Venus cloud-top wind velocities from combined CFHT-ESPaDOnS Doppler velocimetry and VEX/VIRTIS cloud tracking – April 2014 coordinated observations

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Context

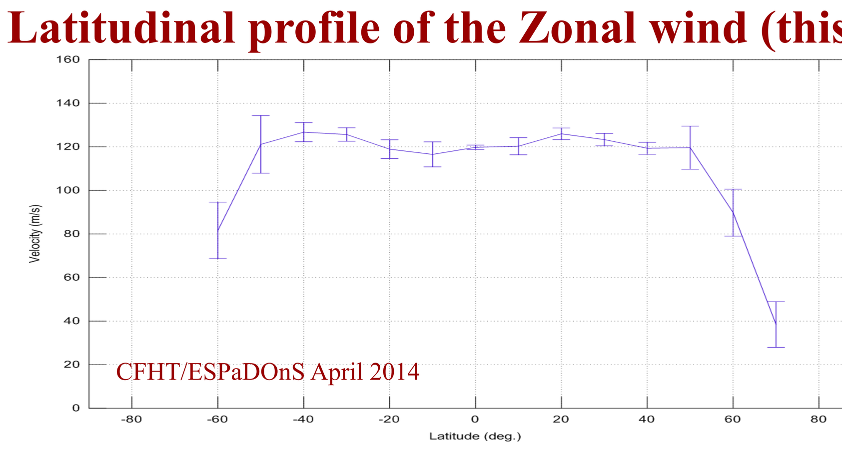
During the Venus Express spacecraft operations, a continuous effort has been made to coordinate its operations with observations from the ground using various techniques and spectral domains (Lellouch and Witasse, 2008).

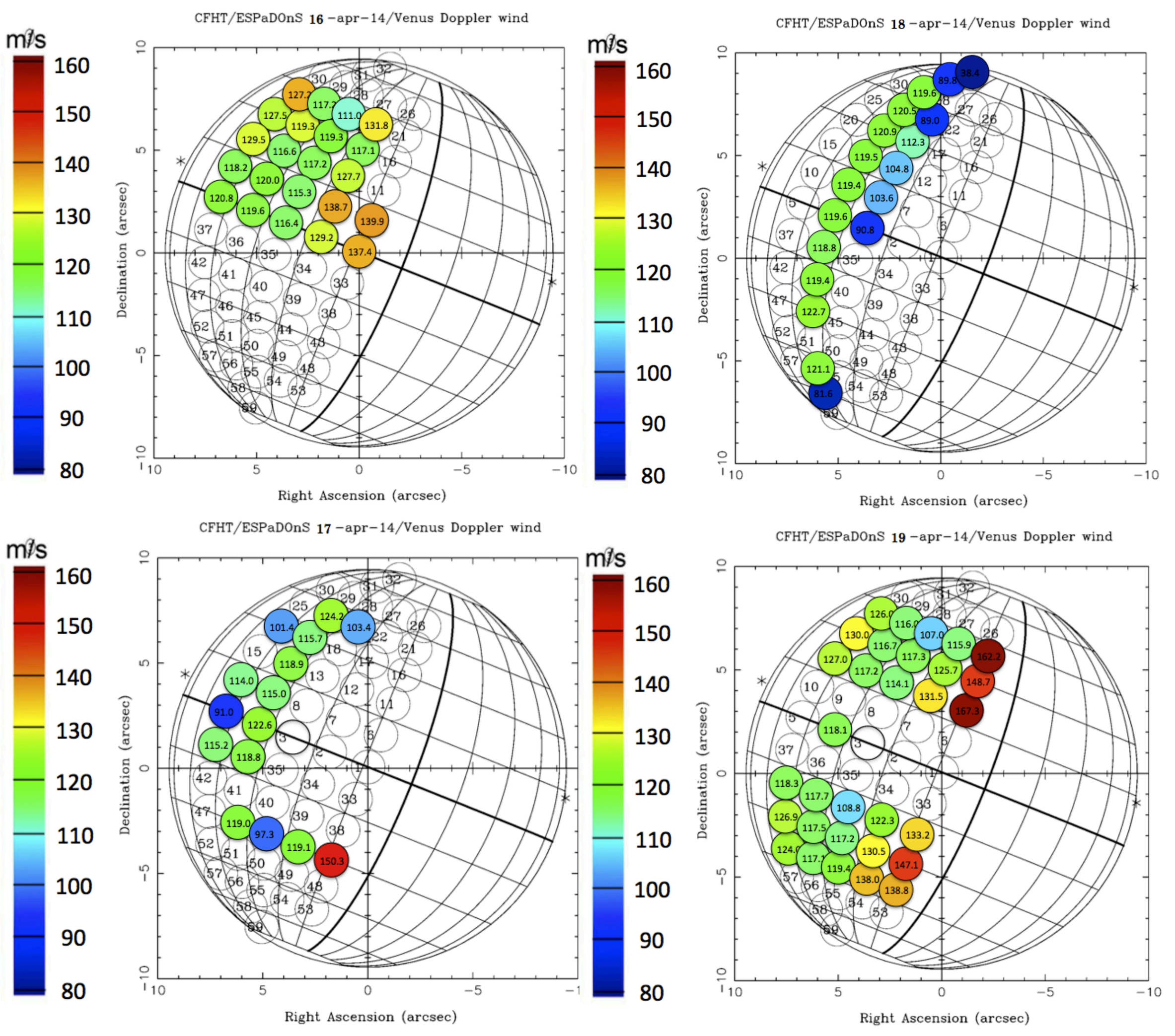
A complete characterization of the venusian superrotation is crucial for understanding its driving mechanisms. In the lower mesosphere (65-85 km), visible observations of Doppler shifts in solar Fraunhofer lines have provided the only Doppler wind measurements near the cloud tops in recent years (Widemann et al., 2007, 2008, Machado et al., 2012, 2014). The region is important as it constrains the global mesospheric circulation in which zonal winds generally decrease with height while thermospheric subsolar–antisolar (SS-AS) winds increase (Bougher et al., 1997; Lellouch et al., 1997).

