Revista Brasileira de Geofísica
RBGf
Brazilian Journal of Geophysics

Revista Brasileira de Geofísica (2011) 29(2): 239-246

ISSN 0102-261X
www.scielo.br/rbg

PLASMA BUBBLE ZONAL DRIFT CHARACTERISTICS OBSERVED BY AIRGLOW IMAGES OVER BRAZILIAN TROPICAL REGION

Igo Paulino[1], Amauri Fragoso de Medeiros[2], Ricardo Arlen Buriti[2],
Hisao Takahashi[3], José Humberto Andrade Sobral[4] and Delano Gobbi[5]

Recebido em 5 fevereiro, 2010 / Aceito em 15 julho, 2011
Received on February 5, 2010 / Accepted on July 15, 2011

ABSTRACT. Using airglow images observed at São João do Cariri (7.4°S, 36.5°W; dip angle: –11°S) from September 2000 to April 2007, plasma bubble zonal drifts for ninety-seven geomagnetically quiet nights (Dst index higher than –30 nT) were calculated. The plasma bubble eastward averaged drifts presented an increase from 18:00 to 22:00 local time (LT), and followed by a deceleration. The plasma bubbles observed during high solar activity were faster after 22:00 LT. Eastward drifts observed during the summer, after 21:00 LT, were higher than drifts observed during the equinox months. Few nights had plasma bubble eastward drifts higher than 100 m/s and almost all bubbles disappeared after 02:00 LT. Averaged zonal drifts observed between –9.5 and –5.5°S were almost constant, primarily, around 23:00 LT.

Keywords: plasma bubble, airglow, ionosphere.

RESUMO. Usando imagens de aeroluminescência coletadas em São João do Cariri (7,4°S, 36,5°W; latitude de dipolo magnético: –11°S) no período de setembro de 2000 a abril de 2007, foi possível calcular a deriva zonal de bolhas de plasma em noventa e sete noites geomagneticamente calmas (índice Dst maior que –30 nT). As derivas zonais médias das bolhas de plasma aumentaram das 18:00 até as 22:00 horas locais (HL) e desaceleraram em seguida. As bolhas de plasma observadas durante a atividade solar alta foram mais rápidas após as 22:00 HL. As derivas zonais de bolhas de plasma no verão, depois das 21:00 HL, foram maiores que nos meses de equinócio. Poucas noites apresentaram bolhas de plasma com derivas superiores a 100 m/s e quase todas as bolhas desapareceram depois das 02:00 HL. As derivas médias zonais observadas entre –9,5 e –5,5°S foram praticamente constantes, principalmente, por volta das 23:00 HL.

Palavras-chave: bolhas de plasma, aeroluminescência, ionosfera.

[1]Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, Jd. da Granja, P.O. Box 515, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3208-7167; Fax: +55 (12) 3208-6990 – E-mail: igo@dae.inpe.br

[2]Universidade Federal de Campina Grande, Av. Aprígio Veloso, 882, Bodocongó, 58429-140 Campina Grande, PB, Brazil. Phone/Fax: +55 (83) 2101-1196 – E-mail: afragoso@df.ufcg.edu.br; rburiti@df.ufcg.edu.br

[3]Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, Jd. da Granja, P.O. Box 515, 12227-010 São José dos Campos, SP, Brazil. Phone/Fax: +55 (12) 3208-7145 – E-mail: hisaotak@laser.inpe.br

[4]Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, Jd. da Granja, P.O. Box 515, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3208-7147; Fax: +55 (12) 3208-6990 – E-mail: jsobral@dae.inpe.br

[5]Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, Jd. da Granja, P.O. Box 515, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3208-7144; Fax: +55 (12) 3208-6990 – E-mail: delanogobbi@laser.inpe.br

INTRODUCTION

Large-scale plasma bubbles or depletions are nocturnal tropical phenomena of the ionospheric F-region. Radar measurements reveled that the plasma bubbles can reach widths ~ 400 km in the east-west direction (Clemesha, 1964), and altitudes 100s-1000s km (Woodman & LaHoz, 1976). Normally, these irregularities extend hundreds of kilometers along the geomagnetic field lines (e.g., Sobral et al., 1980a, 2009).

Airglow observations of the plasma bubbles were reported early by Van Zandt & Peterson (1968). Later, Weber et al. (1978) observed that the bubbles and geomagnetic lines were quasi-aligned. In Brazil, the first observations were reported by Sobral et al. (1980a,b). They observed that the plasma bubbles vary the intensity of the airglow emissions and these variations were associated with an abrupt decrease of plasma density. A considerable improvement in the plasma bubble measurements was done by Taylor et al. (1997) during the Guará Campaign that started to use CCD cameras in the observations.

The Rayleigh-Taylor instability process in the bottom side of the F-region is the most accepted mechanism to explain the generation of the plasma bubbles (Dungey, 1956), but the seeding mechanism is an important topic of research (Fritts et al., 2009). Several works have pointed out gravity waves as a possible seeding (e.g., Kelley et al., 1981; Rottger, 1982; Huang & Kelley, 1996; Abdu, 2001; Abdu et al., 2009; Kherani et al., 2009; Takahashi et al., 2009; Vadas & Fritts, 2009; Makela et al., 2010; Paulino et al., 2011). However, others studies have pointed out that the post sunset plasma flow vortex system is more effective in seeding plasma bubbles (Kudeki & Bhattacharyya, 1999; Kudeki et al., 2007).

