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On the one dimensional energy balance model of Mars atmosphere - ice cap system

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In this study, one dimensional energy balance model is newly constructed to clarify the properties of the Martian climate system. This model takes into account the CO2 condensation on the CO2 ice caps. We investigate the responce of the Martian climate system, particularly the temperature distribution, CO2 condensation flux onto the CO2 ice caps, and the cap size, to the variation of the solar constant, obliquity and atmospheric pressure given as boundary conditions and the coefficient of horizontal heat flow given as a model parameter.

It is not able to simply adopt energy balance model used to study the earth climate to Mars. On Mars, the main constituent of atmosphere, CO2, condenses or evaporates on the ice caps. Therefore the surface temperature is fixed to the CO2 condensation temperature, which is a function of the atmospheric pressure, all over the CO2 ice caps. In this case, the latitudinal temperature gradient becomes discontinuous at the boundaries of the ice caps, which makes impossible the exact integration of the partial differential equation describing the latitudinal heat flow. Physically, the thermal energy transported from lower latitudes concentrates at the boundaries of the ice caps. No previous study has considered the above problem carefully. The calculations by Nakamura and Tajika (2001), for example, include physical contradictions.

This study provides a solution to the above problem by introducing a correction flux which distributes all the thermal energy flowing into the cap boundaries over the ice caps uniformly. The ice cap area is determined as the area where planetary infrared flux is larger than the sum of the solar flux and the correction flux. The excess of cooling is compensated by the release of latent heat for CO2 condensation. From this we can determine the rate of CO2 condensation and the growth of ice caps.

Results obtained by this study are summerized as follows.

1. The response of the ice line latitude to the change of the atmospheric pressure

1) The case without horizontal heat flow

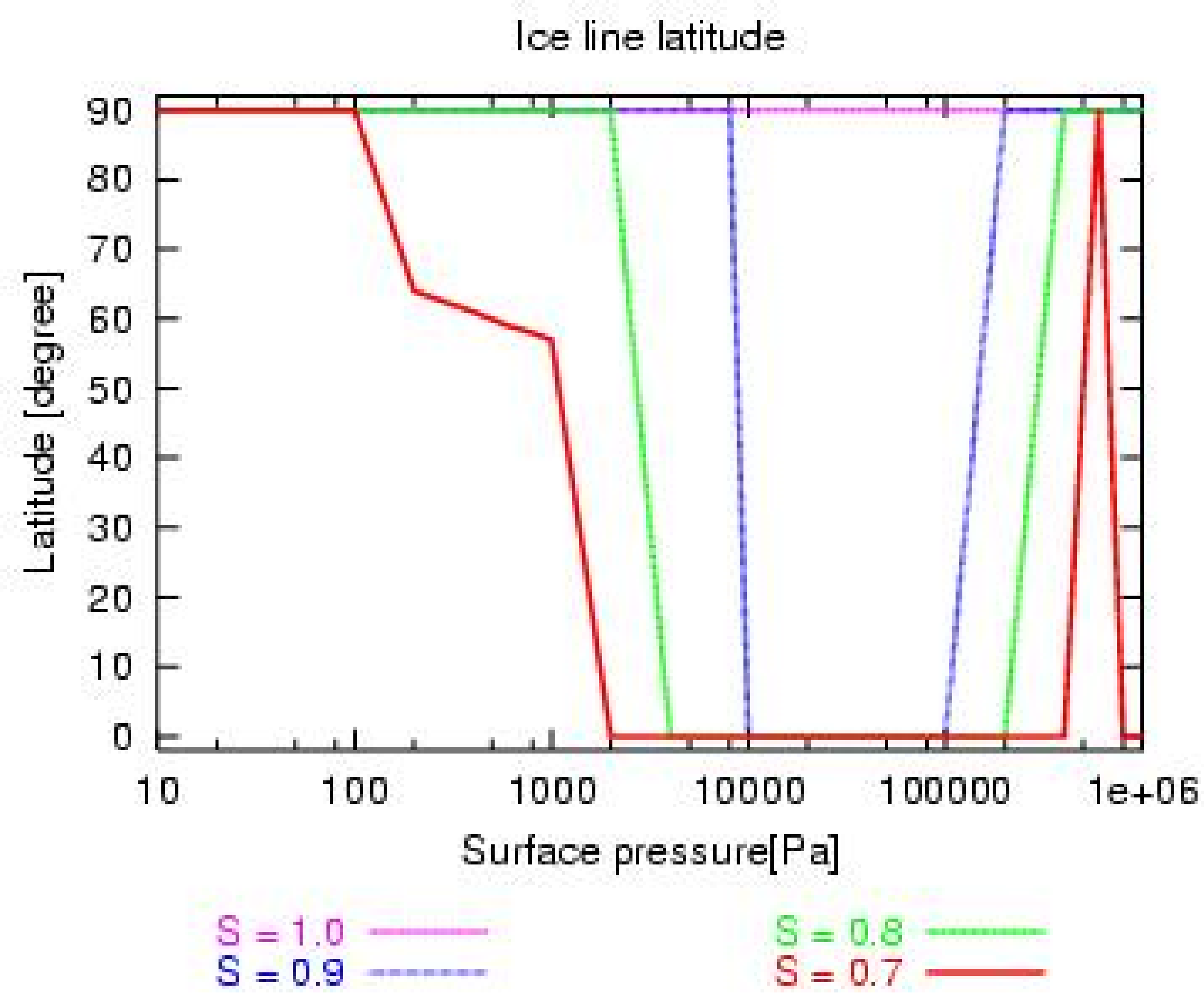
When the solar constant and obliquity are present values, ice cap is formed under the atmospheric pressure higher than 100 Pa. The ice cap extends to lower latitude as the atmospheric pressure increases from 100 Pa because the condensation temperature increases. The area of ice cap is maximum under 30000 Pa of the atmospheric pressure. As the atmospheric pressure increases higher than 30000 Pa, the area of ice cap decreases. It is caused by the increase of surface temperature associated with greenhouse effect.

2) The case with horizontal heat flow

In this case, the coefficient of the horizontal heat flow is proportional to the atmospheric pressure. There is no ice cap under any atmospheric pressure at the present solar constant and obliquity. This is because that the heating of polar region increases by the horizontal heat flow. When the solar constant is 0.7 times that of present value, the model climate has three solutions: partial ice covered, global ice covered and ice free solution(figure). The ice cap is formed under the atmospheric pressure higher than 100 Pa. The ice cap extends to lower latitude as the atmospheric pressure increases from 100 Pa and it reaches the equator at 2000 Pa. At 200000 Pa, the model climate state jumps from global ice covered solution to ice free solution. The ice free solution is caused by that even if the horizontal temperature gradient is small, the amount of horizontal heat flow can be large under high atmospheric pressure and then the surface temperature become horizontally uniform. The horizontally uniform surface temperature is observed when the obliquity.

2. The accumulation rate of CO2 on the ice cap

The order of magnitude of accumulation rate of CO2 on the ice cap is 1 cm/day. The formation time of present Martian permanent ice cap estimated by using the accumulation rate is 1000 years.


Ice line latitude
Latitude [degree]
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
100000
1e+06
Surface pressure[Pa]
S = 1.0
S = 0.9
S = 0.8
S = 0.7