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A SEARCH FOR EVIDENCE OF TIDAL ACTIVITY IN OH(3, 1) AIRGLOW EMISSIONS RECORDED AT MAYNOOTH (53.23° N, 6.35° W)

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ABSTRACT

Spectra of the Meinel hydroxyl emissions in the wavelength range 1.0-1.6 μm, which originate at altitudes close to the mesopause, have been obtained, using a Fourier transform spectrometer at Maynooth (53.23°N, 6.35°W), Ireland, on all suitable nights during the period December 1992 to July 1995. Rotational temperatures and integrated band intensities have been calculated from the spectra of the OH (3, 1) vibrational band. These data have been analysed for evidence of tidal activity. Our results show a post sunset increase in the emission brightness throughout the year; over 70% of the time this is followed by a decline to a midnight minimum, after which the emission rate recovers to a secondary maximum in the early morning. The months of September and October show a completely different pattern with the intensity and temperature data showing a pre-midnight maximum followed by a steady decline until dawn. A cross-correlation of the intensity and temperature data reveals a periodic variation with a period in the range 8-12 hours for all months.

INTRODUCTION

It is now well known that atmospheric tides are the result of thermal forcing, due in large measure to the absorption of solar ultraviolet radiation by water vapour in the troposphere and absorption of extreme ultraviolet by ozone near the stratopause and lower mesosphere, in contrast to ocean tides which are the result of gravitational forcing (Lindzen, 1990). These tides are responsible for transporting energy upwards to the upper mesosphere and thermosphere where the waves break and dissipate their energy. Ground-based observations of airglow emissions have long been used to study temperature and density variations produced by atmospheric tides (e.g., Petitdidier and Teitelbaum 1977; Takahashi *et al.*, 1984; Myrabø and Harang, 1988 and references therein), even though these measurements can be adversely affected by the presence of thin clouds (Lowe and Turnbull, 1995). The emissions of atomic and molecular oxygen (557.7 nm, and Herzberg bands), sodium and hydroxyl (Meinel bands) are among the most frequently used for this purpose. Airglow fluctuations are due mainly to fluctuations in the number densities of the species that react to produce excited states. Temperature fluctuations are also important in part because the reaction rates depend on temperature. In this study we use variations in airglow brightness recorded in Ireland in the period from December 1992 until July 1995 to examine the influence of atmospheric tides on the concentration of vibrationally excited OH species.

OBSERVATIONS

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 (53.23°N, 6.35°W), Ireland. Sample spectra of the OH(3, 1) and OH(4, 2) bands recorded by the spectrometer are shown by Mulligan *et al.* (1995). In this study, 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 (1987). Each integration period was of 5 minutes duration. The mean value of temperature and intensity were determined for each night, taking into account the uncertainty on each individual measurement. All of the measurements for a particular night were then normalised to the mean for that night and were binned into half-hourly intervals averaged over an entire month in an effort to reduce the effect of fluctuations caused by gravity-wave and other planetary scale disturbances. Figure 1a shows the monthly averaged nocturnal variation in brightness of the OH(3, 1) band at half-hourly intervals for December 1992. Supporting evidence is available in the form of the corresponding variation in the rotational temperature derived from this band. A substantial increase in intensity occurs shortly after sunset and is followed by a steady decrease to a minimum near midnight. The brightness of the band then recovers to its mean value over the next four hours, after which it begins to decay again before sunrise. Data for all months show an increase in the intensity of the band immediately after sunset and is thought to be due mainly to increasing concentrations of ozone in the absence of photolysis. At night, in the absence of photolysis of O_2 and H_2O, odd oxygen and odd hydrogen must decrease, giving rise to a steady decrease of OH emission during the night as frequently observed (Battaner and López-Moreno, 1979).

