Study of the Ionospheric Sporadic E-layers at São Luís - MA (Brazil) during Storm-Time: Observations on the Maximum and Minimum Phases of Solar Cycles 23.

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Abstract

Sporadic layers are high-density regions with a sharp thickness lower than 10 km occurring at E region heights. They have large daily variability and distinct features relative to altitude and latitude. These features are believed to be associated with their morphology and mechanisms of generation. In the present paper we summarize the results of a study on the presence of ionospheric sporadic E-layers at São Luís, Brazil (2º31´ S, 44º16´ W) during the occurrence of intense magnetic storms on the maximum and minimum phases of solar cycle 23. We have used frequency parameters obtained from a digital ionosonde to show that the Es layer can behave in a particular way, during the disturbed periods, depending upon the magnetic activity level and its latitudinal location.

Introduction

The ionosphere is a natural layer of plasma in the atmosphere, which envelopes the Earth from an altitude of approximately 60 to 2000 km. It is divided in regions, identified as D, E and F depending upon its major content and main ionization process (Rishbeth and Garriott, 1969). In the E-region, ionization enhancements named sporadic E (Es) layers are important examples of the irregular structure of the lower ionosphere and can be formed due to different processes. Gravity waves (Hook, 1970; Lanchester, 1991, Jayachandran, 1998) or tidal motions (Chimmonas, 1971) can drive vertical shears of horizontal neutral winds, which leads to horizontal convergence of ionization in the middle and low latitudes. A comprehensive study about wind shear has been published by Whitehead (1971, 1989). In high latitudinal sector, other processes are associated to Es layers development, such as particle precipitation (Sauli and Bourdillon, 2008). However, during some special condition particle precipitation can also be associated with presence of Es-Layers in low latitude (Abdu, 1993). The Es layers are classified in several types, according to the different mechanisms of formation and locations of observation. The ordinary Es layers observed at São Luís is the type "q", which are associated to equatorial electrojet (EEJ) current instabilities (Kivelson and Russell, 1995).

Batista and Abdu (1977) studied the presence of Es layers on the middle latitudes region, during quiet and disturbed periods before, during, and after the magnetic storm. They showed that the critical frequency (foEs) and cut-off frequency (fbEs) of the Es layer had relevant characteristics. One of the observed characteristics was the increment in the fbEs during the recovery phase. Resende et al. (2007) studied the presence of Es layers on the equatorial region during quiet and disturbed periods before, during, and after the magnetic storm that occurred in October 2003. Characteristics similar to the ones observed by Batista and Abdu (1977) were seen in the fbEs parameter. Also, it was observed a decrease in the foEs parameter during the main phase of the storm. In the present work, we study similarities and differences between the frequency parameters behavior of Es layer during the maximum and minimum phase of solar cycle 23 on disturbed periods. Indeed, the ionospheric profiles obtained from digital sounders at São Luís were analyzed and discussed in terms of disturbance activity aiming to identify possible evidences of the reaction of the Magnetosphere-Ionosphere system to strong magnetic storms in the ionospheric parameters.

Methodology and Data Selection

The basic analysis is based on interpretation of some parameters derived from ionograms obtained by a digital ionosonde installed on the dip equator at the Brazilian sector. The digital ionosonde is a high-frequency radar that consists of a transmitter system, a receiver system, a transmitting antenna and several receiving antennas. It transmits short pulses of radio frequencies in a log periodic antenna and receives the echoes with another antenna array. The pulses are transmitted with 10 kW peak power (500 W of average power). The data collected for the digital sounders are echoes reflected by ionospheric layers having electron density corresponding to the frequency of the transmitted signal. The ionosonde 30 MHz, with 1 MHz of frequency step.

