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Recent results obtained by the SOIR instrument on board Venus Express: Vertical profiles of carbon species

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Abstract

The SOIR instrument (Solar Occultation in the IR) performs solar occultation measurements in the IR region (2.2 - 4.3 µm) at a resolution of 0.12 cm^{-1}, the highest on board Venus Express. It combines an echelle spectrometer and an AOTF (Acousto-Optical Tunable Filter) for the order selection.
The wavelength range probed by SOIR allows for a detailed chemical inventory of the Venus atmosphere at the terminators in the upper mesosphere and lower thermosphere (80 to 180 km) with an emphasis on vertical distribution of the gases. In particular, measurements of CO2 and CO density and rotational temperature vertical profiles have been routinely performed. Comparisons with the hydrostatic equilibrium allowed us to derive information concerning the dynamical behavior of the atmosphere at the terminators. The approach as well as some results will be described.

1. Introduction

Venus is a very warm and dry planet with a dense atmosphere composed mainly of carbon dioxide (CO_2, 96.5%) and Nitrogen (N_2, 3.5%). Chemically active species, such as sulfuric bearing gases (OCS, SO_2) and halides (HCl, HF) have already been reported. Measurements have been performed essentially in the mesosphere below 100 km and below the clouds. Information about minor atmospheric constituents, their concentration, reactions, sources and sinks is incomplete, as for example only scarce measurements have been performed above 100 km altitude. In particular, photochemical models of the middle atmosphere would benefit from abundance measurements of Cl-bearing gases.
The SOIR (Solar Occultation in the IR) spectrometer is an extension mounted on top of the SPICAV instrument [1]. SPICAV/SOIR is one of the seven instruments on board Venus Express, a planetary mission of the European Space Agency (ESA) that was launched in November 2005 and inserted into orbit around Venus in April 2006 [2].

2. The SOIR instrument

SOIR is an Echelle grating spectrometer operating in the IR, combined with an acousto-optic tunable filter (AOTF) for the selection of the diffraction grating orders. The free spectral range (FSR) of the Echelle spectrometer, i.e. the spectral interval in which there is no interference or superposition of light from adjacent orders equals 22.38 cm^{-1}, whereas the bandwidth of the AOTF was originally designed to be 20 cm^{-1}, as measured on ground before launch [3]. The real measured bandwidth of SOIR is ~24 cm^{-1} [4], creating some order leakage on the detector. The wavenumber domain that can be investigated by the SOIR instrument extends from 2256 to 4369 cm^{-1}, and is divided into 94 smaller ranges corresponding to the different orders (from 101 to 194). The detector width for orders 101 to 122 is smaller than the FSR of 22.38 cm^{-1} and hence the detector will miss part of the spectrum. For orders 123 to 194 the inverse happens: the detector width is equal to or larger than the FSR and the detector will not be completely covered by the selected order.
The AOTF is driven by high radio frequencies (RF) that may be tuned for selecting the bandpass wavenumber range. The AOTF is a fast-response solid state TeO2 optical filter, whose transfer function has been extensively investigated in [5] and may be approximated by the sum of sinc squared functions, where sinc(x) is defined as $\sin(\pi x)/\pi x$, x being the independent variable, here the RF. The main lobe of the sinc square-like function has a full width at half maximum (FWHM) of about 24 cm^{-1}. The shape of the AOTF transfer function varies significantly along the wavenumber range [5].
Raw spectra, registered by SOIR and transmitted to Earth, need dedicated processing in order to upgrade

them to a calibrated data set. This involves detector non-linearity correction, spectral calibration and division by a reference solar spectrum. Ideally the reference spectrum that is taken outside the atmosphere would be measured with an identical relative slit position with respect to the solar disk. Attitude drift of the spacecraft, however, makes the slit float which results in a gradual linear change of the intensity. This effect is also corrected for [4].

The wavenumber calibration, i.e. converting the pixel number of the detector to wavenumber using the position of known solar lines, includes a correction for the Doppler effect as the speed of the satellite projected on the line of sight may vary during an occultation, but also from one orbit to the other.

3. The solar occultation technique

The solar occultation technique used by SOIR allows the derivation of unique information about the vertical structure and composition of the Venus mesosphere [6]. SOIR is looking towards the Sun and records spectra on a one second cycle basis. Solar occultations occur when the line of sight of the instrument crosses the atmosphere of Venus. The projection of the centre of the slit on the limbs during each single measurement defines the tangent altitude. Because the spacecraft is moving along its orbit, the instrument sounds the atmosphere of the planet at different tangent altitudes.

The orbit of Venus Express is very eccentric with its apocentre, located above the North Polar Region, at an altitude of 180 to 250 km above the ground. The pericentre, above the South Polar Region, reaches 65,000 km. For this reason, the vertical resolution of the measurement, depending on the distance of the satellite to the limb, will be dependent on the latitude of the measurement : high Northern latitude (60° to 90°) measurements have a very good vertical resolution, the layer thicknesses are small (from 200 m to 700 m); measurements at lower latitudes (-30° to 60°) have an average vertical resolution ranging from 700 m to 2 km; Southern latitudes (-90° to -30°) have a very poor vertical resolution, with layer thicknesses greater than 2 km, up to 5 km.

3. Method and Results

The analysis code is based on the ASIMUT program [6] and has been adapted in Matlab in order to improve the retrieval procedure, i.e. by providing the determination of the temperature [7]. The algorithm uses the onion peeling approach. The retrieval method based on the Optimal Estimation (OEM) has been fully described in [7], only some results concerning the retrieval of the vertical profiles of the density of carbon containing species (CO, CO2) will be presented here.

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