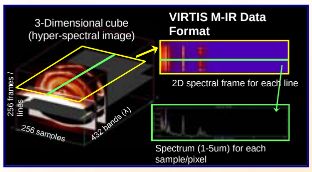
The thermal structure of the Venus mesosphere as observed by VIRTIS/Venus Express

A. Migliorini[1], D. Grassi[1], S. Lebonnois[2], L. Montabone[2,3], P. Drossart[4], G. Piccioni[1], [1] *INAF Roma* , [2] Laboratoire de Meteorologie Dynamique, Paris, [3]*AOPP, Univ. of Oxford, Oxford,* [4]*LESIA Observatoire de Paris,*
contacting e-mail: **Alessandra.Migliorini@iasf-roma.inaf.it**

Venus Express and VIRTIS

Venus Express is ESA's first mission to Earth's nearest planetary neighbor. Launched on 9 November 2005 from Baikonur, the spacecraft arrived at its destination on 11 April 2006. The spacecraft moves on a stable elliptical orbit with a period of 24 hours. The pericenter is at 250 km altitude from the north pole, whereas the apocenter is at 66000 km altitude from the south.

The main objective of the mission is to study the complex dynamics and chemistry of the atmosphere, as well as its interactions with the surface, which provides clues about the surface's characteristics. It also studies the interplanetary environment (solar wind, plasma and magnetic field) to better understand the evolution of the planet.



VIRTIS (Visible and InfraRed Thermal Imaging Spectrometer) is an imaging spectrometer which allows Venus Express to map details of the Venus planet from the surface to the upper atmosphere.

The hyper-spectral images obtained in the infrared cover a wide spectral range (1.0 μm-5.1 μm) with very good sampling capabilities (~10 nm), which make them highly valuable for the study of morphology, dynamics and composition of the atmosphere and to map details of Venus from the surface, while the visible channel covers the range 0.3 μm-1.1 μm, with a spectral sampling of ~2 nm.

In this investigation, data acquired with the IR channel are used.

Theory

Temperatures in the Venus atmosphere have been investigated in detailes by entry probes that returned accurate profiles at high vertical resolution and in a wide altitude range (Seiff, 1983). Up to about 40 km, the temperature profile is quite similar over the entire planet because the latitude and day-night variations are less than 5 K. On the other hand, in the altitude range 60-100 km, inside and above the cloud layer, variability with latitude and local time was significant, though not yet confirmed. Below 60 km, investigation by Venera 10-12 probes and the Pioneer Venus probes allowed to create the Venus International Reference Atmosphere (VIRA) models, currently used by the scientific community for Venus atmosphere modelling (Seiff et al., 1985).

The mesosphere in the altitude range 60-100 km was investigated by the VEGA 2 probes. The thermal structure was probed in the northern hemisphere (Zasova et al., 2007).

Recent measurements with VeRa instrument on board Venus Express spacecraft revealed a cold collar region at about on both hemispheres. A great agreement with the VIRA and VIRA-2 models is found at 65 km; a discrepancy of about 30 K is found at the pressure of 1 bar (Tellmann et al., 2009).

Indirect measurements of the atmospheric temperature in the Venus mesosphere were performed with the VIRTIS instrument (Grassi et al., 2008; 2010; Migliorini et al., 2011), and here presented.

Method

VIRTIS data in the infrared spectral range, acquired in the night side of Venus are inverted to retrieve the temperature fields of Venus atmosphere in the 100-1 mbar pressure range (approx 65-85 km), in the northern and southern hemispheres of the planet. A typical VIRTIS spectrum is shown in figure 1. It is dominated by the two strong CO_2 absorption bands, centered at 4.3 μm and 4.8 μm. The main CO band is evident as a continuum depression centered at 4.6 μm. The spectral region around 4.3 μm is used for the present investigation.

From the radiative transfer equation, for a given vertical distribution of optically active species, the atmospheric temperature as a function of total opacity is equivalent to atmospheric temperature as a function of pressure (or altitude). The retrieval code (Grassi et al., JGR, 2008) simulates the spectrum of the Venus night side, taking into account both clouds and CO_2, on the basis of the radiative transfer equation. The aerosol density as a function of pressure is initialized to the average values derived from Venera 15 Fourier Transform Spectrometer (FTS) data (Zasova et al., 1999). A relaxation method, based on iterative simulated and observed spectra (see figure 1), is used to determine the temperature profile that provides better match with data, as quantified by a X^2 test. The total retrieval error on air temperature is within 1-2 K in the 100-1 mbar pressure range, as it is shown in figure 2. At high altitudes, the limiting factor is represented by the instrument noise. This atmospheric region is in fact probed by VIRTIS channels with strong CO_2 absorptions located in the center of the band, where the signal to noise ratio is very poor. On the other hand, below 65 km, the errors in the retrieved aerosol densities is the main cause of temperature retrieval errors.

