Diurnal mesospheric tidal winds observed simultaneously by meteor radar in Costa Rica (10°N, 86°W) and Cariri (7°S, 37°W)

Ricardo A. Buriti[1], Wayne Hocking[2], Paulo P. Batista[3], Igo Paulino[1], Ana R. Paulino[4], Marcial Garbanzo-Salas[5], Barclay Clemesha[3] (in memoriam), Amauri F. Medeiros[1]

[1]Unidade Acadêmica de Física, Universidade Federal de Campina Grande, C. Grande, 58429-900, Brazil
[2]Department of Physics and Astronomy, University of Western Ontario, London, N6A3K7, Canada
[3]Instituto Nacional de Pesquisas Espaciais, S. J. dos Campos, 12227-010, Brazil
[4]Departamento de Física, Universidade Estadual da Paraíba, C. Grande, 58429-500, ~~Brasil~~Brazil
[5]Departament of Atmospheric, Oceanic and Planetary Physics, Universidad of Costa Rica, San Jose, 11501-2060, Costa Rica

Correspondence to: Ricardo A. Buriti (rburiti@df.ufcg.edu.br)

Abstract. This paper presents a study of diurnal tidal winds observed simultaneously by two meteor radars ~~sited either~~located on each side of the equator in the equatorial region. The radars ~~are~~were located in Santa Cruz (10.3°N, 85.6° W), Costa Rica (hereafter CR) and ~~in~~ São João do Cariri (7.4°S, 36.5° W), Brazil (hereafter CA). The distance between the sites is 5800 km. Harmonic analysis ~~was~~has been used to obtain amplitudes and phases (hour of peak amplitude) for diurnal, semidiurnal and terdiurnal tides between 82 and 98 km altitude, but in this ~~paper~~work we concentrate on the diurnal component. The period of observation was from April 2005 to January 2006. The results were compared to the GSWM-09 model. ~~In general, seasonal agreement between observation and model diurnal tide was qualitatively satisfactory for CA zonal amplitude. However, magnitudes~~ Magnitudes of zonal and meridional amplitudes from November to January for CR were quite different ~~to~~from the predictions of the ~~GSWM-09. Peak zonal amplitudes (~25 m/s) in CR were observed in September and December between 90 and 94km. In regard to~~model. Concerning phases, the agreement between model and radar meridional tidal phases ~~to~~at each site was good, and a vertical wavelength of 24 km for the diurnal tide was observed practically every month, although ~~at times~~on some occasions determination of the vertical wavelength was difficult ~~mainly to~~, especially for the zonal component, due to non-linear phase variations with height. ~~In regard to~~For the diurnal zonal amplitude, there ~~are~~were notable differences between the two sites. ~~This is probably because while the sites are somewhat complementary, the responses to variability of water vapor heating and latent heat release during weak positive phase of Southern Oscillation Index (ISO), or La Niña, at the two sites are quite different and it could explain such~~We attribute this site-to-site difference of the diurnal zonal amplitude to the nonmigrating component of the tide and propose that an anomaly was present in the troposphere in the winter (Northern Hemisphere) of 2005-2006 which produced substantial longitudinal variation.

Keywords: MLT dynamics, meteor wind, diurnal tide.

1 Introduction

Atmospheric tides are driven principally by solar heating which results in significant day-night differential heating~~, and~~; they are dynamically very dominant at mesospheric and lower thermospheric heights.~~-~~ Thermal excitation due to absorption of solar radiation by water vapor (at infrared wavelengths) and ozone (at ultraviolet wavelengths), coupled with latent heat release due to deep convection at low altitudes~~-~~, results in expansion and contraction of atmospheric pressure/density fields, creating modes of oscillation with very well-defined characteristics. Such oscillations are particularly easy to observe in the lower thermosphere through their impact on wind fields, temperature, airglow and ionospheric parameters (e.g., Taylor et al., 1999; Buriti et al., 2005; Forbes et al., 2008). Because of this, tides are very important to the ionosphere-thermosphere system~~, and linear~~. Linear and non-linear interactions between solar atmospheric tides, gravity waves, and planetary waves have been studied~~ in order to~~, aimed at a better ~~describe~~description of the dynamics of the atmosphere from low to high altitudes (e.g., Garcia and Solomon, 1985; Teitelbaum et al., 1989; Meyer, 1999, Thayaparan ~~e~~et al., 1995). The classical theory of tides is moderately well-established ~~because~~but it ~~neglect~~neglects, for example, mechanical forcing and dissipation, ~~considering~~and considers the atmosphere horizontally stratified and isothermal. ~~But many~~Many issues about interaction, excitation and temporal variability require further understanding. Those two mechanisms~~ which~~, forcing and dissipation, drive migrating and ~~non-migrating~~nonmigrating tides~~, mentioned above,~~ and are, basically, dependent on how the solar radiation heats the planet, ~~according to~~ which in turn is dependent on seasonality and the distribution of the ocean and continental plates on the Earth´s surface~~, which~~. This makes the global heating different ~~to both~~for the two hemispheres. ~~It~~A complete description of the forcing is very complex because many others parameters and mechanisms~~, Coriolis´s force according to latitude, that make the dynamics of atmosphere different around the globe, should~~ must be included to describe realistically the dynamics of the atmosphere. ~~The presence of~~In some cases, tides in the wind fields observed by various methods (including meteor radar), ~~showed~~show good agreement with the Global Scale ~~Waves~~Wave Model (GSWM) ~~in some cases~~ (Hagan~~, et al.,~~ and Forbes, 2002, 2003;~~-~~Yuan et al., 2006; Ward et al., 2010; Chang, et al., 2012,). Previous studies ~~about~~of tides in the equatorial region ~~showed~~have shown that, in the altitude-range between 82 km and 98 km, the diurnal (24-hr period) amplitude is generally more significant than the semidiurnal mode for both zonal and meridional components (Buriti, et al., 2008; Davis et al., 2013). Tides also have a dependence on altitude and season. That behavior is in accordance with tidal theory for the propagation of the (1,1) Hough mode (Chapman and Lindzen, 1970; Forbes, 1982).

Frequently, the observed meridional diurnal ~~mode~~phase in the equatorial region presents a ~~better~~more well-defined behavior as a function of altitude and season~~,~~ than the zonal component (Deepa, et al., 2006; Buriti, et al., 2008; Davis et al., 2013) which makes the calculation of the meridional vertical wavelength more accurate relative to the zonal component. ~~The~~Perhaps this difference occurs because the nonmigrating tides have relatively more important impact on the zonal wind field at low latitudes. As noted, the semidiurnal mode (period of 12 ~~hours~~hour) is generally weaker than the diurnal mode in the low latitudes and equatorial regions. The terdiurnal and ~~quadiurnal~~quarterdiurnal tides are also present but with even smaller amplitudes, but nonetheless ~~do~~they play some role in ~~mesopheric~~mesospheric dynamics (~~e.g.~~Tokumoto et al., 2007; Guharay et al., 2018).

This paper concentrates on diurnal tides observed simultaneously with meteor radars installed in Santa Cruz, Costa Rica (hereafter CR) and São João do Cariri (CA), Brazil, with our focus being on the period from April 2005 to January 2006 (inclusive). Both radars, separated by 5800 km, are very similar~~,~~ in construction and ~~they~~operation to each other. They are located in opposite hemispheres but very close to the equator. Their latitudes are ~~almost complementary~~very similar. The paper first presents a brief overview of the background wind at both sites, and then proceeds to a comparison between diurnal ~~tides~~tidal characteristics. Amplitudes are discussed first, followed by phases. A discussion then follows.

Interesting results include a peak in amplitude observed in the diurnal zonal amplitude at the Costa Rican site in December which is not predicted by the model, and a clear anti-phase between CR and CA in regard to the diurnal meridional component.