The frequency parameters of Es layer analyzed in this study are its critical frequency (foEs) and its cut-off frequency of the Es layer (fbEs). This later is also named blanketing frequency because it is the frequency up to which the transmitted signal is blocked and does not reach the higher ionospheric regions The ionograms are usually obtained every 15 minutes. Therefore, our analysis of the foEs and fbEs variability have 15 minute time resolution.

The Dst index was chosen to characterize the level of magnetic disturbances. As an example, the graph of the Figure 1 shows the variation of the Dst index throughout the April in 2000. It shows an intense magnetic storm, which occurred on April 4. In the main phase, when the index sharply decreases its intensity, the Dst index reached -80 nT. The recovery phase, characterized for the ascent of the index until reaching the quiescent values, seems to have lasted until around midday on April 8. Later on, several storms and sub-storms are observed on April 9, 14, 18, 24 and April 27.

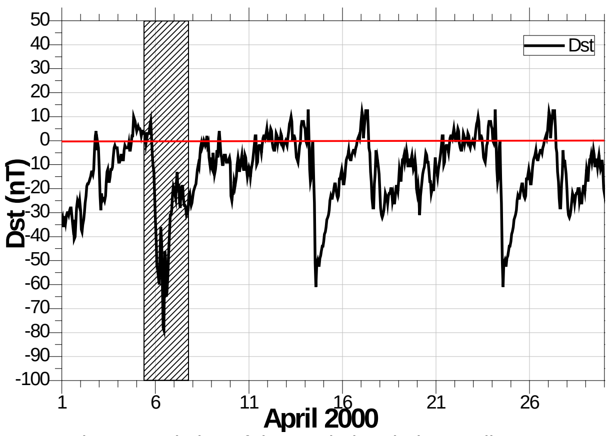

Fig. 1 - Variation of the Dst index during April 2000.

The above example illustrates a selected storm that occurred during the solar maximum. Several other intense stormed were also observed during active solar period. However, very few intense storms were observed during solar minimum on the cycle 23. Indeed, we were able to identify only two, despite to have identified several moderated storms. Unfortunately, we experienced the some a lack of data that restricted our analysis to the selected disturbed periods enrolled in the TABLE 1, which covers the solar cycle 23.

TABLE 1: List of days on the solar cycle 23 when magnetic storms were identified.

Phase	Month	Year	Days
Maximum	April	2000	03,04,05,06,07,08,09,10
	November	2001	04,05,06,07,08,09,10,11
Minimum	April	2006	12,13,14,15,16,17
	December	2006	14,15,16,17,18

Results and Discussions

In the upper panels of figure 2, we present the diurnal variation of the frequencies related to the Es layer (fbEs and foEs) for the period between April 3 and 10, 2000 and between November 4 and 11, 2001 during the solar maximum on the cycle 23 derived from the digisonde data. The time referrers to universal time (UT) at São Luís. In the bottom panels of the same figure, we present the fbEs and foEs diurnal variation for the period between April 12 and 17, 2006, and between December 14 and 18, 2006, representing the solar minimum on cycle 23. The identification storm phases are superimposed to each graph. The number (1) corresponds to what we have classified as initial phase. The number (2) identifies the main phase of the geomagnetic storm. And the number (3) marks the period that we have considered as the recovering phase, limited to the time when the Dst index reached close to zero.

A simple analysis of the evolution of the foEs before and during the magnetic storms reveals a subtle characteristic observed only in November 2001. There seems to be a tendency of the foEs to decrease its peak values during the main phase of the storm, when the peak values around 10.5 MHz observed before the storm reduced to below 10 MHz on November 6, and persisted under this level until November 10, when the recovery phase toke place and the peak values increased to 11.5 MHz. On the others periods, this “step” was not clearly observed. In fact, the foEs presented a typical variation pattern. For nighttime observation during all the days the foEs varied between 2 and 5 MHz, accept for November 7, 2001; April 12 and 13, 2006. For daytime observation the foEs peak frequency laid on an average value around 11 MHz. Some remarkable peaks of foEs were observed on April 4, 2000 (13.5 MHz at 8 UT); April 10, 2000 (14.5 MHz at 12 UT); November 4, 2001 (13.5 MHz at 10 UT), all during solar maximum.

