Formation of the polar caps in the Martian paleo-environment

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Fluvial suraface features suggests that H2O was distributed globally over the Martian surface. At present, however, H2O is observed only at the polar caps. Under what climate condition did H2O gather to the polar caps? We constructed an climate model and investigated the process of polar cap formation.

The result are summarized as follows.

1. The present atmospheric pressure is determined by the balance between the sublimation rate at the summer pole and the condensation rate at the winter pole.

2. When the surface is globally covered by ice sheets, the atmospheric pressure between 10^4 Pa and 10^5 Pa can't existed stably.

3. When the surface is globally covered by ice sheets, the polar caps cannot be formed within 4.6 Gyr in the present atmospheric pressure.

Fluvial surface features strongly suggest that H2O was distributed globally over the Martian surface. At present, however, H2O is observed only at the polar caps. Under what climate conditions did H2O gather to the polar caps? To answer this question, we constructed a climate model and investigated the process of polar cap formation.

Among the studies on Martian climate, widely accepted one is Gierasch and Toon(1973)(G&T). They suggested that the Martian atmospheric pressure is the vapor pressure on the polar cap, because the main atmospheric component(CO2) can condense onto the polar cap. By solving the energy balance equations of the polar region under various atmospheric pressures, they estimated the surface temperature of the polar cap. Assuming the vapor pressure equilibrium between the CO2 polar cap and the atmosphere, G&T deduced the stable atmospheric pressure which agrees with the present one. Their model has been used in many studies until now.

However, the model of G&T involves several problems. One is that they solved the yearly averaged energy balance only at the polar region, and assumed the equatorial temperature to be constant. In fact, the equatorial temperature should be determined by the energy balance. Futhermore, the polar temperature is different between the summer and winter polar regions. Another problem is that they did considered an atmospheric greenhouse effect.

In this study, we modified the G&T model as follows. We solved the seasonally averaged energy balance at the summer and winter poles and the equator. This model includes not only heat advection by the atmospheric motion but also a greenhouse effect by introducing radiative-convective equilibrium structure of gray atmosphere. H2O is transported from the equatorial region to the polar region by advection of atmosphere. Here, we assume that H2O is saturated in the atmosphere. We carried out the calculation for two cases of the surface albedo: one is that only the polar caps are covered by ice sheets, the other is that the surface is covered with ice sheets globally.

The results are summarized as follows.

1. Under the present atmospheric pressure, the surface temperature of the summer pole is higher than CO2 condensation temperature, and that of the winter pole is otherwise. This means that CO2 sublimes at the summer pole, and condenses at the winter pole. That is, the present atmospheric pressure is determined by the balance between the sublimation rate at the summer pole and the condensation rate at the winter pole. This result is very different from the G&T model which proposes that the atmospheric pressure is determined by the vapor pressure equilibrium between the CO2 polar cap and the atmosphere.

2. When the surface is globally covered with ice sheets, the solar flux absorbed by the equatorial region decrease, and therefore the temperature decrease globally. If the atmospheric pressure is between 10^4 Pa and 10^5 Pa, the surface temperature is lower than the CO2 condensation temperature at any regions. That is, CO2 condenses globally. Therefore, the atmospheric pressure in this range cannot exist stably.

3. When the surface is covered with ice sheets globally, the polar caps cannot be formed within 4.6 Gyr under the present atmospheric pressure, because of low cold pressure in the cold atmosphere. If the surface was once covered with ice sheets globally, two scenarios be considered as below, for formation of the present polar capscan.

One is that the surface CO2 was all sublimed once and the atmospheric pressure became more than 10^5 Pa. The other is that globally covered ice sheets removed partially due to sublimation and the surface albedo decreased. In both case, the temperature may rise enough for H2O to gather to the polar caps in a short time scale.