3D modelling of the Early Mars Climate and Water cycle

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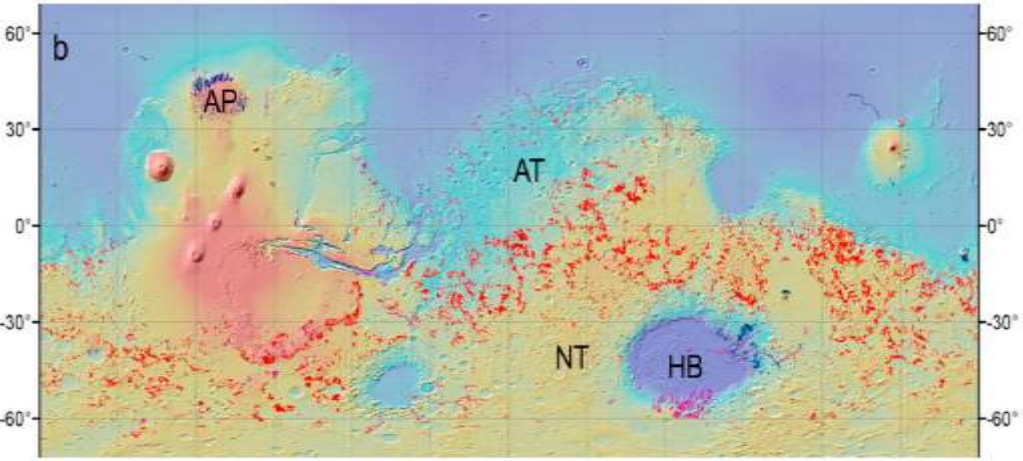
Context: Early Mars

More and more clues from minerology and geomorphology suggest that early Mars was different than today, with liquid water flowing. But key questions remains:

- Were the conditions suitable for liquid water **episodic** or **stable** on longer time scales ?
- Role of **hydrothermalism** (volcanic, impact) ?

Map of valley networks



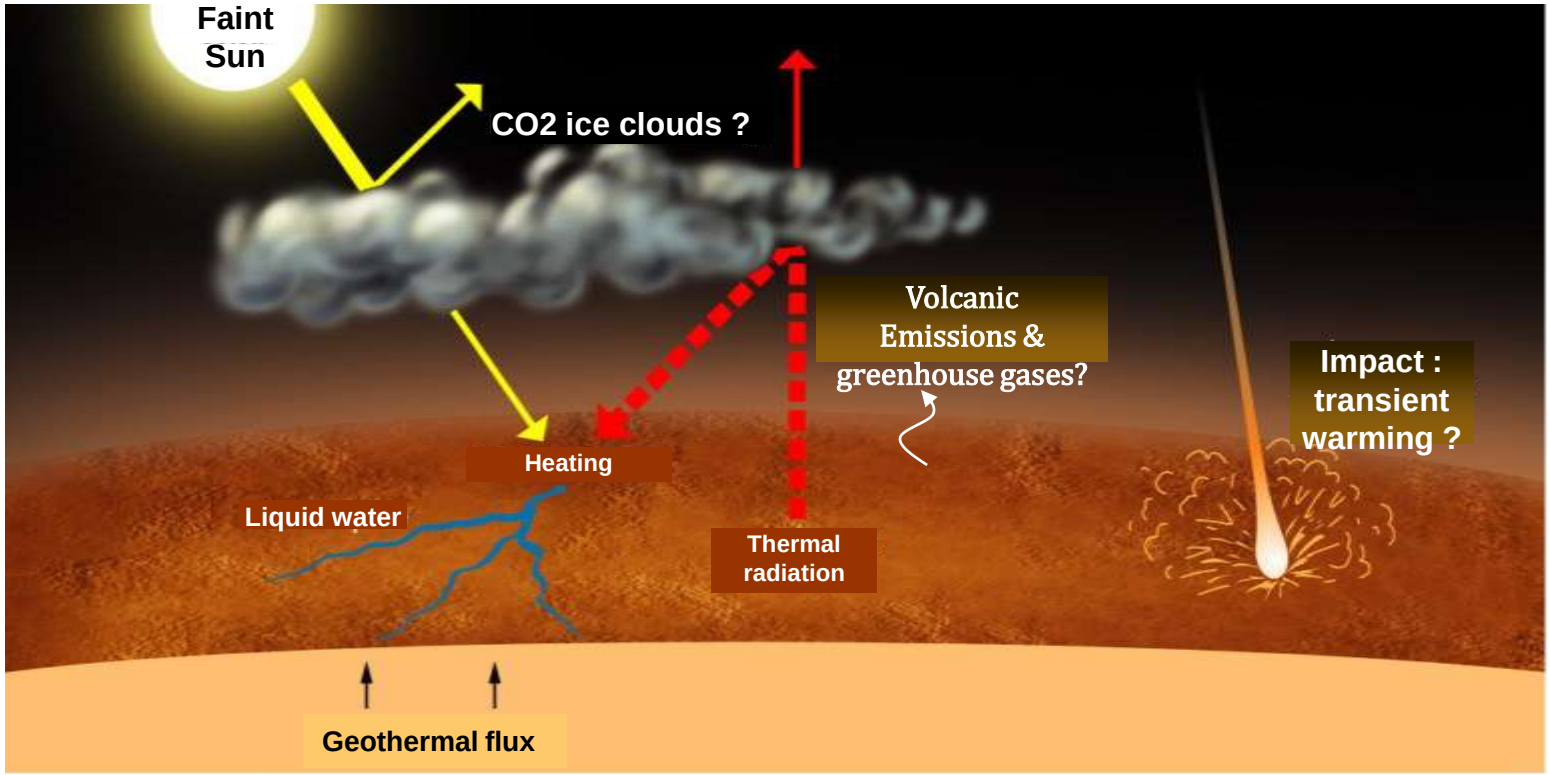
Hynek et al. 2010

Map of hydrous minerals:

Phyllosilicates and chlorites Hydrated sulfates or zeolites Opaline silica

Poulet et al. DPS 2010

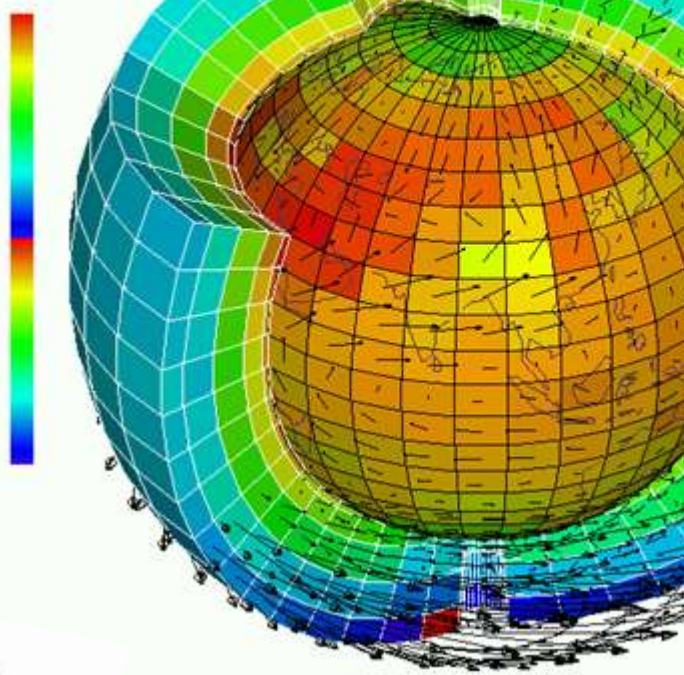
Early Mars was different:
⇨The early Mars Climate enigma



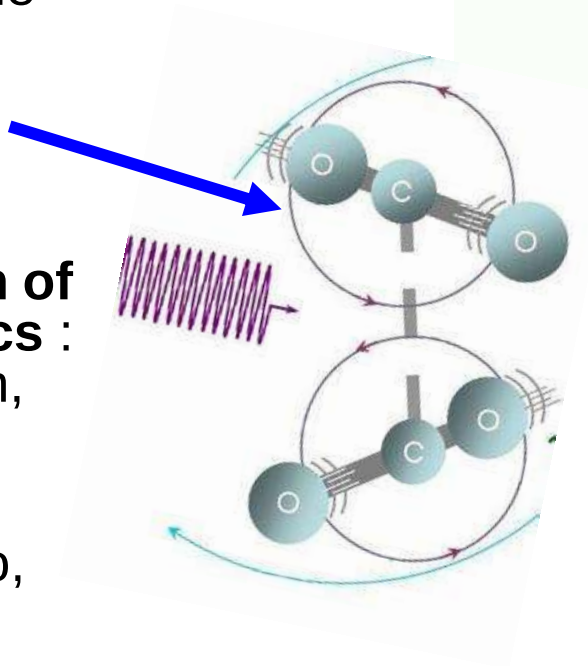
The question today: what would be the climate on a Mars-like planet with

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

A Global Climate Model (GCM) for early Mars



- **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



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

CO_2-CO_2 collision-induced absorption

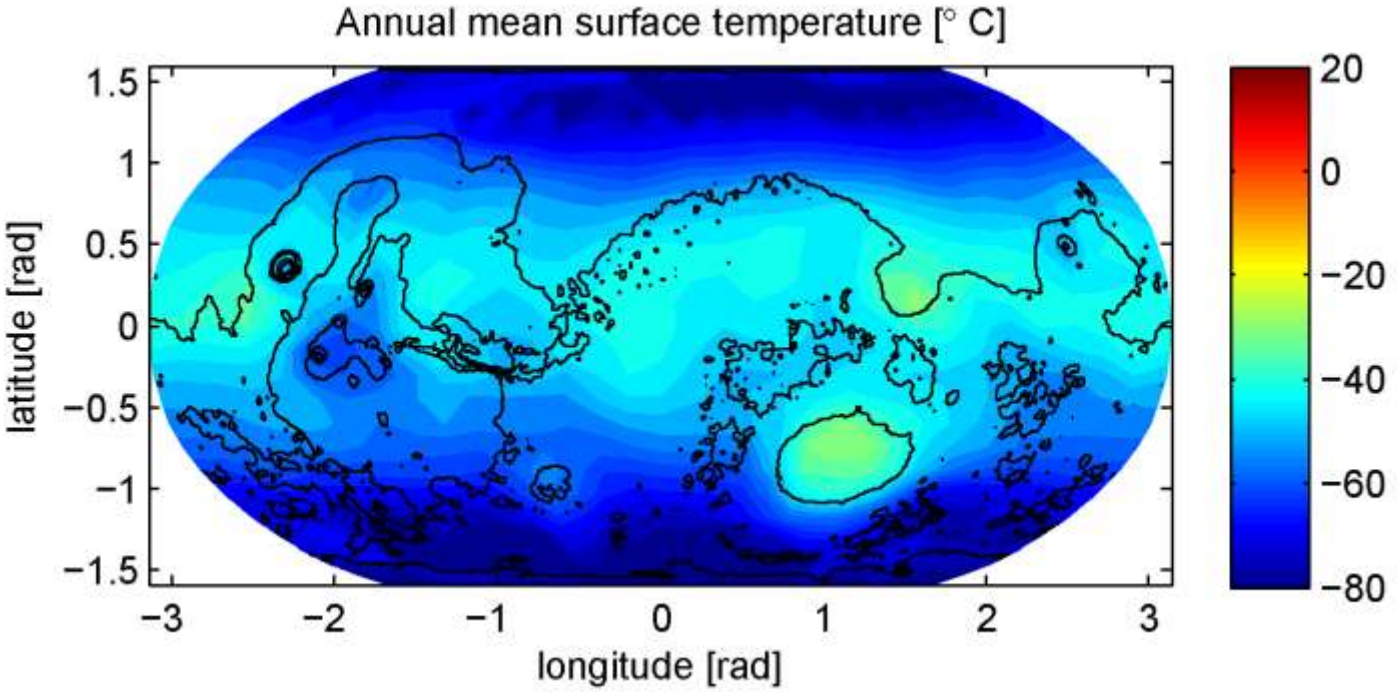
New parametrisation

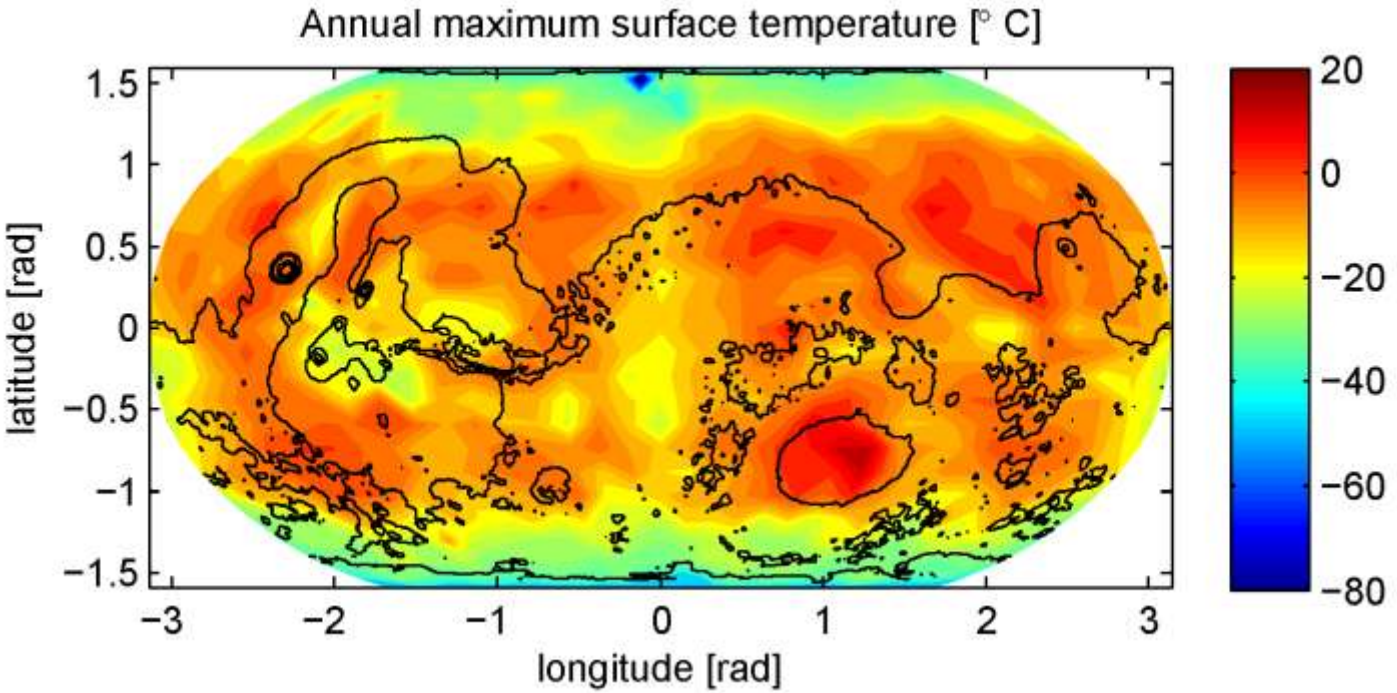
⇨ **Reduced CO_2 greenhouse effect !**

(*Wordsworth et al.* Icarus 2010)

