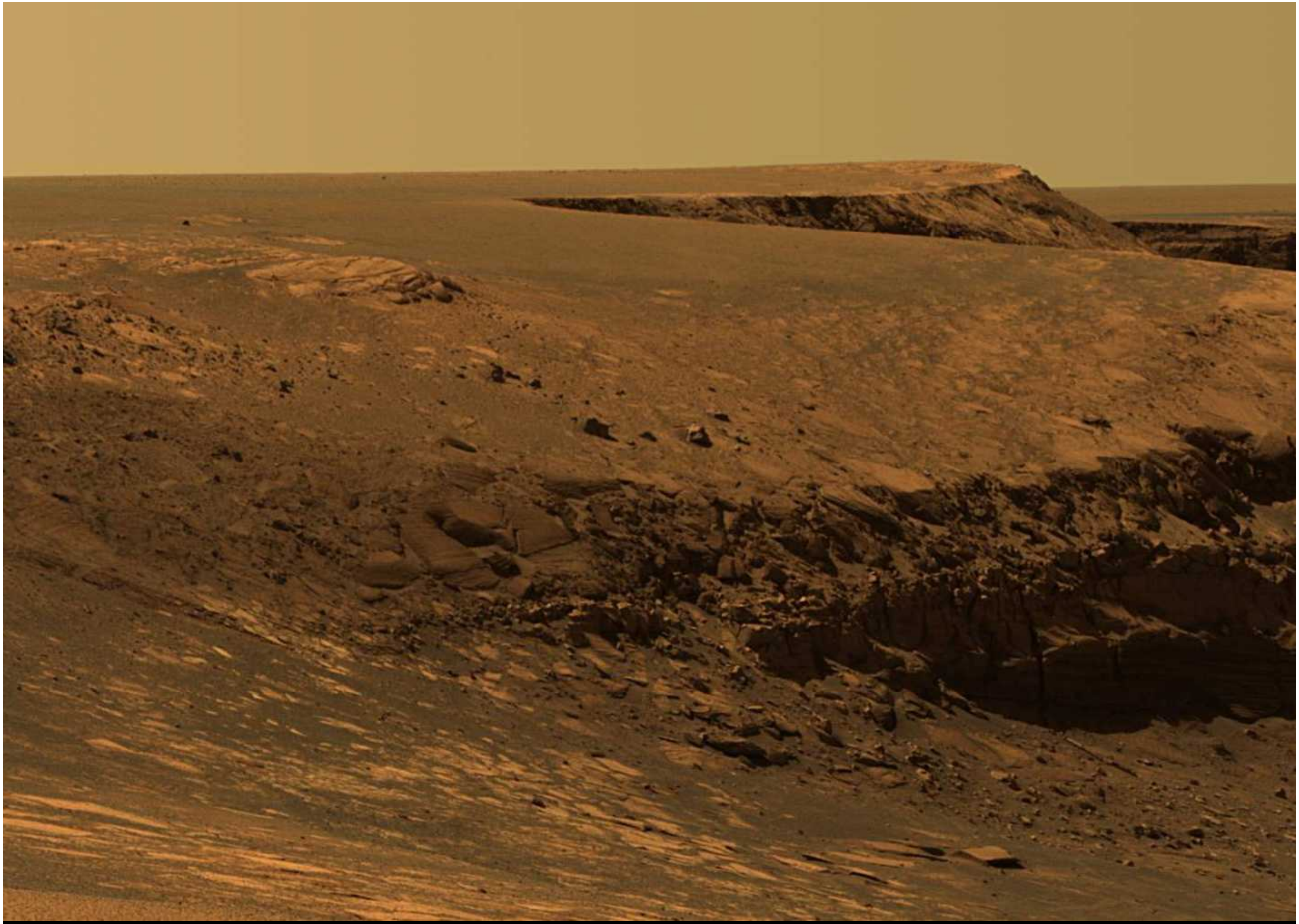
Mars Express OMEGA (*Bibring et al. 2005)*

Detection of sulfate layered deposits (see also Gendrin et al. 2005)

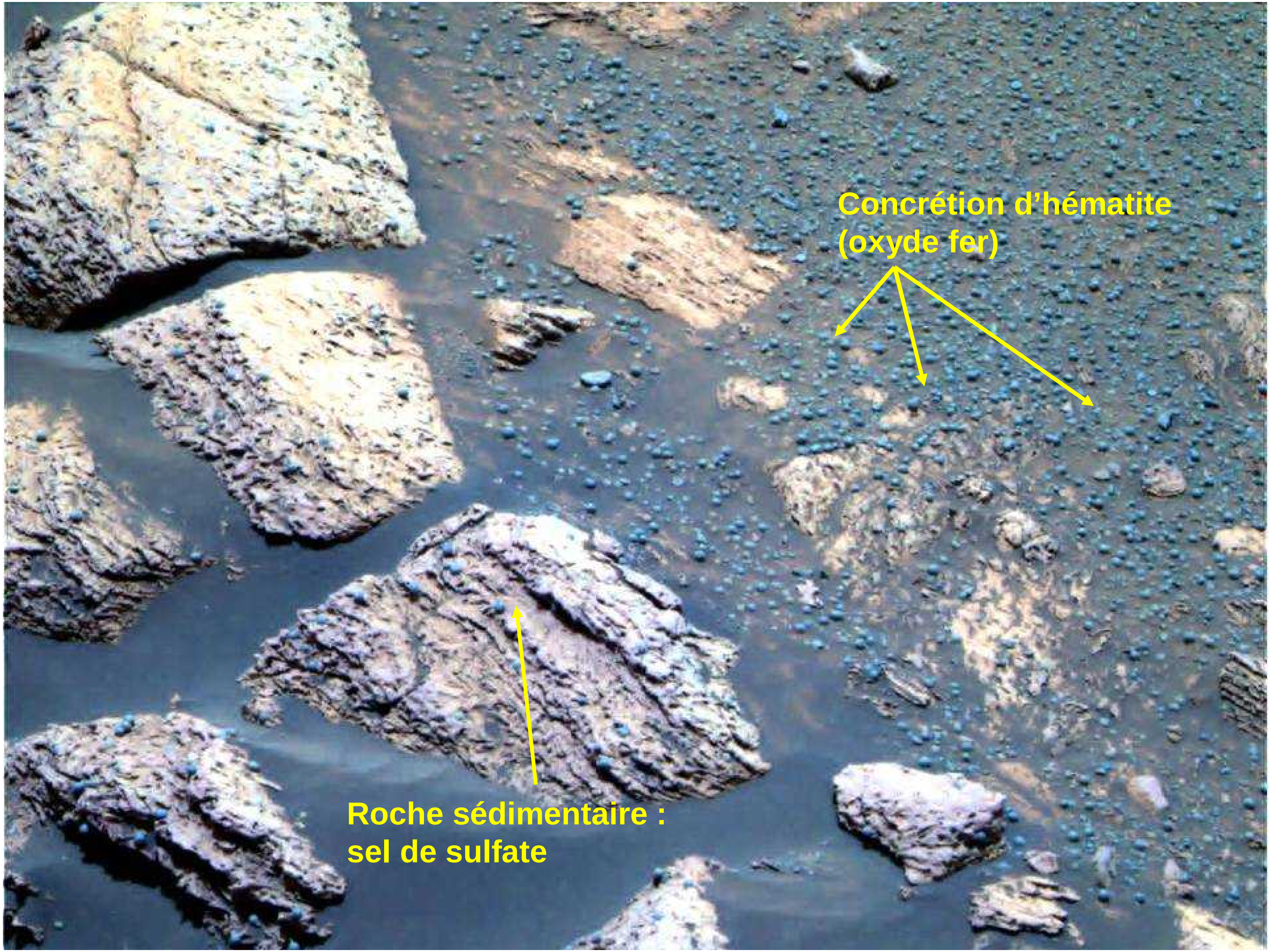

Sulfate rich sediments
Condor Chasma canyon
Mars Express
Omega/HRSC

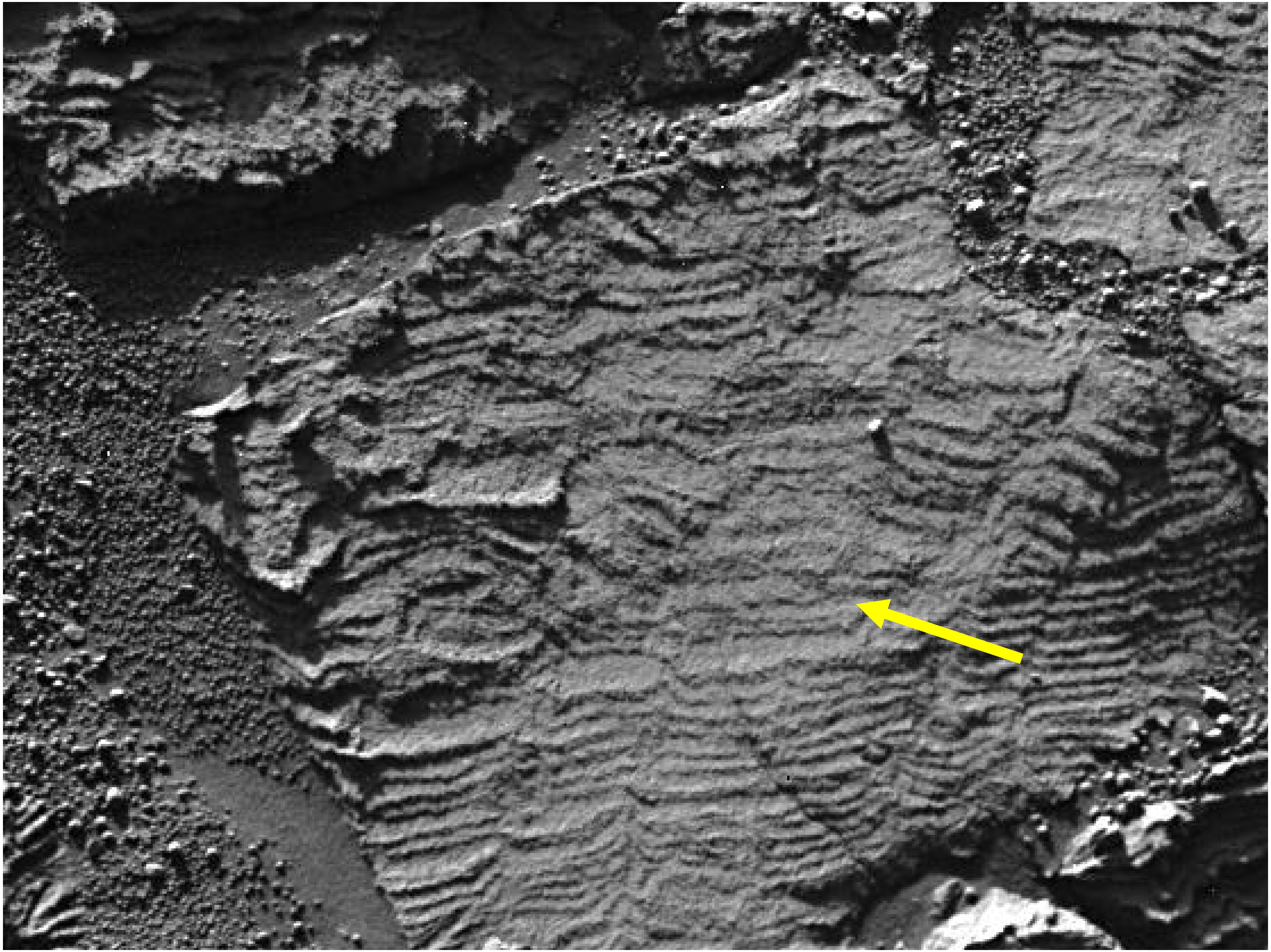


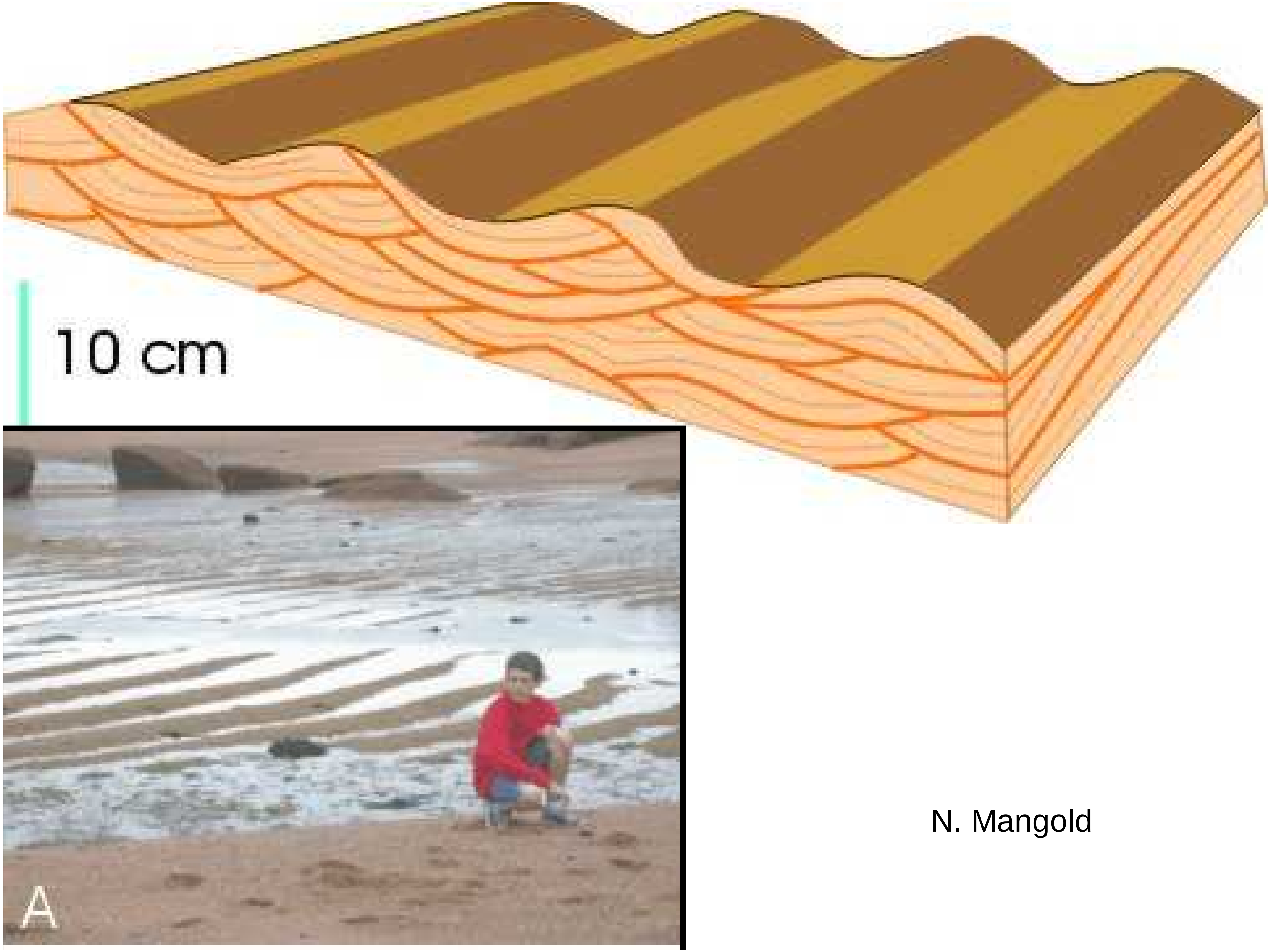
OMEGA maps, © IAS: Gendrin et al. 2005, Bibring et al. 2005, 2006



Sulfate cliff in Victoria crater (Rover NASA Opportunity)


Concrétion d'hématite
(oxyde fer)
Roche sédimentaire :
sel de sulfate





N. Mangold

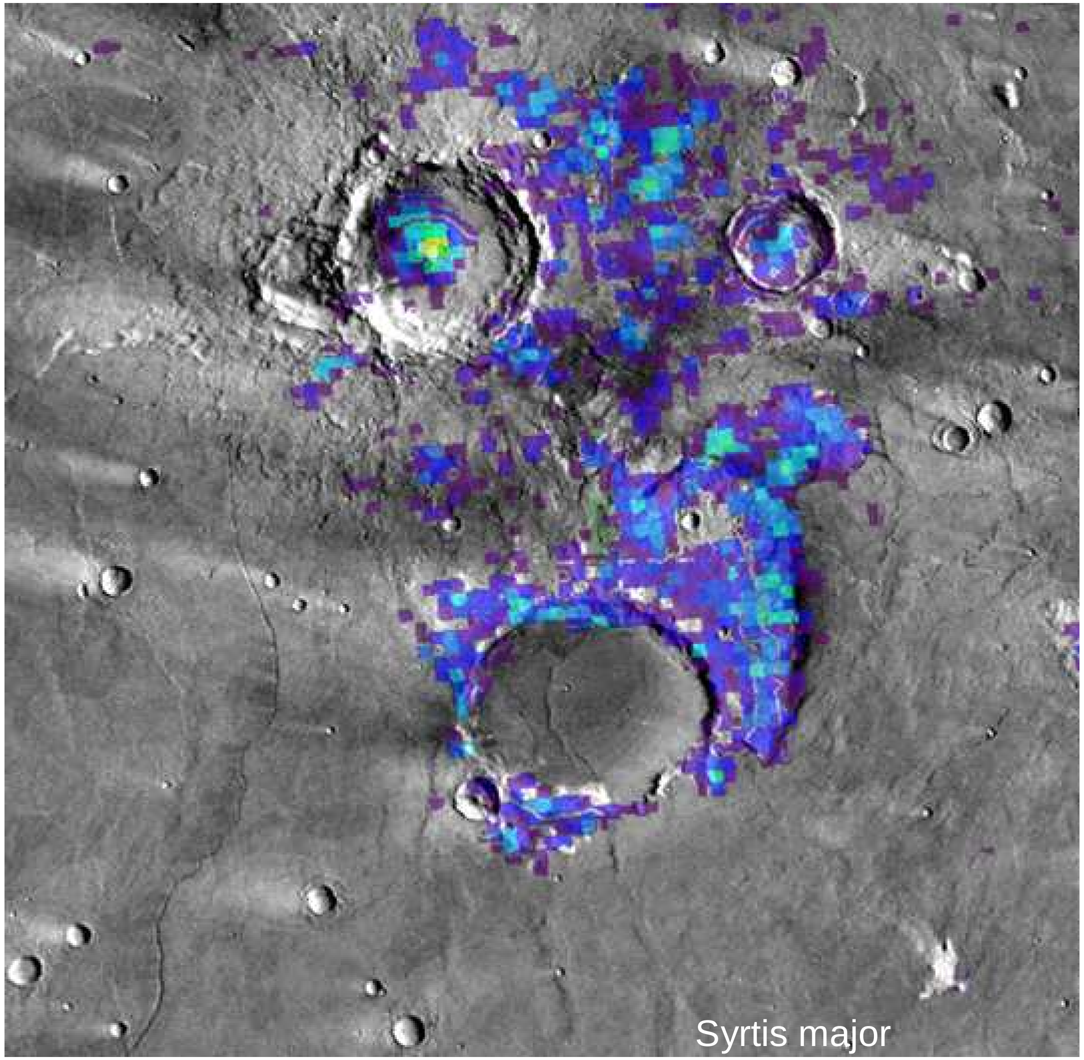
« clays »

phylosilicate: smectite
(Nontronite)

• Clay are formed by water alteration over geological timescale ⇨ Large water surface reservoir, runoff ?

