Quasi-2-day wave observed in the equatorial and low latitudes MLT regions of the Southern Hemisphere

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Abstract

Simultaneous observations of the atmospheric neutral winds in the mesosphere and lower thermosphere (MLT) region by meteor radar have been carried out at São João do Cariri (7.4° S, 36.5° W) and Cachoeira Paulista (22.7° S, 45.0° W). From the wind variability we investigate the planetary-scale quasi-two-day waves, which are present at both the sites during the winter of 2004 and summer of 2004/2005. The amplitude of the meridional component was larger than that of the zonal component, reaching a maximum value of ~60 m/s at the equatorial site and ~25 m/s at the low latitude site during the winter. During the January-February period the 2-day wave was very similar at the two sites, with a maximum amplitude of ~50 m/s. The phase propagation with height shows a descending mode and upward energy propagation. The vertical wavelength estimated for Cachoeira Paulista was longer than for São João do Cariri, for all of the observed events. Cross-spectral analysis showed a significant coherence between the quasi-two-day oscillations observed at the two sites. From the phase difference between the two sites we concluded that São João do Cariri leads Cachoeira Paulista. These results are compatible with a westward propagating wave.

Introduction

The well-known quasi-two-day wave is a prominent feature of the upper mesosphere and lower thermosphere (MLT) region. This wave is a planetary scale oscillation that migrates westward, which maximize soon after the summer solstice and has been observed by ground-based and satellite techniques. Quasi-two-day waves are those oscillations with periods between 40-60 h and, in general, their amplitudes for the meridional wind component are greater than for the zonal at middle and high latitudes. Equatorial and low latitude observations have revealed the presence of this wave during the boreal and austral summers as well (Harris and Vincent, 1993; Palo and Avery, 1996; Gurubaran et al., 2001; Lima et al., 2004). Most studies have used simultaneous radar and satellite measurements to determine the zonal structure of the wave. In the Southern Hemisphere the zonal wavenumber 3 prevails (Muller and Nelson, 1978; Rodgers and Prata, 1981; Limpasuvan and Wu, 2003). In the Northern Hemisphere, zonal wavenumbers between 2 and 5 have been reported, with wavenumbers 3 and 4 being the more important (Meek et al., 1996; Thayaparan et al., 1997).

The quasi-two-day wave was interpreted as a manifestation of the Rossby-gravity (3, 0) normal mode (Salby, 1981). Using a mechanical model based on primitive equations, realistic background winds and analytic temperatures, Salby (1981) showed that the (3, 0) mode produces a significant response in the summer mesosphere. Hagan et al. (1993) performed a succession of numerical experiments using a linearized spectral model that includes realistic wind and temperature fields and dissipation effects, and also found a response to the Rossby normal mode in the lower thermosphere compatible with the observations. An alternative explanation was proposed by Plumb (1983). Based on a one-dimensional model, he showed that a 2-day wave with a zonal wavenumber 3 can be the product of zones of baroclinic instability above the summer stratospheric westward jet. Pfister (1985) extended the simulations to two dimensions and found peaks in the unstable wave growth at zonal wave numbers 2-4, with periods between 1.4 and 3 days. The possibility that the 2-day wave could be caused by a combination of the two mechanisms was suggested by Randel (1994) and, Norton and Thuburn (1996). Salby and Callaghan (2001) also explored the possibility that the 2-day wave could be produced by a mixture of the two excitation mechanisms.

In the present study, we investigate some aspects of the quasi-two-day wave observed in the horizontal winds obtained simultaneously in the equatorial and low latitudes MLT regions of the Southern Hemisphere, during winter 2004 and summer 2004/2005.

Meteor winds and data analysis

This study is based on hourly mean wind measurements collected simultaneously over São João do Cariri (7.4° S, 36.5° W) and Cachoeira Paulista (22.7° S, 45° W), Brazil. The data series cover the time interval from June 2004 to February 2005. The winds data were obtained by similar systems, called SKiYMET meteor radars. Both systems operate at a frequency of 35.24 MHz and use an interferometric

receiver antenna array. From the relative phases of the signals at the various antennas together with the echo range information, the position of the meteor is accurately located. The radial wind velocity is determined from the Doppler shift. Details of the system, operation mode and the meteor detection for the SKiYMET radar are described elsewhere (Hocking et al., 2001).

