Submission No.:01095

Energy spectra of atmospheric motions simulated by a high-resolution general circulation model of Venus

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The dynamics of the Venus atmosphere is unclear because of the lack of observational data. Many researchers have developed General Circulation models (GCM) for the Venus atmosphere and have attempted to simulate atmospheric motions of Venus. Because the planetary rotation period of Venus is much longer than the Earth, long-term integrations are needed for the solution to achieve a statistically steady state. Therefore, the simulations have been performed by low-resolution ($\sim$ T21; i.e., about 5.6 deg x 5.6 deg grids) models. We have developed a simplified Venus version of the AFES (Atmospheric GCM for the Earth Simulator) (Sugimoto et al. 2012) and performed a very high-resolution simulation. In this paper, we report and discuss kinetic energy spectra obtained from the high-resolution simulation.

The dynamical core of AFES is descretized by the spectral method in horizontal. The model resolution is T159 (i.e., about 0.75 deg x 0.75 deg grids) and L120 (Δz is about 1 km). In the model, the atmosphere is dry and forced by the solar heating with the diurnal change and Newtonian cooling that relaxes the temperature to the zonally uniform basic temperature which has a virtual static stability of Venus with almost neutral layers. To prevent numerical instability, the biharmonic hyper-diffusion is included with 0.01 days of e-folding time for the truncation wavenumber. The coefficient of the vertical eddy diffusion is 0.15 m^2 s^{-1}. A sponge layer is set above 80 km to prevent the reflection of waves. The dry convective adjustment scheme is used to avoid statically unstable state. A fast zonal wind in a solid-body rotation and the temperature field that balances (gradient wind balance) with the zonal wind are given as the initial state. Time-integrations are performed until the solution achieves a statistically steady state.

We calculate the horizontal kinetic energy per unit mass per unit wavenumber from the spectral coefficients of the vertical vorticity and horizontal diffusion (Koshyk & Hamilton 2001). The energy decreases by –5/3 power law in a range from wavenumber 4 to 45. Both in lower and higher wavenumber sides, the energy shows higher decreasing rate.

A feature of the energy spectral of aircraft observations (Nastrom & Gage 1985) and high-resolution GCM calculation of the Earth (Takahashi et al. 2006) is that the energy decreases by –3 power law in low-wavenumber range ($n < 80$) and by –5/3 power law in higher range. Terasaki et al. (2011) have reported that the –3 power law in synoptic scale is due to Rossby waves and the –5/3 power law in the mesoscales is due to gravity waves. The energy spectrum that we have obtained shows –5/3 power law in the wavenumber range lower than the Earth cases. This implies that the gravity waves may dominant even in scales of several thousand kilometers in the Venus atmosphere. A reason for the Rossby wave not being dominant in these scales may be the slow planetary rotation. The effect of the hyper-diffusion may appear in the range near the truncation wavenumber.

[Acknowledgement] This study was conducted under the joint research project of the Earth Simulator Center with title “Simulations of Atmospheric General Circulations of Earth-like Planets by AFES.”

Keywords: Venus atmosphere, general circulation model, high-resolution, kinetic energy spectra