EPSC Abstracts
Vol. 11, EPSC2017-788-2, 2017
European Planetary Science Congress 2017

Short-period planetary-scale waves found in a Venus GCM

M. Takagi (1), N. Sugimoto (2), H. Ando (1), and Y. Matsuda (3)
(1) Kyoto Sangyo University, Kyoto, Japan (takagi.masahiro@cc.kyoto-su.ac.jp / Fax: +81-75-705-1714), (2) Keio University, Yokohama, Japan, (3) Tokyo Gakugei University, Koganei, Japan

Abstract

Short-period waves or disturbances at the cloud levels in the Venus atmosphere are investigated using a GCM. Preliminary results show that two kinds of waves with periods of about 5.5 and 7.5 Earth days are found at 40–80 km levels. At 68 km, vortical motions and disturbances with remarkable zonal winds are predominant at mid-latitudes at 40°–70° and low-latitudes equatorwards of 30°, respectively. The structure of the low-latitude disturbances are similar to that of the equatorial Kelvin wave. Because phase speeds of these waves are the same, it is suggested that they form a planetary-scale coherent structure symmetric about the equator.

1. Introduction

In previous observations of the Venus atmosphere, it has been pointed out from the cloud motions that the so-called Kelvin and Rossby waves exist at the cloud top levels whose periods are about 4 and 5 Earth days, respectively [2, 4]. However, their structures and/or generation mechanisms remain unclear at present. New observational results on the atmospheric superrotation and various waves are being provided from the Akatsuki mission which has started observations from December 2015, by which the three-dimensional structures and wave activities of the Venus atmosphere at the cloud levels will be elucidated in the forthcoming future.

In order to interpret the observational results in terms of dynamics, and elicit as much information from them as possible, the Venus atmospheric dynamics should be investigate theoretically and numerically. In the present study, the short-period waves with periods shorter than 10 Earth days found at the cloud levels are investigated using a Venus GCM named VAFES [7].

2. Model

VAFES is a full nonlinear GCM with simplified physical processes for the Venus atmosphere based on the primitive equations on the sphere, which enables us reproduce realistic structures of the Venus upper atmosphere at the cloud levels such as the baroclinic instability waves, the cold collar, the thermal tides, and so on [8, 1]. The model atmosphere extends from the ground to about 120 km, and 120 levels are taken at a regular spacing of 2 km. The horizontal resolution is T63 (192×96 grid points in longitude and latitude). The vertical eddy viscosity with a constant coefficient of 0.15 $\mathrm{m^2\,s^{-1}}$ is used. The horizontal eddy viscosity is represented by the second-order hyper-viscosity, whose damping time for the maximum wavenumber is approximately 0.1 Earth days. The value of physical parameters are set adequately for the Venus atmosphere. The solar heating is based on the previous observation [9]; but it is neglected above 80 km in the present study. The temperature field is relaxed to a prescribed horizontally uniform field, $T_0(z)$, which is taken from the Venus international reference atmosphere (VIRA) [6]. See our previous work [8] for more details of the model.

The initial condition is an idealized superrotating state. The zonal wind is assumed to be in the solid body rotation; its velocity increases linearly with altitude from the ground to 70 km, which is 100 $\mathrm{m\,s^{-1}}$ at the equator at 70 km, and constant above this level. It is assumed that the planet rotates from west to east, as the Earth, and eastward is positive. The initial temperature distribution is cyclostrophically balanced with the initial zonal wind.

Using this initial state, we perform a nonlinear numerical integration for more than 5 Earth years. The model atmosphere reaches a quasi-equilibrium state within about 1 Earth year, in which the wind and temperature fields are stably maintained for more 4 Earth years, as shown in the previous studies [8]. In the present study, we analyze the data obtained for the last 1 Earth year in the quasi-equilibrium state. The sampling rate is every 6 hours.

3. Preliminary results

It has been shown from the Fourier analysis that two kinds of waves are found with periods of about 5.5 and 7.5 Earth days at broad vertical levels of 40–80 km. The

5.5-day and 7.5-day waves have significant amplitudes in the zonal winds at low-latitudes and latitudes from mid-latitudes to the polar region, respectively. On the other hand, in the meridional winds, they have at mid-latitudes and the polar region, respectively. It is thought that the 5.5-day wave is related to the baroclinic instability waves [8].

