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SEASONAL VARIATIONS OF CHARACTERISTICS OF THE HYDROXYL AIRGLOW

V.V. Bakanas, and V.I. Perminov *(Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Pyzhevsky 3, Moscow 119017, Russia, e-mail: meso@ifaran.ru)*

Abstract. Observations of hydroxyl emission bands in the near infrared range 0.77-1.04 μm were performed at Zvenigorod Observatory (56N, 37E), Russia, during the period of 2000-2001. Analysis of the observed emission intensities and rotational temperatures revealed a dependence of the amplitudes and phases of their seasonal variations on the hydroxyl vibration level *v*.

Introduction

In atmospheric investigations the ground-based observations of the hydroxyl airglow have been used when exploring temperature, dynamics and gas components in the mesopause region (Ulwick et al., 1987; Schubert et al, 1990; Semenov, 2000). Analysis of OH airglow characteristic variations, based on the data reported through the last decades, was performed by Semenov and Shefov (1999). In the present study, new ground-based observations of the intensity and rotational temperature of the hydroxyl airglow with different vibration excitation are presented. The observations have been conducted at the Zvenigorod Observatory (56N, 37E) during the period of 2000-2001. Some features in the seasonal behavior of the hydroxyl characteristics are discussed.

Observations

Night airglow in the near infrared range 0.77-1.04 μm is observed at Zvenigorod Observatory by a spectrograph equipped with a high-sensitive CCD-camera. A description of the instrumentation, spectrum and processing technique has been given by Semenov et al. (2002). The records of the airglow spectrum are corrected to the spectral sensitivity of the instrumentation. The absolute calibration of intensity of the spectral lines has been performed with the radiation source, which, in turn, was calibrated on the radiation spectrum of the Capella (α Aur) star. Observations of the airglow were typically performed during clear weather. Signal accumulation time was 10 minutes. This provided a good accuracy for determination of the intensity of the emission lines and rotational temperature. The error in evaluating intensities of most emission lines was 1-3 %. The error in the measurements of the rotational temperature did not exceed 3 K.

Analysis and discussion

We analyzed reduced to the midnight (i.e. averaged over the time interval from ~ 23 h 30 min to 0 h 30 min of the local time) observations of the OH emission bands (3-0), (4-1), (6-2), (7-3) and (9-4). It is necessary to maintain uniform sampling through the seasons. In the period close to summer solstice only 1 hour of observation is possible at the latitude of 56N.

To determine the rotational temperatures, P1-branch lines of the (3-0), (6-2) and (9-4) bands were used. The procedure of rotational temperature deriving is analogous to that applied by Shefov (1961), Turnbull and Lowe (1983) and Hecht et al. (1987). In the present study the rotation-vibration transition probabilities were taken as in the work of Langhoff et al. (1986). Using the measured rotational temperature and intensity of one of the first two lines of the P1-branch of a band, it is possible to determine the total intensity of a band (Piterskaya and Shefov, 1975).

Observations of OH band intensities for 88 nights of 2000-2001 are shown in Figure 1. To reveal seasonal variations the data on intensity of each band have been fitted a function of two cosinusoids with the periods of 365.25 and 182.625 days by the least square technique. The characteristics of the calculated seasonal variations are presented in Table 1. Also shown in the Table are standard deviations corresponding to the 68 % confidence interval. One can see that the main features in the seasonal variations are as follows.

(1) For higher vibration levels ($v \geq 6$), the amplitudes of the annual harmonics (approximately 20 % of the corresponding mean annual intensities) can exceed by factor 3 those of the semi-annual harmonics. For lower levels ($v \leq 5$) the amplitudes of the annual and semi-annual harmonics are close to each other (10 to 13 % of the mean annual intensities).

(2) Maximum phase of the annual harmonic at all vibration levels is around winter solstice. However, the annual variations of the emission intensity from higher vibration levels lead those from lower ones, the phase shift being 33 days in the case of the ninth and third vibration levels. Maximum phases of the semi-annual harmonics are close to summer and winter solstices. The phase dependence on a vibration level is rather vague.

