The Venus oxygen nightglow and density distributions

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Summary

Observing Venus nightglow is a key tool to understand the composition and the dynamics of its atmosphere. Results deduced from observations can be implemented to produce a data model of Venus atmosphere. For instance, the Visible and Infra-Red Thermal Imaging Spectrometer (VIRTIS) instrument on board the Venus Express spacecraft is very useful to analyze the $O_2(a^1\Delta)$ nightglow at 1.27 µm in the Venus mesosphere. Nadir observations can be used to create a statistical map of the emission on Venus nightside. It appears that the maximum of the emission is located near the antisolar point. Limb observations also provide information on the altitude and on the shape of the emission layer. Combining nadir observations and vertically integrated limb observations improves the statistics of the emission map on Venus nightside. An associated limb profile can also be deduced for any point of the nightside. Given all these $O_2(a^1\Delta)$ intensity profiles, O_2* density profiles can be calculated. O density profiles can also be calculated as long as CO_2 density profiles are available. These can be retrieved either from the VTS3 model or from SPICAV stellar occultation measurements. Finally, three-dimensional maps of excited molecular and atomic oxygen densities can be generated. The oxygen density map shows significant differences from the VTS3 model predictions.

Introduction

Atomic oxygen is a major constituent of the Venus nightside atmosphere 15–20 km above the homopause located near 135 km (Gérard *et al.* 2008a). The atomic oxygen density can be deduced from the $O_2(a^1\Delta)$ emission. The $O_2(a^1\Delta)$ nightglow in the Venus upper mesosphere has been observed at 1.27 µm using data from the Visible and Infra-Red Thermal Imaging Spectrometer (VIRTIS) instrument on board the European Venus Express spacecraft (Drossart *et al.* 2007; Piccioni *et al.* 2009). The VIRTIS-M-IR medium-spectral resolution imaging spectrometer can be used to observe the $O_2(a^1\Delta)$ nightglow either in nadir or limb modes. Using nadir observations, Gérard *et al.* 2008b and Piccioni *et al.* 2009 found that the emission peak was statistically located around the antisolar point. Connes *et al.* 1979 suggested that the reaction scheme leading to the radiative deexcitation of the $O_2(a^1\Delta)$ molecules may be written:

$$2O + CO_2 \rightarrow O_2* + CO_2 \quad (k)$$

$$O_2* \rightarrow O_2 + h\nu \quad (A)$$

$$O_2* + CO_2 \rightarrow O_2 + CO_2 \quad (C_q)$$

where O_2* represents excited oxygen molecules, k=2.5x10^{-32} cm^6 s^{-1} is the first reaction rate coefficient, A=2.19x10^{-4} s^{-1} is the Einstein coefficient of the 1.27 µm transition and Cq=2x10^{-20} cm^{-3} s^{-1} is the quenching coefficient. Based on these reactions and VIRTIS-M-IR nadir and limb $O_2(a^1\Delta)$ observations, it is possible to deduce O density profiles (Gérard *et al.* 2009). $O_2(a^1\Delta)$ density profiles can also be calculated with CO_2 density profiles obtained either with the Venus International Reference atmosphere (VIRA) model or with stellar occultation observations from the Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Venus (SPICAV) instrument on board Venus Express (Bertaux *et al.* 2007).

The $O_2(a^1\Delta)$ nightglow and density

Because of the spacecraft's polar elliptical orbit, nadir measurements are preferentially made while VIRTIS observes the southern hemisphere. Instead, limb observations are collected in the northern hemisphere. Nadir observations have to be corrected for the contribution of the thermal emission of the planet (Cardesin-Moinelo 2009; Piccioni *et al.* 2009) and limb observations are vertically integrated to simulate nadir observations. Combining nadir observations in the southern hemisphere and limb observations from the northern hemisphere provides a statistical global map of the $O_2(a^1\Delta)$ emission (Figure 1). A region of enhanced emission appears around the antisolar point, with a maximum brightness of 1.6 MR (1 Rayleigh, R, corresponds to the brightness of an extended source emitting 10^6 photons cm^{-2} s^{-1} in 4π sr). This is in good agreement with previous results from Gérard *et al.* 2008b and Piccioni *et al.* 2009 who respectively obtained 3.0 MR and 1.2 MR for the maximum brightness of the $O_2(a^1\Delta)$ emission at the antisolar point.

