J. Astron. Space Sci. 18(1), 21-26 (2001)

STUDIES OF GRAVITY WAVES USING MICHELSON INTERFEROMETER MEASUREMENTS OF OH (3-1) BANDS

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(Received April 9, 2001; Accepted May 8, 2001)

ABSTRACT

As part of a long-term program for polar upper atmospheric studies, temperatures and intensities of the OH (3-1) bands were derived from spectrometric observations of airglow emissions over King Sejong station (62.22° S, 301.25° E). These measurements were made with a Michelson interferometer to cover wavelength regions between 1000 nm and 2000 nm. A spectral analysis was performed to individual nights of data to acquire information on the waves in the upper mesosphere/lower thermosphere. It is assumed that the measured fluctuations in the intensity and temperature of the OH (3-1) airglow were caused by gravity waves propagating through the emission layer. Correlation of intensity and temperature variation revealed oscillations with periods ranging from 2 to 9 hours. We also calculated Krassovsky's parameter and compared with published values.

Key words: airglow, gravity wave, michelson interferometer

1. INTRODUCTION

Various optical remote sensing programs have been conducted to obtain an understandings of the energetics and dynamics of the Mesosphere and Lower Thermosphere (MLT) between 50 to about 200 km. Proposed spacecraft missions such as NASA-TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) is one of these programs aimed to improve our knowledge on the upper atmosphere. There are several reasons that this research is important to society beyond the importance of pure scientific interest. Most satellite operating organizations often require accurate specification of the space environment for use in satellite drag calculations. Variance of the space environment caused by solar variability and internal gravity waves and tides at altitudes below 200 km can directly and indirectly affect orbiting space objects. Many aspects of mission planning, lifetime prediction, design, control, tracking, on-board fuel requirements, re-entry, and collision avoidance rely on knowledge of the upper atmosphere and its response to external forcing such as waves and tides. For example, it has been documented that large waves propagating from the lower atmosphere have directly affected Space Shuttle re-entry (Killeen et al. 1991).

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It is also important that the effect of increasing greenhouse gases such as CO_2 from human activities could result in a significant modification of the MLT environment. It has been hypothesized that the increased upper atmospheric CO_2 levels could cool the region by increasing the amount of 15 μm radiation to space. Furthermore, enhanced tropospheric disturbances might lead to a measurable increase in wave activity that could alter eddy diffusion as high as the thermosphere, thus increasing thermal conductivity and further cooling the MLT. The most important mechanism of energy gain and loss in the MLT region are; absorption of solar UV, exothermic chemical reactions, radiative cooling, adiabatic expansion and compression, wave breaking and tidal dissipation, airglow emission, and Joule heating. Typically, downward energy transport is negligible, but even a small fluxes of upward propagating waves have profound effects on the MLT. Large amounts of energy are deposited by waves and tides which dissipate and break in the region. These waves also greatly influence the composition of the region. It is known that the overall latitudinally dependent temperature distribution in the middle atmosphere arise from the balance between the net radiative effects and the local temperature changes produced by dynamics (Andrews et al. 1987). However, near the mesopause, waves and tides are known to induce substantial departures from this balance. The Earth's airglow layers have been extensively used as a tool to study the upper atmosphere both from the ground and space. The atmospheric emission reflects the density, temperature, and velocity of the atmosphere at the peak altitude of the layer and it is possible to determine geophysical parameters using the airglow emission. In particular, OH Meinel layer has been used to study atmospheric waves and tides in the MLT. Rocket-born observations of individual OH vibrational-rotational bands identified its peak altitude at 87$\pm$3 km (Baker & Stair 1988). The distribution of rotational lines within a band is expected to represent the kinetic temperature of the gas because rotational relaxation is sufficiently rapid in this region.

The Polar Sciences Laboratory, KORDI has installed and run a Michelson interferometer at King Sejong Station (KSS) as a part of upper atmospheric research program. Preliminary results from measurements at KSS were analyzed and reported (Won et al. 1999, 2001). In this paper, we present characteristics of gravity waves over KSS by performing a spectral analysis to individual nights of data.

