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Height profiles of OI 630 nm and OI 557.7 nm airglow intensities measured via rocket-borne photometers and estimated using electron density data: a comparison

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Resumen

Fotómetros y sensores para medidas de densidad electrónica a bordo de cohetes de sondeo brasileños Sonda III fueron lanzados desde Natal (5.8º S, 35.2º W), Brasil. El primero en 11 de Diciembre de 1985 (20:30 hora local) y el otro en 31 de Octubre de 1986 (22:59 hora local). La carga científica consistió de fotómetros para medir emisiones de oxígeno atómico OI 557.7 nm (línea verde) y OI 630 nm (línea roja) en la ionosfera nocturna, dispuestos paralelamente al eje de giro del cohete, y dos sondas de densidad electrónica: una sonda de Langmuir y la otra tipo capacitiva de alta frecuencia, utilizadas para medir la densidad electrónica ionosférica y la presencia de fluctuaciones espaciales. Los valores de densidad electrónica medidos desde esos vuelos de cohetes y otros parámetros obtenidos en los modelos IRI-2001 y MSIS-E 90 han sido utilizados para obtener perfiles de tasa de emisión volumétrica de los oxígenos atómicos OI 557.7 nm y OI 630 nm. Esos datos son comparados con perfiles de altitud obtenidos a partir de los datos de los fotómetros. Tomando como base este estudio comparativo, realizamos una discusión.

Palabras clave: Luminiscencia del cielo nocturno, cohete de sondeo, densidad electrónica, eficiencia cuántica, oxígeno atómico.

Abstract

Rocket-borne photometers and electron density probes were launched on-board two Brazilian Sonda III rockets from Natal (5.8º S, 35.2º W), Brazil, one on December 11, 1985 (20:30 LST) and the other on October 31, 1986 (22:59 LST). The payload consisted of photometers for the OI 557.7 nm and OI 630 nm emission lines, mounted parallel to the spin axis of the rocket, a Langmuir probe (LP) and a High Frequency Capacitance Probe (HFC) used to measure the ionospheric electron density and its spatial fluctuations. The photometers were used to measure the intensities of the green and red emission lines of atomic oxygen from the nocturnal ionosphere. The measured values of electron densities from these rocket flights and other parameters from IRI-2001 and MSIS-E 90 models are used to obtain volume emission rate profiles of the atomic oxygen OI 557.7 nm and OI 630 nm. These are compared with the height profiles of the respective emission lines obtained from the rocket-borne photometers. A discussion is carried out of the results of these comparative studies.

Key words: Airglow, sounding rocket, ionosphere, electron density, quantum yield, atomic oxygen.

Introduction

Airglow measurements conducted by photometers on-board a sounding rocket provide an excellent opportunity to investigate the vertical profiles of the upper atmosphere emission layers and to test the performance of atmospheric and ionospheric models for a given latitude and time.

Two scientific rocket payloads to investigate the ionospheric electron density profile and the intensities of the oxygen emission lines in the nocturnal E and F region were launched from Natal (5.8º S, 35.2º W), Brazil, on December 11, 1985 (20:30 Local Time) and on October 31, 1986 (22:59 Local Time).

The nightglow emission and electron density profiles were obtained, respectively, from forward-looking airglow photometers; high-frequency capacitance (HFC) and Langmuir probes (LP).

The purpose of this paper is to provide a comparison of the height profiles of the volume emission rates estimated from the integrated intensity measurements of the on-board photometers and similar height profiles calculated from parameters provided in the literature, measured electron density values and data from the MSIS-E 90 and IRI-2001 models (Hedin, 1991; Bilitza, 2001). The electron density data used are from either the IRI-2001 model or from on-board plasma probe measurements.

Experimental data and model inputs

In both the experiments reported here, the scientific payloads and the telemetry systems were developed at the National Institute for Space Research (INPE) and the sounding rockets of Sonda III type were provided by the Institute of Aeronautics and Space of the Center for Aerospace Techniques (IAE/CTA, Brazil).

