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16.Summary/Notes

Sporadic E over Cachoeira Paulista (11°57'S, 22°32'E Geomag) undergoes enhancements for short intervals (1-3 hours) within 1-3 days after the initiation of a magnetic storm of moderate intensity. The ambient night E region ionization deduced from $f_b E_s$ during such enhancements are comparable to or greater than the regular daytime maximum ionization. These and the range spread observed in the E_s echoes are interpreted as evidence of magnetic storm associated particle ionization in the E-region of the Geomagnetic Anomaly.

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MAGNETIC STORM ASSOCIATED DELAYED SPORADIC E ENHANCEMENTS IN THE BRAZILIAN GEOMAGNETIC ANOMALY

by

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Abstract

Sporadic E-layer behaviour over Cachoeira Paulista ($11^{0}57$'S, $22^{0}32$'E Geomag.), located near the centre of the Brazilian Geomagnetic Anomaly, is investigated during magnetically disturbed periods. Significant enhancements in the Es-layer parameters, ft Es and fb Es, take place for short periods (2-3 hours) following a magnetic disturbance of moderate intensity. The enhancements, however, are delayed by 1-3 days with respect to the initiation of a disturbance. The electron density enhancements in the Es layer infered from fb Es during such events are at times an order of magnitude larger than undisturbed values. Also during some night events the ambient E-region electron densities appear comparable to the regular daytime maximum values. The Es-traces in the ionogram during these events exhibit range spread in the echoes resembling the a-type Es known to occur over auroral latitudes under disturbed conditions. These results are interpreted as evidence of enhanced charged particle precipitation in the E region over the Geomagnetic Anomaly following magnetic disturbances. The results also provide evidence that the E region response over our station is delayed with respect to the magnetic activity.

MAGNETIC STORM ASSOCIATED DELAYED SPORADIC-E ENHANCEMENTS IN THE BRAZILIAN GEOMAGNETIC ANOMALY

Introduction

Sporadic-E behaviour during magnetically disturbed periods has different characteristics over stations located at different geomagnetic latitudes. Over the auroral latitude a positive correlation between sporadic E occurrence and magnetic activity was observed by Smith (1957), while for midlatitude the correlation was negative (see also, Layzer, 1972). At stations located at low geomagnetic latitude, zero or very weak positive correlation has been reported (Smith, 1957; Bandyopadhyaya and Montes, 1963; Huang, 1965, and Closs, 1969). In this paper we present results of a preliminary investigation of magnetic storm effects on sporadic E layer phenomena over Cachoeira Paulista (11^{0}57' S, 22^{0}32'E geomagnetic), a low geomagnetic latitude station, located very close to the centre of the Brazilian Geomagnetic Anomaly. A recent study by the authors (Abdu and Batista, 1977) on Es phenomena over Cachoeira Paulista, for a few months during 1973-74, showed that during this period the Es occurrence was a regular feature of the daytime and nighttime ionosphere over this station and also that blanketing type Es (with f_b Es $\geq$ 2.3 MHz) occurred at night having monthly average f_b Es comparable at times to its daytime maximum values.

A study of specific cases of Es behavior during a few magnetic storms of moderate intensity (being defined here as storms during which the three hourly planetary index K_p, rose to above 4) is undertaken in the present work. During all the storms of moderate intensity that we examined the E_s parameters, $f_t E_s$ and $f_b E_s$, showed well-defined enhancements of appreciable magnitude. The enchancements, however, were not simultaneous with changes in K_p but occurred within 1-3 days after the initiation of the storm.

. Presentation of the Results

A case of enhancement in $f_t E_s$ and $f_b E_s$ (scaled quarter hourly) following a storm that started with an SC at 0345 LT on 16, Oct. 73 is shown in Fig. 1. The magnetic index K_p indicated moderate disturbance ($K_p > 4$ for much of the time) after the storm on 16, 17 and most of 18 October. A pronounced enhancement in the E_s occurred near the midnight of 16-17 October when the $f_t E_s$ and $f_b E_s$ reached 12.5 MHz and 6.5 MHz respectively. At the time of this enhancement the magnetogram for Vassouras, Rio de Janeiro, showed near recovery from the storm main phase and the H component of the field showed minor fluctuations, of amplitude 1-5γ and periods of few minutes. Since $f_b E_s$ represents the approximate plasma frequency of the E_s layer (Reddy and Mukunda Rao, 1968), the E_s layer electron density during the maximum of the event near 00 LT would be around 5×10^5 cm^{-3}, which is a factor of two higher than its regular daytime maximum (around 2×10^5 cm^{-3}, corresponding to the daytime maximum of the monthly mean $f_b E_s$ of 4 MHz for October). These values for the layer peak electron densities may not suggest that the E region ambient densities near midnight were also higher proportionally to the daytime values, because the daytime regular E_s layers occur around 120 Km (and mostly of c-type) whereas the E_s layer during this event occurred near 100 Km, where the lower diffusion coefficient for the ions would permit higher ratios for the peak to ambient densities of the layer to exist. Nevertheless, considerations similar to those discussed by Abdu and Batista (1977) would show that the f_b E_s near midnight might indicate an ambient electron density near 100 Km of at least the order of 10^5 cm^{-3}. It is pertinent to point out that during this event and most of the others to be described shortly, whether they occurred during day or night, the height of the E_s layer remained nearly constant around 100 Km in the course of the growth and decay of the f_b E_s.