In the last three decades, the plasma bubbles have been largely studied in Brazil. Some aspects are well known, like the seasonality of occurrence (e.g., Sahai et al., 1998; Pimenta et al., 2001b; Sahai et al., 1999, 2000; Sobral et al., 2002; Paulino et al., 2007) and the relationship with the pre-reversal enhancement (PRE) after sunset (e.g., Batista et al., 1996; Abdu, 2005). The dynamic has also been exhaustively studied (e.g., Fagundes et al., 1995a,b; Santana et al., 2001; Pimenta et al., 2003a,b; Abalde et al., 2004; Arruda et al., 2006; Sobral et al., 2009, 2011; Paulino et al., 2010), and it is known that, during the magnetic quiet time, the plasma bubble zonal drifts are strongly coupled to the thermospheric wind, and are dependent on the solar cycle (e.g., Sahai et al., 2004). Outside Brazil, some airglow observations have contributed significantly for the understanding of the plasma bubble morphology and dynamics (e.g., Mendillo & Baumgardner, 1982; Mendillo et al., 1997; Otsuka et al., 2002; Martinis et al., 2003; Makela et al., 2006; Yao & Makela, 2007; Makela & Miller, 2008).

Characteristics of the nighttime plasma bubble eastward averaged drifts and their latitudinal variations obtained from an all sky imager deployed at São João do Cariri (7.4°S; 36.5°W) are presented and discussed in this paper.

INSTRUMENTATION AND OBSERVATIONS

Airglow images have routinely been taken at São João do Cariri since September 2000 by an all sky imager. This imager is an optical instrument that takes high resolution images and it is designed with a fish eye lens, a CCD camera, an optical system, and an interference filter wheel. The whole system is controlled by a microcomputer. The CCD camera consists of a large area (6.45 cm^2), high resolution and 1024×1024 back-illuminated array with a pixel of 14 bits. The high quantum efficiency, low dark noise level (0.5 electrons/pixel/s), low readout noise (15 electrons rms) and high linearity (0.05%) of this device made it possible to achieve quantitative measurements of the airglow emission. The camera uses a fast $(f/4)$ all sky telecentric lens system that enables monochromatic images of the plasma bubble to be obtained with a time integration of typically 90 s for the OI 630 nm emission. The images were binned on-chip down to 512×512 resolution to enhance the signal-to-noise ratio (see Medeiros et al., 2004). The OI 630 nm airglow emission is produced in the bottom side of the ionospheric F-region, between ~ 220 and 300 km height, and represents an important tracer for the ionospheric studies. The main production mechanism of this emission is the dissociative recombination process (e.g. Peterson & Van Zandt, 1969).

In this paper, we are presenting results of an almost seven years database, from September 2000 to April 2007. Ninety-seven magnetically quiet nights were chosen, i.e., nights which the Dst index is higher than –30 nT, and do not have any characteristics of magnetic storms. Plasma bubble zonal drifts were estimated using a methodology similar that was published by Pimenta et al. (2001a), however, we have used the entire depletion motion instead of the border motions.

Due to limitations of the local imager field of view, the images correspond to a view angle of approximately 168°. For a fixed altitude of ~ 250 km, this field of view corresponds to a diameter of ~ 2400 km. Figure 1 shows a projection of an airglow image area (dashed circle) and some plasma bubbles on an unwarped image (512 km $\times$ 512 km) centered at São João

