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Questions future missions to Venus should address: point of view of an atmosphere modeler

Sebastien Lebonnois
Laboratoire de Météorologie Dynamique (LMD/IPSL), Sorbonne Université, ENS, PSL Research University, Institut Polytechnique de Paris, CNRS, Paris, France (sebastien.lebonnois@lmd.jussieu.fr)

Abstract

As new projects of missions are proposed to renew with Venus exploration in the next decades, recent climate models can be of great help to identify and highlight questions that are still unaddressed despite recent mission datasets. Based on the recent investigations done with the IPSL Venus Global Climate Model, this presentation offers the point of view of a modeler of Venus's atmosphere on the questions that will need to be addressed by future investigations, and the measurements required to answer them. These questions include planetary-scale wave activity, cloud structure, sulfur cycle, radiative forcing in the deep atmosphere, near-surface atmospheric structure, and the interactions between the surface and the cloud region. Possible platforms to obtain the needed measurements are also discussed, without getting too much in the feasability of such ideas. Topics are listed from cloud-top to surface. Though everything is connected in a GCM, each of these questions could be addressed separately from the others and lead to more robust simulations. However, if a priority needs to be emphasized, constraining the heating rate distribution is essential.

1. Introduction

Our current understanding of the climate of Venus has greatly progressed during the last decade [1], with the wealth of data brought to us by the Venus Express and Akatsuki missions, the new observations that are now done from Earth, and the development of realistic climate simulations with state-of-the-art GCMs (General Circulation Models, or Global Climate Models depending on their capabilities).

However, many questions remain unanswered, that will require new data to be obtained by the next missions to Venus. The goal of this presentation is to use the experience acquired with the IPSL Venus GCM [2, 3], to suggest the most needed measurements to better understand Venus's atmospheric processes.

2. Atmospheric dynamics in the cloud region

Progresses have been made on our understanding of the superrotation of Venus's atmosphere [1, 4]. The respective role of mean meridional circulation, thermal tides and planetary-scale waves is clarified. However, it is still difficult to reconcile the planetary-scale wave activity deduced from available observations at the cloud-top that are always limited in their coverage, and the GCM simulations. It would be extremely valuable to have a more complete view of these waves at cloud-top, but also in the middle and lower clouds.

In order to do so, a full view of the cloud layers with continuous monitoring is needed. This coverage could be obtained with a primary orbiter associated to 1 or 2 smallsat-size orbiters located on the same circular orbit of radius around 40000 km, regularly separated along the orbit, and a multi-filter camera on each orbiter, with capabilities similar to VMC/Venus Express and LIR/Akatsuki, and with filters for oxygen nightglow and CO_2 non-LTE emissions (see e.g. the recent VAMOS project). With such an instrument, these platforms would permit to retrieve the mean wind field in the clouds, planetary-scale waves in the cloud region, thermal tides, bowshaped topographical waves, seismic-induced waves, gravity waves of all sorts, continuously. In addition, it would provide a continuous view of the context in which evolves any aerial platform that may be present at the same time in the atmosphere. This would give us major informations about Venus atmospheric dynamics in and above the cloud layer.

3. Cloud structure and atmospheric composition

The nature and distribution of cloud particles in the main cloud layers, but also in the hazes above 70 km altitude and below the cloud base, are major characteristics needed to understand the climate of Venus. It affects the radiative transfer and energy deposition as well as the sulfur cycle. Crucial measurements would need to cover small sizes (around 0.1 micron), but also large sizes (larger than a couple of microns), to solve the question of the different modes.

Profiling of the cloud particle distribution in the different cloud layers would be very useful to constrain what is going on in the clouds in term of gas/particle exchanges, microphysics, and radiative transfer. Profiling SO_2 and other sulfur molecules in the same region would be crucial to understand the sulfur cycle. Currently, we don't understand how there can be 0.1 ppm of SO_2 near the cloud-top and 100 ppm at the cloud-base. The chemistry and current understanding of the sulfur cycle are unable to explain this gradient [5]. Measuring the amount of UV absorber (and its correlation with SO_2 and local dynamical structures, such as upwelling or downwelling regions) and its vertical distribution would help to better understand its role in the overall system of the cloud region, its link to chemistry and to dynamics.

All these profiles could be obtained from variable-altitude balloon platforms. The latitudinal variations of these profiles are also needed, in particular for high latitudes where these variations are known to be significant, and important for the polar region thermal structure and dynamics [3].

4. Radiative forcing

Based on the experience of the IPSL Venus GCM, the overall dynamics of the atmosphere is very sensitive to the net solar energy deposition in and below the clouds [3]. It is crucial to improve our knowledge of the net solar, infrared and UV fluxes in the atmosphere, and to get accurate measurements of their profile from cloud-top to deep in the atmosphere. Below the clouds, in the 30-50 km altitude range, the role of the radiative energy deposition is even more important than in the cloud. It completely controls the temperature profile in the deep atmosphere [6, 2, 3]. This is also related to the haze that is present in this region and which properties are still unknown. Measuring the energy deposition and the distribution of haze particles in this region would be crucial for the energy budget of the atmosphere. Though improving our knowledge of the cloud and haze particle distributions could improve the modeling of radiative transfer, a direct measurement of the heating rates would be a strong constrain on GCM forcings, putting these measurements on top of the priority list.

5. Near-surface atmospheric structure

The last 10 km above the surface are almost unknown. The questions raised by the interpretation of the unique VeGa-2 temperature profile [7] have profound consequences on the processes going on in this region and at the surface, and they will never be answered without in-situ probes. These probes (from light dropsondes to heavy landers) will need to measure temperature and pressure profiles, of course, but they should also measure atmospheric composition (N_2, SO_2), providing answers to key questions about surface/atmosphere interactions. The SO_2 profile in the deep atmosphere is still debated since the VeGa probes measurements [8].

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