2 Instruments and Observation

The both meteor radars~~ used~~ are called SKiYMet radars. These are All-Sky Interferometric meteor radars which consist of a transmitter antenna in the form of a 3-element Yagi, and a set of 5 receiver ~~antenna~~antennas comprising 2-element Yagis. The radars are installed in different locations, namely~~-~~ in São João do Cariri, PB, Brazil (7.4°S, 36.5°W) and Santa Cruz, Costa Rica (10.3°N, 85.6°W). The distance between the sites is about 5800 km, and they are at similar latitudes either side of the equator (10°N and 7°S). The first uses a frequency of 35.24 MHz and the second one operates at 35.65 MHz. The radars run 24 hours per day without interruption, and provide meridional and zonal wind data at altitudes between 80 and 100 km. Weather conditions do not interfere with observations. Basically, the wind is measured when an ionized meteor trail, formed when a meteoroid collides with the atmosphere, reflects the radio-wave emitted by the transmitter antenna. The echo is detected by 5 receiver antennas. The phase-shift between each pair of antennas gives information about the direction in which the meteor trail was observed, the time delays of the transmitted pulses give the range to the target, and the Doppler shift of the received signal gives the radial velocity. ~~Typically several thousand meteor trails are detected per day. Radial velocities observed by the radar present a standard deviation between 1 and 2% (Clemesha et al., 2009).~~ This combination of data allows generation of a wind-field as a function of height and time (Hocking et al., 2001). Concerning the standard deviation of amplitude and phase, it is important to note that for each hour of a composite day, several thousand meteor trails are detected by the radar. The consequence of this is that the errors in determination of the amplitude and phase can be estimated to be less than 10% and 1 hour, respectively. The temperature of the mesosphere at the height of peak meteor detection (~90 -92 km) can also ~~can~~ be determined by meteor radar (Hocking, 1999), but we will only concentrate on the wind field. In our case, we determine information of winds every 2 hours centered at altitudes of 82, 85, 88, 91, 94 and 98 km, in order to make optimum use of the data, which are non-uniformly distributed in height.

In the present work, we will use CR data corresponding to the period from 14th April 2005 to 29th January 2006, with a gap of data from 17th November to 13th December. Data from CA for the same period will be presented for comparison. A study of one year of background mean winds, as well as diurnal and semidiurnal tides observed in both the zonal and meridional components above CA during 2004-2005, has previously been reported by Buriti et al., (2008).

The Global Scale Waves Model (GSWM-09) used in this work includes migrating and ~~non-migrating~~nonmigrating tides with zonal ~~wavenumber~~wavenumbers from eastward 6 to westward 6 ~~results~~. Briefly, ~~this software~~it is a 2-dimensional model that solves the linearized and extended Navier-Stokes equations for a particular period and wavenumber *s* as function of latitude (from 87°S to 87°N), altitude (from 0 to 124 km) and month (from January to December). It incorporates fields of mean wind (zonal), pressure, temperature and other important physical parameters from empirical models, such as MSISE-90 (Hedin, 1991). Depending on the altitude range, information on wind comes from different models and satellite observation. For example, between the stratosphere and the mesopause, winds are provided by the High Resolution Doppler Interferometer - HRDI - on board the UARS satellite. Details about the GSWM can be obtained on HAO's homepage and a vast number of papers, such as Hagan et al, (1997~~;~~, 2002~~;~~, 2003~~;~~), Manson et al., (2002~~;~~) and Pancheva et al., (2001). Information about tidal parameters determined by GSWM0-09 ~~are~~will be presented at specific altitudes ~~that are not exactly coincident~~, chosen to be closest to the radar heights (e.g.~~;~~., see Fig. ~~4 and~~ 5~~), but they are close.~~ and 6).

2.1 Background winds

In order to set up the background conditions for the tides, we ~~will here~~ present wind variations on the time scale of months, and present the background wind observed in CR and CA. ~~Fig.~~Figure 1 shows the monthly averages of zonal (left) and meridional (right) winds in CR and CA. Data ~~of~~from February ~~and~~to March are missing for CR~~.~~ because the meteor radar presented technical problems.

Comparing monthly mean winds at the two sites, some interesting results are evident. In general, both sites seem to present a clear annual and semiannual behavior, particularly in regard to the zonal wind. At heights of 82-91 km, the maximum eastward mean wind at CA is observed in June, while the maximum in CR is present in December. This is almost a 6 month

Formatado: Fonte: 10 pt, Cor da fonte: Pre

Formatado: Espaçamento entre linhas: 1.5 linhas

Formatado: Inglês (Reino Unido)

delay, as might be expected due to the fact that the radars are in different hemispheres. The meridional winds are quite different at the two sites, although strong southward flows above CA in June-July and strong northward flows in December over CR are evident.

A ~~semiannual~~ harmonic analysis to derive semiannual oscillation - not presented in detail in this text - was carried out in ~~regard to~~ these data. Briefly, not considering annual oscillation, the semiannual zonal amplitude decreased between 82 and 94 km from ~15 m/s to 6.3 m/s in CR with maximum values ~~in~~on day ~160 of the year ~~~160~~ (June 9th~~).~~) or ~342 (December 8th). The amplitude ~~at~~in CA also decreased similarly to CR, and presented ~~the~~ maximum values close to 160 doy ~~160.~~ (day of year). The meridional component, on the other hand, is predominately northward in CR and southward at CA in the range between 82 and 98 km. Meridional amplitude values in CR and CA are practically the same, except ~~to~~at 98 km height where the value of CA is ~~double if compared to~~ twice of that above CR. In general, the semiannual meridional ~~amplitudes~~amplitude did not ~~presented~~present values above 5 m/s ~~to each~~at any specific altitude in the range studied in this work. ~~Differently of zonal component, the meridional phase in CR between 82 and 85 km was in day 66 (or ~ doy 248), while CA was in doy 165.~~

3 Diurnal tide

We now turn to tidal analyses. The analysis of CR and CA winds, in order to determine information about the diurnal tides, was similar to the procedure described in Hocking (2001) and Buriti et al. (2008). First of all, a superposed epoch averaging of winds at two-hour steps was made, producing monthly means at 0100, 0300, ..., 2300 ~~hour~~hr (local time). After that, a standard least~~-~~ mean squares fitting technique was used to obtain amplitude, phase and DC values for each month. It is known that diurnal oscillation of meridional wind in regions close to the equator ~~present~~presents good regularity in amplitude and phase according to altitude, and our results confirmed this. ~~Because of this~~Consequently, a precise vertical wavelength is easier to calculate for the meridional wind than for zonal wind. A very interesting observation can be made regarding the diurnal phase of the meridional wind at the two sites. They are completely out of phase. In other words, if the wind has maximum magnitude towards the south at CA, then at the same local time in CR, the meridional wind has maximum magnitude towards the north.

In ~~Figs.~~Figures 2~~, 3, 4, and~~ to 5, information about amplitudes and phases of the GSWM-09 and radars installed in CR and CA are presented for 6 different altitudes. The altitudes used for the GSWM-09 do not coincide exactly with the specific altitudes of the radars, but nonetheless the comparisons between radar data and the GSWM-09 are still easy to make. We now turn to more detailed discussions, beginning with the zonal diurnal tide.

3.1 Zonal diurnal amplitude

A general view of the observational diurnal tidal amplitudes in CR and CA, as well as the GWSM-09 at both sites, can be seen in Fig. 2. In CR and CA the mean amplitudes, considering all months and altitudes, were close to 10 ± 5.7 m/s, but there is a clear difference between them. While CR values were above the average for November-January at all altitudes, CA values were largely below the average for altitudes between 82 and 91 km height for practically the whole period of observation. Also, amplitudes in CR were small between 82 and ~~98 km~~98km for May-July. CA presented similar results in October-January, but with a 6 ~~months of~~month difference ~~if~~ compared to ~~CA observation~~CR observations. Comparing to the model, CA is closer to the model only in November and December in the range between 82 and 98 km height. A good agreement between model and observation is specifically observed in September at CA. Both ~~increase the~~sites show increasing amplitude from 91 to 98 km. The presence of large amplitudes in September seems to be a common feature between the sites; in CR the amplitude increased to values of ~24 m/s at an altitude of ~94 km in September and December. On the other hand, CA presented values above 18 m/s between 91 and 98 km (32 m/s) in September. But, the small amplitude predicted by the GSWM-09 in October-December between 82 and 91 km height is not observed over CR. On average, considering the dependence of amplitude with altitude, the amplitude in CR increased from 82 km (7.8 m/s) to 91 km (15 m/s), then decreased to 98 km (6.6 m/s). CA presented a minimum at 85 km altitude~~-~~ (5.8 m/s), and increased almost linearly to 15.6 m/s at 98 km. ~~Comparing visually~~Visually comparing the figures, GWSM-09 seems to ~~represent~~ qualitatively represent the CR and CA observation~~.~~ fairly well.

3.2 Meridional diurnal amplitude

Figure 3 shows the meridional diurnal tides observed in CR and CA ~~and~~, as well as those predicted by the GSWM-09. Both sites show, according to the model, amplitudes above 20m/s in July-September and January-April at altitudes between 82 and 98 km, and minimum amplitudes in May-June and November. Observationally, CR presents larger amplitudes compared to CA, mainly in December. Comparing CR with CA, it is clear that they are similar to each other in this regard. The amplitudes in CR increase in July after presenting a minimum in May-June. On average, considering data from April to January in the range of 82 to 98 km of altitude, diurnal amplitudes in CR and CA were 23.3 ± 11.4 m/s and 22.6 ± 9.2 m/s, respectively. ~~Differently~~Differing from CA, in December CR presented ~~in December~~ a pronounced maximum, with values above 50 m/s at 94 km, which is not predicted by the GSWM-09 model. Details about ~~difference~~differences between model and radar ~~will be show~~are shown in Figure 4.

