Zonal winds in the Venus mesosphere from VIRTIS/VEx temperature sounding

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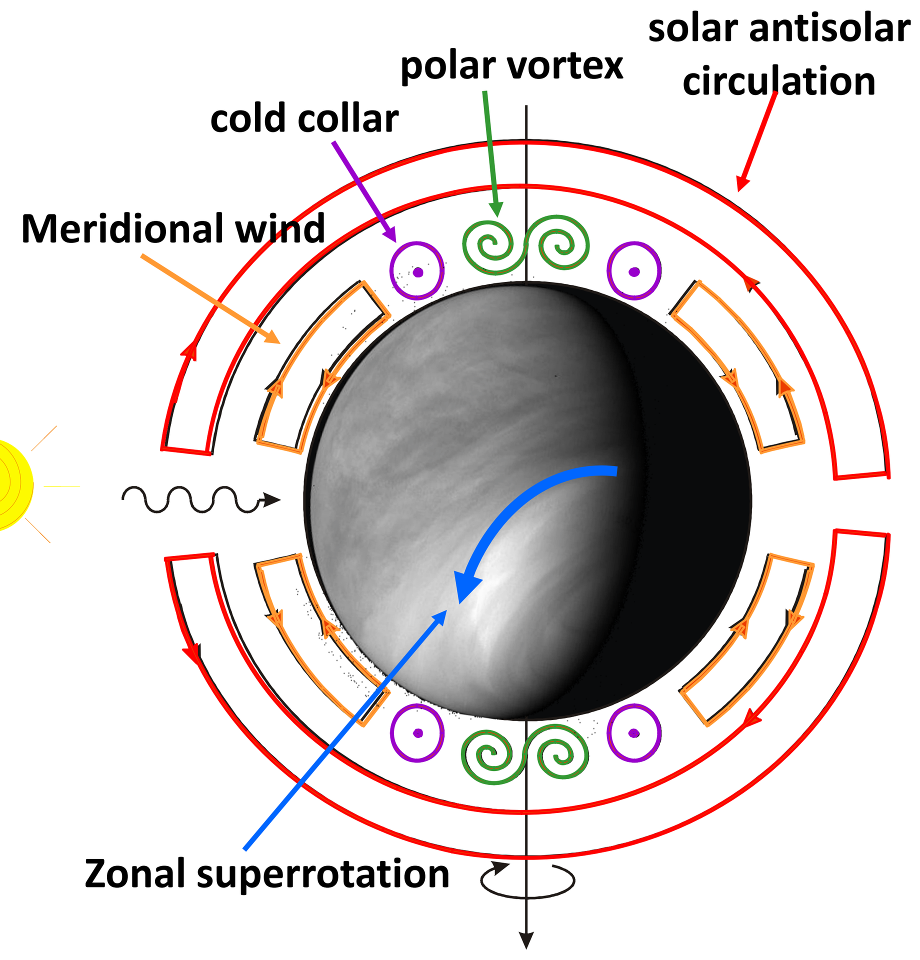
Venus atmosphere dynamics: a general scheme

