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Comparison of scenarios for Martian valley network formation using a 3D model of the early climate and water cycle

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Abstract

Despite the extensive geological evidence for flowing water on Mars up to four billion years ago, there is as yet no comprehensive explanation for its occurrence. Here, based on our 3D simulations of the Martian water cycle under a faint young Sun and denser CO2 atmosphere, we compare two possible climate scenarios for valley network formation: a multiple-bar CO_2 atmosphere with sufficient greenhouse warming to allow long-term surface liquid water, and a 'thin atmosphere' (0.2 to 1 bar), mainly frozen scenario in which only episodic flowing water is possible. The former case unequivocally predicts sufficient rainfall for valley network formation but is in conflict with current constraints from atmospheric evolution theories. In the latter scenario, ice typically migrates to the southern highlands due to the correlation of temperature with altitude, although only transient melting is possible due to the lower temperatures.

1. Introduction

Abundant geological evidence, both chemical and morphological, now exists for the presence of liquid water on Mars in the Noachian and Hesperian eras. Explaining where this water came from, and in particular whether it was the consequence of a warmer climate or episodic, possibly catastrophic events, is the central problem of Martian paleoclimate research.

We have addressed the problem of water on Early Mars via three-dimensional simulations that assume a fainter young Sun and denser CO_2 atmosphere. We have investigated the Martian climate and water cycle for a range of atmospheric pressures, in order to better understand the possible conditions in this era. Our objectives are to investigate the feasibility of steady-state warm, wet early Martian climate, and more generally, to identify conditions that lead to an accumulation of H_2O (water or ice) in the Noachian valley network regions.

2. Method

We use the new LMD Terrestrial Climate Model, which has been specifically developed for the study of a diverse range of atmospheres, including the Martian paleoclimate. The model combines the LMDZ dynamical core and basic physics parameterizations (boundary layer scheme, soil physics, dry convection etc.) with a new generalized radiative transfer scheme based on the correlated-*k* method. We model the collision-induced absorption of CO_2 using an improved parameterization that predicts a slightly reduced greenhouse effect [4]. The radiative effects of clouds (CO_2 and H_2O for Early Mars) and aerosols are included via the Toon et. al (1989) scheme [1], with Mie theory used to calculate their radiative properties. A self-consistent water cycle is included: both water vapour and ice are treated as active tracers with radiative effects, and moist convection, latent heat changes and precipitation microphysics are taken into account. Surface albedo changes due to ice / water are included, and surface hydrology is treated using a simple bucket scheme.

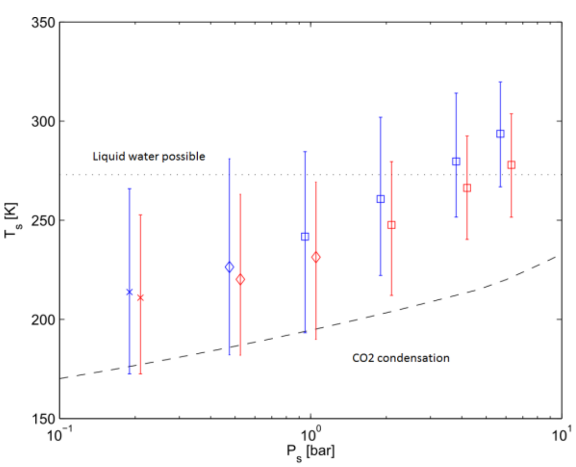

Figure 1: Mean and extremal surface temperatures vs. surface pressure for 3D simulations with dry (red) and humid (blue) CO_2 atmospheres.

3. Results

Climatology

CO_2 clouds have been debated as a possible source of warming in the denser early Martian atmosphere [2-3]. We model their formation, evolution and radiative effects in 3D, including simplified cloud microphysics. Using reasonable assumptions on the cloud particle sizes and microphysics, 2-5 bars CO_2 is necessary to warm the (dry) planet up to the melting point of water. When the radiative effects of water are included, the moderate cooling effect of low altitude H_2O clouds is more than compensated for by the greenhouse effect of H_2O vapour, resulting in higher overall temperatures for a given CO_2 pressure (Figure 1).

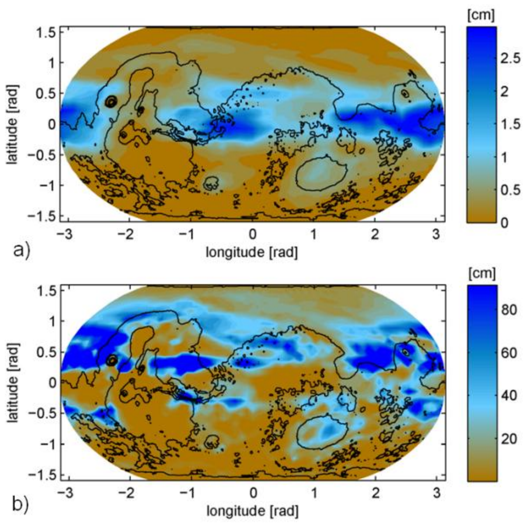

Figure 2: a) Annual mean water column amount and b) annual total rainfall for an Early Mars simulation starting with a northern ocean, 5-bar CO_2 atmosphere, and 25° obliquity.

Constraints on the global water cycle.

We find the amount of precipitation over the valley network regions depends strongly on the local distribution of water sources. In the warm, wet scenarios, significant transport of water to the valley highlands only occurs if oceans are present in Hellas and the north. In the frozen scenarios, light snowfall over long timescales leads to the accumulation of ice in the southern highlands.

Surface topography

Constraints from crater counting and other sources indicate that the main period of valley network formation occurred around the same time as the Tharsis bulge was forming. To better understand the effect of Tharsis on the global Martian water cycle, we are currently performing additional simulations with modified surface topography (Figure 3).

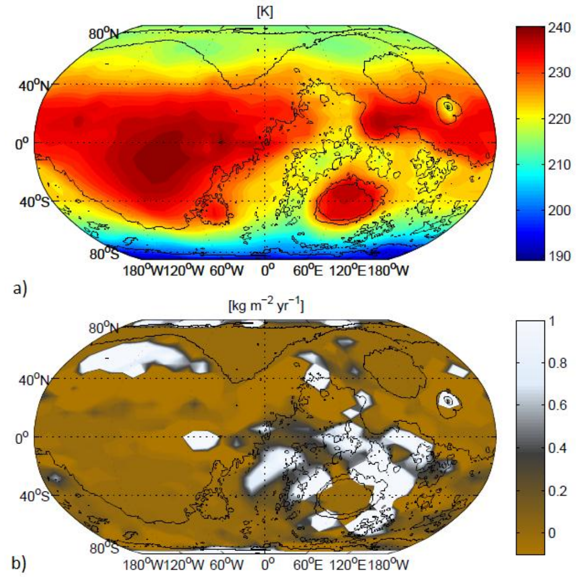

Figure 3: a) Annual mean surface temperature and b) annual net ice deposition for a 1 bar simulation with 25° obliquity, modified topography and initial water sources in Hellas and the northern plains.

4. Conclusions

- With CO_2 cloud and water vapour warming included, long-term surface liquid water requires a multiple-bar CO_2 atmosphere.

- Under a 0.5 to 1 bar atmosphere, ice slowly migrates to the equatorial and southern highlands. Transient warming in these regions should lead to episodic melting events.

References

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