Thermospheric dark band structures at low latitudes in the Southern Hemisphere under different solar activity conditions: A study using OI 630 nm emission all-sky images

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[1] Using ground-based measurements we investigate the occurrence of dark band structures in the OI 630 nm nightglow emission all-sky images in the Brazilian low latitude region during the periods from January 1990 to December 1990 (high solar activity period-HSA), May 1995 to July 1996 (low solar activity period-LSA) and from January 1997 to December 1999 (ascending solar activity period-ASA). Unfortunately we do not have all-sky images for the descending phase of solar activity period. The OI 630 nm images obtained during these periods show thermospheric Dark Band Structures (DBS) in the low latitudes region propagating from southeast to northwest. These dark patches moved with average speed of about 50–200 m/s at an altitude of 220–300 km, which is the typical altitude range of the OI 630.0 nm airglow emission. Only during low solar activity period (LSA) and ascending solar activity period (ASA), the DBS occurrences were observed in the OI 630 nm nightglow emission all-sky images. It should be pointed out that these thermospheric/ionospheric events are not related to geomagnetic disturbed conditions. In this paper, we present and discuss this phenomena in the Brazilian sector under different solar activity conditions. A possible mechanism for generation of these dark band structures is presented. **Citation:** Pimenta, A. A., D. C. M. Amorim, and C. M. N. Candido (2008), Thermospheric dark band structures at low latitudes in the Southern Hemisphere under different solar activity conditions: A study using OI 630 nm emission all-sky images, *Geophys. Res. Lett.*, **35**, L16103, doi:10.1029/2008GL034904.

1. Introduction

[2] The response of the F-region ionosphere due to the passage of gravity waves has been studied by a large number of authors throughout the last five decades. In these studies, the neutral gravity waves are assumed to be the driving force, and the ionosphere reacts through collisions with neutral particles (the reaction that the ionization imposes on the neutral particles). *Hines and Hooke* [1970] showed that at F-region heights, this back-coupling may be important and contributes to the hydromagnetic or ohmic losses of energy from neutral gravity waves. Although the variety of sources of gravity waves might seem to generate a roughly random azimuthal spectrum of gravity waves in the lower atmosphere, or at least one which varied from

location to location, ionospheric disturbances generated by atmospheric gravity waves are well known to propagate only in restricted azimuthal directions.

[3] The airglow imaging technique has been widely used to measure thermospheric and ionospheric structures using the OI 630 nm emission, which has an emission layer in the bottomside of the F layer at 200–300 km [*Mendillo et al.*, 1997; *Sahai et al.*, 2004; *Abalde et al.*, 2004; *Pimenta et al.*, 2004]. All-sky imaging system measurements of medium-scale TIDs (MSTIDs) which we refer to here as Dark Band Structures (DBS) are comparatively rare and only recently have their spatial signatures in the mid-low latitudes OI 630 nm airglow been reported [*Mendillo et al.*, 1997; *Garcia et al.*, 2000; *Kelley et al.*, 2002; *Shiokawa et al.*, 2003; *Otsuka et al.*, 2004; *Martinis et al.*, 2006; *Pimenta et al.*, 2008]. *Mendillo et al.* [1997] and *Garcia et al.* [2000] identified MSTIDs like bands on the OI 630.0 nm emission images at Arecibo (Puerto Rico) and these bands appeared in the imager field of view like alternating enhancements or depletions in the OI 630.0 nm emission brightness, or like single dark or light bands. On the other hand, the optical signatures of the low-latitude MSTIDs/DBS in the southern hemisphere are dark band structures (low intensity region) aligned in northeast-southwest propagation towards northwest. Sometimes it appears that the structures are resolved as a series of clear wave crests, with a horizontal wavelength well defined [*Pimenta et al.*, 2008]. Also, we observed two events of DBS where the structures had a large wave front like a solitary wave. However, these events were difficult to specify the wavelength of the bands by all-sky images, mainly due to their large zonal extension.