• In very ancient terrains: unburried deposits by impacts, eolian or flow erosion

•However subsurface (e.g. hydrothermal) process cannot be dismissed

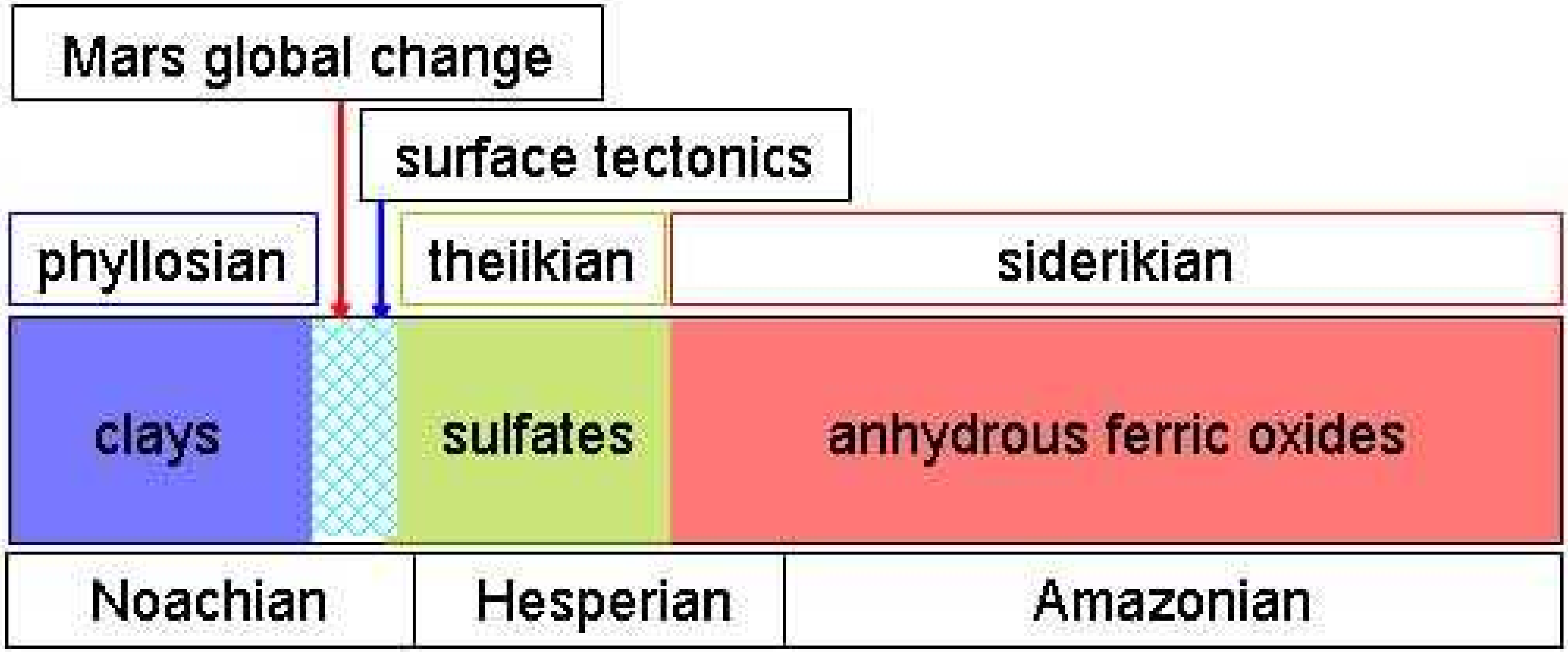


Adapted from Bibring et al. 2005
See also Poulet et al. 2005
Bibring et al. 2006


50 m
HIRISE : Nilisyrtis

Mars History as seen from OMEGA mineralogical data

(Bibring et al. 2006)



Early Noachian:

Favourable to clay formation lots of surface water, alkaline hydrous environment

Later

acidic hydrous environment for sulfates : less active water cycle?

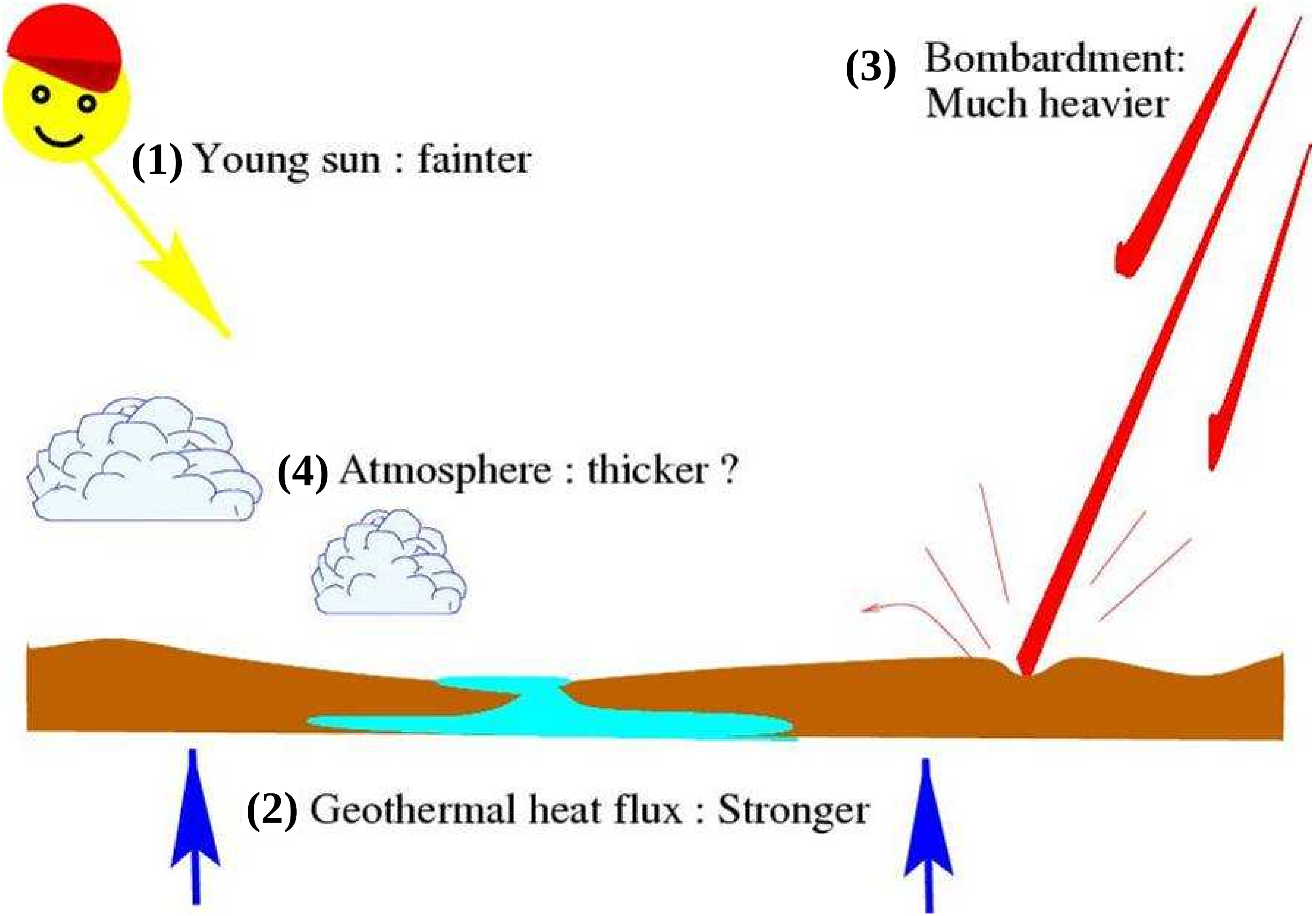
Since then:

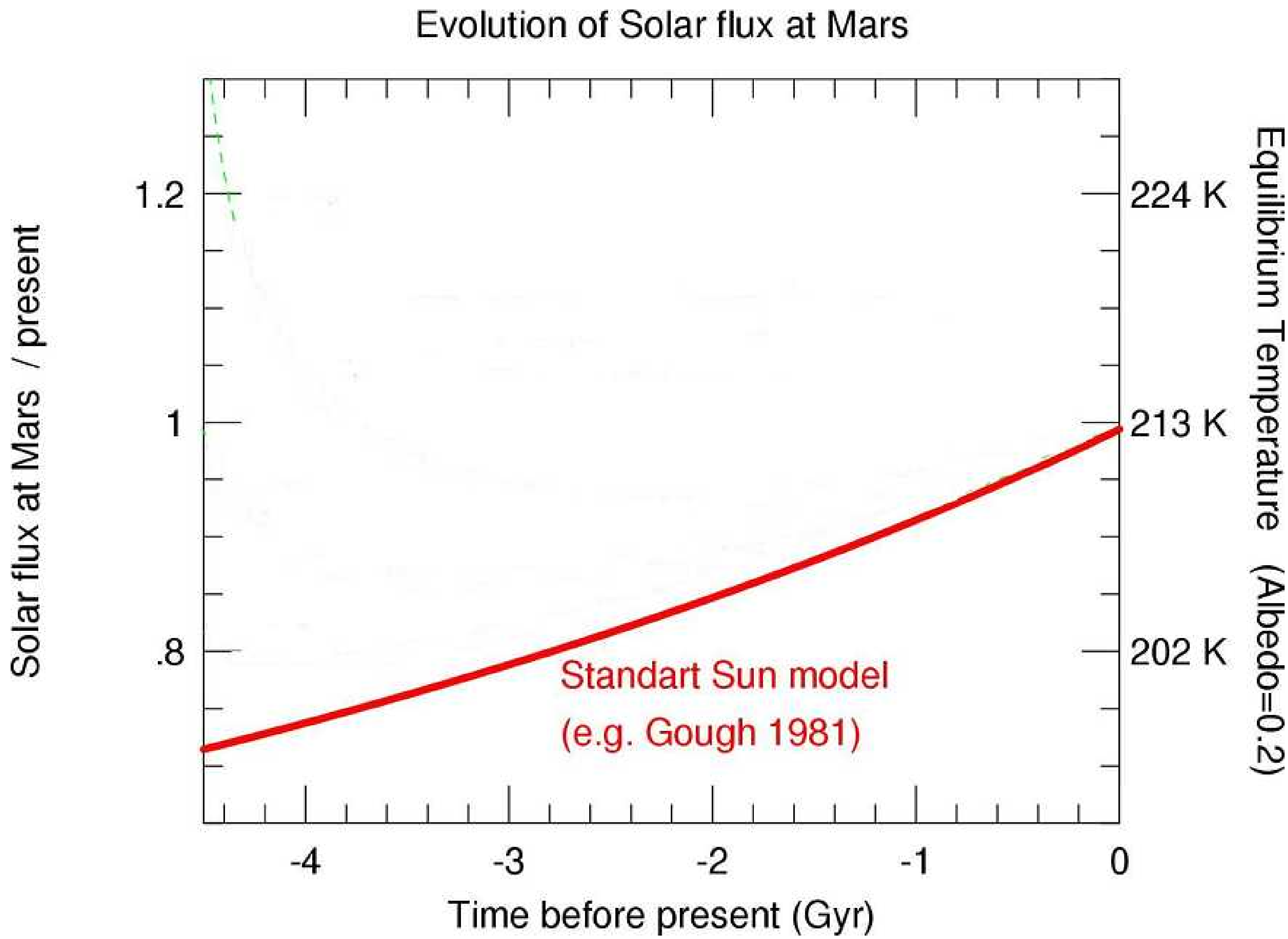
no chemical trace of sustained surface liquid water. anhydrous environment for oxides


?
Things were different on early Mars ...

Why was early Mars different ?

Different boundary conditions compared to present :

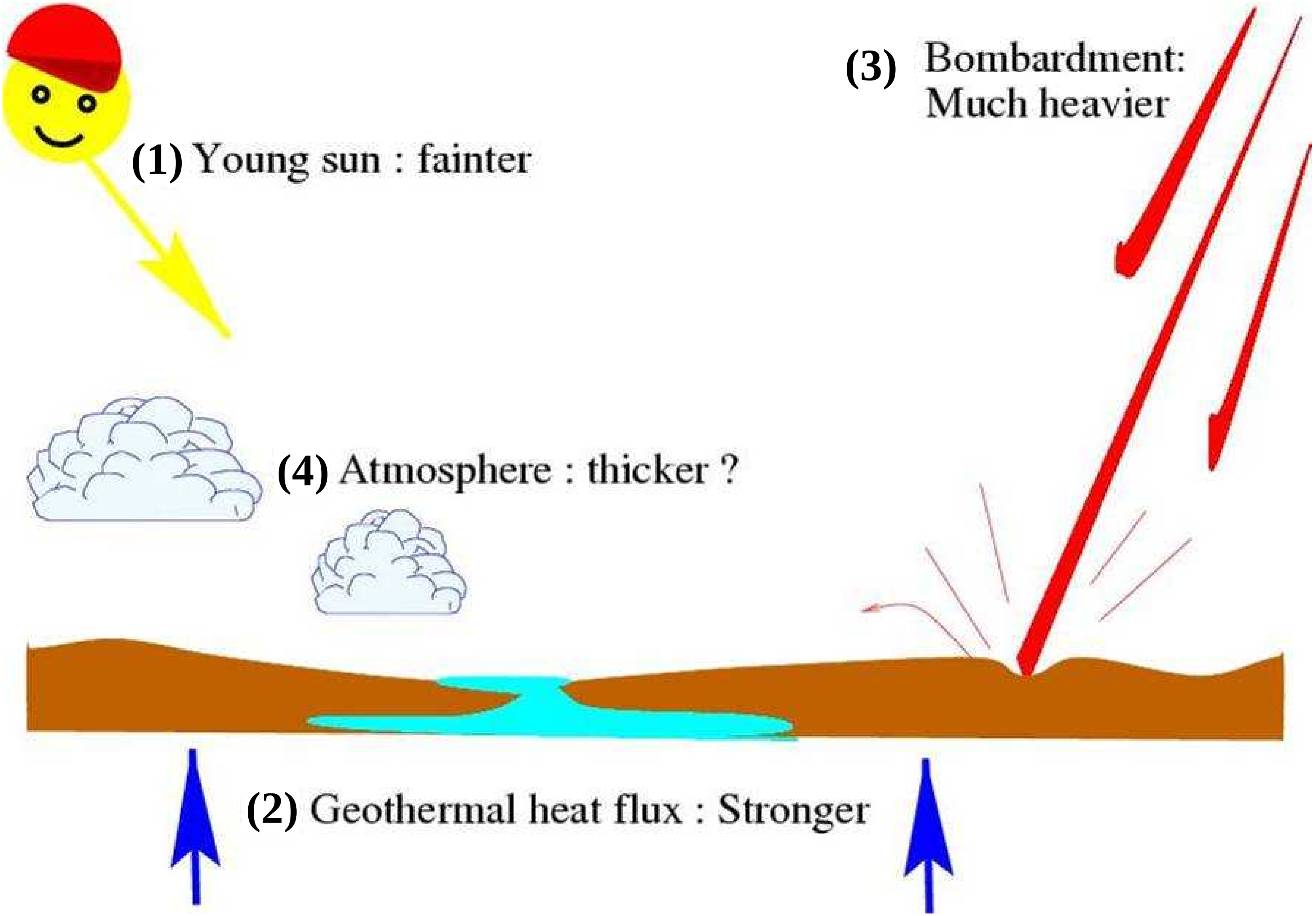


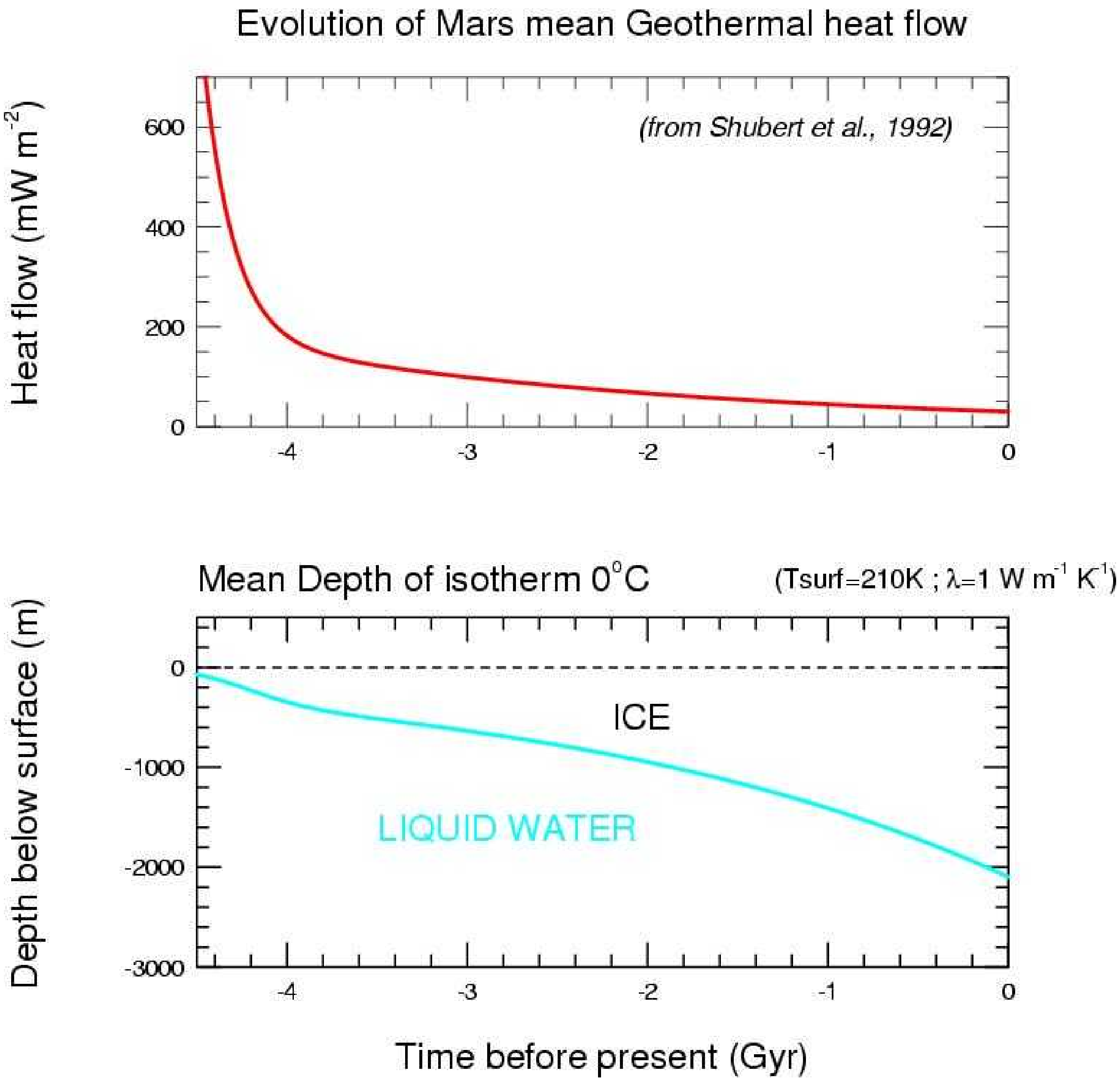


Evolution of Solar flux at Mars
Solar flux at Mars / present
1.2
1
.8
224 K
213 K
202 K
Equilibrium Temperature (Albedo=0.2)
Standart Sun model
(e.g. Gough 1981)
-4
-3
-2
-1
0
Time before present (Gyr)

Why was early Mars different ?