A more extensive time series, for three consecutive days, covering the magnetic disturbances and E_s enhancements, for the event in Fig. 1 and three others, is presented in Fig. 2 together with the K_p indices for the respective cases. The first of these cases presents the E_s behaviour following an SSC that occurred near 00 LT on 21 May 73. Considering that the diurnal maximum in the monthly mean f_t E_s and f_b E_s for May were around 5 and 4 MHz respectively, the first significant enhancement seems to have taken place on the second day of the storm, 22 May 73, between 16-18 LT. This was followed by pronounced enhancements on 23 May, around 15 LT and again at 20 LT, during which the f_t E_s and f_b E_s reached 13 MHz and 9 MHz respectively in the first event and 7.8 MHz and 7.5 MHz in the second event. The electron densities in the E_s layer during the maximum of the 15 LT event were a factor of 5 greater than the diurnal maximum in the regular E_s layers. A similar enhancement was present in the nighttime case as well. The height of the E_s layer was nearly constant at 100 Km during both the events. At the times of these events the magnetic disturbance index had returned to normal ($K_p \leq 3$) and the local magnetograms (presented for all the four cases in Fig. 3) show almost complete recovery in the magnetic field with only minor fluctuations (weaker than in the 16-17 October event) present in the H component of the field. We may note that in the present two events the f_b E_s reached maximum values in ≤ 15 minutes, the time resolution of the observation.

In the third case presented in Fig. 2 the magnetic storm, not accompanied by an SC, started near midday on 24th Nov. 73 and the largest disturbance occurred on 25th Nov. The first E_s enhancements after the storm were observed around 14 LT and 19 LT on 27th (no E_s data were available from 05 LT on 25th until 1045 LT on 26th Nov.). The local magnetic field had almost recovered from the stormtime disturbance and showed small scale fluctuations in the H component during the 14 LT event more conspicuously than in the case of 19 LT event (Fig. 3). E_s enhancements took place at 19 LT on 28 Nov. also with similar features as on the previous day. The E-region electron density enhancements for these events would be nearly of the same order of magnitude as in the 16-17 Oct. midnight event. However, the delay with respect to the storm commencement is considerably more in this case.

The last case presented in Fig. 2 corresponds to the storm that occurred with an SC near 20 LT on 21 Nov. 75. The first E_s enhancement appears to have occurred around midnight of 22-23 Nov. when f_t E_s showed some increase with no appreciable change in the plasma frequency of the layer. More pronounced E_s enhancement took place around 14 LT on 23 Nov., when f_t E_s and f_b E_s reached 10 MHz and 8 MHz respectively. Magnetic disturbance had almost subsided during the enhancements and, as in the previous cases, the H component of the field showed minor fluctuations. A careful examination of the E_s data for 22 Nov. shows that at the time of high magnetic activity the E_s occurrence was somewhat reduced; a feature that resembles the midlatitude cases of negative correlation between the two (Layzer 1972). More data will be needed to confirm the existence of any such negative correlation over our station with simultaneous values of K_p (or preferably with local K-values).

The E_s parameters plotted on 21 Nov. before the SSC also seem to be high compared to the monthly mean diurnal maximum of 6 MHz and 5 MHz for the $f_t\ E_s$ and $f_b\ E_s$ respectively. Though the magnetic disturbance which preceded this enhancement took place on 17 Nov. with $K_p > 4$ the daily sum of K_p for that day (=22) was considerably smaller than for the other cases discussed before. Also the enhancements observed during the day time are in the c-type E_s at virtual heights of 115-120 Km decreasing gradually to 105 Km during the enhancement around 18 LT (an exception to all other events for which the virtual heights were near 100 Km).

For the four cases of E_s enhancements, shown in Fig. 2, the peak deviation of $f_t\ E_s$ and $f_b\ E_s$ and the rms deviation for the month at the respective hours are presented in table 1. The magnetic storm association of these events is borne out by the fact that the observed deviations in the E_s parameters are many times the standard deviations. In the course of the operation of the ionosonde at Cachoeira Paulista for some months in 1973-75 a few more such events have been observed. A superposed epoch analysis taking zero time as that of the peaks in the E_s enhancements is presented in Fig.4 for seven events for which reasonable coverage of data for four days before and after the events existed (separate curves for f_t E_s and f_b E_s are presented, also 15 minute values are plotted for ± 10 hrs from the peak of the event, while hourly means are plotted for the rest of the time). The K_p values appear significantly higher for 3 days before the E_s enhancement, with the majority of the points lying above twice the standard deviation referred to a mean (shown by the broken line together with the 98 percent confidence width of the mean) taken from a group representing ± 20 days, plotted in the lower part of the figure. If we take means of the K_p for groups of 3 days before and after the E_s enhancement, it is seen that the value immediately before the E_s enhancement is the highest in the group and has a deviation twice the standard deviation of the group. Thus the probability that the occurrence of high K_p values for 3 consecutive days before the E_s enhancements is a random phonomenon is very small.

Discussion:

The ionization enhancements in the E region during these events appear quite significant considering, particulary, the evening and midnight cases. The ambient E-region electron densities, for example, during the midnight event of 16-17 October and the 20 LT event of 23 May could be shown to be of the order of 10^5 cm^{-3} or higher from considerations of winds, recombination coefficients and diffusion coefficients for these heights. Estimation based on different criteria also would lead to similar values for the ambient densities. As an example we consider the event of 20 LT on 23 May during which the f_b E_s enhancement of upto 7.5MHz took place in