The applied technique takes advantage from a well proved method, applied to previous space observations in the infrared with the OIR Pioneer Venus instrument (Zasova et al., 2007).

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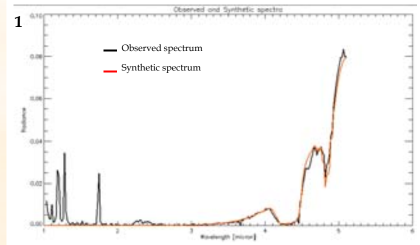

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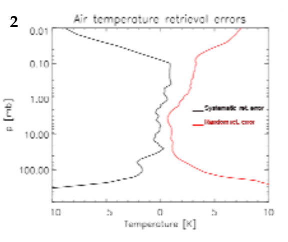


Results

3a

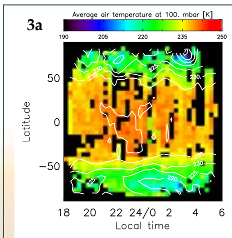
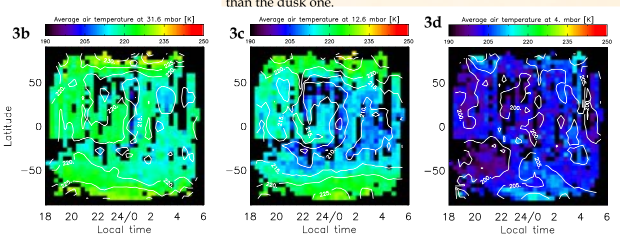


Fig. 3. Temperature fields at selected pressure levels.

At **100 mbar** (**a**, height of about 65 km) temperatures are higher on the dusk side with respect to the dawn, with a local maximum at equator between 22h and 24 h local time. A temperature increase is observed close to midnight at equatorial latitudes. The cold collar structure (Taylor et al., 1980) at 60° on both hemispheres is colder and more prominent on the dawn side, with the coldest region at about 3 h local time.

At **31.6 mbar** (**b**, height of about 70 km), the cold collar structure disappears. Temperature is about 10 K higher at poles than equator. Moreover, the temperature field is slightly warmer from 20 h to 21 h at almost all the latitudes. The dawn side is colder than the dusk one.

3b 3c 3d



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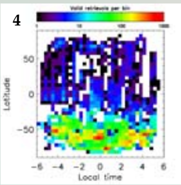


At **12.6 mbar** (**c**, about 75 km), a local minimum of temperature is observed at mid latitudes close to midnight, while local maxima are found at 20-21 h and 23 h local time, in both hemispheres. On average, the temperature is about 15-20 K warmer at polar than mid latitudes.

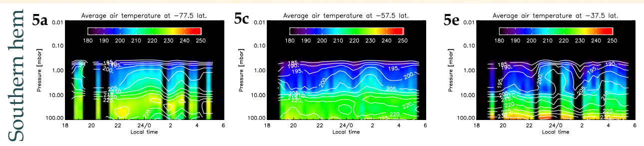
At **4 mbar** (**d**, 80 km height), the temperature decreases on average of about 10 K with respect to the temperature at 12.6 mbar. The dawn side is the warmest one, over the entire considered local times. A local minimum is observed at 20-22 h local time in the southern hemisphere and perhaps a weaker one at 22 h local time in the northern hemisphere.

Fig. 4. Coverage for the analyzed data. A better coverage is obtained in the southern hemisphere because of the spacecraft orbit geometry.

Fig 5. Temperature maps at selected latitudes: at 77.5°S (a), 77.5°N (b), 57.5°S (c), 57.5°N (d), 37.5°S (e), 37.5°N (f), and 2.5°N (g). Horizontal axis represents local time (in hours) while the vertical one is pressure (in mbar). The southern and the northern hemispheres are compared in this case. There are clear similarities in the thermal fields. Moreover, no significant variations in the temperature range are observed from one hemisphere to the other.

At 77.5°, the air temperature is locally colder in the cold collar region on the morning side, while it is warmer at 3 h local time moving to 10 mbar. On average, temperature decreases with decreasing pressure levels. Some wave-like structures could be present around 5 mbar in the dawn quadrant. The trend is observed on both hemispheres (see figures **5a** and **5b**).

At 57° (figures **5c** and **5d**), temperature is more uniform over time, though a local maximum is possibly detected at 2 h local time. In the cold collar region, a local minimum is observed in the morning side.

