Proc. Indian Acad. Sci. (Earth Planet. Sci.), Vol. 89, Number 1, March 1980, pp. 109–114.

Experimental evidence of gravity waves at 80–90 km altitude from OH night airglow observations

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MS received 19 September 1978; revised 20 December 1979

Abstract. Measurements of intensities at two fixed wavelengths in the OH (7–2) band were carried out at Mt Abu (24·6° N, 76·7° E) from 1973–76 to estimate neutral temperature in the region of 80–90 km altitude. It was observed that on some nights the temperature in this region shows periodic oscillations throughout the night. It was found from statistical analysis that the periods of these fluctuations are comparable to the theoretically predicted periods of internal gravity waves.

If the periodic temperature variations observed in this region are attributed to the influence of gravity waves, according to the Hines theory only the magnitude of the horizontal component of wave-induced wind velocity can be computed. Using the measured relative temperature fluctuations it is found that the magnitude is 15–30 m/sec.

Keywords. Mesospheric temperature; gravity waves; OH airglow; airglow photometry.

1. Introduction

For computation of the temperature of OH emitting layer, we have used a new method in which the ratio of the intensity of one of the rotational lines to that of total R branch of OH rotational vibration band is used. The method and experimental set up are described in detail in a previous paper (Majmudar and Kulkarni 1975).

For the estimation of temperature in the 80–90 km altitude region, OH (7–2) band in nightglow emission is chosen, as it is not contaminated by other radiations, its P branch is well resolved and Q and R branches are well separated from P branch. The intensities of $P_1(3)$ line ($\lambda = 6922 \cdot 8$ Å) and the total R branch ($\lambda = 6838$ Å) of OH (7–2) band were monitored from Mt Abu (26·4° N, 72·7° E) with photoelectric filter photometer at the interval of 5 min on several clear nights in three years, 1973–76. Thus the ratio $I(P_1(3))/I(\Sigma R)$ is measured experimentally. This ratio is also calculated theoretically at different temperatures from synthetic spectrum of OH (7–2) band. The experimentally obtained ratio is compared with that obtained theoretically and thus the temperature is determined. The accuracy of temperature measurement is about 5%.

2. Error estimation in temperature determination

Temperature is estimated from the ratio of two intensity measurements mentioned earlier. The possible errors in the measurements of intensities of ΣR branch and the $P_1(3)$ line are mainly due to (i) the transmission weighing of the filters, (ii) the reading accuracy of the recorded deflections (essentially signal-to-noise ratio on the record) and (iii) the errors in the absolute calibration of the photometer with a ^{14}C secondary standard of photometry which include (a) long term variation of the source and (b) its change in radiance with temperature. The above points were considered for error estimation.

3. Selection of data

For the study of the nocturnal variation in temperature, we had chosen the nights on which observations were available for more than 6 hr. Thus about 85 nights were available for analysis. Observations were taken on moonless and cloudless clear nights.

It was observed from analysis of the data that though on many nights the temperature remained constant or had different trends in nocturnal variation, on about 33% of total number of nights, the variation in temperature shows the periodic oscillations. In this paper, only these results are discussed.

4. Results

For analysis of periodic oscillations, the nights on which the observations showed *a priori* oscillations on visual inspection were chosen. Harmonic analysis was carried out to get the rough estimate of the frequencies present in data. This was obtained by estimating the coefficients A_0, A_m and B_m in the following equation:

$$Y_{(t)} = A_0 + 2\sum_{m=1}^{N-1} A_m \cos 2\pi\, mft + \sum_{m=1}^{N-1} B_m \sin 2\pi\, mft, \tag{1}$$

where $Y_{(t)}$ is the signal at time t, f is the frequency and N is the total number of data points. The amplitude of variation in percentage was calculated from A_m and B_m. The frequencies were chosen in such a way that corresponding to these frequencies more than 5% of variation is obtained. Using initial values of A_0, A_m and B_m corresponding to these frequencies a nonlinear regression model was fitted to get the best value of parameters. Afterwards linear regression model and t test were used to test the significance of the parameters and hence the corresponding frequencies of the temperature fluctuations were determined. Calculations turn out to be quite lengthy, therefore a detailed study of only 9 nights was undertaken. The sampling interval for analysis of periodic fluctuations in temperature is 5 min so it is impossible to detect periods less than 10 min. Periods of 10 to 400 min were found to be present in temperature fluctuations. Results of 9 nights are summarised in table 1.

