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Combination of SOIR/VEX observations and VTGCM simulations to decipher the mesosphere and lower thermosphere of Venus

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Introduction

Carbon dioxide is the main component of Venus' atmosphere, with a mean volume mixing ratio (VMR) of 96.5 % up to an altitude of 120 km. Above this, its VMR decreases with altitude as CO_2 is photo-dissociated on the dayside of the planet by solar ultraviolet radiation, forming carbon monoxide and excited oxygen atoms. As the main constituent of the Venus atmosphere, carbon dioxide is of great interest in order to describe the physics of the atmosphere at the terminator.

This region is a place where dynamical processes change rapidly with altitude. The global circulation of the Venus upper mesosphere and thermosphere is estimated to be a combination of two distinct flow patterns: (1) a relatively stable subsolar to antisolar (SS-AS) circulation cell driven by solar (EUV-UV-IR) heating (above 120 km), and (2) a highly variable retrograde superrotating zonal (RSZ) flow (above the cloud tops). The effects of the superposition of these 2-wind components in the Venus upper atmosphere are observed in measured temperature, density, and nightglow distributions. However, the dynamical processes driving this variability are still poorly understood.

The VAST data

SOIR is one of the three channels of the SPICAV/SOIR instrument [1] flying on board the ESA Venus Express mission [2]. This high-resolution infrared spectrometer performs solar occultation observations of the Venus atmosphere, and so defines unique vertical profiles at the terminator of many key species [3,4,5].

This study focuses on carbon dioxide density and temperature vertical profiles. A subset of 59 observations (black dots in Fig. 1), which cover the complete altitude range, has been considered to define the Venus Atmosphere from SOIR measurements at the Terminator (VAST) [5]. The selected measurements are obtained for a wide range of latitudes between 2006 and 2011. The dataset is divided as a function of latitude in 5 regions (0°-30°, 30°-60°, 60°-70°, 70°-80°, 80°-90°) and a morning – evening symmetry is assumed.

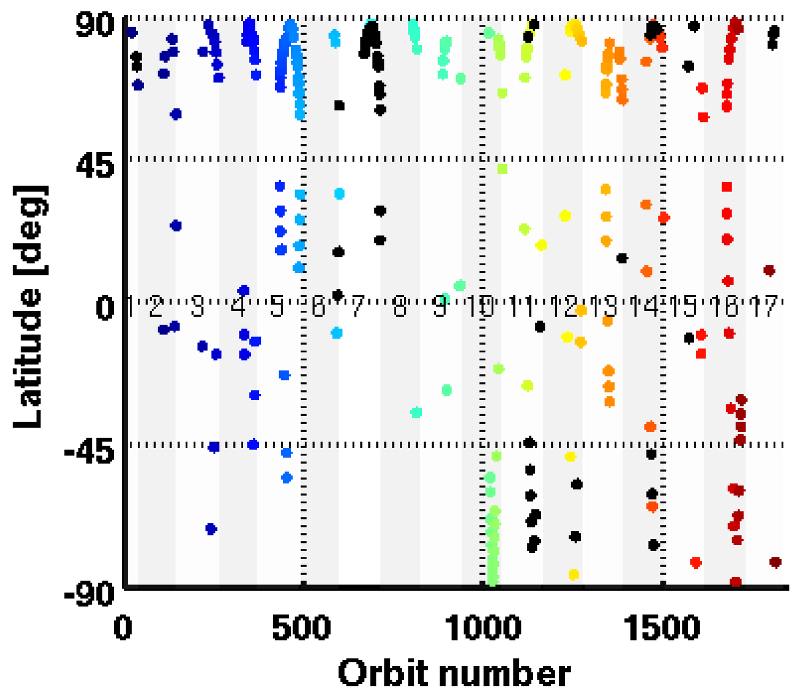


Figure 1: Map of SOIR observations. In black, the subset used for VAST.

