ATMOSPHERIC GENERAL CIRCULATIONS OF SYNCHRONOUSLY ROTATING TERRESTRIAL PLANETS: DEPENDENCE ON PLANETARY ROTATION RATE.
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Introduction: Recent observational studies have presented the evidence for the existence of near earth sized planets within habitable zones around red dwarfs. The habitable zones associated with red dwarfs are located very close to the stars because of their small lominocity, so that the planets in the habitable zones are expected to be tidally locked. On such planets, daysides and nightsides are permanently fixed, so that "habitability" may be limited unless significant day to night heat transport is realized in the atmosphere.

The structure of general circulation of the atmosphere on synchronously rotating planets is yet to be well understood. In the present paper, we investigate the variety of climates on synchronously rotating terrestrial planets with a wide range of variation of the planetary rotation rate. Merlis and Schneider [1] show that considerably different structure of atmospheric general circulation develop on a very slowly rotating planet and a fast rotating planet, but the structure of the circulation in the intermediate planetary rotation rates are not fully explored.

Numerical Model and Set-up of experiments: We employ a general circulation model (GCM). A simple hydrological processes including the moist convective adjustment scheme [2] is implemented. The heating rate due to infrared radiation is calculated with the assumption of gray absorption of water vapor. Whole of the planetary surface is assumed to be flat and covered with thin layer of water. We perform 18 experiments with the planetary rotation rate varied from zero to the Earth's value. Other parameters such as orbital parameters, planetary radius, solar constant, and the amount of the atmosphere are set to the Earth's values. The numerical integration is begun from isothermal state (280K) and continued for 2000 days in each experiment, and the latter half is used for analysis.

Results: The results confirm the existence of two regimes of circulation structure as the two end members, which are, the slow rotation states in which super-rotation emerge (Fig.1) and the fast rotation states in which mid-latitude westerly jets develop (Fig.2). However, closer examination of longitudinal and temporal variation of the atmospheric motion may warrant further division of the slow rotation regime: the amplitude and phase of wavenumber one planetry scale waves, which strongly affect the temperature contrast in higher latitude, vary considerably within the range of slower planetary rotation rate (Fig.3 and Fig.4), whereas strong vacillation with significant asymmetry between north and south hemispheres develop within the range of faster rotation rate (Fig.5).

In spite of the variation of structure of the general circulation, the total amount of heat from the day hemisphere to the night hemisphere is insensitive to the planetary rotation rate (Fig.6). However, the partition of the heat transport into sensible heat and latent heat varies considerably responding to the variation of rotation rate: the latent heat transport is almost zero at very slow planetary rotation, increases to the largest value in intermediate rotation rates, and decreases as more earth-like rotation rate is approached.

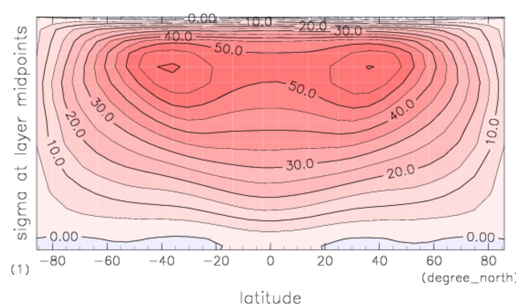

Fig.1 Time mean zonal mean eastward wind in the case with planetary rotation rate of 0.15 times that of the earth.

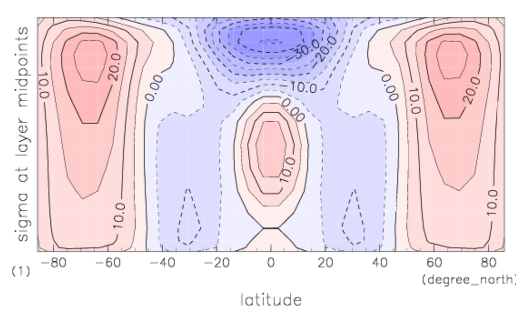

Fig.2 Time mean zonal mean eastward wind in the case with planetary rotation rate of 0.8 times that of the earth.

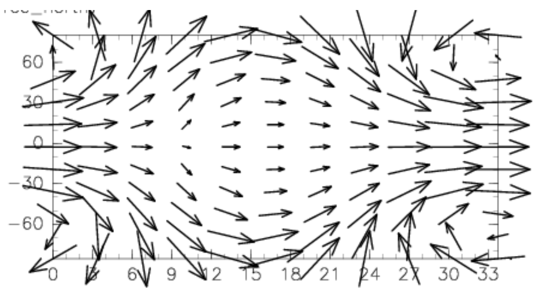

Fig.3 Time mean horizontal wind in the upper troposphere in the case with planetary rotation rate of 0.15 times that of the earth. Strongest wind vector is about 150 m/s.

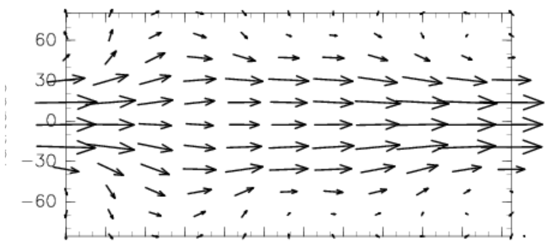

Fig.4 Time mean horizontal wind in the upper troposphere in the case with planetary rotation rate of 0.5 times that of the earth. Strongest wind vector is about 120 m/s.

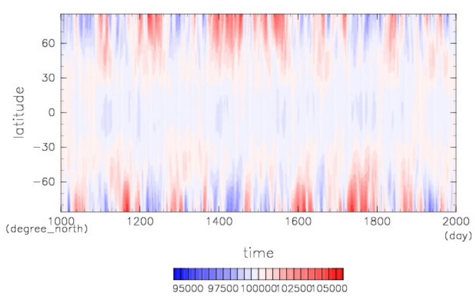

Fig.5 Time evolution of zonal mean surface pressure in the case with planetary rotation rate of 0.5 times that of the earth.

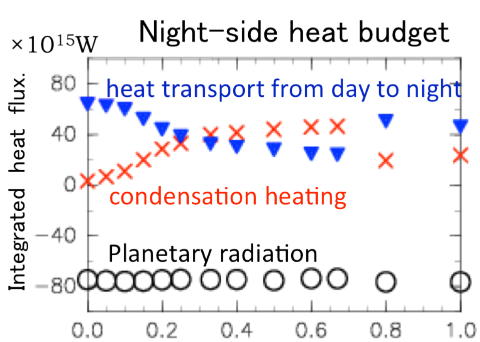

Fig.6 Heat budget of the night hemisphere in cases with different planetary rotation rate. The rotation rate is normalized by the Earth's value.

References:

[1] Merlis, T.M. and T. Schneider (2010) J. Adv. Model. Earth Syst., 2, Art.#13. [2] Manabe, S. et al (1965) Mon. Wea. Rev., 93, 769-798.