2. BACKGROUNDS

2.1 Gravity Waves

The gravity waves are produced by the opposing action of gravitational and pressure forces on a parcel of air which has been displaced from equilibrium in the vertical direction. Consider the motion of a parcel of air in such a region after it has been displaced upward from its equilibrium position. Finding itself denser than its surroundings, it decelerates, and sinks back to its equilibrium level, and overshoots, whereupon it finds itself warmer and lighter than its surroundings, so that it decelerates, and so on. In this way, it finds itself in oscillation about its equilibrium position.

Gravity waves are known to be important because of their ability to allow one region of the atmosphere to influence other regions by transporting energy and momentum from lower regions to the upper atmosphere (Hines 1960). Gravity waves represent only a minor component of the motion in the lower atmosphere. Above 75 km, however, atmospheric motion is probably dominated by gravity waves. Tidal oscillations are a special case of gravity waves having a particular horizontal scale and a particular period. Sources of gravity-wave excitation are numerous and varied. The gravity waves may be generated by airflow over irregular and unevenly heated topography. In addition, gravity waves are generated in the auroral zone by the heat and momentum input associated with variations in energetic particle precipitation. Taylor et al. (1994) observed gravity wave fluctuation from a severe thunderstorm in the troposphere.

The response of the airglow emissions to the passage of gravity waves has been the subject of numerous studies. Krassovsky (1972) first established a link between rotational temperatures, observed hydroxyl intensity and the propagation of gravity waves through the emission layers. Walterscheid et al. (1987) combined simple chemistry and dynamics to model the wave-driven fluctuations in the OH nightglow and calculated the relative amplitudes and phases between the fluctuations in temperature and brightness as functions of wave period and the effect that changes in the scale height of oxygen and horizontal wavelengths would have on these parameters.

The correlation between the intensity and temperature measurements of the hydroxyl airglow, caused by adiabatic compression and rarefication of air in the mesopause can be described by Krassovsky's ratio (Krassovsky 1972);

$$|\eta| = \frac{(\Delta I/\bar{I})}{(\Delta T/\bar{T})} \qquad (1)$$

and its phase ϕ by the relative phase of the fractional brightness and temperature oscillations. Here, ΔI is the nightglow brightness variation and ΔT is the variation in the ambient average temperature of the emission layer. The value of $|\eta|$, is a complex quantity and is frequency dependent (Schubert & Walterscheid 1988). It also depends on the height of the emission layer and on the local scale height, H, of atomic oxygen around the peak in the OH emission layer (Tarasick & Hines 1990).

2.2 Spectral Analysis

For a qualitative analysis of the presence of correlative waves, we performed a spectral analysis. The detailed procedures are based on Sivjee et al. (1987). Before calculating the power spectrum, smoothing must be done to get rid of spurious power which may be caused by the "unbalanced" ends of the real, finite data set. A 10% cosine taper was applied to the beginning and ends of the data set for this reason. Auto-covariance function was then calculated (Jenkins & Watts 1968) using a Tukey spectral window. The Fourier transform of auto-covariance function yields power spectral density of either intensity (C_{II}) or temperature (C_{TT}). The amplitude (A_I, A_T) of power spectrum is proportional to the square root of the power spectral density. It is necessary to look for the presence of correlated waves in the intensity and temperature data because gravity waves induce intensity and temperature oscillations simultaneously. The measure of the correlation between intensity and temperature waves can be obtained by calculating the squared coherency spectrum, ${K_{TI}}^2$ as

$${K_{TI}}^2 = {A_{TI}}^2/(C_{II}C_{TT}) \qquad (2)$$

where ${A_{TI}}^2$ is the square of cross-density amplitude. The squared coherency varies between 0 and 1. Based on the discussion by Bloomfield (1976) and Jenkins & Watts (1968), the definition of Krassovsky's ration, $|\eta|$ may be most accurately calculated as:

$$|\eta| = \frac{A_{TI}}{C_{TT}}\frac{\bar{I}}{\bar{T}} \qquad (3)$$

The quantity A_{TI}/C_{TT} is known as the gain estimate. The phase estimate and its standard deviations are determined from equations (9.3.11) and (10.4.4) of Jenkins and Watts (1968).