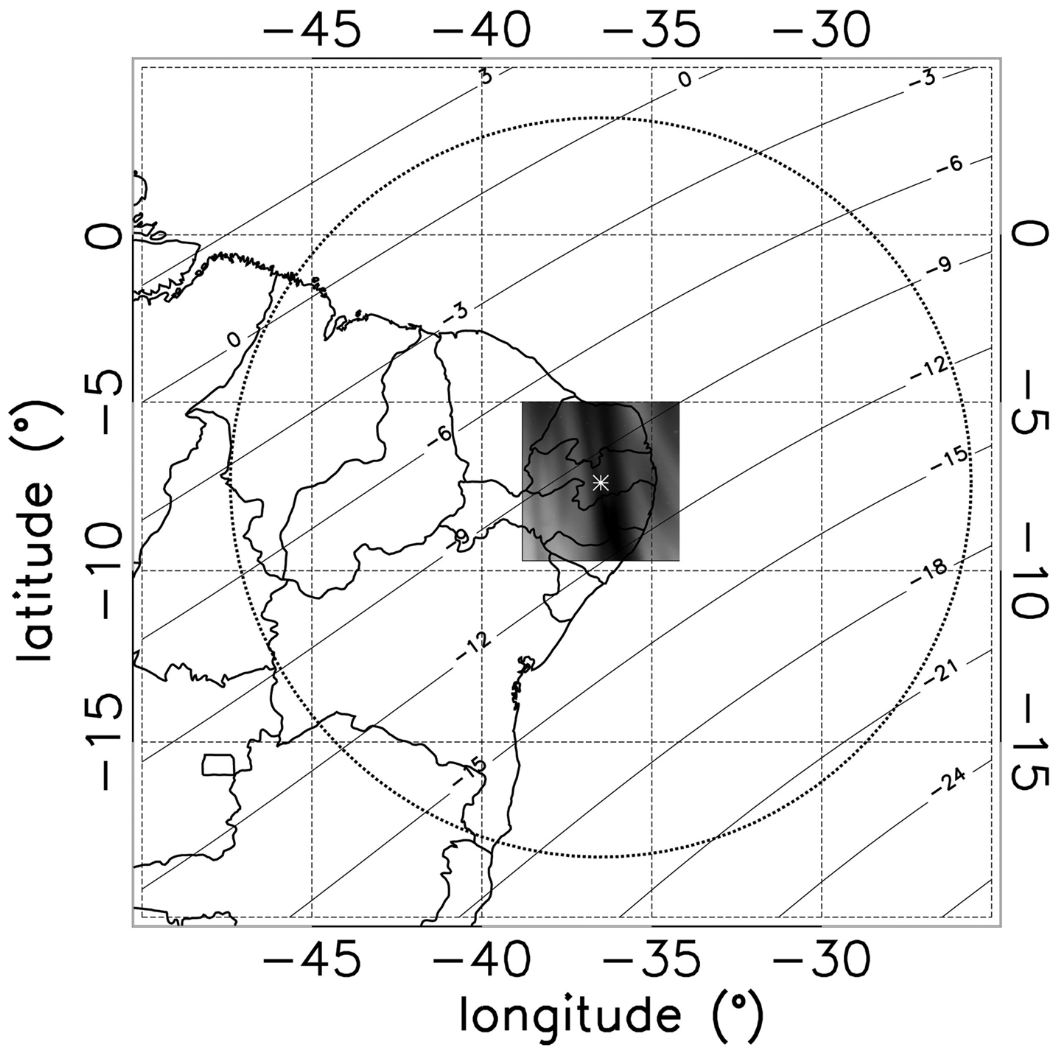

Figure 1 – Imager localization at São João do Cariri (white star) and its field of view (dashed circle) on Brazilian map. An OI 630 nm unwarped image (512 km × 512 km for 28 October 2003) is also shown.

do Cariri (white star), the solid lines represent dip latitudes at ∼ 250 km for October 2003 based on International Geomagnetic Reference Field (IGRF) model.

RESULTS AND DISCUSSIONS

Figure 2 shows the plasma bubble eastward averaged drifts during the nighttime. Open square curve represents the averaged drifts hourly binned over all observed period. The error bars are the standard deviation of the mean for each hour. Dashed star curve is the high solar activity (HSA) period (September 2000 to December 2002), and the dotted diamond curve is the low solar activity (LSA) period (January 2006 to April 2007). Solar activity has been delimited using the F10.7 cm solar flux index. All nights with F10.7 cm index lower than 80 $\times 10^{-22}$ $Wm^{-2}Hz^{-1}$ were classified as LSA. Whereas, the HSA nights were assumed as F10.7 cm index higher than 140 $\times 10^{-22}$ $Wm^{-2}Hz^{-1}$. The mean curve showed an increase from 18:00 LT (∼ 40 m/s) until 22:00 LT (∼ 65 m/s). After this time, the plasma bubbles decelerated until 05:00 LT (∼ 20 m/s). HSA and LSA curves showed a similar tendency, however, after 22:00 LT, the plasma bubble observed during the HSA were faster than LSA plasma bubbles.

The plasma bubble eastward averaged drifts were broken down according to the seasons, these results are shown in Figure 3. Dotted diamond curve is the averaged drifts for the equinox months (September, October, November, March, April, and May). Dashed star curve represents the summer months (December, January and February). Again, the error bars are the

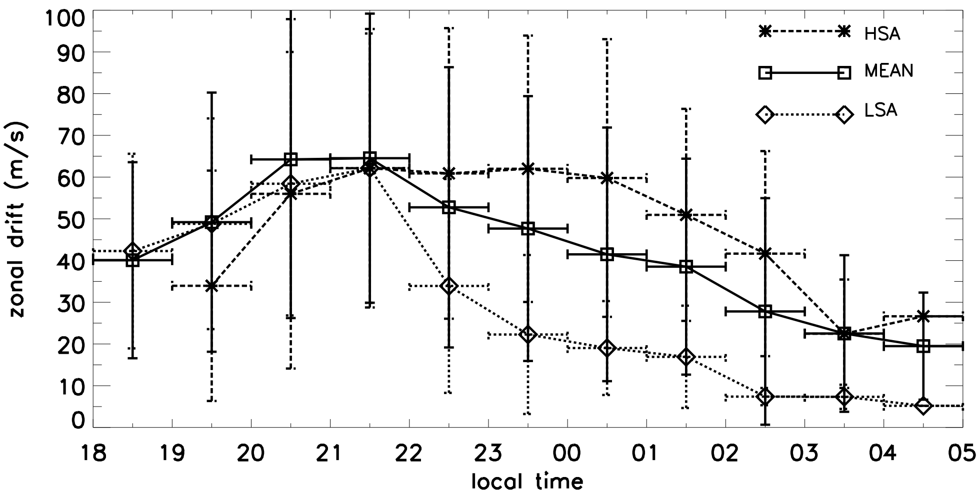

Figure 2 – Local time variation of the plasma bubble zonal mean drifts (squares). Dashed stars are the high solar activity (September 2000 to December 2002). Dotted diamonds represent the low solar activity (January 2006 to April 2007).

