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Planetary wave oscillations in mesospheric winds, equatorial evening prereversal electric field and spread F

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[1] Analysis of the MLT region winds measured by a meteor radar and the evening F region vertical plasma drift (prereversal zonal electric field -PRE) measured by digisondes over low latitude sites in Brazil, provide evidence of planetary wave (PW) scale oscillations of episodic nature simultaneously at mesospheric and F region heights. ~4-day and 7-day periods are found to dominate the event analyzed. The PW scale oscillations in the PRE produces strong modulation in the equatorial spread F (ESF) irregularity processes as diagnosed by the digisondes. Considerations on the PRE development mechanism involving the E layer integrated conductivity including the effect of metallic ions and tidal winds point to the source of the PRE oscillations to be PW modulation of E region tidal winds. The PW oscillations in PRE appear to be an important source of the day-to-day variability in the ESF.
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1. Introduction

[2] Coupling processes involving planetary waves (PW) are believed to play a significant role in the day-to-day variabilities of the equatorial atmosphere-ionosphere system. PW scale oscillations have been identified in the equatorial electrojet current -EEJ [*Forbes and Leveroni*, 1992; *Abdu et al.*, 2006a], equatorial ionization anomaly [*Chen*, 1992] and equatorial F layer height and vertical plasma drift [*Abdu et al.*, 2006a; *Takahashi et al.*, 2005]. The influence of the PWs on the PRE has important consequences for the day-to-day variability in the ESF irregularity generation, which is primarily driven by the PRE. However, evidence on direct association between the PW forcing as observed in the mesosphere and the ionospheric response in terms of the PRE, and hence in the ESF, is lacking. Only geomagnetically quiet observational data can tell us about the ionospheric response features arising from upward propagating PWs. In this paper we present the first evidence of PW scale oscillations in the PRE with simultaneous such oscillations in mesospheric winds.

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2. Experimental Data

[3] The study is based on the mesospheric wind observations by a SkiYmet meteor radar [*Hocking et al.*, 2001] at Cachoeira Paulista (CP): (22.6°S, 45°W; dip: −32°) and F region vertical plasma drift measured by digisondes [*Reinisch*, 1996] at Cachimbo (CX) (9.47°S, 54.83°W, dip: −3°) close to the dip equator, and Campo Grande (CG) (20.44°S; 54.64°W; dip: −22°) closer to CP. The meteor wind data were processed at 1-hour and 3-km resolutions. The vertical drift of the bottom-side F-layer was obtained at 5-minute resolution using the true height h(f) values from digisondes, as dh(f)/dt. The drift velocity thus obtained is a reliable measure of the vertical plasma drift in the evening hours when the F layer rises to above ~300 km due to the PRE. We will be discussing the possible mechanism of how PWs could influence the processes responsible for the generation of the PRE as well as the role of the PRE as a major cause of the widely observed day-to-day variability in the ESF development.

3. Results

[4] An example of the vertical drift V_Z calculated for a few "quiet" days is shown in Figure 1. In Figure 1 (top) the V_Z calculated from digisonde data is compared with the model by *Scherliess and Fejer* [1999]. The observed Vz evening peak, V_{zp}, due to the PRE agrees reasonably well with the modeled drifts on some days only (the days 332 and 338 may be noted). The large day-to-day variations in the V_{zp} amplitude does not appear to be associated with the variations in the indices, F10.7, $\sum$Kp, and D_{st}, also plotted in Figure 1. This paper focus on such quiet time variations in the PRE to show that they are associated with PW scale oscillations in the MLT region winds observed simultaneously in a nearby geographic region by a meteor radar.

3.1. Association Between Mesospheric Winds and the PRE

[5] Figure 2a shows the peak amplitude of the PRE (V_{zp}) over CX, and CG, from day 270 (September 27) to day 342 (December 08). On some days the V_{zp} amplitude reaches the order of 80 m/s over CX and 50 m/s over CG, the day-to-day oscillations attaining the order of 50 percent at both the locations. The bottom two plots show the Morlet wavelet power spectra of the V_{zp} over the two stations wherein wave periods ranging from ~2 to ~15 days may be noted (inside the arc defining the edge effect in the analysis). The oscillation periods ranging from ~2 to 7 days during the day interval 305–320 may especially be noted. They appear well correlated at the two stations except for some possible local effects considering their North–South