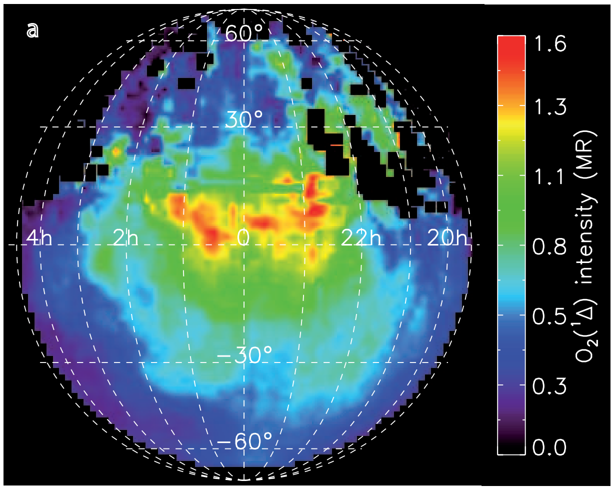

Figure 1: Statistical map of the $O_2(a^1\Delta)$ nightglow Soret *et al.* 2010

By comparing the nadir intensity of each pixel to the value obtained by vertically integrating the local profile deduced from the inverse Abel transform of a limb profiles, it is possible to normalize the vertical emission rate profile. The normalized limb profile is calculated by applying the Abel transform to this local profile. Finally, a three-dimensional map of the $O_2(a^1\Delta)$ emission is obtained.

The excited O_2 density can then easily be calculated by dividing the local emission rate by the Einstein coefficient of the 1.27 µm transition (A = 2.19×10^{-4} s^{-1}). The deduced three-dimensional map of the molecular oxygen density shows the same morphology as Figure 1. The mean value at the peak is 2.0×10^9 cm^{-3} and the mean altitude of the peak is 99.2 km.

The CO_2 density distribution

CO_2 density profiles have been obtained from the VTS3 model and from observations made with the SPICAV instrument. At a given altitude, it appears that CO_2 densities predicted by VTS3 are equal for a fixed solar zenith angle. Based on these results, the 114 SPICAV stellar occultation observations were averaged by steps of 15°, depending on their distances to the antisolar point. The major difference between those two CO_2 density distributions appears beyond 50° of solar zenith angle, where the SPICAV densities show a pronounced drop while the VTS3 model predicts an important increase.

The O density distribution

The oxygen density can finally be deduced from molecular oxygen and CO_2 densities:

$$[O](z) = \sqrt{[O_2*](z)\frac{A + C_q[CO_2](z)}{k\varepsilon[CO_2](z)}}$$

where [O] is the atomic oxygen density, [O_2*] is the excited O_2 density, z is the distance from the center of Venus and ε is the efficiency of the $a^1\Delta$ state production. [CO_2] is the CO_2 density which can be deduced either from the VTS3 model or SPICAV observations. In both cases, the hemispheric mean O density at the peak is 2.0×10^{11} cm^{-3}. At 103 km, O densities are larger with the VTS3 CO_2 densities around the antisolar point while they are lower than the O densities calculated with the SPICAV CO_2 dataset near the terminator. The mean altitude of the O density peak is higher when using CO_2 densities from VTS3.

These results can be compared to the O densities directly derived from the VTS3 model and which are currently the only ones available. Whatever the altitude, the atomic oxygen densities are equal along a given solar zenithal distance (Figure 2) which can hardly reproduce the reality. The mean value at 103 km is 0.64×10^{11} cm^{-3} which is about three times less than for the O density calculated with CO_2 densities from VTS3 and SPICAV.

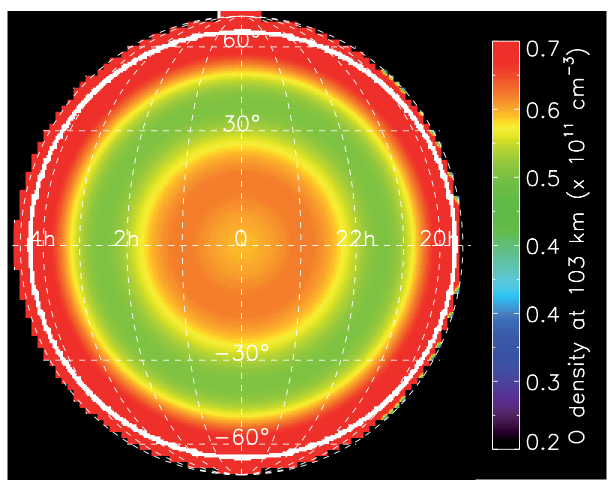

Figure 2: Statistical map of the O density obtained with the VTS3 model at 103 km

Conclusions

So far, only O density values from the VTS3 model, based on extrapolation of measurements collected by the Pioneer Venus mass spectrometer above 140 km were available. Here, we obtain a three-dimensional map of the atomic oxygen density based on observations by VIRTIS at 1.27 µm and measurements of the CO_2 density with stellar occultations by SPICAV. A complete three-dimensional statistical map of the $O_2(a^1\Delta)$ nightglow has also been built by combining limb and nadir observations to obtain a coverage of Venus nightside both in the northern and in the southern hemispheres. A three-dimensional statistical map of the excited molecular oxygen density has been deduced. The current results can be used to improve the composition accuracy of Venus nightside atmosphere in some three-dimensional models.

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