Cyclostrophic wind in Venus mesosphere from the Venus Express temperature retrievals

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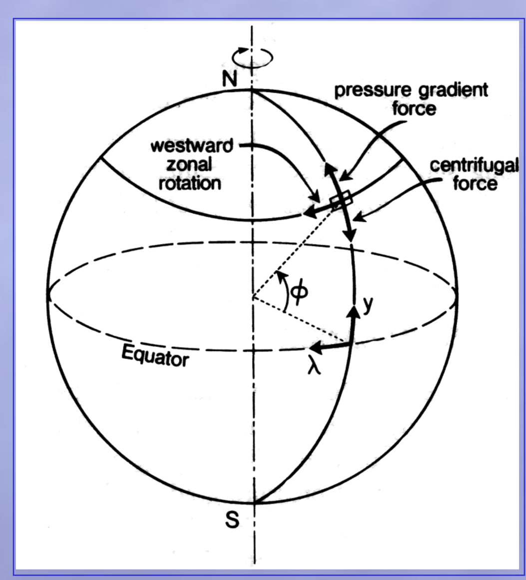
Abstract: Cyclostrophic balance is a special approximation of the thermal wind equation that implies the balance between the equatorward component of the centrifugal force and the meridional pressure gradient. This equation gives a possibility to reconstruct the zonal wind *u* if the temperature field is known, together with a suitable lower boundary condition on *u*. [Leovy, 1973] first noted that the strong zonal winds at the cloud tops in Venus atmosphere are well described by the cyclostrophic approximation. Venus is not the only body in the solar system where cyclostrophic approximation is valid. Saturn's satellite Titan, like Venus, is a slow rotator and the strong zonal winds in its stratosphere are in cyclostrophic balance. The cyclostrophic approximation is also valid on smaller scales, such as in Earth cyclones or Mars and Earth dust devils.

Here we present retrievals of the cyclostrophic wind in Venus mesosphere derived from VIRTIS and VeRa/Venus Express temperature soundings. VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) sounds Venus south hemisphere in the altitude range 65 – 90 km with a very good spatial and temporal coverage [Grassi, 2008]. VeRa (Radio Science Experiment) observes both north and south hemispheres between 40 – 90 km of altitude with a vertical resolution of ~100 m [Tellmann, 2008]. Thanks to Venus Express capabilities, the variability of zonal wind with latitude, altitude and local time was analyzed in detail. The main features of the retrieved winds are: (1) a midlatitude jet with a maximum speed up to 140 ± 15 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 [Piccialli et al., 2008]. Cyclostrophic wind shows satisfactory agreement with the cloud-tracked winds derived from the Venus Monitoring Camera (VMC/VEx) UV images, a disagreement is observed at the equator and near the pole due to the breakdown of the cyclostrophic approximation. Knowledge of both temperature and wind fields allowed us to study stability of the atmosphere with respect to convection and turbulence. The Richardson number Ri was evaluated from zonal field of measured temperatures and thermal winds. The atmosphere is characterized by a low value of Richardson number from ~45 km up to ~60 km altitude at all latitudes that corresponds to the lower and middle cloud layer indicating an almost adiabatic atmosphere. A high value of Richardson number was found in the region of the midlatitude jet indicating highly stable atmosphere. The necessary condition for barotropic instability was verified: it is satisfied on the poleward side of the midlatitude jet, indicating the possible presence of wave instability.

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:



