Mars Climates: Early & present-day Mars

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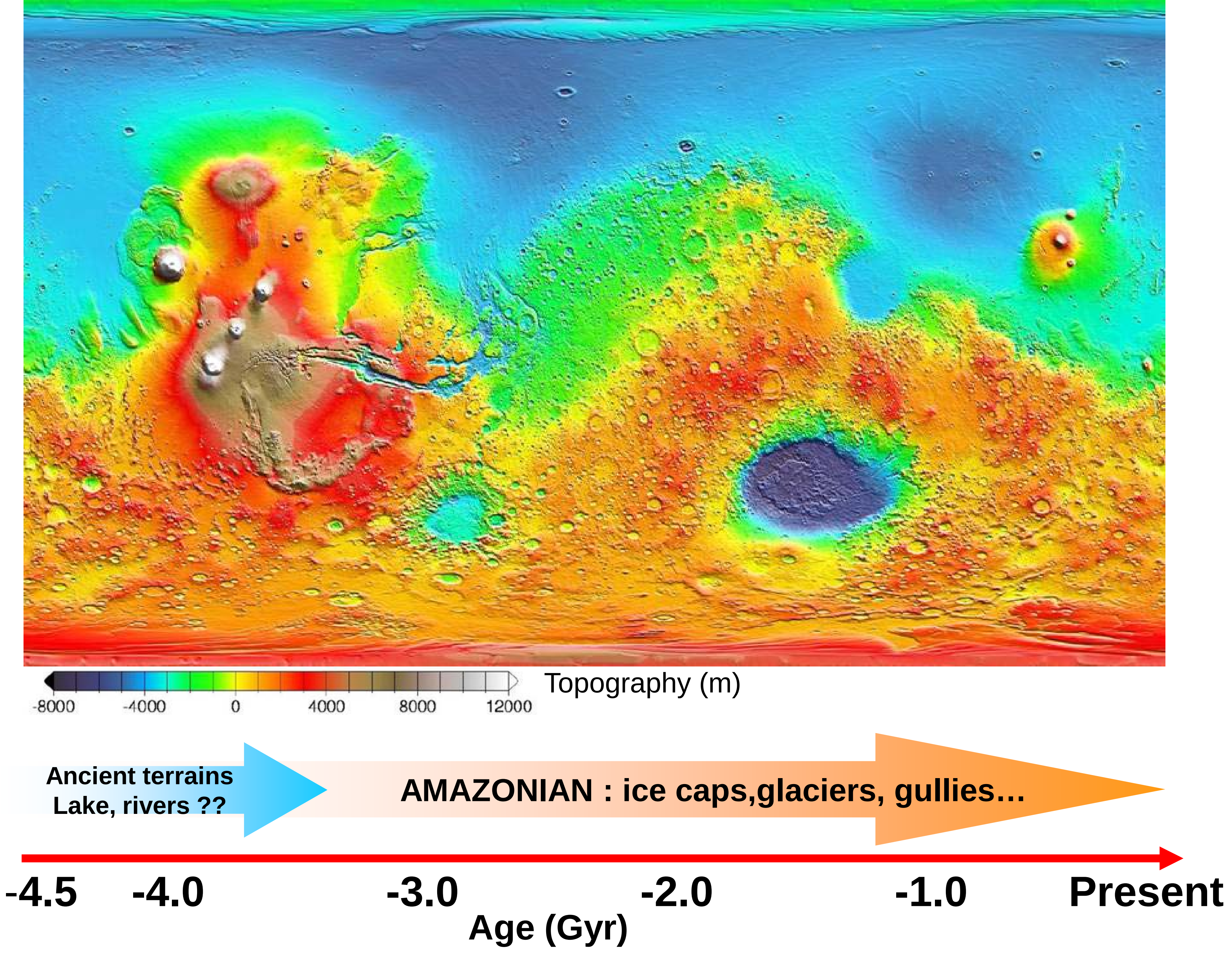
Outline

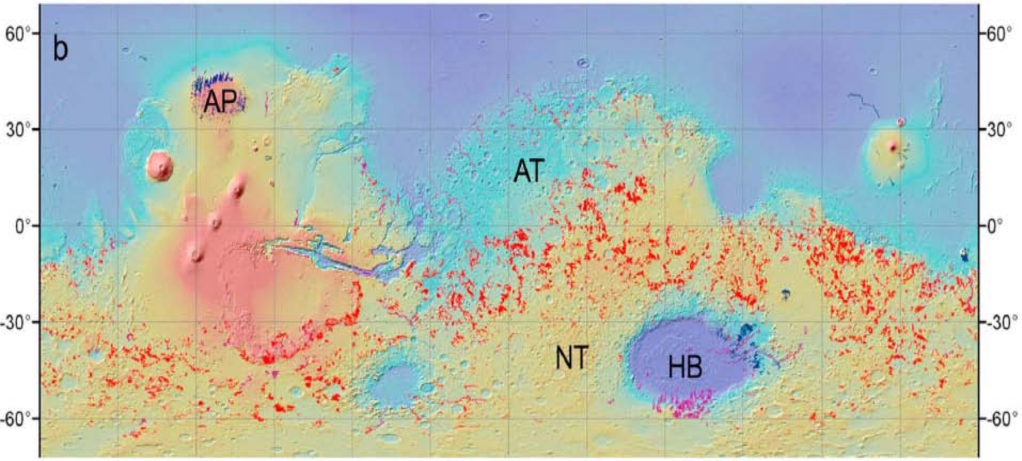
- The early Mars climate (~3.8 billions years ago)
  - Was why early Mars climate different ?
- Present day Mars Climate
  - Calendar
  - CO_2 cycle
  - Methane on Mars ?


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

Context: Early Mars

More and more clues from **geomorphology** (valley networks, erosion rates, layered deposits, deltas, etc.) and **minerology** (hydrous minerals) suggest that **early Mars was different than today**, with liquid water flowing.

Map of valley networks



Hynek et al. 2010

Map of hydrous minerals:

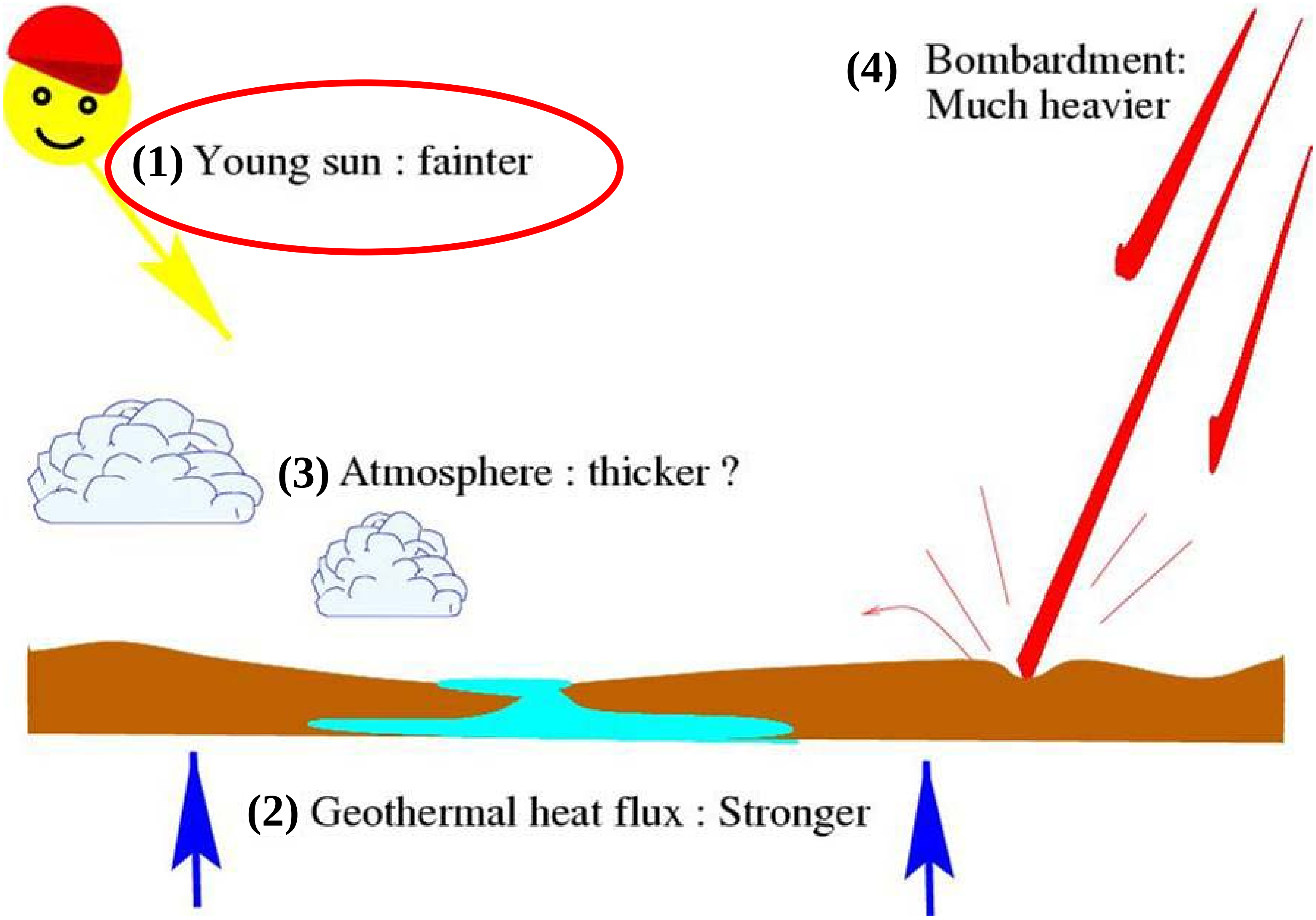
Phyllosilicates and chlorites **Hydrated sulfates or zeolites** **Opaline silica**

Poulet et al. DPS 2010

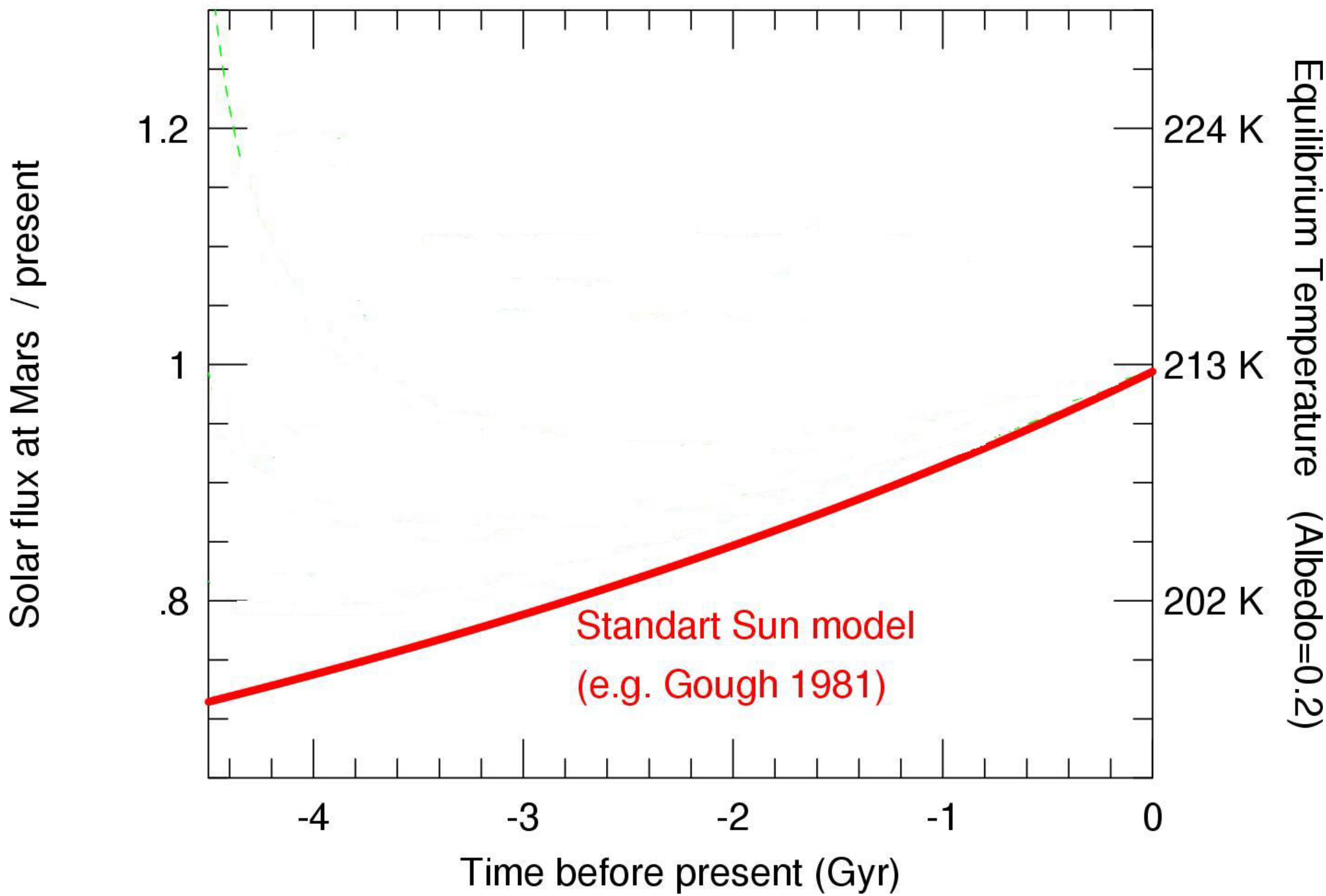

?
Things were different on early Mars ...
copyright kees veenenbos

Why was early Mars different ?

Different boundary conditions compared to present :

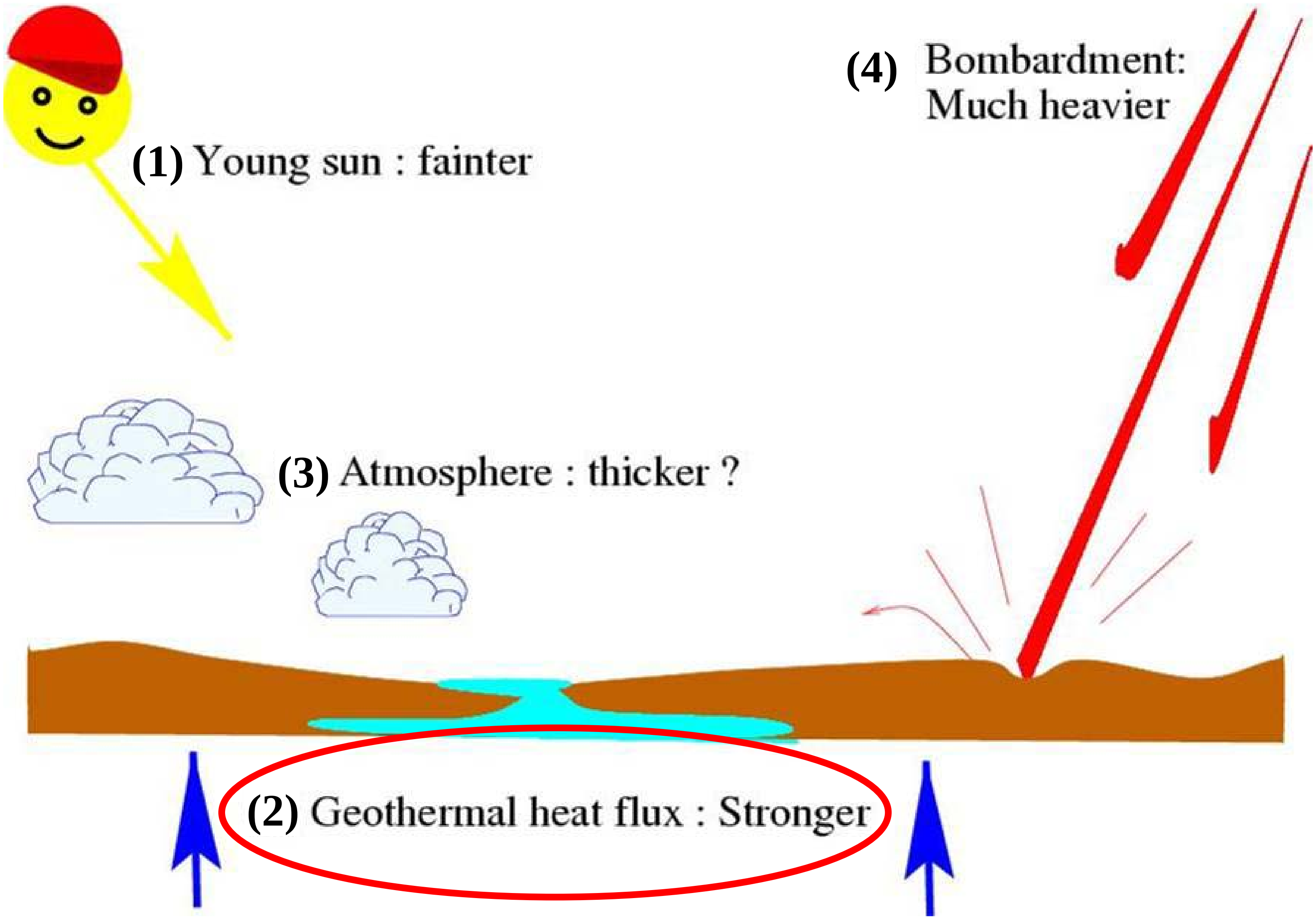


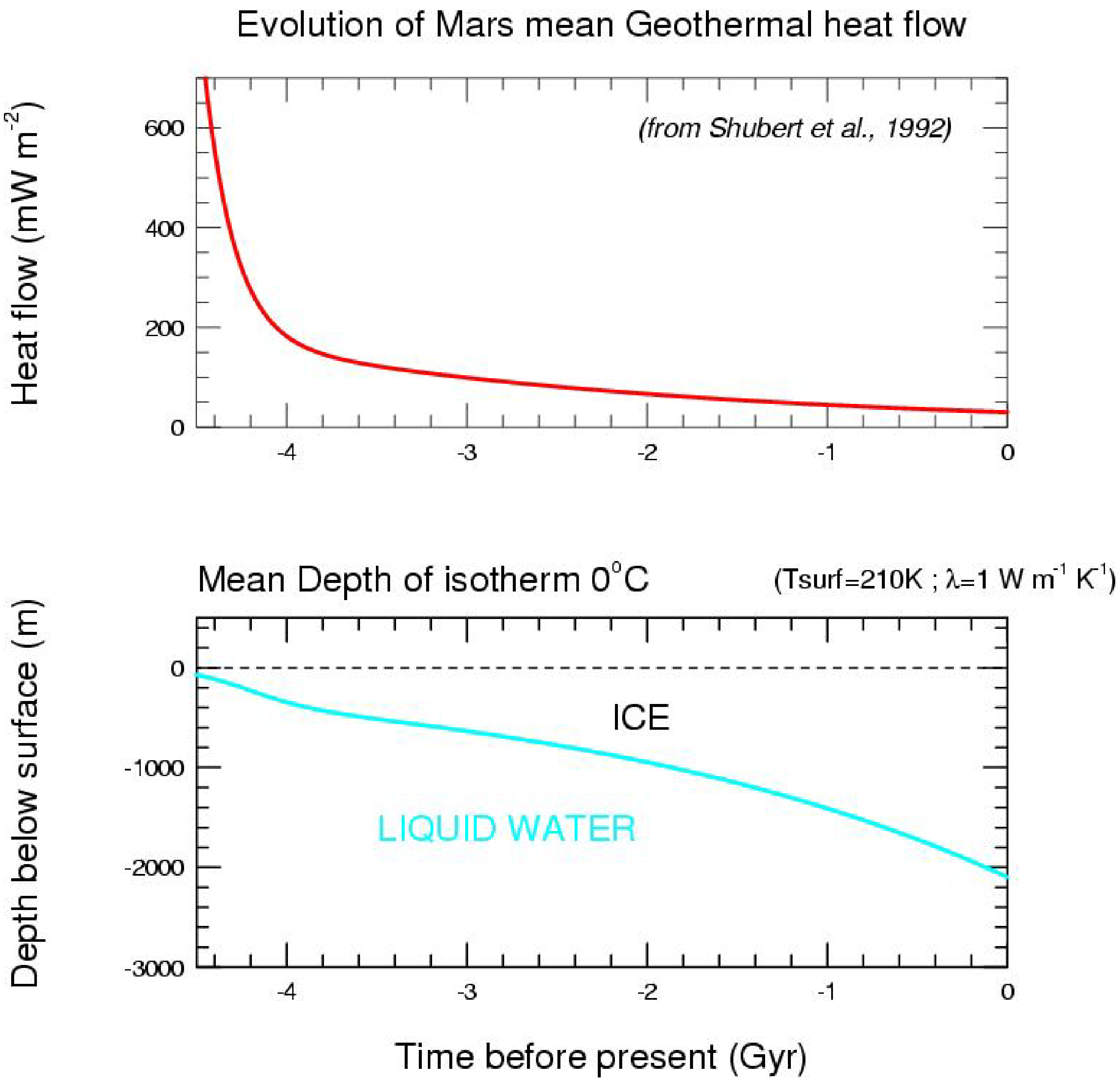
Evolution of Solar flux at Mars



Why was early Mars different ?

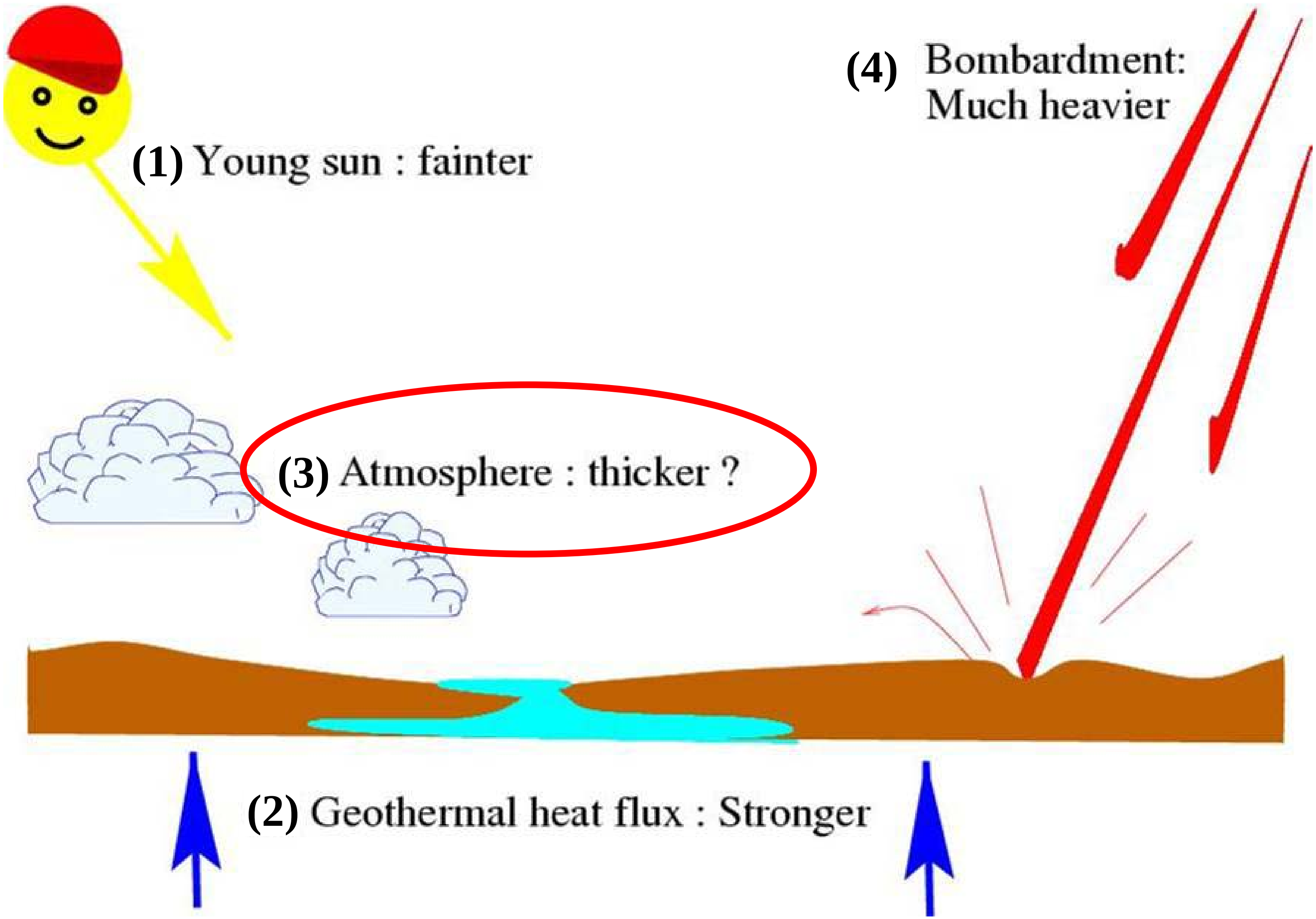
Different boundary conditions compared to present :




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)
ICE
LIQUID WATER
0
-1000
-2000
-3000
-4
-3
-2
-1
0
Time before present (Gyr)

Why was early Mars different ?

Different boundary conditions compared to present :

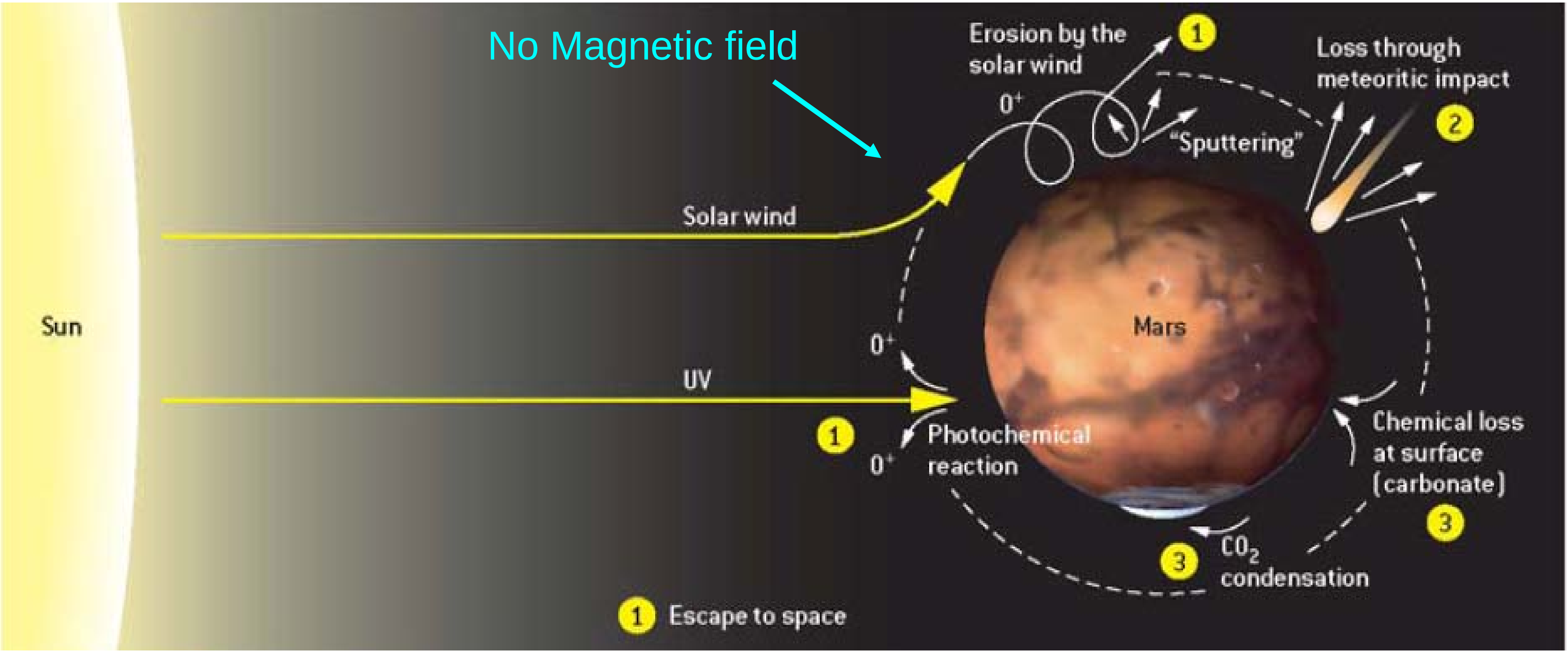


"Warm and wet" Mars explained by a thicker atmosphere: the canonic view

(e.g. Pollack et al. 1987, Kasting et al. 1991, Forget and Pierrehumbert 1997)

1. Mars initial inventory included about ~10 bars of CO_2
2. A several bars CO_2 atmosphere was able to warm early Mars (Greenhouse effect)
3. The atmosphere was lost by escape to space (sputerring, impacts), conversion to carbonate, freezing….

How Mars may have lost its early atmosphere:



CU/LASP • GSFC • UCB/SSL • LM • JPL

NASA Mars Orbiter MAVEN (*Mars Atmosphere and Volatile EvolutioN,* Launch:2013*)* will investigate the escape process on Mars, to understand the past…

Early Mars explained by a thicker atmopshere: the canonic view

(e.g. Pollack et al. 1987, Kasting et al. 1991, Forget and Pierrehumbert 1997)

1. Mars initial inventory included about ~10 bars of CO_2
2. A several bars CO_2 atmosphere was able to warm early Mars (Greenhouse effect)
3. The atmosphere was lost by escape to space (sputerring, impacts), conversion to carbonate, freezing….

Problems:

- A thick martian CO_2 atmosphere climate is not easy to model (greenhouse effect lower than expected)

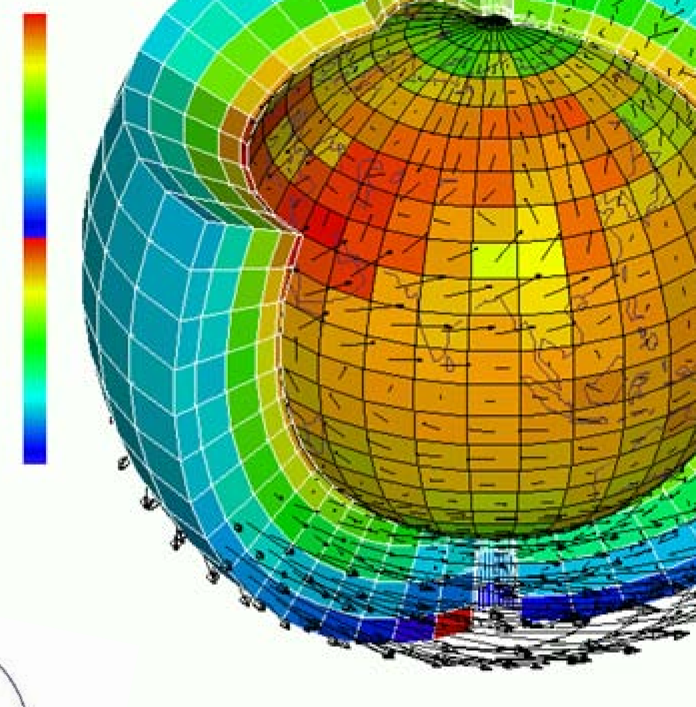
Modelling Mars with a thick CO2 atmosphere

A simple question : what would be the climate on a Mars-like planet with

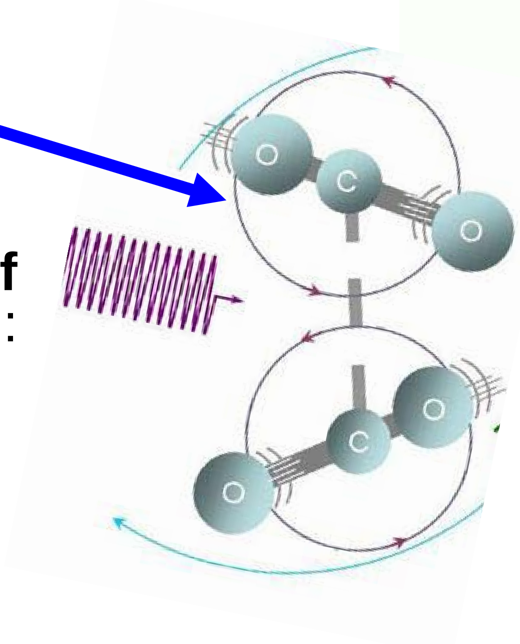
- a **faint sun** (0.75   today) and
- a **thicker CO_2 atmosphere** (0.5, 2, 5 bars) ?

MANY studies on this single subject (e.g. *Pollack et al. 1987, Kasting 1991, Forget and Pierrehumbert 1997, Mischna et al. 2000, Colaprete et al. 2002, Forget 2004, Wordsworth et al. 2010, etc...*

A Global Climate Model (GCM) for early Mars (LMD)



- **LMDZ grid point dynamical core, 64x48 x15 layers**
- **New radiative transfer core:**
  - Toon et al. (1989) two-stream method for the aerosols
  - Correlated-k for the gaseous absorption



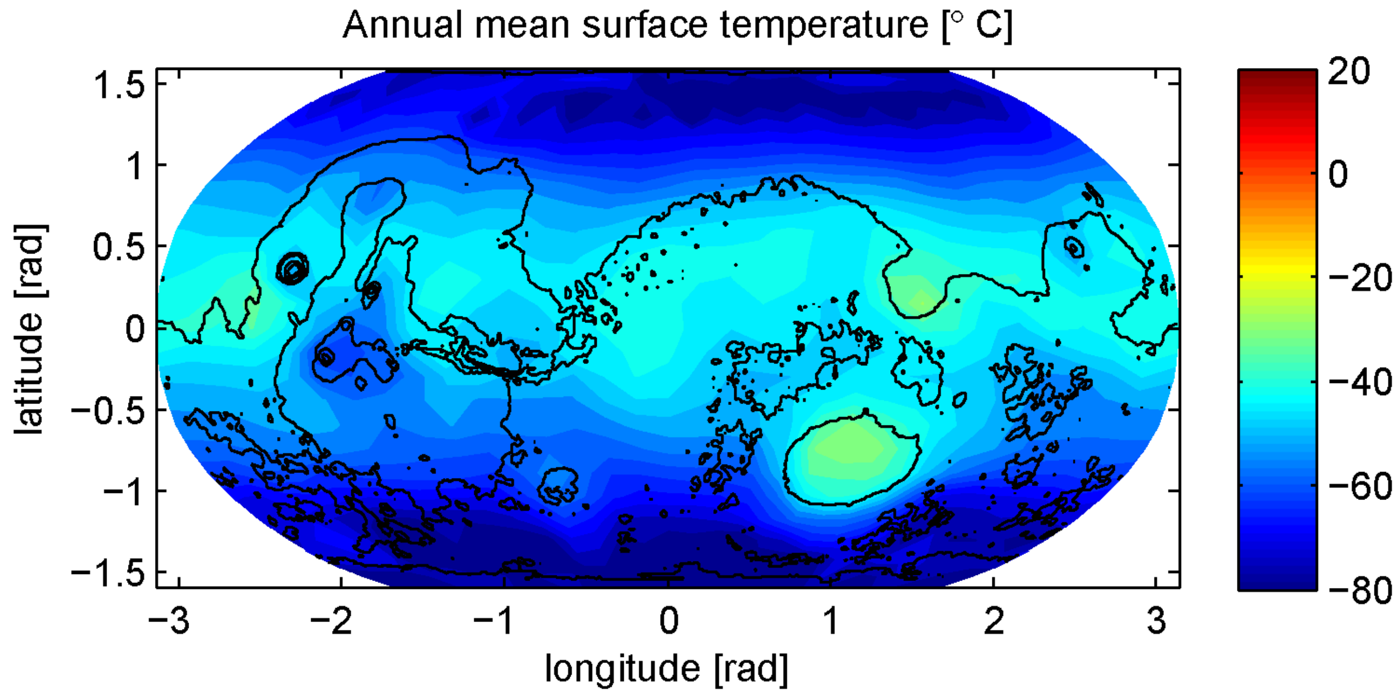
CO_2-CO_2 collision-induced absorption
New parametrisation
⇨ **Reduced CO_2 greenhouse effect !**

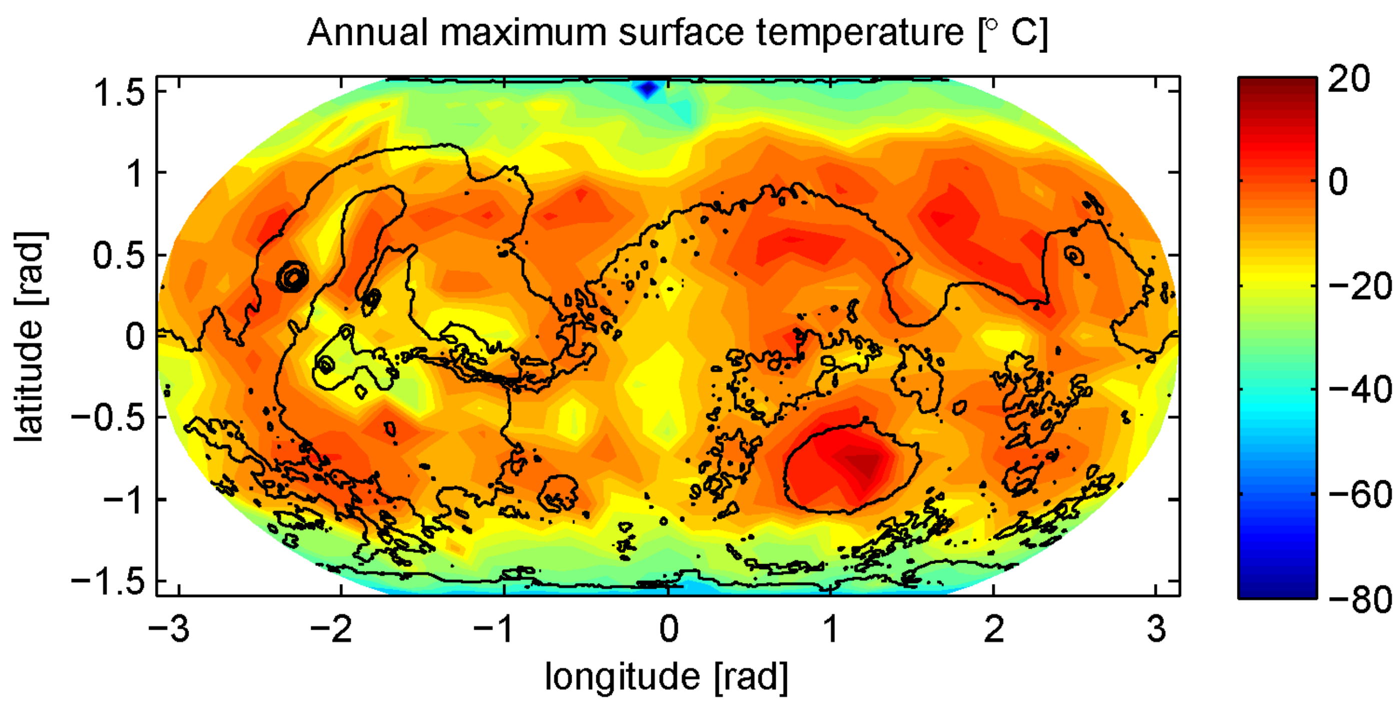
(*Wordsworth et al.* Icarus 2010)

- **Simple parametrisation of CO2 cloud microphysics** : condensation, nucleation, transport, sedimentation
- **Surface properties:**
  - Fixed surface albedo, thermal inertia
  - Present-day martian topography
- Circular orbit