0.5 bar

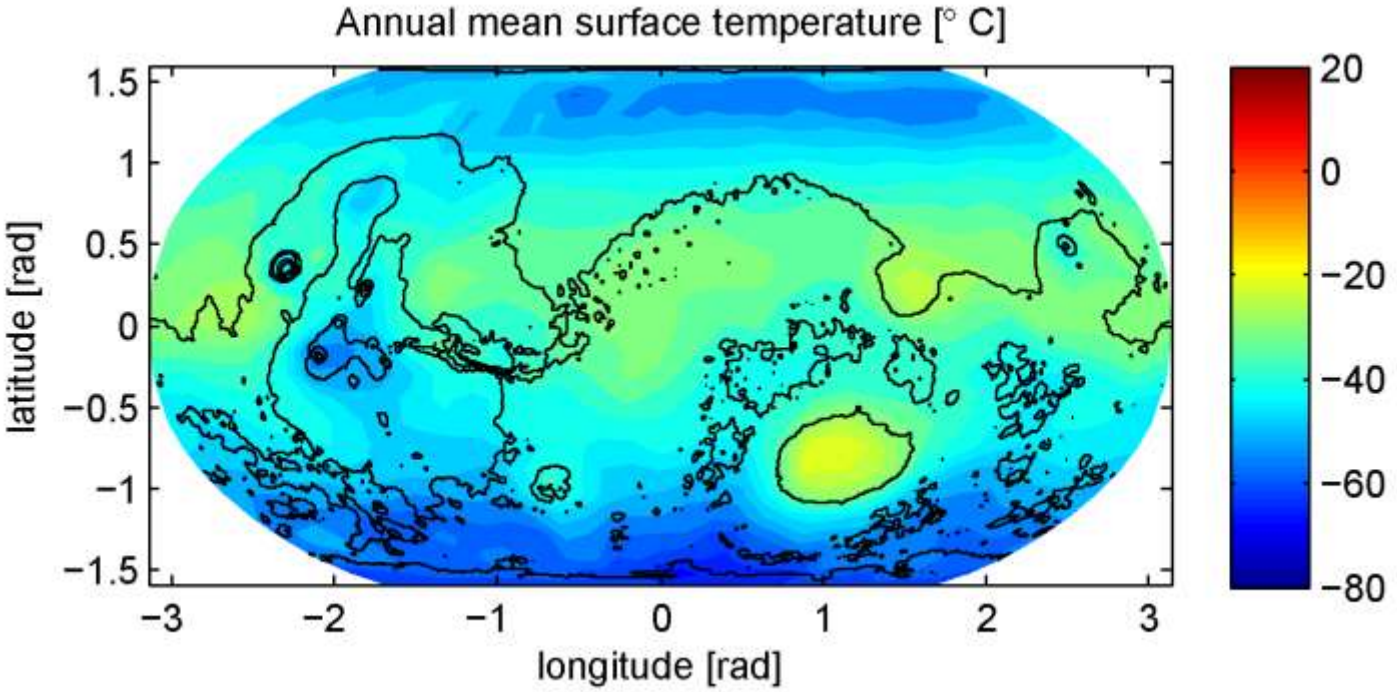
Surface CO2 ice

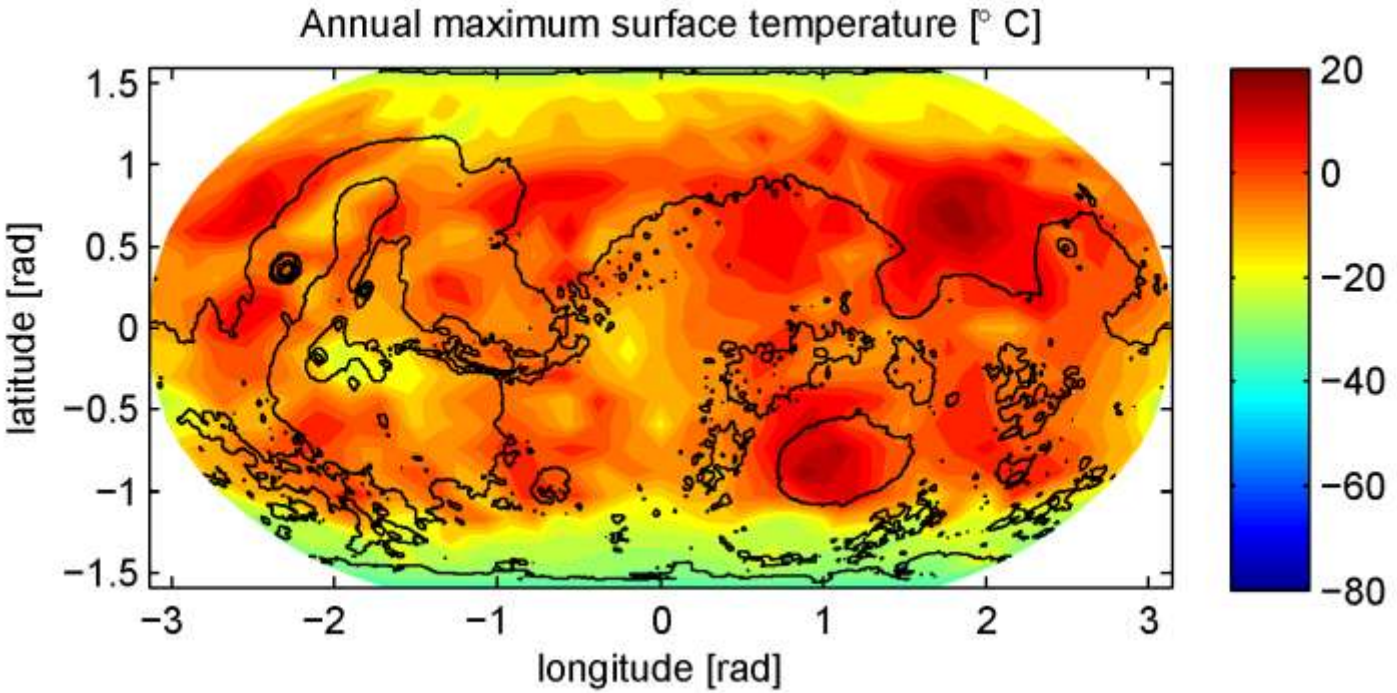




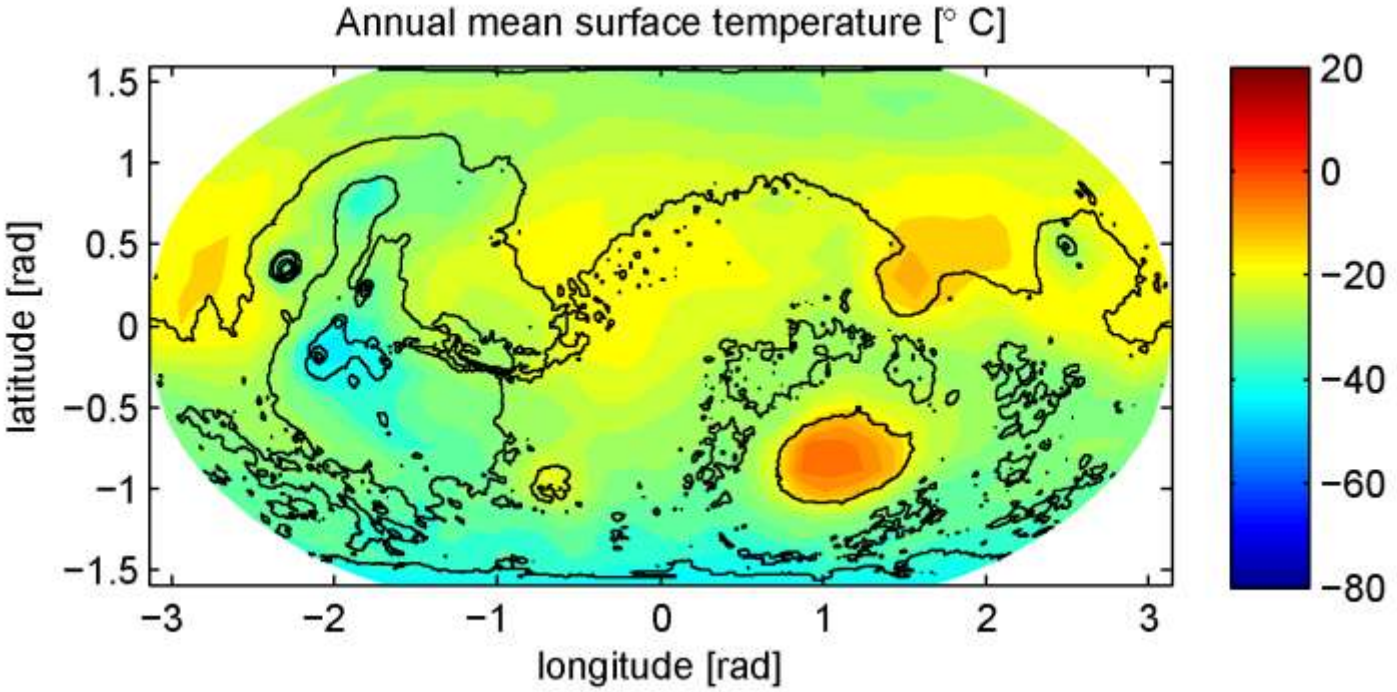
1 bar

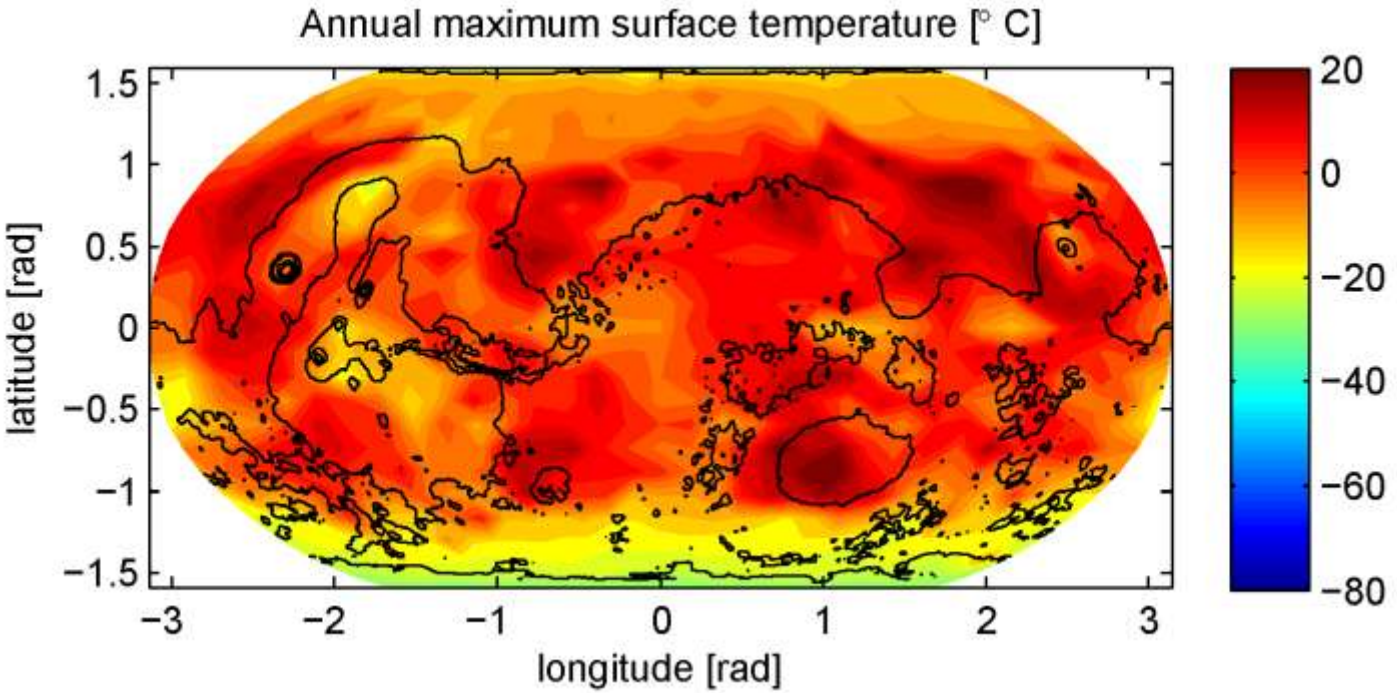
Surface



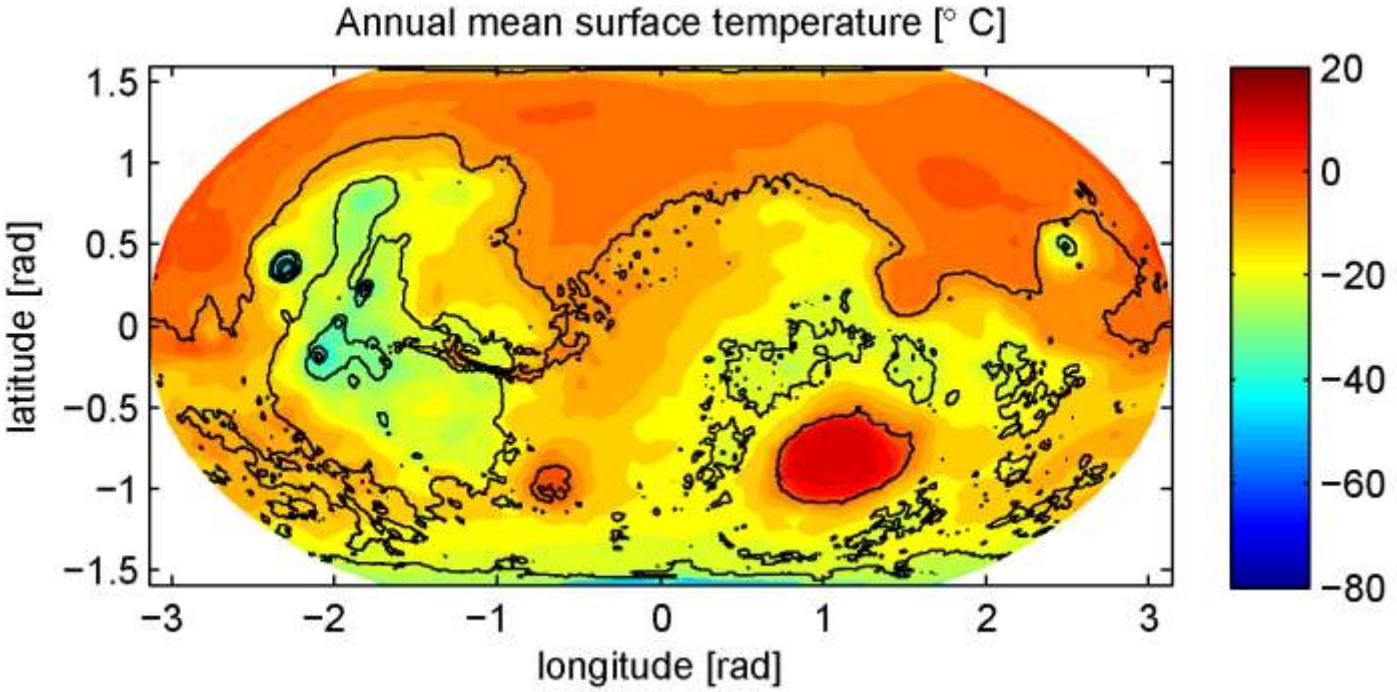


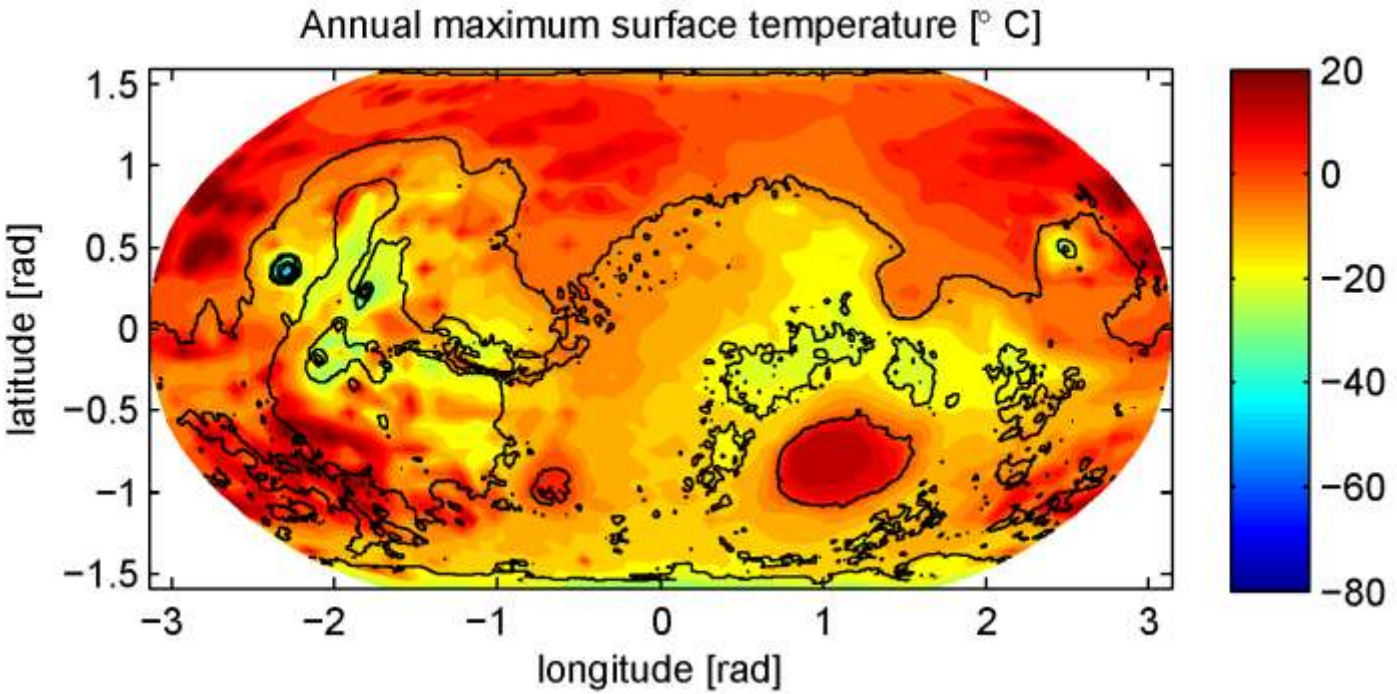
2 bar


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

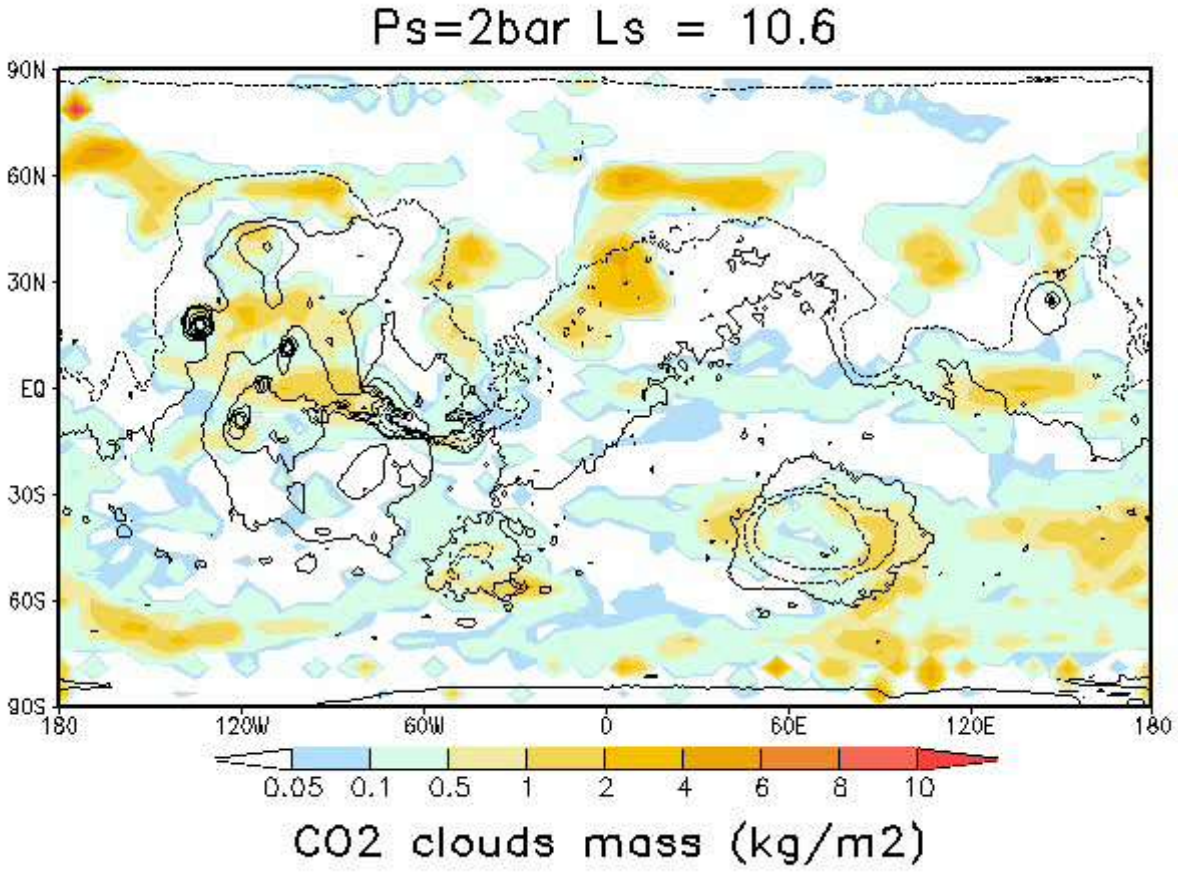

Annual maximum surface temperature [° C]
latitude [rad]
longitude [rad]
1.5
1
0.5
0
−0.5
−1
−1.5
−3
−2
−1
0
1
2
3
20
0
−20
−40
−60
−80

