A numerical study on the solar constant dependence of ocean planet climates: the effect of oceanic heat capacity and oceanic heat transport

*Yuta Kawai[1,2], Yoshiyuki O. Takahashi[1], Masaki Ishiwatari[5], Seiya Nishizawa[2], Shin-ichi Takehiro[4], Kensuke Nakajima[3], Hirofumi Tomita[2], Yoshi-Yuki Hayashi[1,6]

1. Kobe Univ. , 2. RIKEN AICS., 3. Kyusyu Univ., 4. Kyoto Univ., 5. Hokkaido Univ., 6. Department of Planetology/CPS

1. Introduction

In order to obtain a deeper understanding of the diversity of exoplanet climates, our research group has investigated various climates on some idealized planets, for example, a planet globally covered with ocean (ocean planet). Ishiwatari et al. (2007) (hereinafter, referred as INTH07) explored the solar constant dependence of climates on a ocean planet using an atmospheric general circulation model (AGCM), but ocean general circulation was not considered. Recently, the effect of ocean general circulation is beginning to be discussed in the field of planetary climates. In particular, Rose (2015) indicated the appearance of a new stable climatic state related to ocean heat transport by exploring ocean planet climates with a coupled atmosphere-ocean-sea ice model. In order to understand the role of ocean in planetary climates, our research group is also conducting solar constant dependence experiments in INTH07 with considering ocean general circulation using a coupled model. Recently, we obtained a climatic regime diagram of ocean planet climates. Furthermore, in order to see the role of ocean clearly, the corresponding swamp/60 m slab ocean experiments are performed. However, in particular for 60 m slab ocean, the strong dependence of partially ice-covered solutions on initial conditions were found, and so it is difficult to discuss the influence of ocean heat transport on ice-line. After that, we have realized that the problem could be reduced by modifying a calculation of surface albedo. In this presentation, we show some results of solar constant dependence experiments of ocean planet climates with the modified method.

2. Model and Experimental setting

We use our developing coupled atmosphere-ocean-sea ice model. The atmosphere model is an AGCM, DCPAM, in which 3-dimensional primitive equations are solved. As in INTH07, we use a gray atmosphere radiation scheme (Nakajima et al., 1992), moist convective adjustment and large-scale condensation scheme (Manabe et al., 1965). The ocean and sea-ice model are zonally averaged 2-dimensional models. In the ocean model, hydrostatic Boussinesq equations are solved. The effect of meso-scale eddies and convection are parameterized (Gent and McWilliams, 1990; Marotzke, 1991). The sea ice model is a thermodynamics model and the horizontal transport is parameterized. While the dependence of surface albedo on temperature is a step function (the value is set to 0.5 if surface temperature is lower than -10℃, otherwise 0), grid point value of surface albedo is applied to the cell averaged value where the sub-grid scale profile of temperature is represented by a linear function. Three oceanic configurations are considered: swamp, 60 m slab and dynamic ocean. We explore the climates in the range of solar constant (S) between 1150-1550 W/m^2. The number of atmosphere model grid is 64x32x16 for S≦1450 W/m^2, and 64x32x32 for S>1450 W/m^2. The number of grid points on ocean and sea ice models is 64x60 and 64, respectively. For most of cases, the initial condition is a rest atmosphere and ocean with 280 K, but partially ice-covered solutions are also used. The temporal integration for swamp/slab ocean cases is basically performed over about 300 years, and, for dynamic ocean cases, over about 10,000 years with periodically synchronous coupling.

3. Numerical result

We find that the discontinuity of surface albedo and low meridional resolution cause the strong dependence of partially ice-covered solutions on initial condition, which are essentially same as the discussion in Held and Suarez (1974). The modified method of surface albedo reduces the problem significantly, and we have been able to compare the climates between three oceanic treatments. Most of ice-line latitudes for partially ice-covered states are nearly independent of the existence of oceanic heat capacity or oceanic heat transport. This result indicates that, in our experimental setting, the difference of the oceanic treatments has no effective influence on the global energy budget. However, some differences of atmospheric fields between oceanic treatments can be seen. For example, for S=1380 W/m^2, the strength of atmospheric meridional circulation in the case of slab ocean is about three times as strong as one in the case of dynamic ocean, and, for the latter case, the atmospheric heat transport at low and mid-latitude is two thirds of ones for swamp/slab ocean. In order to clarify why the global energy budget remains nearly unchanged between three oceanic treatments, we will analyze the contribution of some terms in atmospheric energy equation and the latitudinal distribution as near future work.

Keywords: coupled atmosphere-ocean-sea ice model, dependence of ocean planet climates on solar constant, ice-albedo feedback