0.5 bar

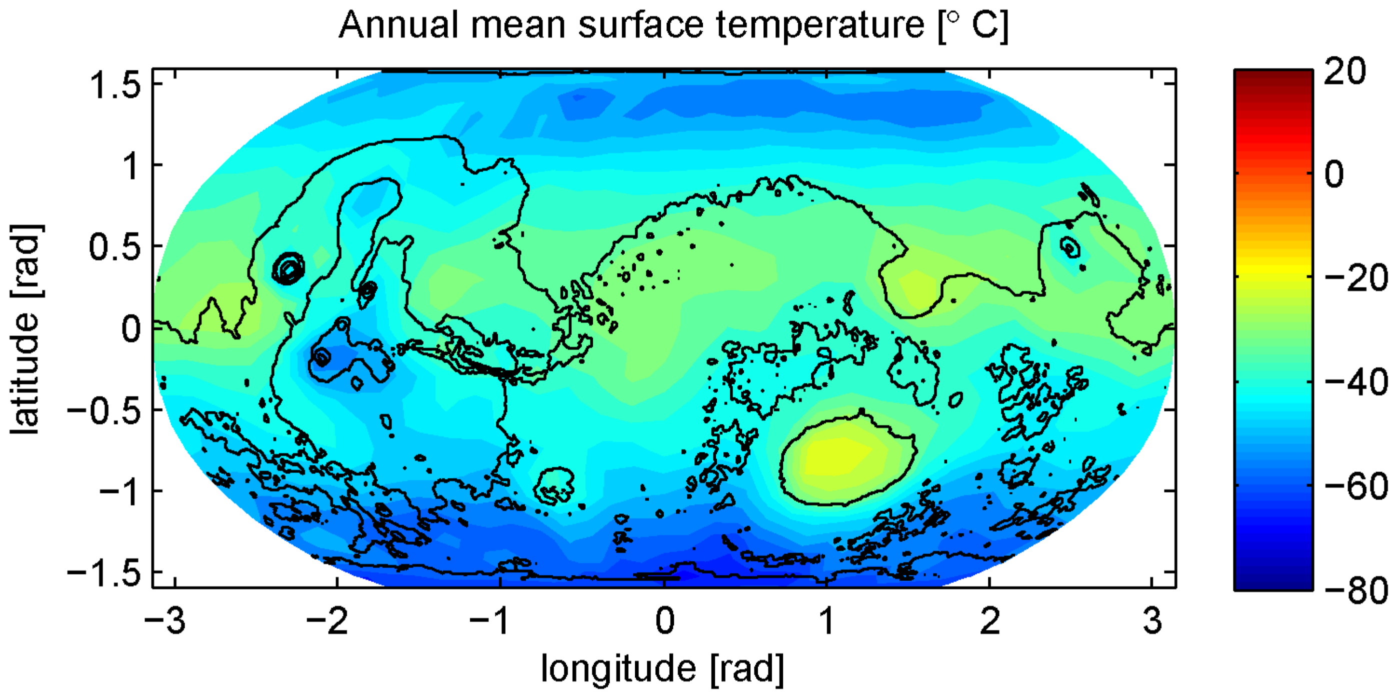
Surface CO2 ice

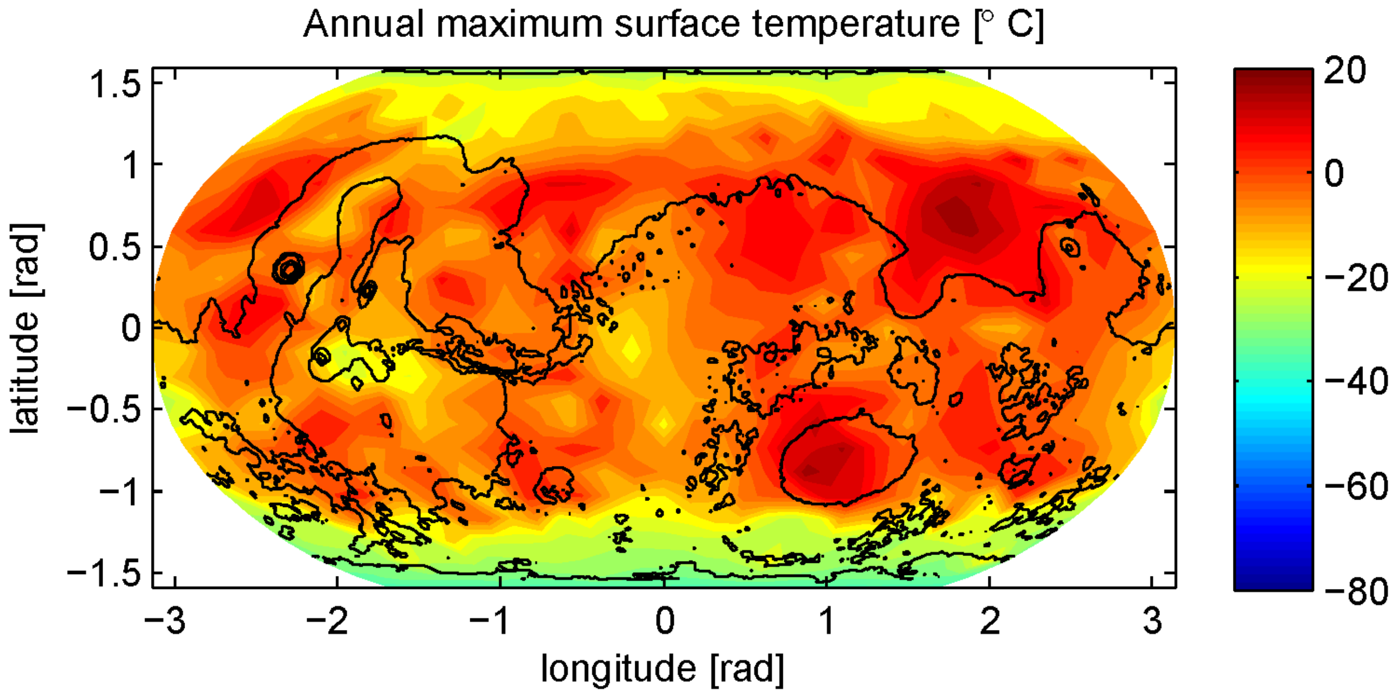




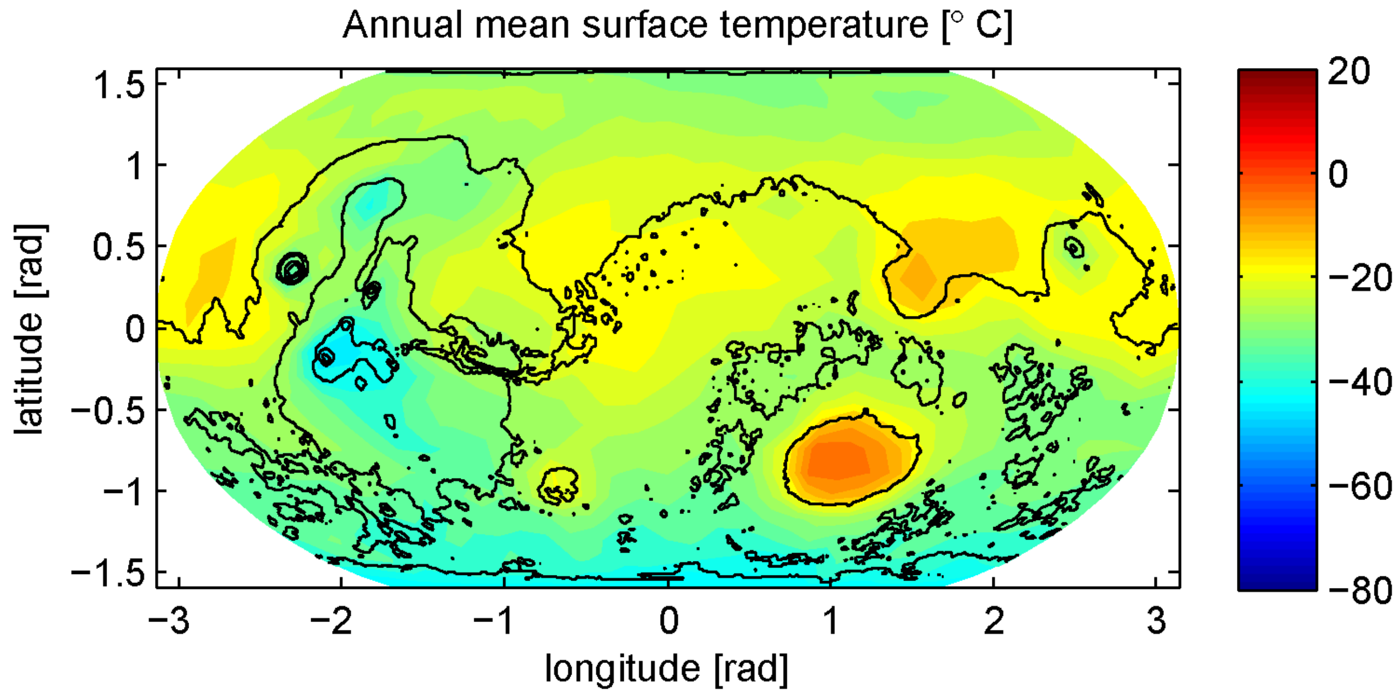
1 bar

Surface

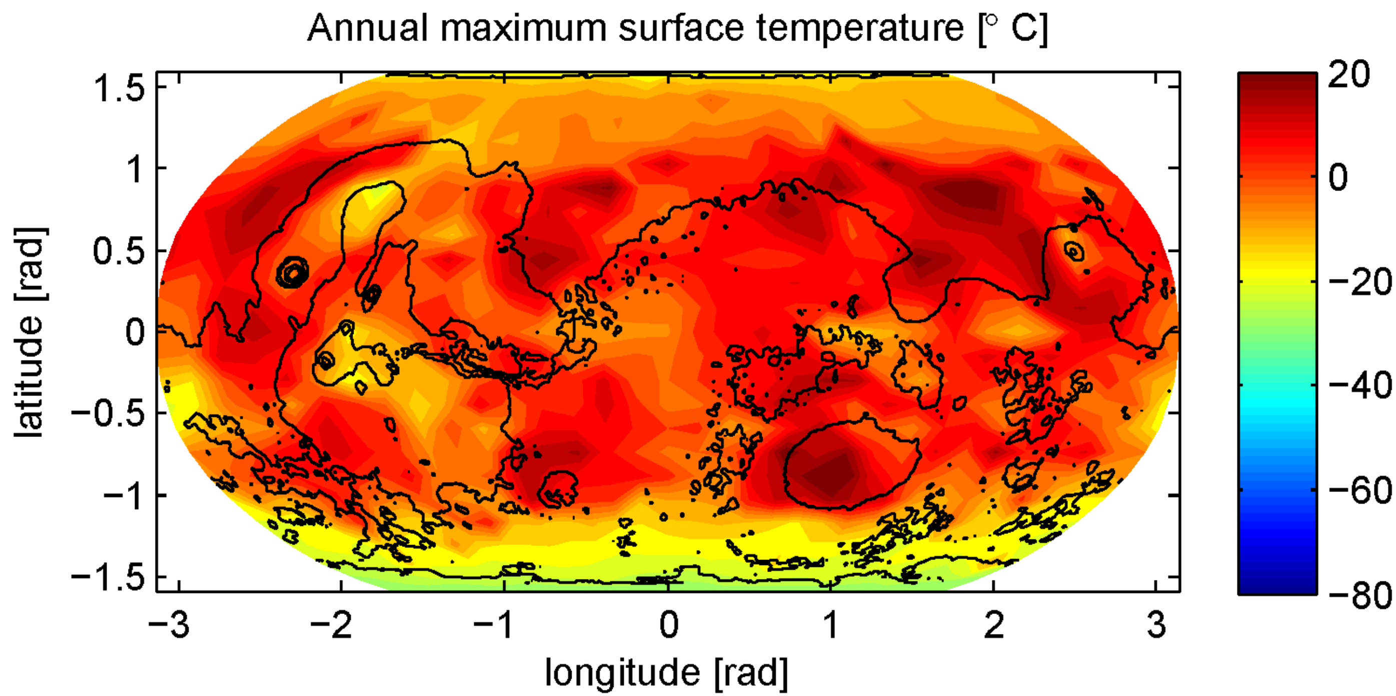




2 bar

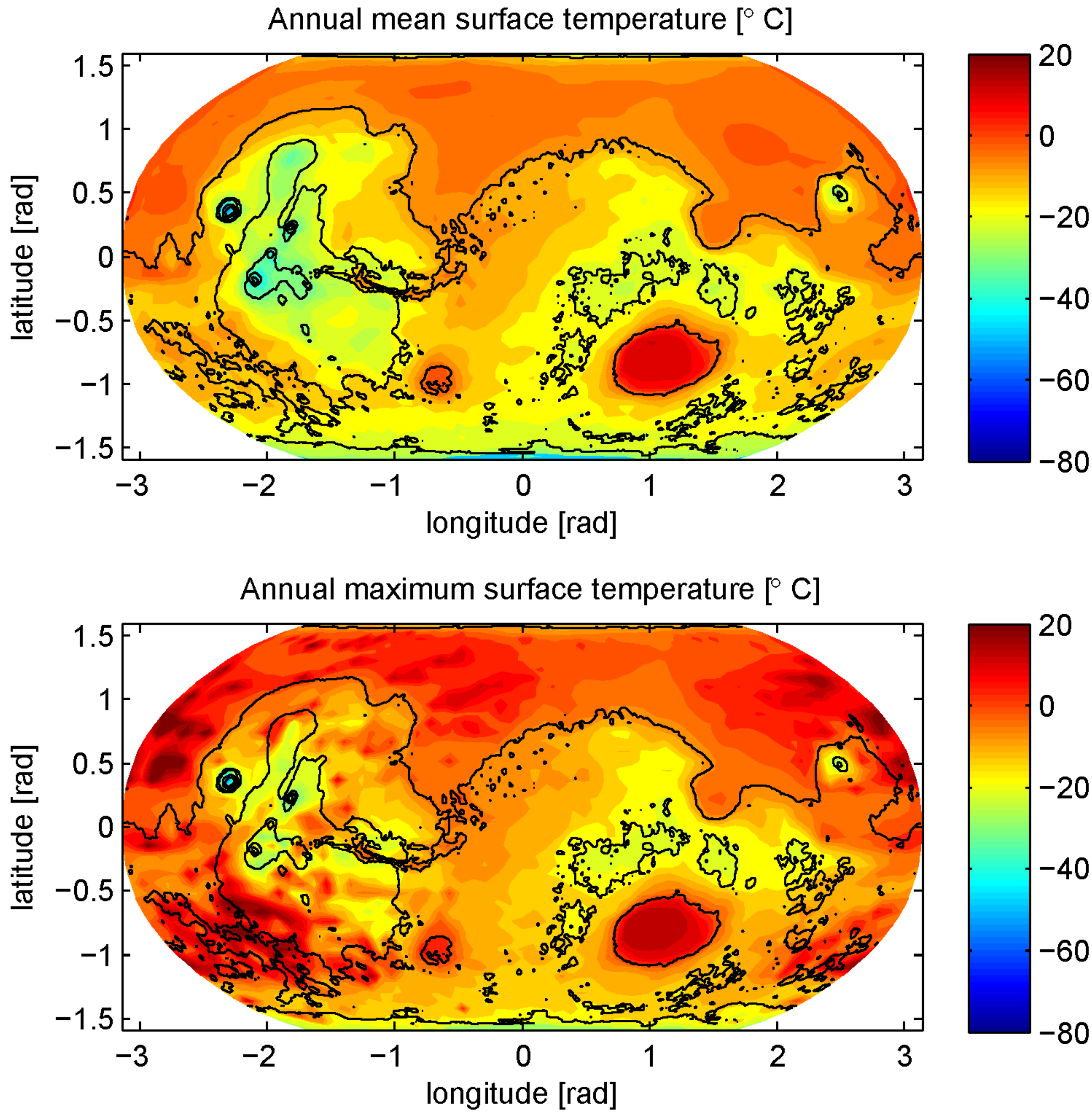


Annual mean surface temperature [° C]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
20
0
−20
−40
−60
−80



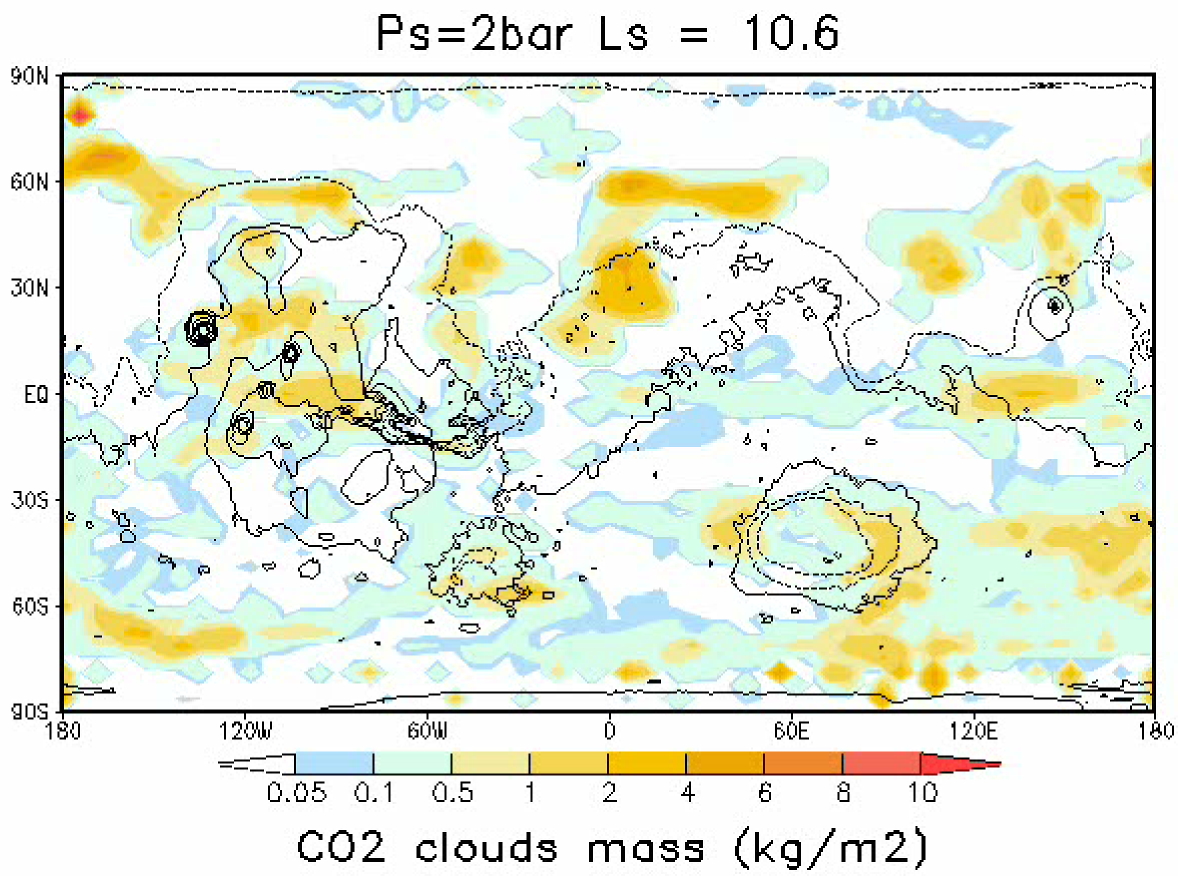
Annual maximum surface temperature [° C]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
20
0
−20
−40
−60
−80

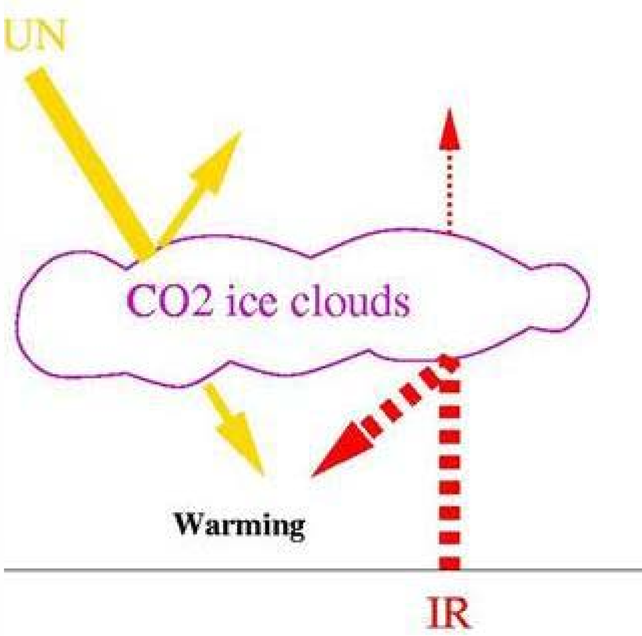
5 bar



Annual mean surface temperature [° C]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
20
0
−20
−40
−60
−80
Annual maximum surface temperature [° C]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
20
0
−20
−40
−60
−80

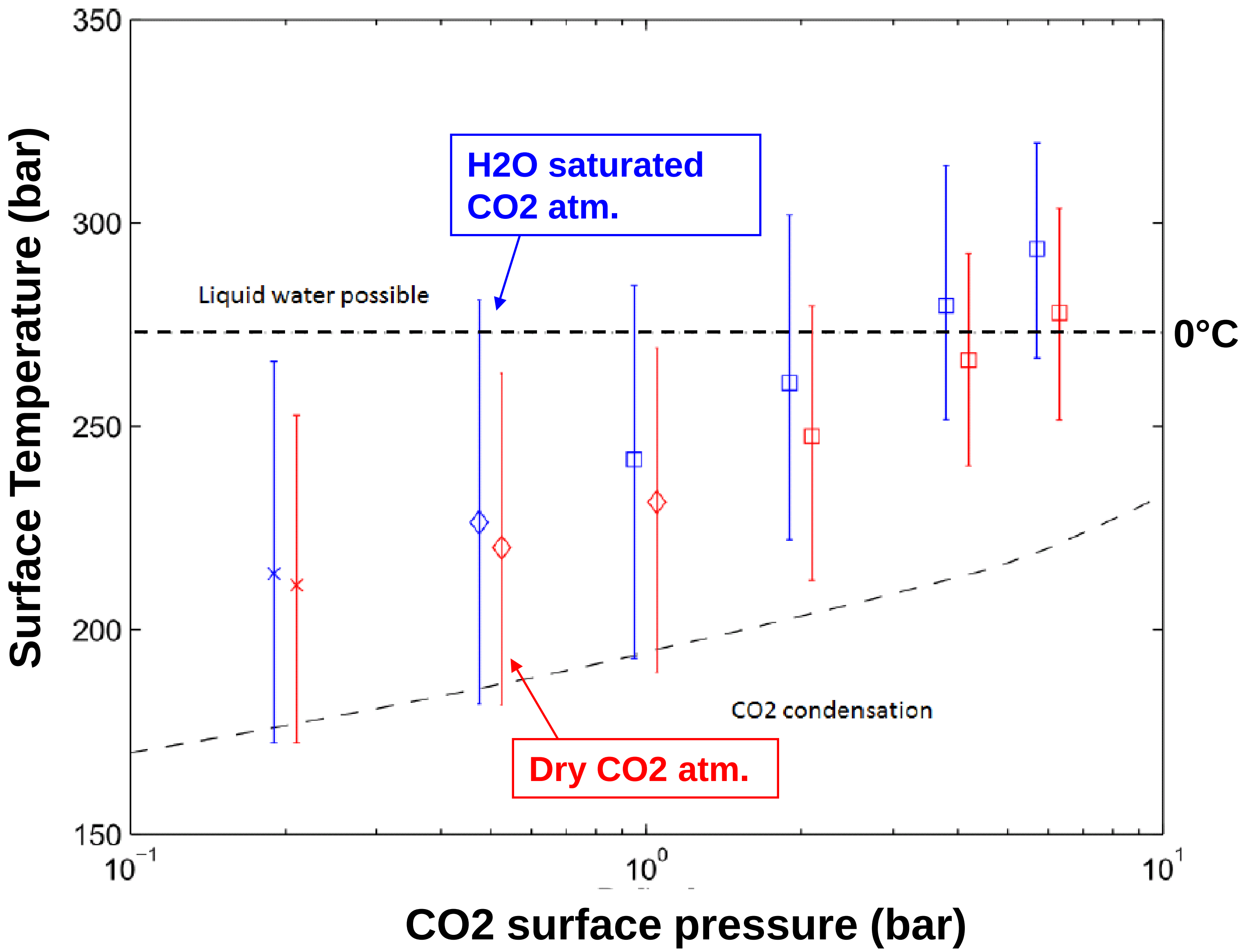
CO2 ice clouds warming: 15 to 20K





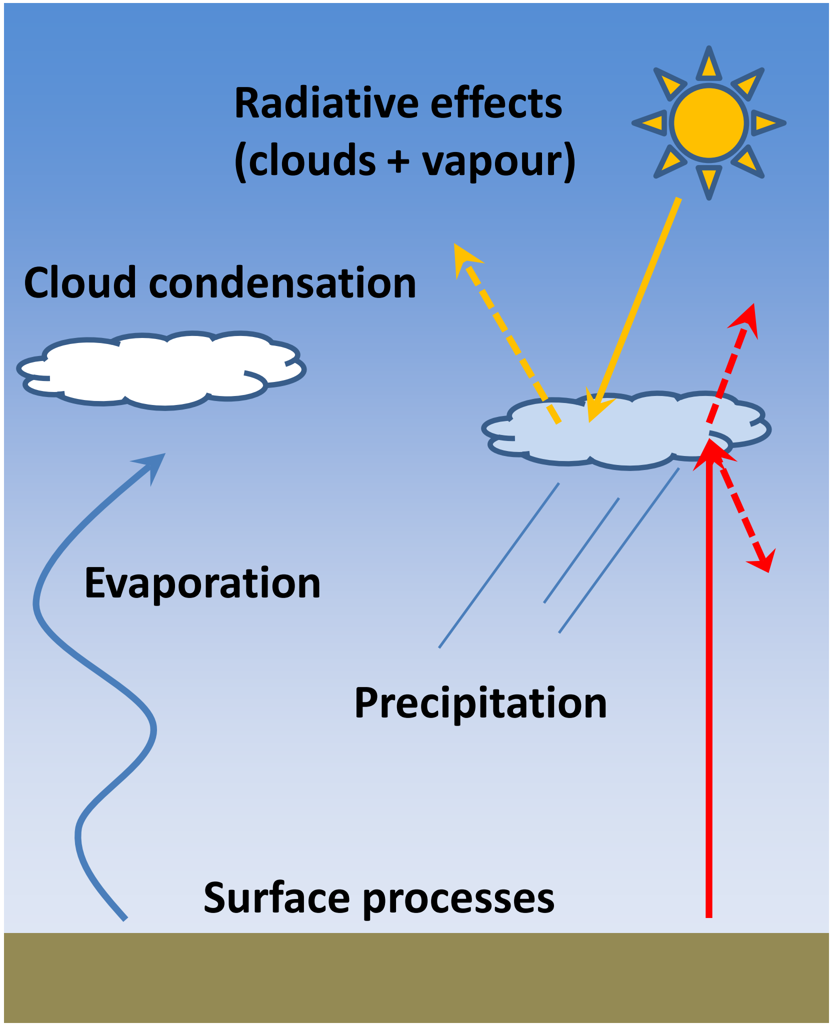
Forget and Pierrehumbert 1997

Additional greenhouse effect from Water vapor ?

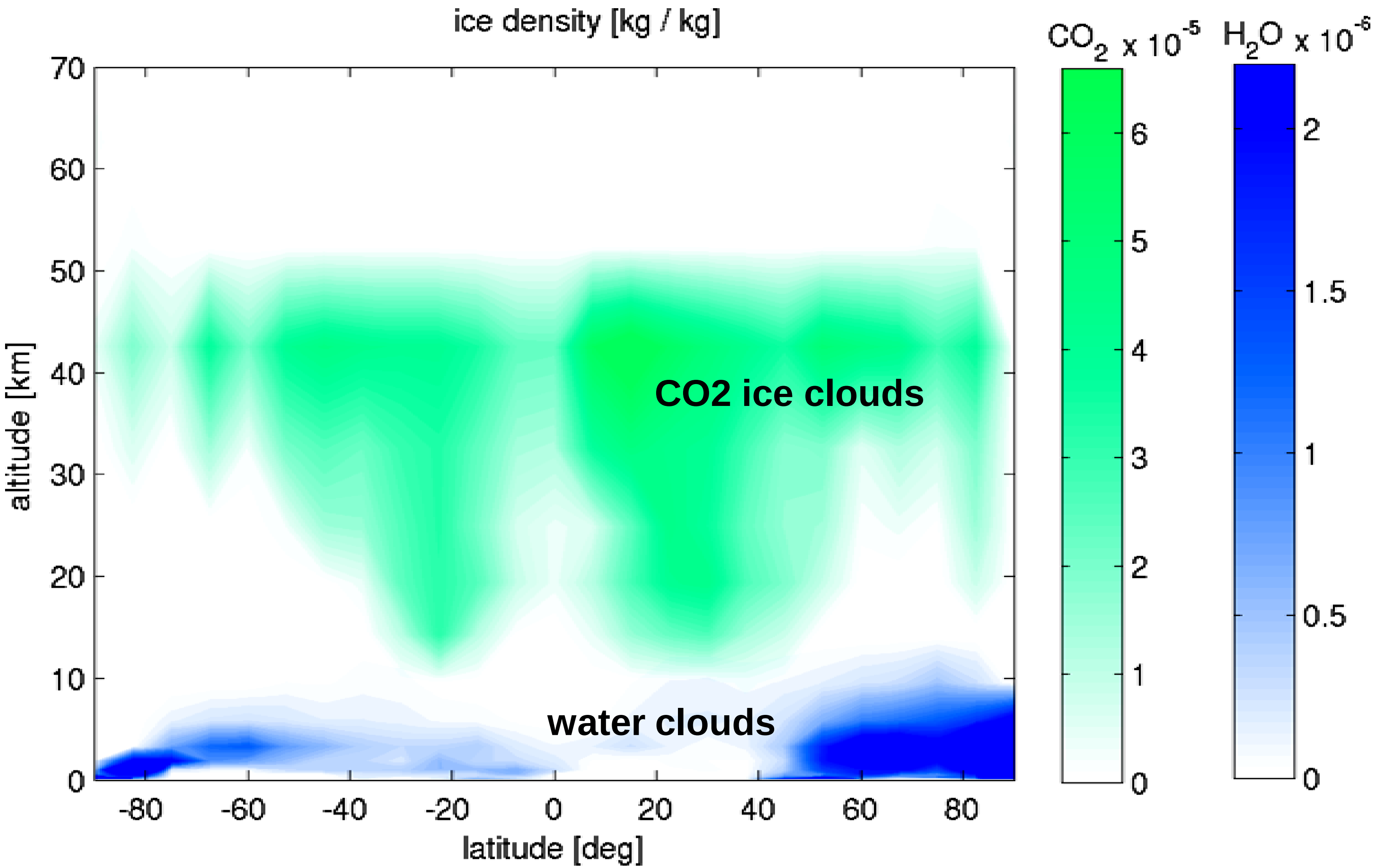


Adding a water cycle

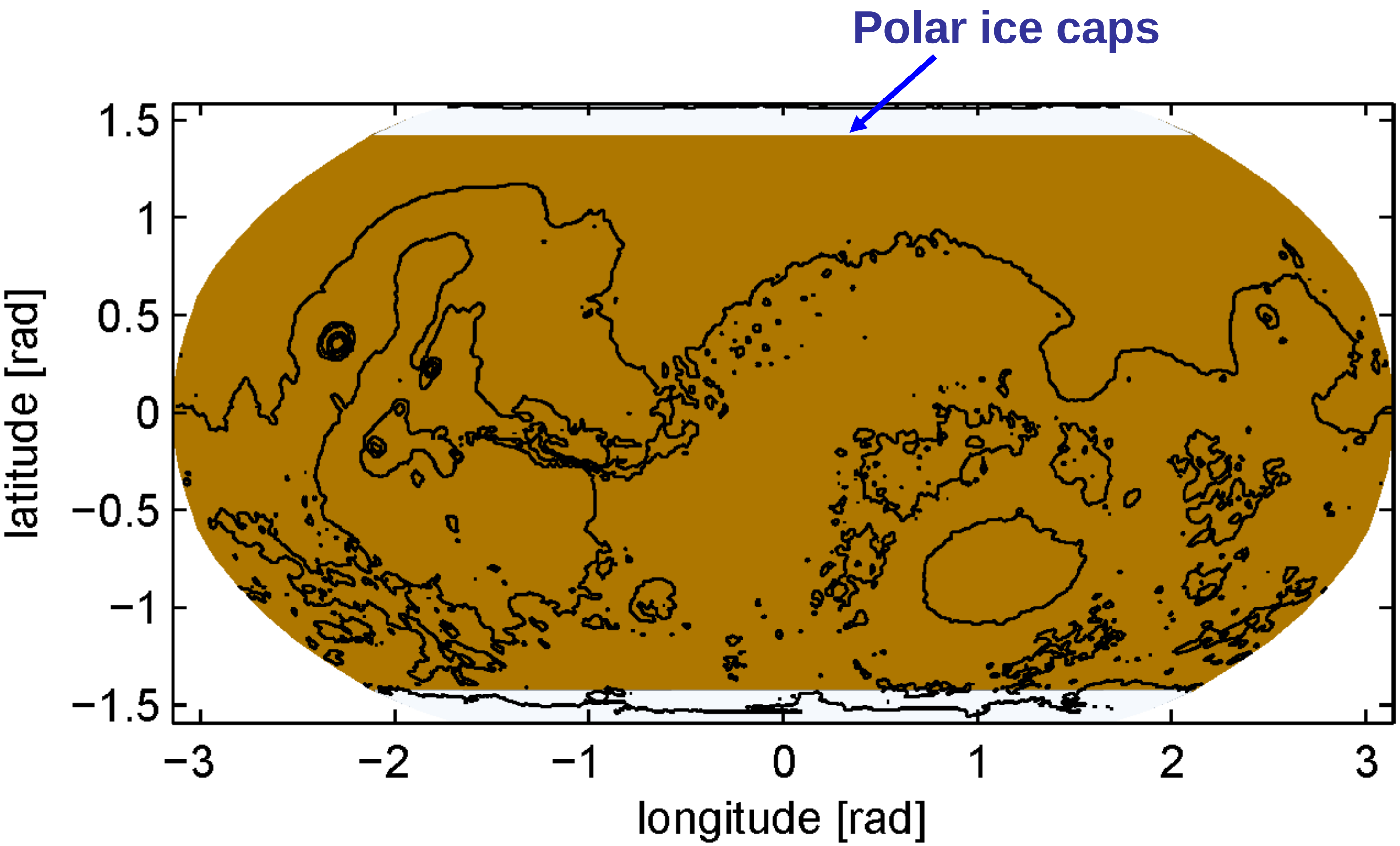
- We include radiative effects of vapour and cloud tracers
- Assume fixed CCN distribution, but variable mean cloud particle sizes
- Simple convective relaxation (Manabe scheme), 100% cloud fraction assumed
- 'Bucket' surface hydrology for the moment



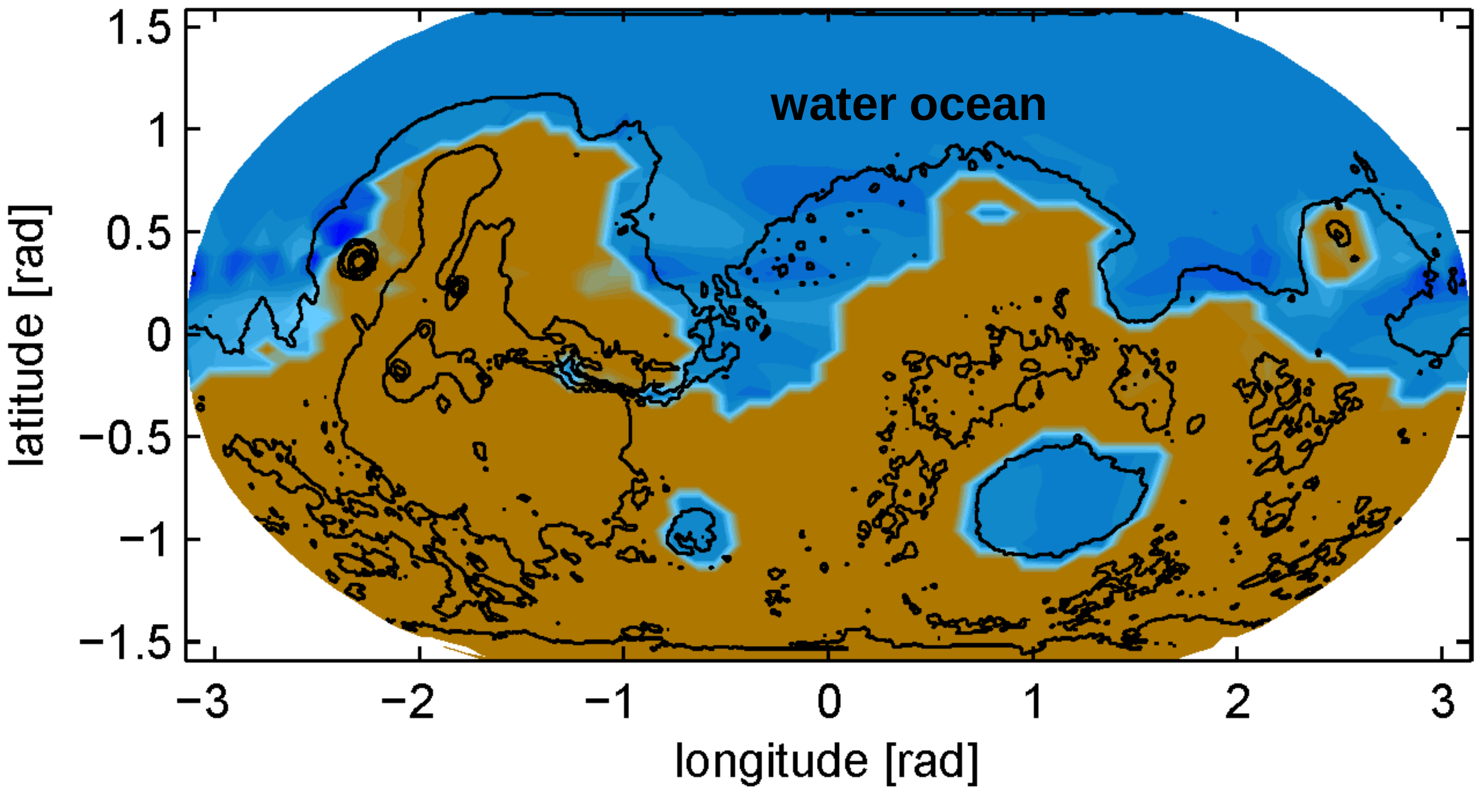
CO2 and H2O cloud cover (2 bars)



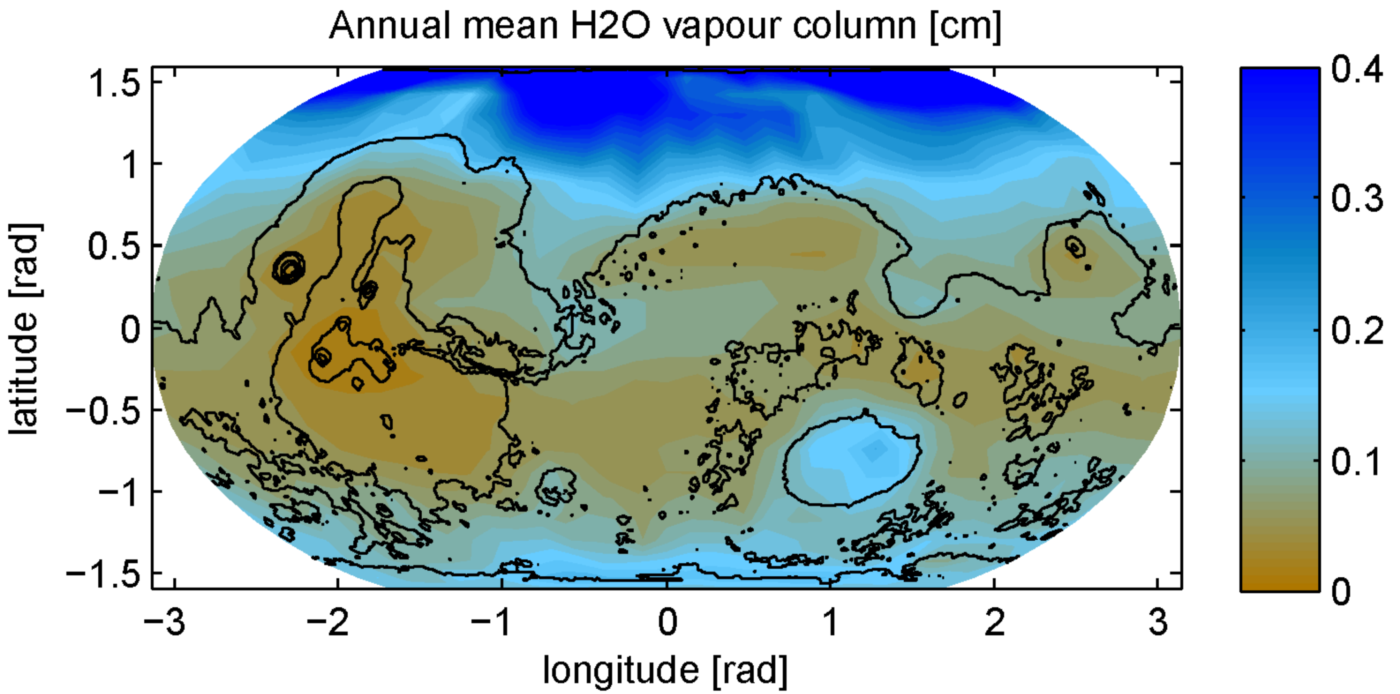
3D initial conditions for H2O

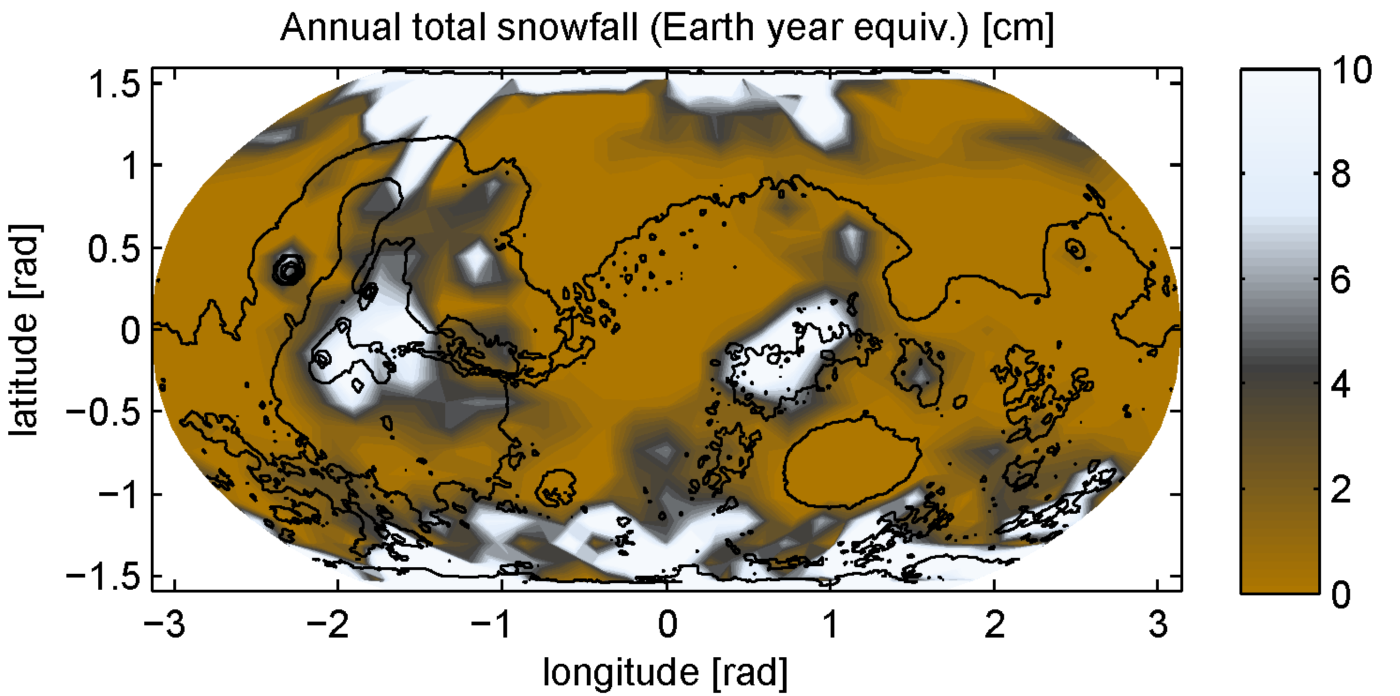


3D initial conditions for H2O

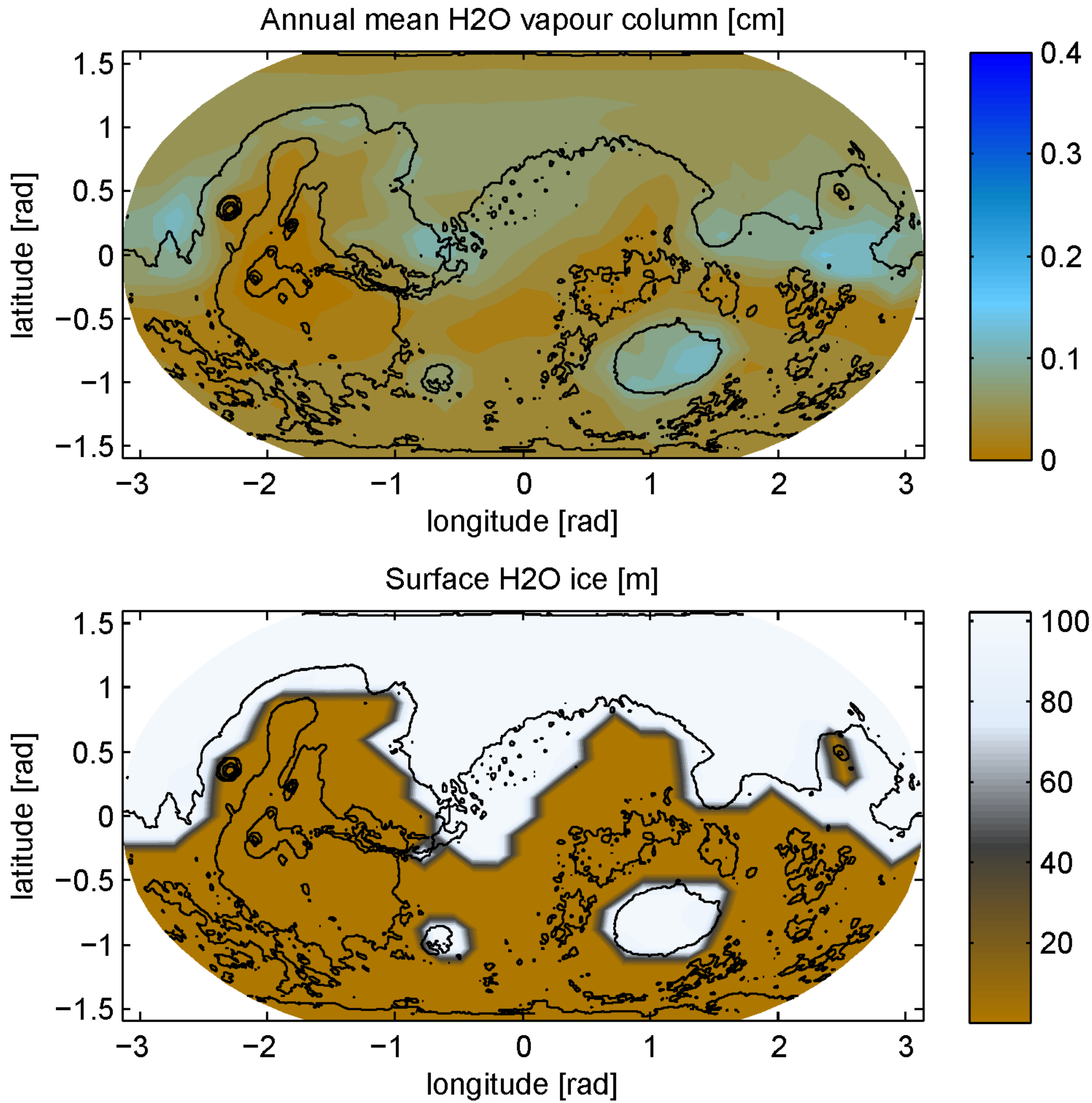


2 bar, icecaps

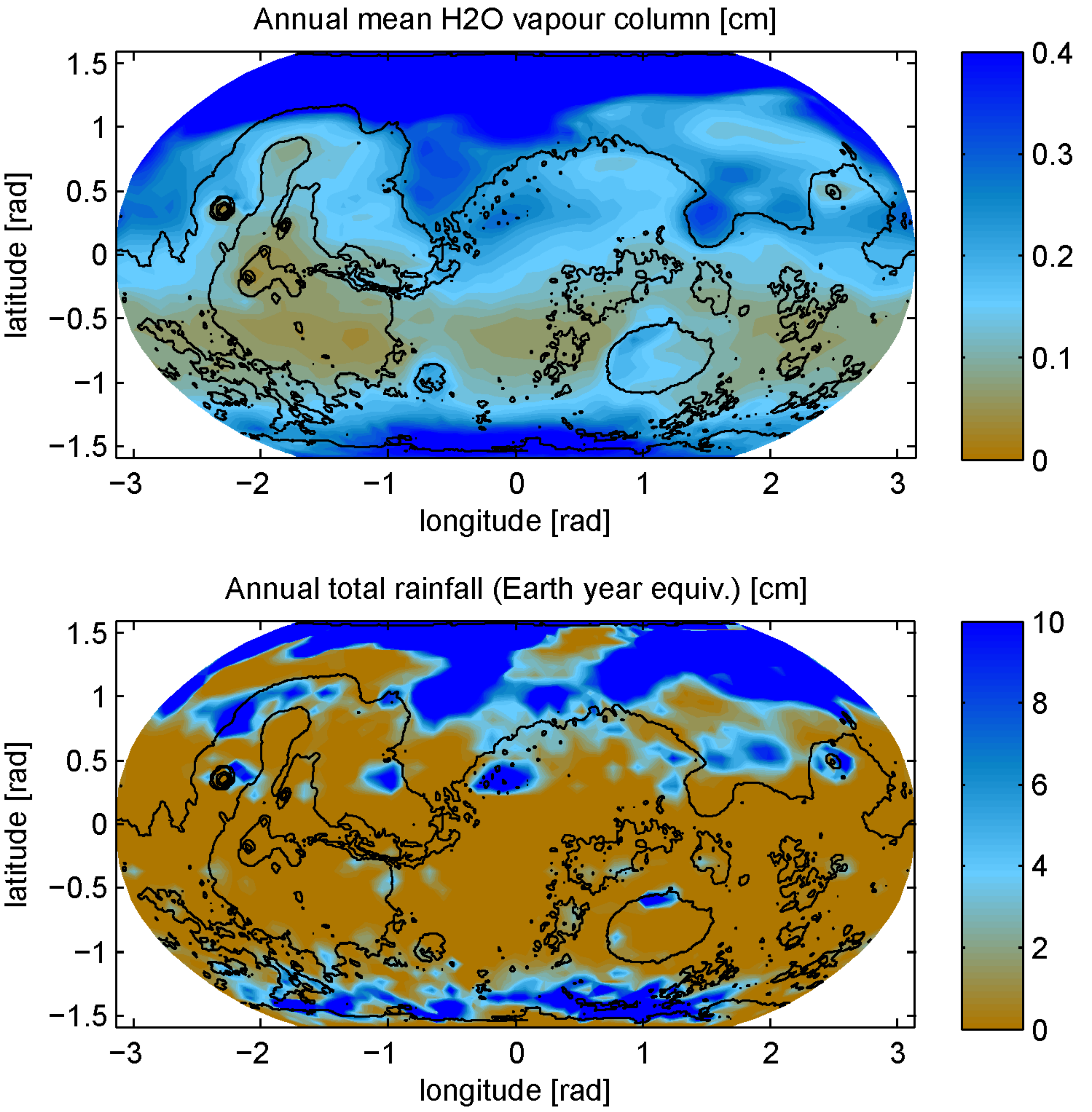


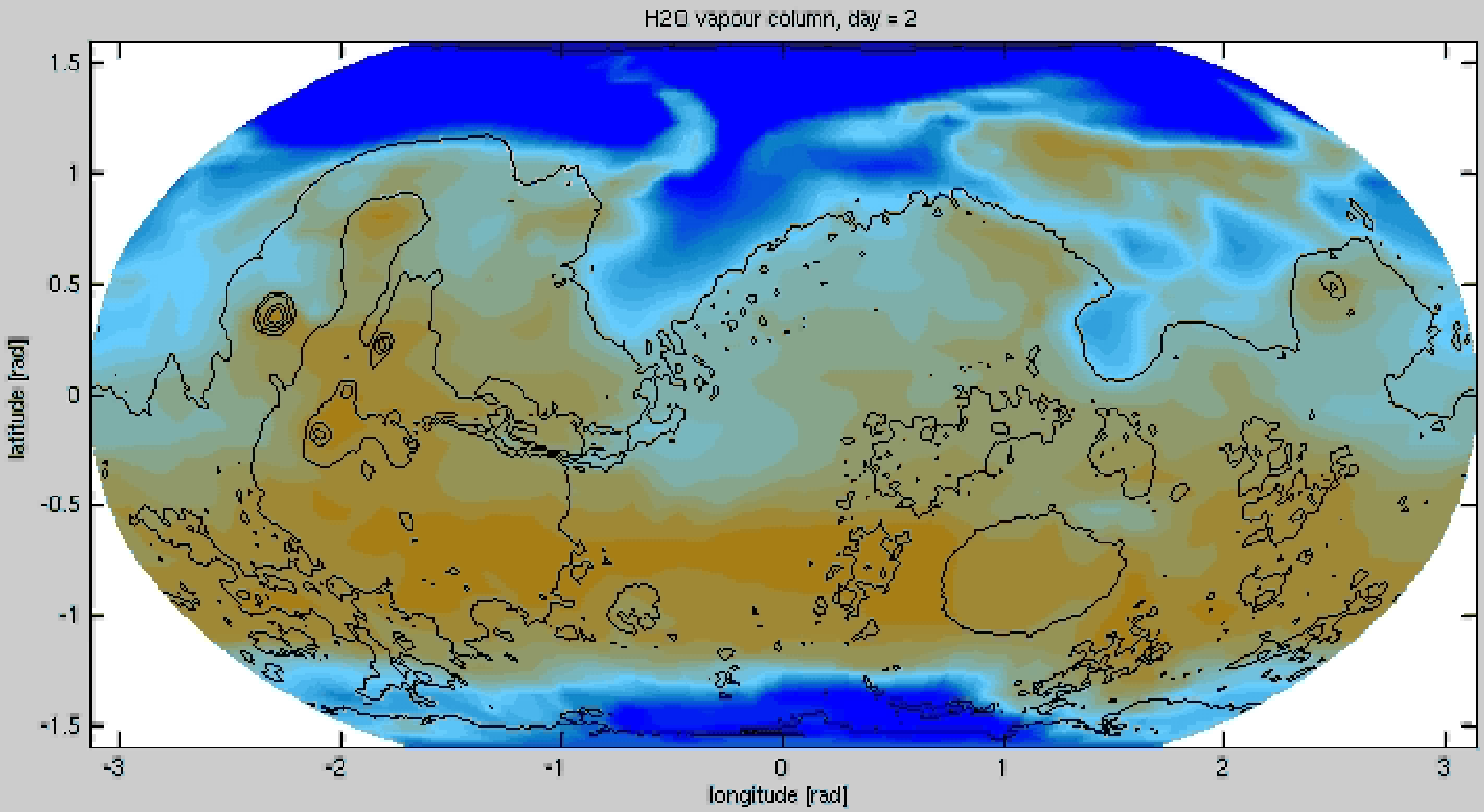


2 bar, ocean

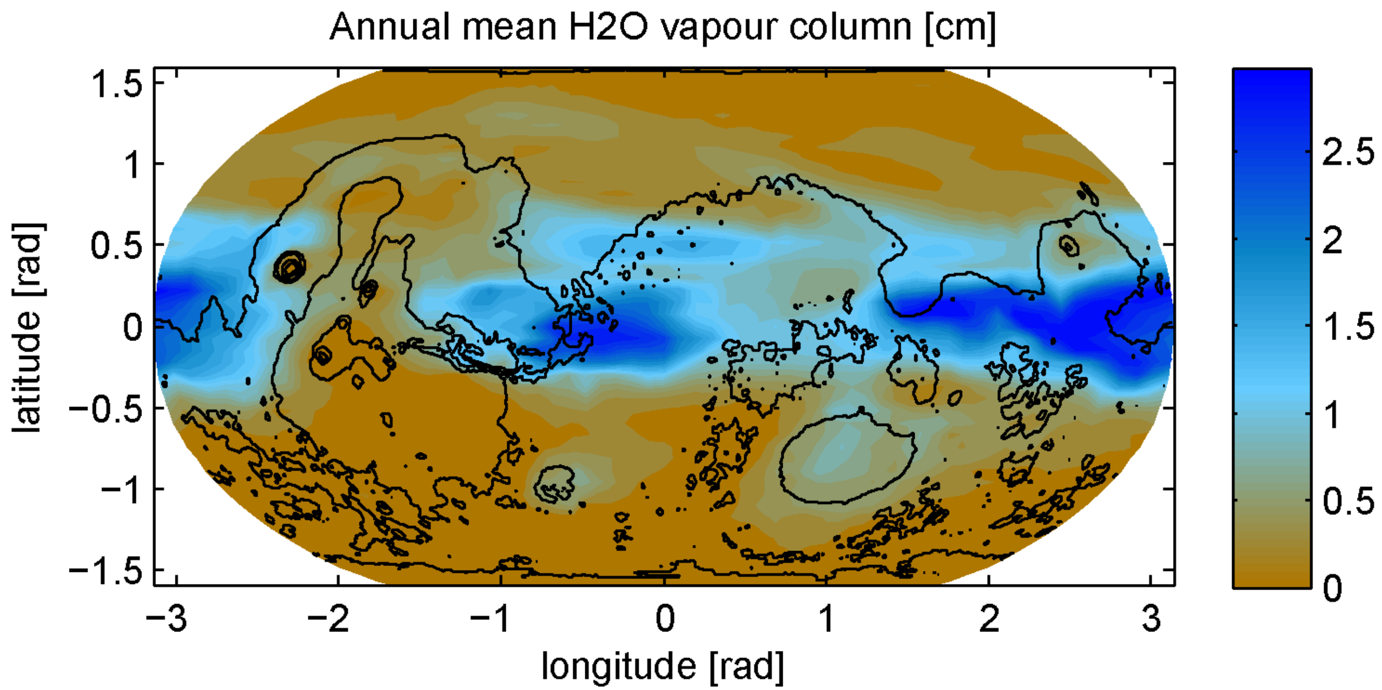

Annual mean H2O vapour column [cm]
latitude [rad]
longitude [rad]
1.5
1
0.5
0
−0.5
−1
−1.5
−3
−2
−1
0
1
2
3
0.4
0.3
0.2
0.1
0
Surface H2O ice [m]
latitude [rad]
longitude [rad]
100
80
60
40
20

