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Mesospheric Reduction of the Chemical Heating Rates by Nightglow Emissions at 23^0S and 4^0S

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ABSTRACT

Simultaneous observations of several nightglow emissions have been carried out at Fortaleza (4^0S, 38^0W) and Cachoeira Paulista (23^oS, 45^o W), Brazil, since 1987. Using the OH Meinel (9,4) and O_2 atmospheric b(0,1) bands observed at these two stations during the period from 1987 to 1994, we present and discuss the night-time reduction in chemical heating rates by these mesospheric airglow emissions. The total emission rates of the OH Meinel bands and O_2 atmospheric b(0,0) and O_2 infrared atmospheric ($^1\Delta_g$) bands were calculated using the reported data for the relative band intensities $I(v^{/},v^{//})/I(9,4)$, $I(O_2b(0,0))/I(O_2\ b(0,1))$ and $I(O_2\ (^1\Delta_g))/\ I(O_2b(0,1))$. This study showed that the reduction in chemical heating rates (RCH) by the OH Meinel bands, at both the locations, has seasonal variations with monthly mean values varying from 0.4 K/day* to 0.9 K/day* (where day* means averaged over the night). However, the RCH rates due to the radiation in the Meinel bands at Cachoeira Paulista presented a weak ter-annual variations, whereas at Fortaleza semi-annual variations were observed. Also, the RCH rates by O_2* showed semi-annual variations at both locations, presenting values from 0.05 K/day* to 0.25 K/day*.

INTRODUCTION

During the recent decades airglow intensity variations have been extensively used to study the propagation of waves in the upper atmosphere, such as tides and gravity waves (see e.g., Takahashi et al., 1985; Fagundes et al., 1995). However, the mesospheric airglow emissions are also important sinks of chemical energy. The energy accumulated in chemical form is released primarily through exothermic chemical reactions leading to heating, but if the products formed by the chemical reactions are eletronically or vibrationally excited then a fraction of the chemical energy will be converted into atomic and molecular internal energy and it may be radiated away as photons reducing the amount of energy available for chemical heating. Using the nightglow OH(9,4) and O_2 atmospheric b(0,1) band emission intensities observed at Fortaleza (4^oS, 38^oW) and Cachoeira Paulista (23^oS, 45^o W), Brazil, during the period from 1987 to 1994, we present and discuss in this paper the monthly averaged variations of the night-time reduction in chemical heating rates by these mesospheric airglow emissions.

During the daytime the solar UV radiation gets through the atmosphere and a fraction of this radiation is absorbed by the upper atmosphere, but not all the energy which was absorbed in the upper atmosphere is converted immediately in the atmosphere heating. The solar radiation absorbed in the upper atmosphere is converted into three different forms:(a) translational energy, e.g. heating, (b) chemical potential energy and (c) atomic and molecular internal energy. Since the atmospheric heating is very complicated as it is not a one-step process, to describe the time variation of the temperature it is very useful if it is possible to calculate the flux in each energy channel (thermal, chemical potential, internal, kinetic, radiant, vertical and horizontal transports, conduction, and energy transformation to and from kinetic internal and chemical potential) separately. A detailed about the evaluation of the heating efficiency and kinetic parameters for OH nightglow in the middle atmosphere can be found in Mlynczak and Solomon (1991, 1993) .

