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Modeling Venus' clouds with the moment method: paving the way for 3D GCM simulations

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Abstract

We describe a project to model the microphysics of Venusian clouds. The goal of the project is to complete the IPSL Venus 3D GCM with a cloud microphysics module.

1. Introduction

Venus is a terrestrial planet, which is enshrouded by clouds. The thickness of this cloud layer is more or less 20 km. The clouds are thin, like cirrus on Earth but they are stratified and create a large opacity.
The cloud layers are surrounded by haze above and below. Moreover, this cloud system is divided by properties of particle size distribution into three layers: the upper cloud deck (56.5 to 70 km), the middle cloud deck (50.5 to 56.5 km) and the lower cloud deck (47.5 to 50.5 km) [2]. The aerosols that constitute the clouds are composed of a H_2SO_4-H_2O solution. The solid state of aerosols is still debated [2,8]. There is only one complete in-situ profile on cloud droplets measured by Pioneer Venus during its descent [2]. The upper cloud deck and the upper haze were studied by several missions like Venus Express [11]. The droplet radii distributions can be divided in several size modes. The mode 1 (mean radius $\overline{r} \simeq 0.2\mu\text{m}$) is the smallest but has the largest number concentrations. Modes 2 ($\overline{r} \simeq 1.0\mu\text{m}$) and 3 ($\overline{r} \simeq 3.5\mu\text{m}$) hold most of the condensed mass [2]. The division in modes 2 and 3 of the largest particles and the existence of mode 0 and 2' are still debated [2,12,10].
The cloud top and base and the thickness change with latitude and the particle size has a latitudinal dependence [12,5]. In addition, an unknown UV absorber is present in the cloud layers and may be related to clouds.
At last, the clouds affect the radiative balance, the sulfur chemical cycle, the dynamics and the atmospheric structure of Venus.

2. Modelling

2.1. The IPSL Venus GCM

The Venus Global Climate Model has been developed at the Laboratoire de Météorologie Dynamique (LMD, France) [4]. The characteristics of this model include radiative transfer, dynamics, atmospheric chemistry, diurnal cycle and a full topography defined by Magellan mission's data. With this full GCM, the Venusian atmosphere is simulated between 0 and 150 km.

However, there are still some problems with vertical temperature description and with the representation of the cold collar. They may be due to the simple description of the cloud layers in the model [4]. Thus, to achieve better simulations of the Venus climate, the GCM needs a microphysical model.

2.2. VenLA

The Venus' cloud model VenLA is developed at LATMOS [6]. It is a 1D sectional microphysics model based on [3]. VenLA is computationally too demanding to be integrated in the IPSL Venus GCM, which is why we need to develop another method.

2.3. The moment method

The moment method is a statistical method to describe a distribution function with few parameters called moments. On the I interval ($I = \mathbb{R}_+$) with the nth moment, the distribution $f(x)$ is defined with the moment scheme by:

$$M_n(f) = \int_I x^n f(x) dx \qquad (1)$$

When applied to a particle size distribution, each moment M_n is associated with a meaningful parameter of the distribution. With the equation (1), the moment of order 0 is the total number of particles N and the moment of order 3 is the total volume of the particle

population.
In our case, we consider a log-normal size distribution function (2) [9]:

$$f(x) = \frac{N}{\sqrt{2\pi}\sigma_x} \exp\Big(- \frac{(x-\overline{x})^2}{2\sigma_x^2}\Big) \qquad (2)$$

Where x is a radius, $\overline{x}$ is the mean radius of the aerosol distribution and σ_x is the variance.
The moments will be the tracers in the 3D GCM. A tracer is a quantity that we follow in the modeling calculation. The calculation time of a simulation is proportional to the number of tracers in the model: with few tracers is faster than lots of tracers. With a sectional model like VenLA, each bin is a tracer, which means tens or hundreds of tracers would be added to the GCM. This is why the moment method with two or three moments may be a good method to develop a microphysical module for a global model like the Venus GCM.

2.4. Modeling approach

We are developing a 1D cloud model with the equations of microphysical processes solved with the moment scheme.
Then we will make comparison between our model and the high and low resolution VenLA simulations. With these tests, we will study the ideal number of moments that we need in the model and the moments that we will use: the mean radius, the variance or/and the total number of particles in the distribution.
We will present the first results of our 1D model with the moment scheme and a comparison with the results of high and low resolution VenLA 1D.

3. Summary and Conclusions

The moment method is already used in the IPSL Mars GCM [7] and the IPSL Titan GCM [1] to describe the cloud microphysics. Therefore, it is interesting to use it also in the Venus GCM.
Here we present a status report on the development of the moment method cloud module. The development of this model will allow us to have a better understanding of Venusian climate with a complete GCM.

4. Perspectives

The goal of this model development is to simulate in three dimensions the formation and the evolution of clouds on Venus. It will be integrated in the IPSL Venus 3D GCM to obtain the more complete Venusian climate model.

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