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Plasma blobs observed by ground-based optical and radio techniques in the Brazilian tropical sector

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[1] Ground-based optical and radio observations were carried out in the tropical region in Brazil, during the period from October 1998 to September 2000, and on several occasions we detected F-region plasma blob (localized discrete plasma density enhancement) events. These are the first observations of blobs in the tropical F-region using combined ground-based optical and radio techniques. All-sky images were used to map the spatial extension and temporal location of plasma blobs and ionosonde and photometer measurements were used to measure the plasma densities. Interesting cases of plasma blob events were observed on October 07, 1999 and March 04, 2000 over Cachoeira Paulista (22.7°S, 45.0°W; magnetic latitude 13.25°S, declination 20°W), showing discrete plasma density enhancements near regions of plasma density depletion structures in the OI 630.0 nm emission images. In these two cases, the electron densities were enhanced by a factor of, approximately, 2 above the background level. In this paper we report the first ground-based observations of the plasma density enhancements, or blobs, and their association with equatorial spread-F plasma depletions, and suggest a possible mechanism for their generation. *INDEX TERMS:* 2423 Ionosphere: Ionization mechanisms; 2427 Ionosphere: Ionosphere/atmosphere interactions (0335); 2437 Ionosphere: Ionospheric dynamics; 2439 Ionosphere: Ionospheric irregularities. **Citation:** Pimenta, A. A., Y. Sahai, J. A. Bittencourt, M. A. Abdu, H. Takahashi, and M. J. Taylor (2004), Plasma blobs observed by ground-based optical and radio techniques in the Brazilian tropical sector, *Geophys. Res. Lett.*, *31*, L12810, doi:10.1029/2004GL020233.

1. Introduction

[2] Plasma irregularities have been frequently observed in the ionosphere. Specifically, in tropical F-region, most of these irregular structures show depletions of electron density, as compared to the background ionospheric plasma density, which are frequently called equatorial spread-F (ESF). On the other hand, discrete F-region electron density enhancements or plasma blobs, with densities increased by a factor of two, or more, above the background density, have been measured in "situ" by satellite in the tropical F-region [e.g., *Watanabe and Oya*, 1986; *Le et al.*, 2003; *Park et al.*, 2003]. Using data from the Hinotori satellite, with altitude of 650 km, *Watanabe and Oya* [1986] reported the first observations of localized regions of plasma density enhancements in addition to plasma depletions in the nightside tropical F-region. They showed that these electron density enhanced regions have similar east-west scale sizes as the plasma depletions and that, within these regions, the plasma density is enhanced by a factor of, approximately, 2 above the background level. In addition, their statistical study showed that the occurrence probabilities of the plasma depletions and plasma blobs appear to be complementary to each other. Recently, *Le et al.* [2003] and *Park et al.* [2003], using data from ROCSAT-1 (observations at ~600 km altitude), DMSP (observations at ~800 km altitude) satellites, and KOMPSAT-1 (observations at ~685 km altitude) and DMSP satellites, respectively, also detected plasma blobs in association with large-scale plasma depletions. It is important to understand the morphology and dynamics of these structures, since they are associated with large phase and amplitude scintillation in trans-ionospheric radio signals. In this paper we report, for the first time, ground-based observations of plasma blobs in the tropical region and their association with ESF plasma depletions, using simultaneous optical and radio techniques. Furthermore, we suggest possible mechanism for plasma blob generation.