5 bar, icecaps

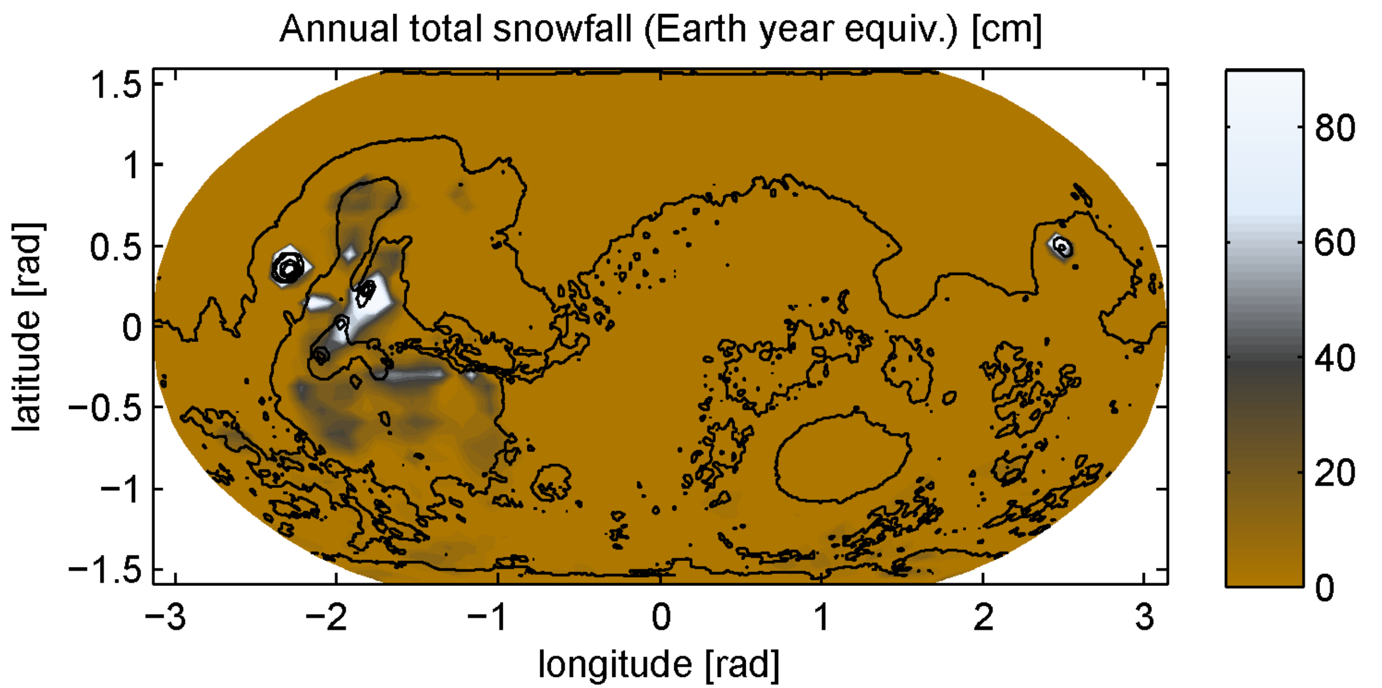



H2O vapour column, day = 2
1.5
1
0.5
0
-0.5
-1
-1.5
latitude [rad]
-3
-2
-1
0
1
2
3
longitude [rad]

5 bar, ocean



Annual mean H2O vapour column [cm]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
2.5
2
1.5
1
0.5
0



Annual total snowfall (Earth year equiv.) [cm]
1.5
1
0.5
0
−0.5
−1
−1.5
latitude [rad]
−3
−2
−1
0
1
2
3
longitude [rad]
80
60
40
20
0

Early Mars explained by a thicker atmopshere: the canonic view

(e.g. Pollack et al. 1987, Kasting et al. 1991Forget and Pierrehumbert 1997)

1. Mars initial inventory included about ~10 bars of CO2
2. A thick CO2 atmosphere was able to warm early Mars (Greenhouse effect)
3. The atmosphere was lost by escape to space (sputerring, impacts), conversion to carbonate, freezing….

Problems:

- The early Mars climate with a thick CO2 atmosphere is not easy to model

⇨ Several bars of CO_2 may be required

- **Could the Martian atmosphere be that thick 4 billions years ago ?**

Could Mars have had a 3-5 bars atmospheres of CO_2 4 billions years ago ?

The initial Mars inventory was probably > 10 bars BUT recent studies suggest a much thinner inventory for the Noachian Martian atmosphere:

- Primordial atmosphere of Mars was probably removed quickly (*Tian et al., 2009)*
- Tharsis outgassing (*Phillips et al.,2001*) has probably been overestimated. *Morschhauser 2011*: "In the Noachian, only 240-270 mbars of CO_2 can be outgassed"
- After the heavy bombardment, atmospheric escape was probably weak (*Leblanc and Johnson* 2002; *Barabash* et al. 2007; *Lammer et al.* 2011)

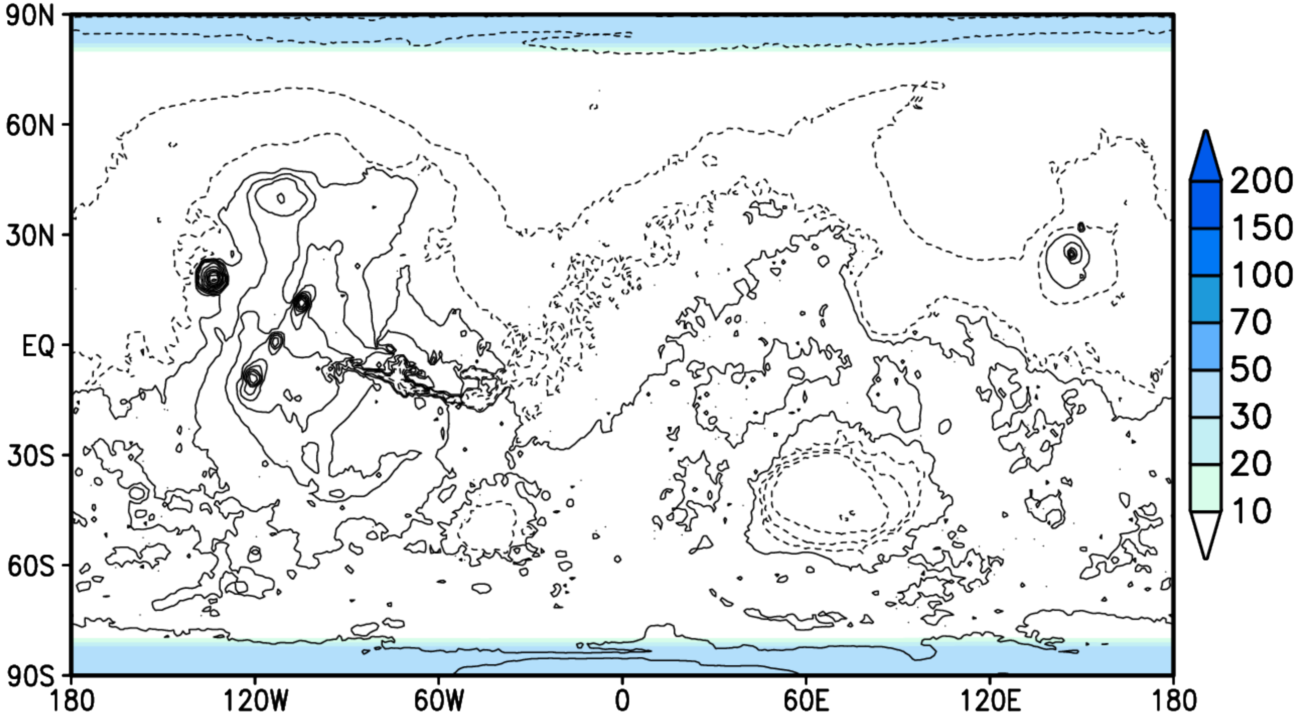
⇨ 500 mbar of CO_2 may be an upper limit on ancient Mars ?

Ongoing work: Mars with ~500 mbar of CO_2

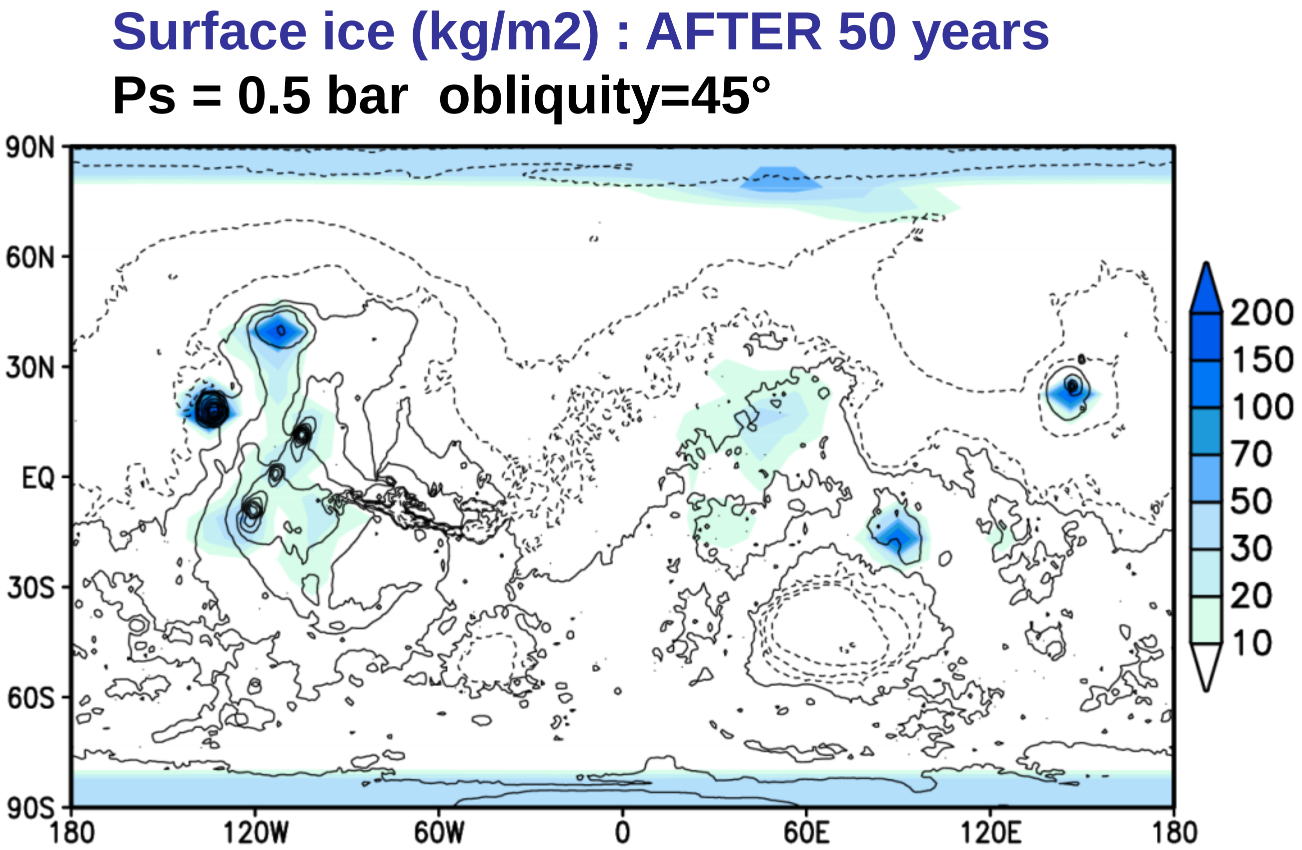
Starting with limited polar caps: HIGHER obliquity (45°)

Surface ice (kg/m2) : Initial state

Ps = 0.5 bar obliquity=45°

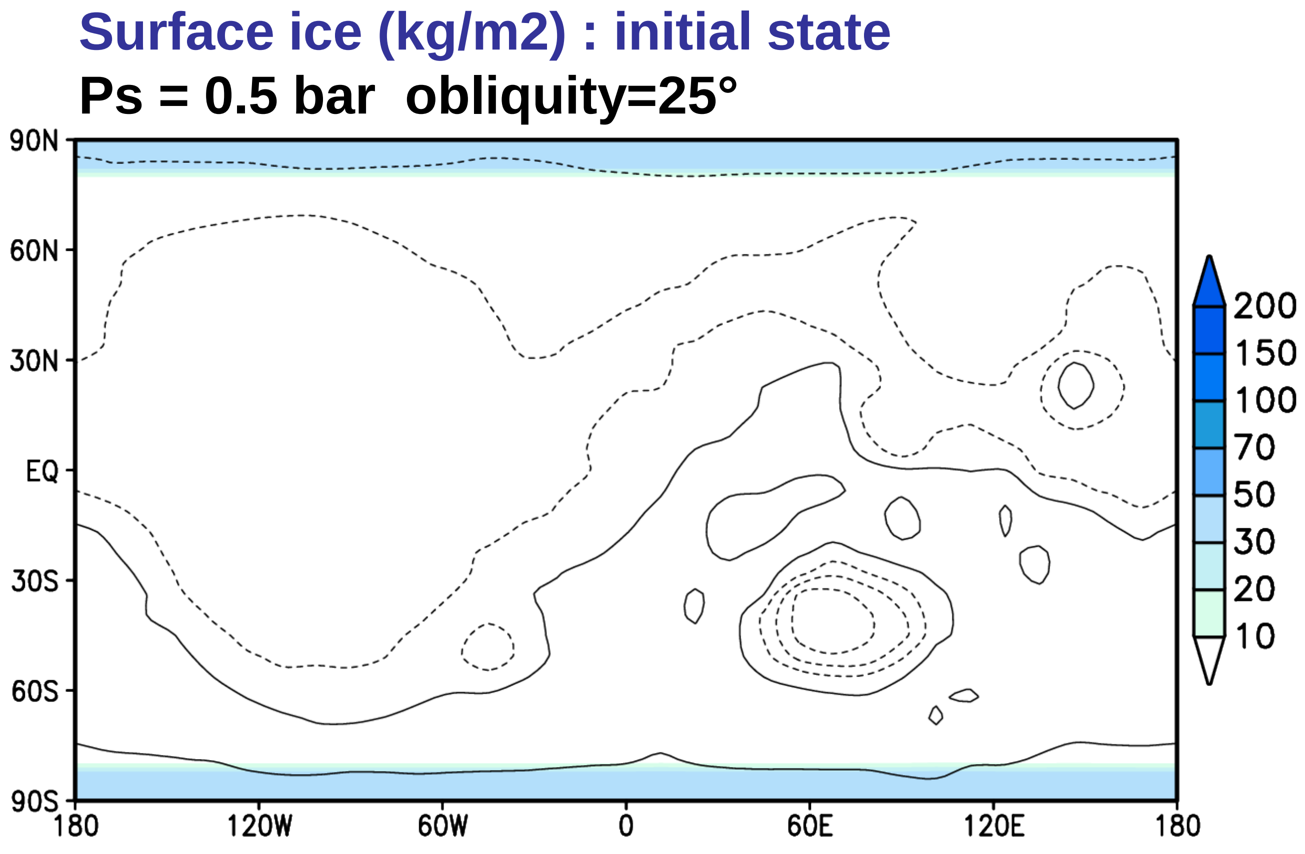


Starting with limited polar caps: HIGHER obliquity (45°)



Starting with limited polar caps: REMOVING THARSIS

Next step: remove the LHB basin

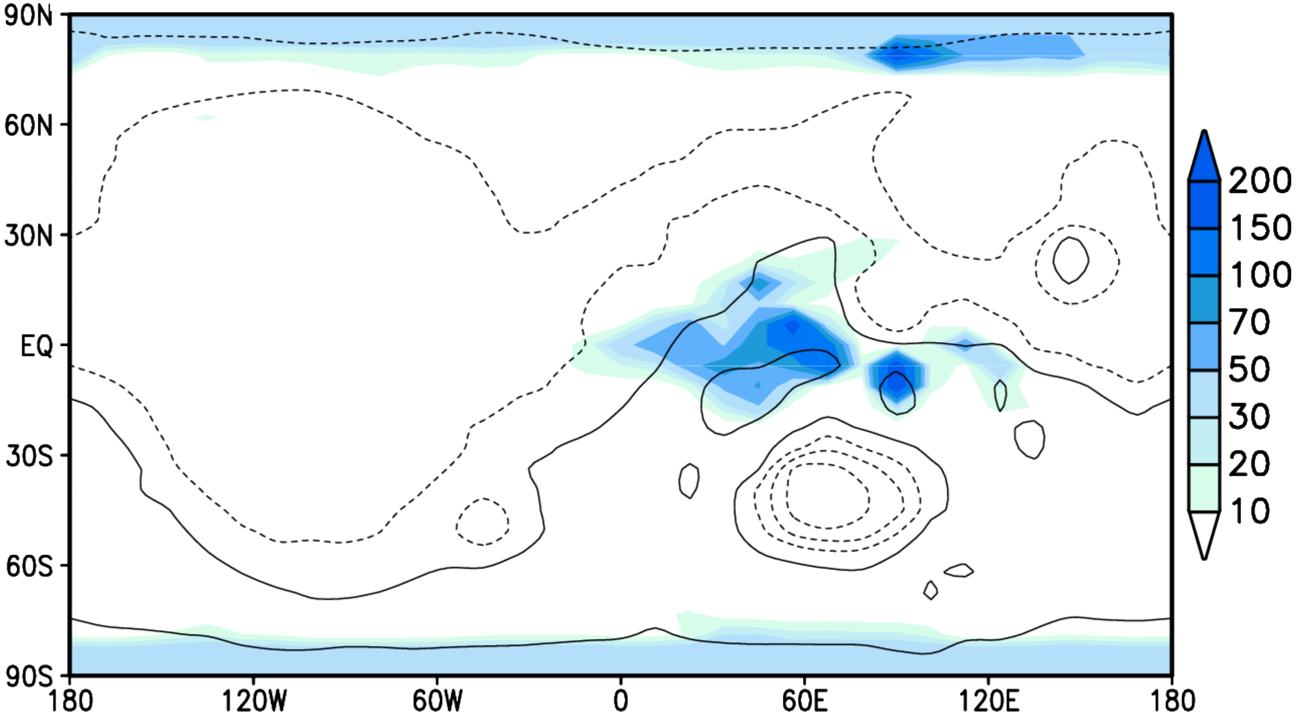


Starting with limited polar caps: REMOVING THARSIS

Next step: remove the LHB basin

Surface ice (kg/m2) : AFTER 50 years

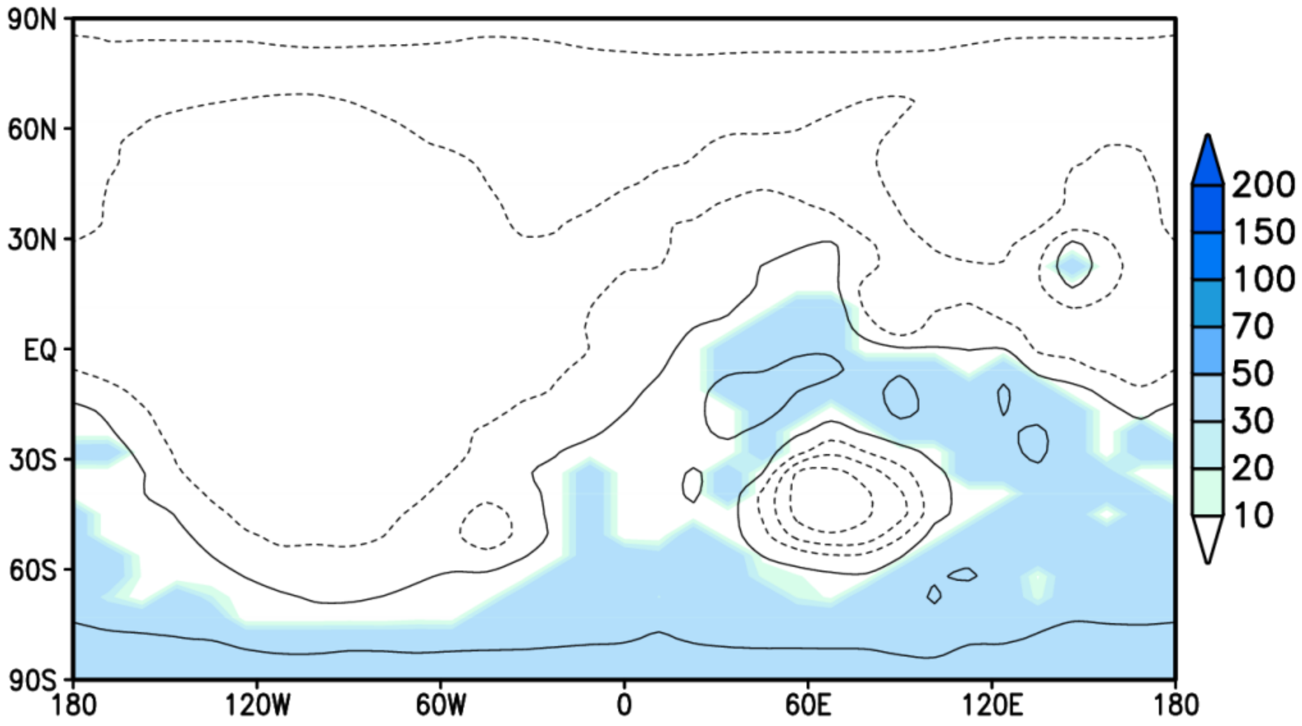
Ps = 0.5 bar obliquity=25°



Starting with a global ice sheet on the colder plateau

Surface ice (kg/m2) : Initial state

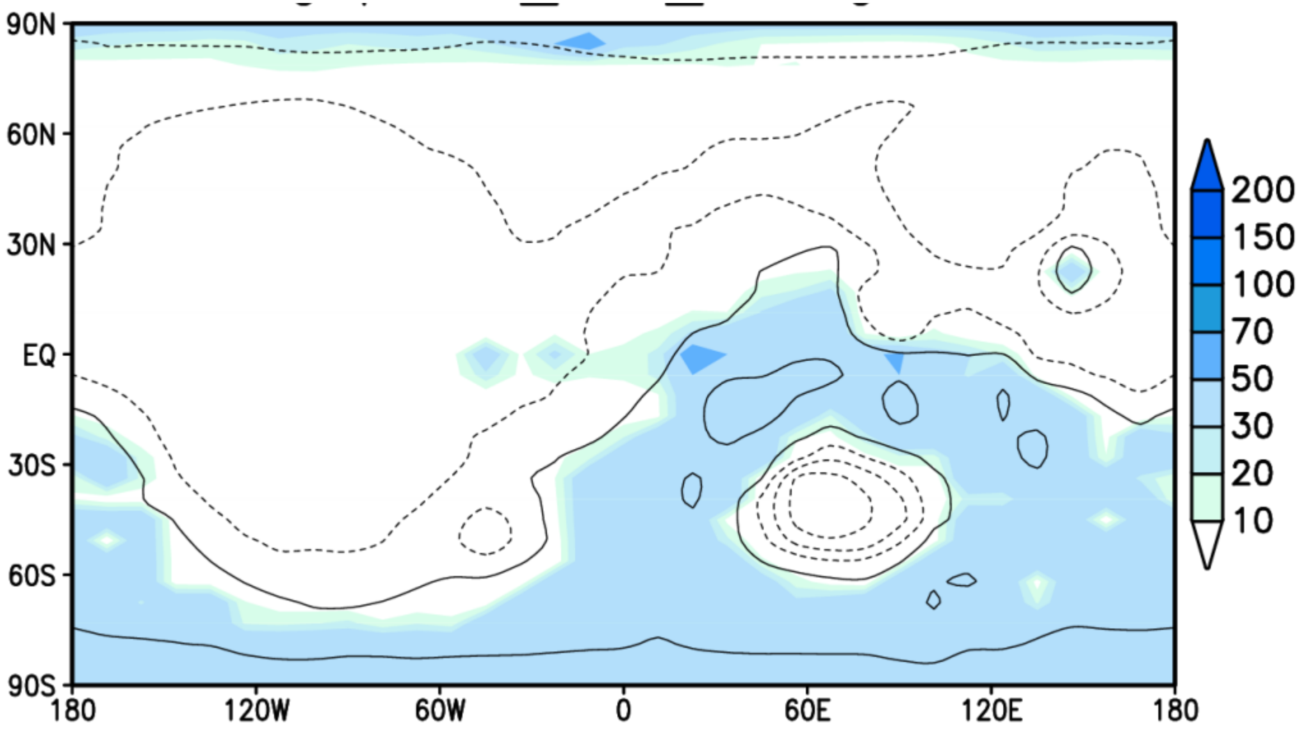
Ps = 0.5 bar obliquity=25°



Starting with a global ice sheet on the colder plateau

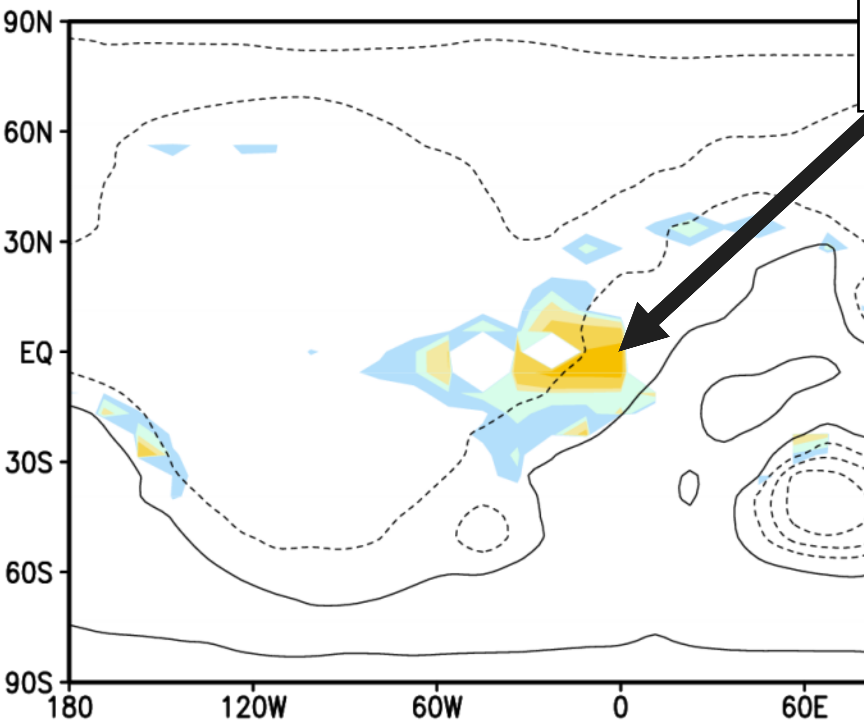
Surface ice (kg/m2) : AFTER 50 years

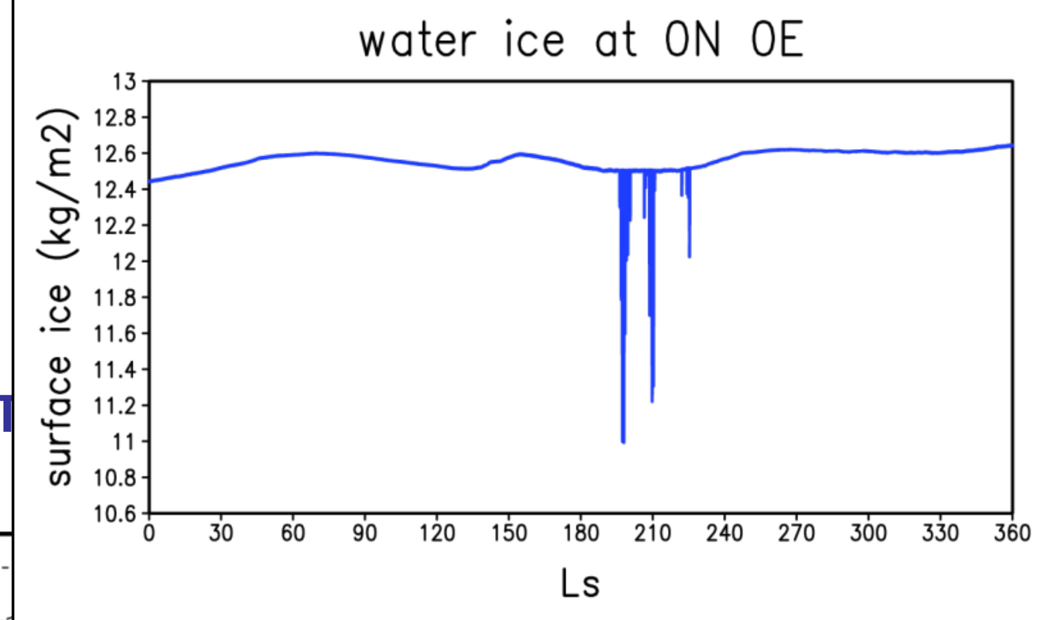
Ps = 0.5 bar obliquity=25°

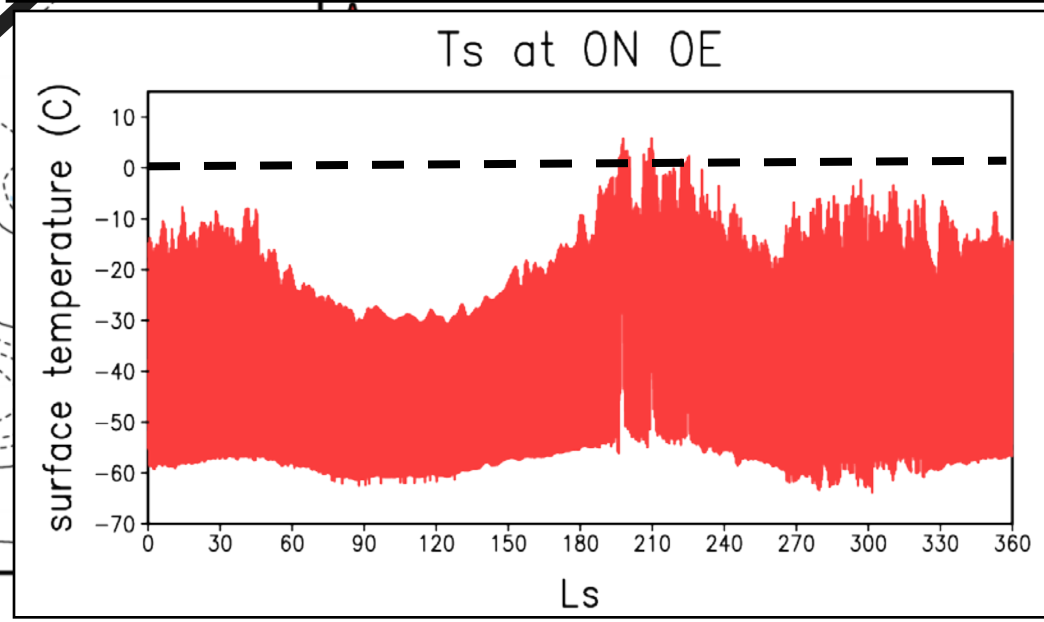


Starting with a global ice sheet

MELTING ice (arb. units) : AFT
Ps = 0.5 bar obliquity=25°

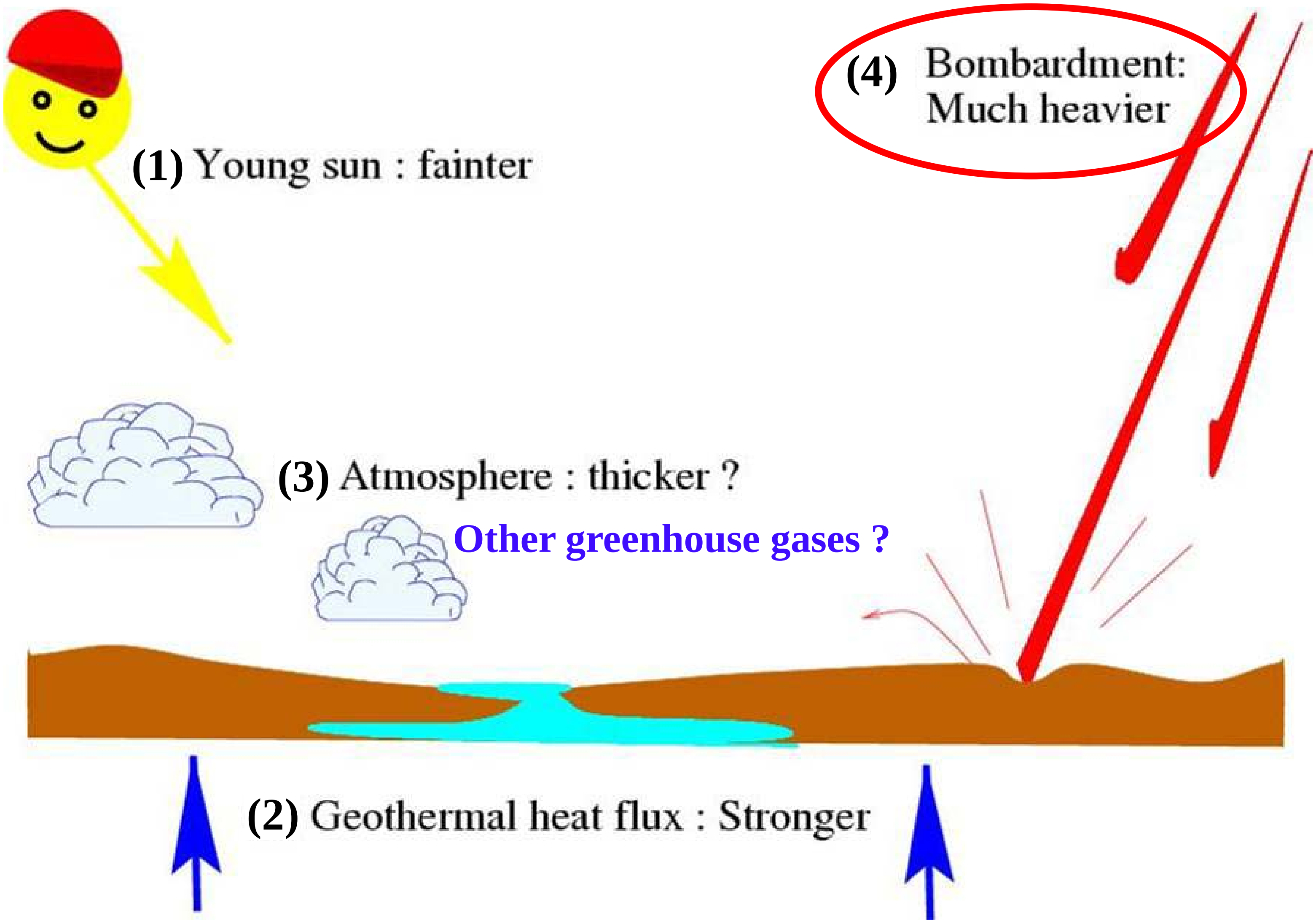






Why was early Mars different ?

Different boundary conditions compared to present :



Rôle of Impacts ?

- Valley networks and many landforms related to liquid water are contemporaneous with the large impacts from the late heavy bombardments
- Impacts:
  - **Local melting of ice if present** (glaciers, mantling, etc.)
  - **Large impacts can create a "steam atmosphere"** and then rain (Segura et al. 2002, 2008, Toon et al. 2010):
    - So far, the erosion rate estimated from the visible impacts is much lower than what is observed by geologists…
    - Very complex process to model !

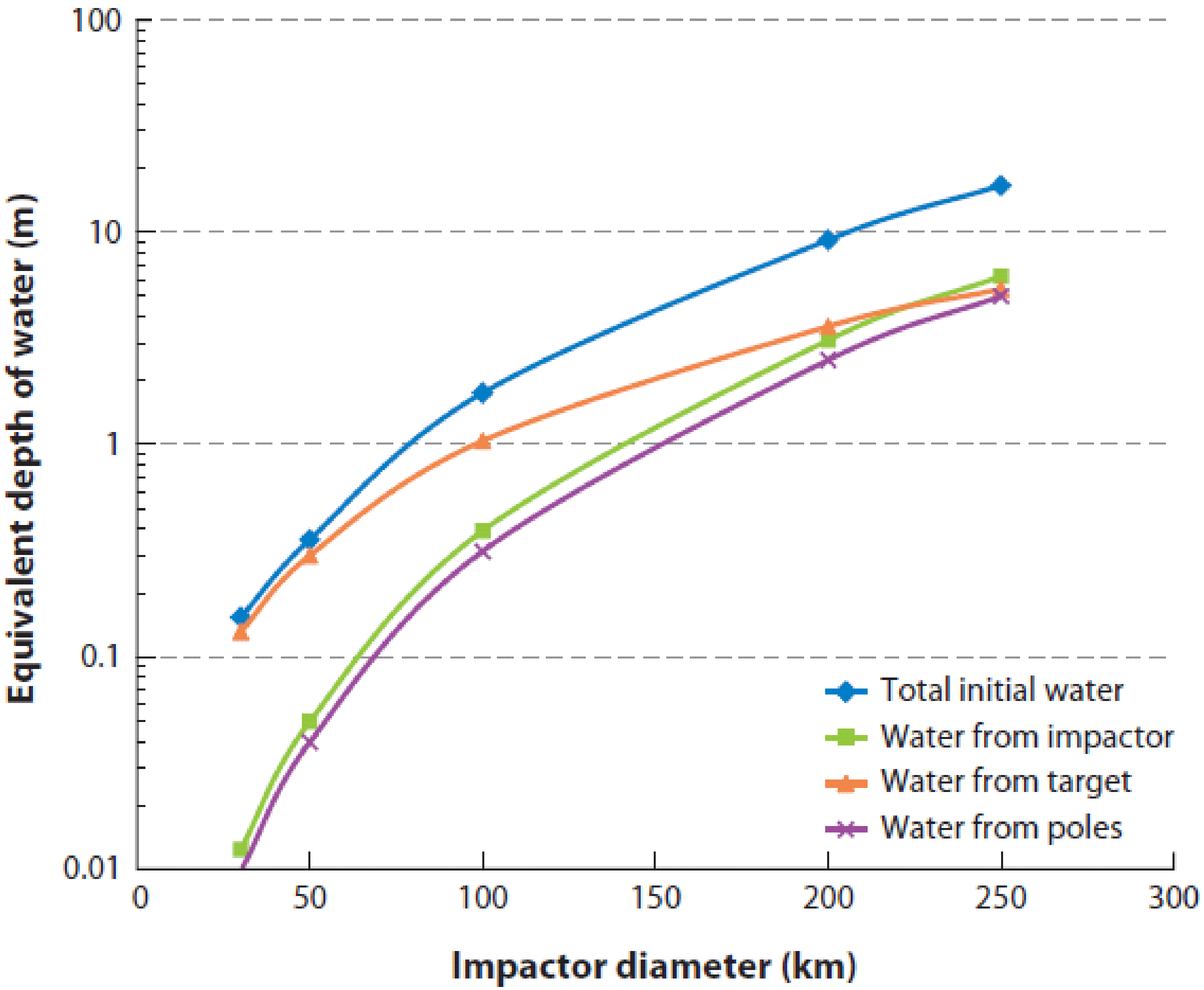


Figure 4

The amount of water mobilized from the impactor, crater, and poles that remains on the planet after the impact, along with their total. From the model of Segura et al. (2002). The amount of water is given as the depth of an equivalent global layer of liquid water.