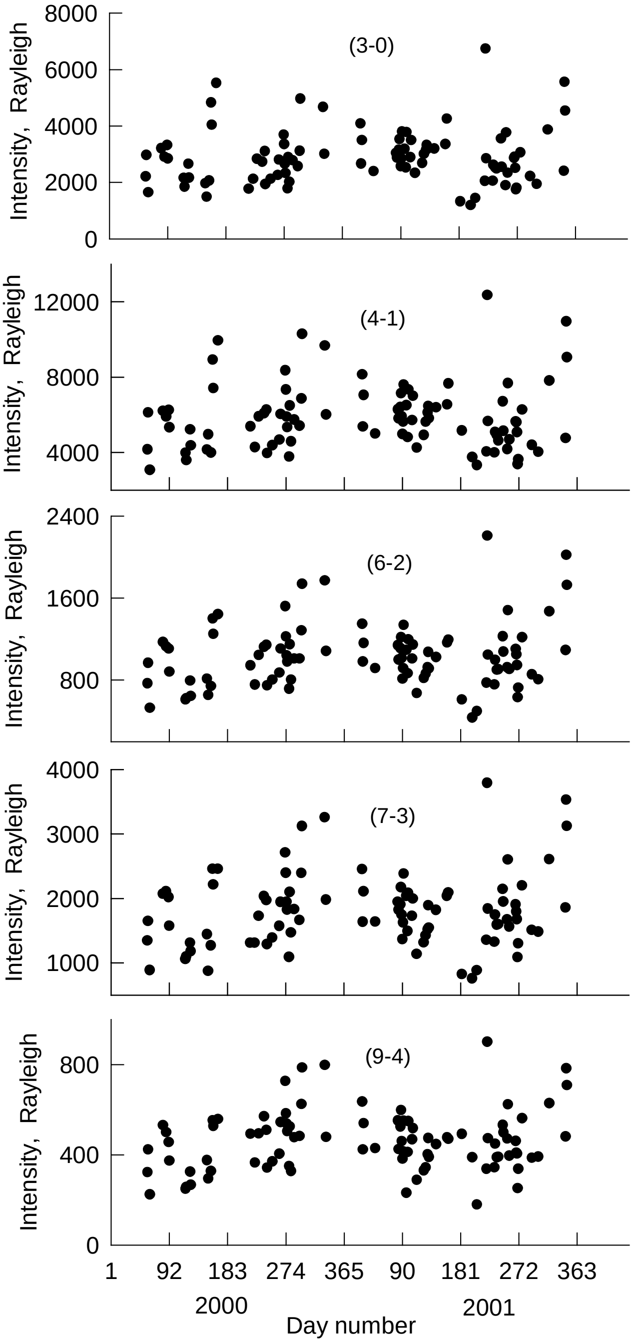

Fig. 1. Intensities of the hydroxyl bands observed during 2000-2001.

In Fig. 1 one can see considerable high-frequency oscillations, which are probably due to planetary waves with periods from 2 to 28 days. In our case of the limited number of observation nights, they can mask seasonal variations and complicate revealing of their characteristics.

Rotational temperature. Figure 2 shows the rotational temperatures corresponding to the third, sixth and ninth vibration levels. The characteristics of the seasonal variations derived by the least square fitting the sum of two cosinusoids with the periods of 365.25 and 182.625 days to the temperature data are given in Table 2. The temperature variations reproduced on the basis of these characteristics are shown by the lines in Figure 2. From Table 2 it is seen that the phases of annual variation maxima are close to winter solstice. The character of the phase dependence on the vibration level is similar to that for the intensity. Moreover, there exists a phase dependence of the semi-annual harmonic of the seasonal temperature variations on the vibration level. The semi-annual variations of rotational temperatures for lower vibration levels lead those for higher vibration level.

It should be noted, that though the mean annual temperatures derived for different vibration levels are close (from 199 to 202 K), the difference between rotational temperatures of the molecules OH with higher and lower vibration excitations can be significant in some periods. This is because of the phase shift in the seasonal variations and difference in the amplitudes of the variations (see Table 2). Thus from the end of June to the beginning of July, September through October and in January the temperature difference between the third and ninth vibration levels is 10 to 16 K. The difference between the temperatures through the year can be described more exactly by the relation

$$\Delta T_{6v} = A_0 + A_1 \cos [2\pi (d - C_1) / 365.25] + A_2 \cos [2\pi (d - C_2) / 182.625] \qquad (1)$$

where ΔT_{6v} is the difference between the temperatures corresponding to the sixth and v vibration levels,

$$A_0 = - 0.24 v^2 + 3.02 v - 9.55 \qquad (2)$$

$$A_1 = 0.89 v^2 - 10 v + 27.81 \qquad (3)$$

$$A_2 = 0.62 v^2 - 6.81 v + 18.51 \qquad (4)$$

$$C_1 = 12.8 v - 68.5 \qquad (5)$$

$$C_2 = - 19 v + 182 \qquad (6)$$

Relation (1) and coefficients (2)-(6) were obtained by the least square fitting of the temperature differences shown in Figure 2.

