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FIRST OBSERVATIONS OF THE DIURNAL AND SEMIDIURNAL OSCILLATIONS IN THE MESOSPHERIC WINDS OVER SÃO JOÃO DO CARIRI-PB, 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, taking advantage of the measurements of meteor winds over São João do Cariri, Brazil (7°S, 36°W), obtained from August 2004 to August 2005. In a preliminary analysis, we have observed that both zonal and meridional wind components exhibited variability with respect to both time and height. The prevailing zonal wind shows a structure characterized by a semiannual oscillation (SAO) and are westward most of the time. The prevailing meridional wind is weaker than the zonal and exhibit an annual cycle. Diurnal and semidiurnal meridional wind oscillations also exhibit time and height variability. In general, the diurnal and semidiurnal amplitudes for the meridional wind component were larger than that for the zonal component. From the phase structures, it was found that the vertical wavelength of the diurnal variations exhibited values from 20 to 30 km for the meridional wind component, whereas for the semidiurnal oscillation they were between 50 and 70 km during equinoxes when the meridional amplitudes were stronger.

Keywords: atmospheric tides, mean winds, mesospheric dynamics, meteor region.

RESUMO. A atmosfera terrestre é um sistema que comporta oscilações periódicas as quais contribuem de maneira significativa na dinâmica da região da alta mesosfera e baixa termosfera. O fato das marés atmosféricas desempenharem um papel importante na dinâmica da média e alta atmosfera já é bem conhecido, e o propósito deste estudo é contribuir para um melhor entendimento acerca das oscilações diurna e semidiurna na região equatorial, utilizando para tanto os ventos meteóricos obtidos entre agosto de 2004 e agosto de 2005 sobre São João do Cariri, Brasil (7°S, 36°O). A partir da análise destes dados foi possível observar que os ventos médios, assim como as oscilações diurnas e semidiurnas, apresentaram além da variação temporal uma variabilidade em função da altura, tanto para a componente zonal como para a meridional. Os ventos médios na direção zonal mostram uma estrutura que é caracterizada por uma oscilação semi-anual, apresentando um escoamento para oeste na maior parte do tempo. Já o escoamento médio na direção meridional apresenta amplitudes menores do que as do zonal e apresenta uma oscilação anual. Em geral, as amplitudes das marés diurnas e semidiurnas para a componente meridional do vento foram maiores do que para a componente zonal. Os comprimentos de onda verticais das oscilações diurnas e semidiurnas foram determinadas a partir das estruturas de fase e apresentaram valores entre 20 e 30 km para a componente meridional. No caso das variações semidiurnas, os comprimentos de onda vertical calculados foram de 50 a 70 km durante os equinócios, quando as amplitudes da componente meridional foram mais intensas.

Palavras-chave: marés atmosféricas, ventos médios, dinâmica da mesosfera, região meteórica.

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INTRODUCTION

Atmospheric tides may be categorized as either migrating or non-migrating. 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, referred 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 the mesosphere and lower thermosphere (MLT) region. From classical tidal theory, 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 & 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., 1995; 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 (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 semidiurnal 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 13 months of the new radar operation.

OBSERVATIONS AND DATA ANALYSIS

In this study we used the MLT equatorial winds measured by meteor radar at São João do Cariri in northeast Brazil (7°S, 36°W). The radar operates in an all-sky configuration and uses transmitting antenna that emits pulses at 35.24 MHz and five receiver antennas forming an interferometric array. The system operates automatically 24 hours, detecting thousands of useful echoes per day. Meteor position is obtained from the relative phases of the echoes at the various antennas, together with the echo range. Radial velocity is determined from the Doppler shift. In this work, the horizontal winds were obtained from August 2004 to August 2005 and 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. In the first step we obtained the monthly parameters for the 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 wind data from one month (Hocking & Hocking, 2002). In the second step, the analysis was performed in 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, to:

$$V(t) = V_0 + \sum_{i=1}^{3} V_i \cos\left(\frac{2\pi}{T_i}t - \phi_i\right)$$

where V_o, V_i, and ϕ_i are the coefficients of the fitting process and represent the prevailing mean, the amplitude, and phase of the ith harmonic component at period of 12, 24, and ∼48 hours for i = 1, 2, or 3, respectively.