Resende et al. (2007) have shown that the fbEs is characterized by a typical diurnal variation during quiet time that resemble the positive phase of a sinusoidal curve. The nighttime value remains quite constant around 1.2 MHz until about 10 UT, when it rises until reaches around 4 MHz close to local midday (15 UT). Then, fbEs slowly decrease to 1.2 MHz during the afternoon. The variation of the fbEs during whole period of occurrence of the storm (initial phase, main phase and recovery phase) showed no significant differences from its typical behavior during quiet time.. However, on April 10, 2000, on the second day of the recovery phase of one storm that occurred during solar maximum, fbEs suddenly increases in a short time scale. The fbEs value peaks at 6 MHz at 10 UT. Significant increases of fbEs on 2nd to 3rd days after magnetic storms had already been observed in middle latitudes. Batista e Abdu (1977) had reported a study from some storms that occurred between 1973 and 1975 in which fbEs reached values superior to 7 MHz. At that time, they had classified some sporadic layers as being of the type “a”. After a careful study of winds and recombination rate, they associated the fbEs increase to particle precipitations from the Van Allen Radiation Belt. In the present study, such a classification was not carried; neither a detailed study of winds. However, the specific case of the peak on April 10 was examined in more details based on a sequence of ionograms.

In figure 3, we present a sequence of ionograms acquired between 09:00 and 17:45 UT on April 10, 2000 in São Luís. The ionograms obtained from 08:00 UT to 10:15 UT reveal the presence of a sporadic layers type “f” (Es-f), which commonly observed in middle latitudes. In the sequence, between 10:30 UT and 12:30 UT, we observe the presence of a sporadic layers type “a” (Es-a), which is rare in equatorial latitudes and is normally associated to particle precipitations in auroral regions. At around 12:45 UT, the strong spread associated with formation of a type “q” sporadic layer (Es-q) is clearly observed in the sequence of ionograms. Therefore, it seems that the peak in the fbEs occurred in the transition from presence of an sporadic E layer type "f" to the type "a".

The real cause of the appearance of these sporadic layers in these exact sequence, which caused this sudden increase in electron density in the E-region, represented by fbEs, is still under discussion. In previous studies by Resende et al. (2007), this phenomenon was associated with counter electrojet. However, a careful study needs to be carried on to evaluate this relationship.

Conclusions

This preliminary work presented some evidences of the reaction of the Magnetosphere-Ionosphere system, observed in ionospheric parameters of the equatorial region, to the effect of the solar activity. The amount of data analyzed is not expressive enough to allow definitive conclusion. Nevertheless, its results indicate that there is a relation between the phase of the solar when the magnetic storm occurs and its effects on the sporadic E-layers at equatorial latitudes. We identified a subtle tendency of the foEs to decrease its peak values during the main phase of magnetic storms. Additionally, remarkable peaks of foEs were observed, but during solar maximum only. Also, the fbEs variation during the whole disturbed period does not differ substantially from its typical behavior during quiet time. However, the fbEs suddenly increased in a short time scale on the recovery phase of one storm during solar maximum. This peak occurred in the transition from presence of an sporadic E layer type "f" to the type "a".

