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Modeling of the Venus atmosphere with the non-hydrostatic general circulation model

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Abstract

A fully non-hydrostatic, gas-dynamics general circulation model of the Venus atmosphere is presented. Simulations demonstrate the development of superrotation in the deep undercloud atmosphere driven by the thermal tide. Polar vortices reproduced by the model in good agreement with observations presumably result from the interaction of superrotation with subsolar-antisolar circulation near the mesopause.

1. Introduction

The dynamics of the Venus atmosphere has long been a challenge for general circulation models. Recent developments [1,2] resulted in successful simulation of zonal superrotation, which appear in good agreement with observations. However, the models meet problems in reproducing circulation of the deep layers of the atmosphere, where zonal wind is underestimated. In turn superrotation reproduced in most current models concentrates in the cloud layer where major part of the solar energy is absorbed[1]. On the other hand, important mesoscale features, such as polar vortices, now well observed and documented[3], are not reproduced in simulations.

We present a new generation gas dynamical general circulation model of the Venus atmosphere. The goal of simulation was to study the mechanisms of the initial phase of superrotation development, and to explore sensitivity to initial conditions and external parameters.

2. The model

The model is based on numerical solution to the full equation set describing viscous, elastic gas dynamics on the rotating sphere. As the model setup described in this paper is greatly simplified in terms of the planet description details, so as it could be considered as a preliminary test bench for the new dynamical core. It uses a uniform grid with 128 nodes in longitude, 64 in latitude and 512 in the vertical, with a fixed vertical step of 200 m. High vertical density and corresponding time step imply serious limitations to the model performance. Taking advantage of hybrid calculations using CUDA technology, which in our case provides calculation rate about 10 times as fast as the physical time, the model was run over the period comparable with few Venusian sols. With realistic initial conditions, this period is sufficient to achieve quasi-steady state of the atmospheric dynamics.

The model has two options of the energy balance description. In the first case, a simple relaxation approximation is used. In the second case, atmospheric radiation fluxes are calculated using line-by-line algorithm. In order to increase performance, radiative transfer calculations are repeated with variable time step depending on altitude. Wind field with retrograde zonal direction and linear increase from the surface to cloud level was adopted as the initial condition.

2. Results

Simulations show that after approximately 6000 hours of physical time the circulation approaches steady state, which is virtually independent from initial conditions. The examples of simulated wind field are shown in Figures 1,2. In contrast with previous models, superrotation develops in a wide altitude range, with zonal wind velocity gradually decreasing downwards. The maximal values of zonal wind velocities are lower than observed, which is probably connected with insufficient thermal forcing.

It is established that the final superrotation rate is highly sensitive to thermal forcing near the mesopause. We attribute the insufficient superrotation rate to weak thermal forcing implied by the model.

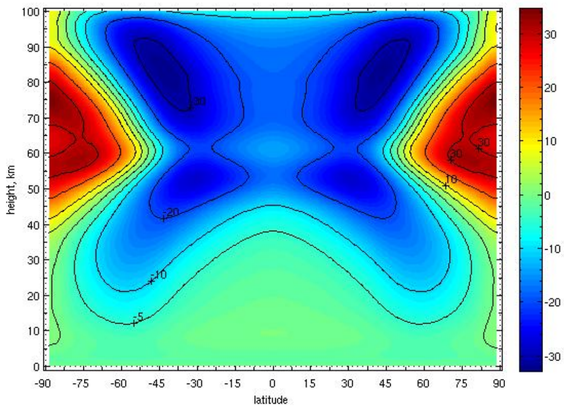

Figure 1: Zonal wind velocity (m/sec) at 270º longitude

However, simulations clearly show that superrotation pattern reproduce most prominent features observed in the Venus circulation system, such as midlatitude jets and polar vortices. Horizontal wind field shown in the Figure 2 implies zonal wave-1 polar vortices forming near the morning terminator, with central longitude depending on height. Although prominent subsolar-antisolar (SS-AS) circulation is not clearly shown in the wind field, it is the interaction between SS-AS and zonal superrotation pattern that may result in the formation of such vortices.

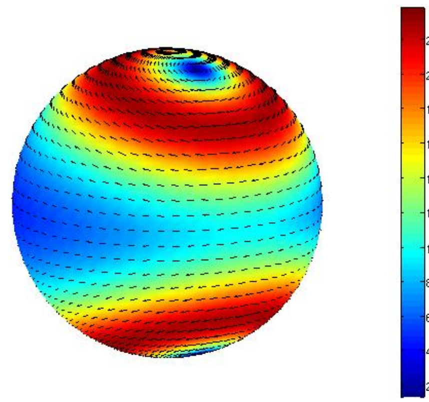

Figure 2: Horizontal wind velocity (m/sec) at 45 km altitude demonstrate polar vortices at the morning terminator.

3. Conclusions

The results presented above show that non-hydrostatic nature of the model may bring new quality to GCM simulation. Further improvement of the model, accounting for Venus topography and more accurate description of the thermal forcing is needed to fit observations.

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