Tidal oscillations in the MLT region over Trivandrum (8°N, 77°E) – results from SKiYMET meteor radar observations

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Abstract. Atmospheric tides are excited by solar heating of water vapour in the troposphere and ozone in the stratosphere. Migrating tides are prominent components in the Mesospheric Lower Thermospheric (MLT) region. The vertical propagation characteristics of atmospheric tides over Trivandrum (8°N, 77°E) in the MLT region during the first year of observations (June 2004 to May 2005) using the All-sky SKiYMET meteor radar are reported. The diurnal tide is the prominent component observed. The amplitude and phase structure shows the vertical propagation of diurnal tides with vertical wavelength of ~ 25 km. The amplitude of meridional components is greater than that of zonal ones. The maximum observed amplitudes of diurnal tides are ~ 40-50 ms^{-1} and that of semidiurnal tides are of 20 ms^{-1}. It is observed that terdiurnal tides are also significant in this region. A comparison with GSWM00 shows similar phase structure but observed amplitudes are more than the model values. The tidal characteristics show significant seasonal variation and signatures of Semi-annual Oscillations are also seen. The observed amplitudes of diurnal tides are maximum during equinoxes.

Index Terms. Atmospheric tides, middle atmospheric dynamics, meteor radar, tidal source.

1. Introduction

Atmospheric tides are global oscillations with period of a solar day and its sub harmonics. They are excited by solar heating of water vapour in the troposphere and ozone in the stratosphere. Tidal oscillations play important role in coupling the lower atmosphere with the middle and upper atmosphere by transporting energy and momentum while propagating up and away from their tropospheric and stratospheric sources. They are the most striking features in the mesosphere and lower thermosphere where they dissipate by various instabilities and nonlinear wave interactions. Sun-synchronous or migrating tides propagate westward with the apparent motion of the sun and are primarily driven by the zonally symmetric absorption of solar IR and UV radiation by tropospheric water vapour and stratospheric ozone. The second class of tidal oscillations are the non-sunsynchronous or nonmigrating tides which can propagate westward, eastward or remain standing. Tidal oscillations exhibit strong seasonal and interannual variations. In the present study, the month-to-month variation of vertical characteristics of atmospheric tides in the MLT region, using all SKy interferometric METeor (SKiYMET) radar at the low latitude station Trivandrum (8.5^0 N), is presented. The horizontal wind observations from radar system are used for the tidal analysis and to study its seasonal variability. These are the initial results from the radar observations, which are compared for the first time with GSWM00 (Hagan and Roble, 2001) model values. Present study serves to assess the present understanding of the tidal characteristics in low latitude MLT region and to compare the GSWM00 predictions with the observations over this latitude.

2. Data and method of analysis

The wind observations from the SKiYMET Meteor Wind Radar, that became operational from June 2004, are used for the present study. This radar system operates at 35.25 MHz with a peak power of 40 kW and is the most powerful radar of this kind. For the present study, the radar transmitted pulsed radiation with a pulse width of 13.2 μm at a pulse repetition frequency of 2144 Hz. Using these meteor observations horizontal wind components in the altitude region of 80-100 km are estimated. The horizontal 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 vertical wind is ignored in the analysis. The horizontal wind data at every hour with an altitude resolution of ~3 km is used for the present study. All the diurnal cycles of zonal and meridional velocities in a month are averaged on an hour-to-hour basis at each altitude to form a composite diurnal cycle. This composite cycle provide a better representation of the tidal structure for a particular month. The composite cycles are obtained for every month from June 2004 to May 2005. These composite diurnal cycles are then subjected to Fourier analysis to get the altitude structure of amplitudes and phases of different tidal components. The following section describes the results obtained from the present analysis. From the vertical profile of amplitude and phase vertical propagation characteristics of tidal oscillations can be studied.