VTGCM

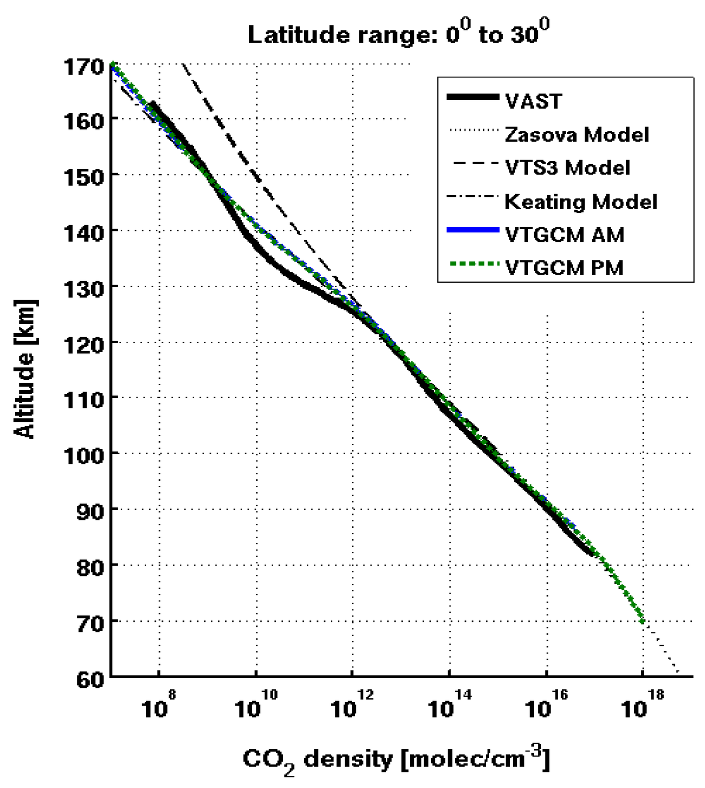
The Venus Thermospheric General Circulation Model (VTGCM) is a 3-D finite-difference hydro-dynamic model of the Venus upper mesosphere and thermosphere (above the cloud tops) [6,7,8,9].

Briefly, the VTGCM solves the time-dependent primitive equations for the upper atmosphere: neutral temperatures, key neutral-ion densities, and three-component neutral winds. Nightglow emission distributions (e.g. NO UV and O_2 IR) are also simulated. The model domain covers a 5° by 5° latitude-longitude grid, with 69 evenly-spaced log-pressure levels in the vertical, extending from approximately 70 to 300 km (70 to 200 km) at local noon (midnight). The most recent version of the VTGCM code [9] addresses the dayside and nightside thermal structure, and its variations, for comparison to available observations.

VTGCM – VAST comparison for CO_2 densities and Temperature

The systematic temperature minimum around 1E^{-5} mbar (~125 km) and the weaker temperature maximum around 5-10 E^{-3} mbar (~115 km) observed in VAST (Fig.2) provide detailed constraints for VTGCM. VTGCM simulations were conducted for conditions appropriate to these SOIR measurements and temperature profiles were extracted from the terminators and were compared with VAST profiles, assuming a North – South hemisphere symmetry. VAST and VTGCM temperature profiles (Fig.2, bottom panels) are compared for two ranges of latitudes. Interestingly, the striking cold layer in VAST is reproduced by VTGCM, as well as the warm layer below, at the correct pressure level. Nevertheless, the magnitude of this feature is much smaller with VTGCM (~40 K) than observed in VAST (~80 K). The outputs of VTGCM differ slightly for the morning and evening terminator for pressure lower than 1E^{-6} mbar (high altitudes) and low latitudes.

VAST temperature results were extended with 200 additional SOIR observations for which information on CO_2 can be retrieved (colored dots in Fig. 1) allowing a 5° latitude binning of the observations. The resulting temperature field (top panel in Fig. 3) confirms the structure of the Venus atmosphere in terms of temperature, i.e. a cold layer surrounded by two warmer layers. It resembles the outputs of VTGCM simulations (bottom panels), yet the temperature of the cold layer is higher by ~40K than in VAST. Differences are observed for the morning and the evening side of the terminator in VTGCM results and will be investigated in VAST once it is extended. The lack of latitude variations in VTGCM outputs maybe not unexpected, since a smooth lower boundary condition is used presently.