Renewed interest on measuring the winds at clouds top from the ground has emerged in the course of the Venus Express. 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 (Markiewicz et al. 2007, Peralta et al. 2007, Luz et al., 2011, Peralta et al., 2012).

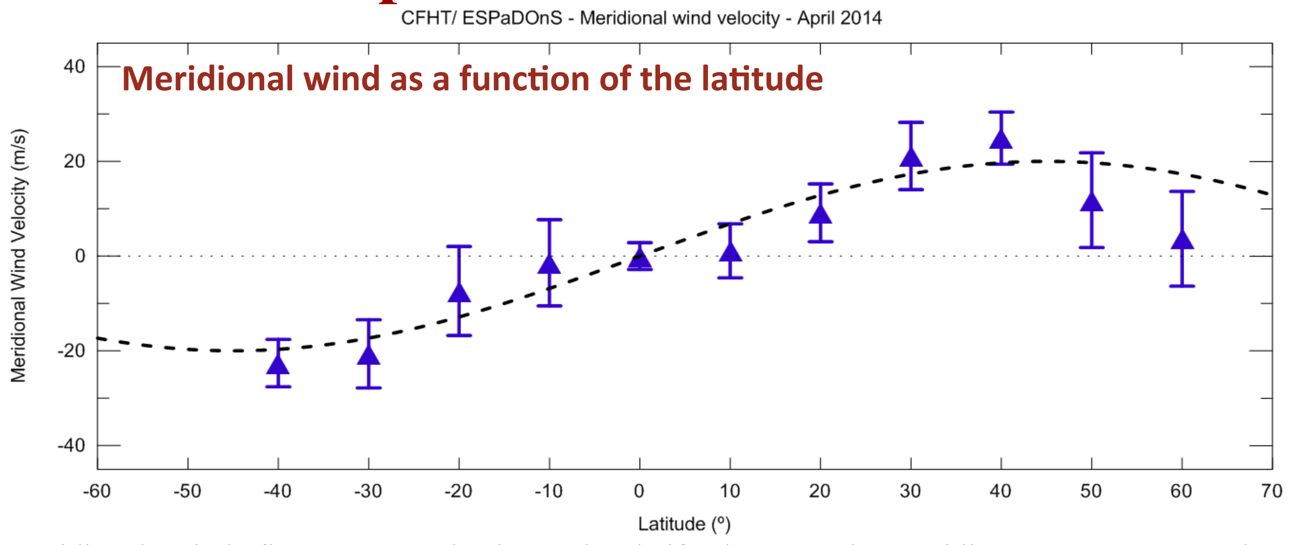
Our main purpose is to provide direct wind measurements using visible Fraunhofer lines scattered at Venus' cloud tops. We use observations from 16-21 Apr 2014 taken with the 3.60-m Canada-France-Hawaii telescope (CFHT) Visible Spectrograph **ESPaDOnS**, and compare results with coordinated observations from Venus Express VIRTIS instrument.