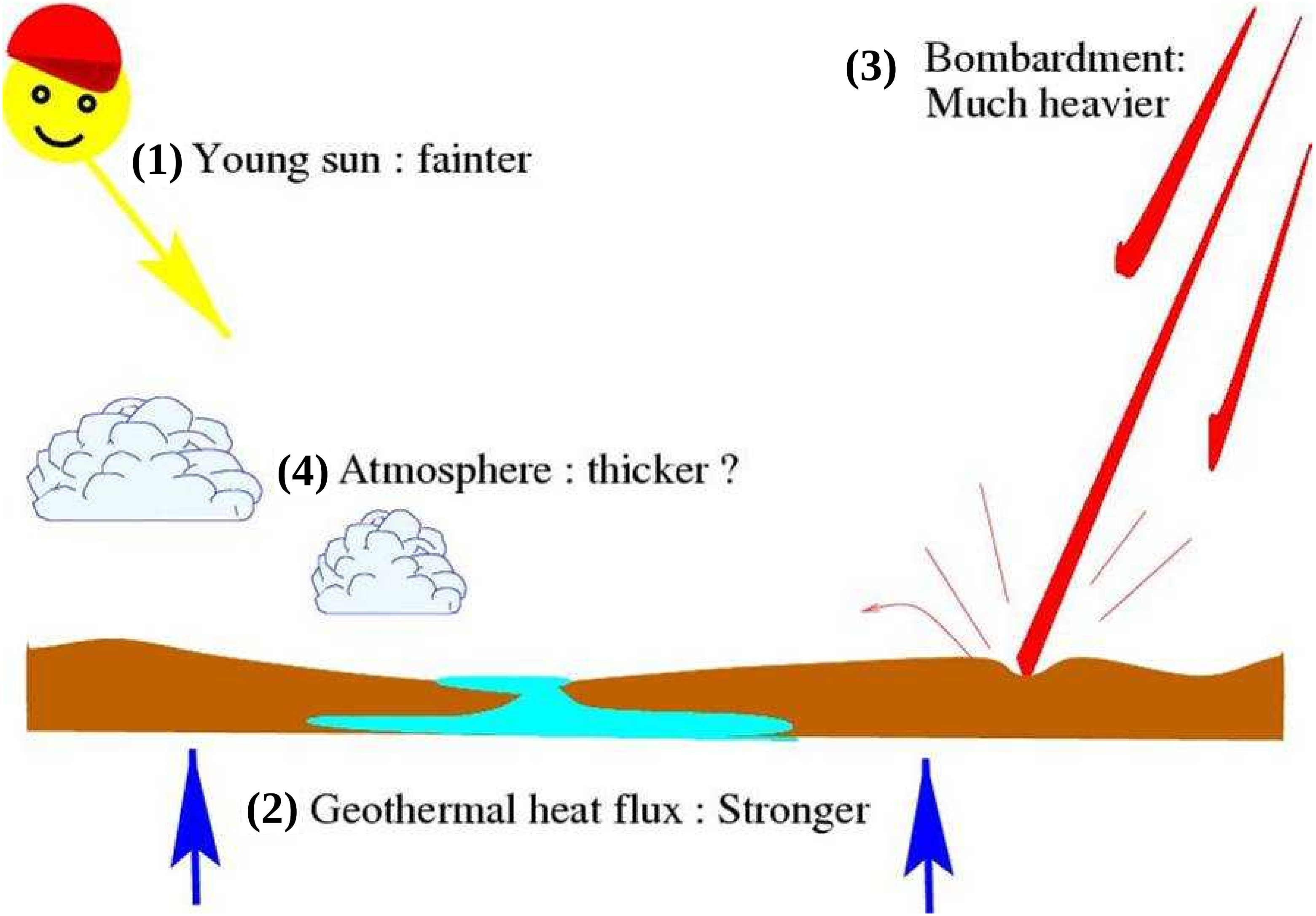
Different boundary conditions compared to present :




Evolution of Mars mean Geothermal heat flow
(from Shubert et al., 1992)
Heat flow (mW m^-2)
600
400
200
0
-4
-3
-2
-1
0
Mean Depth of isotherm 0°C
(Tsurf=210K ; λ=1 W m^-1 K^-1)
Depth below surface (m)
0
-1000
-2000
-3000
ICE
LIQUID WATER
-4
-3
-2
-1
0
Time before present (Gyr)

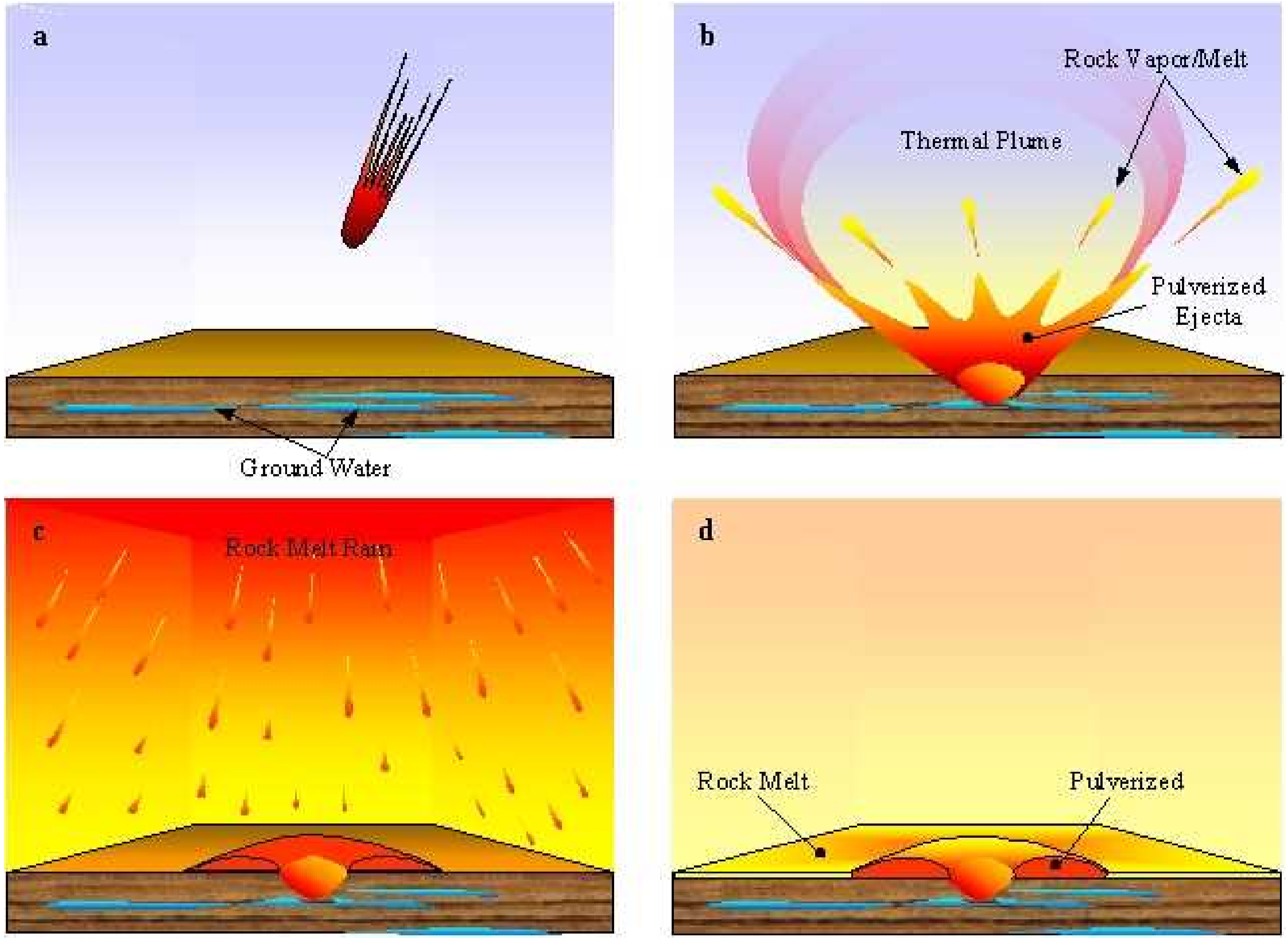
Why was early Mars different ?

Different boundary conditions compared to present :



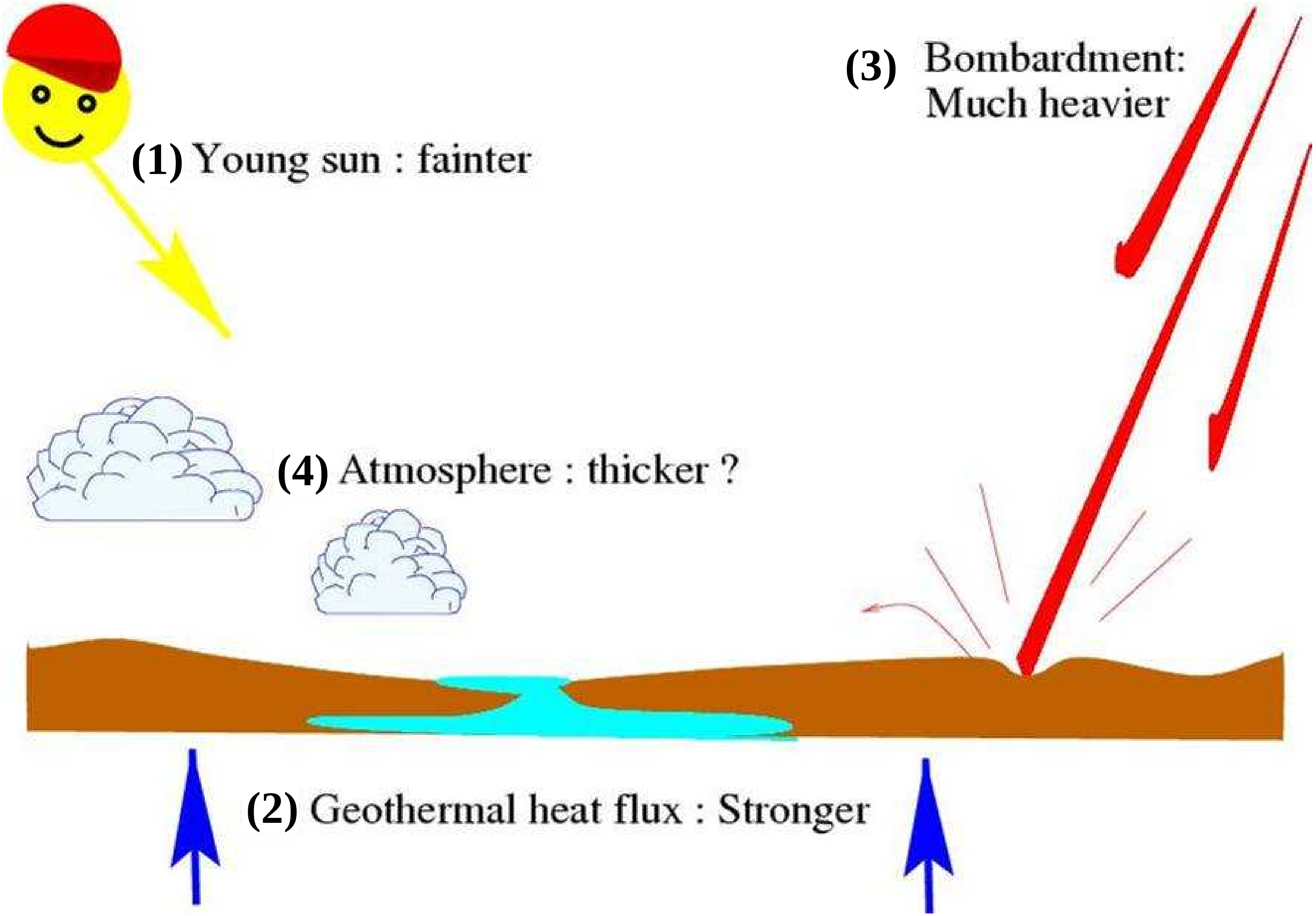
Simulation of Impact : episodic warming

Segura et al. 2004, 2008, Colaprete et al. 2005



Why was early Mars different ?

Different boundary conditions compared to present :



"Early Mars" climate simulations

⇒ **What would be the climate on a Mars-like planet with :**

- A thicker CO_2 atmosphere

  (500 mbars – 2 bars or more ?)

- A faint sun (75% present)

Classical studies : simple 1D model

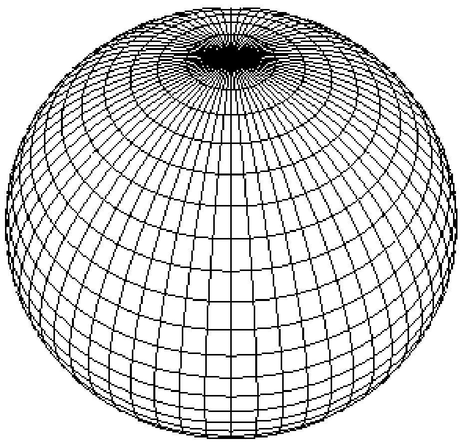
(Pollack et al. 1987, Kasting 1991, Forget and Pierrehumbert 1997, Mischna et al. 2000, Colaprete et al. 2002, etc...

Typical 1D results for a pure CO2 atmosphere, no clouds:

→ Global Annual mean temperatures :

CO2 pressure	Temperature
0.006 bar	-72ºC
0.1 bar	-61ºC
0.5 bar	-50ºC
2.0 bar	-41ºC

⇒ ***Recent results : full 3D Global Climate***



-**Challenge :** solve the **IR radiative transfer** :

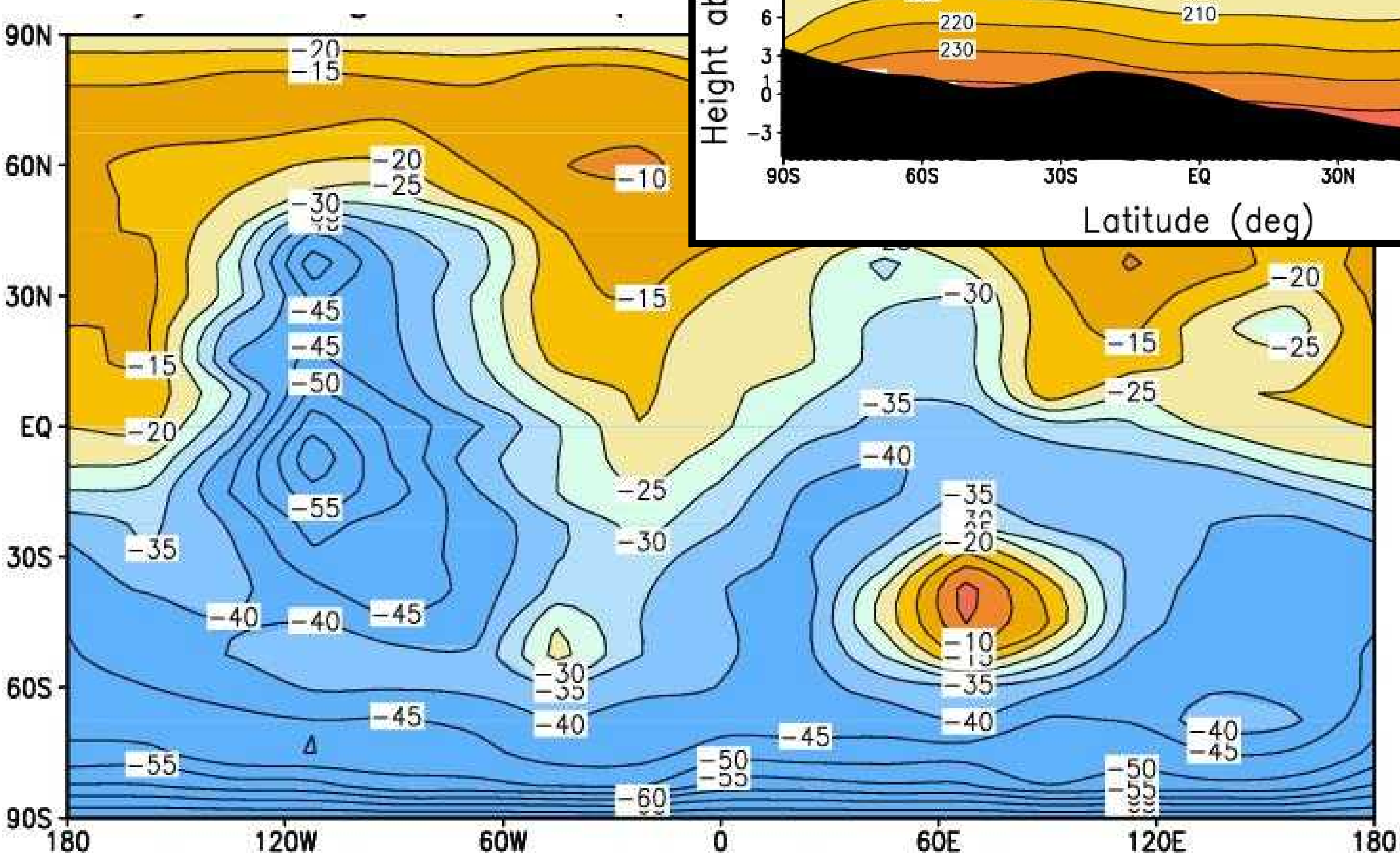
-Thick CO2 atmosphere

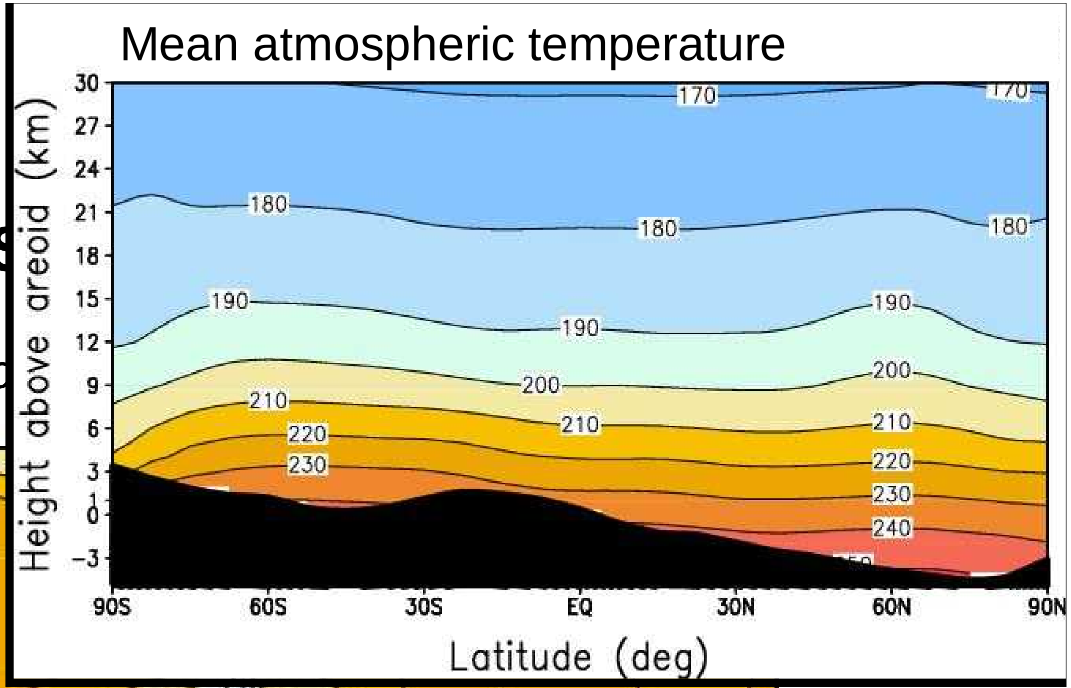
- poorly known collision induced absorptions
- Scaterring of thermal IR radiations

