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Thermal tide mechanism of the Venus atmospheric superrotation

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Abstract

It has been examined how the thermal tide mechanism of the Venus atmospheric superrotation depends on the static stability and the distribution of the solar heating. The results show that the superrotation is maintained in the cases of the large static stability. In the case including the mean zonal component of the solar heating, very fast mean zonal flow appears, which is maintained by the vital semidiurnal tide excited in the cloud levels.

1. Introduction

The atmospheric superrotation is one of the most remarkable features of the Venus atmosphere. In spite of many efforts, the generation mechanism remains unclear. In recent years, numerical experiments with general circulation models (GCMs) have been performed in order to investigate it [14, 13, 8, 5, 6]. The results suggest that both the thermal tide mechanism and the Gierasch mechanism can work in dynamically consistent ways. It should be also pointed out that both the mechanisms are closely related, since the thermal tides and the mean meridional circulation may interact with each other through the mean zonal flow (superrotation) and the associated temperature field. Therefore, it is important to investigate their dynamical interaction.

It has been shown by Takagi and Matsuda [13] that the Venus atmospheric superrotation may be generated and maintained by the thermal tides excited by the solar heating at the cloud levels. The results obtained by Lebonnois et al. [7] also show that the maintenance of the superrotation is strongly affected by the thermal tides. In the thermal tide mechanism, the superrotation is supposed to be sensitive to the static stability, initial condition, distribution of the solar heating, and so on. In this study, we focus on the dependence of the thermal tide mechanism on these parameters which have not been examined in the previous studies yet.

2. Model

A dynamical core of the GCM used in the present study is the same as used by Takagi and Matsuda [13]. The model atmosphere extends from the ground to 120 km, which is divided into 60 layers. Coefficients of vertical eddy viscosity and heat diffusion are 0.015 $m^2\ s^{-1}$ (constant). The fourth order hyper-viscosity is used, whose relaxation time is set to 4–10 Earth days for the smallest scale. Rayleigh friction is not used except in the lowest layer to mimic the surface friction. The specific heat of the Venus atmosphere is strongly dependent on temperature [12]. However, this is neglected in order to “control” the static stability. In the present study, numerical experiments are carried out for several profiles of the static stability. The topography is also neglected.

The vertical profile of the solar heating is based on the Pioneer Venus observations [3]. The radiative process is simplified by Newtonian cooling as follows:

$$\left(\frac{dT}{dt}\right)_{\mathrm{rad}} = Q - \kappa(z)[T - T_{\mathrm{ref}}(z)]$$

The relaxation coefficient $\kappa(z)$ dependent on the height is based on the work of Crisp (1986). The horizontally uniform reference temperature is based on VIRA [11] and slightly modified so as to be consistent with the assumed static stability.

Superrotating flow is given as an initial condition. The zonal velocity increase linearly with height below 70 km. Above 70 km, it is assumed to be constant (100 m s^{-1}). The meridional distribution is assumed to be solid body rotation. The initial temperature distribution is in balance (gradient wind balance) with the given mean zonal flow.

3. Results and remarks

First, we carried out numerical experiments without the zonally averaged component of the solar heating,

Q_0. The results show that the superrotation is maintained in cases of large static stability, as shown in Fig. 1. However, it fades out with time in cases of

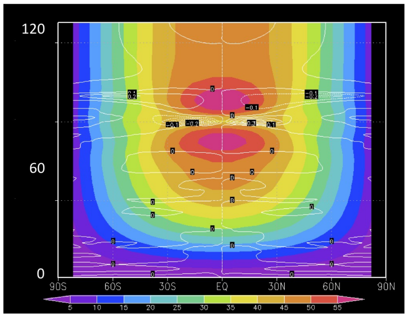

Figure 1: Mean zonal flow in the meridional-height section obtained at 150 Earth years for the case with the static stability of 9 K km^{-1}.

small static stability. The amplitude of the semidiurnal tide is strongly affected by the mean flow at levels where the tide is excited. The difference may by explained by the dispersion relation of the gravity wave, and the thermodynamic balance of the semidiurnal tide. The maintenance of the mean zonal flow depends on the propagating property and the excitation process of the thermal tide, which depend on the mean zonal flow at the same time.

In the cases including the Q_0 component of the solar heating, it is shown that the fast superrotation is generated. The maximum velocity is about 200 m s^{-1} at 80 km in the equatorial region. In these cases, it seems that the deceleration effect of the mean zonal flow in the upper atmosphere is canceled out by the vertical advection of $dU/dz < 0$ above the cloud level, and the strong thermal tide is excited because of the fast mean zonal flow. The momentum is actively exchanged between the cloud and the near ground levels because of the vital semidiurnal tide.

We are going to investigate how the thermal tide mechanism depends on other processes including the heating distribution, initial conditions, sub-grid scale parameterizaions, and so on.

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