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ScienceDirect
Advances in Space Research 41 (2008) 660–669
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

Measurement of mesopause temperature from hydroxyl nightglow at Kolhapur (16.8°N, 74.2°E), India

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Received 19 July 2006; received in revised form 23 April 2007; accepted 3 May 2007

Abstract

The paper reports the nightglow observations of hydroxyl (8–3), (7–2) and (6–2) Meinel band carried out at a low latitude station Kolhapur (16.8°N, 74.2°E, dip latitude 10.6°N), India during November 2002 to May 2005 with the objective of investigating mesopause dynamics based on derived OH rotational temperature. Overall, 132 nights of quality data were collected using filter-tilting photometer and an all-sky scanning photometer. The mean mesopause temperature observed at Kolhapur is 195 ± 11, 196 ± 9 and 195 ± 7 K from OH (8–3), (7–2) and (6–2) band emissions, respectively, using transition probabilities given by Langhoff et al. [Langhoff, S.R., Werner, H.J., Rosmus, P. Theoretical transition probabilities for the OH Meinel system. Journal of Molecular Spectroscopy 118, 507–529, 1986]. Small wave-like variations (periodicities ~ few hours) existing over long period variations in derived temperatures are also present. A steady decrease of emission intensities from evening to dawn hours has been observed in approximately 59% of nights. No significant change of nightly mean temperatures has been noted. Furthermore, about 62% of observed nightly mean temperatures lie within one error bar of MSISE-90 model predictions.

Keywords: Mesopause; Temperatures; Nightglow

1. Introduction

Hydroxyl emissions are the most dominant of nightglow emissions. These emissions are due to rotational vibrational transitions within ground electronic state $X^2\Pi$ of OH (Meinel, 1950). These emissions originate from a region of mesopause centred around 87 km with a layer width of 8 km (Baker and Stair, 1988). The following exothermic ozone–hydrogen reaction is the primary source of excited OH molecules at mesopause heights during nighttime (Bates and Nicolet, 1950):

$$O_3 + H \rightarrow O_2 + OH + 3.34\text{eV}$$

The energy liberated by this reaction is sufficient to excite the OH molecule as high as ninth vibrational state. The calculations by Mlynczak and Solomon (1993) suggest that about 60% of the energy from this reaction is released as heat and the rest is lost as airglow in mesosphere. The real estimate is still an area of significant research. This reaction is also the largest contributor to the chemical heating of the mesopause (Smith, 2004).

The intensity distribution between various lines in the bands can be effectively used for deriving temperatures near mesospheric heights provided that the excited OH molecules are energetically indistinguishable from the surrounding region. This approach has been extensively used for investigating mesopause region in number of studies (Kvifte, 1961, 1967; Takahashi et al., 1974; Meriwether, 1975; Armstrong, 1975; Myrabo, 1986; Scheer and Reisin, 1990; Takahashi et al., 1992, 1994; Hobbs et al., 1996; Mulligan et al., 1995; Sahai et al., 1996; Greet et al., 1998; Sridharan et al., 1999; French et al., 2000; Innis et al., 2001; Burns et al., 2002; Mukherjee and Parihar, 2004; Phillips et al., 2004).

The OH rotational temperature based studies are of importance because they represent the conditions of the

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0273-1177/$30 © 2008 Published by Elsevier Ltd on behalf of COSPAR.
doi:10.1016/j.asr.2007.05.002

coldest part of the terrestrial atmosphere. Mesopause is the most dynamic, chemically active and radiative region sandwitched between lower thermosphere and the lower atmosphere. The gravity waves, tidal forcings (both lunar and solar) and planetary wave phenomena greatly influence mesospheric processes. These hydroxyl emissions carry signatures of these mesospheric processes. The short as well as long term variabilities exhibited by derived OH rotational temperature greatly facilitate in understanding gravity waves, tides and planetary wave phenomena in mesosphere and lower thermosphere. Moreover, the chemistry of mesopause is controlled significantly by temperature and the chemistry is strongly coupled to dynamics, hence, the dynamics of mesopause can be explored from the exact knowledge of mesopause temperature and its variability (Smith, 2004). The tropospheric warming by enhanced greenhouse effects also influences the cooling of the upper mesosphere (Roble and Dickinson, 1989; Golitsyn et al., 1996; Akmaev and Fomichev, 1998; Olivero and Thomas, 2001). Hence, the ground-based observations of OH Meinel band emissions have been widely used to investigate mesopause dynamics based on rotational temperature measurements.

