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The effects of obliquity and carbonate-silicate geochemical cycle on the climate of water-rich extraterrestrial planets

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Water-rich terrestrial planets like the Earth are expected to be found in the extrasolar planetary systems in the near future. To discuss habitability of such planets, we have to investigate characteristic features of climate system of the water-rich terrestrial planets.

One of the key factors which controls climate is 'obliquity', that is, the inclination of planet's axis. The climate of the Earth is stable partly because the Earth's obliquity is stabilized by the existence of the Moon, although it is not the case, in general, for other planets. Considering a large influence of obliquity on the solar energy distribution on the planetary surface, obliquity variations could induce large climate change on the planets.

The climate of extraterrestrial planets with high obliquities was tested by Williams and Kasting (1997). But there are few studies which investigate systematically the effects of obliquity change as well as conditional changes of carbonate-silicate geochemical cycle which could stabilize the climate of the planets.

In this study, we systematically investigate the climate of the water-rich terrestrial planets under various obliquities and solar flux conditions, and with negative feedback mechanism of carbonate-silicate geochemical cycle. We use a one-dimensional energy balance climate model (1D-EBM) with a simple model of carbonate-silicate geochemical cycle, in order to understand characteristic behaviors of the climate system of water-rich terrestrial planets in the extrasolar planetary systems.

We classified the behaviors of the climate system of a planet without carbonate-silicate geochemical cycle (i.e. a constant pCO2), into the following 4 stable solutions:

1) Ice-covered solution (snowball solution): All of the surface of the planet is covered with ice perpetually. This solution exists at low solar flux (i.e. small semimajor axis) condition at all the obliquities. With increasing obliquity, planets become less prone to an ice-free solution.

2) Seasonal-ice-cap solution: The planet is covered partially with ice seasonally. It exists at lower solar flux conditions compared with ice-free solution at low obliquity, shrinking with the increase of the obliquity and disappearing at 54 degrees.

3) Parmanent-ice solution: The planet is covered partially with ice throughout the year. It exists at lower solar flux compared with seasonal-ice-cap solution at the obliquity < 28 degrees.

4) Ice-free solution: There is no ice cover throughout the year. It exists at high solar flux conditions at all the obliquities. The range of ice-free solution extends to a lower solar flux condition with increasing obliquity, indicating that planets with high obliquities are less prone to a snowball solution.

Then, we obtained the following major results;
1. When carbonate-silicate cycle is taken into account, the range of solar flux condition for all the solutions should expand at any obliquities, compared with the cases without carbon cycle, indicating that the carbon cycle make the climate more moderate for the planets with any obliquities.

2. Low latitude permanent-ice cannot exist at any obliquities (even high obliquities). This results does not

support the hypothesis that the large inclination of the spin axis of the Earth triggered low latitude glaciation in Neoproterozoic era.

3.We also calculated the climate mode with different conditions of carbonate-silicate geochemical cycle. According to the result, large CO_2 degassing rate could expand the range of solar flux condition for the warm climate.

In the presentation, we will also focus on how the multiple solutions of the climate are affected by the degassing rate and how the solutions, pCO_2 equilibrium level, and time to escape from snowball state depend on obliquity.