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Sensitivity of atmospheric circulation patterns to rotation of cloud-covered terrestrial planet

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Abstract

The present study investigates atmospheric general circulations of cloud-covered terrestrial planets in sensitivity experiments for planetary rotation, based on a high-resolution idealized Venus AGCM with different planetary rotation. In case of the 243-day rotation period, high-latitude jets extend to the lower atmosphere below the cloud layer, where direct and polar indirect cells are formed. In case of the 16-day period, strong superrotation is formed in the cloud layer in the absence of indirect circulation. In case of the 1-day period, superrotation is located above the cloud layer, and equatorial direct and midlatitude indirect circulations are formed in and below the cloud layer. Structures of direct and indirect meridional cells below the cloud layer control the intensity and location of the superrotation via the angular momentum transports.

1. Introduction

Benchmark tests and inter-comparisons of atmospheric general circulation models (AGCMs) have been conducted in the climate and geophysical fluid dynamics communities. Recently, the AGCM inter-comparisons are extended to Venus. The inter-comparisons among Venus AGCMs [1-2] showed that there are large differences among the models under the same Venus-like condition, and some model parameters influence the general circulation structures. These simplified experiments were applied to a MIROC AGCM for checking the validity of the Venus model, and were extended to the higher resolution (T106) [3].

In the present study, the Venus AGCM benchmark (baseline run in the ISSI inter-comparison among Venus AGCMs [2]) is considered as an idealized Venus atmosphere, and sensitivity experiments for planetary rotation period (1, 16, and 243 days) are conducted in order to elucidate atmospheric general circulation of cloud-covered terrestrial planets.

2. Model

The model setting is the same as the baseline run of CCSR in the ISSI inter-comparison among Venus AGCMs [2], except for the model resolution (T106 in the present study). It is noted that the time constant of 6-order hyper diffusion at maximum wavenumber was set at 30 Earth days in the ISSI inter-comparison [2] and the present study, although the time constant was written at 3 Earth days in Table 8.1 of [2] (because Yamamoto missed the correction in the proof). The thermal forcing around the cloud layer far from the surface is given by the meridional temperature difference and Newtonian cooling. In the present sensitivity experiments, the periods of the planetary rotation in Cases V, T, and E are set at 243, 16, and 1 Earth days, respectively.

3. Results

Case V (Venus condition) is conducted as the control run. High-latitude jets of >30 m/s extend to the lower atmosphere below the cloud layer. Direct and polar indirect circulations are seen around the jets. In the case of the 16-day rotation period (same as Titan's one, Case T), high-latitude jets are strong (>80 m/s) in the cloud layer. The direct circulation is predominant in and below the cloud layer, while the indirect circulation is not. The angular momentum is efficiently pumped up by the direct circulation, in which the zonal-mean vertical wind is upward (downward) at the equator (pole). In contrast to the slowly rotating planets (Case V and Case T), superrotational flow of >50 m/s is located above the cloud layer in a fast rotating planet with a 1-day rotation period (Case E). We can see equatorial direct and midlatitude indirect circulations in and below the cloud layer. Small polar direct cells are also seen near the surface. In the presence of the multiple cells, similar to Earth, superrotation is not strong in and below the cloud layer.

4. Summary

We can find three different types of atmospheric general circulations of cloud-covered terrestrial planets, dependent on the planetary rotation. In Case V, the superrotation extends to the lower atmosphere below the cloud layer, where direct and polar indirect circulations are formed. In Case T, strong superrotation is formed in the cloud layer in the absence of the indirect circulation. In Case E, the superrotation is located above the cloud layer, and the equatorial direct and midlatitude indirect circulations are formed in and below the cloud layer. The structures of direct and indirect meridional cells below the cloud layer control the intensity and location of the superrotation via the angular momentum transports. The dynamical mechanism will be discussed in the presentation, based on the analysis using the transformed Eulerian-mean equation system.

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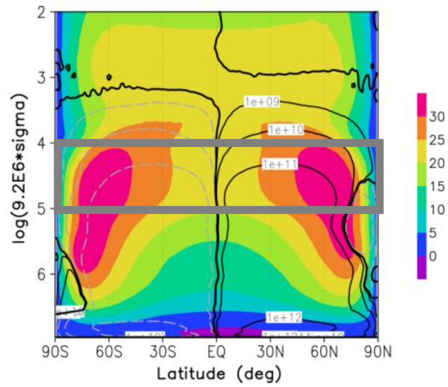

Figure 1: Zonal wind and stream function in Case V (243-day rotation period). Gray rectangle shows cloud layer.

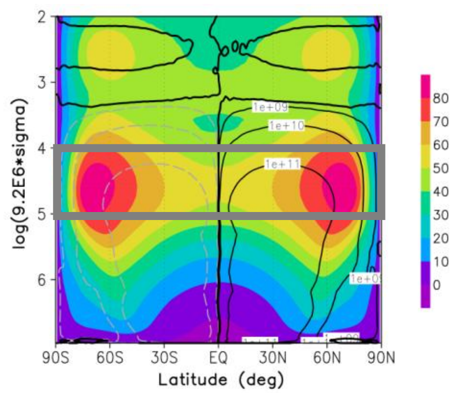

Figure 2: Zonal wind and stream function in Case T (16-day rotation period). Gray rectangle shows cloud layer.

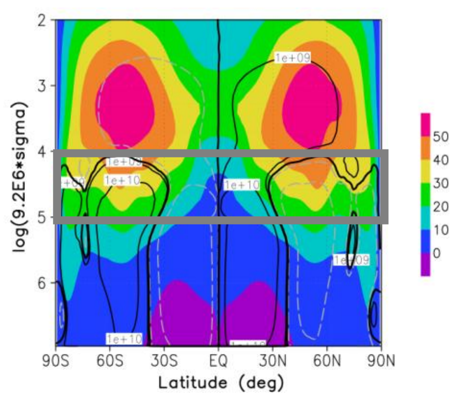

Figure 3: Zonal wind and stream function in Case E (1-day rotation period). Gray rectangle shows cloud layer.