Meteor radar observations of solar tides and planetary waves interaction in the MLT region

K. K. Kumar, V. Deepa, T. M. Antonita and G. Ramkumar

Space Physics Laboratory, Vikram sarabhai space center, Thiruvananthapuram-695022, India

Abstract. Tides and planetary wave interactions in the MLT region using meteor radar observations over Trivandrum (8.5°N, 77°E) are discussed. Continuous zonal and meridional wind measurements in the MLT region during the period of August 2004 to August 2005 are used for the present analysis. Using the hourly wind data, tidal amplitudes are estimated on a daily basis and it has been observed that tidal amplitudes do show variations shorter than seasonal time scales. Time series data of diurnal, semidiurnal and terdiurnal amplitudes are obtained and the same is subjected to the wavelet analysis, which revealed the tidal variability at planetary wave scales. The present results also showed the seasonal dependency of modulation of tides by the planetary scale waves, which can be directly attributed to the variability in the source of both tides and planetary waves. Another important observation from the present analysis is tidal variability at 20-30 days periodicity. Variation of tidal amplitudes at planetary wave scales gives evidence for wave-wave interaction beyond doubts and variability at 20-30 day periodicity suggests the role of solar activity in controlling the MLT region dynamics. The results of present investigations, thus, brought out the salient features of wave-wave interactions in the MLT region over this latitude.

Index Terms. Planetary waves, solar tides, wave-wave interaction and radar remote sensing.

1. Introduction

Studies on the MLT region in the past emphasized the importance of this enigmatic region of the Earth's atmosphere. Especially, the MLT region neutral dynamics, which plays a decisive role in structure and variability of the ionosphere, is the cynosure of many atmospheric scientists. In any field of science, there should be a constructive interaction among theory, models and observations. These interactions help to represent the particular aspect in a more realistic manner in numerical models. In the field of MLT dynamics, theory of tides is well developed and models are also developed to some extent. However, the observations, which bridges theory and models are limited. In this regard, many observational platforms, both ground based and space borne, have been developed to continuously monitor the MLT region. The MLT region dynamics has been addressed experimentally over the past three decades by chain of MF/HF/meteor radars that can determine wind system between 60 and 100 km (Vincent, 1984; Manson and Meek, 1986). Measurements from incoherent scatter radars have also been used to extend the range of observations of the MLT into the lower thermosphere (Johnson, 1991; Salah, 1994), providing information on tides and tidal variability.

Gravity waves, planetary waves, and tides pervade the middle atmosphere, which are ubiquitous features of all planetary atmospheres. Atmospheric waves generated by dynamical processes propagate vertically and horizontally, dissipate, interact non-linearly, and profoundly influence the flows of momentum, energy, and constituents on a global basis. Measurements from the ground and recently from the Upper Atmosphere Research Satellite (UARS) have shown that diurnal tides in the MLT experience large seasonal and interannual variation. It has been shown that tidal amplitudes do modulated by the planetary waves. Tides and planetary waves and their effects have been reviewed by Forbes (1994). Evidence of interactions between semidiurnal tides and PW/GW were also reported. A recent study of the Christmas Island showed larger periods 25-60days of tidal variations and association with tropical tropospheric intraseasonal variability. It is also been observed that the tide amplitude modulations are not strictly global but exhibit considerable local variations as well. By now, it is well established that the tidal perturbations are mainly due to vertically propagating waves excited in the stratosphere and troposphere triggered by the absorption of sunlight by water vapor and ozone. More recent observations have provided evidence of strong tidal modulations by planetary waves and of the associated gravity wave motions as well but via mechanisms not yet understood. There are very limited observations on wave-wave interaction in the MLT region to arrive at any general conclusion.

Many studies have been carried out in the past to study the seasonal variation of atmospheric tides using meteor radar observations over Trivandrum. However, there were no attempts to study the modulation of tidal amplitudes by planetary waves, which can be directly attributed to lack of continuous observations. In this regard, the present work attempts to study the tidal variability at scales less than a season. Section 2 describes the experimental set up, section 3 presents results and discussion, and concluding remarks are given in section 4.