RESULTS AND DISCUSSION

Prevailing winds

The prevailing zonal and meridional winds measured from August 2004 to August 2005 are presented in Figure 1. The prevailing zonal wind shows a structure characterized by a semiannual oscillation (SAO). During most of the time, the prevailing zonal wind is westward (negative values), and strong winds occur during the early part of the equinox period, reaching about –40 m s^{-1} for heights below 84 km. During the first part of the summer, the

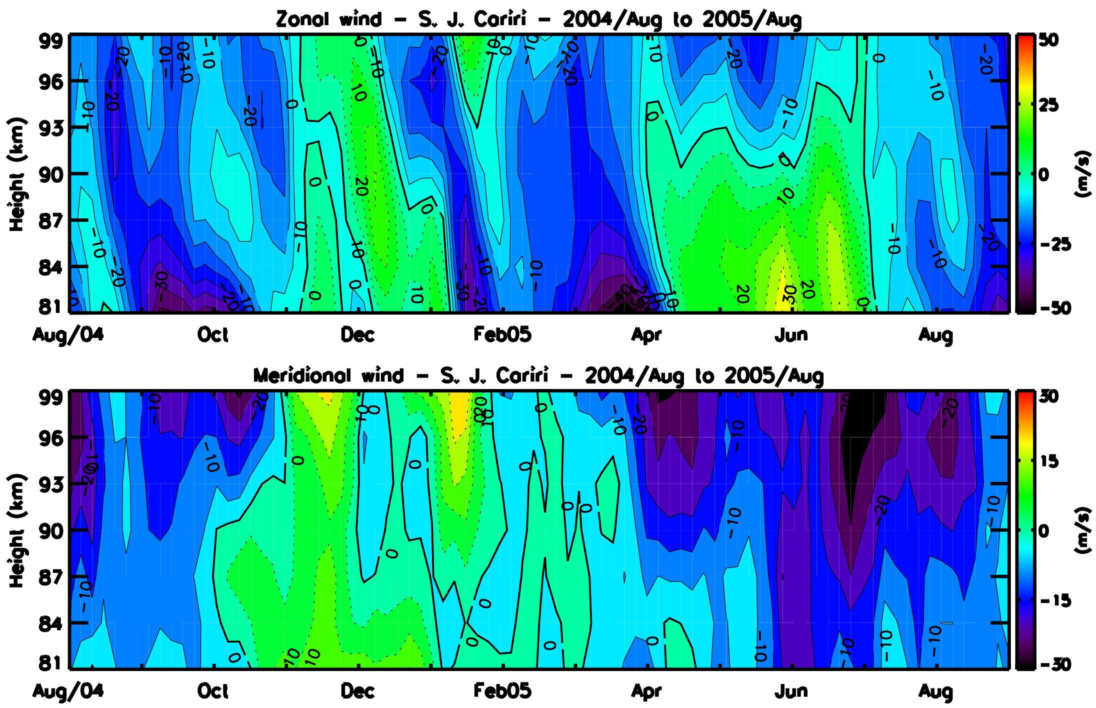

Figure 1 – Time-height cross sections of the monthly prevailing zonal (top) and meridional (bottom) wind components from August 2004 to August 2005. Solid (dotted) contours denote westward or southward (eastward or northward) motions. Contours intervals are 5 m/s.

prevailing zonal wind is eastward (positive values) in the whole height range and, from April to July 2005, the prevailing zonal wind is eastward at heights below 96 km, reaching maximum amplitude at the beginning of June for heights below 87 km. As can be observed in Figure 1, the zonal wind contours descend with time at an average rate of about 20 km month^{-1}. This feature has already been reported from equatorial wind data by Vincent (1993). The prevailing meridional wind is weak and exhibits an annual cycle with southward (negative values) winds from August to October 2004 and from March to August 2005. During the interval from about November 2004 to February 2005 the prevailing meridional wind is predominantly northward (positive values). In contrast with the zonal winds, the strongest meridional winds occurred for heights above 96 km, reaching values near 25 m s^{-1} and –25 m s^{-1} during winter and summer equinoxes, respectively.