3D simul

Annual mean S

Faint sun Pur CO2 No cl





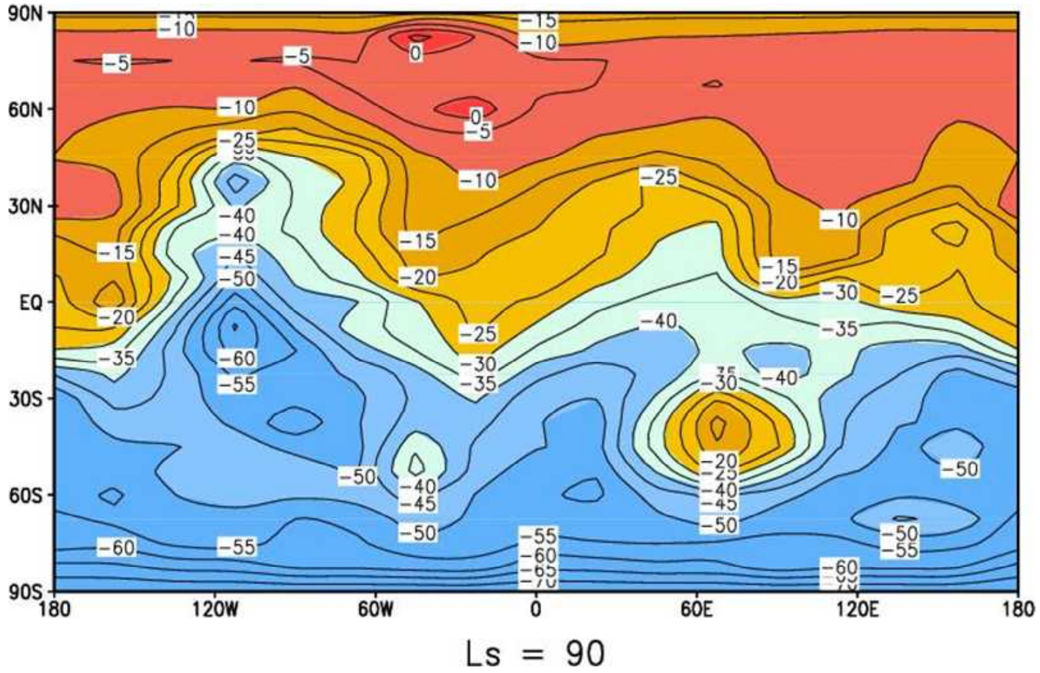
Forget et al. 2005

Diurnal Mean Surface Temperature (°C)

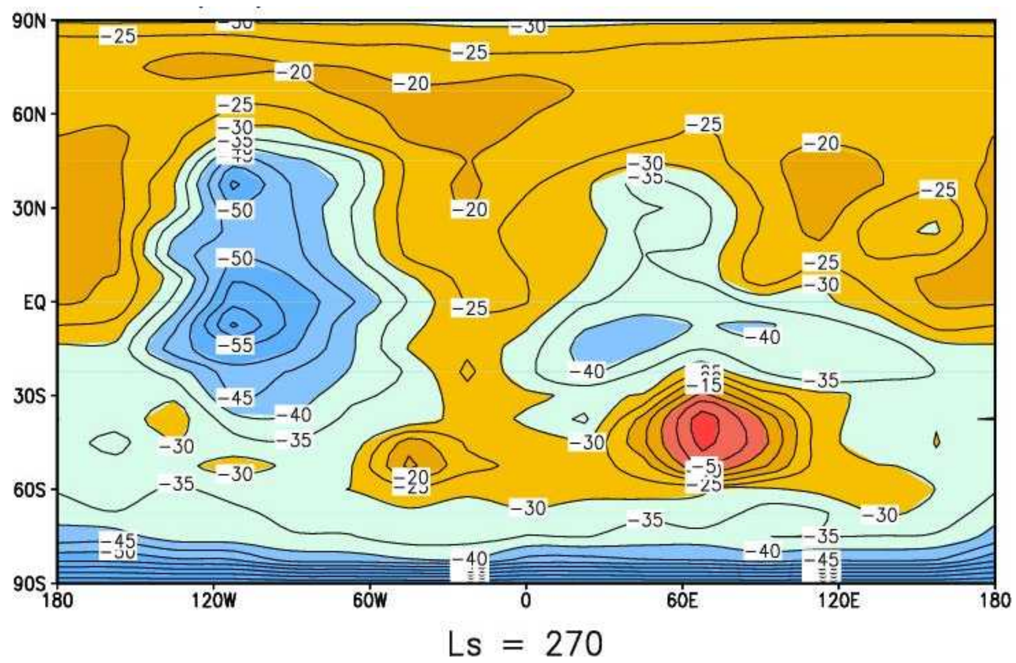
with <Ps>=2bars

Pure CO_2 gas, faint sun, excentricity=0°, current obliquity

Northern Summer



Southern Summer



The meaning of local surface temperature and liquid water :

(assuming pressure >> triple point of water)

- **Local Annual mean temperature > 0°C**
  ⇨ Deep ocean, lakes, rivers are possible
- **Summer Diurnal mean temperature > 0°C**
  ⇨ Rivers, lakes are possible and flow in summer, but you get permafrost in the subsurface.
- **Maximum temperature > 0°C** *(e.g. summer afternoon temperature):*
  ⇨ Limited melting of glacier. Possible formation of ice covered lake though latent heat transport ?

⇨***Examples of annual mean temperatures on Earth:***

Fairbanks (AK) : -3ºC

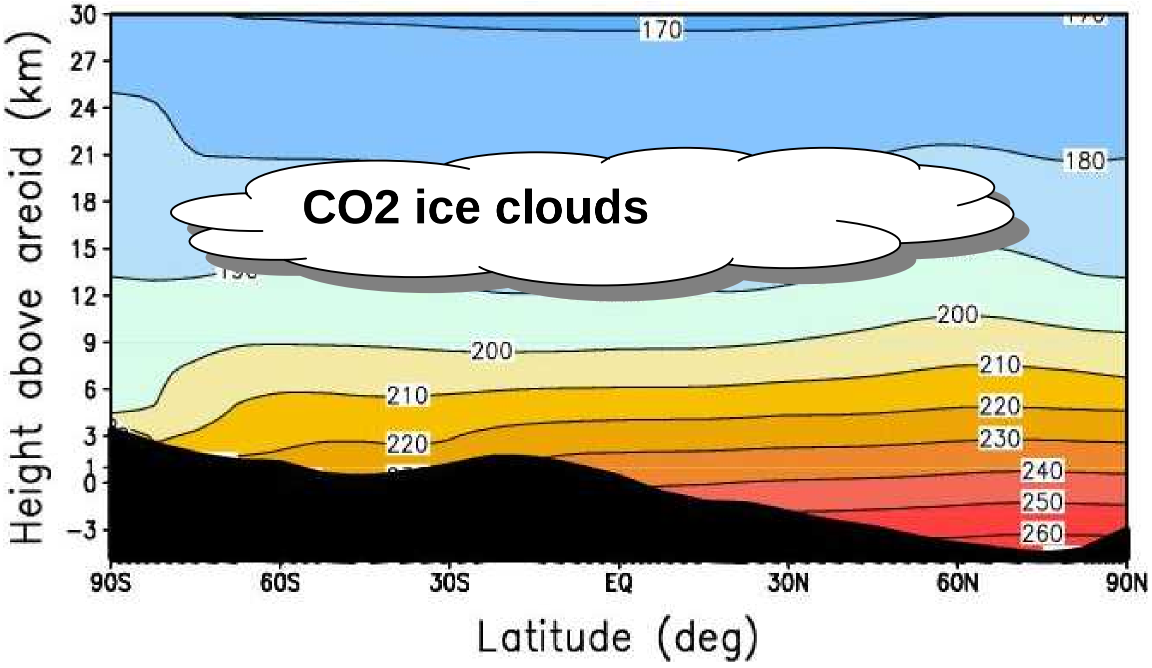
Barrow (AK) : -12ºC

Antarctica Dry Valley : -15ºC – -30ºC

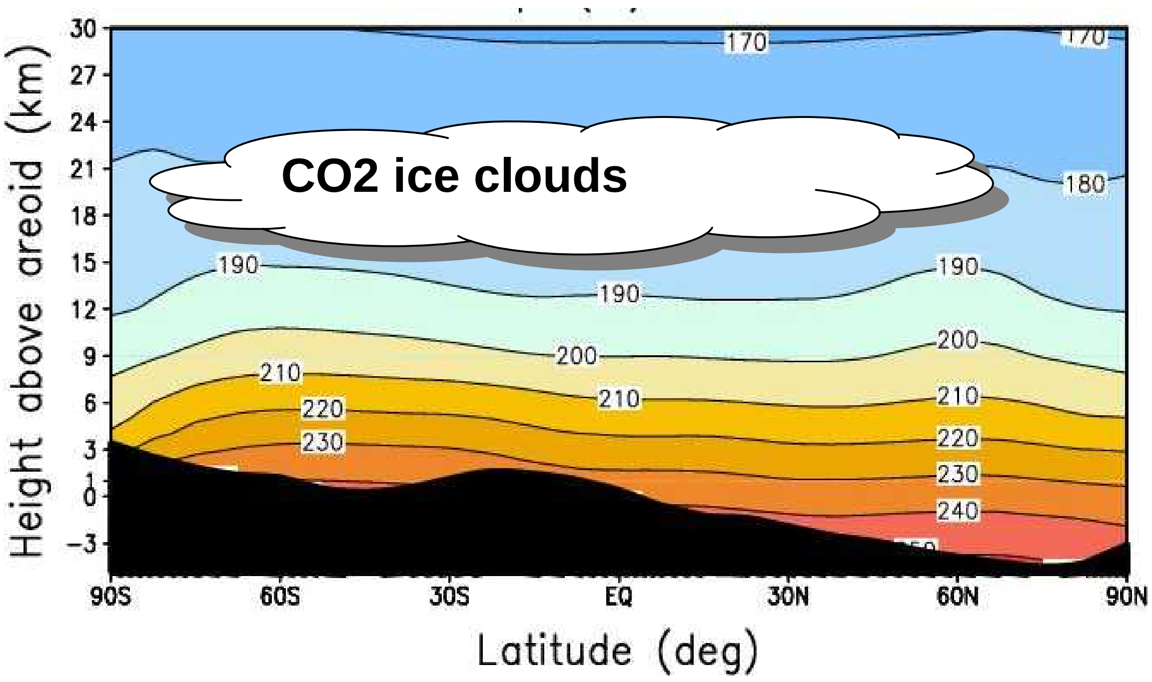
Zonal mean temperatures

- Atmosphère : 2bars CO_2
- Faint sun 75% present

Northern Summer



Southern Summer

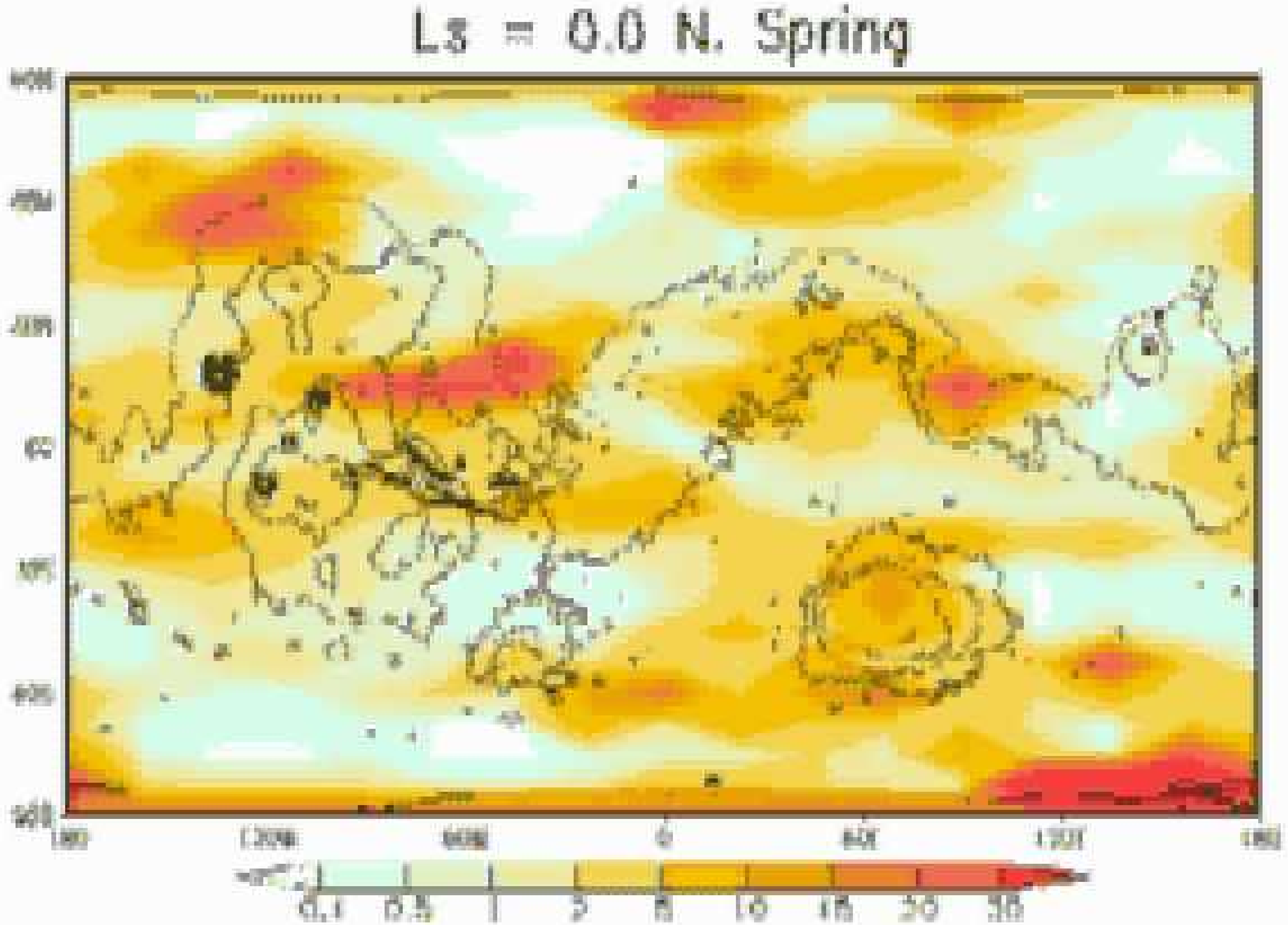


excentricity=0°, current obliquity

Simple CO_2 ice cloud scheme

1. In each model mesh: If T<Tcond : condensation and latent heat release $\Rightarrow$ T=Tcond
2. CO_2 ice is splitted in small particles (The number of particle / kg is prescribed)
3. Transport and mixing by winds, turbulence, convection
4. Gravitional sedimentation
5. Interaction with Solar and IR radiation (assuming Mie theory and Hansen et al. (1996) radiative properties
6. If T>Tcond : sublimation to get T=Tcond or no more ice

