DRASTIC CLIMATE CHANGE OF MARS INDUCED BY H_2O ICE CAPS. T. Nakamura and E. Tajika, Department of Earth and Planetary Science, The University of Tokyo (7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan; kijun@eps.s.u-tokyo.ac.jp, tajika@eps.s.u-tokyo.ac.jp).

Introduction: Behaviors of the Martian climate system have been investigated in several studies [e.g., 1-5]. If the Martian climate was warm and wet owing to the greenhouse effect of CO_2 in the past as suggested by many geomorphological features, a drastic climate change (climate jump or climate collapse) due to decrease in the amount of CO_2 in the atmosphere must have occurred during the evolution from a warm condition to the present cold condition [1, 3]. The climate jump is caused by a runaway condensation of dense CO_2 atmosphere into large CO_2 ice caps. These studies, however, did not consider the effect of H_2O ice. If the Martian climate was warm and wet, the formation of H_2O ice should have preceded CO_2 condensation (that is, the climate jump) because the freezing point of H_2O is much higher than that of CO_2. Because the ground covered with H_2O ice has higher albedo than the bare ground, the formation of H_2O ice might have affected the climatic evolution of Mars. Yokohata et al., (2002) examine the effect of H_2O ice on the Martian climate. They assume the latitudinal extent of H_2O ice (iceline) as a free parameter. Actually, however, the latitude of iceline should be determined according to the climatic condition. In this study, we estimate the extent of H_2O ice by using an energy balance climate model and investigate the relation between the H_2O ice formation and the CO_2 condensation. We examine the possibility that the appearance of H_2O ice cap itself triggers the runaway condensation of CO_2.

Model: We adopt a time-dependent latitudinally-one-dimensional energy balance climate model for Mars based on the model developed by [5]. We treat the energy balance of the ground and the atmosphere separately. The model considers the latitudinal temperature distribution and the meridional heat transport. We also consider seasonal changes of the amount of CO_2 ice and the latent heat owing to sublimation and condensation of CO_2. The atmospheric pressure should change owing to changes in the amount of the CO_2 ice. We can obtain a stable periodic solution as a steady state by solving the energy balance and the CO_2 exchange among the atmosphere, the CO_2 ice.

We estimate the latitude of H_2O-iceline by using the same method as the case for the terrestrial climate system; it is empirically determined by assuming the annual mean surface temperature at the iceline to be 263 K. [e.g., 7]. We assume the albedo of the ground covered with H_2O ice to be the same as that of CO_2 ice cap, which is higher than that of bare ground.

Results: Figure 1 shows a typical result of the energy balance model for the Earth. The latitude of H_2O-iceline is shown as a function of the partial pressure of CO_2 in the atmosphere under the present solar flux. There are three branches of solution; H_2O-ice-free branch, H_2O-partial-ice branch, and H_2O-ice-covered branch. In the H_2O-partial-ice branch, the portion with a positive slope (solid line in the figure) represents stable solutions, and the portion with a negative slope (dotted lines) corresponds to unstable solutions [7]. The climatic jump would occur from one stable branch to another owing to the ice-albedo feedback. Arrows in Figure 1 indicate hystereses of the climatic state.

The results for the Martian case are shown in Figure 2. The horizontal axis represents the atmospheric CO_2 pressure, and the vertical represents the latitude of H_2O iceline (the areal extent of H_2O ice caps). The 70% value of today's solar luminosity and the present-day obliquity are assumed in this result.

As the result for the Earth, there are three branches of steady state solution: H_2O-ice-free branch, H_2O-partial-ice branch, and H_2O-ice-covered branch. However, it appears that all the H_2O-partial-ice branch has a negative slope, and is hence unstable. This would be due to the strong ice-albedo feedback mechanism which is caused by the strong meridional heat transport under the high atmospheric pressure. The ice-albedo feedback is a positive feedback mechanism which makes the climatic state unstable. Also in the terrestrial case, the stable H_2O-partial-ice solution cannot be obtained from the energy balance model when the larger meridional heat transport than present is assumed. As a result, the stable solutions are limited either to the H_2O-ice-free branch or the H_2O-ice-covered branch. A climate jump would occur from the H_2O-ice-free to the H_2O-ice-covered branch via a runaway growth of H_2O ice caps when the atmospheric pressure decreases to the end of the H_2O-ice-free branch (indicated by an arrow in Figure 2). It should be noted that this climate jump results in the discontinuous change of H_2O-ice extent caused by the ice-albedo feedback, but is qualitatively different from the climate jump with the runaway CO_2 condensation/sublimation.

