Stability of CO2 ice clouds in early Martian atmosphere

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The geomorphological evidences suggest that early Mars had warm and wet climate and liquid water could stably exist on the surface. However, there is difficulty in explaining such warm climate by greenhouse effect of dense CO2 atmosphere because the solar luminosity was smaller than today (Kasting, 1991).

Recently, however, the scattering greenhouse effect of CO2 ice clouds is proposed as a candidate mechanism creating early warm climate (Pierrehumbert and Erlick, 1998). This is owing to that the backward scattering of the planetary radiation is larger than that of solar radiation by ice clouds. However, ice clouds may evaporate by heating of the solar and planetary radiation, so the stability of CO2 ice clouds is not confirmed. Yokohata et al (2003) investigated the conditions under which ice clouds can exist stably, and shown that ice clouds may exist stably by self-cooling when it has certain cloud parameters. However, their atmosphere-cloud model is too simple to treat the influence of the infrared radiation from the ground and lower atmosphere. So, this study evaluates the radiative transfer processes in ground-atmosphere system and reexamines the stability of CO2 ice clouds.

We use a one-dimensional radiation model and assume pure CO2 atmosphere. The vertical temperature distribution is given by dry CO2 adiabatic lapse rate, and the cloud layer is defined as the region where the temperature is lower than the condensation temperature. We consider the cases with the surface temperature 273 K (melting point of H2O) and 293 K and the surface pressures between 1 and 3 atm. The value of solar luminosity is 0.75 times of today. Emission and absorption of CO2 radiation are described by the band model and band parameters are taken from Houghton (2002) with the spectrum interval of 5 cm^-1. We divide lower atmosphere into 10 layers, and calculate the infrared radiation spectrum incident into clouds layer. Cloud particle radius is taken 1.0x10^-5 m and surface density 3.2 x 10^-3 kg/m^2, they are the representative parameters causing large scattering greenhouse effect. If the absorptions of planetary and solar radiations are smaller than the infrared emission of ice clouds, CO2 will condense and the cloud layer can exist stably.

The value of solar radiation has seasonal variation about 20% from the mean value because the orbit of Mars is elliptic. It also has lalitudinal variation. So, we consider these variations and calculated for the cases of global and seasonal mean value and different values. First, in the case of the mean solar radiation, the ice clouds can exist stably independent on the surface pressure and temperature. Even when the seasonal variation is taken into account, the same results are obtained. However, the cloud layer around the subsolar point is calculated to be unstable under low atmospheric pressures smaller than 2.2 atm. When the averaged solar radiation is given, the absorption of solar radiation is 1/10 times as much as that of planetary radiation, so the contribution of solar radiation is small for cloud layer heating. Solar radiation becomes important, however, in the region around the subsolar point.

In our calculations, the ice cloud layer can exist stably when pressure is larger than 2.2 atm. However the stability depends on the intensity of solar radiation and the surface temperature when the pressure is smaller than 2.2 atm. The cloud temperature increases with the surface pressure. This increases the thermal emission from cloud layer as well as the absorption of infrared radiation from the lower atmosphere. However, the increase rate of infrared absorption is smaller than that of cloud emission, so the cooling of cloud layer is strengthened as the atmospheric pressure increases. This result suggests that large atmospheric pressure may be required for the scattering greenhouse effect to effectively operate in early Mars.