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Simulations of Venus atmospheric superrotation, SS-AS circulation and polar vortices with the non-hydrostatic general circulation model

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Abstract

We present the results of the first fully non-hydrostatic Venus GCM. In a relaxation approximation, the model reproduces major observed features of the Venus atmospheric circulation: superrotation maximizing in midlatitude jets, subsolar-antisolar (SS-AS) circulation above 100 km, and polar vortices. Maintaining the circulation pattern close to observations requires additional heat source in the polar regions above the cloud layer. Extra heating over the poles presumably results from the radiative impact of the underneath atmospheric layers in turn warmed up by the convergent heat flux driven by mesoscale eddies and meridional circulation.

1. Introduction

Recent investigations by Venus Express mission have resulted in dramatic change on the Venus atmosphere, its dynamics and chemistry. In addition to well known phenomena in the Venus atmosphere such as zonal superrotation, new features have been revealed, including polar vortices resembling terrestrial hurricanes[1], strong temperature inversion due to transition from superrotation to SS-AS circulation[2] etc. Such a detailed view presents serious challenge for current general circulation models, very few of which are capable to reproduce the whole picture of the Venus atmospheric dynamics. It is now generally accepted that the superrotation is primarily driven by thermal tides, but the details of energy and momentum exchange are not clear. Models meet difficulties with reproducing superrotating zonal flow deep enough in the lower atmosphere [3]. Finally the nature of the polar vortices and what causes their striking similarity to cyclonic storms remains unknown. Development of a coupled model valid at different scales and capable of reproducing observed features would help in understanding of mutual connections between these circulation elements.

2. The model

We present the first non-hydrostatic general circulation model of the Venus atmosphere based on the full set of gas dynamics equations. The model uses uniform grid with the resolution of 1.2 degrees in horizontal and 200 m in the vertical direction. Model domain extends to 120 km. In the current version thermal forcing is simulated by means of relaxation approximation with specified thermal profile and time scale. The model takes advantage of hybrid calculations on graphical processors using CUDA technology in order to increase performance. Simulations with different relaxation profiles and heating scenarios have been undertaken in order to understand the sequence of energy and momentum exchange required for the maintenance of the current circulation pattern.

3. Results

After relatively short equilibration taking about 1-2 Venusian sols, circulation reveals superrotation with maximum zonal velocity about 60 m/s which is twice as low compared to observations (Fig. 1). Increasing diurnal thermal contrast would result in increasing superrotation rate but the distribution of flow will become less realistic. Remarkable feature of the superrotation is concentration of zonal flow within two jets centered at ~60° latitude in each hemisphere at about 70 km from the surface, consistent with observations. Zonal crossection of the velocity field in Fig. 1 also shows gravity wave perturbations with typical wavelength from 20 km in the lower atmosphere to 6-10 km above the cloud layer. It worth noticing that maintenance of such a pattern requires additional heating of the polar regions to stabilize zonal motion in the upper part of the model domain and to prevent upward drift of superrotation core.

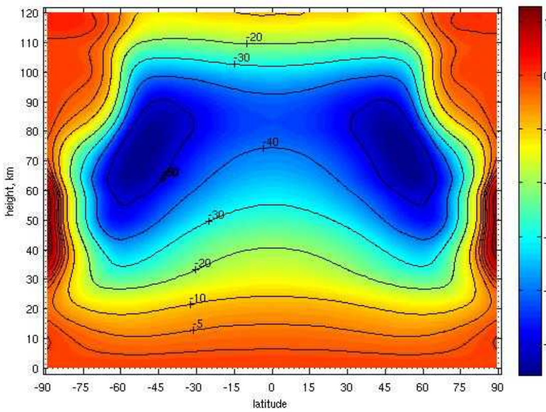

Fig. 1: Superrotation pattern revealed by instant crossection of the zonal velocity vs. latitude and height.

In the transition region between dominance of superrotation and SS-AS circulation, strong thermal inversion may develop in the nighttime and near the evening termoinator, consistent with CO_2 vertical profiling [2]. We believe that this inversion results from adiabatic heating in the downwelling brainch of SS-AS circulation.

Another striking feature of the simulations is the development of an off-axis vortices over the poles, associated with upwelling mean motion and resembling terrestrial cyclones. Vortices are shifted to the morning terminator with sun-sinchronous direction of the shift depending on altitude. Fig. 2 shows maps of vorticity (contour) and vertical velocity (color) over the North pole in polar projection. General structure of the vortex is consistent with observations and resembles terrestrial cyclones. However importaint mesoscale features observed on Venus, such as 'eye' with downwelling motion and perturbed by 2 or 3 small vortices, are not resolved by the model.

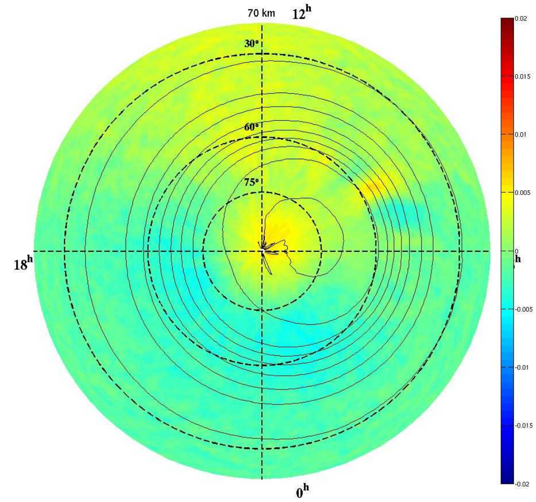

Fig. 2: Distribution of absolute vorticity (contour) and vertical velocity (color map) in polar projection according to modeling.

We suggest that extra heating of the pole caused by mesoscale turbulence and complex radiative processes inside cloud layer may provide conditions for the development of persistent cyclonic vortices which may in turn play a role in the meridional momentum transport necessary to maintain superrotation.

Acknowledgements

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