GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L17105, doi:10.1029/2008GL035043, 2008

Statistical analysis of the occurrence of medium-scale traveling ionospheric disturbances over Brazilian low latitudes using OI 630.0 nm emission all-sky images

C. M. N. Candido,[1] A. A. Pimenta,[1] J. A. Bittencourt,[1] and F. Becker-Guedes[2]

Received 16 June 2008; revised 29 July 2008; accepted 7 August 2008; published 13 September 2008.

[1] In this work we report a statistical analysis of the occurrence frequency of medium-scale traveling ionospheric disturbances (MSTIDs) observed over Cachoeira Paulista (22.7°S, 45.0°W, −13.2° mag lat), Brazil. The optical signatures of the low-latitude MSTIDs in the southern hemisphere observed in the OI 630.0 nm emission images can be a single dark band structure or alternating dark/light bands aligned in the northeast-southwest direction and propagating towards northwest. Because this feature these events were also referred as thermospheric dark band structures. The statistical study is based on 28 events of MSTIDs observed during seven years of optical data, obtained during low, medium, and high solar activities, for geomagnetically quiet nights. We find that the occurrence frequency of the MSTIDs presents a maximum during low solar activity, decreasing during medium solar activity with no occurrences during high solar activity. Also, the occurrence rates are greater near the June-solstice months.

Citation: Candido, C. M. N., A. A. Pimenta, J. A. Bittencourt, and F. Becker-Guedes (2008), Statistical analysis of the occurrence of medium-scale traveling ionospheric disturbances over Brazilian low latitudes using OI 630.0 nm emission all-sky images, *Geophys. Res. Lett.*, *35*, L17105, doi:10.1029/2008GL035043.

1. Introduction

[2] Traveling ionospheric disturbances (TIDs) are recognized as fluctuations of the plasma densities that propagate equatorward under a large spectral range of velocities, horizontal scales, and periods. From the observed similarities between the TID features and gravity waves, *Hines* [1960] proposed that the TIDs were the manifestation of gravity waves at ionospheric heights. TIDs are classified in two classes according to their horizontal wavelengths: large-scale TIDs (LSTIDs) and medium-scale TIDs (MSTIDs) [see *Hocke and Schlegel*, 1996]. LSTIDs present velocities greater than 300 m/s and are generated during auroral heating/geomagnetic activity at high latitudes. The MSTIDs present velocities under 300 m/s and can be originated at high and mid latitudes. *Perkins* [1973] proposed that the TIDs were associated to electrodynamic instabilities at mid-latitudes - Perkins instability [*Hamza*, 1999]. The origin of the MSTIDs can be, or not, associated to geomagnetic disturbed conditions [*Mendillo et al.*, 1997; *Sahai et al.*, 2001]. It is believed that, during quiet conditions, they are associated to convective activity on tropospheric regions, but this question is still under extensive investigation [*Waldock and Jones*, 1987; *Lastovicka*, 2006]. Several techniques have been used to investigate TIDs since the 50's first observations [*McNicol et al.*, 1956; *Hines*, 1960]. *Behnke* [1979] used incoherent radar and identified plasma bands aligned from northwest to southeast, propagating to southwest, at Arecibo (Puerto Rico). *Bowman* [1992] used ionosondes in the Australian mid-latitudes and verified the association between TIDs and mid-latitude spread- F. GPS receivers have shown that the MSTIDs can introduce fluctuations on the TEC (Total Electronic Content) and raise scintillations on the GPS signals [*Ogawa et al.*, 2002; *Hajkowicz*, 2007]. The electrified nature of the TIDs has been observed with incoherent radar systems and satellites [*Miller et al.*, 1997; *Saito et al.*, 1998]. Wide-angle optical imaging systems have been extensively used since the 90's for mapping the dynamic features of MSTIDs, mainly by OI 630.0 nm emission all-sky imaging [*Mendillo et al.*, 1997; *Pimenta et al.*, 2008]. The OI 630.0 nm emission comes from the recombination process of O_2^+ at the F-region bottom side and has an emission peak around 250 km. The OI 630.0 nm emission intensity is strongly dependent on the vertical motions of the F-layer, with a smaller dependence on the electron density. Hence, fluctuations on the plasma density and on the F-region heights are observed like variations in the brightness of the OI 630.0 nm emission. *Mendillo et al.* [1997] and *Garcia et al.* [2000] identified nightglow structures like bands in the OI 630.0 nm emission images at Arecibo (Puerto Rico), a medium-latitude station. These bands can appear in the imager field of view like alternating enhancements or depletions in the OI 630.0 nm emission brightness, or simply like single dark or light bands. *Shiokawa et al.* [2003] performed simultaneous observations of MSTIDs using all-sky imager, Fabry-Perot interferometer and satellite data to study the influence of polarization electric fields on the MSTID formation. *Otsuka et al.* [2004] reported the geomagnetic conjugated nature of the MSTID structures using two wide-angle imaging systems at Sata (Japan) and Darwin (Australia). At the Southern American sector, TIDs were rarely mentioned [*Sobral et al.*, 1997; *Martinis et al.*, 2006; *Pimenta et al.*, 2008] and only recently MSTIDs events have been reported. *Martinis et al.* [2006] reported one case of quiet geomagnetic conditions MSTID using OI 630.0 nm images at El Leoncito, Argentina. After that, *Pimenta et al.* [2008] showed some events of MSTIDs at a low-latitude Brazilian site (22.7°S, 45.0°W, 13.2°S mag. lat).

