Zonal thermal winds in Venus mesosphere

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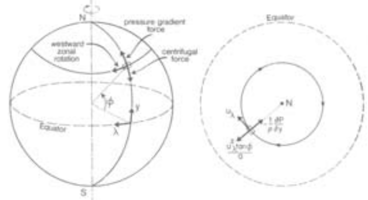
Abstract: Venus' mesosphere extends from 60 km to 100 km of altitude and it lies between two different regimes of atmospheric circulation. In the upper part of the mesosphere (~ 100 km) a solar – antisolar circulation, driven by the contrast in temperature between dayside and nightside, flows with speeds of about 120 m s^{-1}. At the cloud top (~65 km of altitude) a strong zonal super-rotation with speed of about 90 m s^{-1} can be observed. Various methods of observation have been used to directly infer wind speeds at different altitudes: groundbased observations of dopplershift in CO_2 10 µm band [1] and in many CO millimiter lines [2] are used to probe the solar-antisolar circulation at the base of the thermosphere while tracking of clouds in ultraviolet (UV) and near infrared (NIR) images gives information on wind speeds at cloud top (70 km altitude) and within the clouds (~47 km, ~61 km altitude) ([3]; [4]). At altitudes where direct observations of winds can not be inferred it is possible to retrieve zonal wind speeds from the vertical temperature structure using a special approximation of the thermal wind equation: the cyclostrophic balance. Previous studies ([5]; [6]; [7]) have shown that on a slowly rotating planet like Venus strong zonal winds at cloud top are well described by the cyclostrophic approximation which assumes the balance between the equatorward component of the centrifugal force and the meridional pressure gradient force. Here we derive zonal winds using the cyclostrophic approximation from VIRTIS and VeRa temperature retrievals. VIRTIS sounds the Venus southern hemisphere in the altitude range 65 – 90 km with a very good spatial and temporal coverage [8]. VeRa observes both north and south hemispheres between 40 – 90 km of altitude with a vertical resolution of ~500 m [9]. The main features of the winds are: (1) the midlatitude jet with a maximum speed of 80 – 90 ± 10 m/s which occurs around 50°S latitude at 70 km altitude; (2) the fast decrease of the wind speed from 60°S toward the pole; (3) the decrease of the wind speed with increasing height above the jet [10]. The comparison with cloud tracked winds shows a good agreement at midlatitudes; a disagreement is observed near the equator due to the breakdown of cyclostrophic approximation. A good description of zonal winds at midlatitudes is obtained applying the cyclostrophic balance but a more general expression for the thermal wind equation is needed especially at higher latitudes where eddies and turbulent motions can not be neglected.

Cyclostrophic balance

Since Venus is a very slow rotating planet the strong zonal wind near the cloud top and just below it can be assumed to be in cyclostrophic balance:

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



u = zonal velocity
a = Venus radius
y = poleward pointing cartesian coordinate

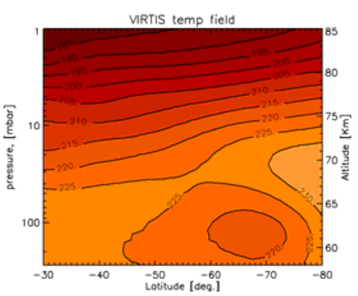
$\xi = -\ln\frac{P}{P_{ref}}$

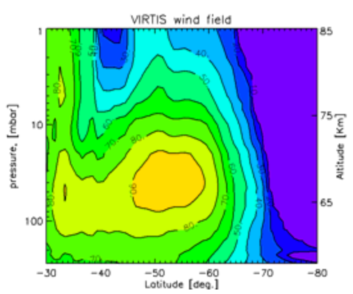
Thermal wind equation:

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

- Left figure:
  - Zonal mean temperature field as observed by VeRa for the nightside [9].
  - VeRa sounds the atmosphere in the altitude range 40 – 90 km with a vertical resolution of ~100 m.
- Right figure:
  - Retrievals of the zonal winds from VeRa temperature field assuming as lower boundary condition the cloud-tracked winds at ~48 km altitude retrieved by [4]. The main feature is the midlatitude jet with peak velocity of about 140 m/s centered at ~42°S at the cloud top (~70 km).
- VIRTIS – VeRa comparison:
  - VIRTIS temperatures are systematically lower than VeRa temperatures near the equator at cloud top. Main reason could be that VIRTIS temperature retrievals are strongly affected by the presence of clouds at 65 km of altitude.
  - VeRa midlatitude jet is shifted toward the equator compared to VIRTIS jet. This can be due in part to differences in temperatures.

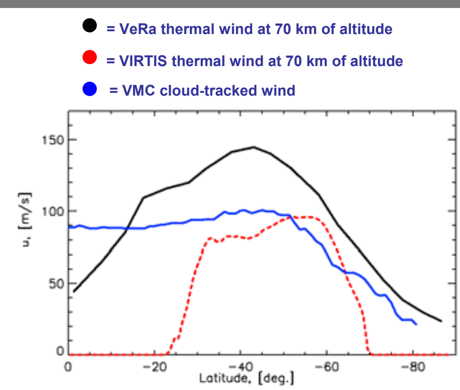
VIRTIS temperature & zonal wind field





- Left figure:
  - Zonal mean temperature field as observed by VIRTIS/M for the nightside [8].
  - Between 75–90 km of altitude, temperatures on isobaric surfaces generally increases toward the pole, this feature is known as the Warm polar mesosphere.
  - Near the cloud top level and just below it (53-68 km altitude), it's possible to observe a vertical temperature inversion known as the Cold collar.
- Right figure:
  - Retrievals of the zonal winds from VIRTIS temperature field assuming as lower boundary condition at 275 mbar the equation adopted by [11]. Three main features can been observed:
    - A midlatitude jet with peak velocity of about 90 m/s centered at ~50°S at the cloud top (~70 km).
    - Fast decrease of zonal winds poleward from 60°S with zero velocity reached at 70°S.
    - Gradual decrease of thermal wind with altitude above the jet.

Comparison with cloud tracked winds



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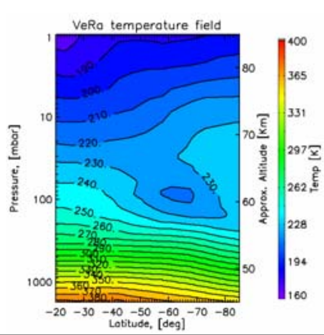
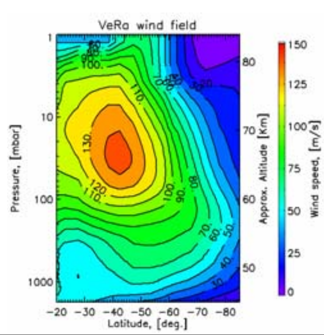
- Comparison with VMC UV at 70 km altitude:
  - VIRTIS:
    - Good agreement below 45°S
    - Near equator breakdown of Cyclostrophic approx
    - VIRTIS – Nightside/ VMC – dayside
  - VeRa:
    - Jet speed higher compared to VMC wind.
    - near equator breakdown of cyclostrophic approx.

VeRa temperature & zonal wind field





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