Numerical Experiments of Atmospheric General Circulations on a Synchronously Rotating Planet

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Introduction

More than 300 exoplanets have been discovered. Many of these planets orbit nearby the central star, and are thought as synchronously rotating planets because of the strong tidal force of the star. We expect the existence of synchronously rotating terrestrial planets that have liquid water on their surface, since low mass stars (e.g. M dwarfs) have low luminosity.

Joshi et al. (1997) studied the climate state of a synchronously rotating terrestrial planet with pure CO_2 atmosphere. By the use of general circulation model (GCM), they showed that the nightside of the planet is warm enough not to cause condensation of the atmospheric component if the surface pressure is higher than O(100 hPa). Based on the result, they concluded that the synchronously rotating planet is habitable
However, they did not include water in their model. The atmospheric structure may be affected by the existence of water.

Our objective is to investigate the climate state of a synchronously rotating planet which includes water vapor by the use of a GCM.
The effects of synchronous rotation are described by comparing the results between synchronous and non-synchronous cases.
Further, we examine the dependence of climate state on rotation speed.

Model Description

We use our General Circulation Model, dcpam5 (http://www.gfd-dennou.org/library/dcpam/index.htm.en). The experimental settings are as follows:

Governing equation: primitive equation
Physical processes:
・Moist convective adjustment (Manabe *et al.*, 1965)
・Large scale condensation (Manabe *et al.*, 1965)
・Radiation
  ・short wave: no absorption and no scattering
  ・long wave: absorption by H_2O
・Surface condition: swamp (wet surface with zero heat capacity)
・Vertical mixing (Mellor and Yamada, 1974) level 2

・Planetary radius: 6.371 x 10^6 [m]
・Axial inclination: 0
・Eccentricity: 0
・Solar constant: 1380 [W m^{-2}]
・Rotational speed: 4.848 x 10^{-5} - 7.272 x 10-5 [s-1]
・Gravity acceleration: 9.8 [m s^{-2}]
・Mean surface pressure: 10^5 [Pa]
・Surface albedo: 0

Model parameters

・Spatial resolution
 ・Number of grid point:
  ・Longitude : 64, Latitude : 32
 ・Number of layers: 16
 ・Truncation wave number: 21
・Integration period: 35000 [days]
 (last 33000 days is used for the analysis)
・Time step: 8 [minutes]

Initial condition

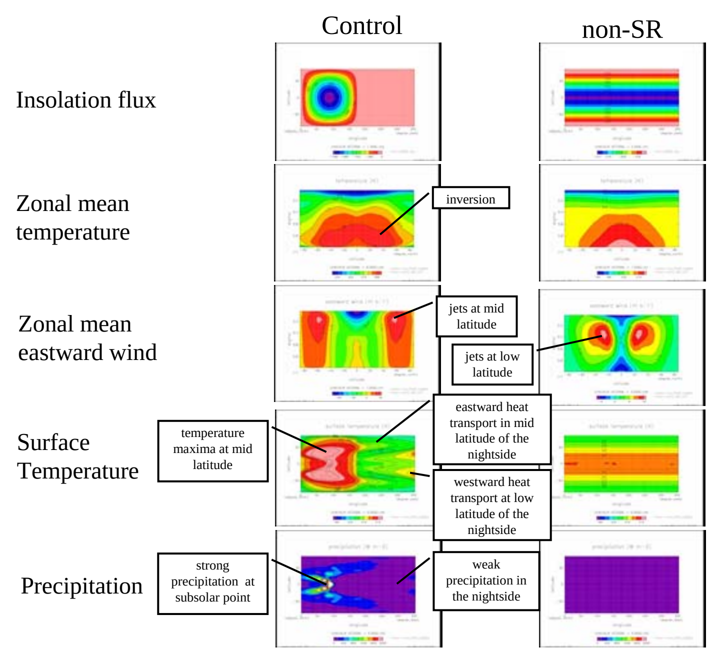
・Temperature: 280K with small disturbance
・Wind velocity: 0

Run summaries

run name	Ω (s^{-1})	Insolation pattern
Control	7.272 x 10^{-5}	Synchronous
Case 2/3	4.848 x 10^{-5}	Synchronous
Case 4/5	5.818 x 10^{-5}	Synchronous
non-SR	7.272 x 10^{-5}	Earth (daily and annual mean)

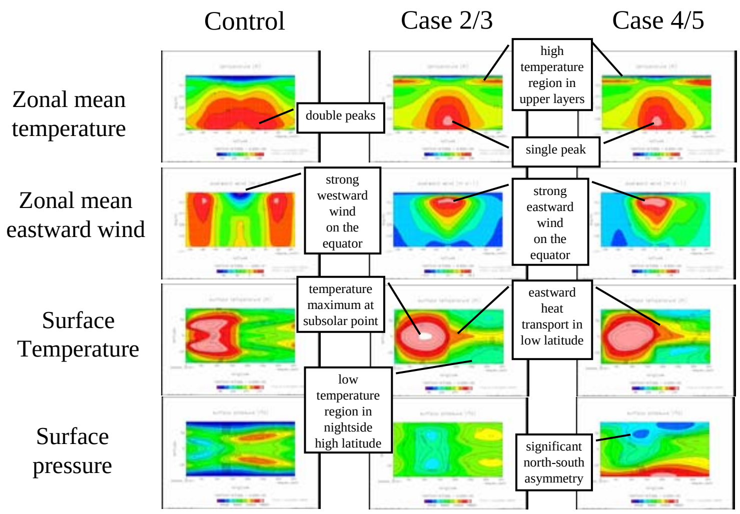
Results

A. Comparison between Control and non-SR



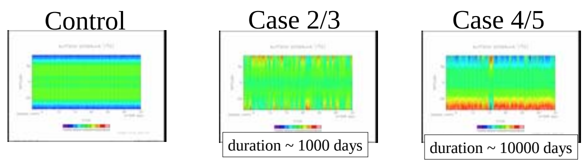
B. Dependence of long term mean circulation on rotation speed

・North-south asymmetric circulation is maintained in Case 4/5, though the boundary condition is equatorially symmetric.



C. Timeseries of zonal mean surface pressure

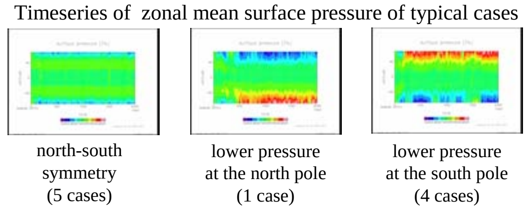
・Exchange of north-south asymmetric pattern occur aperiodically in the Case 2/3 and 4/5.



D. Dependence of circulation on initial condition in Case 4/5

・We performed 10 runs with different temperature disturbances (2000 days).
・Symmetry and asymmetry pattern emerged according to initial state.

Timeseries of zonal mean surface pressure of typical cases



Conclusion

・In the case of the rotational speed is same as the Earth, following process are suggested to be important for the heat transport from the dayside to the nightside of a synchronously rotating planet which includes water.
 ・Heat transport by atmospheric circulation on the equator (equatorial wave?)
 ・Latent heat transport and condensation heating by baroclinic eddy in mid-latitude
・North-south asymmetric climate is likely to emerge when the rotational speed is smaller than the Earth's value.
 ・In the Case 2/3, only north-south asymmetric climate is emerged.
 ・In the Case 4/5, north-south symmetric and asymmetric climate emerges according to its initial condition.

Acknowledges

We used programs of GFD Dennou Club (http://www.gfd-dennou.org/index.html.en) for simulations and visualization.

References

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