$\leq$ 15 minutes (the time resolution of the observation). It seems that a wind system which could produce blanketing type E_s layers is unlikely to undergo changes with such short time scales (see Layzer, 1972). Further, the fact that the virtual height of the E_s layer (which was around 100 Km) did not change during the course of the event, implies that the observed $f_b\ E_s$ enhancement resulted from a corresponding increase in the source of ionization over the observing station with a time scale of the order of 15 minutes or less. If we consider metallic ion E_s layers then it would be necessary to assume that the conditions for the E_s layering were already prevailing at these times and that molecular ions were produced by an enhanced source of ionization such that sufficient numbers of them were converted to metallic ions by a charge transfer mechanism with a time constant, $\{k([O_2^+] + [NO^+])\}^{-1}$, which did not exceed 15 minutes. (This time constant corresponds to the conversion of metal atoms to metal ions by reaction $M+X^+ \rightarrow M^+ +X$, where $X^+ = O_2^+$ or NO^+, and ignoring the metal atom production rate during this period). Assuming a value for the charge transfer coefficient, k, of 6×10^{-9} $cm^3\ sec^{-1}$, as deduced by Narcisi (1968), the ambient molecular ion density $[O_2^+] + [NO^+]$ should be, at least, of the order of 2×10^5 cm^{-3} for explaining the observed risetime of $\leq$15 minutes. If, on the other hand, we assume molecular ion E_s layer, the ambient density required to produce the observed $f_b\ E_s$ could be still higher. In fact, at such high ambient densities, the E_s layering by the wind - shear mechanism might not be very significant, unless winds were very strong. In the case of the midnight event of 16-17 October the source of ionization seems to have intensified more slowly. Based on monthly mean $f_b\ E_s$ values for some months in 1973 the authors have shown (Abdu and Batista, 1977) that an ambient nighttime E-region ionization of around 5×10^4 cm^{-3} might be present regularly during that period. Our present results demonstrate that the nighttime ionization undergoes siginificant enhancement associated with magnetic disturbances, a fact that might suggest a particle origin for the source of ionization. Positive correlation, observed between K_p and nighttime E-region ionization changes derived from analysis of rocket profiles of intermediate layers, has been attributed by Geller et al (1975) to possible presence of energetic electron precipitation over midlatitude night E region. In an earlier work based on a riometer absorption event (Abdu et al, 1973) evidence for particle precipitation in the D-region over the geomagnetic anomaly, following a SC of a severe magnetic storm, has been presented.

The E_s trace in the ionogram of 0015 LT on 17th October 73, Fig. 5, shows almost complete blanketing of the F-trace and also, significant spread in the range of the E_s echoes. This resembles the a-type E_s known to occur over auroral latitudes during magnetic disturbances. Some degree of spread is generally present on most nights, but intensification, of which the figure represents a typical case, takes place following magnetic disturbances in all the cases that we have examined so far. In the daytime example for 1345 LT on 23 May 73 the spread is relatively less pronounced, probably,due to the ionospheric absorption of the weak spread echoes (The variation in the degree of the spread with frequency, seen in these ionograms, is most likely caused by a corresponding variation in the transmitted power of the sounder). A comparison with the ionogram of 1345 on 22 May, also shown, illustrates that the virtual height of the E_s trace during significant storm effects had decreased to 100 Km or sometimes even less. In view of the well known association among magnetic activity, particle precipitation and a-type E_s over auroral latitude (see for exemple, Reddy et al., 1969), the appearence of an E_s trace in our ionogram resembling the a-type E_s might lend direct support to our suggestion of a particle origin for the source of ionization. However, unlike auroral latitudes, winds over our station should be sufficiently effective in producing blanketing type layers; thus the blanketing traces in our ionograms that also exhibit large range spread seem to be an interesting phenomenon that merits more detailed investigation.

Over the Brazilian geomagnetic anomaly no investigation of E_s behaviour during magnetic disturbances has been reported before. The E_s response observed is, with a time delay that varies from one event to the other, of 1-3 days with respect to the initiation of the storm. Such delayed response of the E region to magntetic disturbances is hitherto unknown and is difficult to fit with any established class of E region disturbances. Two aspects of delayed ionospheric response to magnetic storms seem pertinent to mention here: (1) "Storm after-effect" in the midlatitude D-region, is a recognized phenomenon (Belrose and Thomas, 1968; Lauter and Taubenheim, 1970, Beynon and Williams, 1974) and has been interpreted as being caused by precipitation of energetic electrons that radially diffuse into the inner radiation zone, following their injection into the outer zone in the initial phase of a storm (Spjeldvik and Thorn, 1975) and (2) Equatorward propagating disturbances carrying changed thermospheric composition, initiated by the electrojet heating of the auroral E region, have been invoked (see Rishbeth, 1974 and Davis, 1974) to explain F-region negative storm effects over middle and low latitudes. This latter aspect seems very unlikely to contribute to the delayed E_s enhancements under discussion, because (a) the observed delay of around 3 days, in some cases, is too long for the speed of propagation of such disturbances; (b) rapid increases in f_t E_s, such as those observed at 14 LT and 20 LT on 23 May 1973, can not be explained; (c) night enhancement in the E-region electron densities may not be explained by composition changes; and (d) the effect of neutral atmospheric propagation disturbances in the E region should be observable at other low and midlatitudes stations as well. Since our observation presents definite cases of ionization enhancements with short time scales, irrespective of the delay factor, they would more likely fit in with the interpretation invoking particle precipitation in the geomagnetic anomaly. The observed delay of 1-3 days might be characteristic of the processes by which particles enter the lower L-shells passing through the geomagnetic anomaly, following their injection into the outer zone in the initial phase of the storm. It might be pertinent to note, judging from the times of occurrences of most of these events, that they seem to have a tendency to occur around the dusk meridian rather than around the dawn meridian. These aspects also merit more detailed investigation.

Conclusions:

The following conclusions may be drawn from the present study:

(1) Enhancements in the E_s parameters, f_t E_s and f_b E_s, take place in the Brazilian Geomagnetic Anomaly following a magnetic storm of moderate intensity, within 1-3 days after the initiation of the storm and each enhancement lasts typically for 1-3 hours. During these events the local

magnetogram shows near recovery from the storm effect and the H component of the field generally exhibits minor fluctuations of few minutes period.

(2) The enhanced f_b Es suggests significant increases in the ambient electron densities near 100 Km, with nighttime enhanced densities often comparable to the regular E-region daytime ambient densities.

(3) The pattern and magnitude of the night enhancements, together with the nature of the E_s-trace exhibiting range spread of the echoes similar to the a- type Es, observed over auroral latitude, would suggest a particle origin for the source of the observed ionization enhancements.

More detailed study on these types of E_s enhancements and related features will be undertaken as more data become available.

