Nocturnal variations of the Venus upper cloud scale height

Andrea Longobardo (1), E. Palomba (1), D. Grassi (1), A. Migliorini (1), G. Piccioni (1) and P. Drossart (2)

(1) IAPS-INAF, Via Fosso del Cavaliere 100, 00133 Rome, Italy; (2) LESIA, Observatoire de Paris, CNRS, Université Pierre et Marie Curie, 92195 Meudon, France

Contact e-mail : andrea.longobardo@iaps.inaf.it

1. Introduction

The thermal structure of the Venusian atmosphere above 30 km and the optical/physical properties of cloud layers (e.g. scale height, cloud top, number density), change with latitude [1-4]. Moreover the diurnal variability of the thermal structure of the upper cloud region (extending from 63 to 72 km) also has been observed [5-6].

The upper cloud region can be monitored by applying the relation in the yellow box (Eq. (1)), obtained by Diner's radiative transfer model [7] and valid for $0.4<\cos\theta<0.9$ at wavelengths characterised by upper cloud thermal emission, i.e. 3-5 μm [8]. The application of Eq. (1) on Galileo-NIMS data allowed to estimate the upper cloud scale height at near-equatorial latitudes (i.e. H=4.1±0.6 km) [8], but the relation does not work in the cold collar region, centered at -65° and 65 km [1], where scale height and lapse rate are very low.

$$T = T_0 + C \ln\cos\theta \qquad (1)$$

θ: emission angle
T: observed brightness temperature
T_0: brightness temperature in a Nadir observation
$C = H\Gamma$
H : upper cloud scale height and Γ: upper cloud lapse rate

In this work, the upper cloud region is studied at different latitudes and local times during the night-time, by retrieving the parameters of Eq. (1) from a statistical analysis on VIRTIS-VeX data.

2. Data analysis

The considered dataset is composed by 1725 images (i.e. 10^7 pixels) provided by the infrared channel of VIRTIS-M [9]. Data were inverted to obtain brightness temperature at 3.72 μm and 4.00 μm and different latitude/local time intervals were selected (see below).

For each wavelength and interval, ten brightness temperature families have been empirically defined (Fig. 1), by means of a statistical analysis, described in [10]. Eq. (1) has been fitted on data from each family to infer T_0 and C.

Scale height as function of latitude. Four latitude intervals (LI), within which atmospheric and cloud coverage can be considered similar, have been choosen and are shown in the green box. Lapse rates provided by the VIRA (Venus International Reference Atmosphere) model [2] were used to retrieve the scale height relative to each latitude interval family.

LI 1: *from -40° to 0°*
LI 2: *from -50° to -40°*
LI 3: *from -60° to -50°*
LI 4: *from -70° to -60°*

LI12: *from -50° to 0°*
LI3: *from -60° to -50°*
LI4: *from -70° to -60°*

Early night: *from 22:30 to 0:30*
Middle night: *from 0:30 to 2:30*
Late night: *from 2:30 to 4:30*

Scale height as function of latitude and local time. Three latitude intervals and three local time intervals have been considered (see cyan box). Temperature profiles at different latitudes and local times have been obtained, by developing a retrieval code, which simulates the Venus spectrum nightside (taking into account both clouds and CO_2), and by applying a relaxation method, based on iterative comparison between simulated and observed spectra [5-6]. These profiles allow to retrieve lapse rate, and hence scale height, for every latitude/local time interval.