Latitudinal profile of the Zonal wind (this work)



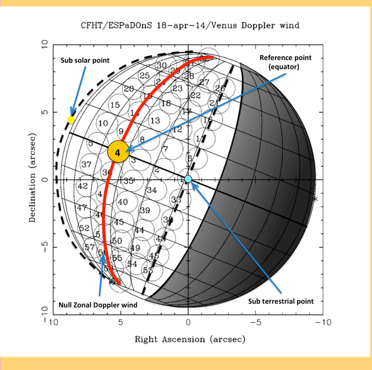


Latitudinal profile of the meridional wind

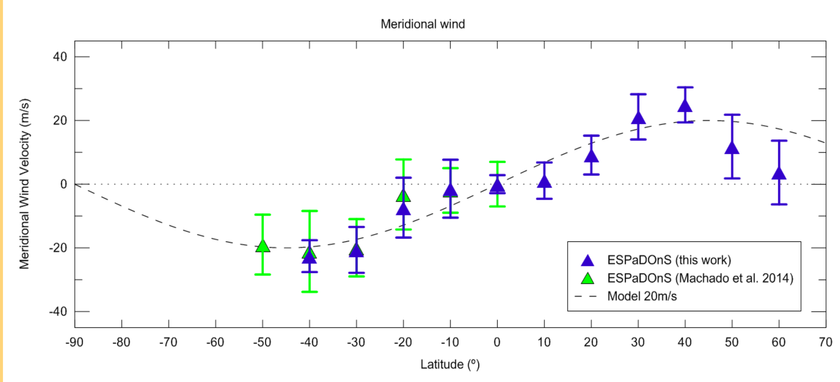


Meridional wind flow measured along the half phase angle meridian. We compare the measurements with a model of a 20 ms^{-1} meridional upper branch flow. Regarding the chosen referential, in both hemispheres the meridional wind is receding from equator towards the poles.

Meridional wind – measurement method



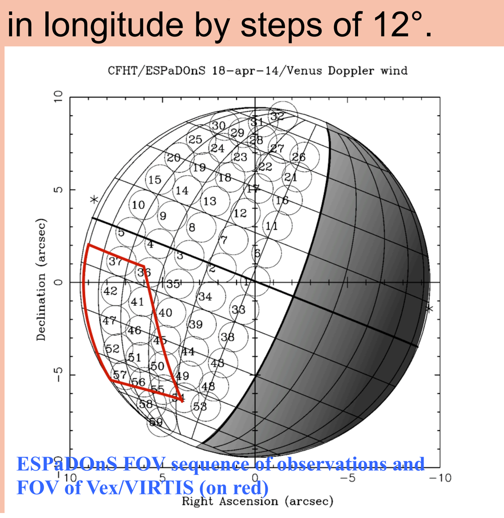
The Doppler shift due to particle motion parallel to equator vanishes at the half phase angle meridian, where: (1) the Doppler shift from the motion between the Sun and Venus upper clouds particles; and (2) the Doppler due to the motion between the observer and Venus clouds, resulting from the topocentric velocity of Venus cloud particles in the observer's frame; cancel each other. Since, in the single scattering approximation, the Doppler shift measured in solar light scattered on Venus dayside is the result of the sum of these two instantaneous motions terms: The measured Doppler shift along the half phase angle is related just to the meridional wind flow, since the Doppler contribution from the zonal wind is cancelled along this particular meridian (Machado et al. 2014).