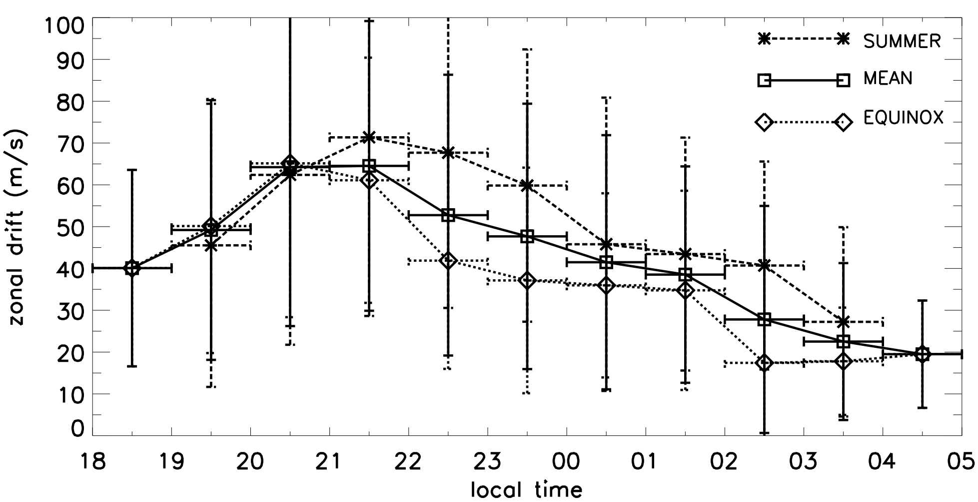

Figure 3 – Similar to Figure 2, but, in this case, the seasonal variation was broken down. Dashed stars represent the summer months (December, January, and February). Dotted diamonds are the equinox months (March, April, May, September, October, and November).

standard deviations of the hourly averaged drifts. The plasma bubbles observed during the summer were faster than the plasma bubbles observed during the equinox months after 21:00 LT.

Vertical electric fields generated by E- and F-region dynamos drive the ionospheric plasma drifts (e.g. Haerendel et al., 1992). During the nighttime, the E-region density is strongly reduced and, then, the F-region dynamo dominates the ionospheric plasma dynamics. Otherwise, the neutral thermospheric wind is the main driver of the F-region dynamo and the geomagnetic field develops an important role for the nocturnal plasma bubble dynamics, because they are flux tube integrated. Eccles (1998) simplified model can help in the understanding of this mechanism, that is,

$$V_\varphi = U_\varphi^P = \frac{\Sigma_P^F U_\varphi^{PF} + \Sigma_P^E U_\varphi^{PE}}{\Sigma_P}\,, \qquad (1)$$

where V_φ is the zonal plasma drift. U_φ is the neutral zonal wind integrated along of the magnetic field line. Σ is the integrated electric conductivity, the subscript P represents the Pedersen component, and the superscripts E and F indicate E- and F-region, respectively.

Looking to the Eq. (1), it is possible to see that the zonal plasma drift is proportional to neutral zonal wind and is weighted by Pedersen conductivity. If the E region Pedersen conductivity became negligible, the zonal plasma drift will be directly controlled by the variations of the neutral thermospheric zonal wind. Secondary variations can be expressive due to the E region ionization enhancements by the energetic particle precipitations, in South America, for instance. It has often been found near the South Atlantic Anomaly region (Abdu et al., 1998, 2003). The second weak hump showed in Figures 2 and 3 (solid line at 01:30 LT) was also predicted by Arruda et al. (2006) in their theoretical model, it can be associated with minor contributions due to vertical electric field variations. Therefore, the solar activity dependence and the seasonal variation of the plasma bubble eastward drifts could be related with modification in the thermospheric neutral wind system.

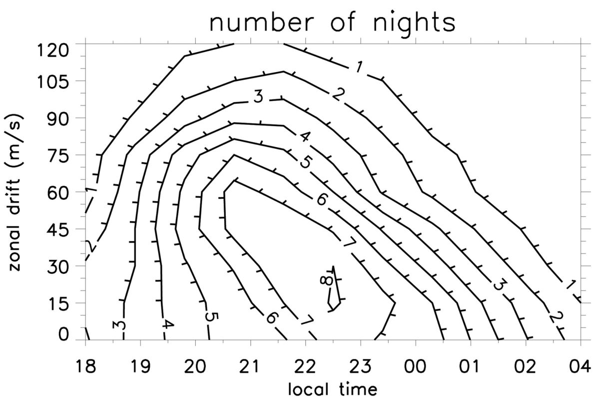

Figure 4 – Three dimensional histogram showing the number of observed night with regards to the local time (x-axis) and zonal drifts (y-axis). Contours show the same values of observed nights.

Figure 4 shows a three dimensional histogram of the numbers of observed night with a given velocity at a given time, the abscissa is the local time, the ordinate is the plasma bubble eastward drifts, and the contours are the number of observed nights. This plot is useful to identify simultaneous variations on the time and eastward drifts of the observed plasma bubbles. This plot is a more expansive visualization of Figures 2 and 3. A peak is clear around 22:00-23:00 LT with drifts of 15-60 m/s. Few nights had plasma bubbles faster than 100 m/s. Another interesting aspect was that most of the plasma bubbles disappeared after 02:00 LT. These results compare with the result by Arruda et al. (2006) over Cachoeira Paulista in the spring and summer for two years, however, the drifts in the present work were slower. The nocturnal variations of the zonal plasma bubble mean drifts are similar to those reported by Otsuka et al. (2002), Martinis et al. (2003), Pimenta et al. (2003a), Yao & Makela (2007), and Abalde et al. (2004). The seasonal and solar activity variations were shown theoretically by Arruda et al. (2006), while the geomagnetic activity influences on the plasma bubble drifts were discussed in more details by Sahai et al. (2004).