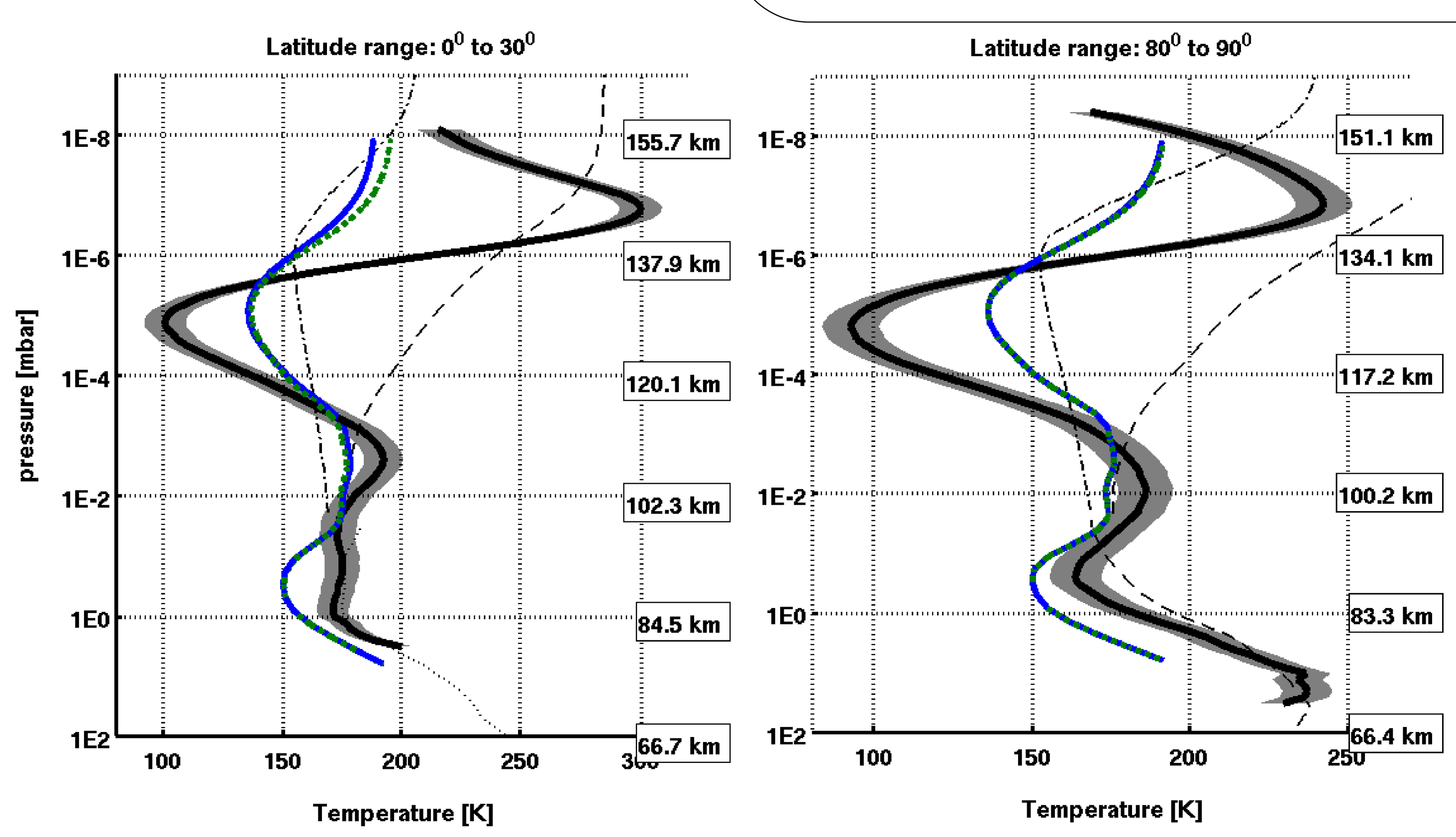