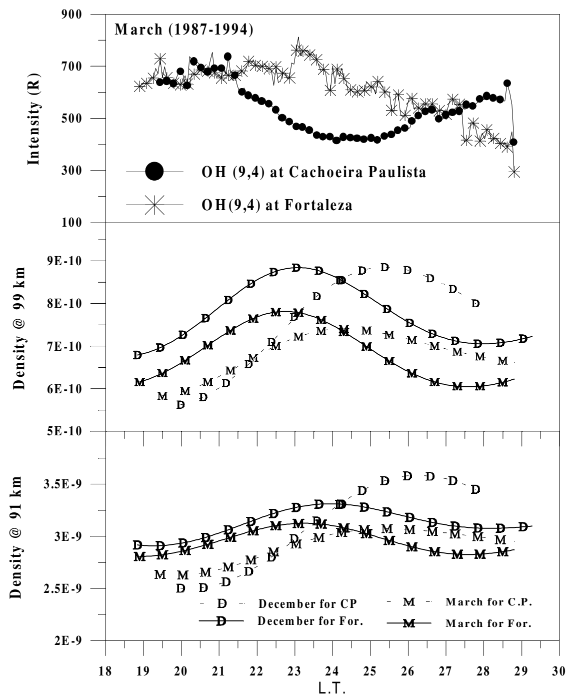

Figure 1- Monthly averaged nocturnal variation of the emisssion OH(9,4) intensities at Cachoeira Paulista (23^0S) and Fortaleza (4^0S) for March (1987-1994) and the neutral densities calculated for March December at 91 and 99 km atitude using MSIS-90

OBSERVATIONS

There are two Brazilian nightglow observatories which have been operating on a routine basis for more than 10 years, one at Cachoeira Paulista (23°S, 45° W) and the other at Fortaleza (4°S, 38°W). Two similar multi-channel tilting filter-type photometers observe the $O_2b(0,1)$ and OH (9,4) band emissions at these observatories. The photometers were constructed at INPE and can measure the zenith intensities of the OI 630.0 nm, OI 557.7 nm, $O_2b(0,1)$, NaD and OH(9,4) emissions and the rotational temperatures of the OH(9,4) and $O_2b(0,1)$ bands. The main characteristics of the photometers which are operating at the Brazilian airglow observatories are described by Takahashi et al. (1989).

The zenith intensities of the $O_2b(0,1)$ and OH(9,4) bands used to infer the mesospheric **RCH** by nightglow were observed between the years 1987 and 1994. Also, to infer the **RCH** as a function of the height, we used a weighting function (α *(z)*) which was calculated from the simultaneous observations of the OH(8,3) and $O_2b(0,0)$ volume emission profiles (for more details see Fagundes et al., 1997).

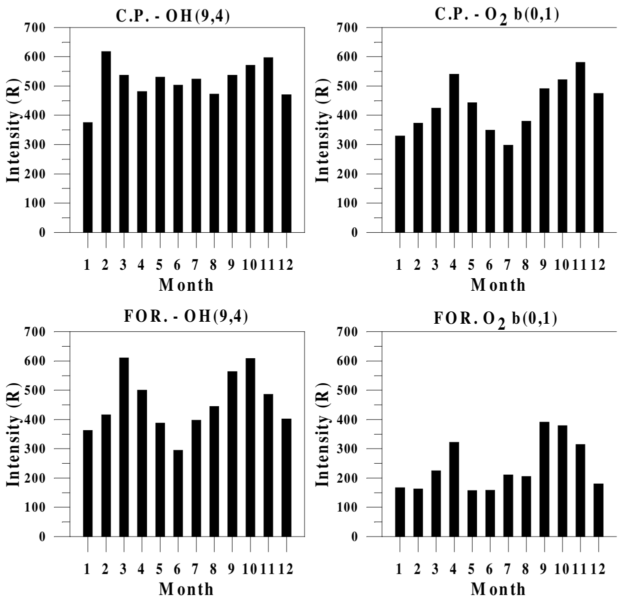

Figure 2 - Monthly means of the OH(9,4) and $O_2b(0,1)$ at Cachoeira Paulista 23^0S and Fortaleza 4^0S.

REDUCTION OF THE CHEMICAL HEATING (RCH) RATES BY NIGHTGLOW

Fagundes et al., (1997) calculated the whole OH Meinel bands intensities using the OH*($v^{/}$,$v^{//}$)/OH(9,4) relative band intensities from Llewellyn et al. (1978). Also single reference wavelengths were used for each rotational band structure (band origin) in order to calculate the energy associated with the photons that comes from the OH Meinel bands (Coxon and Foster, 1982). The whole O_2^* atmospheric bands intensities ($O_2b(0,0)$, $O_2b(0,1)$ and O_2 ($^1\Delta_g$)) were estimated using the results published by Harris (1983), Greer et al. (1986), McDade et al. (1986,1987). In this way, the monthly averaged variations of the OH Meinel and O_2* band intensities were calculated using the observed monthly averaged nocturnal variations of the OH(9,4) and $O_2b(0,1)$ band intensities. Fig. 1 shows the monthly averaged nocturnal variations of the OH(9,4) band for March at Cachoeira Paulista and Fortaleza, respectively (top panel) and nighttime neutral density variations r(z,t) for March and December from MSIS-90 (Hedin, 1991), used in the calculation of the RCH at 91 km and 99 km altitude (middle and lower panels, respectively).

