EPSC Abstracts
Vol. 10, EPSC2015-54, 2015
European Planetary Science Congress 2015

A mysterious structure of Venusian upper polar atmosphere reproduced by a general circulation model

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Abstract

The polar cold collar, a cold band zonally surrounding the warm polar vortex at ~60˚ latitude, is a unique feature observed at the ~65 km level in the Venus atmosphere. As this structure has been observed in numerous previous observations, the cold collar and warm polar vortex are robust features in the Venus upper atmosphere [1]. We performed numerical simulations of Venus atmospheric circulation using a general circulation model (GCM) named AFES for Venus, and observed that these features are reproduced in close agreement with the observations. The cold collar and warm polar vortex might be contributed to residual mean meridional circulation closely related to thermal tides. The present results suggest that the thermal tides might be crucial for the structure of the Venus upper polar atmosphere at and above cloud levels.

1. Introduction

Venus atmospheric dynamics has been studied numerically using GCMs. However, there were no numerical studies which succeeded in reproducing a unique structure of the Venus polar atmosphere in realistic model settings.

Thermal tides are planetary scale waves excited by the solar heating. In the Venus atmosphere, they are strongly excited at the cloud levels because a large part of the solar flux is absorbed there [2]. However, their effects on the atmospheric structure in the polar region have not yet been examined. In this study, we investigate the structure of the Venus upper polar atmosphere using a GCM named AFES for Venus. To examine the dynamical effects of thermal tides, we perform two numerical experiments with observation-based distributions of solar heating: one with the diurnal components (Case A) and one without them (Case B). The thermal tides are excited only in Case A. See Sugimoto et al. (2014) [3] for the details of the model settings.

2. Results and Discussion

Fig. 1 shows the time evolution of the horizontal temperature distribution at ~68 km obtained in Case A. The cold collar surrounds the warmer polar region at ~60°N. The maximum temperature difference between 60°N and the pole is ~20 K. As shown in Fig. 1, zonal components with wavenumbers of zero and one are predominant in the temperature distribution in the cold collar.

Figs. 2a and 2b show latitude–height distributions of zonal- and temporal-mean zonal wind and temperature above the cloud top level averaged over two Venusian solar days (~234 Earth days) obtained in Cases A and B. The axis of the midlatitude jet in Case A is located at a lower latitude and altitude than in Case B. This might be due to the momentum transport by thermal tides. In Case A, the temperature decreases with latitude in association with the positive vertical shear of the mean zonal wind in the equator-side of 60°N with height below 70 km; whereas the temperature increase with latitude in the pole-side of 70˚N with height above 67 km. A remarkable cold collar is observed at 67–70 km levels at 60°–70° latitudes along with the polar warm region indicated by red color near the north pole. In Case B, on the other hand, temperature monotonically decreases with latitude in the region below 75 km height. The polar warm region shrinks and shifts to a region above 76 km indicated by light blue color near the north pole. The cold collar also appears in Case B at latitudes of 60°–70° at ~80 km levels; however, the temperature difference between the cold collar and polar region is less than 5 K, which is considerably smaller than that in Case A, and not clearly shown in Fig. 2b. Figs. 2c and 2d show temporally averaged residual mean meridional circulation by arrows and mass stream function by contours, in Cases A and B, respectively. In Case A, the residual mean meridional circulation above the cloud-top level (~70 km) reaches the polar region and remarkable downward motion occurs, which warms the atmosphere through adiabatic heating and forms the polar warm region. Also in Case B, the downward motion of the residual mean meridional circulation is observed in the polar region. However, it is three times slower than that in Case A, and the adiabatic heating rate associated with the downward flow in the polar region in Case B is much lower than that in Case A.

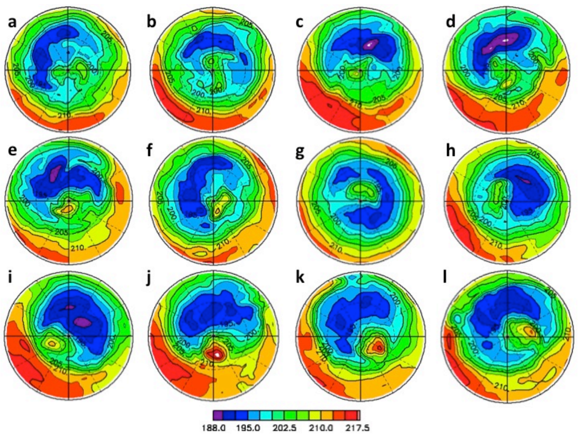

Figure 1: Time evolution of temperatures (K) in the polar plot at the altitude of ~68 km (the pressure level of 4×10^3 Pa) in Case A. The time interval of respective figures is one day.

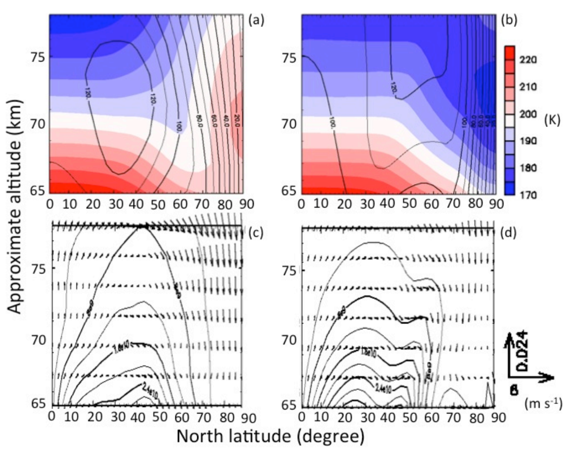

Figure 2: (Top) Meridional cross sections of the zonal- and temporal-mean zonal wind (solid line) and (colour shade); and (Bottom) the residual mean meridional circulation (vector) and mass stream function (contour). Left (a and c) and right (b and d) figures are for Cases A and B, respectively.

3. Summary

Our simulations elucidate the importance of thermal tides for the Venus atmospheric circulation around the cloud-top level (~70 km). The cold collar and polar warm region can be explained by the downward motion of the residual mean meridional circulation, which is closely related to thermal tides. This is qualitatively similar to Earth's sudden stratospheric warming, which is related to the meridional circulation induced by upward propagating Rossby waves [4]. The present work is helpful for interpreting numerous observations and features of the Venus upper atmosphere.

Acknowledgements

We are grateful to Dr. Y. J. Lee for the useful suggestions. This study was conducted under the joint research project of the Earth Simulator Center entitled "Simulations of Atmospheric General Circulations of Earth-like Planets by AFES."

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