ON THE CHALLENGE OF SIMULATING THE EARLY MARS ENVIRONMENT WITH CLIMATE MODELS. F. Forget, M. Turbet, E. Millour, L. Kerber, R. D. Wordsworth, J. W. Head, Laboratoire de Météorologie Dynamique, IPSL, CNRS, Université Paris 6, Paris, France (forget@lmd.jussieu.fr), Jet Propulsion Laboratory, Caltech, CA, USA, Harvard University, Cambridge MA, USA, Brown Univ., Providence, RI, USA.

Introduction. Yes, there is compelling evidence and widespread agreement that water flowed on the surface on early Mars, at least episodically. But we still do not know when or how this happened, or if the incision of the valley networks was before Mars "true polar wander". Nevertheless, based on the new ideas that are regularly proposed, and the constant improvement of the climate models, there is hope ahead.

At the 4th Conference, we wish to review some of the climate modelling studies recently conducted (notably using the LMD 3D climate model). We shall describe the work performed in the recent years, notably since the 3rd Early Mars conference, but will focus on the most recent advances and new ideas (It can be noted here that excellent reviews on the subject, covering studies published until 1 to 2 years ago, have recently been published [1,2]).

The CO$_2$-H$_2$O atmosphere solution. A pure CO$_2$-H$_2$O atmosphere under early Mars conditions cannot easily warm the planet to explain the geological record. Yet, 3D simulations of early Mars with a CO$_2$ atmosphere thicker than today have simulated an interesting environment, different from today.

Icy highland. The key difference is related to the fact that, if the surface pressure is high enough, the elevated regions are colder than the low lying plains [3], providing a cold trap where water tends to accumulate as snow and ice in high altitude [4,19], and a process to constantly replenish these reservoirs. Interestingly, the resulting distribution of glaciers is in somewhat good agreement with the observed valley networks [4,5,18].

Icy highlands before Mars "true polar wander". An interesting twist in the icy highland-valley network correlation is the possibility of a late "polar wander" of Mars [6]. If one assume that the growth of Tharsis induced a reorientation of the planet with respect to its spin axis, and that this took place after the incision of the valley network, then the distribution of the valleys along a small circle tilted with respect to the equator is found to correspond to a southern-hemisphere latitudinal band in the pre-TPW geographical frame. Even more than with the current Mars map, this points to a climate origin to explain the Valley Network distribution [6].

Icy highlands and the preservation of early Noachian phyllosilicates. Furthermore, if one explores the location of the possible ice reservoir on a "pre-Noachian Mars" with a simple topography, it is interesting to find that ice tends to accumulate where the major phyllosilicate deposits are now found. This have been suggested to provide a means to protect the deposits throughout Noachian, and explain their current location [10].

CO$_2$ ice clouds. Once assumed to provide an attractive solution to the early Mars climate enigma thanks to their scattering greenhouse effect [7], CO$_2$ ice clouds are now considered to provide a limited surface warming because of their limited coverage [3] and detailed optical properties [8]. Yet they warrant further study with more detailed models.

Water ice clouds. High altitude water ice clouds could, in theory, provide a very strong greenhouse effect. The interesting findings by Urata and Toon [9] on this subject cannot easily be reproduced in other models [4,11]. However this also warrants further studies with a high resolution model including an extended domain. We will present new results on this subject at the conference.

![Fig. 1. Key climate processes on Early Mars. Adapted from [17]](image-url)
CO₂ ice cap and glaciers. Mars with a CO₂ atmosphere thicker than today is a place where CO₂ condensation can form spectacular CO₂ ice glaciers [3, 12] that may have played a role in Mars geology and past climate [20]. This is interesting to study and detail.

**Obliquity variations.** The large martian orbital variations must have played a role in the early Mars climate system. However, while summertime diurnal mean surface temperatures above 0°C (a condition which could have allowed rivers and lakes to form) are predicted for obliquity larger than 40° at high latitudes, they are not in locations where most valley networks or layered sedimentary units are observed. Nothing in the climate record suggests a link between high obliquity excursions and flowing water [3,4, 15].

**Spectroscopic issues.** Interestingly, the spectroscopy of a CO₂ atmosphere thicker than a few hundreds of millibars atmosphere remains an active field of research (see Turbet et al., abstract 1, this issue), with several remaining issues.

**Volcanoes, Impacts, catastrophic outflow and episodic warming.**

If a thick Mars CO₂ atmosphere only yields a cold and icy planet, one has to take into account additional processes to warm it and melt significant amounts of water to explain the geological record.

**The climatic impact of impacts** is, within that context, a key process to study. This is discussed in the companion paper by Turbet et al. (This issue, abstract 2).

**The consequence of catastrophic outflows.** It has been speculated that the catastrophic flooding that formed the Hesperian outflow channel events could have induced significant rainfall and caused the formation of late-stage valley networks. However, 3-D Global Climate Model simulations [16] designed to reproduce the impact of a wide range of outflow channel formation scenarios suggest that these events have a limited effect, and that they cannot trigger long-term greenhouse global warming.

**Volcanic activity** could have supplemented such an early atmosphere with additional greenhouse gases such as SO₂, H₂S, CH₄, NH₃, and H₂O and boost the greenhouse effect for some time if their concentration could be raised to an adequate level and for a sufficient duration.

**Volcanic SO₂.** Following many modeling studies, Kerber et al. [13] recently used the LMD GCM to explore the possible climates induced by releases of SO₂. SO₂ was found to be incapable of creating a sustained greenhouse on early Mars. Even in the absence of aerosols, local and daily temperatures rise above 273 K only for limited periods with favorable background CO₂ pressures. In the presence of even small amounts of aerosols, the surface is dramatically cooled for realistic aerosol sizes. Brief, mildly warm conditions were found to require the co-occurrence of many improbable factors, while cooling is achieved for a wide range of model parameters.

**The H₂–CH₄ seducing solution.**

Ramirez et al. [14] argued that H₂ emitted from volcanoes into a thick CO₂-dominated atmosphere could have significantly warmed the planet assuming a very reducing mantle and a very high rate of volcanism. This scenario was thus not easy to prove right. However, Wordsworth et al. [15] recently showed that in this study the strength of the greenhouse effect induced by the CO₂–H₂ collision-induced absorption could have been significantly underestimated (by using the available spectroscopic properties, originally derived for an N₂ atmosphere instead of CO₂). Furthermore, they reported that methane could also have acted as a powerful greenhouse gas on early Mars due to CO₂–CH₄ Collision Induced Adsorption in the critical 250–500 cm⁻¹ spectral window region. The required outgassing fluxes become more realistic, and the scenario is very interesting. At the conference, we will present new simulations performed with atmospheres including H₂ and CO₂.