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Nighttime photochemical model and nightglow on Venus

Vladimir A. Krasnopolsky (1,2)
(1) Catholic University of America, Washington, DC, USA, (2) Moscow Institute of Physics and Technology, Moscow, Russia (vlad.krasn@verizon.net)

Abstract

The previous model for Venus' nighttime atmosphere [5] is updated to account for the nighttime ozone [8] and improved spectroscopy of the OH nightglow [11]. Nighttime chemistry is induced by fluxes of O, N, H, and Cl with mean values of 3×10^{12}, 1.2×10^{9}, 10^{10}, and 10^{10} cm^{-2} s^{-1}, respectively. They are proportional to column abundances of these species in the daytime atmosphere [7] above 90 km, and this favors their validity. The model includes 86 reactions of 29 species. Ten schemes of the OH excitation are discussed, and a chosen scheme fits the observed OH band distribution in the $\Delta v = 1$ sequence [11]. An alternative model without the Cl flux is suggested as well.

1. Introduction

Detailed observations of the Venus nightglow by Venus Express require an adequate model for the nighttime photochemistry. We combined in [6] the basic observational data for the O_2 and O nightglows on the Earth and Venus with the laboratory and theoretical studies and suggested a model of excitation, energy transfer, and quenching of the oxygen emissions that fits the basic constraints. We also made a model for the nighttime atmosphere [5] with photochemistry induced by fluxes of O, N, and H from the dayside atmosphere. The model agreed with the observational data available at that time.

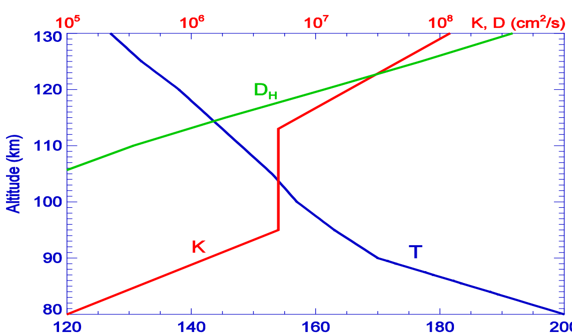

Fig. 1. Temperature and eddy diffusion profiles in the model. D_H in CO_2 is shown for comparison.

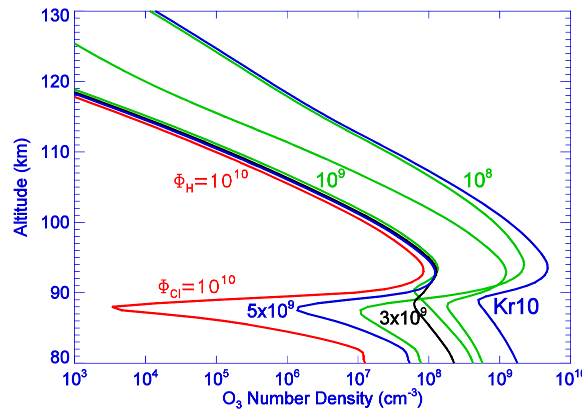

Fig. 2. Ozone profiles for various fluxes of H and Cl at the upper boundary. The best fit to [8] is red.

However, later the SPICAV stellar occultations [8] revealed an ozone layer near 95 km with a peak density that is smaller than predicted by [5] by a factor of ~60. Furthermore, detailed data on the OH band distribution and their mean intensities [11] became available. These facts stimulate a significant revision of the model [5].

2. Photochemical model

Temperature and eddy diffusion profiles in the model are shown in Fig. 1. Reactions with H and Cl are the only processes to reduce the nighttime ozone on Venus. The reaction set in [5] is insufficient for large fluxes of H and Cl, and we add 25 reactions to the model. Profiles of O_3 calculated for various fluxes of H and Cl are shown in Fig. 2. Fluxes of O and N at 130 km are fixed at their values from [5]: $\Phi_O = 3\times10^{12}$ and $\Phi_N = 1.2\times10^{9}$ cm^{-2} s^{-1}. The model fits the SPICAV ozone for $\Phi_H = \Phi_{Cl} = 10^{10}$ cm^{-2} s^{-1}. The ozone profile for $\Phi_H = 10^{10}$ cm^{-2} s^{-1} without Φ_{Cl} agrees with the observed O_3 above 90 km but grows to 4×10^{8} cm^{-3} at 80 km. However, the observed ozone becomes uncertain near 80 km because of the aerosol extinction, and the model without supply of Cl is our alternative model that is not discussed here.