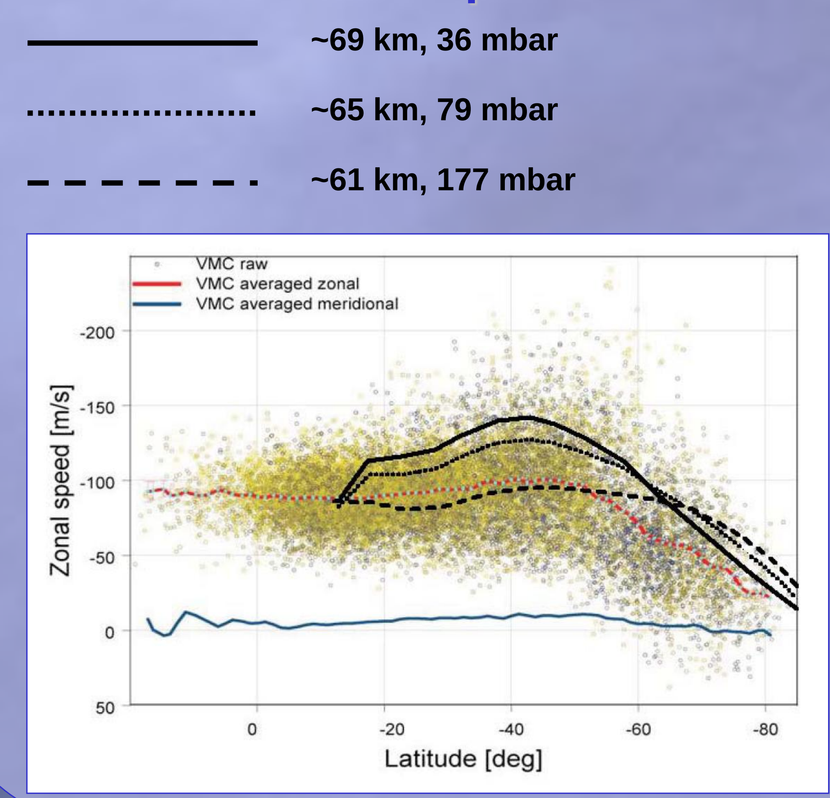
$$\frac{u^2 \tan\phi}{a} = -\frac{1}{\rho}\frac{\partial P}{\partial y}$$

u = zonal velocity
a = Venus radius
y = poleward pointing cartesian coordinate
$\xi = -\ln\frac{P}{P_{ref}}$

Thermal wind equation:

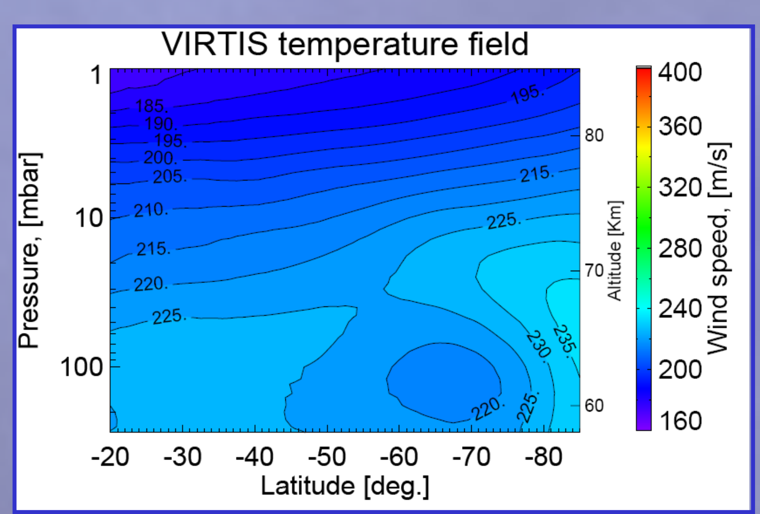
$$2u\frac{\partial u}{\partial \xi} = -\frac{R}{\tan\phi}\frac{\partial T}{\partial \phi}$$

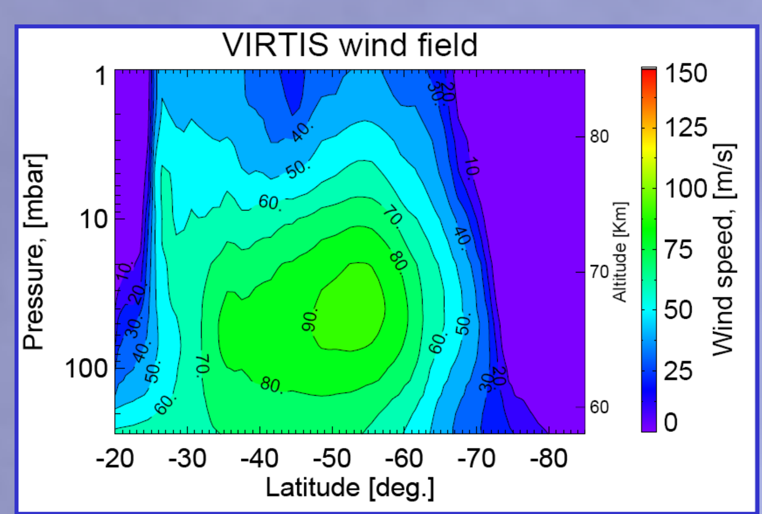
Comparison with cloud tracked winds



- Comparison between the latitudinal profiles of VeRa cyclostrophic wind and VMC-UV cloud-tracked wind (Khatuntsev, personal communication):
  - Validation of cyclostrophic balance in the latitude range 20 -75 S
  - Jet speed higher compared to VMC winds
  - near equator breakdown of cyclostrophic approx.