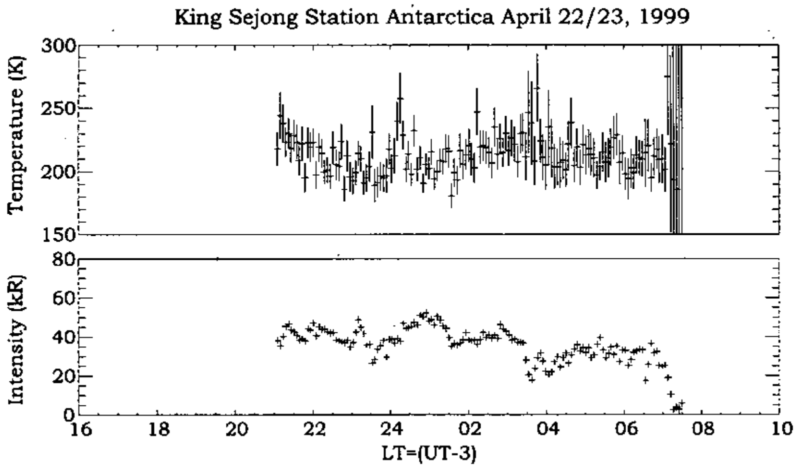

Figure 1. A plot of rotational temperatures and airglow intensities measured on the night of April 22, 1999 with error bars (statistical uncertainties) superimposed.

3. RESULTS

The Michelson interferometer was installed at KSS in February 1999, and has been in routine operation, making zenith measurements of Meinel OH (3-1) band. An intensive operational effort has been made between April and June, 1999 with the observations only limited by the weather condition. The location of KSS is near 62° S where night time is still shorter than 24 hour polar night. Therefore, it is easier to observe short-period waves than longer period oscillations. One sample result from our MI is shown in Fig. 1, a composite plot of the rotational temperatures and intensities of OH (3,1) on the night of April 22, 1999. The vertical lines represent uncertainties, indicating the passage of cloud during the time of observation near 03 UT and 06:30 UT and after 10 UT. Despite the span of cloud cover from time to time, a visible peak-to-peak change of the variation in both temperature and intensity is seen from the figure. These variations suggest the modulation of OH chemical and dynamical processes around the mesopause where the peak emission occurs. In order to quantify the frequency content, we have performed power spectral analysis of temperature and intensity on the data shown in Fig. 1. Before applying a spectral analysis, however, we eliminated those data during periods of cloud cover, then averaged the remaining data in 30-minute interval. By doing the 30-minute interval average, we could fill the gap resulted from the filtering process, hence make the data evenly spaced.

Fig. 2 shows the power spectrum of temperature smoothed by a Tukey window. A large and distinct peak occurs around the 8-hr period and an another peak appears in the shorter period as well. For a qualitative analysis of the presence of correlative waves, the squared coherency spectrum is calculated using procedures described in Sivjee et al. (1987) and displayed in Fig. 3. Now, the peak occurs near a 9-hr period, slightly shifted towards longer periods as compared with Fig. 2. The calculated values of Krassovsky's ratio (Krassovsky 1972), $|\eta|$ and ϕ following Sivjee et al. (1987), are 3.8 and 41°, respectively. The corresponding $|\eta|$ and ϕ for the peak near 2.4-hr period are 5.9 and -23°. The same technique was applied to measurements taken on relatively clear night (March 23, June 2 and June 17) and the calculated Krassovsky's values for the distinct peaks are listed in Table 1. Also listed in the Table 1 are observations obtained at different times and locations.