[4] It should be pointed out that these thermospheric events are not related to geomagnetic disturbed conditions, as the nights for which data are presented are geomagnetically quiet ($K_p < 2$). It is important to note that, unlike equatorial spread F, these structures are not aligned with the magnetic meridian but rather are aligned from NW to SE in the northern hemisphere [*Garcia et al.*, 2000] and SW to NE in the southern hemisphere [*Martinis et al.*, 2006; *Pimenta et al.*, 2008]. In this paper, using all-sky images in the OI 630 nm emission, we present and discuss these phenomena in the Brazilian sector under different solar activity conditions. A possible mechanism for generation of these dark band structures is presented.

2. Measurement Techniques and Observation

[5] All-sky images of the OI 630.0 nm emission from Cachoeira Paulista (22.7°S, 45°W, magnetic declination ~20°W, magnetic latitude ~13°S) were analyzed from January 1990 to December 1990 (high solar activity period,

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Figure 1. All-sky images in the OI 630 nm emission obtained on September 07, 1997. In this example, the DBS entered from the southeast and moved across the field of view towards northwest, with an average speed of about 160 m/s.

average $10.7 \text{ cm solar cycle flux} > 180 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$), May 1995 to July 1996 (low solar activity period, average $10.7 \text{ cm solar cycle flux} < 70 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$) and from January 1997 to December 1999 (ascending solar activity period, average, $10.7 \text{ cm solar cycle flux}$ from $70 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$ to $170 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$) in order to investigate the DBS in the low latitude region in the Brazilian sector. During low solar activity period (LSA), 23 events of DBS were detected whereas in the ascending solar activity (ASA) period 09 events were observed. However, during the high solar activity period (HSA) we do not observe DBS in the all-sky images.

[6] The All-sky imager used in this study uses a 10 cm diameter interference filter with a bandwidth of 1.35 nm and records intensified monochromatic images on 35 mm film using a conventional single lens reflex camera. The images were recorded at interval of 20 min with 40s exposure time (for more details, see *Pimenta et al.* [2001a]). An important characteristic of the imager is the relationship between zenith angle and image size. A zenith angle of approximately 90° encompasses $\pm 15^\circ$ latitude/longitude from the zenith, which is equivalent to a horizontal diameter of approximately 3600 km at 275 km altitude. The OI 630 nm image observations were carried out on 12–13 nights around new moon periods, when weather conditions permitted.

[7] Figure 1 shows a example of raw all-sky images in the OI 630 nm emission obtained on September 07, 1997,

from 20:40 to 23:40 LT. The local time (LT) at Cachoeira Paulista is 3 hours behind of the universal time (UT). In these images sequence, a large wave front entered from the southeast and moved across the field of view toward northwest with an average phase velocity of about $160 \text{ m/s} \pm 10 \text{ m/s}$ (obtained from the image sequence) and passed over Cachoeira Paulista at 22:40 LT. The structure is dark, indicating low emission corresponding to zones of the F-region above of 200–300 km. All the sequence images analyzed here present similar features, with dark bands propagating towards northwest. The white arrows in Figure 1 indicate the DBS propagating from SE to NW.

3. Results and Discussion

[8] This is the first statistical study of DBS observed in the southern American sector, using an OI 630.0 nm emission all-sky imaging system. On the basis of 5 years of observations of the OI 630 nm airglow images at Cachoeira Paulista, Brazil, we investigated the statistical characteristics of the DBS as a function of nocturnal variation and solar activity. In a total of 2437 clear-sky hours, we observed 189 hours with DBS. The structures are frequently observed in the southern hemispheric during the low solar activity period and in the ascending phase of solar activity period. However, we do not observe the DBS during the high solar activity period. We identified DBS in the OI 630 nm airglow images as wave structures with horizontal scale sizes of approximately of 100–400 km and periods of 0.5–2.0 hours. However, we have some DBS events with scale size higher than 500 km and periods around 3–5 hours.