Table 1. Periodicities for fluctuations in temperature.

Date	Periods in minutes
31–10–1975	10, 235
2–12–1975	120, 213, 281
4–12–1975	112, 145, 230
30–12–1975	213
4–01–1976	38, 41, 48, 106, 114, 154
27–01–1976	12, 91, 370
4–02–1976	46, 90, 106, 145
28–04–1976	13, 112, 152
29–04–1976	46, 58, 110

These nights are further classified in three groups according to the periodicities in fluctuations.

(i) long periodicity of the order of 4 to 6 hr,

(ii) short periodicity of the order of 10 to 120 min.

(iii) both long and short periods present.

Through experience, to some extent, one can identify nights on which periodicities are likely to emerge. On detailed harmonically statistical analysis of the data periodicities are found in some nights. Figures 1, 2 and 3 show the temperature data of the nights on which long, short and long with short periodicities appeared.

Hines (1960) predicted 10 to 200 min periods for IG waves in the 90 km region. Various investigators measured the temperature in this region by using the airglow technique. It may be noted that except for Rai and Fejer (1971) all these observations were at middle to high latitudes (more than 45° from the equator). Krassovsky (1972) and Shagaev (1974) measured the intensity of a few lines of the P branch of OH (4–1) band in three different sections of the sky with the help of a spectrograph. Meriwether (1975) measured the intensity of two P_1 lines of OH (8–3) band with a photometer for the estimation of temperature. The measurement of intensity was carried out by using a tilting filter technique. Armstrong (1975) estimated the temperature from measurements of the intensities of four P_1 lines of OH (6–1) band by Ebert–Fastie spectrometer. All these investigators observed periodic fluctuations in temperature during some nights. The periods reported by them are in the range of 5 to 200 min. Rai and Fejer (1971) inferred the period of 200 min in temperature fluctuation from a rocket experiment. They used the grenade rocket technique. Recently Manson and Meek (1976) reported that the IG waves with periods greater than 2 hr are detected at this altitude range. These results are obtained from the extensive analysis of radiometeor data.

Our results at tropical latitudes closely resemble to those reported by other investigators as stated above. It may be concluded that the periodic fluctuations observed in temperature are possibly due to the passage of gravity waves through the mesopause region.

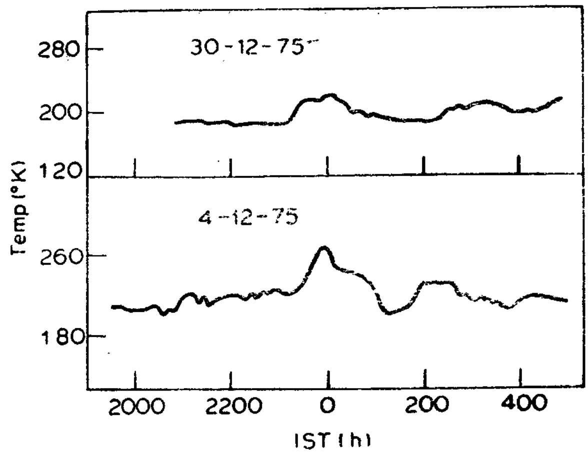

Figure 1. Long periodicity (≈ 4 hr) in temperature fluctuations.

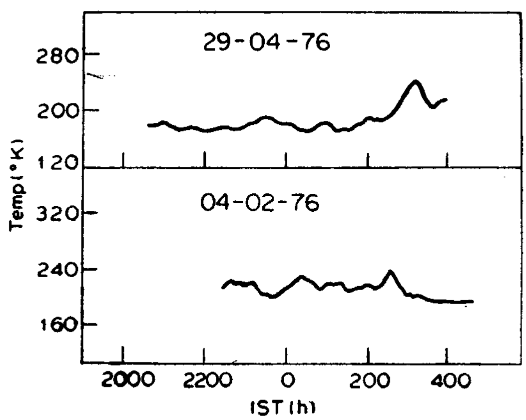

Figure 2. Short periodicity (≈ 10 to 120 min) in temperature fluctuations during two typical nights.