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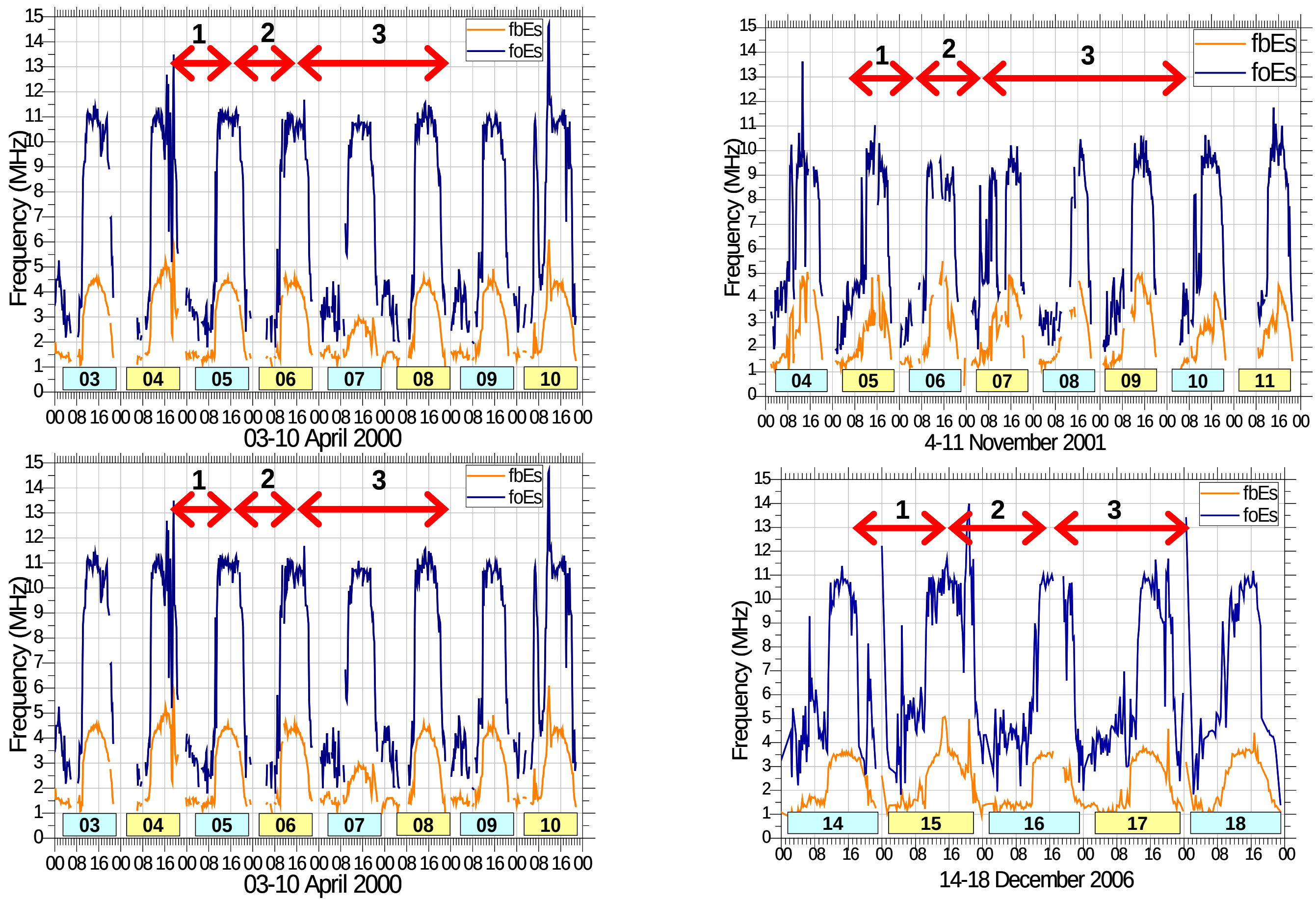

Fig. 2 - Diurnal variation of the frequencies related to the Es layer (fbEs and foEs) for the period (top left) between April 3-10, 2000, (top right) between November 4-11, 2001, (bottom left) between April 12-16, 2006 and (bottom right) between December 14-18, 2006, given in hour UT at São Luís.

