A coupled atmosphere–hydrosphere global climate model of early Mars: “cool and wet” scenario for the formation of water channels

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We present the results of a newly-developed 3-dimensional Paleo Martian Global Climate Model (PMGCM) assuming the CO_2/H_2O atmosphere under the ‘Faint Young Sun’ (solar luminosity of ~75% of the current value) with surface pressures between 0.5 and 2 bars. The PMGCM also has a hydrologic cycle module which includes ocean thermodynamics, water vapor advection / convection / condensation / precipitation processes, and surface fluvial activities (e.g. fluvial and sediment transport). Martian water channels have been thought to be the evidences of warm climate enough for the long-term fluvial systems on early Mars during Noachian and Hesperian boundary (3.8-3.6Ga). This study tries to evaluate the quantitative inference from the early Martian environment to their formations, by a coupled atmosphere-hydrosphere global climate model of early Mars.

In the calculation with the surface pressure of higher than 1.5 bars, the PMGCM indicated that early Martian surface environment would be ‘cool’, between ‘warm’ and ‘cold’. ‘Cool’ means that the mean surface temperatures during spring to autumn seasons are high (> 273 K) enough to allow the seasonal melting of snow-ice deposits and low (< 273 K) to produce lots of snow precipitation and accumulation during winter. We discussed the mechanisms which could be responsible for the surface warming on early Mars; (1) variable thermal inertia in the ground depending on soil water content, and (2) higher modeling top altitudes compared to previous models. We performed additional experiments and showed that (1) and (2) could express ~3 K and ~15 K surface warming, respectively.

In addition, the PMGCM indicated ‘wet’ surface environment characterized by precipitation and seasonal melting of snow/ice (neither ‘dry’ nor ‘permanent frozen’ states). Fluvial sediment transport in southern low-mid latitudes are enough to reproduce the Martian valley networks within a relatively short timescales, less than 10 million years. In our study, the most of VNs identified by previous observational studies are well reproduced. However, we also found some discrepancies between numerical modeling and observations (e.g. *Sabaea Terra* and *Arabia Terra*). We obtained following explanation for those mismatches: 1) In the era of the Noachian and the Hesperian, Tharsis loading had not started or completed, which allow zonal transport of water vapor and precipitation toward *Terra Sabaea*. 2) As mentioned in *Davis et al*., (2016), VNs in *Arabia Terra* might been hidden underneath surface ground due to different erosion such as lava or sediment brought by subsequent volcanic activity in early Mars. 3) Some VNs could had formed by groundwater sapping or glaciation processes.

We suggest that the moderate climate, i.e., ‘cool and wet’ condition between ‘warm and wet’ and ‘cold and frozen’ would be preferable to explain the fluvial activity on early Mars. It does not request ‘non-climatic mechanisms’ such as meteorite impacts warming.

Keywords: Martian atmosphere, Martian hydrosphere, Martian paleo climate, Martian valley networks