Diurnal variations

Figure 2 shows the monthly mean vertical profiles of the diurnal oscillation amplitudes and phases observed in the zonal (solid) and meridional (dotted) wind components during the period from August 2004 to August 2005. In general, monthly diurnal amplitudes for the zonal wind field are weak below 87 km for all observed months and increases with height above 87 km, reaching its maximum at 99 km. The monthly diurnal amplitudes for the meridional wind component increase with height, reaching maximum values of about 40 m s^{-1} at 90 km in October 2004 and at 93 km in April 2005. In general, the diurnal amplitudes for the meridional component exceed that for zonal component, mainly below 96 km. The vertical structures of the diurnal phase for the meridional wind showed a descending phase which is compatible with upward energy propagation for all months. The vertical wavelengths for the meridional wind component, estimated from the phase structures, are compatible with the westward symmetric propagating diurnal tidal mode (1, 1) for all months, with values ranging from 20 to 30 km. For the zonal winds, the vertical structure of the diurnal phase does not show descending phases for all months, and the vertical wavelengths are larger in some months (such as September and November 2004; April and May 2005), indicating evanescent modes.

The temporal variations of the diurnal oscillation amplitudes versus height for the 13 months analyzed, smoothed by five day running means, are shown in Figure 3 for the zonal and meridional wind components. The diurnal amplitudes used here were obtained from harmonic analysis of sliding four-day segments of hourly winds stepped by one day. It is observed that the diurnal tide zonal and meridional amplitudes exhibit variability with