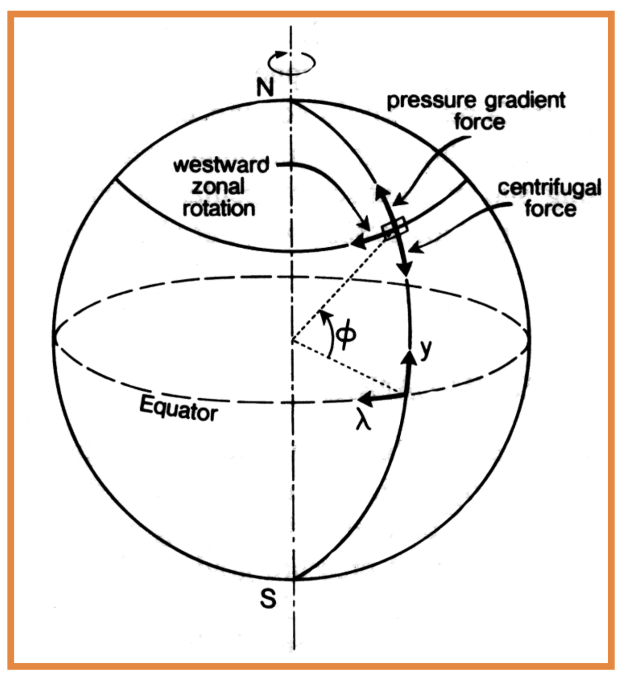
- Venus' mesosphere (**60-100 km** altitude) is a transition region characterized by different dynamical regimes [1]:
  - Solar-antisolar circulation:
    - V ≈ 100 m/s
    - Above 120 km altitude
  - Zonal super-rotation:
    - V ≈ 100 m/s
    - From surface to 70 km altitude
  - Meridional wind:
    - V ≈ 10 m/s
    - At cloud tops (~70 km)
  - Polar Vortex:
    - Rotates in 2.8 (earth) days
    - At cloud tops
  - Midlatitude jet (cold collar):
    - V ≈ 120 m/s
    - 70 km altitude



Cyclostrophic balance

- Different techniques have been used to obtain direct observations of wind at various altitudes: **tracking of clouds** in ultraviolet (UV) and near infrared (NIR) images give information on wind speed at cloud top (~70 km altitude) [2] and within the clouds (~61 km, ~66 km) [3], while **ground-based measurements** of Doppler-shift in CO_2 band at 10 µm [4] and in several CO millimeter lines [5] sound thermospheric and upper mesospheric winds, showing strong variability.
- In the mesosphere, at altitudes where direct observations of wind are not possible, zonal wind fields can be derived from the vertical temperature structure using the **thermal wind equation**.
- In the mesospheres of slowly rotating planets, like Venus and Titan, strong zonal winds are assumed to be in **cyclostrophic balance**. This suggests equality between the equatorward component of the centrifugal force and the meridional pressure gradient force [11,12].

$$\frac{u^2 \tan\phi}{a} = -\frac{1}{\rho}\frac{\partial P}{\partial y} \qquad (1)$$



- Applying **Eq. (1)** is not always possible, since it is difficult to measure pressure remotely. On the contrary, Venus temperature structure is routinely measured, thus, eq. (1) needs to be re-written in a form that directly relates the zonal wind speed u to the vertical temperature structure T.

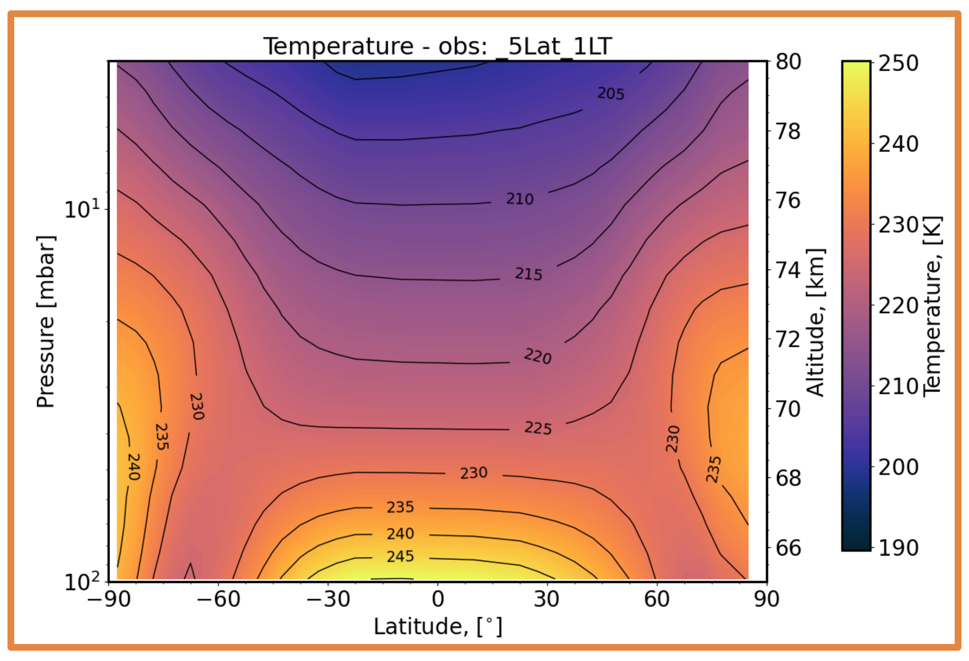
u = zonal velocity
a = Venus radius
y = poleward pointing cartesian coordinate
$\xi = -\ln\frac{p}{p_{ref}}$ $\quad p_{ref} = 100$ mbar