To examine the amplitude intensifications of the quasi-2-day wave activity, the wind data from June 2004 to February 2005 for both sites were subjected to harmonic analysis. The analysis was performed for sliding four-day segments stepped by one day. The quasi-2-day amplitudes and phases of the zonal and meridional wind components were fitted in a least-mean-square sense, assuming that semidiurnal, diurnal and quasi-2-day oscillations were present in the horizontal wind components at all times. Figure 1 shows the amplitudes of the 2-day oscillations for both the zonal and meridional components for the layer centered at 90 km in the time interval from June 2004 to February 2005. It can be seen from this figure that the 2-day activity has maximum amplitude during the solstice months, i.e. for time intervals from about day 212 (July 30, 2004) to day 243 (August 30, 2004) and from about day 356 (December 21, 2004) to day 414 (February 17, 2005). As can be seen, as at other sites, during 2-day wave events the meridional amplitudes were larger than the zonal, reaching maximum values of ~60/25 (winter) and ~50/45 m/s (summer) at Cariri/C. Paulista. The meridional amplitudes indicates the weaker presence of 2-day activity at other times of the year, mainly over São João do Cariri. In this work, the winter and summer occurrences of the 2-day wave will be analyzed only for the meridional component.

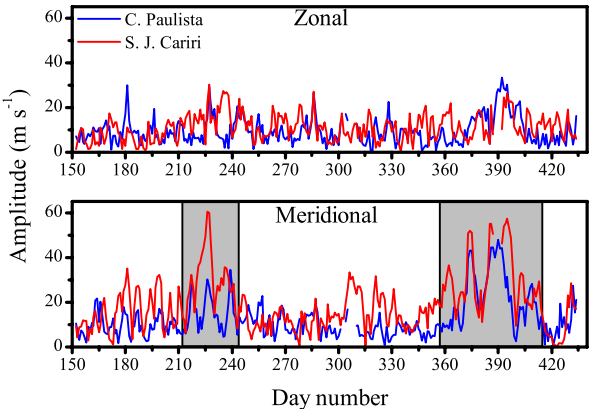

Figure 1 – Daily amplitudes of the 2-day oscillations at 90 km in São João do Cariri (red line) and Cachoeira Paulista (blue line) for zonal (upper panel) and meridional (bottom panel) components from June, 2004 to February, 2005.

To verify the behavior of the 2-day wave in the time domain, the meridional winds at the two sites were subjected to a band pass filter with cutoff periods of 42 and 54 h. Figure 2 shows filtered winds of the 2-day wave observed at 90 km for winter (2004) and summer (2004/2005) months. As can be seen, during winter 2004 the 2-day wave was more intense at the equatorial site than at the low latitude site, suggesting a leakage of the wave from summer hemisphere to winter hemisphere. During summer 2004/2005 the occurrence of the 2-day wave was very similar at the two sites, mainly during the interval from about day 370 to day 406 (January 04 to February 10). In general, the intense activity at the equatorial site were longer than at the low latitude site.

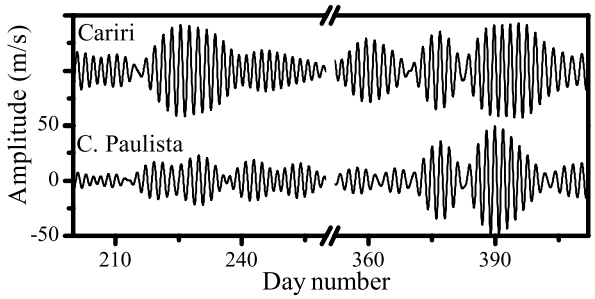

Figure 2 – Meridional component of the winds observed at 90 km in S. J. do Cariri and C. Paulista during 2004 winter and 2004/2005 summer. Data have been band-pass filtered to retain only periods between 42 h and 54 h.

To obtain information about the behavior of the amplitude and phase of the 2-day wave as a function of height, the results obtained by harmonic analysis, for meridional winds measured during the strongest events at both sites, are shown in the Figure 3.

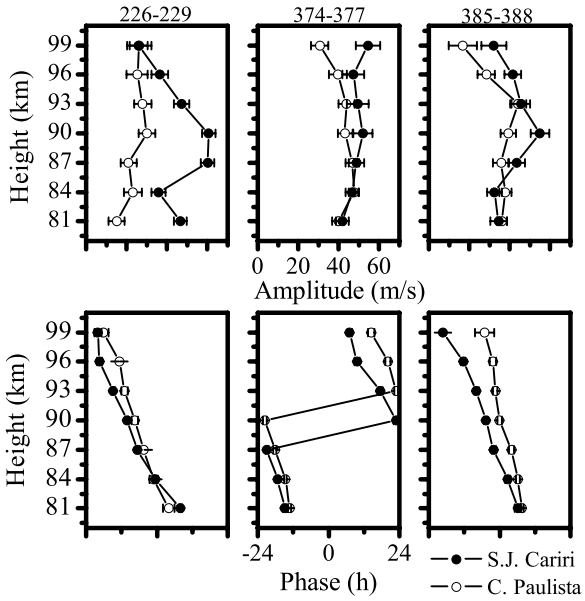

Figure 3 – Two-day wave meridional amplitude and phase as a function of height for 3 groups of four days obtained by harmonic analysis.