Herein, OH rotational temperatures – a proxy of mesopause temperature and derived from OH (8–3), (7–2) and (6–2) nightglow observations, from a low latitude station Kolhapur (16.8°N, 74.2°E, dip latitude 10.6°N), India are presented. Temperatures were derived from the pairs of emission intensities using widely used "*ratio approach*". The succeeding section gives the outline of the method of retrieving temperatures from pairs of emission intensities. This report presents nocturnal variation of different emission intensities, and night-to-night variability of nocturnal mean temperature for OH (8–3), OH (7–2) and OH (6–2) band observations. The results of comparison of the nightly average temperature with the predictions of MSISE-90 model (Hedin, 1991) at 87 km altitude above Kolhapur have also been presented. The dependence of nightly mean temperature *F* 10.7 cm solar flux has also been reported. Probably this is the first extensive report of mesopause temperature measurements using OH nightglow from Indian subcontinent.

2. Method of temperature retrieval

Now, the initial population of the excited OH* molecules produced from above mentioned (Section 2) ozone–hydrogen reaction is significantly non-thermal (Charters et al., 1971). The degree of thermalization depends upon the radiative lifetime of excited OH* molecule and its collision frequency. The radiative lifetime of the excited OH* molecules in vibrational state $\upsilon' = 8$, 7 and 6 is of the order of a few milliseconds (Table 1), whereas the collision frequency prevalent at mesopause is $\sim 3 \times 10^4\ \mathrm{s}^{-1}$ (US Standard Atmosphere, 1976). These suggest that the excited OH* molecules in vibrational state $\upsilon' = 8$, 7 and 6 undergo more than 110 number of collisions before radiative de-excitation which is considered far enough for effective thermalization (Sivjee and Hamwey, 1987). Hence, the initial non-thermal distribution of OH rotational states can be assumed to obey Boltzmann distribution and the rotational temperature determined spectroscopically from the rotational line intensity can be taken to be ambient temperature of mesopause.

Table 1
Lifetime of different vibrationally excited OH molecules (based on Turnbull and Lowe, 1989) and minimum number of collisions suffered before radiative de-excitation (Collision frequency at 87 km $\sim 3 \times 10^4\ \mathrm{s}^{-1}$, US Standard Atmosphere (1976))

Vibrationally excited state	Radiative lifetime (ms)	Collision frequency (s^{-1})	Minimum collisions suffered before radiative de-excitation
$\upsilon' = 8$	3.85–6.3	3×10^4	115
$\upsilon' = 7$	4.69–7.9	3×10^4	140
$\upsilon' = 6$	6.01–10.3	3×10^4	180

Following Mies (1974), the photon intensity of a particular rotational line for such a thermalized distribution is given by following expression,

$$I(J'', \upsilon'' \leftarrow J', \upsilon') = N_{\upsilon'} \bar{A}(J'', \upsilon'' \leftarrow J', \upsilon') \times \frac{2(2J'+1)}{Q_{\upsilon'}(T_{\mathrm{rot}})} \times \mathrm{e}^{-\frac{E_{\upsilon'}(J')}{kT_{\mathrm{rot}}}} \tag{1}$$

And following Herzberg (1950), the relative intensity of a rotational component with wavelength λ for such a thermalized distribution is given by,

$$I(J') = (constant) S(J', J'') \lambda^{-3} \mathrm{e}^{-\frac{E_{\upsilon'}(J')}{kT_{\mathrm{rot}}}} \tag{2}$$

where J', J'' are rotational quantum numbers (single primed quantities represent upper state and double primed ones the lower state); υ', υ'' are vibrational quantum numbers; $N_{\upsilon'}$ is the total concentration of the molecules in upper vibrational state; $[\bar{A}](J'', \upsilon'' \leftarrow J', \upsilon')$ is Einstein transition probability for indicated transition; $S(J', J'')$ is the line strength for the indicated transition; $E_{\upsilon'}$ (J') is the upper state term value; k is Boltzmann constant; T_{rot} is the rotational temperature; $Q_{\upsilon'}$ (T_{rot}) is the partition function of the upper vibrational state.

Using Eq. (1) or (2), OH rotational temperatures for a particular Meinel band can be derived either from the ratio of line to line intensity approach or from line to branch intensity approach. In present study, OH (8–3) and OH (6–2) rotational temperatures have been derived from the ratio of emission intensity of P_1 (2) to P_1 (4) line of the respective Meinel band system using Eq. (1), where as, OH (7–2) rotational temperatures have been derived from the ratio of P_1 (3) line intensity to integrated R – branch emission intensity using Eq. (2). The transition probabilities given by Langhoff et al. (1986) have been used. French et al. (2000) and Phillips et al. (2004) have reported that the transition probabilities given by Langhoff et al. (1986) are the closest to the experimentally determined values. In a private communication, Prof. French (Australian Antarctic