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Meridional and Zonal winds at Venus' atmosphere from Cloud-tracking, Doppler techniques and comparison with modelling

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Abstract

We present final results of the meridional wind in both Venus' hemispheres and spatial and temporal variability of the zonal wind, based on coordinated observations at Venus cloud-tops based with two complementary techniques: Ground-based Doppler velocimetry and cloud-tracked winds using ESA Venus Express/ VIRTIS-M imaging at 0.38 μm. Cloud-tracked winds trace the true atmospheric motion also responsible for the Doppler-Fizeau shift of the solar radiation on the dayside by super-rotating moving cloud-tops with respect to both the Sun and the observer (Machado et al., 2014). Based on this complementarity, we performed a new coordinated campaign in April 2014 (Machado et al., 2017) combining both Venus Express observations and ground-based Doppler wind measurements on the dayside of Venus' cloud tops at Canada-France-Hawaii telescope at a phase angle $\Phi = (76 \pm 0.3)^{\circ}$. We also present final results based on observations of Venus' bottom of the cloud deck, carried out with the Near Infrared Camera and Spectrograph (NICS) of the *Telescopio Nazionale Galileo* (TNG), in La Palma, on July 2012. We observed for periods of 2.5 hours starting just before dawn, for three consecutive nights. We acquired a set of images of the night side of Venus with the continuum K filter at 2.28 microns, which allows to monitor motions at the lower cloud level of the atmosphere of Venus, close to 48$\sim$km altitude. Our objective is to measure the horizontal wind field in order to characterise the latitudinal zonal wind profile, to study variability, to help constrain the effect of large scale planetary waves in the maintenance of superrotation, and to map the cloud distribution. We will present results of cloud tracked winds from ground-based TNG observations and winds retrieved from coordinated space-based VEx/VIRTIS observations. The observational results will be compared with the ground-to-thermosphere 3D model developed at the Laboratoire de Meteorologie Dynamique in Paris (Gilli et al. 2017), whose zonal wind predictions above 60 km seem to be consistent with available measurements (Peralta et al. this issue).

1. Winds at cloud tops

With the high-resolution spectrograph ESPaDOnS at Canada-France-Hawaii Telescope (CFHT), the complete optical spectrum, from 370 to 1050 nm, is collected over 40 spectral orders in a single exposure at a resolution of about 80,000. Our choice of observing dates offers the best compromise between observability at Mauna Kea and the need to (i) maximize the angular diameter of Venus and spatial resolution on the disk, and (ii) minimize Venus phase angle and illuminated fraction as only the dayside hemisphere is observed. In the single scattering approximation, the Doppler shift measured in solar light scattered on Venus dayside is the result of two instantaneous motions: (1) a motion between the Sun and Venus upper clouds particles, which scatter incoming radiation in all directions including the observer's [4, 5, 6]; this Doppler velocity is minimal near Venus subsolar point; (2) a motion between the observer and Venus clouds, resulting from the topocentric velocity of Venus cloud particles in the observer's frame; this effect is minimal near Venus sub-terrestrial point. The measured Doppler shift is the sum of those two terms. It therefore varies with planetocentric longitude [11, 12].

Venus Express cloud top wind measurements based on tracking using images taken with the VIRTIS instrument [3, 9] indicate nearly constant zonal winds in the Southern hemisphere between 0 and 55 deg S. The analysis and results show (1) additional confirmation of the the coherence, and complementarity, in the re-

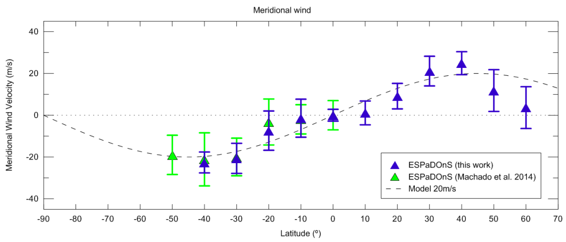

Figure 1: Meridional wind measured along both hemispheres at cloud top level (∼70 km).

sults provided by these techniques, on both spatial and temporal time scales of the two methods; (2) first-time estimation of the meridional component of the wind in other planet using the Doppler velocimetry technique, with evidence of a symmetrical, poleward meridional Hadley flow in both hemispheres; (3) spatial and temporal variability of the zonal flow with latitude and local time, with a significant increase of wind amplitude near morning terminator.

2. Winds at the bottom of the cloud layer

The lower Venusian atmosphere is a strong source of thermal radiation, with the gaseous CO_2 component allowing radiation to escape in windows at 1.74 and 2.28 μm. At these wavelengths radiation originates below 35 km, and unit opacity is reached at the lower cloud level, close to 48 km. Therefore, in these windows it is possible to observe the horizontal cloud structure, with thicker clouds seen silhouetted against the bright thermal background from the low atmosphere [1, 8]. We carried on observations at TNG telescope with the near-infrared camera (NICS). Our objective is to provide direct absolute wind measurements and a map of cloud distribution at the lower cloud level in the Venus troposphere, in order to complement Venus Express (VEX) and other ground-based observations of the cloud layer wind regime. By continuous monitoring of the horizontal cloud structure at 2.28 μm (NICS Kcont filter), it is possible to determine wind fields using the technique of cloud tracking [3, 7]. Cloud displacements in the night side of Venus were computed taking advantage of a phase correlation between images technique [6].

The absolute spatial resolution on the disk was ∼ 100 km/px at disk centre, and the (0.8-1") seeing-limited resolution was ∼ 400 km/px. By co-adding

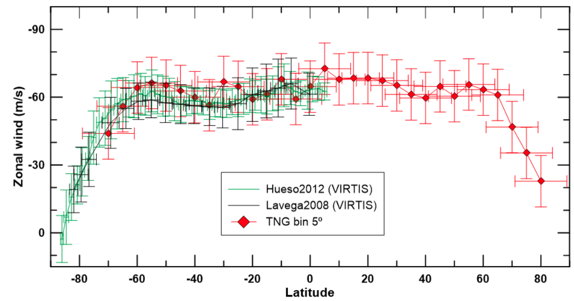

Figure 2: Zonal wind measured at the bottom of the cloud layer (∼48 km) and comparison with previous measurements in the southern hemisphere [3, 9].

the best images and cross-correlating regions of clouds the effective resolution was significantly better than the seeing-limited resolution [7]. In order to correct for scattered light from the (saturated) day side crescent into the night side, a set of observations with the Br_γ filter [10, 13] were performed.

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