Comparisons ~~in~~between GSWM-09 and radar are shown in Fig. 4 for both zonal and meridional diurnal amplitudes ~~between GSWM-09 and radar~~ in the range of 82 to 98 km from April 2005 to January 2006 ~~are shown in Fig. 4~~. In order to match the altitude gates of model and radar, we calculated the mean of observed ~~amplitude~~amplitudes from 85 to 88 km heights, which ~~supposed to be~~is applicable at a new altitude (86.5 km). The result was compared to the specific altitude of 86.3 km of the model. ~~Figure~~ Fig.4 represents the ~~percent variance~~difference in percentage of zonal and meridional amplitude from model and radar ~~to~~for each altitude and month, ~~in~~for both CR and CA. It is important to ~~inform~~note that ~~the color scale is not~~

~~symmetrical concerning the~~positive values~~. Positive values~~ in the graphs mean that the value ~~of~~from the model is ~~bigger~~higher than that observed by radar. In regard to zonal amplitude, the ~~big~~large blue area in ~~Figure 6a is~~Fig.4a occurs because the observed amplitude in December at 86-94 km height was ~~higher, and it is not predicted by~~ considerably larger than the model~~. Months~~ outputs. The months from April to October present ~~a~~the smallest ~~difference~~differences between model and radar. ~~At CA, on~~ On the other hand, in CA, considering altitudes above 86 km, the amplitude observed by the radar ~~seems to approach to~~generally agree with the model, except in October when this difference ~~increase~~increased to ~70%. The meridional component in CR, similarly to the zonal one, ~~also presented~~ showed a large blue area in November-January ~~a huge blue area~~ which indicates that observed ~~amplitude~~amplitudes are more than 100% of the model. This is because meridional diurnal ~~amplitude~~amplitudes observed by the radar also increased significantly in December above 91 km height. An interesting feature observed at CA was two big blue areas in meridional amplitude separated by reddish area with values below 60%. Comparing zonal and meridional components observed in CR and CA, we can say that the meridional amplitude seems to be more ~~conveniently~~accurately described by the GSWM-09 than the zonal.

3.3 Zonal diurnal phase

Figure 5 shows the observed and model zonal ~~phase~~phases at different altitudes ~~in~~at CR and CA as a function of month of the year ~~to~~for each interval of altitude. The zonal phase (in Local Time) presented some interesting results. These included a clear uniform phase difference in altitude in CR, except for January 2006~~; a large variation of phase at CA for altitudes of 82-91 km from July to January; May-July and November presented only small variations of phase according to altitude, suggesting, perhaps, a dominant evanescent mode or non-migrating tide.~~ . The phase in CR, in contrast to CA, shows a clear linear dependence on altitude in most months, which makes it possible to determine the wavelengths of the tidal propagation assuming a quasi-monochromatic wave. A decrease of the phase between May and January is generally evident. Also, an upward propagation of the diurnal tide is clear, especially in CR where the phase decreases as the altitude increases. The vertical wavelength was obtained considering the altitude as an independent variable, but some additional criteria were considered in order to extract reliable vertical ~~wavelength~~wavelengths. In particular, a linear regression of at least 4 altitudes in sequence was required, and the fit was only accepted if the R-squared value was above 0.9. The results for CR and CA, on average, were 25.4 ± 4.0 km and 22.7 ± 7.3 km respectively. Because the zonal diurnal ~~phase at~~phases in both CR and CA normally showed ~~evidence of modal superposition between the altitudes~~undefined behavior with height, only 4 months were available to determine the vertical ~~wavelength~~wavelengths using the above criteria. According to the GSWM-09, the vertical wavelength in CR and CA should be about 27.4 ± 2.1 km and 29.3 ± 4.8 km, respectively. ~~It~~This is almost 8% and 30% higher (respectively) than ~~that one~~the ones observed in CR and CA. We discarded very long vertical wavelengths in our analysis simply because of the criteria discussed above. Large vertical wavelength could be indicative of evanescent structure or a presence of other mode of oscillation, e.g., nonmigrating modes; in addition, gravity wave breaking can act to increase the vertical wavelength (Ortland and Alexander, 2006).~~ Nevertheless, it seems that the GSWM-09 does overestimate the vertical wavelengths.~~

The zonal diurnal phase, according to the GSWM-09, has ~~difference~~differences in values in CR and CA. Comparing the same ~~altitude to~~altitudes in CR and CA, the difference of phase between ~~CR and CA~~them, from April to March, ~~in~~on average, is 3.1 ± 0.2 hr. ~~With~~In regard to observational ~~and~~versus model results, ~~it is clear~~ the irregularity of phase shift from CA ~~according to months which~~ as a function of month makes ~~the~~an observational comparison, ~~depend~~which depends on the altitude and month, practically impossible. On the other hand, the difference between CR and model, even ~~presenting~~allowing for some discrepancies at a specific altitude and month, is 0.2 ± 4 hr, ~~in~~on average.

3.4 Meridional diurnal phase

The meridional phase (in Local Time) presents a behavior quite different to that of the zonal component. ~~Figure~~ Fig.6 presents the meridional phase observed by radar and by GSWM-09 in CR and CA. It is clear that ~~a~~an observed downward phase propagation is evident at both sites, and a small decrease of phase from June to January occurs. The regularity of phase with altitude permitted us to estimate the vertical wavelength, using the criteria mentioned ~~ealier~~earlier, for all months with data. The results were vertical wavelengths of 25.1 ± 5.3 ~~m/s~~km and 25.6 ± 4.6 ~~m/s~~km in CR and CA, respectively. According to GSWM-09, the vertical wavelengths in CR and CA should be 24.5 ± 0.8 km and 24.2 ± 1.0 km. An interesting feature observed was the difference of phase, in Local Time, between CR and CA. At the same altitude and month, the difference in the time of maximum ~~at~~in CR compared to CA was 13.3 ± 2.3 ~~hours~~hr, on average, if we consider that CR is ahead of CA. Considering phases calculated by GSWM-09 between 82 and 98 km, the difference between CR and CA should be, on average, 8.7 ± 0.6 ~~hours.~~ hr. The GSWM-00, an earlier version of the model that does not include ~~non-migrating~~nonmigrating tides, shows the difference between CA and CR should be 12.0 ± 1.6 ~~hours~~hr, on average. That result is close to the ~~observations~~radar determinations.

4 Discussion

The observational results were compared ~~to~~with the Global-Scale Wave Model (GSWM), version 2009, which is the newest one. In general, the GSWM-09 predicts the meridional component more ~~satisfactory~~satisfactorily than the zonal one. However, just as for the zonal amplitude, the meridional component also showed large quantitative differences between model and observed results in most months. When comparisons are made between the sites, June and July present similar results for zonal and meridional amplitude, respectively. In August and October, the zonal winds at 82 km in CR and CA are similar in magnitude but they are different in November-December. The increase of the zonal and meridional diurnal amplitude in CR in December was not observed in CA and it is not predicted by the model.

Formatado: Fonte: 12 pt

Davis et al., (2013~~,~~), reported a study of the diurnal amplitude of meteor ~~wind~~winds observed at Ascension Island (8°S, 14°W) from 2002 to 2011. They show in ~~Fig.~~Figure 6 of their work a composite-year monthly~~ wind of~~ mean zonal and meridional diurnal amplitudes as a function of month and altitude which present a~~ good agreement to CA and~~ good agreement to the GSWM-09 model. The availability of 9 years of data may have smoothed out irregularities that arise in ~~any one year; this is not our case.~~a short period of observation; even so, there is a good similarity between Ascension and one year of data in CA. In that work, they also have compared their observation with the Canadian Middle Atmosphere Model (eCMAM) and the Whole Atmosphere Community Climate Model (WACCM) (Fomichev et al., 2002; Du et al., 2007).

