Amplitudes and phases of the diurnal and semidiurnal tide observed in mesospheric OH(3, 1) emissions over Maynooth, Ireland

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ABSTRACT

Spectra of the mesospheric OH(3,1) emission have been recorded by an FTIR spectrometer at Maynooth (53.2°N, 6.4°W), Ireland on all suitable nights during the period December 1992 to July 1995. A total of 370 nights observations have been obtained. Each spectrum is acquired in a 5 minute integration period, and has been analysed to yield a value of rotational temperature and brightness associated with the (3,1) band. Each of these measurements has been normalised to the mean value for the particular night on which it was recorded in an effort to extract the amplitude and phase of the variations. The normalised data have been binned at half-hourly intervals for each month so as to minimise the contribution to the variations from gravity waves and short period planetary scale oscillations. Harmonic analysis has been performed to determine an amplitude and a phase of both the diurnal and semidiurnal oscillations for each month in the period under study. The results of this investigation are presented and they are compared with the predictions of the theoretical model of Forbes and Gillette.[1]

Keywords: mesosphere, atmospheric tides, hydroxyl emissions, ground-based observations.

1. INTRODUCTION

Ground-based observations of airglow emissions have long been used to study temperature and density variations produced by atmospheric tides.[2, 3, 4] The bands of emission lines from the hydroxyl radical discovered by Meinel[5, 6] over half a century ago are among the most frequently used for this purpose. These bands emanate from a broad layer (half-width 6-10 km) centred on an altitude of 87 km[7]. The brightness of these bands in the near infrared combined with improvements in Fourier transform spectroscopy over the past few years has enabled observers to derive rotational temperatures from recorded spectra with uncertainties less than 3 K using integration times less than 5 minutes. Such measurements made in Ireland during the period from December 1992 until July 1995 have been used in this study to examine the influence of tides on the atmospheric temperature in the region close to the mesopause. These results are compared with the predictions of the model of Forbes and Gillette[1] at 54° N and 87 km in altitude. This was also the model selected by Hecht *et al.*[8] for comparison with temperature measurements from the $O_2(0,1)$ Atmospheric band and the OH Meinel (6,2) band made during the ALOHA-93 campaign.

2. MEASUREMENTS AND ANALYSIS

Good quality infrared spectra in the range 1.0 -1.6 μm were acquired with a Bomem FTIR infrared spectrometer on 370 nights in the period December 1992 to July 1995 at Maynooth (53.2°N, 6.4°W), Ireland. Each integration period was of 5 minutes duration. Sample spectra of the OH(3,1) and OH(4,2) bands recorded by the spectrometer are shown in Mulligan *et al.*[9] Here the $P_1(2)$, $P_1(3)$ and $P_1(4)$ lines of the OH(3,1) band were used to determine a rotational temperature and the integrated brightness of the entire band following the method outlined by Sivjee and Hamwey[10]. All of the measurements recorded in a given night were used to determine the mean temperature for that night, taking account of the uncertainty on each observation. Each measurement was then normalised to the mean for its own particular night. The normalised values for each month were then binned into half-hourly intervals to reduce the influence of gravity-waves and other planetary wave disturbances. Fig. 1a. shows the result of this process for December 1992. There is a fairly obvious sinusoid present in the temperature data, with a minimum around 2130 UT and a maximum near 0200 UT; this variation with local time has been reported by several observers in the past.[2, 11]

Since the length of the data record is much less than 24 hours, we attempted to estimate the temperature variation resulting from tides by fitting the data using a non-linear least squares fitting technique with both a 24-hour and a 12-hour sinusoid as follows:

$$\begin{aligned} T = 1 + a_{24}\cos(2\pi t/24) + b_{24}\sin(2\pi t/24) \\ + a_{12}\cos(2\pi t/12) + b_{12}\sin(2\pi t/12) \end{aligned} \tag{1}$$

where T is the normalised temperature and t is the universal time in hours. The amplitude of each harmonic is determined from $(a^2+b^2)^{1/2}$, while the phase is given by $\tan^{-1}(b/a)$. The resulting best fit curve is shown in Fig. 1a. together with the predictions of the model of Forbes and Gillette[1] for December solstice at 54° N and 87 km in altitude. It can be seen that the variation predicted by the model is in-phase with the measurements, but the amplitude of the observations is more than twice the model prediction. A possible explanation for this discrepancy might be that the model assumes average solar activity conditions, whereas December 1992 is only a short time after the maximum of solar cycle 22.

