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Generation mechanism of precessing circulation of the Venus polar vortex

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Abstract

Recent infrared measurements conducted in Venus Express showed the short-period temporal variation of the polar vortex, implying that the rotation period of the atmosphere in the polar region oscillates quasi-periodically. However, the mechanism to generate it has been unknown. Here we show the observed short-period variations are well reproduced for the first time by a Venus general circulation model. These variations are caused by short-period disturbances related to barotropic instability in the polar region. The zonally averaged zonal wind velocity changes quasi-periodically due to meridional transport of zonal momentum associated with a zonal wavenumber-1 component of the short-period disturbances; the mean zonal velocity increases (decreases) when the disturbances are inclined on the longitude-latitude plane toward northeast (northwest) direction. Our present result suggests that the vacillation of the polar vortex occurs in the Venus as well as the Earth, and shows that barotropic instability plays a crucial role to induce the vacillation in both planets.

1. Introduction

Interesting unique features are known in the Venus polar atmosphere at the cloud levels. The cold collar is a distinguishing thermal structure observed at high latitudes at about 65 km altitude, which is a local cold latitude band surrounding the warm polar region ([1], [2]). In the warm polar region, axi-asymmetric temperature disturbances with zonal wavenumbers of 1 and/or 2 have been observed by infrared measurements, which rotate around the pole with the period of ~3 Earth days ([1], [2]).

Temporal variations of the structure of the Venus polar vortex have been suggested from the recent infrared measurements in Venus Express mission ([3], [4]). It is indicated that the vortex center rotates around the pole in a precessional motion with nearly constant but temporally varying angular velocity. Interestingly, the rotational motion of the vortex center is accelerated and decelerated quasi-periodically with a period of ~3 Earth days. It is also inferred that these motions might be attributed to the axi-asymmetric eddies generated by barotropic or baroclinic instabilities. However, these infrared measurements of the Venus polar atmosphere were not performed for a long period continuously, it is difficult to investigate a mechanism of the temporal variation of the polar vortex.

Atmospheric GCM for the Earth Simulator for Venus (VAFES) ([5], [6]) succeeded in reproducing the cold collar and the warm polar region, and elucidating the generation mechanism of these thermal structures ([7]). Furthermore, it also reproduced the short-period axi-asymmetric temperature disturbances seen in the warm polar region ([7]), which is in good agreement with infrared and radio occultation measurements ([1], [2], [3], [4]), and showed their three-dimensional structures. In the present study, we used VAFES to investigate the mechanism of the short-period temporal variation of the polar vortex suggested by the previous infrared measurements ([3], [4]).

2. Results

In this study, we focus on the short-period disturbances with the period of less than 10 Earth days. Figures 1a and 1b show the latitude-time distributions of the zonally averaged zonal wind superimposed on the zonally averaged horizontal momentum flux associated with the zonal wavenumber-1 component of short-period disturbances at the latitudes of 60˚N–90˚N at 57 km and 70 km altitudes. At both altitudes, the oscillation pattern of the zonally averaged zonal wind speed is closely related to the sign of the horizontal momentum flux at latitudes poleward of 75˚N: the wind speed increases (decreases) when the sign is positive (negative) and then the horizontal momentum is transported toward the pole (low and middle latitudes). Recent work by VAFES indicated that the short-period disturbance is related to barotropic instability in the polar region, then it is possible that the quasi-periodical oscillation of the zonally averaged zonal wind speed shown in Figures 1a and 1b is also connected with barotropic instability. Figures 1c and 1d show the latitude-time distributions of the meridional gradient of the absolute vorticity at latitudes poleward of 60˚N at 57 km and 70 km altitudes. There are a lot of timings when it is equal to zero at the latitudes poleward of 75˚N at 57 km altitude and 80˚N at 70 km altitude. This suggests that the necessary condition where barotropic instability occurs is satisfied near the pole. It is also confirmed that the short-period oscillation of the zonally averaged zonal wind speed is mainly associated with the horizontal momentum flux. Then barotropic instability seems to play an important role in generating this oscillation in our model.

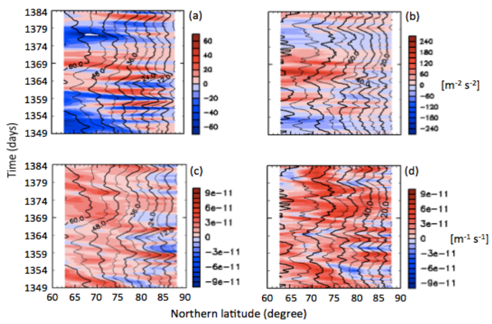

Figure 1: Latitude-time distributions of (Top) the zonally averaged momentum flux associated with zonal wavenumber-1 component of the short-period disturbances and (Bottom) meridional gradient of absolute vorticity. The black contour shown in each panel represents the zonally averaged zonal wind speed. Left (**a** and **c**) and right (**b** and **d**) columns are at 57 km and 70 km altitudes. The latitude and time ranges are 60˚N–90˚N and 1349–1384 Earth days, respectively.

3. Summary and Conclusions

Vacillation in the Earth's polar vortex, which is the quasi-periodical variation of the zonally averaged zonal wind speed in the polar region, is often observed. Our results suggest that the vacillation might also occur in the Venus polar vortex, implying that the atmospheric motion in it is unstable. In case of the Earth, it is theoretically shown that the vacillation is attributed to the short-period disturbance related to barotropic and/or baroclinic instability in a forced-dissipative polar vortex system ([8]). Our results also indicate that the quasi-periodic oscillation of the zonally averaged zonal wind speed is related to barotropic instability in the Venus polar region. Therefore, barotropic instability might be the main generation mechanism of the vacillation common to the Earth and Venus atmospheres.

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