Column abundances of O, N, H, and Cl above 90 km in a global-mean model [7] are proportional to the adopted fluxes in our basic model, and this favors their validity. The model (Fig. 3) agrees with the observed CO [1] and O_3 [8] and predicts significant abundances of Cl_2, ClO, and $ClNO_3$. The Cl_2 lifetime at night is much longer than the duration of the night (~2 days), and the calculated Cl_2 is overestimated by our steady-state model. The calculated ClO could be measurable by the UV stellar occultations near 85 km.

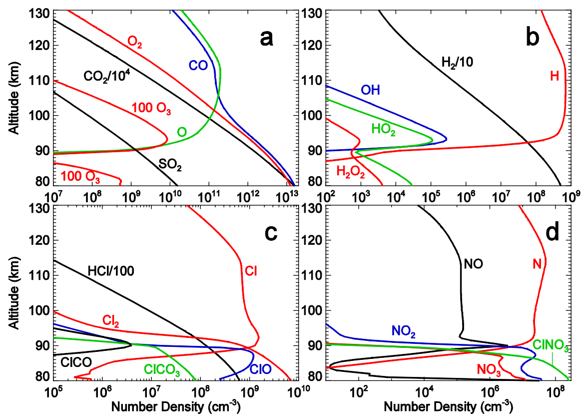

Fig. 3. Vertical profiles of species in the basic model.

Vertical profiles of the O_2 and NO nightglows at 1.27 μm and in the UV range, respectively, are shown in Fig. 4a. They are in excellent agreement with the VEX observations [10, 3]. Profiles of two reactions that may excite the OH nightglow are shown in Fig. 4b. Excitation yields for $H+O_3$, transition probabilities, and quenching rate coefficients by CO_2 are taken from [2], and the latter are scaled by $300/T$ for $T = 187$ K [5]. Ten excitation schemes have been tested with various v" in the quenching of OH(v') by CO_2. The best fit is for a scheme without excitation by $O+HO_2$ (Fig. 4c). An alternative scheme involves excitation of OH in $O+HO_2$ up to v = 4, in accord with [4]. However, the OH nightglow profile in this model is displaced down by ~2 km relative to those observed in [11].

3. Variations of nightglow and O_3

These variations are induced by varying fluxes at 130 km in our model. The nightglow vertical intensities and the O_3 peak density are determined by the following relationships:

$$4\pi I_{O2} = 127(\Phi_O/10^{12})^{1.22} \text{ kR} \quad (1)$$

$$4\pi I_{NO} = 225(\Phi_N/10^9)(\Phi_O/10^{12})^{0.35} \text{ R} \quad (2)$$

$$4\pi I_{OH} = 1.2\,(\Phi_O/10^{12})^{1.4}\,\frac{X^{1.47-0.46\ln X}}{Y^{1.43+0.65\ln Y}} \text{ kR}; \quad (3)$$
$$X = \frac{\Phi_H}{10^{10}},\ Y = \frac{\Phi_{Cl}}{10^{10}}$$

$$[O_3]_{max} = \frac{2.2\times10^7\,(\Phi_O/10^{12})^{1.2}}{Y^{0.74+0.8\ln Y}} \text{ cm}^{-3} \quad (4)$$

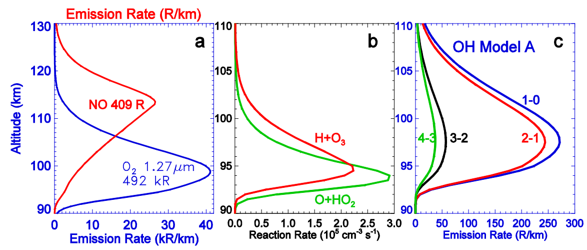

Fig. 4. Vertical profiles of the O_2 1.27 μm and NO UV total (γ+δ bands) nightglow (a), two reactions of excitation of the OH nightglow (b), and four bands of the OH nightglow in the $\Delta v = 1$ sequence (c).

Acknowledgement

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