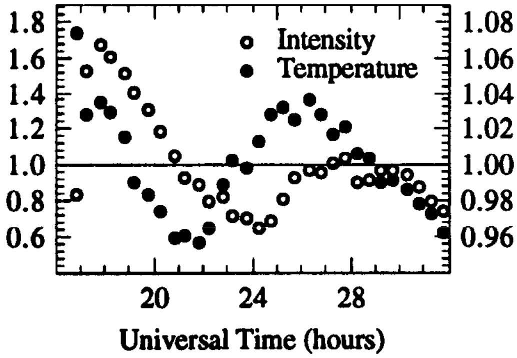

Fig. 1a. Nocturnal intensity and temperature variations normalised to mean value for December 1992. Sunset occurs shortly after 16 UT over the entire month.

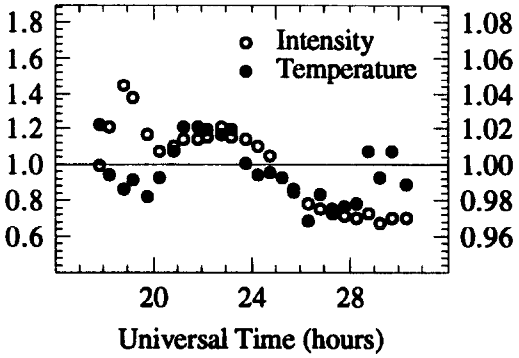

Fig. 1b. Nocturnal intensity and temperature variations normalised to mean value for October 1993. Sunset times: 18.8 UT at the beginning of the month; 17 UT at the end.

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, e.g., Petitdidier and Teitelbaum (1977) and Lowe (1995). The intensity data shows a similar sinusoid with a phase lag of about 2 hours, but it appears to be superimposed on a decline. This is similar to the diurnal variation reported by Takahashi *et al.* (1977) in OH(8, 3) emissions recorded at 23°S, in which the most frequently observed intensity variation was a midnight minimum. The amplitude of our OH intensity variations is much greater (a factor of between 6 and 8 being typical) than the temperature changes in our data.

This general pattern of a midnight minimum followed by an increase in the post-midnight period in both intensity and temperature data 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, but the data tend to show an increase in intensity following midnight. Density and temperature perturbations (Takahashi *et al.*, 1977) and variations in eddy diffusion (Moreels *et al.*, 1977), resulting from todal wave energy input, have been advanced as possible explanations for the increase in OH brightness following midnight. From August onwards a new pattern emerges which has its maximum development in October. Figure 1b shows the corresponding intensity and temperature variations for October 1993: the phase of the sinusoid-like intensity variation has changed from its December value so that the maximum now occurs near 2300 with the minimum appearing after 0400 UT. The temperature variation has also undergone a phase shift and is now approximately in-phase with the intensity variation. Data for November shows a recovery towards the pattern shown in Figure 1a and by December the pattern has re-established itself completely. This general trend in the annual behaviour of the diurnal variation is maintained throughout the period under study here.

ANALYSIS AND DISCUSSION

Lowe (1995) 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 1km 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. Lowe *et al.* (1995) have shown that the decay of the hydroxyl after sunset occurs first at the bottom side of the atomic oxygen profile, and progresses upward in altitude. This results in an increase in the mean emission altitude of the OH, and a corresponding change in the temperature derived from the OH according to the shape of the temperature profile. One might therefore expect radiance changes associated with the post-twilight decay of OH to correlate with temperature changes according to the temperature gradient in the vicinity of the mesopause. The October data presented in Figure 1b shows a rapid rise in temperature at the end of the night that is not accompanied by any increase in radiance, despite the fact that the radiance and temperature fluctuations are in phase near mid-night. This temperature rise may be the result of the mean OH emission height moving through a minimum that is located at a lower altitude in October than in December. Shepherd *et al.* (1995) found a similar correspondence between the O(^{1}S) 557.7 nm airglow emission rate and the mean height of the emission layer at the geographic equator from WINDII data. The strong dependence on local time led Shepherd *et al.* (1995) to conclude that the effect is tidally driven.

