The Early Mars Climates Enigmata

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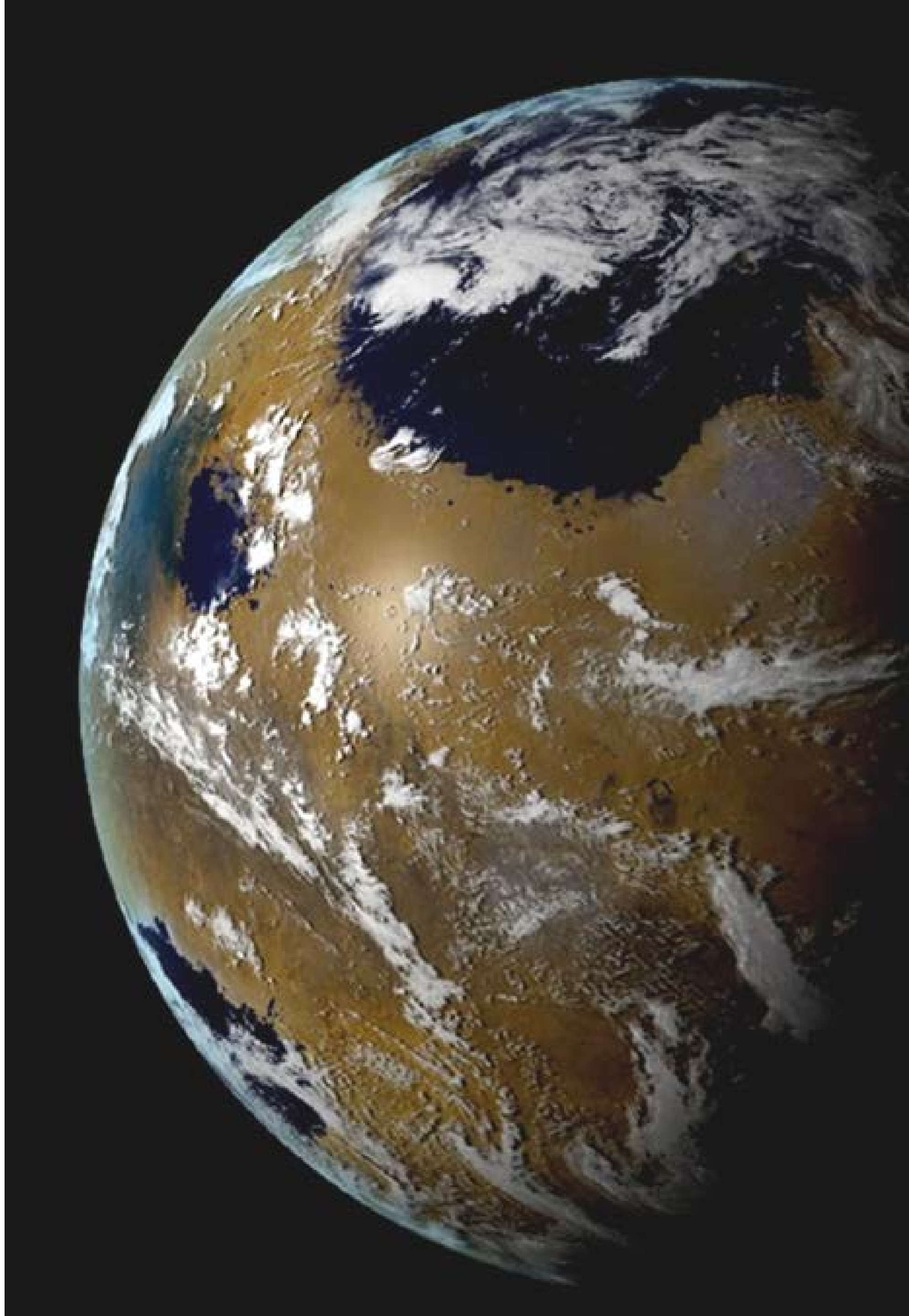
Early Mars/Paleoclimate panel
Planetary Science Decadal Survey 2022-2032
February 9, 2021