On the left side: comparison between our previous meridional wind Doppler measurements (Machado et al. 2014) and the ones from the present work.

Coordinated 2014 observations at CFHT and Venus Express

High-resolution spectra of Fraunhofer lines in the visible range (0.37–1.05 μm) were obtained with CFHT/ESPaDOnS at 16-21 April 2014. The complete optical spectrum was collected over 40 spectral orders at each point with 2-5 seconds exposures, at a resolution of about 80000. Were observed various points of the dayside hemisphere at a phase angle of 67 degrees, between +70 and -70°by steps of 10°in latitude, and +70°to -12°to sub-Earth meridian in longitude by steps of 12°.



ESPaDOnS FOV sequence of observations and FOV of Vex/VIRTIS (on red)

These observations were coordinated with VMC and VIRTIS-M observations from ESA's Venus Express (VEx) mission. from ESA's Venus Express (VEx) mission.

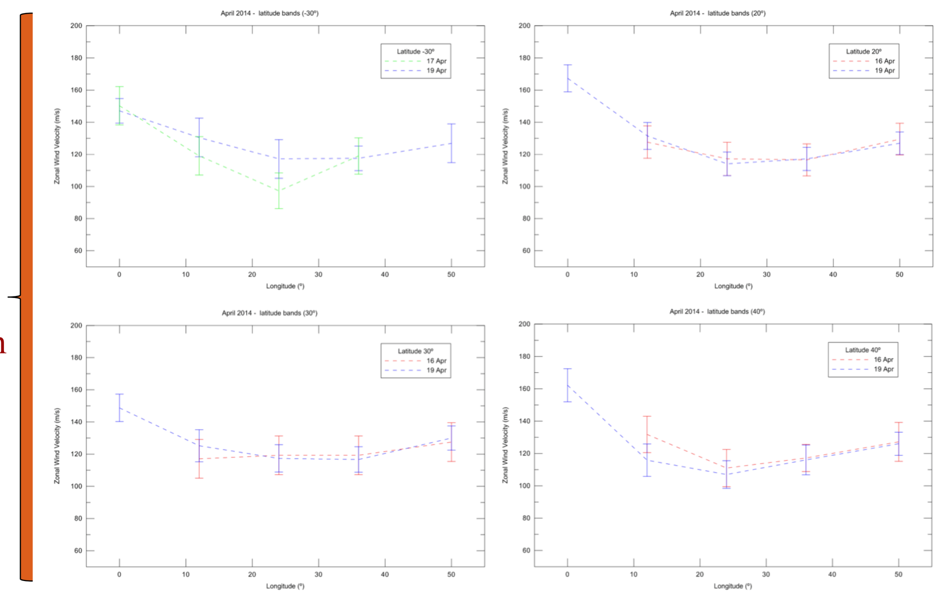
16 April 2014: orbit 2918 (data VMC and VIRTIS-M)
17 April 2014: orbit 2919 (only VMC)
18 April 2014: orbit 2920 (only VMC)
19 April 2014: orbit 2921 (only VMC)
20 April 2014: orbit 2922 (only VMC)
21 April 2014: orbit 2923 (data VMC and VIRTIS-M)