2. Observations

[3] The all-sky imaging technique offers a unique capability to characterize, simultaneously, the morphology of depleted flux tubes and blobs over regions spanning several million square kilometers. Observations of the OI 630 nm nightglow emission, using the Utah State University monochromatic wide-angle imager with CCD camera (180° field of view), have been carried out at Cachoeira Paulista (22.7°S, 45°W), Brazil, from October 1998 to September 2000. The OI 630 nm emission is produced in the bottomside of the F-region (250–300 km) by the O_2^+ dissociative recombination process and is widely used to monitor important F-region ionospheric processes. Full details of the ground-based all-sky imaging system used in this study have been presented earlier [*Pimenta et al.*, 2001]. During the period of the OI 630 nm imaging observations, blobs were observed on 17 nights. However, we selected the nights that showed the formation phase of the plasma blobs at the zenith of Cachoeira Paulista. Using this criterion, only two nights with well-defined plasma blobs were found during the pre-midnight period. On these nights, geomagnetic activity was moderately quiet, with Dst > −20 nT. In addition, to complement the all-sky imaging observations, we include photometer and ionosonde observations in the

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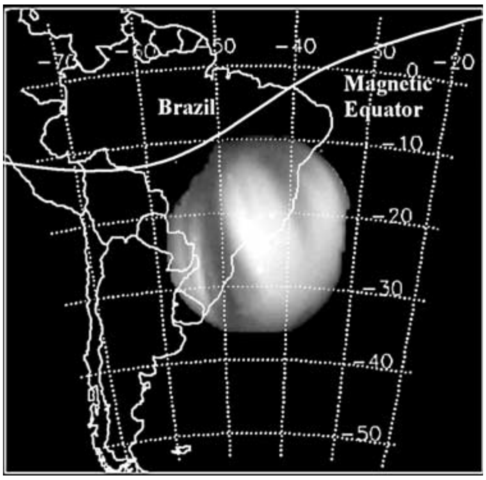

Figure 1. Location of the OI 630.0 nm emission all-sky imager at Cachoeira Paulista with it respective field of view (considering an emission height at 250 km).

present study. These complementary data were obtained from a photometer and a Digisonde 256 operating on a routine basis at Cachoeira Paulista, which provide a good idea of the absolute intensity and ionospheric behavior during plasma blob events in the low latitude region. The tropical region in the Brazilian sector is adequately covered by the all-sky imaging system, as shown in the map in Figure 1.

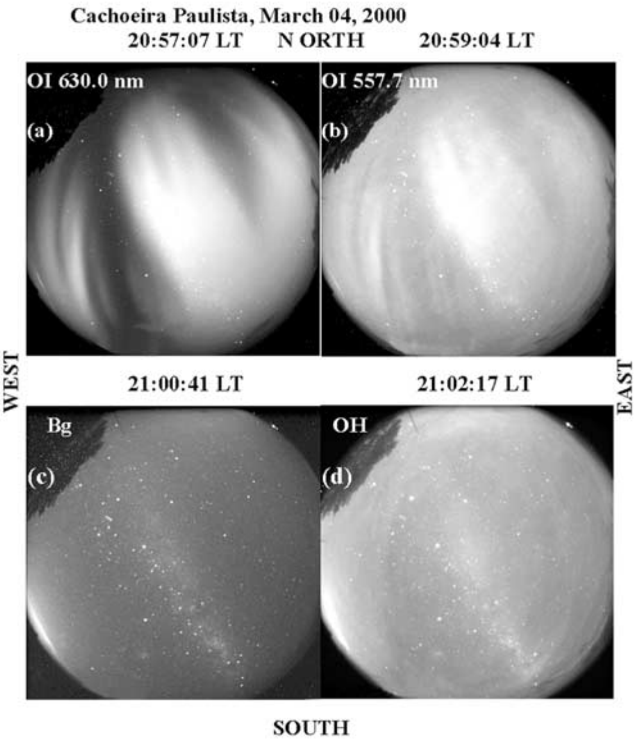

Figure 2. All-sky images obtained at Cachoeira Paulista on March 04, 2000. A blob is observed near the image center in the OI 630.0 nm emission (a) and in the OI 557.7 nm emission (b), associated with intensity enhancements in the F-region emissions produced through the O_2^+ dissociative recombination process. Plots (c) and (d) show the background and OH emissions in the mesosphere, respectively.