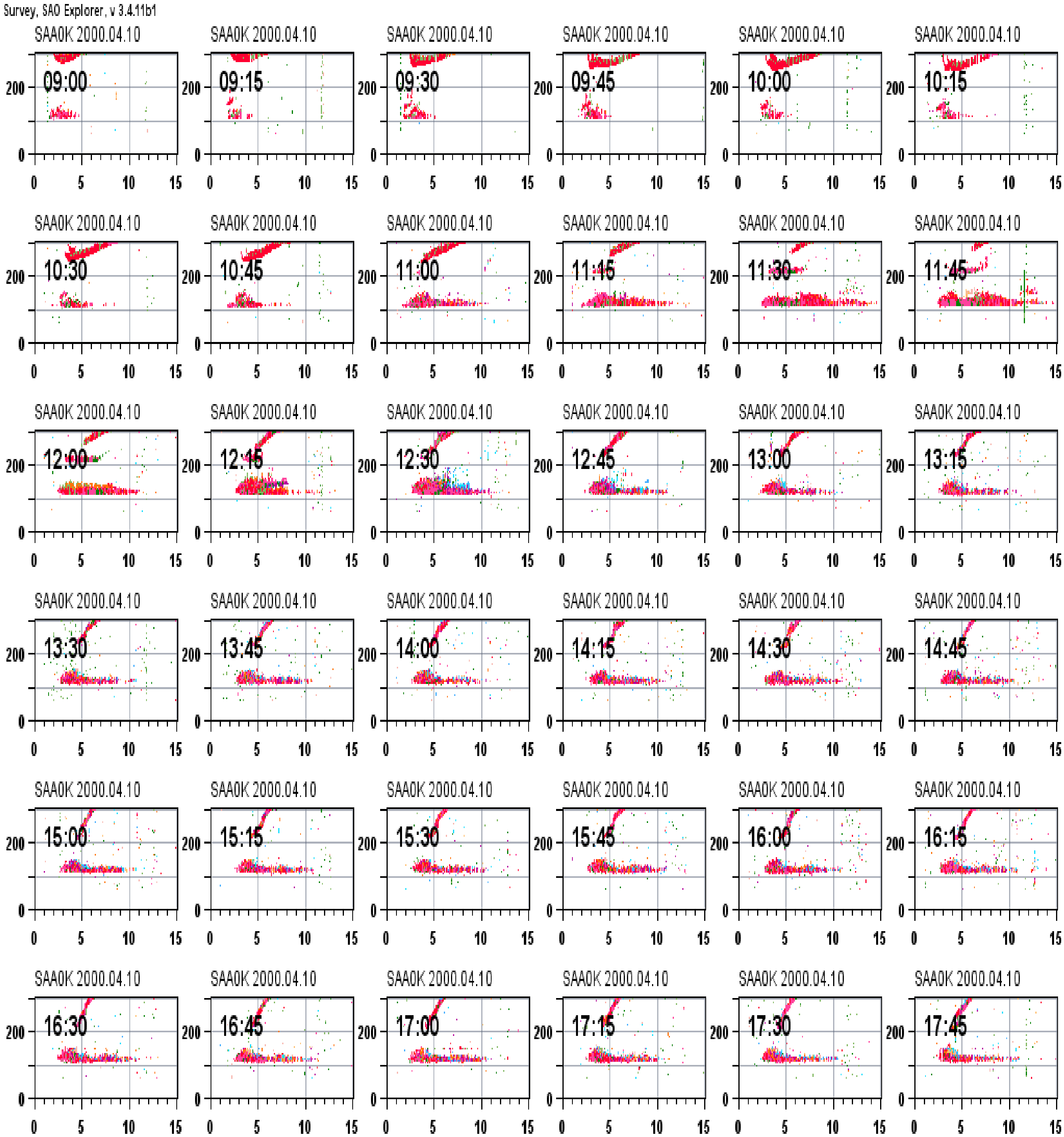

Fig 3. - Sequence of ionograms gotten in São Luís - MA (2º 31' S, 44º 16') in day 04 of April of 2000 between 09 and 17:45 UT

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