F-region nocturnal zonal plasma drift velocities of the brazilian equatorial ionosphere during maximum solar

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Abstract

This study focused on the nocturnal zonal plasma drift velocities of ionosphere (F region) at equatorial latitude regions of the Brazil. The zonal plasma drifts result from equatorial latitude electrodynamics with influences from the E and F region conductivities and neutral wind shears in altitude and latitude. The analysis is interpreted using the simple plasma drift model (Eccles, 1998a,b) and monochromatic digital images of OI630nm emission, which allow direct visualization of ionospheric bubbles. The digital images were obtained by optical imager system operating at São João do Cariri (equatorial geographic latitudes: 7.4ºS; 36.5ºW; 19^{o}S dip latitude) from January to December 2001 (maximum solar activity). In this period, 48 quiet nights (ΣK_P<24o) presented the signature of ionospheric bubbles and the zonal drift velocities were calculated (observational results). The geophysical conditions of each quiet night were considered in equations of the simple plasma drift model in order to obtain the theoretical zonal plasma drift velocities between 18LT and 6LT. The theoretical and observational results were grouped seasonally. The theoretical results showed two humps around 20LT-21LT and 2LT–4LT that were present in observational results. Observational results were smaller (greater) than theoretical results before (after) 22LT-23LT being earlier in the Summer. The discrepancies between the theoretical and observed results apparently were due to the neutral wind magnitudes provided by HWM93 empirical model. The Summer 2001 season presented the theoretical and observed results in better agreement considering the bars of variance.

Introduction

The ionospheric bubbles are large-scale flux-tube aligned electron density depletions generated by the collisional gravitationally driven Rayleigh-Taylor plasma instability (Haerendel, 1992) in the bottomside nocturnal equatorial F region. The dynamics of ionospheric bubbles over the Brazilian region has been extensively studied by means of observations utilizing optical and radio techniques. The OI630nm emission optical imaging technique, initialized by Weber et al. (1978), offers a convenient way of monitoring processes in the lower F region.

The OI630nm emission comes from a layer between 250km and 300km. After 20LT, the centroid height of the emission layer is found at ~250km remaining constant within $\pm$10km (Martinis et al., 2003). The OI 630nm emission intensity depends on the height profiles of O_2 (molecular oxygen) and N_e (electron density). Since that the O_2 profiles in height are relatively uniform within 15^o dip latitude, the OI630nm emission depends almost exclusively upon the instantaneous structure of the N_e profiles (Mendillo and Baumgardner, 1982). So, as ionospheric bubbles are electron density depletions, an abrupt reduction in the OI630nm emission intensity proportionally to the depletion degree occur. Then, monitoring OI630nm emission is possible to visualize the signature of ionospheric bubbles with spatial and temporal variations.

The generation and development processes of ionospheric bubbles have been the subjects of a number of observational and theoretical studies (Woodman and La Hoz, 1976; Weber et al., 1978; Zalesak et al., 1982; Sahai et al., 1994; Sobral et al., 1980a,b; Taylor et al., 1997; Keskinen et al., 1998 and many other relevant papers). The zonal plasma drifts of equatorial F region have been thoroughly studied theoretically by Haerendel et al., (1992); Çakir et al., (1992); Haerendel and Eccles (1992); Eccles (1998) and by a variety of experimental techniques: incoherent scatter radar (Fejer et al., 1991; Basu et al., 2004; Kudeki and Bhattacharyya, 1999), scanning OI 630nm photometers and imagers systems (Sobral and Abdu, 1991; Sobral et al., 1985, 1990, 1999; Martinis et al., 2003; Terra et al., 2004), VHF polarimeters and digital ionosonde (Abdu et al., 1985; 1998), spaced-antenna scintillation systems (Valladares et al., 1996), imagers on board satellites (Sagawa et al., 2003) and GPS systems (Kil et al., 2000; de Paula et al., 2002; Kintner et al., 2004).

In this study, the OI630nm digital images were obtained by optical imager system operating at São João do Cariri (equatorial geographic latitudes: 7.4ºS; 36.5ºW; 19°S dip latitude) from January to December 2001 (peak of maximum solar activity, F10.7cm=181.4). In this period, 101 nights have been observed of which 48 nights occurred ionospheric bubbles in geomagnetically quiet conditions (ΣK_P<24o). That is, during the nights studied, the average 3-hour Kp values did not exceed 3 and therefore the zonal drift velocities can be considered to be relatively unaffected by the geomagnetic activity. The zonal drift velocities of ionospheric bubbles were obtained for 48 quiet nights and grouped seasonally (observational results).

In the study of the zonal plasma drifts by OI630nm digital images it is essential to consider zonal plasma drift velocities equal to the zonal drift velocities of ionospheric bubbles with well-developed structure, namely, a structure strongly coupled with the ambient plasma flow.