3. Results and Discussion

[4] Figures 2a and 2b show typical examples of the raw plasma blob observed on March 04, 2000, by all- sky imaging in the OI 630.0 nm and OI 557.7 nm emissions, respectively. The center of each image corresponds to the location of Cachoeira Paulista. The bright regions are associated with intensity enhancements in these emissions, which are related to F-region ionization enhancements and its downward vertical motions. In addition, Figures 2c and 2d illustrate the background and OH emission intensities. Note that the plasma blob appeared only in the OI 630.0 nm and OI 557.7 nm, which are representative F-region emissions by the dissociative recombination process. Figure 3 illustrates a sequence of OI 630 nm all-sky unwarped images obtained from 19:52:57 LT to 21:04:15 LT, showing the formation phase of airglow depletion bands during the post-sunset period in association with plasma blob formation. Unwarped images correspond to a mapped area of the processed image of 1024 × 1024 km, assuming an emission altitude of 250 km. In this image sequence, a blob can be seen clearly near the density depletion bands exactly in the zenith of Cachoeira Paulista, from 20:49:59 LT to 21:04:15 LT. The nearly continuous sequence of images makes it possible to optically track the discrete plasma density enhancement and depletion regions. To obtain an estimate of zonal drift velocities from the imaging data, we first scan the optical images from west to east to obtain a cross-section of the brightness and depletion patterns for each plasma blob and plasma bubble. Then, these cross-sectional scans are subjected to a correlation analysis leading to the best fit spatial shifts required to match the time between images. A succession of such space

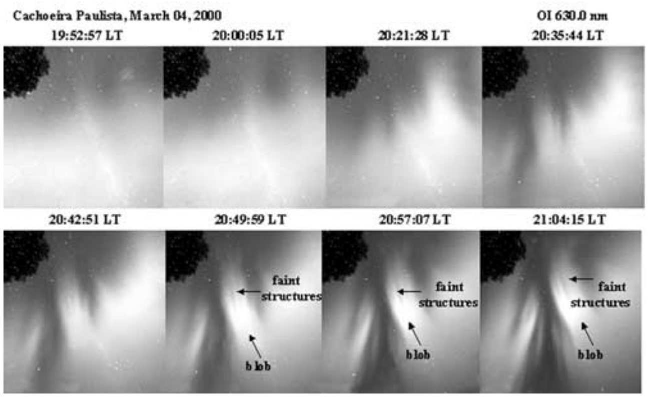

Figure 3. Sequence of the OI 630 nm all-sky images obtained from 19:52:57 to 21:04:15 LT, on the night March 04, 2000, showing the formation phase of airglow depletion bands during the post-sunset period in association with plasma blob formation. Unwarped images correspond to a mapped area of the processed image of 1024 × 1024 km, assuming an emission altitude of 250 km. The dark region in the upper left corner of the images is due to trees in the field of view. The arrows indicate the locations of the plasma blob region.

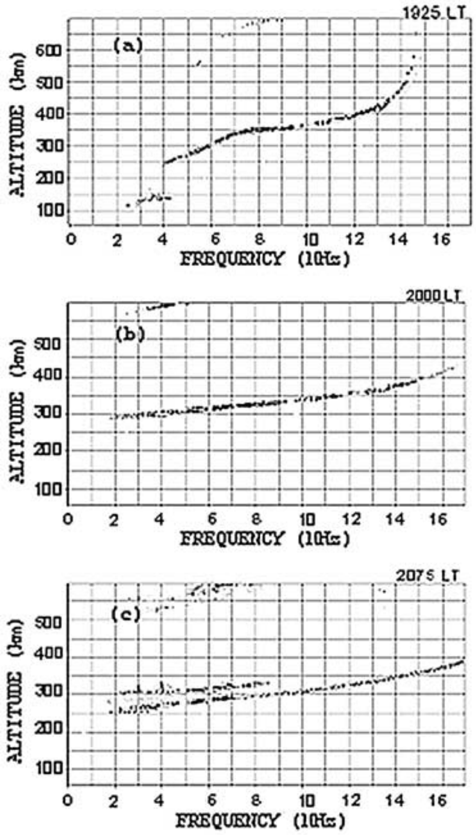

Figure 4. Ionograms obtained at Cachoeira Paulista on March 04, 2000. (a) Background ionosphere before the plasma blob event; (b) and (c) shows that, during the plasma blob occurrence, the F-layer critical frequency (foF2) and height (hmF2) could not be measured, as foF2 exceeded 17 MHz (upper limit of the operating frequency).