When we assume the initial state of Mars to be the H_2O-ice-free state (very warm condition), both the H_2O ice caps and the CO_2 ice caps do not exist as long as the atmospheric pressure is more than ~3.9 bars under the 70% solar luminosity. If the atmospheric pressure decreases to 3.9 bars, the H_2O ice caps begin to form and extend drastically to the equator caused by the strong ice-albedo feedback. When the atmospheric pressure is lower than 3.9 bars, only the H_2O-ice-covered branch exists, and the surface of Mars is covered globally with H_2O ice. According to Figure 3, the runaway condensation of CO_2 would occur at the atmospheric pressure of 4.2 bars when the surface is entirely covered by H_2O ice. Therefore, the climate jump to the H_2O-ice-covered branch should trigger the runaway CO_2 condensation.

The results above may be valid only when the ancient Mars had a very similar surface condition to the present-day Earth. For example, if Mars was a wet land-planet, the H_2O ice would not formed until the atmospheric CO_2 pressure decreased further [8]. However, the result that the global H_2O ice can trigger the runaway CO_2 condensation would not change because it is easier for CO_2 to condense under weaker greenhouse effect. However, if Mars was warm but dry, the H_2O ice would have been formed but restricted within rather small area due to the lack of water. In such a case, the H2O-ice formation would not have triggered the runaway condensation of CO_2 and further decrease in the atmospheric pressure would have been required for it (Figure 3). In any case, the runaway condensation of CO_2 could have been triggered or promoted by H_2O-ice cover formed before the condensation of CO_2.

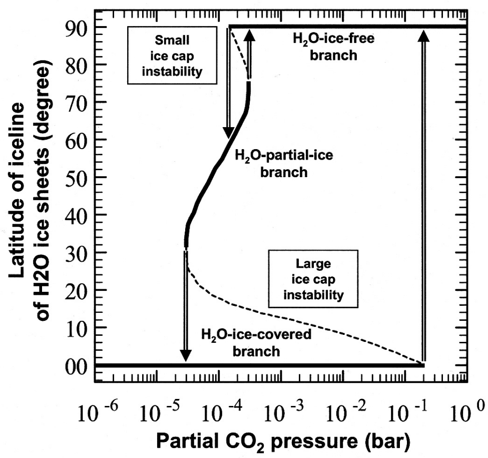

Figure 1: Result of the North-type energy balance model for the Earth.

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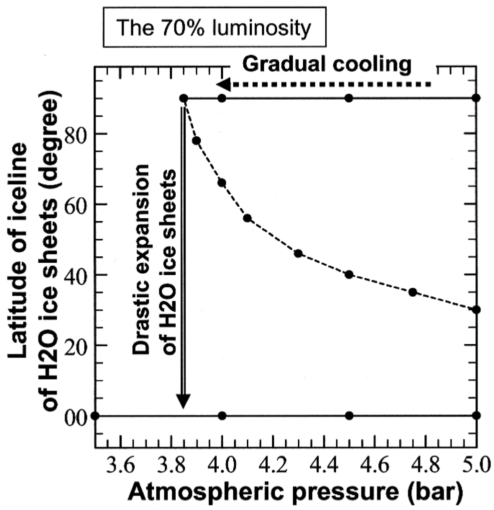

Figure 2: The extent of H_2O ice caps as a function of atmospheric CO_2 pressure for the past Mars.

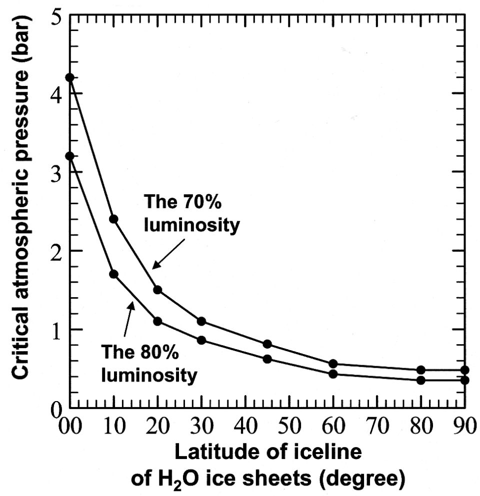

Figure 3: Critical atmospheric pressure for the runaway condensation of CO_2 under the present obliquity. The runaway condensation occurs when the atmospheric pressure falls below the critical pressure.