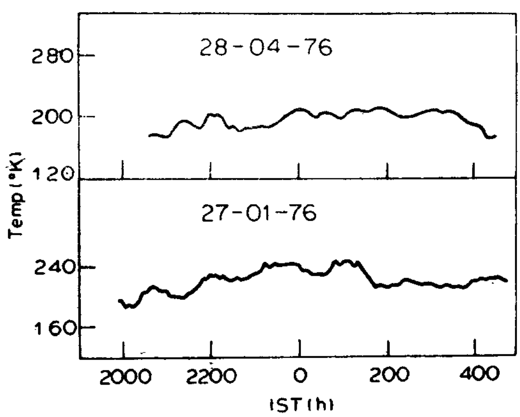

Figure 3. Short and long periodicity in temperature fluctuations during two typical nights.

5. Computation of horizontal component by wave-induced wind velocity

Hines (1965) postulated that in the 80–100 km region reversible adiabatic heating is produced which could be exhibited as a fluctuation in temperature. The fractional variations in temperature ($\triangle T/T$) are related to U_s, the wave-induced horizontal component of neutral wind speed by

$$\triangle T/T = \pm\, i\,(\gamma - 1)^{1/2}\ C^{-1}\, U_s, \tag{2}$$

where i indicates a phase quadrature between the time or place of maximum in T and U_s, while the plus or minus uncertainty can be eliminated if the horizontal direction of phase propagation is known in relation to direction of U_s. γ is the ratio of specific heats and C is the velocity of sound. $\triangle T$ is measured relative to the night-time mean temperature. It is reasonable to assume γ and C as constant parameters in 80–100 km region for estimation of U_s from the measured values for $\triangle T/T$.

As the term i in equation (2) implies, each harmonic component of gravity wave wind field is in quadrature with the corresponding periodic fluctuations in $\triangle T/T$ and it is not possible to eliminate the additional uncertainty in phase and direction of U_s with respect to $\triangle T$ from the present data. Only the magnitude of U_s in equation (2) corresponding to the dominant periodic component of fluctuations in temperature is inferred by using the amplitude obtained from our measured temperature. The dominant period is inferred by using fast fourier transform (FFT) technique. On many occasions, our results show the amplitude of about 10° to 15° K and the magnitude of U_s corresponding to this amplitude is found to be about 15 to 25 m/sec. The results in detail for two typical nights are presented in table 2.

Rai and Fejer (1971) at Natal–Brazil (6° S) have reported the average variations in temperature of the order of 50° K in the 95 km region. The magnitude of the horizontal component of wave velocity calculated by us from observed fluctuations in temperature is smaller by a factor of two to three compared to the measured value of wind velocity given by Rai and Fejer. The fluctuation in temperature observed by them is also larger than what we have observed on an average.

Kochanski (1964) at 38° N latitude reported the value of U_x equal to 40 m/sec at 95 km from his " sodium cloud " experiment during twilight. He has shown that the U_s in 80–100 km region increases from 20 m/sec to 50 m/sec with height.

Table 2. Magnitude of the horizontal component of wave induced wind velocity from the observed temperature fluctuations in the mesosphere.

Date	Average temperature T(° K)	Dominant period (minutes)	Amplitude ΔT(° K)	U_s m/sec (magnitude)
30–12–1975	198	213	15	25
17– 1–1976	219	91	9	14

Recently, Moreels and Herse (1977) photographed OH nightglow in the near infrared and found two regular wave systems moving with horizontal velocity of 15 to 20 m/sec.

From the analysis of periodic oscillations in temperature and comparison of our results with others, it is clear that internal gravity waves exist at an altitude 80–90 km region and on many occasions affect the mesospheric temperature. However, it is difficult to predict the propagation of IG waves at the mesopause region from these observations.

6. Conclusions

(i) Temperature in 80–90 km region does not always remain constant as depicted by models during a night, but shows different types of variations.

(ii) Fluctuations in temperature are observed on some nights and the periods of fluctuations are found to be in the range of 10 to 400 minutes.

(iii) It is pointed out that the periodic fluctuations observed in temperature are possibly due to the passage of gravity waves through the mesospheric region.

(iv) From the measured variation in temperature corresponding dominant periodic components of fluctuation are determined. The amplitudes of dominant component of 10° K to 15° K give the magnitude of horizontal wind component from 15 to 25 m/sec in the 90 km region.

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