Method

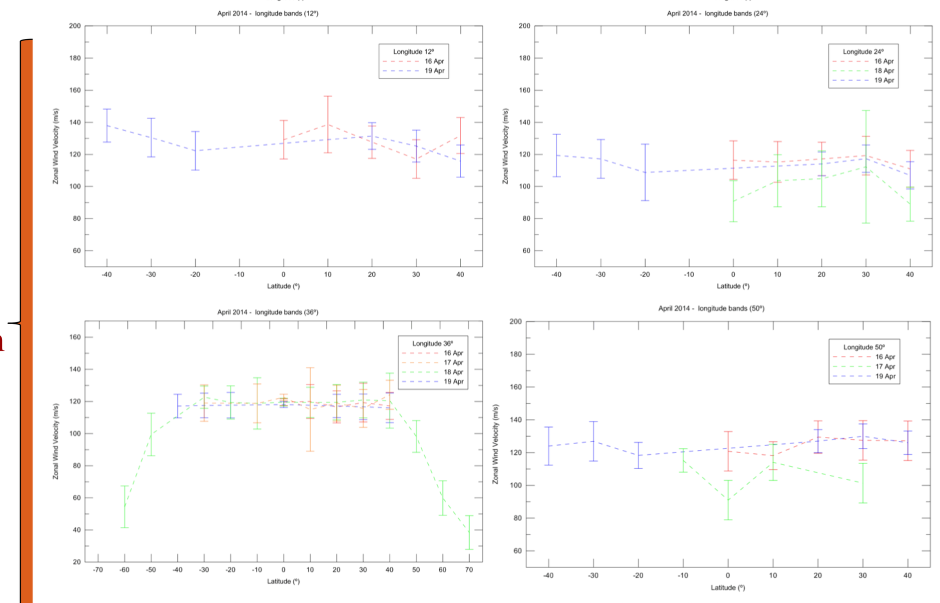
- Methods applied in recent planetary wind measurements using high-resolution spectroscopy in the visible range (Luz et al., 2005a, 2006; Widemann et al., 2007; Gabsi et al., 2008; Widemann et al., 2008, Machado et al. 2014) all address the fundamental problem of maintaining a stable velocity reference.
- We need to address line-of-sight wind amplitude variations (or wind latitudinal gradients) on the order of 5-10 m/s (Widemann et al., 2007), which cannot be achieved by single line fitting.
- It becomes necessary to measure relative Doppler shifts between two sets of absorption lines (Connes, 1985), while simultaneously monitoring the change in spectral calibration with time (Widemann et al., 2008, Machado et al. 2014).
- The measured Doppler shifts using CFHT/ESPaDOnS have individual formal accuracies of 5-10 m s^{-1}, and their signs and magnitudes are generally consistent with zonal winds inferred from cloud tracking.

Temporal and spatial variability of the Zonal wind

Latitude bands of Zonal Wind (comparison between observational days)

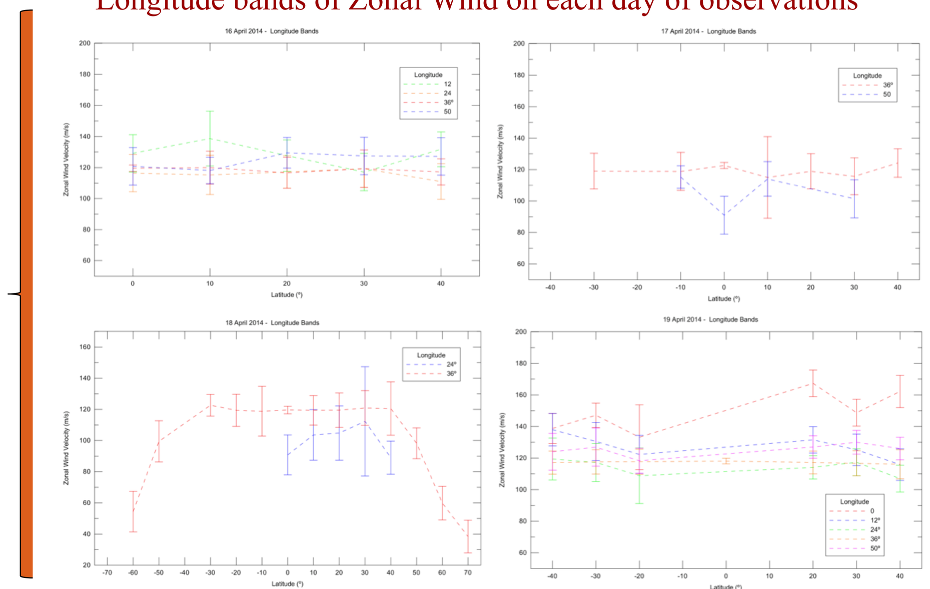


Longitude bands of Zonal Wind (comparison between observational days)

