Weakly forced atmospheric GCMs : lessons from model comparisons

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Weakly forced atmospheric GCMs : Lessons from model comparisons

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Abstract

Even when forced with mostly identical physical parametrizations, general circulation models (GCMs) of Venus produce significant dispersion in the simulated zonal wind fields and meridional circulations. Horizontal resolution, lower boundary layer parametrization and initial state are among the most sensitive aspects, and consistent trends are not obtained between models (or even by the same model at varying resolution).

When comparing simplified temperature forcing with realistic radiative transfer in the LMD Venus GCM, it is also clear that the description of this forcing is critical to understand the meridional circulation, and therefore the dynamical cycle of angular momentum in this sensitive atmosphere.

The role of numerical aspects is also obvious in the case of Titan, another weakly forced atmosphere in superrotation. Modeling Titan's stratospheric superrotation has proved difficult, and recent GCM successes highlight that our ability to model these processes correctly is highly sensitive to numerical aspects, especially horizontal dissipation.

These studies show us that modelers need to keep humble and aware of the difficulty to assess robust behaviour with only one GCM. Intercomparison of different GCMs is a useful way to identify robust interpretations from model-dependent aspects.

1. Introduction

With the success of the European Venus Express mission, Venus' atmosphere has been put once more in the spotlight of international research. Many groups around the world are analysing observational datasets, from space and ground-based campaigns. To support and complement these analyses, efforts have been made to develop new Venus atmospheric models. This is also the case for the atmosphere of Titan, with the wealth of data coming from the Cassini-Huygens mission.

In the context of a working group gathered at the International Space Science Institute (Bern, Switzerland), several specialists in the modeling of Venus' and Earth's atmospheres came together, and decided to assess current models of the Venusian atmosphere through an intercomparison project, based on available models, though limited to models that use a simplified thermal forcing.

Lessons learned during this work will be developed here, but the reflexion will also be extended to another aspect of Venus atmospheric modeling (the role of radiative transfer) and to difficulties met in the Titan atmopheric modeling community.

2. Venus GCMs: an intercomparison study

The modeling of the circulation of Venus' atmosphere has always been a challenge. Most of the GCMs developed for Venus have been adapted from Earth GCMs, and have used simplified physical and radiative parameterizations. The results from these different models vary widely, and may even be contradictory in some respects.

The idea of comparing the results of different models forced with the same physical parameters is not new. In the case of Venus, it was recently done using numerical experiments with three different dynamical cores (Lee and Richardson, 2010). We extended the comparison to five additional models: the Kyushu/Tokyo CCSR/NIES GCM (Yamamoto and Takahashi, 2003); the Paris LMD GCM in a simplified radiative forcing configuration (Lebonnois et al, 2010); the Open University spectral GCM; the UCLA/LLNL Aerospace CAM GCM (Parish et al, 2011); and the Oxford GCM (Lee et al, 2007).

Each team ran a set of simulations to compare the behavior and the sensitivities of the different GCMs. Planetary parameters, horizontal and vertical resolutions, vertical eddy coefficient, surface friction, sponge layer and thermal forcing were chosen as similar to each other as possible. However, the dynamical cores and the horizontal dissipation parameters varied between models. Under such similar forcings, the wide dispersion of the results is striking. Even the sensitivity of each model to different parameters (such as horizontal resolution, for example) may be different from model to model.

All the GCMs reach superrotation around the cloud layer levels. However, the amplitude of the maximum zonal wind and the shape of the jet regions vary strongly from model to model, without any correlation to the type of dynamical core (spectral, finite differences, finite volumes). The impact of the lower boundary conditions may be very significant, though this again depends on the formulation and on the GCM. The strongest sensitivity is seen for the horizontal resolution. However, the trends of variations from lower to higher resolutions are not fully consistent from one model to the other. Varying the initial conditions also resulted in different behaviour among models.

3. The impact of radiative transfer scheme in the LMD Venus GCM

Apart from the previous models using forced temperature structures, Lebonnois et al (2010) used a complete radiative transfer model to compute the temperature field self-consistently. This change affects strongly the mean meridional circulation, and therefore the overall budget of angular momentum. The shape of the maximum wind speed, as well as the amplitude is significantly altered. The diurnal cycle in this case has a stronger influence than seen in previous works with simplified forcing.

4. The difficult spin-up of Titan GCMs

Since the first version of the IPSL GCM (Hourdin et al, 1995), producing superrotation in Titan's stratosphere has proved very difficult for many models. Recently, a new TitanWRF GCM has managed to spin-up such superrotation from rest (Newman et al, 2011). They have demonstrated the strong influence of horizontal dissipation on this difficult question. The new IPSL GCM version also reproduces many features of Titan's atmosphere (Lebonnois et al, 2011). Comparison between these GCMs should prove useful to decypher the numerical difficulties associated with this atmospheric system.

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References

Hourdin F, Talagrand O, Sadourny R, Courtin R, Gautier D, McKay CP (1995) Numerical simulation of the general circulation of the atmosphere of Titan. Icarus 117:358–374

Lebonnois S, Hourdin F, Eymet V, Crespin A, Fournier R, Forget F (2010) Superrotation of Venus' atmosphere analysed with a full General Circulation Model. J Geophys Res 115:E06006, DOI 10.1029/2009JE003458

Lebonnois S, Burgalat J, Rannou P, Charnay B (2011) Titan Global Climate Model: new 3-dimensional version of the IPSL Titan GCM. Icarus Submitted

Lee C, Richardson MI (2010) A General Circulation Model ensemble study of the atmospheric circulation of Venus. J Geophys Res 115:E04002, DOI 10.1029/2009JE003490

Lee C, Lewis SR, Read PL (2007) Superrotation in a Venus general circulation model. J Geophys Res 112:E04S11, DOI 10.1029/2006JE002874

Newman CE, Lee C, Lian Y, Richardson MI, Toigo AD (2011) Stratospheric superrotation in the TitanWRF model. Icarus 10.1016/j.icarus.2011.03.025

Parish HF, Schubert G, Covey C, Walterscheid RL, Grossman A, Lebonnois S (2011) Decadal variations in a Venus General Circulation Model. Icarus 212:42–65, DOI 10.1016/ j.icarus.2010.11.015

Yamamoto M, Takahashi M (2003) Superrotation and equatorial waves in a T21 Venus-like AGCM. Geophys Res Lett 30:1449, DOI 10.1029/2003GL016924