# Zonal mean structure of Venus atmosphere observed in a Venus general circulation model with explicit radiative transfer

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Zonal mean zonal wind in Venus atmosphere is different from those in other planetary atmospheres. It is a strong prograde wind in all latitudinal ranges and is referred to as super-rotation. This unique zonal wind has been investigated by a lot of previous researchers with numerical simulations as well as ground-based and spacecraft observations. Among the studies with numerical simulations, in 2010s, Lebonnois et al. (2010) and Ikeda (2010) performed general circulation model simulations with an explicit radiative transfer model and successfully represented strong prograde zonal wind. These studies overcome a shortcoming of previous studies, in which models use Newtonian cooling as a radiative forcing.

In our group, we have been developing a general circulation model for planetary atmospheres. In addition, we have just developed a Venus radiation model, which can be used in a general circulation model. In this study, by implementing the radiation model into our general circulation model, we try to perform general circulation model simulations of Venus atmosphere and investigate the zonal mean structure of Venus atmosphere and evaluate differences between previous studies.

The general circulation model used in this study is DCPAM (http://www.gfd-dennou.org/library/dcpam/). The model is based on primitive equation system and the equation system is solved by a spectral transform method. The DCPAM includes physical processes of radiation and turbulent mixing processes. In addition, heat diffusion in soil is considered to evaluate surface temperature. The radiation model implemented into the DCPAM has also been developed in our group, and is based on a correlated k-distribution method. Radiative fluxes calculated by this radiation model are compared well with observed ones. By the use of the model, we performed two experiments with and without surface orographic variation. Resolution of experiments is T15L52, in which the model has 48 (longitude) times 24 (latitude) grids in horizontal direction and 52 layers in vertical direction. Initial conditions for those experiments are the same, and are
motionless atmospheres with horizontally uniform temperature distribution based on VIRA. With this initial condition, the model is integrated for 150000 Earth days with diurnal variation and with no seasonal variation, i.e. zero
obliquity.

Statistically steady states are achieved after about 100000 Earth days from the start of integrations. In steady state, prograde zonal winds with velocity of about 50 m/s in low and middle latitude are maintained at cloud layer in both experiments with and without orographic variation, although the velocity is about a half of that observed in Venus
atmosphere.

Meridional circulation observed in the model has large direct cells in both hemispheres. The direct cells in the experiment without surface orography have vertical extent from the ground up to top of the model, except for low latitude region just above the ground where indirect cells form. However, in the experiment with surface orography, the cells are split in the vertical direction at bottom of cloud layer. In addition to direct cells, several indirect cells are also observed in the experiments. One of those is indirect cell at

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cloud layer in high latitude. Other ones are several indirect cells which extends from the ground up to bottom of cloud layer in the experiment with surface orography. These indicate that the effects of surface orography can be observed below the cloud layer, clearly.

In the presentation, results of analysis on zonal mean structure observed in the model, such as angular momentum, will also be presented.

Keywords: Venus, planetary atmosphere, general circulation model, explicit calculation of radiative transfer

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