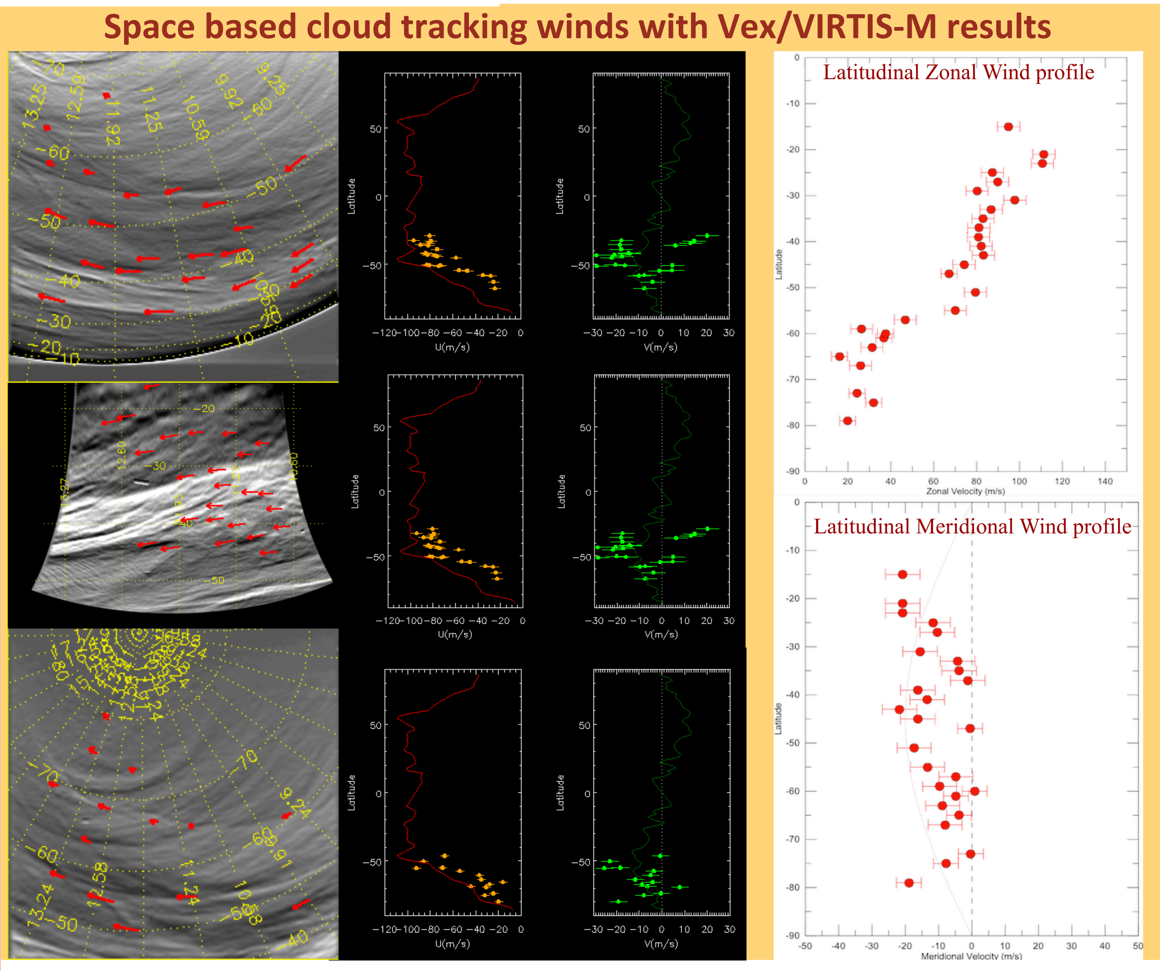


Longitude bands of Zonal Wind on each day of observations

Longitude bands of Zonal Wind measured on each observing day



Space based cloud tracking winds with Vex/VIRTIS-M results

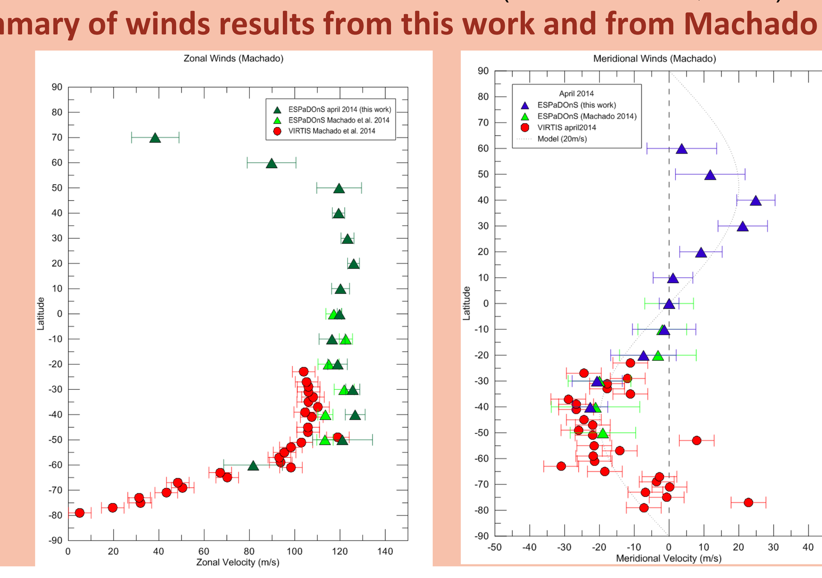


Comparison Ground based Doppler velocimetry and cloud tracking Galileo and VIRTIS UV results