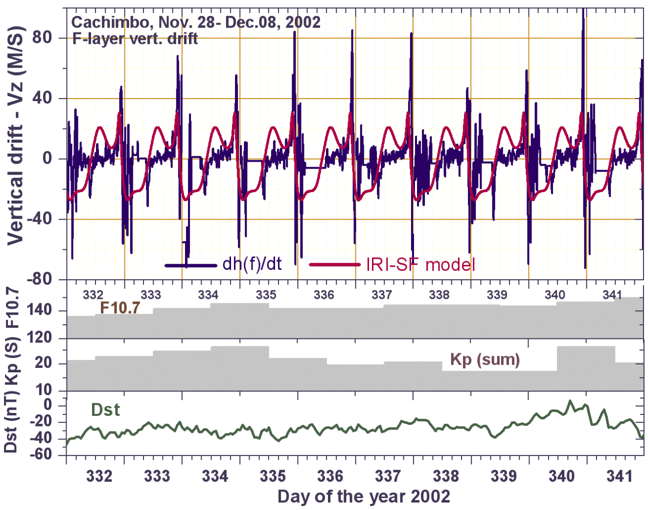

Figure 1. The F region vertical plasma drift obtained as dh(f)/dt at 6 and 7MHz for the period 28 November to 08 December 2002 (blue curve) and the IRI *Scherliess and Fejer* [1999] vertical drift model (pink curve, denoted as IRI-SF). The bottom three plots show the variations in solar flux F10.7, ΣKp and Dst indices.

separation by ~1200 km. We have verified that none of the major periodicities in the V_{zp} is related to any corresponding periods in the magnetic or solar flux indices. In Figure 2c are plotted the wavelet power spectra for the mesospheric wind zonal and meridional component diurnal mean values over CP, for the two heights, 100 km and 95 km. The periods within the solid line contours have 95% confidence level. We note clearly that PW scale periods ranging from ~2 to ~ 7 days that are present in the V_{zp} are present also in the mesospheric winds over CP. The time series plots of the wind amplitudes for the two components presented in Figure 3 show oscillation amplitudes of the order of 90–100 m/s. A decomposition analysis of the wave periods in the V_{zp} and in the wind resulted in the periods 4–5, 7 and 10–11 days as the more prominent ones. The amplitudes of the 4-day and 7-day oscillations are plotted in Figure 4. There seems to be a phase relationship (in the form of downward phase propagation) between the oscillations in V_{zp} and in the winds noticeable in both the 4-day and 7-day periods. Such downward phase propagation has been observed by *Pancheva et al.* [2003] from analysis of sporadic E layer versus mesospheric winds. Being a characteristic feature of the PWs this might be a key point for explaining the connection between the oscillations in the two height regions, the mesosphere and ionospheric dynamo region. We may note that in general the wind oscillations (related to V_{zp}) have more spectral power in its zonal than meridional component. These results demonstrate the existence of a strong vertical coupling, through upward propagating planetary waves, of mesospheric winds with the PRE.

3.2. Planetary Wave Oscillations in PRE and ESF Variability

[6] It is well known that the F layer evening height rise due to the PRE is a major cause for the development of the post sunset ESF irregularities [*Abdu et al.*, 1981; *Fejer et al.*, 1999]. Thus a major consequence of the PW oscillations in the PRE is its contribution to the day-to-day variability in the ESF widely observed under magnetically quiet conditions [*Abdu et al.*, 2006a]. The association between the V_{zp} oscillations and the ESF intensity over CX and CG is presented in Figure 5. The top two plots show the local time distributions of the ESF intensity for each individual