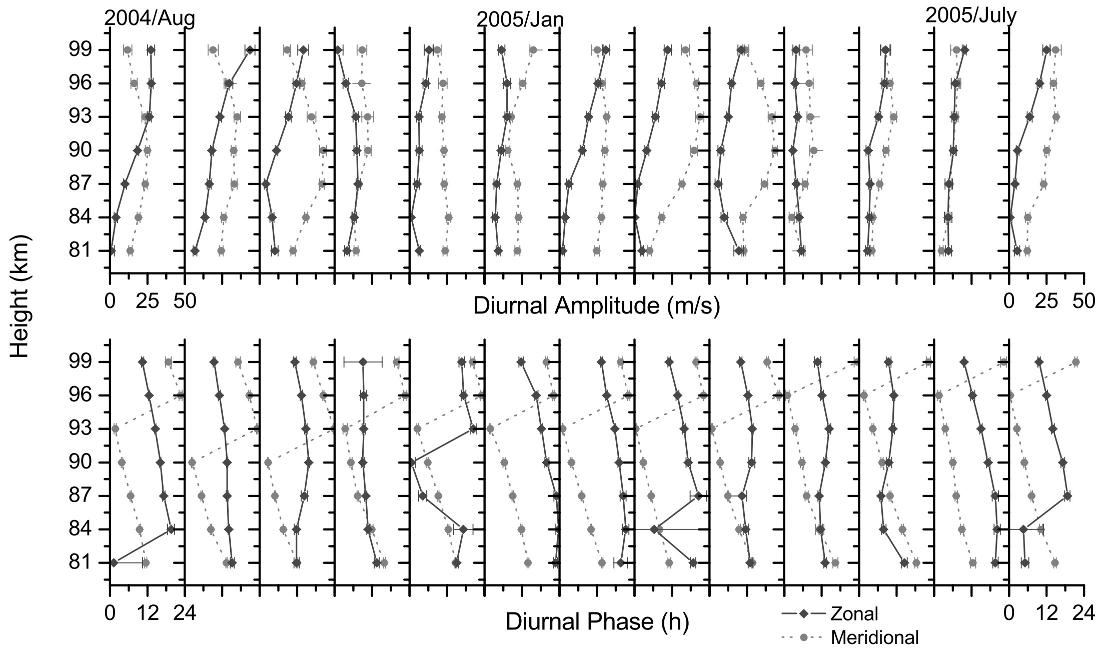

Figure 2 – Height profiles of the monthly diurnal oscillation amplitudes (upper panel) and phases (lower panel) of the zonal (solid) and meridional (dotted) wind components.

time as well as with height. Meridional amplitudes for diurnal oscillations are larger than the zonal amplitudes for heights below 96 km during almost the whole observation period, and it confirms the results already observed for monthly amplitudes. The diurnal zonal amplitudes are strongest for heights above 93 km and its maximum values are reached in the layer centred on 99 km, around August-September 2004, when exceed the meridional amplitudes. The meridional wind component shows maximum amplitudes around 90 km, during September-October 2004 and during February-April 2005. Maximum amplitudes are also observed in a region around 96 km, during July-August 2005.

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 the zonal wind component were generally weak and smaller than those for the meridional wind component. The maximum value for the zonal amplitudes reaching 18 m s^{-1} at 96 km during November 2004 whilst the meridional wind component registered maximum amplitudes during austral equinoxes when it increases with height and reaches a maximum amplitude of about 30 m s^{-1} at 99 km. From the vertical structure of the semidiurnal phase, we can see that the zonal component shows in some occasions an evanescent vertical propagation and ascending phase during June 2005, whereas for the meridional wind component descending phase can be seen for most months. The semidiurnal vertical wavelengths, estimated from the phase structures for the meridional component were larger ranging from 50 to 70 km during equinoxes.

Figure 5 shows the behaviour of the zonal and meridional amplitudes of the semidiurnal tide for heights between 81 km and 99 km, 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 results confirm that, as illustrated in Figure 4, semidiurnal oscillations were more intense during the equinox seasons. 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.

CONCLUSIONS

We have presented a preliminary study of the diurnal and semidiurnal wind oscillations in the MLT region over São João do Cariri – PB. The horizontal winds were obtained during the first 13 months of the new meteor radar operation, from August 2004 to August 2005.

