Formation of Initial CO2 Ice Cap on Mars

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On Mars, the polar ice cap is a huge volatile reservoir, which has played an important roll in controlling the surface environment. The present Martian ice cap is surrounded by the polar layered deposits, suggesting that the cap extent and mass would have changed through the Martian history.

Yokohata et al. (2002) showed that the huge ice caps would be formed on past Mars on the bases of the stability analysis of the atmosphere-cap system using a 2-dimensional (latitudinal-vertical) energy balance climate model. High atmospheric pressure presumed for past Mars is destabilized and the atmospheric CO2 condenses rapidly into the ice caps as the atmospheric pressure is lowered than a critical level (collapse condensation). As a result, CO2 ice caps with mass equivalent to the critical pressure are formed (we call the initial CO2 ice caps hereafter).

It is important to know the mass and shape of initial CO2 ice caps. This is because the global CO2 circulation through the mass exchange process between the atmosphere, regolith and ice cap is dependent on those physical parameters. However, Yokohata et al. 2002 do not find the shape of initial CO2 ice cap, and their estimation of the cap mass needs refinement. They gave the extent of CO2 ice cap as a parameter and also neglected the effect of seasonal change of solar radiation for simplicity.

In this study, we investigate the mass and shape (extent and average height) of initial CO2 ice caps by using a climate model taking into account the effect of seasonal variation. Controlling factors of the initial cap formation are studied by the calculations given various boundary conditions. In this model, the seasonally mean solar flux in Yokohata et al. is changed to the daily mean. For each atmospheric pressure given as model parameter, we determine CO2 net evaporation (difference between total CO2 evaporation in the summer cap and condensation in the winter one). The pressure region for the collapse condensation can be defined as the region under which CO2 net evaporation is negative. The mass of initial CO2 ice cap is calculated from the difference between the maximum and minimum pressures of this region. The extent of initial CO2 ice cap is also defined as that of CO2 ice cap under the minimum pressure.

Our results are summarized as follows:

1) Parameter sensitivity

The mass of initial CO2 ice cap is controlled by the energy balance under the high atmospheric pressure, which is sensitive to parameters especially H2O ice coverage and solar luminosity. The mass of the initial ice cap is large for large H2O ice cover and lower solar luminosity. Though the mass of the initial ice cap is about equivalent to 10^4 Pa atmosphere when we give the present solar luminosity, orbital parameters, and surface albedo. It would be as large as 3.5 * 10^5 Pa when the surface is entirely covered with H2O ice and the solar luminosity is 0.75 times the present value. In addition, the effect of the seasonal variation is also large. This is because CO2 ice cap left in the summer hemisphere has a great influence on the energy balance.

On the other hand, the extent of initial CO2 ice cap is only slightly dependent on the parameters such as H2O ice cover and solar luminosity because it is controlled by the energy balance under low atmospheric pressure. The initial cap extends to the latitude about 85 degree when we give the present solar luminosity, orbital parameters, and surface albedo.

2) Behavior of initial CO2 ice cap.

If the collapse condensation occurred on early Mars, the average height of initial CO2 ice cap would be very large. When H2O ice covers the entire surface and the solar luminosity is 0.75 times the present one, the average height of the initial ice cap is calculated to be 2.6 km (900 m for the present one). In this case, the basal pressure and temperature are calculated to exceed the critical pressure of CO2 and 273 K.