A new view of Earth's sister: Insights following seven years of observation with Venus Express

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Venus Express

Venus Express is the first ESA mission to Venus [1]. Since April 2006 the spacecraft has been performing a global survey of the Venus atmosphere, the plasma environment and the surface. The spacecraft carries the most powerful suite of remote sensing experiments ever flown to the planet. It includes spectrometers, spectro-imagers and cameras, complemented by the radio-science experiment and instruments for plasma investigation (Fig.1). The payload provides continuous imaging of the Venus clouds in a broad spectral range from UV to thermal IR, including spectral transparency "windows" on the night side, that allows to study the cloud morphology in 3D. This poster presents (1) highlights of the clouds investigations by the Venus Monitoring Camera (VMC) and the Visible Infrared and Thermal Imaging Spectrometer (VIRTIS) and (2) radiative balance calculations based in the new model of the cloud and temperature structure.

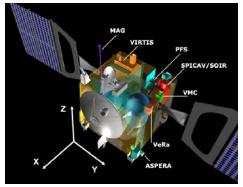


Figure 1. Schematic view of the Venus Express spacecraft with instruments indicated.

Cloud top morphology

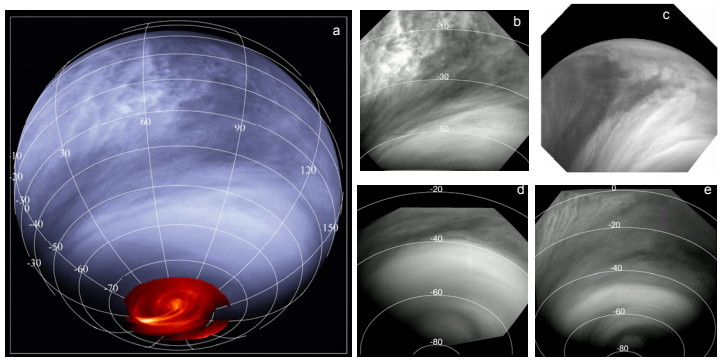


Figure 2. VMC images in UV filter (365 nm): (a) global view of the Southern hemisphere, (b) mid-latitude transition region, (c) sub-solar region, (d, e) "polar cap". Thermal IR image of the vortex eye at the Southern pole is shown in red.

The contrast features seen in the VMC UV images are produced by inhomogeneous distribution of an unknown absorber at the Venus cloud tops (Fig. 2) [2]. The global view is characterized by patchy clouds in the tropics, streaky features in the middle latitudes and bright featureless appearance at the pole. This morphology is governed by the atmospheric structure and dynamics at the cloud tops [3]. Since the UV absorber is responsible for the main portion of deposited solar energy in the Venus atmosphere, its inhomogeneous distribution results in strong contrasts in the radiative energy deposition pattern. For instance, difference in UV albedo and solar incidence angle between low and high latitudes can cause up to a factor of 10 difference in solar energy absorbed by the planet.

Cloud top altimetry

Spectro-imaging by VIRTIS in the near-IR absorption bands of CO_2 and simultaneous UV imaging by VMC provided a global map of the cloud top altitude (Fig. 3). The cloud top altitude (i.e. level of the optical depth τ=1) is remarkably constant at ~73 km all over the planet's low-to-middle latitudes with global depression in the polar regions where the cloud top descends to ~64 km. The depression coincides with the polar eye of the hemispheric vortex [5].

Structure of the cloud tops and its latitudinal variability was derived from the joint analysis of the VIRTIS thermal-IR spectra at 4-5 μm, which are sensitive to both temperature and cloud structure, and the temperature profiles from the VeRa radio occultation experiment [6]. This study confirmed the gradual descent of the cloud top from 67.2 ± 1.9 km in low latitudes to 62.8 ± 4.1 km at the pole. This altitudes are different to those derived from the near-IR spectroscopy due to different wavelength used. The analysis also indicated a decrease of the aerosol scale height from 3.8 ± 1.6 km in low latitudes to 1.7 ± 2.4 km at the pole.