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TABLE 1

TABLE SHOWING THE ENHANCEMENT FEATURES OF SOME OF THE E_s EVENTS DISCUSSED IN THE TEXT

Day and hour of the enhancements			Max. values during the enhancement (MHz)	Monthly mean and the RMS deviation (MHz)	Max. deviation during the enhancement
23 May 1973	14 LT	$f_t E_s$	13.0	4.36, 1.14	9.82
		$f_b E_s$	9.0	3.18, 1.07	5.82
	20 LT	$f_t E_s$	6.7	3.80, 0.88	2.90
		$f_b E_s$	5.0	2.31, 0.78	2.69
16-17 Oct. 1973	00 LT	$f_t E_s$	13.0	3.53, 1.49	9.50
		$f_b E_s$	6.5	2.21, 0.98	4.29
27 Nov. 1973	14 LT	$f_t E_s$	7.2	4.66, 0.46	2.54
		$f_b E_s$	6.7	4.05, 0.60	2.65
	19 LT	$f_t E_s$	12.5	3.99, 1.54	8.51
		$f_b E_s$	6.5	2.59, 0.94	3.91

FIGURE CAPTIONS

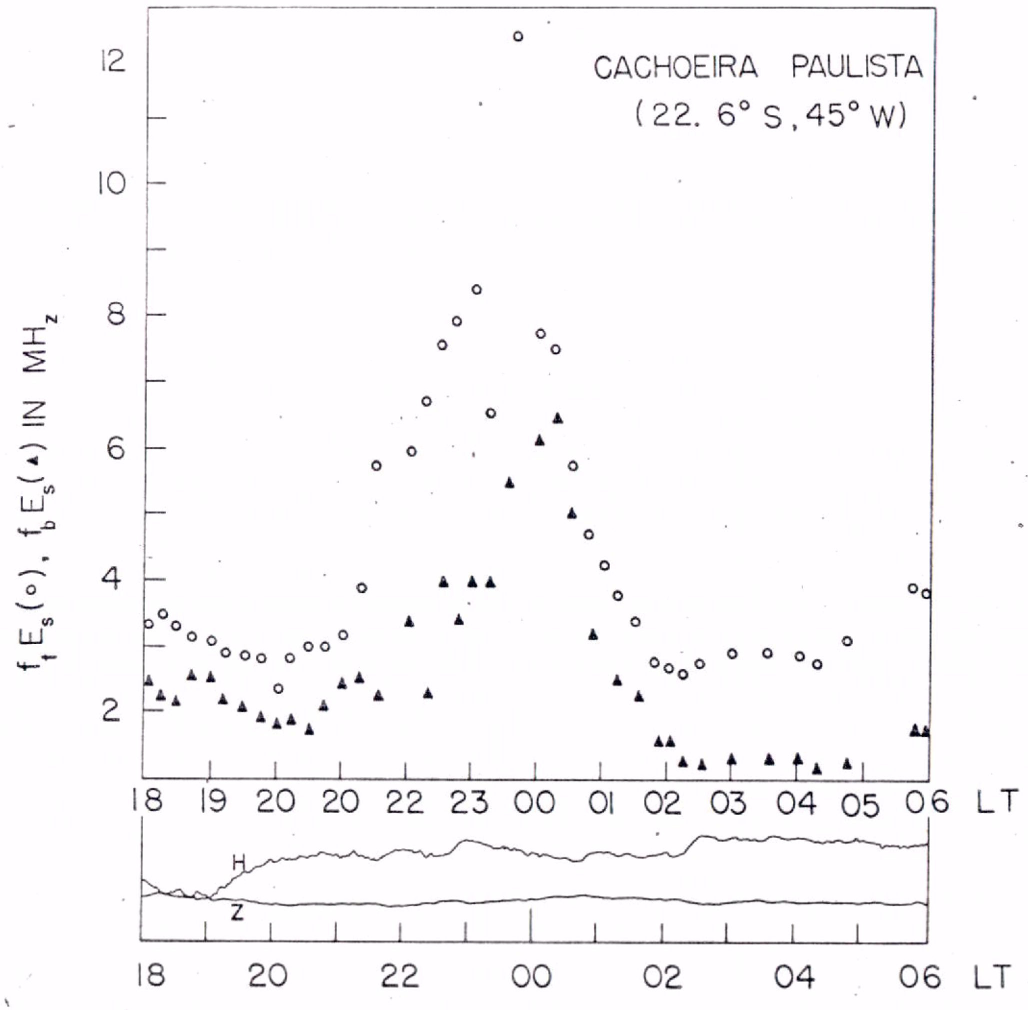
Fig. 1 - A case of $f_t E_s$ (o) and $f_b E_s$ (Δ) enhancement over Cachoeira Paulista, observed around the midnight of 16-17 October 73 (data points are for every fifteen minutes). The lower part of the figure presents magnetogram for Vassouras, Rio de Janeiro, and shows the H and Z component variations during this event.

Fig. 2 - Quarter hourly plots of $f_t E_s$ (o) and $f_b E_s$ (Δ) for three days, corresponding to 4 magnetic storm events described in the text. Three hourly magnetic indices K_p are also plotted as broken line histogram in the same figure.