During the nocturnal period, a strong vertical polarization electric field appears and drives the plasma in the same direction (eastward) and with nearly the same velocity magnitude as the F region neutral winds. The zonal plasma drifts result from electrodynamic processes with a combination of influences from the E and F region conductivities and neutral wind shears in altitude and latitude. It should be remembered that zonal plasma drift velocities are flux-tube integrated velocities. In other words, the net zonal plasma drift velocities at a given geographic location results from the interaction of the neutral winds system along the entire flux-tube. The analysis is interpreted using the simple plasma drift model (coupled ionosphere-electric field model of Eccles (1998a,b)) for the same 48 quiet nights considered in the observational results.

The simple plasma drift model assumes that during the nocturnal period, the E region becomes rarefied and the F region dynamo is efficient in setting the plasma motion. Additionally, this simple model assumes: field lines equipotentials, ionospheric representation to the magnetic equatorial plane and integrated electrodynamic quantities along field line (by Haerendel et al., 1992). So, the equations for the zonal ionospheric plasma drift velocities, or for the vertical polarization electric fields (E_L), can be simplified significantly, namely:

$$E_L = -BU_\varphi^P + \frac{\Sigma_H}{\Sigma_P}\left(BV_L - BU_L^H\right) + \frac{L^{150}}{L}\frac{J_L^{150}}{\Sigma_P} \quad (1)$$

where V_L is the equatorial vertical plasma drift velocity, L is field line apex distance in Earth radii, U_φ^P is the field line integrated and Pedersen conductivity-weighted zonal neutral wind, U_L^H is the similar neutral wind parameter but weighted in Hall conductivity, J_L is the integrated vertical current density and Σ_H and Σ_P are the total field-line integrated Hall and Pedersen conductivities respectively, and **B** is the magnitude of the geomagnetic field (positive northward). The meridional neutral wind component in the nocturnal period is small for the near equator latitudes considered in this study (when it does exist, its main component lies along the magnetic field) (Haerendel et al., 1992).

The last term of Eq. (1) is small for most local times except near to the solar terminator below F region ledge. For simplicity, the last term of Eq. (1) is ignored to provide a simple equation for the zonal plasma drift velocities (V_φ). Then, since $V_\varphi = \frac{-E_L}{B}$, the Eq. (1) becomes:

$$V_\varphi = U_\varphi^P - \frac{\Sigma_H}{\Sigma_P}\left(V_L - U_L^H\right) \quad (2)$$

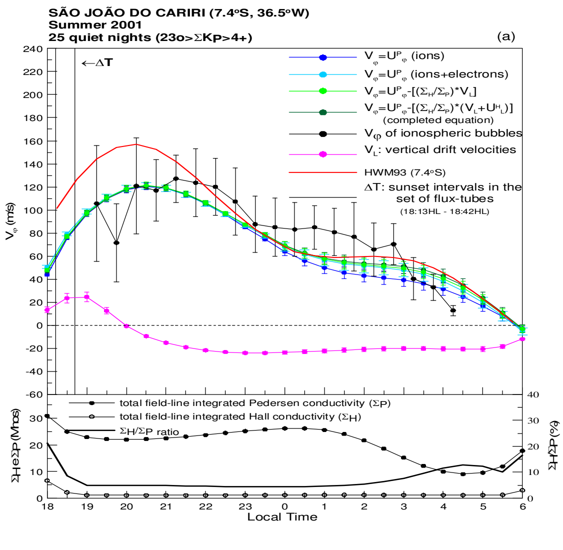
where the exact definitions of the flux-tube integrated quantities are given in the Haerendel et al. (1992).

The geophysical conditions of the 48 quiet nights with signature of the ionospheric bubbles were considered in the Eq. (2) in order to obtain the theoretical zonal plasma drift velocities between 18LT and 6LT (30 minutes intervals). The theoretical results were also grouped seasonally and compared with observational results in the Figure 1.

In Eq. (2), each term has been considered at a time to verify their respective influences. The electron density profiles were obtained from IRI2001 model (International Reference Ionosphere empirical model v.2001), the neutral wind magnitudes from HWM93 model (Horizontal Wind Model empirical model v.1993) by Hedin et al. (1991), the geomagnetic field intensities from IGRF2000 model (International Geomagnetic Reference Field empirical model v.2000) and the equatorial vertical drift velocities from model of the Scherliess and Fejer (1999).

Results

Figure 1 shows the zonal plasma drift velocities obtained by means of Eq. (2) (theoretical results) and by OI630nm digital images (observational results).



