



## **A comparative analysis of Simplified General Circulation Models of Venus atmosphere**

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With the successful Venus Express mission, and future missions planned for Venus exploration in the near future, study of the atmosphere of Venus has been a rapidly expanding field in the last few years. The development of Global Circulation Models (GCMs) has focused on helping researchers to understand the details of the super-rotation mechanism, the large-scale planetary waves and the polar vortices which are seen in this complex atmospheric system.

Several groups that have been developing such tools have joined together within the framework of a working group supported by the International Space Science Institute (ISSI, Berne, Switzerland), and have started to compare how the different models behave under the same forcing conditions. The goal of this intercomparison project is to test how robust the response of the different numerical models is to identical constraints. A similar project has been conducted recently at CalTech (Lee and Richardson, JGR 115, 2010, hereafter LR10) using three different dynamical cores within a common model frame, and we wanted to build upon this first study. We developed a common protocol and conducted many simulations of Venus atmospheric circulation with three additional GCMs: the CCSR model developed in Japan, the LMD model developed in France and the Open University model (OpU) developed in Great Britain. A new model developed in UCLA contributed simulations under very similar conditions, and is therefore added to the project. We add to these new simulations the results of the LR10 study, as well as the results obtained in Oxford by Lee et al. (JGR 112, 2007; Lee, PhD, 2006). These models are using a range of different types of dynamical cores (spectral, finite differences or finite volumes). The baseline common parameters include resolution, initial conditions, planetary and atmospheric parameters as well as several physical parameterizations: thermal forcing, upper and lower boundary conditions. In this work, thermal forcing is reduced to a simple newtonian cooling parameterization with diurnally averaged conditions and no orbital variation of solar forcing.

Comparison between the models shows how the different models spin up from rest, yielding different final states. Though all models do reach states with significantly positive superrotation, the amplitude and shape of the zonal wind fields is highly variable between different GCMs and with changes in model parameters. We have been varying the physical parameters to study the mode sensitivity. The choice of lower boundary conditions (the planetary boundary layer scheme and presence, or absence, of surface topography) at the planet's surface has a significant influence on the deep atmospheric winds. The vertical resolution (number of levels) in the model is demonstrated to have a strong effect in most models. Modifications in the horizontal resolution were also found to be significant, both on the shape and strength of the peak winds and on the deep atmospheric winds. The impact on the peak winds seems to be qualitatively consistent between models, though the impact on the winds deeper in the atmosphere is not. We have also investigated the impact of varying the initial conditions. Most previous experiments have been initialised with an isothermal atmosphere at rest, but we find evidence of different end states in models which were initialised with super-rotating winds, even after very long integration times. These experiments have been conducted with the CCSR, LMD and OpU models. The results vary in detail between the models, though in each case the atmosphere tends to stabilize with much higher peak winds.

Though this work is done using a simplified thermal forcing and therefore may not be fully representative of the real Venus atmosphere, it offers some guidance to the community concerning the degree of complexity and sensitivity of the GCMs currently developed for the Venus atmosphere. It also illustrates interesting differences between dynamical model cores of the type in common use in terrestrial GCMs under conditions which lead to small residual differences becoming highly significant, providing a strong test of model dynamics.