[9] Figure 2b shows that the seasonal occurrence characteristic of DBS during LSA is higher than during ASA from April to August and for the others months exhibit some month to month changes. The occurrence rates are greater near the June-solstice months (winter in the southern hemisphere). The inverse dependence of the MSTIDs/DBS occurrence on solar activity was previously reported by others researchers [*Shiokawa et al.*, 2003; *Kotake et al.*, 2006]. These results reinforce the idea of *Pimenta et al.* [2008], that the increase in absorption of DBS is mainly associated with the increase in electron concentration during the high solar activity period.

[10] Figure 3 shows the nocturnal variations in the occurrence of DBS for LSA and ASA periods and it is noted that the nocturnal variation patterns are different. During the ASA period, the percentage occurrence of DBS increases after 21 LT, reaches its maximum within a short time (23–24 LT) and then decreases until 26.5 LT. In the LSA period, the DBS occurrence increases gradually after 21 LT, reaching its maximum around 25–26 LT and then decreases until 29.5 LT. In addition, we can see that during the LSA period, the DBS nocturnal maximum occurs approximately 2.5 hours later than during the ASA. The nocturnal variation patterns as a function of solar activity suggest that DBS lifetime is larger during LSA than ASA periods. *Pimenta et al.* [2008] estimate that the spatial damping decrement for DBS is associated mainly with the increase in electron concentration and their estimates indicate that the distance of propagation of DBS does not

Figure 2. (a and b) Statistics study of DBS during the periods from January 1990 to December 1990 (high solar activity period-HSA; average 10.7 cm solar cycle flux $>180 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$), May 1995 to July 1996 (low solar activity period-LSA; average 10.7 cm solar cycle flux $<180 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$) and from January 1997 to December 1999 (ascending solar activity period-ASA; average 10.7 cm solar cycle flux from $70 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$ to $170 \times 10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$).

generally exceed 4000 km in the bottomside of the F-region. From this point of view the DBS can propagate distances of several thousands of kilometers during LSA whereas during ASA, the lifetime is relatively lower, as suggest by Figure 3.

[11] Figure 4 shows the DBS speeds and the azimuthal distribution for both LSA and ASA periods. Figures 4a and 4b shows the distribution of speeds plotted at 50 m/s intervals. The length of each line in Figure 4 indicates the velocity of the DBS structures. The methodology used in the computation of the phase velocity is described in detail by Pimenta et al. [2001b]. For LSA (Figure 4a), the

Figure 3. Nocturnal variation in the occurrence of DBS for low solar activity (LSA) and ascending solar activity (ASA).

observed phase velocities are much faster than during the ASA. The DBS in the LSA period (Figure 4a) present velocities from 50 to 200 m/s and exhibit an average value of 120 m/s . On the other hand, during the ASA period, the DBS exhibit velocities from 40 to 130 m/s and an average value of 80 m/s . Figure 4 also shows that the distribution of DBS is highly anisotropic, exhibiting preferred directions to northwestward with azimuths between 280° and 320° . Kelley and Miller [1997] suggested that the azimuthal distribution of ionospheric disturbances is more likely to be a consequence of the electrodynamic response of the ionosphere to gravity wave forcing than it is to be a characteristic of thermospheric gravity waves themselves.

4. On the Perkins Process

[12] Like others researchers, we conjecture that the Perkins instability might be involved in the formation of DBS. The most notable feature of the structures reported here is their tendency to be aligned from northeast to southwest and drift towards the northwest as found in the present observations. Perkins [1973] created a model to study a possible instability of the mid-latitude ionosphere (see Perkins [1973], Kelley and Miller [1997], and Garcia et al. [2000] for Perkins instability theory). It should be noted that the ionospheric Perkins instability, which is a possible cause of MSTIDs/DBS, is an electrostatic instability based on the coupling between ionospheric current and conductivity leading to electric field and conductivity oscillations. This instability can be seeded by neutral wind oscillations, such

Figure 4. Plot showing the nighttime azimuthal distribution and velocity of DBS observed by all-sky images (a) during low solar activity period (LSA) and (b) for descending phase of solar activity period (ASA).

as gravity waves, but just as an initial perturbation for the electrostatic instability. However, the traditional linear Perkins theory is now argued to have two deficiencies that we will address here. First is the well known issue of small growth rate, on the order of 10^{-4} Hz. Another is an apparent wave motion direction error [Garcia *et al.*, 2000], which states that while the averaged large-scale real electric field generates eastward movement during local nighttime hours, observations often display westward moving structures.