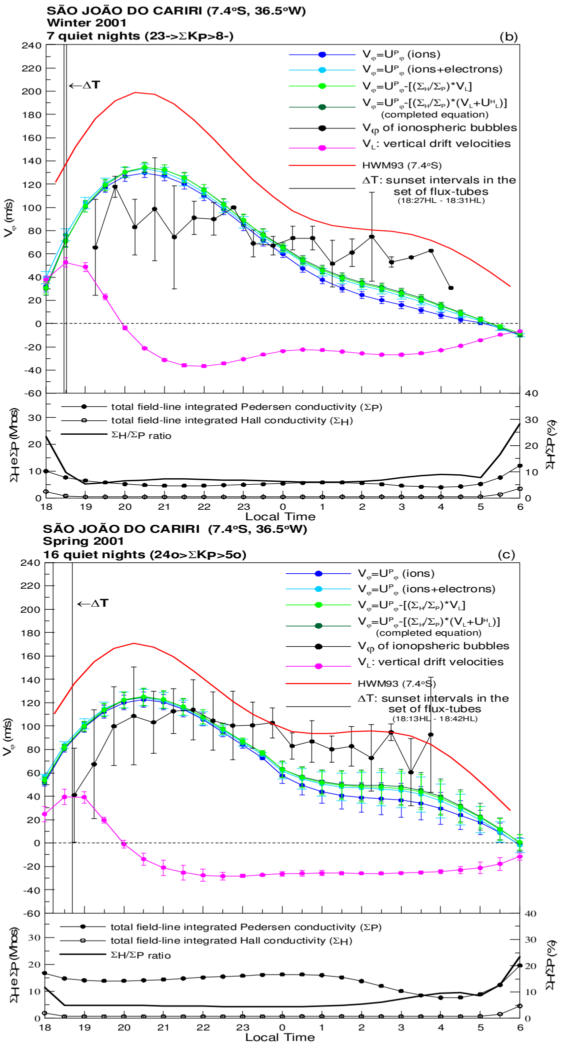


Figure 1 – Theoretical plasma zonal drift velocities (utilizing the simple plasma drift model (Eccles, 1998a,b)) and zonal drift velocities of ionospheric bubbles (utilizing OI630nm digital images) plotted versus local time at São João do Cariri (with variance bars binned in 30 minutes time intervals). The seasons are (a) Summer 2001 (25 quiet nights), (b) Winter 2001 (7 quiet nights) and (c) Spring 2001(16 quiet nights).

The results correspond to 48 quiet nights grouped seasonally, namely, Summer (25 quiet nights), Winter (7 quiet nights) and Spring (16 quiet nights).

In this study, the theoretical results are compared with observational results. The observational results correspond to the zonal propagation of ionospheric bubbles observed over São João do Cariri.

The zonal drift velocities of ionospheric bubbles obtained from the OI630nm digital images were, in general, in agreement with the results from previous studies based on data from scanning photometers (Sobral and Abdu, 1991; Sobral et al., 1999).

Additionally, Figure 1 shows also the vertical drift velocities, total field-line integrated Hall and Pedersen conductivities, $\frac{\Sigma_H}{\Sigma_P}$ ratio, neutral wind magnitudes provided by HWM93 empirical model (geographic latitude: 7.4°S) and the two vertical bars which indicate the beginning and end times of sunset in the set of flux-tubes considered here.

Discussion and Conclusions

In the present study, the theoretical zonal plasma drift velocities, during the 48 quiet nights considered here, follow the direction of the F region neutral winds (eastward) and clearly tended to decrease with local time. These decreases can be verified by Eq. (2) as consequence of decreasing neutral wind magnitudes provided by HWM93 model.

The HWM93 model presented an overestimation of the real zonal neutral winds at early local time. Near midnight and later the difference between the real and modeled zonal neutral winds decreases. Apparently, discrepancies between the theoretical and observational results can be attributed to the neutral wind magnitudes provided by HWM93 model.

The second term of Eq. (2) presented few influences. A possible contribution from the second term would be to increase further the total eastward plasma drifts since the dynamo electric field is westward at this time. The total field-line integrated Pedersen conductivities (variation interval: 2.0 to 24.0Mhos) were larger than the total field-line integrated Hall conductivities (variation interval: 0.1 to 1.1Mhos) so that $\frac{\Sigma_H}{\Sigma_P}$ ratio presented few influences in the zonal plasma drift velocities (independently of the equatorial vertical drift (V_L) and Hall-conductivity-weighted neutral winds (U_L^H) variations). The first term acted primarily in the zonal plasma drift velocities in accordance with Eccles (1998a,b), that is, the zonal drift velocities of ambient plasma are basically equals to the field-line integrated Pedersen conductivity-weighted zonal neutral winds in quiet nights (ΣK_P<24+).

The zonal plasma drift velocities of ionospheric bubbles showed two humps: one around 20LT-21LT and the other around 2LT–4LT. The two humps are related to the neutral wind magnitudes provided by the HWM93 model which presents similar amplitude variations. It should be remembered that the zonal plasma drift velocities at a given geographic location result from the interaction between the neutral winds along the entire flux-tube with the local plasma.

During early night hours, the zonal plasma drift velocities were larger (smaller) than zonal drift velocities of ionospheric bubbles before (after) 22LT-23LT being earlier in the Summer and follow the increasing intensities of the neutral winds provided by HWM93 model.

In general, the zonal drift velocities of ionospheric bubbles were smaller during Spring than during Summer because during the latter season the pressure gradients produced by the solar EUV heating may be greater and, as a consequence, the neutral winds can be more intense resulting in larger zonal drift velocities according to Eq. (2).

A faster decrease with local time was noted in the zonal drift velocities of ionospheric bubbles during Spring than in the Summer also in consequence of the neutral wind intensities.

Finally, the Summer season presented the theoretical and observational results in better agreement considering the bars of variance.

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