The circulation at the nightside lower clouds of Venus with high-precision winds

Javier Peralta[1], Antonio Galeote[1], Yeon Joo Lee[2], Mark Bullock[3], Eliot Young[4], Pedro Machado[5], Daniela Espadinha[5] and Roberto Baena[6]

1 Universidad de Sevilla, Spain; 2 Institute for Basic Science, South Korea; 3 Science and Technology Corp., CO, USA; 4 Southwest Research Institute, CO, USA; 5 Institute of Astrophysics and Space Sciences, Portugal; 6 Universidad Internacional de La Rioja, Spain

Introduction

The study of the atmospheric circulation in planets and moons of our solar system and exoplanets is critical in Meteorology. For reasons yet not fully understood, slowly rotators like Venus, Titan and tidally-locked exoplanets tend to exhibit atmospheres which rotate much faster than the solid globe, a phenomenon called *superrotation* that is extreme in the case of Venus. Its angular momentum budget is a complicated combination of transport by the mean meridional circulation, thermal tides, planetary-scale waves and turbulent eddies [1,2] (see Figure 1).

There have been numerous attempts to characterize the *meridional circulation* through wind measurements via cloud-tracking in images, Doppler winds in spectra and "in situ" with entry probes [3,4] (see Fig. 2a). In addition to its role in the superrotation, the meridional circulation is also critical to compensate radiative imbalances [5] (see Fig. 2b) or understanding the atmospheric chemistry and microphysics [4].

Though winds' accuracy from cloud-tracking (3–10 m s^{-1} in the case of VIRTIS onboard Venus Express **VEx**) [6] and Doppler-shift (5 m s^{-1} for TNG/HARPS) [7] has allowed to disentangle the mean meridional circulation and contribution from thermal tides and other waves at the upper clouds (60–70 km) [2,6,8,9], this is not enough at the deeper clouds (48–60 km) where these contributions seem weaker: the mean meridional circulation does not exhibit clear trends, while the effect of the thermal tides and other waves has not been unquestionably identified [6,10,11].

Methods and dataset

The lower clouds of Venus can be observed on its night side as silhouettes against the thermal emission from the deeper atmosphere thanks to several infrared bands within the range 1–2.5 µm, especially at about 1.74 and 2.3 µm. Conversely to previously reported for the upper clouds where cloud patterns tend to become undistinguishable after 2-4 hours [3], a detailed characterization of the clouds' morphology in Akatsuki/IR2 images revealed longer lifetimes for atmospheric phenomena at the lower clouds [12]. Provided that the velocity error can be approximated as the ratio of the spatial resolution to the time interval ($\delta u = \delta x / \Delta t$), *we can improve wind speed precision by tracking clouds for longer time intervals*.

In this work we used 1.74-µm images obtained with VEx/VIRTIS-M since 28 May 2006 until 27 October 2008. We chose cubes with 256 samples, exposures >0.36 seconds and only orbits containing images separated by time intervals >4 hours. Images were processed and geometrically projected as previous works [6,10]. Cloud-tracked winds were inferred with a semi-automated template matching tool [10].

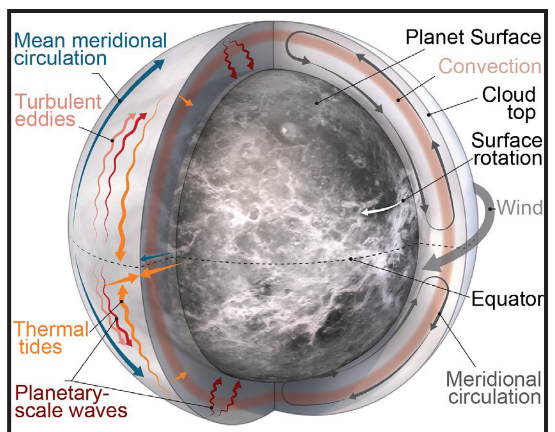

Figure 1: The atmospheric superrotation of Venus is caused by a complicated angular momentum budget among several factors. Sketch from reference [1].

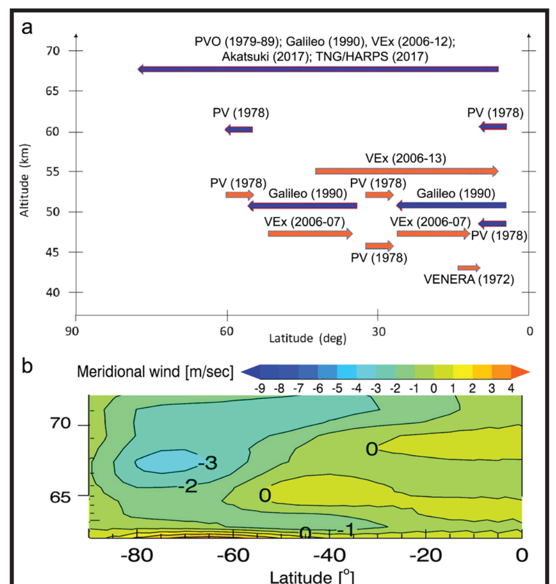

Figure 2a: Mean meridional circulation from wind measurements obtained with cloud-tracking and entry probes [2].

