Influence of Venus topography on the zonal wind and albedo at cloud top level: The role of stationary gravity waves

Jean-Loup Bertaux, Emmanuel Marcq, Igor V. Khatunstsev, Wojciech J. Markiewicz, Alain Hauchecorne, Sébastien Lebonnois, Marina Patsaeva, Alexander Turin, Anna Fedorova

INFLUENCE OF VENUS TOPOGRAPHY ON THE ZONAL WIND AND ALBEDO AT CLOUD TOP LEVEL: THE ROLE OF STATIONARY GRAVITY WAVES.

J.L. Bertaux, **E.Marcq,** *LATMOS/CNRS/UVSQ Guyancourt France (jean-loup.bertaux@latmos.ipsl.fr),* **I.V. Khatunstsev,** *Space Research Institute RAS Moscow, Russia***, W.J. Markiewicz** *MPS Solar System Research, Göttingen, Germany,***A. Hauchecorne,** *LATMOS/CNRS/UVSQ Guyancourt France* **S. Lebonnois,** *LMD/CNRS/UPMC Paris France,* **M. Patsaeva, A. Turin, A. Fedorova,** *Space Research Institute RAS Moscow, Russia***.**

Introduction:

Based on the analysis of UV images (at 365 nm) of Venus cloud top (altitude 67±2 km) collected with VMC (Venus Monitoring Camera) on board Venus Express (VEX), it is found that the zonal wind speed south of the equator (from 5°S to 15°s) shows a conspicuous variation (from -101 to -83 m/s) with geographic longitude of Venus, correlated with the underlying relief of Aphrodite Terra. We interpret this pattern [1] as the result of stationary gravity waves produced at ground level by the up lift of air when the horizontal wind encounters a mountain slope. These waves can propagate up to cloud top level, break there and transfer their momentum to the zonal flow.

Comparison of wind data with topography:

Zonal wind just below equator (average of 6,312 measurements) plotted with longitude correlate quite well with topography, when the wind is shifted by +30°.

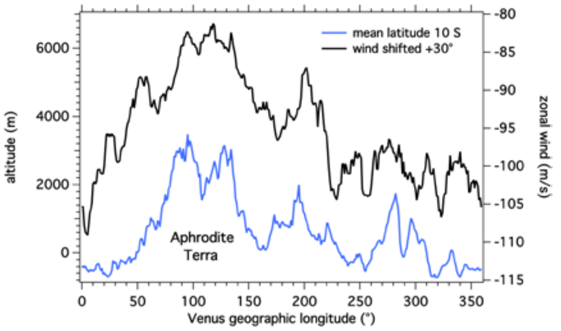


Figure 1. Longitude distributions of the relief altitude and of the zonal wind in the latitude-selected region (from 5°S to 15 °S). Blue curve: altitude in m, left scale. Black curve: zonal wind (m/s), right scale. The longitude for the zonal wind was displaced by +30° from the altitude one, to emphasize the correlation between the zonal wind and the relief, ~65 km below.

We also compare a geographic longitude-latitude map of Venus topography (from 5°S to 45°S, figure 2a, 2b) to a map of the zonal wind in the same latitude range (figure 3), well covered by VMC and containing conspicuous mountains named Aphrodite Terra and Atla Regio. The zonal wind map shows a region of greatly decreased zonal wind, a fact that was totally unexpected and ignored up to now.

There is an obvious correlation between the two maps (topography and wind speed), with the region of minimum wind (absolute speed) being displaced by ~30° downstream. The minimum zonal wind at -82 m/s (in absolute value) is found 30° downstream of Aphrodite Terra, a high altitude region (3,000 m) extending from 40° to 160° in longitude.