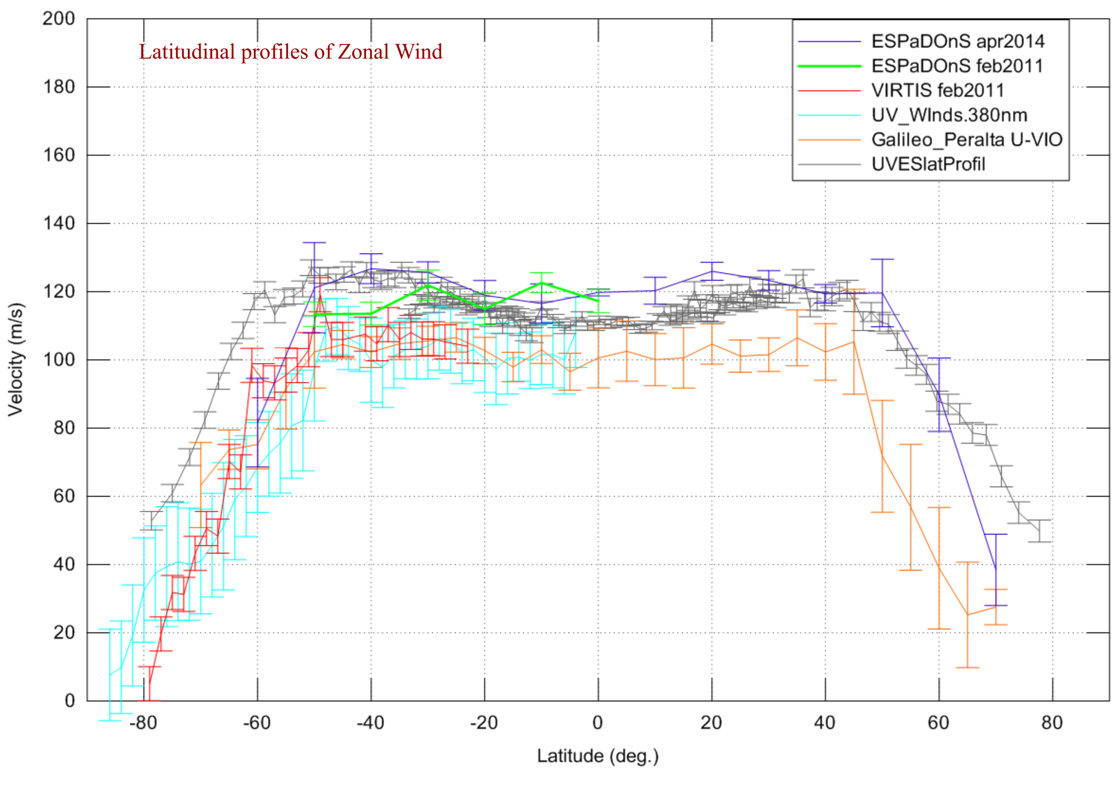
Previous measurements by Pioneer Venus, reanalyzed in Limaye et al. (2007), showed the presence of high latitude zonal jets close to 50 degrees latitude in both hemispheres, with a slight asymmetry between the northern and southern ones.

