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On the challenge of simulating the early Mars environment with climate models and the reducing gas solution

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1. 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 which climate processes operated [1,2]. Each proposed solution has its difficulties. Nevertheless, based on the new ideas that are regularly proposed, and the constant improvement of the climate models, there is hope ahead.

In particular we present new climate simulations performed assuming a significant greenhouse warming produced by reducing gases such as H_2 that could have been outgassed at the time [3-4]. For this purpose we adapted our early Mars LMD Global Climate Model (GCM) [5,6] to account for various quantities of H_2 using updated collision-induced absorption of hydrogen in a CO_2 atmosphere [7], and including a simple representation of the hydrology on the planet.

2. Background

A pure CO_2-H_2O 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 than today. The key difference being related to the fact that, if the surface pressure is high enough, the elevated regions are colder than the low lying plains [5], providing a cold trap where water tends to accumulate as snow and ice in high altitude [6]. Interestingly, the resulting distribution of glaciers is in somewhat good agreement with the observed valley networks [6].

If a thick Mars CO_2 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. Most recent studies suggest that impacts must have played a key role in the climate evolution, but that they cannot explain the formation of valley networks and other evidence supporting the presence surface liquid water [7,8]

Volcanic activity could have supplemented such an early atmosphere with additional greenhouse gases such as SO_2, H_2S, CH_4, NH_3, and H_2 and boost the greenhouse effect for some time if their concentration could be raised to an adequate level and for a sufficient duration. Following many modelling studies, Kerber et al. [9] recently used the LMD GCM to explore the possible climates induced by releases of SO_2. SO_2 was found to be incapable of creating a sustained greenhouse on early Mars. In the presence of even small amounts of aerosols, the surface is dramatically cooled for realistic aerosol sizes.

The H_2-CH_4 seducing solution. Ramirez et al. [3] argued that H_2 emitted from volcanoes into a thick CO_2-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. [4] did some calculations to show that the strength of the greenhouse effect induced by the CO_2–H_2 (and CO_2-CH_4, respectively) collision-induced absorption (CIA) could have been significantly underestimated (by using the available spectroscopic properties, originally derived for an N_2-dominated atmosphere instead of CO_2). The required outgassing fluxes become more realistic, and the scenario is very interesting.

More recently, we have performed measurements [10] of H_2+CO_2 and CH_4+CO_2 mixtures absorptions, that will be presented at the EPSC/DPS 2019 joint meeting. These measurements roughly confirm the theoretical predictions [4], although with some significant deviations in the shape and strength of CIAs.

3. New climate simulations including H_2 warming, adapted topography and various water inventory

We present new numerical simulation of the possible climates on early Mars assuming (1) a thick CO_2 atmosphere with various amount of hydrogen ; (2) a pre-True Polar Wander topography [11] ; and (3) various amounts of water available on the planet. A key point of this model is that we use an algorithm combining LMD GCM simulations with hydrology and glaciology simplified models to calculate the long-term fate of water.

In practice water accumulate in glaciers, crater lakes or oceans depending on the temperature and the water inventory. In colder and arid cases, water tend to accumulate in cold traps (glaciers and lake) at high altitude and latitude, but surface runoff can lead to the formation of low altitude lakes and oceans if there is enough water, with important consequences on the water cycle. The algorithm to represent the evolution of crater lakes and their impact on the climate (through evaporation and albedo effects) is based on the work by Matsubara et al. 2011 [12]. When an ocean is present, we use a simple dynamical ocean model [13] that includes a representation of sea ice.

We will present the results of these informative simulations at the EPSC/DPS 2019 joint meeting. We find that early Mars can remain very dry even if the global mean temperature is above 0°C, because water tend to be cold-trapped in permanent water ice reservoirs located on the southern highlands of Mars (a process enhanced by an ice-albedo feedback).

In warmer/wetter cases, liquid water rainfall and runoff occurs but permanent ice deposits still cover a significant part of the southern highlands. It has been argued that this is an issue, because there is no clear evidence of glacial erosion on these terrains (the “equatorial periglacial paradox” [2,14]. However we found that preventing the formation of glaciers (i.e. raising the mean surface temperature of the highlands roughly above 0°C) requires about 5 times more hydrogen than what is needed to raise the global mean temperature above 0°C, as approximated in 1-D climate models [3].

We also explored the hydrological cycle in these warm cases assuming various water inventories. Some relatively arid simulations are very “promising” with lake formation and runoff in the southern highlands, in good agreement with the observed location of valley networks. However the model tends to predict then the formation of a majority of open-basin lakes in contradiction with the observational evidence that closed-basin lakes outnumber open-basin lakes.

In even wetter cases with a northern ocean, the hydrological cycle can be intense. Lakes and rivers not only form in the highlands but also around the oceanic regions.

4. Conclusions

With regard to runoff and hydrology, our simulations suggest that arid and semi-arid H_2-warmed climates are promising solutions to the early Mars enigma, assuming a topography adapted to late Noachian Mars conditions and a “well-adjusted” surface water inventory. This requires a total amount of reducing gas (here H_2) much higher than predicted by 1-D models. Also, some discrepancies with the geological observations (e.g. the ratio of closed-basin lakes to open-basin lakes) remain.

References

[1] Haberle et al. 2017, The Early Mars Climate System, in "*The atmosphere and climate of Mars*", Cambridge University Press.

[2] Wordsworth 2016. *Annu. Rev. Earth Planet. Sci.* 44:381–408

[3] Ramirez et al. 2014. *Nature Geoscience* 7:59–63

[4] Wordsworth et al. 2017, Geophys. Res. Lett., 44, 665–671.

[5] Forget et al. 2013, *Icarus*, 222, 81– 89.

[6] Wordsworth et al. 2013, *Icarus* 222, 1-19.

[7] Turbet et al. 2019, submitted to *Icarus*, available on https://arxiv.org/abs/1902.07666.

[8] Steakley et al. *Icarus* (2019), in press.

[9] Kerber et al. 2015, *Icarus* 261:133–48.

[10] Turbet et al. 2019, *Icarus* 321:189-199, 2019.

[11] Bouley et al. 2016, *Nature*, 531:344-347, 2016.

[12] Matsubara et al. 2011, *JGR (Planets)*, 116:E04001.

[13] Codron 2011, *Climate Dynamics*, 38:379-389

[14] Ramirez and Craddock 2018, *Nature Geoscience*, 11:230 237.