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Ground and space based cloud-top wind velocities using CFHT/ESPaDOnS (Doppler velocimetry) and VEx/VIRTIS (cloud tracking) coordinated measurements

P. Machado (1), T. Widemann (2), J.Peralta (3) and D. Luz (1)
(1) Institute of Astrophysics and Space Sciences, Observatório Astronómico de Lisboa, Ed. Leste, Tapada da Ajuda, 1349-018 Lisboa, Portugal, (2) LESIA-Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris, France, (3) Institute of Space and Astronautical Science - Japan Aerospace Exploration Agency (JAXA), JAPAN.

Abstract

We will present wind velocity results based in the measurements of the horizontal wind field at the cloud top level of the atmosphere of Venus, near 70 km altitude. Our aim is contribute to the characterisation of the zonal and meridional wind latitudinal profiles on hour and day-timescales. This will be done by tracking Doppler shift of solar and CO_2 lines over the dayside hemisphere in coordination with ESA's Venus Express orbiter. Our observations measured winds at cloud tops at latitudes 60°S-60°N, while Vex/VIRTIS privileged southern latitudes poleward of 45°S. This coordination effort intended to provide a combined monitoring of short-term changes of wind amplitude and directions with extensive spatial coverage.

We present results based on inter comparison of ground-based Doppler velocimetry of cloud-top winds and cloud tracking measurements from the Venus Express spacecraft. Doppler wind velocimetry obtained with the 3.60 m Canada-France-Hawaii telescope (CFHT) and the Visible Spectrograph ESPaDOnS in February 2011 consisted of high-resolution spectra of Fraunhofer lines in the visible range (0.37-1.05 μm) to measure the wind velocity using the Doppler shift of solar radiation scattered by cloud top particles in the observer's direction. The complete optical spectrum was collected at a phase angle $\Phi = (76 \pm 0.3)°$, at a resolution of about 80000.

Both ground-based and Venus Express measurements show considerable day-to-day variability revealing wave propagation and angular momentum transport in latitude which needs to be carefully assessed. ESPaDOnS and the sequential technique of visible Doppler velocimetry has proven a reference technique to measure instantaneous winds. These measurements are necessary to help validating Global Circulation Models (GCMs) [2], to extend the temporal coverage of available datasets. The ground-based observations in the base of this project are critical in their complementarity with Venus Express, which was recently decommissioned.

We compared our measurements with simultaneous observations using the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) instrument from the VEx orbiter. CFHT observations included various points of the dayside hemisphere, between +60°N and 60°S, by steps of 10°, and from sub-Earth longitude $[\phi - \phi_E] = 0°$ to -50° corresponding to 7:30a - 10:50a, while VIRTIS-M UV (0.38 μm) cloud tracking measurements extended on the dayside south hemisphere between 30 and 50°S and 9:05a - 10:50a.

Our analysis technique allows an unambiguous characterisation of the zonal wind latitudinal, local time profile and its temporal variability. We will also present a latitudinal profile of the meridional wind in the mid-latitudes range.

1. Introduction

In the Venus' lower mesosphere (65?85 km), visible observations of Doppler shifts in solar Fraunhofer lines have provided the only Doppler wind measurements near the cloud tops in recent years [4, 5, 7, 8]. The region is important as it constrains the global mesospheric circulation in which zonal winds generally decrease with height while thermospheric SSAS winds increase [1,6]. Renewed interest in measuring the winds at clouds top from the ground has emerged in the course of the Venus Express mission. On Venus Express, atmospheric circulation at 70 km (and as well near 50 km) is being measured from cloud tracking by both VIRTIS-M and VMC instruments [1,3]. However, winds derived in this manner are usually averaged over several days of observations and do not reflect instantaneous wind velocity and its significant

variability at shorter time scales. In addition, cloud tracking is not able to measure wind fields above cloud level, where wind inferences have to rely on indirect hypothesis such as cyclostrophic balance. The main purpose of this study is therefore to provide direct and instantaneous wind velocity measurements using visible Fraunhofer lines scattered by Venus cloud tops.

2. Method

With ESPaDOnS, 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 ; this Doppler velocity is minimal near Venus sub-solar 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. The Doppler shift vanishes at the half phase angle meridian, where both terms cancel each other [5] and we use this meridian as "zero-Doppler-reference" to check for instrumental or calibration drifts. The Doppler velocities are modelled using two kinematical templates for the zonal wind: (1) solid rotation with v zonal = v (equator) $\times$ cos (latitude), (2) uniform retrograde velocity, v zonal = v (equator). Both models are explored within latitudinal range 60S-60N. Once the best fit is obtained, we define the acceptable domain at 2-sigma and also test alternative models, including the combination of both zonal and meridional circulations.

Venus Express cloud top wind indirect measurements based on tracking using images taken with the VIRTIS instrument [1] indicate nearly constant zonal winds in the Southern hemisphere between 0 and 55 deg S, with westward zonal velocities of 105 m/s at cloud tops near 70 km, with detection of a meridional, poleward component with a peak velocity of 10 $\pm$ 10 m/s. However, variability of the zonal velocity is significant over an hour timescale, at all longitudes, rapid changes that are detectable with the Doppler technique, but not with the cloud-tracking used by Venus Express. In CFHT/ESPaDOnS measurements of Feb. 2011, during discretionary run 11AD98, velocity variations at $[\phi - \phi_E] = 0^\circ$ and 30° lat near morning terminator are reported with an amplitude of $\pm$ 18.5 m s^{-1} relative to the mean (day-averaged) Doppler zonal velocity v = 117.5 m s^{-1}, over a period of about 2 hours, revealing local wave activity [5].

We will present the results of our tracking on the short-timescale (daily) changes in the meridional profile of the zonal wind, confirm the detection of the meridional wind and constrain the extent of the Hadley cell, and constrain the presence of a sub-solar to anti-solar thermospheric component near the cloud top layers.

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