$$2u\frac{\partial u}{\partial \xi} = -\frac{R}{\tan\phi}\frac{\partial T}{\partial \phi} \qquad (2)$$

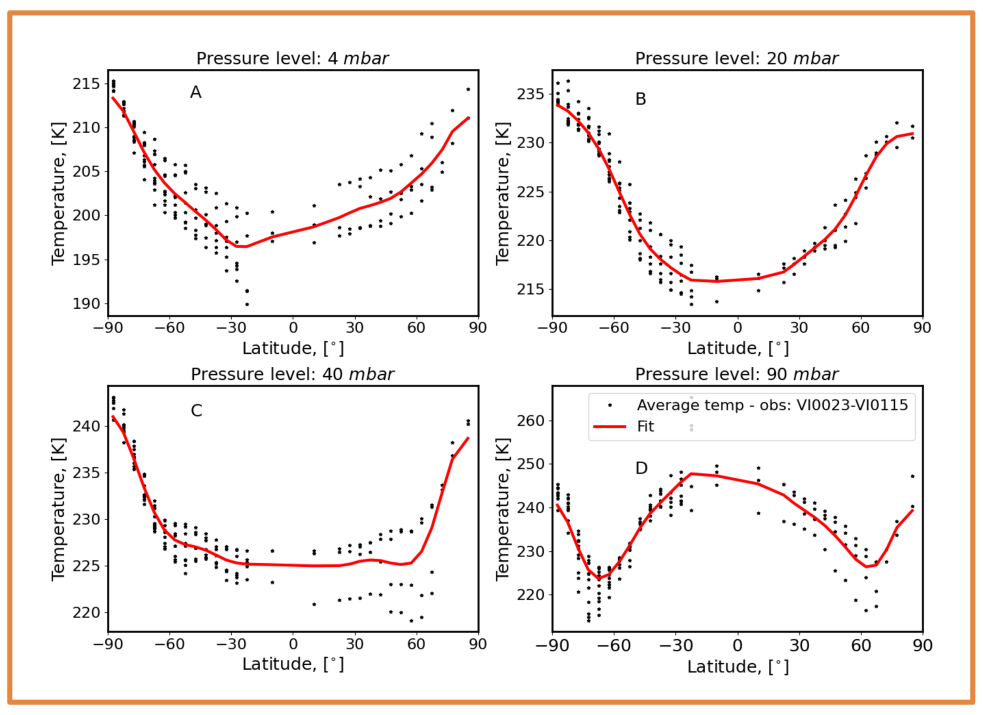
- In order to choose an appropriate **lower boundary condition** for the upward integration, we followed the iterative method described in [13] in order to improve the zonal thermal winds at high latitudes.

Mesospheric thermal structure from VIRTIS-M

- **VIRTIS** (Visible and Infrared Thermal Imaging Spectrometer) is one of the experiments on board the European mission Venus Express. It consists of two channels: VIRTIS-M and VIRTIS-H.
- **VIRTIS-M** is a spectro-imager operating in the spectral range 0.4 – 5.1 µm [16].
- The **VIRTIS-M** instrument probes the nightside (**6 pm – 6 am**) of Venus mesosphere (**65 – 90 km**) on both the northern and southern hemispheres [15,16].
- Data analyzed here was acquired between 14 May 2006 and 15 August 2008 (orbits 23-843).



