Exploration of the Parameter Space for Circulation Regimes of Terrestrial Planetary Atmospheres with Simplified GCM

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1. Introduction

Our explorations of the terrestrial planets within the Solar System have revealed great diversity in their atmospheric circulation regimes, suggesting that a systematic study of the underlying dominating factors necessary[1]. The question we are trying to answer here is whether it is possible to predict the global circulation structures of terrestrial exoplanets, based on a limited set of available planetary parameters. With planetary rotation rate as a starting point, we began building up a multi-dimensional parameter space in which the occurences of a series of circulation regimes are mapped. This kind of parametric approach has a long tradition in the laboratory studies of differentially heated rotating fluids[2] as well as the numerical studies of the Earth's atmosphere[3]. Characterising parameters are usually in dimensionless forms, e.g. thermal Rossby number, Taylor number...

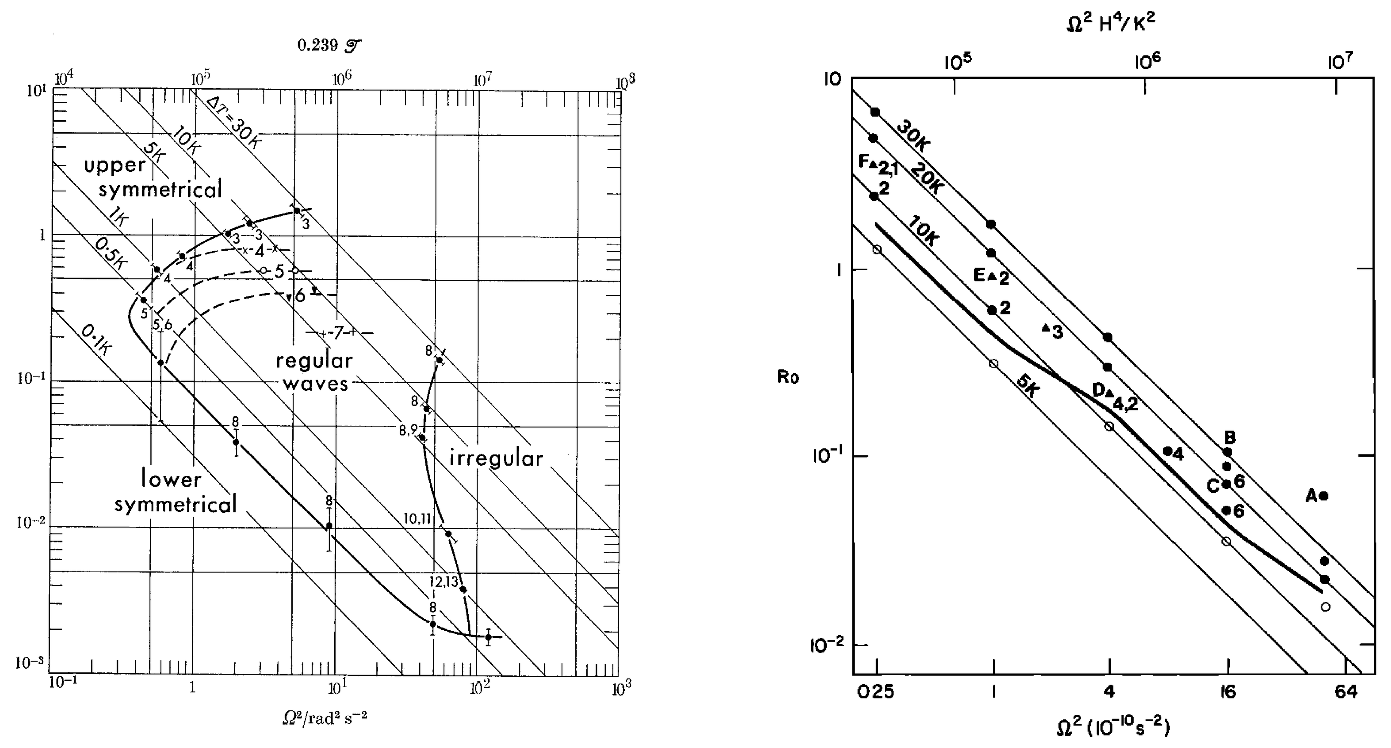

Fig. 1 Regime diagrams obtained using laboratorial rotating annulus (left, from [2]) and numerical GCM experiments(right, from [3])

2. Model and Experiment Design

The model we use is a simplified GCM: PUMA(Portable University Model of the Atmosphere) developed by the Meteorological Institute, University of Hamburg. It has a spectral dynamical core with simple linear physical processes (Rayleigh friction and Newtonian cooling), thus can be viewed as a PDE solver for the dry atmospheric motion.