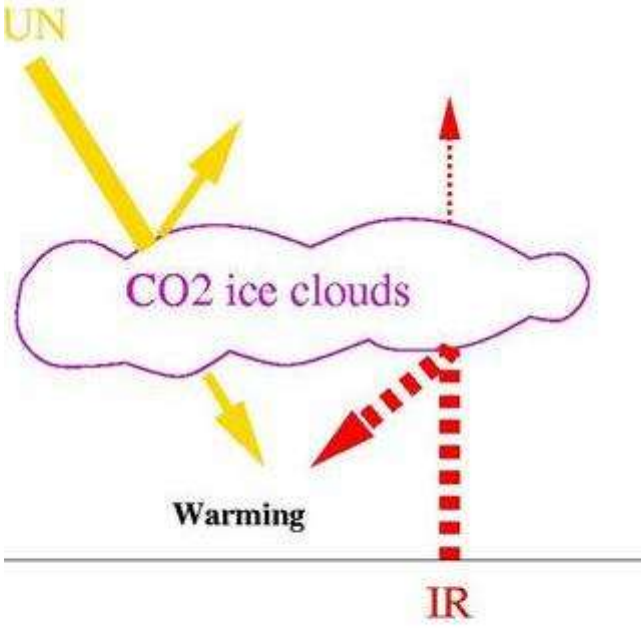
5 bar


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


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

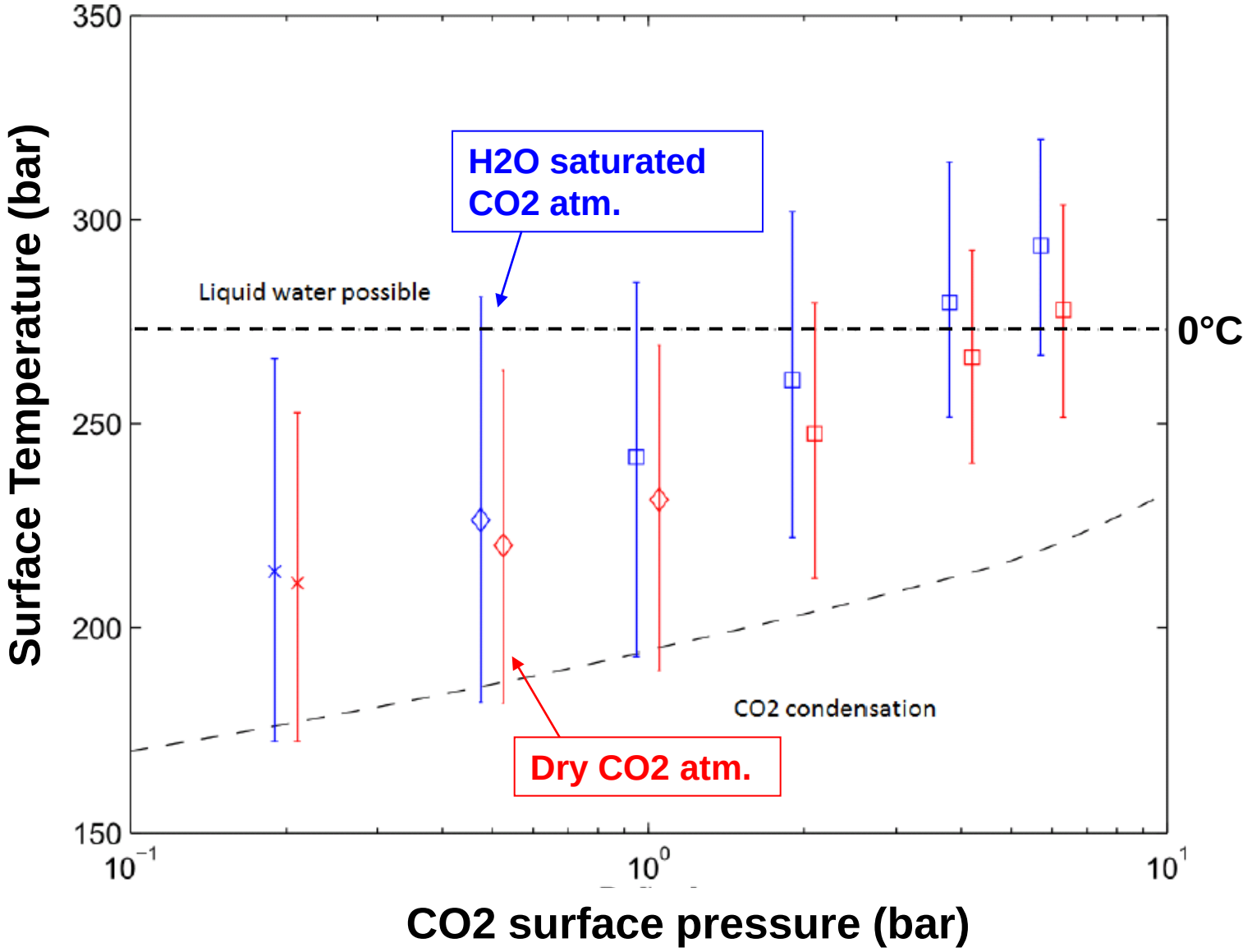
CO2 ice clouds warming: 15 to 20K





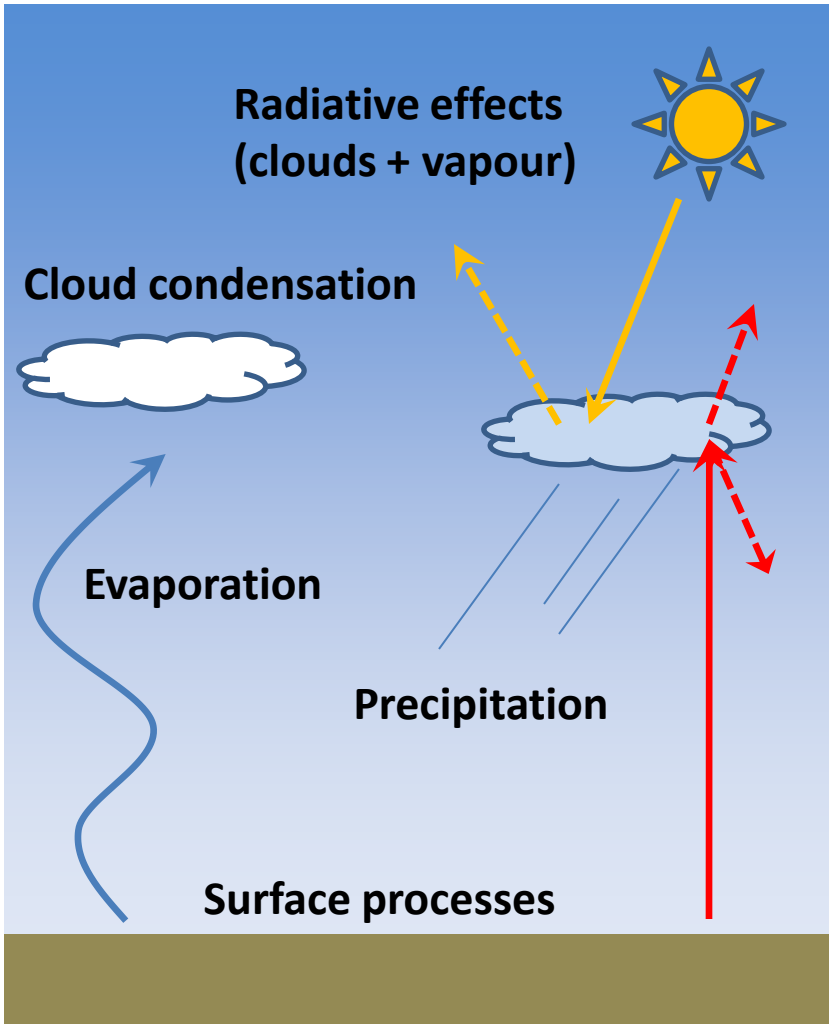
Forget and Pierrehumbert 1997

Additional greenhouse effect from Water vapor ?

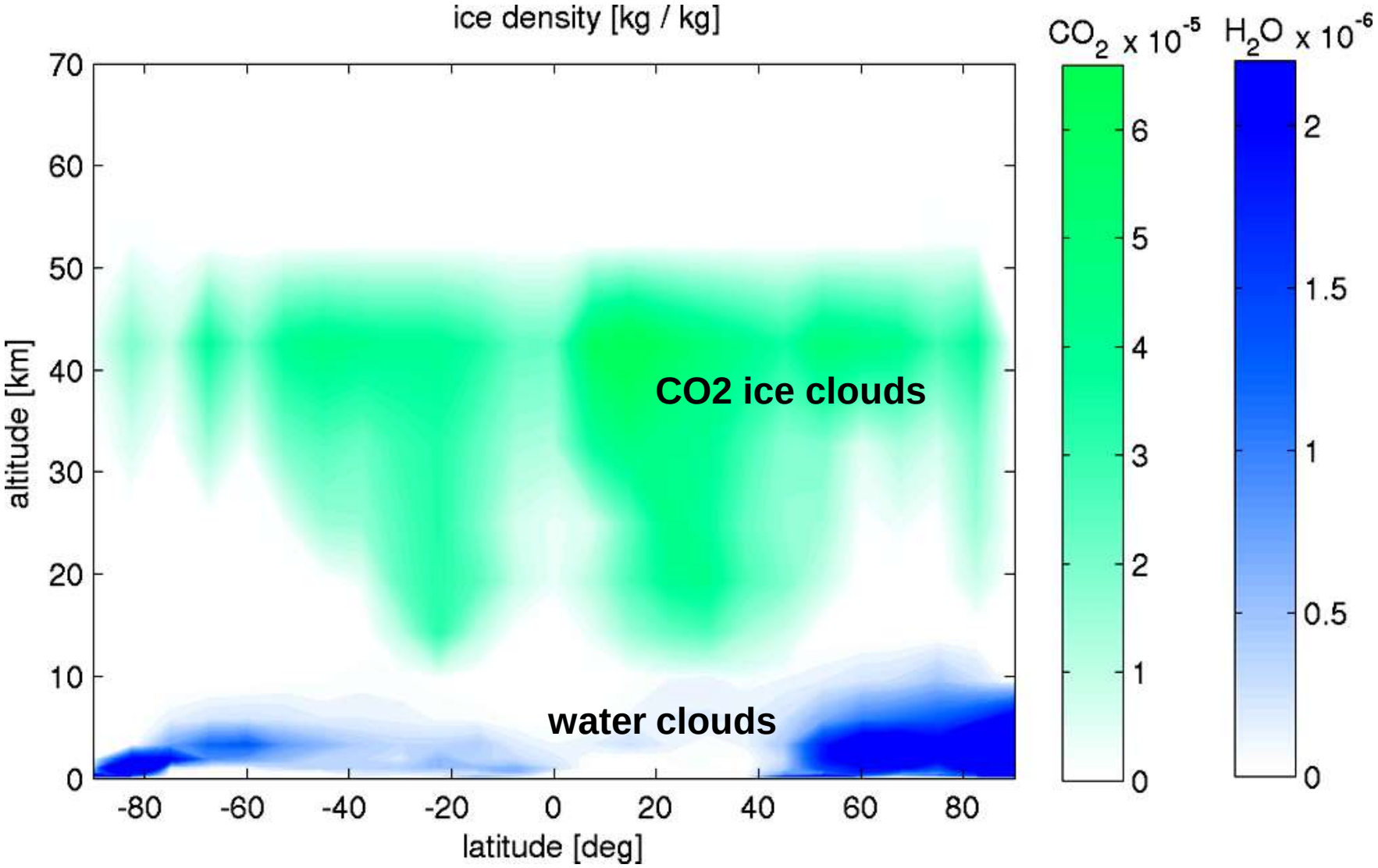


Adding a water cycle

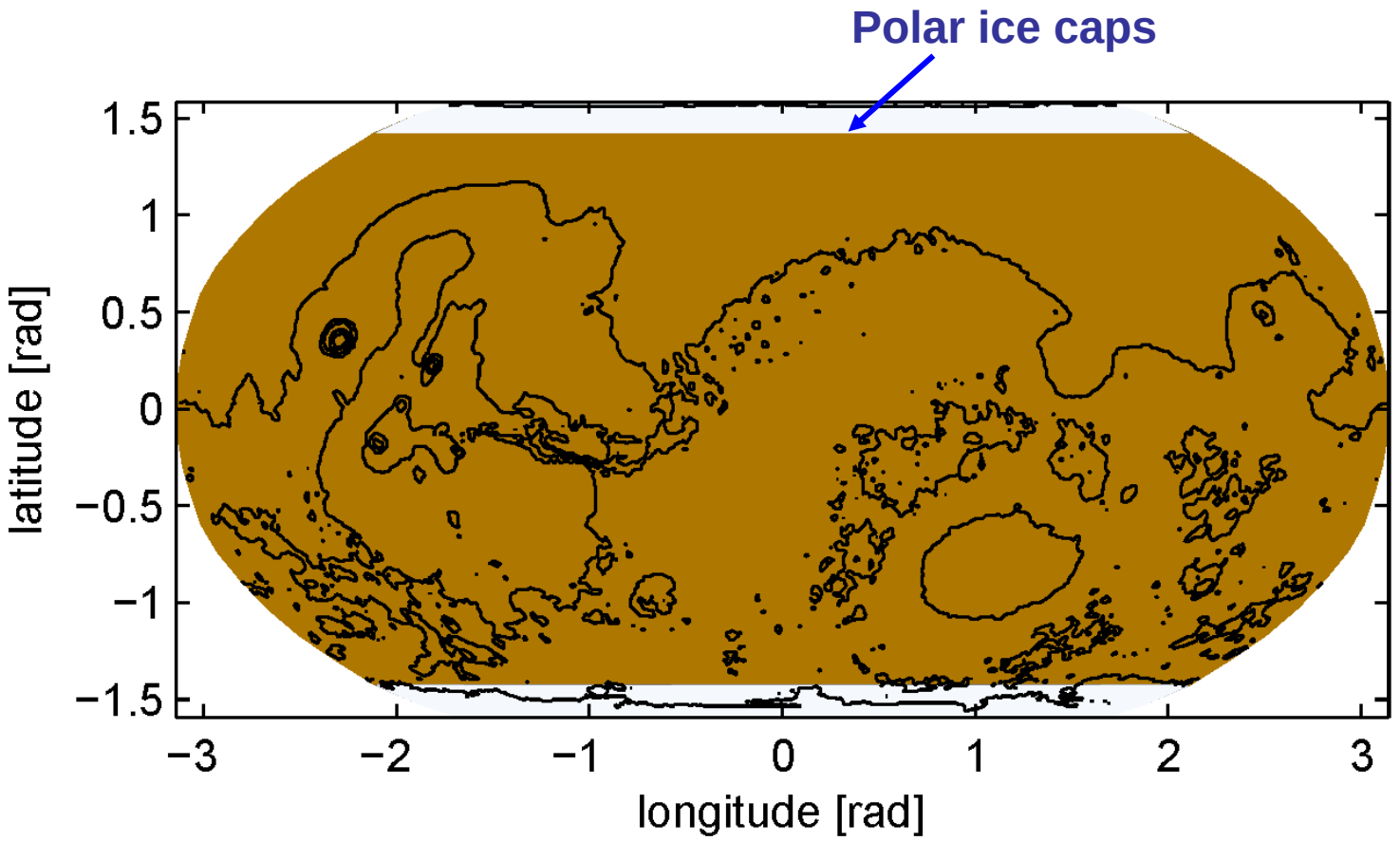
- We include radiative effects of vapour and cloud tracers
- Assume fixed CCN distribution, but variable mean cloud particle sizes
- Simple convective relaxation (Manabe scheme), 100% cloud fraction assumed
- 'Bucket' surface hydrology for the moment



