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Transition between zonal superrotation and subsolar-antisolar circulation of the Venus atmosphere: results of the non-hydrostatic general circulation model.

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Abstract

Non-hydrostatic general circulation model of the Venus atmosphere has been run in the relaxation approximation with thermal forcing implying the excessive heating above the cloud layer and cooling within the clouds in the polar regions. This perturbation of the general radiative heating profile produce convective cell with the direction opposite to the main meridional circulation. These cells include prominent polar vortices characterized with zonal wavenumbers 1..3 and create upper boundary for the tropospheric circulation associated with zonal superrotation. Above the transition region characterized with strong thermal inversion, atmospheric circulation is dominated by the subsolar-antisolar component, which includes complex combination of vortices Altitude and depth of transition region depends on the location and amplitude of the relaxation thermal profile in the polar regions.

1. Introduction

Venus atmosphere is characterized by several distinct circulation patterns. Recent progress in the development of the non-hydrostatic model of the Venus atmosphere has allowed to guess thermal regime resulting in realistic circulation pattern. It has been shown that such prominent features observed in the Venus atmosphere as retrograde zonal superrotation (RZS) within and below the cloud deck, subsolar-antisolar circulation above ~110 km (SS-AS), and polar vortices characterized with downwelling central flow and zonal wavenumbers changing from 1 to 3, could be reproduced at the same time providing that additional perturbation in the polar region is assumed for relaxation thermal profile.

2. The model

We present further development of the first non-hydrostatic general circulation model of the Venus atmosphere based on the full set of gas dynamics equations and employs relaxation thermal profile to mimic radiative forcing [1]. The model has uniform geographical grid with the cell 1.2°×1.2°× 200 m. Vertical extension of the model domain is from the surface to 120 km. Venus topography with the atmospheric grid resolution is included. Several heating modes have been studied using the model relaxation thermal profile. In the nominal case, polar regions are affected by extra cooling below the upper boundary of the cloud layer and extra heating above it, with the maximal perturbation amplitude of 43K. This behavior mimics insulating effect of the optically thick cloud deck below its upper boundary and the continuous daylight heating above it.

3. Results

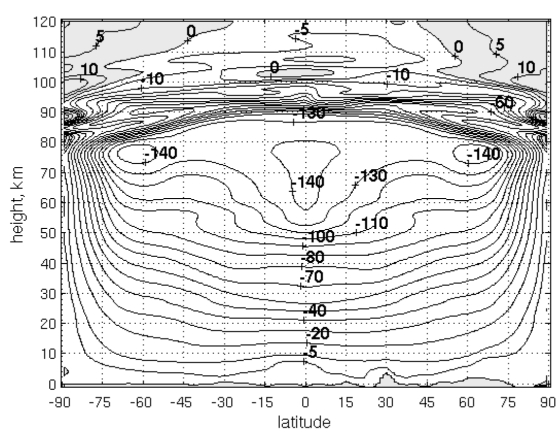

Figure 1: Zonal average pattern of zonal velocity according to simulations.

As it was expected, the inverse thermal contrast in the polar regions has resulted in the development of mesoscale meridional circulation with backward direction. Zonal superrotation is maintained with the maximal velocity of ~140 m/s (Figure 1). Zonal velocity demonstrates nearly linear growth below 80-90 km and abrupt fading in the upper altitudes. Polar atmosphere dynamics is substantially different from the other regions. In the middle of the cloud layer, polar atmosphere is characterized by the downwelling flow up to 0.1 m/s. Polar circulation is perturbed with baroclinic waves with the scale and zonal wavenuymbers, consistent with the observed patterns of the Venus polar vortex. However, above approximately 95 km, circulation pattern substantially changes. Polar vortices are displaced to the dayside and reside near the equator, producing strong divergent flow. In the approximately opposite longitude, a complex system of gravity waves and vortices provide the convergent flow, as shown in Figure 2. The boundary between these two layers characterized with the strong thermal inversion caused by the dynamical heating. Stabilizing role of the polar cells is consistent with cyclostrophic balance, as the warmer polar latitudes result in damping of the zonal flow with altitude.

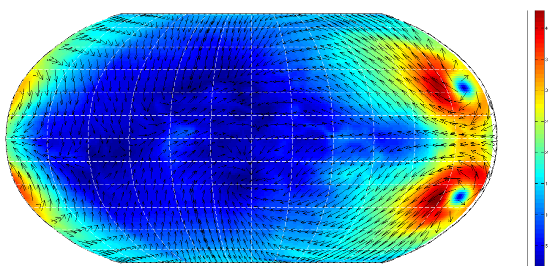

Figure 2: Subsolar-antisolar circulation shown in horizontal velocity field (m/s) at 110 km. Central meridian correspond to the local midnight.

6. Conclusions

Non-hydrostatic general circulation model is capable to reproduce all major observed features of the Venus atmospheric circulation, including the transition between RZS and SS-AS circulation. This transition is driven by changing heating regime in the polar atmosphere, affected by extremely high slant opacity of the cloud deck and the absence of diurnal variations of the solar heating rates above the clouds. More accurate simulations of these regions require development of the detailed radiative transfer model.

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References

[1] I. V. Mingalev, A. V. Rodin, K. G. Orlov. (2012) A nonhydrostatic model of the global circulation of the atmosphere of venus. *Solar System Research* **46**:4, 263-277