Simulation of the early Martian climate with denser CO_2 atmosphere using a general circulation model

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The traces due to obvious liquid flow, which are thought to be made ~3.8 billion years ago, have been found on the Martian surface. They are believed to be made by the flow of liquid H_2O, and the environment of the ancient Mars is thought to be warmer and wetter than today. Several modeling studies have been performed for the investigation of the possible warming processes, but a study using a Martian general circulation model (MGCM) assuming the pure CO_2 atmosphere and the solar radiation corresponding to the time (~75% of today) [Forget et al., 2013] could not reproduce the surface temperature of higher than he melting point of H_2O, ~250 K in maximum, with the surface pressure of between 0.1 and 7 bars.

We are starting to reproduce the ancient Martian environment, in which the liquid flow existed on surface, using the DRAMATIC MGCM [e.g., Kuroda et al., 2005]. As a first step, we simulated the possible climate on early Mars with the pure CO_2 atmosphere and the global average of surface pressure of between 0.1 and 5.1 bars. In our simulations, the intensity of solar radiation is set to be 75% as large as today, assuming the ancient (~3.8 billion years ago) Mars, as well as Forget et al. [2013]. The same obliquity and eccentricity as today and very weak radiative effects of dust (opacity of 0.01) are adopted. Note that our model does not consider the infrared radiative effects of CO_2 ice clouds as implemented in Forget et al. [2013].

In the results of the simulations with the mean surface pressure of lower than 1 bar, the global mean skin temperature is almost constant to be ~192K, which corresponds to the radiative equilibrium temperature. It means that CO_2 infrared radiation in the 15 micro meter band does not work well under such a low temperature. In the simulations with the surface pressure of above 1 bar, global mean skin temperature increases with pressure, along with the CO_2 sublimation temperature. The regions with the surface temperature of near the CO_2 sublimation point (200-210K) spread globally, and it is considered that the emission of latent heat in the condensation processes stabilizes the temperature. However, our simulations show lower mean surface temperature than Forget et al. [2013], maximum for ~30 K with the mean surface pressure of 2-3 bars. The distance of temperature between the models becomes smaller with higher surface pressure, and become almost zero with 5 bars. One of the possible reasons is the radiative cooling of CO_2 ice clouds. In our simulation, column density of CO_2 ice clouds increases with the mean surface pressure of up to ~3 bars, so the absorption of long-wave radiation by the CO_2 ice clouds would possibly be critical. The other is the setting of albedo in the models. Between Forget et al. [2013] and our GCM the albedo of CO_2 ice sheet is different (0.5 and 0.65 correspondingly), which results in the lower surface temperature in our model with the mean surface pressure of 2-3 bars in which the area of CO_2 ice cloud spreads.

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