VIRTIS temperature & zonal wind field



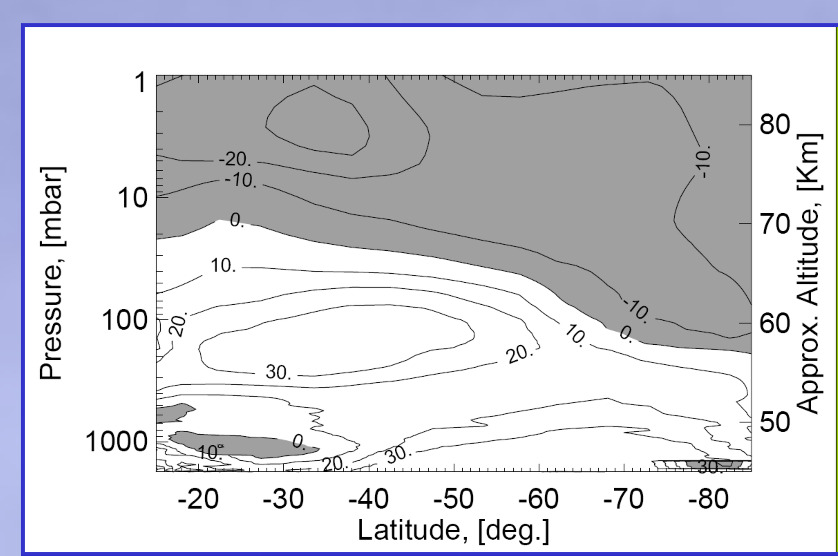


- Left figure:
  - Zonal mean temperature field as observed by VIRTIS/M for the nightside (Grassi et al., 2008).
  - Between 75–90 km of altitude, temperatures on isobaric surfaces generally increases toward the pole, this feature is known as the Warm polar mesosphere.
  - Near the cloud top level and 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 (Counselman et al, 1980). Three main features can been observed (Piccialli et al., 2008):
    - 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.

Vertical wind shear

- Positive wind shear (white)
- Negative wind shear (grey)