3. Results and discussion

Fig.1(a) and 1(b) show the time height variation of zonal and meridional winds for three consecutive diurnal cycles. The red contours represents the westerly and southerly winds and green that of easterly and northerly. There is downward ascending of the wind contours, which is stronger in the case of meridional winds. This is a typical characteristic of wave driven circulation. These figures clearly reveals the presence of diurnal tide in the present observations.

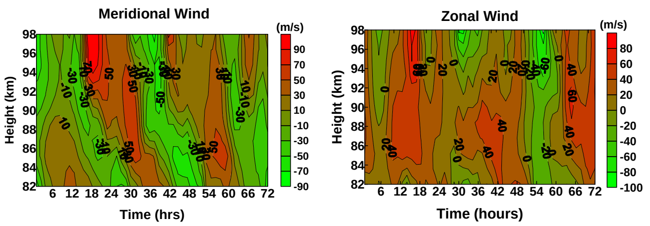

Fig. 1. Time-height contour of the (a) zonal wind and (b) meridional observed during three consecutive days (72 hours). Red contours represents the westerly winds and green the easterly winds.

3.1 Diurnal tides

Fig.2. depicts the altitude profiles of zonal diurnal tide amplitude and phase for four different seasons namely summer, autumnal equinox, winter and vernal equinox from June 2004 to May 2005 (black circles) along with the GSWM00 model predictions (red crosses).

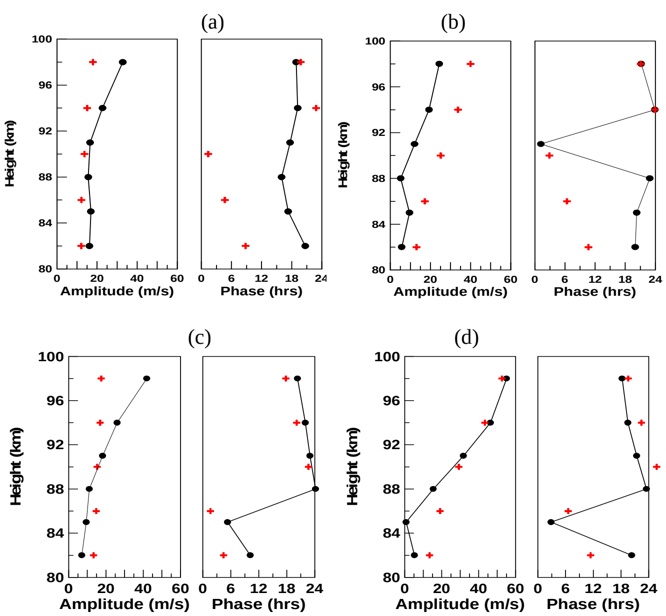

Fig. 2. Height profile of zonal diurnal tidal amplitude and phase for (a) summer (b) autumnal equinox (c) winter (d) vernal equinox during June 2004 to May 2005. Black circles represent the observed values and a red crosses represent the GSWM00 model values.

The GSWM00 is a 2-D model that employs observed distributions of background winds (from HRDI data), temperatures (MSISE 90 model), ozone (HALOE) and water vapor. It includes dynamical processes like eddy diffusion and gravity wave drag. The height profiles of amplitude show an increasing trend with height during all the seasons. The observed amplitudes are in the range of 10 to ~60 ms^{-1}. The maximum amplitude is observed during autumnal equinox. A general observation of these height profiles reveals that during all the four seasons the model underestimates the tidal amplitudes, especially at the higher altitudes. The phase profiles show downward propagation with time indicating upward wave propagation. The phase values are consistent with model values during winter and vernal equinox. These phase profiles are used to estimate the vertical wavelengths, which are found to be ~25 km. This wavelength is consistent with the migrating diurnal component corresponding to the classical (1,1) mode (Forbes and Groves, 1987). In the (s, n) mode 's' represents the zonal wavenumber and 'n' the meridional index respectively for the Hough mode for the tidal oscillation.