We have employed the cross-correlation technique described by Sivjee *et al.* (1987) in an effort to identify periodic variations that are present in both the intensity and temperature data for each month. Figures 2a is a plot of the square of the amplitude of the cross-spectral density as a function of frequency for December 1992. A large peak is present at a frequency of 0.1 per hour corresponding to a 10-hour period. The corresponding plot for October 1993 shown in Figure 2b also shows a dominant peak at a period commensurate with a semidiurnal tide, but the limited length of the dataset precludes the identification of the actual period. These plots are typical of the results of the cross-correlation analysis for all months.

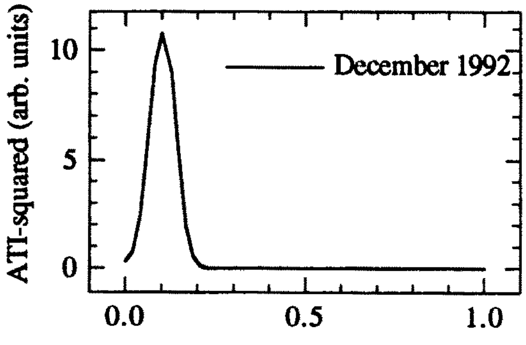

Fig. 2a. The square of the amplitude of the cross-spectral density versus frequency for December 1992.

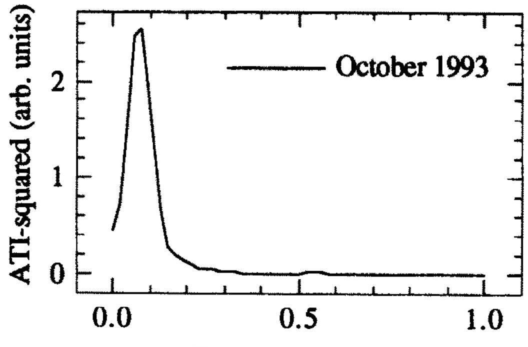

Fig. 2b. The square of the amplitude of the cross-spectral density versus frequency for October 1993.

Krassovsky's ratio, η_E, defined as, $(\Delta I/\bar{I})/(\Delta T/\bar{T})$, where $\bar{I}$ and $\bar{T}$ represent the mean value of intensity and temperature respectively and ΔI and ΔT represent deviations from the mean, provides a quantitative measure of the effect of tides and gravity waves on OH nightglow. We have calculated values of η_E for four months centred on the winter solstice, and in all cases values are in the range 6-10, while the phase angle showed no apparent trend. These results are in reasonable agreement with values reported by Viereck and Deehr (1989) for gravity waves with periods of the order of 12 hours. Walterscheid and Schubert (1995) have determined values of η_E for a suite of tidal modes and for travelling planetary waves by applying the theory of tidally driven fluctuations in the OH airglow, generalised to account for emission from an extended layer, to airglow fluctuations due to both migrating and zonally symmetric tides and free travelling planetary (Rossby) waves. Their calculations suggest that the variations observed at Maynooth are the result of zonally symmetric tides with periods of 12 hours or less.

In conclusion, our study of the OH(3, 1) data has shown that (1) monthly averaged values of the integrated band brightness at half-hourly intervals show periodic variations with periods in the range 8-12 hours which suggest that the source of these variations may be tidal in origin; (2) the predominant pattern is a post-sunset increase in intensity followed by a decrease to a midnight minimum, after which a recovery to a secondary maximum occurs in the early morning; (3) rotational temperatures calculated from this band show similar variations with a phase lead of 1-2 hours over intensity variations during most months; (4) the pattern for September and October shows a pre-midnight maximum in intensity followed by a steady decline following midnight: temperature and intensity variations appear to be in-phase during these months; (5) the pattern is repeated on an annual cycle basis over the period of this study; (6) the amplitude of the intensity variations is consistently 6-8 times larger than the temperature variations.

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