Simulation of the ancient Martian climate with denser pure CO2 atmosphere using a general circulation model, DRAMATIC MGCM

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The fluid traces on the Martian surface are thought to be made before ˜3 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, under higher temperature of larger atmospheric pressure than today. Several modeling studies have been performed to investigate this possibility. The solar insolation at that time is thought to be ˜75% of today from a standard stellar evolution model. In this condition, the study by a Martian General Circulation Model (MGCM) assuming the pure CO_2 atmosphere could not reproduce the surface temperature higher than 273K with surface pressure in 0.1-7bars [Forget et al., 2013, hereafter F13), which is so-called the 'Early faint Sun paradox'. On the other hand, according to the study of Graedel et al. [1991], early solar mass was possibly heavier, and, then, the luminosity was possibly higher than expected (100˜150% of the present value). It may work to make the temperature of the early Martian environment above the H_2O melting point. From this viewpoint, we are starting to reproduce dependence of the ancient Martian environment on the solar luminosity between 75% and 150% of the present value using our MGCM, DRAMATIC [e.g., Kuroda et al., 2005]. It can also provide the threshold conditions between 'frozen' and 'liquid' conditions of Martian-like planets with pure CO_2 atmospheres.

At first, in order to check the validity of our model, we simulated the possible climate on early Mars with 75% of today's solar luminosity under the pure CO_2 atmosphere with globally-averaged surface pressure of 0.1-2bars(realistic pressure range of early Mars). The obliquity, eccentricity, surface albedo and thermal inertia are set to be the same as F13 for the comparison with this result. Our model has the vertical 49 layers with the model top of ˜90 km height (2-3 km of layer thickness in most altitude range), while F13 has 15 vertical layers and the model top of ˜50 km height (detailed layer thicknesses are not shown in F13). This difference enables our model to emulate CO_2 ice clouds up to the upper level where thick CO_2 ice clouds (30˜40km thickness) are formed globally. The radiative effects of CO_2 ice on the surface are also considered in solar and infrared wavelengths, although the radiative effects of dust are not considered.

In the results of our simulations, the global mean surface temperature increased with pressure. The thickness and distribution of CO_2 ice clouds was sensitive to the definition of super-saturation, and optical thickness of CO_2 ice clouds becomes globally ˜30% thicker in the no super-saturation case than in the 35% super-saturation case, but much thinner than that of F13, and the distribution of CO_2 ice clouds does not change very much in both cases. The radiative effects of CO_2 ice clouds affect to increase the global-mean temperature for several K in maximum, while ˜10 K in F13, due to the difference of the layer thickness in the models. In low and mid-latitudes where many fluid tracers are left, the temperature changes seasonally between 220 and 250 K at surface pressure above 0.5bar. Our result is consistent with F13 that the ancient climate could not keep the temperature above 273K with the solar luminosity of 75% of today.

Next, we started to simulate the solar luminosity above 100% of the present value with the surface pressure between 0.5 to 2 bars. In the case of surface pressure with 0.5 bars, annual mean surface temperatures greatly increase with solar luminosity and overcome 273K with the solar luminosity of between 125% and 150% (54% - 64% of the Earth's solar intensity). Moreover, high temperature area is distributed in mid-low latitudes, where valley networks are mostly discovered. Hereafter, we are starting to investigate in the cases of surface pressure of 1.0 bar and 2.0bar and detailed threshold of solar intensity of overcoming the H_2O melting point.