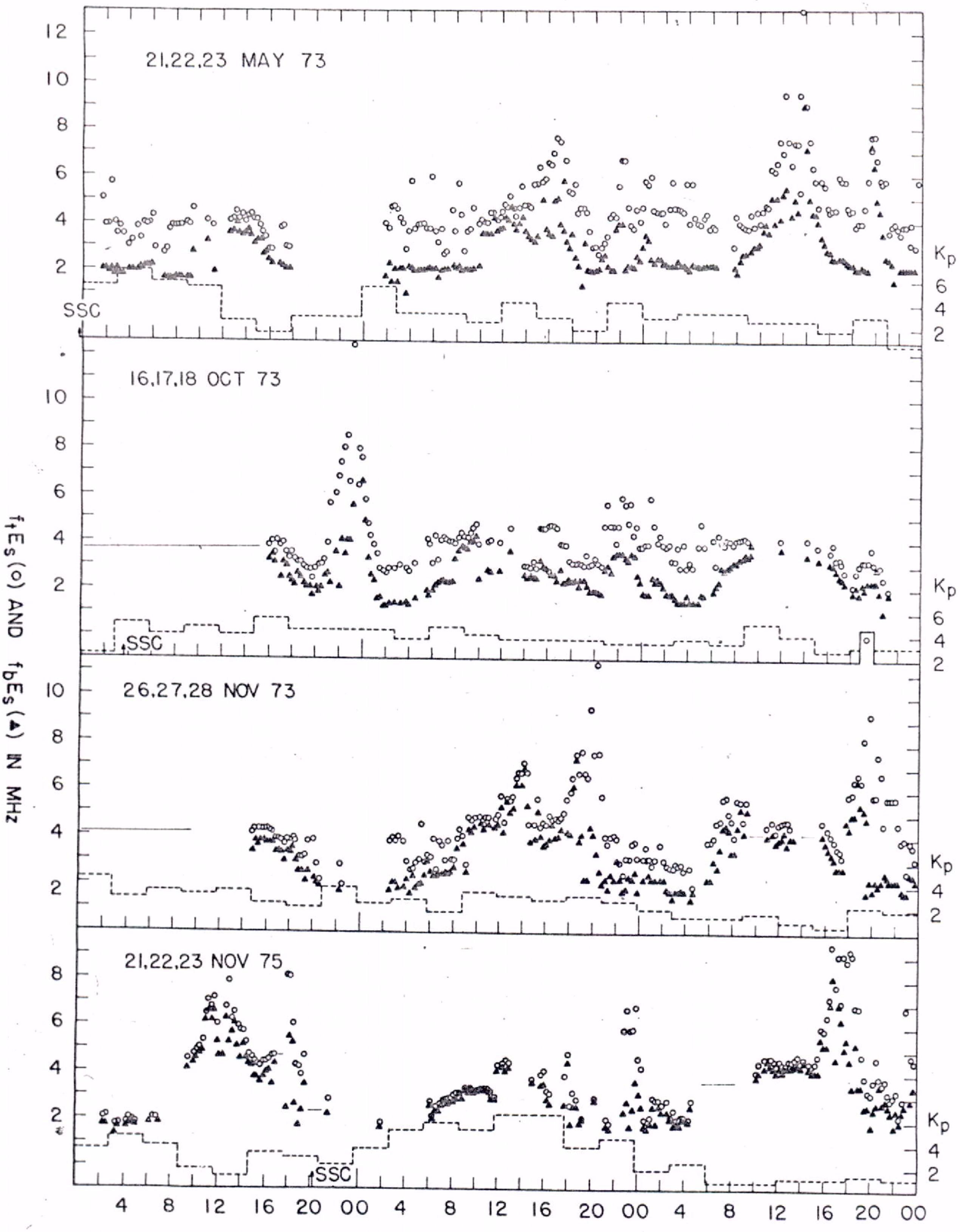
Fig. 3 - Magnetograms for Vassouras, Rio de Janeiro, for two days, covering the E_s events corresponding to the 4 cases shown in Fig. 2. The times of the E_s events are indicated by patches of broken lines.

Fig. 4 - A superposed epoch analysis of 7 events showing the means of $f_t E_s$ and $f_b E_s$ for 4 days before and after the events taking zero time as that of the maximum of the E_s event. The corresponding mean K_p values and their standard deviation are shown in the lower part of the figure. Mean K_p variation for ± 20 days from the E_s event is shown in the last part of the figure.

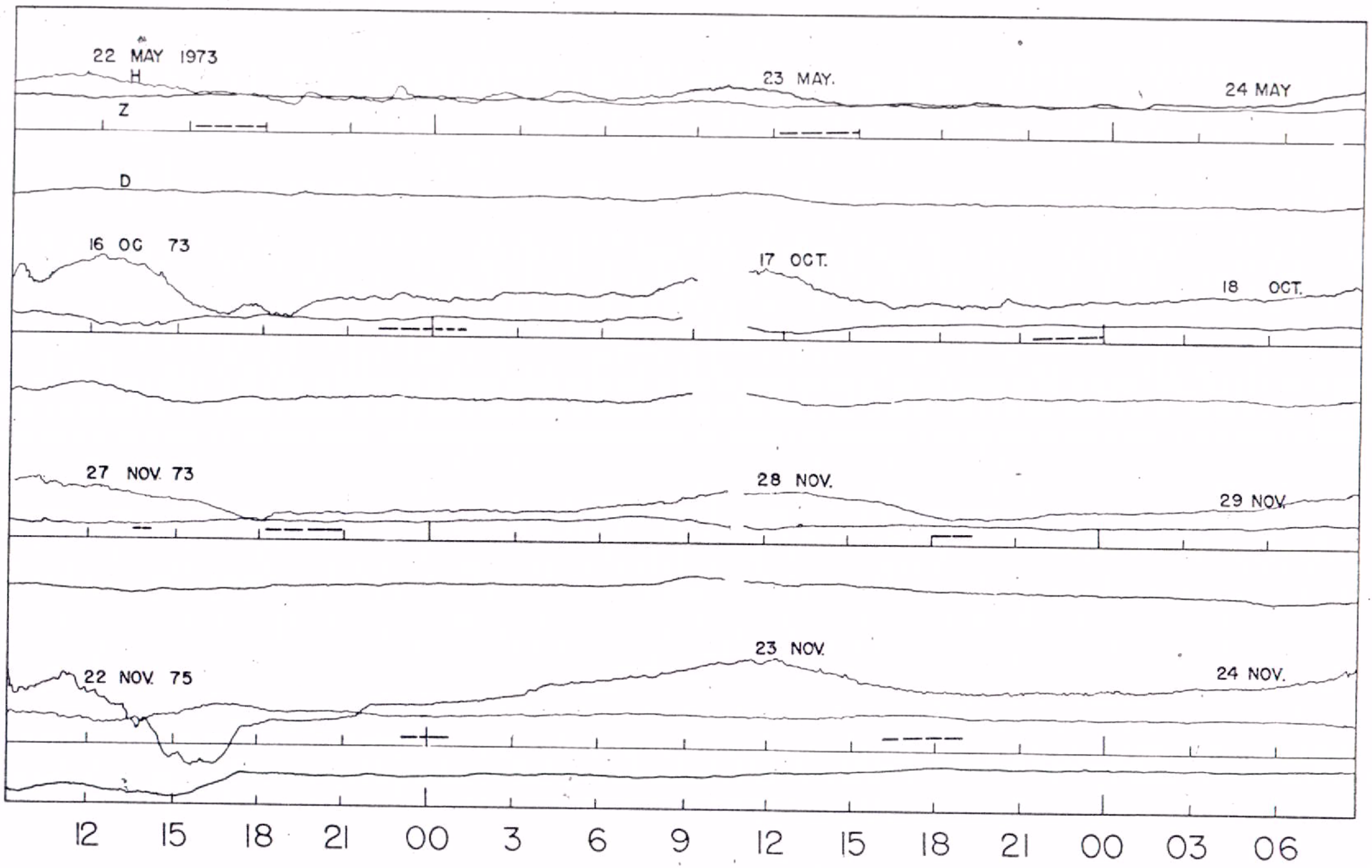
Fig. 5 - Sample ionograms showing characteristics of the E_s traces during some storm effects. (The ionograms of 1345 on 22 May 73 is shown for comparison with that of 1345 on 23 May when the storm effect was more significant). The range spread in the E_s trace in the 0015 ionogram of 17 October 73 may be noted.