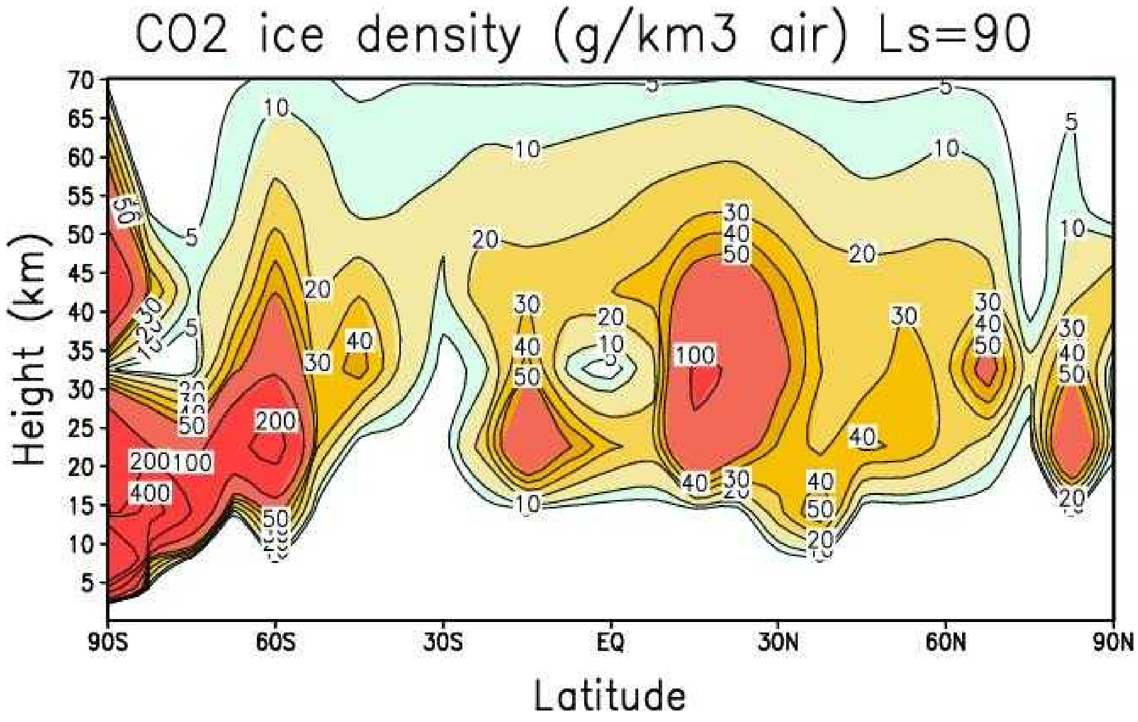
CO_2 ice clouds coverage (opacity) (mean Ps = 2 bar)

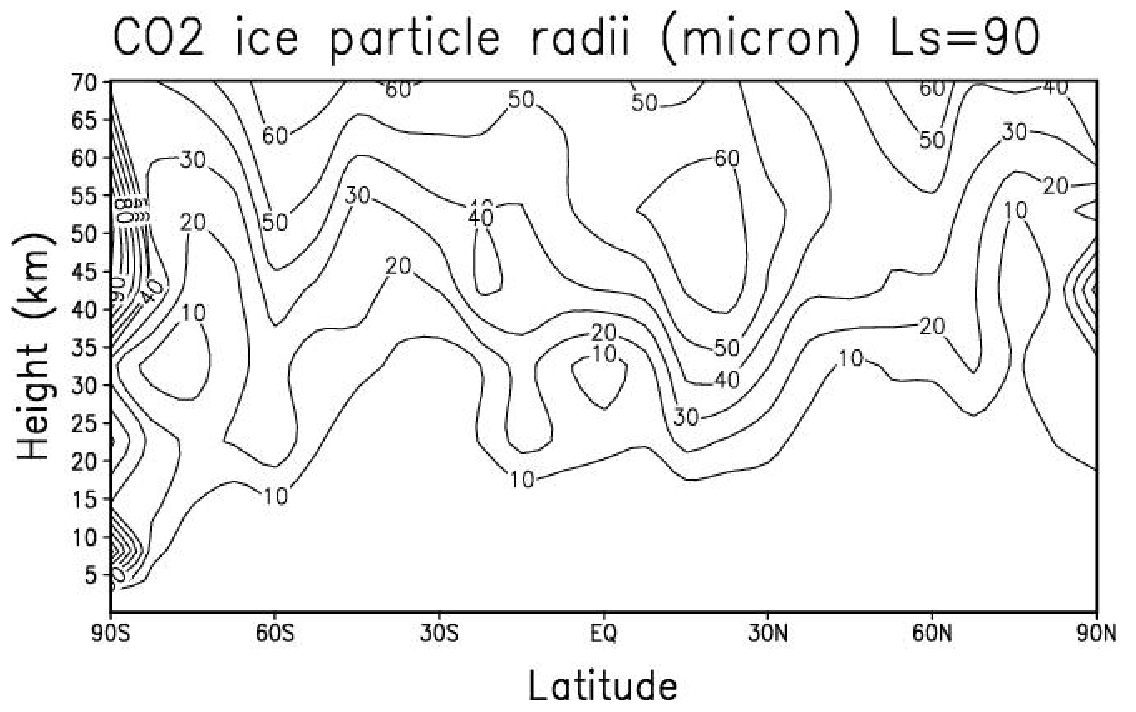


CO_2 ice opacity

CO2 ice clouds vertical structure

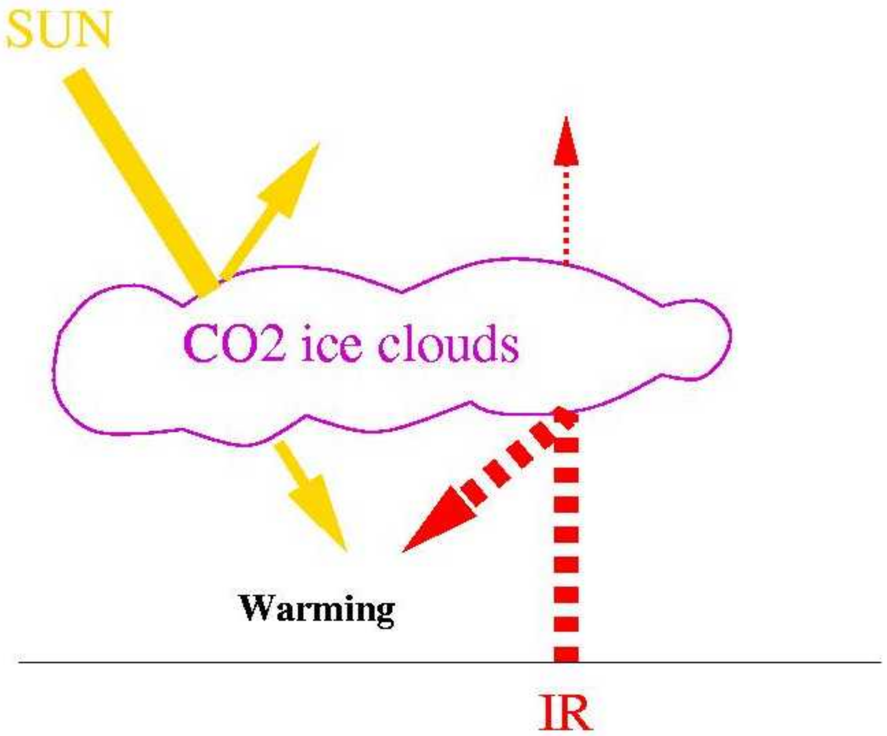
(example : Northern summer 10^5 particles/kg_{air})





Scattering Greenhouse effect of CO_2 ice clouds

Forget and Pierrehumbert, Science 1997

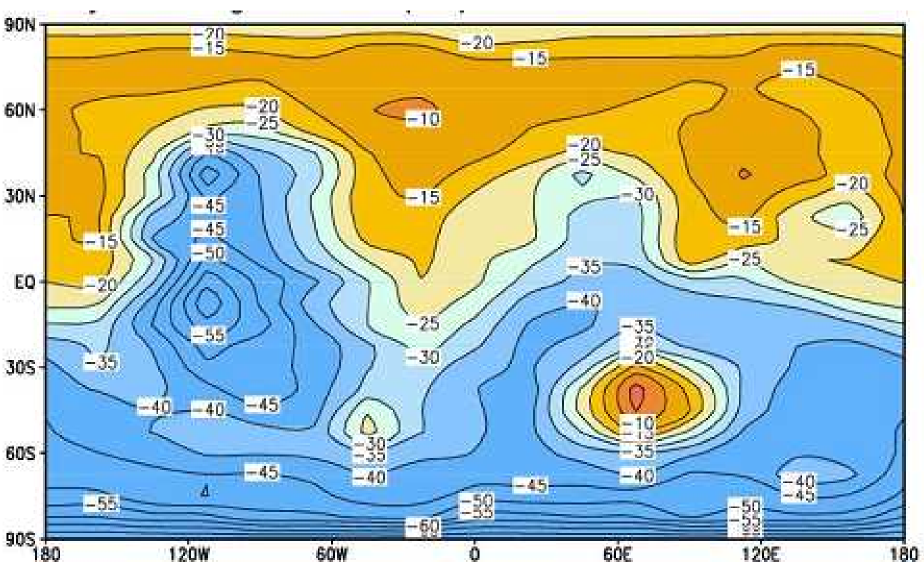


Impact of simulated CO_2 ice clouds scaterring greenhouse effect on surface temperature

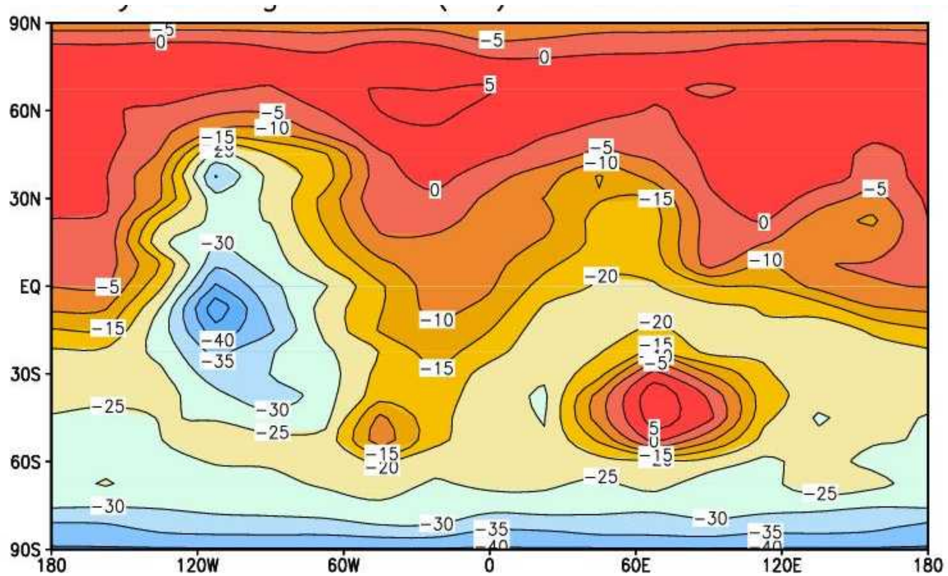
<Ps> = 2 bar

Annual mean Surface Temperature (°C)

