THE ENVIRONMENTAL EFFECT OF METEORITIC IMPACTS ON EARLY MARS WITH A VERSATILE 3-D GLOBAL CLIMATE MODEL. M. Turbet¹, F. Forget¹, V. Svetsov², H. Tran¹, J-M Hartmann¹, Ozgur Karatekin¹, C. Gillmann³, O. Popova², & J. Head⁴. Laboratoire de Météorologie Dynamique, IPSL, UPMC (martin.turbet@lmd.jussieu.fr), ² Institute for Dynamics of Geospheres, Russian Academy of Sciences, Leninskiy Prospekt 38-1, Moscow 119334, Russia, ³ Royal Observatory of Belgium, Avenue Circulaire 3, 1180 Uccle, Belgium. ⁴ Brown University, Providence, RI 02912, USA.

Introduction: There are now numerous 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 CO₂-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. CH₄ and/or H₂ [17-19]. For more information, we refer you the the review presented by Forget et al., this issue.

Meanwhile, 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 may be contemporaneous with the Late Heavy Bombardment that took place 3.8 Gya.

We model here the environmental effect of meteoritic impacts with a 3-D Global Climate Model, to explore if they could trigger the warm conditions and the precipitation rates required to explain the formation of the valley networks.

Method: This study was performed with the versatile 3-Dimensions LMD Generic Global Climate Model (GCM). The model works with a sophisticated water cycle that includes the formation of H₂O and CO₂ ice clouds [15,16,24], and for various atmospheres made of CO₂/N₂/H₂O. 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].

Compared to previous studies [16,20-24,26], here we carefully incorporated the radiative effect of spectroscopic features (line widths at half-maximum, far line absorptions and Collision Induced Absorptions) typical of CO₂/H₂O rich [28-30] post-impact atmospheres. As an illustration, far-line IR opacities can be increased by 1-2 orders of magnitude, when broadening properly H₂O lines by CO₂ instead of air. For more information on these new spectroscopic refinements, we refer the reader to the poster presented by Martin Turbet (this issue).

Effect of large impact events: We simulated the climatic impact of large meteoritic impactors (D_{impactors}>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.

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

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 effect [31].

When a hot, steam atmosphere forms after a large meteoritic impactor hits early Mars, our 3-D climate 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.

To test this idea, 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. Our goal is to derive from these simulations estimates of the amount of rainfall/snowmelt that could be expected after impact events depending on their size, composition, velocity, etc. We will present our preliminar results at the Fourth International Conference on Early Mars.


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

**Effect of middle-size impact events:** We estimate that moderate-size impact events (5km < D_impactor < 50km, N_events ~ 3x10³ [32]) being much more numerous, they are potentially the best candidates to be at the origin of the formation of 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.