Diurnal and semidiurnal variations in the mesospheric winds observed at São João do Cariri-PB, Brazil: a preliminary study

Lourivaldo Mota Lima, Fábio F. O. Silva and Ana R. S. Paulino UEPB, Brazil
Ricardo A. Buriti and Amauri F. de Medeiros UFCG, Brazil
Paulo P. Batista, Barclay R. Clemesha and Hisao Takahashi INPE, Brazil

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Abstract

The terrestrial atmosphere is a dynamical system in which periodic oscillations are present and play a significant role in the dynamics of the upper mesosphere and low thermosphere (MLT). It is already well known that atmospheric tides play an important role in the dynamics of the MLT region, and the purpose of this study is to extend our knowledge of diurnal and semidiurnal oscillations in the equatorial MLT region, taking advantage of the measurements of meteor winds over São João do Cariri, Brazil (7° S, 36° W), which started in June 2004. In a preliminary analysis, we have observed that both wind components exhibited variability with respect to both time and height. Diurnal and semidiurnal oscillations also exhibited time and height variability. In general, the diurnal and semidiurnal amplitudes for meridional wind component were larger than the zonal component. From the phase structure, it was found that the vertical wavelength of the diurnal variations assumed values from 21 to 26 km for the meridional wind component, whereas for semidiurnal variations, the vertical wavelengths assumed values between 50 and 90 km.

Introduction

Atmospheric tides may be categorized as either migrating or nonmigrating. Migrating solar tides are global-scale waves which propagate westward following the apparent motion of the Sun, with dominant periods of 24-h and 12-h, and are referred to as diurnal and semidiurnal tides, respectively. Migrating diurnal tides in the lower atmosphere are excited primarily by direct absorption of sunlight by water vapor in the troposphere and stratosphere. In the tropics, an additional contribution to diurnal tidal excitation is latent heat released in convective processes. The semidiurnal tide is mainly excited by ozone absorption in the upper stratosphere and lower mesosphere. Diurnal and semidiurnal tides transport momentum and energy upward into MLT region. From classical tidal theory (e.g., Chapman and Lindzen, 1970), the first symmetric propagating diurnal tidal mode (s=1, n=1), where s and n denote the zonal wavenumber and meridional index, respectively, is mainly confined to low latitudes and, in accordance with mechanistic models (Forbes and Vial, 1989; Hagan et al., 1999a, 2001), its amplitude for horizontal winds maximizes for latitudes around 20 degrees. The amplitude of the migrating solar semidiurnal tide is generally lower than the diurnal tide, with the amplitude peaking in the lower thermosphere at about 50 degrees of latitude for zonal and meridional wind fields and having a secondary set of maxima over equatorial regions (Hagan et al., 1999a).

Diurnal and semidiurnal fluctuations in the MLT region have been extensively observed from ground-based radar measurements of horizontal winds, obtained by medium frequency (MF) and meteor radars, mainly at middle and high latitudes. The observational knowledge of the diurnal tides from the High Resolution Doppler Imager (HRDI) on the Upper Atmosphere Research Satellite (UARS) have confirmed the general global and seasonal tidal structures found by ground based radars (e. g., Burrage et al., 1995a, 1995b; Hagan et al., 1999b).

Seasonal and interannual variability of the atmospheric diurnal and semidiurnal tides have been studied by MF and meteor wind radars at equatorial and lower latitudes regions (Reddi and Ramkumar, 1997; Vincent et al., 1998; Tsuda et al., 1999; Batista et al., 2004). However, the behavior of tides in these regions is still poorly understood.

To extend our knowledge of the diurnal and semi-diurnal oscillations in the equatorial MLT region, in the present study we used the measurements of meteor winds over São João do Cariri, Brazil, obtained during the first 9 months of operation of the new radar.