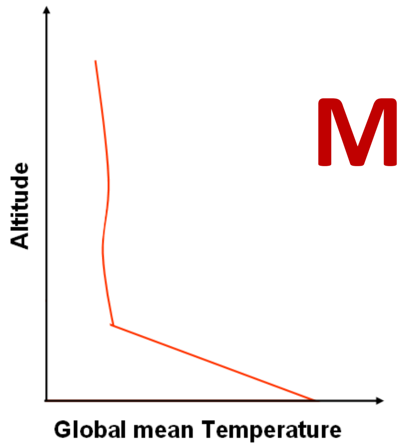
Sorry: no references are cited in this presentation (except figures)



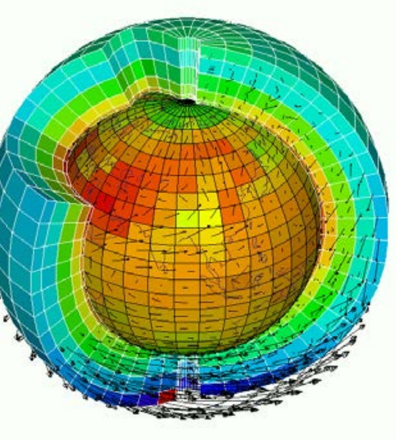
Which atmospheres for early Mars ?

- Direct constraints from rocks
  - From rock samples (meteorites, MSR). *Gas inclusion* ?
  - Clues from geology and mineralogy
- Constraints from our understanding of the formation of the Noachian atmosphere
  - Most likely **no atmosphere accumulated before 4.1 Ga** because of early EUV heating (possible sporadic atmosphere sduring strong volcanic degassing)

    ⇨ ***To be confirmed by geo observations ?***
  - After 4.1 Ga: which atmosphere could form from late outgassing & impacts ?
- Constraints from our understanding of the loss of the Noachian atmosphere
  - Escape
  - Crustal reservoir sinks (not only carbonates ?)



Modeling the Noachian-Hesperian ClimateS



1. 1D global radiative convective models

⇨ **To evaluate global mean surface temperature with various atmospheres**

2. 3D General Circulation model

⇨ **To evaluate local surface temperatures & their variations with season, obliquity, the role of clouds, atmospheric circulation etc…**

3. 3D Global Climate model with realistic surface reservoirs produced by a converged water cycle with hydrology/cryology models

⇨ **Necessary to evaluate rain, snow melting, runoff, lakes evolution, etc.**

WARNING: Getting warm temperatures without modeling water can be misleading:

- **Water affects temperatures** (latent heat, thermal inertia, albedo)
- **Water tends to accumulate in the coldest regions** (cold traps).

⇨ With a limited water inventory, a very warm climate is necessary to get liquid water in cold traps (Dune planet)

