Evolution of residual CO2 ice cap and climate changes on Mars

Kaoru Takayama[1], Tokuta Yokohata[1], Masatsugu Odaka[2], # Kiyoshi Kuramoto[2]

[1] Earth and Planetary Sci., Hokkaido Univ, [2] Earth and Planetary Sci., Hokkaido Univ.

http://www.ep.sci.hokudai.ac.jp/~shwlab

Abundant geological evidence including the outflow-channels and polar deposits strongly suggests that Mars has experienced significant climate changes through its history. Partitioning of CO2 among the atmosphere, polar caps and regolith plays an important role in controlling the state of martian climate. Such climate changes would be caused by the variability of CO2 partitioning, which may be triggered by changes of boundary conditions such as the solar flux, obliquity and total CO2 mass on Mars. In the past studies, residual CO2 ice cap has been treated as a reservoir with infinite capacity or constant thickness without considering the formation processes, having inhibited the quantitative treatment of CO2 partitioning. In this study, we construct a new climate model, which can calculate the ice cap topography consistently. We apply this model to the partitioning of CO2 on Mars, and discuss the past climate change and evolution of polar topography.

CO2 is assumed to be partitioned among the atmosphere, ice caps and regolith, which is dependent on the latitudinal surface temperature profile. The temperature profile is calculated as a function of latitude and the atmospheric pressure using a two-dimensional energy balance model [1]. The topography of ice cap is calculated by solving the equation of mass conservation taking into account CO2 condensation, evaporation and ice flow.

First, let us examine the responses of ice cap extent for various atmospheric pressures. The CO2 ice caps extend to lowest latitude when the atmospheric pressure is about to 10^4 Pa (corresponding to the atmospheric mass of 10^17 kg) under the condition of 0.85 times of the present value for the solar radiation and 25.19 degrees for the obliquity. This is because the CO2 condensation temperature increases with pressure and then the condensation of CO2 ice occurs more easily, but further increase in atmospheric pressure decreases ice cap extent since the greenhouse effect and the meridional heat transport warm up the high latitudes. When the atmospheric pressure is higher than 10^5 Pa, ice caps entirely evaporate. When the CO2 ice caps form, their height increases with latitude. The lower the latitude of ice cap extent, the larger the ice cap height at poles.

