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Water vapor near Venus cloud tops from VIRTIS-H/Venus express observations 2006–2011

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ABSTRACT

This work aims to give a summary of the water vapor at the cloud top of Venus atmosphere using the complete set of observations made using high spectral resolution channel (-H) of Visible and Infrared Thermal Imaging Spectrometer (VIRTIS), on board the ESA Venus Express orbiter, to measure the cloud top altitude and the water vapor abundance near this level. An initial analysis of these measurements by Cottini et al. (2012) was limited to data in 140 orbits in the period 2007–2008. These observations were limited to the Northern hemisphere due to observational geometry in this early part of the mission. In the present paper, the analysis is extended to a larger dataset covering the years 2006–2011, significantly improving the latitudinal coverage. Altitude of the cloud tops, corresponding to unit optical depth at a wavelength of 2.5 μm, is equal to 69 ± 1 km at low latitudes, and decreases toward the pole to 62–64 km. The water vapor abundance is equal to 3 ± 1 ppm in low latitudes and it increases reaching a maximum of 5 ± 2 ppm at 70–80° of latitude in both hemispheres, with a sharp drop in the polar regions. This can be explained by the specific dynamics of the atmosphere of Venus affecting the distribution of water vapor such as the transfer of water vapor in the Hadley cell and the dynamic in the polar vortex. The average height of the cloud tops and the H_2O near this level are symmetric with respect to the equator. As a function of local solar time, the water vapor shows no particular dependence, and the cloud tops exhibit just a weak maximum around noon. Over 5 years of observations the average values of the cloud top altitude and the water vapor were quite stable in low and middle latitudes, while in high latitudes both quantities in 2009–2011 years are systematically higher than in 2006–2008. Short period variations increasing with latitude are observed, from approximately less than ± 1 km for cloud tops and ± 1 ppm for water vapor in low latitudes to, respectively, ± 2 km and ± 2 ppm in high latitudes. As a rule there is no correlation between variations of the cloud top altitude, the water vapor content, and the UV brightness. However, numerous examples can be found when UV dark features, with a characteristic size of a few degrees of latitude (several hundred kilometers), coincide with regions of higher cloud tops.

1. Introduction

Water vapor plays an important role in the formation of clouds, in the chemistry and in the thermal balance of the atmosphere of Venus, which makes it one of the main objects of remote sensing measurement methods. The sulfuric acid clouds (aqueous solution of sulfuric acid – H_2SO_4, e.g. Esposito et al., 1997) surround Venus completely. They are divided into upper, middle and lower clouds (e.g. Esposito et al., 1983) and have played a key role in the evolution of the planet and its atmosphere. The main cloud deck of Venus spans from about 46 km of altitude (lower cloud) to an upper boundary layer situated around 65 km, with haze layers expanding down to 30 km – while the first 30 km of atmosphere are composed of clear CO_2 air – and upwards for a further 10 km (e.g. Esposito et al., 1983).

The sulfuric acid in the clouds is produced through photochemical reaction (e.g. Yung and DeMore, 1982; Krasnopolsky and Parshev, 1981) of H_2O and SO_3 near the cloud tops, at altitudes of

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60 km or higher (upper clouds), where SO_2 is oxidized to SO_3. Oxygen is made available through photodissociation of carbon dioxide into carbon monoxide and atomic oxygen. In the middle clouds (about 50–57 km) the H_2SO_4 vapor nucleates then to cloud particles and a downward diffusion and sedimentation of H_2SO_4–H_2O droplets occurs (e.g. Krasnopolsky and Pollack, 1994). At the bottom of the clouds H_2SO_4 evaporates due to higher atmospheric temperature (e.g. Ragent and Blamont, 1980) and diffuses downward. The vapor then incurs on thermal decomposition into SO_2 and H_2O at about 38 km of altitude; vertical mixing from regions below the main cloud layer diffuses upward sulfur dioxide and water in the clouds and up to the cloud top, enriching the clouds of these gases and giving origin to a convective cycle (e.g. Krasnopolsky and Pollack, 1994). Therefore the region of the cloud top is a thin, but highly active photochemical layer where the main production of the sulfuric acid droplets from SO_2 and H_2O occurs; the determination of their abundances and variability over space and time play a key role in understanding clouds properties and dynamics.

Numerous observations have demonstrated high variability of water vapor, from fractions to tens and even hundreds of ppm, which have been attributed to real variability, model errors, and different effective altitude ranges of sounding. Mesospheric water vapor abundance has been previously measured with different techniques and at various wavelengths from microwaves to visible. A brief review and references of previous results can be found in Cottini et al. (2012). See also further reviews in Koukouli et al. (2005), Sandor and Clancy (2005), Gurwell et al. (2007), and Krasnopolsky (2010a).

More recent ground based spectroscopic measurements of water vapor near the cloud top (Krasnopolsky, 2010b; Krasnoplosky et al., 2013) and measurements from the instrument on the Venus Express spacecraft-VIRTIS (Cottini et al., 2012) and SPICAV (Fedorova et al., 2014)-are generally well consistent with each other but still demonstrate some noteworthy differences. In particular, temporal variability and absolute values of H_2O abundance measured from different spectral ranges deserve to be better understood and will be discussed in the Section 3 of this paper.