---

[1] Aeronomy Division, Instituto Nacional de Pesquisas Espaciais, Sao Jose dos Campos, Brazil.

[2] Physics and Astronomy, Universidade do Vale do Paraíba, Sao Jose dos Campos, Brazil.

0094-8276/08/2008GL035043

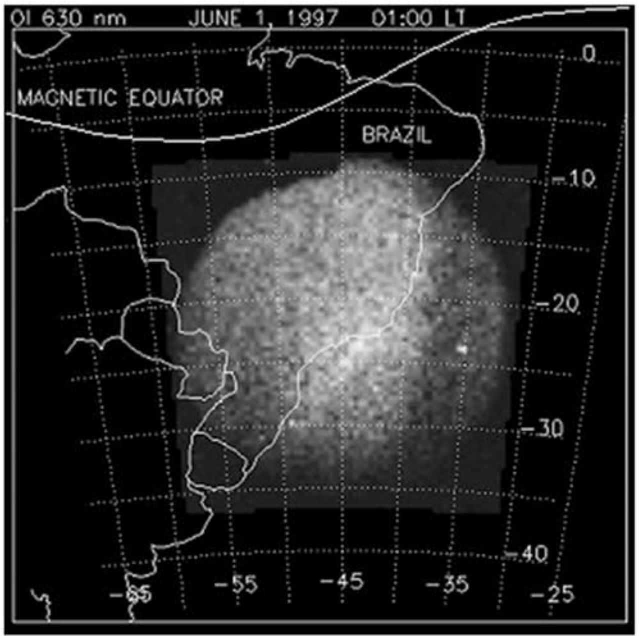

Figure 1. Location of the optical observation site: Cachoeira Paulista (22.7°S, 45.0°W, −13.2° mag lat).

They verified the occurrence of light/dark band structures in the OI 630.0 nm emission all-sky images aligned along the northeast-southwest direction and propagating towards northwest. Also, they verified that the passage of the thermospheric dark bands structures/MSTIDs over Cachoeira Paulista, Brazil, were associated with the F-region rise (h'F and hmF2) and depletions in the plasma density (foF2). In addition, the bands can be or not associated with the occurrences of spread-F in the ionograms [*Candido*, 2008]. In this paper we present a statistical study of the occurrence frequency of these dark band structures/MSTIDs based on the seven years of optical imaging of the OI 630.0 nm emission during low, medium and high solar activities. Features like dependence on solar activity and annual variation are verified.