It would be difficult to explain the dependence of the characteristics of variations in the emission intensity and rotational temperature of hydroxyl on its vibration level without considering the height shift of the layers of emissions with different vibration levels of OH. The models of hydroxyl emission excitation give a height shift between the

Table 1. Characteristics of seasonal variations of the hydroxyl band intensities

OH band, (v′-v″)	Mean annual intensity, Rayleigh	Amplitude of annual variation, Rayleigh	Maximum phase of annual variation, day number	Amplitude of semi-annual variation, Rayleigh	Maximum phase of semi-annual variation, day number
(9-4)	470±10	95±15	335±7	30±10	167±9 350±9
(7-3)	1840±40	360±60	341±6	120±45	155±11 338±11
(6-2)	1060±20	180±35	341±7	70±25	157±10 340±10
(4-1)	6050±130	800±200	356±8	600±150	157±6 340±6
(3-0)	2950±70	360±100	3±11	300±85	156±7 339±7

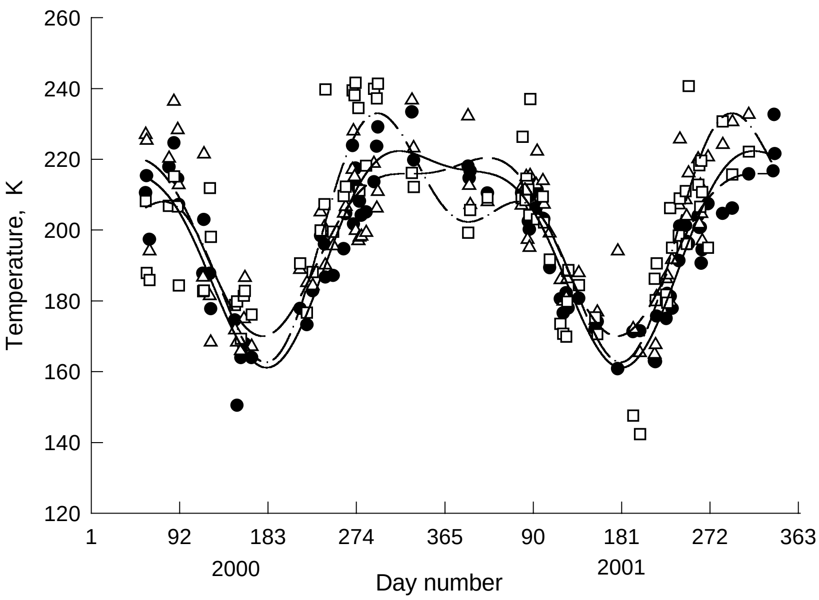

Fig. 2. Rotational temperatures observed and reconstructed of the bands (3-0) (triangles, dash line), (6-2) (closed circles, solid line) and (9-4) (squares, dash-dot line).

upper and lower emission layers ~2 to 3 km (McDade, 1991; Perminov et al., 1993; Makhlouf et al., 1995). The rocket measurements show a more significant height shift of 5 km (Lopez-Moreno et al., 1987). Lidar observations of temperature suggest an essential height dependence of the amplitudes and phases of the seasonal variations in the region of 80 to 100 km (She and von Zahn, 1998). These features imply that the dependence of the characteristics of variations in the emission intensity and rotational temperature of hydroxyl on its vibration level is probably due to the height shift of the OH emission layers and height dependence of the seasonal atmospheric dynamics.