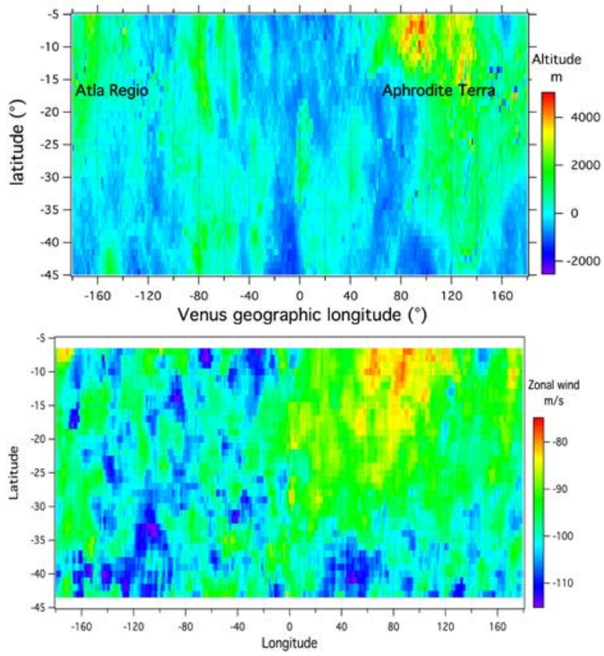


Figure 2a (top). Partial topographic map of Venus. Altitude is color coded. The latitude coverage of the map is limited from 5° S to 45° S to match the map of zonal wind. The zonal wind is blowing right to left from East to West, toward decreasing longitudes. Figure 2b (bottom). Map of the zonal wind speed in m/s (color coded).

We propose that stationary gravity waves (Fig.3) are generated by the horizontal wind flowing over a relief; then they propagate upward up to the altitude where they break and transfer their momentum to the general circulation. Since they are stationary, they decelerate the zonal flow.

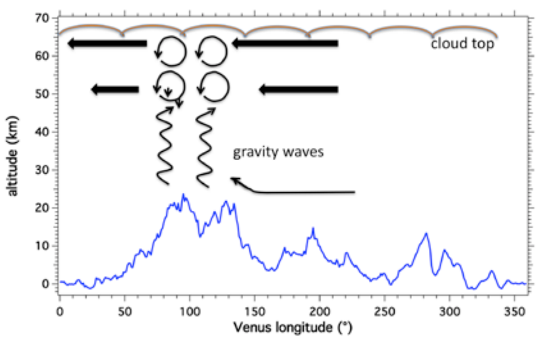


Figure 3. Sketch of gravity waves generated by interaction of the zonal wind on the mountains, propagating upward, breaking in the altitude region 50-60 km and decelerating

the zonal wind at this altitude and higher. The altitudes of the relief is exaggerated by a factor 7 for better clarity.

Mapping of UV albedo and H_2O at cloud top:

The UV albedo measured by VMC at 365 nm shows also a longitude variation correlated with the wind (figure 4).

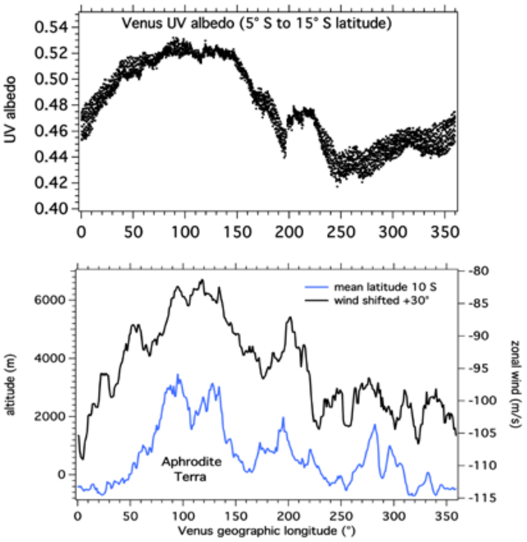
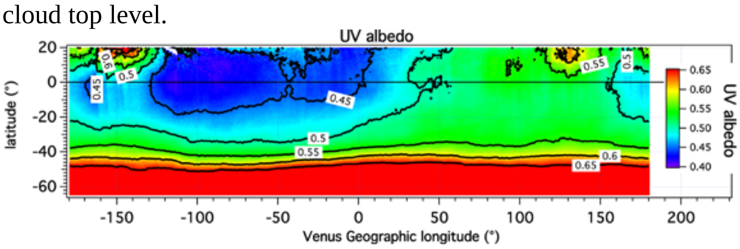


Figure 4. Latitude averages between 5 ° S and 15 °s of altimetry, zonal wind, and UV albedo. The curve of zonal wind is shifted 30° to the right to emphasize the correlation with the relief. The albedo points are representing averages within 1x1° latitude-longitude bins.

