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The Effect of Obliquity Change on the Multiplicity of Stable Solutions of the climate System of Water-rich Terrestrial 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 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 common for other planets in general. 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. We therefore investigate the effects of obliquity change systematically on the climate of the Earth-like planets in order to understand characteristic behaviors of the climate system of water-rich terrestrial planets in the extrasolar planetary systems. In this study, we adopt a one-dimensional energy balance climate model (1D-EBM).

Under the seasonal condition of the insolation, the behavior of the climate system can be classified into 4 stable solutions: ice-covered solution, seasonal-ice solution, parmanent-ice solution, and ice-free solution. The condition of each stable solution varies with obliquity. The seasonal-ice solution disappears at the obliquity larger than 54 degrees. At high obliquity, the temperature at high latitude exceeds the temperature at low latitude, and this indicates that, at high obliquity, glaciation occurs from equatorial region and deglaciation occurs from polar region.

If the obliquity exceeds 54 degrees, partial-ice solution disappears, and there would be only two stable solutions, that is, ice-free solution and ice-covered solution. The climate may oscillate between the two extremes owing to perturbations to the climate system.

There is a hypothesis which assumes the Earth's obliquity larger than 54 degree before ca 600 million years ago in order to explain low-latitude glacial sediments recorded in the Neoproterozoic strata (Williams, 1993). It is however appeared that there may be only ice-free solution and globally ice-covered solution under that condition. Low-latitude glacial sediments cannot be explained without assuming the globally ice-covered state. It is therefore concluded that the large obliquity hypothesis is equivalent to assume the snowball Earth hypothesis (Kirschvink, 1992).