Observations and data analysis

In this study we used the MLT equatorial winds measured at São João do Cariri in northeast Brazil (7° S, 36° W) by meteor radar. The system, a SKiYMET meteor radar, has operated continuously since May 31, 2004. In the present analysis, we used the horizontal winds obtained during the interval from June 2004 to February 2005. Details of the system, operation mode and the meteor detection for the SKiYMET radar are described elsewhere (Hocking et al., 2001). Briefly, the meteor radar uses an antenna that transmits pulses at 35.24 MHz and five receiver antennae forming an interferometric array. Meteor position is obtained from the relative phase of the echoes at the multiple antennas together with the echo range. Radial velocity is determined from the Doppler shift. In this work, the zonal and meridional winds were estimated in 1-hour time bins and in seven atmospheric layers of 4 km thickness each, with a height overlap of 0.5 km.

To determine the wave characteristics, the time series of the hourly-average winds were subjected to harmonic analysis. The analysis was performed in two ways. Firstly, we obtained the monthly parameters for prevailing wind, diurnal and semidiurnal variations, using a superposed epoch analysis, in which meteors are binned into hourly bins as a function of time of day, using data winds from one month (Hocking and Hocking, 2002). Secondly, the analysis was performed for sliding four-day segments of hourly winds stepped by one day and the wave parameters determined in the least mean square sense, supposing that semidiurnal, diurnal and 2-day oscillations were present in the horizontal wind components at all times.

a. Prevailing winds

Figure 1 shows the zonal (blue line) and meridional (red line) prevailing winds for each month from June 2004 to February 2005. During most of the time the zonal prevailing wind is westward with high velocities in September and October, reaching about –35 m/s in the layer centred on 81 km. During June, the zonal prevailing wind is eastward in the whole height range and is very weak in July. The meridional prevailing wind is southward for all heights between June and September. In October the meridional wind is southward only above 90 km, while in November it is northward in the whole height range. In January the meridional wind is northward only above 90 km. During December and February the meridional prevailing wind is weak.

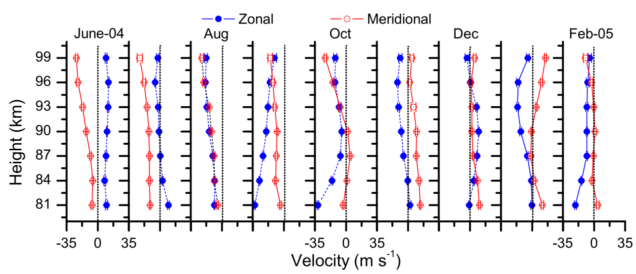

Figure 1 – Height profiles of the monthly mean winds over São João do Cariri. Eastward and northward are positive for the zonal (blue) and meridional (red) mean winds, respectively.

b. Diurnal variations

Figure 2 shows the monthly mean vertical profiles of the diurnal oscillation amplitudes and phases observed in the zonal (blue) and meridional (red) wind components during the first 9 months. Monthly diurnal amplitudes for zonal and meridional wind components show maximum values in September and October, respectively. During June and July the diurnal amplitudes for both components show the same values at all heights. In general, the diurnal amplitudes for zonal wind component are weak below 90 km for all observed months but exceed the meridional amplitudes at greater heights on some occasions. The vertical structures of the diurnal phase for the meridional wind component are compatible with upward energy propagation for all months, whilst the zonal wind component on some occasions shows descending phase. The vertical wavelengths, estimated from the phase structures, are compatible with the westward symmetric propagating diurnal tidal mode (1, 1) only for the meridional wind component, which assumes values ranging from 21 to 26 km, except during June and July which show larger vertical wavelengths. The zonal winds show larger vertical wavelengths for all months observed, indicating evanescent modes.

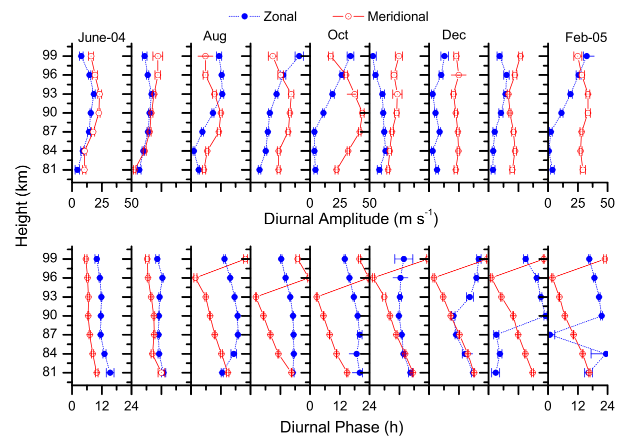

Figure 2 – Height profiles of the monthly amplitudes (upper panel) and phases (lower panel) of the zonal (blue) and meridional (red) wind components.

