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放射輸送を考慮したモデルで再現された金星下層大気の大循環
General circulation of the Venus lower atmosphere simulated by a GCM with a new radiative transfer model

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The atmospheric superrotation is one of the most remarkable features of the Venus atmosphere. In recent years, several numerical experiments with general circulation models (GCMs) have been performed to investigate the generation mechanism of the Venus atmospheric superrotation (Yamamoto and Takahashi 2003; Takagi and Matsuda, 2007; Lee et al., 2007; Hollingsworth et al., 2007; Kido and Wakata, 2008). The results suggest that both the Gierasch mechanism (Gierasch, 1975; Matsuda, 1980) and the thermal tide mechanism (Fels and Lindzen, 1974; Plumb, 1975) may explain the atmospheric superrotation in dynamically consistent ways. However, in these studies, the radiative process is extremely simplified by Newtonian cooling. Since the Venus atmosphere is optically very thick in the infrared region, this simplification cannot be justified at all, especially in the Venus lower atmosphere. It has been also pointed out by Hollingsworth et al. (2007) that only extremely weak atmospheric superrotation is generated when realistic solar heating is adopted. In order to understand the real generation mechanism of the atmospheric superrotation, the radiative processes should be improved. Recently, Lebonnois et al. (2010) carried out numerical simulations by using a GCM combined with a radiative transfer model based on Eymet et al. (2009). Their results show that the atmospheric superrotation with about 70 m/s is obtained above about 40 km, while the mean zonal wind remains very weak below.

In the present study, a radiative transfer model applicable to the Venus atmosphere (Takagi et al., 2010) is incorporated into a three-dimensional general circulation model to investigate the generation mechanism of the atmospheric superrotation by focusing on the mean meridional circulation. A dynamical core of the GCM is the same as used by Takagi and Matsuda (2007). The model atmosphere extends from the ground to about 100 km, which is divided into 50 layers at a regular spacing of 2 km. The horizontal resolution is T10 (triangular truncation at wave number 10). Temperature dependence of the specific heat at constant pressure is taken into account (Staley, 1970). Horizontal eddy viscosity is represented by the second-order hyperviscosity with relaxation time of 1 Earth day for the maximum wave number component. Rayleigh friction is not used in the present model except at the lowest level, where the surface friction acts on horizontal winds. In addition, the dry convective adjustment scheme is used to restore the temperature lapse rate to the neutral one when an atmospheric layer becomes statically unstable. The solar heating is zonally averaged and prescribed in the present study. The vertical profile is based on the works of Tomasko et al. (1980) and Crisp (1986).

After numerical integration for 100 Earth years, it is found that the mean zonal flow with remarkable jets is generated in 30-70 km. Meridional temperature difference is only few K degrees near the cloud top level. This is consistent with the weak zonal flows obtained in this simulation in view of thermal wind balance. A weak local maximum (7-8 m/s) is observed in the equatorial region at 70 km. Weaker midlatitude jets are also found at about 40 km. Below 30 km, the mean zonal flow remains very weak. The temperature contrast between the equator and poles is less than 1 K at these levels. The mean meridional circulation splits into two cells which extend from 20 to 50 km and from 50 to 80 km. The maximum velocity of the mean meridional flow is about 12 m/s at about 67 km near 60 N/S. The mean meridional circulation simulated in the model splits into three parts. The upper two cells seem persistent. The present result implies that the atmospheric superrotation may be strongly affected by the mean meridional circulation in the lower atmosphere, and the Gierasch mechanism may not work in the Venus atmosphere.

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