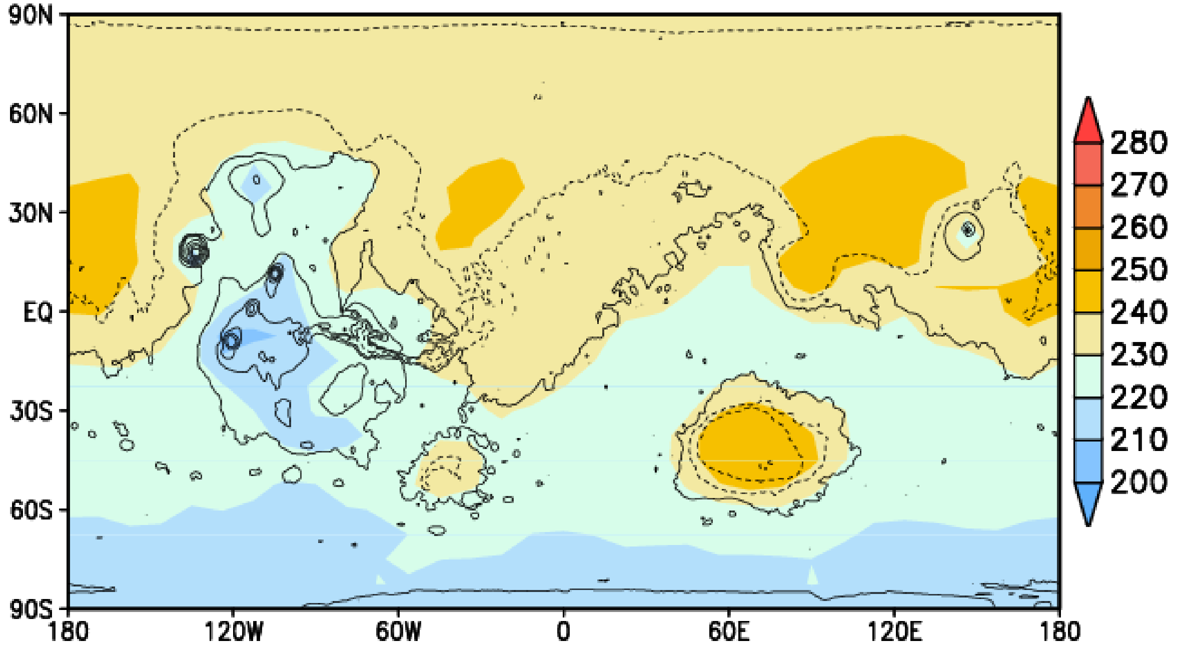
Modeling the Noachian-Hesperian ClimateS with CO_2

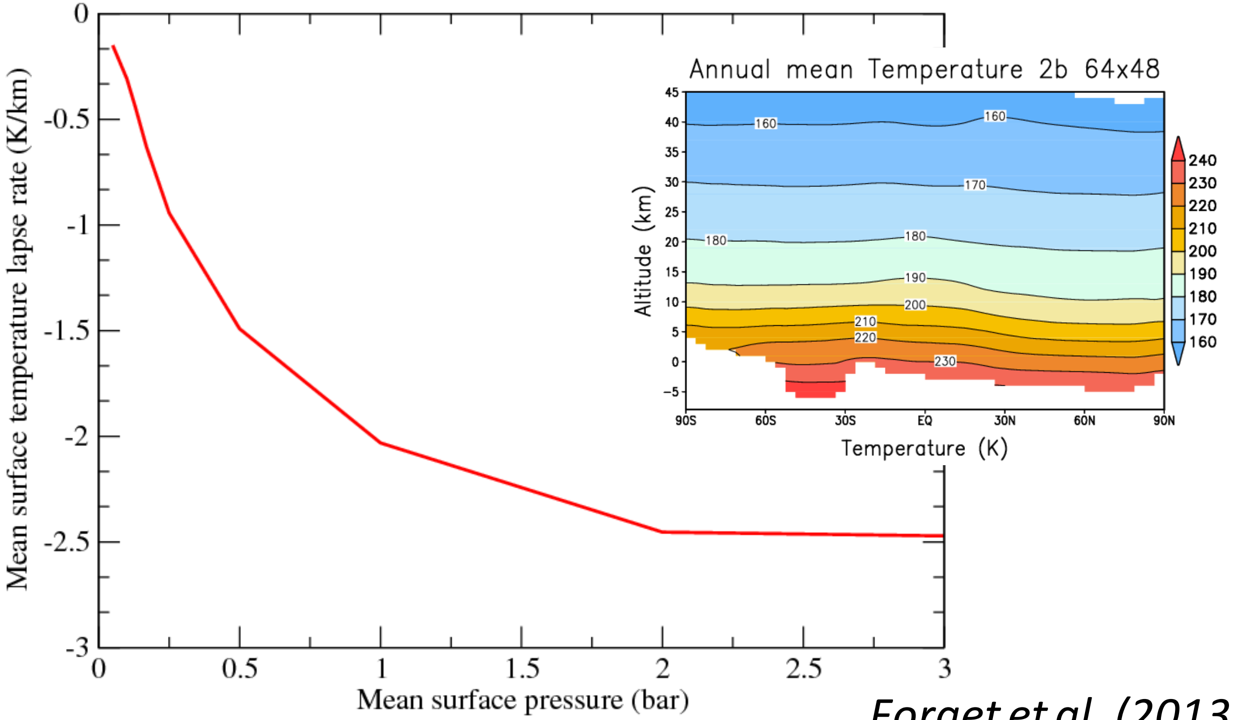
- **Modeling with a thick $CO_2 + N_2 + H_2O$ atmosphere**
  - Mars not warm enough for rivers
  - With a thicker atmosphere, cold early Mars is different than today: cold highland and warm plains ⇨ **"Icy highland scenarios"**
  - A "surprise" warmer solution could still be discovered (e.g. with improved models of clouds or aerosols) but it is unlikely.