WITHOUT CO_2 ice clouds



WITH CO_2 ice clouds

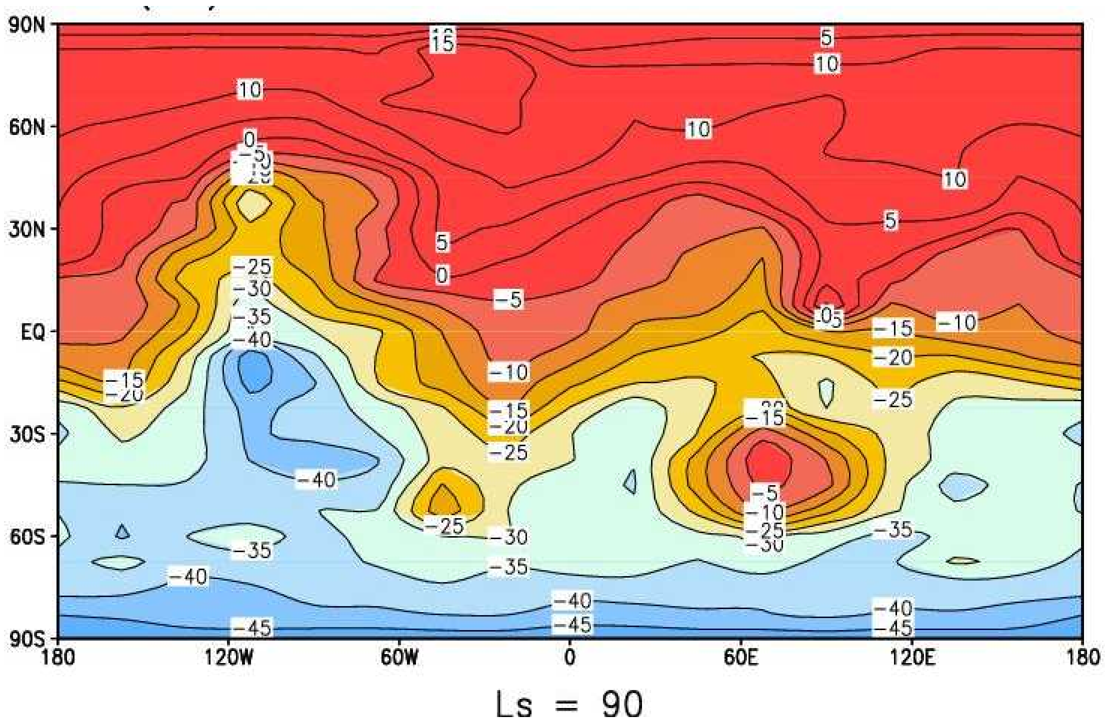


Diurnal Mean Surface Temperature (°C) with CO_2 ice clouds

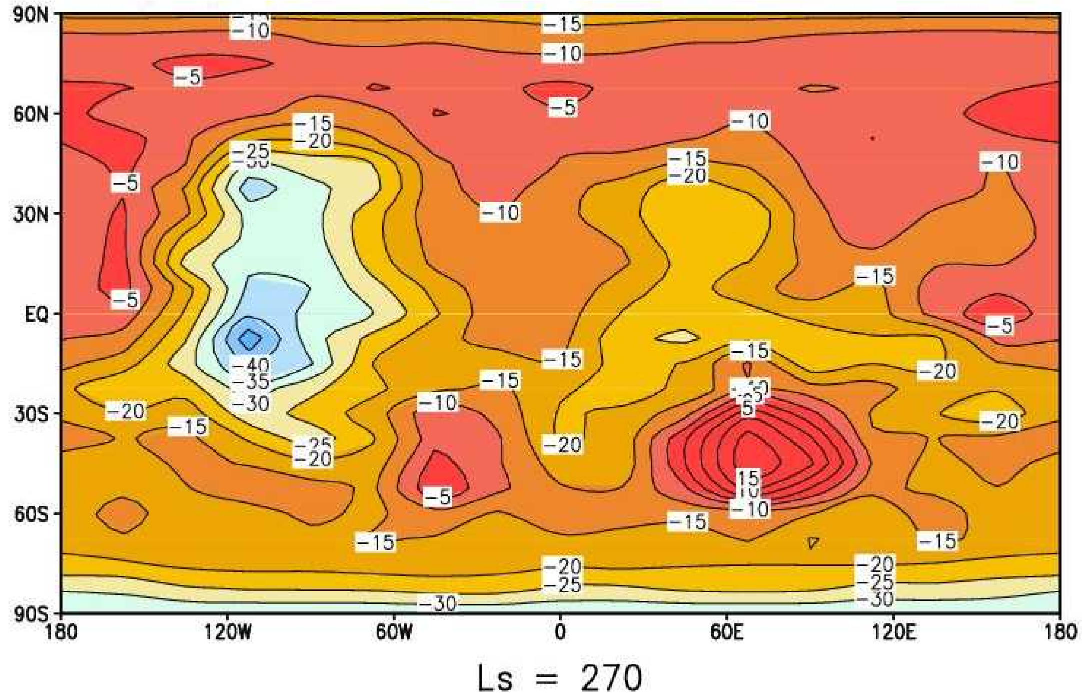
with <Ps>=2bars

Pure CO_2 gas, faint sun, excentricity=0°, current obliquity

Northern Summer



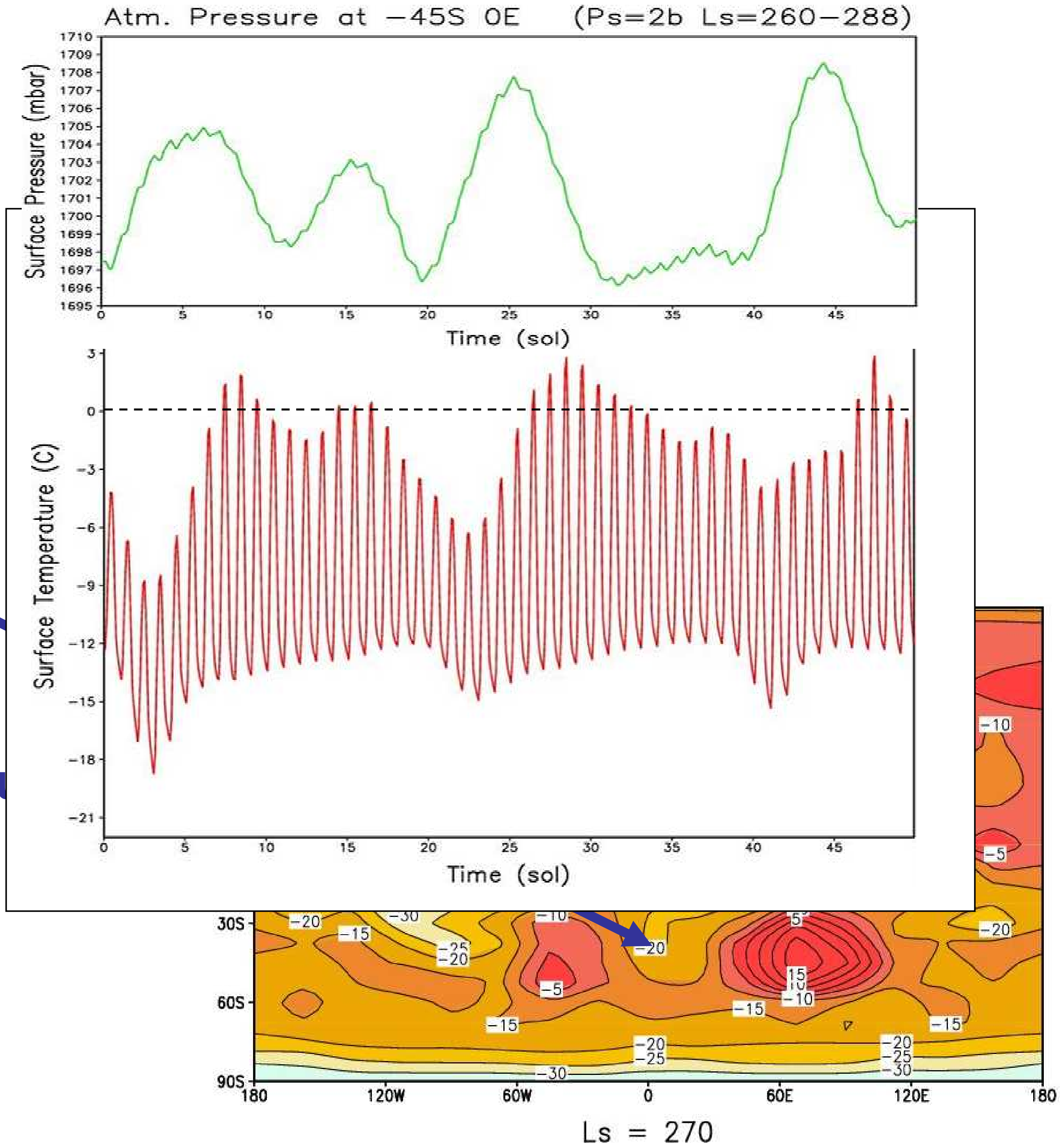
Southern Summer



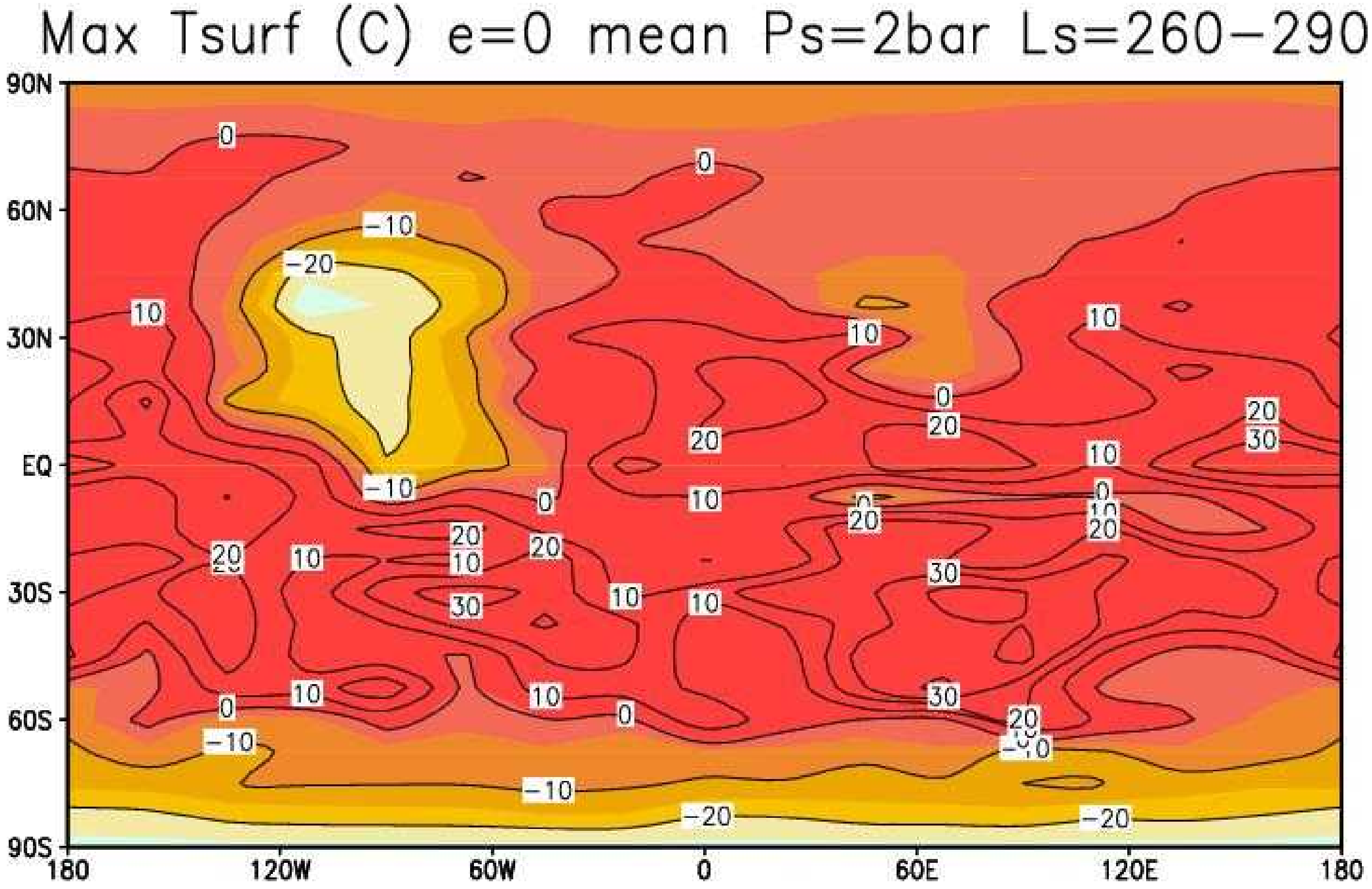
Note : Other orbital parameters do not allow to warm much…

45ºS 0ºE

Southern Su



Maximum surface temperature during southern summer (ºC)