The time behaviour of the amplitude of the diurnal tide for seven atmospheric layers, smoothed by a five day running mean, are shown in Figure 3 for zonal and meridional wind components. The zonal component is represented by blue filled areas, whilst the red line represents the meridional wind component. It is observed from this figure that the zonal and meridional amplitudes exhibit variability with time as well as with height. Confirming the results already observed for monthly amplitudes, the meridional amplitudes for diurnal oscillations are larger than zonal amplitudes for heights below 96 km during almost the whole observation period. For layers above 93 km the zonal and meridional amplitude values have the same magnitude, with some occasions when zonal amplitudes exceed the meridional ones. The maximum zonal amplitude of the diurnal oscillation is about 60 m s^{-1}, which occurs in the layer centred on 99 km, around September 25 (day 269). The meridional wind component show maximum amplitudes up to 60 m s^{-1} at 90 km, near October 22 (day 296). A second amplitude peak is also observed in a region centred on 99 km, near November 15 (day 320).

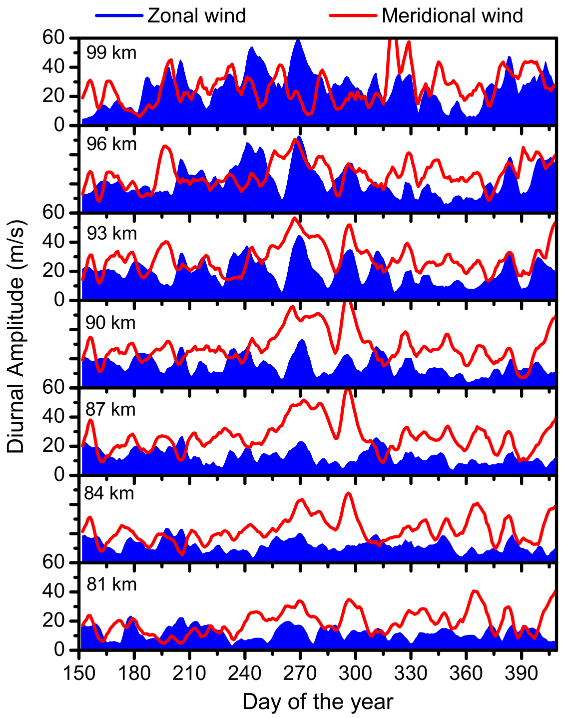

Figure 3 – The amplitude of the diurnal tides over São João do Cariri for zonal (blue areas) and meridional (red lines) components, for winds observed from June 2004 to February 2005. The data have been smoothed with a 5-day running mean.

c. Semidiurnal variations

The monthly amplitudes for semidiurnal variations over São João do Cariri are shown in Figure 4. As can be seen in this figure, the semidiurnal amplitudes are weaker than the diurnal ones. The semidiurnal amplitudes for zonal wind component were generally weak and smaller than the meridional wind component. The maximum value for zonal amplitudes reached 18 m s^{-1} at 96 km during November whist the meridional wind component registered a maximum amplitude of 32 m s^{-1} at 99 km during October. From the vertical structure of the semidiurnal phase, we can see descending phase for the zonal wind component for months from August to November, whereas for the meridional wind component the descending phase can be seen for months from September to December. The zonal wind component showed occasions of descending phase, and the meridional component showed larger vertical wavelengths for some months. The vertical wavelengths, estimated from the phase structures for months from August to November, assumed values from 50 to 90 km.

Figure 5 shows the behaviour of the zonal and meridional amplitudes of the semidiurnal tide for seven atmospheric layers, smoothed by a five day running mean. The components are represented as in Figure 3.

