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The Atmospheric General Circulation of Synchronously Rotating Planets: Dependence on Planetary Rotation Rate

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Abstract

We numerically investigate general circulation of moist atmosphere on synchronously rotating planets to examine the dependence of the atmospheric structure on planetary rotation rate. Three representative surface temperature patterns associated with different structure of heat transport appear. However, total amount of energy transport from dayside to nightside has only weak dependence on planetary rotation rate.

1 Introduction

Most of exoplanets ever discovered exist in the vicinity of central stars. Even in the vicinity of stars, mild climates may be realized and liquid water may exist on the planetary surface if central stars have low luminosity (e.g., M star). Such planets are expected to be synchronously rotating, and to have perpetual dayside and nightside, due to strong tidal force of central stars. Under the existence of such large day-night contrast of incident flux, day-night contrast of the atmospheric structure are expected to be strongly influenced by the structure of circulation responsible for energy transport from dayside to nightside.

A numerical experiment on moist atmospheres on synchronously rotating planets was performed by Merlis and Schneider (2010) [1]. With general circulation model (GCM), they showed the existence of two circulation regimes as will be discussed later. However, their analysis was restricted to only two extreme cases :$\Omega = \Omega_E$ case and $\Omega = \Omega_E/365$ case, where Ω_E is present terrestrial planetary rotation rate, and details of dependence on planetary rotation rate were not discussed. In this study, we will perform a parameter experiment in which larger number of values of planetary rotation rate are used than in the experiment by [1], aiming for revealing the varieties of the surface temperature distributions and atmospheric circulation patterns of synchronously rotating planets.

2 Model

The model utilized is dcpam5 [2], which is based on three-dimensional primitive equation system on a sphere. The atmosphere consists of dry air and water vapor. Dry air is assumed to be transparent. Water vapor is assumed to absorb infrared radiation, and the absorption coefficient is constant and independent of wavelength. Condensed water is removed from system instantly. Moist convective adjustment scheme is employed to represent cumulus convection. The planetary surface is assumed to be covered with ocean whose heat capacity is zero. Surface albedo is set to be zero.

Eighteen experiments are performed with various values of planetary rotation rate ranging from zero to Ω_E. Although a synchronously rotating planet without rotation does not exist in the real world, numerical experiment with such a virtual configuration would be useful to understand the dependence of atmospheric circulations on planetary rotation rate. In all experiments, the planetary radius, averaged surface pressure, solar constant etc. are set to be Earth's values. The inclination and eccentricity are assumed to be zero, so that the insolation pattern is geographically fixed.

The equations are discretized horizontally with the spectral method, and vertically with the finite difference method. The horizontal resolution is 32×64 that corresponds to spectral truncation T21. The number of vertical layer is 16. For each case, the result during last 1000 Earth days of 2000 Earth days calculation is analyzed.

3 Results

Statistically steady states are obtained in all cases. Fig.1(a) shows surface temperature distribution of the case of $\Omega = 0$. Surface temperature pattern is characterized by concentric circular isotherms. This is accompanied by direct circulation which has concentrated updraft around subsolar point and almost uniform downward motion elsewhere.

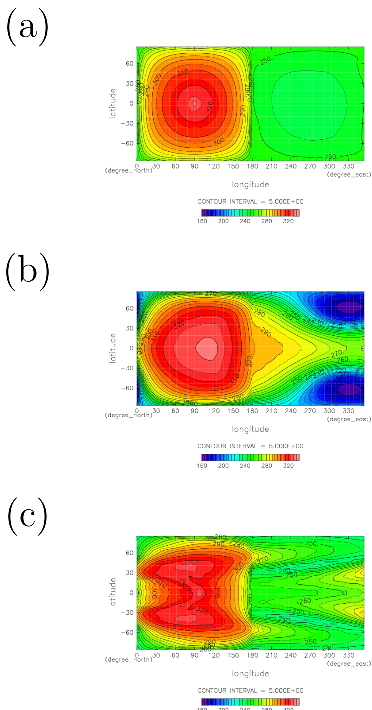

Figure 1: Horizontal distribution of surface temperature [K]. Contour interval is 5 K. Subsolar point is set to be 90 degrees of longitude at the equator. (a) $\Omega = 0$, (b) $\Omega = 0.15\ \Omega_E$, (c) $\Omega = \Omega_E$.

Fig.1 (b) shows surface temperature distribution of the case of $\Omega = 0.15\ \Omega_E$. Warm area extends eastward from 180° E along the equator. The warm area correspond to the area of moist air advected from the dayside by the westerly wind, i.e., super-rotation, which develops significantly in this case.

Fig.1 (c) shows surface temperature distribution of the case of $\Omega = \Omega_E$. In each (north or south) hemispheres, there are two latitudes where strong heat transport from dayside to nightside occur. A pair of warm areas extend westward along 30° N and 30° S. The other pair of warm areas extend eastward along 50° N and 50° S. The former pair and the latter pair of warm areas correspond to time mean easterly and westerly areas around planetary surface, respectively.

4 Concluding remarks

The results of cases $\Omega = 0$ and $\Omega = \Omega_E$ are similar to those of "slowly rotating regime" and "rapidly rotating regime" obtained by [1], respectively. The significance of the circulation structure realized in case $\Omega = 0.15\ \Omega_E$ was not mentioned in [1]. In all experiments, surface temperature in nightside is well correlated with the content of water vapor, which provide strong "blanketing effect". Although the structure of heat transport has diversity depending on the planetary rotation rate, total amount of energy transport from dayside to nightside (figures not shown) depends only weakly on planetary rotation rate.

In this study, the value of solar constant is fixed. Numerical experiments with increasing solar constant is required to investigate condition which equilibrium state obtains.

Acknowledgements

Calculations are performed by SX8-R of the NIES supercomputer system. We used visualization software developed by Dennou Ruby Project for drawing.

References

[1] Merlis, T. M. and T. Schneider, 2010: Atmospheric dynamics of Earth-like tidally locked aquaplanets. *J. Adv. Model. Earth Syst.*, **2**, Art. #13, 17 pp.

[2] Takahashi, Y. O., M. Ishiwatari, S. Noda, M. Odaka, T. Horinouchi, Y. Morikawa, Y.-Y. Hayashi, DCPAM Development Group, 2010: DCPAM: planetary atmosphere model, http://www.gfd-dennou.org/library/dcpam/, GFD Dennou Club.