Table 2. Characteristics of seasonal variations of rotational temperatures of hydroxyl

Vibrational level	Mean annual temperature, K	Amplitude of annual variation, K	Maximum phase of annual variation, day number	Amplitude of semi-annual variation, K	Maximum phase of semi-annual variation, day number
3	202±1	23±2	363±2	8±1	81±4 264±4
6	199±1	29±1	358±1	9±1	93±2 276±2
9	201±1	24±2	337±3	17±2	97±2 280±2

Conclusion

The spectrographic observations of the hydroxyl emission bands in the spectral range of 0.77-1.04 μ were performed at mid-latitudinal observatory Zvenigorod in the period of 2000-2001. Based on these observations, seasonal variations in the OH intensities and rotational temperatures were obtained. The main feature of these variations is dependence of their amplitudes and phases on hydroxyl vibration level excitation, which can be interpreted in terms of the height shift of the hydroxyl emission layers and height dependence of seasonal atmospheric dynamics.

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References

Hecht, J. H., R. L. Walterscheid, G. G. Sivjee, A. B. Christensen, and J. B. Pranke, Observations of wave-driven fluctuations of OH nightglow emission from Sondre Stromfjord, Greenland, *J. Geophys. Res*., 92, 6091-6099, 1987.
Langhoff, S. R., H.-J. Werner, and P. Rosmus, Theoretical transition probabilities for the OH Meinel system, *J. Mol. Spectr.*, 118, 507-529, 1986.
Lopez-Moreno, J. J., R. Rodrigo, F. Moreno, M. Lopez-Puertas, and A. Molina, Altitude distribution of vibrationally excited states of atmospheric hydroxyl at levels v=2 to v=7, *Planet. Space Sci.*, 35, 1029-1038, 1987.
Makhlouf, U. B., R. H. Picard, and J. R. Winick, Photochemical-dynamical modeling of the measured response of airglow to gravity waves. 1. Basic model for OH airglow, *J. Geophys. Res.,* 100, 11289-11311, 1995.
McDade, I. C., The altitude dependence of the OH($X^2\Pi$) vibrational distribution in the nightglow: some model expectations, *Planet. Space Sci.*, 39, 1049-1058, 1991.
Perminov, V. I., A. I. Semenov, N. N. Shefov, and V.V. Tikhonova, Estimates of seasonal variations in the altitude of the emitting hydroxyl layer, *Geomagn. Aeron.*, 33(3), 364-369, 1993.
Piterskaya N. A., and N. N. Shefov, Intensity distribution of the OH rotation-vibration bands, in *Aurorae and Airglow*, edited by V. I. Krassovsky, Publishing House “Nauka”, Moscow, No. 23, 69-122, 1975.
Semenov, A. I., and N. N. Shefov, Empirical model of hydroxyl emission variations, *Int. J. Geom. Aeron.*, 3(1), 229-242, 1999.
Semenov, A. I., Long-term temperature trends for different seasons by hydroxyl emission, *Physics and chemistry of the Earth*, 25, 525-529, 2000.
Semenov, A. I., V. V. Bakanas, V. I. Perminov, Yu. A. Zheleznov, and V. Yu. Khomich, The near infrared spectrum of the emission of the nighttime upper atmosphere of the Earth, *Geomagn. Aeron.*, 42, 390-397, 2002.
Schubert, G., R. L. Walterscheid, J. H. Hecht, and G. G. Sivjee, Temperature gradients at mesopause heights inferred from OH nightglow data, *J. Geophys. Res.*, 95, 19061-19067, 1990.
She, C. Y., and U. von Zahn, Concept of a two-level mesopause: support through new lidar observations, *J. Geophys. Res.*, 103, 5855-5863, 1998.
Shefov, N. N., On determination of the rotational temperature of the OH bands, in *Spectral, Electrophotometrical and Radar Researches of Aurorae and Airglow*, edited by V. I. Krassovsky, Publishing House of the Academy of Sciences of the USSR, Moscow, No. 5, 5-9, 1961.
Turnbull, D. N., and R. P. Lowe, Vibrational population distribution in the hydroxyl night airglow, *Can. J. Phys*., 61, 244-250, 1983.
Ulwick, J. C., K. D. Baker, D. J. Baker, A. J. Steed, W. R. Pendleton, K. Grossmann, and H. G. Bruckelmann, Mesospheric minor species determinations from rocket and ground-based i.r. measurements, *J. Atmos. Terr. Phys.*, 49, 855-862, 1987.