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Thermal structure of Venus upper atmosphere by a self-consistent ground-to-thermosphere GCM

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Abstract

We present here the thermal structure of the upper atmosphere of Venus predicted by a full self-consistent Venus General Circulation Model (GCM). The Venus GCM developed at *Laboratoire de Meteorologie Dynamique* (LMD) [1] is currently operational up to 150 km and it is one of the leading models in the community. Recent improvements (i.e the inclusion of physical processes relevant in the upper atmosphere, the coupling with a photochemical model) contributed to a better understanding of the upper mesosphere/lower thermosphere of Venus. Our aim is to describe the role of radiative, photochemical and dynamical effects in the observed thermal structure of those upper layers, and to evaluate the impact of current parameterisations and theoretical uncertainties on the temperature fields. Several sensitivity tests will be performed to understand the data-model discrepancies and to improve the comparison.

1. Introduction

The successful European Space Agency's Venus Express (VEx) mission marked the beginning of a new era for the exploration of our neighbour planet. After eight years in orbit (2006-2014) exceeding its planned life, a considerable amount of data from several instruments on board were collected. Direct measurements taken by aerobraking manoeuvres at the end of the mission, together retrievals by VIRTIS ([2]) and SPICAV-SOIR ([4, 3]) above 90-100 km provided an extremely valuable piece of information on local atmospheric densities and temperature of a region very difficult to sound, and surprisingly more variable than expected. In addition to this, a number of ground based observational campaigns have noticeably complemented the satellite observations during VEx mission. The scientific community has been doing several efforts to carry out a systematic inter-comparison and validation of both satellite and ground-based telescope measurements within an international context of several international projects. All those efforts contribute to an unprecedented insight into the complex dynamical mechanisms going on the atmosphere of our sister planet. Nevertheless, VEx also raised new challenging questions to be answered. Sophisticated climate models and synergies with the data analysis are fundamental to interpret the observed results and to help building a consistent picture of the spatial and temporal evolution of the Venus atmosphere.

2. An improved Venus LMD-GCM

The Venus GCM developed at LMD [1], based on the tools and experience gathered for the GCM of the Earth's, has been used to study the role of thermal tides in the super-rotation of Venus atmosphere and to compute consistent temperature fields, from the surface up to 100 km, which helped to interpret recent VEx measurements. In the last 5 years, the Venus LMD-GCM has been noticeably improved by the inclusion of a self-consistent radiative transfer module, the ongoing development of a microphysical module, the inclusion of a photochemical model and by the extension up to the lower thermosphere (150 km). The vertical extension of the model mainly consisted in the implementation of physical processes relevant to the thermal balance of the upper atmosphere of Venus from 100 to 150 km. In particular, the role of non-LTE processes, EUV heating and thermal conduction has be taken into account, and proper parameterisations for GCMs implemented. Here we adopted the methodology developed for the Mars GCM ([5]), consisting of 1-parameter analytical formula to reproduce the solar heating rates in those upper regions, and a simplified non-LTE model for the 15-μm cooling. It is assumed that the net solar absorption depends mainly on the density of the atmosphere, and to a smaller degree on the solar zenith angle, thermal structure and atomic oxygen abundance. EUV absorption is also included assuming an efficiency of 21 % and the variation of the EUV solar flux with the solar cycle is considered. Molecular viscosity and molecular diffusion also have an impact on the winds and on the composition of the atmosphere, respectively. Thanks to these improvements the current LMD Venus GCM is actually able to provide a full self-consistent and quantitative description of the Venusian upper atmosphere and to perform a more comprehensive comparison with available dataset.

2.1 Results: thermal structure

Figure 1 shows the mean temperature field after 10 venusian days (about 6 terrestrial years) at equatorial regions (30S-30N), plotted here as function of local time (hours) and pressure (Pa). This simulation is performed by the LMD Venus GCM fully-coupled, for the first time up to about 150 km, with the LATMOS photochemical model ([6]). The predicted structure is mainly a combination of radiative and dynamical effects. The strong local maximum observed during daytime is due to solar absorption by CO_2 near-infrared bands (1-5 μm) between 1-0.1 Pa, and a local minimum (at about 10^{-2}-10^{-3} Pa) is produced by thermal cooling via CO_2 non-LTE transitions around 15μm. Above 10^{-3} Pa (140 km altitude) EUV absorption by CO_2, O and a number of minor species, together with thermal conduction, dominate. The nighttime warm layer produced by subsidence of day-to-night circulation air is clearly observed around the anti-solar point. Those main features have been also recently observed in the upper atmosphere of Venus by VEx. Despite that, a number of data-model discrepancies (e.g different pressure level and intensity of the local maximum, colder morning terminator, etc) indicate that radiative, photochemical and dynamical effects have to be further investigated. We are currently working to tune the model in order to produce reference simulations capable to reproduce, as accurately as possible, the observed vertical and horizontal structure of the temperature in the upper mesosphere/lower thermosphere of Venus. The impact of current parameterisations and theoretical uncertainties (i.e solar heating rates, relaxation/collisional coefficients, EUV efficiency) on the temperature fields will be evaluated and sensitivity tests performed to understand the data-model discrepancies and to improve the comparison with all available dataset.

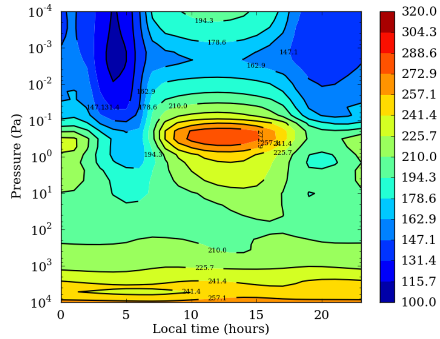

Figure 1: Local time-pressure cross sections of "mean" temperature fields predicted by LMD-VGCM after 10 Venus days, averaged at equatorial latitudes 30S-30N.

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