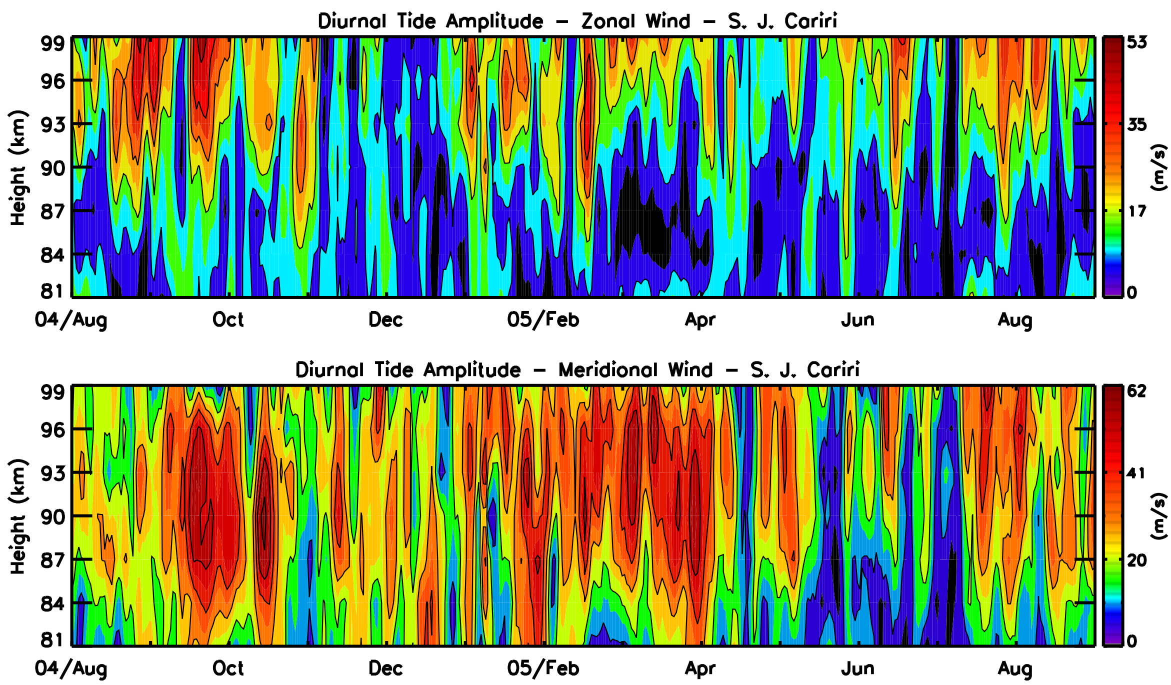

Figure 3 – Diurnal oscillation amplitudes of the zonal (upper panel) and meridional (lower panel) components as a function of altitude and time at São João do Cariri-PB from August 2004 to August 2005. The amplitudes were smoothed by a 5-day running mean.

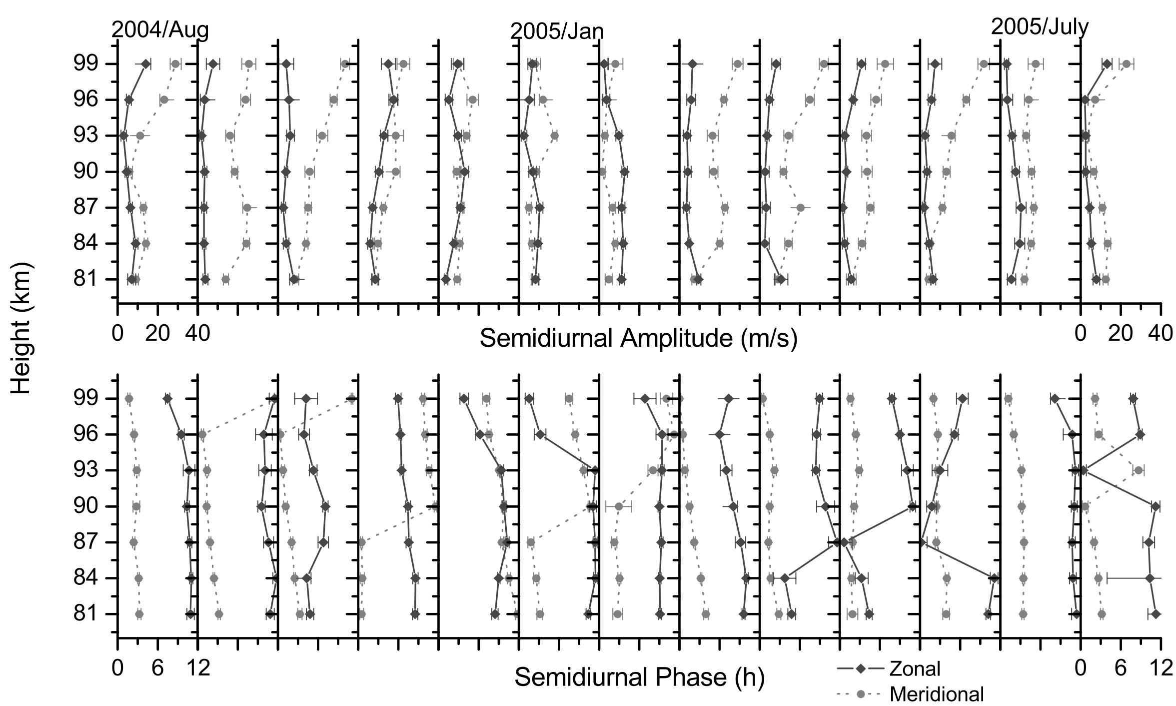

Figure 4 – Same as Figure 2, but for the semidiurnal tide.

