Quantitative evaluation of the cumulus convection schemes for the implementation into the Paleo Martian Global Climate Model

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Current Mars has a lot of fluvial traces, which are supposed to be made during the late Noachian and early Hesperian boundary (3.85-3.6 Ga). If these traces are created by the fluvial activity, the climate of early Mars should be ‘warm and wet’ enough for the long-term existence of liquid water on its surface. However, solar luminosity at that time would be weaker by 20-30 % of today’s value and preclude early Mars from keeping clement climate (‘Faint young Sun paradox’). Previous studies using 3-dimensional Mars Global Climate Models (MGCMs) have revealed that pure CO_2 atmosphere, even assuming 2~7 bars, was hard to reproduce the surface temperature above 273 K [e.g. *Kasting*, 1991; *Forget et al*. 2013].

We newly developed a 3-dimensional Paleo MGCM (PMGCM) with ancient ocean on its surface below a sea level of -2.54 km, including the absorptions of CO_2 / H_2O gases, CO_2 / H_2O ice clouds, thermodynamics of land / ocean, and hydrological processes [*Kamada et al*., submitting to Icarus]. This model reproduced the clement surface environment enough for liquid water on surface and could create the most of fluvial channels by hydrological processes. However, a part of fluvial channels in our model could not be reconciled with observed ones on current Mars (e.g. *Sabaea Terra*). Some explanations for these mismatches may be considered by 1) Noachian and early Hesperian boundary, the Tharsis rise had not finished or completed, which would enable wind system to transport water vapor towards the leeward regions such as Sabaea Terra, and/or 2) some of fluvial channels would have formed by glaciation.

Another possible reason is that our model has excluded the cumulus convection scheme, only included large-scale condensation process for the precipitation process. This process could be crucial for atmospheric stability and affect the distribution and the amount of precipitations on early Mars. Therefore, as the next step, we are newly introducing the cumulus convection scheme based on Kain-Fritsch scheme [*Kain and Fritsch,* 1993]. This scheme is appropriate for low-middle resolution GCMs to reproduce the cumulus lifetime including creation, developing, declining, and eliminating atmospheric instability by one cumulus in a grid. Another candidate is Relaxed Arakawa-Schubert scheme [*Moorthi and Suarez*, 1991] which is often introduced to terrestrial GCMs. However, it is not obvious whether this scheme could be adapted to early Mars, because it is based on several terrestrial empirical assumptions when calculating cloud-base mass flux which cannot be simply adopted to the CO_2 / H_2O atmosphere in our model.

In order to do the trade-off between those two schemes, we evaluate the differences of precipitation created by both schemes. First, we do the test in our model but under the present Earth conditions (1 atm, N_2 / O_2 atmosphere, present solar flux at 1 AU). We suppose that both schemes would show the similar results in precipitation distribution and amount as long as performed on present Earth models. Next, we change parameters such as surface pressures (wet CO_2 atmosphere of 0.5-2.0 bars), atmospheric compositions, and solar flux for early Mars as our PMGCM conditions. These results will provide the differences and the validity of those schemes to apply for early Mars. In this paper, we will provide a first summary of these results.

Keywords: cumulus convection scheme, Mars