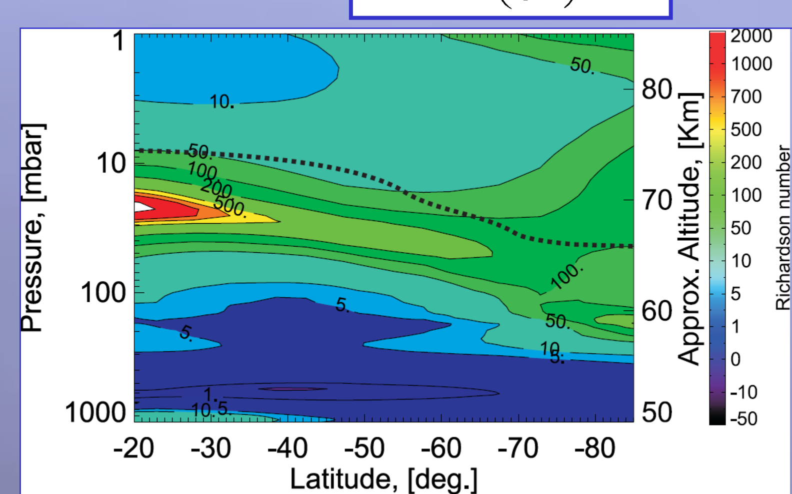
$du/d\xi \quad [ms^{-1}]$



Convective stability – Richardson number

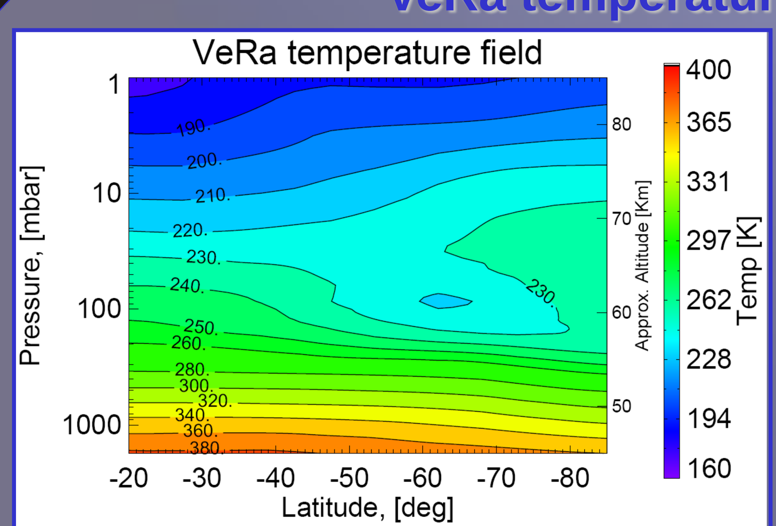
$$Ri = \frac{\frac{g}{T}\left[\left(\frac{dT}{dz}\right) - \Gamma\right]}{\left(\frac{\partial u}{\partial z}\right)^2}$$

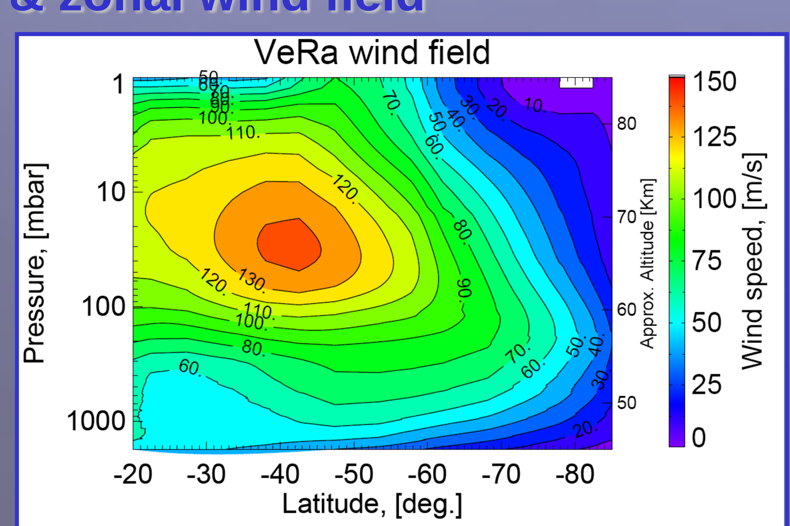
$Ri < 0$ Convection
$Ri < 1$ Turbulence
$Ri >> 1$ Stable condition



- Between 60-70 km altitude Ri reaches large values, this level corresponds to the jet core. Thus, this region is characterized by an high stability.
- Below 60 km altitude Ri has low or negative values indicating the possible formation of turbulence or convection at these altitudes.

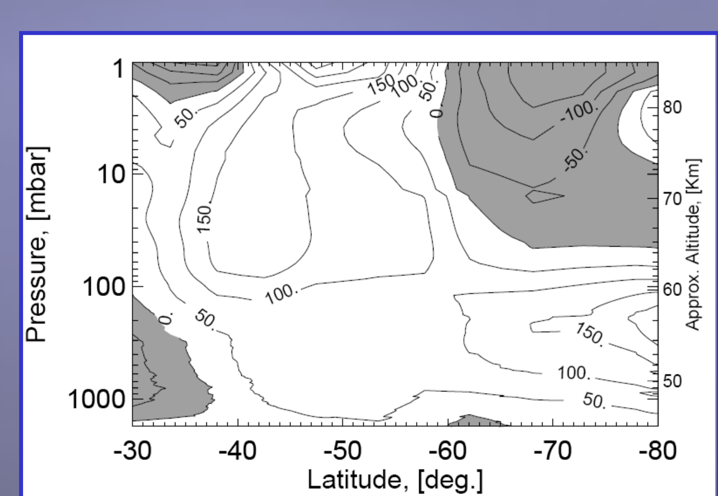
VeRa temperature & zonal wind field





- Left figure:
  - Zonal mean temperature field as observed by VeRa for the nightside (Tellmann et al., 2008).
  - 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 Sanchez-Lavega et al. (2008). 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).

Barotropic instability



- Instability associated with horizontal shear in a zonal flow.
- Necessary condition for barotropic instability is the Rayleigh's criterion:

Rayleigh's criterion:

$$\frac{1}{r}\frac{\partial}{\partial \phi}\left(u\tan\phi - \frac{\partial u}{\partial \phi}\right) = 0$$

- White = positive values
- Grey = negative values

- The Rayleigh's criterion is satisfied on the poleward side of the midlatitude jet, indicating the possible presence of wave instability.