Figure 5 shows a contour plot of the plasma bubble zonal mean drifts with regards to local time and latitudes. This plot was made averaging the plasma bubble drifts for all latitudes covered between –9.5 and –5.5°S and for all observed nights. The nocturnal variation observed in Figures 2 and 3 were preserved in almost all latitudes. However, it is possible to see that the zonal drifts around the zenith were smaller after 20:00 LT until the end of the night. During the first two hours, does not had any defined pattern, and around 22:00-23:00 LT there were little latitudinal variations. The reduction of plasma bubble eastward drifts during the night can be a consequence of neutral thermospheric wind reduction as reveled by the Horizontal Wind Model (see Pimenta et al., 2003b, for instance). Similar results were also found by Pimenta et al. (2003a) over Brazilian tropical region. Martinis et al. (2003) showed also a latitudinal variation of the plasma bubble drifts as observed by two imagers separated of ~ 10 degrees.

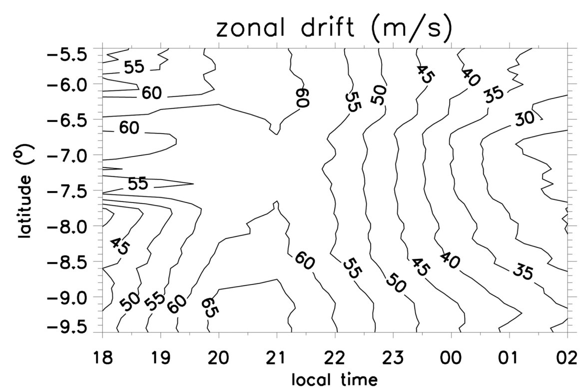

Figure 5 – Latitudinal and local time variations for the plasma bubble zonal mean drifts. Contours are the same drift lines.

It is important to note that, in the present work, the OI 630 nm emission peak was assumed to be located at 250 km height. However, the emission peak undergoes changes during the course of a night due to vertical variations of F-region. This vertical motion of the plasma may affect lightly the bubble drifts. For instance, if the OI 630 nm peak was assumed at 300 km, instead of 250 km, the plasma bubble drifts will increase by about 20%. Pimenta et al. (2003b) pointed out further details about the assumption of OI 630 nm peak be considered constant all the time. Furthermore, Abalde et al. (2004) presented a methodology of calculation of OI 630 nm peak based on variations of FpF2 observed by ionosonde. They obtained better results using OI 630 nm peak height based on simultaneous ionospheric observations.

CONCLUSIONS

Airglow images observed at São João do Cariri from September 2000 to April 2007 reveled several characteristics of the plasma bubble eastward drifts. It was obtained 97 quite nights with Dst index larger than –30 nT. The primary observed results are summarized as following:

1. The plasma bubble eastward averaged drifts at São João do Cariri increased from 18:00 to 22:00 LT, after this, the bubbles were decelerated until the end of the night;
2. After 22:00 LT, the plasma bubble eastward averaged drifts were faster during high solar activity;
3. The bubbles observed during the summer months were faster than bubbles observed during the equinox months;
4. Most of the observed nights presented plasma bubbles between 22:00-23:00 LT with drifts of 15-60 m/s;
5. Plasma bubble zonal drifts do not vary significantly between –9.5 and –5.5°S, primarily around 23:00 LT.

ACKNOWLEDGEMENTS

The Cariri imager was financed by CNPq/PRONEX grant No. 76.97.1079.00. This work has been supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico and Fundação de Amparo à Pesquisa do Estado de São Paulo (2008/1769-8). We appreciate the effort by the science team WDC for Geomagnetism (Kyoto Dst index service) for making the data available.

REFERENCES

ABALDE JR, FAGUNDES PR, SAHAI Y, PILLAT VG, PIMENTA AA & BITTENCOURT JA. 2004. Height-resolved ionospheric drifts at low latitudes from simultaneous OI 777.4 nm and OI 630.0 nm imaging observations. J. Geophys. Res., 109: A11308, DOI: 10.1029/2004JA010560.

ABDU MA. 2001. Outstanding problems in the equatorial ionosphere-thermosphere electrodynamics relevant to spread F. Journal of Atmospheric and Solar-Terrestrial Physics, 63(9): 869–884.

ABDU MA. 2005. Equatorial ionosphere-thermosphere system: Electrodynamics and irregularities. Advances in Space Research, 35: 771–787.

ABDU MA, JAYACHANDRAN PT, MacDOUGALL J, CECILE JF & SOBRAL JHA. 1998. Equatorial F region zonal plasma irregularity drifts under magnetospheric disturbances. Geophysical Research Letters, 25: 4137–4140.

ABDU MA, BATISTA IS, TAKAHASHI H, MacDOUGALL J, SOBRAL JHA, MEDEIROS AF & TRIVEDI NB. 2003. Magnetospheric disturbance induced equatorial plasma bubble development and dynamics: A case study in Brazilian sector. Journal of Geophysical Research, 108(A12): 1449, DOI: 10.1029/2002JA009721.

