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, CO2 (and some water)

Northern spring

CO2 ice

Water ice clouds

Dust

NASA/JPL/MSSS
Mars climate: a complex system

Atmospheric circulation

Vapor, ice
Radiative effects

scavenging
transport
condensation
heat transport
flow

Dust cycle

CO₂ cycle

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

- Sublimation
- Transport
- Clouds
- Condensation

NORTHERN SUMMER

Solar Flux
Mars water cycle

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

Clouds
N. Summer Tropical Cloud belt

(TES thermal IR obs. Smith, 2001)
N. Summer
Tropical Cloud belt

NASA/JPL/MSSS
MAP of clouds:

N. Summer

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

<table>
<thead>
<tr>
<th>N summer</th>
<th>fall</th>
<th>winter</th>
<th>spring</th>
<th>summer</th>
<th>fall</th>
</tr>
</thead>
</table>

TES Water-Ice Opacity (825 cm⁻¹), Scale: τ = 0 (purple) - 0.15 (red)

TES Temperature at 0.5 mbar, Scale: T = 150 (purple) - 215 K (red)

Phoenix
Image from Phoenix SSI camera
Phoenix Observations
Lidar Measurements of Dust and Clouds

SOL 099

Dust
Cloud
Cloud (ice fog)
Fall streaks

Whiteway et al. 2008
Fall Streaks

Whiteway et al. 2008

http://australiasevereweather.com/
Lidar Measurements of Martian Clouds

SOL 095

Altitude [km]

Backscatter Coefficient [cm$^{-2}$sr$^{-1}$] $\times 10^{-5}$

02:18 02:33 02:47 03:02 03:16
Local Time

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
H₂O 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)

$Ls = 0 - 90\square$ (MGS year 3)

Blue: Albedo boundary (water frost)

Red: Thermal boundary (CO2 frost)
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

$L s = 348$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 18$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 48 \degree$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 78$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$\text{L}_s = 108 \degree$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 138$

LMD GCM

TES Observations

*Figures from John Wilson!*
Zonal mean temperature

$L_s = 168$ 

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 198$

LMD GCM

TES Observations

*Figures from John Wilson!*
Zonal mean temperature

$L_s = 228$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 258$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 288$

LMD GCM

TES Observations

Figures from John Wilson!
Zonal mean temperature

$L_s = 318 \degree$

LMD GCM

TES Observations

Figures from John Wilson!
Modelling the water cycle
Seasonal cycle

Simple GCM Simulation

MGS TES Observations
Modelling the water cycle

Transport

Convection

Boundary layer

Sublimation

Condensation

“Cloud model”: (Montmessin et al. 2004)
SEASONAL WATER CYCLE OBSERVATION

MODEL
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…

Langevin et al., 2005
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):

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>N. Summer</th>
<th>Fall</th>
<th>N. Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>No accumulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

⇒ No accumulation outside the polar regions
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

What about surface liquid water?
Liquid water on Mars

Haberle et al. 2003
Liquid water on Mars?

Pure water
Only if $T > 0 {}^\circ$C and $P_s > 610$ 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
    
    \[
    P_{H_2O} = P_{abs} \times [H_2O] \ll P_{abs}
    \]

⇒ Pure Liquid water impossible except in lower plains ($P_s > 6.1$mb) 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)
Topography (m), AMAZONIAN: ice caps, glaciers, gullies…

-4.5 -4.0 -3.0 -2.0 -1.0 Present

Age (Gyr)

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

V.E. 100:1

(a) 70° N 94.8° E

(b) 70° S 260.4° E

Distance over Ground (km)

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

SPLD surface
Basal interface

MARSIS Data

MOLA Topo

Nadir groundtrack 500 km

2682
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

cosmic rays

Neutrons
Neutron Spectrometer, NASA Mars Odyssey, 2001

Cosmic rays

Less Neutrons

Ice
An ice-rich layer discovered by Mars Odyssey 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)
First Ground View of the Mars Polar Region
 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
Glacier-like landforms on Mars at mid-latitudes

Topography (m)

Head et al. 2006
Hartmann et al. 2003

EARTH
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 $\pm 1.3^\circ$

Mars: variations between $0^\circ$ et $>60^\circ$

Laskar et al. 2004
Laskar and Robutel 1993
Touma and Wisdom 1993
Earth obliquity: variations ±1.3°

Mars: variations between 0° and >60°

Climate changes resulting from obliquity variations
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
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
\((\text{precipitable} - \text{microns})\)

On present-day Mars:

Same, but 45° Obliquity
\((\text{Circular orbit})\)
Ice accumulation rate (mm/yr)
high resolution simulation (2° x 2°)

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

Forget et al. Science 311, p368, 2006
The formation of glacier:

Ice accumulation rate (mm/yr) in a new very high resolution simulation

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

cloud ice column Ls=125–155
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: \( \text{H}_2\text{O} \text{ ice} \)
White CO2 ice

*Bibring et al. 2004*

CO2 mainly (H2O minor) | H2O (no CO2) | No ice

Thin CO2 layer <10 m

H2O layer (seems thin?)