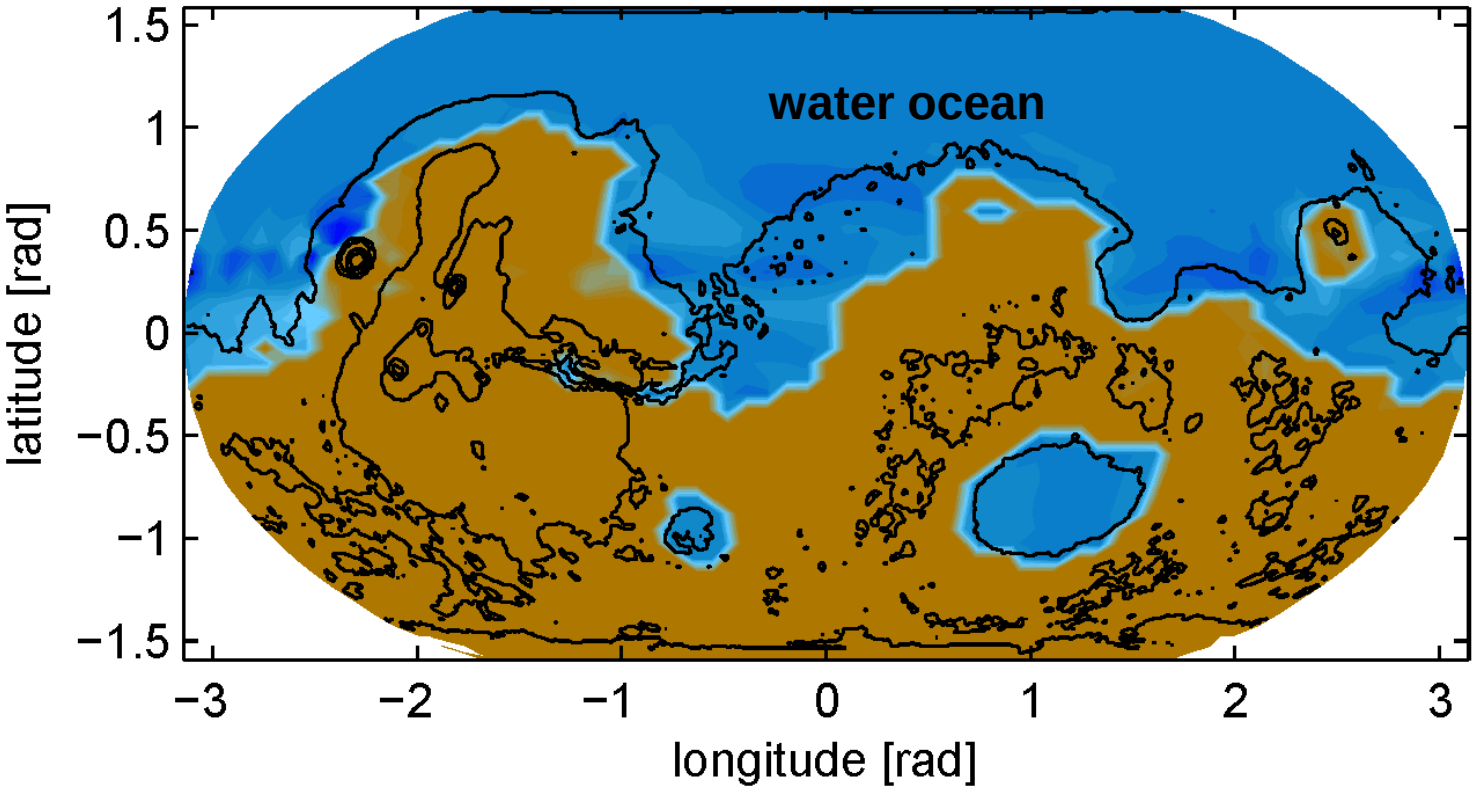
CO2 and H2O cloud cover (2 bars)