ABDU MA, ALAM KHERANI E, BATISTA IS, DE PAULA ER, FRITTS DC & SOBRAL JHA. 2009. Gravity wave initiation of equatorial spread F/plasma bubble irregularities based on observational data from the SpreadFEx campaign. Ann. Geophys., 27: 2607–2622.

ARRUDA DC, SOBRAL JHA, ABDU MA, CASTILHO VM, TAKAHASHI H, MEDEIROS AF & BURITI RA. 2006. Theoretical and experimental zonal drift velocities of the ionospheric plasma bubbles over the Brazilian region. Advances in Space Research, 38: 2610–2614.

BATISTA IS, MEDEIROS RT, ABDU MA, SOUZA JR, BAILEY GJ & DE PAULA ER. 1996. Equatorial ionospheric vertical plasma drift model over the Brazilian region. Journal of Geophysical Research, 101(A5): 10887–10892.

CLEMESHA BR. 1964. An investigation of the irregularities in the F-region associated with equatorial type spread-F. Journal of Atmospheric and Terrestrial Physics, 26: 91–122.

DUNGEY JW. 1956. Convective diffusion in the equatorial *F* region. Journal of Atmospheric and Terrestrial Physics, 9(5-6): 304–310.

ECCLES JV. 1998. A simple model of low-latitude electric fields. Journal of Geophysical Research, 103: 26,699–26,708.

FAGUNDES PR, SAHAI Y, BITTENCOURT JA & TAKAHASHI H. 1995a. Relationship between generation of equatorial F-region plasma bubbles and thermospheric dynamics. Advances in Space Research, 16: 117–120.

FAGUNDES PR, SAHAI Y & TAKAHASHI H. 1995b. Investigation of OI 557.7 nm and OI 630.0 nm nightglow intensity ratios during the occurrence of equatorial F-region plasma bubbles. Journal of Atmospheric and Solar-Terrestrial Physics, 57: 929–932.

FRITTS DC, ABDU MA, BATISTA BR, BATISTA IS, BATISTA PP, BURITI R, CLEMESHA BR, DAUTERMANN T, DE PAULA ER, FECHINE BJ, FEJER BG, GOBBI D, HAASE J, KAMALABADI F, KHERANI EA, LAUGHMAN B, LIMA PP, LIU H-L, MEDEIROS A, PAUTET P-D, RIGGIN DM, RODRIGUES FS, SÃO SABBAS F, SOBRAL JHA, STAMUS P, TAKAHASHI H, TAYLOR MJ, VADAS SL, VARGAS F & WRASSE CM. 2009. Overview and summary of the Spread F Experiment (SpreadFEx). Ann. Geophys., 27: 2141–2155.

HAERENDEL G, ECCLES JV & CAKIR S. 1992. Theory for modeling the equatorial evening ionosphere and the origin of the shear in the horizontal plasma flow. Journal of Geophysical Research, 97: 1209–1223.

HUANG C-S & KELLEY MC. 1996. Nonlinear evolution of equatorial spread *F*2. Gravity wave seeding of Rayleigh-Taylor instability. Journal of Geophysical Research, 101(A1): 293–302, DOI: 10.1029/95JA02210.

KELLEY MC, LARSEN MF, LaHOZ C & McCLURE JP. 1981. Gravity Wave Initiation of Equatorial Spread F: A Case Study. Journal of Geophysical Research, 86: 9087–9100.

KHERANI EA, ABDU MA, DE PAULA ER, FRITTS DC, SOBRAL JHA & DE MENESES JR FC. 2009. The impact of gravity waves rising from convection in the lower atmosphere on the generation and nonlinear evolution of equatorial bubble. Ann. Geophys., 27: 1657–1668.

KUDEKI E & BHATTACHARYYA S. 1999. Postsunset vortex in equatorial F-region plasma drifts and implications for bottomside spread-F. Journal of Geophysical Research, 104: 28163–28170.

KUDEKI E, AKGIRAY A, MILLA M, CHAU JL & HYSELL DL. 2007. Equatorial spread-F initiation: Post-sunset vortex, thermospheric winds, gravity waves. Journal of Atmospheric and Solar-Terrestrial Physics, 69: 2416–2427.

MAKELA JJ & MILLER ES. 2008. Optical observations of the growth and day-to-day variability of equatorial plasma bubbles. Journal of Geophysical Research (Space Physics), 113: A03307, DOI: 10.1029/2007JA012661.

MAKELA JJ, KELLEY MC & NICOLLS MJ. 2006. Optical observations of the development of secondary instabilities on the eastern wall of an equatorial plasma bubble. Journal of Geophysical Research (Space Physics), 111: A09311, DOI: 10.1029/2006JA011646.

MAKELA JJ, VADAS SL, MURYANTO R, DULY T & CROWLEY G. 2010. Periodic spacing between consecutive equatorial plasma bubbles. Geophysical Research Letters, 37: L14103, ISSN 0094-8276.

MARTINIS C, ECCLES JV, BAUMGARDNER J, MANZANO J & MENDILLO M. 2003. Latitude dependence of zonal plasma drifts obtained from dual-site airglow observations. Journal of Geophysical Research, 108: 1129.

MEDEIROS AF, BURITI RA, MACHADO EA, TAKAHASHI H, BATISTA PP, GOBBI D & TAYLOR MJ. 2004. Comparison of gravity wave activity observed by airglow imaging at two different latitudes in Brazil. Journal of Atmospheric and Solar-Terrestrial Physics, 66: 647–654, DOI: 10.1016/j.jastp.2004.01.016.