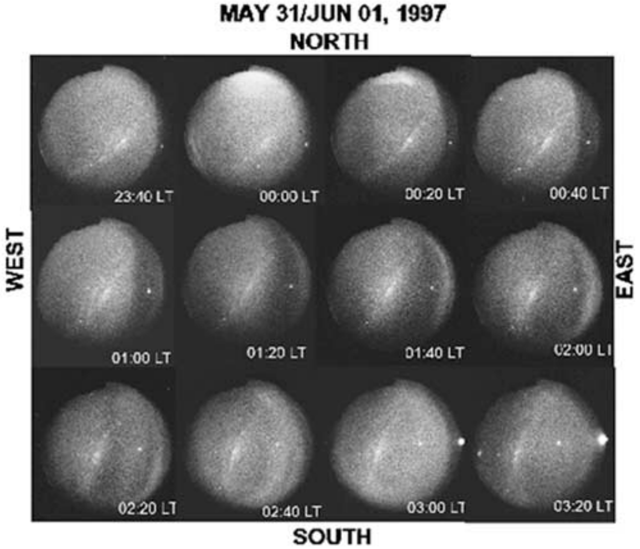

Figure 2. Sequence of raw images of the OI 630.0 nm emission obtained on the night May 31 – June 01, 1997, between 23:40 and 03:20 LT (LT = UT − 3).

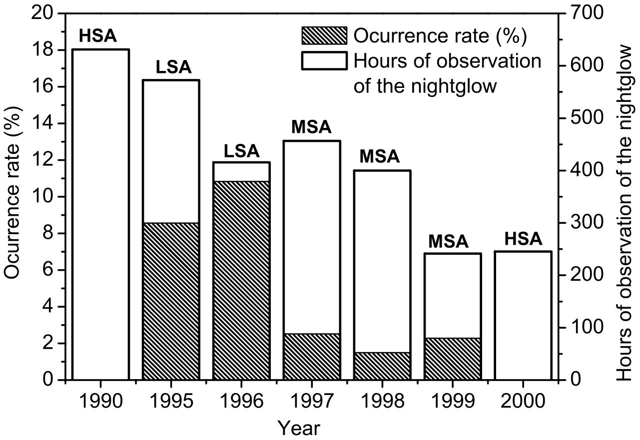

Figure 3. Rate of occurrence (percentual) of dark band structures/MSTIDs relative to the total number of hours of OI 630.0 nm optical imaging observations (left-hand side vertical axis) and the number of hours of observation of the nightglow (right-hand side vertical axis), for each year at Cachoeira Paulista (22.7S, 45W).

2. Observations

[3] A wide-angle imaging system, donated by the Boston University and installed at Cachoeira Paulista – CP – (22.7°S, 45.0°W, 13.2°S mag lat), has routinely performed all-sky imaging observations of the OI 630.0 nm nightglow emission. The system uses a 10 cm interference filter for the OI 630.0 nm emission with a bandwidth of 1.35 nm. The monochromatic images were recorded on a 35 mm film with a conventional camera [*Mendillo and Baumgardner*, 1982; *Sahai et al.*, 1994]. Figure 1 shows the location of the observation site at CP and the imager field of view assuming an emission height at 250 km. The observations were made during the new moon period and under good sky conditions. Figure 2 shows a sequence of raw images of the OI 630.0 nm emission obtained on May 31/Jun 01, 1997, where we can see a dark band structure propagating to northwest between 23:40 and 02:40 LT. The OI 630.0 nm images show the MSTID structures like single dark band structures or alternating dark and light fronts aligned from NE to SW and propagating towards NW. It is somewhat difficult to specify the wavelength of the bands, mainly due to their large zonal extension. In some cases they present widths greater than 1000 km. All the sequence images analyzed here present similar features, with dark bands propagating towards northwest.