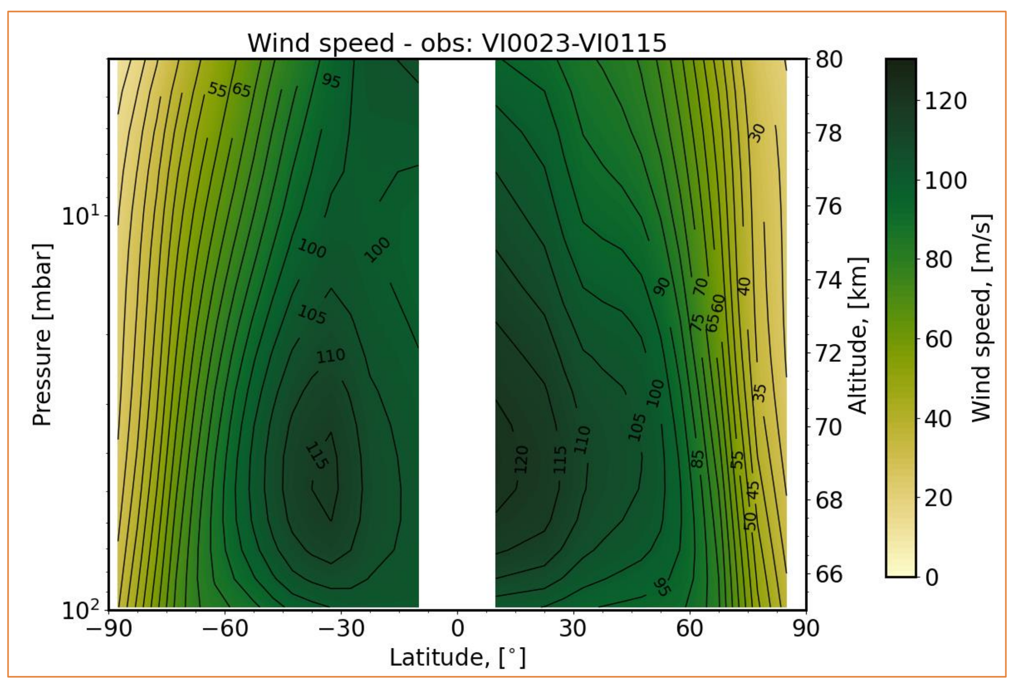
- **Fig. on the right** shows the latitude-altitude **temperature field** obtained averaging VIRTIS-M average profiles in bins of 5° lat and 1hr.
- At the cloud top (~65 km) an inversion in the vertical temperature profiles is clearly visible between ~45–75° latitude (**Cold collar**).
- Above ~70 km altitude an increasing of temperature toward the pole can be observed (**Warm polar mesosphere**).

