Ice sheet formation on synchrnously rotating earth-like planets in M-dwarf abitable zones

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It is considered that terrestrial planets near M-dwarf are synchronously rotating (Von Bloh et al, 2007). Some of such planets exist in the habitable zone defined by vertical one-dimensional atmospheric models and are expected to have liquid water on their surface. However, in synchronously rotating planets, there is a possibility that all of liquid water are lost since water vapor transported form warm day-side to cold night-side is condensed on night-side surface as ice. In order to examine this problem, Menou (2013) conducted atmospheric general circulation model (AGCM) experiments using a synchronously rotating planet configuration with surface water of 50m depth. He estimated ice sheet thickness formed on the planet surface based on the calculated amounts of precipitation and surface evaporation. The result is that the amount of ice sheet on night-side can reach the all amount of surface water given to the planet. In his estimation, GCM results obtained without topography were utilized. Since surface height will change according to the growth of ice sheet, atmospheric circulation are influenced by topography of ice sheet and distributions of precipitation and surface evaporation are also changed. Therefore, the ice sheet thickness can be different from the values estimated by Menou (2013). In this study, in order to consider the effect of the topography produced by ice sheet formation in the night-side, we perform GCM experiment with changing surface height distribution.

The model utilized is DCPAM5(https://www.gfd-dennou.org/library/dcpam/). Atmospheric constituents and parameters such as planet radius are same as those of Earth. We perform two kinds of experiments: one is aqua-planet experiment in which all surface are covered with water or ice, the another is land-planet experiment in which initial water of 20cm depth is given to day-side surface and water transport on the surface is neglected. In land-planet experiment, surface liquid water distribution is determined by atmospheric transport. The value of surface albedo is fixed to 0.15. First, integration for 1500 days with no topography is performed, then thickness of ice sheet is prognosed with considering melting of ice at the bottom of ice sheet and condensation of ice on the surface calculated from distributions of precipitation and surface evaporation. Then, using the horizontal distribution of surface height estimated by the above method, integration for 1500 days is performed and ice sheet height is prognosed again. With repeating these procedures, we search for equilibrium states in which ice sheet thickness becomes constant in time. The results of land planet experiment show that an equilibrium state with ice sheet over 4000m height can be obtained. Contrary to this, in aqua-planet experiment, equilibrium state are not been obtained in our experiment. Ice sheets with height over 10000m are formed in the night-side, although the value of ice sheet height is transient. The result of the experiment with topography determined by the above estimated ice sheet height show that day-side surface temperature become lower than 273K, and therefore, globally ice-covered state can emerge. As for the reason, we consider that day-side surface is cooled by cold air blowing from night-side with high elevation to day-side with low elevation. Since albedo change due to the ice sheet formation is neglected in our experiments, our result suggests that the atmospheric circulation influenced by ice sheet topography can produce globally ice-covered state.

Keywords: synchronously rotating planets, atmospheric general circulation model, ice sheet, globally ice-covered state, existence of liquid water