3. Statistical Study

[4] We have analyzed seven years of OI 630.0 nm emission all-sky images covering high, medium and low solar activity periods for geomagnetically quiet nights. The index F10.7 was used to classify the solar activity in high (HSA), medium (MSA) and low (LSA). The Kp was used to classify the geomagnetic conditions. All the studied nights

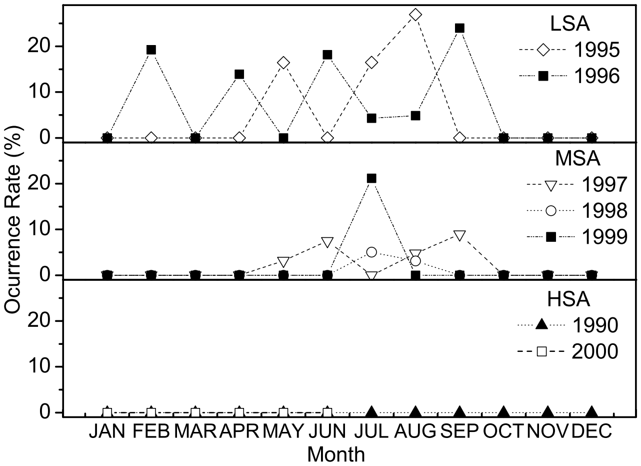

Figure 4. Monthly occurrence rates of dark band structures/MSTIDs, based on seven years of OI 630.0 nm emission observations, for each solar activity period: low solar activity (LSA), medium solar activity (MSA), and high solar activity (HSA).

showed Kp index ≤ 2, so they are classified as quiet geomagnetic nights. The study considers the number of hours of optical observations of the OI 630.0 nm emission, under good weather conditions, and the number of hours of occurrence of dark/light band structures, in order to determine the occurrence frequency of these structures. Figure 3 shows the occurrence frequency of dark/light band structures during all the seven years of optical imaging. The occurrence rate shows a peak (11%) during low solar activity, decaying to 3% during medium solar activity. During high solar activity (1990) there were no occurrences, despite the elevated number of hours of observations (~600 hours). During the year 2000, measurements were performed only during the first six months, and no occurrences were observed. To verify possible seasonal features we have analyzed the occurrence rates considering the hours of optical imaging observations under good weather conditions and the hours of occurrence of dark band structures in each month, during all the years of observations. Figure 4 shows the occurrence rates during LSA, MSA and HSA. During LSA years, there are observations of dark bands structures between February and September, with most of the occurrences in the months near the June solstice (winter in Southern American). In the MSA years, the maximum occurs again in winter in July. *Martinis et al.* [2006] reported the occurrence of MSTIDs over El Leoncito, Argentina, during December. It is possible that the no-observation of MSTIDs at Brazilian low latitudes have been affected by the bad weather conditions (possibly rain and clouds during summer in the southern hemisphere). So, more observations are necessary to clarify this point. During HSA there were no occurrences of thermospheric dark band structures. Similar characteristics were observed at other sites. *Garcia et al.* [2000] analyzed two years of optical data and verified a tendency of the MSTIDs to occur during low solar activity periods. Also, the occurrence rate was greater during the winter months at Arecibo. However, *Shiokawa et al.* [2003] observed an inverse dependence of the MSTID occurrence with solar activity at Japanese mid-latitudes. Further, they observed a maximum of occurrence during the June solstice (summer in northern hemisphere).