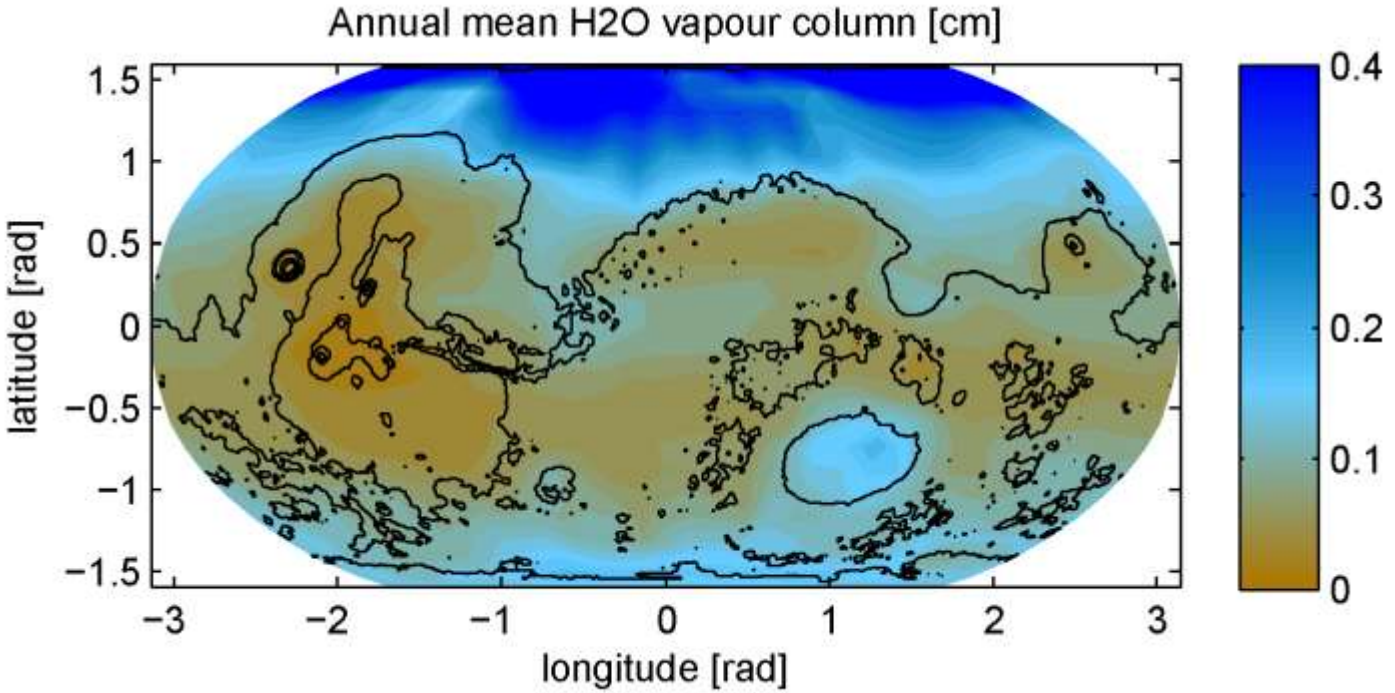
3D initial conditions for H2O

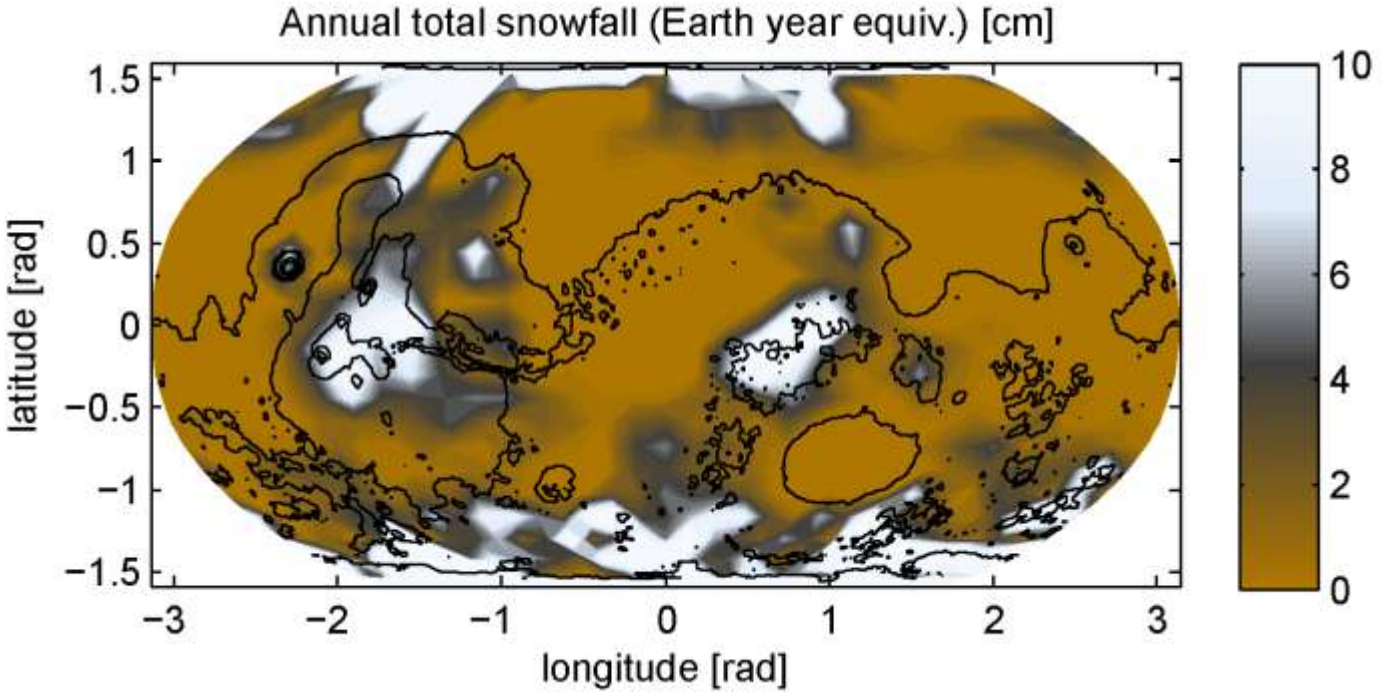


3D initial conditions for H2O

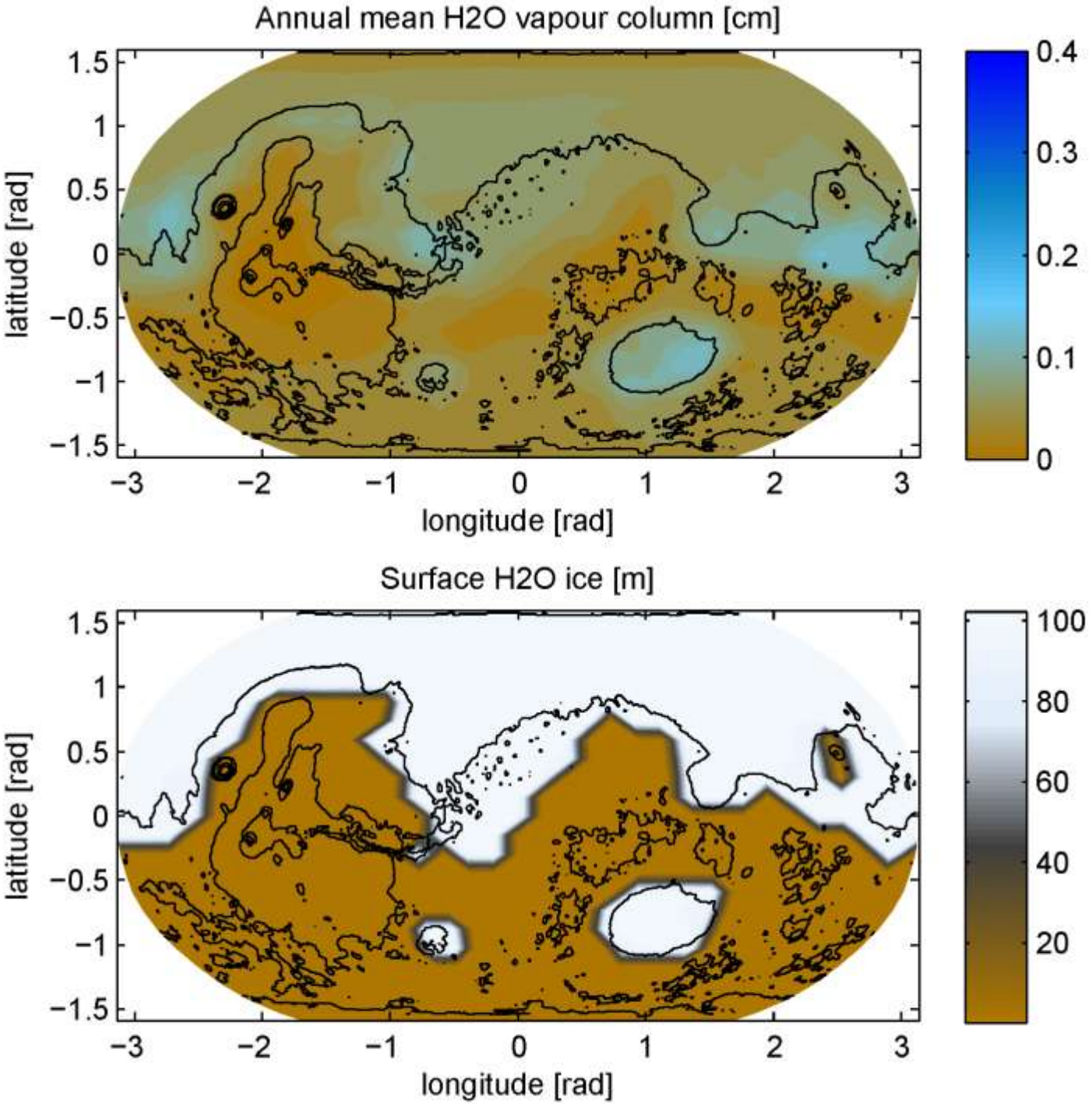


2 bar, icecaps

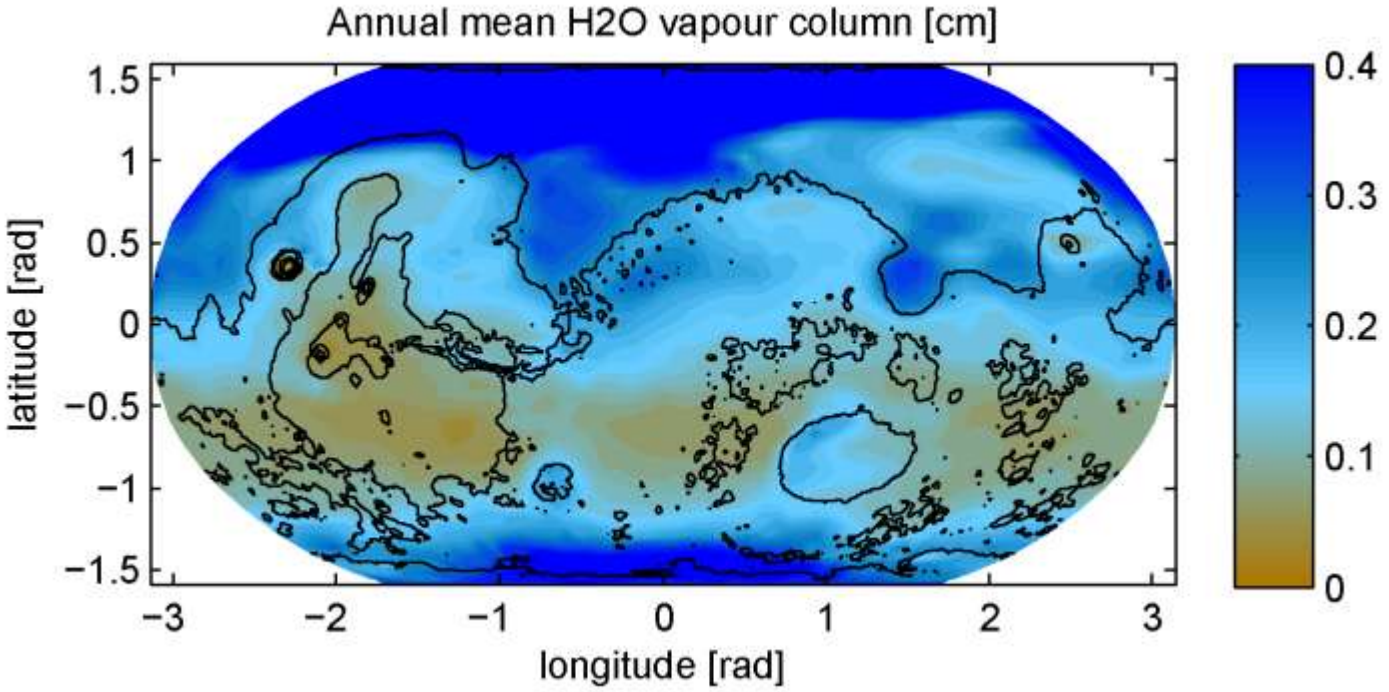


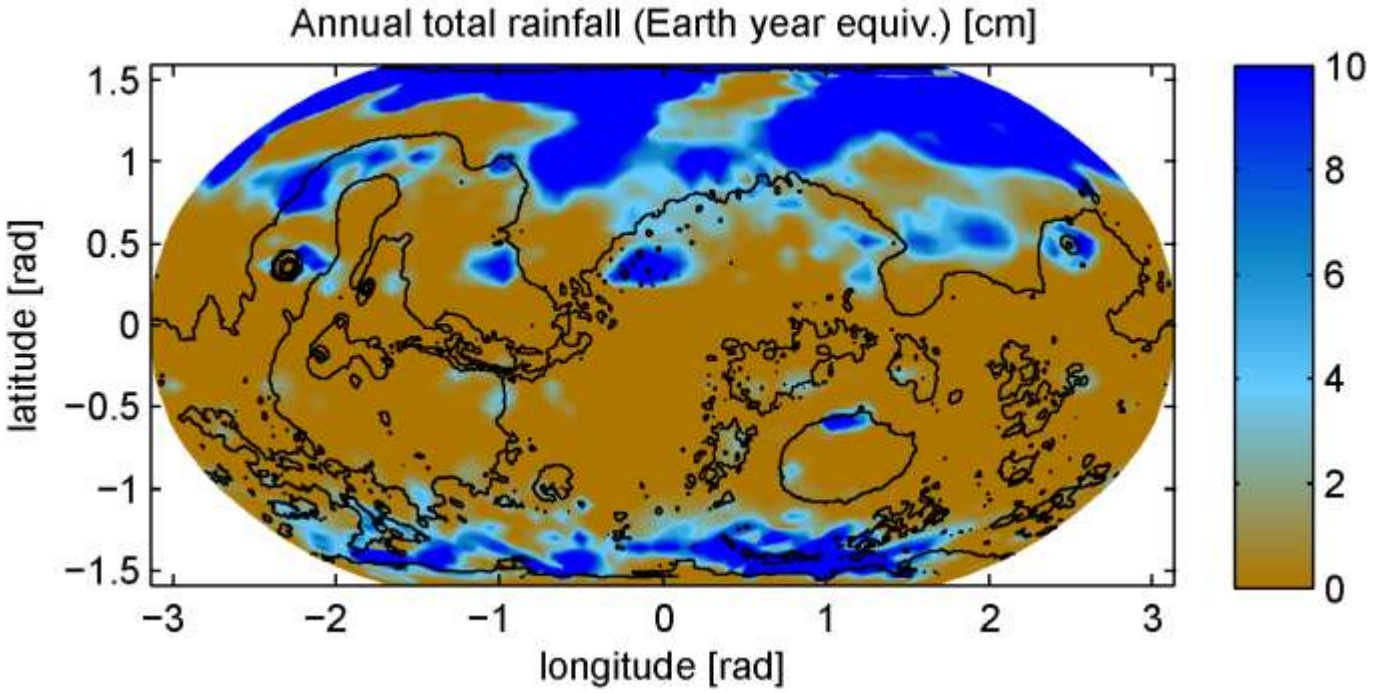


2 bar, ocean

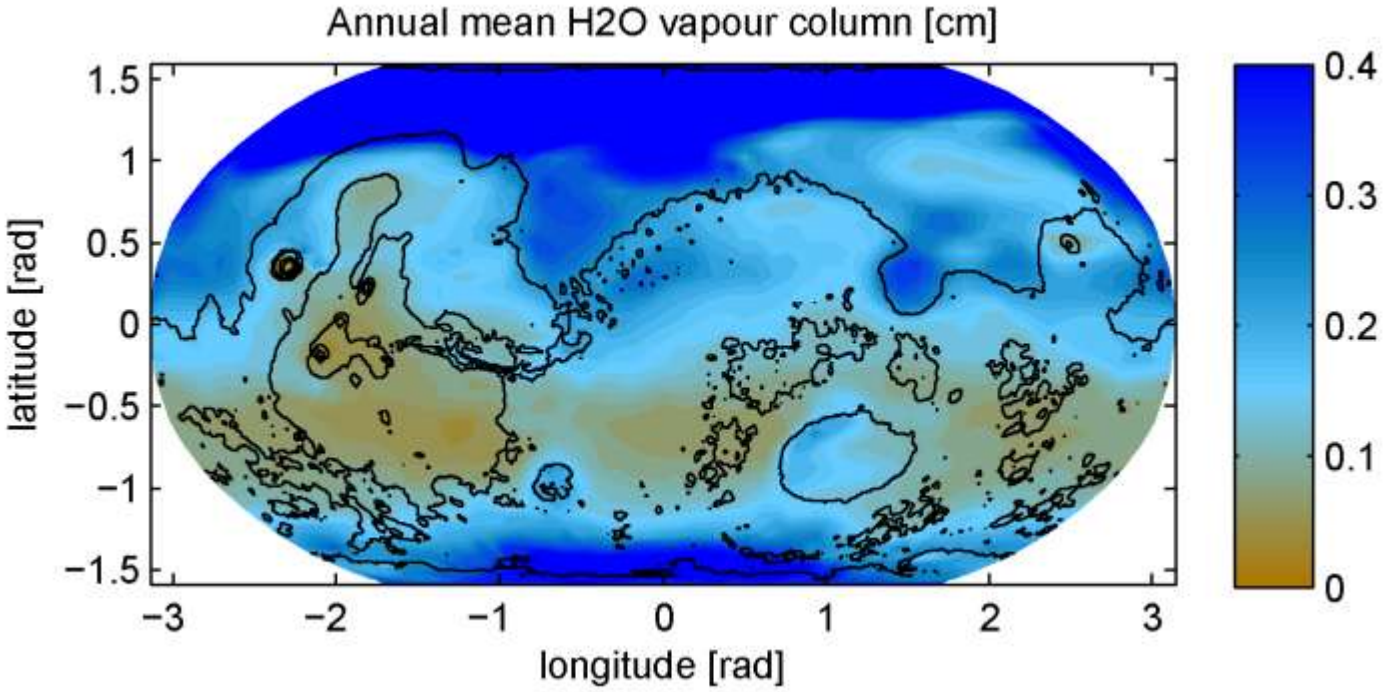

Annual mean H2O vapour column [cm]
latitude [rad]
longitude [rad]
1.5
1
0.5
0
−0.5
−1
−1.5
−3
−2
−1
0
1
2
3
0.4
0.3
0.2
0.1
0
Surface H2O ice [m]
latitude [rad]
longitude [rad]
100
80
60
40
20