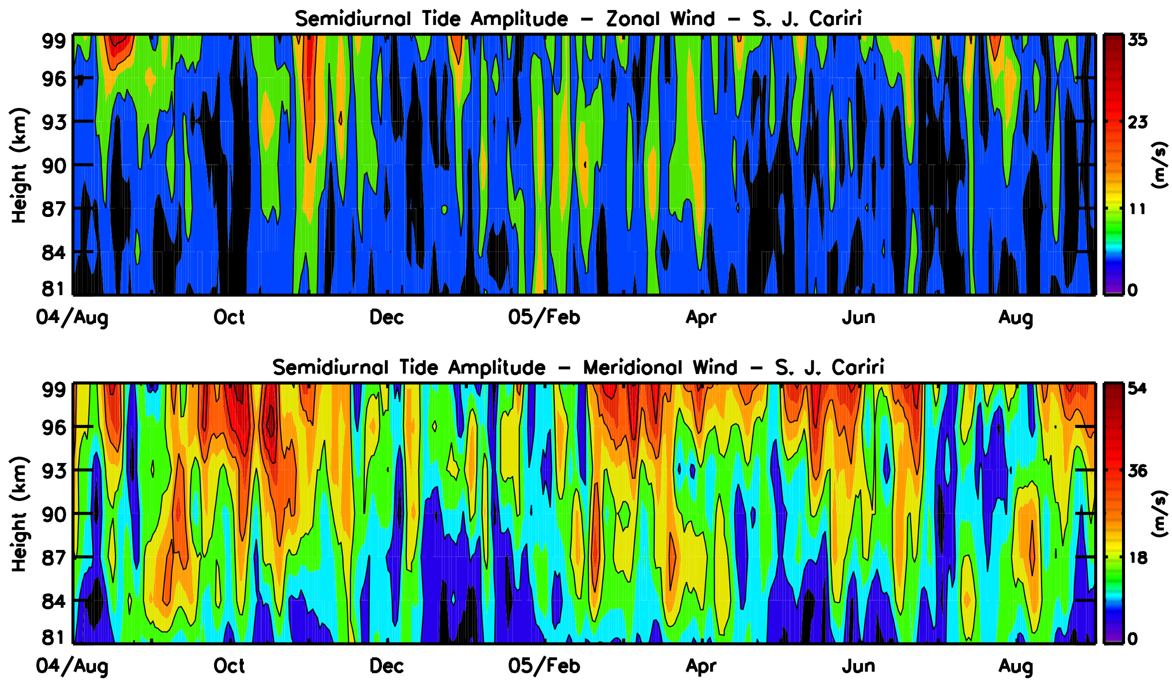

Figure 5 – Same as Figure 3, but for the semidiurnal tide.

The mean winds showed variability with both time and height for both components with zonal wind characterized by a semi-annual oscillation and meridional wind by an annual cycle. Part of 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, ranging from 20 to 30 km and derived from the phase structure for diurnal variations, are compatible with the diurnal tidal (1, 1) mode for the meridional wind component. For the zonal wind component, diurnal oscillations showed descending phase for some months and large vertical wavelengths on other occasions indicating evanescent modes. The semidiurnal oscillations presented large vertical wavelength for the meridional component during equinox months, with values ranging from 50 to 70 km.

A number of different causes have been suggested by different authors to explain the temporal variations that are observed in the amplitudes of the diurnal and semidiurnal oscillations, whose time scales can be from days to years. One possible explanation for these temporal variations could be the non-linear interaction between tides and planetary waves (Teitelbaum et al., 1989; Teitelbaum & Vial, 1991). 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 in order to clarify these issues.

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