The zonal diurnal ~~amplitude~~amplitudes calculated by GSWM-09 ~~to~~ in the range between 82 and 98 km altitude for CR and ~~CR~~CA are, in general, ~~very~~ similar~~, as well as~~ in behavior to the meridional component. ~~The difference, basically, is~~ Both components present a decrease in amplitude during summer and winter solstices months. However the magnitude of the meridional ~~component~~diurnal amplitude is ~~double~~twice that of the zonal one ~~because atmospheric tides are more important to~~ during the whole year. Concerning the diurnal phase, the model presents a regular phase variation in time and altitude for both components. That regular variation was not observed by the radar in zonal diurnal phase, in contrast to the meridional one. The reason is possibly related to the influence of nonmigrating modes, which are in turn dependent on the zonal background wind ~~at low latitudes. An~~field (Hagan and Forbes, 2002, 2003). Also, an increase in zonal and meridional amplitude at 88-98 km height in CR was observed in December which is not predicted by the model.~~ Geographic~~

The geographic and climate conditions in CR and CA are quite dissimilar. ~~It~~For example, it would be reasonable to expect different behavior of the tides at the two sites because of~~, e.g.,~~ their different levels of response to water vapor absorption and tropospheric latent heat release by large-scale deep convection. Lieberman et al., (2007~~,~~), modeled how the variations of diurnal tropospheric heating due to water vapor and latent heat could affect the amplitude of the meridional tidal winds in the mesosphere. This work concentrated ~~in~~on 1997-1988, when the ENSO (El Niño -Southern Oscillation) was very strong. Because water vapor heating presents a migrating component, it is ~~to be~~ expected that it ~~rules~~helps define the migrating tide in the mesosphere wind~~; on~~. On the other hand, the ~~non-migrating~~nonmigrating component is driven by thermal forcing ~~the~~ which is associated with water vapor heating and latent heat~~. In~~ effects. The last months of the 2005~~-2006 was a~~ period was one of weak positive phase for the Southern Oscillation Index (SOI). ~~It~~This means that the water of the eastern and central tropical Pacific Ocean was cooler, ~~or~~so that the La Niña phenomenon was occurring. Thermal excitation due to absorption of solar radiation by water vapor ~~decrease~~would have decreased at that time, and the effect in the mesosphere could decrease too~~, on the other hand, during La Niña period exists a tendency to be wetter than normal in CR and CA, which~~. This could explain the increase ~~the latent heat due to deep convection in the troposphere.~~ in amplitude in zonal and meridional components only in CR in December and January, which is not predicted by the model.

Specifically, the climate is desert-like at CA but very tropical in CR, which is a country of width ~120 km from southwest to northeast, surrounded by the Atlantic (east) and Pacific (west) ~~Ocean~~Oceans. São João do Cariri, on the other hand, is a city in the country of the Northeast of Brazil, having the Atlantic Ocean 190 km to the east and 250 km to the north. The Pacific Ocean is 4800 km to the west. CA is located in the driest region in Brazil. Some reports have proposed that latent heat release is important to semidiurnal tides (Hagan and Forbes, 2003, Zhang et al., 2010). Lindzen (1978) originally considered that latent heat release is not important to the diurnal tide. Since then, however, many reports about the possibility of diurnal tides, including migrating and ~~non-migrating~~nonmigrating, in the MLT being affected by ground-level sources in the tropical region have been published (Hamilton, 1981; Hagan, 1996; Forbes et al., 1997). Hagan et al., (1997) showed the importance of the seasonality of convective activity in the Troposphere ~~to~~on the diurnal amplitude of the meridional wind at 21°N; it is strong in January and weak in July. This clear dependence is due to the diurnal amplitude of the effective rainfall rate that varies with months. So, convective activity could explain the difference in behavior of the zonal and meridional components ~~behavior between~~in CR and CA. Ascension Island, which is located practically in the middle of the Atlantic Ocean, has a desert climate with total precipitation of only 200 mm per year. This is almost half that of CA, and ten times less than CR. As we have presented above, CA (and Ascension) ~~tends~~tend to be closer to the model predictions than CR. It is likely that ~~others~~other modes of oscillation (including ~~non-migrating~~nonmigrating tides), which are more sensitive to latent heat release, are present in the CR winds.

5 Conclusions

Formatado: Fonte: Não Negrito

~~Ten months of simultaneous observation of mesospheric winds by meteor radar installed in CR and CA have been analyzed in order to compare tidal winds, with emphasis here on the amplitudes and phases of zonal and meridional diurnal tides. A comparison of these observed parameters have been made to those predicted by GSWM00 model. Background winds were, briefly, presented in the work. The monthly zonal winds at CA presented a semiannual oscillation similar to CR, with values of amplitude close to 15 m/s at 82 km, decreasing to ~6 m/s at 94-98 km height. The meridional winds, on the other hand, were small relative to the zonal ones, at least for altitudes above 85 km at both locations. The zonal and meridional diurnal tidal parameters showed interesting results. CR presented a peak in diurnal zonal amplitude in September at 94 km, in general agreement with the GSWM-09 model. December also presented a peak at 91 km but, in contrast to the September case, this was not predicted by the model. With regard to the meridional winds, observations in CR presented a peak at 94 km height in December, while the model predicted a peak earlier, in October. CA showed no strong activity at all in the meridional tides in the September to December time-frame. In a general way, diurnal meridional parameters measured over CA compared better to the GSWM. Vertical wavelengths measured at the site were often in broad agreement with the GSWM, being in the range 25-30 km, with the observational data showing slightly shorter vertical wavelengths. Detailed comparisons (summarized in Fig. 6) showed periods of good agreement and periods of poor agreement with the GSWM. The case has been made that the very different climates at the two sites (with CA being desert-like and CR being very tropical~~

~~which can be a consequence of large scale tropospheric phenomena that take care far away from the sites) may be producing significant non-migrating tides, especially over CR. A longer-term study over many years may help clarify this possibility.~~The results presented in this work, specifically about diurnal oscillations, showed that mesospheric winds observed by meteor radars installed in CR and CA during 2005, in general, are in agreement with the GSWM-09, especially in the meridional wind. In CA, e.g., comparison between model and observation shows a great accordance between them, with minimum amplitude increasing according to height in the solstice of winter and maximum values from August to January. On the other hand, in CR, we can note some discrepancies between observation and model. In CR an increase of amplitude was observed in December between 91 and 98 km height, which is not predicted by the model. Also, in May-June, the meridional amplitude was low in the range of height of this work. The GSWM-09 predicts two minima, in May-June and October-December. Concerning the phase, we could say that CA, again, presented a better accordance with the model. The higher discrepancies between observation and model happened for zonal winds in CA and especially in CR. Again, the model can reproduce CA results better than CR in terms of amplitude. We suggest that this is because of the presence of active nonmigrating modes in CR, which are not predicted by the model. That anomaly could be, e.g., a higher participation of water vapor absorption and tropospheric latent heat release by deep convection due a weak La Niña effect being more important in CR than CA. A longer-term study over many years could help clarify if anomalous behavior in diurnal amplitude could be associated to variability of convective activity over sites of the radars.

Data availability: All meteor radar data can be requested from INPE and UWO. Contact Dr. Paulo Batista (paulo.batista@inpe.br) and Prof. Wayne Hocking (whocking@uwo.ca)

~~Authors~~Author contributions: Ricardo Buriti is responsible for the operation of the radar at CA and has written the manuscript and made the analyses of data using software provided by Wayne Hocking. The same software is used on the CR meteor radar, which was also built ~~and~~ by W. Hocking using grants from NSERC in Canada~~.~~. Paulo Batista and B. Clemesha (in memoriam) ~~is~~are responsible for the data and for the meteor radar of CA. I. Paulino, A. Paulino and A. Medeiros have contributed to the discussion of the manuscript. M. Garbanzo-Salas is a collaborator of W. Hocking and responsible for operation of the CR meteor radar.

Competing interests: The authors declare they do not have any competing interests.

Acknowledgements

This work is partially supported by National Council for Scientific and Technological Development (CNPq) under process 307247/2016-7~~.~~ and Paraíba State Research Foundation (FAPESQ) - 002/2019. We also thank the Federal University of Paraíba for facilities to install ~~and to operate~~ the meteor radar. Construction and support of the CR radar was supplied by the Natural Sciences and Engineering Research Council of Canada. The Land and buildings at the CR site were supplied by the University of Costa Rica. We thank Xiaoli Zhang of Department of Aerospace Engineering Sciences, University of Colorado, for making the GSWM-09 results available.

References

Buriti, R. A., Hocking, W. K., Batista, P. P., Medeiros, A. F., and Clemesha, B. R. Observations of equatorial mesospheric winds over Cariri (7.41S) by a meteor radar and comparison with existing models, Ann. Geophys., 26,485–497, doi.org/10.5194/angeo-26-485-2008, 2008.

Chang, L. C., Ward, W. E., Palo, S. E., Du,J., Wang, D.-Y., Liu, H. L., Hagan, M. E., Portnyagin,Y~~.~~., Oberheide, J., Goncharenko, L. P., Nakamura, T., Hoffmann, P., Singer, W., Batista, P., Clemesha, B., Manson, A. H., Riggin, D. M., She, C.-Y., Tsuda, T., and Yuan, T.: Comparison of diurnal tide in models and ground-based observations during the 2005 equinox CAWSES tidal campaign, J. Atmos. Sol-Terr. Phys.,78-79, pp. 19-30, doi:10.1016/j.jastp.2010.12.010, 2012.

