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General circulation in the Venus lower atmosphere

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Abstract

A numerical model has been improved in order to investigate atmospheric general circulation in the Venus lower atmosphere. A preliminary result shows that the mean zonal flow maintained by the thermal tide mechanism is strongly dependent on the solar heating, which controls angular momentum exchange between the atmosphere and the planet in the lowest layer.

1. Introduction

The atmospheric superrotation is one of the most remarkable phenomena in the Venus atmosphere. In recent years, it has been investigated by use of general circulation models (GCMs) [11, 9, 6, 4, 5]. The results suggest that the superrotation may be generated and maintained independently by the Gierasch mechanism (GM) [2, 7] and the thermal tide mechanism (TTM) [1, 8]. It is noted, however, that some of these models include unrealistically strong solar heating, which excites large cells of the mean meridional circulation extending from the ground to the cloud levels, and that GM may not work without it [4]. Recently, it has been pointed out by use of the realistic solar heating that the superrotation is likely to be maintained by both TTM and GM, at least at the cloud levels [10].

In the present study, by extending the work of Takagi et al. (2013), we focus on the superrotation in the lower atmosphere below the cloud levels in order to examine how angular momentum required for the generation of the atmospheric superrotation is supplied from the solid part of Venus in GM and TTM.

2. Model

A general circulation model used in the present study is based on Takagi and Matsuda (2007, 2013). The model atmosphere extends from the ground to about 120 km. Horizontal and vertical resolutions are set to T21L76 (a triangular truncation at wavenumber 21 with 76 layers). It is noted that the vertical resolution is much improved below 30 km in order to resolve downward propagation of the thermal tide near the ground. The layer depth at each altitude is shown in Figure 1. Coefficients of vertical eddy diffusion and heat diffusion are assumed to be a constant, 0.015 $\mathrm{m^2\,s^{-1}}$, except in the lowest layers below 5 km which is assumed to be the planetary boundary layer. 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.

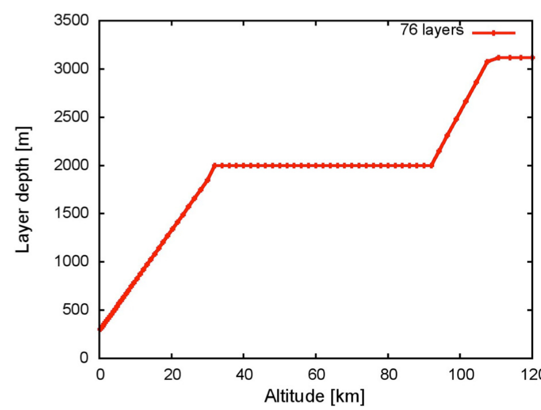

Figure 1: Layer depth at each altitude.

A vertical profile of the solar heating is based on the Pioneer Venus observations. Above 80 km, the solar heating is neglected. In order to investigate the combined effect of TTM and GM, the horizontal distribution of the solar heating is decomposed into Fourier components: $Q = Q_0 + Q_1 + Q_2 + \cdots$, where subscripts denote zonal wavenumbers. In the present study, Q_0 and Q_2 components, which excite the mean meridional circulation and the semidiurnal tide, are taken into account. Q_1 component is omitted because TTM is not so affected by the diurnal tide [9]. The infrared radiative process is quite simplified by Newtonian cooling as follows:

$$\left(\frac{dT}{dt}\right)_{\rm rad} = Q - \kappa\left(T - T_{\rm ref}(z)\right). \qquad (1)$$

The relaxation coefficient $\kappa(z)$ dependent on altitude is based on the work by Crisp (1986). The temperature distribution toward which the temperature is relaxed by Newtonian cooling is horizontally uniform, whose vertical profile is based on VIRA and slightly modified so as to be consistent with the assumed static stability. A weakly stratified layer in the cloud is taken into account in the present study. The specific heat of the Venus atmosphere is dependent on temperature. However, this is neglected in order to control the static stability. The topography is also neglected in the present study.

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 $\mathrm{m\,s^{-1}}$). 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

The preliminary result indicates that the mean zonal flow in the lowest layer, which controls angular momentum exchange between the atmosphere and the planet, strongly depends on the solar heating. Figure 2 shows the meridional profile of the mean zonal flow at the lowest level obtained in the TTM case. Since the surface friction is assumed to be proportional to the velocity, the total angular momentum of the atmosphere increases for this profile.

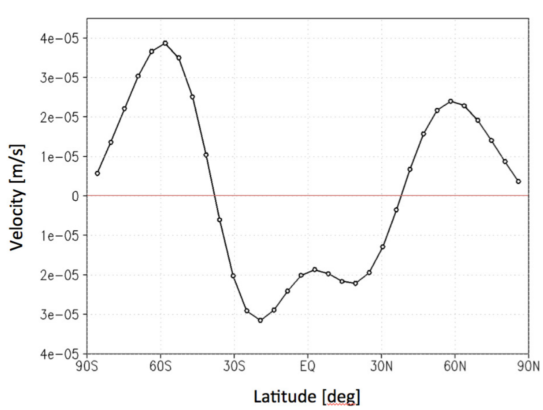

Figure 2: Meridional profile of the mean zonal flow at the lowest layer obtained in the TTM case.

We will also examine how the general circulation in the lower Venus atmosphere depends on the model parameters and the initial conditions.

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