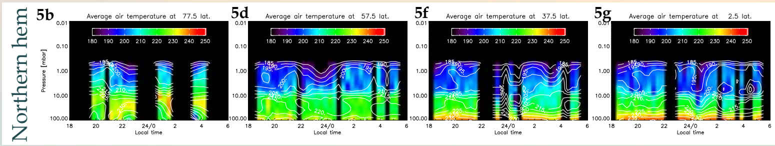


At intermediate latitudes (figures **5e** and **5f**), the region close to the top of the cloud deck at about 100 mbar becomes warmer, with atmospheric temperature decreasing with pressure. In the region below 10 mbar (which corresponds to altitudes above 75 km) a local maximum close to midnight is observed on both hemispheres. Moreover, the dawn side is the warmest on both hemispheres.

At equatorial latitudes (figure **5g**), temperature of the cloud top slightly decreases towards both terminators. A pattern of local maxima and minima are present in the pressure region 10-1 mbar.

No intrinsic variations from the North to the South seem to be present.

In addition, the thermal structure seems not to be symmetric with respect to local time. The cold collar structure, which is the most important one at 100 mbar, is more pronounced in the morning side, as well as the polar warming. Above 10 mbar, air temperature in the equatorial region is slightly colder during late evening than at morning.



Vertical profiles

6a 6b 6c

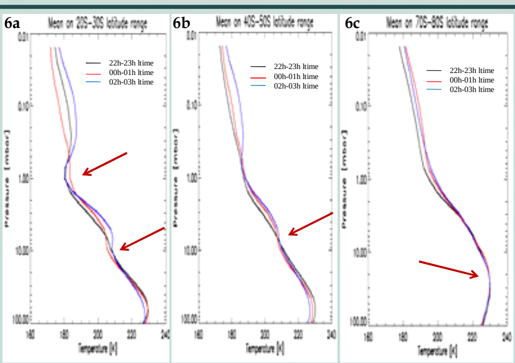


Fig. 6. Vertical profiles at 20-30°S, 40-50°S, and 70-80°S are shown in figure **6a-c** for three different local times. Close to equator (**fig. 6a**), two regions where significant changes in the lapse rate are observed around 10 and 1 mbar. Temperature maximum is at about 70 mbar at all the local times.

Regions with variation of the lapse rate are observed at 10 mbar at midnight and 02-03 h local time (see **fig. 6b**). Before midnight vertical profile decreases monotonically a part from an adiabatic lapse rate close to 1 mbar. Temperature maximum is at about 70 mbar.

Monotonous decrease in temperature with decreasing pressure is observed close to the south pole (**fig. 6c**). Temperature is maximum at about 30 mbar, probably because of the polar compression.

Conclusions

Investigation of the thermal structure on the night side of Venus in the 100-1 mbar pressure range (~ 65-85 km height) reveals that at the cloud top altitude (100 mbar) the major structure observed is the cold collar feature. Dichotomy between the morning and the evening sides is observed, the former being the coldest in the range 100-10 mbar. At lower pressures, above 80 km height, the trend is reversed, and the dusk side becomes the coldest one. Several maxima and minima of temperature values are observed with respect to local time. By applying the GCM Venus Model (described in Lebonnois et al., 2009), these features observed on the VIRTIS maps can be interpreted as indications of diurnal and/or semidiurnal thermal tides.

Finally, despite the sparse sampling on the northern hemisphere, we can conclude that there are similarities between the thermal behavior on the two hemispheres.

About Exoplanets

Though the investigation of the exoplanets atmospheres from ground is still difficult in the visible (Leight et al. 2003), several efforts have been spent in the detection, observation and modeling feasibility from space (Rowe et al., 2006). Thermal brightness measurements from photometry and spectroscopy are now providing the first insights into the atmospheric composition and thermal structure (Perryman, 2011).

The present techniques for investigation of exoplanets are able to provide temperature profiles of planetary atmospheres. These data are important to study climatology, and they can provide hints for the habitability of the planets. In the present work we show how vertical profiles vary with local time and latitude even on a very slowly rotating planet with almost no tilting of the vertical axis. In particular, the thermal inversions observed at 10 mbar and 1 mbar at equatorial and mid latitudes are indications of energetic processes which take place in the Venus atmosphere, like for example the nightglow emissions.

Grassi et al., JRG, 2008; Grassi et al., JGR, 2010; Lebonnois, et al., JGR, 2010; Leight et al., MNRAS, 2003; Menou and Rauscher, ApJ, 2009; Migliorini et al., Icarus , 2011; Perryman, 2011; Rowe et al., ApJ, 2006; Seiff, 1983; Seiff et al., Ad.Sp.Res., 1985; Taylor et al., JGR, 1980; Tellmann et al., JGR, 2009; Zasova et al., Ad.Sp.Res., 1999; Zasova et al., P&SS, 2007.

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