In the experiment conducted in 1985 to investigate the characteristic features of large scale electron density depletions associated with equatorial spread-F events, the payload was equipped with OI 557.7 nm and O_2 A(0,0) 761.9 nm deployable airglow photometers and two plasma probes to measure, respectively, the airglow emissions and electron density during a plasma bubble irregularity event. At the time of launch the F-region was high and showed a well developed bubble, and so the F-region component of OI 557.7 nm was too small to enable a reliable profile to be obtained (Clemesha and Takahashi, 1993).

Under quiet ionospheric conditions, in the experiment of October, 1986, were measured similar parameters except that the O_2 A(0,0) 761.9 nm photometer was replaced by an OI 630 nm photometer. Its principal objective was to study the equatorial ionosphere during a period of maximum airglow emission, which generally occurs in the absence of plasma bubbles (Muralikrishna and Abdu, 1992). Both experiments were successful and more details can be found in the literature (Takahashi *et al.*, 1987; Gobbi, 1988; Abdu *et al.*, 1990; Takahashi *et al.*, 1990; Abdu *et al.*, 1991; Gobbi *et al.*, 1992; Clemesha and Takahashi, 1993).

For the sake of comparison, we carried out calculations of volume emission rate based on published values of reaction rate coefficients and quantum yields, and atmospheric models as described above (Table 1). The model developed by McDade *et al.* (1986), gives the volume emission rate of the OI 557.7 nm in the heights of E region as,

$$V_{557.7} = \frac{A_{557.7} k_1 [O]^3 \{[N_2] + [O_2]\}}{\{A_S + k_5 [O_2]\}\{C^{O_2} [O_2] + C^O [O]\}} \tag{1}$$

where $A_{557.7}$ is the O(^1S-^1D) transition probability; A_S is the inverse of the $O(^1S)$ radiative lifetime; k_5 is the coefficient for quenching of $O(^1S)$ by O_2; [ ] denotes concentration in cm^{-3}; the coefficients C^{O2} and C^O are the empirical $O(^1S)$ excitation parameters defined by McDade *et al.* (1986) and related to the properties of the unidentified precursor of $O(^1S)$. These coefficients are listed in Table 1.

In the F region, the volume emission rates $V_{557.7}$ and V_{630} (Sobral *et al.*, 1993) are given, respectively, by,

$$V_{557.7} = A_{557.7} \frac{\Theta f(^1S)\, \gamma_1 [e] [O_2]}{k_1^* [O] + k_2^* [O_2] + k_3^* [N_2] + A_s} \tag{2}$$

$$V_{630} = A_{630} \frac{\Theta f(^1D)\, \gamma_1 [e] [O_2]}{k_1^{**} [O] + k_2^{**} [O_2] + k_3^{**} [N_2] + k_4^{**} [e] + A_D} \tag{3}$$

where A_i values are Einstein transition coefficients; $[e]$ is the electron density; Θ is the $\frac{[O^+]}{[e]}$; f(^1S) and f(^1D) are, respectively, the $O(^1S)$ and $O(^1D)$ quantum yields in O_2^+ dissociative recombination; γ_1, k_i^* and k_i^{**} values are reaction rates whose values used are listed in Table 1.

Table 1

Coefficients used in this work.

Coefficients		**References**
$k_1 = 4.7\text{x}10^{-33} (\frac{300}{T})^2$	cm^6 s^{-1}	Gobbi *et al.* (1992)
$k_5 = 4.0\text{x}10^{-12} \exp(\frac{-865}{T})$	cm^3 s^{-1}	Melo *et al.* (1996)
$\gamma_1 = 2.0\text{x}10^{-11}$	cm^3 s^{-1}	Bates (1988)
$k_1^* \leq 2.0\text{x}10^{-14}$	cm^3 s^{-1}	Gobbi *et al.* (1992)
$k_2^* = 4.9 \text{ x } 10^{-12} \exp(\frac{-885}{T})$	cm^3 s^{-1}	Gobbi *et al.* (1992)
$k_3^* \leq 5.0\text{x}10^{-17}$	cm^3 s^{-1}	Atkinson and Welge (1972)
$k_1^{**} = 8.0\text{x}10^{-12}$	cm^3 s^{-1}	Abreu *et al.* (1986)
$k_2^{**} = 3.2\text{x}10^{-11}$	cm^3 s^{-1}	Link and Cogger (1988)
$k_3^{**} = 2.3\text{x}10^{-11}$	cm^3 s^{-1}	Link and Cogger (1988)
$k_4^{**} = 6.2\text{x}10^{-10}$	cm^3 s^{-1}	Link and Cogger (1988)
$A_s = 1.35$	s^{-1}	McDade *et al.* (1986)
$A_{557.7} = 1.18$	s^{-1}	Nicolaides *et al.* (1971)
$A_D = 7.45\text{x}10^{-3}$	s^{-1}	Sobral *et al.* (1993)
$A_{630} = 5.63\text{x}10^{-3}$	s^{-1}	Sobral *et al.* (1993)
$C^o = 211$		McDade *et al.* (1986)
$C^{O_2} = 15$		McDade *et al.* (1986)