and time shifts leads to a zonal velocity versus local time relation for the blob and bubble. The mean eastward velocities of the plasma blob and plasma bubble were, approximately, 130 m/s and 145 m/s, respectively. Furthermore, the blob showed, typically, east-west and north-south extensions of 100–140 km and of 130–170 km, respectively. On the other hand, ionosonde measurements at Cachoeira Paulista also showed a strong increase of plasma density within the blob boundary, as presented in Figure 4. Unfortunately, when the plasma blob appeared, the ionosonde was set to cover a frequency range of 1–17 MHz, so that the ionosonde was not able to register the enhanced critical frequency of the F-layer (foF2). Figure 4a shows the ionograms obtained at 19:25 LT with the critical frequency of the F-layer close to 14.5 MHz, before the occurrence of the plasma blob. However, the ionograms in Figures 4b and 4c show only partial F-layer electron density profiles, due to abrupt electron density enhancement that characterizes plasma blob, when foF2 became out of scale (>17 MHz). To estimate the average bottomside electron density, from simultaneous ionosonde measurements of the virtual minimum height (h′F) and of the OI 630 nm airglow intensities, during the plasma blob event, we used the methodology described by *Weber et al.* [1980]. The estimates showed that the average bottomside electron density increases by a factor of 2, from background

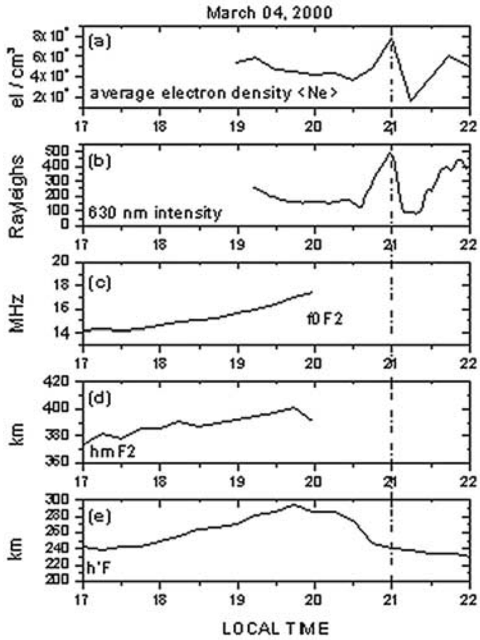

Figure 5. (a) Calculated bottomside average electron density; (b) OI 630 nm zenith intensity; (c) critical frequency of the F-layer (foF2); (d) F-region peak height (hmF2); and (e) F-region minimum virtual height (h′F). Data obtained on March 04, 2000, near the equatorial anomaly southern crest, showing the occurrence of plasma density enhancement, or blob around 21 LT.

ionosphere to blob, as seen in Figure 5a. The vertical dashed line denotes the maximum in the electron density enhancement over Cachoeira Paulista. In addition, the OI 630.0 nm intensity starts to increase around 20:40 LT, reaching a maximum at 20:50 LT, which coincides with the occurrence of the plasma blob in the all-sky imaging system. Another interesting plasma blob event was observed on October 07, 1999, in both the OI 630 nm and OI 557.7 nm airglow emissions at the zenith of Cachoeira Paulista, as shown in Figure 6. However, the blob was found to move much more slowly than the depletion region. The mean eastward velocities of the plasma blob and plasma bubble were 80 m/s and 140 m/s, respectively. Furthermore, the blob showed, typically, east-west and north-south extensions of