4. Discussion

[5] This is the first statistical study of MSTIDs observed in the Southern American sector, using OI 630.0 nm emission all-sky imaging. The analysis of several years of optical data, enclosing low, medium and high solar activities, reveals an inverse dependence between the occurrence rate and the solar activity. The observed occurrence rates are about 11% during LSA, and about 3% during MSA. During HSA there were no observations of dark band structures. This inverse dependence of the MSTID occurrence on solar activity was also previously reported by other researchers at south mid-latitudes or in the northern hemisphere [*Bowman*, 1990; *Garcia et al.*, 2000; *Shiokawa et al.*, 2003]. The plasma and neutral densities play an important role on the development and propagation of MSTIDs, through the ion-neutral collision frequency. The generation of MSTIDs at mid-latitudes is generally attributed to the electrodynamic instability described by *Perkins* [1973]. *Kelley and Fukao* [1991] have estimated the growth rate of the Perkins instability (γ_P) for mid-latitudes and verified that, even though γ_P is very small ($\sim 10^{-4}$ s), it is significantly higher for minimum solar activity than for high solar activity, in agreement with the MU and Arecibo radar observations. The growth rate, γ_P, is inversely proportional to the average ion-neutral collision frequency (ν), according to the equation

$$\gamma_P = (g/H\langle\nu\rangle)\left[sin^2 D sin^2(\theta/2)/cos(\theta)\right] \qquad (1)$$

where g is the acceleration due to gravity, H is the neutral scale height, D is the declination angle and θ is the angle between the zonal electric field and the east direction. So, during low solar activity periods, when the plasma and neutral densities are smaller, γ_P is consequently higher. Also, considering that the MSTIDs are a manifestation of gravity waves at ionospheric heights, it is important to consider the influence of ion-drag on the propagation of plasma structures. The ion-drag will be greater when the plasma and neutral densities are higher. In the mid 60's *Gershman and Grigor'yev* [1965], using MHD theory, verified the influence of the plasma density on the conditions for propagation of TIDs. From their calculations it is estimated that the TIDs suffer maximum absorption at F-layer peak heights, where the plasma density is higher. So the plasma structures may propagate long distances if they are below the F-layer peak. *Shiokawa et al.* [2002] pointed out an equatorward limit to the propagation of MSTIDs over Japan. This feature was attributed to the presence of the equatorial anomaly in the tropical region and to the consequent influence of ion-drag (due to the higher plasma density) on the propagation of MSTIDs. Otherwise, *Bowman* [1992] reported a well-defined inverse sunspot-cycle occurrence rate of MSTIDs and spread-F at mid-latitude stations. He pointed out the possible influence of the neutral particle densities variations during minimum and maximum solar activities on the propagation of gravity waves that reach ionospheric heights. As mentioned by *Hines* [1960], in the absence of strong dissipation, the gravity waves may reach higher altitudes and their amplitudes are higher. Also, it must be noted that γ_P is inversely related to average ion-neutral collision frequency (equation 1), which may increase the occurrence frequency of MSTIDs at mid-latitudes during the winter solstice months. The occurrence rate observed at low latitudes near the June solstice months can be explained accordingly, due to the lower neutral and plasma densities during this period. *Batista and Abdu* [2004] performed an analysis of the ionospheric parameters (hmF2 e foF2) at Cachoeira Paulista, Brazil, during high and low solar activity periods and verified that the foF2 parameter reach their lowest values between May and September, between post-midnight and pre-sunrise hours. We believe that these conditions can be the main factors of the MSTIDs propagation over low latitudes sites. So, the propagation of MSTIDs to low latitudes can be influenced by the lower neutral densities and mainly by the lower plasma densities during those times.

5. Summary and Conclusions

[6] We have presented the first statistical analysis of the occurrence frequency of MSTIDs observed in the southern American sector, using OI 630.0 nm emission all-sky images. The main statistical features are summarized: 1) There is an inverse dependence between the MSTID occurrence rate and solar activity. The occurrence frequencies observed at low latitudes are about 11% during LSA and about 3% during MSA. There were no occurrences during HSA. 2). The occurrence rates are higher during the June solstice; MSTIDs were not observed around December (summer) solstice. 3) The plasma and neutral density variations seem to play an important role on the observed statistical features of MSTID occurrence, due to their influence on ion-drag, on the growth rate γ_P and on the propagation conditions of MSTIDs.

