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The impact of meteoritic impacts on the early Martian environment

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1. Introduction

There is now a large number of evidences that liquid water flowed on early Mars: high erosion rates, sedimentary deposits, hydrated minerals and geomorphological clues including dry river beds and lakes [1-14]. Sophisticated climate modelling under ancient Mars conditions assuming a faint young Sun and CO_2-dominated atmospheres have not been able yet to produce liquid water or significant precipitations anywhere on the planet [15,16], unless incorporating additional reduced greenhouse gases, e.g. CH_4 and/or H_2 [17-19].

It has been suggested that warm & wet conditions required to explain the formation of the aforementioned geological evidences could have been transient and produced in response to meteoritic impacts [16,20-23]. This scenario is seducing because the formation of the valley networks is contemporaneous with the Late Heavy Bombardment that took place 3.8 billions years ago.

We model here the environmental effect of meteoritic impacts to explore if they could trigger the warm conditions and the precipitation rates required to explain the formation of the valley networks.

2. Method

This study was performed with the 3D LMD Generic Global Climate Model (GCM). The model works with a sophisticated water cycle that includes the formation of H_2O and CO_2 ice clouds [15,16,24], and for various atmospheres made of $CO_2/N_2/H_2O$. Simulations were performed with resolution grids of 3°x3°x40 levels (in latitude x longitude x altitude). We used both the present-day MOLA and ancient Mars topographies [24-26], when appropriate. More details on the model can be found in [15,16,24,26,27].

3. Results

3.1 Large impact events

We simulated the climatic impact of large meteoritic impactors ($D_{impactor}$>100km, N_{events} ~ 10) hitting the surface of Mars at velocities ~10km/s, by forcing initially the atmosphere/surface/subsurface at temperatures up to 600 Kelvins, and vaporizing up to several bars of water vapor.

Our main result is that, *whatever the initial impact-induced temperatures and water vapor content injected, warm climates cannot be stable and are in fact short-lived* (lifetime of ~ 5-7 martian years per bar of water vapor injected). The results of Segura et al. 2012 [22], which would require extremely high supersaturation levels of water vapor to work, are at odd with our findings. Note that we obtain minimum outgoing thermal radiation fluxes that are in good agreement with recent studies on the runaway greenhouse [28].

When a hot, steam atmosphere forms after a large meteoritic impactor hits early Mars, our 3D GCM simulations indicate that the IR thermal emission to space is roughly 200W/m² higher than the incoming stellar radiation (under Faint Young Sun), *everywhere on the planet*. At the altitude of IR emission to space, water vapor condenses, releasing ~ 200W/m² of latent heat, everywhere on the planet. Consequently, a 100%, thick cloud cover forms, producing precipitation (rainfall, here) uniformly distributed on the planet. This mechanism is summarized in Fig 1.

Warm & wet conditions that follow the largest impact events recorded on Mars should not only have been short-lived, but should also have produced thick 100% cloud coverage, responsible for precipitation patterns uniformly distributed on the planet, and thus uncorrelated with the position of the valley networks.

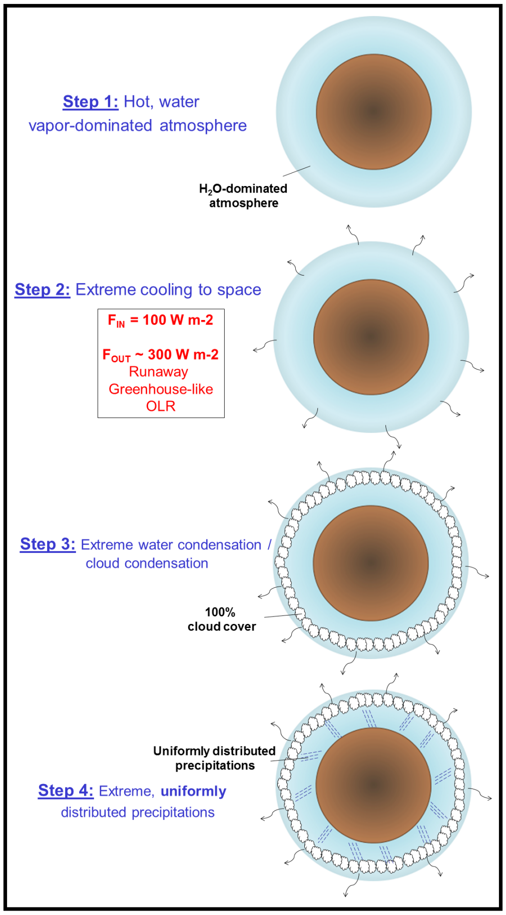

Figure 1: Sketches of the physical processes occuring after a post-impact hot, steam atmosphere forms on Early Mars.

Compared to previous studies [16,20-24,26], we carefully took here into account the radiative effect of spectroscopic features (far line absorptions and Collision Induced Absorptions) typical of CO_2-H_2O rich [29-31] post-impact atmospheres. In particular, we find that far-line IR opacities can be increased by 1-2 orders of magnitude, when broadening properly H_2O lines by CO_2 (instead of air). We will present the effect of these new spectroscopic refinements on the climate modelling of impact events at the 2017-EPSC conference.

3.2 Middle-size impact events

We estimate that moderate-size impact events (5km $< D_{impactor} < 50$km, $N_{events} \sim 3\text{x}10^3$ [32]) being much more numerous, they are potentially the best candidates to form the Noachian valley networks. They could in fact melt the ice that tends to accumulate preferentially in the regions where the rivers were sculpted ('Icy Highlands' scenario [16,25]). This scenario is particularly appealing because it would be an efficient mechanism of recharge of the valley network water sources between two impact-induced melting events.

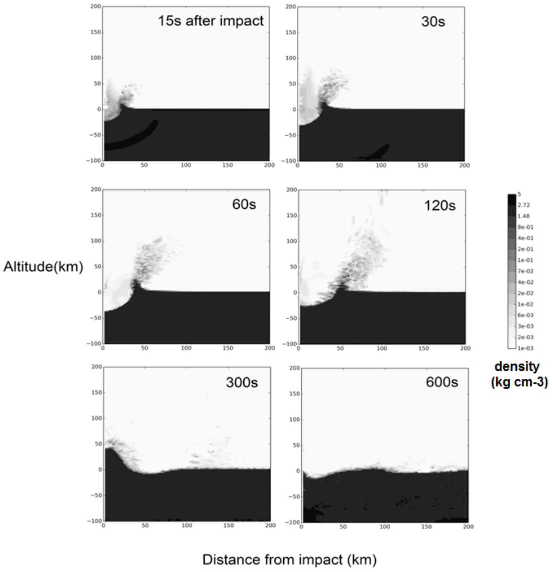

Figure 2: Time lapse of SOVA hydrocode simulations showing the volumetric density of materials following a ~15km diameter comet hitting Mars surface at 10km/s.

We will present preliminar estimates of the amount of rainfall/snowmelt that should be expected after impact events depending on their size, composition, velocity, … For this, we use the SOVA hydrocode [33] for short-term modelling of impact cratering. It provides us with post-impact temperature fields, injection of volatiles, ejecta and dust distribution (Fig 2) that serve as input for the LMD Generic Global Climate Model.

References

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