Lowe[11] compared monthly averaged rotational temperatures derived from OH emissions, similar to those presented in this paper, with the altitude of peak emission of the OH layer obtained from data recorded by the WINDII instrument onboard the UARS satellite. His results consistently showed that a decrease in temperature coincided with an increase in the height of the peak of the OH layer; a 1 km change in the peak height corresponded approximately to a temperature change of 9K. Lowe interpreted these results as being suggestive of a raising and lowering of the height of the OH layer in response to tidal forcing.

Fig. 1b. shows the equivalent data for February 1994. Also shown in this figure is the model prediction for equinox conditions. It might be expected that February would be more closely represented by equinox conditions, but is more accurately represented by solstice predictions on this occasion. This general pattern of a pre-midnight maximum followed by a minimum in the post-midnight period is maintained during the months January to May. The short length of the data record for June and July make it difficult to discern any particular pattern.

From August onwards a new pattern emerges which is at its most well developed in October. Fig. 1c shows the situation for October 1993: the phase of the sinusoid-like variation has changed from its December value so that the maximum now occurs near 2200 with the minimum appearing after 0300 UT. This behaviour is not well represented in the model by either solstice or equinox predictions. The November data show a recovery towards the pattern shown in Fig. 1a and Fig. 1b, and by December the pattern has re-established itself completely. The data for 1994 and 1995 show a similar behaviour and encourage us to believe that the changes described are sustained from year to year.

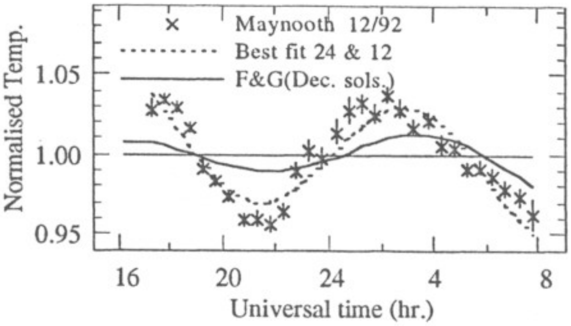

Fig. 1a. Normalised temperatures (x - Dec. 1992 at Maynooth; dotted line - best 24 and 12 hour fit to data; solid line - Forbes and Gillette (1982) for December solstice).

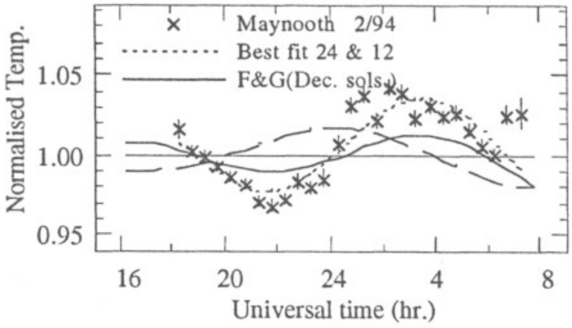

Fig. 1b. Normalised temperatures (x - Feb. 1994 at Maynooth; dotted line - best 24 and 12 hour fit to data; solid line - Forbes and Gillette (1982) for December solstice; long dash - F&G (1982) for equinox).

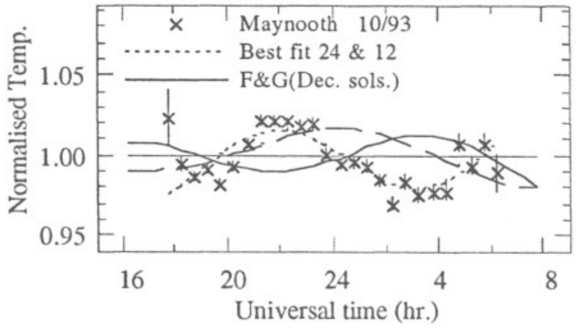

Fig. 1c. Normalised temperatures (x - Oct. 1993 at Maynooth; dotted line - best 24 and 12 hour fit to data; solid line - Forbes and Gillette (1982) for December solstice; long dash - F&G (1982) for equinox).

The procedure described in the foregoing paragraph has been repeated for each month during the period December 1992 to July 1995. We found that fitting a 24-hour plus 12-hour period to the data for the months April through August produced very large uncertainties in the fitted parameters because of the rather short length of the data record for these months at 54° N. We therefore present results only for the months September through March. Fig. 2a. shows the amplitude of the diurnal variation derived in this analysis for each of the months in question. Also shown in this figure are the predictions of the model of Forbes and Gillette[1] at the equinoxes and at December solstice.

The model predicts very little variation between equinox and solstice conditions. The mean amplitude of the diurnal variation calculated over all the months in this figure is 2.95 K which is in very good agreement with the model prediction. Fig. 2b. shows a similar plot for the amplitude of the semidiurnal variation. The model predicts a larger amplitude for winter solstice than at equinox; this pattern is observed in the winter of 1992/93 and 1994/95, but the opposite behaviour has been found in the winter of 1993/94. Generally the model predictions and measurements are in reasonable agreement, although the measurements suggest that the seasonal amplitude modulation is larger than in the model.

