Simulation of the early Martian climate using a general circulation model, DRAMATIC MGCM: Impacts of thermal inertia

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There are many fluid traces on the Martian surface supposed to be made before ~3.8 billion years ago. If they were made by the liquid H_2O, the environment of the ancient Mars should be suitable for huge amount of liquid water, at least under higher temperature and larger atmospheric pressure than today. In order to reproduce such early Martian climate, several modeling studies have been performed so far. The solar insolation at that time is thought to be ~75% of today from a standard stellar evolution model. In this condition, a preceding study using the LMD Martian General Circulation Model (MGCM), with vertical 15 layers up to ~50 km altitude assuming the pure CO_2 atmosphere, showed that the surface temperature above 273 K could not be reproduced in the range of the surface pressure in 0.1 - 7 bars [Forget et al., 2013, hereafter F13], which is so-called the 'Early faint Sun paradox'.
In F13 the discussion of the effects of thermal inertia on the surface temperature was simplified, just describing the differences of results between the soil (surface albedo of ~0.22 in average and thermal inertia of 250 J $s^{-1/2}$ m^{-2} K^{-1}, hereafter the unit is omitted) and ice (surface albedo of 0.4 and thermal inertia of 1,000) surfaces. If ancient Martian surface was covered with wet and ice-free soil, the thermal inertia should become much larger than that of today, with the surface albedo of lower than 0.4 (the ground covered by ice). In this case, the results of surface temperature should be different from those which have been shown in F13.
From this point of view, we performed the simulations of the ancient Martian environment, especially focusing on the sensitivity of thermal inertia, using our improved MGCM, DRAMATIC (Dynamic, RAdiation, MAterial Transport and their mutual InteraCtions) [e.g., Kuroda et al., 2005]. We assumed the pure CO_2 atmosphere as F13. We have implemented the radiative effects of CO_2 gas assuming the sub-Lorentzian profile [Fukabori et al., 1986] and considering also the collision induced absorptions [Gruszka and Borysow, 1997]. For the comparison with F13’s results, the obliquity, eccentricity, surface albedo and thermal inertia are set to be the same as their standard simulation. Also the vertical coordinate of the model is set to 15 layers to ~50 km altitude, as well as F13, and horizontal resolution is set to 64x32 (5.625deg latitude by 5.625deg longitude). The radiative effects of CO_2 ice clouds are also considered in solar and infrared wavelengths as well as F13, although the radiative effects of dust are not considered.
At first, in order to check the validity of our model, we simulated with globally constant thermal inertia of 250 (soil) for the globally averaged surface pressure of 0.1 –3 bars (realistic pressure range of early Mars). The results showed that annual mean surface temperature in the equilibrium state increased with surface pressure, but the annual mean temperature was ~225 K for 2 bars and ~237 K for 3 bars, far below the H_2O melting point. The infrared optical depth of CO_2 ice clouds reached the highest value of τ ~1.4 for the surface pressure of 1.5 bars, probably because of the profiles of CO_2 condensation temperature and simulated annual-mean temperature against surface pressure which indicated the most favorable production of CO_2 ice clouds at ~1.5 bars. The radiative effects of CO_2 ice clouds affect to increase the global mean temperature for several Kelvins in maximum, while ~10 K in F13.
Next, we simulated with globally constant thermal inertia of between 1,000 (ice) and 5,000 (wet soil assumption) for the surface pressure of 2 and 3 bars. The results showed that annual mean surface

temperature in the equilibrium state greatly increased with increased thermal inertia. Daily mean surface temperatures in northern low- and mid-latitudes and Hellas basin, where are in low altitude and considered to be the places of ancient ocean/lake, are above 273 K almost throughout the Martian year for 3 bars and thermal inertia of 5,000.
Our results suggest that the surface conditions could be the key of the existence of liquid water in early Mars. The surface with high thermal inertia may be able to produce the surface temperature higher enough to keep liquid water even with the pure CO_2 atmosphere under the solar insolation which was ~75% of today.

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