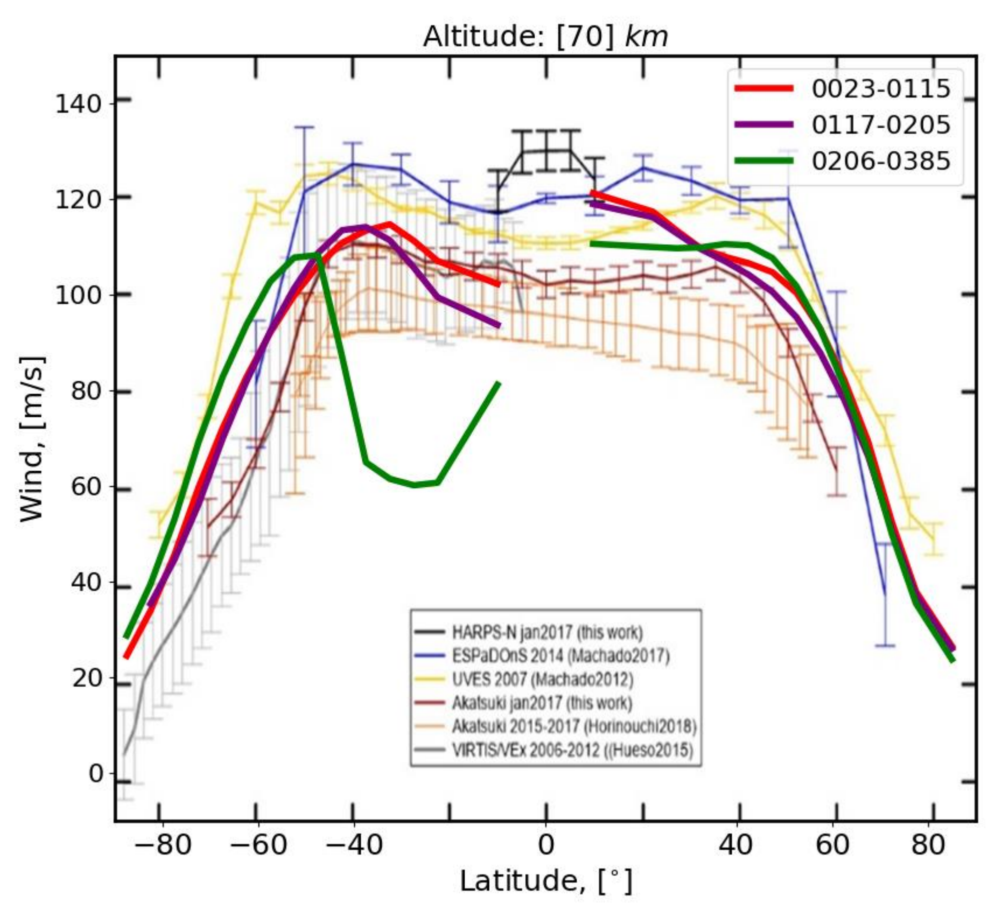


- **The Figure on the left** shows **meridional temperature profiles** at constant pressure levels.
- Temperature averages for orbits 23-115.
- Fitting curves used to evaluate the latitudinal temperature gradient (Eq. 2) are also shown (solid lines red).

Zonal thermal winds from VIRTIS-M temperature retrievals

- **Zonal thermal winds** were retrieved from VIRTIS-M temperature fields on both the northern and southern hemispheres.
- The most significant features that can be observed in the wind field are (**Fig. on the right**):
  i. A **midlatitude jet** related to the thermal feature known as the cold collar, the jet is more pronounced in the South hemisphere.
  ii. The decrease of the wind speed towards the pole.





- The **Fig. on the left** shows **latitudinal wind profiles** at 70 km derived from: **VIRTIS** (red, violet, and green solid lines) for different orbits ranges.
- We compare VIRTIS winds to previous space and ground-based observations (background figure from Goncalves R. et al., 2020 [3]).
- VIRTIS winds lie well within previous observations, with the exception of the green curve, which shows a strong decrease at -30° . Probably, a better filtering of VIRTIS temperatures is needed.

Conclusions & Future work

- **Zonal thermal wind was retrieved from VIRTIS-M temperature profiles for both hemispheres on the nightside between 65 – 90 km altitude.**
  - Differences in the thermal structure between the two hemispheres account for the differences in the wind field.
- **Cyclostrophic balance permits a good approx. of midlatitude jet:**
  - The main mechanisms responsible for maintaining the zonal super–rotation and its transition to the solar–antisolar circulation are still poorly understood.
  - We need a more general expression for the thermal wind equation, especially to investigate the dynamics of the polar region.
  - Cyclostrophic winds are in good comparison with previous observations obtained with different techniques.
- **Future work:**
  - Better refinement of temperature profiles, adding filtering criteria.

References: [1] Sanchez-Lavega, A. et al. (2017); [2] Goncalves R. et al., 2020; [3] Hueso, R. et al. (2012); [4] Rengel et al. (2008); [5] Sornig et al. (2008); [6] Counselman et al. (1980); [7] Newman et al. (1984); [8] Roos-Serote et al. (1995); [9] Piccialli et al. (2008); [10] Piccialli et al. (2012); [11] Leovy (1973); [12] Flasar et al. (2005); [13] Mendonca et al. (2012); [14] Drossart et al. (2007); [15] Migliorini et al. (2012); [16] Grassi et al. (2014).