An experiment on the appearance of the complete evaporation of a land planet with a general circulation model

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1 Introduction

Exoplanets are planets which belong to stellar systems out of our solar system. Exoplanets have diversity : they have various ranges of mass, planetary radius, semi-major axis and so on (http://exoplanets.org/). Some exoplanets have mass similar to Earth's mass. It is considered that some of such small mass planets are terrestrial planets, and their major constituent is rock. Assuming life similar to those of the Earth, exoplanets are expected to be habitable if liquid water exists on planetary surface. Since consideration on the existence condition of liquid water on planetary surface is important, many numerical experiments have been performed in order to estimate of terrestrial exoplanets (Noda et al., 2017 etc.).

Abe et al. (2011, hereafter AASZ2011) is one of the efforts for estimating climates of exoplanets. They investigate climate of a land planet by using an atmospheric general circulation model (GCM). A land planet is a planet which has much smaller water on a planetary surface than that of the Earth. According to AASZ2011, a land planet can retain liquid water on the planetary surface for larger net insolation than that for an aqua planet which is covered with ocean. If the value of net insolation exceeds a threshold value, all of surface water evaporate completely.

In this study, the appearance of the complete evaporation in a land planet is examined. The first purpose of this study was to examine the dependence of the appearance condition of the complete evaporation in land planet on obliquity and planetary rotation rate. However, the result of preliminary experiment showed that there was a possibility of non-existence of the complete evaporation state. Therefore, the purpose of this study is to reconsider the appearance of the complete evaporation in a land planet.

2 Model and experimental settings

GCM used in this study is DCPAM5(`http://www.gfd-dennou.org/library/dcpam/`). The basic equations are primitive equations. Radiation scheme for Earth's atmosphere is used. The model includes processes of vertical diffusion, cloud convection and large scale condensation.

The horizontal resolution is T21, the number of vertical level is 26. The values of solar constant S are given as S=1365, 1900, 2400, 3600 W/m^2. Both of obliquity and eccentricity are 0. The values of the Earth are given as planetary radius, planetary rotation rate, gravity and so on. For the surface condition, two kinds of conditions are used: one is an aqua planet condition that all of the surface is covered with a swamp ocean, the other is a land planet condition that a bucket model is applied to all of the surface. Two initial states are used: a statistical equilibrium state of an aqua planet experiment with S=1365 W/m^2, and a runaway greenhouse non-equilibrium state obtained with S=2000 W/m^2 in an aqua planet experiment.

3 Results

In all of experiments, statistical equilibrium states are obtained because an equatorial region is dry and an equatorial radiation is not limited. Result of the land planet experiment with S=2400 W/m^2 shows that almost all of water exist in soil and the complete evaporation does not appear (Fig **??**). Net insolation at 2000 days (figure not shown) reaches 450 W/m^2 which exceeds the threshold value obtained by AASZ2011 for the appearance of the complete evaporation. In order to confirm the dependence of a initial state, experiment with the non-equilibrium state as a initial state is performed. In this experiment, the complete evaporation does not appear. In order to confirm whether the complete evaporation appears or not with increased a solar constant, the experiment with S=3600 W/m^2 is performed. Also in this case, the complete evaporation does not appear. The value of net insolation exceeds the threshold value with 670 W/m^2.

In land planet experiments, the Hadley and Ferrel circulations appear, which are the circulation pattern similar to those of the Earth. As for the hydrologic cycle, precipitation occurs only in the region where evaporation occurs: the equatorial region and the polar region. Almost no horizontal advection of vapor occurred. Almost all surface water is localized in the polar region except for slight amount in the equatorial region. The reason why surface water retains in polar region is that temperature in the polar region is kept to be low values due to zero obliquity.

4 Conclusion

The above results suggest that there is a possibility that water is retained in the surface with net insolation larger than the threshold value obtained previous study(AASZ2011). One of the reasons why the complete evaporation does not occur is that temperature in the polar region is kept to be low value. Further investigation is necessary for considering the appearance condition of the complete evaporation with experiment changing obliquity.

Fig.1 Horizontal mean water amount as a function of time for the land planet experiment with S=2400 W/m^2. Abscissa is time [days]. Time at the leftside is 5475 day : initial day of the experiment. Solid line and broken line represent surface water in soil and vertically integrated water vapor, respectively.