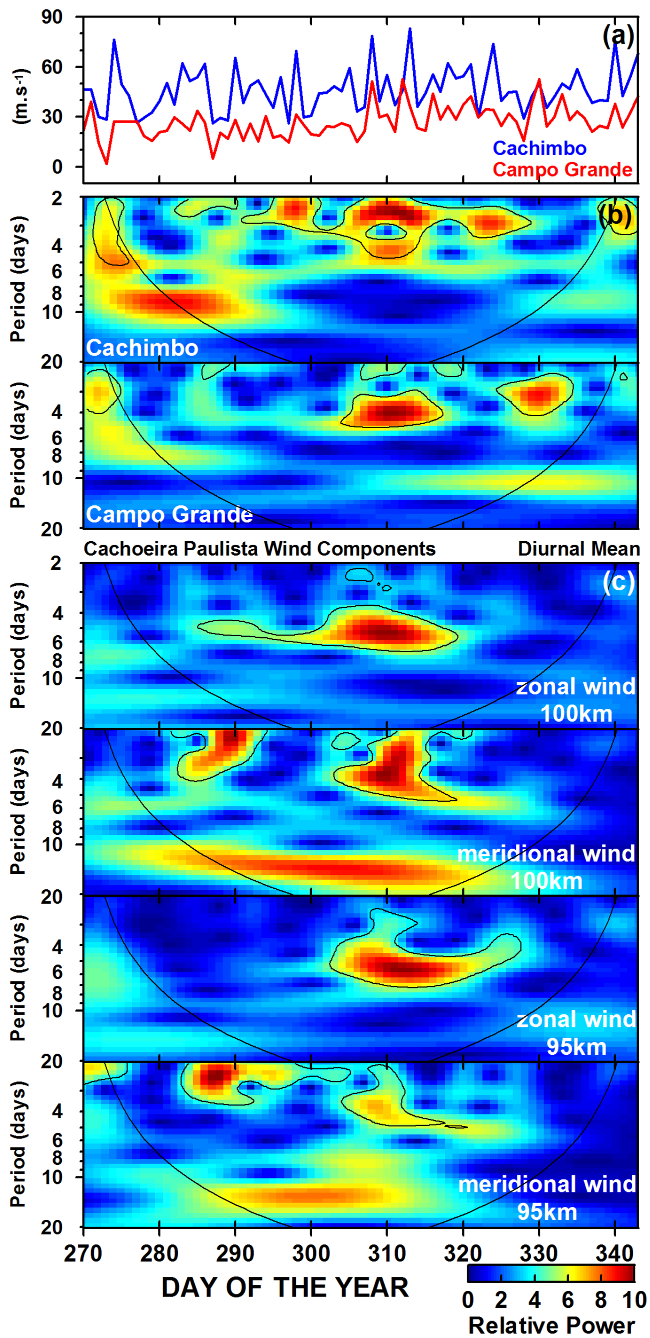

Figure 2. (a) Vertical drift velocity (V_{zp}) variations over CX and CG for the period October-December 2002; (b) Morlet wavelet power spectral distribution of V_{zp} oscillations over the two stations; (c) wavelet spectral distribution of the daily means of mesospheric zonal and meridional winds at 100 km over Cachoeira Paulista (the top two plots) and at 95 km (the bottom two plots).

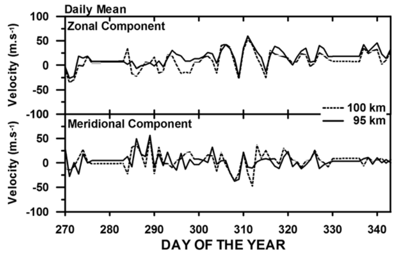

Figure 3. Time series plots of the mesospheric zonal and meridional wind amplitudes corresponding to their daily mean values of Figure 2.

night. Some of the large oscillation amplitudes of V_{zp} that are influenced mainly by PW oscillation are indicated by arrows. As a demonstration of the cause-effect relationship we may note that the total absence of spread F on day 289 and its occurrence on the next day is directly related to the small and large V_{zp} values, respectively. Examples of such cases can be noted around the days 313–314. 328–330 and 340–341. However such relationship varies significantly from case to case. (See for example, the days 307–308, 338–341, and few other days). This is due to the fact that the V_{zp} attaining a threshold value is an important prerequisite for the instability initiation while the continuing ESF growth will depend upon other factors such as the meridional/trans-equatorial winds through their role to modify the integrated conductivity of the unstable flux tubes [*Abdu et al.*, 2006b]. A detailed discussion of these aspects is beyond the scope of this paper. The results presented here do demonstrate that PW induced oscillations in the PRE is an important cause of the ESF day-to-day variability.

4. Discussion and Conclusions

[7] An important question concerns the interactive processes connecting the MLT winds to the PRE. The existing model calculations do not support any significant penetration of PWs into the ionospheric dynamo region. [*Forbes*, 1996]. At the same time the generation of the PRE by E- and F-region electrodynamical coupling processes makes it necessary that the PW effects reaching at least the E layer heights be the main cause of the oscillations observed in V_{zp}. 7-day oscillations in middle latitude E_S layers have been shown by *Pancheva et al.* [2003] to be caused by the PW modulation of the diurnal and semidiurnal tidal winds. A tentative explanation of our result can be attempted as follows.

[8] The evening eastward thermospheric zonal wind produces a vertical/downward electric field in the F region that leads to the development of the PRE as first modeled by *Heelis et al.* [1974]. The vertical electric field can be represented as:

$$E_z = U_y \times B_0[\Sigma_F/(\Sigma_F + \Sigma_E)] \quad (1)$$

where U_y is the thermospheric zonal wind, B_0 is the geomagnetic field intensity, and $\sum_E$ and $\sum_F$ are the integrated conductivities, respectively, of the E- and F-regions [*Abdu et al.*, 2006a]. Due to the faster post sunset decay of $\sum_E$, as compared to $\sum_F$, E_z tends to increase toward the nightside, and the application of curl-free condition to such an electric field could lead to the enhanced zonal electric field (PRE), as originally proposed by *Rishbeth* [1971]. The amplitude of the PRE is very sensitive to the longitudinal/local time gradient in the $\sum_E$ [*Abdu et al.*, 2004]. This gradient is determined by the post sunset ionization decay by recombination and the vertical plasma transport by tidal winds (possibly modulated by planetary waves as stated before). We have modeled the electron density distribution of the post sunset E layer under action of tidal winds to determine the resulting modification of the $\sum_E$ and its longitudinal/local time gradient. The modeling took into account the presence of the main metallic ions (Fe^+ and Mg^+) besides the principal molecular and atomic ions of the E-region (for details of the calculations see *Carrasco* [2005]). The results of calculations are plotted in Figure 6 for varying amplitudes of the zonal wind (A_y) and the meridional wind (A_x) by different percentages of their basic values, and they show significant variation both in the conductivity values and its local time gradients depending upon the amplitude and phases of the winds. The changes in the $\sum_E$ and its local time/longitude