2. Experimental setup

Recently, a state of the art allSKy interferometric METeor (SKiYMET) meteor radar is installed at Trivandrum as an offshoot of Middle atmospheric dynamics (MIDAS) program to divulge the MLT region dynamics. The meteor radar system is a multi-channel coherent receiver pulsed radar, utilizing sophisticated software and computing techniques to acquire, detect, analyze and display meteor entrance events. Various calculations are performed in real-time on the detected meteor echoes. The results of these calculations can provide information about the nature of the meteor, such as the orbit and speed of travel on entering the atmosphere. Further, the resulting meteor trail is carried along (advected) by the electrically neutral atmospheric wind. By observing how the meteor trail drifts with time, deductions can be made about the speed and direction of the atmospheric wind at the altitude at which the meteor was observed. The wind is obtained by measuring the radial velocity of every meteor detected and then combining these measurements in an all sky manner. Radial velocities are determined by using both auto and cross correlation functions associated with meteor detections, and using the rate of change of phase near zero lag to determine the radial velocity. The instrument detects a sufficient number of meteor echoes throughout the day to obtain a comprehensive picture of the wind field. Analysis of the decay time of the meteor trail allows the determination of absolute measurements of mesospheric temperatures. Four three-element Yagi antennas are used for transmission, and five two-element Yagi antennas are used for reception. The radar electronics are housed in an equipment building adjacent to the antenna system. Table 1 shows the important specification of the radar system

For the present study, the meteor radar is operated 365 days round the clock. The meteor radar provided valuable wind information in the MLT region in the height domain of 82-100 km with a time resolution of 1 hour. These datasets are readily used for studying the diurnal/semidiurnal tides, planetary weaves and their interaction.

Table 1. Specification of SKiYMET radar at Trivandrum

Operating frequency	35.25 MHz
Peak power	40 kW
Maximum duty cycle	Up to 15%.
Pulse width	Programmable (1 -200 μs)*
Pulse repetition frequency	Programmable (1Hz-50 KHz)*
Bandwidth	~1.5 MHz
Sensitivity	-107 dBm
Dynamic range	62-122 dB
TX & Receiver antenna	Circularly polarized Yagi

*For the present experiment 13.3μs pulse with 2144 Hz pulse repetition frequency is used.

3. Results and discussion

The hourly zonal and meridional wind data obtained using the meteor radar observations during August 2004-August 2005 are used for the present study. The time series of zonal and meridional wind is constructed, which form a basis for the present analysis. The 24-hour time series wind for continues four days are used for constructing the composite diurnal cycle. Fig. 1 shows the composite diurnal cycle of zonal and meridional winds at 94 km height region. The composite diurnal cycle is constructed using four diurnal cycles as discussed earlier. From the Fig. 1, it is evident that the zonal winds are dominated by the diurnal tide while meridional wind is dominated by the semidiurnal tide. These composite profiles are readily subjected to Fourier analysis to get the diurnal/semidiurnal/terdiurnal tide amplitudes.

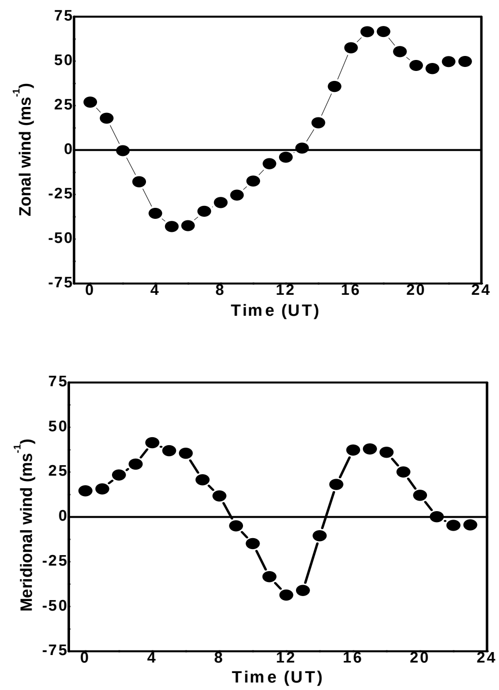

Fig. 1. Composite diurnal cycle of zonal (top) and meridional (bottom) winds at 94 km height region.

To study the day-to-day tidal variability, a 4-day moving template is used to construct the composite diurnal cycle, which is then subjected to Fourier analysis to get the tidal amplitudes. One year of data is subjected to above-mentioned analysis and time series of tidal amplitudes are obtained at six different heights (82, 85, 88, 91, 94 and 98 km) of MLT region. The top panel of Fig. 2 depicts the time series of zonal diurnal, semidiurnal and terdiurnal tide amplitudes for the observational period at 94 km. Even though, the tidal amplitudes at 94 km are presented in the figure, the time series at all other heights are also constructed. The time series data thus obtained is subjected to wavelet analysis to study the tidal variability at different scales. Wavelet analysis has been chosen to study the time evolution of tidal variability. As a matter of fact, Fourier transformation cannot resolve