Polar deposits (ice free at surface)

*N. Mangold - Bibring et al. 2004*
Ice accumulation -75000 years ago
Perihelion = Northern summer (today)

Montmessin et al. 2007

Net transport of Water ice from North pole to south pole : south polar cap
High Obliquity Simulation with a water ice cap at the south pole

(Forget et al. 2005)

Yearly accumulation rate (mm/year) (10th year simulation)
run15 total H₂O column Ls=265–290

Wind at 3 km $100\text{ m/s}$
GCM simulation

Location of glacier-like landforms

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

Location of glacier-like landforms

Head et al. 2005
HRSC
Head et al. 2005
HRSC
GCM simulation

Location of glacier-like landforms

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

Surface ice budget (mm/yr); Obliquity= 20 deg.
Surface ice budget (mm); Obliquity = 20 deg.
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°

Tharsis Glaciers

Map of icy lobate debris Aprons (Squyres 1979)
Water source = Tharsis Glaciers

Obliquity = 35°
ICE ACCUMULATION RATE (daily mean)

sol = 499 N. Fall

(g/m²/sol)
Dust opacity = 2.5  Obliquity = 35°  Ls(perihelion)=90°

Water source = Tharsis Glaciers
Gullies “recently” formed by liquid water


- 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)
Simulated diurnal mean surface temperature at various obliquity
(max temperature = near summer solstice)

a) Lat = 40S

b) Lat = 70S

c) Southward slope = 30 deg

(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°:  \( \tau = 2.5 \)
Can we understand the structure of the

Formation d'une calotte polaire de glace d'eau

Aux hautes latitudes, une partie de la glace retourne au pôle, une partie reste sous quelques centimètres de sédiments

Une couche de glace d'eau recouvre les hautes latitudes dans chaque hémisphère

Calotte de glace d'eau

Disparition des glaciers aux basses et moyennes latitudes

Disparition des calottes permanentes de glace d'eau
氷の極冠の形成

高緯度では氷の一部が
傾向をどおり、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

氷の極冠

氷の極冠の消失

氷の層は両半球の高緯度地域を
おおう

氷塊の消失

低・中緯度地域における氷塊の形成
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?
Obliquity (degrees)
Polar ice accumulation (mm/yr)

- Eccentricity=0
- Ecc =0.093; Lp =270 deg
- Ecc= 0.093; Lp= 90 deg

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: Northern 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 ?**
Topography (m),

AMAZONIAN: ice caps, glaciers, gullies...

Ancient terrains
Lake, rivers ??

Age (Gyr)
-4.5 -4.0 -3.0 -2.0 -1.0 Present
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 \(\Rightarrow\) 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
- Mineralogy related to water alteration
100 km

Time

Apparent erosion rate

Craddock and Maxwell, 1993
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

extended sulfate-rich area

Mars Express Omega

Sulfate cliff in Victoria crater  (Rover NASA Opportunity)
Roche sédimentaire : sel de sulfate

Concentration d’hématite (oxyde fer)
« 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
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:

1. Young sun: fainter
2. Geothermal heat flux: Stronger
3. Bombardment: Much heavier
4. Atmosphere: thicker?
Evolution of Solar flux at Mars

Standart Sun model
(e.g. Gough 1981)

Time before present (Gyr)
Why was early Mars different?

Different boundary conditions compared to present:

1. Young sun: fainter
2. Geothermal heat flux: Stronger
3. Bombardment: Much heavier
4. Atmosphere: Thicker?
Evolution of Mars mean Geothermal heat flow

(from Shubert et al., 1992)

Mean Depth of isotherm 0°C

(Tsurf=210K; λ=1 W m⁻¹ K⁻¹)

Depth below surface (m)

Time before present (Gyr)

ICE

LIQUID WATER
Why was early Mars different?

Different boundary conditions compared to present:

1. Young sun: fainter
2. Geothermal heat flux: Stronger
3. Bombardment: Much heavier
4. Atmosphere: Thicker?
Simulation of Impact: episodic warming

Why was early Mars different?

Different boundary conditions compared to present:

(1) Young sun: fainter

(2) Geothermal heat flux: Stronger

(3) Bombardment: Much heavier

(4) Atmosphere: thicker?
“Early Mars” climate simulations

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

– A thicker CO2 atmosphere
  (500 mbars – 2 bars or more ?)