At other surface pressures

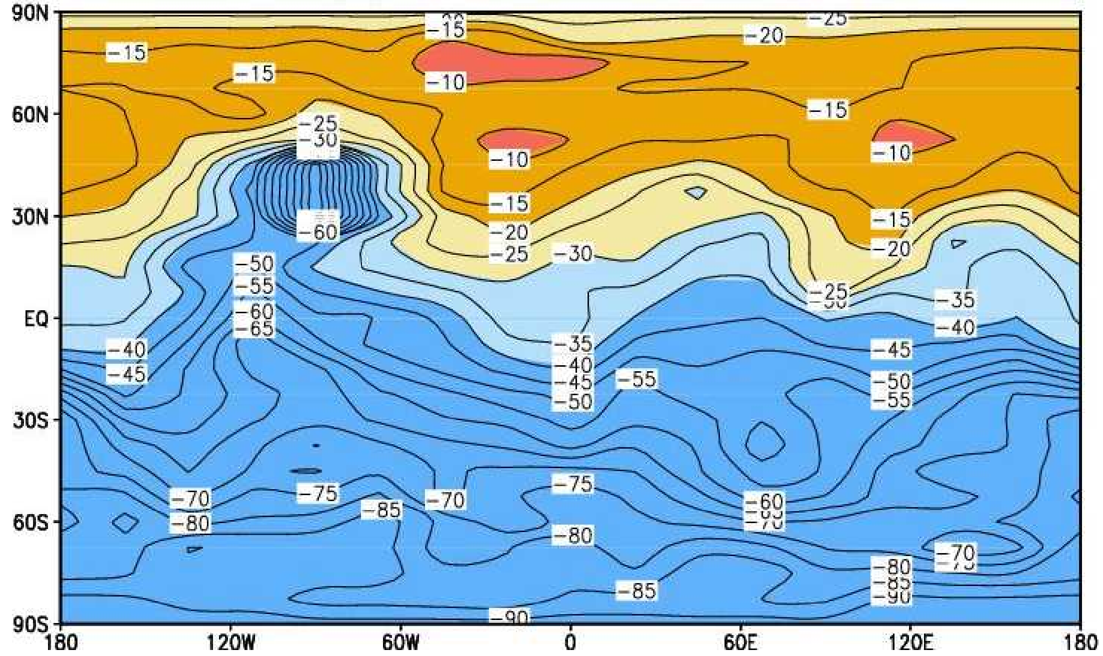
– 2 bars
– *0.5 bars*

Diurnal Mean Surface Temperature (°C) with CO2 ice clouds

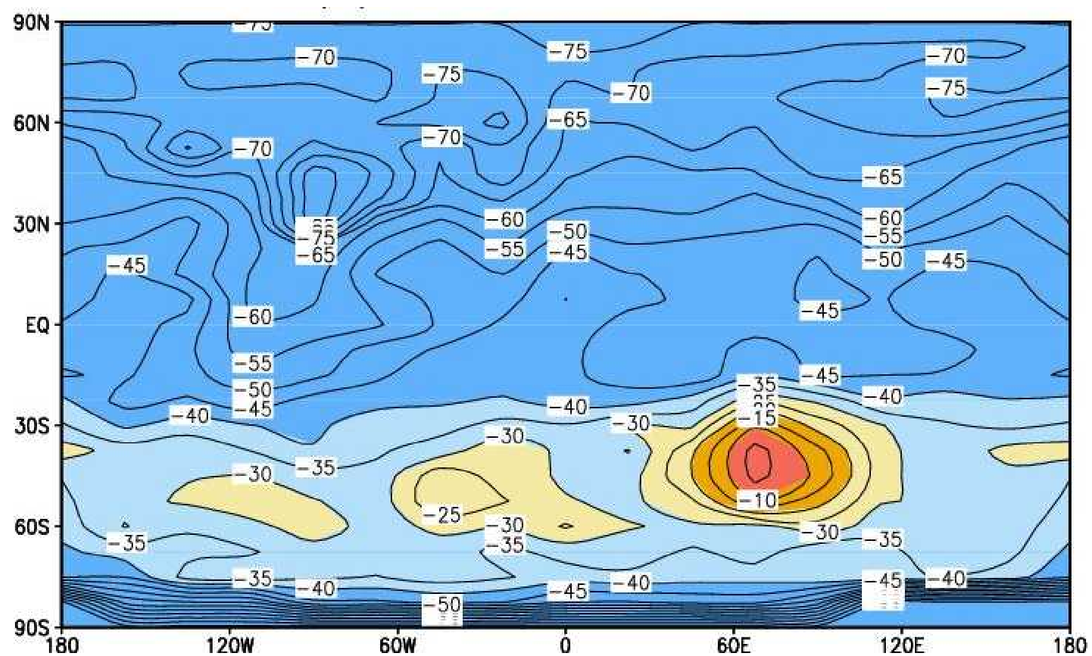
with <Ps>= **<u>0.5 bars</u>**

Pure CO2 gas, faint sun, excentricity=0°, current obliquity

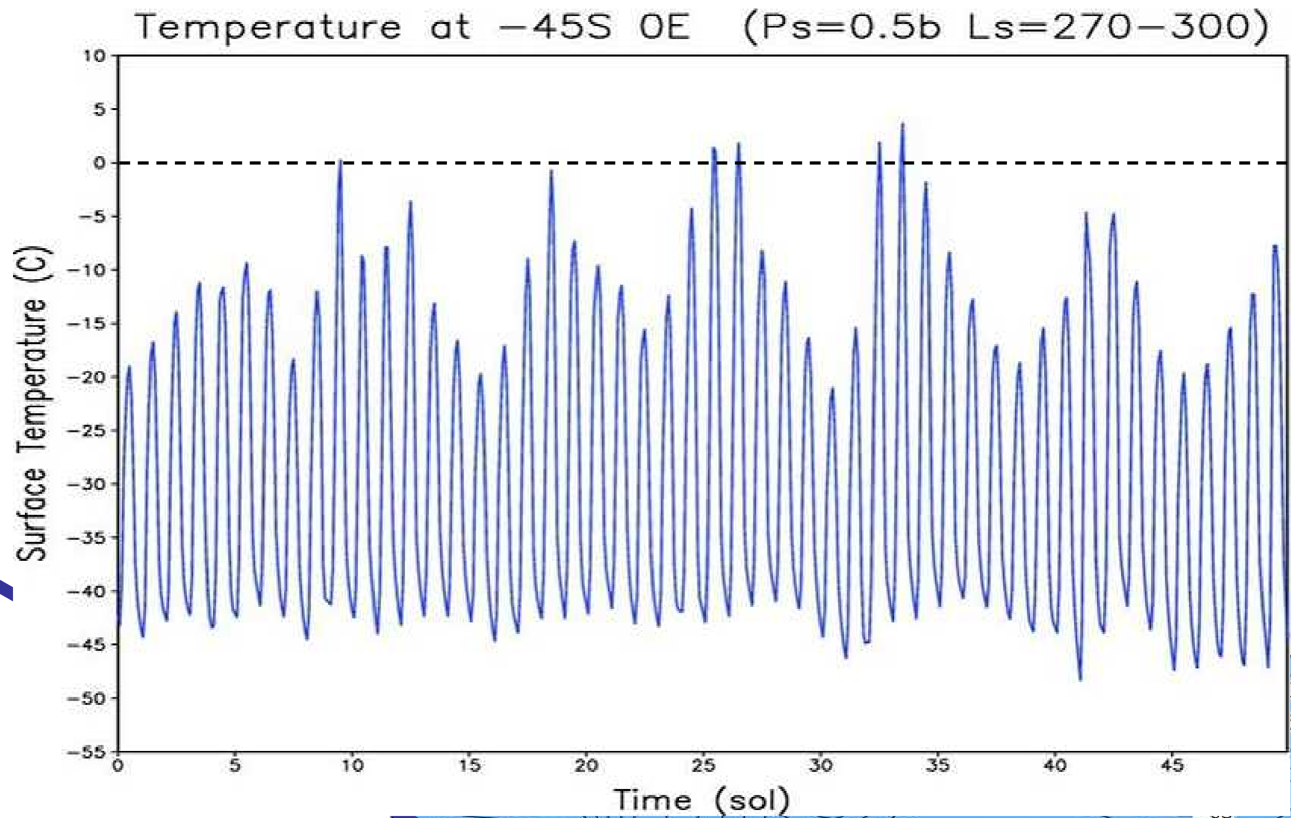
Northern Summer



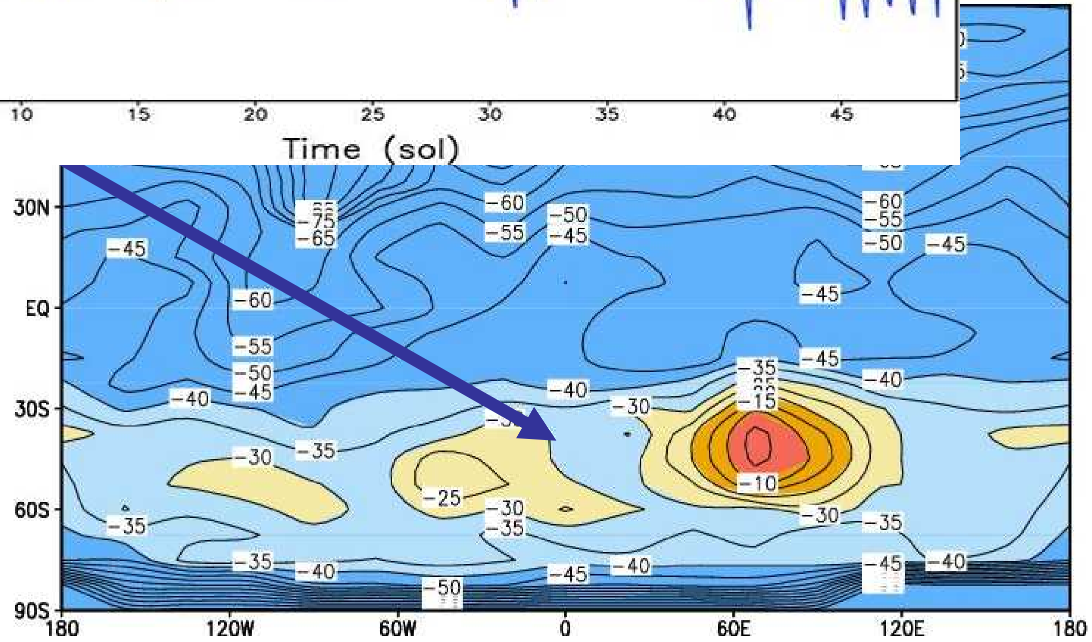
Southern Summer



45ºS 0ºE

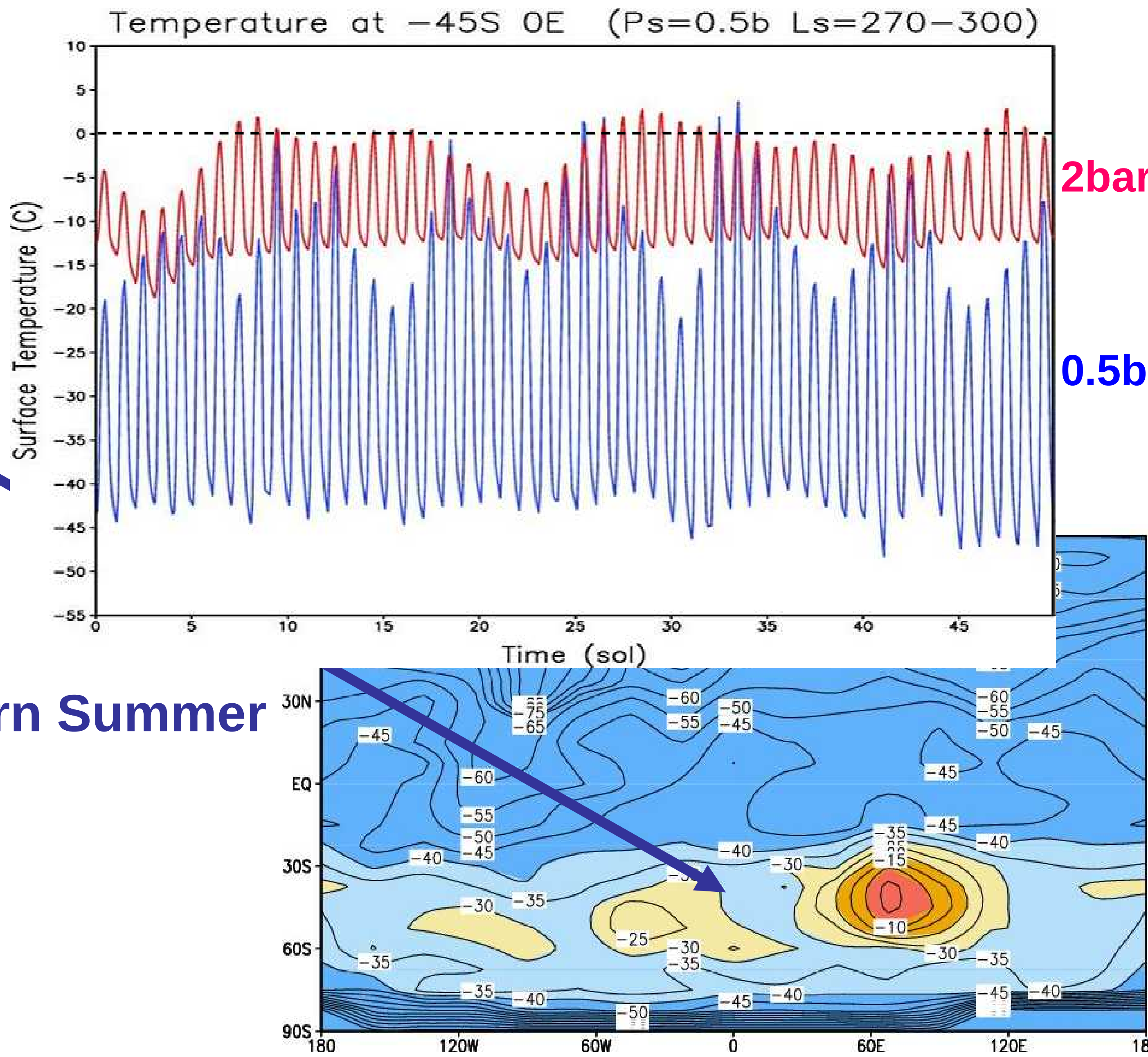


Southern Summer



45ºS 0ºE

Southern Summer



2bars

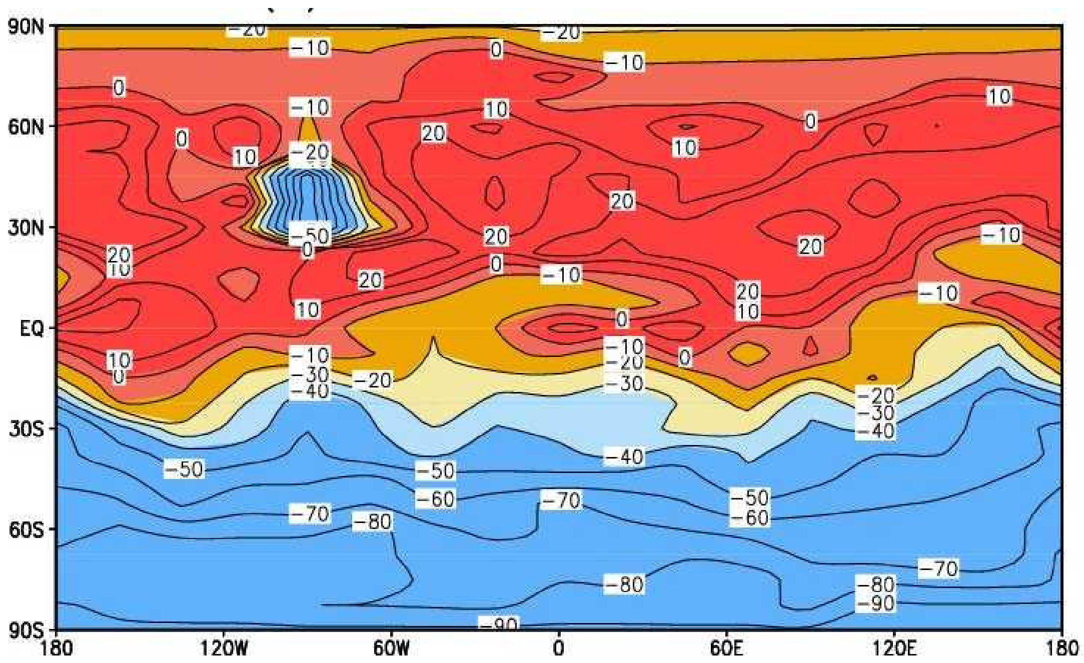
0.5bars

MAXIMUM Surface Temperature (°C) with <Ps>=2bars

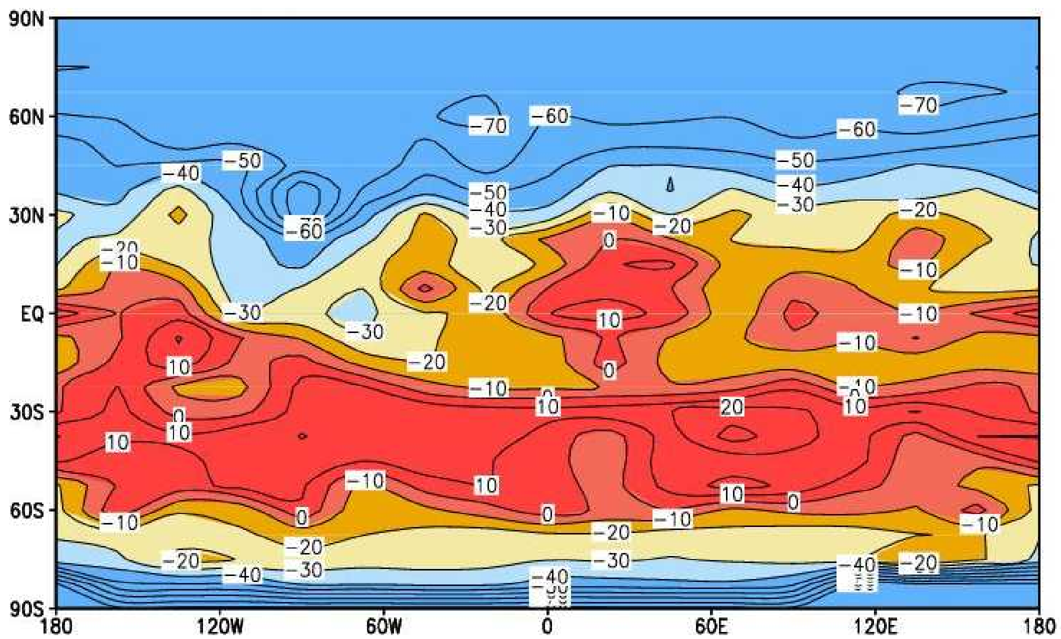
with CO_2 ice clouds

Pure CO_2 gas, faint sun, excentricity=0°, current obliquity

Northern Summer



Southern Summer



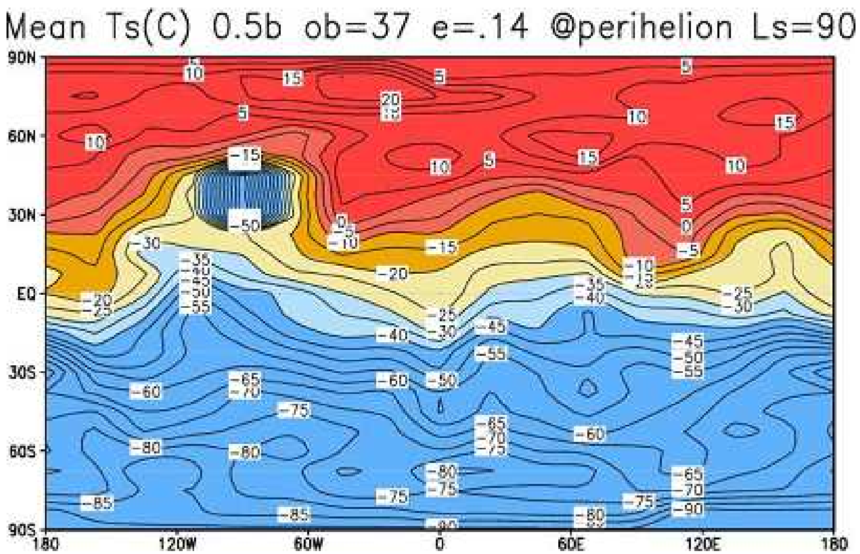
Case of favorable orbital parameters with Ps = 0.5 bars

Maximum excentricity (e=0.14)

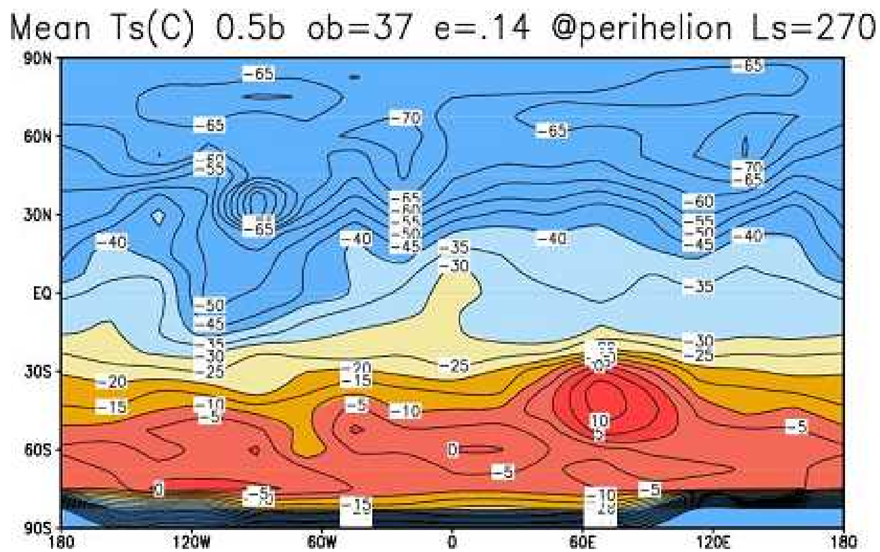
“high” obliquity = 37.62 (average Mars obliquity)

(Laskar et al. 2004)

Daily mean surface temperature

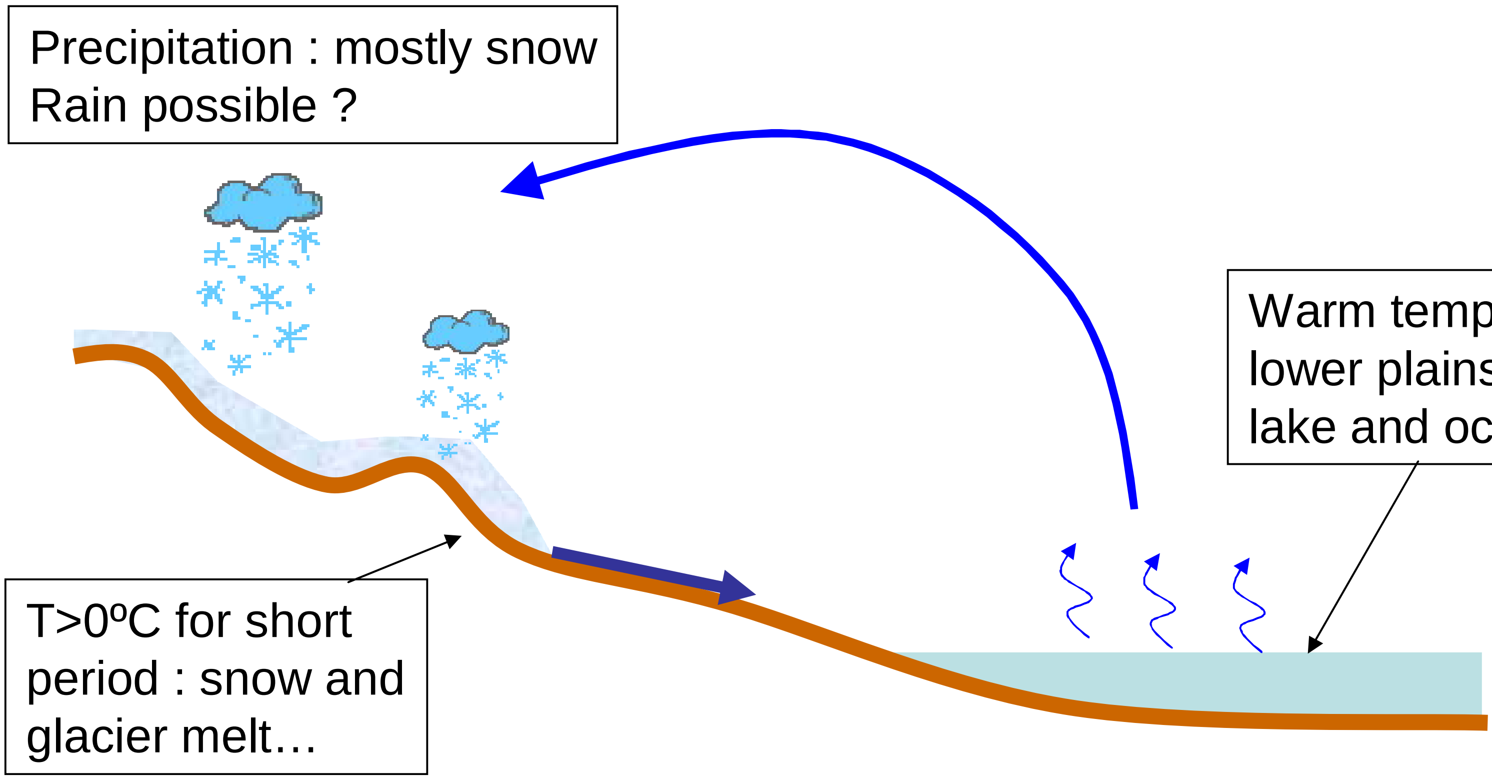


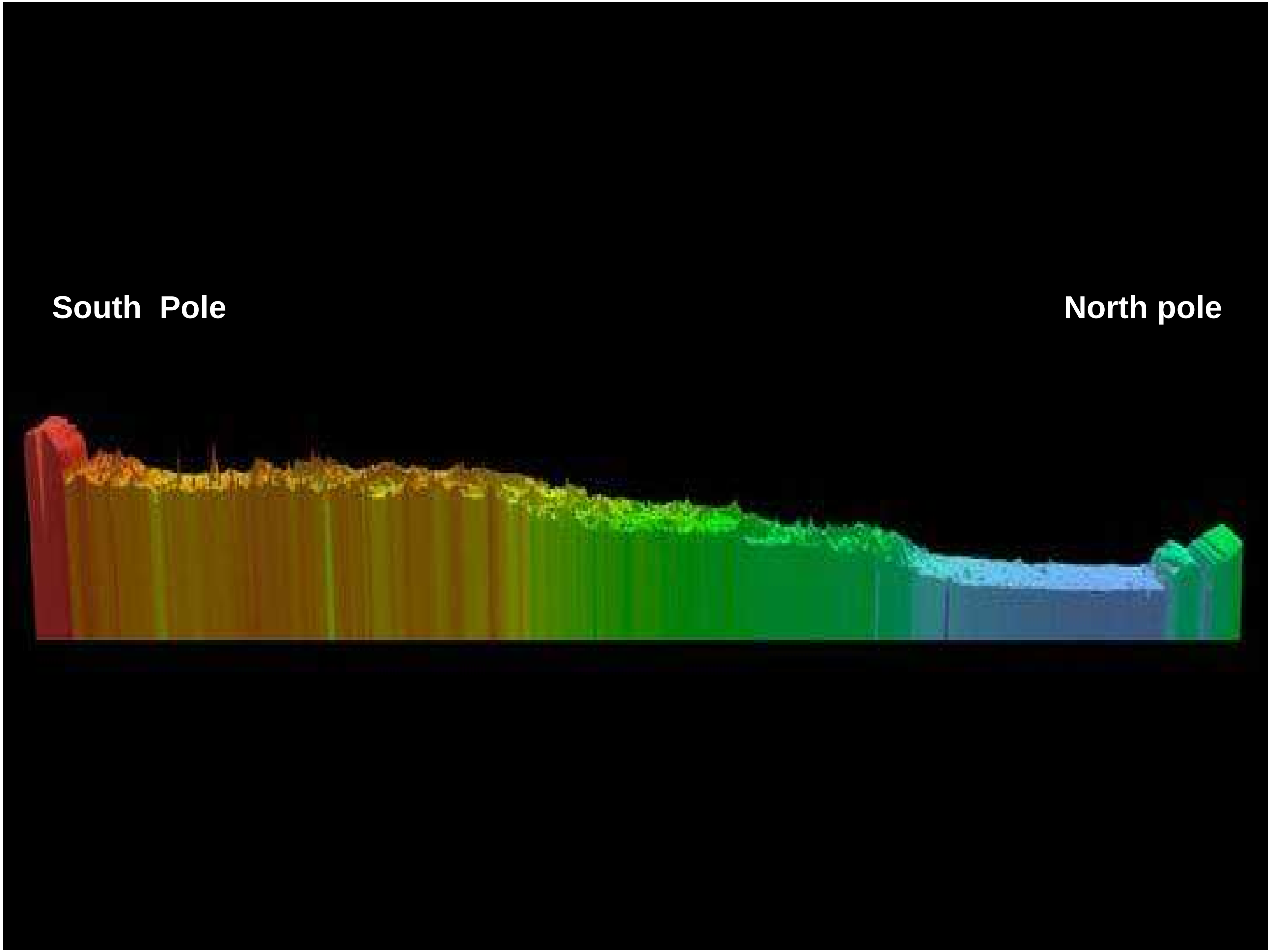
Northern summer



Southern summer

Speculation : the water cycle on this early Mars




South Pole
North pole

Dorsa argentea :
Remnant of an
hesperian
massive
Ice cap built with
a thicker
atmosphere ?