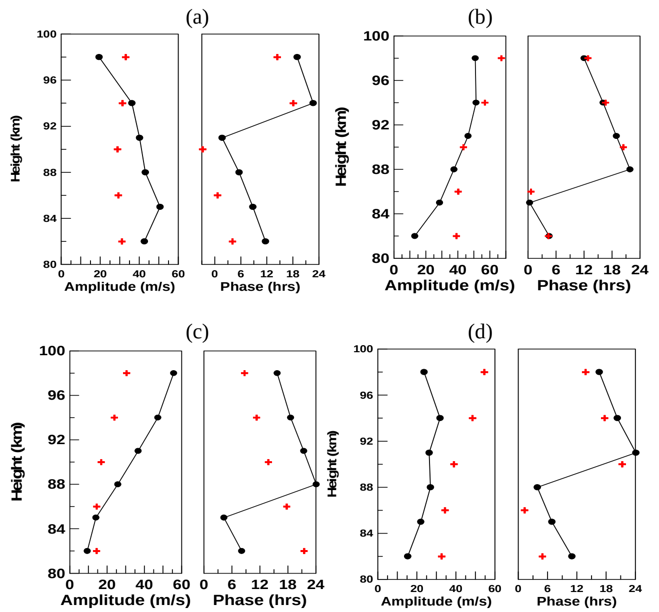

Fig. 3. Same as for fig. 2 but for meridional winds.

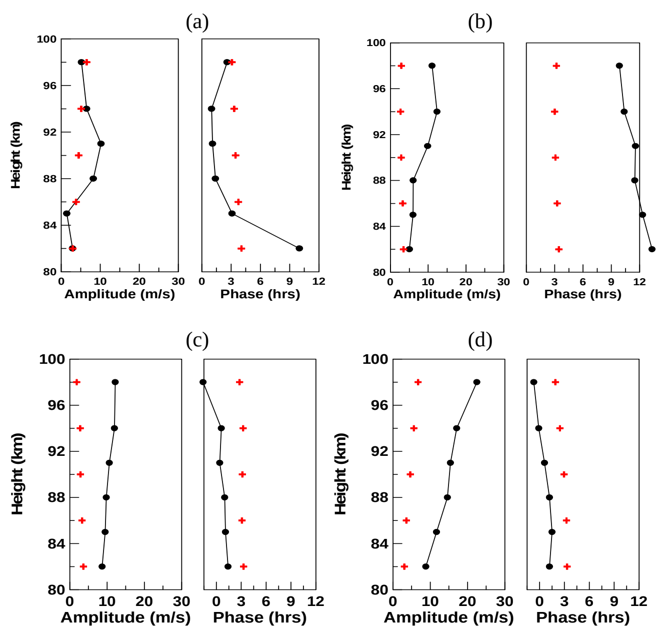

Fig. 4. Same as for fig. 2 but for semidiurnal zonal winds.

Fig. 3 shows the height profiles of amplitude and phase for meridional diurnal tides. The amplitude of meridional diurnal tides is greater than that of zonal component. The GSWM00 model values also shows that over this latitude the diurnal tidal amplitudes of meridional wind are larger than that of zonal winds. The amplitude increases with height during autumnal equinox and winter. During summer the amplitude decreases with height. During vernal increases with height upto 90 km and then decreases. Phases decrease with height during all four seasons. Phase values are consistent with model values. The vertical wavelength of meridional diurnal component is also ~25 km, indicating that the observed diurnal component is that of (1, 1) mode.

