Warming of early Mars induced by CO_2 ice clouds: Estimations of cloud condensation flux, column density and radius by a one-dimensional radiation model

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Geomorphological evidence suggests that the early (3.8 Gyr ago) Martian climate was warm enough for liquid water to exist stably on the surface [1], but the mechanism of climate warming has not been fully clarified yet. Because of the photochemical stability, CO_2 may be the main constituent of the past atmosphere. Even if Mars had a thick CO_2 atmosphere, however, the high temperature of upper troposphere due to the latent heat of CO_2 condensation would weakened the greenhouse effect under the faint young sun. Therefore the warm climate cannot be sustained by CO_2-H_2O atmosphere when the radiation processes of clouds are neglected [2].

Recently, the scattering greenhouse effect of CO_2 ice clouds has been proposed to explain this climate [3]. If the backward scattering of the planetary radiation is larger than that of solar radiation by the clouds, we can expect climate warming. The previous studies have shown that the level of greenhouse effect strongly depends on not only the atmospheric pressure but also cloud parameters (cloud particle radius and column density). Climate becomes warm when these parameters take appropriate values [3,4,5]. However, mechanisms determining such values have not been examined. So, we calculate radiative transfer of cloud layer to estimate the feasible values of cloud parameters from condensation flux and examine the atmospheric pressure condition appropriate for climate warming.

Our calculations suggest that the cloud parameters take values appropriate for enough causing the greenhouse effect when the column number density of cloud particle nearly equals to that of the present atmospheric dust on Mars, and the atmospheric pressure more than about 1 bar is minimum requisite to induce warm and wet climate.

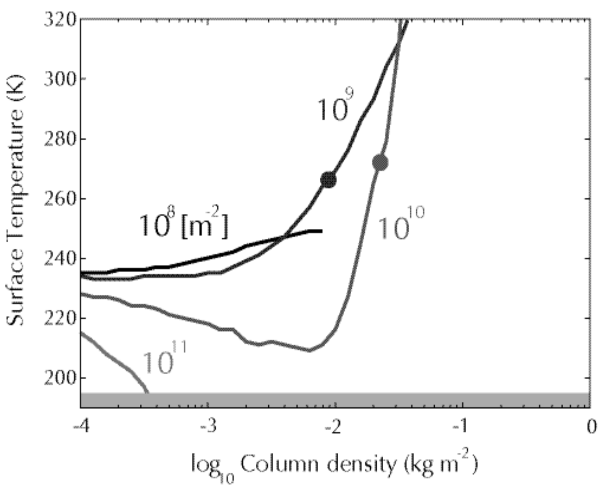

Fig.1: The surface temperature under radiative balance as a function of cloud column density and column number density of cloud particle (displayed with the curves) when the surface pressure is fixed at 1 bar. At the grey region, the surface temperature is lower than the CO_2 condensation temperature. At the conditions represented by circles, the condensation-evaporation equilibrium is achieved. This figure shows that the surface temperature rises to nearly freezing point of water when column number density of cloud particle is from 10^9 m^{-2} to 10^{10} m^{-2} which nearly equals that of the atmospheric dust on the present Mars.

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