Toon et al. 2010

Conclusions 2 : "ancient" climate

Why was early Mars different ?.

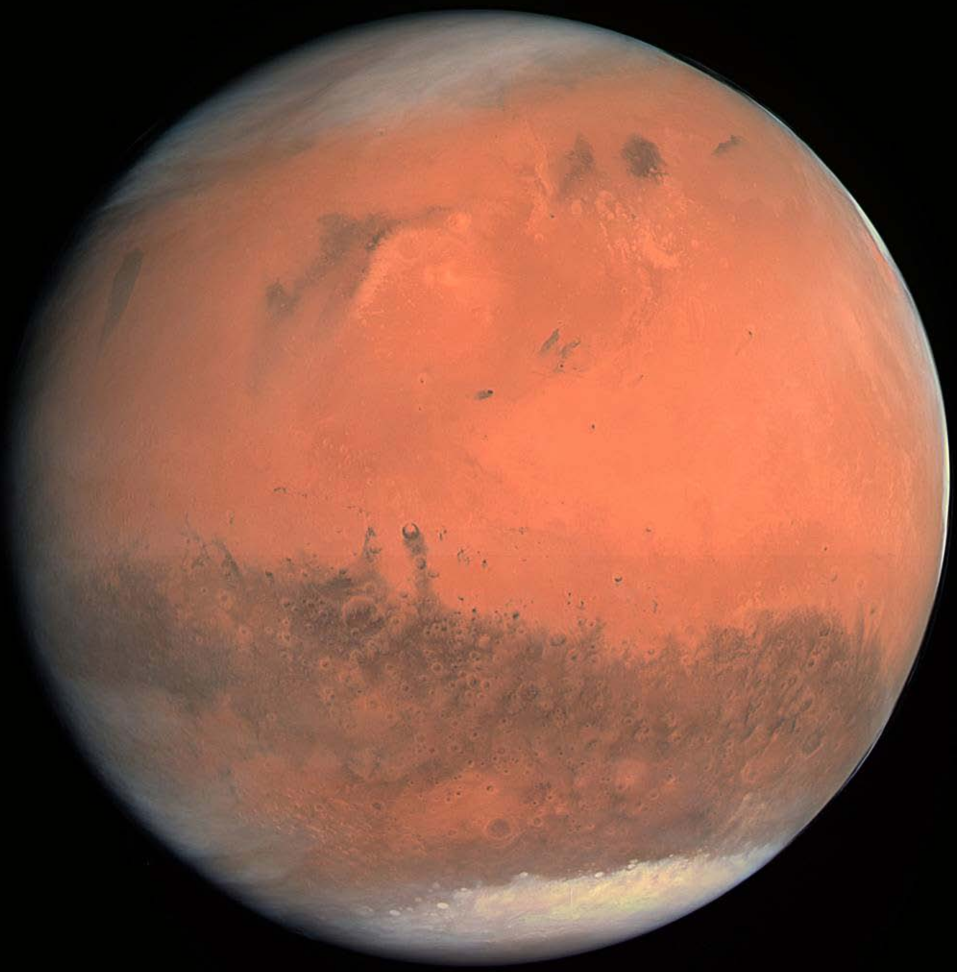
"Warm and wet Mars" thanks to a strong greenhouse effect ?

– CO2 gas greenhouse effect lower than previously thought

– Warm, wet Mars possible, BUT with very thick CO_2 atmosphere : probably not realistic

⇨ Key questions remains:

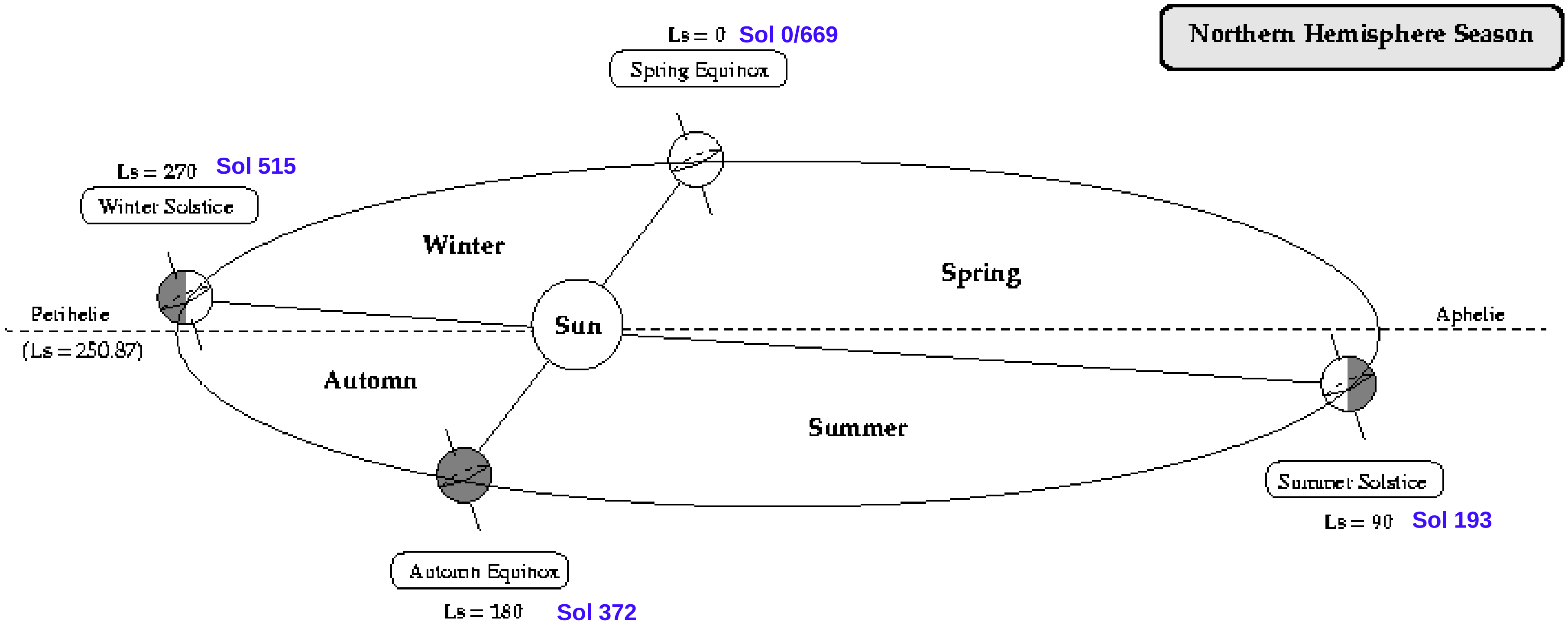
- Were the conditions suitable for liquid water episodic or stable on longer time scales ?
- Role of glaciers, hydrothermalism ?
- Role of Impacts ?



Back to present-day Mars

The Martian Calendar

Date: Ls = Solar longitude   1 Martian days= 1 sol = 88775 s = 24h40'



Martian years (now used by most of the community) (Clancy et al. 2000) :

- « Martian year 1 » start on april 11,1955

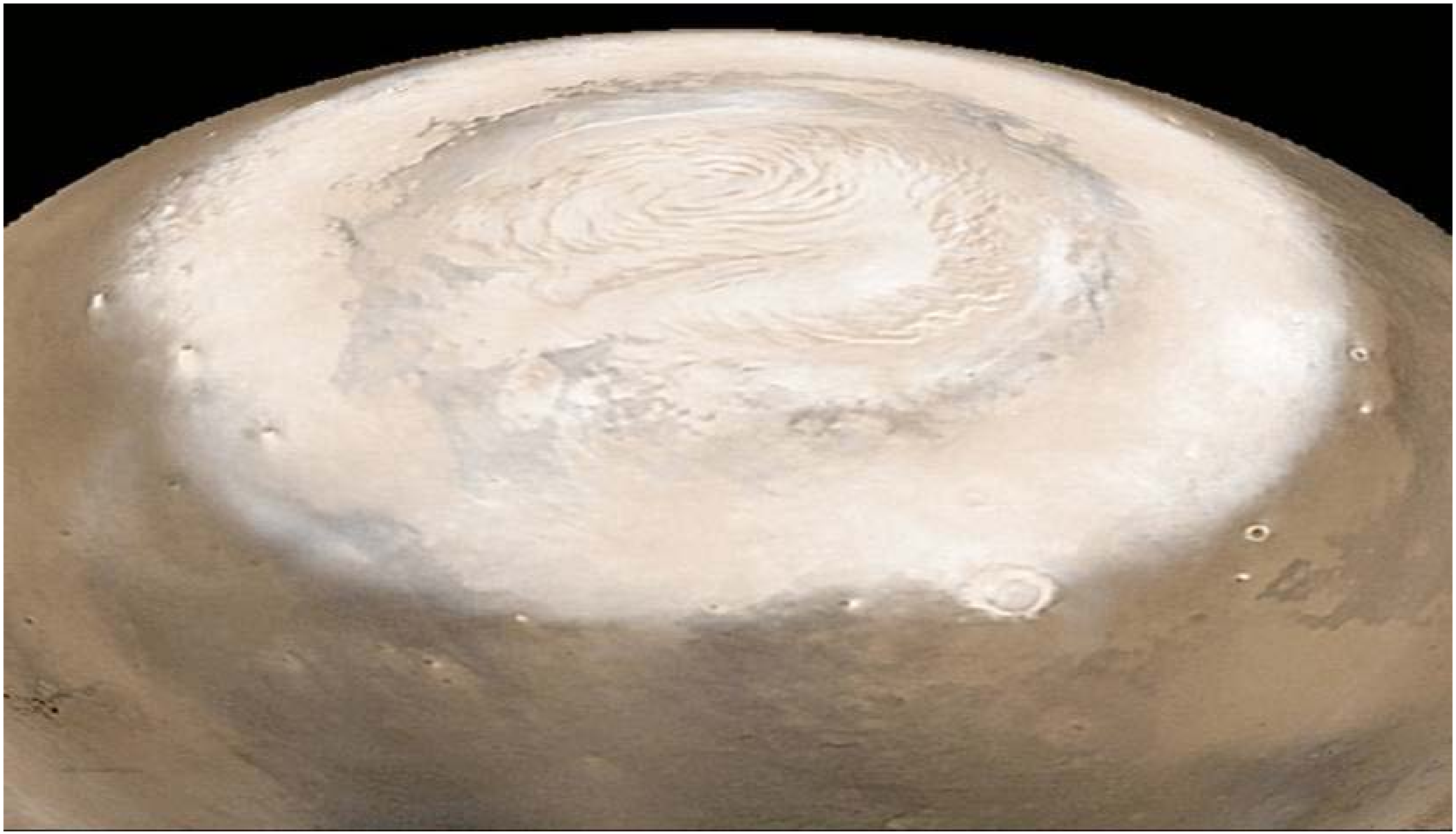
- « Martian year 24 » = 1999-2000 , 25 = 2001-2002, 27 = 2004-2005, etc…

- Today we are Ls= 320° , Martian year 30

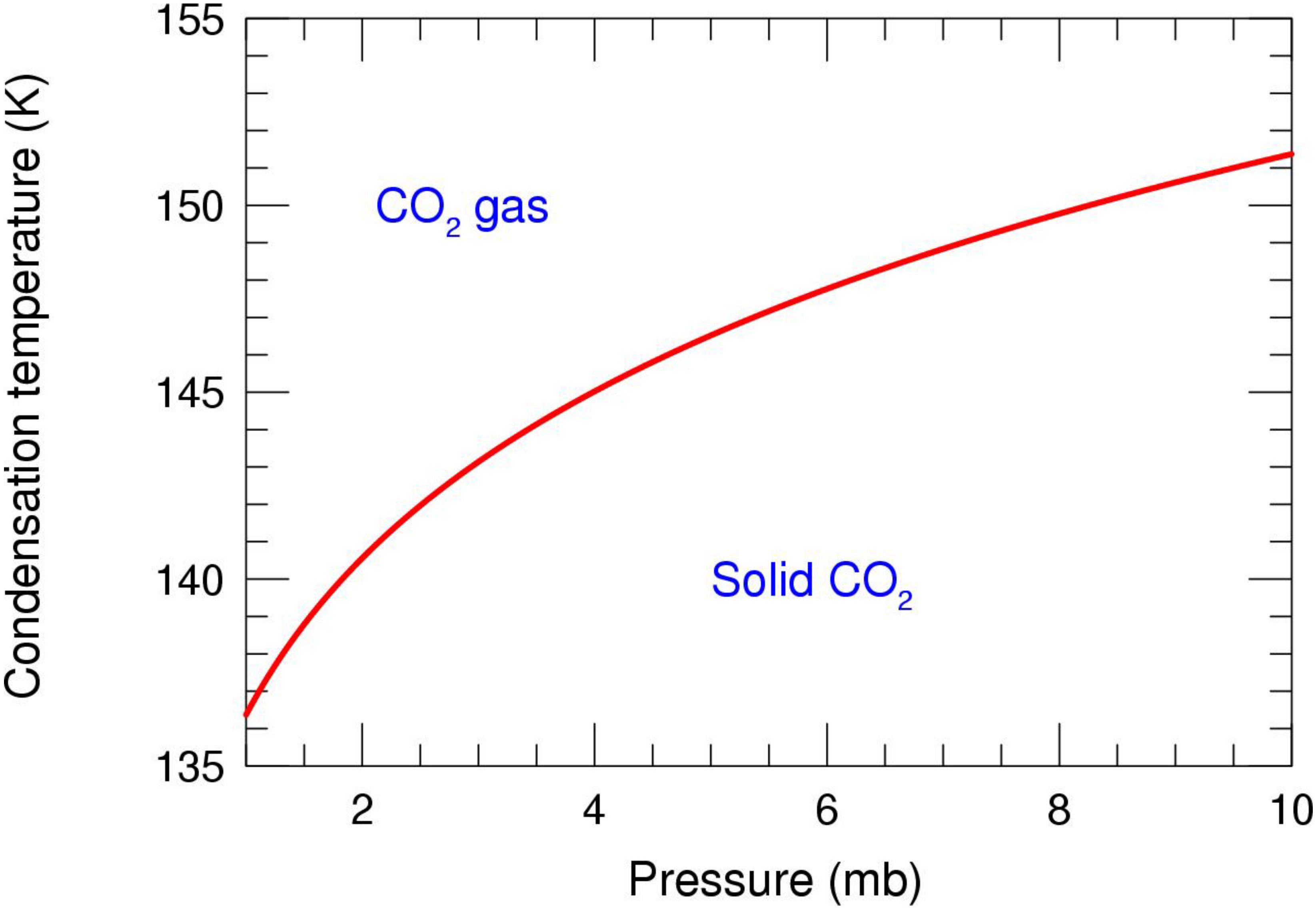
Earth-Mars date Converter: http://www-mars.lmd.jussieu.fr/mars/time/martian_time

Mars CO_2 cycle

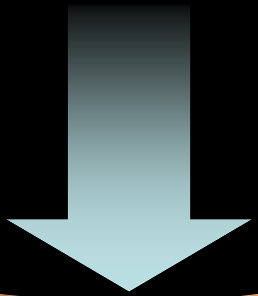
(mosaic of the northern polar cap in spring)



CO_2 phase change on Mars



Winter : polar night

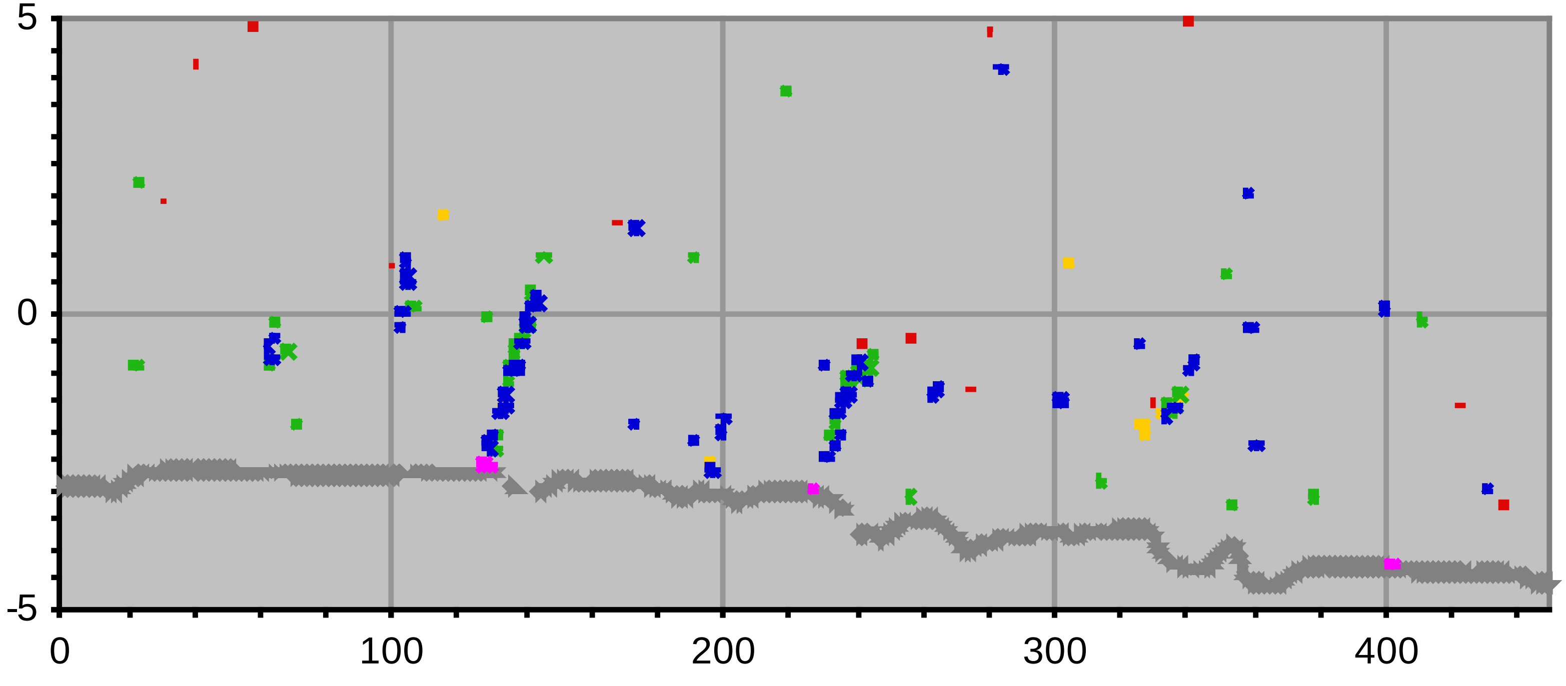


145K

Different kinds of polar CO2 ice clouds observed by the laser altimeter MOLA

(Pettengill and Ford 2000)

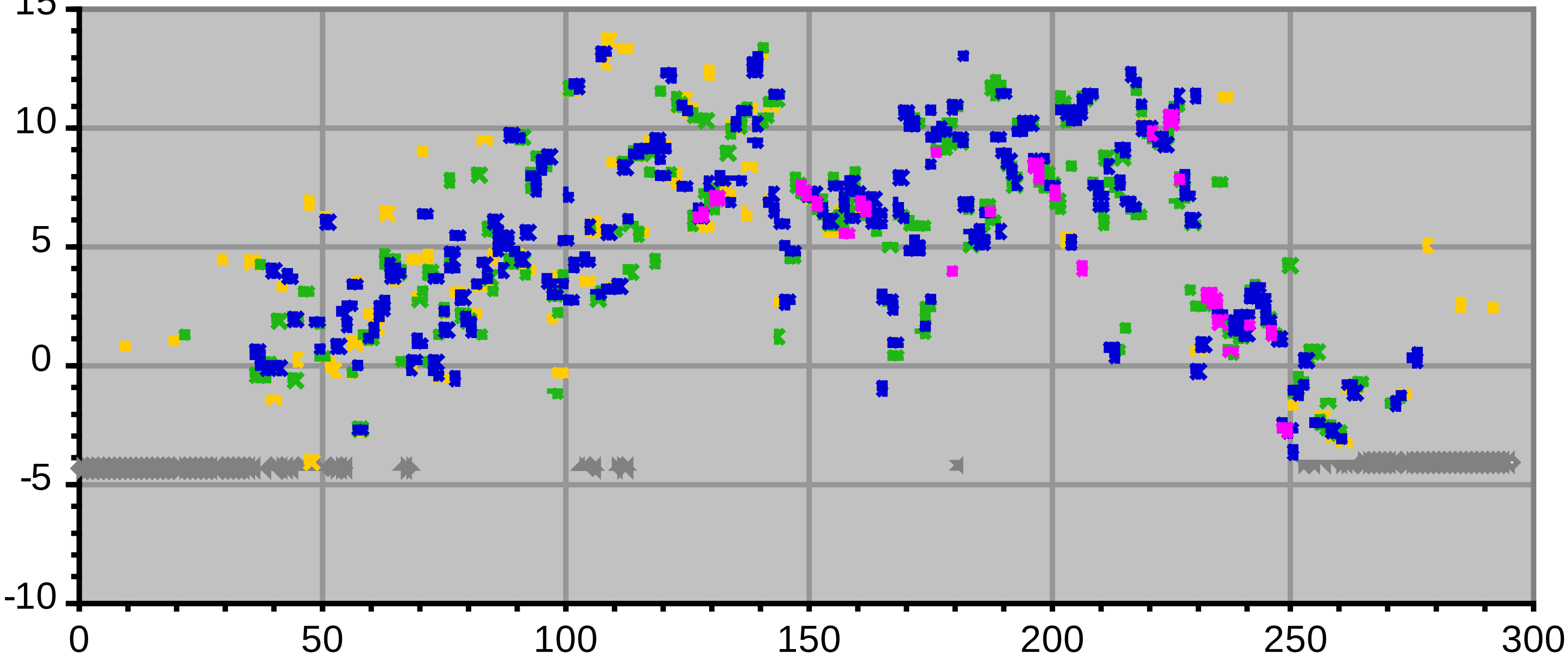
Isolated clouds linked to topography features



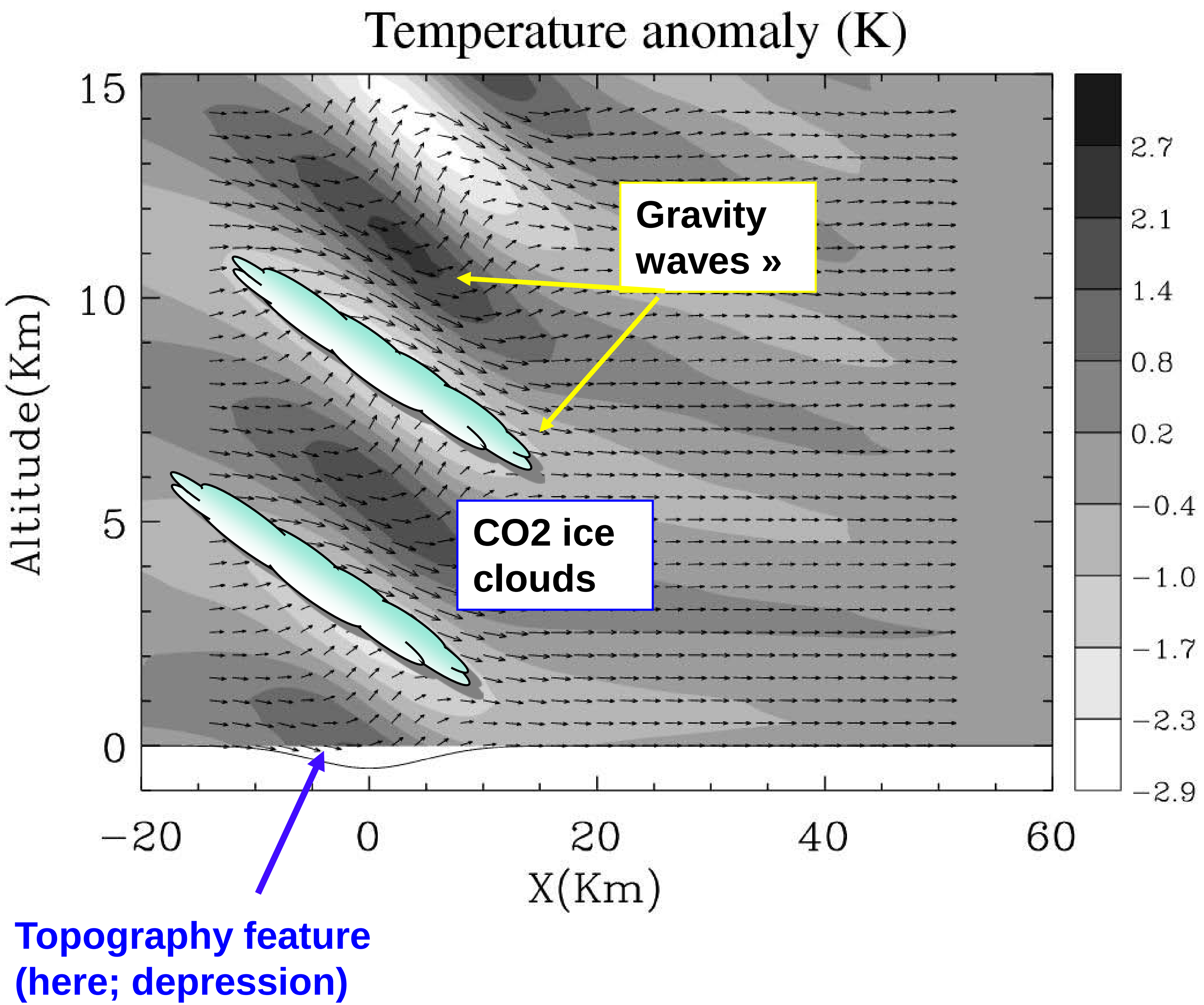
Different kinds of CO2 ice clouds observed by the laser altimeter MOLA

((Pettengill and Ford 2000)

Train of clouds ?

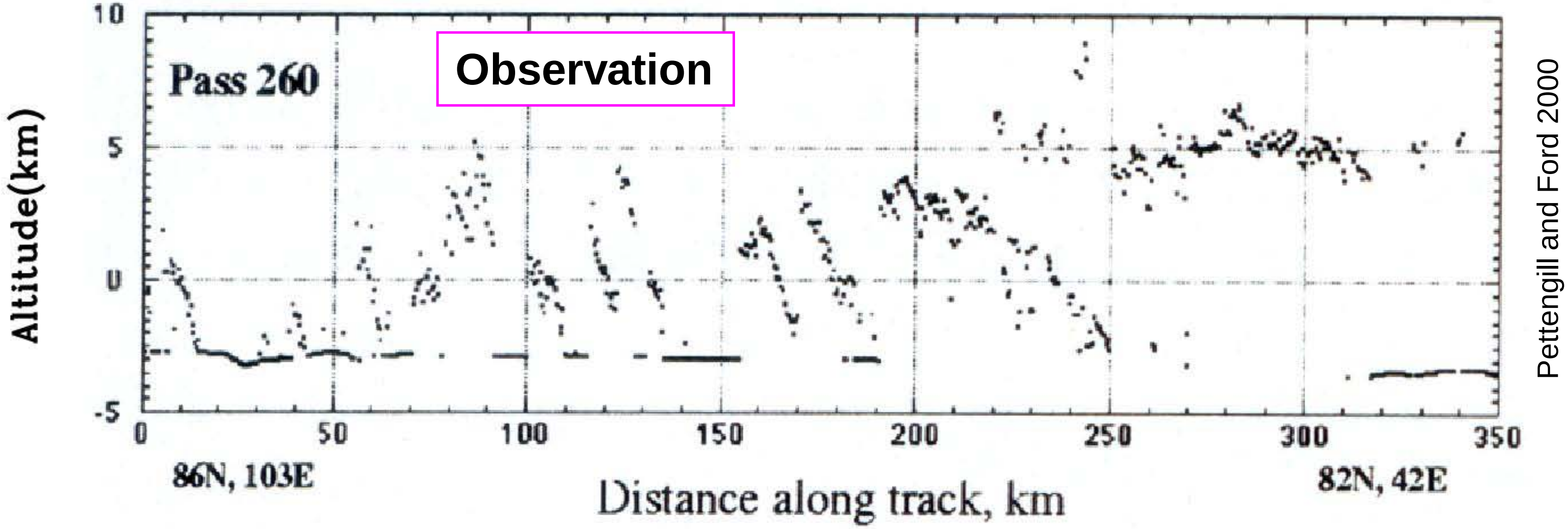


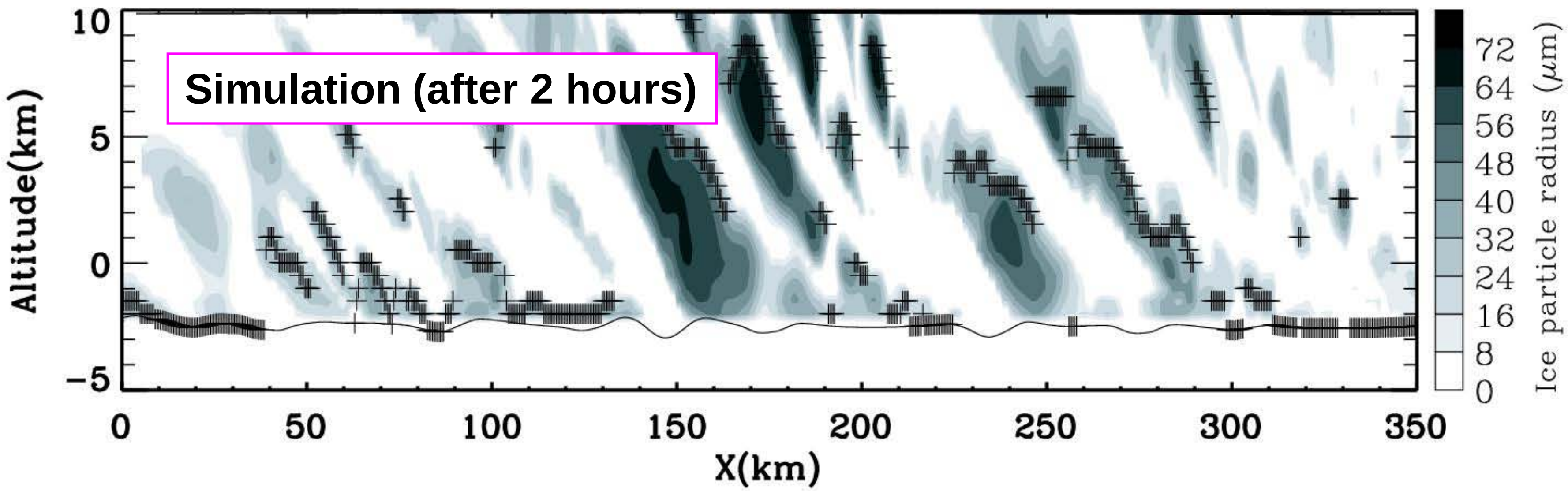
2d Mesoscale modelling in the polar night (Tobie et al. 2003)



Simulation over realistic topography: Large scale flat topography

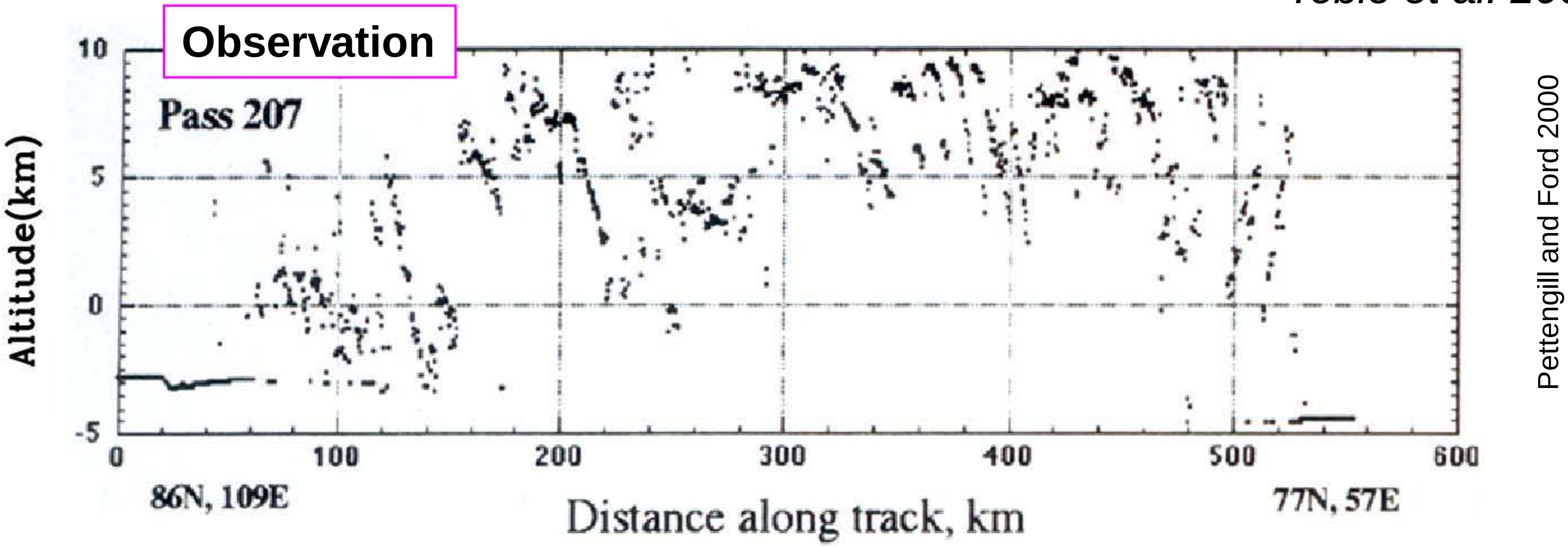
Tobie et al. 2003

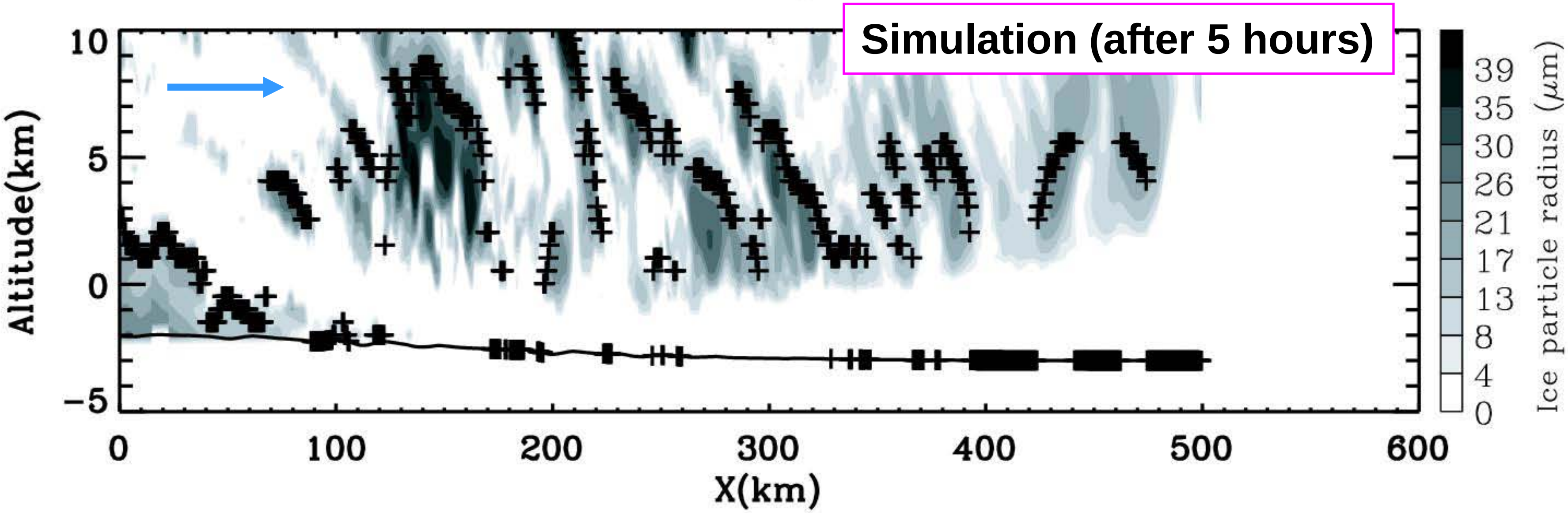




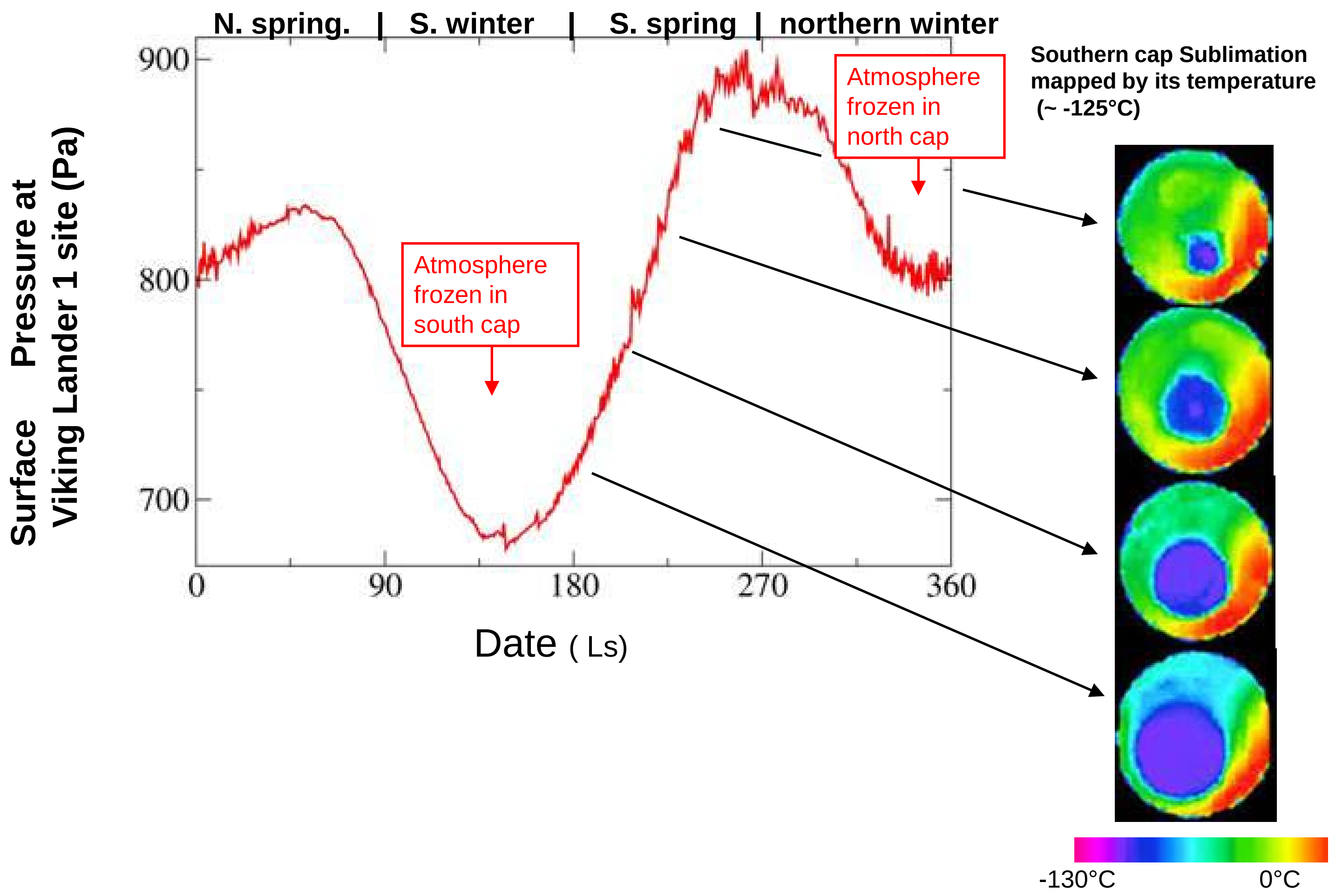
Simulation over realistic topography: Large scale downward air motion

Tobie et al. 2003

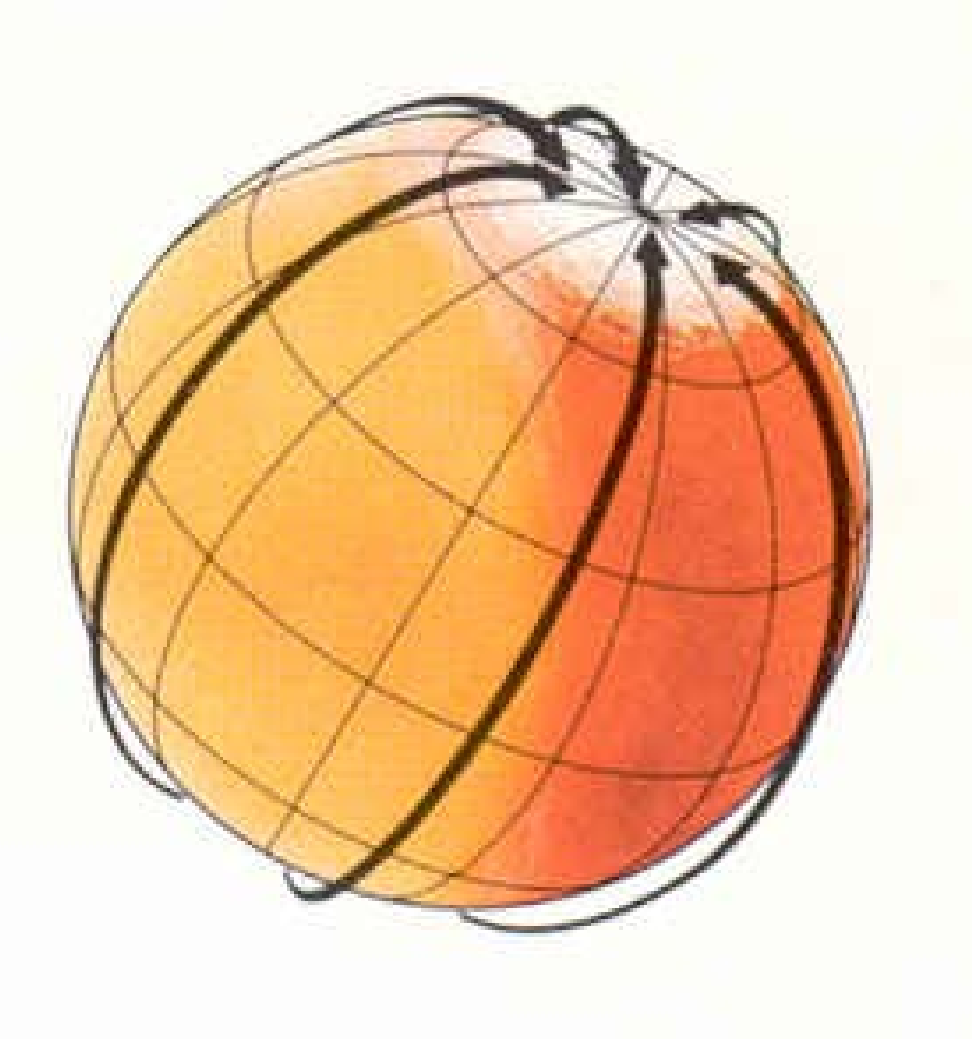




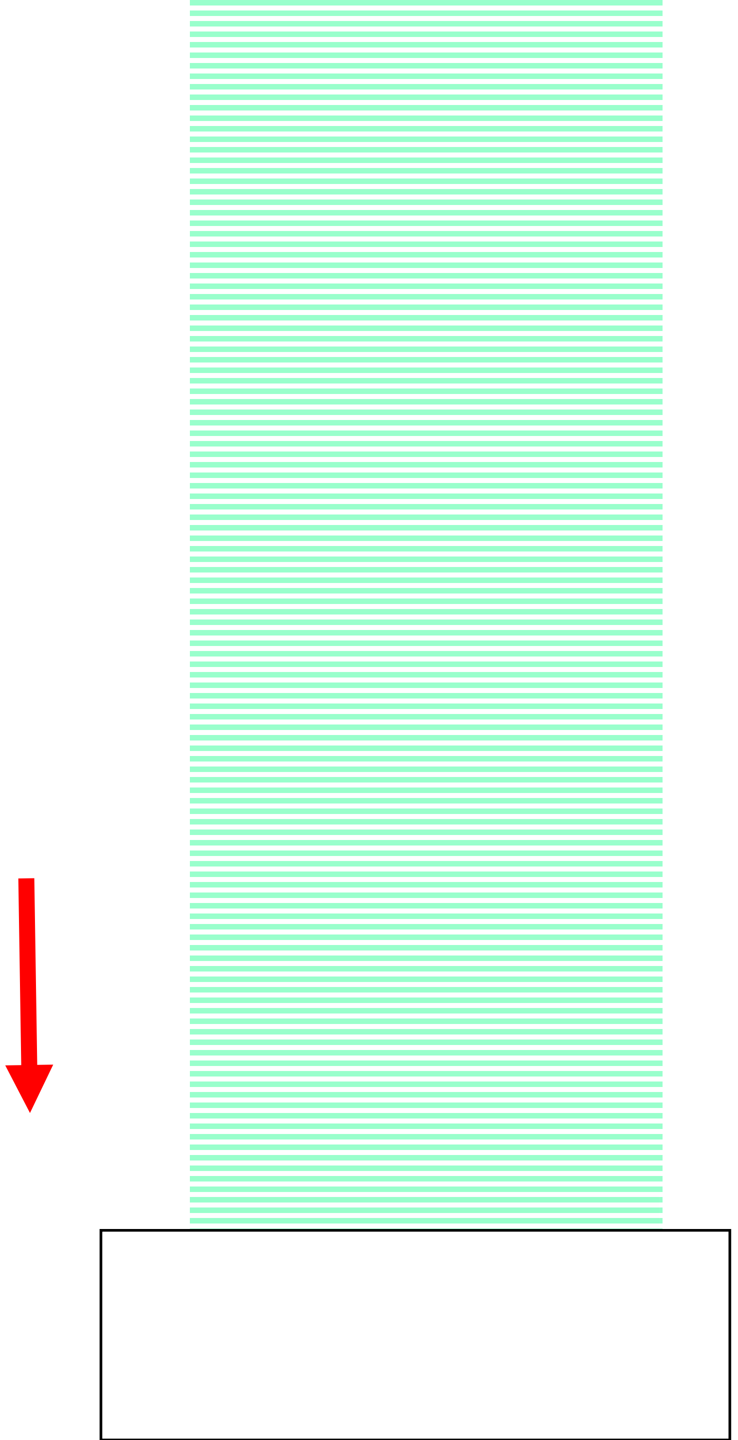
Atmospheric Pressure at Viking 1 Lander site