On figure 5a is displayed a geographic map of the UV albedo at 365 nm measured by VMC. It is an average of 1442 images obtained over 7.5 years from VEX orbit 30 (May 2006) to orbit 2714 in September 2013 (more than 12 Venus years). While the UV albedo poleward of 40°S is pretty uniform and higher than near the equator, a well known fact [2] there are totally unexpected structures at other places nearer the equator, both in longitude and latitude.

At the same time, a map of H_2O at cloud top level was recently obtained [3] from the near-infrared spectral feature at 1.38 µm detected in the solar back-scattered radiation (from SPICAV IR instrument on Venus Express). It reveals (fig.5b) There is more H_2O poleward of 60° of latitude than elsewhere in both hemispheres, which is due to the decrease of H_2O mixing ratio with altitude and lower cloud altitude by ~6 km at high latitudes.

In the low latitude regions from -30 to +30° of latitude, the H_2O mixing ratio is pretty uniform at 5.5- 6 ppmv, except for a conspicuous region, centered slightly below the equator and reaching 7 to 7.5 ppmv. This region extends from -130° to + 30° of longitude. This H_2O feature is statistically solid, and it demonstrates an increased upwelling of air in this particular region. The geographic maps of H_2O and UV albedo show a striking similarity in the low latitude regions, at least up to 40° of latitude. The region of low UV albedo coincides with the region of increased water vapor both in longitude and latitude, as shown by the iso-contours at 6.5 ppmv. We conclude that the UV absorber is present in upwelling regions, and therefore it must be produced below the cloud top level.



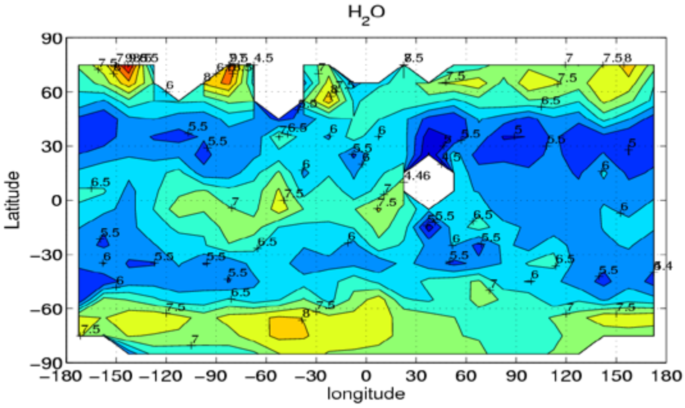


Figure 5a top. Venus geographic map of the UV albedo. The number of points per bin ranges from ~1000 to 5000. Iso-contours of UV albedo are drawn.

Figure 5b bottom. Geographic distribution at cloud top altitude of H_2O mixing ratio (reproduced from Fedorova et al. [2016]). Iso-contours are indicated in ppmv.

A plausible scenario:

Conservation of matter indicates that, since the divergence of the horizontal wind field at cloud top is different from 0, it requires a convergence of the vertical motion of air to compensate. There is upwelling in the longitude range of wind acceleration (from +60 to -30° after proper re-shift of the wind longitude profile) as revealed by H_2O map. This upwelling motion brings water vapor and the UV absorber from below, which is then transported horizontally in the general flow, as a plume of a minor constituent. Further downstream, a sign reversal of the zonal flow longitude derivative is encountered, around 190° longitude (or -170°), where the upwelling ceases, the UV albedo increases and water vapor decreases along downstream.

Acknowledgements. Venus Express is an ESA mission.

References:

[1] Bertaux et al., Influence of Venus topography on the zonal wind and albedo at cloud top level: the role of stationary gravity waves, *J. Geophys Res., in revision*, 2016

[2] Limaye and Suomi, A normalized view of Venus, *J. Atmos. Sci.*, **34**, 205– 215, 1977

[3] Fedorova, A., E. Marcq, M. Luginin, O. Korablev, J.-L. Bertaux, and F. Montmessin, Variations of the water vapor and the cloud haze in the Venus' mesosphere from SPICAV/VEx observations, *Icarus*, 2016.