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# Dependence of the runaway threshold on water distributions on the surface of Earth-like planets

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Liquid water is one of the most important material not only for its large effect on planetary climate but also as a controlling factor of the habitability [e.g. Kasting et al., 1993]. Water planets, which are planets with liquid water on their surface, can be divided in 3 types: 'ocean planets', 'partial-ocean planets', and 'land planets'. Ocean planets have enough water to cover their surface entirely. Partial-ocean planets, which are like the Earth, have an interconnected ocean and lands. Land planets have little water in scattered lakes around both Poles [Abe et al., 2013, Hawaii, Kona]. The type of the water planet is determined by the balance between the surface water transport, which depends on the amount of water and topography, and the atmospheric water transport, which depends on the global circulation.

Surface water on each water planet is unstable and entirely vaporized when the planet receives insolation above a certain critical value. It is because of the positive feedback of the greenhouse effect of water vapor. This phenomenon is called the runaway greenhouse. In the following, the critical insolation is called 'runaway threshold' [e.g. Abe and Kasting 1988; Nakajima et al, 1992; Kopparapu et al., 2011].

Abe et al. [2011] discussed the difference of the runaway threshold between Earth-sized ocean planets and land planets using a 3-D model for the first time. They found that the surface water of land planet is significantly stable than that of ocean planet against the large insolation. While an ocean planet gets unstable and the runaway greenhouse occurs when the insolation reaches about 130% of that on the present Earth, a land planet remains stable until the insolation reaches 170%. However, a land planet that they represented is only one of the various situations of land planets, and they didn't mention the effect of variety of surface water distributions on the planetary climate.

Takao [2013] showed the dependence of the runaway threshold on latitudinal surface water distribution using the combination of meridional energy balance model (EBM) and the vertical radiative-convective equilibrium model. He suggested that runaway threshold of the Earth-sized water planet varies with the degree of latitudinal localization of surface water. Nevertheless, his 1-D EBM was so simple that he could neither discuss about the effects of longitudinal distribution of surface water, nor include dynamical global circulation.

In this study, we perform numerical experiments to clarify the effects of the surface water distribution on runaway threshold of Earth-sized planets with a 3-D model, GCM.

We use CCSR/NIES AGCM 5.4g [Numaguchi, 1999], which includes dynamical atmospheric circulation, radiative transfer, formation of clouds, and so on. While this model is adapted to the present Earth, it cannot calculate the change of surface water distribution determined by the water amount and topography. Therefore, we assumed the surface water distribution, which is determined as a result of the balance between the surface and atmospheric water transport in reality, and used it as the boundary condition. Then, we raised the insolation gradually until the surface water got unstable for each surface distribution, and evaluated the runaway threshold.

We found that the degree of localization of surface water significantly affects the runaway threshold, and it varies from 180% (extremely localized land planet) to 130% (ocean planet) continuously. Even if no surface water is given low latitudes area initially, because the Hadley circulation transports water to such area, when the initial surface water area reaches adequately low latitudes, the runaway threshold is almost the same as that of ocean planets, that is, 130%. We also investigated the dependence on the longitudinal water distribution. As a result, even if the total area of surface water is the same, there are about 10% of differences in the runaway threshold depending on its distribution.

Keywords: runaway greenhouse, GCM, Earth-like planet