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Mean meridional circulation in the Venus atmosphere

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Abstract

A realistic radiative transfer model applicable to the Venus atmosphere has been incorporated into a 3D general circulation model in order to investigate the mean meridional circulation. The result obtained for the zonally averaged solar heating shows that the mean meridional circulation splits into vertically stacked cells at 30–80 km levels. Mean zonal flow with midlatitude jets is induced by the mean meridional circulation at the cloud levels. However, it remains weak below 30 km.

1. Introduction

The atmospheric superrotation is one of the most remarkable features of the Venus atmosphere. In recent years, numerical experiments with general circulation models (GCM) have been performed to investigate its generation mechanism [14, 12, 7, 4, 5]. The results suggest that both the thermal tide mechanism [2, 9] and the Gierasch mechanism [3, 8] can work as the generation mechanism of the superrotation in dynamically consistent ways.

It has been pointed out by Hollingsworth et al. [2007] that mean meridional circulation excited by a realistic distribution of the solar heating splits into vertically stacked cells, and the mean zonal flow (the atmospheric superrotation) remains extremely weak.

Recently, Lebonnois et al. [6] carried out numerical simulations by using a GCM combined with a radiative transfer model based on Eymet et al. [1]. The result shows that the mean meridional circulation splits into several cells in the cases with realistic solar heating, and the mean zonal flow remains weak below the cloud layer. This feature seems consistent with that of Hollingsworth et al. [4].

In the present study, we would like to focus on the mean meridional circulation in the Venus atmosphere, and its dynamical effects on the superrotation. In order to explain the generation mechanism of the superrotation, we must investigate interaction among the mean meridional circulation, the mean zonal flow, and the thermal tides.

2. Model

A dynamical core of the GCM used in the present study is the same as used by Takagi and Matsuda [12]. The model atmosphere extends from the ground to about 100 km, which is divided into 50 layers. Coefficients of vertical eddy viscosity and heat diffusion are 0.1 and 0.01 $\mathrm{m^2\,s^{-1}}$, respectively. The temperature dependence of the specific heat is taken into account [11]. The solar heating is zonally averaged and prescribed in the present study. The diurnal variation of the solar heating is neglected in order to focus on the mean meridional circulation. The topography is also neglected. The initial state for time integration is assumed to be an atmosphere at rest. The initial temperature distribution, which is horizontally uniform, is based on the Venus International Reference Atmosphere (VIRA) [10].

The radiative transfer model in the infrared region is based on Takagi et al. [13]. The spectral range 0–6000 $\mathrm{cm^{-1}}$ is divided into 10 channels. The one-dimensional radiative-convective equilibrium temperature profile obtained by the present radiative transfer model for the solar heating averaged over the sphere is in good agreement with the observed temperature profile as shown in the work of Takagi et al. [13].

3. Results

Figure 1 shows clearly that the mean meridional circulation splits into two cells, which extend from 30 to 50 km and 50 to 80 km, respectively. Below 20–30 km, the mean meridional circulation consists of several small cells which fluctuates temporally.

It is shown in Figure 2 that the mean zonal flow (superrotation) with midlatitude jets appears in 30–70 km. The maximum velocity is about 14 $\mathrm{m\,s^{-1}}$ in the jet regions at 60 km, which is much less than observed values. Below 30 km, the mean zonal flow remains very weak, namely less than 2 $\mathrm{m\,s^{-1}}$.

It may be suggested from the present result that the

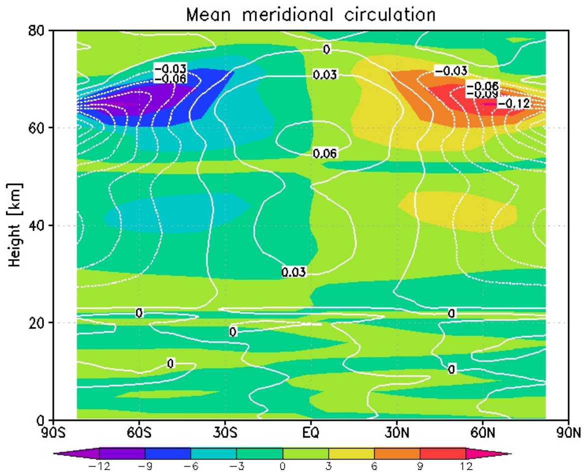

Figure 1: Meridional-height distribution of mean meridional wind $(\mathrm{m}^{-1}\,\mathrm{s}^{-1})$ obtained at 100 Earth years.

robust meridional circulation forced by the realistic solar heating is maintained only in 30–80 km, and consists of the vertically stacked cells. The mean zonal flow induced by this kind of the mean meridional circulation is much weaker than the observed superrotation.

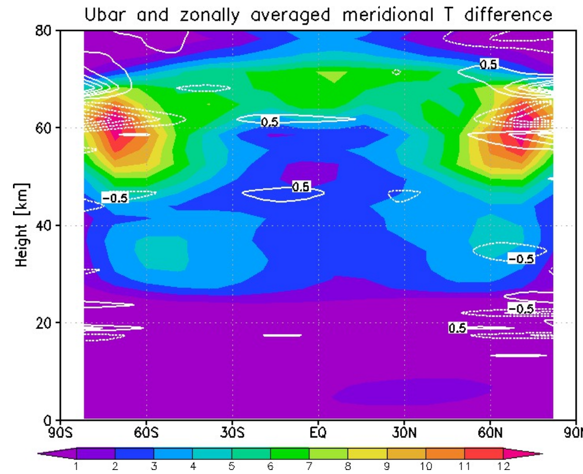

Figure 2: Same as in Figure 1 but for mean zonal wind.

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