The condensation flow

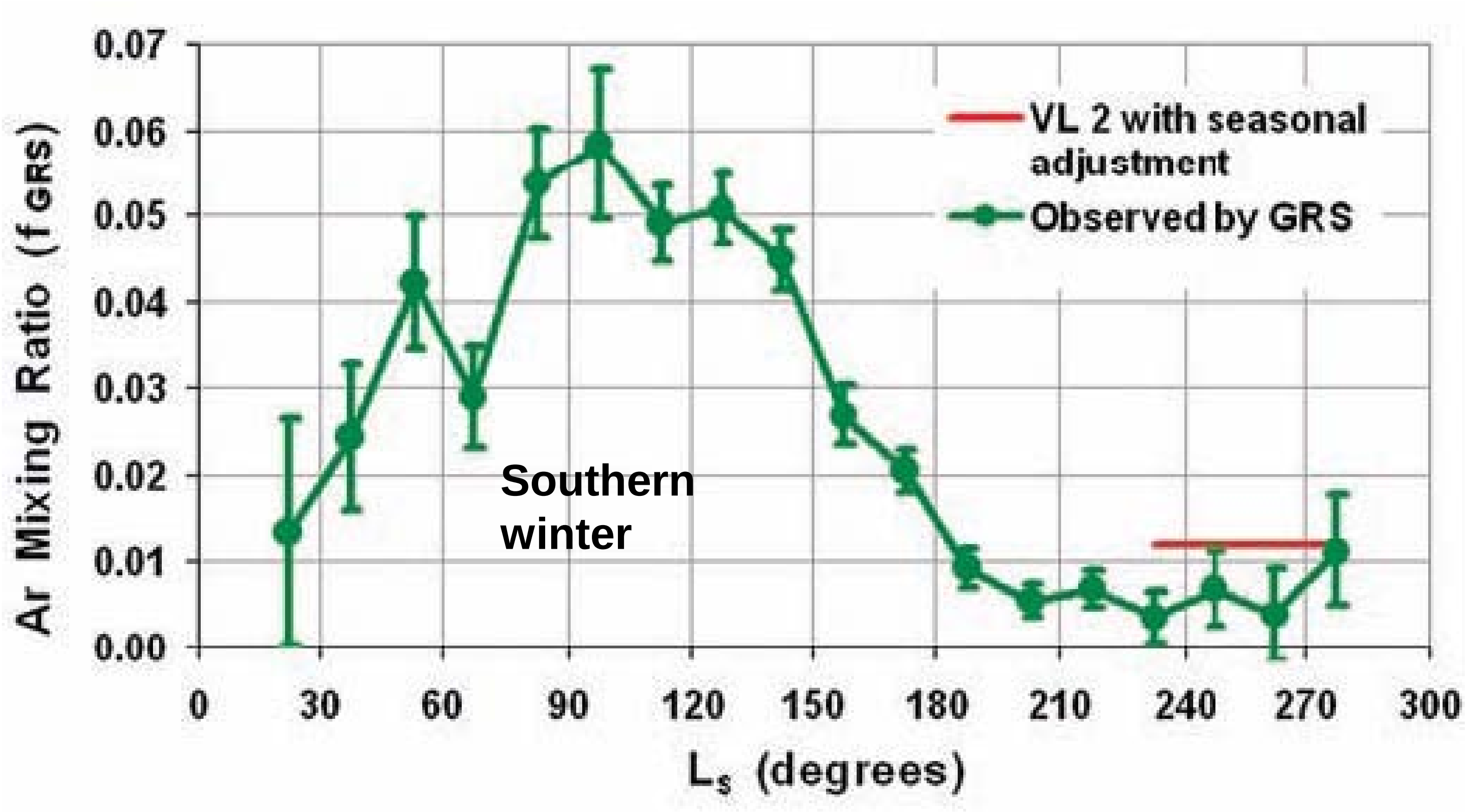


Another polar night phenomenon: Condensation of CO_2 induce enrichment of other gases



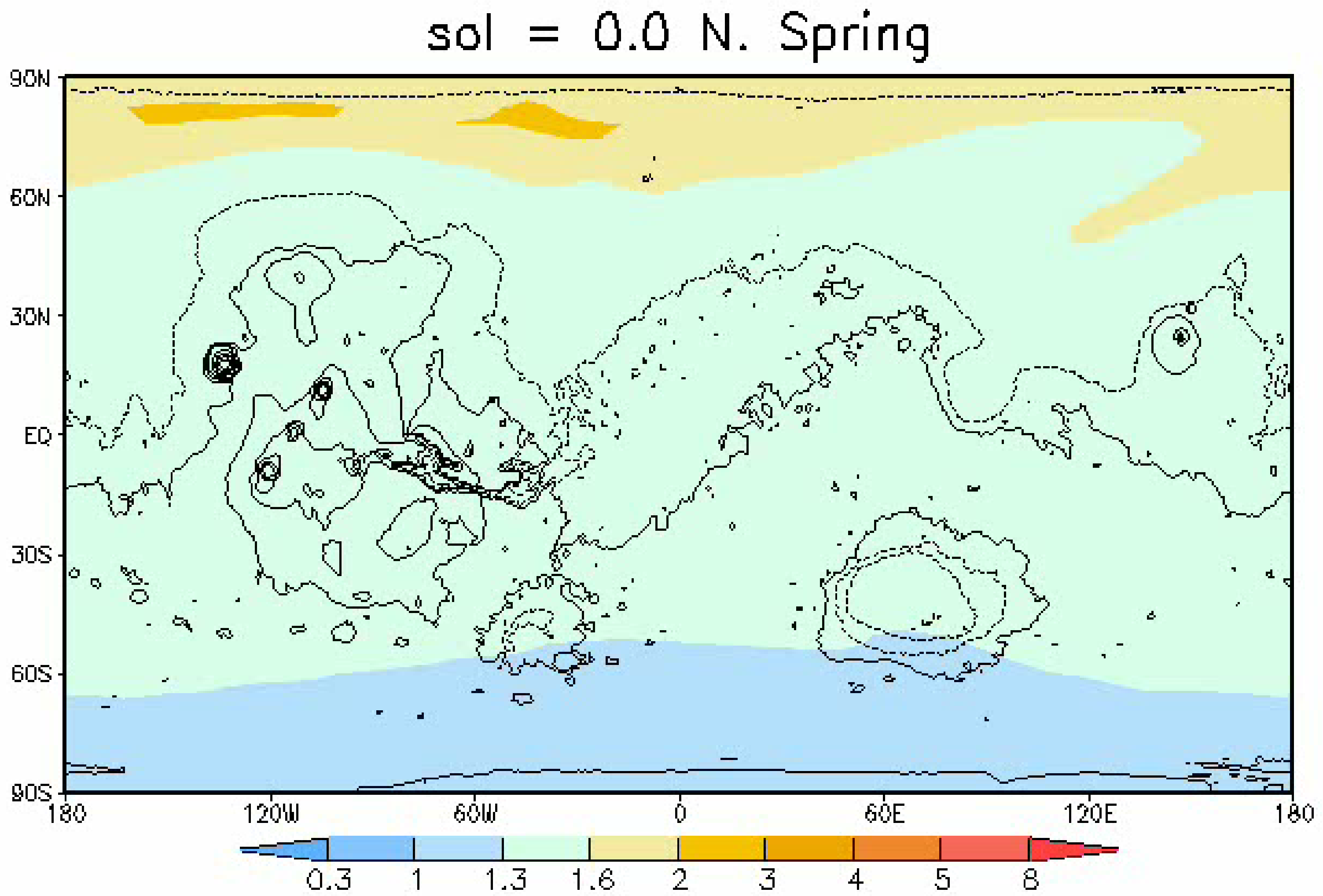
Detection of Argon enrichment due to CO2 condensation by Mars Oddyssey Gamma Ray Spectrometer (GRS)

(mean Ar mixing ratio in 75°S-90°S)



Sprague et al. 2004, 2007

Argon column averaged mixing ratio (%) (LMD GCM simulation)



Change of atmospheric composition near the surface

- In the polar region originally :
  - 95% CO_2,
  - 5% non-condensible gas (N_2, Ar, etc…)
- Only CO_2 condense. Other gas are left behind
- More atmosphere is transported into the polar regions…
- Polar atmosphere is enriched in non-condensible gas (N_2, Ar)

⇨ In the polar night, the near surface composition is different than CO_2 … and less dense :

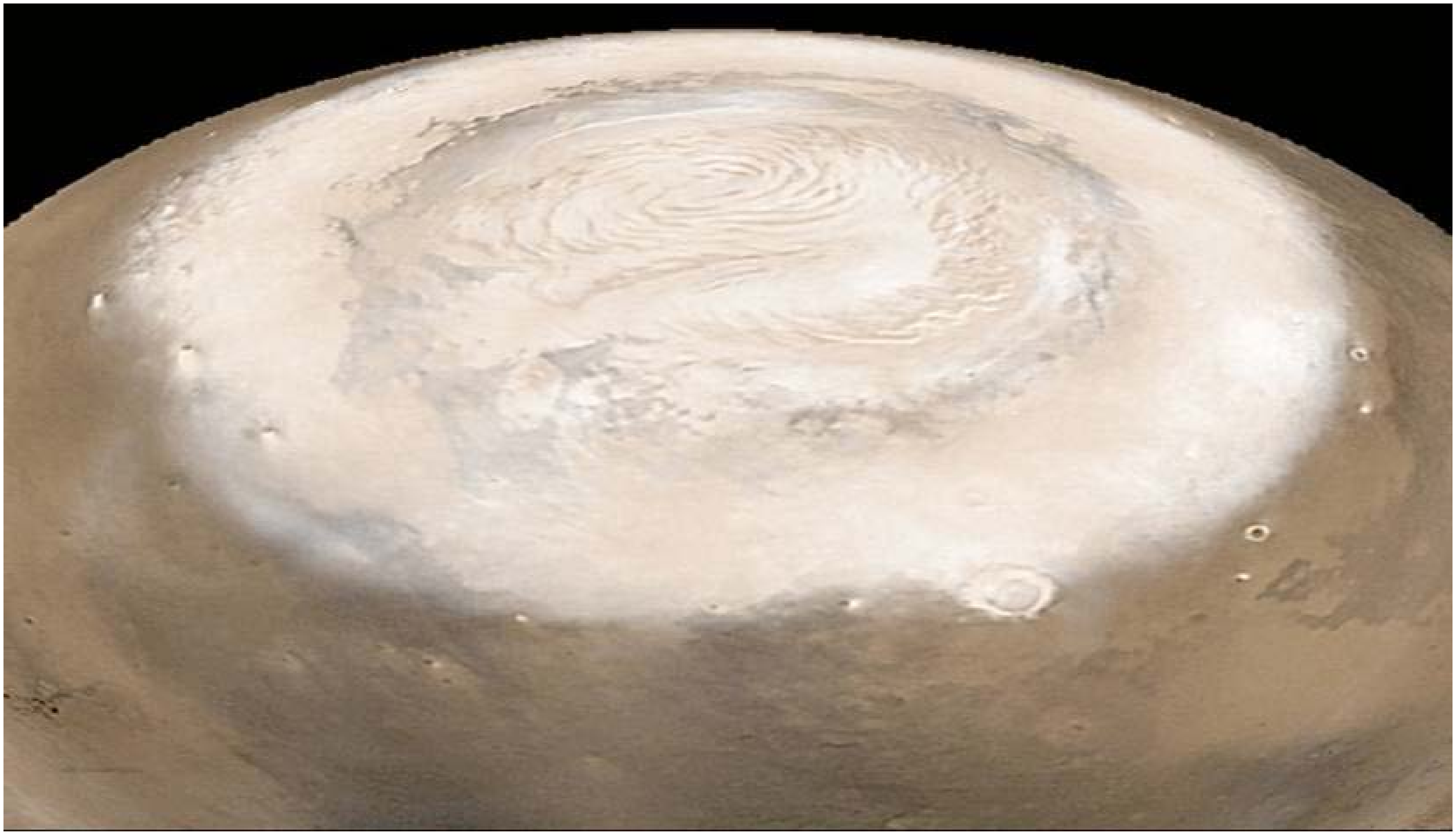
  - CO_2 : m = 44.0E-3 kg mol-1
  - Non-condensible gas (N_2, Ar) m = 32.37E-3 kg mol-1

⇨ Density Induced convection, affect circulation, etc…

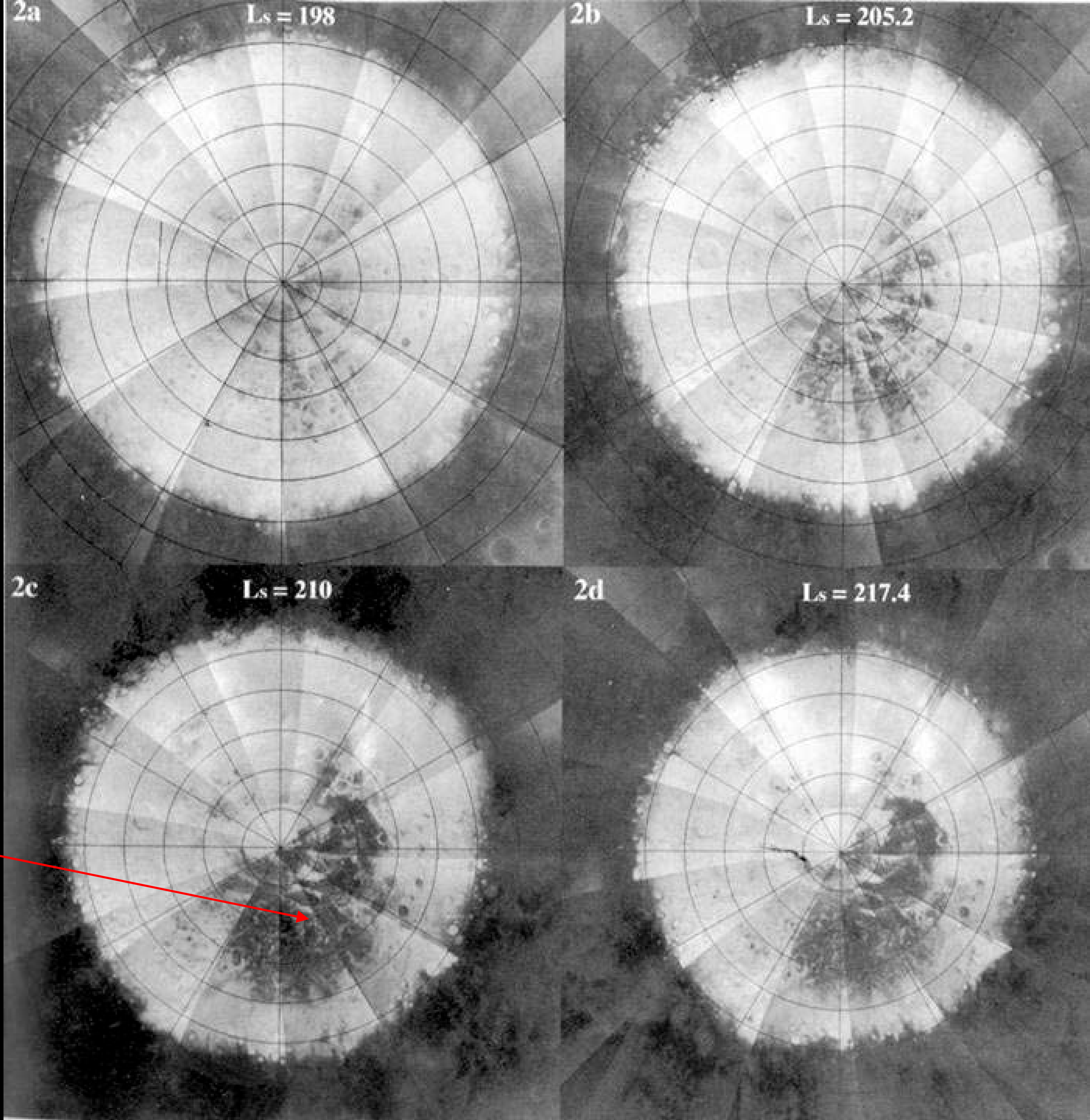
⇨ **Very « alien » meteorology** *(Forget, Science 2005)*

Seasonal CO_2 ice cap in spring

(mosaic of the northern polar cap)

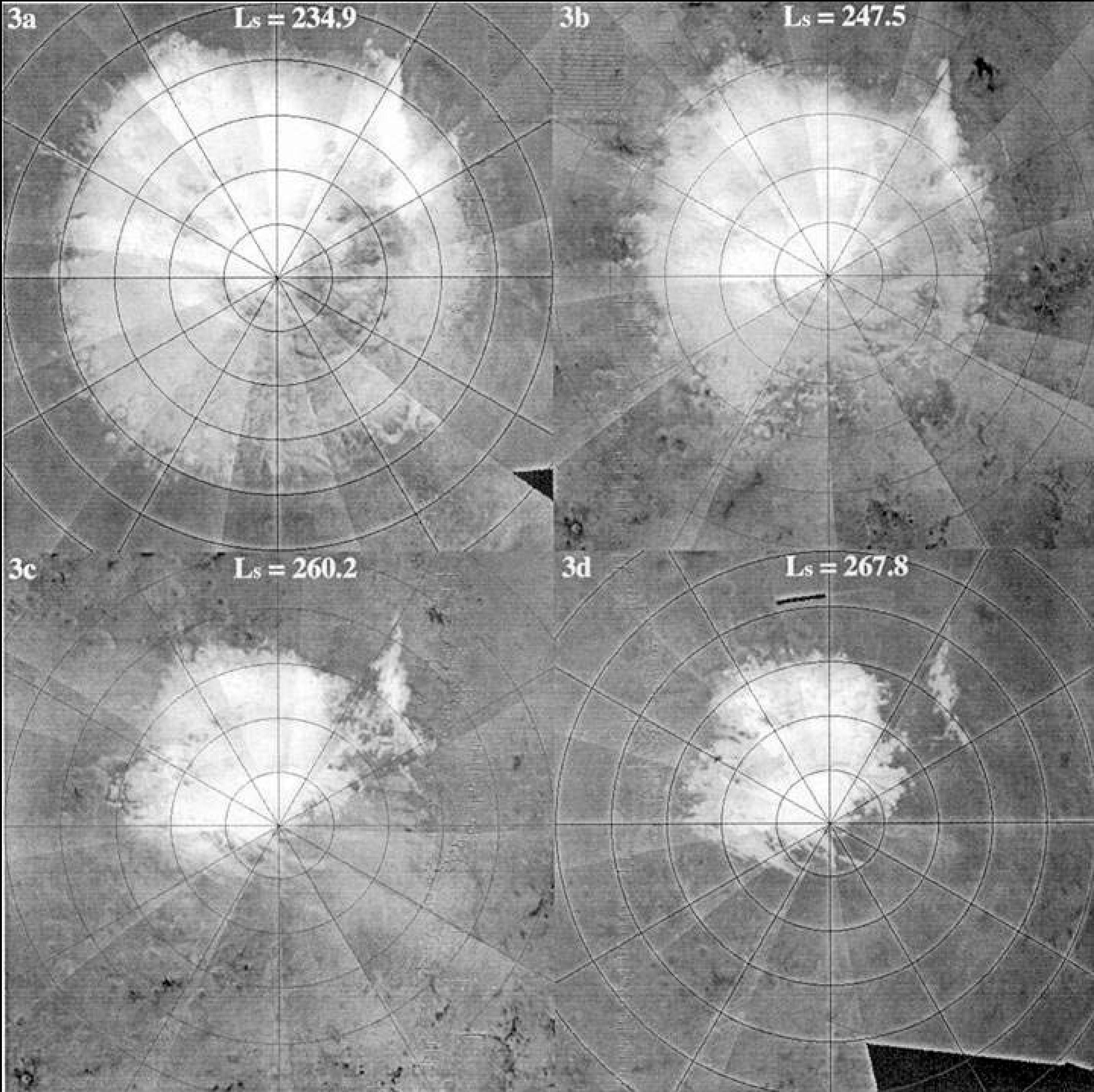


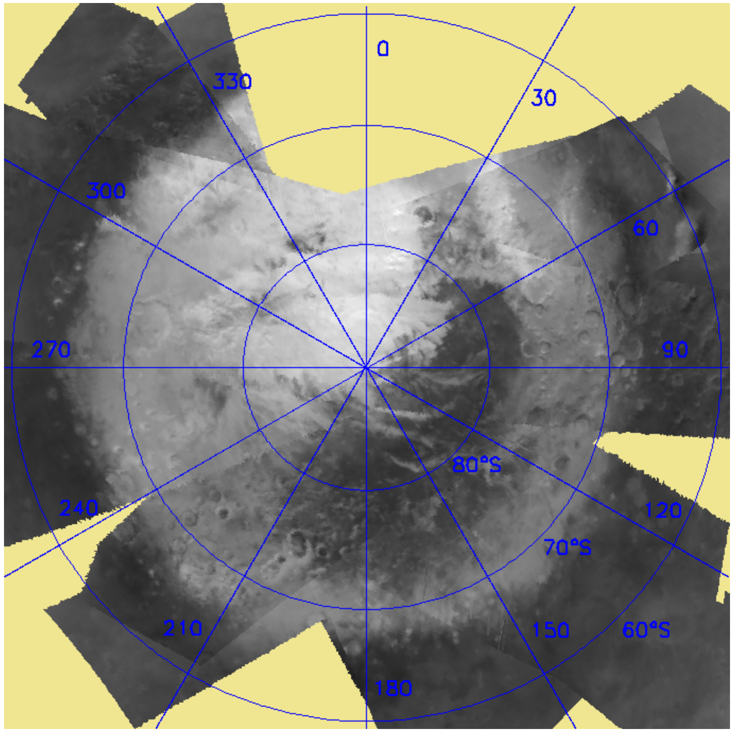
Recession of the south polar cap (*James et al. 2002*)



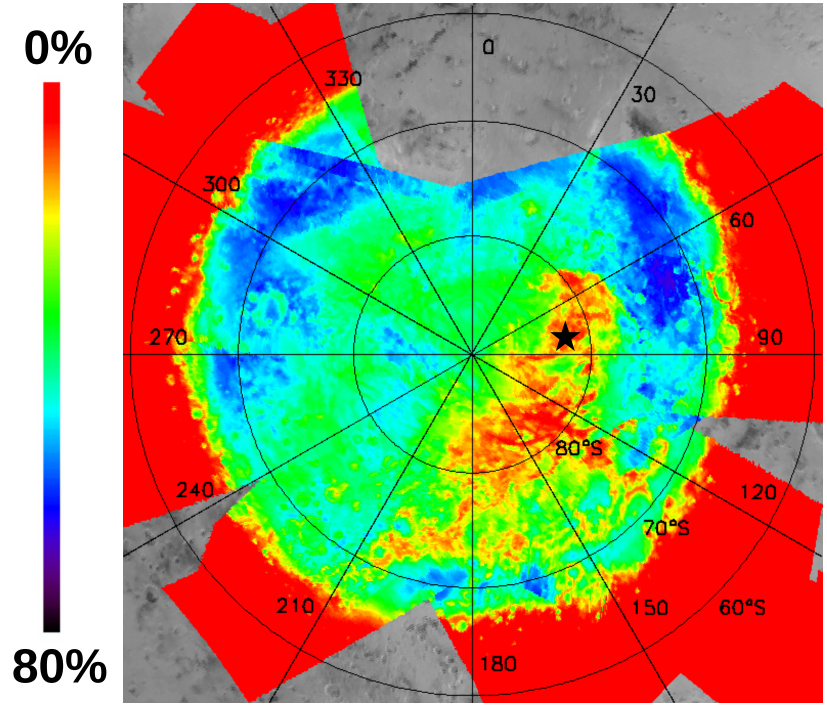
Cryptic region: Dark, but remains at CO2 frost temperature !

Recession of the south polar cap (*James et al. 2002*)





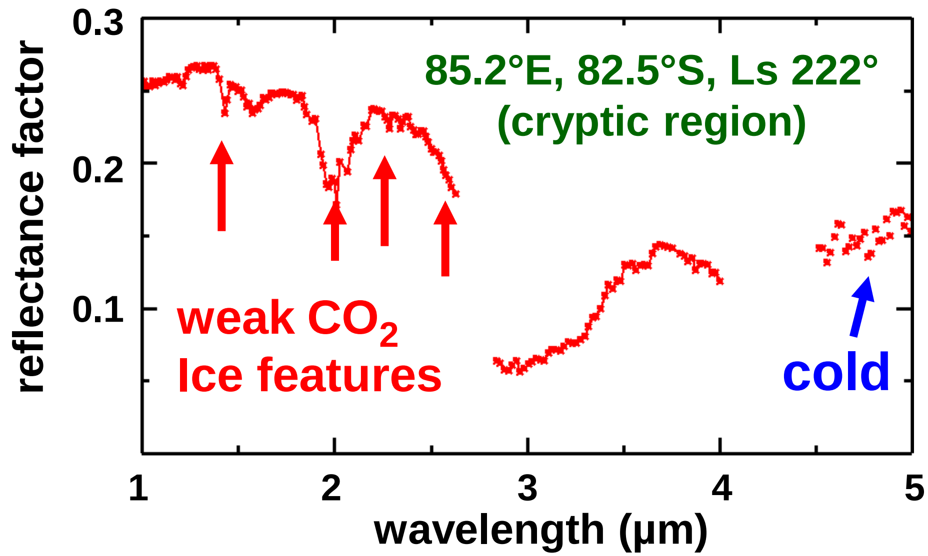
Ls 222°



CO_2 ice band depth (1.435 μm)

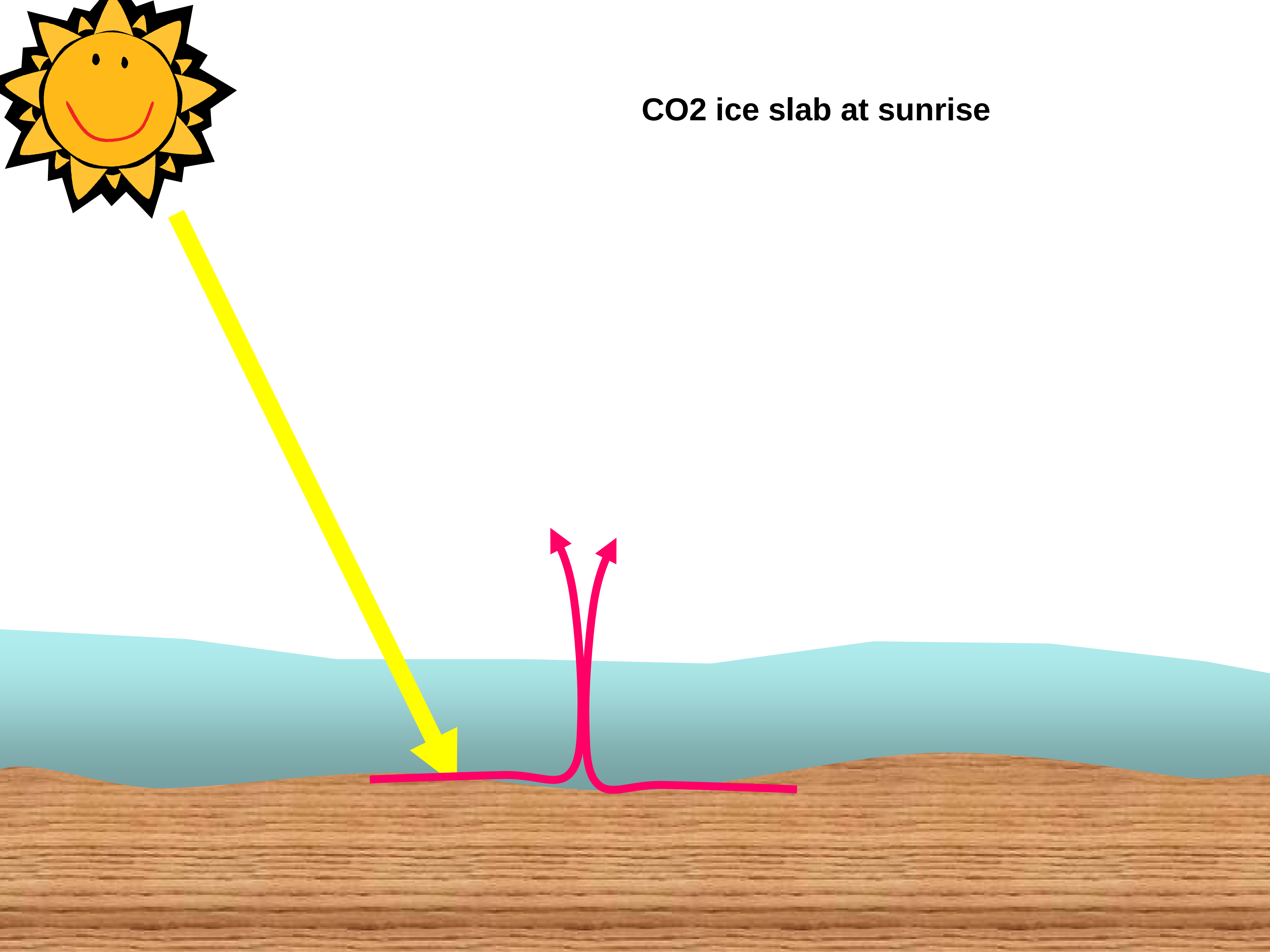
« Cryptic region » (Ls 195° – 235°)
Seen by Mars Express OMEGA
Imaging spectrometer

CO_2 ice is <u>covered</u> by dust !!

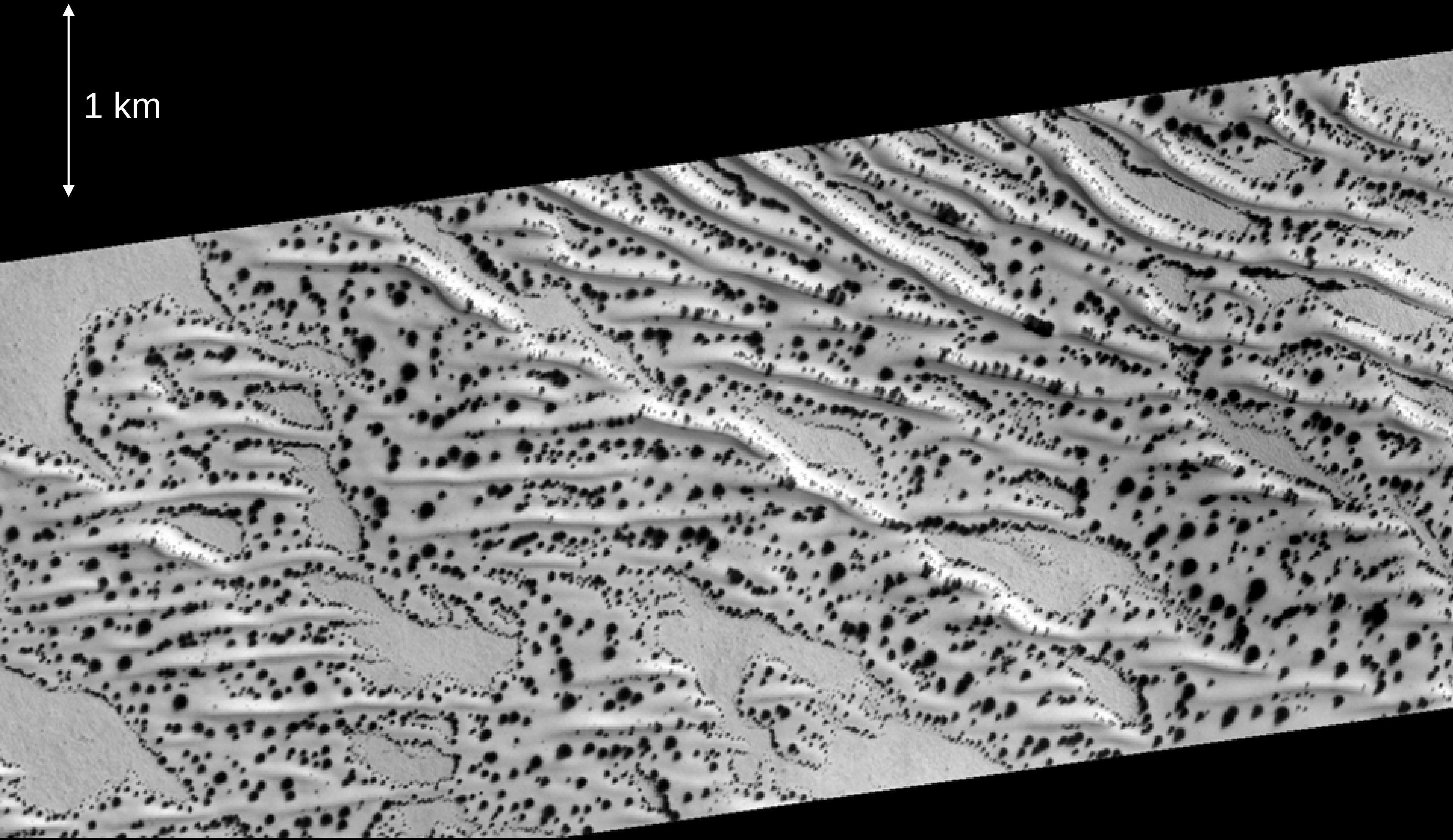


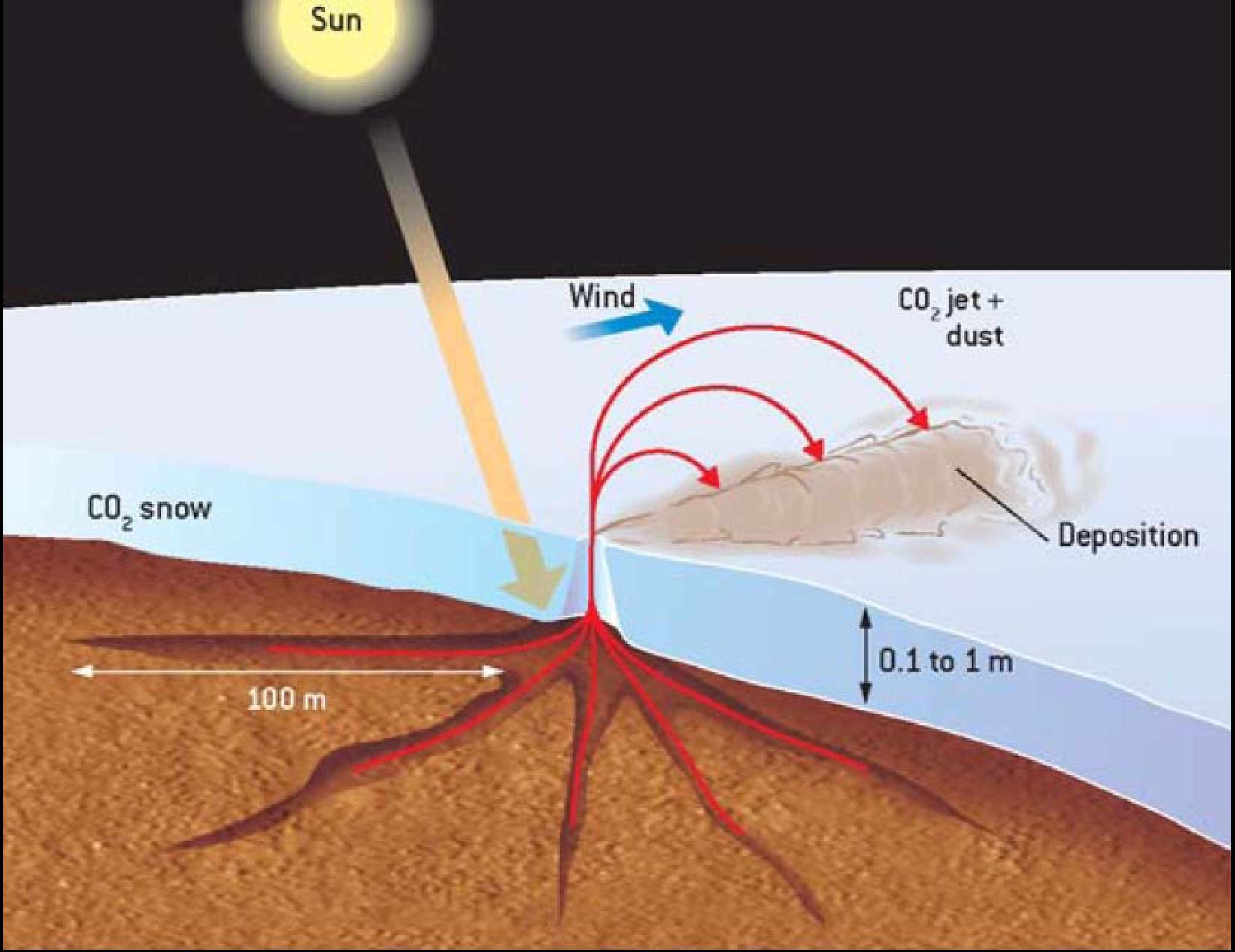
Langevin et al., Nature, 08 / 2006

CO2 ice slab at sunrise

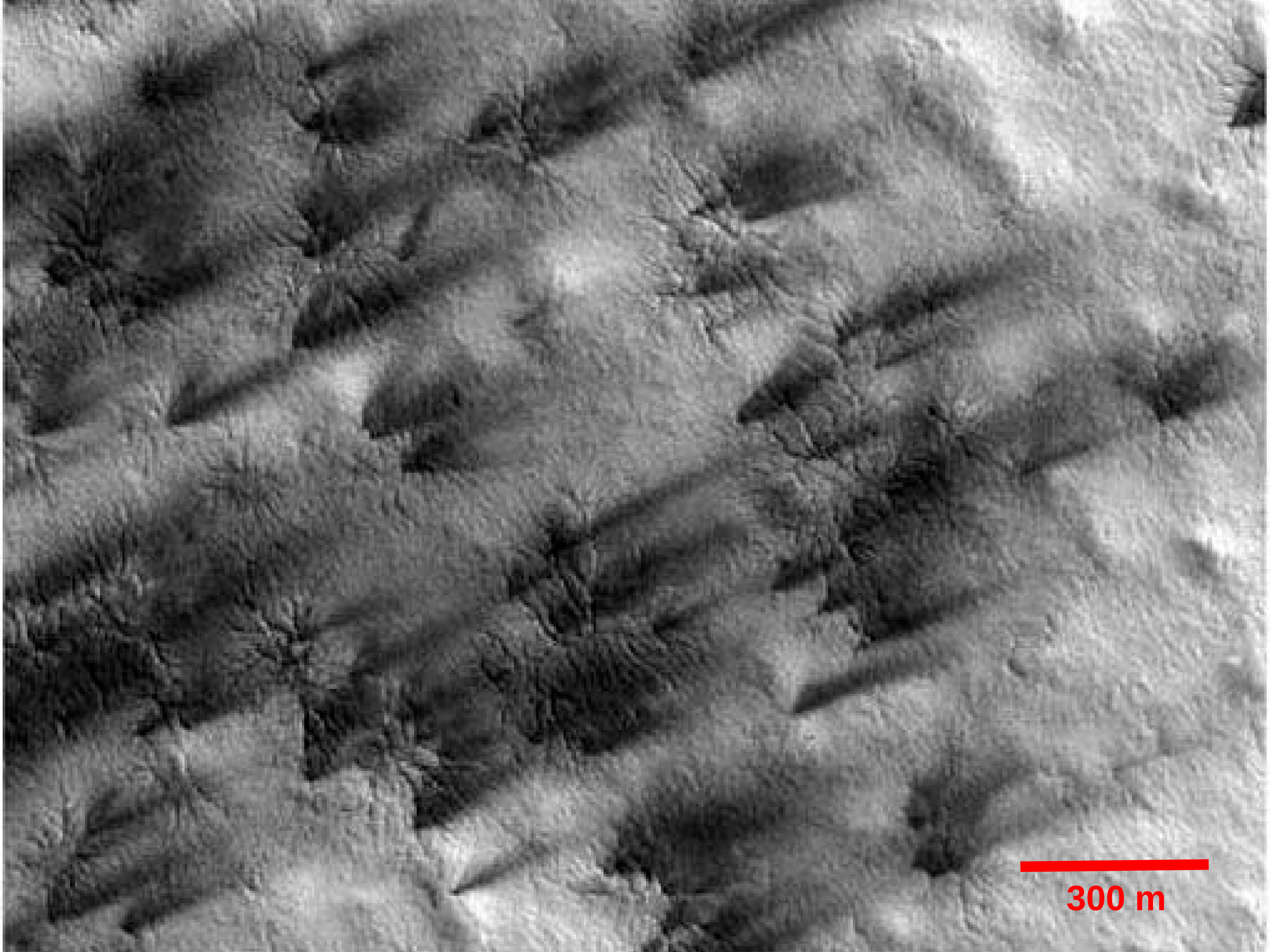


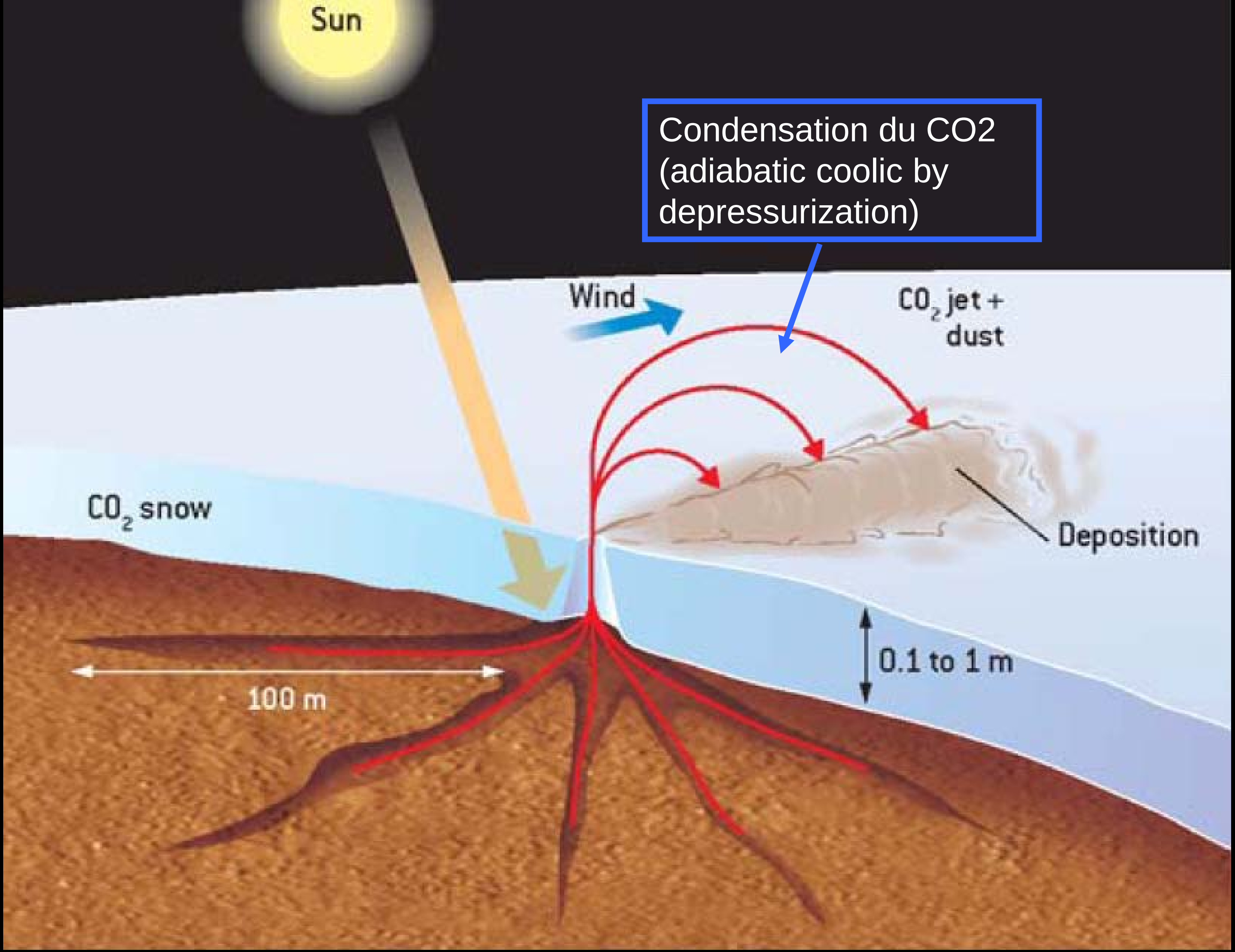
Sublimation of CO2 ice and snow





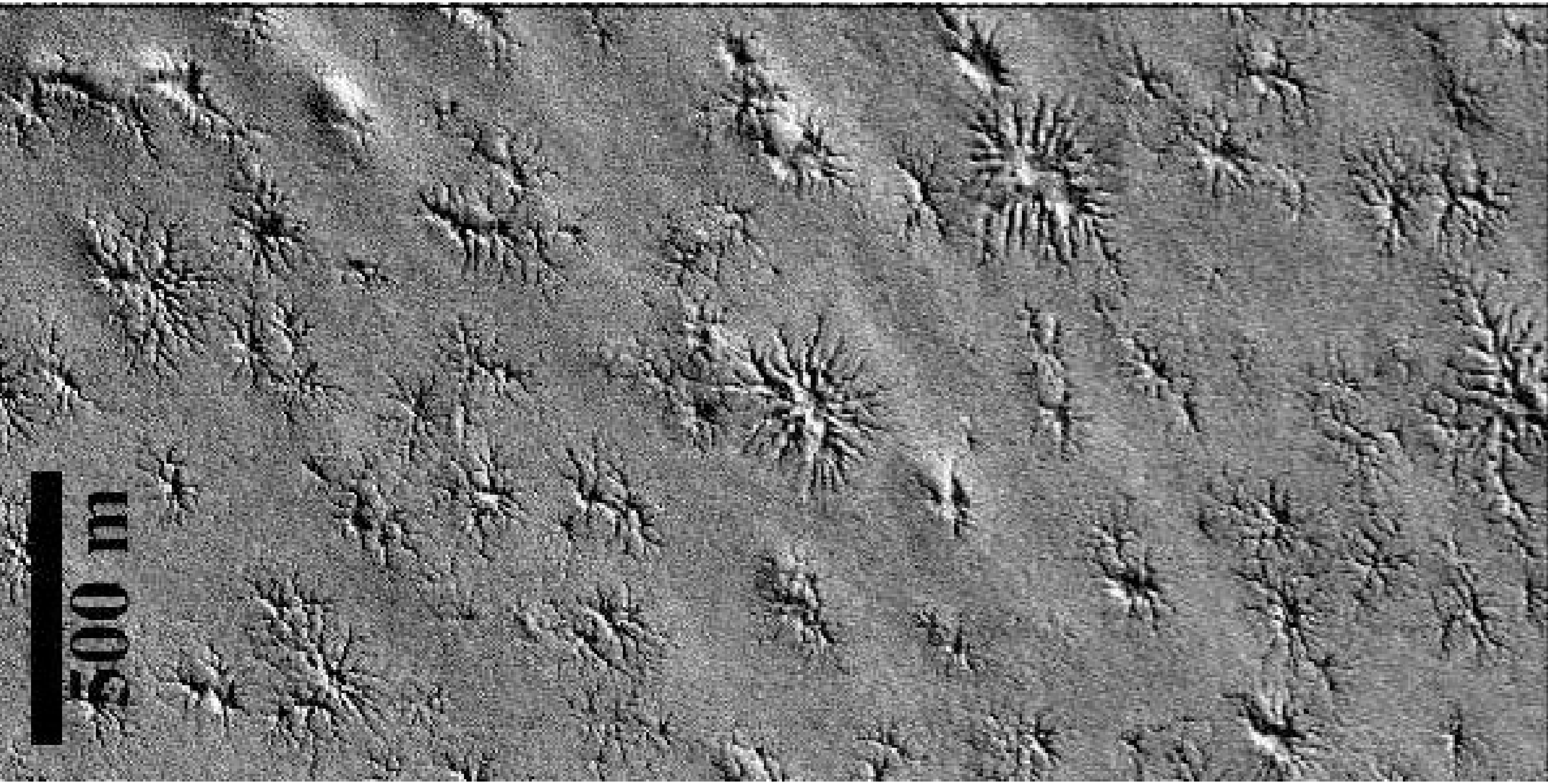
Sun
Wind
CO2 jet + dust
CO2 snow
Deposition
0.1 to 1 m
100 m