An extensive study of water vapor, its variability and possible correlation with the clouds density and altitude, obtained with measurements acquired by VIRTIS-H over time and space, is hence of particular importance.

2. Observations and method

VIRTIS, the Visible and Infrared Thermal Imaging Spectrometer (Drossart et al., 2007) on board the Venus Express mission started to observe Venus in 2006 (Svedhem et al., 2009). It covers a spectral range from UV to thermal IR: 0.3–5 μm. To measure the content of water vapor near the cloud top and the relative altitude we use its VIRTIS high-resolution subsystem (-H), an echelle grating spectrometer with eight diffraction orders focused on a 270 × 438 pixel array detector (CCD). These eight partially overlapped spectra with variable spectral resolution of 1–3 nm are added to form a VIRTIS-H spectrum, which covers a spectral range from 2 to 5 μm. The day-side spectrum of solar radiation scattered and reflected by the atmosphere of Venus contains absorption bands of atmospheric gases. Their depths depend on the cloud layer altitude and the gas abundances. In particular, the absorption band of CO_2 and H_2O between 2.48 and 2.60 μm in the VIRTIS-H day side spectrum (Fig. 1) are used to determine the cloud top altitude (Ignatiev et al., 2009; Cottini et al., 2012), defined as the altitude of unity optical depth in the considered spectral range, and water vapor abundance near this level (Cottini et al., 2012). Simultaneous measurements of the Venus spectrum in the range from 0.3 to 1 μm made with the moderate spectral resolution mapping channel (-M) of the VIRTIS instrument have been recently calibrated (version 2.0 of the VIRTIS calibrated dataset, released in 2013 on ESA's Planetary Science Archive) and can be used to investigate a possible correlation of the clouds and water vapor with the UV absorber.

Due to the polar orbit of the Venus Express satellite (details can be found in Svedhem et al., 2009) a typical track of the VIRTIS-H field of view footprint on the cloud surface during one measurement session (orbit) extends along a meridian from one pole to another or covers just a limited latitude range. This geometry enables building of latitudinal profiles of measured values for different local solar time (Fig. 2). The Venus Express orbit is highly elliptic and the field of view footprint size and the distance between measurements depend on the distance to the planet and the observation angle. Accordingly, the spatial resolution is changing from several kilometers to more than 100 km.

First VIRTIS-H observations of Venus, up to orbit 500, were not included in Cottini et al. (2012); they were initially unavailable because of a challenging calibration due to a contamination of the dark signal (used in the computation of the instrument responsivity)

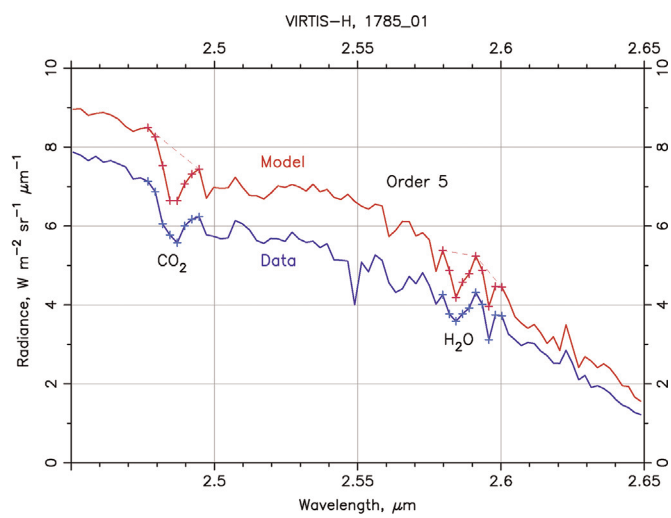

Fig. 1. VIRTIS-H day-side part of the spectrum including absorption bands of CO_2 and H_2O between 2.48 and 2.60 μm that are used to determine the cloud top altitude and water vapor abundance near this level in the measured (blue) and calculated (red) spectra, orbit 1785, order of diffraction 5. Spectral channels used for the retrievals are marked with +. Dashed lines represent the continuum.

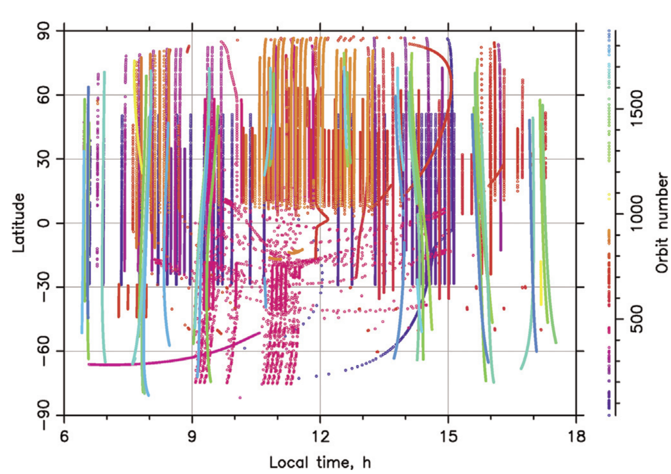

Fig. 2. Coverage in latitude and local time of Venus' VIRTIS-H spectra used to measure the water vapor content: 250 orbits between Venus Express orbit 42 and 1871 acquired during the years 2006–2011, for a total of about 90,000 spectra. Color coding corresponds to the orbit numbers given on the right scale.