Figure 1 shows a horizontal structure of the short-period wave observed at 68 km. The short-period components are extracted by a high-pass filter with a cut-off period of 10 Earth days. It is found that vortex motions dominate at mid-latitudes, whose horizontal wind velocity is about 40 $\mathrm{m\,s^{-1}}$. In low-latitudes equatorwards of 30°, zonal winds with a zonal wavenumber of 1 are predominant, whose velocity is about 20 $\mathrm{m\,s^{-1}}$. Phase velocities of these waves observed at mid- and low-latitudes are the same. The present result suggests that a planetary-scale coherent structure which is symmetric about the equator and extends from the equator to mid-latitudes exists at the cloud top levels asociated with these waves. The symmetry about the equator has also been observed in UV cloud images and brightness temperatures at the cloud top levels [5]. Its generation mechanism remains unclear, but it may be related to the shear instability found in a shallow water system [3].

In the lower cloud levels (50–60 km), it is found that vortical motions with a zonal wavenumber of about 5 dominate at low-latitudes. It is also pointed out that streak structures extending to down-stream regions are found in the vertical winds at mid- and high-latitudes. These streak structures are associated with remarkable divergence and convergence of the horizontal winds. It is suggested that these structures are similar to recent nightside cloud images obtained by the IR2 camera onboard Akatsuki.

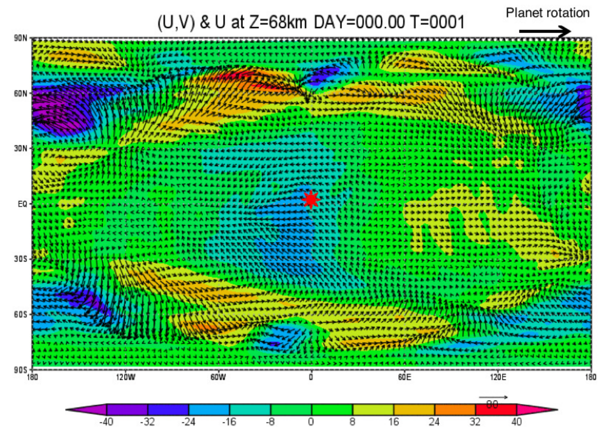

Figure 1: Horizontal structure of the short-period disturbances obtained at 68 km: horizontal winds (vectors) and zonal wind velocity (colors). Note that the subsolar point is located at (0°E, 0°N), the center of the figure.

References

[1] Ando, H., N. Sugimoto, M. Takagi, H. Kashimura, T. Imamura, and Y. Matsuda (2016), The puzzling Venusian polar atmospheric structure reproduced by a general circulation model, Nat. Commun., 7:10398, doi:10.1038/ncomms10398.

[2] Del Genio, A. D., and W. B. Rossow (1990), Planetary-scale waves and cyclic nature of cloud top dynamics on Venus, J. Atmos. Sci., 47, 293–318.

[3] Iga, S., and Y. Matsuda (2005), Shear Instability in a Shallow Water Model with Implications for the Venus Atmosphere, J. Atmos. Sci., 62, 2514–2527.

[4] Kouyama, T., T. Imamura, M. Nakamura, T. Satoh, and Y. Futaana (2015), Vertical propagation of planetary-scale waves in variable background winds in the upper cloud region of Venus, Icarus, 248, 560–568.

[5] Sato, T. M., H. Sagawa, T. Kouyama, K. Mitsuyama, T. Satoh, S. Ohtsuki, M. Ueno, Y. Kasaba, M. Nakamura, and T. Imamura (2014), Cloud top structure of Venus revealed by Subaru/COMICS mid-infrared images, Icarus, 243, 386–399.

[6] Seiff, A., J. T. Schofield, A. J. Kliore, F. W. Taylor, S. S. Limaye, H. E. Revercomb, L. A. Sromovsky, V. V. Kerzhanovich, V. I. Moroz, and M. Ya. Marov (1985), Adv. Space Res., 5, 3–58.

[7] Sugimoto, N., M. Takagi, and Y. Matsuda (2014), Baroclinic instability in the Venus atmosphere simulated by GCM, J. Geophys. Res. Planets, 119, 1950–1968, doi:10.1002/2014JE004624.

[8] Sugimoto, N., M. Takagi, and Y. Matsuda (2014), Waves in a Venus general circulation model, Geophys. Res. Lett., 41, 7461–7467, doi:10.1002/ 2014GL061807.

[9] Tomasko, M. G., L. R. Doose, P. H. Smith, and A. P. Odell (1980), Measurementsof the flux of sunlight in the atmosphere of Venus, J. Geophys. Res., 85, 8167–8186.