Head et al. 2007

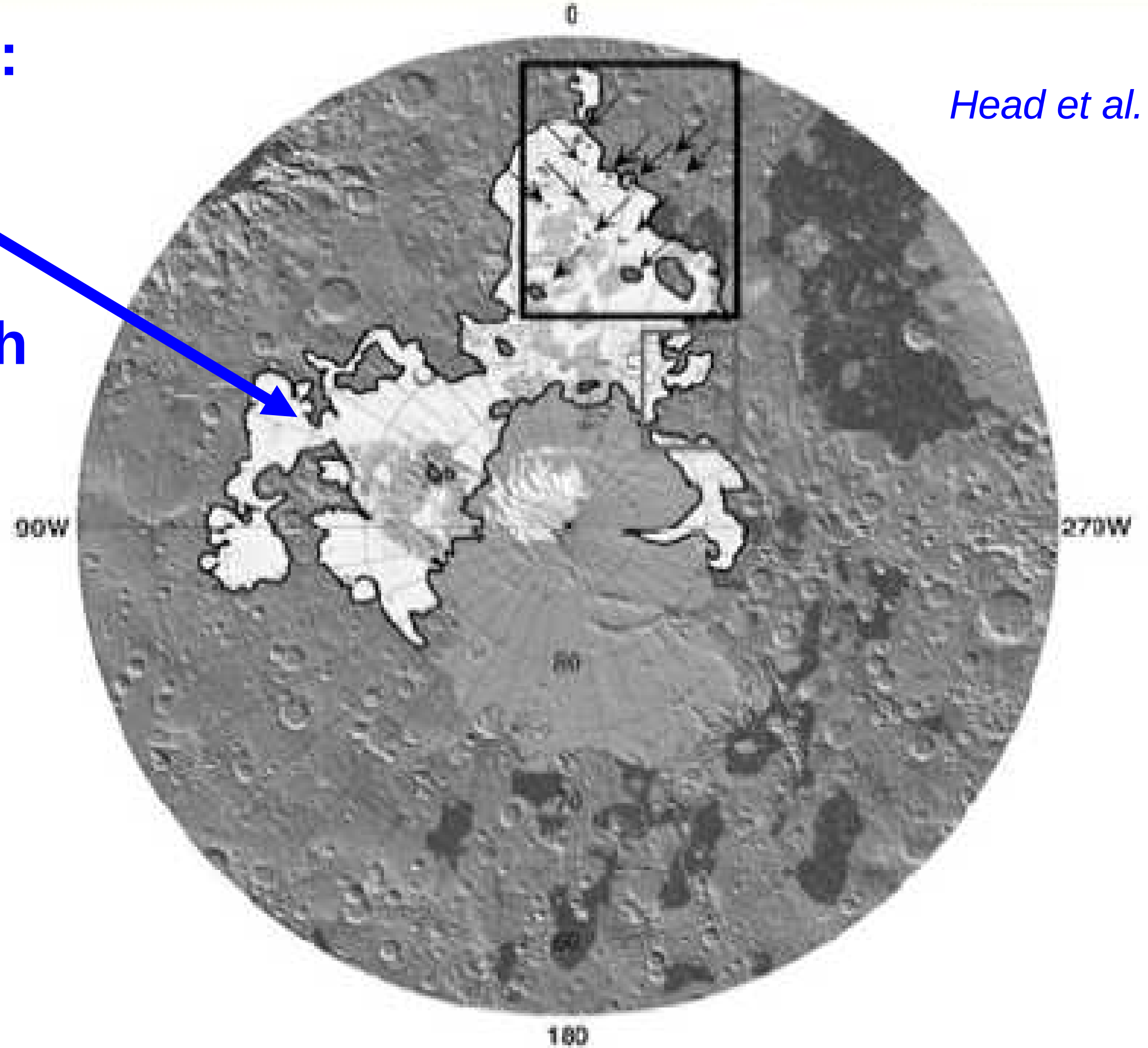
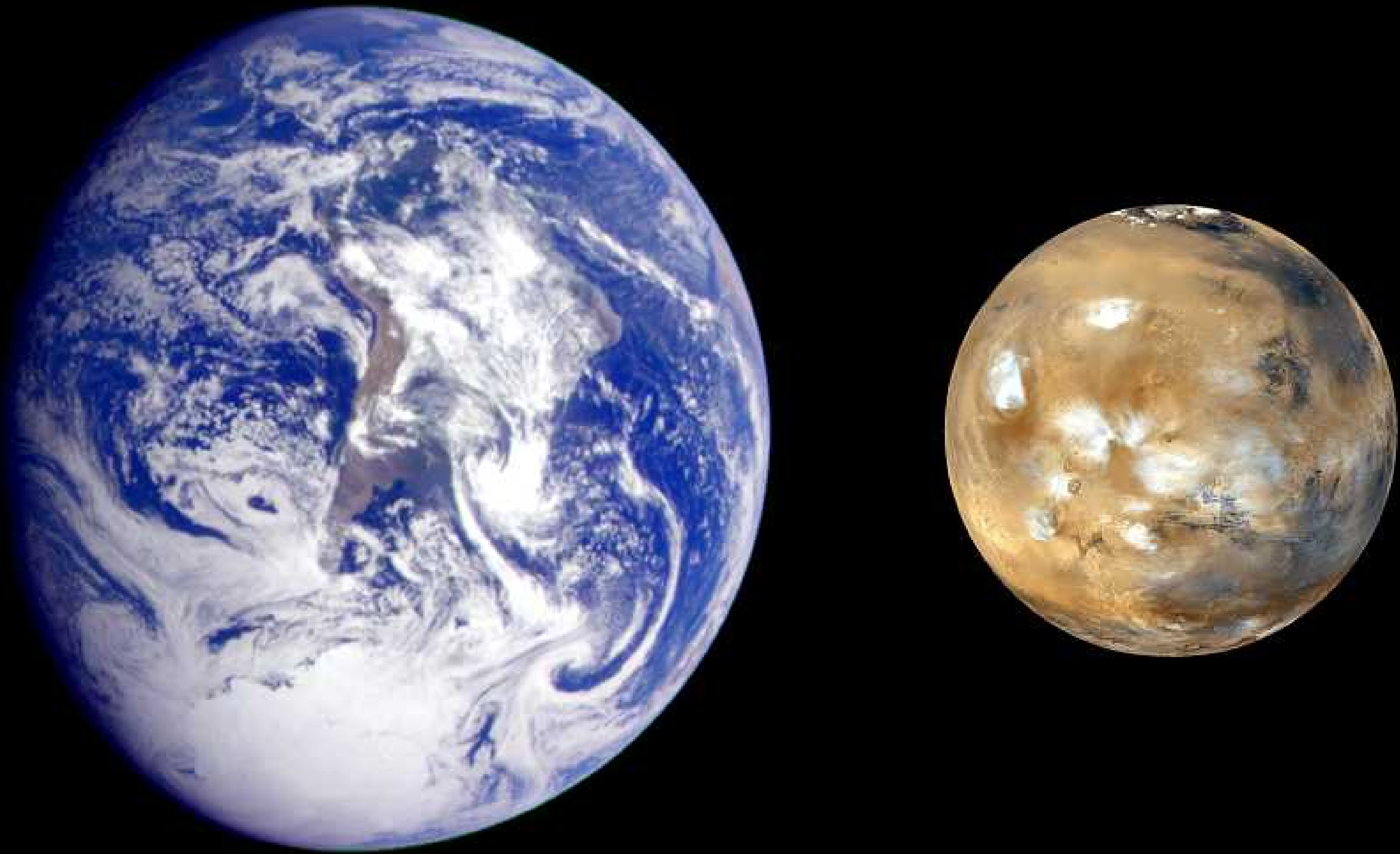


Fig. 1. Geological map of south polar region showing SPLD (smooth gray), the underlying DAF (white and light gray), Hesperian ridged plains (black) and the Noachian cratered terrain (rough gray); boxes show location of volcanoes [19] and marginal melting [23].

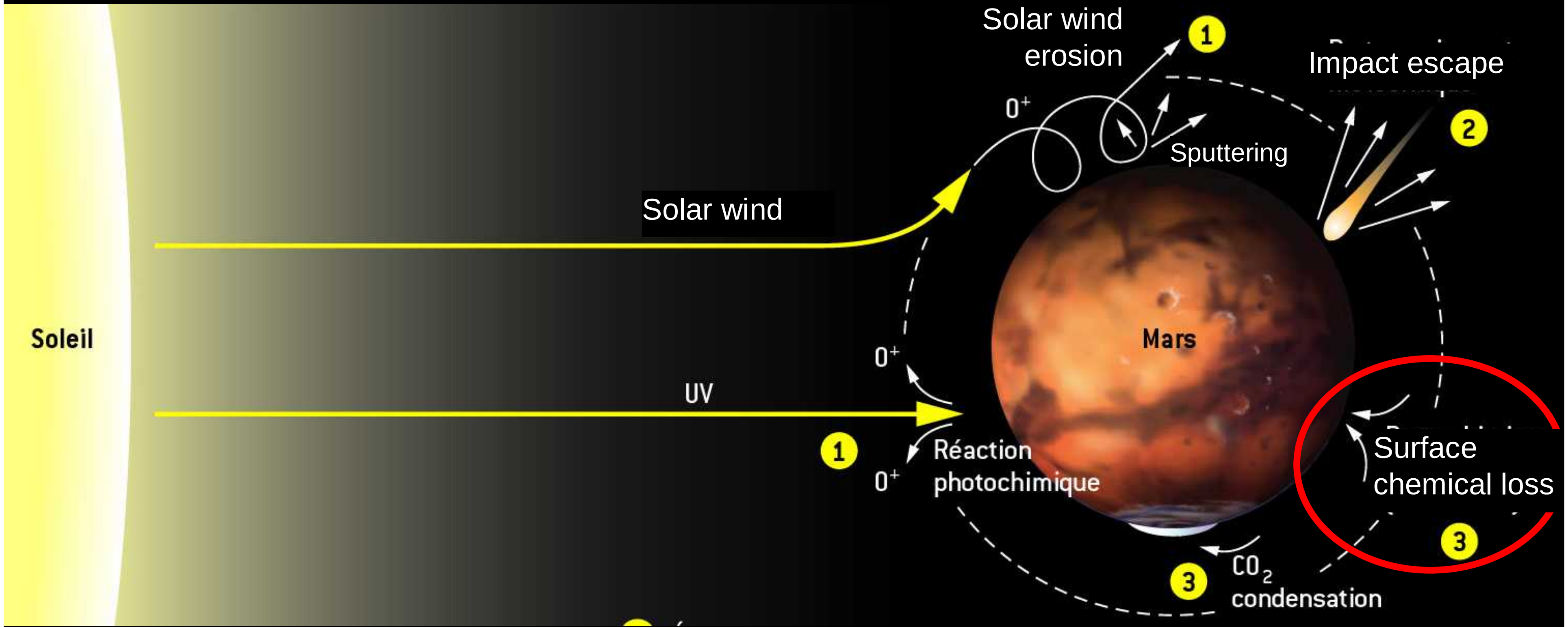
Still many issues with theearly Mars climate enigma

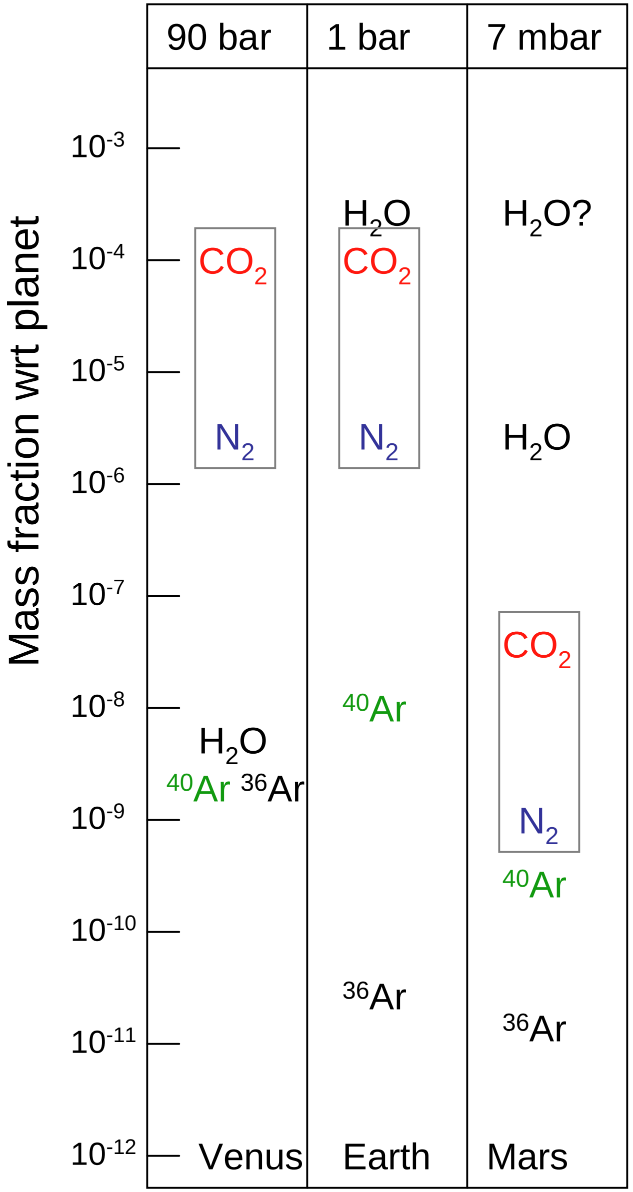
- CO2 gas Greenhouse effect lower than expected because of spectroscopic issues (Collision Induced absorption; *Wordsworth et al. 2010*)
- Other Greenhouse gases at work ? e.g. H2S and SO2 (e.g. *Johnson et al. 2008, 2009*). Most possible gases are photochemically short-lived, however.thick,
- cold, dry CO2 atmospheres may be photochemically unstable with respect to conversion to CO. (*Zahnle et al. 2008*)
- …..

Why did Mars follow a path so diferent than the Earth ?



Why did Mars lose most of its atmosphere ?





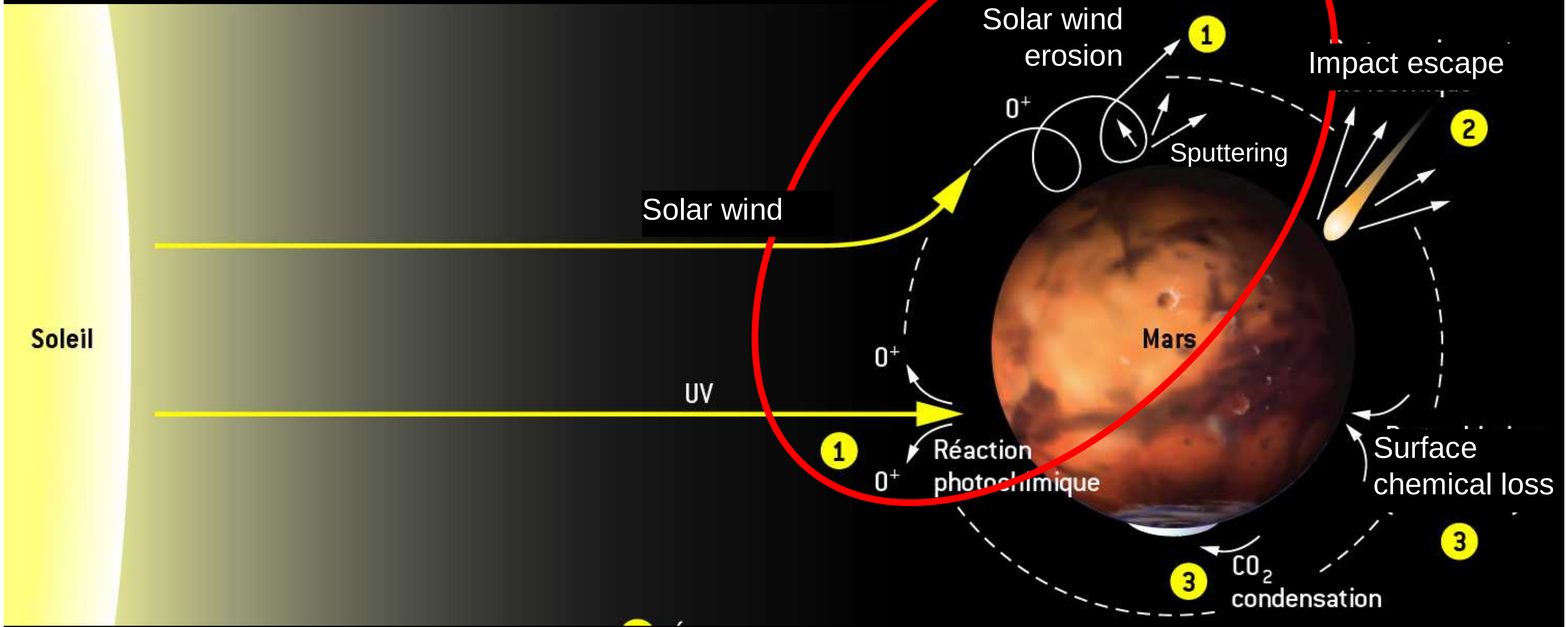
The fate of Mars atmosphere : clues in the Volatile inventory of terrestrial planets

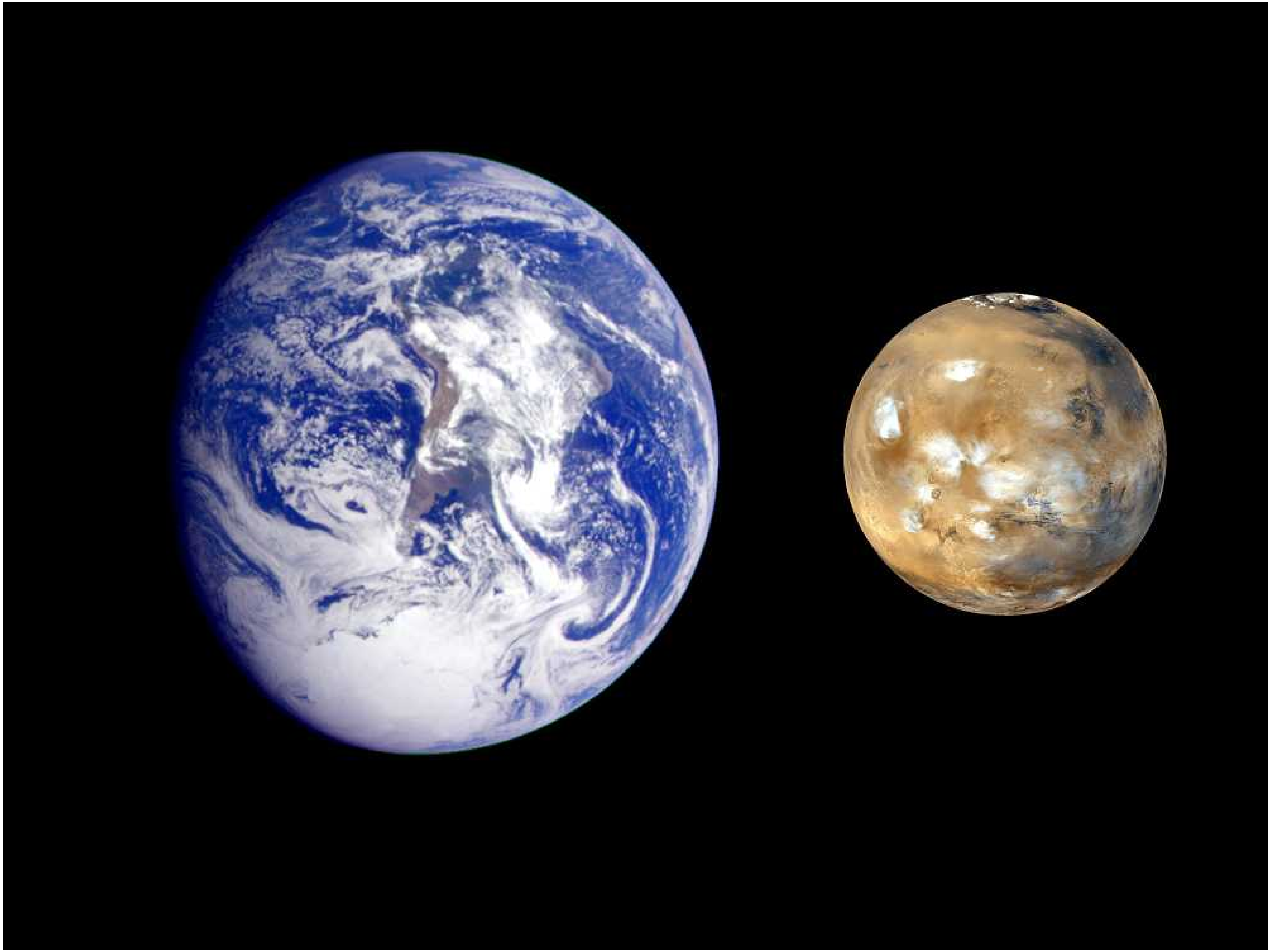
- Martian CO_2 and N_2 are similarly depleted by a factor 3000 with respect to Earth and Venus : probably not coincidental.
- N_2 does not easily form nitrates : good candidate for escape.
- Most of CO_2 should have escaped.

- ^{40}Ar : depletion by a factor 30 only : probably due to later outgassing (because radiogenic).

Chassefiere 2005

Why did Mars lose most of its atmosphere ?





- Thank you
- **どうもありがとうございました**

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- **フランソワ フォルジェ**, **フランソワ コスタール**, **フィリップ ロニョーネ**, **水谷 仁**, 2009: **火星・赤い惑星の**46**億年史--火星の科学入門最新版**, **ニュートンプレス**.