– A faint sun (75% present)
Classical studies: simple 1D model

Typical 1D results for a pure CO2 atmosphere, no clouds:
→ Global Annual mean temperatures:

<table>
<thead>
<tr>
<th>CO2 pressure</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.006 bar</td>
<td>-72°C</td>
</tr>
<tr>
<td>0.1 bar</td>
<td>-61°C</td>
</tr>
<tr>
<td>0.5 bar</td>
<td>-50°C</td>
</tr>
<tr>
<td>2.0 bar</td>
<td>-41°C</td>
</tr>
</tbody>
</table>

⇒ Recent results: full 3D Global Climate
- Challenge: solve the IR radiative transfer:
  - Thick CO2 atmosphere
  - Poorly known collision induced absorptions
  - Scattering of thermal IR radiations
3D simulations with $P_s = 2$ bar

Annual mean Surface Temperature (°C)

Forget et al. 2005

Faint sun, Pur CO2, No clouds, $\text{excentricity} = 0°$, current obliquity

Mean atmospheric temperature

Forget et al. 2005
Diurnal Mean Surface Temperature (°C)

with \(<Ps>=2\)bars

*Pure CO2 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)**: -3°C
- **Barrow (AK)**: -12°C
- **Antarctica Dry Valley**: -15°C – -30°C
Zonal mean temperatures

- Atmosphère : 2bars CO2
- Faint sun 75% present

Northern Summer

Southern Summer

excentricity=0°, current obliquity
Simple CO2 ice cloud scheme

1. In each model mesh: If $T<T_{\text{cond}}$, condensation and latent heat release $\Rightarrow T=T_{\text{cond}}$
2. CO2 ice is split into small particles (The number of particle / kg is prescribed)
3. Transport and mixing by winds, turbulence, convection
4. Gravitational sedimentation
5. Interaction with Solar and IR radiation (assuming Mie theory and Hansen et al. (1996) radiative properties)
6. If $T>T_{\text{cond}}$, sublimation to get $T=T_{\text{cond}}$ or no more ice
CO2 ice clouds coverage (opacity) (mean Ps = 2 bar)
CO2 ice clouds vertical structure

(example: Northern summer $10^5$ particles/kg$_{air}$)
Scattering Greenhouse effect of CO2 ice clouds

Forget and Pierrehumbert, Science 1997
Impact of simulated CO2 ice clouds scattering greenhouse effect on surface temperature

\[ <P_s> = 2 \text{ bar} \]

Annual mean Surface Temperature (°C)

WITHOUT CO2 ice clouds

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

with \(<Ps>=2\)bars

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

Northern Summer

Southern Summer

Note: Other orbital parameters do not allow to warm much...
Atm. Pressure at -45S 0E (Ps=2b Ls=260-288)

Surface Pressure (mbar)

Surface Temperature (°C)

Ls = 270

45°S 0°E

Southern Summer
Maximum surface temperature during southern summer (°C)

Max Tsurf (°C) e=0 mean Ps=2bar Ls=260–290
At other surface pressures

- 2 bars
- 0.5 bars
Diurnal Mean Surface Temperature (°C) with CO2 ice clouds with \(<P_s> = 0.5\) bars

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

Northern Summer

Southern Summer
Temperature at -45°S 0°E (Ps=0.5b, Ls=270-300)

Surface Temperature (°C)

Time (sol)

45°S 0°E

Southern Summer
Southern Summer

Temperature at -45°S 0°E (Ps=0.5b Ls=270–300)

Surface Temperature (°C)

Time (sol)

2bars

0.5bars

45°S 0°E
MAXIMUM Surface Temperature (°C) with $<P_s>=2$bars

with CO2 ice clouds
Pure CO2 gas, faint sun, eccentricity=0°, current obliquity

Northern Summer

Southern Summer
Case of favorable orbital parameters with $P_s = 0.5$ bars

Maximum eccentricity ($e=0.14$)

“high” obliquity = 37.62 (average Mars obliquity)

(Laskar et al. 2004)

Daily mean surface temperature

[Graphs showing temperature distribution for Northern and Southern summers]
Speculation: the water cycle on this early Mars

Precipitation: mostly snow
Rain possible?

$T > 0^\circ C$ for short period: snow and glacier melt...

Warm temperature in lower plains: liquid water lake and oceans?
Dorsa argentea: Remnant of an hesperian massive Ice cap built with a thicker atmosphere?
Still many issues with the early 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 different 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).

*Chassefière 2005*
Why did Mars lose most of its atmosphere?

1. Solar wind erosion
2. Impact escape
3. Surface chemical loss

- Solar wind
- UV
- Œdiation photochimique
- Sputtering
- CO₂ condensation
• Thank you
• どうもありがとうございました


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