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A numerical experiment on dependence of the atmospheric structure of a synchronously rotating planet on planetary radius

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In this study, a parameter experiment with a general circulation model (GCM) is performed in order to examine dependence of the climate of a synchronously rotating aquaplanet on planetary radius. Most of previous numerical studies on climates of exoplanets with mass similar to Earth's use experimental configuration imitating particular exoplanets, and parameter study with various values of planetary radius has not been performed. Heng and Vogt (2011) performs a numerical experiment with changing values of planetary radius and gravitational acceleration from 1.46 times of Earth's values to 1.71 times for the purpose of investigating the climate of Gliese581g. They show that surface temperature has its maximum value and minimum value at the subsolar point and anti solar point, respectively. However, the result may be changed with more large value of planetary radius, since the circulation pattern may change due to the decrease of radius of deformation compared to planetary radius. We examine the dependence of atmospheric structures for wide range of planetary radius.

The GCM utilized in this study is DCPAM5 (Dennou-Club Planetary Atmospheric Model; Takahashi et al., 2013). The governing equations for dynamical process are the primitive equations. For horizontal direction, the triangular truncation of the spectral transform method is used. As vertical axis, sigma is adopted, The surface of planet is entirely covered with ocean with zero heat capacity (swamp ocean). Earth's values are used for gravitational acceleration, dry air mass, and solar constant. For planetary rotation rate, an estimated value for Gliese 581g is adopted. For synchronously rotating planet configuration, the axial inclination is set to be zero, and the solar insolation distribution is fixed to the planetary surface. Values of planetary radius $R*$($R*$is planetary radius normalize by Earth's value) is changed from 0.5 to 8.0.

The result of GCM experiment shows that surface temperature averaged over night side decreases with the increase of $R*$. The value of the case with $R*$=1.0 is 15 K lower than that of the case with $R*$=8.0. In horizontal distribution of surface temperature, the value in high-latitudinal region of the night side decreases with the increase of $R*$. On the other hand, surface temperature at the subsolar point increases with the increase of $R*$. Subsolar surface temperature of the case with $R*$=1.0 is 20 K higher than that of the case with $R*$=8.0. The amount of day-night energy transport decreases with the increase of $R*$, which is consistent with the increase of the difference of surface temperature between the day side and the night side. The results imply that a climate state with large spatial difference in surface temperature tends to appear in synchronously rotating planet with large planetary radius.

Keywords: exoplanets, synchronously rotating planets, planetary radius, general circulation model