A numerical experiment on occurrence condition of the runaway greenhouse state with a atmospheric general circulation model

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Aiming for assessing the potential habitability of extrasolar terrestrial planets, the existence condition of liquid water on planetary surfaces has been discussed (e.g., Kasting et al., 1993). One of the main issues is the examination on the occurrence condition of the runaway greenhouse state. The runaway greenhouse state is defined as a state in which incident flux given to the atmosphere exceeds the radiation limit: the upper limit of outgoing longwave radiation (OLR) emitted from the top of the moist atmosphere on a planet with ocean (Nakajima et al., 1992). In the runaway greenhouse state, thermal equilibrium cannot be realized. Recent studies utilizing atmospheric general circulation models (AGCMs) discuss that atmospheric circulation and cloud albedo significantly affect the occurrence condition of the runaway greenhouse state (e.g., Leconte et al., 2013; Yang et al., 2013; Wolf and Toon, 2015). However, our speculation is that the runaway greenhouse state emerges when global mean absorbed solar radiation flux exceeds the maximum values of OLR. In order to confirm our speculation, we perform a numerical experiments with an AGCM. We examine the response of modeled atmospheric states to the increase of solar flux considering two spatial and temporal distributions: one for synchronously rotating planets with fixed dayside and nightside, and the other for an Earth-like, non-synchronously rotating planets with diurnal and seasonal changes. We use the AGCM developed by our research group, DCPAM (http://www.gfd-dennou.org/library/dcpam). Subgrid physical processes are parameterized with standard methods used in terrestrial Meteorology. The amount of cloud water is calculated with integrating a time dependent equation including generation, advection, turbulent diffusion, and extinction of cloud water. Extinction rate of cloud water is assumed to be proportional to the amount of cloud water, and extinction time is given as an external parameter. The entire surface is assumed to be a ``swamp ocean'' with zero heat capacity. The results of our experiment show that horizontal deviation of OLR decreases with increasing the value of solar constant regardless the radiation scheme (grey scheme or non-grey scheme), existence of clouds, and solar flux distribution. It seems that runaway greenhouse state appears when global mean absorbed solar radiation flux exceeds the maximum values of OLR. Our results suggest that the occurrence condition of the runaway greenhouse state is determined by a common mechanism, although the maximum value of OLR differs among runs with different conditions.

Keywords: runaway greenhouse state, exoplanet, radiation limit, atmospheric general circulation model, habitability

