Warming of early Mars induced by CO_2 ice clouds: a negative feedback mechanisms for controling cloud cloumn density

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Geomorphological evidence suggests that Martian climate was warm enough for liquid water to exist stably on the surface about 3.8 Gyr ago (Carr, 1996), but mechanisms of the climate warming have not been fully clarified yet. Because of the photochemical stability, CO_2 may be the main constituent of the past atmosphere as well on the present Mars. Even if Mars had a thick CO_2-H_2O atmosphere, however, the warm climate cannot be sustained when radiation processes of clouds are neglected (Kasting, 1991). Recently, the scattering greenhouse effect of CO_2 ice clouds has been proposed to explain such warm climate (Pierrehumbert and Erlick, 1998). Previous studies have shown that the level of the greenhouse effect strongly depends on cloud parameters (cloud particle size and column density) and the warm climate is possibly achieved when these parameters take appropriate values (Pierrehumbert and Erlick, 1998; Mischna et al. 2000; Yokohata et al. 2002). However, mechanisms determining such values have not been examined. So, we calculate radiative transfer to estimate the possible values of the cloud parameters under condensation-evaporation equilibrium and examine the atmospheric pressure condition appropriate for the climate warming.

We use a one-dimensional, radiative-convective model for the CO_2-H_2O atmosphere. We assume is vertical temperature profile as follows; the stratospheric temperature is given by radiative equilibrium as a thin grey atmosphere. The tropospheric temperature lapse rate is H_2O moist adiabat. The cloud exists in a layer with temperature below the CO_2 condensation temperature and the temperature lapse rate of this layer follows the CO_2 moist adiabat (i.e. the CO_2 saturation vapor pressure curve). The solar luminosity is taken to be 75 % of the present values (Gough, 1981) and the surface albedo to be 0.216 according to observations (Kieffer et al, 1977). For the non-scattering layers (the stratosphere and the troposphere under the cloud layer), we calculate radiative transfer by using the two-stream approximation. The absorption coefficients of gas are calculated by the line-by-line integration the absorption line parameters with HITRAN2000. For the cloud layer where scattering occurs, we calculate the radiative transfer adopting the delta-eddington approximation. The optical coefficients of the cloud particles are derived from the refractive complex indices of CO_2 ice (Warren, 1986) by Mie theory. The absorption coefficients of gas in this layer are calculated by the random model with band parameters given by Houghton (2002). We calculate net cooling rate of cloud layer by the radiation processes and convent it to the condensation rate of CO_2.

Disturbance of the column density is suppressed around a certain density if the cloud particle size is given 7.5 - 20 microns. The condensation rate decreases as the surface temperature and column density increase. If the particle size is kept, the surface temperature increases under the radiative equilibrium as the column density increases. The condensation rate becomes negative i.e. evaporation of cloud occurs when the column density increases too much. Since the positive condensation increases the column density whereas evaporation decreases it, column density may approaches to a equilibrium value under which condensation rate becomes zero and the condensation-evaporation equilibrium is archived. Under this equilibrium the cloud column density and particle size have a relationship. Note that they are treated independent parameters in these previous studies. Surface temperature about 270 K is obtained under these equilibriums when the atmospheric pressure is given to be at 1 bar and cloud particle size 7.5 - 20 microns. The surface temperature under the equilibriums increases as the atmospheric pressure increases. So, our calculations suggest that the atmospheric pressure more than about 1 bar is a minimum requisite to induce the warm and wet climate.