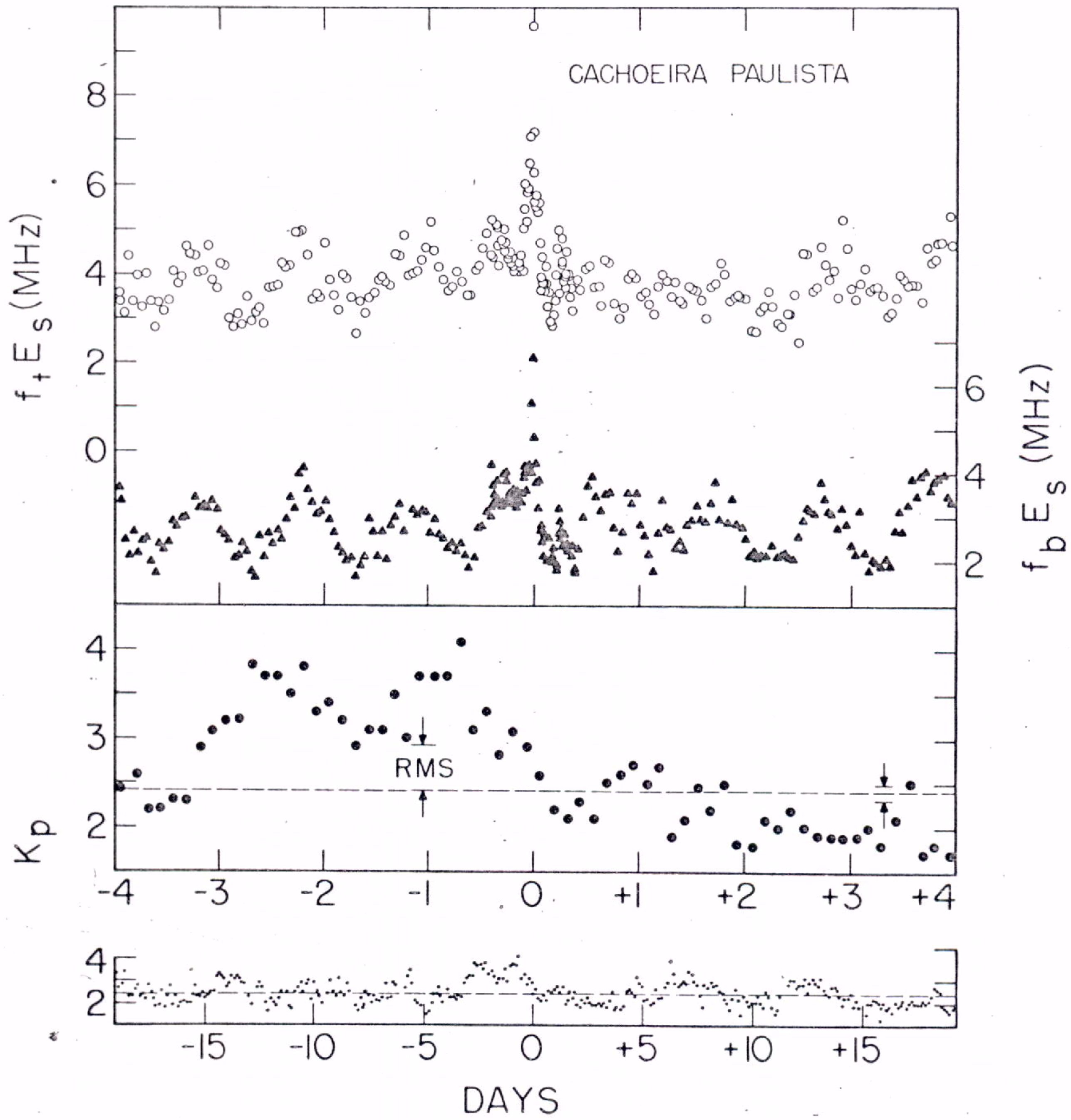
OCT 16, 17, 1973



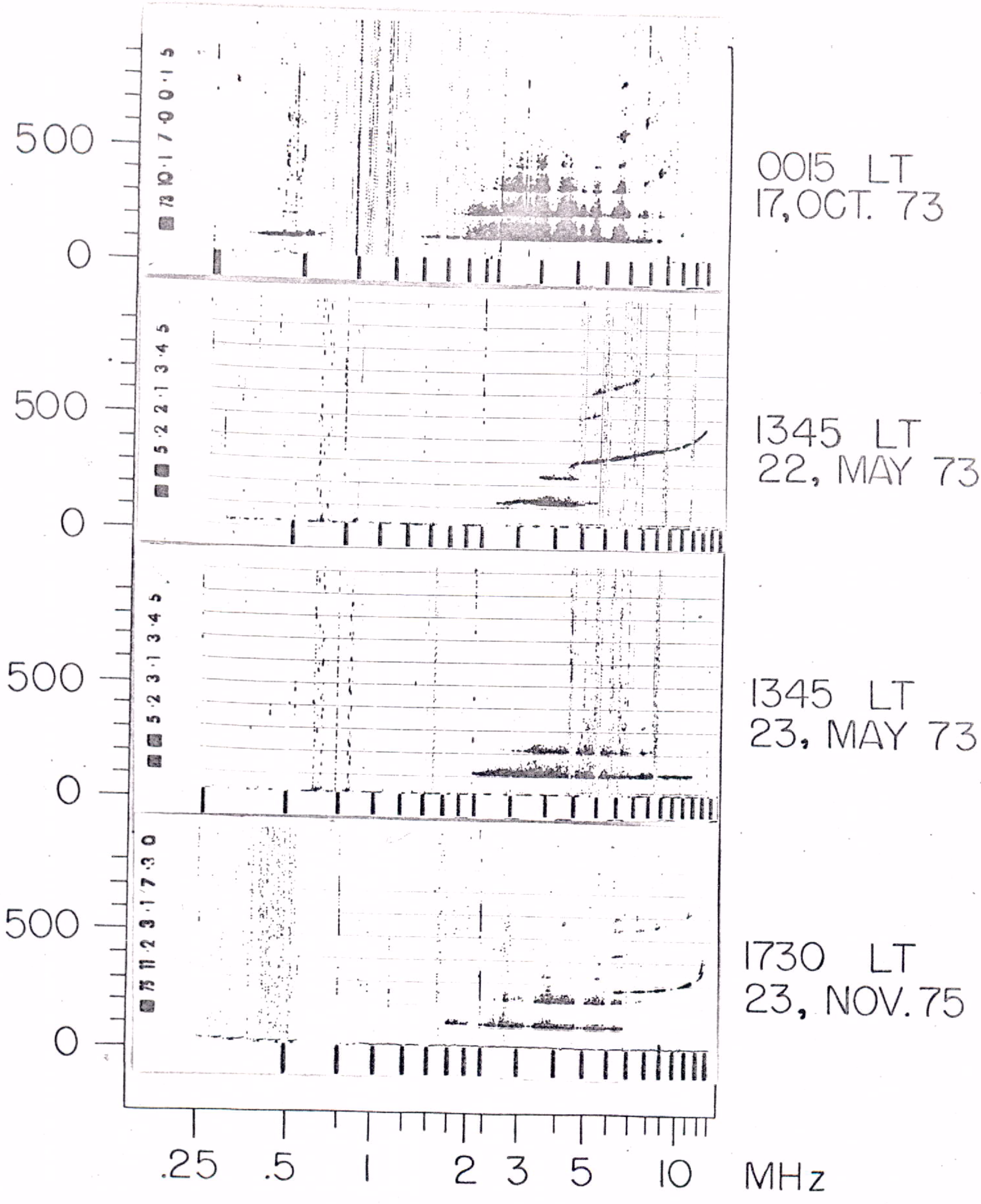
f_tE_s AND f_bE_s OVER CACHOEIRA PAULISTA (12°s, 22°E)



MAGNETOGRAMS FOR VASSOURAS, R. DE JANEIRO



CACHOEIRA PAULISTA
$f_t E_s$ (MHz)
$f_b E_s$ (MHz)
RMS
Kp
DAYS



IONOGRAMS OVER CACHOEIRA PAULISTA

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01 SID/SCD
02 984
03 INPE-984
04 CEA
05 S
06 as
10 Batista, Inez Staciarini
10 Abdu, Mangalathayil Ali
12 Magnetic storm associated delayed sporadic e enhancements in the brazilian geomagnetic anomaly
16 Abdu, Mangalathayil Ali
20 4777-4783
30 Journal of Geophysical Research
31 82
32 29
40 En
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42 <E>
58 DAE
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61 <PI>
62 INPE
64 Oct. <1977>
68 PRE
76 AERONOMIA
83 Sporadic E layer behavior over Cachoeira Paulista (11 degree 57'S, 22 degree 32'E geomagnetic coordinates), located near the center of the Brazilian Geomagnetic Anomaly., is investigated during magnetically disturbed periods. Significant enhancements in the Es layer parameters, ftEs and fbEs take place for short periods (2-3 hours) following a magnetic disturbance of moderate intensity. The enhancements, however, are delayed by 1-3 days with respect to the initiation of a disturbance. The electron density enhancement in the Es layer inferred from fbEs during such events are at times an order of magnitude larger than undisturbed values. Also, during some night events the ambient E region electron densities appear comparable to the regular daytime maximum values. The Es traces in the ionograms during these events exhibit range spread in the echoes resembling the a-type Es, know to occur over auroral latitudes under disturbed conditions. These results are interpreted as evidence of enhanced charged particle precipitation in the E region over the geomagnetic anomaly following magnetic disturbances. The results also provide evidence that the E region response over our station is delayed with respect to magnetic activity.