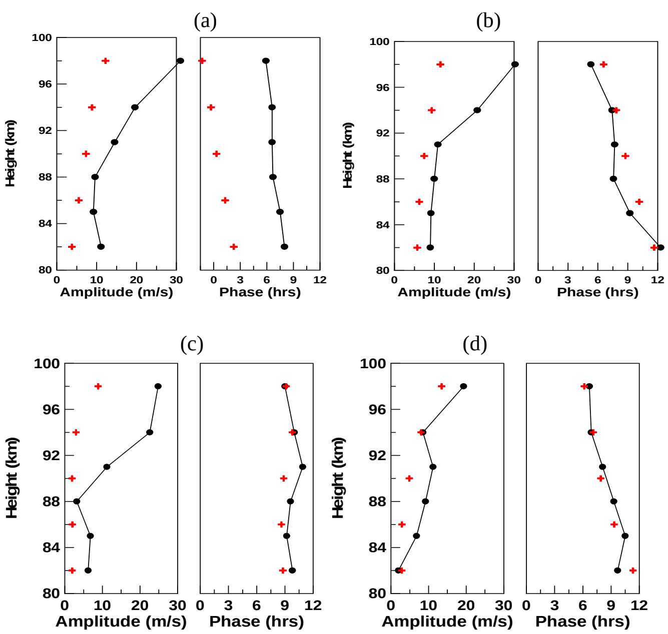

Fig. 5. Same as for fig.2 but for semidiurnal meridional winds

The observations of Zhang et al., (2004) over Arecibo (18^0N) using incoherent scatter radar showed that the amplitude of meridional component is stronger than that of zonal diurnal tide. They inferred that two types of tide co-exist in the altitude region of 95-110 km; a strong upward propagating diurnal tide and a much weaker semidiurnal tide. The diurnal tide had vertical wavelength of about 22 km with amplitudes 20-25 ms^{-1} and 50-60 ms^{-1} for the zonal and meridional winds respectively. They observed a phase shift of 6 hrs between the two components. Coordinated radar observation of atmospheric diurnal tides over the equatorial region Jakarta (6^0S, 107^0E), Potianak (0.03^0N, 109^0E), Christmas Island (2^0N, 158^0W) were carried out by Tsuda et al.,(1999). They also observed that the amplitudes of diurnal tides were larger in meridional component than the zonal. The amplitude is ~10 ms^{-1} for zonal diurnal tide and ~20 ms^{-1} for meridional diurnal tide.

3.2 Semidiurnal tides

Fig. 4 and 5 show the amplitude and phase profiles of zonal and meridional semidiurnal tides for each month during the present observational period. The amplitude increases with height for both the components as expected during all the seasons except for summer in the case of zonal component. During summer the amplitude values increase upto 90 km and then decrease. During winter the amplitude values remain constant with height for zonal wind. The rate of increase of amplitude with height varies from season to season. The growth of zonal wind amplitude is larger during vernal equinox (i.e., from 10 ms^{-1} at 82 km to 20 ms^{-1} at 98 km). During other seasons the amplitude values increase from ~ 5 ms^{-1} at 82 km to ~10 ms^{-1} at 98 km. The amplitude of meridional component is greater than that of zonal component as observed in the case of diurnal tidal amplitudes. The amplitude of meridional wind increases with height for all the seasons. The rate of increase is larger during summer and autumnal equinox. During these seasons the amplitude has a maximum value of 30 ms^{-1} at 98 km.

The observed amplitude values are greater than that of model values. Observations at Christmas Island showed monthly mean semidiurnal meridional amplitudes are in the range of 10-15 ms^{-1} (Burrage et al., 1995). The semidiurnal tidal amplitude observed using HRDI wind data at the latitude of ~20^0 N is ~25 ms^{-1} during April and May and is 20-25 ms^{-1} at the equator during June to August (Burrage et al., 1995). Thus, the present observations show largest semi diurnal amplitudes in meridional winds as compared to other geographical locations.