300 m

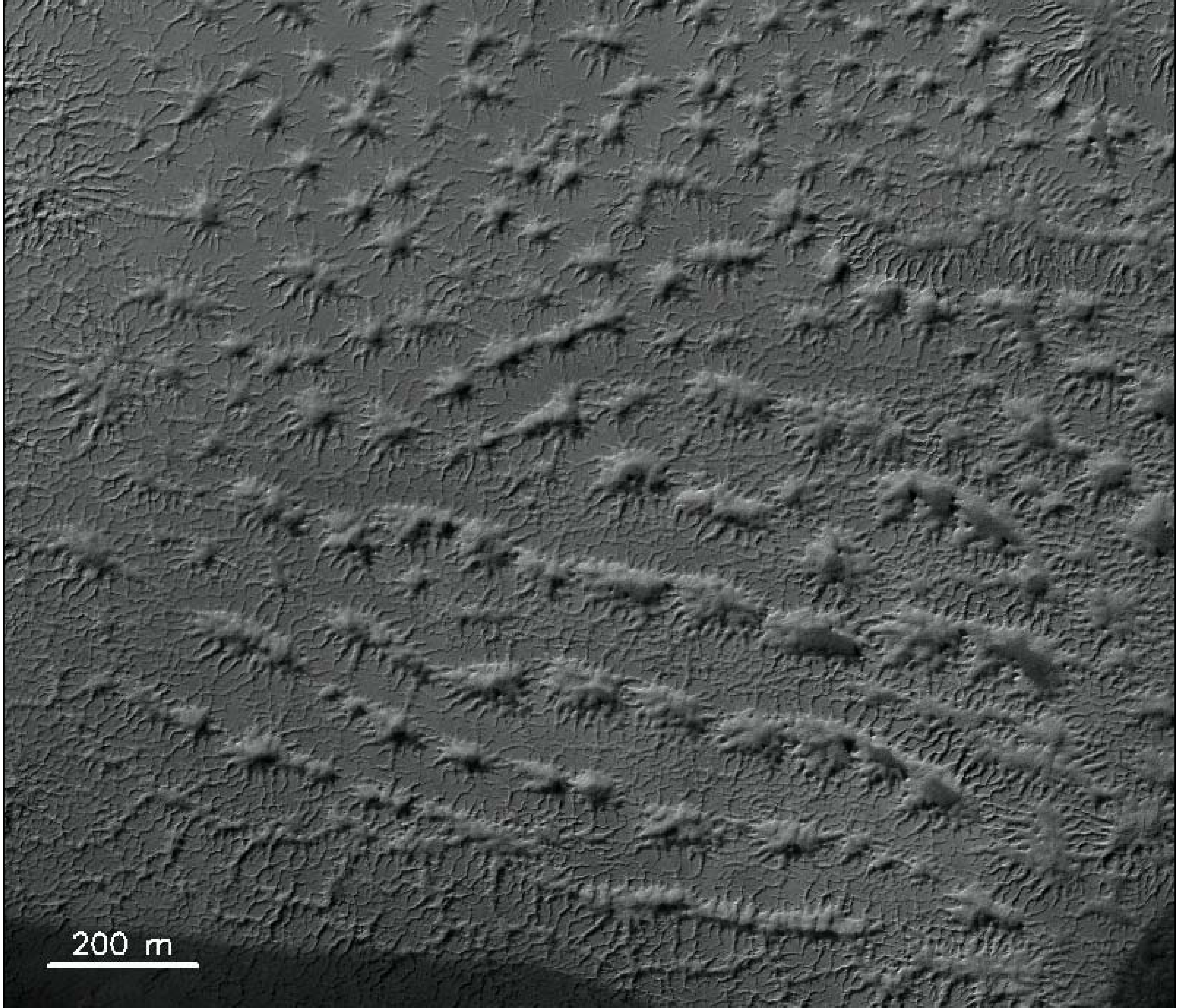

Sun
Condensation du CO2
(adiabatic coolic by
depressurization)
Wind
CO2 jet +
dust
CO2 snow
Deposition
100 m
0.1 to 1 m

Formation of “Spider” in the “criptic” region

(Piqueux et al. 2003, Kieffer et al. 2006)



)

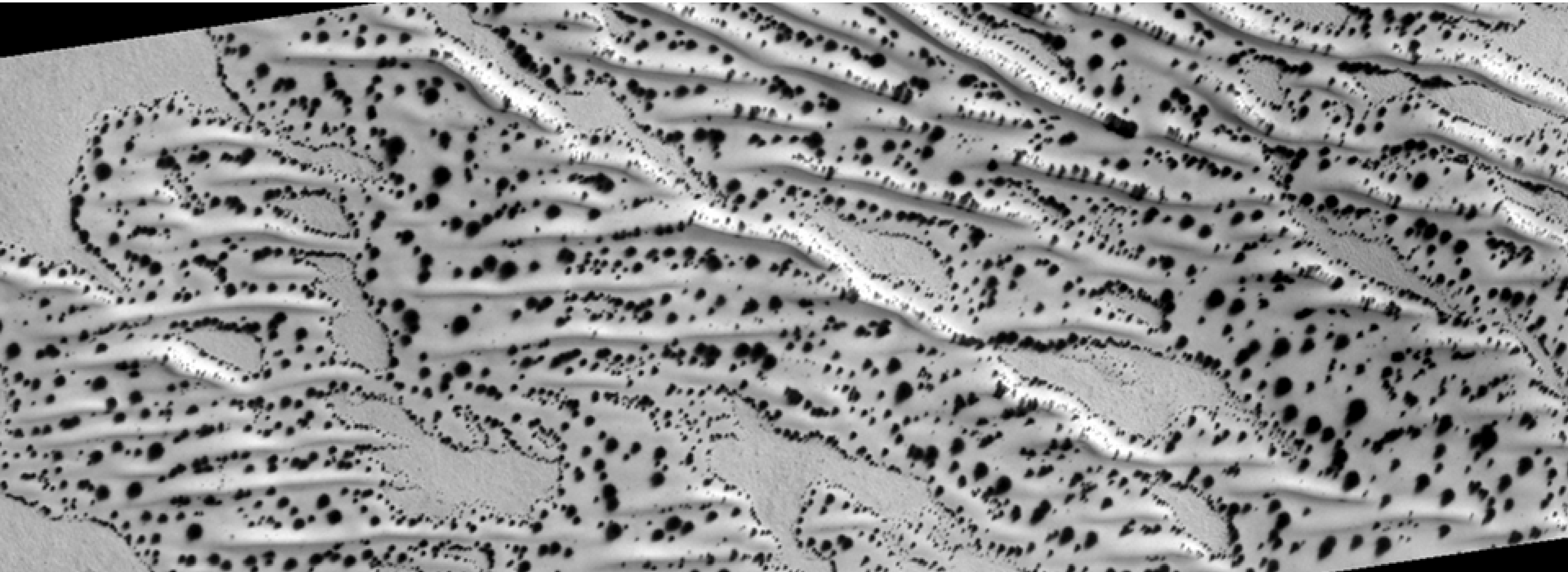

200 m

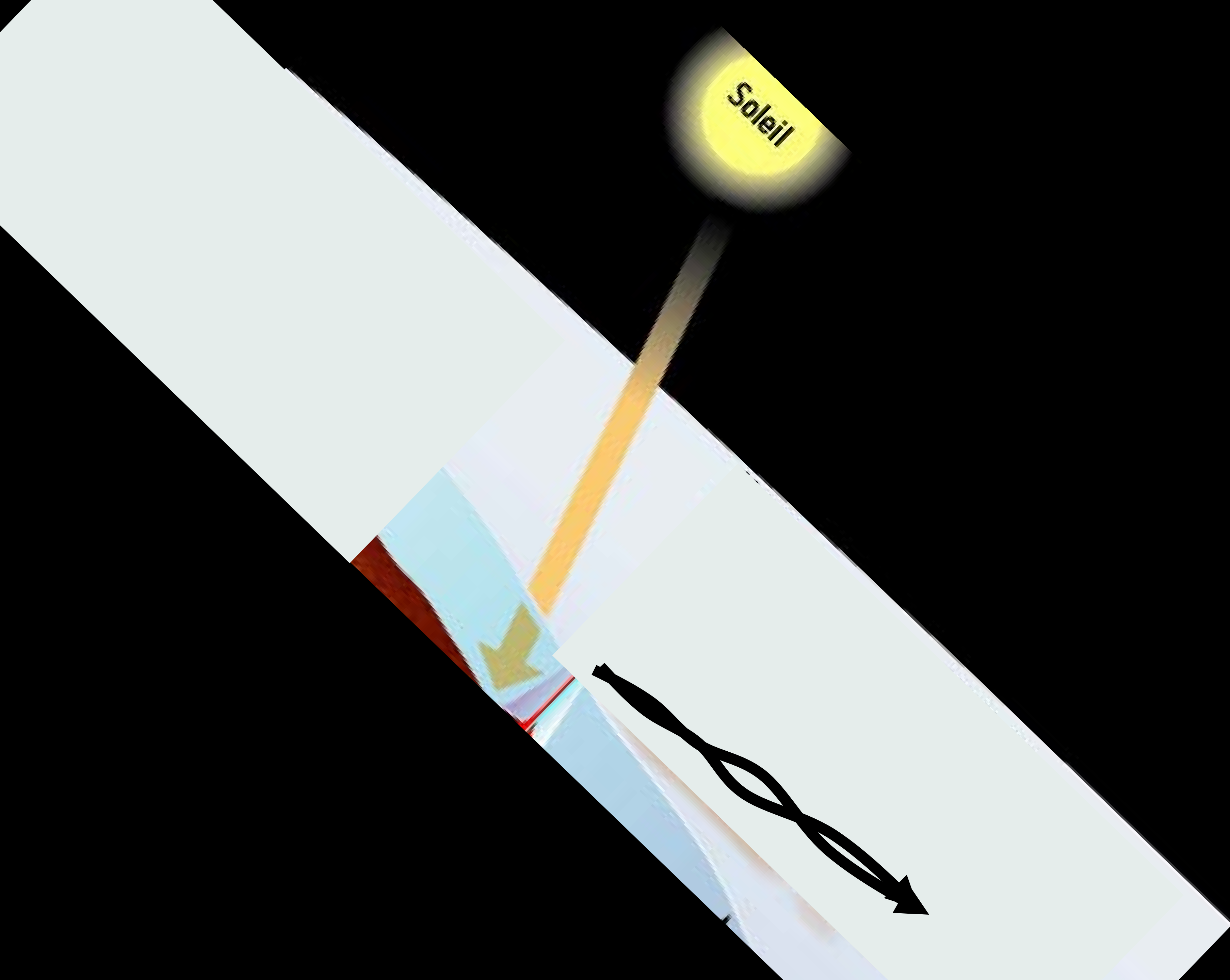
Astrobiology and darks spots on Mars (at -135°C…)

An « interesting » litterature !!! **:**

Gánti et al: **Dark Dune Spots: Possible Biomarkers on Mars?.** *Origins of Life and Evolution of the Biosphere,* v. 33, Issue 4, p. 515-557 (2003).

Szathmáry et al. **Life in the dark dune spots of Mars: a testable hypothesis** *Planetary Systems and the Origins of Life,* Cambridge University Press, Cambridge, UK, 2007, p.241




Soleil

Hansen et al. 2011: Seasonal Erosion and Restoration of Mars' *Northern Polar Dunes*

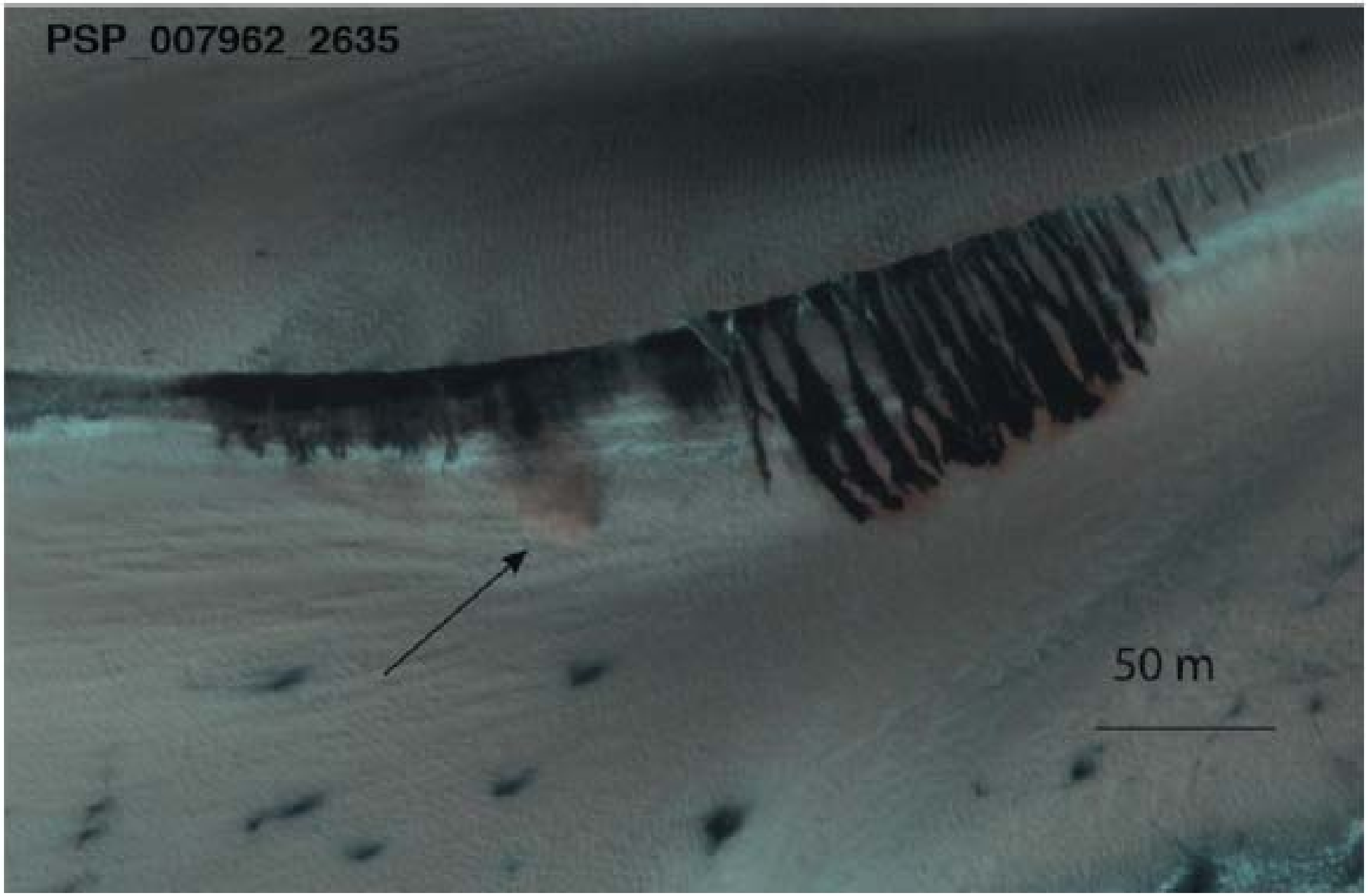
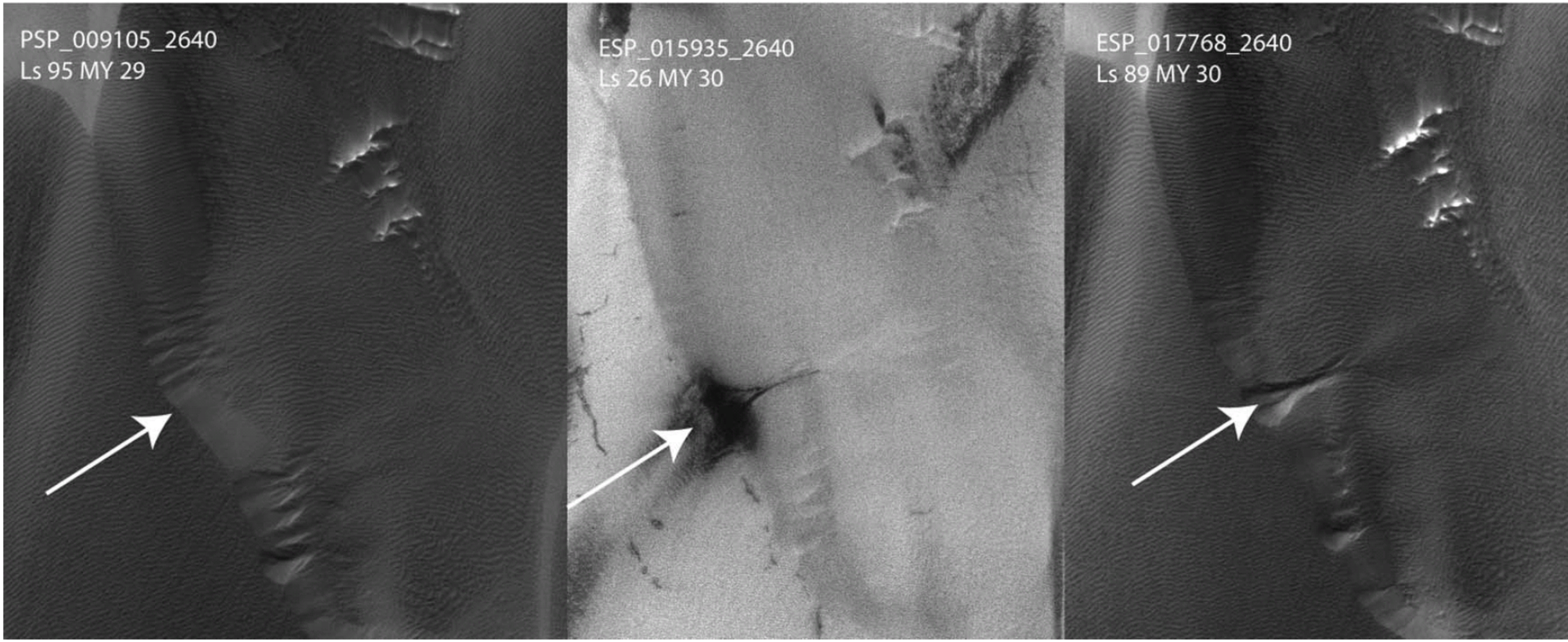
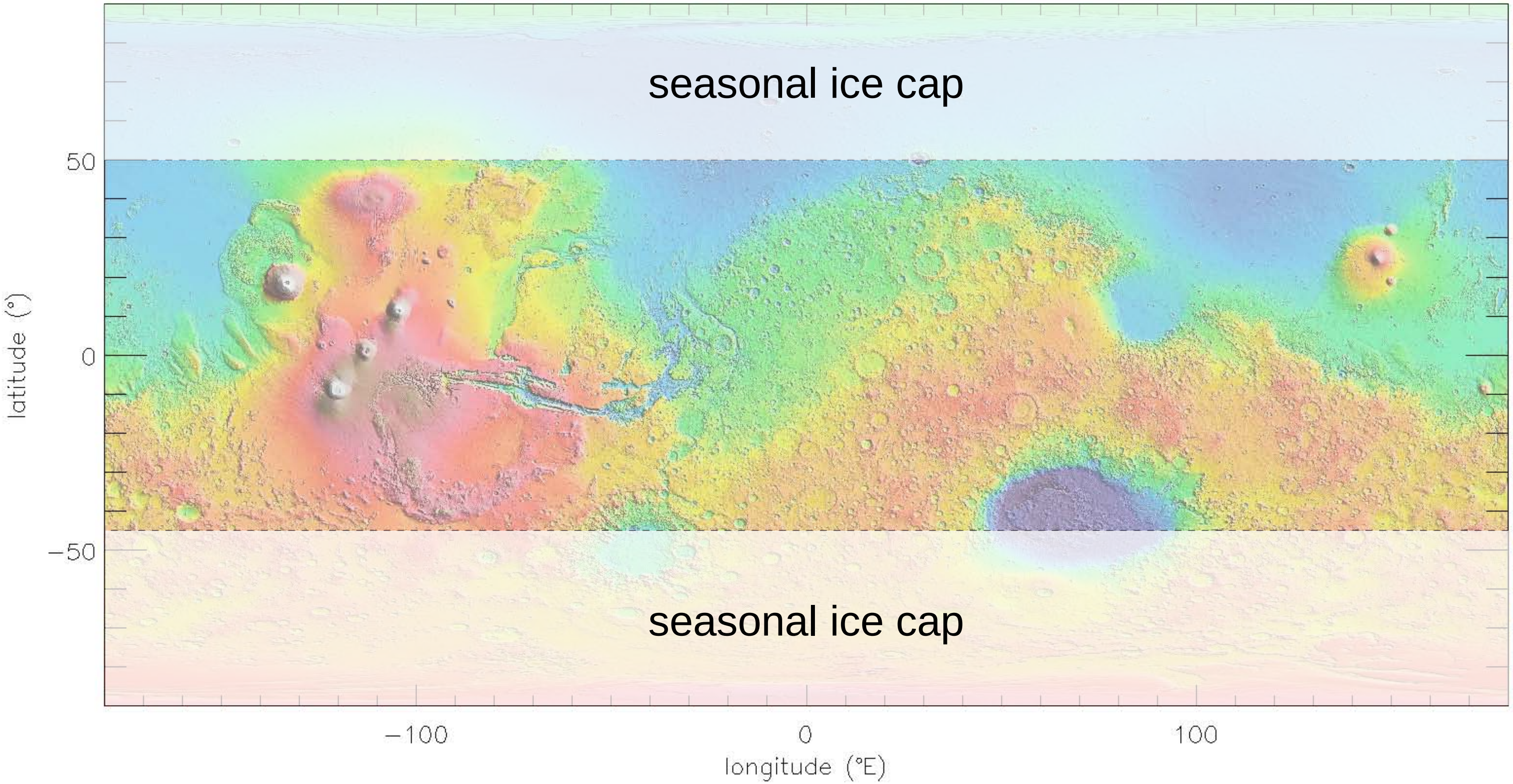


Fig. 1. Slope streaks and a small cloud of dust (arrow) kicked up by sand and ice cascading down the dune slope are captured in this subimage acquired at 83.5°N, 118.6°E. Imaged at $L_s = 55.7$ (*35*), dunes are still covered by seasonal ice. This particular dune is ~40 m high. North is up; light is from the lower left. The dark slope streaks visible in the image are postulated to be sand that has been released from the brink of the dune to slide down and cover seasonal ice.

Hansen et al. 2011: Seasonal Erosion and Restoration of Mars' *Northern Polar Dunes*

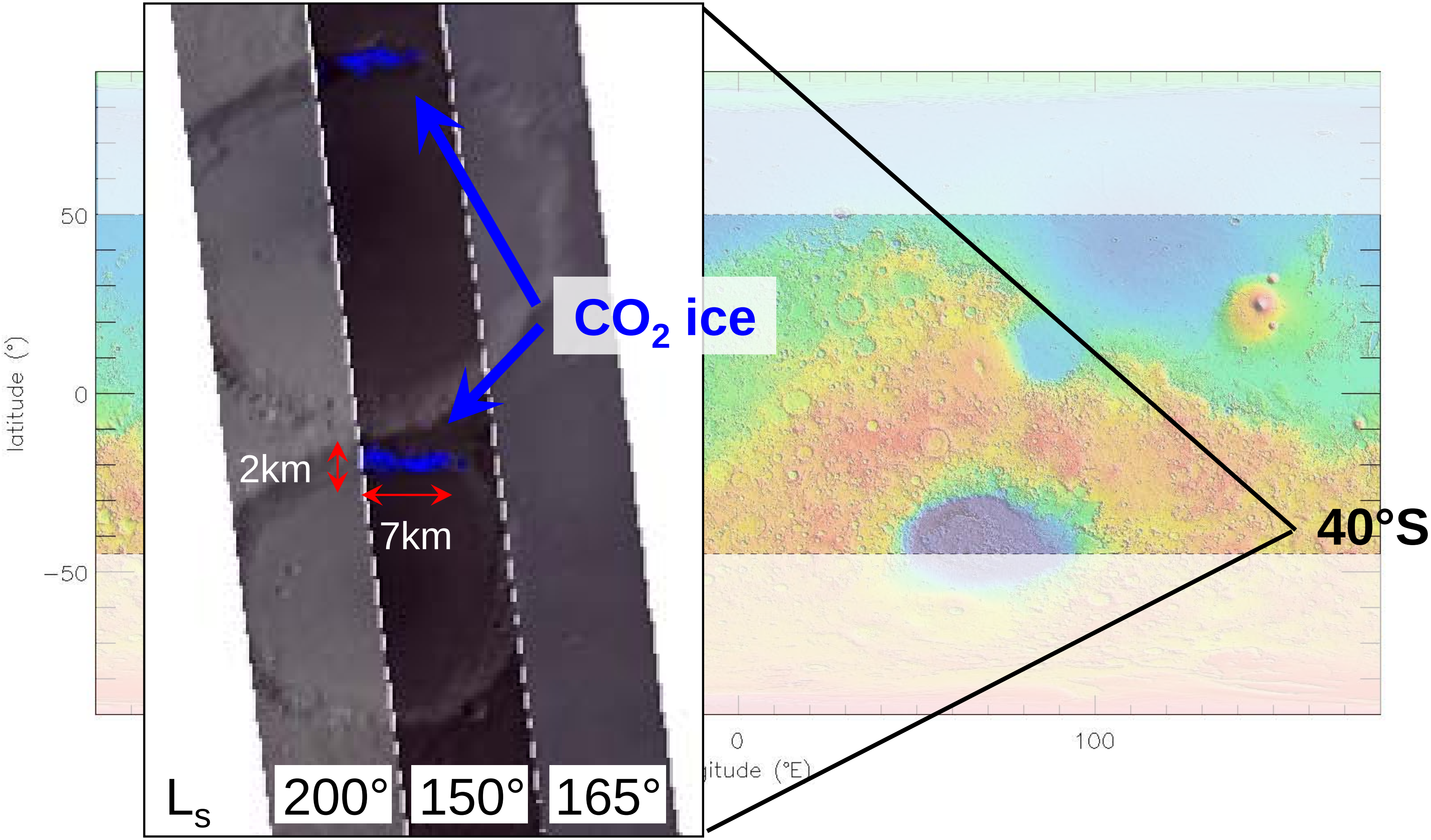


CO2 ice outside the polar caps ? Search using Omega and Crism imaging spectrometer **(Mathieu Vincendon)**



Ice on flat surface is observed down to ~ 50°N / 45°S in fall and winter

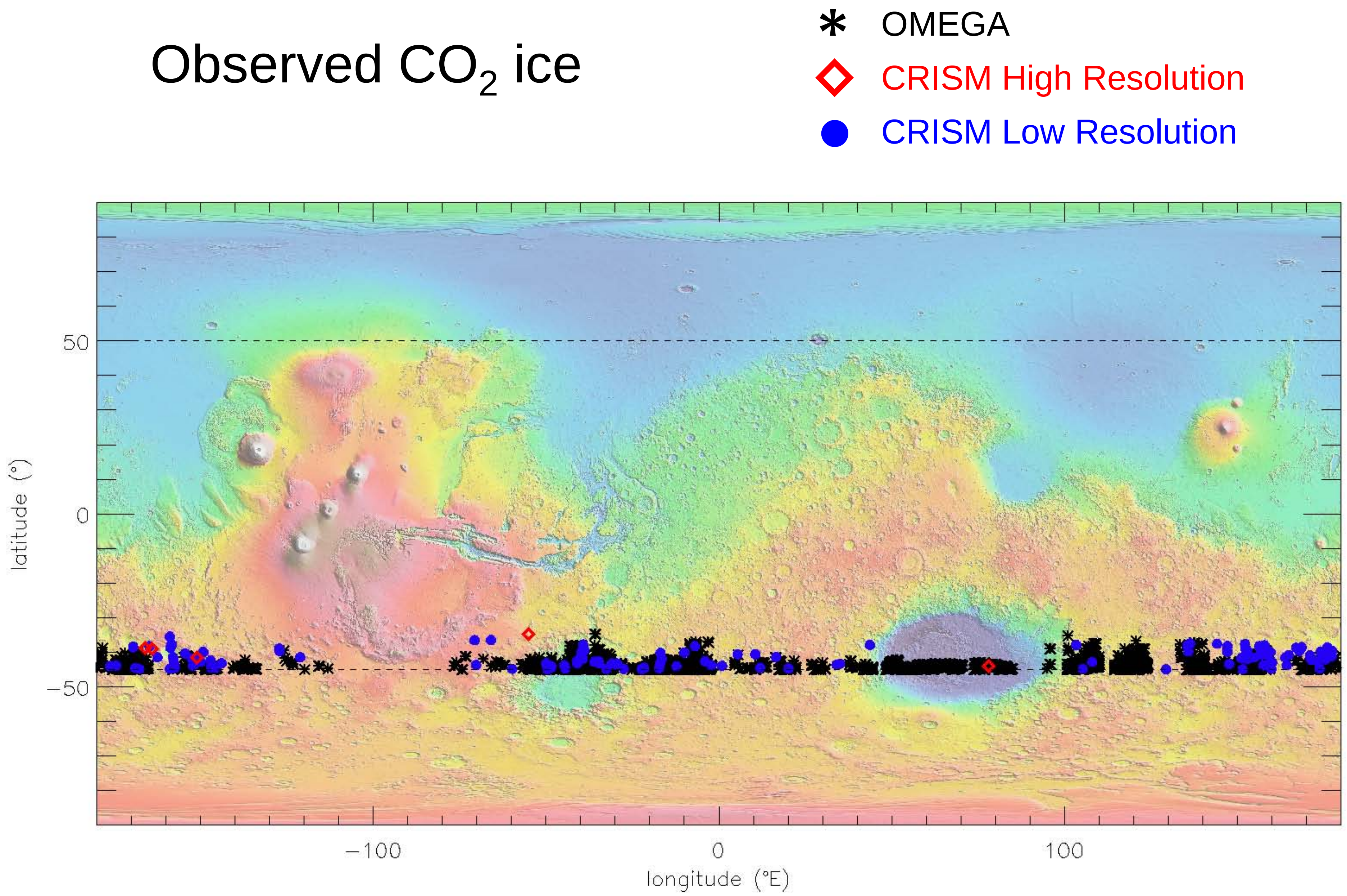
On pole facing slopes, ice is stable closer to the equator



CRISM “MSP” data – 230 m spatial resolution

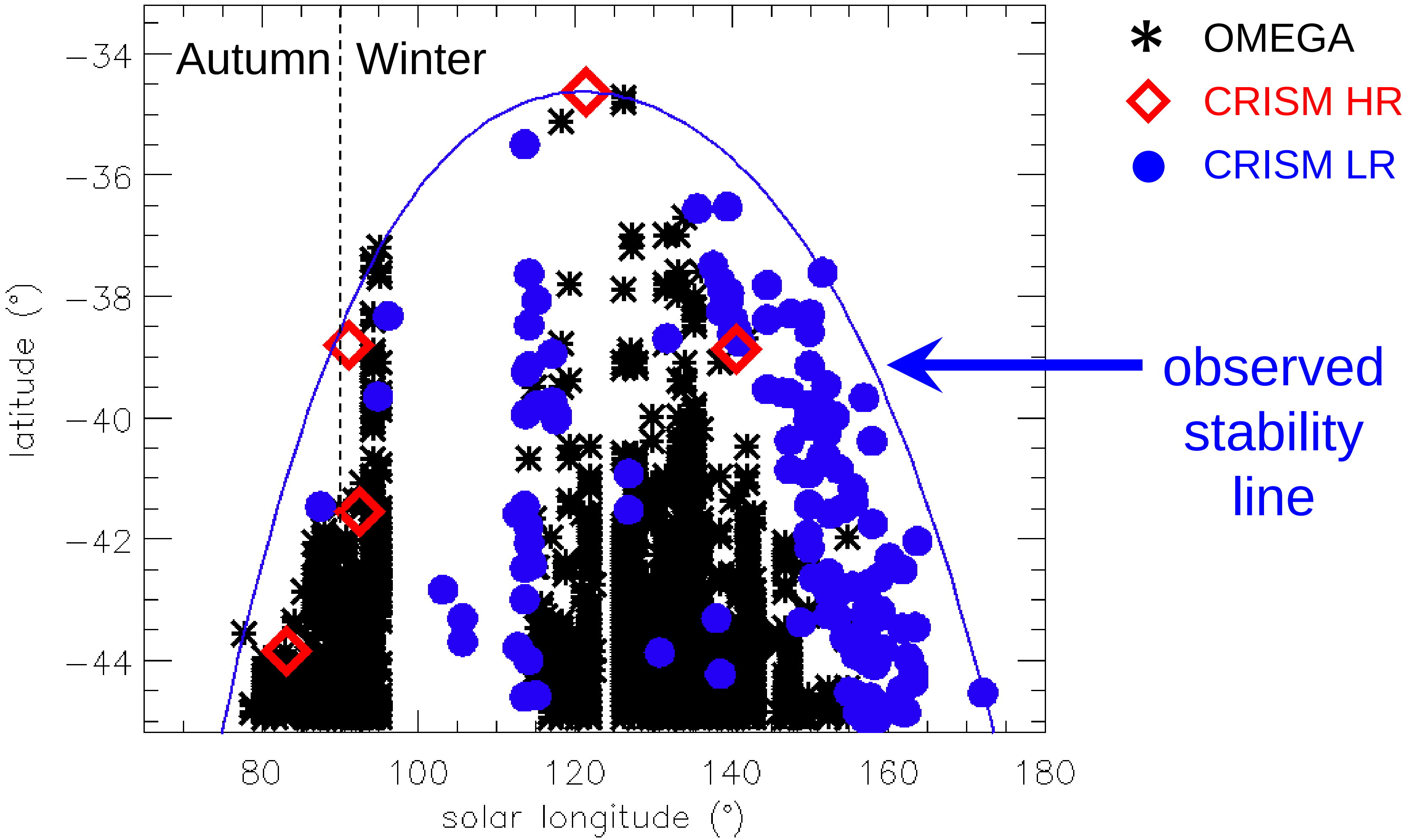
Vincendon et al. 2009

Observed CO_2 ice



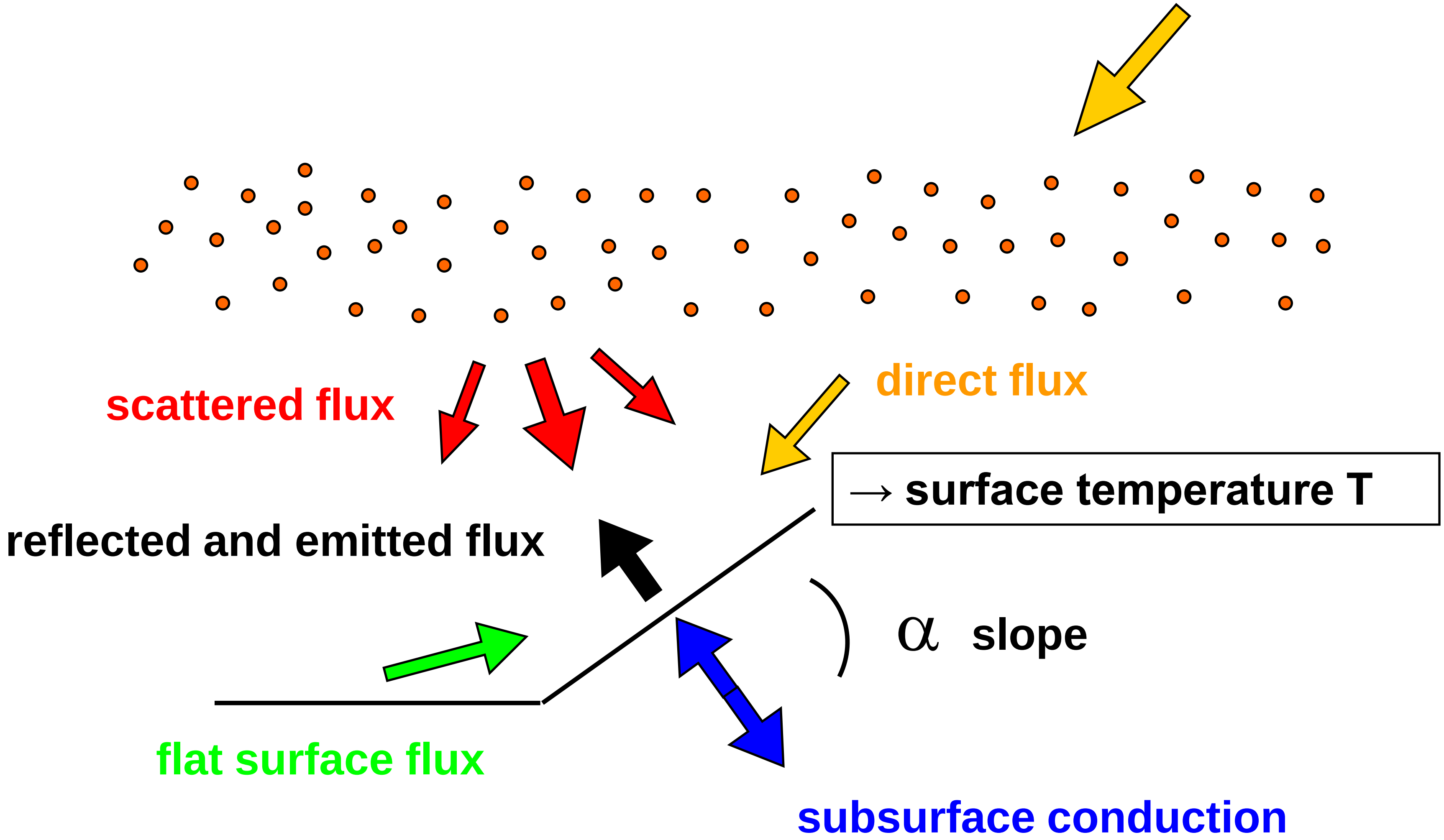
Vincendon et al. 2009

Observed CO_2 ice stability pattern (latitude versus season)



Vincendon et al. 2009

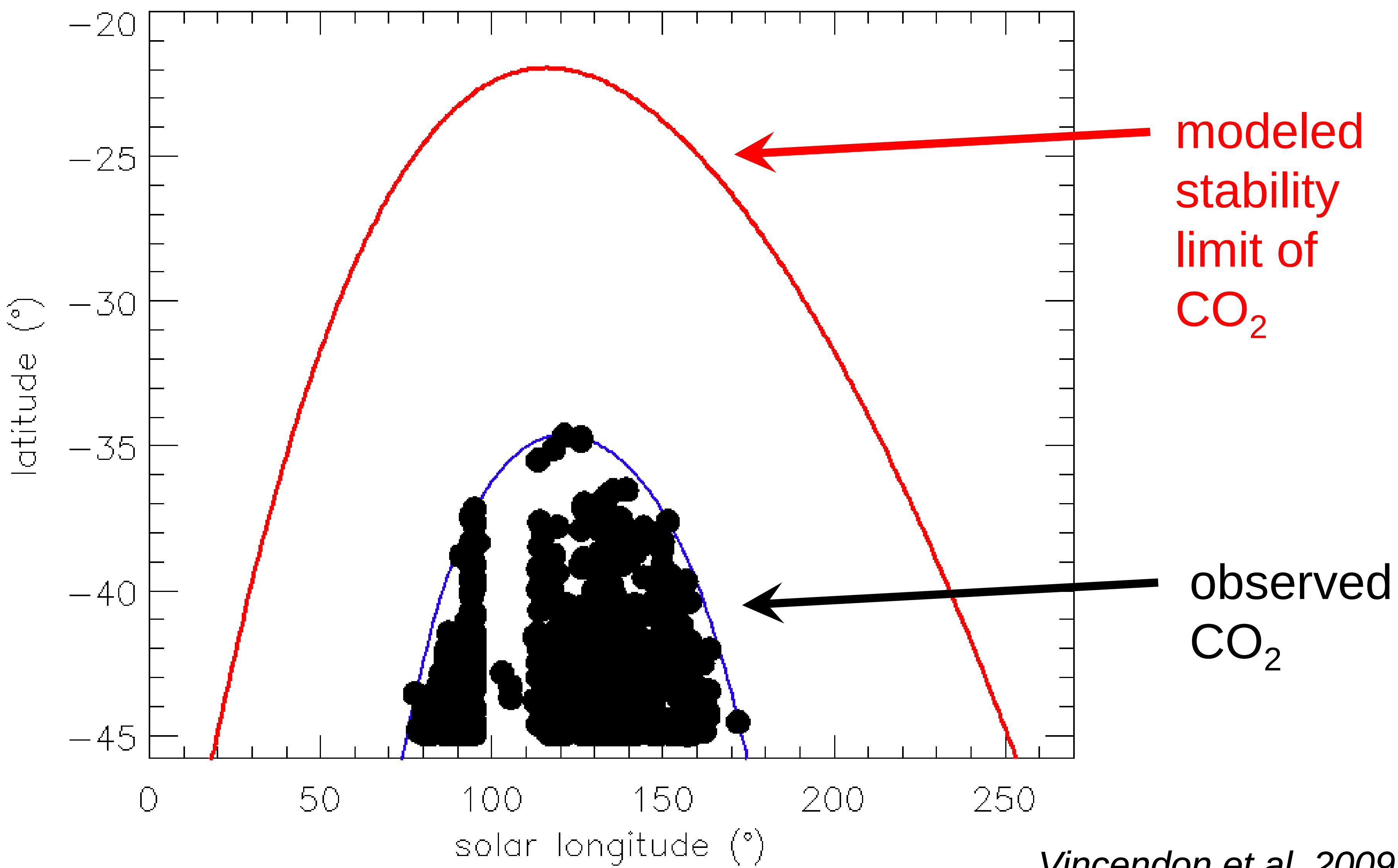
A 1D local energy balance code derived from the LMD GCM is used to predict the stability of ice