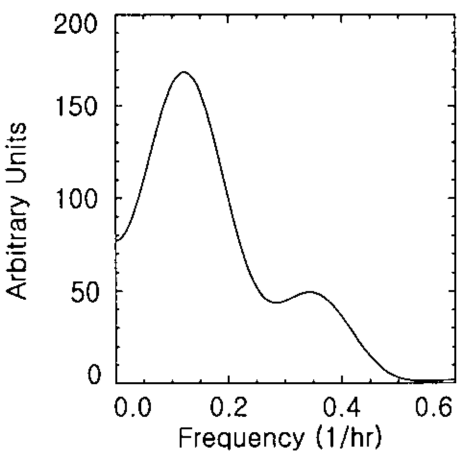

Figure 2. Power spectral density of OH rotational temperature for Figure 1.

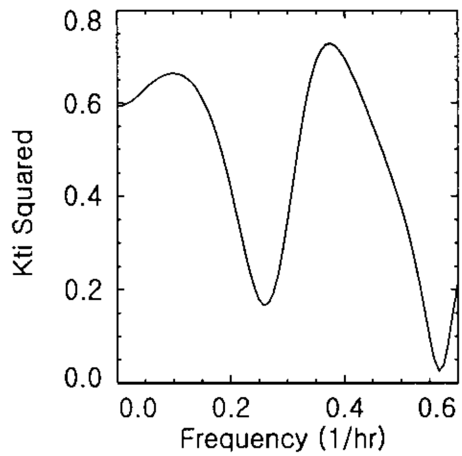

Figure 3. Squared coherency of OH band intensity and rotational temperature for Figure 1.

Among various results from literatures, we selected only those that are similar in period with our observations to provide a qualitative comparison. The quantity η depends on the characteristics of the background atmosphere, including height of peak OH emission and densities and scale heights of the minor constituents involved in OH photochemistry at the peak emission latitude (Walterscheid et al. 1987). Considering these adjustable parameters affecting the value of η, these values for Krassovsky's ratio measured at KSS are in reasonable agreement with previously published reports (Viereck & Deehr 1989, Swenson et al. 1990) as well as with theoretical predictions for gravity waves driven fluctuations (Walterscheid et al. 1987, Hickey 1988, Schubert et al. 1991). It should be worth to note that one possible reason for the observed difference is in the instrumental field of view used by the different authors. The Michelson interferometer used at KSS has a field of view of 1.3°, which implies a diameter of 2 km at the altitude of the hydroxyl emission layer. Therefore, waves with horizontal wavelengths less than this diameter will not be observed due to cancellation of different phases within the field of view.

4. SUMMARY

A Michelson interferometer was used to measure temperatures and intensities of upper mesosphere by observing the hydroxyl (OH) emission. These results provide information on the gravity waves in the upper mesosphere/lower thermosphere where most waves from below break. We have chosen several days of data and applied spectral analysis to retrieve wave information assuming that the measured fluctuations in the intensity and temperature of the OH (3-1) airglow are caused by gravity waves propagating through the emission layer. Spectral analysis of the OH airglow data indicates various coherent oscillations with periods ranging from 2 to 9 hours. The calculated Krassovsky's ratio for the distinct waves are in reasonable agreement with published results. Continuous measurements of OH intensity and the temperature over a year or longer are expected to reveal the detailed structure of atmospheric waves and their effects on the dynamical/thermodynamical characteristics of the upper atmosphere.

Table 1. Gravity waves characteristics determined from measured OH temperatures and intensities at KSS for the four nights of data. Comparisons are made with observations inferred from published reports.

Measurement	Period (h)	η	ϕ (degree)
March 23	3.1	10.0	12.8
	2.0	2.1	-13
April 22	9.1	3.8	41
	2.4	5.9	-23
June 2	3.3	3.3	-50
	1.9	2.9	18
June 17	5.6	4.2	-57
	2.6	3.5	-35
February 12, 1986 (Hecht et al. 1987)	4.0	3.1	3.1
September 25, 1987 (Viereck & Deehr 1989)	3.7	4.3	12
December 27, 1986 (Swenson et al. 1990)	2.8	3.5	not available

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