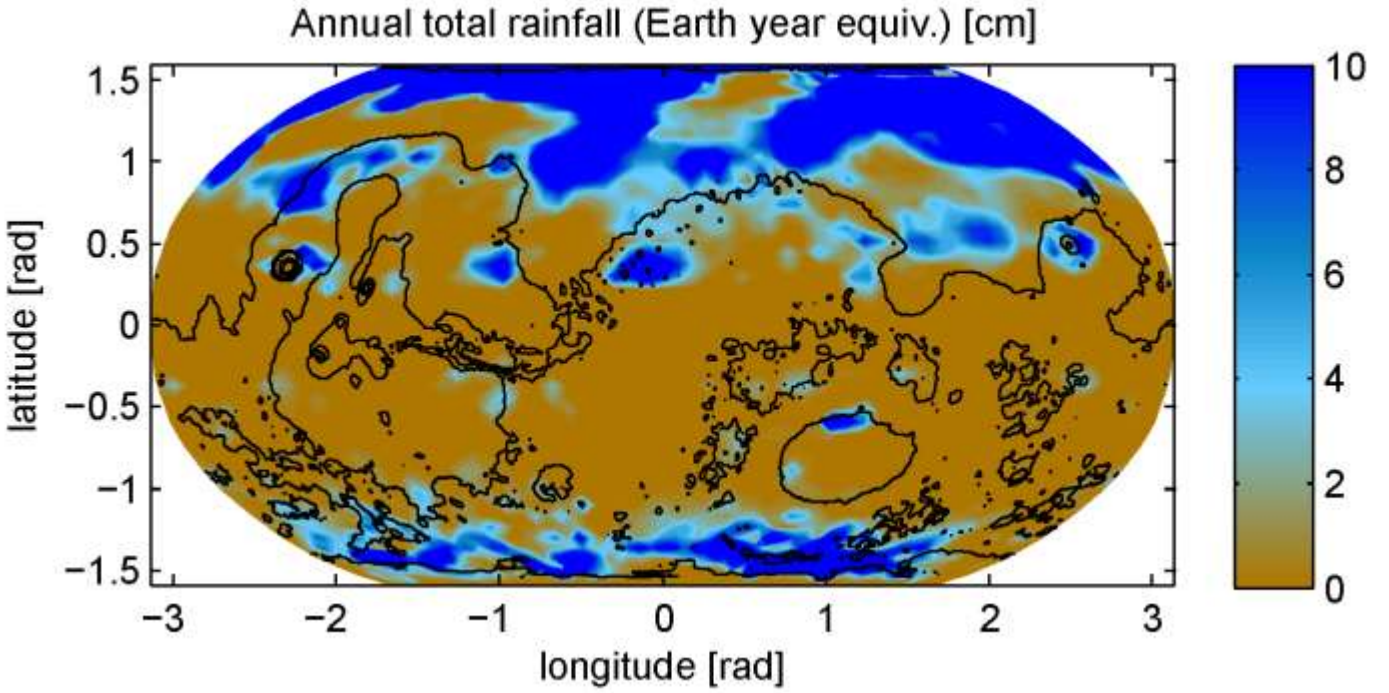
5 bar, icecaps



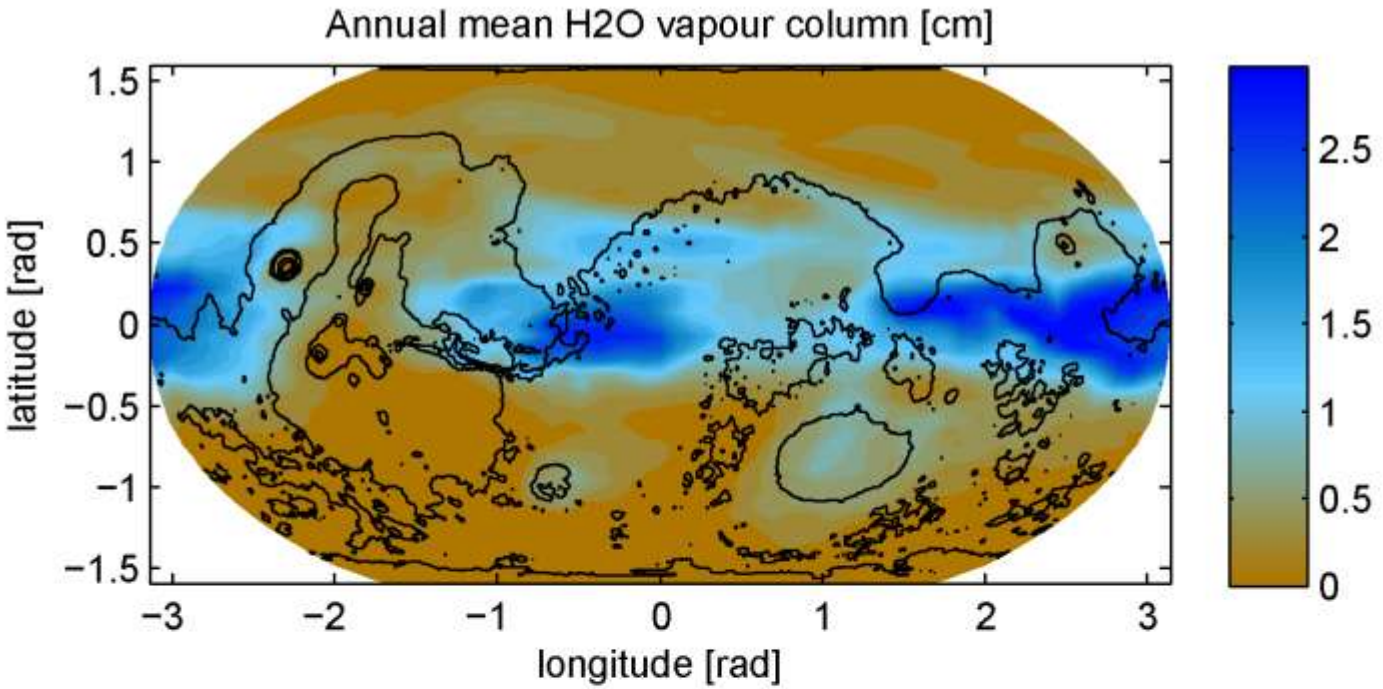


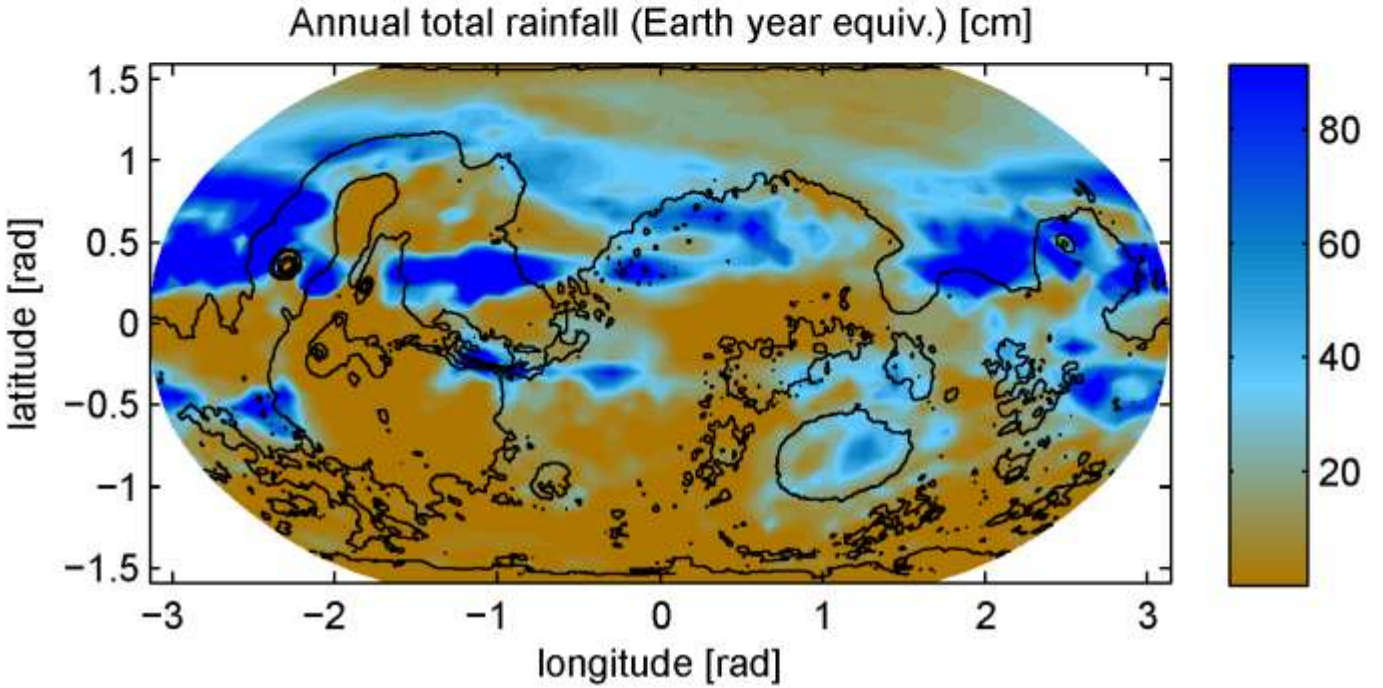
5 bar, icecaps



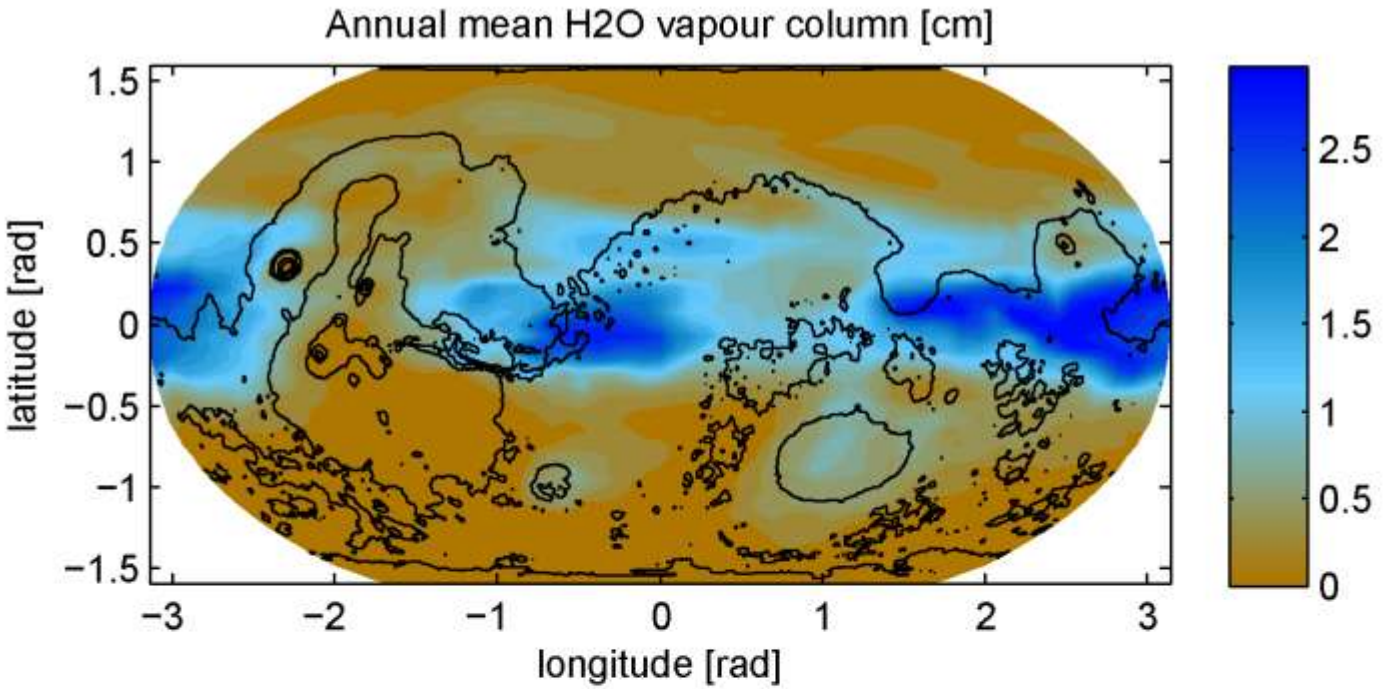


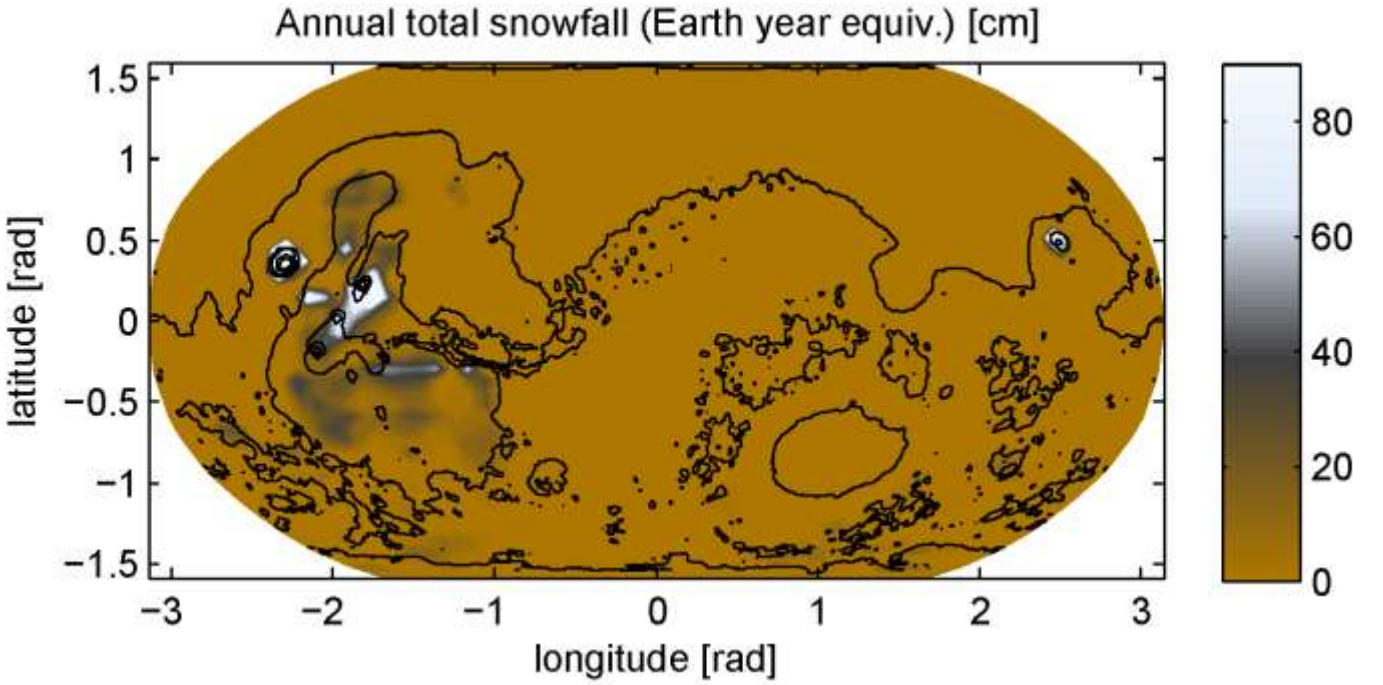
5 bar, ocean


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
2.5
2
1.5
1
0.5
0


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

5 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
2.5
2
1.5
1
0.5
0


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

Wait a minute :5 bars of CO_2 ???

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, 240-270 mbar 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

We Need to explore the behaviour of a cold icy Mars with ~500 mbar of CO2. It will still be very different than today :

- Cold traps in the mountains (like on Earth)
- Liquid water much more stable
- Larger ice inventory ? (less ice sequestered?)
- Some greenhouse effect

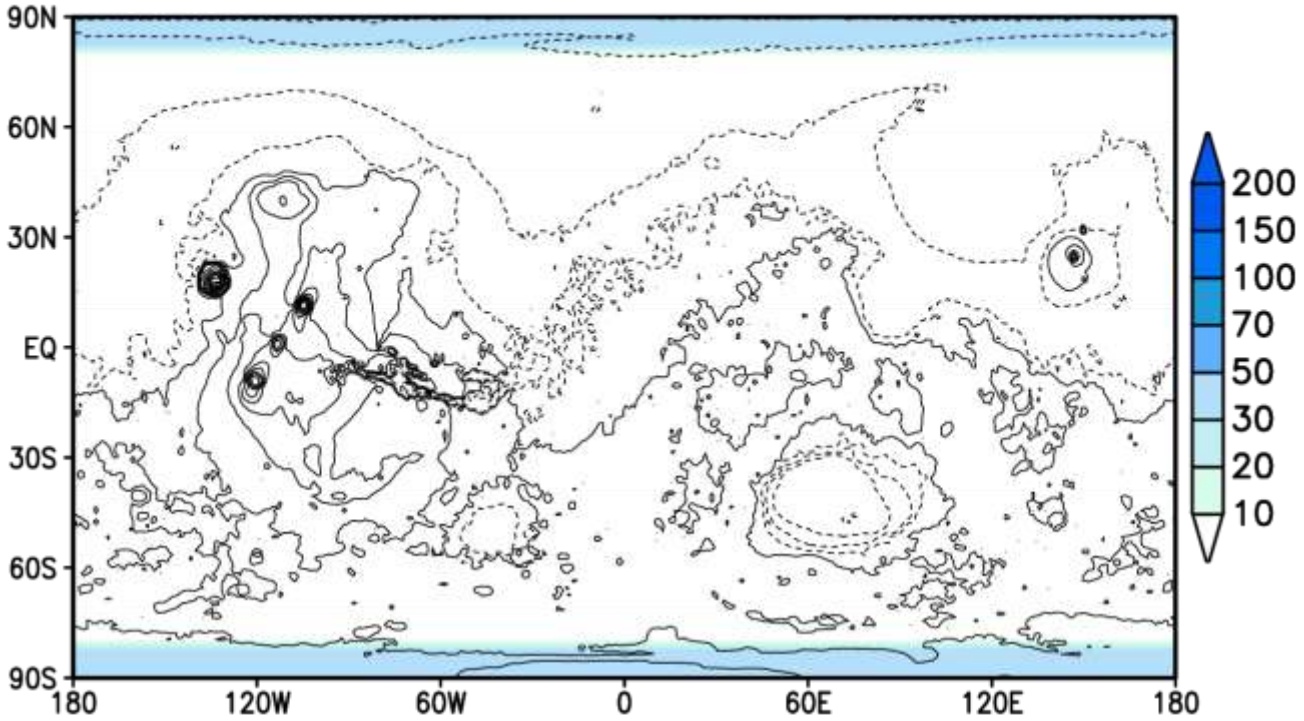
⇨Possible transient melting of seasonal ice and glaciers ?

⇨ Ice trapped at the poles or available in many places to melt with impacts or volcanic events ?

Ongoing work: Mars with ~500 mbar of CO_2

Starting with limited polar caps:

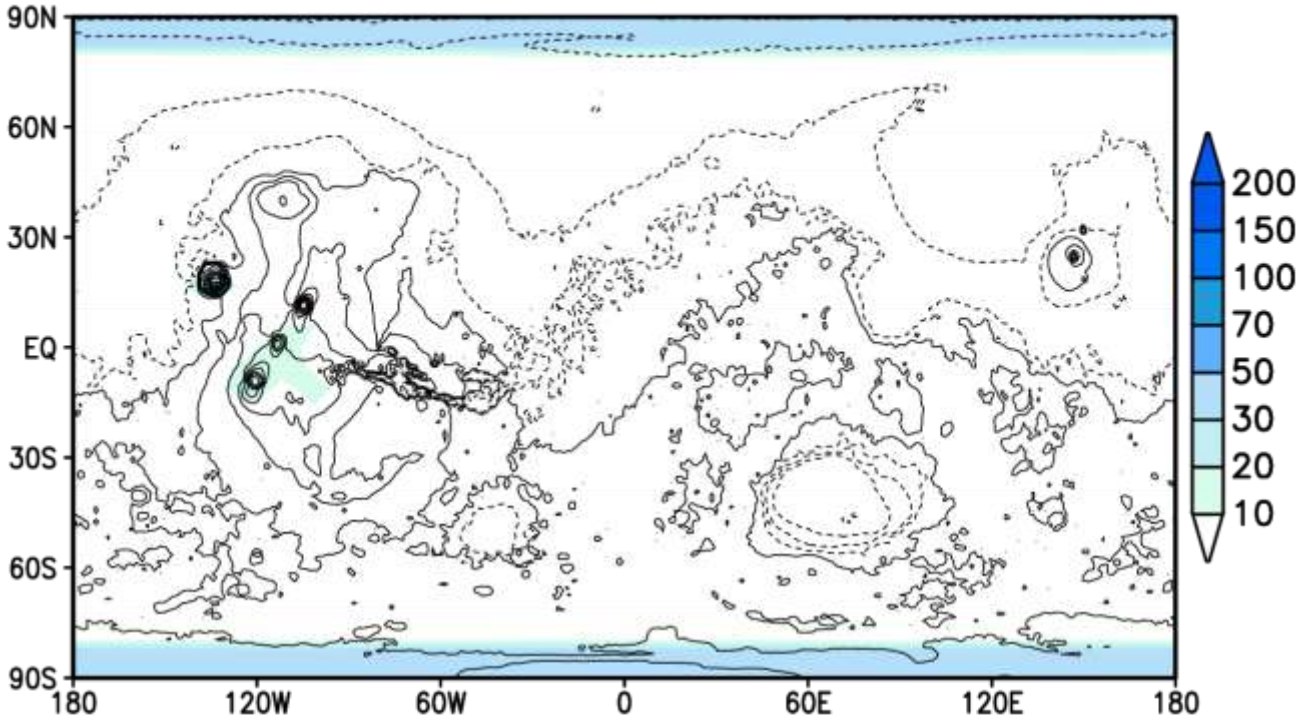
Surface ice (kg/m2) : initial state
Ps = 0.5 bar obliquity=25°



Ongoing work: Mars with ~500 mbar of CO_2

Starting with limited polar caps:

Surface ice (kg/m2) : AFTER 50 years
Ps = 0.5 bar obliquity=25°

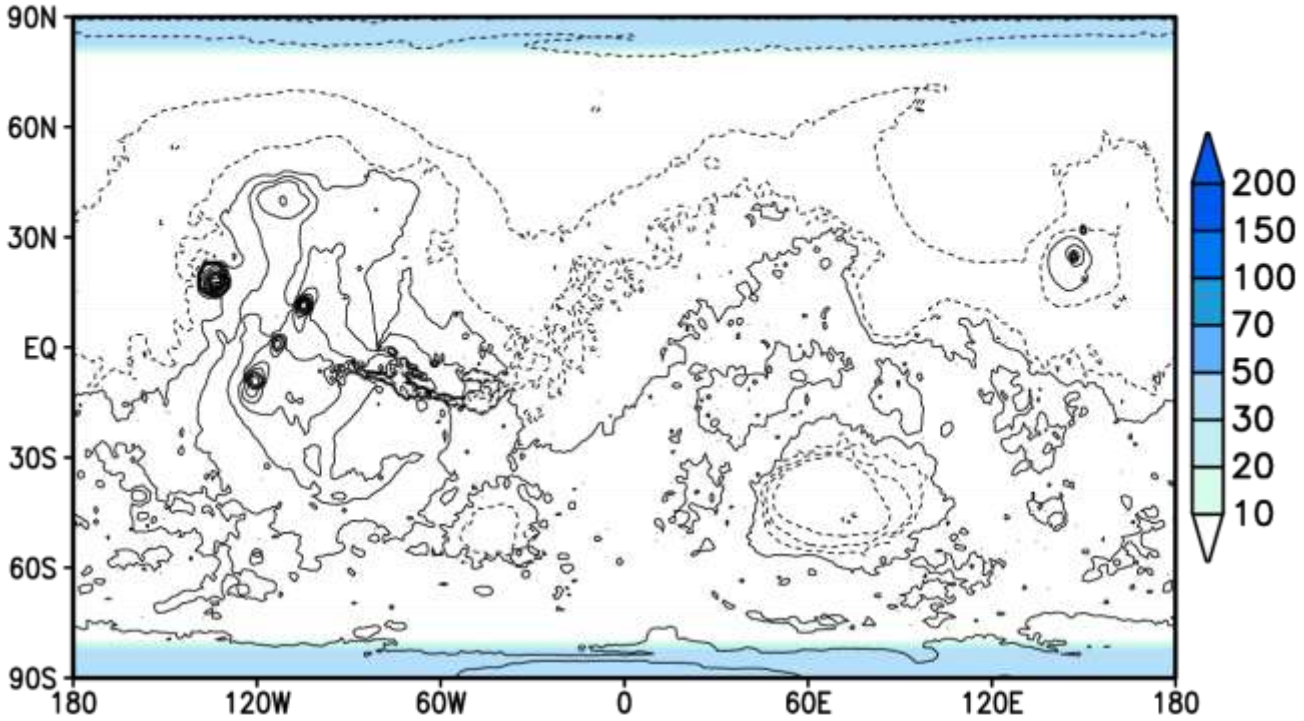


Ongoing work: Mars with ~500 mbar of CO_2

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

Surface ice (kg/m2) : Initial state

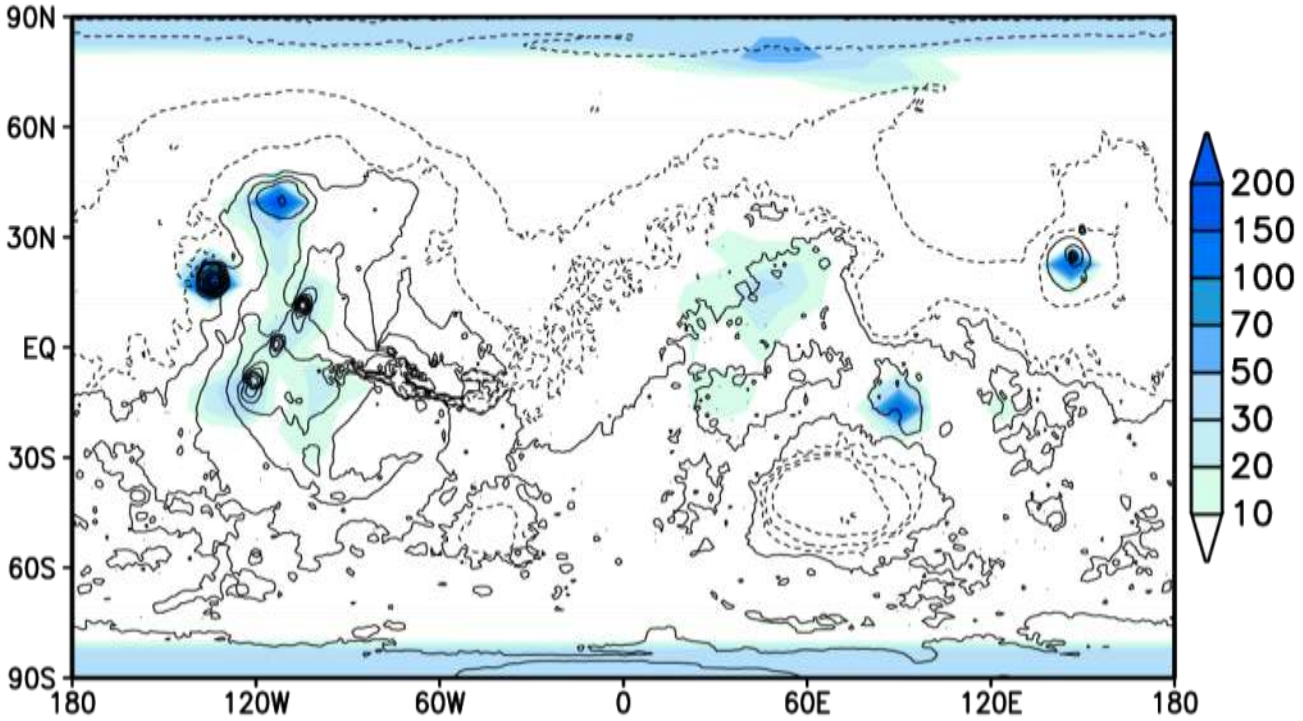
Ps = 0.5 bar obliquity=45°



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

Surface ice (kg/m2) : AFTER 50 years

Ps = 0.5 bar obliquity=45°

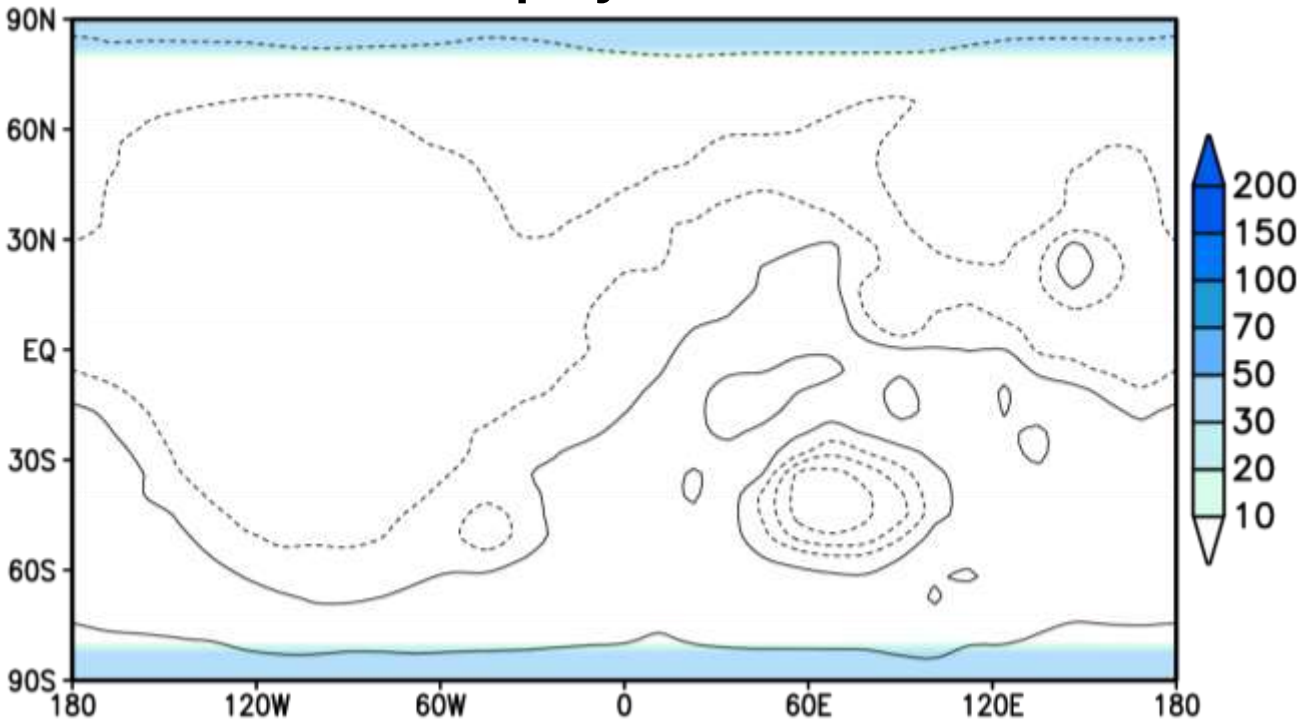


Starting with limited polar caps: REMOVING THARSIS

Next step: remove the LHB basin

Surface ice (kg/m2) : initial state

Ps = 0.5 bar obliquity=25°

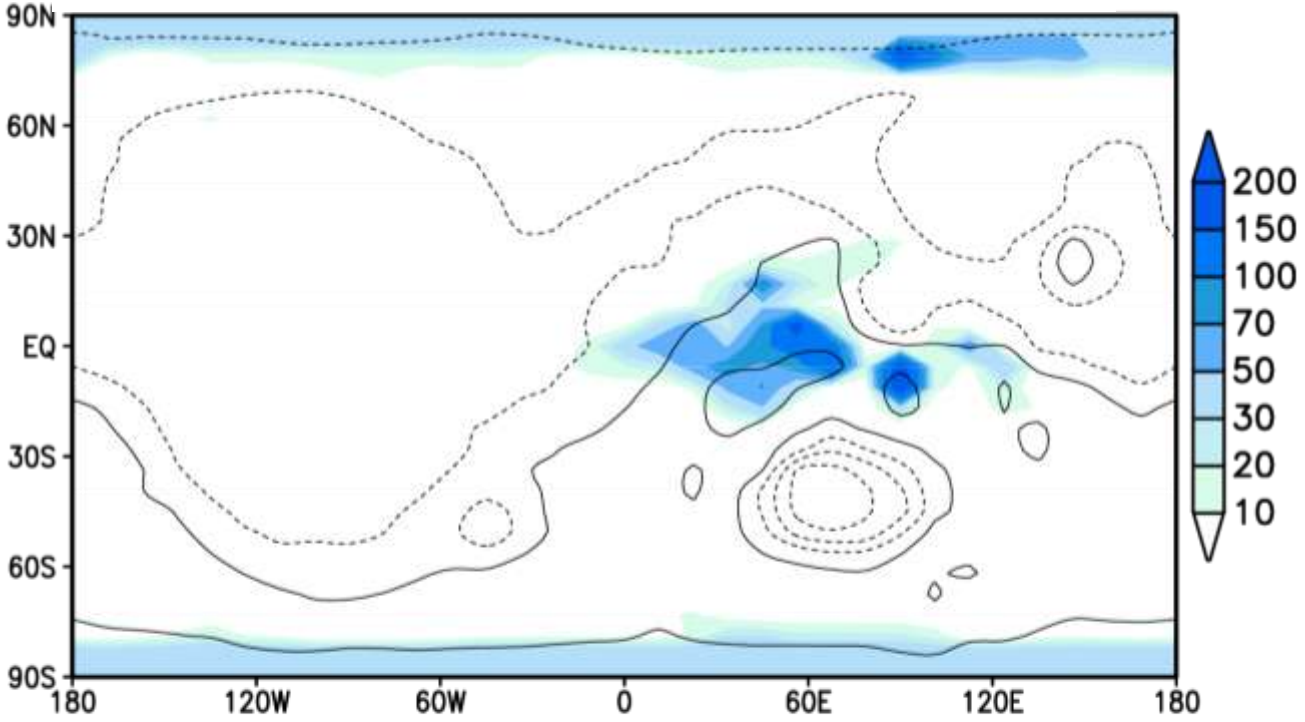


Starting with limited polar caps: REMOVING THARSIS

Next step: remove the LHB basin

Surface ice (kg/m2) : AFTER 50 years

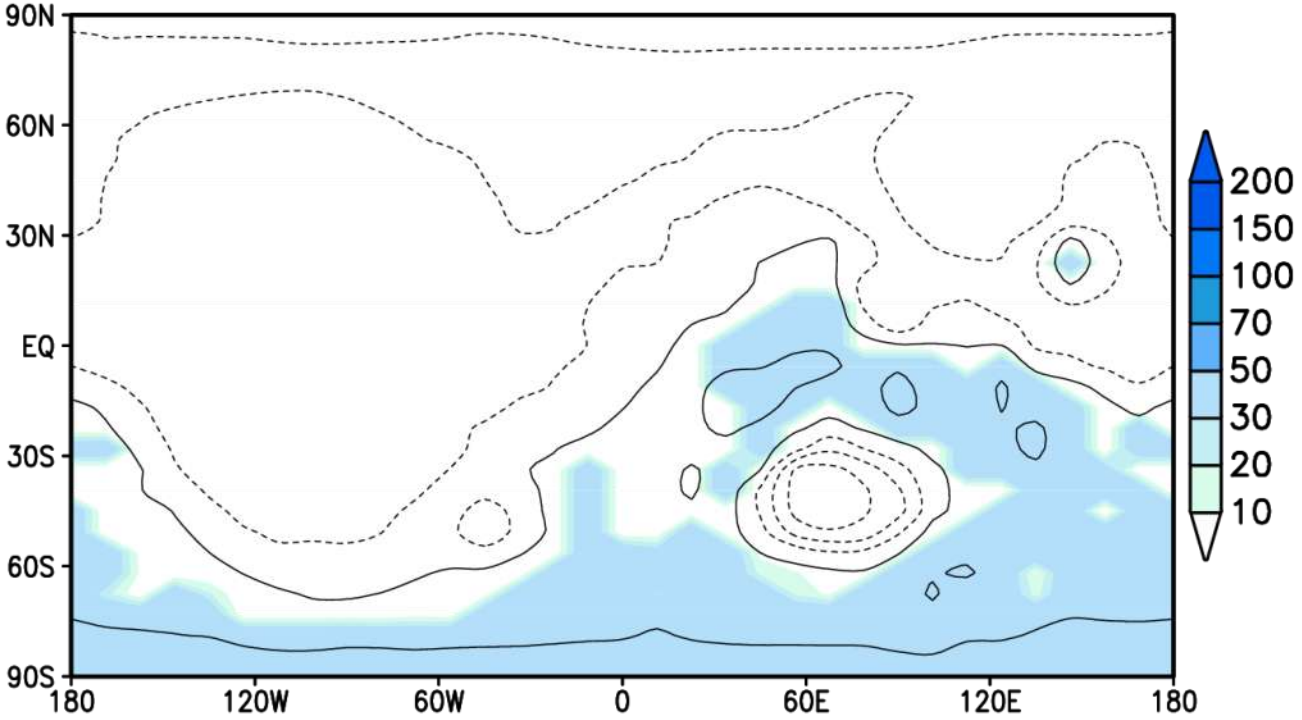
Ps = 0.5 bar obliquity=25°



Starting with a global ice sheet on the colder plateau

Surface ice (kg/m2) : Initial state

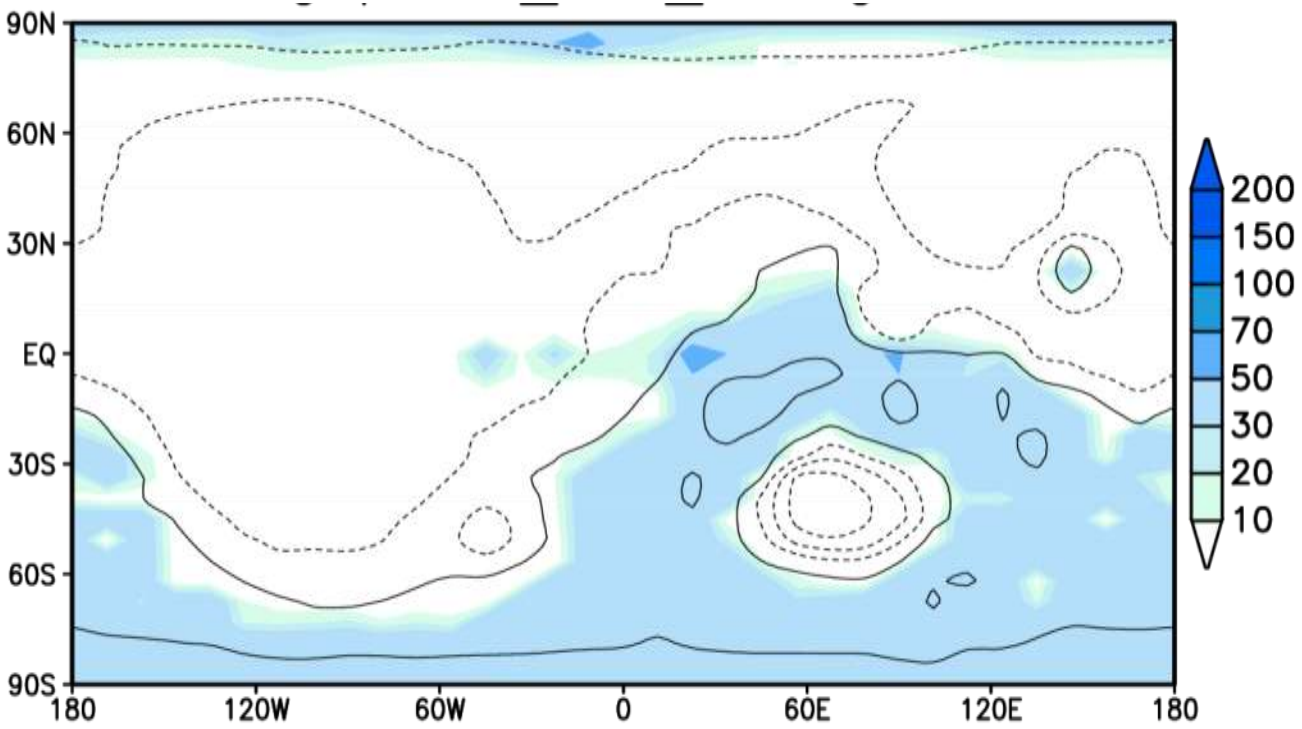
Ps = 0.5 bar obliquity=25°



Starting with a global ice sheet on the colder plateau

Surface ice (kg/m2) : AFTER 50 years

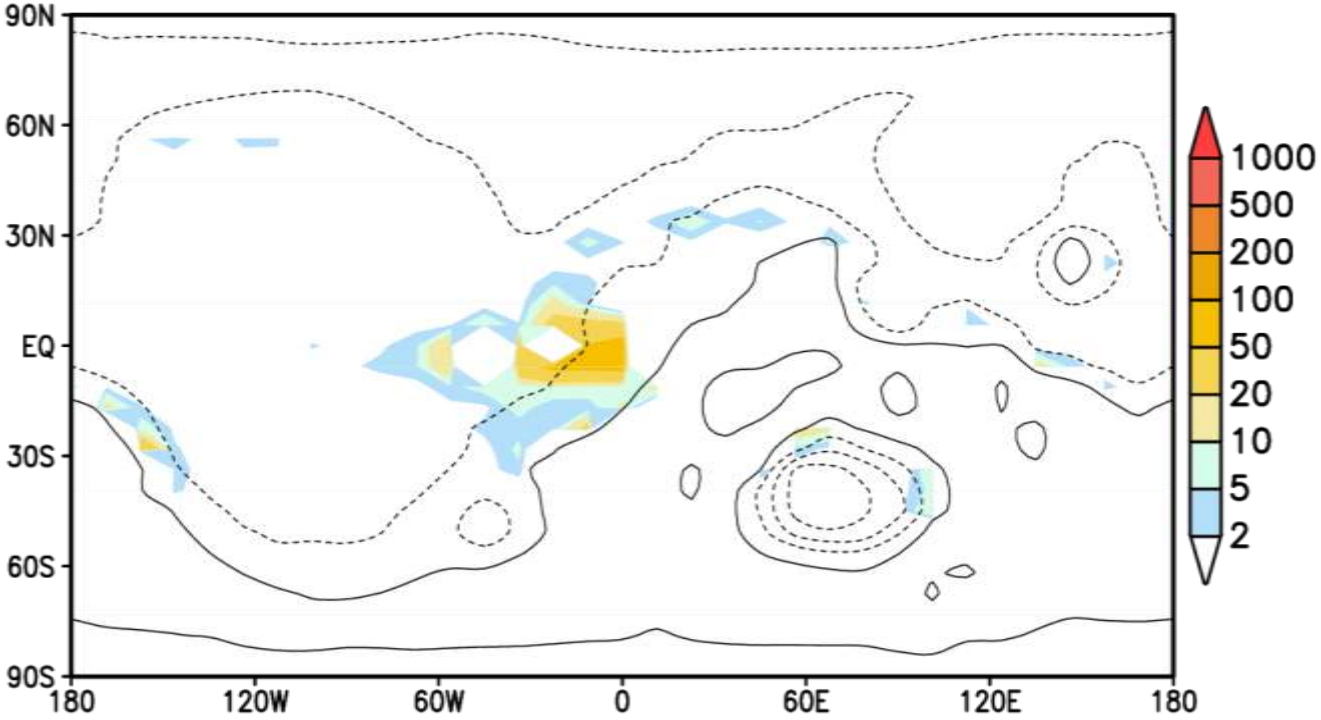
Ps = 0.5 bar obliquity=25°



Starting with a global ice sheet on the colder plateau

MELTING ice (arb. units) : AFTER 50 years