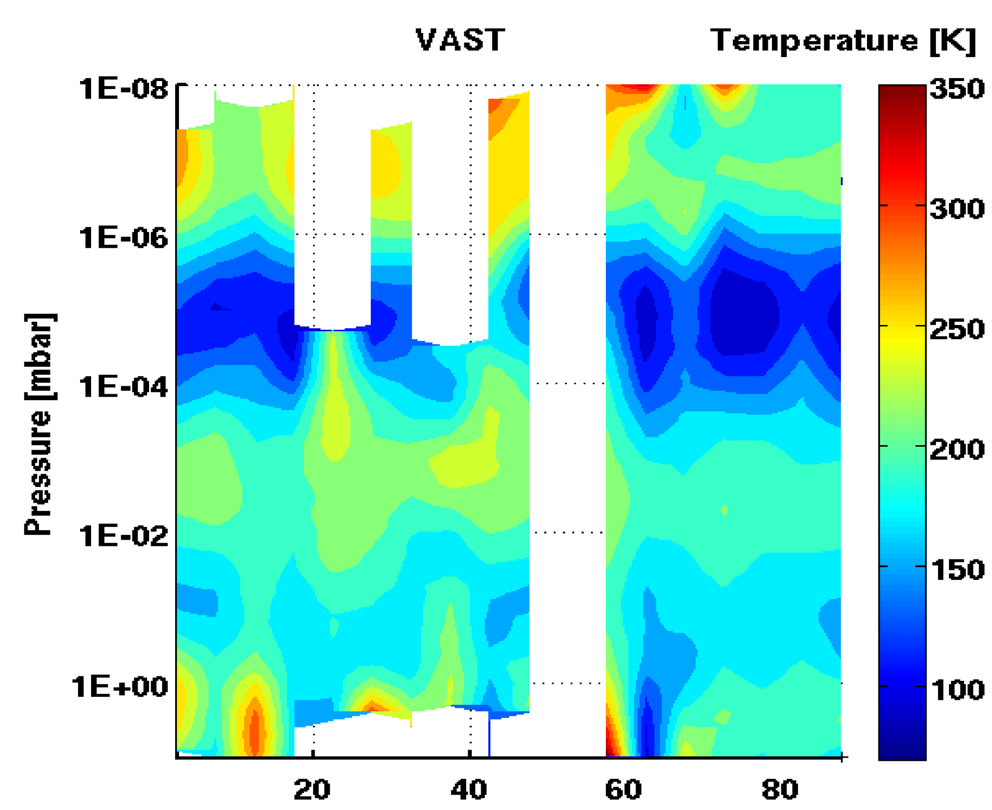