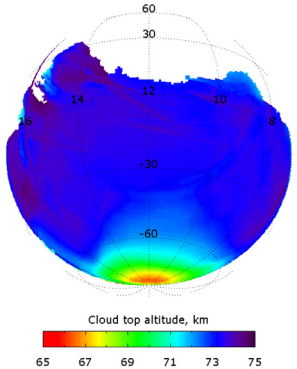
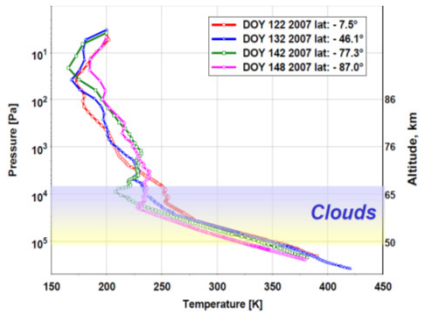


Figure 3. Altitude of the Venus cloud tops

Temperature and cloud structure



The radio-occultation experiment VeRa onboard Venus Express provided more than 700 temperature profiles in the altitude range from 90 km to 40 km (Fig. 4) [7]. The temperature structure changes from monotonous in low latitudes to that with strong inversions in the "cold collar" region and high latitudes (50-70 degrees). Altitudes of minimum temperature in inversions coincide with the position of the sharp cloud top.

Figure 4. Examples of the temperature profiles derived from the VeRa radio-occultation sounding.

VeRa radio occultation experiment allowed building of the latitude-altitude temperature field (Fig. 5) [7]. The cloud top structure correlates with the temperature field. The cloud top descends from ~73 km to ~64 km in the "cold collar" region accompanied by a collapse of the upper haze resulting in strong decrease of aerosol scale height in high latitudes.

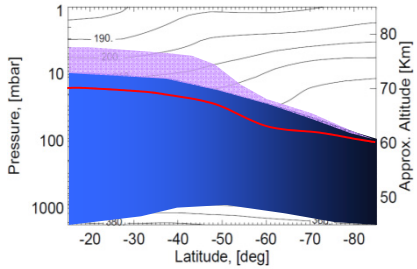


Figure 5. Synthesis of the cloud structure overplotted on the VeRa temperature field. The violet area and the red line schematically show the cloud top and the tropopause.

Dynamics of the Venus mesosphere

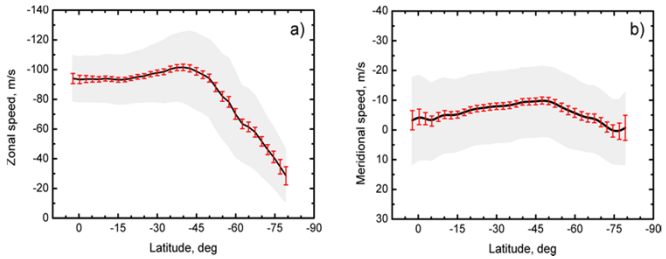


Figure 6. Mean zonal (a) and meridional (b) profiles of the wind speed derived over the period of 10 Venusian years (till Venus Express orbit 2299) by manual cloud tracking. Error bars correspond to 99.9999% ($5\sigma_{\mu}$) confidence interval based on the standard deviation of the weighted mean. Standard deviations are presented by shadowed areas.

VMC provided the largest so far data set of UV images (Fig. 2). They were used for tracking cloud tops winds during about 10 years period [8].

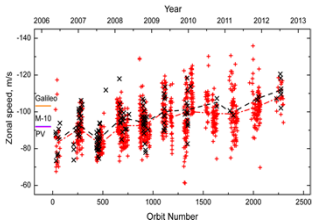


Figure 7. Variations of the mean zonal wind speed at 20°±2.5° S over the mission time. Symbols show orbital averages derived by manual ("x" and black dashed line) and digital ("+" and red dotted line) methods. The results from the Mariner-10 (92 m/s), Pioneer-Venus (91.8±3 m/s) and Galileo (103 m/s) missions for the same latitude zone are presented at the left edge of the plot for comparison.

Thermal wind and cyclostrophic balance

Zonal wind in the Venus mesosphere was derived from the VeRa temperature sounding [7] assuming cyclostrophic balance [9] (Fig. 8). Latitudinal profile of the thermal wind in general match the cloud tracked winds (Fig. 6), although the cyclostrophic wind shows more pronounced mid-latitude jet.

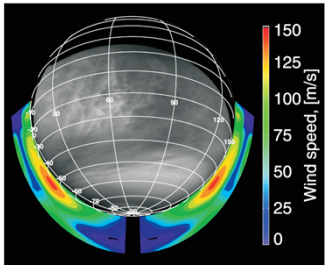


Figure 8. Latitude–altitude cross section of the zonal cyclostrophic wind derived from the VeRa temperature soundings (in color) plotted together with VMC UV image.

