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Contribution from SOIR/VEX to the updated Venus International Reference Atmosphere (VIRA)

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Abstract

The SOIR instrument on-board Venus Express is an infrared spectrometer covering the 2.2–4.3 μm spectral region. This instrument allows the detection of several key species of the Venus atmosphere, including CO_2, CO, H_2O/HDO, HCl, HF and SO_2. From the CO_2 density measurements, temperature is inferred giving information on the thermal structure of the atmosphere. Here we described the kind of data (profiles, latitudinal average, etc.) that will be provided to the updated VIRA compilation.

Keywords: Venus; Reference atmosphere; Solar occultation; Vertical profiles; Trace gases; Structure

1. Introduction

The Venus International Reference Atmosphere (VIRA) was compiled by Kliore et al. (1985) presenting a synthesis of the best available data on the neutral atmosphere and the ionosphere of the planet. This was the first attempt to summarise all the knowledge about Venus, providing a common standard reference through tables and averages. The original VIRA chapter dealing with the structure of the atmosphere from the surface to 100 km of altitude (Seiff et al., 1985) included tables of the vertical temperature and density considering no day-night, latitudinal or synoptic variations in the lower atmosphere, but allowing for latitudinal variations in the middle layers (33–100 km). Particulate matter present in the Venus atmosphere included in the VIRA model has been discussed in Ragent et al. (1985), in which plots and tables gave indications on the altitude dependence of the scattering properties, the size and number densities, as well as mass loadings and optical depths. The three recognised aerosols' modes are already fully described and characterised. One chapter (Keating et al., 1985) was devoted to the structure and composition of the upper atmosphere. It gathered tables with temperature, total density, and densities of CO_2, O, CO, He, N, N_2 for altitudes from 100 km to 250 km, considering no latitudinal variations. Data from 100 to 150 km were given only for noon and midnight conditions only, while those for 150–250 km were provided for different local times. Chapter V of the VIRA compilation looked at the known composition of the Venus atmosphere below 100 km altitude (von Zahn and Moroz, 1985).

Since then many missions have yielded new and valuable information. A first attempt to update the VIRA model

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was put forward by Moroz and Zasova (1997). They considered new data provided by the VEGA 1 and 2 UV spectrometers (Bertaux et al., 1996; Linkin et al., 1986), Venera 15 infrared spectrometer and Venera 15 and 16 radio occultation experiments (Moroz et al., 1986; Oertel et al., 1985; Zasova, 1995; Zasova et al., 1996) and radio occultation experiment (Yakovlev et al., 1991), as well as NIMS observations obtained during the Galileo fly-by of Venus in 1990 (Carlson et al., 1993; Collard et al., 1993; Grinspoon, 1993; Roos et al., 1993; Taylor, 1995). They also included reanalysis of previous data (from previous Venera missions and Pioneer Venus) and some ground-based observations for trace gases abundances (Bézard et al., 1990; de Bergh et al., 1995; Pollack et al., 1993). The structure of the Venusian atmosphere was updated by Zasova et al. (2006) taking into account measurements of the vertical temperature profile by the VEGA spacecraft and balloons, the radio occultation measurements of Magellan, Venera 15, and Venera 16, as well as the temperature profiles derived from the Venera15 IR spectrometer. They proposed a model of the atmosphere in the altitude range from 55 to 100 km consisting of tabulated temperature dependent on local time for 5 latitudinal regions (<35°, 35–55°, 50–70°, 70–80°, 85°). Nothing similar was ever done for the composition of the Venusian atmosphere except for an updated version of the initial Table 5-1 of von Zahn and Moroz (1985) given in Moroz and Zasova (1997) and the compilation of observations performed below 100 km (de Bergh et al., 2006) which led to a better knowledge of the vertical profiles of water vapour and of sulphuric species. However, the data corresponding to the higher altitudes (above 100 km) that were investigated in Keating et al. (1985) have never been updated.

The Venus Express mission has however yielded a wealth of new information on the Venus atmosphere, from the surface up to the highest layers of the atmosphere. In particular a series of spectrometers have been sounding the atmosphere to derive new data on the structure but also on the composition. Particularly the SOIR instrument, which is part of the SPICAV suite, is sensitive in a very wide spectral region. In the following, we will briefly describe the instrument and explain the data that could be included into the updated VIRA compilation.

2. Instrument description

The instrument has already been extensively described elsewhere (Bertaux et al., 2007a; Mahieux et al., 2008; Nevejans et al., 2006) and will only be briefly outlined here. SOIR is an Echelle grating spectrometer operating in the IR, combined with an acousto-optic tunable filter (AOTF) for the selection of the recorded wavenumber interval. The wavenumber range covered by the instrument extends from 2200 to 4370 cm^{-1} (2.3–4.5 μm) and is divided into 94 diffraction orders (from 101 to 194). The definition and limits of these diffraction orders are presented in Vandaele et al. (2013). The bandwidth of the AOTF was originally designed to be 20 cm^{-1}, as measured on ground before launch (Nevejans et al., 2006), to allow light from only one order into the spectrometer. However, the measured bandwidth of the AOTF filter is ~24 cm^{-1} (Mahieux et al., 2008). Information from adjacent orders therefore leaks onto the detector. This effect is called superposition of orders hereafter and has to be taken into account in the retrieval method.

The resolution of the SOIR instrument varies slightly from the first to the last order, from 0.12 to 0.20 cm^{-1}, as does the spectral sampling interval which varies from 0.030 cm^{-1} in diffraction order 101–0.055 cm^{-1} in order 194, increasing with the pixel number and the diffraction order. Signal to noise ratio on the SOIR transmittances varies between 250 and 5000 but is typically of the order of 2000. These SNR values are deduced from the recorded spectra as explained in Vandaele et al. (2013).

The retrieval method has been described in detail in several papers introducing the solar occultation method (Vandaele et al., 2008), deriving CO_2 densities (Mahieux et al., 2015a, 2012) and trace gases such as CO (Vandaele et al., 2015a,b), HCl and HF (Mahieux et al., 2015d), SO_2 (Belyaev et al., 2008, 2012; Mahieux et al., 2015b), H_2O and HDO (Fedorova et al., 2008). Temperature and total density, and therefore structure, has been retrieved from the CO_2 observations (Mahieux et al., 2015a, 2010, 2015c, 2012). The SOIR spectra give also access to information on the aerosol content in the upper haze. Light extinction due to aerosols and cloud top altitudes have been obtained (Wilquet et al., 2012, 2009) as well as the H_2SO_4 concentration in the droplets (Wilquet et al., 2014). In the following of the paper, we will describe in detail the data derived from the SOIR instrument, their coverage in terms of latitude, local solar time and altitude. As a general comment, solar occultation observations provide information on a very important region of the atmosphere, i.e. the terminator, the limit between the day and night sides of the planet. As a consequence the observations of SOIR correspond either to 6 am or 6 pm, even if at high latitude the definition of time starts to be meaningless. This region is crucial because it is a place of large longitudinal gradients in temperature and density.

3. Composition derived from SOIR

The spectral range covered by SOIR allows the observation of several key species of the Venus atmosphere, such as CO_2, CO, HCl, HF, H_2O and its isotopologue HDO, as well as SO_2. The retrieval technique to derive CO_2 densities and trace gas densities is the same and has been described in detail in (Mahieux et al., 2010; Vandaele et al., 2008). All spectra recorded during one occultation are analysed all together in an iterative way that finally delivers the densities of the targeted trace gases as well as the CO_2 density and temperature if at least one of the selected wavelength ranges contains CO_2 absorption bands. CO_2 has been observed in almost all occultations, except at the beginning