MENDILLO M & BAUMGARDNER J. 1982. Airglow characteristics of equatorial plasma depletions. Journal of Geophysical Research, 87: 7641–7652, system Entry Date: 05/13/2001 Source: INS-83-006378;EDB-83-061515 Language: English.

MENDILLO M, BAUMGARDNER J, COLERICO M & NOTTINGHAM D. 1997. Imaging science contributions to equatorial aeronomy: initial results from the MIS ETA program. Journal of Atmospheric and Solar-Terrestrial Physics, 59: 1587–1599.

OTSUKA Y, SHIOKAWA K & OGAWA T. 2002. Geomagnetic conjugate observations of equatorial airglow depletions. Geophysical Research Letters, 29: 1753.

PAULINO I, MEDEIROS AF & BURITI RA. 2007. Comportamento sazonal da ocorrência de bolhas de plasma na região tropical do Brasil observado pelo imageamento do airglow na emissão do OI 630,0 nm. Revista Brasileira de Geofísica, 25(Supl. 2): 129–134.

PAULINO I, MEDEIROS AF, BURITI RA, SOBRAL JHA, TAKAHASHI H & GOBBI D. 2010. Optical observations of plasma bubble westward drifts over Brazilian tropical region. Journal of Atmospheric and Solar-Terrestrial Physics, 72: 521–527, ISSN 1364-6826, DOI: 10.1016/j.jastp.2010.01.015.

PAULINO I, TAKAHASHI H, MEDEIROS AF, WRASSE CM, BURITI RA, SOBRAL JHA & GOBBI D. 2011. Mesospheric gravity waves and ionospheric plasma bubbles observed during the COPEX campaign. Journal of Atmospheric and Solar-Terrestrial Physics, 73: 1575–1580, ISSN 1364-6826, DOI: 10.1016/j.jastp.2010.12.004.

PETERSON VL & VAN ZANDT TE. 1969. $O(^1D)$ quenching in the ionospheric F-region. Planetary and Space Science, 17: 1725–1736, ISSN 0032-0633, DOI: 10.1016/0032-0633(69)90049-X.

PIMENTA AA, FAGUNDES PR, BITTENCOURT JA, SAHAI Y, GOBBI D, MEDEIROS AF, TAYLOR MJ & TAKAHASHI H. 2001a. Ionospheric plasma bubble zonal drift: a methodology using OI 630 nm all-sky imaging systems. Advances in Space Research, 27: 1219–1224.

PIMENTA AA, FAGUNDES PR, BITTENCOURT JA & SAHAI Y. 2001b. Relevant aspects of equatorial plasma bubbles under different solar activity conditions. Advances in Space Research, 27: 1213–1218.

PIMENTA AA, BITTENCOURT JA, FAGUNDES PR, SAHAI Y, BURITI RA, TAKAHASHI H & TAYLOR MJ. 2003a. Ionospheric plasma bubble zonal drifts over the tropical region: a study using OI 630 nm emission all-sky images. Journal of Atmospheric and Solar-Terrestrial Physics, 65: 1117–1126.

PIMENTA AA, FAGUNDES PR, SAHAI Y, BITTENCOURT JA & ABALDE JR. 2003b. Equatorial F-region plasma depletion drifts: latitudinal and seasonal variations. Annales Geophysicae, 21: 2315–2322.

ROTTGER J. 1982. Gravity Waves Seeding Ionospheric Irregularities. Nature, 296: 111.

SAHAI Y, FAGUNDES PR, BITTENCOURT JA & ABDU MA. 1998. Occurrence of large scale equatorial F-region plasma depletions during geomagnetic disturbances. Journal of Atmospheric and Solar-Terrestrial Physics, 60: 1593–1604.

SAHAI Y, FAGUNDES PR & BITTENCOURT JA. 1999. Solar cycle effects on large scale equatorial F-region plasma depletions. Advances in Space Research, 24: 1477–1480.

SAHAI Y, FAGUNDES PR & BITTENCOURT JA. 2000. Transequatorial F-region ionospheric plasma bubbles: solar cycle effects. Journal of Atmospheric and Solar-Terrestrial Physics, 62: 1377–1383.

SAHAI Y, FAGUNDES PR, BECKER-GUEDES F, ABALDE JR, CROWLEY G, PI X, IGARASHI K, AMARANTE GM, PIMENTA AA & BITTENCOURT JA. 2004. Longitudinal differences observed in the ionospheric F-region during the major geomagnetic storm of 31 March 2001. Annales Geophysicae, 22: 3221–3229.

SANTANA DC, SOBRAL JHA, TAKAHASHI H & TAYLOR MJ. 2001. Optical studies of the ionospheric irregularities over the Brazilian region by nocturnal images of the OI 630 nm emission. Advances in Space Research, 27: 1207–1212.

SOBRAL JHA, ABDU MA & BATISTA IS. 1980a. Emission studies on ionosphere dynamics over low latitude in Brazil. Annales Geophysicae, 36: 199–204.

SOBRAL JHA, ABDU MA, BATISTA IS & ZAMLUTTI CJ. 1980b. Association between plasma bubble irregularities and emission disturbance over Brazilian low latitudes. Geophysical Research Letters, 11: 980–982.

