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Vertical structure of CO2 cloud layer in a thick atmosphere on early Mars

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Geomorphological evidence suggests that Martian climate was warm enough to support flowing water on the surface about 3.8 Gyr ago. Because of the photochemical stability, CO2 was likely the major component of the past atmosphere as well on the present Mars. However, it remains an open question whether or not a thick CO2 atmosphere caused sufficient greenhouse effect under a faint young sun. Indeed, 1D radiative-convective model shows that increase in temperature at upper troposphere due to CO2 condensation would significantly weaken the greenhouse effect when cloud optical effects are neglected (Kasting 1991).

Recently, the scattering greenhouse effect of CO2 ice clouds is accepted as a candidate for warming mechanism (Pierrehumbert and Erlick 1998). Radiative properties of cloud layer are characterized by two parameters, cloud particle size and column density. The maximal greenhouse warming can occur when the particle size is between 10 to 20 micron which backscatters IR radiation effectively (Pierrehumbert and Erlick 1998). In addition, the column density of 10ˆ-1 kg/mˆ2 causes the maximal cloud radiative forcing while a denser cloud layer suppresses the greenhouse effect owing to the increase in the reflection of solar radiation (Yokohata et al. 2002).

The equilibrium temperature profiles of thick CO2 atmospheres have been investigated using 1D radiative-convective model including cloud optical effects (Forget and Pierrehumbert 1997; Mischna et al. 2000). For example, the surface temperature rises up to 280 K when the cloud optical depth of 10 is given (with atmospheric pressure of 2 bar, mean radius of cloud particles of 10 micron). It has also shown that the surface temperature falls associated with decrease in the tropospheric lapse rate under a thicker cloud layer. This is because the surface does not receive sufficient solar radiation owing to thick clouds.

However, the all those studies had not clarified the conditions for formation and sustenance of cloud layer. For example, Mischna et al. (2000) assumed that clouds exist even when atmospheric temperature is much higher than CO2 condensation temperature.

In this study, we investigate the growth and maintaining processes of clouds to examine whether or not a cloud layer favorable for greenhouse effect can be formed and kept in a thick CO2 atmosphere on ancient Mars. The cloud particle size and optical depth may change through the processes as follows; 1) coalescence by particle collision, 2) removal from cloud layer due to particle settling and 3) condensation (evaporation) by radiative cooling (heating). The estimated timescale of each process based on numerical calculations shows that the radiative process dominantly controls cloud conditions. This is because 1) the average time of particle collision is long (nearby 100 hours, when condensation nuclei mixing ratio is taken to terrestrial continental ones), 2) for micron-sized particle, the settling velocity is very small (nearby 1 cm/s) and 3) condensation of evaporation of cloud particles proceeds very quickly (nearby 100 seconds) because condensable species CO2 is the major component of the atmosphere.

Based on the above-mentioned consideration, stable clouds should satisfy at least two following conditions simultaneously; 1) the cloud temperature is equal to condensation temperature and 2) the radiative equilibrium is satisfied at a cloud layer. Because cloud optical properties depend on particle size and optical depth, such conditions give a relationship between these parameters. For single cloud layer case, a cloud layer with particle size of 7 micron and optical depth of about 1 are formed with equilibrium surface temperature 270K when the atmospheric pressure and column number density of condensation nuclei are kept at 1 bar and 10ˆ10 mˆ-2, respectively. We will discuss multiple cloud layers case in this presentation.