Results and discussion

E-region OI 557.7 nm emission

At the time of launch on December 11, 1985, the F-region was high and showed a well developed plasma bubble. The F-region component of OI 557.7 nm, therefore was too small to enable a reliable profile to be obtained (Gobbi *et al*., 1992). For this launch, therefore, we present only OI 557.7 nm profiles corresponding to the E-region.

The comparison between E-region OI 557.7 nm profiles derived from the first experiment and that calculated utilizing equation (1) are shown in Fig. 1. The figure presents three profiles, one from MSIS-E 90 and two derived from the 1985 experiment (upleg and downleg). Gobbi *et al*. (1992) suggest that the difference between the upleg and downleg profiles indicates the existence of large horizontal gradients in the E region atomic oxygen profile in both space and time, probably as a result of dynamical effects.

There is also in the Fig. 1, a good relation between the altitude of the profile peaks for MSIS-E 90 and upleg, however both the maximum volume emission rate and the profile shape are in disagreement. This suggests that the profiles of the neutral constituents from the model are not sufficiently realistic, besides the chosen kinetic model and uncertain coefficients to provide a more reliable $V_{557.7}$ profile.

F-region OI 557.7 nm and OI 630 nm emissions

The dissociative recombination of O_2^+ is the main source of the atomic oxygen excited species $O(^1D)$ and $O(^1S)$ in the nocturnal F-region (Bates, 1992). For the second experiment, the launch took place at a time when the layer was descending and when no spread-F was present, since under those conditions stronger dissociative recombination airglow intensity levels are expected (Sobral *et al*., 1992).

In Fig. 2., the OI 557.7 nm experimental volume emission rate profile (upleg) derived from Sobral *et al*.(1992) is compared with profiles calculated using equation (2). The theoretical profiles in Fig. 2-A were calculated with $f(^1S) = 5.0 \times 10^{-2}$ (Takahashi *et al*., 1990), the measured electron density data (upleg and downleg), IRI electron density data and MSIS-E 90 model. A preliminary analysis of Fig. 2-A shows that the calculated emissions have peak emission heights located above the experimental peak. In fact, low F-region is a typical feature on days of no spread-F activity (Muralikrishna and Abdu, 2006). The downleg profile presented appears more realistic considering the smooth profiles of upleg and IRI, while the upleg profile above 280 km is in good agreement with experimental profile.