- **Solution with an early Sun warmer than expected ?**
  - not yet completely rejected (a more massive Sun is predicted by some recent theories and young star observations, but for 100 Myr, not 1Gyr)

⇨ ***This could be checked using***

  - *Remaining signatures of the early solar wind*
  - *The effects of a solar mass-loss history on the orbital dynamics in the planetary system, (signatures in the geological record ?)*





Forget et al. (2013)

Warming early Mars with other greenhouse gases

- **NH_3** : photochemically unstable
- **Volcanic SO_2 and H_2S** : climate affected by aerosols
- **Exotic ideas : N_2O, H_2O_2,** CF3Br, CF2Cl2, …
- **The new trend :** **H_2** & CH_4 ?
  - **Need a background pressure** (greenhouse effect only induced by collision induced absorption or "CIA") >> 0.5 bars
  - Recent progress in the H_2 & CH_4 CIA absorptions coefficients measured in the lab.
  - H_2 escapes quickly, CH_4 is photolized ⇨ **Significant sources are required :**
    - **Highly Reduced mantle** ? ⇨ Outgassing of H2 directly and/or CH4, later photolized in H_2. Then what about CO_2 ?
    - Serpentinization ?
    - Production of H_2 and CH_4 in the thermal plumes of impacts ?

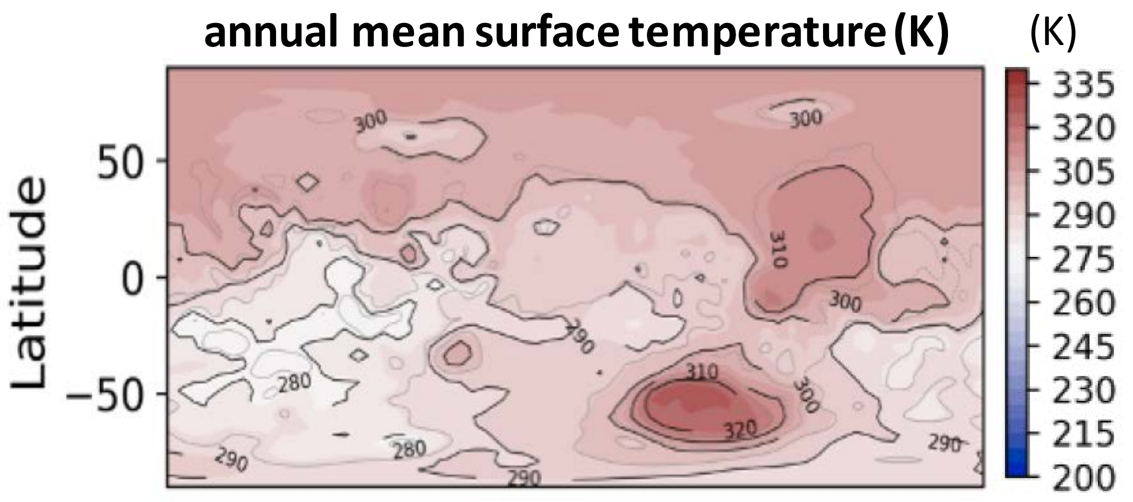
    ⇨ ***What evidences are in the rock records ?***

