The winds of Venus during the Messenger's flyby

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Introduction:

During the Venus Express mission several coordinated observational campaigns were successfully organized to complement the spacecraft's acquisition of data, taking advantage of the impressive development of new generations of instrumentation and telescopes in ground based observatories, along with the revolution in the amateur community with affordable/fast cameras allowing to perform lucky imaging. The most complete campaign was carried out from 23 May to 9 June 2007, joining efforts when NASA's Messenger spacecraft made its second flyby of Venus towards its way to Mercury the 5 of June 2007 at 23:10 UTC [1]. Messenger, Venus Express and ground-based observers acquired a varied set of Venus atmospheric data, although most of it was published in separate publications [2–6], while the images taken by Messenger never were used to measure the winds on Venus. In this work, we present the Venus winds obtained with the images taken by Messenger and we afford the most detailed characterization ever made of the instantaneous state of the Venus atmosphere, combining wind measurements from three different techniques and data from nine instruments.

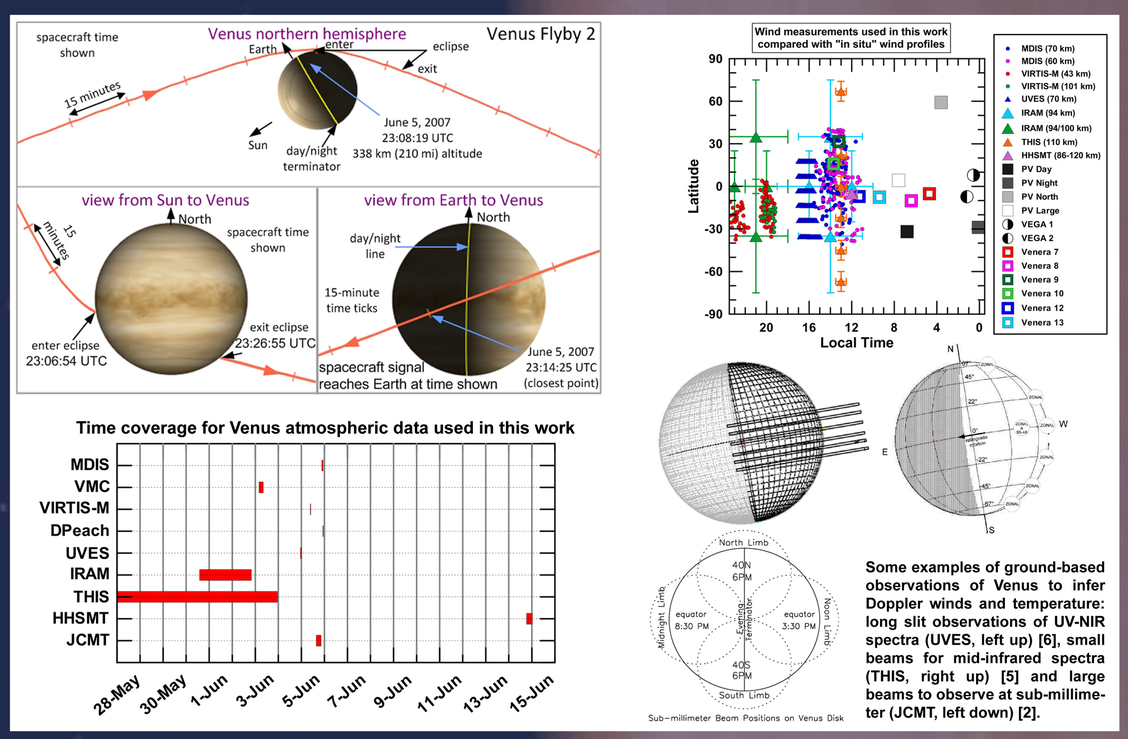
Data acquisition around the flyby:

We compiled images and derived data acquired about the 5 of June 2007 (2nd flyby of Messenger), covering evening and early night of Venus from the south pole to northern mid-latitudes. Winds were obtained at several vertical levels combining three well-known methods:

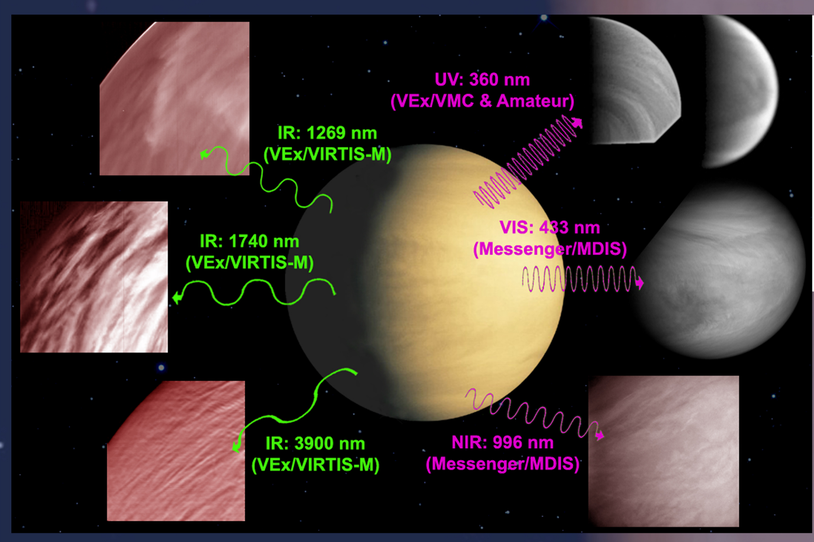
- Cloud tracking: using the images from cameras onboard Messenger (MDIS) [1], Venus Express (VIRTIS-M and VMC) [7] and also from ground-based small telecopes (D. Peach). Wavelengths sense at the dayside heights of 60 and 70 km from scattered sunlight (300-998 nm), while at the nightside we can sense 43 km using the lower clouds' opacity (1.74 μm), 65 km with the upper clouds' thermal emission (3.9 μm), and about 101 km by tracking the oxygen nightglow (1.27 μm).

- Doppler-shift: with ground-based observations we can sense winds at 70 km with the scattered Fraunhofer lines (VLT/UVES) [6], between 90-100 km measuring sub-millimeter CO lines (IRAM and HHSMT) [3,4], and about 110 km by means of mid-IR heterodyne spectroscopy (THIS) [5].

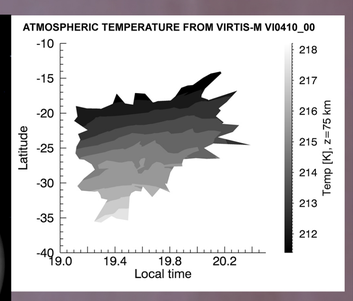
- Thermal Wind equation: zonal winds within 59-90 km (where cyclostrophic balance applies) were deduced using night temperatures (VIRTIS-M) [7] and day temperatures from sub-millimeter CO lines (JCMT) [2].



Some examples of ground-based observations of Venus to infer Doppler winds and temperature: long slit observations of UV-NIR spectra (UVES, left up) [6], small beams for mid-infrared spectra (THIS, right up) [5] and large beams to observe at sub-millimeter (JCMT, left down) [2].



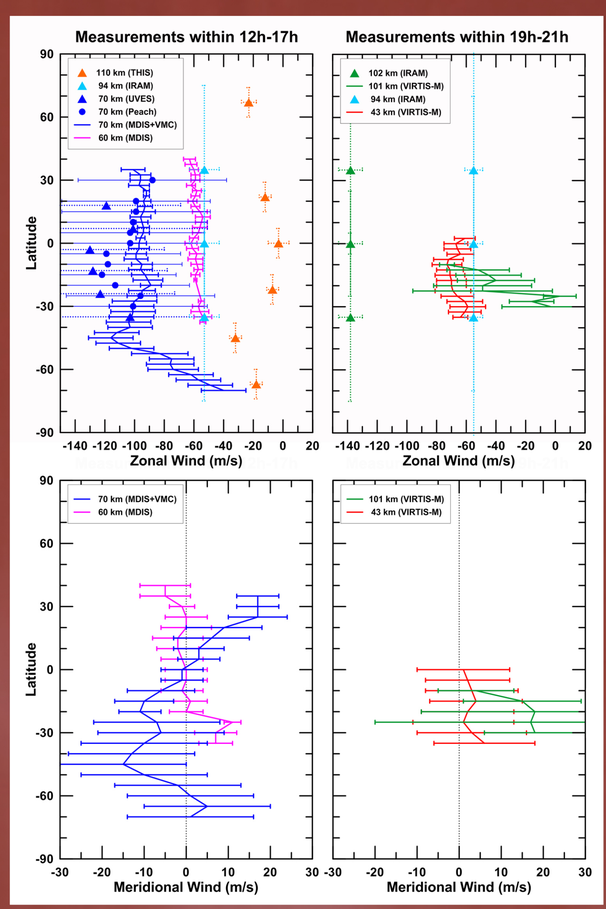
[LEFT]: morphology of the clouds and oxygen nightglow as exhibited by the images taken with spacecraft remote sensing (Messenger and Venus Express) and ground-based telescopes (D. Peach).