SOBRAL JHA, ABDU MA, TAKAHASHI H, TAYLOR MJ, DE PAULA ER, ZAMLUTTI CJ, AQUINO MG & BORBA GL. 2002. Ionospheric plasma bubble climatology over Brazil based on 22 years (1977-1998) of 630 nm airglow observations. Journal of Atmospheric and Solar-Terrestrial Physics, 64: 1517–1524.

SOBRAL JHA, ABDU MA, PEDERSEN TR, CASTILHO VM, ARRUDA DCS, MUELLA MTAH, BATISTA IS, MASCARENHAS M, DE PAULA ER, KINTNER PM, KHERANI EA, MEDEIROS AF, BURITI RA, TAKAHASHI H, SCHUCH NJ, DENARDINI CM, ZAMLUTTI CJ, PIMENTA AA, DE SOUZA JR & BERTONI FCP. 2009. Ionospheric zonal velocities at conjugate points over Brazil during the COPEX campaign: Experimental observations and theoretical validations. Journal of Geophysical Research (Space Physics), 114: A04309.

SOBRAL JHA, DE CASTILHO VM, ABDU MA, TAKAHASHI H, PAULINO I, GASPARELO UAC, ARRUDA DCS, MASCARENHAS M, ZAMLUTTI CJ, DENARDINI CM, KOGA D, MEDEIROS AF & BURITI RA. 2011. Midnight reversal of ionospheric plasma bubble eastward velocity to westward velocity during geomagnetically quiettime: Climatology and its model validation. Journal of Atmospheric and Solar-Terrestrial Physics, 73: 1520–1528, ISSN 1364–6826, DOI: 10.1016/j.jastp.2010.11.031.

TAKAHASHI H, TAYLOR MJ, PAUTET P-D, MEDEIROS AF, GOBBI D, WRASSE CM, FECHINE J, ABDU MA, BATISTA IS, PAULA E, SOBRAL JHA, ARRUDA D, VADAS SL, SABBAS FS & FRITTS DC. 2009. Simultaneous observation of ionospheric plasma bubbles and mesospheric gravity waves during the SpreadFEx Campaign. Ann. Geophys., 27: 1477–1487.

TAYLOR MJ, ECCLES JV, LABELLE J & SOBRAL JHA. 1997. High resolution OI (630 nm) image measurements of F-region depletion drifts during the Guará campaign. Geophysical Research Letters, 24: 1699–1702.

VADAS SL & FRITTS DC. 2009. Reconstruction of the gravity wave field from convective plumes via ray tracing. Ann. Geophys., 27: 147–177.

VAN ZANDT TE & PETERSON VL. 1968. Detailed maps of tropical nightglow enhancements and their implications on the ionospheric F2 Layer. Annales Geophysicae, 24: 747–749.

WEBER EJ, BUCHAU J, EATHER RH & MENDE SB. 1978. North-south aligned equatorial airglow depletion. Journal of Geophysical Research, 83: 712–716.

WOODMAN RF & LaHOZ C. 1976. Radar Observations of *F* Region Equatorial Irregularities. Journal of Geophysical Research, 81: 5447–5466.

YAO D & MAKELA JJ. 2007. Analysis of equatorial plasma bubble zonal drift velocities in the Pacific sector by imaging techniques. Ann. Geophys., 25: 701–709, DOI: 10.5194/angeo-25-701-2007.

NOTES ABOUT THE AUTHORS

Igo Paulino graduated in Physics at Universidade Federal de Campina Grande (UFCG) in 2006. In 2008, he got a Master's degree in Meteorology at UFCG. He is currently a Ph.D. candidate at Instituto Nacional de Pesquisas Espaciais (INPE). His area of interest is the Dynamics of the Mesosphere and Lower Thermosphere (MLT) region.

Amauri Fragoso de Medeiros graduated in Physics at Universidade Estadual da Paraíba (UEPB) in 1984. He obtained his M.Sc. in Science Teaching at Universidade de São Paulo (USP) in 1995, and his Ph.D. in Space Geophysics at INPE in 2001. He is a professor at Physics Department of the UFCG. His research interest is studying the Dynamics and Chemistry of the MLT region.

Ricardo Arlen Buriti graduated in Physics at Universidade Federal da Paraíba (UFPB) in 1984. He obtained his M.Sc. in Physical Chemistry at USP in 1987, and his Ph.D. in Space Sciences at INPE in 1997. He is a professor at Physics Department of the UFCG, and his present research interests include the Dynamics and Chemistry of the MLT region.

Hisao Takahashi is a researcher at Instituto Nacional de Pesquisas Espaciais (INPE) since 1970. He received his B.Sc. and M.Sc. in Physics at Niigata University (1968, 1970) and obtained his Ph.D. in Space Sciences at INPE (1980). His research interests include Airglow, Dynamics and Chemistry of the MLT region.

José Humberto Andrade Sobral graduated in Electronic Engineering at Escola Nacional de Engenharia do Rio de Janeiro (present UFRJ). He obtained his M.Sc. in Space Science at INPE in 1969 and his Ph.D. in Electrical Engineering at Cornell University in 1973. He has been a researcher at INPE since 1967 in the field of study of Aeronomy.

Delano Gobbi is Physicist at Universidade Federal do Rio Grande do Sul (UFGRS), 1984. He received his M.Sc. and Ph.D. in Space Science at INPE in 1988 and 1993, respectively. Actually, he is a researcher at INPE and studies the Dynamics and Chemistry of the MLT region.