Figure 2: VAST and VTGCM vertical profiles for the CO_2 density (top) and the Temperature (bottom). VTGCM profiles are given for each side of the terminator, in blue for the morning side and in green for the evening side. The density is given in altitude scale while temperature is in pressure scale. For the VAST 0° to 30° latitude bin (left), the output of the VTGCM is for 15° latitude and for the VAST 80° to 90° latitude bin (right), the output of the VTGCM is for 85° latitude. The gray envelope is the confidence range for VAST.



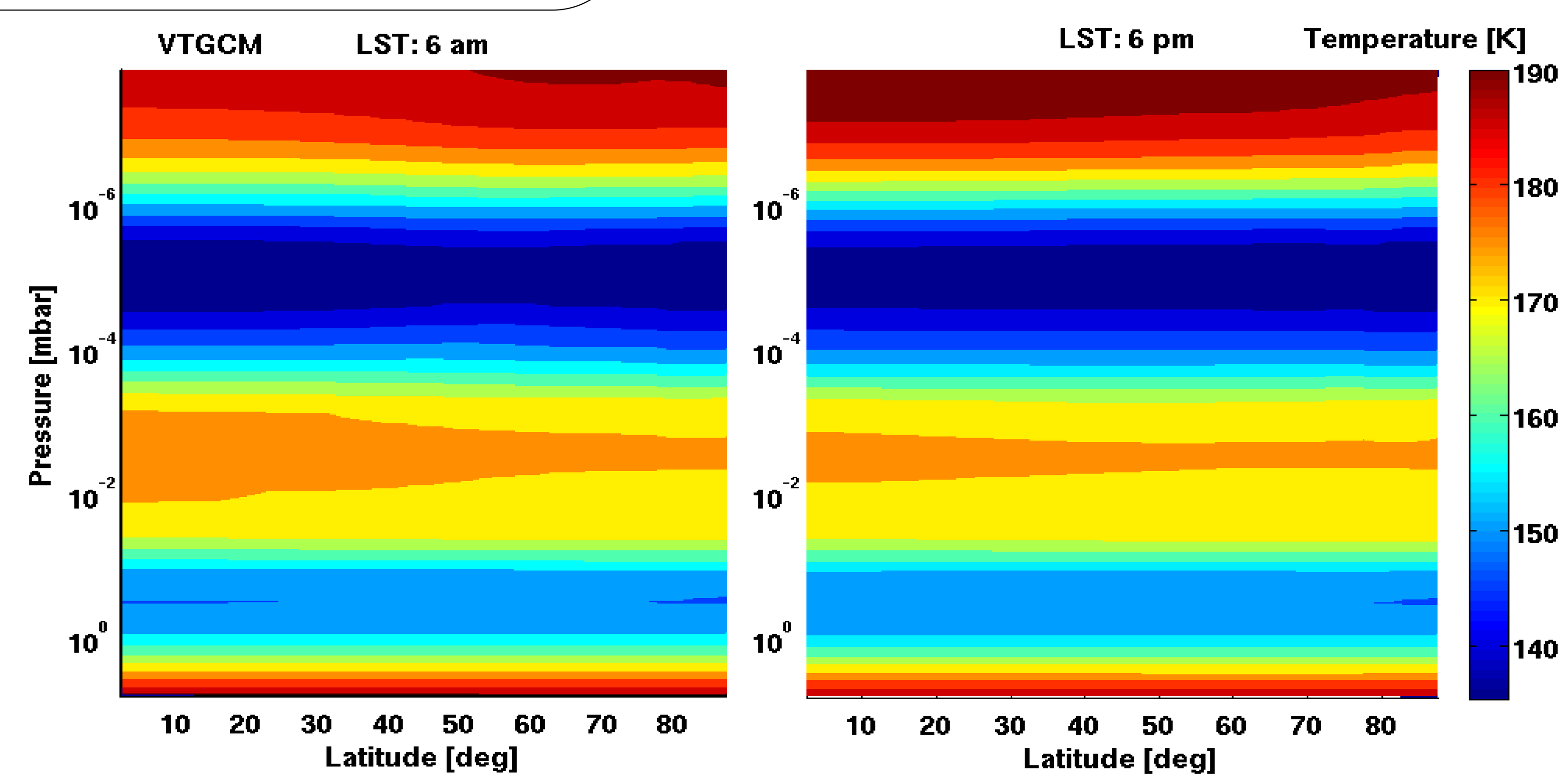


Figure 3: VAST (top) and VTGCM (bottom) temperature field. VTGCM temperatures are given for each side of the terminator, the morning side is left and the evening side right. For both, 5° latitude bins are used.

In conclusion, the use of VTGCM to analyze and interpret the VAST data can contribute to a better characterization of the Venus middle and upper atmosphere RSZ and SS-AS wind components. VAST will be further refined and improved with additional CO_2 measurements expanding the sampling periods and locations available for data-model comparison. Additional VTGCM simulations will be performed for the purpose of fine-tuning parameters that control variability of the structure of the Venus middle-upper atmosphere (~80-200 km). For instance, an improved lower boundary for the VTGCM will be specified, based upon lower atmosphere GCM codes, in order to capture upward propagating tides and planetary waves. Also, gravity wave drag parameters will be varied to control the magnitudes of cross terminator winds. Finally, solar EUV-UV fluxes will be specified to correspond to the range of changing fluxes encountered during the SOIR data sampling period examined.

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