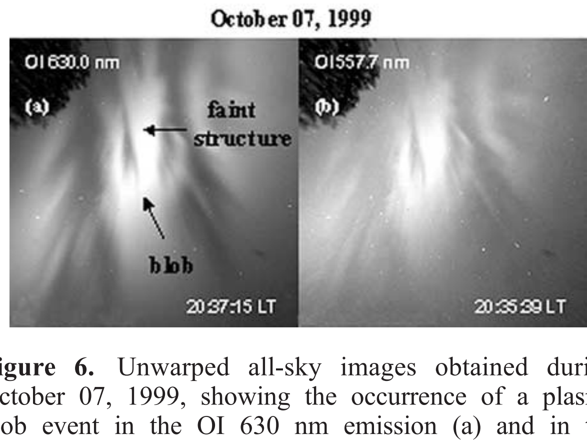

Figure 6. Unwarped all-sky images obtained during October 07, 1999, showing the occurrence of a plasma blob event in the OI 630 nm emission (a) and in the OI 557.7 nm emission (b).

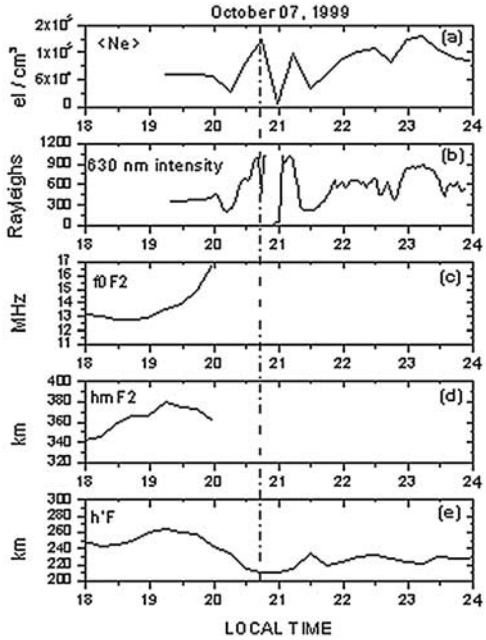

Figure 7. As in Figure 5, but on October 07, 1999.

150–180 km and of 190–240 km, respectively. Figure 7 shows the time variation of the ionospheric parameters obtained from ionosonde and photometer measurements. During the blob occurrence at 20:45 LT, the estimated average bottomside electron density increases by a factor of 2, from background ionosphere to blob. In addition, the average electron density varies by a factor of 10 from outside to inside the plasma bubble at 21:00 LT (relative to background ionosphere at 19:25 LT). The observations show that the blob occurs within two plasma bubbles, separated in longitude. Also, the plasma bubble structures, seen as faint structures north of the blobs (Figures 3 and 6) do not evolve southward. *Le et al.* [2003] suggested that, in the upward motion of the plasma bubble, the field-aligned plasma pressure gradient at the poleward edges of the depletions produce an equatorward force that drives plasma particles to move toward the equator. Therefore, the density depletions cannot extend to higher latitudes and remain limited by the anomaly crests. The polarization electric field that is generated within the bubble can be mapped along the magnetic field lines to higher latitudes, beyond the limited density depletion structure. In this way, the polarization electric field within the flux tube moves the high-density plasma at the anomaly crests upward so that density increments occur just above the flux tube. A combination of plasma dynamic processes associated with bubble formation and the equatorial anomaly fountain effect, near the anomaly crest, may provide the conditions for the formation of a plasma blob within adjacent plasma bubbles.

4. Summary

[5] In summary, our observations from ground-based optical and radio measurements, have shown the occurrence of a localized ionospheric plasma density enhancement, associated with plasma bubbles, similar to the satellite observations reported by *Le et al.* [2003] and *Park et al.* [2003]. Within these density enhancements structures, the plasma density may be increased, by more than twice above the background density. In addition, from the vertical ionospheric plasma drift velocity variations (see h′F variation in Figures 5 and 7), it is seen that the blob develops just after the reversal of the electric field, when the drift velocity changes from upward (eastward electric field) to downward (westward electric field). The density increments can be further reinforced if the background ionosphere moves downward in the region near the equatorial anomaly crest.

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