Chapman, S. and Lindzen, R. S.: Atmospheric Tides: Thermal and Gravitational, D. Reidel, Dordrecht. 1970.

Clemesha, B. R., Batista, P. P., Buriti, R. A. and Schuch, N.: Seasonal variations in gravity wave activity at three locations in Brazil. Ann. Geophys., 27, 1059-1065, 2009.

Davis, R. N., Du, J., Smith, A. K., Ward, W. E., and Mitchell, N. J.: The diurnal and semidiurnal tides over Ascension Island (8°S, 14°W) and their interaction with the stratospheric quasi-biennal oscillation: studies with meteor radar, eCMAM and WACCM, Atmos. Chem. Phys., 13, 9543-9564, doi:10.5194/acp-13-9543-2013, 2013.

Deepa, V., Ramkumar, G., Antonita, M., Kumar, K. K., and Sasi, M. N.: Tidal oscillations in the MLT region over Trivandrum (8°N, 77°E) – results from SkiYMET meteor radar observations, ILWS Workshop 2006, GOA, February 19-24, 2006.

Du, J., Ward, W. E., Oberheide, J., Nakamura, T., and Tsuda, T.: Semidiurnal tides from the Extended Canadian Middle Atmosphere Model (CMAM) and comparisons with TIMED Doppler Interferometer (TIDI) and meter radar observations, J. Atmos. Sol-Terr. Phys., 69, 2159–2202, doi:10.1016/j.jastp.2007.07.014, 2007.

Fomichev, V. I., Ward, W. E., Beagley, S. R., McLandress, C., Mc-Connell, J. C., McFarlane, N. A., and Shepherd, T. G.: Extended Canadian Middle Atmosphere Model: Zonal-mean climatology and physical parameterizations, J. Geophys. Res., 107, 4087, doi:10.1029/2001JD000479, 2002.

~~Forbes, J.M., Hagan, M.~~Forbes, M. J.: Atmospheric tides: 1. Model description and results for the solar diurnal component, L. Geophys. Res., 87, 5222-5240, doi:10.1029/JA087iA07p05222, 1982.

Forbes, J. M., Hagan, M. E., Zhang, X., and Hamilton, K.: Upper-atmospheric tidal oscillations due to latent heat release in the tropical troposphere, Ann. Geophys., 15, 1165-1175, doi:10.1007/s00585-997-1165-0, 1997.

Forbes, J. M., Zhang, X., Palo, S., Russell, J., Mertens, C. J. and Mlynczak, M~~.,~~.: Tidal variability in the ionospheric dynamo region, J. Geophys. Res., 113, A02310, doi:10.1029/2007JA012737, 2008.

Garcia, R. R. and Solomon, S.: The effect of breaking gravity waves on the dynamics and chemical composition of the mesosphere and lower thermosphere, J. Geophys. Res., 90, 3850-3868, doi:10.1029/JD090iD02p03850, 1985.

Guraray, A., Batista, P. P., Buriti, R. A., and Schuch, N. J.: On the variability of the quarter‐diurnal tide in the MLT over Brazilian low‐latitude stations, Earth Planets Space, 70, 140, doi: 10.1186/s40623-018-0910-9, 2018.

Hagan, M. E.: Comparative effects of migrating solar sources on tidal signatures in the middle and upper atmosphere, J. Geophys. Res., 101, 21, 213-21, 222, 1996.

Hagan, M. E., McLandress, C., and Forbes, J. M.: Diurnal tidal variability in the upper mesosphere and lower thermosphere, Ann. Geophys., 15, 1176-1186, doi:10.1007/s00585-997-1176-x, 1997.

Hagan, M. E. and Forbes, J. M.: Migrating and nonmigrating diurnal tides in the middle and upper atmosphere excited by tropospheric latent heat release, J Geophys Res, 107(D24), 4754, doi:10.1029/2001JD001236, 2002.

Hagan, M. E. and Forbes, J. M.: Migrating and nonmigrating semidiurnal tides in the upper atmosphere excited by tropospheric latent heat release. J. Geophys. Res., 108(A2), 1062,doi:10.1029/2002JA009466, 2003.

Formatado: Espaçamento entre linhas: 1.5 linhas

Formatado: Inglês (EUA)

Hamilton, K.: Latent heat release as a possible forcing mechanism for atmospheric tides, Mon. Weather Rev., 109, 3-17, doi:10.1175/1520-0493, 1981.

Hedin, A. E.: Extension of the MSIS thermosphere model into the middle and lower atmosphere, J. Geophys. Res., 96, 1159–1172, doi:10.1029/90JA02125, 1991.

Hocking, W. K.: Temperatures using radar-meteor decay times, Geophys. Res. Lett., 26, 21, 3297-3300, doi:10.1029/1999GL003618, 1999.

Hocking, W. K., Fuller, B., and Vandepeer, B.: Real-time determination of meteor-related parameters utilizing modern digital technology, J. Atmos. Sol-Terr. Phys., 63, 155–169, doi:10.1016/S1364-6826(00)00138-3, 2001.

Hocking, W. K.: Middle atmosphere dynamical studies at Resolute Bay over a full representative year: Mean winds, tides, and special oscillations, Radio Sci., 36(6), 1795-1822, doi:10.1029/2000RS001003, 2001.

Lieberman, R. S., Riggin, D. M., Ortland, D. A., Nesbitt, S. W., and Vincent, R. A., Variability of mesospheric diurnal tides and tropospheric diurnal heating during 1997-1998, J. Geophys. Res, 112, D20110, doi:10.1029/2007JD008578, 2007.

Lindzen, R. S.: Effect of daily variations in cumulonimbus activity on the atmospheric semidiurnal tide, Mon. Wea. Rev., 106, 526-533, doi:10.1175/1520-0493(1978)106, 1978.

Manson, A. H., Meek, C., Hagan, M., Koshyk, J., Franke, S., Fritts, D., Hall, C., Hocking, W., Igarashi, K., MacDougall, J., Riggin, D., and Vincent, R.: Seasonal variations of the semi-diurnal and diurnal tides in the MLT: multi-year MF radar observations from 2–70°N, modelled tides (GSWM, CMAM), Ann. Geophys., 20, 661–677, doi:10.5194/angeo-20-661-2002, 2002.

Meyer, C. K.: Gravity wave interactions with mesospheric planetary waves: A mechanism for penetration into the thermosphere-ionosphere system, J. Geophys. Res. 104, A12, 28181-28196, doi:10.1029/1999JA900346, 1999.

Ortland, D. A. and ~~alexander~~Alexander, M. J.: Gravity waves influence on the global structure of the diurnal tide in the mesosphere and lower thermosphere, J. Geophys. Res, 111, A10S10, doi:10.1029/2005JA011467, 2006.

Pancheva, D., Mitchell, N. J., Hagan, M. E., Manson, A. H., Meek, C. E., Luo, Yi, Jacobi, Ch., Kürschner, D., Clark, R. R., Hocking, W. K., MacDougall, J., Jones, G. O. L., Vincent, R. A., Reid, I. M., Singer, W., Igarashi, K., Fraser, G. I., Nakamura, T., Tsuda, T., Portnyagin, Yu., Merzlyakov, E., Fahrutdinova, A. N., Stepanov, A. M., Poole, L. M. G., Malinga, S. B., Kashcheyev, B. L., Oleynikov, A. N., and Riggin, D. M.: Global scale tidal structure in the mesosphere and lower thermosphere during the PSMOS campaign of June–August 1999 and comparisons with the Global Scale Wave Model, J. Atmos. Sol-Terr. Phys., 64, 1011-1035, doi:10.1016/s1364-6826(02)00054-8, 2001.

Taylor, M. J., Pendleton Jr, W. R., Gardner, C. S., States, R. J.: Comparison of terdiurnal tidal oscillations in mesospheric OH rotational temperature and Na lidar temperature measurements at mid-latitudes for fall/spring conditions, Earth Planets Space, 51, 877-885, 1999.

Teitelbaum, H., Vial, F., Manson, A. H., Giraldez, R., and Massebeuf, M.: Non-linear interaction between the diurnal and semidiurnal tides: terdiurnal and diurnal secondary waves, J. Atmos. Terr. Phys., 51,627–634, doi:10.1016/0021-9169(89)90061-5, 1989.

Thayaparan, T., Hocking, W. K. and MacDougall, J.: Observational evidence of tidal/gravity wave interactions using the UWO 2 MHz radar, Geophys. Res. Letts., **22**, 373-376, doi:10.1029/94GL03270, 1995.

Tokumoto, A. S.; Batista, P. P.; Clemesha, B. R .: Terdiurnal tides in the MLT region over Cachoeira Paulista (22.7ºS; 45ºW). Revista Brasileira de Geofisica, v. 25, p. 69-78, doi:10.1590/S0102-261X2007000600009, 2007.

