GCM experiments on occurrence condition of the runaway greenhouse state: aquaplanets and landplanets.

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Introduction: Aiming for assessing the potential habitability of extrasolar terrestrial planets, the existence condition of liquid water on planetary surfaces has been discussed (e.g., [1]). 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[2]. In the runaway greenhouse state, thermal equilibrium cannot be realized. Numerical experiments on the runaway greenhouse state for various conditions has been performed by the use of atmospheric general circulation models (AGCMs). For aquaplanets which are covered with ocean all over the surface, it has been discussed that atmospheric circulation affects the occurrence condition of the runaway greenhouse state under Earth-like condition (e.g., [3]) and that cloud albedo significantly affects the occurrence condition under synchronously rotating planet condition[4]. GCM experiments for landplanets has been also performed. A land planet is a planet which possesses water on its surface much less than Earth. It was shown that the runaway greenhouse state does not emerge for the value of solar constant of 1.7 times of present Earth's value[5]. Above described previous studies did not examine the dependence of the occurrence condition of the runaway greenhouse state on parameters such as planetary rotation rate, obliquity, and so on. One may think that the occurrence condition of the runaway greenhouse state changes with planetary rotation rate since large scale atmospheric circulation structure, and hence water vapor distribution in the atmosphere, changes according to the values of planetary rotation rate[6]. However, our speculation is that, regardless of planet configurations, 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 for various experimental setups.

Model: We use the AGCM developed by our research group, DCPAM (http://www.gfd-dennou.org/library/dcpam). The basic equations of DCPAM are primitive equations in spherical geometry. 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. Solar constant is varied from 1.0 times to 2.3 times of present Earth's value. Two kinds of spatial and temporal distribution of solar flux are used: 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. For the horizontal discretization, we use the spherical spectral transform method with triangular truncation at total wavenumber 21 (T21). As the vertical coordinate, $\sigma = p/p_s$ is adopted, where p_s is surface pressure. The number of vertical levels is set to 26.Following two series of experiment are performed: (1) Aquaplanet series. The entire surface is assumed to be a ``swamp ocean" with zero heat capacity. (2) Landplanet series. A bucket model[7] is applied to all of the surface. Three initial conditions for ground water are used: uniform distributions with 20, 40, and 60 cm depth of water.

Results: In aquaplanet series experiments, the upper limit of OLR emerges with increasing the value of solar constant regardless the 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. This results suggest that the occurrence condition of the runaway greenhouse state is determined by a common mechanism. In presentation, we will also show the results of landplanet series experiment.

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