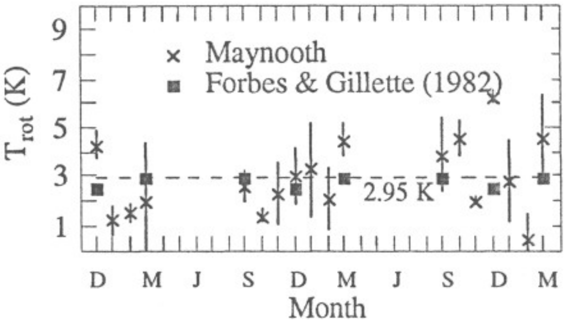

Fig. 2a. Amplitude of diurnal tide observed in OH(3,1) rotational temperatures (12/92 - 3/95). The dashed line is the mean value measured in this study.

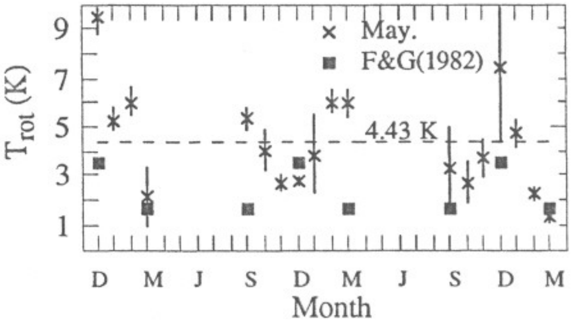

Fig. 2b. As in Fig. 2a. but for semidiurnal tide.

Fig. 3a and Fig. 3b show the predictions of the model and the measurements of the phase of both the diurnal and semidiurnal variation respectively. Very little variation is expected for the phase of the diurnal oscillation, but the measurements show considerable variation in this quantity. No consistent pattern is evident in the results; a steady slippage occurs in the phase from +6 hours in December 1992 to -6 hours in March 1993, whereas a steady advance of the phase takes place from -11 hours in September 1993 to +4 hours in March 1994. The variation in the phase of the semidiurnal oscillation does slightly better in this regard; equinox phase values tend to be positive, whereas winter solstice tends to have negative phases in agreement with the model predictions. Once again the model appears to underestimate the strength of the seasonal modulation of the phase as measured by the OH temperature results.

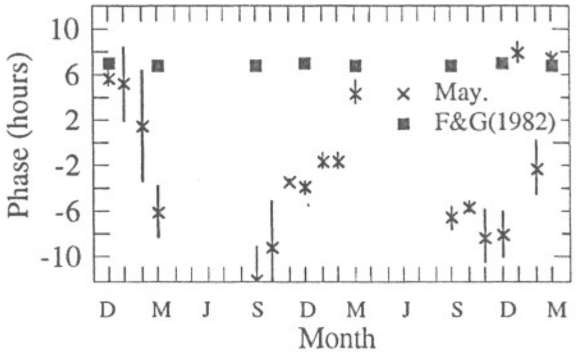

Fig. 3a. Phase of diurnal tide observed in OH(3,1) rotational temperatures at Maynooth (12/92 - 3/95).

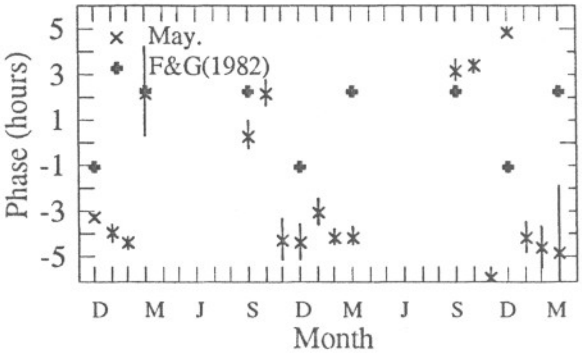

Fig. 3b. As in Fig. 3a. but for semidiurnal tide.

3. CONCLUSION

The model of Forbes and Gillette[1] predicts the correct behaviour of the amplitude of the diurnal temperature variation at 87 km and 54° N as measured by the OH emissions recorded at Maynooth. The amplitude of the semidiurnal temperature variation shows some correspondence with the Maynooth measurements, but the winter solstice value in the model may be too low. The model predictions for the phase variation of the semidiurnal oscillation in temperature show some correspondence with the observations, but the phase variation of the diurnal component is dramatically different from the approximately constant value predicted by the model. It will be necessary to examine a much longer data record to determine the seasonal variation of the phase with any significant degree of confidence.

4. ACKNOWLEDGEMENT

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