Ward, W. E., Oberheide, J., Goncharenko, L. P., Nakamura, T., Hoffmann, P., Singer, W., Chang, L. C., Du, J., Wang, D.-Y., Batista, P., Clemesha, B., Manson, A. H., Riggin, D. M., She, C.-Y., Tsuda, T., and ~~T.~~ Yuan, T.: On the consistency of model, ground-based, and satellite observations of tidal signatures: Initial results from the CAWSES tidal campaigns, J. Geophys. Res., 115, D07107, doi:10.1029/2009JD012593, 2010.

Yuan, T., ~~et al. (2006),~~She, C. Y., Hagan, M. E., Williams, B. P., Tao Li, Arnould, Kan, Kawahara, T. D., Acott, P. E., Vance, J. D., Krueger, D., and Roble, R. G.: Seasonal variation of diurnal perturbations in mesopause region temperature, zonal, and meridional winds above Fort Collins, Colorado (40.6°N, 105°W), J. Geophys. Res., 111, D06103, doi:10.1029/2004JD005486~~.~~, 2006.

Zhang, X., Forbes, J. M., Hagan, M. E.: Longitudinal variation of tides in the MLT region: 1. Tides driven by tropospheric net radiative heating, J. Geophys. Res. 115, A06316, doi:10.1029/2009JA014897, 2010.

Formatado: Cor da fonte: Preto, Inglês (EU

Formatado: Normal, À esquerda, Recuo: À esquerda: 0 cm, Primeira linha: 0 cm, Espaçamento entre linhas: simples

Figures

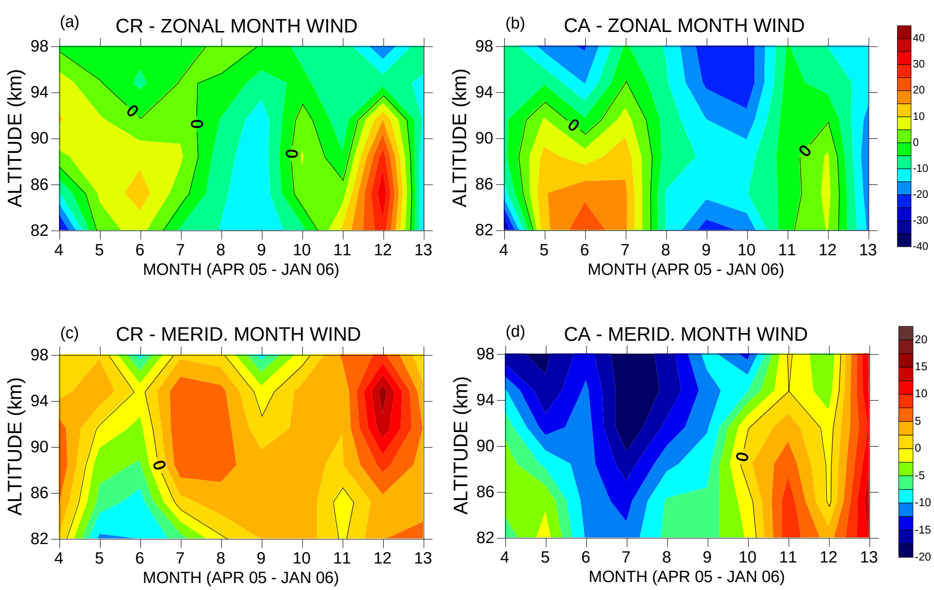


Figure. 1: Monthly averages of zonal (top) and meridional winds in CR (a and c) and CA (b and d) from April 2005 to January 2006. The color scales used for the zonal and meridional winds in the graphs are different.

Formatado: Fonte: Não Itálico
Formatado: Fonte: Não Itálico
Formatado: Fonte: Não Itálico
Formatado: Fonte: Não Itálico

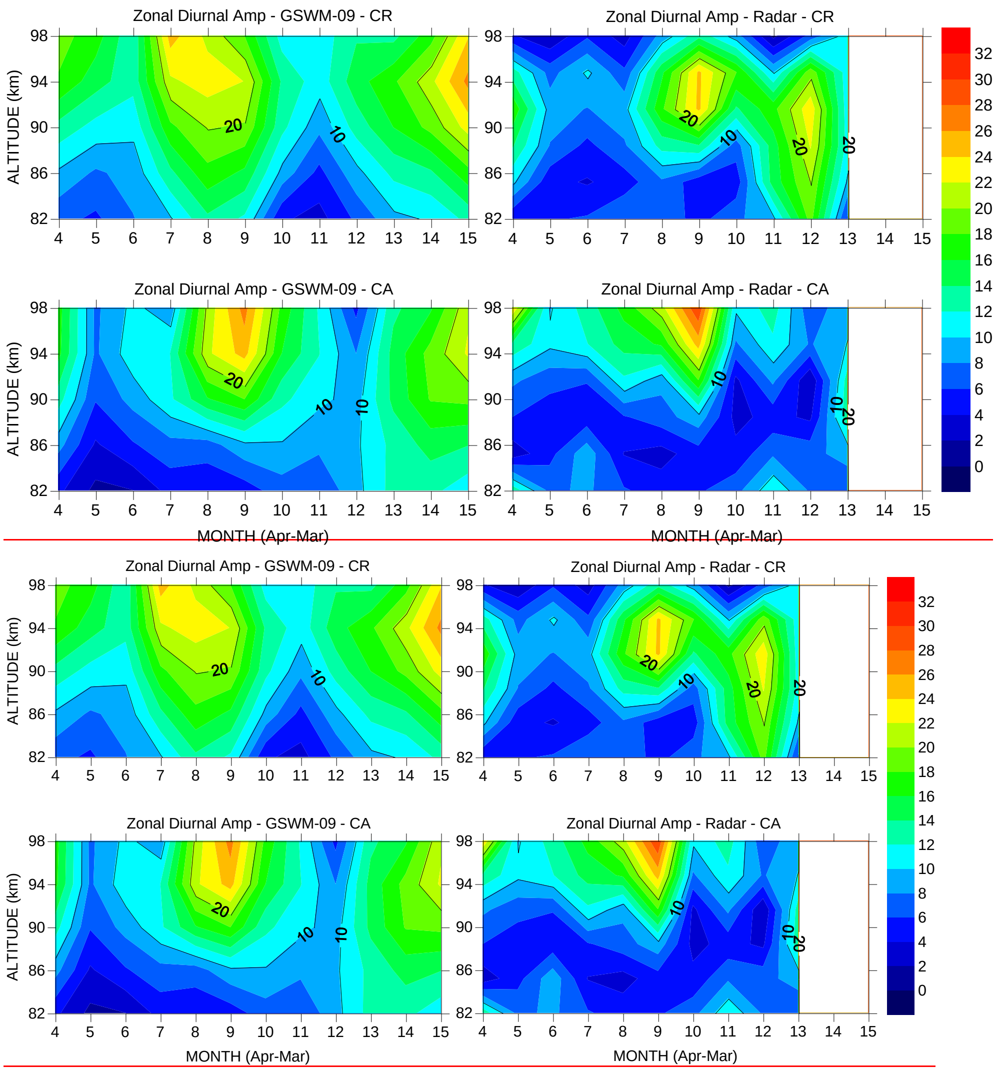
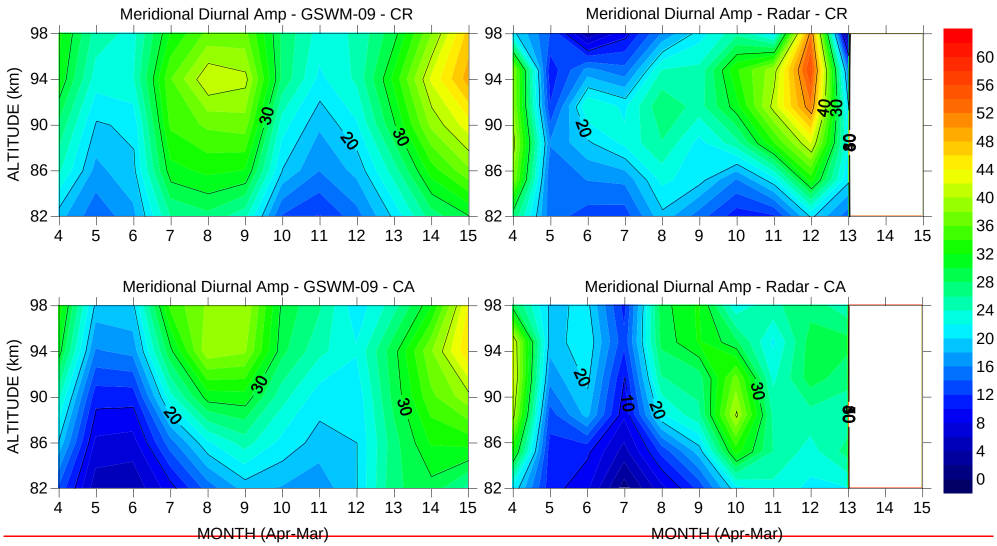


Figure. 2: The left-hand panels show diurnal zonal amplitudes as predicted by the GWSM-09 model in the range between 82 and 102 km height from April to March in CR and CA. The right-hand panels show diurnal zonal amplitudes observed by radar in CR and CA in the same range from April 2005 to January 2006. The color scale represents the amplitude in m/s.