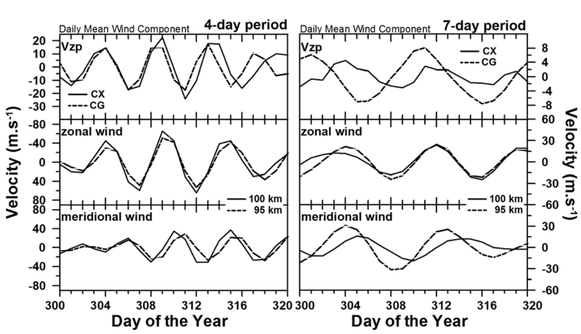

Figure 4. (left) 4-day and (right) 7-day oscillation in the V_{zp} over CX and CG and the corresponding amplitudes of the mesospheric zonal and meridional wind components at 100 km and 95 km.

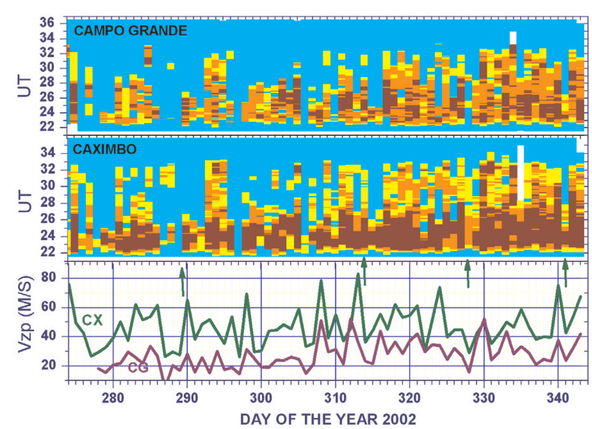

Figure 5. Spread F distributions in UT (=LT + 3hrs) versus the day of the year over (top) CG and (middle) CX. The Spread F intensity scale is calibrated using the numbers '1' for range spreading <100 km, '2' for >100 km and <200 km and '3' for >300 km. The darkest shade corresponds to the highest intensity "3". (bottom) V_{zp} oscillations over CX and CG.

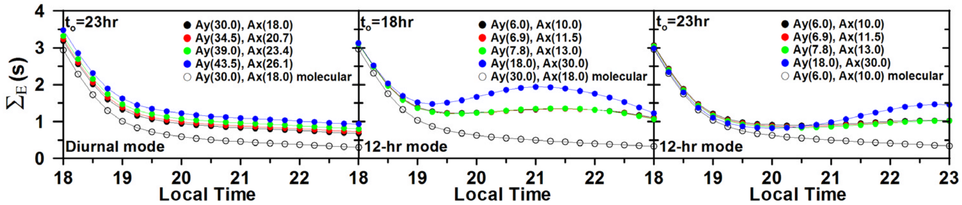

Figure 6. Integrated Pedersen conductivity ($\sum_E$) local time variation around sunset hours for different E region zonal and meridional wind amplitudes, including the contribution from metallic ion chemistry. Calculation using only the molecular ions results in smaller $\sum_E$.

gradient during the hours immediately following the sunset, produced by changes in the E regions winds (especially in the zonal wind) such as that simulated here, can cause significant variation in the amplitude of the PRE as was demonstrated in a recent paper by *Abdu et al.* [2004]. Thus the PW scale oscillations observed in the PRE can be caused by such oscillations in the E region tidal winds that are possibly modulated by the upward propagating PWs detected in the meteor winds. The main conclusions of this work may be stated as follows. Episodes of PW oscillations in the equatorial F region evening vertical drift/zonal electric field (PRE) with periods ranging from ~2 to ~7 days occur concurrent with such oscillations in the mesospheric winds. The oscillations in PRE cause large variations in the post sunset ESF intensity. A tentative explanation is proposed in terms of the changes in E region winds modifying the E region integrated Pedersen conductivity and its post sunset local time gradient, which in turn modifies the PRE. Thus one of the important sources of the day-to-day variability of the ESF seems to reside in the vertical coupling process, through planetary-tidal wave interaction, of the equatorial atmosphere-ionosphere system.

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