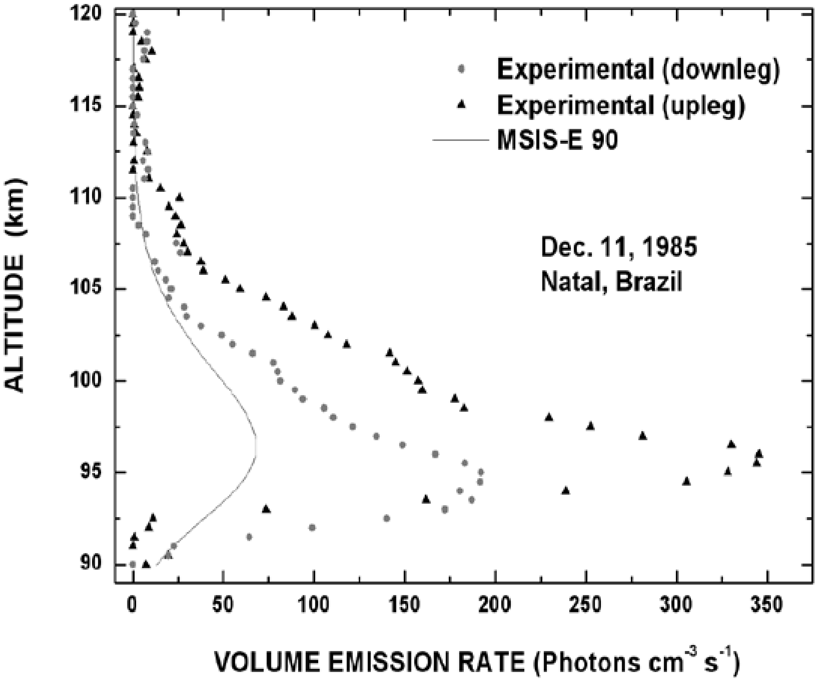

Fig.1. Comparison between OI 557.7 nm green line volume emission rate profiles derived from the experiment conducted in 1985 and calculated by MSIS-E data.

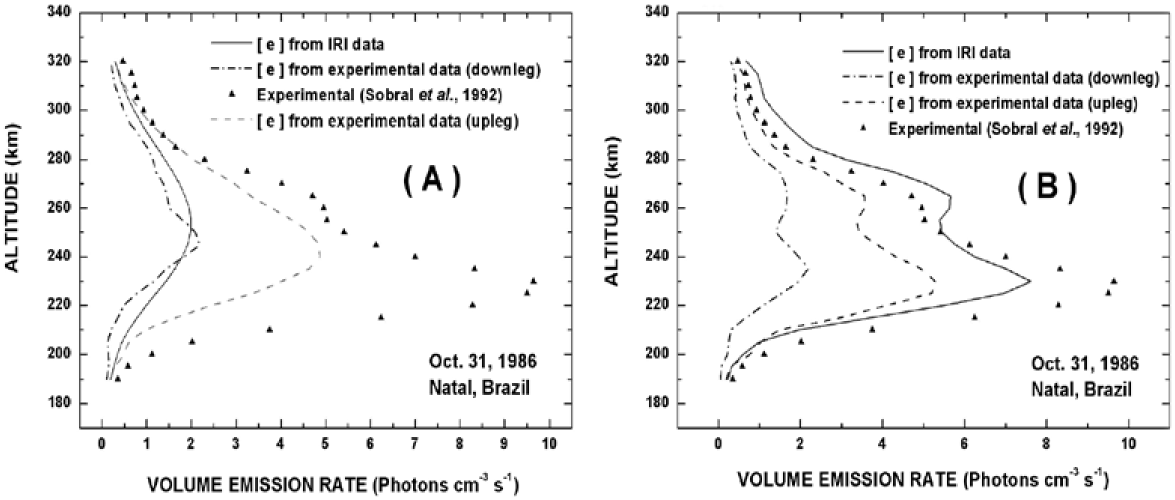

Fig. 2. Comparison between OI 557.7 nm green line volume emission rate profiles derived from the experiment carried out in October 31, 1986 (Sobral *et al*., 1992) and calculated profiles. (A) The theoretical profiles with constant quantum yield f(^1S) = 5.0 x 10^{-2} (Takahashi *et al*., 1990) were evaluated from experimental data of electron density (upleg and downleg) and IRI electron density data. (B) The theoretical profiles with height-dependent profile for f(^1S) obtained from Sobral *et al*. (1992) were also evaluated from experimental data of electron density (upleg and downleg) and IRI electron density data.

The same procedure and inputs were assumed to calculate the theoretical profiles shown in Fig. 2-B, except that the f(^1S) obtained from Sobral *et al* . (1992) is height-dependent. In that figure we can see that the shape of calculated profiles are more similar to experimental profiles than those shown in the Fig. 2-A. It is also interesting to note that the heights of theoretical maximum peaks are in good agreement with the experimental peak. Also here the upleg profile in the Fig. 2-A above 280 km is in excellent concordance with experimental profile.

The Fig. 3 shows a comparison between OI 630 nm volume emission rate profiles calculated by equation (3) and the experimental upleg profile derived from the photometer measurements. The theoretical profiles in the Fig. 3-A were calculated with f(^1D) = 1.2 (Link and Cogger, 1988). Analogously to the above procedure, we also used IRI and experimental electron density data. We can see in Fig.3-A a type of variability similar to the profiles presented in Fig.2-A.