87 anomalias magneticas
87 tempestades magnéticas
87 atraso
87 Região E
88 magnetic anmalies
88 magnetic storms
88 delay
88 E region
88 magnetic disturbances
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MAGNETIC STORM ASSOCIATED DELAYED SPORADIC E ENHANCEMENTS IN THE BRAZILIAN GEOMAGNETIC ANOMALY

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Abstract. Sporadic E layer behavior over Cachoeira Paulista (11°57'S, 22°32'E geomagnetic coordinates), located near the center of the Brazilian Geomagnetic Anomaly, is investigated during magnetically disturbed periods. Significant enhancements in the E_s layer parameters, f_tE_s and f_bE_s take place for short periods (2-3 hours) following a magnetic disturbance of moderate intensity. The enhancements, however, are delayed by 1-3 days with respect to the initiation of a disturbance. The electron density enhancement in the E_s layer inferred from f_bE_s during such events are at times an order of magnitude larger than undisturbed values. Also, during some night events the ambient E region electron densities appear comparable to the regular daytime maximum values. The E_s traces in the ionograms during these events exhibit range spread in the echoes resembling the a-type E_s, know to occur over auroral latitudes under disturbed conditions. These results are interpreted as evidence of enhanced charged particle precipitation in the E region over the geomagnetic anomaly following magnetic disturbances. The results also provide evidence that the E region response over our station is delayed with respect to magnetic activity.