Composition of the Venus atmosphere

Composition of the Venus atmosphere is investigated by two techniques. SOIR/SPICAV measures vertical profiles of trace gases in the mesosphere above the cloud tops. Below the clouds (30-40 km) VIRTIS provided global mapping of several key minor species (Fig. 9).

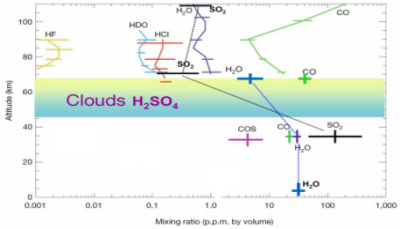


Figure 9. Composition of the Venus atmosphere from the SOIR/ SPICAV and VIRTIS spectro-scopic investigations.

Atmospheric escape

ASPERA experiment measures escape of ions and energetic neutrals (Fig. 10). Total flux of escaping O^+ ions is 2.7 10^{24} s^{-1} with H^+/O^+~2.6. The ions escape mainly though the plasma sheet region.

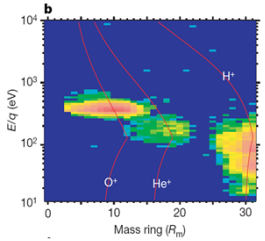
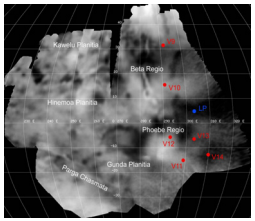


Figure 10. ASPERA mass-charge diagram showing signatures of ions.

Thermal imaging of the surface



VIRTIS and VMC experiments provided imaging of the Venus surface in the 1 μm transparency window (Fig. 11) that allowed to derive maps of the surface emissivity variations and make conclusions about the surface composition and rate of volcanism [10-12].

Figure 11. VMC mosaic of the Venus surface in 1 μm transparency window.

References

1. Svedhem, H., D.V. Titov, F. Taylor, O. Witasse. Venus Express mission. J. Geophys. Res. 114, 3-21, 2009.
2. Titov, D.V., W.J. Markiewicz, N.I. Ignatiev et al.. Morphology of the cloud tops as observed by VMC, Icarus 217, 682-701, 2012.
3. Titov, D.V., F.W. Taylor, H. Svedhem et al.. Atmospheric structure and dynamics as the cause of ultraviolet markings in the clouds of Venus, Nature 456, 620-623, 2008.
5. Ignatiev, N.I., D.V. Titov, G. Piccioni et al.. Altimetry of the Venus cloud tops from the Venus Express observations. J. Geophys. Res. 114, 405-414, 2009.
6. Lee, Y.J., D.V. Titov, S. Tellmann et al.. Vertical structure of the Venus cloud top from the VeRa and VIRTIS observations onboard Venus Express, Icarus, 217, 599-609, 2012.
7. Tellmann, S., Pätzold, M., Häusler et al.. The structure of the Venus neutral atmosphere as observed by radio science experiment VeRa on Venus Express. J. Geophys. Res. 114, 2008.
8. Khatuntsev, I.V., M.V. Patsaeva, D.V. Titov et al.. Cloud level winds from the Venus Monitoring Camera imaging, Icarus 226 (2013), pp. 140-158, 10.1016/j.icarus.2013.05.018.
9. Piccialli, A., S. Tellmann, D.V. Titov et al.. Dynamical properties of the Venus mesosphere from the radio-occultation experiment VeRa onboard Venus Express, Icarus 217, 669-681, 2012, doi: 10.1016/j.icarus.2011.07.016.
10. Smrekar, S.E., E.R. Stofan, N. Mueller et al.. Recent hot spot volcanism on Venus from VIRTIS emissivity data, Science 328, p 605, 2010.
11. Basilevsky, A.T., E.V. Shalygin, D.V. Titov et al.. Geologic interpretation of the near-infrared images of the surface taken by the Venus Monitoring Camera, Venus Express. Icarus 217, pp 434-450, 2012.
12. Shalygin, E.V., A.T. Basilevsky, W.J. Markiewicz et al.. Search for ongoing volcanic activity on Venus: Case study of Maat Mons, Sapas Mons and Ozza Mons volcanoes. Planetary and Space sci., v73, p 294-301, 2012.