[UP/RIGHT]: Night Venus brightness temperatures calculated by fitting VIRTIS-M cubes radiance at wavelengths 4.24-4.54 μm and 4.77-5.01 μm with a suitable Radiative-Transfer Model [8].

A 3D day/night view of the winds on Venus:

Combining the measurement techniques described before, we were able to infer the zonal and meridional component of the wind speed at different levels of the atmosphere in both day and nightside of Venus, providing a 3D view of Venus circulation far more complete than previous from the instrument VIRTIS-M [9]. Cloud tracking with the MDIS images was only possible combining a first image displaying the full disk with a mosaic of higher spatial resolution ones taken about 80 minutes later with Messenger much closer to the planet. Southern latitudes were complemented with VMC.

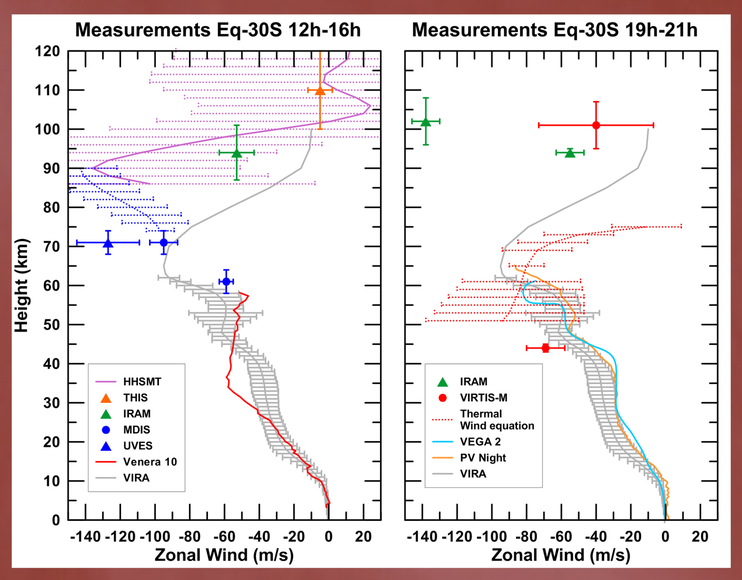


The meridional profiles of zonally averaged winds were obtained for the local time intervals 12h-17h and 19h-21h. Both zonal and meridional components at the dayside exhibit the expected profile and magnitude of the global averages during the VEx mission [10]. Poleward circulation is suggested at the cloud tops, and the different measurements of the zonal component at 70 km are in good accordance within the error bars.

Results at high altitudes suggest a progressive decay of the zonal wind in the results for the dayside, Tracking of the oxygen nightglow implies negative sign for both wind components, suggestive of a SS-AS circulation which is also confirmed by the SS-AS component of about 300 m/s measured by IRAM [3].

Winds were averaged to facilitate coherent comparisons. Measurements in the dayside seem to follow a vertical profile with zonal wind peaking about 20 km above the level of the cloud tops.

Nightside results suggest a different profile, with zonal wind decaying at a lower altitude and high dispersion for the winds above 90 km.



Conclusions:

Ground-based observations coordinated with space missions are shown to be a powerful tool to characterize planetary atmospheres. Combining data from feature tracking, Doppler-shift and thermal wind equation obtained by 9 instruments, we present the most complete 3D view of the Venus winds ever obtained, covering the day and night about the evening terminator, both hemispheres and 4 values of altitude. Vertical profiles of the zonal wind were inferred as a valuable reference for Venus General Circulation Models and providing valuable information about the circulation in the transition region. Similar campaigns are expected to be carried out during 2016-2017 in coordination with the Akatsuki mission, whose orbit insertion was successfully performed in December 2015.

References

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