Using thermodynamical principles we can write the mesospheric nightglow contribution to the **RCH** as follows:

$$\frac{dT}{dt} = \frac{1}{C_p \, \rho} Q_{airglow} \qquad (1)$$

where *T* is the temperature, *Cp* is the specific heat at constant pressure, *r* is the bulk neutral density of the atmosphere, *Q* is the energy loss rate by airglow emission ($Q_{Airglow} = -N_f \, h \, c/\lambda$), N_f is the number of photons emitted per second per unit of volume (*Rayleigh*=10^6 *photons* s^{-1} cm^{-2} *per column*), *h* is the Planck's constant [J s], *c* is the speed of the light [m/s.]and λ is the emission wavelength of the band origin [m].

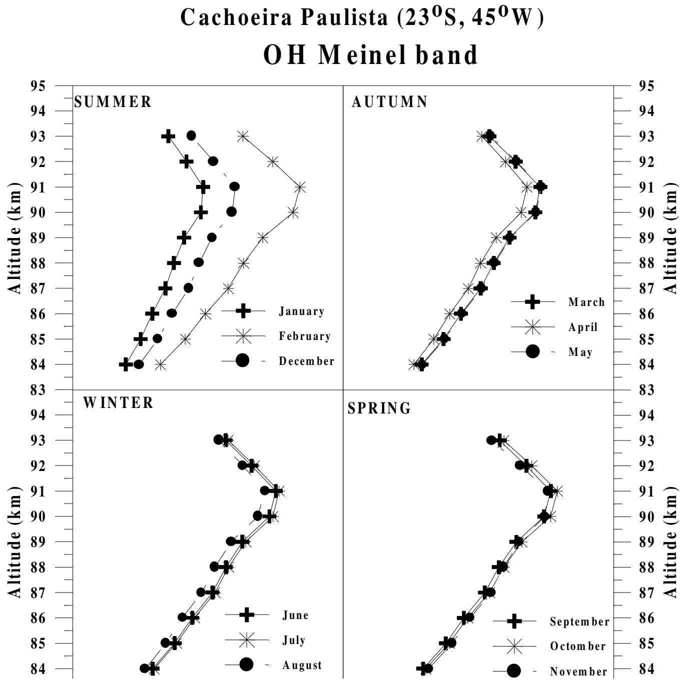

Figure 3 -Seasonal Variations of the reduction in chemical heating rates as a function of the altitude due to the OH Meinel bands at Cachoeira Paulista.

In this paper we followed the same procedure adopted by Fagundes et al. (1997) to calculate $Q_{airglow}$ [Joule/second] as a function of altitude, which is to transform the observed ground-based intensity into volume emission rate profile using a weighting function which was obtained using from the volume emission profile observed by a rocket photometer experiment. The weighting function is given by, $\alpha(z)=I(z)/I(total)$, where *I(z)* is the volume emission rate for 1 km interval in the vertical profile and *I(total)* is the total column volume emission rate of the vertical profile ($\alpha(z)$ from Fagundes et al.,

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1997). Then, the **RCH** by one of the emissions from the mesosphere is given by,

$$\frac{dT}{dt} = -\frac{1}{C_p\,\rho}\,10^7\,\alpha(z)\,\frac{I(t)\,h\,c}{\lambda} \qquad (2)$$