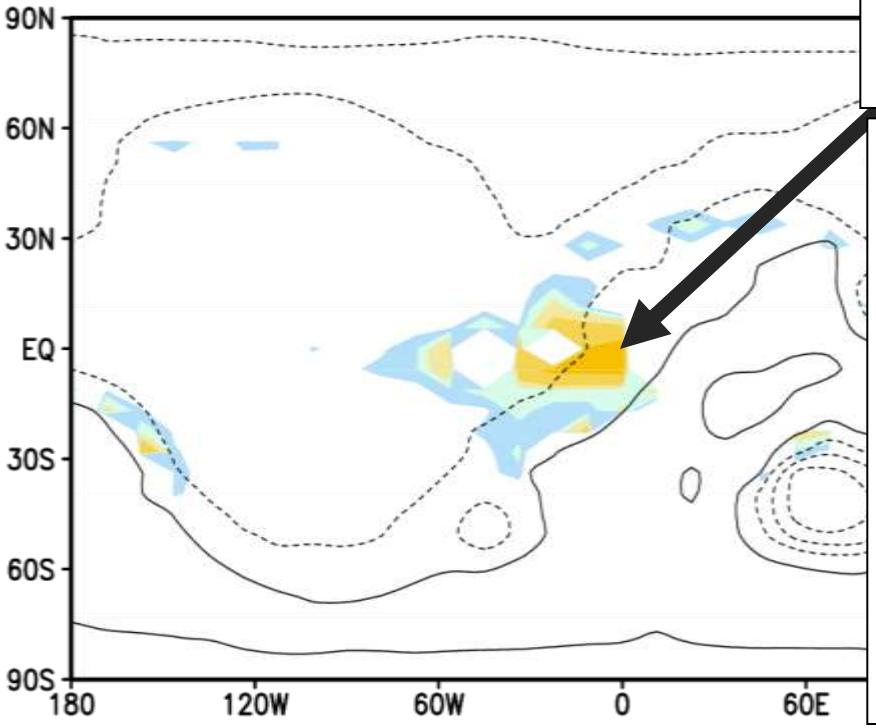
Ps = 0.5 bar obliquity=25°

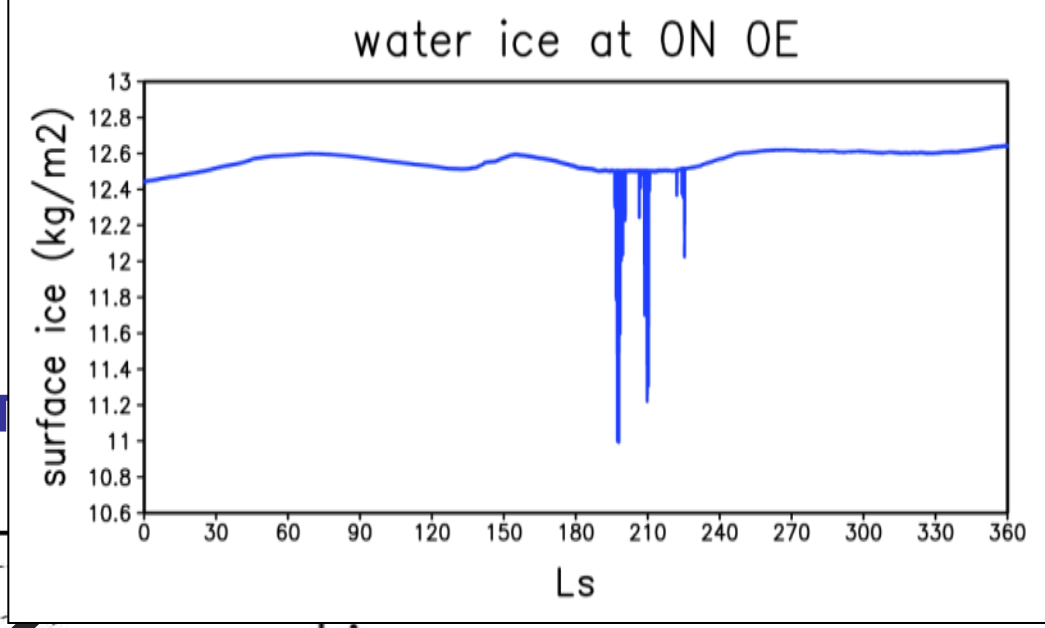


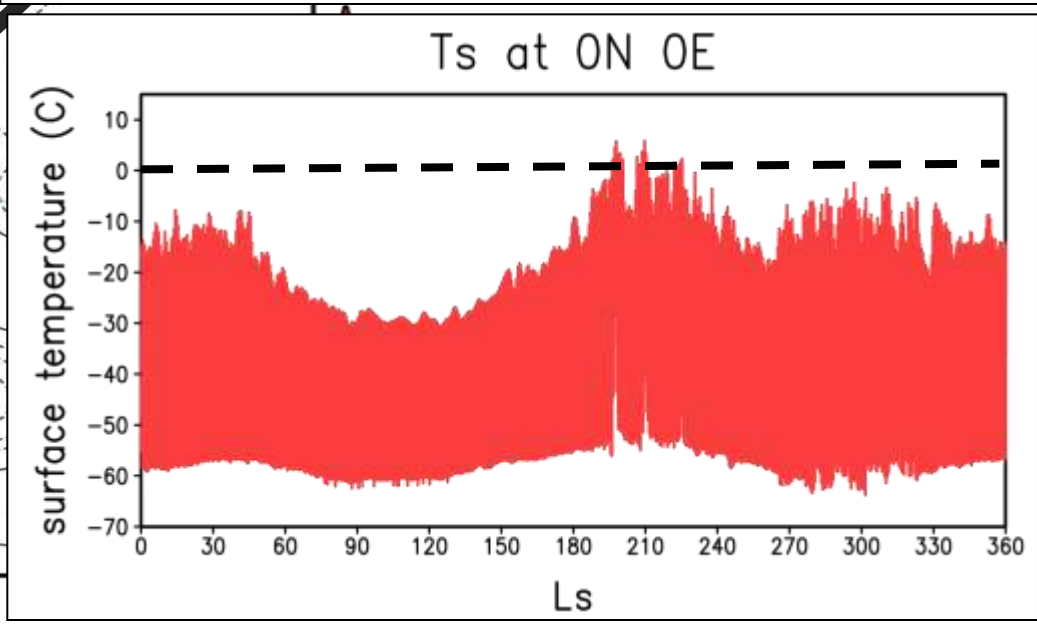
Starting with a global ice sheet

MELTING ice (arb. units) : AFT

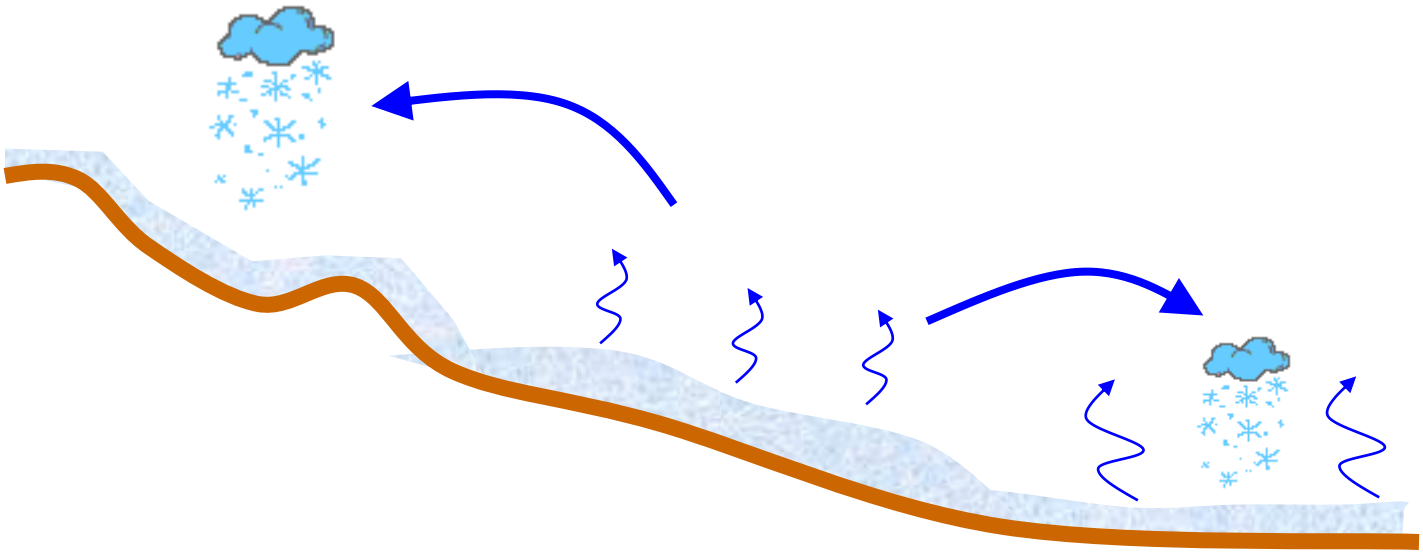
Ps = 0.5 bar obliquity=25°







A ongoing study : determine where the ice reservoir will stabilize



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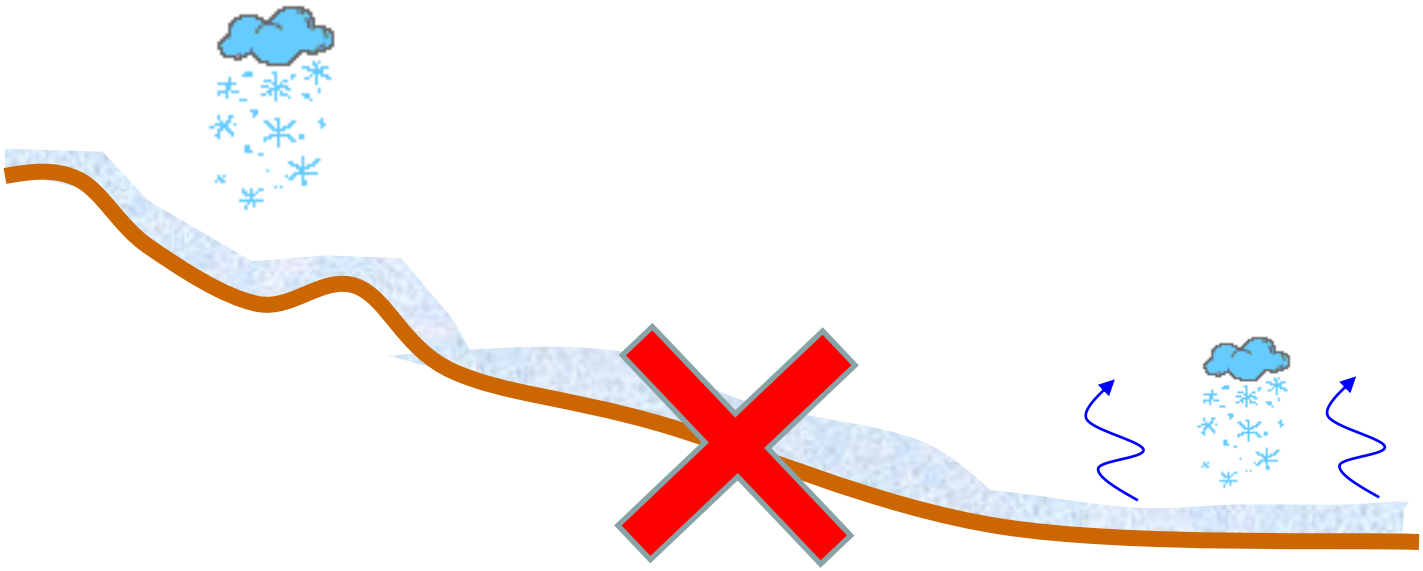
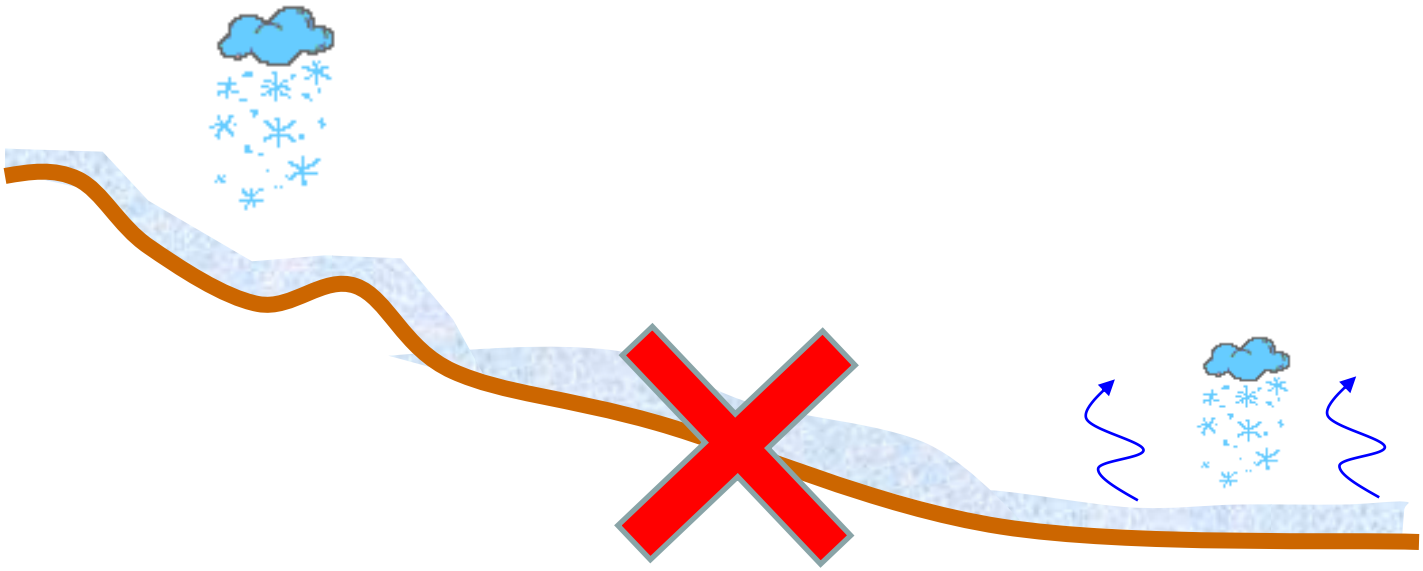


A ongoing study : determine where the ice reservoir will stabilize



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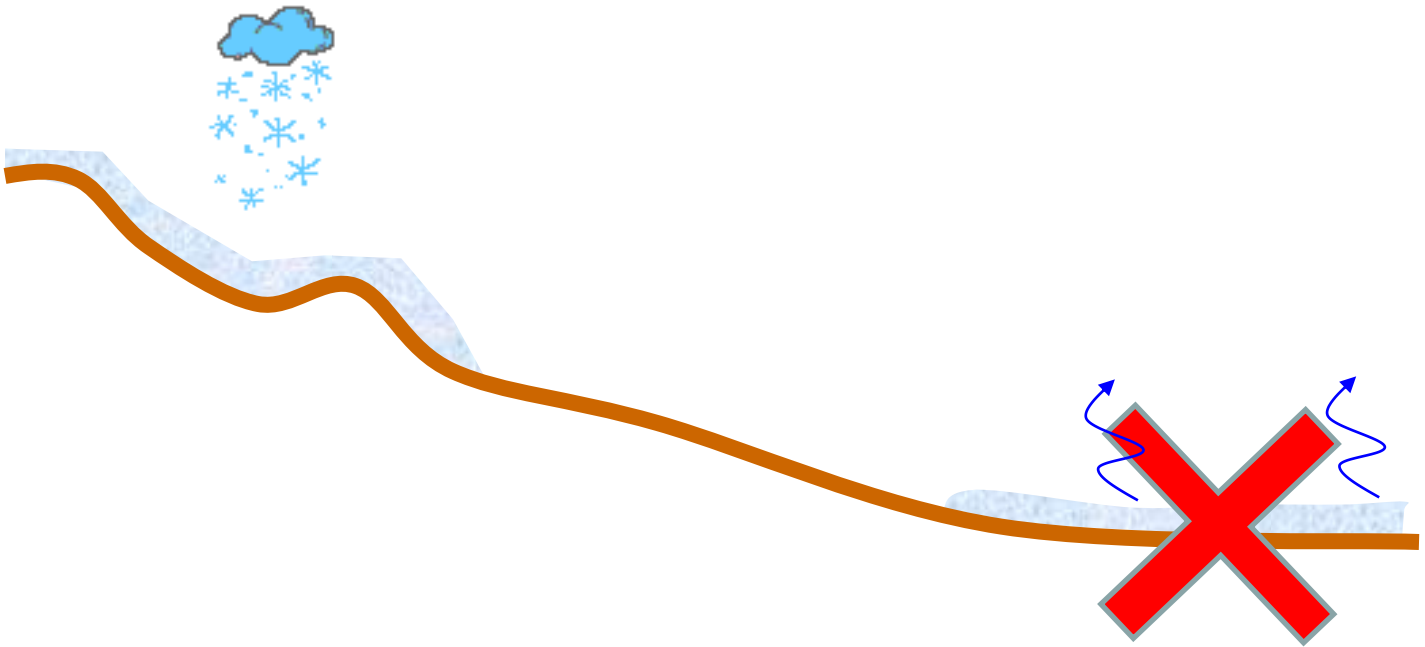

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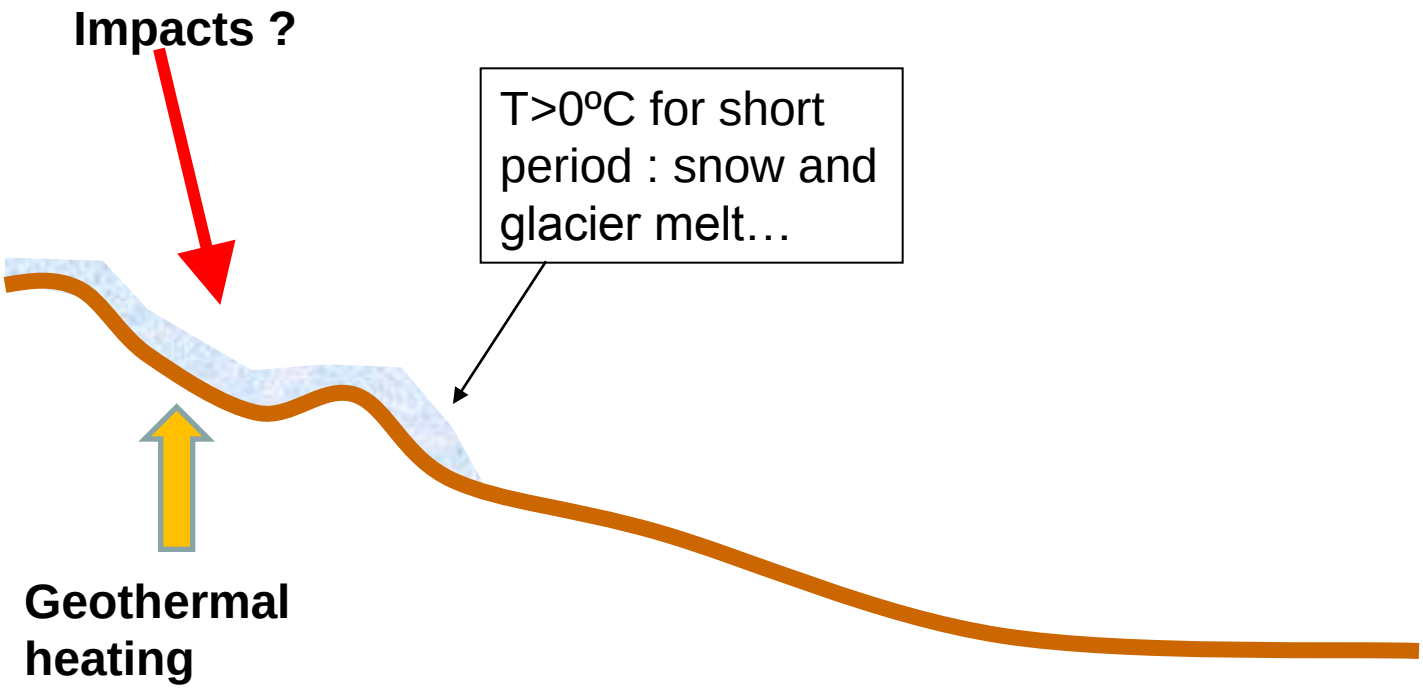

Preliminary conclusions

3D GCM simulations of an early Mars CO_2-H_2O climate and water cycle.

- CO2 gas greenhouse effect lower than previously thought (weaker Collision Induced Absorption)
- Significant warming by CO_2 clouds
- Adiabatic warming in lower plains.

- Warm, dry Mars possible, BUT with very thick CO_2 atmosphere
- Colder, icy ancient Mars scenario with a few hundreds of mbars currently explored. More work required to better understand where the water reservoir will be stabilized, melting,etc…
- To be continued…