Figure 2b: Zonally-averaged meridional winds compensating the net radiative energy imbalance estimated with the model by Lee et al. [3].

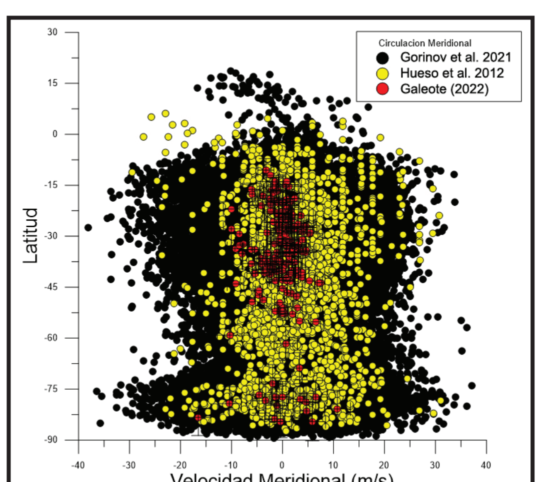

Figure 3: Comparison of individual meridional winds with VIRTIS as measured by Hueso [6], Gorinov [11] and this work [13]. Our preliminary results encompass 17 orbits from Sept 2006 until March 2007.

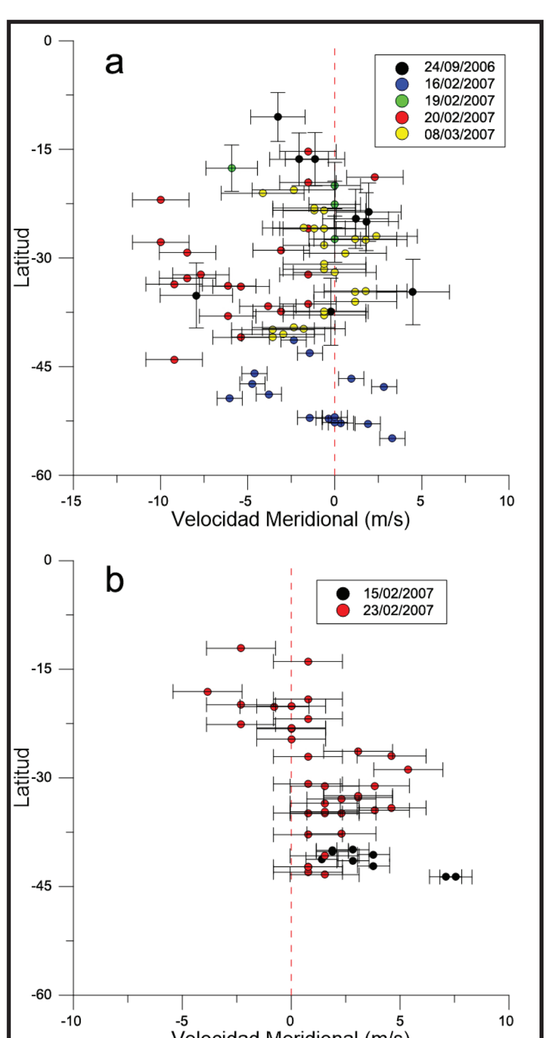

Figure 4: Examples of different trends observed in the meridional winds, sometimes polewards (a) and other times equatorwards (b).

Preliminary Results

From a total of 921 orbits inspected in the dataset of the infrared channel of the VEx/VIRTIS-M dataset, we found that only 137 orbits fulfilled the previous requirements for obtaining wind speeds of higher accuracy. Unfortunately, several reasons prevent numerous high-precision winds:

- VEx not always spotted the same cloud area as the spacecraft approached the planet in each orbit.
- Clouds between 40ºS–70ºS are frequently featureless [6,10] or subject to quick changes in shape.
- During some periods, clouds change too fast.

For these preliminary results. we used pairs of images with resolution ranging 20–80 km per pixel and intervals of 4–5 hours, obtaining wind errors within 0.7–2.6 m s^{-1}. We obtained a total of 167 speeds equatorward of 60ºS and 18 poleward of 60ºS. We highlight the following results:

a) New wind speeds with errors up to one order of magnitude better than in previous works: less dispersion than other reports? (see Figure 3).
b) No clear dependence with the local hour (arguably due to the low number of measurements?)
c) Meridional trend variable with time and latitude (see Figure 4), consistent with Gorinov et al. [11].

What's next?

We will extend the number of high-accuracy winds to cover the full dataset of VEx/VIRTIS and the year 2016 with Akatsuki(IR2 [10], aiming to accurately characterrize of the thermal tides, the mean meridional circulation or even possible effects due to Lee waves [14].

Acknowledgements

JP thanks EMERGIA funding by Junta de Andalucía in Spain (code: EMERGIA20_00414). We are grateful to the VIRTIS team. Data available at ESA Planetary Science Archive.

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