[7] **Acknowledgments.** We would like to thank M. Mendillo for the OI 630 nm emission all-sky images used in this work. Also, the authors thank the Brazilian agencies: CNPq, for the financial support through the process 476937/2006-0, and FAPESP, by the grant 2008/50553-8.

References

Batista, I. S., and M. A. Abdu (2004), Ionospheric variability at Brazilian low and equatorial latitudes: Comparison between observations and IRI model, *Adv. Space Res.*, *34*, 1894–1900.

Behnke, R. (1979), *F*-layer height bands in the nocturnal ionosphere over Arecibo, *J. Geophys. Res.*, *84*, 974–978.

Bowman, G. G. (1990), A review of some recent work on midlatitude spread-*F* occurrence as detected by ionosondes, *J. Geomagn. Geoelectr.*, *42, 109–138.*

Bowman, G. G. (1992), Upper-atmosphere neutral-particle density variations compared with spread-*F* occurrence rates at locations around the world, *Ann. Geophys.*, *10*, 676–682.

Candido, C. M. N. (2008), Study of the ionospheric irregularities observed on the Brazilian low latitude sites, thesis, 286 pp., Inst. Nac. de Pesqui. Espaciais at Sao Jose dos Campos, Sao Jose dos Campos, Brazil.

Garcia, F. J., M. C. Kelley, J. J. Makela, and C. S. Huang (2000), Airglow observations of mesoscale low-velocity traveling ionospheric disturbances at midlatitudes, *J. Geophys. Res.*, *105*, 18,407–18,415.

Gershman, B. N., and G. I. Grigor'yev (1965), Theory of moving ionospheric disturbances (magnetohydrodynamic absorption), *Geomagn. Aeron.*, *5*, 2248–2255.

Hajkowicz, L. A. (2007), Morphology of quantified ionospheric range spread-F over a wide range of mid-latitudes in the Australian longitudinal sector, *Ann. Geophys.*, *25*, 1125–1130.

Hamza, A. M. (1999), Perkins instability revisited, *J. Geophys. Res.*, *104*, 22,567–22,575.

Hines, C. O. (1960), Internal atmospheric gravity waves at ionospheric heights, *Can. J. Phys.*, *38*, 1441–1481.

Hocke, K., and K. Schlegel (1996), A review of atmospheric gravity waves and traveling ionospheric disturbances: 1982–1995, *Ann. Geophys.*, *14*, 917–940.

Kelley, M. C., and S. Fukao (1991), Turbulent upwelling of the midlatitude ionosphere: 2. Theoretical framework, *J. Geophys. Res.*, *96*, 3747–3753.

Lastovicka, J. (2006), Forcing of the ionosphere by waves from below, *J. Atmos. Sol. Terr. Phys.*, *68*, 479–497.

Martinis, C., J. Baumgardner, S. M. Smith, M. Colerico, and M. Mendillo (2006), Imaging science at El leoncito, Argentina, *Ann. Geophys.*, *24*, 1375–1385.

McNicol, W. E., H. C. Webster, and G. G. Bowman (1956), A study of spread-*F* ionospheric echoes at night at Brisbane - I. Range spreading (experimental), *Aust. J. Phys.*, *9*, 247–271.

Mendillo, M., and J. Baumgardner (1982), Airglow characteristics of equatorial plasma depletions, *J. Geophys. Res.*, *87*, 7641–7651.

Mendillo, M., J. Baumgardner, M. Colerico, D. Nottingham, J. Aarons, B. Reinish, J. Scali, and M. Kelley (1997), Investigations of thermospheric-ionospheric dynamics with 6300-A images from the Arecibo observatory, *J. Geophys. Res.*, *102*, 7331–7343.