Vincendon et al. 2009

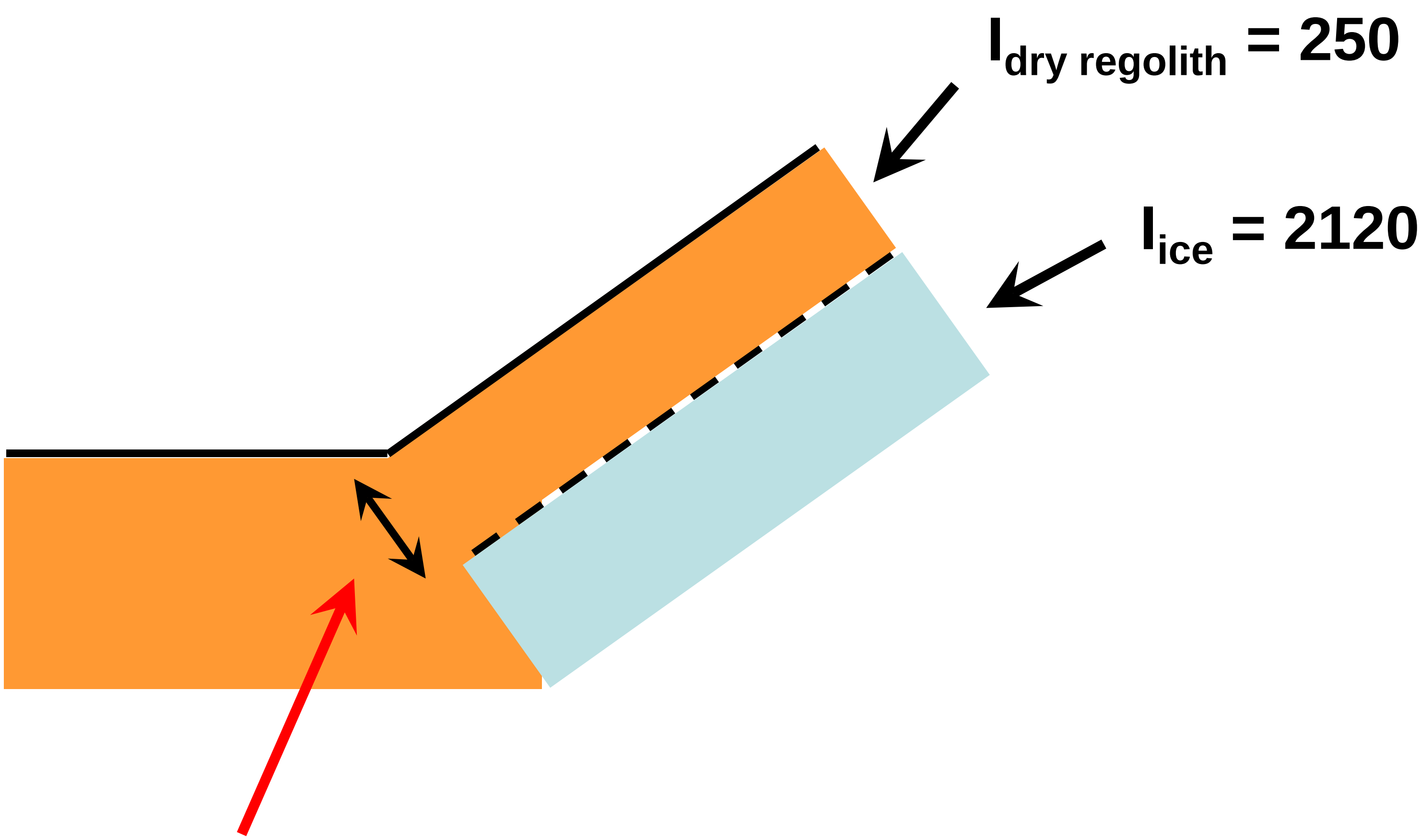
First prediction of the model: ice stability over-predicted

a source of heat localized on slopes is required



Vincendon et al. 2009

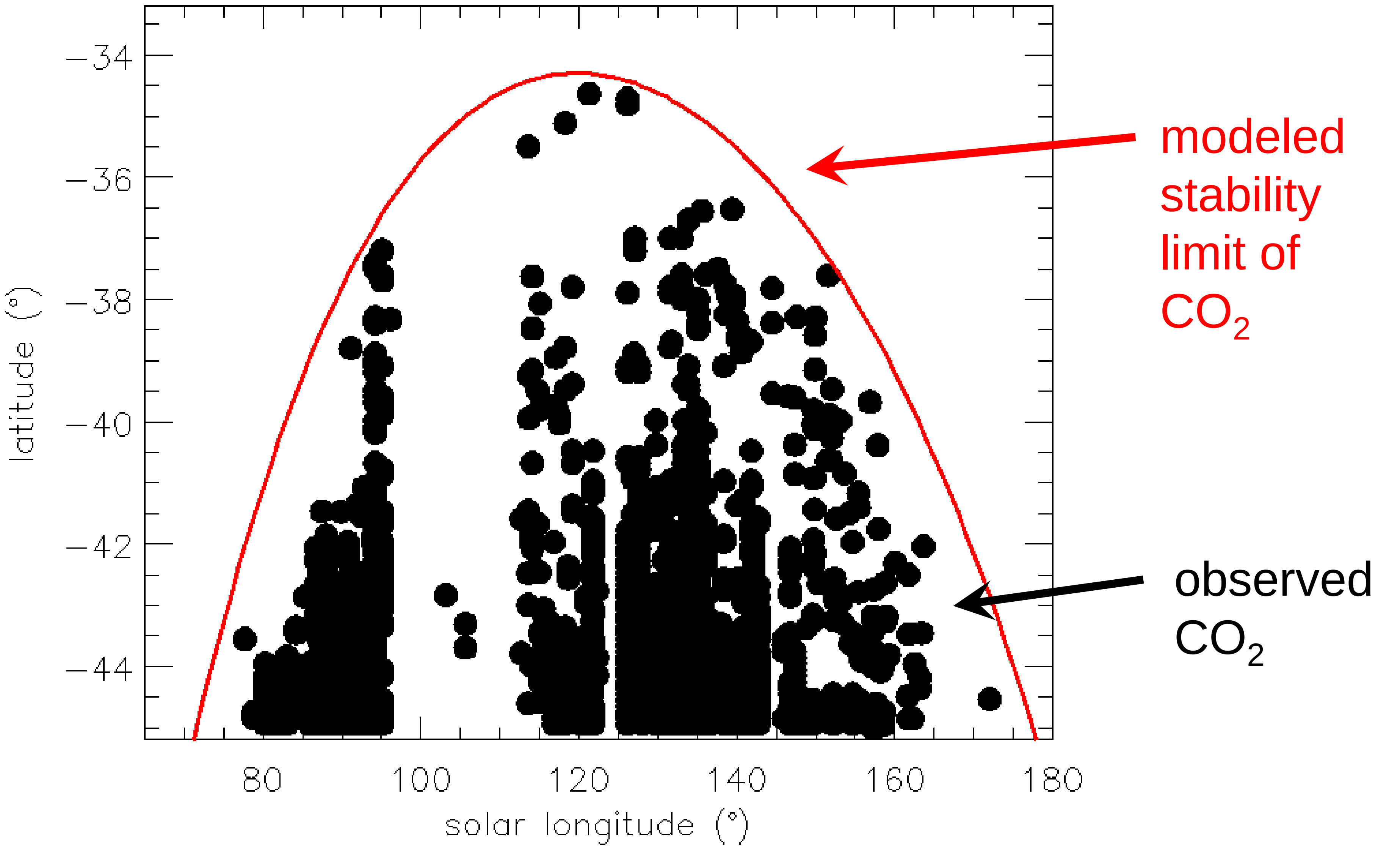
Ground model: dry regolith above H_2O ice rich regolith



Ice table depth: free parameter, latitude dependent

Vincendon et al. 2009

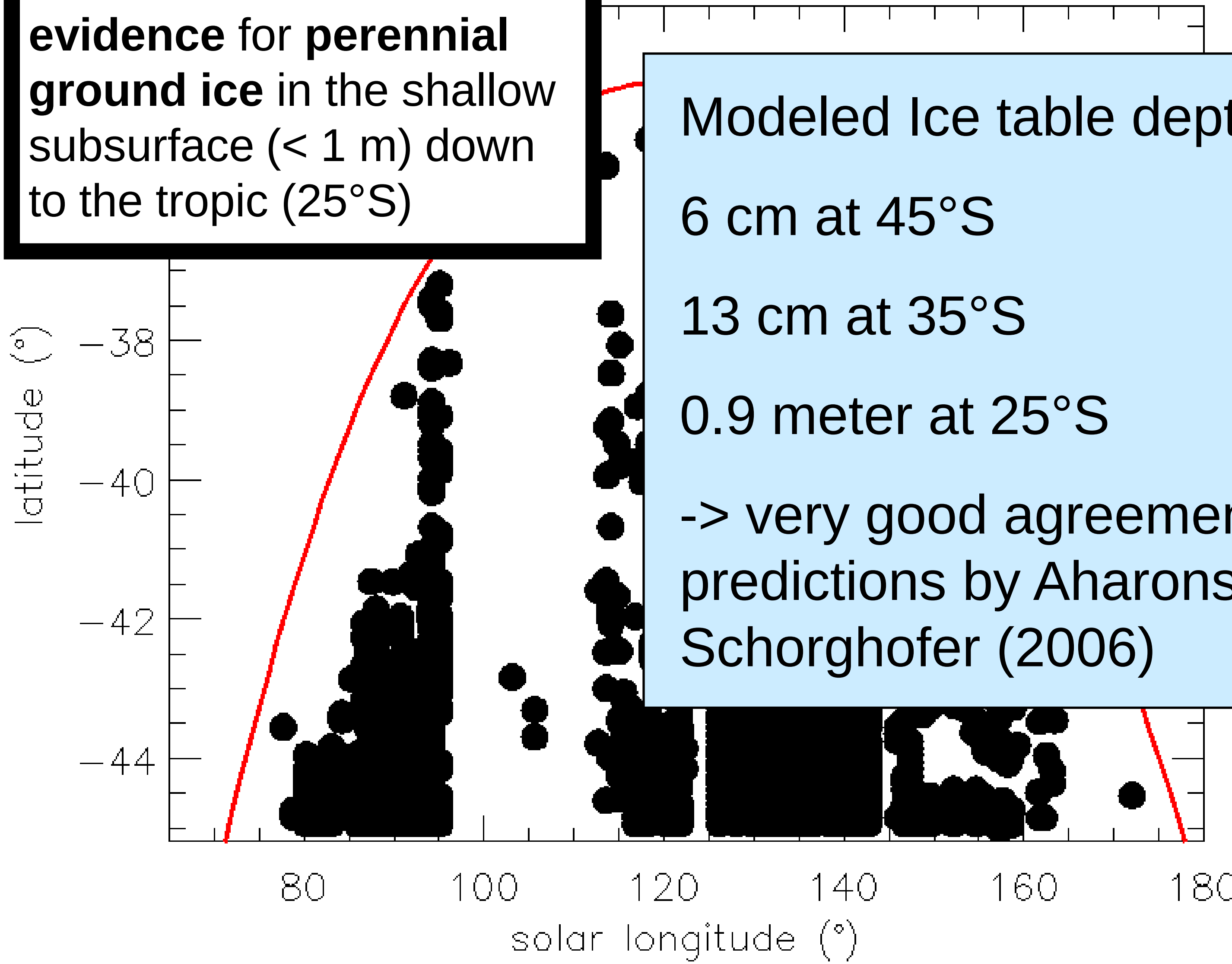
Result with ground H_2O ice



Vincendon et al. 2009

Result with ground H_2O ice

first observational evidence for **perennial ground ice** in the shallow subsurface (< 1 m) down to the tropic (25°S)



Modeled Ice table depths:

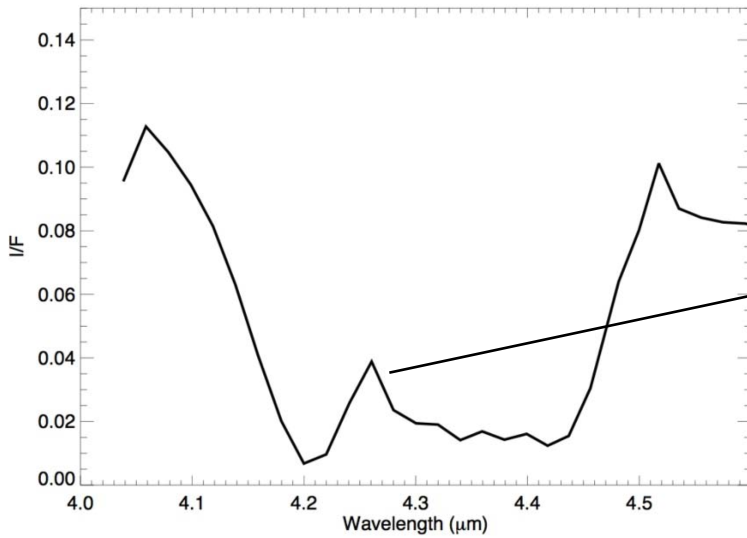
6 cm at 45°S

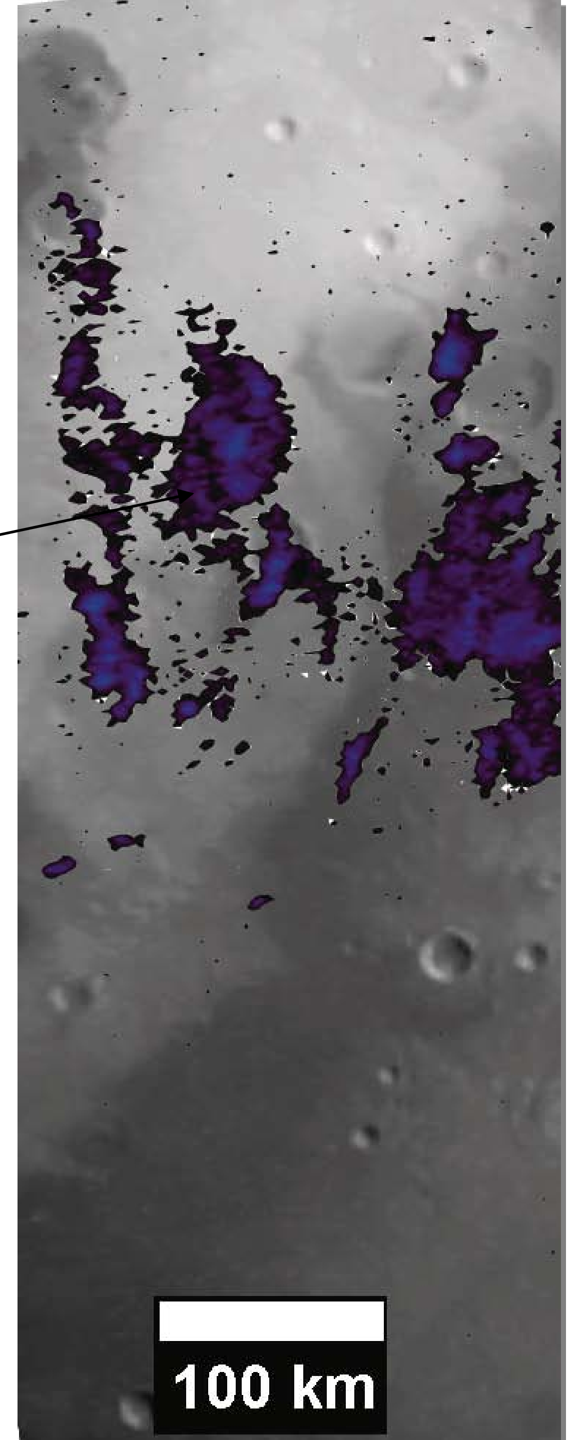
13 cm at 35°S

0.9 meter at 25°S

-> very good agreement with predictions by Aharonson & Schorghofer (2006)

Detection of high altitude CO_2 ice clouds with OMEGA (Montmessin et al. 2007)



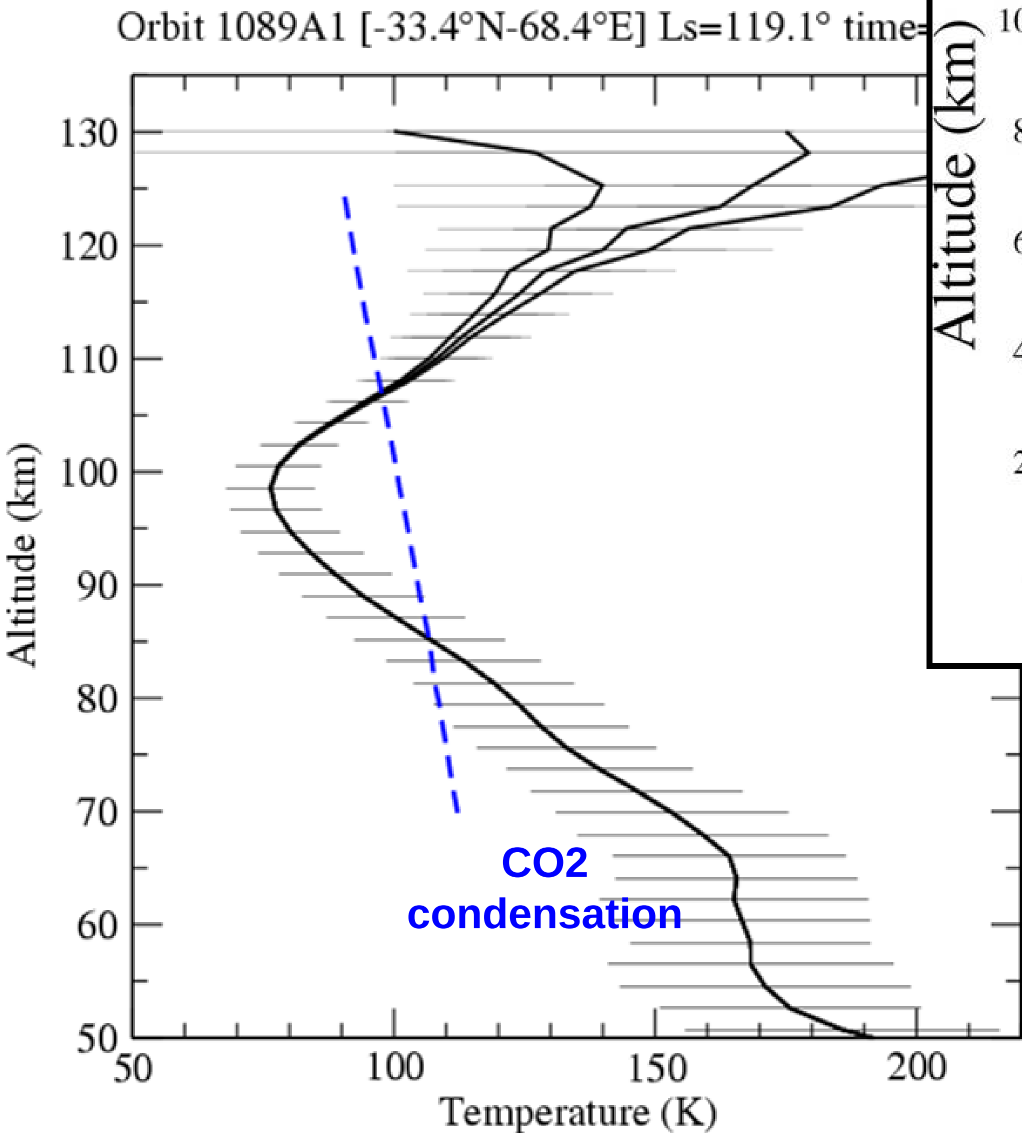


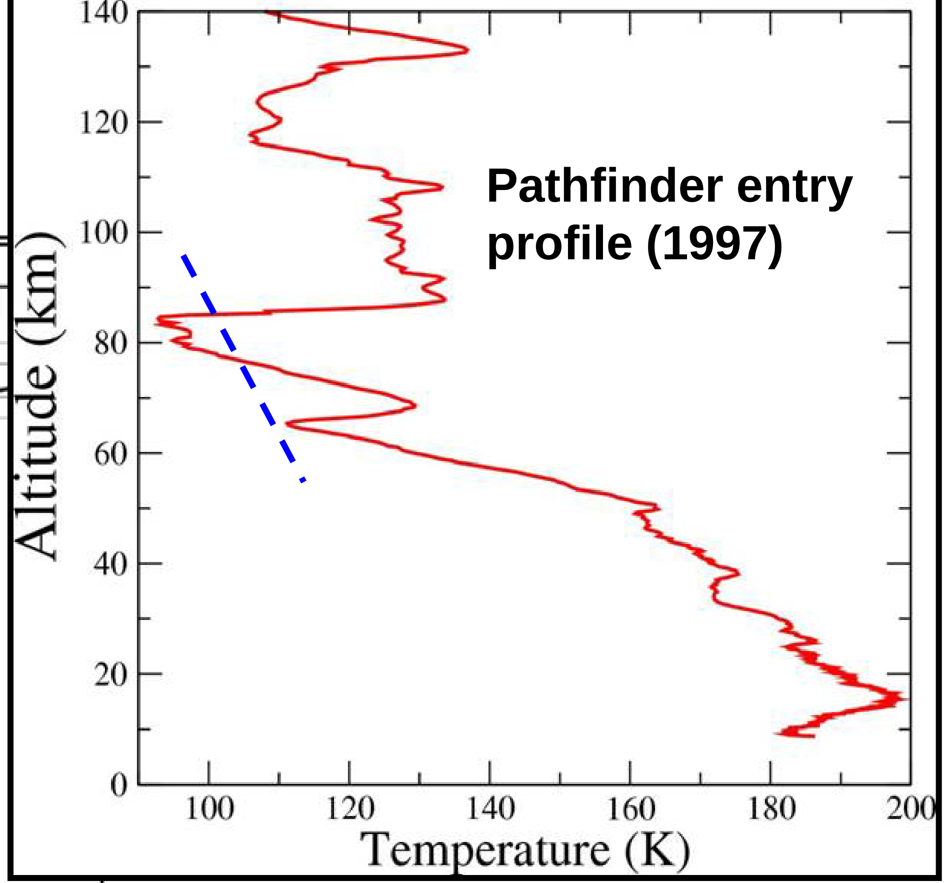
Opacity > 0.2
Altitude ~80 km
Reff up to 1.5 μm

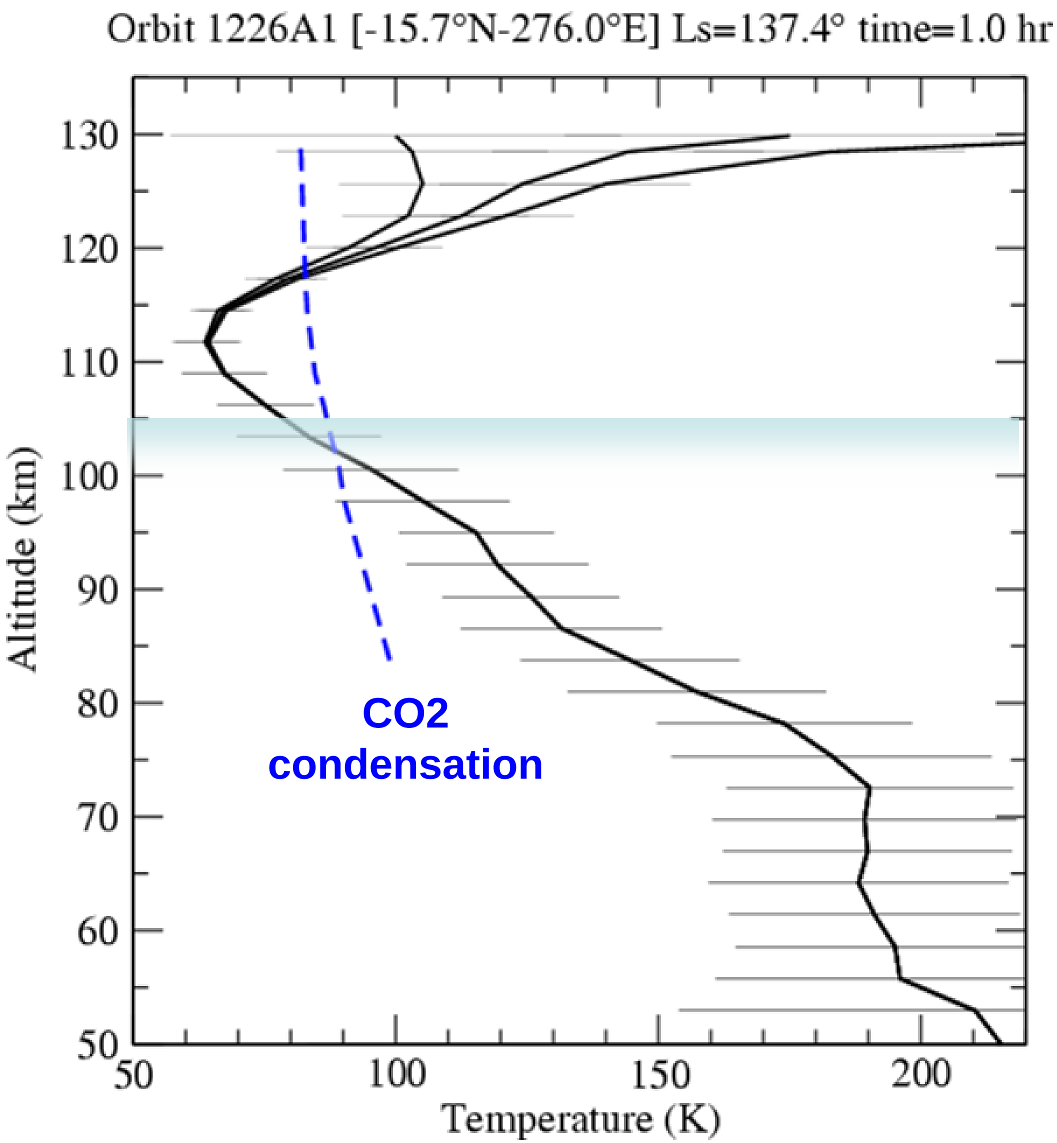
First spectroscopic identification by Mars Express (PFS, OMEGA, Formisano et al. 2006, Montmessin et al. 2007)
Observations by MOC & TES (Clancy et al. 2007), SPICAM (Montmessin et al. 2006), VMC, THEMIS (McConnochie et al.)

SPICAM stellar occultation

Forget et al. 2009



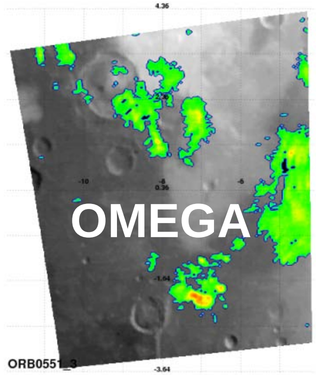


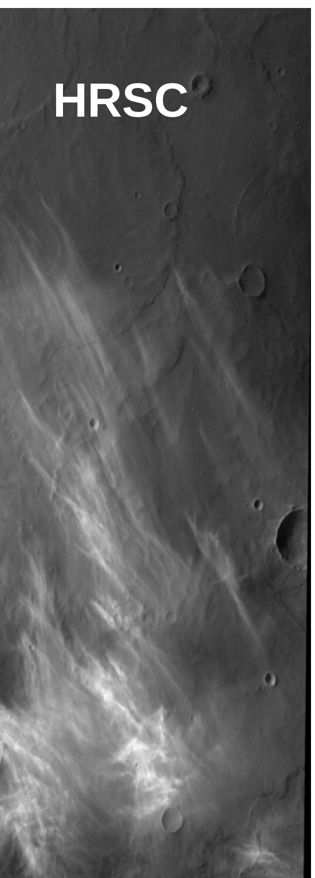


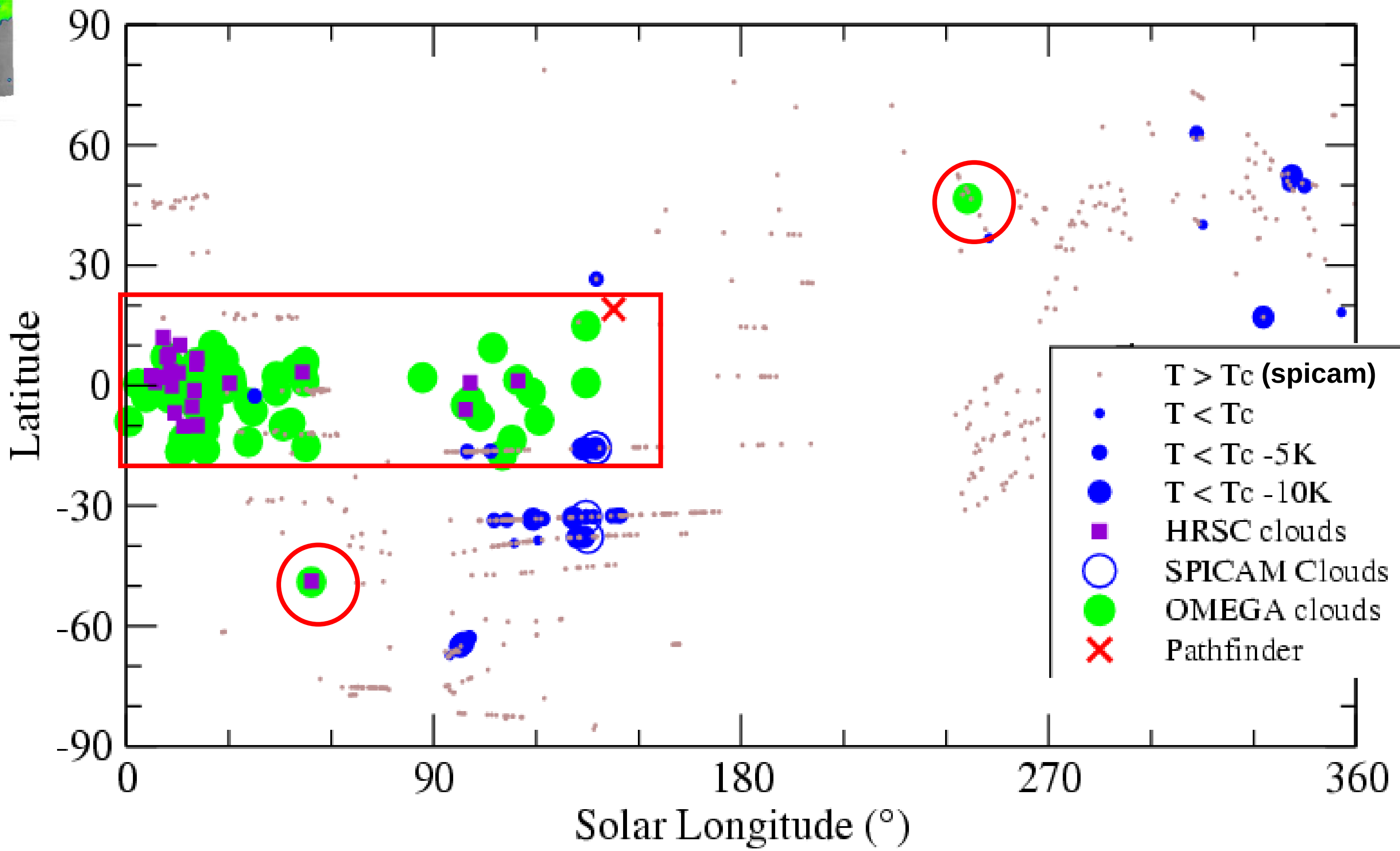
Detached aerosol layer simultaneously in the stellar occultation

Montmessin et al., Icarus 2006

Seasonal evolution map







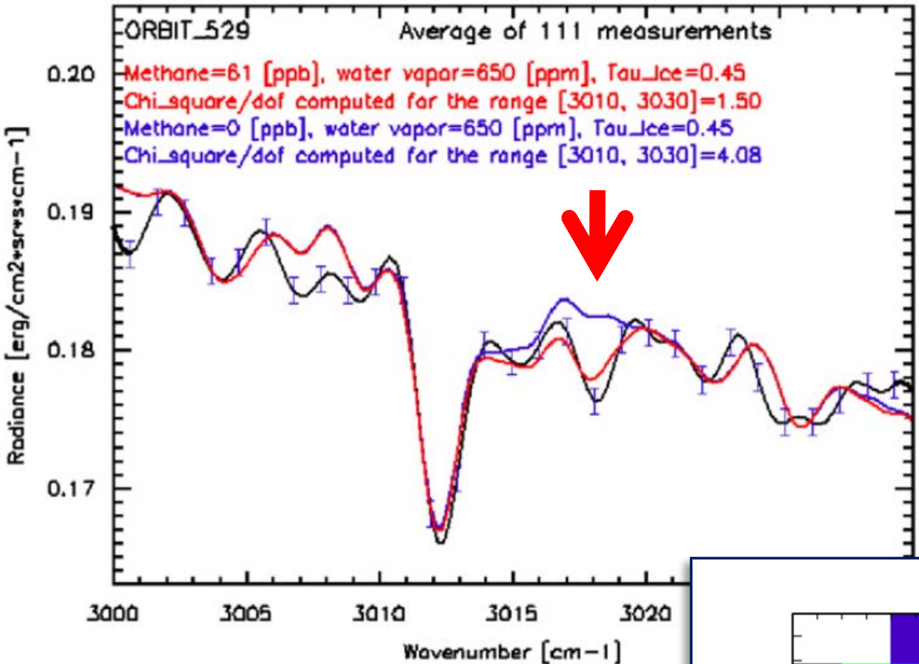
Detection of Methane on Mars

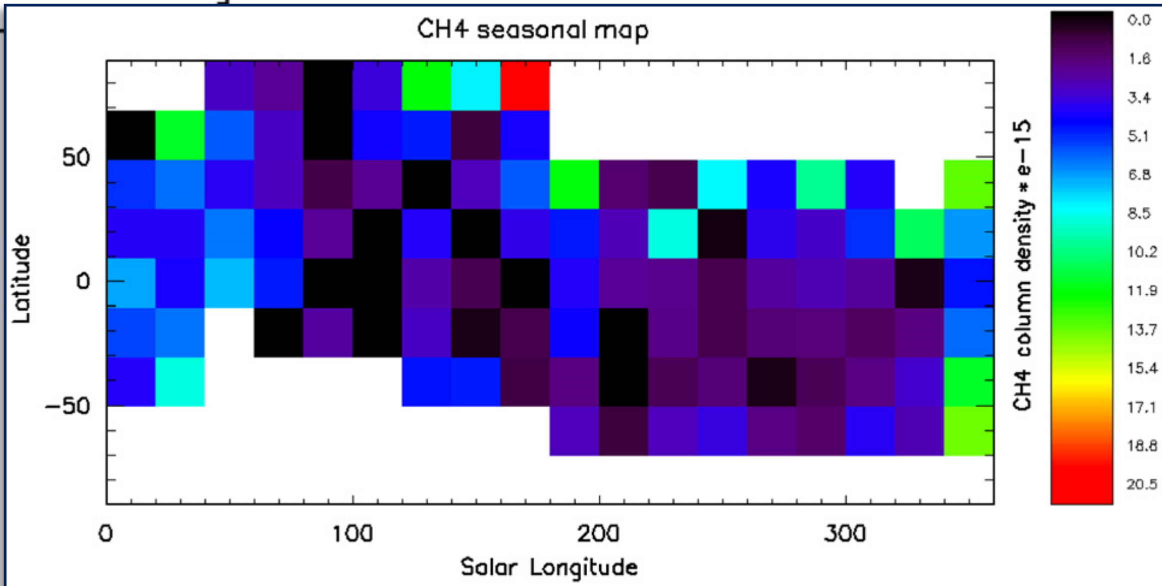
- Mars Express PFS spectrometer (Formisano et al. 2004, Geminale et al. 2008, 2010)
- Telescopic observations (FTS au CFHT, Krasnopolsky et al. 2004)
- Telescopic Observations (Mike Mumma, Geronimo Villanueva, 2004, 2009)
- + Thermal IR detection TES sur Mars Global Surveyor (Fonti and Marzo. 2010) ??

Methane (PFS: 3018 cm-1)

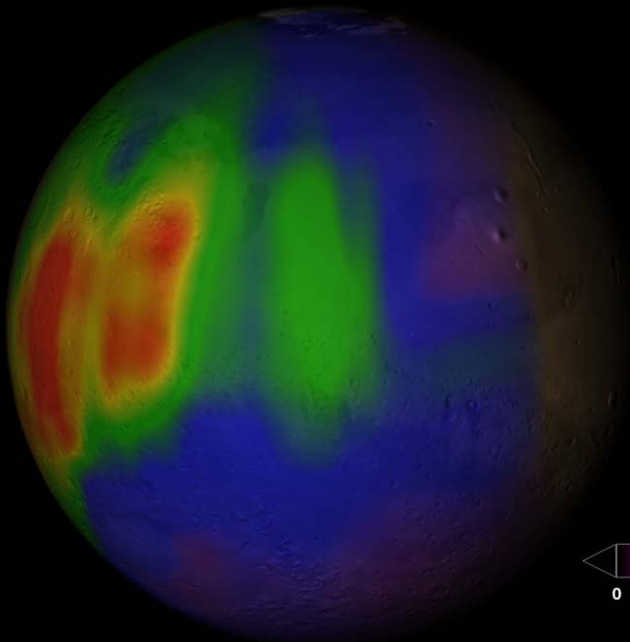
- Difficult detection by Formisano et al. (Science 2004)

Geminale et al. 2008

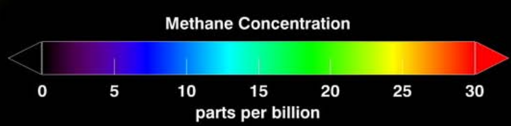


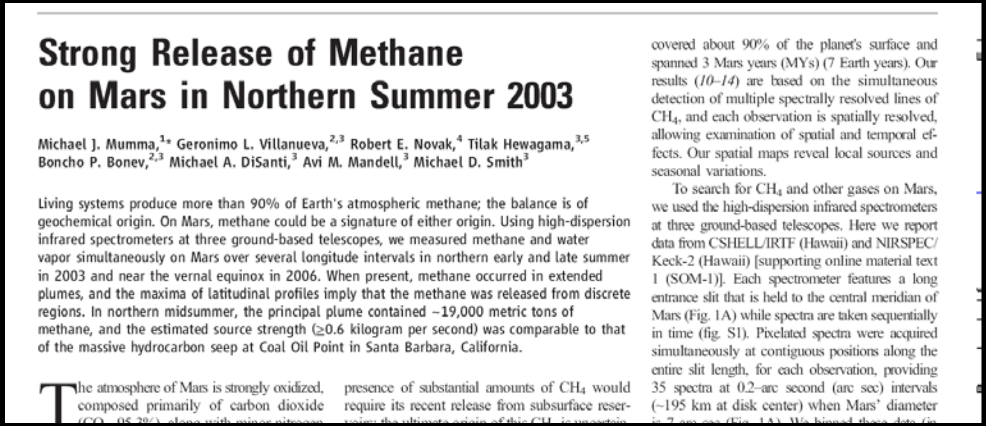


January 15th, 2009



Methane release:
Northern summer





Strong Release of Methane on Mars in Northern Summer 2003

Michael J. Mumma,[1*] Geronimo L. Villanueva,[2,3] Robert E. Novak,[4] Tilak Hewagama,[3,5] Boncho P. Bonev,[2,3] Michael A. DiSanti,[3] Avi M. Mandell,[3] Michael D. Smith[3]

Living systems produce more than 90% of Earth's atmospheric methane; the balance is of geochemical origin. On Mars, methane could be a signature of either origin. Using high-dispersion infrared spectrometers at three ground-based telescopes, we measured methane and water vapor simultaneously on Mars over several longitude intervals in northern early and late summer in 2003 and near the vernal equinox in 2006. When present, methane occurred in extended plumes, and the maxima of latitudinal profiles imply that the methane was released from discrete regions. In northern midsummer, the principal plume contained ~19,000 metric tons of methane, and the estimated source strength (≥0.6 kilogram per second) was comparable to that of the massive hydrocarbon seep at Coal Oil Point in Santa Barbara, California.

The atmosphere of Mars is strongly oxidized, composed primarily of carbon dioxide

presence of substantial amounts of CH_4 would require its recent release from subsurface reser-

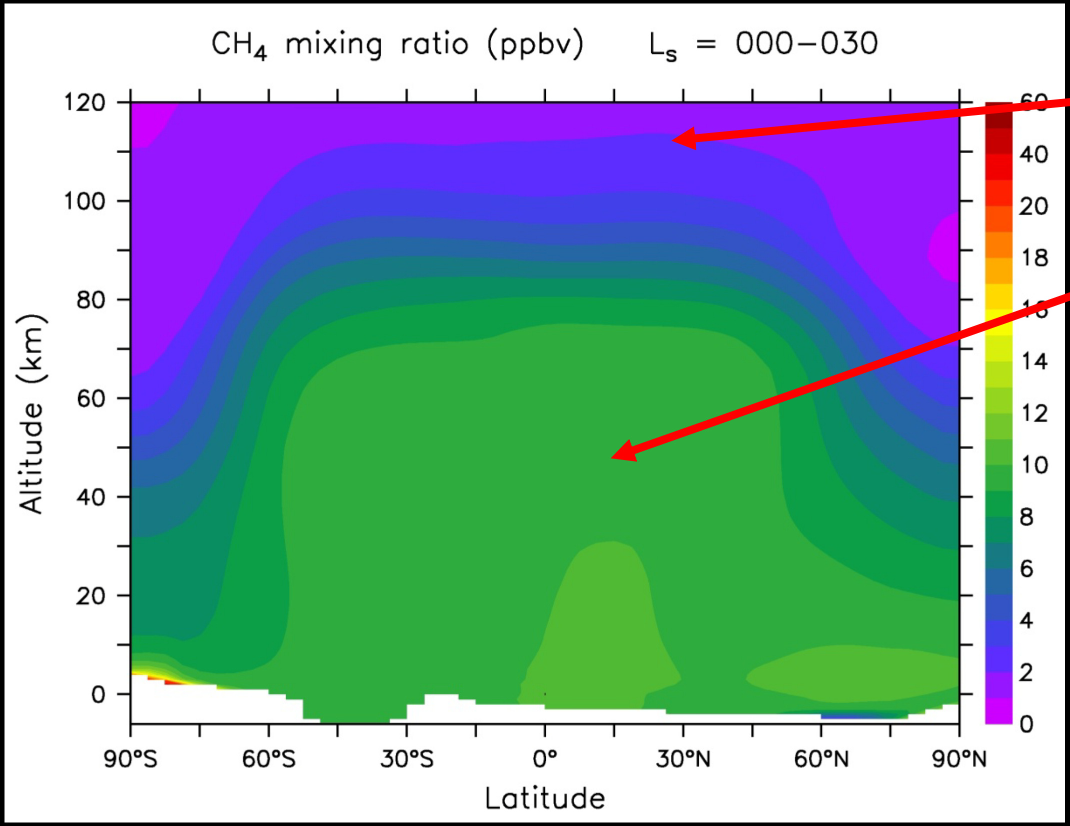
covered about 90% of the planet's surface and spanned 3 Mars years (MYs) (7 Earth years). Our results (*10–14*) are based on the simultaneous detection of multiple spectrally resolved lines of CH_4, and each observation is spatially resolved, allowing examination of spatial and temporal effects. Our spatial maps reveal local sources and seasonal variations.