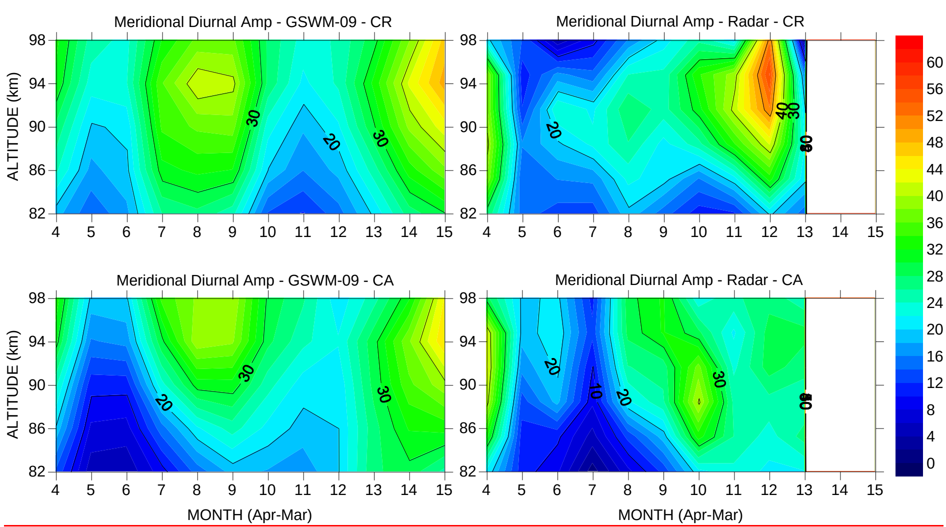


Figure. 3: Same as Fig. 2, but for meridional amplitude. The color scale is the double of the Fig. 2.

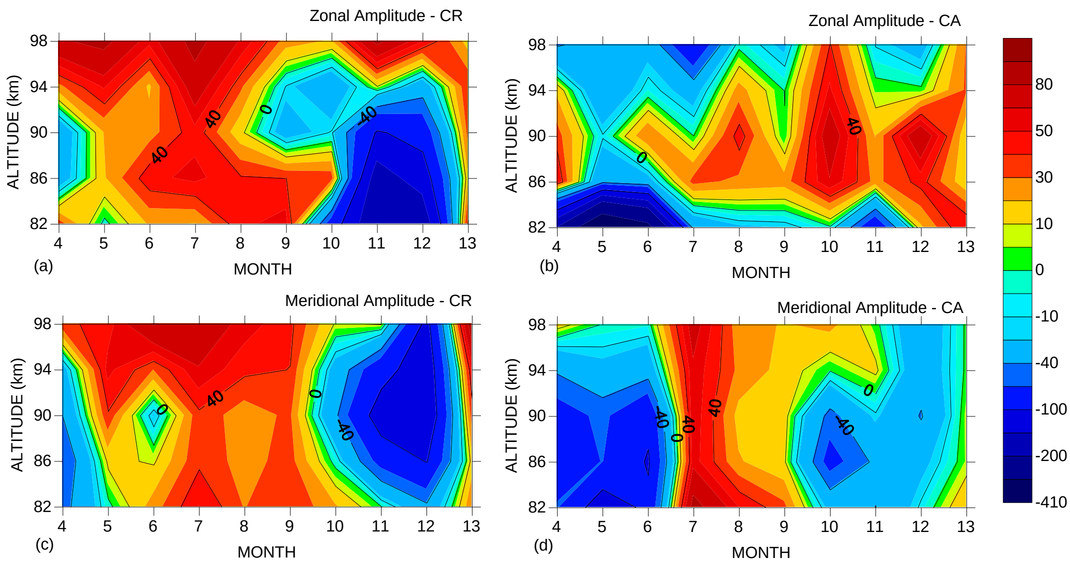


Figure. 4: ~~Percent variance~~Difference in percentage ((model – radar)*100/model) between GSWM-09 and radar diurnal amplitude ~~to~~for zonal (a and b) and meridional (~~a~~c and d) components ~~to~~at CR and CA from April 2005 and January 2006.

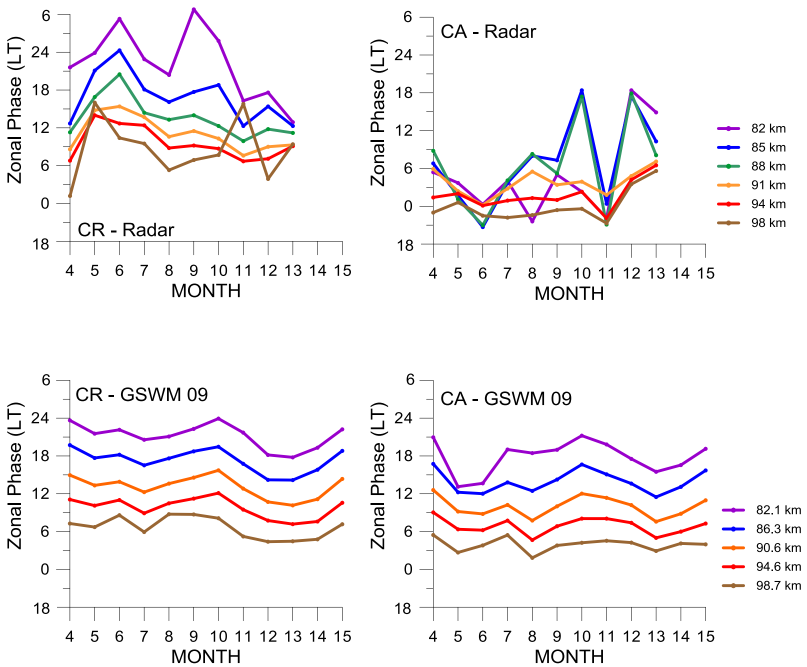


Figure. 5: Zonal diurnal phase in LT for CR (upper left), and CA (upper right) from April 2005 to January 2006, and GSWM-09 ~~(below~~for CR (lower left) and CA (lower right) from April to March. The height gates for the radar data and the GSWM-09 data are not quite the same, but close enough for visual comparisons.

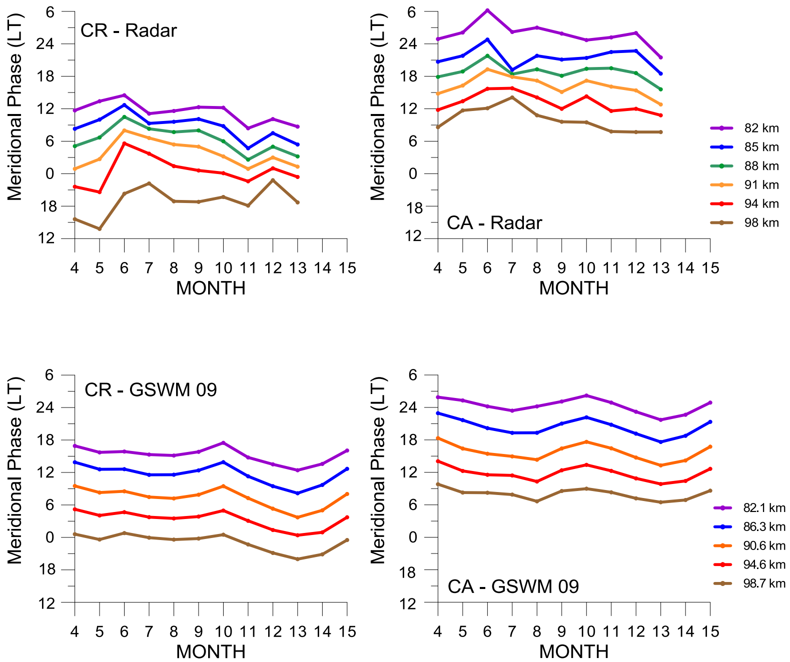


Figure. 6: Meridional diurnal phase in LT for CR (upper left), and CA (upper right) from April 2005 to January 2006, and GSWM-09 ~~(below~~for CR (lower left), and CA (lower right) from April to March. The height gates for the radar data and the GSWM-09 data are not quite the same, but close enough for visual comparisons.