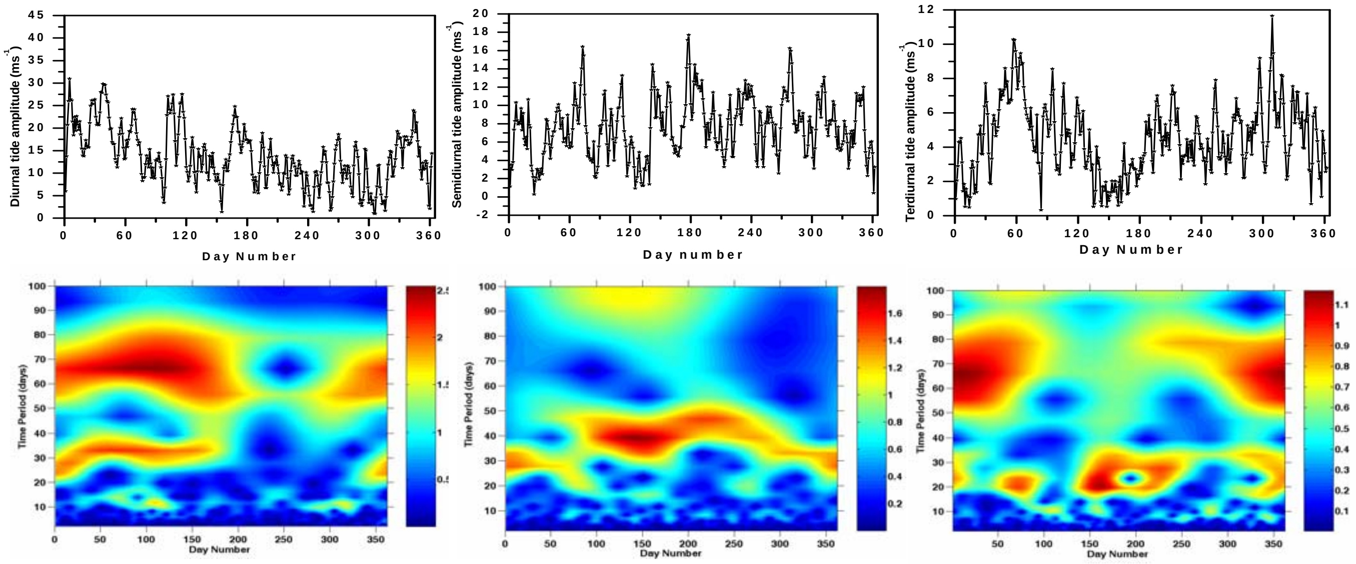

Fig. 2. Top panel**:** Time series plot of zonal diurnal, semidiurnal and terdiurnal amplitudes during August 2004 to August 2005 at 94km. Bottom panel: Corresponding wavelet spectrum of diurnal, semidiurnal and terdiurnal amplitudes.

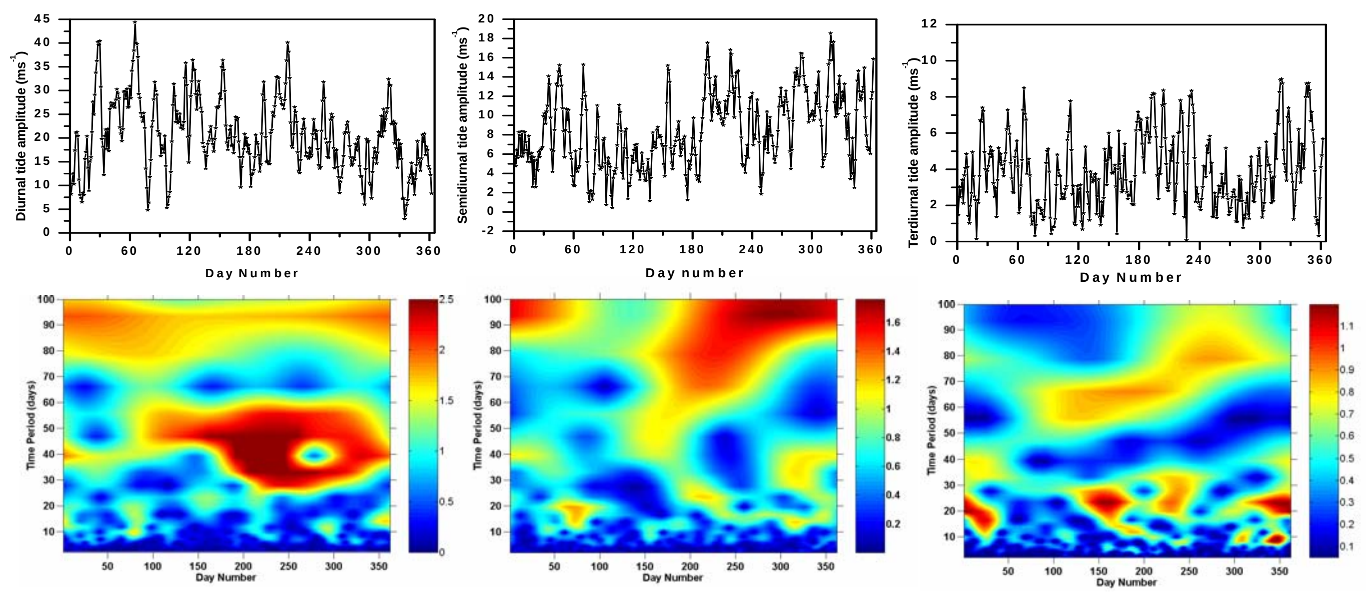

Fig. 3. Same as Fig. 2 but for meridional tides.