To search for CH_4 and other gases on Mars, we used the high-dispersion infrared spectrometers at three ground-based telescopes. Here we report data from CSHELL/IRTF (Hawaii) and NIRSPEC/Keck-2 (Hawaii) [supporting online material text 1 (SOM-1)]. Each spectrometer features a long entrance slit that is held to the central meridian of Mars (Fig. 1A) while spectra are taken sequentially in time (fig. S1). Pixelated spectra were acquired simultaneously at contiguous positions along the entire slit length, for each observation, providing 35 spectra at 0.2–arc second (arc sec) intervals (~195 km at disk center) when Mars' diameter

Mumma et al., *Science*, 323, 1041, 2009

Methane in the LMD GCM

- CH_4 chemistry implemented in the GCM photochemical package
- Uniform initialisation: 10 ppbv
- No source



$CH_4 + h\nu \rightarrow$ products

$CH_4 + O(^1D) \rightarrow$ products

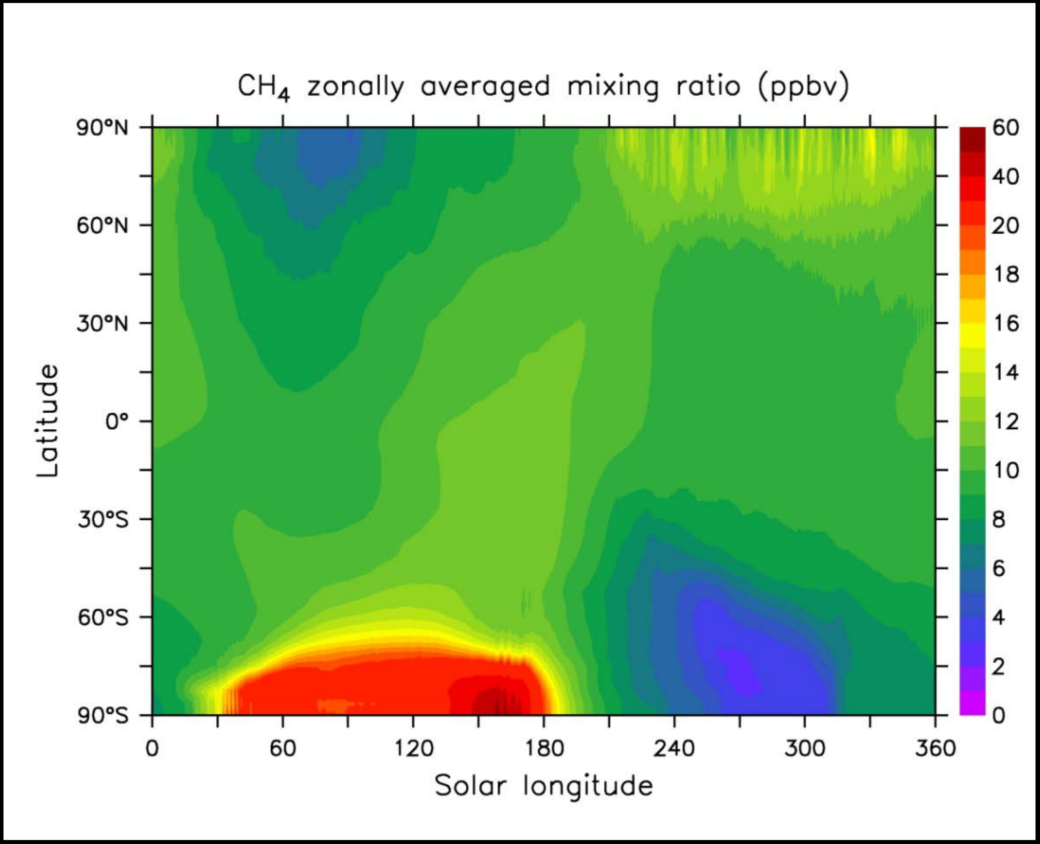
$CH_4 + OH \rightarrow CH_3 + H_2O$

Lifetime:
- derived from a 100-year simulation
- 330 terrestrial years

Source:
- Mars: 260 tons terrestrial year^{-1}
- Earth: 582×10^6 tons year^{-1}

2000 cows

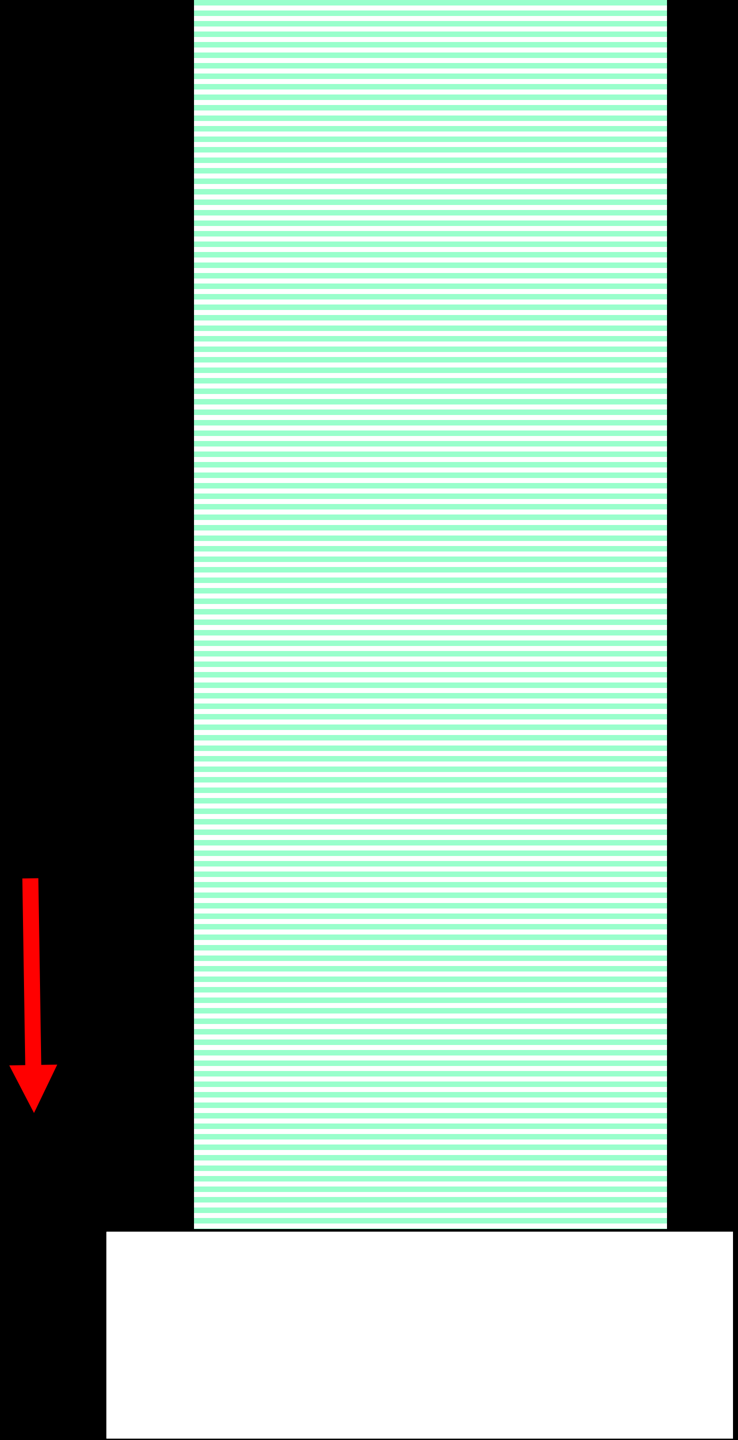
LMD CH_4 seasonal cycle



Lefevre and Forget

Surface condensation of CO_2 in the polar regions

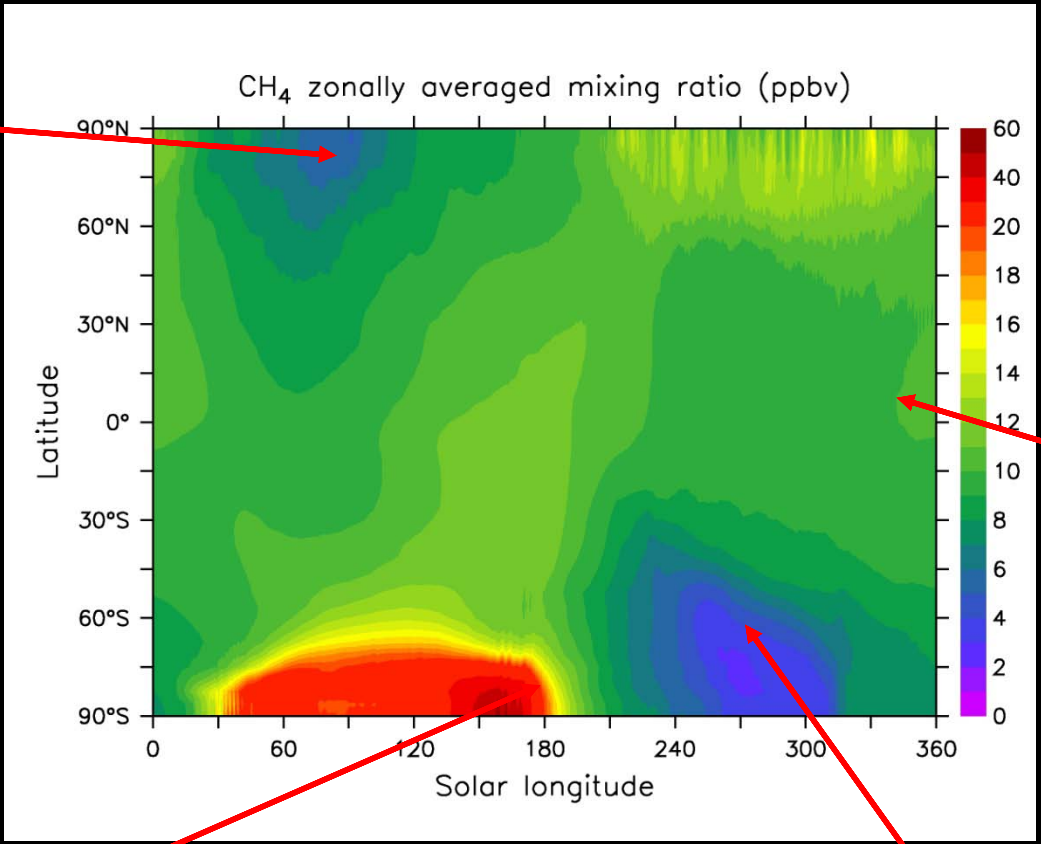
Near Surface enrichment of other gases like methane



LMD CH_4 seasonal cycle

PFS sees a maximum here

Formisano et al., 2007



All instruments see a minimum here

Geminale et al., 2008

Mumma et al., 2009

CSHELL/NIRSPEC see a minimum here

Mumma et al., 2009

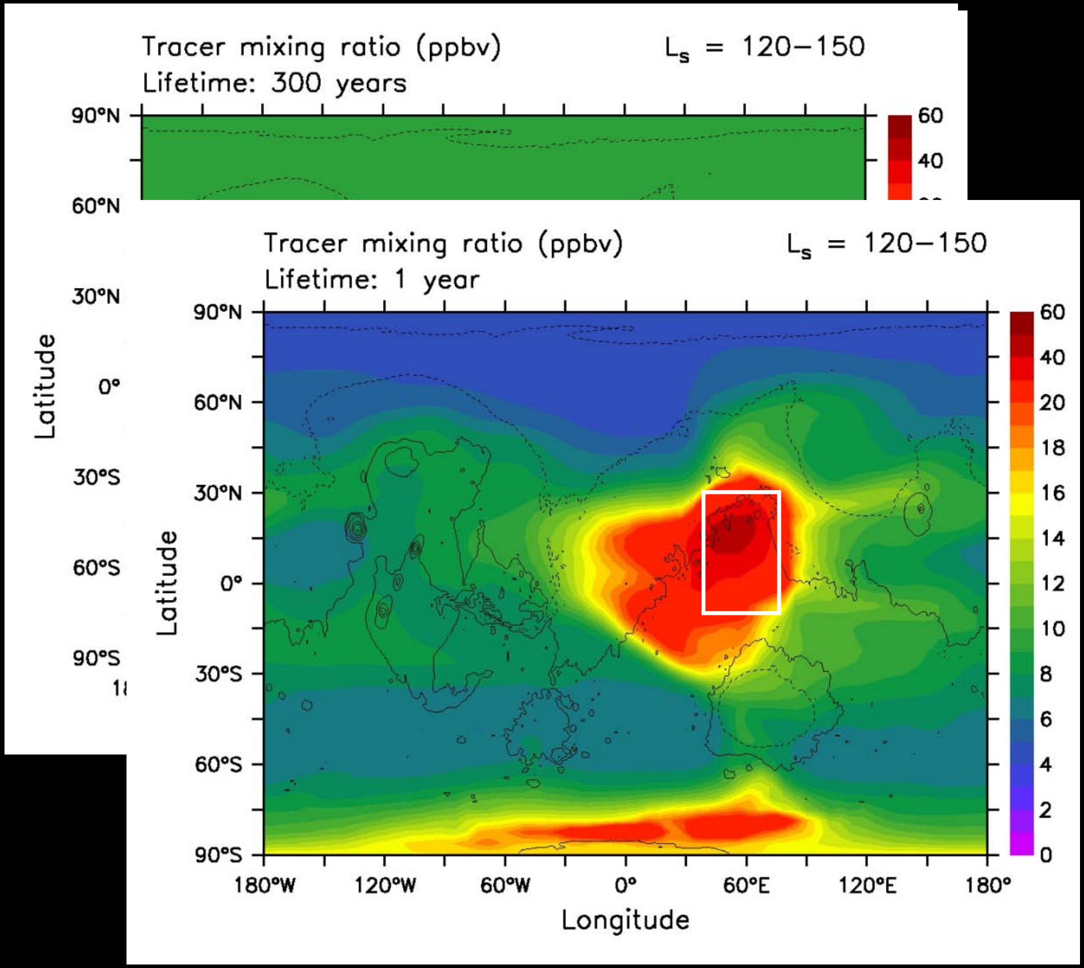
CSHELL/NIRSPEC see a maximum here

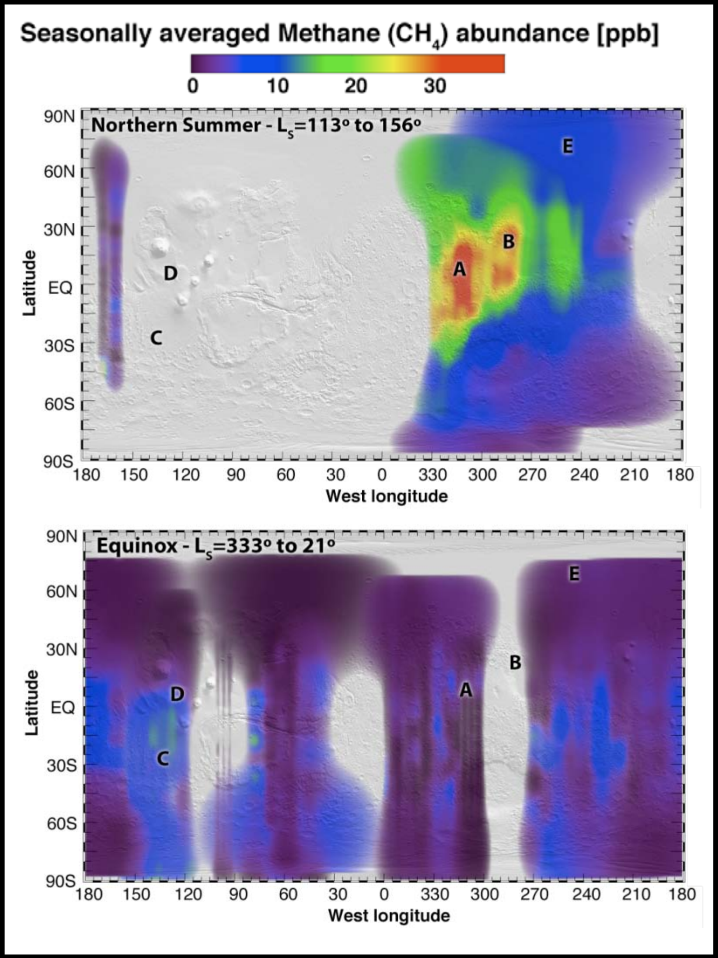
Mumma et al., 2007

- A (much) stronger source is needed → stronger sink → shorter lifetime

Shorter lifetime ?

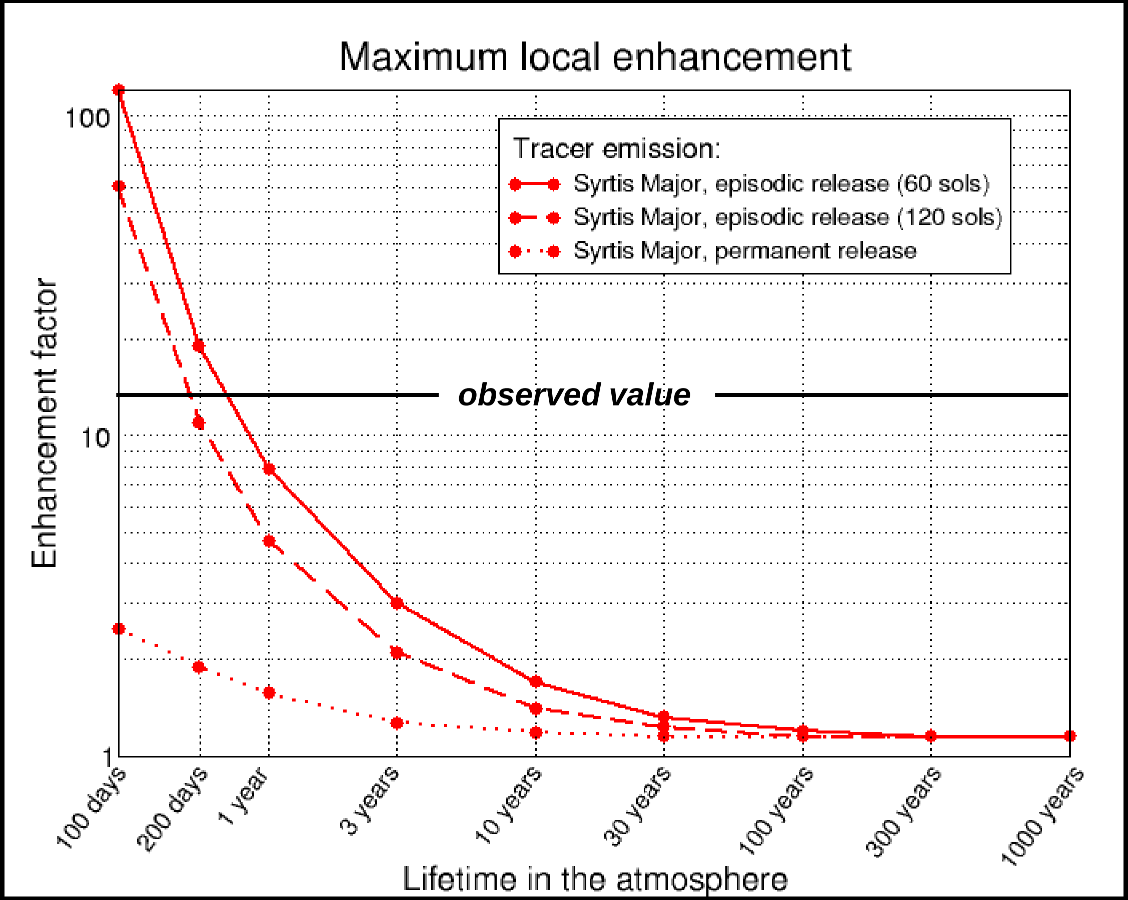
- Idealised tracers released from Syrtis Major
- Permanent or episodic source (Ls ~ 150°)
- Various lifetimes (1000 years to 100 days)

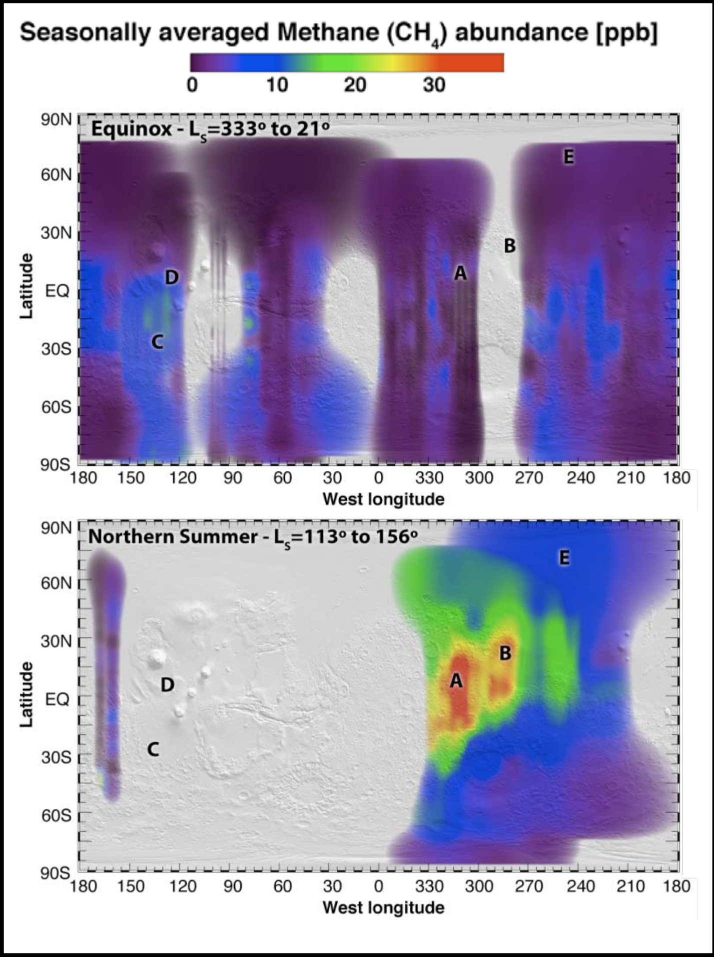




Observations (Mumma et al., 2009)

Enhancement factor





Observations (Mumma et al., 2009)

In the most favourable case, the methane lifetime must be of ~ 200 days to satisfy the observations. This implies:

1. A source of ~150 000 tons year^{-1}
   - 600 000 cows
   - comparable to the yearly production of methane by serpentinisation along the entire Mid Atlantic Ridge on Earth (60 000-130 000 tonnes, Keir et al., 2005):

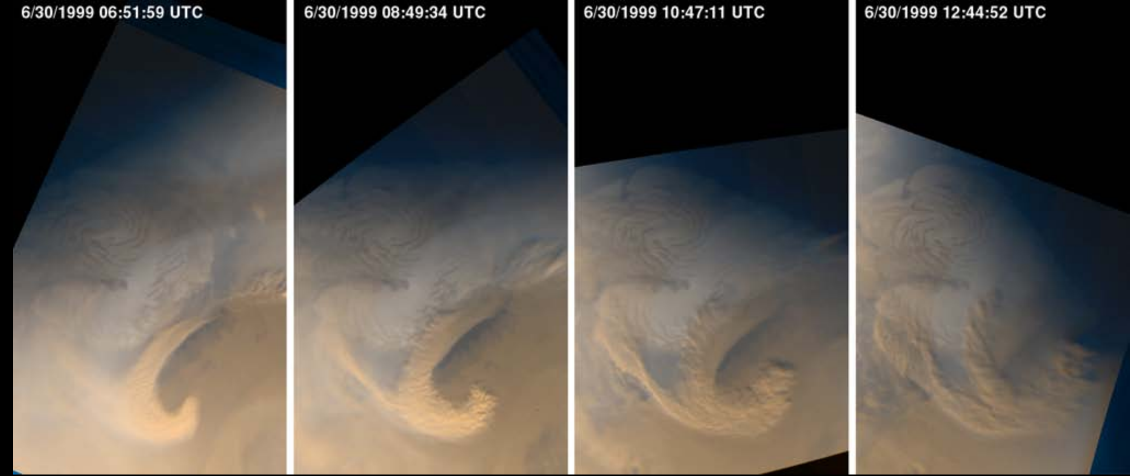
$$\underset{\text{olivine}}{(Mg, Fe)_2SiO_4} + H_2O \rightarrow \underset{\text{serpentine}}{Mg_3Si_2O_5(OH)_4} + \underset{\text{magnétite}}{Fe_3O_4} + H_{2(aq)}$$

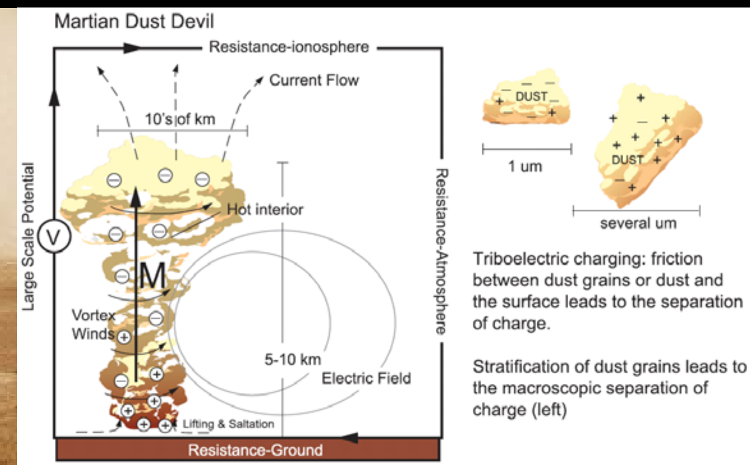
$$CO_{2(aq)} + 4H_{2(aq)} \rightarrow CH_4 + 2H_2O$$

2. A sink that is 600 times faster than predicted by the « standard » chemistry.
   - Missing gas phase process ? unlikely
   - Heterogeneous chemistry ? Recent laboratory data indicate very low reactivity (Gough et al., 2009).
   - Adsorption/desorption with the regolith ? Not efficient (Meslin et al. 2010)
   - More exotic mecanisms ? Electrochemistry ?

Electrochemical loss ?

DeLory et al., *Astrobiology*, 2006
Atreya et al., *Astrobiology*, 2006
Farrell et al., *Geophys. Res. Lett.*, 2007





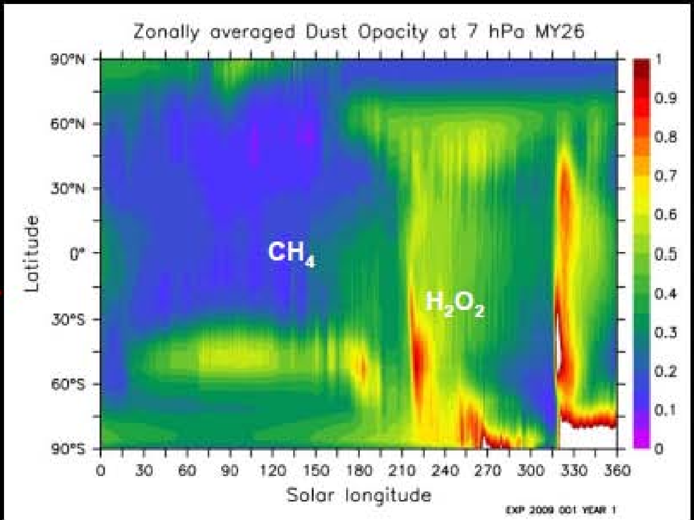
$CO_2 + e^- \rightarrow CO + O^-$

$H_2O + e^- \rightarrow OH + H^- \rightarrow \ldots \rightarrow H_2O_2$

$CH_4 + e^- \rightarrow$ products

Simulation with tribolectricity

$E \approx 25$ kV m^{-1} for $\tau_{vis} \geq 2$

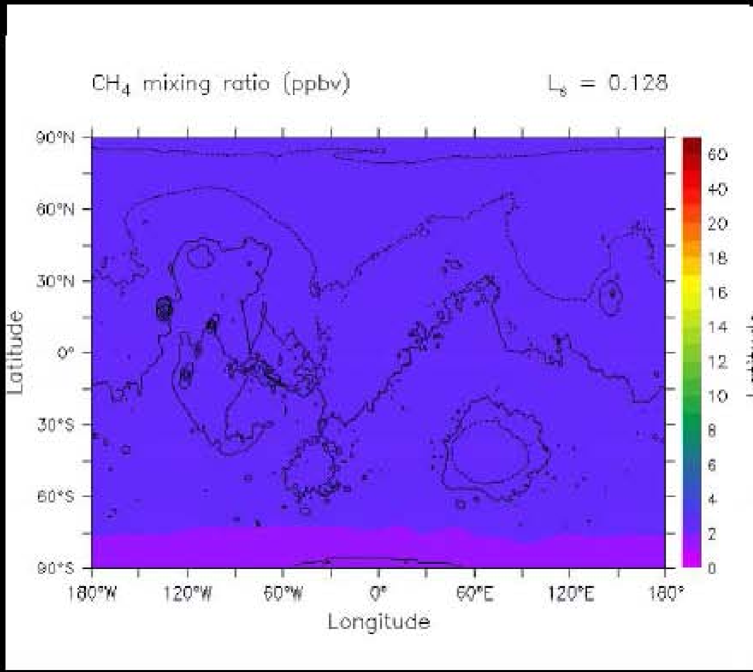


TES dust opacity

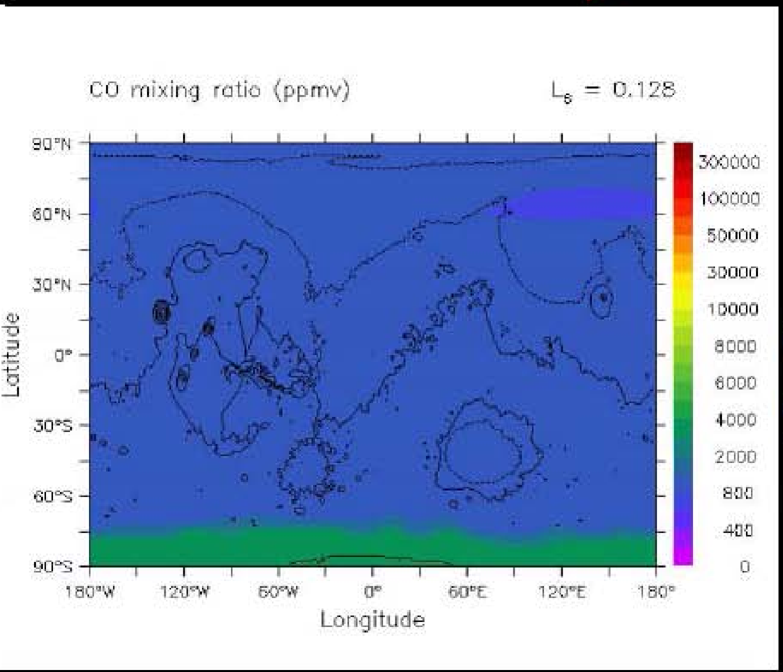
MY26 (2002-2004)

50 times as large as the observations

CH_4



$CH_4 + e^- \rightarrow$ products

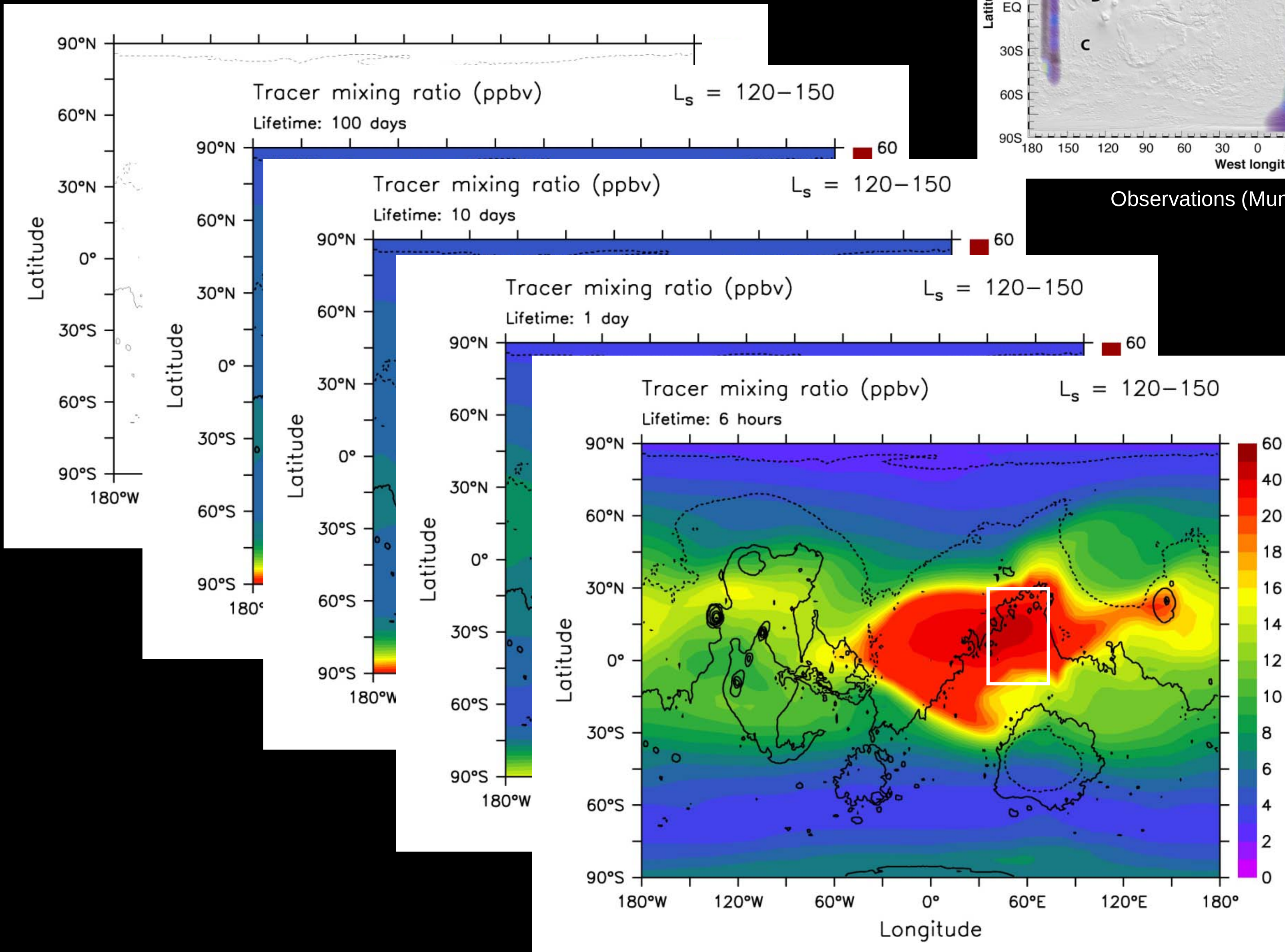


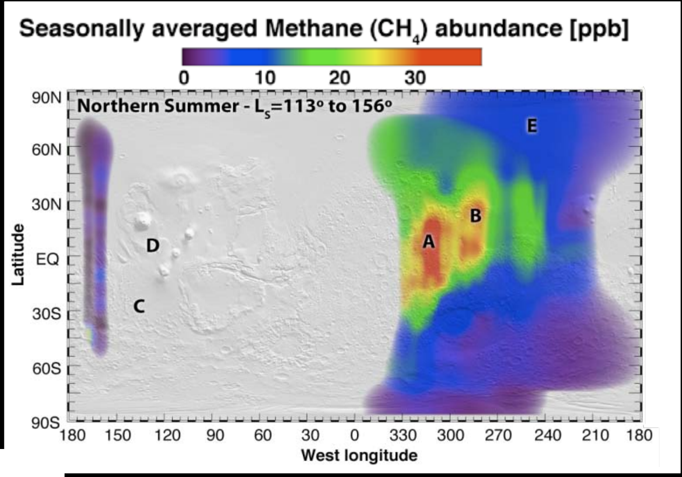
$CO_2 + e^- \rightarrow CO + O^-$

CO

observations: ~800 ppmv

Simulations with idealised tracer





Observations (Mumma et al., 2009)

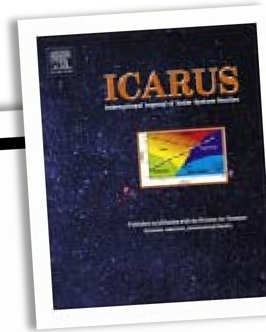
LETTERS

Observed variations of methane on Mars unexplained by known atmospheric chemistry and physics

Franck Lefèvre[1] & François Forget[2]

The detection of methane on Mars[1–3] has revived the possibility of past or extant life on this planet, despite the fact that an abiogenic origin is thought to be equally plausible[4]. An intriguing aspect of the recent observations of methane on Mars is that methane concentrations appear to be locally enhanced and change with the seasons[3]. However, methane has a photochemical lifetime of several centuries, and is therefore expected to have a spatially uniform distribution on the planet[5]. Here we use a global climate model of Mars with coupled chemistry[6–8] to examine the implications of the recently observed variations of Martian methane for our understanding of the chemistry of methane. We find that photochemistry as currently understood does not produce measurable variations in methane concentrations, even in the case of a current, local and episodic methane release. In contrast, we find that the condensation–sublimation cycle of Mars' carbon dioxide atmosphere can generate large-scale methane variations differing from those observed. In order to reproduce local methane enhancements similar to those recently reported[3], we show that an atmospheric lifetime of less than 200 days is necessary, even if a local source of methane is only active around the time of the observation itself. This implies an unidentified methane loss process that is 600 times faster than predicted by standard photochemistry. The existence of such a fast loss in the Martian atmosphere is difficult to reconcile with the observed distribution of other trace gas species. In the case of a destruction mechanism only active at the surface of Mars, destruction of exponential decay of methane in a long-term simulation that did not include any source. We find that the global atmospheric mass of methane is reduced by a factor of e after 330 terrestrial years. This lifetime is consistent with past estimations based on globally averaged models (250–670 terrestrial years[2,9,10]), but here integrates the effects of spatial and seasonal variations in ultraviolet flux, water vapour and ozone. From this estimation, the source flux of methane at the Martian surface must be 260 tonnes per year ($260\,t\,yr^{-1}$) for a steady-state value of 10 p.p.b.v. (parts per billion by volume). This may be compared with the terrestrial value of $582 \times 10^6\,t\,yr^{-1}$ (ref. 11).

Can such a faint source create variations in the observed methane field? Evidently, such variations are favoured if the source itself shows some degree of spatial or temporal variability. To investigate this possibility, we introduced a highly localized and sporadic source in the GCM. We chose the area and timing of the methane release to coincide with the important local maximum (40–50 p.p.b.v.) observed[3] in northern summer 2003: methane is released at the surface in a single grid cell of the model located in Syrtis Major (10° N, 50° E), and the emission is assumed to occur for only 60 sols (one sol is a Martian day) around solar longitude $L_s = 150°$. The amount of methane injected into the atmosphere during this period is constrained to balance the global photochemical loss integrated over the Martian year. Figure 1a displays the methane distribution obtained during the period of emission. The local release of methane does not produce any significant enhancement or plume in the source region. In contrast with the observation, the model shows an essen-



Is there methane on Mars?

Kevin Zahnle[a,*], Richard S. Freedman[a], David C. Catling[b]

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ABSTRACT

There have been several reports of methane on Mars at the 10–60 ppbv level. Most suggest t
is both seasonally and latitudinally variable. Here we review why variable methane on Mars
and chemically implausible, and then we critically review the published reports. There
mechanism for destroying methane chemically on Mars. But if there is one, methane oxi
deplete the O_2 in Mars's atmosphere in less than 10,000 years unless balanced by an
unknown source of oxidizing power. Physical sequestration does not raise these questions
tion in the regolith or condensation in clathrates ignore competition for adsorption sites or
tent with clathrate stability, respectively. Furthermore, any mechanism that relies on meth

Zahnle et al. main criticism

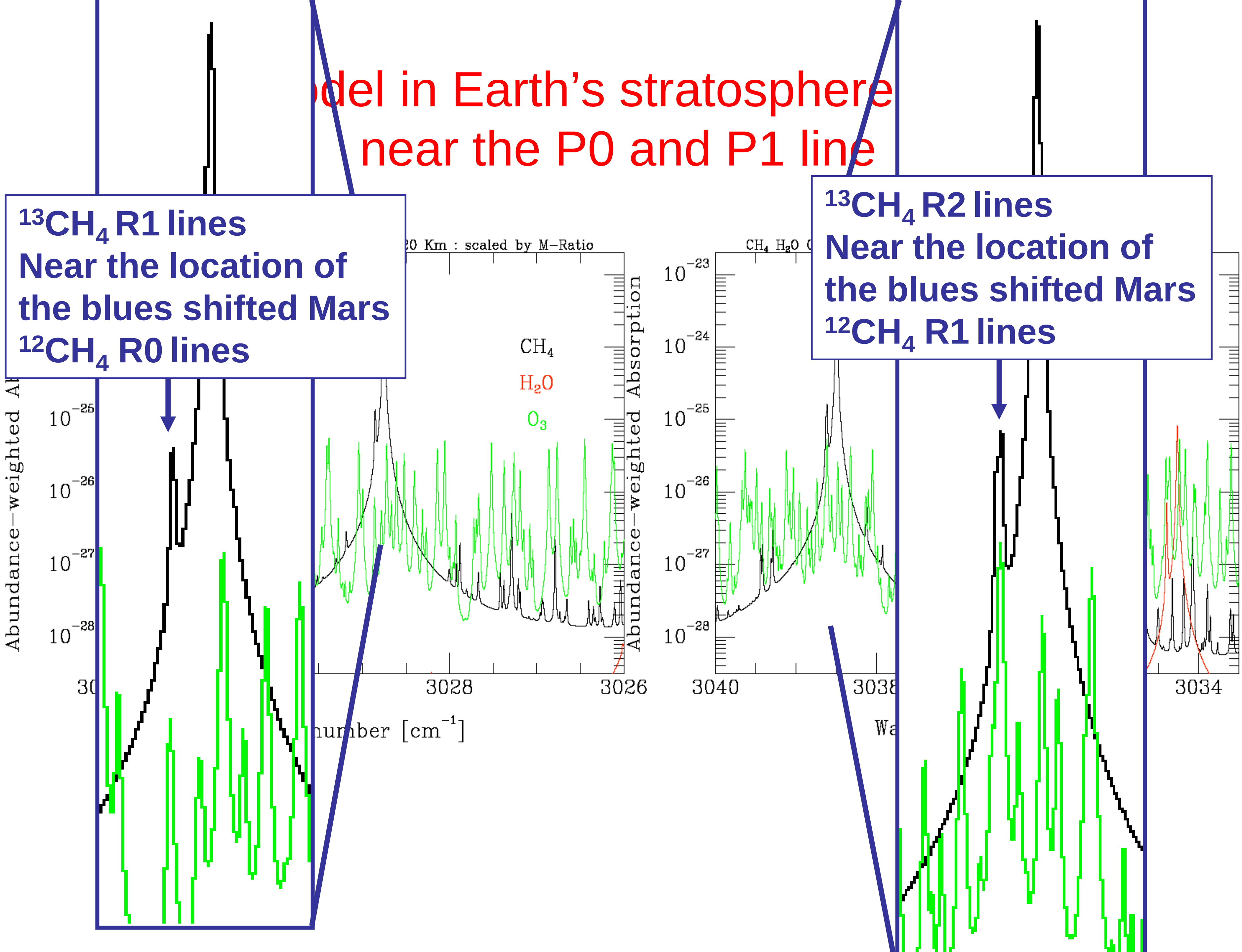
- Mars CH_4 lines must be observed through Earth CH_4 lines, which is only possible when Mars lines are Doppler shifted (and thus shifted to the side of the strong CH_4 Earth line)

- Near the location of the blues shifted Mars $^{12}CH_4$ R lines: Earth $^{13}CH_4$ R lines = Mumma et al. detection

- Near the location of the blues shifted Mars $^{12}CH_4$ R lines = No detection

Reply by Mumma et al. : Of course we take that into account !!

…odel in Earth's stratosphere near the P0 and P1 line



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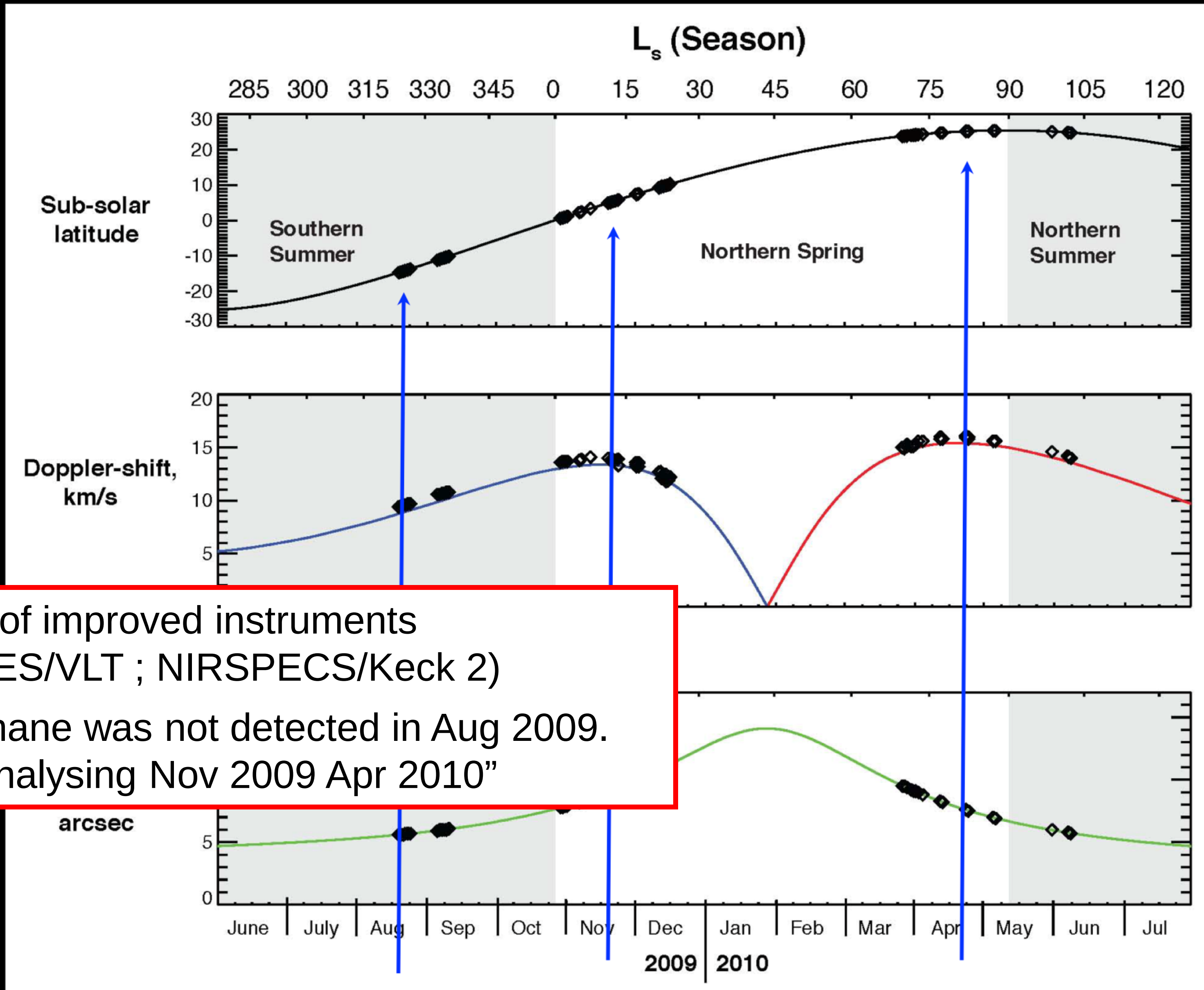
News from Mumma et al. 2011

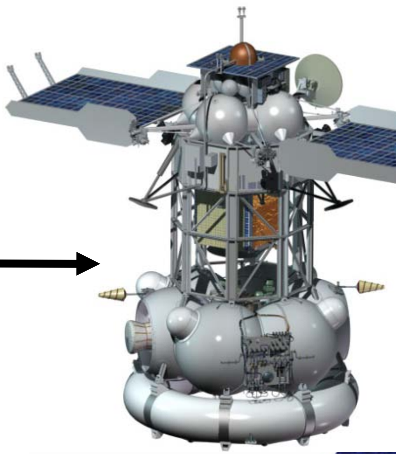
Mars Observing Circumstances 2009-2010



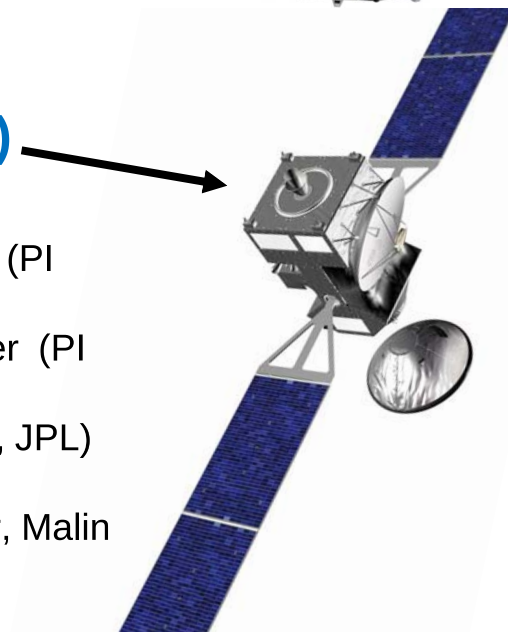
- Use of improved instruments (CRIRES/VLT ; NIRSPECS/Keck 2)
- “Methane was not detected in Aug 2009. Now analysing Nov 2009 Apr 2010”

Futures observations of Methane (and other trace gases)

- More from Terrestrial telescopes
- Mars Science Laboratory: observations start in ~summer 2012 (tunable diode laser)
- Phobos Grunt (Phobos sample return, Russia) spectrometer AOST and TIMM-2 (solar occulation) observations start 01/2013



- **Mars Trace Gas Orbiter (ESA-NASA 2016)**



5 instruments :

- **MATMOS** Mars Atmosphere Trace Molecule Occultation Spectrometer – (PI Paul Wennberg, Caltech).
- **SOIR -NOMAD**High Resolution Solar Occultation and Nadir Spectrometer (PI :Ann C. Vandaele, Bellgium)
- **EMCS** ExoMars Climate Sounder – (infrared radiometer) (PI J. Schofield, JPL)
- **HRSC**I High Resolution Color Stereo Imager (PI: Alfred McEwen)
- **MAGIE**: Mars Atmospheric Global Imaging Experiment (PI Bruce Cantor, Malin Space Science Systems, San Diego.)