The zonal and meridional amplitudes of the semidiurnal tide also exhibit variability with both time and height. The amplitudes increase with height, reaching maximum values in the layers centred at 96 and 99 km, for both components. In general, the meridional amplitudes for the semidiurnal tide are larger than the zonal amplitudes for all heights and times.

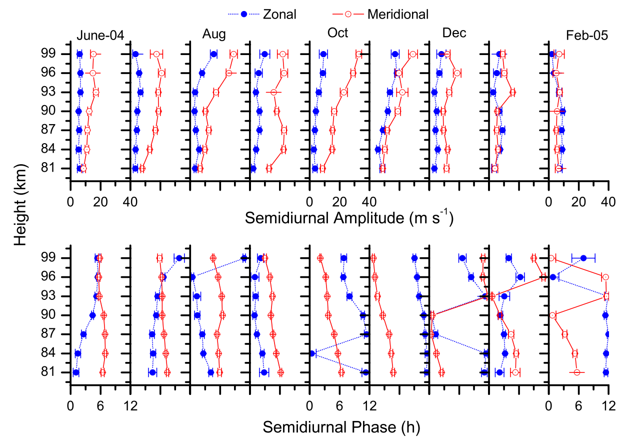

Figure 4 – As in Figure 2, but for semidiurnal tide.

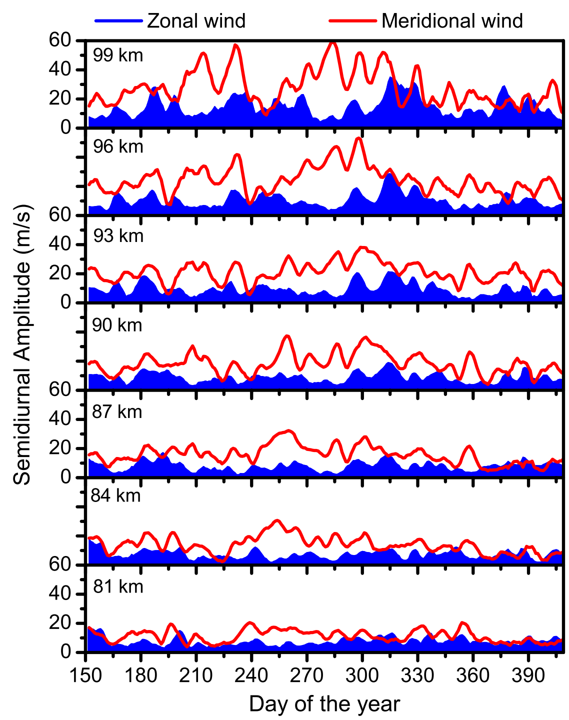

Figure 5 – As in Figure 3, but for semidiurnal tide.

Summary and Conclusions

We have presented a preliminary study of the diurnal and semidiurnal wind variations in the MLT region over São João do Cariri-PB. The horizontal winds were obtained during the first 9 months of operation of a new meteor radar, from June 2004 to February 2005.

The winds showed variability with both time and height for both components. This variability has been ascribed to atmospheric waves, such as, gravity waves, planetary waves and atmospheric tides. Diurnal and semidiurnal oscillations showed significant amplitudes, which also exhibited time and height variability. In general, the diurnal and semidiurnal amplitudes of the meridional wind component were larger than those of the zonal component. The vertical wavelengths (from 21 to 26 km) derived from the phase structure for diurnal variations are compatible with the diurnal tidal mode (1, 1) for the meridional wind component. However, larger vertical wavelengths are also noted. For the zonal wind component, diurnal variations showed large vertical wavelengths for all months observed. The semidiurnal variations present large vertical wavelength during some months, with values ranging from 50 to 90 km.

Attention should be drawn to the variations that are observed in the amplitudes of the diurnal and semidiurnal tides, with time scales of days to years. A number of different causes have been suggested by different authors to explain this variability. One candidate is non-linear interaction between tides and planetary waves (Teitelbaum et al., 1989; Teitelbaum and Vial, 1991; Pancheva et al, 2002). Thus, further study is desirable to investigate tidal variability and possible wave-wave coupling in the equatorial MLT region. Operation of the meteor radar continues in São João do Cariri, and further studies will be carried out with a view to clarifying these issues.

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