- However, long temporal averages of cloud-tracked winds by the Galileo SSI (Peralta et al., 2007), and by Venus Express VMC and VIRTIS (Sánchez- Lavega et al., 2008; Moissl et al., 2009) do not display clear evidence for high latitude jets at cloud tops, although shorter time scale averages of VMC measurements in Moissl et al. (2009) indicate that jets may occur but are short lived.
- Rather than being discrepant, different wind measurements provide important insight into the variability of the circulation.
- We measure instantaneous zonal winds providing additional evidence for the occasional presence of jets and, in general, for variability. The realization that latitudinal wind profile with jets such as measured by Pioneer Venus is likely to be barotropically unstable (Limaye et al. 2009), is an argument in favour of variability.
- Our ESPaDOnS present work observations of small scale perturbations (and in previous work of Machado et al. 2014 and with VLT/UVES (Machado et al., 2012).

Summary of winds results from this work and from Machado et al. 2014



Comparison between Ground based Doppler velocimetry (VLT/UVES and CFHT/ESPaDOnS) and Space based cloud tracking Galileo and VIRTIS UV results



Conclusions and Prospects

- The data taken at CFHT/ESPaDOnS on 16-21 April 2014, in coordination with Vex/VIRTIS measurements, allows monitoring the wind variability at cloud tops.
- For Doppler velocimetry, at visible wavelengths, the optical depth reaches unity at 70 km (Ignatiev, 2009), which is also the altitude studied with cloud tracking in the UV, with both VEx/VIRTIS and VEx/VMC (Sánchez-Lavega et al., 2008; Moissl et al., 2009). This allows a direct comparison of magnitudes and spatial variations obtained with VLT/UVES, Pioneer Venus, Galileo (SSI) and Venus Express.
- We obtained a latitudinal profile of the meridional wind along both North and South hemispheres. The measured meridional wind flow reveals high consistency with a 20 m/s meridional wind model.
- Our Doppler retrievals are in general good agreement with previous measurements based on cloud tracking (Del Genio and Rossow, 1990; Limaye et al., 2007; Peralta et al., 2007; Sánchez-Lavega et al., 2008; Moissl et al., 2009).
- We retrieved the same order of magnitude and latitudinal variation of Pioneer Venus, Galileo and VEx/VIRTIS measurements, which cross-validates both techniques and provides reasonable confirmation that cloud tracking and Doppler methods both retrieve the velocities of air masses to first order.
- The cloud tracked winds based on VIRTIS-M observations show relevant variability, although it is difficult to compare with the Doppler winds due to a significant interval from the two sets of observations.
- The Doppler velocimetry is currently the only ground-based technique able to derive instantaneous wind's velocities, allowing cross-comparison with cloud-tracked winds from VEx VIRTIS-M and VMC UV images, and the study of short-term variability.

References

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Acknowledgements

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