We ran the model without terrain irregularities at the lower boundary so that the model can act as a more generic "prototype" atmosphere. To investigate the sensitivity of the circulation to planetary rotation rate, we conduct a series of experiments ranging from $\Omega = 8\Omega_E$ to $\Omega = 1/16\Omega_E$. Resolution is T42 for runs with rotation rates lower than that of the Earth, and T127 for high rotation runs

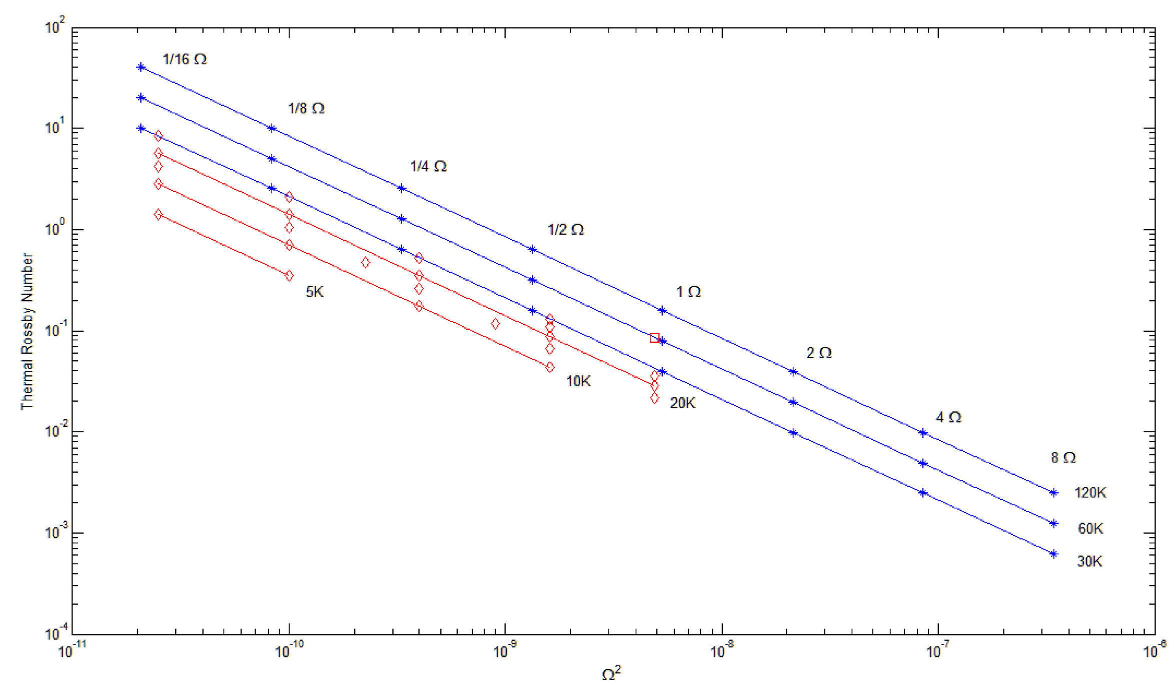

Fig. 2 Experiments (Blue) shown in parameter space. Red lines and boxes represent the experiments done by Geisler et al.[3]