Response to the Reviewer #1 – second review.

First of all, thank you very much again. Your suggestions surely have improved the manuscript. Referee's comments are in standard font, our responses are in itallics.

2nd review of "Diurnal mesospheric tidal winds observed simultaneously by meteor radar in Costa Rica and Cariri" by Buriti et al.

I appreciate the author's effort to address my questions and comments in my first review. The paper is greatly improved and scientifically sound. It would make the paper more insightful if the author could utilize GSWM09 to discuss a little more about the different diurnal tidal wind behaviors at these two sites. For example, the author could generate contour plots of tidal wind amplitude seasonal variations for the migrating tide DW1 and nonmigrating tide DE2 and DE3 at these two locations. This may help identifying the driving force of the distinct tidal wind seasonal changes at CR and CA, making the discussion more completed. The model should have the outputs for these diurnal tidal components.

You have raised an interesting point. Initially we worked with the GSWM-00 model. Then, according to a reviewer suggestion, we changed to the GSWM-09 because it considers nonmigrating oscillation modes too. So, we contacted Dr. Xiaoli from University of Colorado in order to get the amplitude and phase of diurnal and semidiurnal components, which including migrating and nonmigrating modes, generated by the model. Because we did not run the model, it is impossible for us generate contour plots according to your suggestion. Your idea is valid and very interesting, but it is not applicable for now. Maybe, we can work on it in the future. The idea of this manuscript was only to present the results observed at both location and present some modest discussion about it.

Some minor comments:

Line 42, Not sure what "These two mechanisms" are. Please specify.

Resp: The two mechanisms are forcing and dissipation. We have changed the text to suit.

Line 53-55, please provide the reference on this statement.

Resp. We have provided three references: two of them were already cited in the text, and a new one by Deepar et al., 2006 has been added. All show irregularity of phase with altitude.

Line 93, remove "this software" and replaced it with "it".

Resp: Done.

Line 101, please consider to replace "not exactly coincident with" with "closest to" .

Resp: Done.

Line 102, delete "but they close".

Resp: Done.

Line 105, delete "will here".

Resp: Done.

Line 107, "Data in February and March are missing for CR" due to…? Please specify.

Resp: we added "because the meteor radar presented technical problems".

Line 146, replace "between the" with "for both".

Resp: Done.

Line 168, please consider to replace "height was quite higher" with "was considerably larger than the model outputs".
Resp: Done.

Line 169, replace "Month" with "The results".
Resp: Done.

Line 170, replace "seems to approach to" with "generally agree with".
Resp: Done.

Line 171-172, please consider to delete "also presented" and modify the sentence as "showed a large blue area in November-January which indicates….".
Resp: Done.

Line 175-176, delete "of the two,".
Resp: Done.

Line 179, add "some" in front of "interesting results".
Resp: Done.

Line 182, add "with long vertical wavelength" after "non-migrating tide".
Resp: Done.

Line 189-190, "show evidence of model…". I am not sure I fully understand this statement. Please consider to rephrase.
Resp: Yes, you are right. So, we changed the sentence to "Because the zonal diurnal phase in CR and CA, normally, showed undefined behavior with height, only 4 months were available to determine the vertical wavelength using the above criteria."

Line 192, about the difference between the model and experimental results, considering the uncertainties in both the measurement and the model, these are not big differences and not unacceptable.

Resp: We decided to remove the last sentence of this paragraph ("Nevertheless, it seems that the GSWM-09 does overestimate the vertical wavelengths")

Line 215, replace "observational" with "radar".
Resp: Done.

Line 240, Should be "The geographic conditions".
Resp:We changed to "The geographic and climate conditions"

Line 243, delete “could effects”.
Resp: Done.

Line 245, delete “to be”.
Resp: Done.

Response to the Reviewer #2 – second review.

First of all, thank you very much again. Your suggestions surely have improved the manuscript. Our answer and comments are in italic font.

Review report of the revised manuscript entitled "Diurnal mesospheric tidal winds observed simultaneously by meteor radar in Costa Rica (10° N, 86° W) and Cariri (7° S, 37° W)" by Buriti et al. Although the authors revised the manuscript, it still requires further revision as there exist a couple of issues that weaken the content of the paper.

Major points

Abstract should be modified with essential information in concert with the present findings. Similarly, the section 5 (conclusions) should be more precise. In my view section 5 is rather a summary of the present work.

Answer: *Thank you, we have rewritten those parts.*

L.114-121: The description of the semiannual oscilation parameters, e.g., amplitude phase etc. directly from the wind (Figure 1) looks incongruous. Authors should restructure this part in order to express the information clearly and maintain the flow of the text.

Answer: *Yes, we agree that there is, a priori, incongruence between text and figures. Because we presented only semiannual oscillation, there are two peaks during the year. One is in ~160 doy and other in 342 doy (December 8th). It is clear that in December the wind is stronger in CR (in CA the zonal wind is stronger in June). It was showed in the paper of Buriti et. al., 2008, that there is a contribution of annual component to zonal and meridional winds which was not showed here because the data set of CR is less than one year. In the first version of the manuscript we presented both components (annual and semiannual) but we called special attention to the annual harmonic results. So, in the new version we only presented semiannual results from a simple harmonic analyses considering only semiannual component. We mentioned December in the text too. Hopefully this makes the description clear.*

Fig. 4: Large percentage deviations between the model and observations persisting over significant time span implies poor comparison among them. Authors should address this issue carefully.

Answer: *In the first version of the manuscript we chose some specific altitudes and months to compare observation and model. It was suggested that we could make a plot where we could compare all data together. This kind of comparison, considering time and altitude, can make the difference increase considerably. Sometimes, we guess, a general comparison is more adequate to this kind of work. But, important points that we have discussed in the text are clearly showed in Fig. 4.*

Other points

L. 70: Correct "5 receiver antenna…" to "5 receiver antennas…."

Done

L. 82: The error in amplitude should be mentioned in absolute value rather than percentage.

Answer: *The software we have used to analyses meteor wind observed by meteor radars gives us the error as a percentage. In term of absolute values, we could say that the error, varies from 1 to 4 m/s. This error is associated, basically, with the number of days used to make the composite day of each month.*

L. 93: Remove "software" from the sentence.
Done

L. 114: Correct "A semiannual harmonic analysis" to "A harmonic analysis to derive semiannual oscillation…"
Done

L. 116: Correct "doy (day of year) 160" to "160 doy (day of year)".
Done

L. 143: Correct "compared to CA" to "compared to CR".
Done

L. 161: Correct "will be show" to "will be shown".
Done

L. 165: The caption of the figure 4 indicates percentage deviation. However, the text mentions "percent variance".
Done

L. 167: Correct "model is bigger" to "model is higher".
Done

L. 208: The unit of the vertical wavelength should be "km".
Done

L. 226: The authors cursorily mentioned "good agreement" between the model and observations and hence the information is not clear.

Answer: *We changed this sentence to " They show in Figure 6 of their work a composite-year monthly-mean zonal and meridional diurnal amplitudes as a function of month and altitude which present a good agreement to the GSWM-09 model "*

We also changed part of the paragraph in order to make it clearer to the reader.

L. 235: "That regular variation was not observed in zonal diurnal phase, in contrast to the meridional one". It seems that the authors mean radar observations here.

Answer: *This has been changed to "That regular variation was not observed by the radar in zonal diurnal phase, in contrast to the meridional one."*L. 243: There is a repetition in the sentence "could effects could affect…"
Answer: *We have corrected it.*

L. 260: The relationship between the convective activity and rainfall causing higher amplitude of tide in January than July remains obscure and should be elaborated further.

It is well established that nonmigrating tides depend on how Sun heats the planet, which depends in turn on seasonality and geographic conditions. Thermal forcing (water vapor heating and latent heat) is associated, in general, with convection in the troposphere. The model, considers normal atmospheric conditions according to month and location. Plots of precipitation anomaly from NOAA show that a positive anomaly happened in December in CR. So, if precipitation is associated with deep convection, we could suggest that the increase of zonal amplitude in December in CR was because tropospheric latent heat and water vapor absorption were relevant in that period. So, we need to be cautious and wish to suggest this, but we don´t want to affirm too definitely that it is true. Probably we could go deeper in this subject if we investigate all those parameters simultaneously during a couple of years. But we do not wish this to be too much of a focus for this paper. So, the idea of this work was, in advance, to present interesting results from meteor radars from two different places with roughly complementary latitudes but for the same time period of observation.

I am sorry to reiterate that the English is not up to the mark and should undergo thorough checking. The language requires substantial refinement to reach a satisfactory level. Grammar needs to be corrected at various places in the text carefully.

Answer: *We tried to improve the level of the text.*