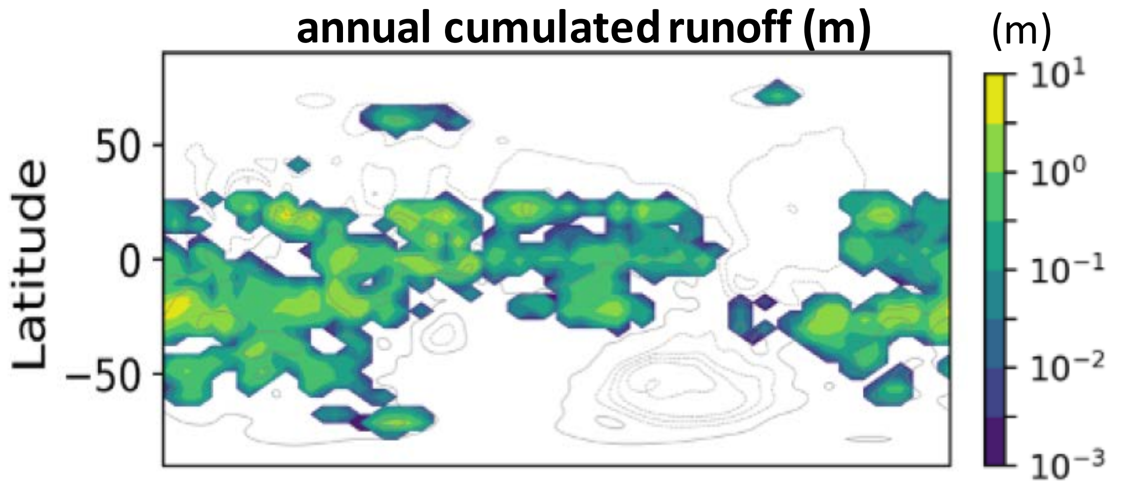
Modeling the Noachian-Hesperian ClimateS with $CO_2 + H_2$

- **Recent 3D simulations by Global Climate Models**

  Ames, ROCKE-3D, LMD, PMGCM (Japan)

  ⇨**promising results**, with possible runoff over valley network locations for fundamental reasons.
- **Large parameters space to explore** (obliquity, orbit, water inventory, atmospheric composition, topography, model parameters, etc.)
- Models are not yet complete enough to simulate the evolution of lakes, glaciers, the formation of seas, etc…





Turbet and Forget (2021)

The climatic impacts of impacts

- **A few large ancient impacts** (crater >> 100 km)
  - should induce short (tens of years) warming, with deluge-style precipitation (unless H_2 CH_4 are produced ?)
  - can affect the geo heat flux for millions of years
  - happened earlier than valley networks
  - BUT : strong erosion and alteration, regolith layers formation
- **Many more smaller impacts** (10 km < craters < 100 km)
  - production of ice-melting ejecta layers ?
  - maximum melt production ~10-1000 times lower than what is needed for the valley network
- **YET : Large impacts must have left climate-induced signatures in the geological records.**
- Could impacts explain very late fluvial forming events ?

Inputs needed from geological studies

- **Modelers need more constraints from geomorphology and mineralogy**
  - *sometime observations not useful by themselves can constrain climate models*
- **Consensual**, quantitative (corrected from observational biases) measures are useful *(even with debates on the interpretation)*.

  Examples:
  - Reliable map of terrains with a given age with or without fluvial features.
  - Detailed temporal relationship between fluvial forming events/ craters / volcanoes
  - Presence of glaciers on Noachian & Hesperian Mars ?
  - Runoff estimation, open-closed-basins distributions, etc.
- We must elucidate the **links between hydrous minerals and climate**, and their timing
  - Example: Which philosilicate are produced by surface liquid water, hydrothermalism, impacts, Primordial alteration by a steam atmosphere, etc.
- What was **Mars topography through time** (True Polar Wander ?)

Final comment

Using terrestrial analogs and experience can be misleading on Mars

- On recent Mars : wrong interpretation of gullies, RSL, spiders
- On early Mars: exotic process must be imagined and further studied:
  - Examples:
    - Fast erosion in impacts-made regolith
    - Signature of intense precipitation after impacts
    - Geomorphology in a world were eolian erosion dominates fluvial erosion for extremely long duration…
    - Signature of CO_2 glaciers…

⇨ Numerical modeling and lab experiments can help