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, which would preclude early Mars from such ‘warm and wet’ climate (‘Faint young Sun paradox’). Previous studies using 3-dimensional Mars Global Climate Models (MGCMs) have revealed that pure CO_2atmosphere, 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 a clement surface environment enough for liquid water on surface and could create most of fluvial channels by hydrological processes. However, the fluvial channels reproduced in our model were partly not consistent with observations on current Mars (e.g. *Sabaea Terra*). There are several explanations for the inconsistencies, such as 1) in 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 modelhad excluded the cumulus convection scheme, considering only the large-scale condensation process for the precipitation. This process could be crucial for resolving atmospheric instability and affect the distribution and the amount of precipitations on early Mars. Therefore, as the next step, we are newly introducing a cumulus convection scheme. One candidate is the Relaxed Arakawa-Schubert scheme [*Moorthi and Suarez*, 1991] which is often introduced to terrestrial GCMs. However, it is not clear whether this scheme could be adapted to early Mars, because it is a simplified scheme taking the empirical processes of the Earth into account for the calculations of the cloud mass flux, which may not be simply adopted to the CO_2/ H_2O atmosphere of early Mars. On the other hand, the Kain-Fritsch scheme [*Kain and Fritsch,* 1993], which is appropriate for middle resolution GCMs to reproduce the cumulus lifetime including creation, developing, declining, and deletion phases by one cumulusin a grid,is considered to be more suitable for PMGCM. It directly calculates the vertical structure of the cumulus without using the empirical assumption of the Earth.Though it is inferior to the Relaxed Arakawa-Schubert scheme in terms of ensemble, it is meaningful to introduce this scheme with high accuracy if we aim for high resolution in the future.Ultimately, we intend to calculate PMGCM with high resolution (both vertical and horizontal), verify the validity of the PMGCM introducing the cumulus convection model, and consider the influence on the running water topography.

In order to do the trade-off between those two schemes, we evaluated the differences of heat balance and precipitation created by both schemes. First, we did the test under the present terrestrial condition (1bar, N_2/ O_2atmosphere, present solar flux at 1 AU). We supposed that both schemes would show the similar results in radiation balance and precipitation on the present terrestrial models. However, in the actual calculation results, the cloud structure had wider range of clouds in the low altitude with the Kain-Fritch scheme. That is because the characteristics of detrainment for each scheme are different. As the next step, we are changing parameters such as surface pressures (wet CO_2atmosphere of 0.5-2.0 bars), atmospheric compositions, solar flux, and terrain for early Mars as our PMGCM conditions. And we analyze the cloud structure generated by Kain-Fritsch scheme and qualitatively and quantitatively compare the change of water vapor transport with the case without cumulus convection scheme. In this paper, we plan to provide a first summary of those results.

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