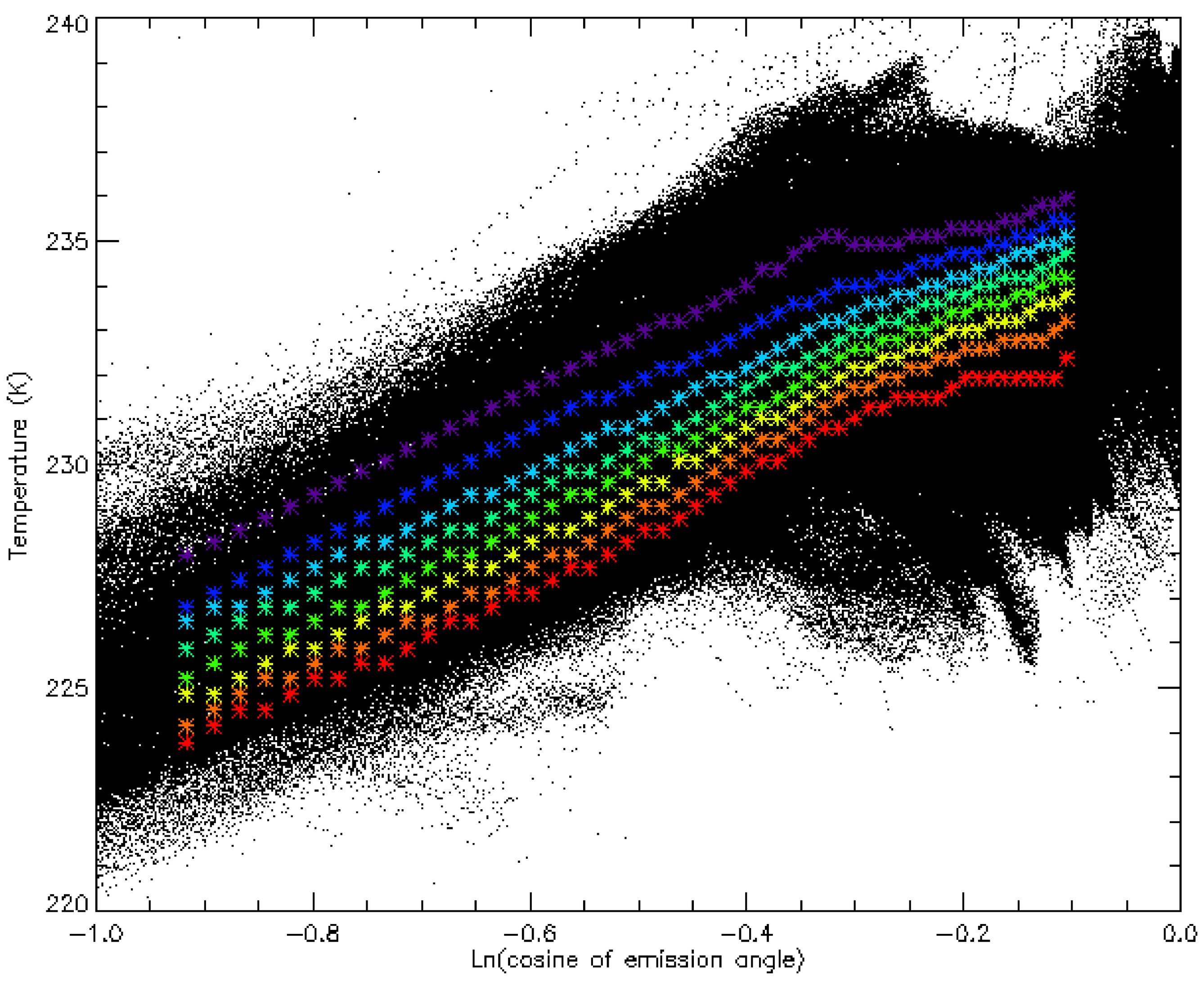

Figure 1. Observed temperatures at latitudes between -50° and 0°, at local times between 22:30 and 00:30 and at 3.72 μm, as function of ln (cosθ). Different colors correspond to different brightness temperature families.

3. Scale height as function of latitude

Results are shown in Table 3 [10].

Brightness temperature decreases poleward, in particular it drops below -50°, where a cloud opacity increase is expected [1,3,4].

Results at LI1 and LI2 are similar (and for this reason the two intervals are merged in the interval L12 in the next study). The retrieved upper cloud scale heights agree with the literature estimates, i.e. about 4 km [1,3,8]: this can be considered a good validation of our statistical approach.

At LI3, the calculated scale height is affected by a strong uncertainty, especially at higher temperatures. This reflects the strong variations of lapse rate within this interval, not only with latitude but also with local time. Furthermore a more accurate analysis is needed at these latitudes.

Finally, at LI4 no linear behaviour is observed, i.e. scale height and/or lapse rate are very low. This is reasonable, since we are observing the cold collar region, where these conditions are met.

Latitude	T_0 (K)	H (km)
LI1	231-238	3.7±0.3
LI2	228-238	4.5±0.8
LI3	231-238	3-9
	226-231	4-5
LI4	NO FIT	

Table 1. Brightness temperature and upper scale height retrieval at different latitude intervals [10].

4. Scale heigth as function of latitude and local time

Results are shown in Table 2.

Brightness temperature decreases poleward and during the night.

Scale height is independent on local time at LI12, and only in the late night and at temperature lower than 230 K, Eq. (1) does not work.

Between -60° and -50°, the retrieved scale height in the early night and in the middle night at higher temperature is similar to the near-equatorial value. Otherwise, in the middle night at lower temperatures and in the late night, Eq. (1) behaves as in LI4, i.e. no linear behaviour of T with $\cos\theta$ is observed (Fig. 2).

These results can be interpreted with concern to the cold collar extension. In the early night, it is located between -70° and -60°, whereas in the middle night it extends equatorward of -60° (as a matter of fact, at these latitudes colder temperatures correspond to absence of linear beahviour). Finally, during the late night, the cold collar regions spans from -70° to -50° and can extend also poleward of -50°, as evidenced by the poor fits at LI12 for T<230 K .

Latitude	*Early night*	*Middle night*	*Late night*
LI12	T_0=231-238 K H=4-5 km	T_0=230-236 K H=4-5 km	T_0=230-236 K H=4-5 km T_0 < 230 K NO FIT
LI3	T_0=226-238 K H=3.5-5 km	T_0=230-236 K H=3.5-5 km T_0 < 230 K NO FIT	NO FIT
LI4	NO FIT		

Table 2. Brightness temperature and upper scale height retrieval at different latitude and local time intervals.