As can be seen in this figure, in general, maximum amplitude values occur for heights around 90 km at both sites. The behavior of the phase with height shows that the time of the maximum meridional wind, at both sites, is earlier at greater heights, suggesting a descending phase and upward energy propagation. From the phase structures, we estimated the vertical wavelengths. The results showed that at Cachoeira Paulista the vertical wavelengths (~40, ~50, and ~67 km) were longer than at São João do Cariri (~30, ~35, and ~35 km), for all 3 strong events.

Cross-spectral analysis provide another way to explore the relation between the dynamics at São João do Cariri and Cachoeira Paulista. Mean cross-spectra were computed for 7 atmospheric layers using 10-day meridional wind segments and the results for day intervals 226-235, 370-379 and 390-399, are shown in the Figure 4. The mean square coherence values are significant at periods near 2 days for all 3 considered segments. This means that, when a quasi-two-day peak in the spectrum appears at equatorial latitudes, it emerges at low latitudes too. From the phase plot is possible to observe that on average São João do Cariri leads Cachoeira Paulista. These results are consistent with westward propagation of the quasi-two-day wave

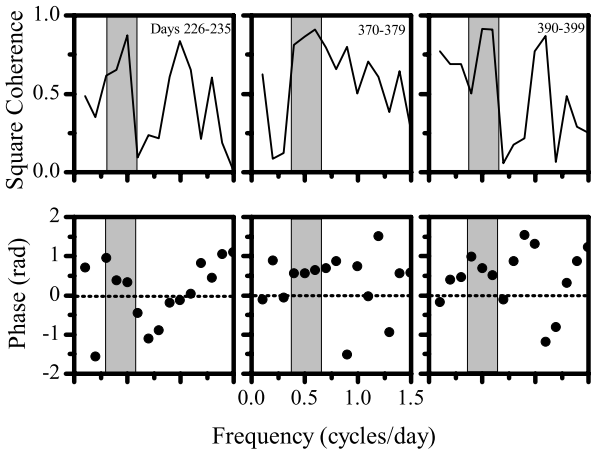

Figure 4 – Mean square coherence (top) and cross-spectral phase (bottom), for 7 atmospheric layers, between meridional wind measured at S. J. do Cariri and C. Paulista during 2004 winter and 2004/2005 summer.

Summary and Conclusions

Simultaneous observations of the meteor winds at São João do Cariri and Cachoeira Paulista, in the equatorial and low latitude MLT regions, respectively, have shown the presence of a 2-day wave during the winter of 2004 and the summer of 2004/2005. Because the zonal wind does not exhibit strong bursts in the two-day oscillation during the observation period, the analysis was focused on the meridional component.

Harmonic analysis showed simultaneous quasi-two-day activity events in equatorial and low latitude wind data during August, 2004 and January-February, 2005. The characteristics of the ~2-day wave events in horizontal winds over two sites are in accordance with those reported in the literature (Harris and Vincent, 1993; Lima et al., 2004).

Early observations from equatorial latitudes at Christmas Island (2^o N, 157^o W) and from low latitudes at Kauai (22^o N, 160^o W), in the Northern Hemisphere and, at Townsville (19^o S, 147^o E) and at Cachoeira Paulista, in the Southern Hemisphere, displayed significant amplitudes during both solstices in both wind components (Harris and Vincent, 1993; Fritts and Isler, 1994; Craig et al., 1983; Lima et al., 2004). Significant amplitudes for ~2-day oscillations during winter solstices are predicted theoretically as being due to leakage of the 2-day wave across the equator from the summer hemisphere. In our analysis we observed that the August 2004 event was intense at the equatorial site and weak at the low latitude location, suggesting the possible leakage of the quasi-two-day wave from the Summer Hemisphere during winter. During January-February 2005, the 2-day wave was very similar at the two sites.

The quasi-two-day wave amplitudes reached maximum values of 60 m/s at the equatorial site during the winter event and ~50 m/s at both sites during summer events. The vertical phase structure shows descending phase and the vertical wavelengths estimated for Cachoeira Paulista were longer than at São João do Cariri, for all observed events. The vertical wavelengths take values from 40 to 67 km at Cachoeira Paulista and from 30 to 35 km at São João do Cariri. The equatorial results are in agreement with recent investigation for Ascencion Island (7.9° S, 14.4° W) (Pancheva et al., 2004), whilst the low latitude results are in agreement with those also recently published by Lima et al. (2004), and with earlier studies for locations such as Christmas Island (Harris and Vincent, 1993), Tirunelveli (Gurubaran et al., 2001), Kauai (Fritts and Isler, 1994), Townsville (Craig et al., 1980), and Adelaide (Craig and Elford, 1981).

Cross-spectral analysis showed significantly coherence between the quasi-two-day activity observed at the two sites, showing that when a quasi-two-day peak appears in the equatorial region it will most often be seen also at low latitudes. From the phase difference between the two sites, we observed that on average São João do Cariri leads Cachoeira Paulista. These results are compatible with a westward propagation wave.

Acknowledgments

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