cannot resolve transient frequencies. This is exactly the topic where wavelet analysis scores over Fourier analysis. The wavelets are by construction very localized functions being able to resolve frequency transitions during short time periods. For the present study Morlet wavelet function has been used as mother wavelet. The bottom panel of Fig. 2 shows the wavelet spectra of diurnal, semidiurnal and terdiurnal tide amplitudes. The y-axis represents the time period of the oscillation in days and x-axis shows the day number. The y-axis is limited to 2-100 days as we are interested to study the tidal variability on less than a season. This figure readily reveals that tidal amplitudes do show the variability at different scales. The diurnal tides show the prominent oscillations at 60-70, 20-30 and 10-20 day periods. All of these oscillations show the significant seasonal variations in the amplitudes of these oscillations. This is one of the advantages of wavelets, which allows to study the time evolution of particular oscillation. The low period (10-20 day) oscillations, which are centered around ~16 days, is the prime focus of the present study. These oscillations are directly attributed to well known quasi 16-day planetary wave. It is very interesting to note the tidal variability at quasi 16- day periodicity, which gives the direct evidence for modulation of tides by planetary waves. However, by examining the wavelet spectra of zonal diurnal tide, it can be seen that there are only two pulses of such modulation during the observational period.

The first thing it confirms is that there is a seasonal variation of tides and planetary wave interaction. It is known that both tides and planetary wave activity have seasonal variation and it is obvious to expect seasonal variation in their interaction. The present results prove this point beyond doubts. The tidal variability at quasi 16-day planetary wave scale is also observed in both semi and terdiurnal tides as shown in the bottom panel of Fig.2. However, the amplitudes are gradually decreasing from diurnal to terdiurnal tide. The number of modulation events seen in the terdiurnal tide during the observation period is more as compared to diurnal and semidiurnal tide. One more interesting thing to be noted here is, the semidiurnal tide shows the variability at less than 10-day periodicity, which can be due to interaction of semidiurnal tide with quasi 6-day planetary wave. All the spectra depicted in this figure corresponds to 94 km, however, wavelet spectra are estimated at all heights (figures are not shown). It is observed that the amplitude of modulation increases with height as expected, which also confirms the consistence of the present method.

Fig.3. shows the tidal variability and corresponding wavelet spectra for meridional winds. The first observation of this figure confirms that the meridional diurnal tide has large amplitudes as compared to the zonal diurnal tides. This particular result is consistent with earlier studies reported form this latitude. It is very interesting to note more number of pulses of modulation of meridional tides by quasi 16-day planetary wave as compared to the zonal tides. These modulations also show the seasonal variations. All the three, diurnal, semidiurnal and terdiurnal show the modulation at planetary wave scale. Thus, the present observations reveal the tidal variability at planetary wave scale giving the evidence for wave-wave interaction in the MLT-region. It is also been observed that the modulation shows the seasonal variation. It will be very interesting to study the causative mechanism for this preferential modulation in time, which will be the topic of future studies.

Apart from planetary wave scales, both zonal meridional tides show significant variability at periods 60-70, 40-50 and 20-30 days. The first two periods can be attributed to intraseasonal oscillations, which has tropospheric origin. Even though, 20-30 day period come under intraseasonal oscillation, the present results show that this period is centered around ~ 27 days giving the evidence for the role of solar activity. The excitation of tides in the atmosphere depends on the absorption of solar radiation by water vapor in the troposphere and ozone in the stratosphere. Here comes the role of solar activity in modulating the tidal amplitudes. The present observations, thus, revealed that the tidal amplitudes show variability at different scales less than a season.

4. Concluding remarks

Continuous meteor radar observations of MLT region during August 2004 to August2005 have given the evidence for wave-wave interaction in the MLT region. Using the wavelet analysis it has been shown that the zonal and meridional tides are modulated by the quasi 16-day planetary wave. The number of modulation pulses are more in meridional tides as compared to the zonal tides. It is also been observed that there exits a tidal variability close to quasi 6-day periodicity. However, the quasi 6-day variability is observed predominantly in zonal semidiurnal tides. The modulation has also shown the seasonal variation, which in turn depends on seasonal variation of both tides and planetary waves. Other long period tidal variability is seen at 60-70, 40-50 and 20-30 day periods.

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