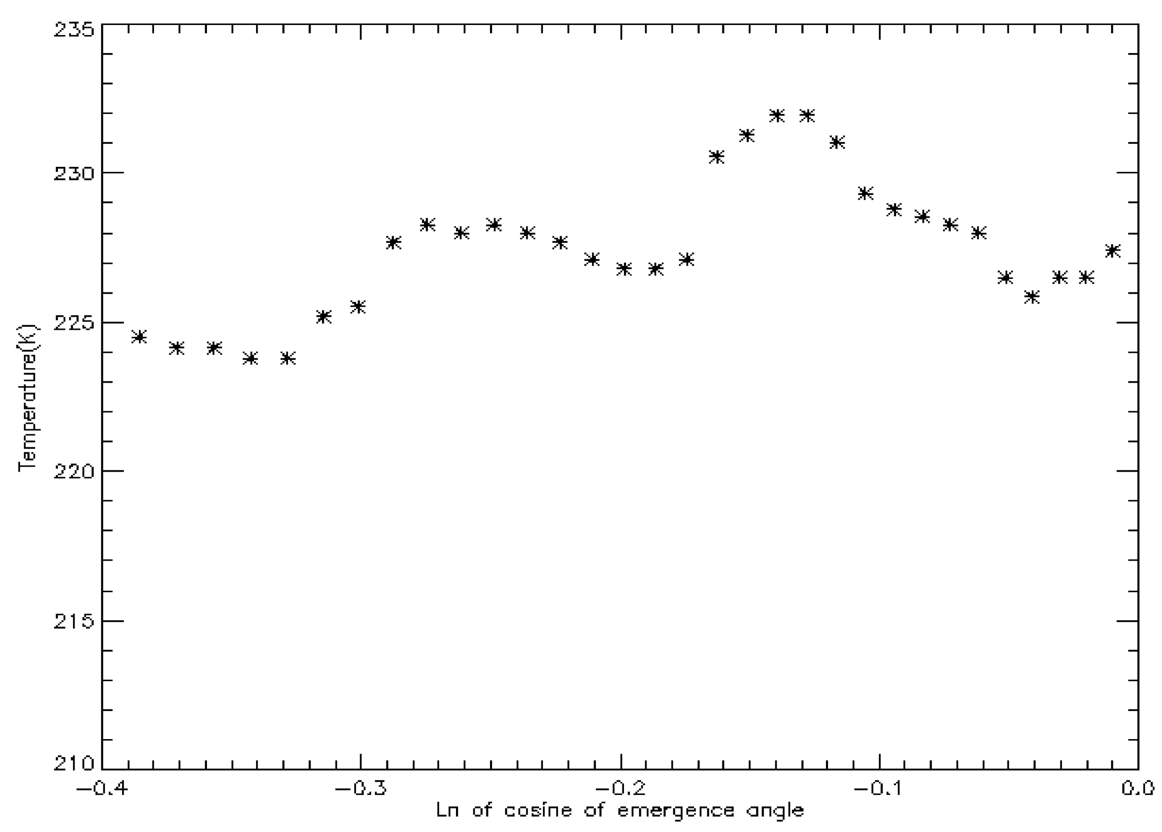

Figure 2. Observed temperatures at LI4, in the early night and at 3.72 μm, as function of ln (cosθ).

5. Conclusions

A statistical analysis on VIRTIS-VeX data has been developed to monitor the upper cloud region of the Venusian atmosphere. In particular, brightness temperature and scale height have been inferred at different latitudes and local times.

Temperature decreases poleward and at increasing local time. In particular, the decrease poleward of -50° can be due also to cloud opacity increase.

According to previous literature estimates, we found a scale height between 4 km and 5 km between -50° and 0°. The same value is obtained between -60° and -50° but only if these latitudes do not comprise the cold collar, i.e. in early and middle night.

As a matter of fact, the cold collar region is located between -70° and -60° before 00:30, but extends poleward of -60° between 00:30 and 2:30, and poleward of -50° after 2:30.

Acknowledgements

ASI supports VIRTIS and the Venus Express mission through the contract ASI-INAF I/050/10/0. ASI and CNES are also thanked for their support.

References

[1] Zasova, L. V. *et al*. (2007), *Planet. Space Sci.,* 55, 1712-1728; [2] Seiff, A. (1985), In: *VIRA (Venus Interbational Reference Atmosphere), Adv. Spa. Res.*, V5, N11; [3] Ignatiev N. *et al*. (2009), *JGR*, 114, E00B43, doi: 10.1029/2008JE003320; [4] Barstow, J. *et al.* (2012), *Icarus*, 217, 542-560; [5] Grassi, D. *et al*. (2010), *JGR*, 115, E09007, doi: 10.1029/2009JE003553; [6] Migliorini, A. *et al*. (2012), *Icarus*, 217, 640-647; [7] Diner, D. J. (1978), *J. Atmos. Sci*., 35, 2356-2361; [8] Roos, M. *et al*. (1993), *Planet. Space Sci.*, 41, 7, 505-51; [9] Piccioni, G (2007), *ESA Special Publications*, 1-27; [10] Longobardo, A. *et al*. (2012), *PSS*, 69, 62-75.