The phase decreases slightly with height indicating upward propagation of semidiurnal tides with large vertical wavelengths. Phase values are consistent with model values except during autumnal equinox for zonal component and during summer for meridional component. The vertical wavelength of zonal component obtained is ~100 km. The vertical wavelength obtained for meridional component is ~64 km which shorter than that of zonal component. The larger vertical wavelengths (>100 km) correspond to the vertical wavelength of the (2, 2) symmetrical mode (Forbes, 1982). The higher order semidiurnal components such as (2, 4), (2, 5) or (2, 7) have much shorter vertical wavelength values. The present observations show that the (2, 2) mode with wavelength ~ 100 km is generally stronger compared to other modes. Higher order modes show strong signatures in the meridional wind during some months. Forbes (1982) reported that the (2, 2) mode grows exponentially upto about 70 km and at higher altitudes its amplitude decreases due to dissipation. Above this altitude, higher order modes (2, 4), (2, 5) and (2, 7) become more prominent. Present observations also show the similar signature and thus consistent with the earlier studies.

3.3. Seasonal variation

Fig. 6 (a) shows the time-height section of diurnal tidal amplitudes for zonal winds. This plot readily reveals the seasonal variation of tidal activity in the MLT region. The tidal amplitudes show maximum activity above 90 km. The maximum value is observed during autumnal and vernal equinox. Earlier observations also showed that diurnal tides maximize over low latitudes and are strongest in the equinoxes (Burrage et al., 1995). Fig. 6 (b) shows the seasonal variation of diurnal tide amplitudes for meridional winds. In meridional wind also, the maximum tidal activity is observed above 90 km. The enhanced activity is observed during winter. During summer, maximum meridional amplitudes are observed below 90 km.

(a) (b)

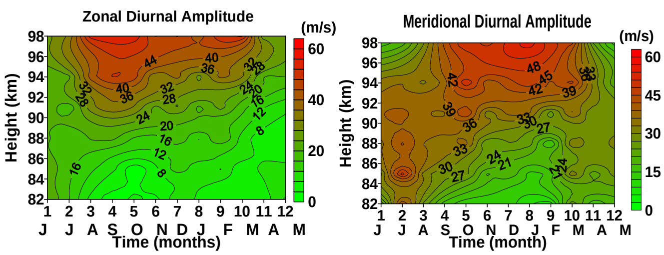

Fig. 6. Time-height contours of (a) zonal and (b) meridional diurnal amplitude showing the seasonal variation starting from June 2004 to May 2005. Contour intervals are 4 ms^{-1}.

Signatures of Semi Annual Oscillation (SAO) can be seen in the diurnal tidal variability. Hagan et al., (1999) reported pronounced SAO in meridional diurnal wind amplitude observed by HRDI over 20^0 latitude at 95 km altitude. They attributed this to seasonally variable gravity wave drag and eddy dissipation on the diurnal tide signatures in the MLT diurnal tidal variability. In a recent study by Wu et al., (2005) shows the observations of diurnal tide in the Microwave Limb Sounder (MLS) temperature data and its seasonal variations. They observed that the MLS gravity wave variances in the upper stratosphere maximize during the onset of the MLT tidal intensification where the MLT winds are expected to play an important role in modulating tidal amplitude. Oberheide et al., (2005) studied the month to month variability of meridional diurnal tide using TIMED Doppler Interferometer (TIDI) wind measurements from 40°S to 40°N. They suggest that the observed variability could be attributed to a combination of tides forced by latent heat release in the tropical troposphere and non-linear interaction between quasi-stationary planetary waves and the tidal oscillation.

4. Summary and concluding remarks

This paper reports the results from first year of observations using SKiYMET radar at Trivandrum (8°N, 77°E). The diurnal tidal component is observed to be prominent throughout the period of observation. The amplitude of meridional diurnal tide is stronger than zonal diurnal tidal amplitude. The amplitude of diurnal tide is ~50 ms^{-1} and vertical wavelength is ~ 25 km. The observed amplitudes and phases of diurnal and semidiurnal tides are compared with GSWM00 model. The observed amplitudes are greater than model values. However, the observed phase structures of tides have shown similarities with model predictions.

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