Fagundes et al. (1997) showed that the **RCH** by the OH Meinel band between 84 km to 93 km can be written as follows,

$$\Delta T = -1.68\,x\,10^{-12}\,\alpha_1(z)\int\frac{I_{(9,4)}(t)}{\rho(z,t)}\,dt \qquad (3)$$

where $\alpha_1(z)$ is the weighting function for the OH Meinel band, $I_{(9,4)}\,(t)$ is the observed OH(9,4) emission intensities and $\rho(z,t)$ is the back-ground atmosphere density taken from MSIS-90. Also, Fagundes et al. (1997) showed that the reduction of the chemical heating by O_2* (O_2b(0,1), O_2b(0,0) and O_2 ($^1\Delta_g$)) between 92 km to 101 km is given by,

$$\Delta T = -9.96\,x\,10^{-14}\,\alpha_2(z)\int\frac{I_{o_2b(0,1)}(t)}{\rho(z,t)}\,dt \qquad (4)$$

where $\alpha_2(z)$ is the weighting function for O_2* and $I_{O_2}b(0,1)(t)$ is the observed emission intensity.
Integrating the Equations (3) and (4) with time steps of 5 min using the parameters $\alpha(z)$, neutral densities $\rho(z,t)$ from MSIS-90 (see Fig. 1) and the monthly averaged nocturnal variations $I_{(9,4)}(t)$ and $I_{O_2}b(0,1)(t)$ (see Fig. 1), the **RCH** can be calculated.

RESULTS AND DISCUSSION

The monthly means of the OH(9,4) and O_2b(0,1) bands emission intensities for Cachoeira Paulista and Fortaleza are shown in Fig.2. Notice that the OH(9,4) band monthly mean intensities at the two locations show a similar range of values from about 300 R to 600 R, but present different annual variations. The O_2b(0,1) band monthly mean intensities show a range of values from about 300 R to 600 R for Cachoeira Paulista and 150 R to 350 R for Fortaleza . The OH(9,4) band monthly mean intensities at Fortaleza show a very clear semi-annual variation with maximum in March and October and minimum in December/January and June (Fig 2). At Cachoeira Paulista the OH(9,4) band monthly mean intensities present a ter-annual variation, see the Fig. 2 for more details. The O_2b(0,1) band monthly mean intensities present a very clear and similar semi-annual variation at the two sites, with maxima around the equinox months.Using regular nighttime observations of the OH(9,4) and O_2b(0,1) band emission intensities (Cachoeira Paulista 23^{0}S and Fortaleza 4^{0}S), the observed OH(8,3) and O_2b(0,0) band emission profiles at 2.5^{0}S, the nightime neutral density variations from MSIS-90 and thermodynamical principles were used to calculate the monthly averaged nocturnal mesospheric reduction in chemical heating **(RCH)** rates as a function of height.

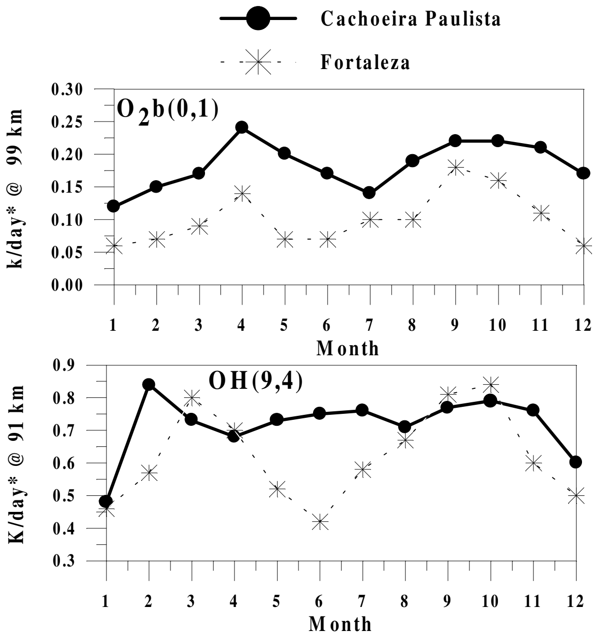

Figure 4- Variations of monthly peak of the reduction in chemical heating rates for OH Meinel and O_2* bands.