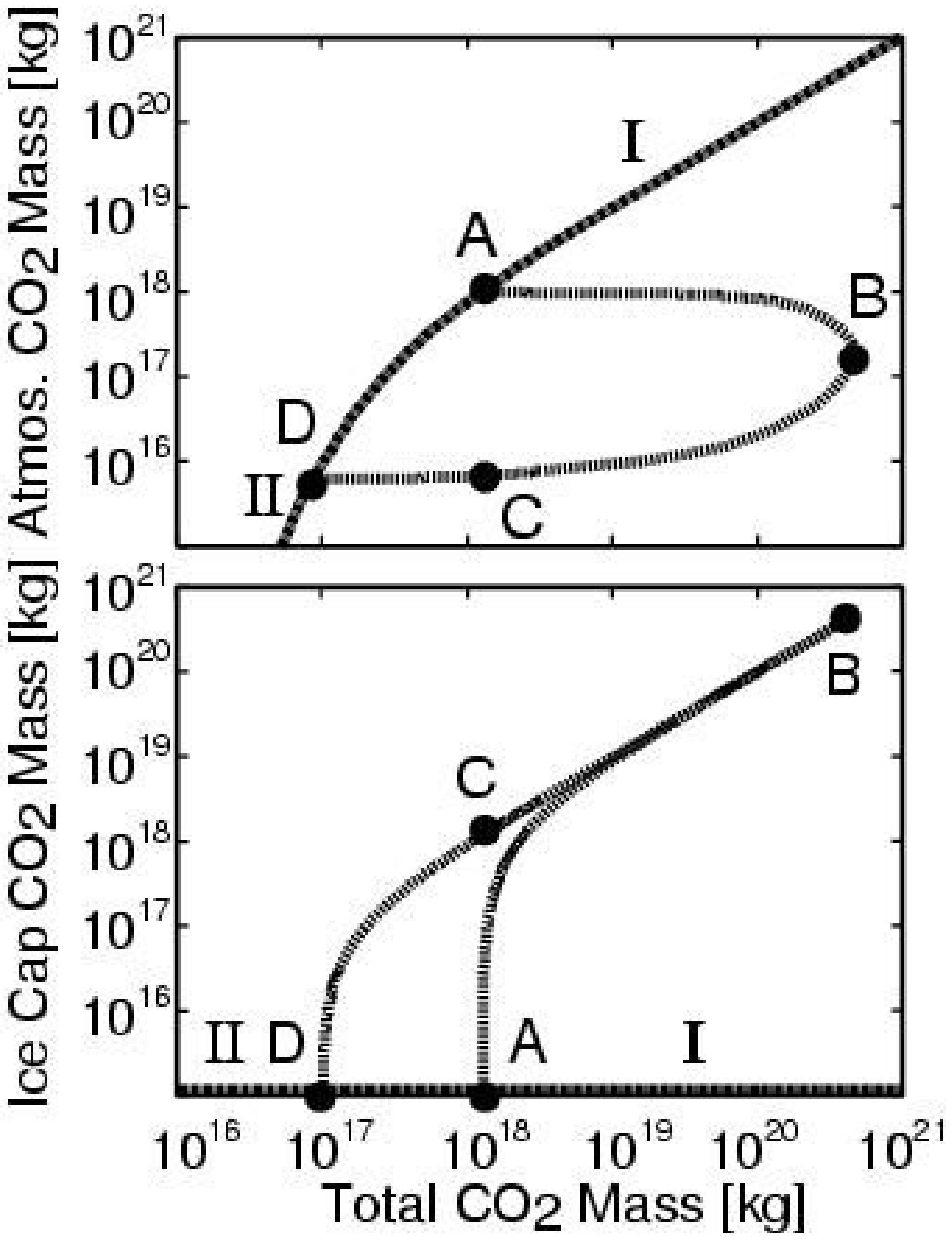
Figure shows the masses of the atmospheric CO2 and ice cap CO2 as a function of total CO2 on Mars under energy balance states. The dotted curves indicate the solutions where ice caps exist. On the other hand, the dash-dotted curves indicate the solutions without ice caps. The regolith CO2 mass is kept within 10^17--10^18 kg when the total CO2 mass is larger than 10^18 kg.

When the total CO2 mass is large enough, most of CO2 is partitioned into the atmosphere. When the total CO2 mass decreases, the atmospheric pressure and surface temperature also decrease along the path I. When the system reaches the point A, the growth of ice caps becomes possible due to the condensation of atmospheric CO2. We call this point the ice cap initiation point. When ice cap begins to form, it grows to the maximum extent C due to the effect of ice albedo feedback and ice flow, and the climate is kept cold with low atmospheric pressure. The seasonal change of solar radiation and albedo effect of H2O ice sheet may also trigger the CO2 ice cap formation.

The mass and topography of initial ice cap, which formed in the past Mars, are estimated by the difference of atmospheric pressure between A and C. In this calculation, the ice cap mass at C is 10^18 kg with the iceline latitude of 80 degrees and polar height of 1.5 km. This extent is similar to that of the observed polar deposits.

Figure: Atmospheric (upper) and ice cap (lower) CO2 masses as a function of total CO2 mass. See main text for details.

References
[1] Yokohata et al. 2002, Icarus 159, 439-448.
[2] Toon et al. 1980. Icarus 44, 552-607.


Atmos. CO_2 Mass [kg]
Ice Cap CO_2 Mass [kg]
Total CO_2 Mass [kg]
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
I
II
A
B
C
D