3. Results and Discussions

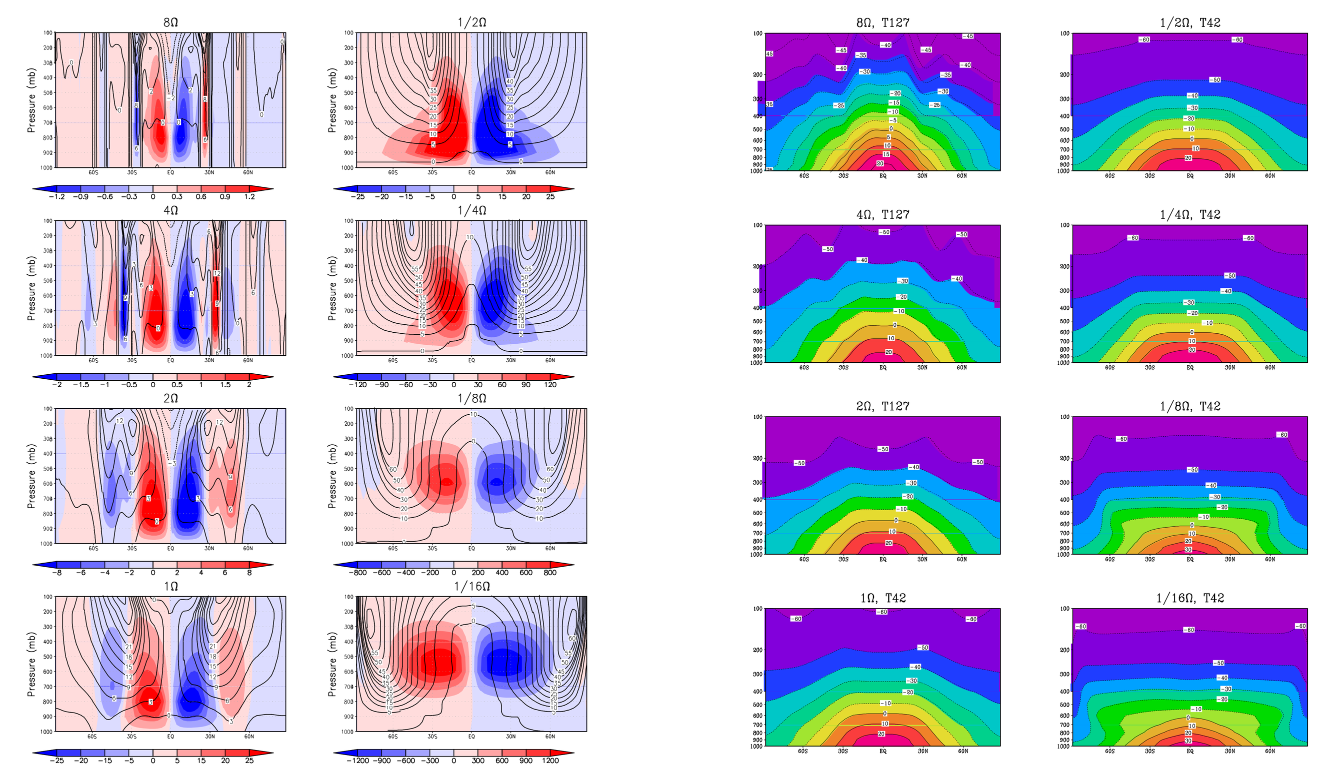

Fig. 3 Zonal and temporal mean diagnostic fields of experiments with various rotation rates. Left: zonal mean zonal wind (contour) and meridional mass streamfunction (shaded, unit 10^9kg/s); Right: zonal mean temperature.

Multiple jet streams appear as the rotation rate increases, like what we observed on the gas giants within the Solar System. Hadley cell expands greatly as the rotation rate decreases, leading to a much smaller horizontal temperature gradient. Staircase-like features can be found in the temperature field at higher rotation rates, indicating the development of alternating eastward and westward jets and baroclinic zones.

Eddy activity is shown in the figures below. High rotation rate runs exhibit multi-band structures with broad wavenumber spectrum and small eddy scale. Low rotation rate runs show greater wave amplitude with small wavenumber (1 or 2).