Notice that the energy lost by the OH* and O_2* band emissions never enter in the atmospheric heat budget, but affect the chemical heating efficiencies. According to Mlynczak and Solomon (1993) depending on the model used the heating rates due the reaction of H with O_3 at night are from 4 to 6 k/day and 3.7 to 5.5 k/day at around 89 km and 91 km of altitude, respectively. Therefore, chemical heating efficiencies for the reaction [H + O_3 $\rightarrow$ OH + O_2] are about 90%-96% and 86%-88% at around 89 km and 91 km, respectively. Also the heating rates associated with O-atom recombination reached a maximum of 7 K/day (Mlynczak and Solomon,1993). Since the **RCH** by O_2* bands are from 0.1 to 0.18 K/day, then the heating efficiency of the reactions associated with atomic oxygen is about 98%.
In Fig. 3 are shown the monthly behaviours of the **RCH** in K/day* as a function of the height for the OH Meinel at C.P. (where day* means averaged over the night of about 10 hours of observations). Also in Fig. 4 are shown the monthly behaviours of the **RCH** for the OH Meinel bands at 91 km and O_2* bands at 99 km, where the peaks of the **RCH** are located.
The seasonal variations of the **RCH** by OH Meinel bands as a function of the height (84 km to 93 km) for C. P. are shown in Fig. 3 . The **RCH** by the OH Meinel bands for all the seasons and for the two locations show a very similar variation as a function of height. The **RCH** is around 0.2 K/day* at 83 km of height and the value of the **RCH** increases monotonicly with height, reaching the peak at 91 km. Notice in Fig. 3 that the peak values of the **RCH** (91 km of altitude) are from 0.4 K/day* to 0.8 K/day* and depends on the month and location, after that the **RCH** reaches its peak at 91 km, the values of the **RCH** decreases monotonicly.
At Cachoeira Paulista the peak of the **RCH,** which occurs at 91 km of height, presents values larger than 0.65 K/day* for almost the whole year (February to November), but during December-January there is a minimum in the **RCH**. However, it is possible to notice a weak ter-annual seasonal variation of the **RCH** at Cachoeira Paulista (see Fig 4). At Fortaleza a strong semi-annual seasonal variation in the peak of **RCH** is seen, with a maxima in March and October (equinox) of about 0.8 K/day* and a minima in June and January, winter and summer, respectively of about 0.4K/day* (see Fig. 4).

The **RCH** by O_2* bands are about 0.03 K/day* at 92 km of height at the two locations for all the months. However, the **RCH** at Cachoeira Paulista increases faster as a function of height than at Fortaleza and therefore the peak value of the **RCH** which reached at 99 km are larger at Cachoeira Paulista than at Fortaleza.
The peak values of the **RCH** at Cachoeira Paulista presented a semi-annual variation, with a minimum of about 0.1 K/day* during summer and winter and a maximum of about 0.25 K/day* during equinox. At Fortaleza the peak values of the **RCH** also presented a semi-annual variation and its minimum value is around 0.06 K/day*, during summer and winter, and its maximum is around 0.18 K/day* during equinox. However as pointed out before, the **RCH** at Cachoeira Paulista by O_2* is stronger than at Fortaleza.

CONCLUSIONS

Based on 8 years (1987 to 1994) of nightglow (OH(9,4) and O_2b(0,1) bands) observations in the low latitude (Cachoeira Paulista, 23°S) and equatorial (Fortaleza, 4°S) region, the monthly averaged nocturnal variations of the OH(9,4) and O_2b(0,1) emission intensities were calculated. Then using the observed monthly averaged nocturnal variations of the OH(9,4) and O_2b(0,1) bands, the observed volume emission profiles OH(8,3) and O_2b(0,0) bands observed at Alcântara (2°S) and the MSIS-90 model, we calculated the **RCH** as a function of height by the OH Meinel bands (84 km to 93 km) and [O_2b(0,0)+O_2b(0,1)+O2($^1\Delta_g$)] bands (92 km to 101 km) as a function of height at the two location cited above.The main features are summarised below:

a)The **RCH** by the OH Meinel bands showed a weak ter-annual variation at Cachoeira Paulista and a semi-annual variation at Fortaleza. The magnitude of the **RCH** is almost the same during August to April, however during May to July the **RCH** is 30% to 80% stronger at Cachoeira Paulista than at Fortaleza.

b)The **RCH** by [O_2b(0,0)+O_2b(0,1)+O2($^1\Delta_g$)] bands showed a quite similar semi-annual variation both at Cachoeira Paulista and Fortaleza, with maxima during April and September and minima during June. However the **RCH** by O_2* is 40% to 180% stronger at Cachoeira Paulista than at Fortaleza, depending on month.

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