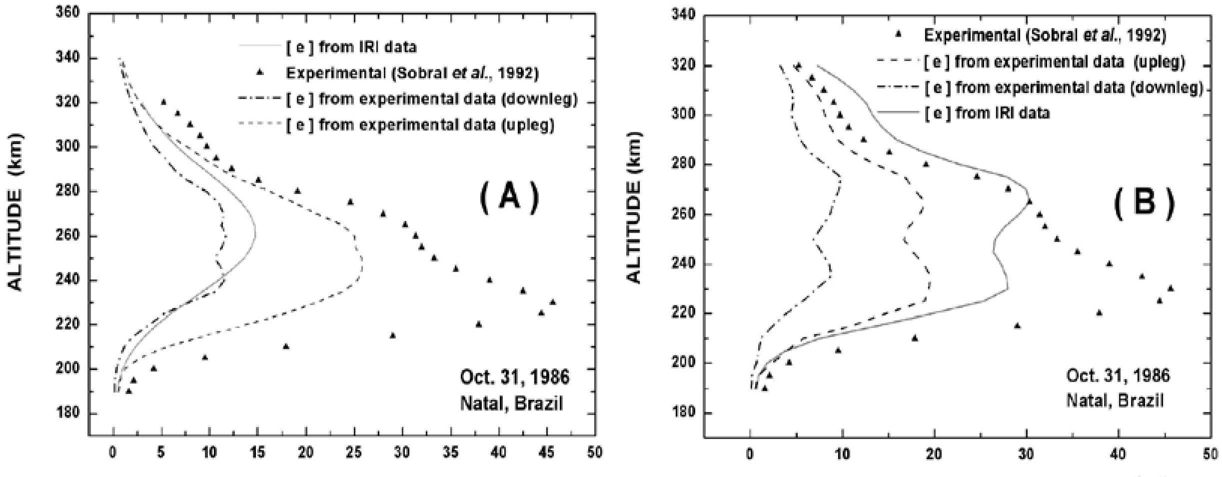

Fig. 3. Comparison between OI 630 nm red line volume emission rate profiles derived from the experiment carried out in October 31, 1986 (Sobral *et al*., 1992) and calculated profiles. (A) The theoretical profiles with constant quantum yield f(^1D) ~ 1.2 (Link and Cogger, 1988) were evaluated from experimental data of electron density (upleg and downleg) and IRI electron density data. (B) The theoretical profiles with height-dependent profile for f(^1D) obtained from Sobral *et al*. (1992) were also evaluated from experimental data of electron density (upleg and downleg) and IRI electron density data.

The emission rate theoretical profiles in Fig.3-B calculated using a height-dependent quantum yield f(^1D) profile (Sobral *et al*., 1992), present shapes more similar to the V_{630} experimental profile than those calculated with a height-independent fixed value of f(^1D).

Conclusions

The comparison between E-region OI 557.7 nm profile calculated and those derived from the December 11, 1985 experiment suggests that in the context of that chosen kinetic model, the neutral constituents profiles from MSIS-E 90 model and coefficients from literature don't provide a good agreement with the experimental profiles.

Also, in the case of F-region, adopting a quenching scheme, profiles of the neutral constituents from MSIS-E 90 model, coefficients and quantum yields from the literature, besides electron density data from either the IRI-2001 or plasma probe measurements, it was possible to calculate vertical profiles of the volume emission rate of the OI 557.7 nm and OI 630 nm emissions to compare with the experimental emission profiles measured on October 31, 1986. With respect to this case, some conclusions may be summarized as follows:

a) The quantum yield values constant with height in the calculation of OI 557.7 nm and OI 630 nm emission profiles, may not be a realistic option;

b) The derivation to calculate the height-dependent quantum yields proposed by Sobral *et al*. (1992), also involves the use of model values, so f(^1S) and f(^1D) profiles must be treated with caution at some height intervals;

c) Calculated emission rate profiles would closely match the measured emission rate profiles through adjustments in the coefficients, quenching scheme, quantum yield values and model data applicable to the equatorial region.

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