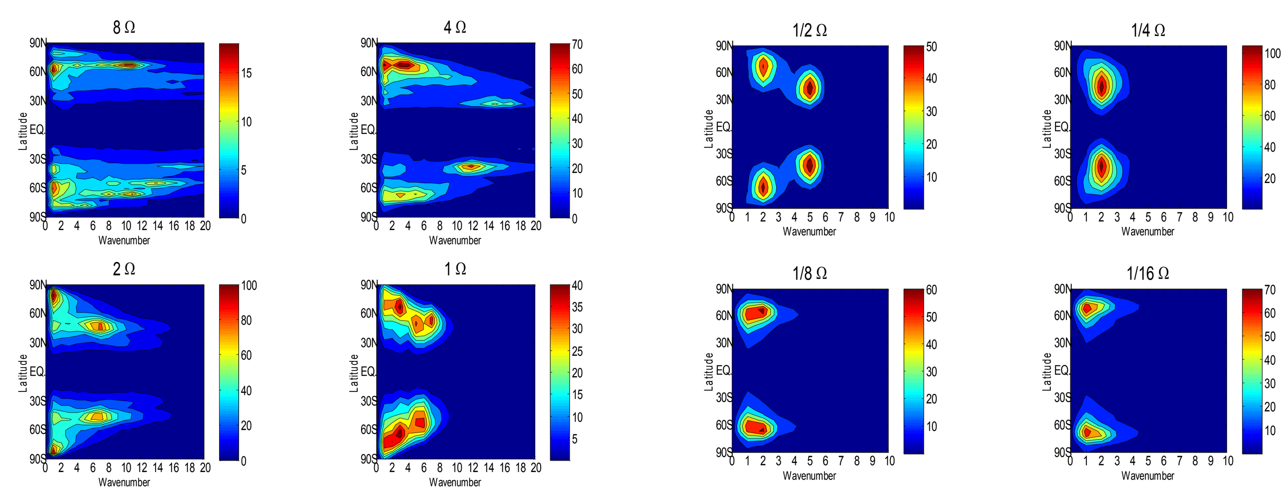

Fig. 4 FFT spectrum of the geopotential height field at 300mb. Colours represent the Fourier amplitude.

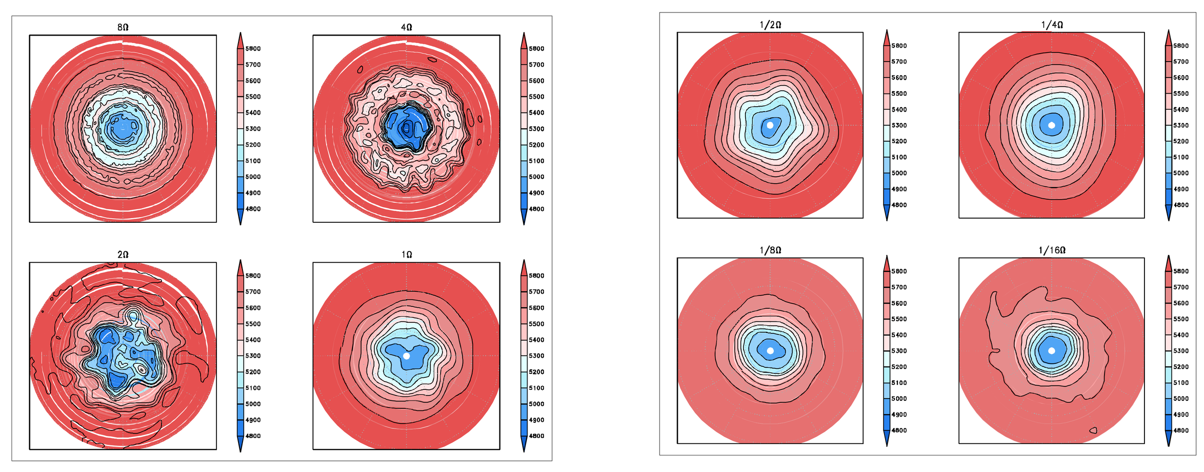

Fig. 5 Snapshots of the geopotential height at 500mb level.

4. Future Work

A physically more reasonable representation of radiative processes (possibly a two-band atmosphere with constant transmission in each band) will be developed to replace the Newtonian cooling, so that the radiative properties of the atmosphere can be taken into account. Works in the far future will also include the orbital parameters like planetary obliquity, orbital eccentricity and so on to encompass the exotic conditions we encountered on exoplanets (e.g. tidally-locked states, extreme obliquity).

[1].Read, P. (2010) Dynamics and circulation regimes of terrestrial planets. *Planetary and Space Science*. In press.

[2].Hide, R. and Mason, P. J. (1975) Sloping convection in a rotating fluid. *Advances in Physics*, 24: 47-100.

[3].Geisler, J. E., Pitcher, E. J., and Malone, R. C. (1983) Rotating fluid experiments with an atmospheric general circulation model, *Journal of Geophysical Research*, 88: 9706-9716.