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Simulation of Venusian atmosphere by AFES (Atmospheric general circulation model For the Earth Simulator)

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Abstract

We have developed an atmospheric general circulation model (AGCM) for Venus on the basis of AFES (AGCM For the Earth Simulator) and performed a very high-resolution simulation. A superrotation consistent with observations is reproduced with a realistic solar heating. Baroclinic waves appear in a weakly stratified layer with large vertical shear of the basic zonal flow at the cloud level. Rossby and Kelvin waves generated in the model are consistent with observations. Furthermore, a realistic polar cold collar is reproduced in the polar region. Spectral analyses of the horizontal kinetic energy are also performed in the results with a high-resolution simulation (T159L120).

1. Introduction

So far, low-resolution GCMs have been used to simulate phenomena in the Venus atmosphere. This is mainly because of the extremely long spin-up time to generate a superrotation from a motionless state. Furthermore, in order to generate a superrotation, most of the previous GCM studies have included unrealistic strong solar heating and static stability. In the present study, we have constructed a new model based on AFES to perform realistic high-resolution simulations of the Venus atmosphere.

Many observational studies have reported signals of planetary-scale Rossby- and Kelvin-type waves at the cloud top. However, the waves obtained in the previous numerical studies are not consistent with observations. This is partly because the fast mean zonal flow has not been reproduced realistically in the models. Further, the weakly stratified layer in the cloud layer has been neglected in their models. Observational studies also suggest that small-scale gravity waves play important roles at the cloud level.

In the present study, we perform simulations with very high resolutions to investigate properties of disturbances in a wide range of scales in the Venus atmosphere. The neutral waves and the polar cold collar are important targets to take advantage of a high resolution model.

2. Model

AFES simulations are performed with simplified physical processes adopting the values of physical constants appropriate for Venus. The experimental settings basically follow those of the previous AFES simulations [1]. The highest resolution used in the present simulations is T159L120, which is equivalent to a horizontal grid size of about 79 km. The vertical domain extends from the ground to about 120 km with almost the constant grid spacing of 1 km. Simulations with T63L120 and T42L60 resolutions, are also performed.

The physical processes adopted in the model are vertical eddy diffusion with a constant diffusion coefficient of 0.15 m2/s, the Newtonian cooling, and the Rayleigh friction at the lowest level representing the surface friction. In the upper region above about 80 km, a sponge layer is assumed. In addition, the model includes a 4th-order horizontal diffusion with an e-folding time for the maximum wavenumber of about 0.01 days for T159, 0.03 days for T63, and 0.1 days for T42 simulations. The coefficients of the Newtonian cooling are based on the previous study. The equilibrium temperature distribution toward which temperature is relaxed by the Newtonian cooling is the prescribed horizontally uniform temperature distribution based on observations. We adopt a realistic profile of solar heating. Vertical and horizontal distributions of the solar heating are based on Tomasko et al. [2].

The vertical temperature profiles of the initial conditions are constructed based on the observed vertical distribution of static stability. The initial condition for wind velocity is zonally symmetric, solid-body superrotating flow, which is determined by the gradient wind balance; zonal velocity at the equator linearly increases from zero at the ground up to 100 m/s at the altitude of 70 km, and above there the atmosphere is in a solid-body rotation with the same speed as that at 70 km. From this initial condition, time integration is performed for four Earth years for T159 and T42 simulations and ten Earth years for T63 simulation.

3. Results

Starting from the idealized superrotation, the model atmosphere reaches a quasi-equilibrium state within one Earth year. The zonal-mean zonal flow, which is accompanied with weak mid-latitude jets, has almost constant velocity of 120m/s in latitudes between 45°S and 45°N at the cloud top levels. This meridional distribution of the zonal flow agrees very well with observations. Strong latitudinal temperature gradient is produced at 45–70 km, where the temperature difference between the equator and the pole is more than 25 K. Strong baroclinicity, i.e., large vertical shear of the zonal flow is maintained at mid-latitudes in the weakly stratified layer extending from 50 to 70 km by the solar heating.

The horizontal structure of the baroclinic waves observed at 70 km for T63 simulation is shown in Fig. 1. In mid-latitudes between 30° and 60° the zonal wave number 1 component of geopotential height is predominant. These disturbances are in phase with temperature deviations at the altitude of 60 km (color). The result suggests that so-called Rossby waves observed at the cloud top are generated by the baroclinic waves excited at around the altitude of 60 km. The period of the waves is about 5.8 days. These wave characteristics are in good agreement with the observed so-called Rossby waves.

Below the altitude of 50 km, planetary-scale waves with zonal wave number 1 appear in the low latitudes between 30°S and 30°N, where zonal winds are predominant. The horizontal structure of the equatorial waves is similar to the so-called Kelvin waves. The period of the equatorial waves is about 6.2 days which is consistent with those observed at the levels of 50–60 km. These results are summarized in [3].

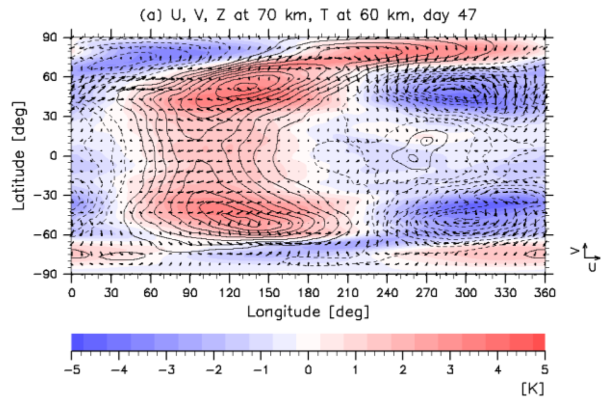

Figure 1: Horizontal distributions of geopotential height (black contours) and horizontal flow (black vectors) associated with the short-period disturbances at 70 km height, and temperature deviation at 60 km height (color shades) at day 47 from ten Earth years. A band-pass filter between the periods of 2 and 8 Earth days is applied. Contour intervals are 25m and vector units are 50m/s.

4. Summary and Conclusions

We have performed a very high-resolution simulation for Venusian atmosphere by AFES. Rossby and Kelvin waves generated in the model are consistent with observations. The results indicate that the realistic vertical distribution of static stability with thermal tides and sufficient model resolution are crucial for reproducing the Venus atmosphere.

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