Miller, C. A., W. E. Swartz, M. C. Kelley, M. Mendillo, D. Nottingham, J. Scali, and B. Reinisch (1997), Electrodynamics of midlatitude spread *F*: 1. Observations of unstable, gravity wave-induced ionospheric electric fields at tropical latitudes, *J. Geophys. Res.*, *102*, 11,521–11,532.

Ogawa, T., N. Balan, Y. Otsuka, K. Shiokawa, C. Ihara, T. Shimomai, and A. Saito (2002), Observations and modeling of 630 nm airglow and total electron content associated with traveling ionospheric disturbances over Shigaraki, Japan, *Earth Planets Space*, *54*, 45–56.

Otsuka, Y., K. Shiokawa, T. Ogawa, and P. Wilkinson (2004), Geomagnetic conjugate observations of medium-scale traveling ionospheric disturbances at midlatitude using all-sky airglow imagers, *Geophys. Res. Lett.*, *31*, L15803, doi:10.1029/2004GL020262.

Perkins, F. (1973), Spread *F* and ionospheric currents, *J. Geophys. Res.*, *78*, 218–226.

Pimenta, A. A., M. C. Kelley, Y. Sahai, J. A. Bittencourt, and P. R. Fagundes (2008), Thermospheric dark band structures observed in all-sky OI 630 nm emission images over the Brazilian low-latitude sector, *J. Geophys. Res.*, *113*, A01307, doi:10.1029/2007JA012444.

Sahai, Y., J. Aarons, M. Mendillo, J. Baungardner, J. A. Bittencourt, and H. Takahashi (1994), OI 630 nm imaging observations of equatorial plasma depletions at 16^0 s dip latitude, *J. Atmos. Sol. Terr. Phys.*, *56*, 1461–1475.

Sahai, Y., K. Shiokawa, Y. Otsuka, C. Ihara, T. Ogawa, K. Igarashi, S. Miyazaki, and A. Saito (2001), Imaging observations of midlatitude ionospheric disturbances during the geomagnetic storm of February 12, 2000, *J. Geophys. Res.*, *106*, 24,481–24,492.

Saito, A., T. Iyemori, L. G. Blomberg, M. Yamamoto, and M. Takeda (1998), Conjugate observations of the mid-latitude electric field fluctuations with the MU radar and the Freja satellite, *J. Atmos. Sol. Terr. Phys.*, *60*, 129–140.

Shiokawa, K., Y. Otsuka, M. K. Ejiri, Y. Sahai, T. Kadota, C. Ihara, T. Ogawa, K. Igarashi, S. Miyazaki, and A. Saito (2002), Imaging observations of the equatorward limit of midlatitude traveling ionospheric disturbances, *Earth Planets Space*, *54*, 57–62.

Shiokawa, K., C. Ihara, Y. Otsuka, and T. Ogawa (2003), Statistical study of nighttime medium-scale traveling ionospheric disturbances using midlatitude airglow images, *J. Geophys. Res.*, *108*(A1), 1052, doi:10.1029/2002JA009491.

Sobral, J. H. A., G. L. Borba, M. A. Abdu, I. S. Batista, H. Sawant, C. J. Zamlutti, H. Takahashi, and Y. Nakamura (1997), Post-sunset wintertime 630.0 nm airglow perturbations associated with gravity waves at low latitudes in the South American sector, *J. Atmos. Sol. Terr. Phys.*, *59*, 1611–1623.

Waldock, J. A., and T. B. Jones (1987), Source regions of medium scale traveling ionospheric disturbances observed at midlatitudes, *J. Atmos. Terr. Phys.*, *49*, 105–114.

F. Becker-Guedes, Physics and Astronomy, Universidade do Vale do Paraíba, Sao Jose dos Campos 12244-000, Brazil.

J. A. Bittencourt, C. M. N. Candido, and A. A. Pimenta, Aeronomy Division, Instituto Nacional de Pesquisas Espaciais, Sao Jose dos Campos 12227-010, Brazil. (claudia@laser.inpe.br)