[13] Behnke [1979], using the Arecibo radar in an incoherent scatter mode, reported that localized bands in the F-region ionosphere moved from northeast to southwest across the observed region (in the northern hemisphere). This is the same direction reported for the angle-of-arrival measurements of classic mid-latitude spread-F by a number of researchers using ionosonde techniques. As discussed by Kelley and Fukao [1991], the great preponderance of angle-of-arrival data suggests that the disturbances in the ionosphere, which cause mid-latitude spread-F, are such that in the southern hemisphere the preferred direction is from the southeast while in the northern hemisphere it is from the northeast. In addition, the occurrence rate of mid-latitude spread-F has considerable annual and also solar-cycle variations [Bowman, 1960]. Also, Kelley and Fukao [1991] showed that the growth rate determined by Perkins is considerably higher during sunspot minimum conditions than during sunspot maximum for comparable altitudes of the ionospheric F-layer, and this is consistent with our observations (our events were observed only during low solar activity and ascending solar activity periods).

[14] In addition, field-aligned irregularities (FAI) in the nighttime mid-latitude E region have been observed with very high frequency (VHF) radars [Yamamoto *et al.*, 1991; Tsunoda, 1998]. Yamamoto *et al.* [1991] show that quasi-periodic (QP) echoes appear intermittently at altitudes of sporadic E (Es) layer with periods of 5–20 min. The occurrence rate of the QP echoes shows distinct a seasonal variation with a maximum in summer (northern hemisphere) and rises abruptly after the local sunset and decreases after midnight. On the other hand, Shiokawa *et al.* [2003] have investigated statistical characteristics of the MSTID observed in the 630 nm airglow images in Japan for 1998–2000. Their results show that most of the observed MSTID propagate southwestward, and that their occurrence rate has a major peak near midnight in summer. These seasonal and local time variations of MSTID occurrence are statistically consistent with those of the QP echo region occurrence. Furthermore, both MSTID and QP echo regions have wave-like structures stretched from NW to SE and propagate southwestward. These similarities between two phenomena suggest that the electrodynamical coupling between the E and F regions through the geomagnetic field plays an important role in the generation of the MSTID and E region FAI at night. Clearly, observations in mid-latitudes are needed to further clarify if the Perkins or coupled E–F region instabilities are involved in the generation mechanism and damping of the MSTIDs/DBS.

5. Summary

[15] Measurements of the two-dimensional properties of Dark Band Structures (DBS) in the nighttime thermosphere/

ionosphere using OI 630 nm nightglow emission all-sky images in South American during HSA, LSA and ASA are presented for the first time. The observed features of the DBS as a function of nocturnal variation and solar activity can be summarized as follows:

[16] 1. The DBS occurrences were observed in the OI630 nm nightglow emission all-sky images only during low solar activity period (LSA) and ascending solar activity period (ASA).

[17] 2. The most notable feature of the structures reported here is their tendency to be aligned from northeast to southwest and to drift towards the northwest at an altitude of approximately of 200–300 km.

[18] 3. It should be pointed out that these thermospheric events are not related to geomagnetic disturbed conditions, as the nights for which data are presented are geomagnetically quiet ($K_p < 2$).

[19] 4. The nocturnal variation patterns as a function of solar activity suggest that DBS lifetime is larger during LSA than ASA periods.

[20] 5. The nighttime azimuthal distribution of DBS observed during LSA and ASA periods is highly anisotropic, exhibiting directions to northwestward with azimuths between 280° and 320° .

[21] 6. We conjecture that the Perkins instability might be involved in the formation of DBS structures and that the Perkins direction has minimum damping. Clearly, observations in mid-low latitudes are needed to further clarify the generation mechanism and damping of the DBS.

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