Introduction

Sporadic E behavior during magnetically disturbed periods has different characteristics over stations located at different geomagnetic latitudes. Over the auroral latitude a positive correlation between sporadic E occurrence and magnetic activity was observed by Smith [1957], while for mid-latitudes the correlation was negative (see also Layzer [1972]). At stations located at low geomagnetic latitudes, zero or very weak positive correlation has been reported [Smith, 1957; Bandyopadhyaya and Montes, 1963; Huang, 1965; Closs; 1969]. In this paper we present results of a preliminary investigation of magnetic storm effects on sporadic E layer phenomena over Cachoeira Paulista (11°57'S, 22°32'E geomagnetic coordinates), a low geomagnetic latitude station located very close to the center of the Brazilian Geomagnetic Anomaly. A recent study by Abdu and Batista [1977] on E_s phenomena over Cachoeira Paulista, for a few months during 1973-1974, showed that during this period the E_s occurrence was a regular feature of the daytime and the nighttime ionosphere over this station and also that blanketing-type E_s (with $f_bE_s \geq 2.3$ MHz) occurred at night having monthly average f_bE_s comparable at times to its daytime maximum values.

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A study of specific cases of E_s behavior during a few magnetic storms of moderate intensity (being defined here as storms during which the 3-hourly planetary index Kp rose above 4) is undertaken in the present work. During all the storms of moderate intensity that we examined the E_s parameters f_tE_s and f_bE_s showed well-defined enhancements of appreciable magnitude. The enhancements, however, were not simultaneous with changes in Kp but occurred within 1-3 days after the initiation of the storm.

Presentation of the Results

A case of enhancement in f_tE_s and f_bE_s (scaled quarter-hourly) following a storm that started with an sc at 0345 LT on October 16, 1973, is shown in Figure 1. The magnetic index Kp indicated moderate disturbance (Kp > 4 for much of the time) after the storm on October 16, 17, and most of 18. A pronounced enhancement in the E_s occurred near midnight of October 16-17, when f_tE_s and f_bE_s reached 12.5 and 6.5 MHz, respectively. At the time of this enhancement the magnetogram for Vassouras, Rio de Janeiro, showed near recovery from the storm main phase, and the H component of the field showed minor fluctuations of amplitudes of 1-5 γ and periods of a few minutes. Since f_bE_s represents the approximate plasma frequency of the E_s layer [Reddy and Mukunda Rao, 1968], the E_s layer electron density during the maximum of the event near 0000 LT would be around 5×10^5 cm^{-3}, which is a factor of 2 higher than its regular daytime maximum (around 2×10^5 cm^{-3}, corresponding to the daytime maximum of the monthly mean f_bE_s of 4 MHz for October). These values for the layer peak electron densities may not suggest that the E region ambient densities near midnight were also higher proportionally to the daytime values, because the daytime regular E_s layer occur around 120 km (and mostly of c type), whereas the E_s layer during this event occurred near 100 km, where the lower diffusion coefficient for the ions would permit higher ratios for the peak to ambient densities of the layer to exist. Nevertheless, considerations similar to those discussed by Abdu and Batista [1977] would show that f_bE_s near midnight might indicate an ambient electron density near 100 km of at least the order of 10^5 cm^{-3}. It is pertinent to point out that during this event and most of the other events to be described shortly, whether the occurred during day or night, the height of the E_s layer remained nearly constant around 100 km in the course of the growth and decay of f_bE_s.

A more extensive time series for three consecutive days, covering the magnetic disturbances and E_s enhancements, for the event in Figure 1 and for

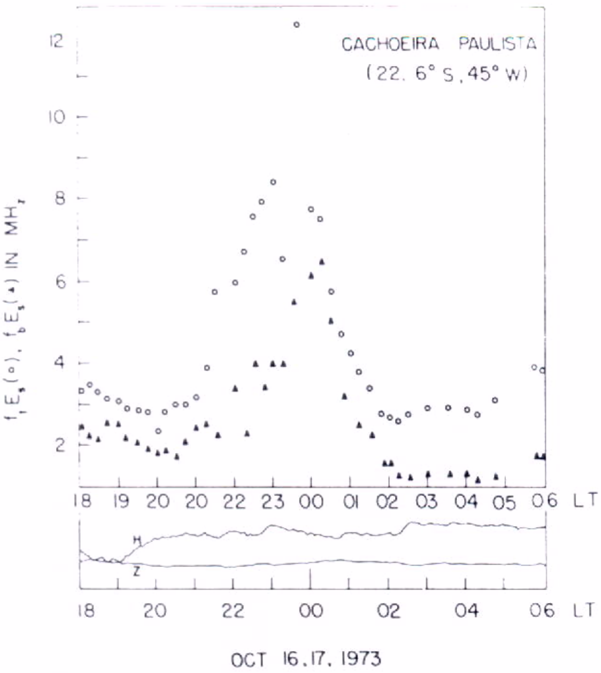


Fig. 1. A case of f_tE_s (circles) and f_bE_s (triangles) enhancement over Cachoeira Paulista observed around midnight of October 16-17, 1973 (data points are for every 15 min). The lower part of the figure is a magnetogram for Vassouras, Rio de Janeiro, and shows the H and Z component variations during this event.

three other events is presented in Figure 2 together with the Kp indices for the respective cases. The first of these cases presents the E_s behavior following an ssc that occurred near 0000 LT on May 21, 1973. Considering that the diurnal maximums in the monthly mean f_tE_s and f_bE_s for May were around 5 and 4 MHz, respectively, the first significant enhancement seems to have taken place on the second day of the storm, May 22, 1973, between 1600 and 1800 LT. This was followed by pronounced enhancements on May 23 around 1500 LT and again at 2000 LT, during which f_tE_s and f_bE_s reached 13 and 9 MHz in the first events and 7.8 and 7.5 MHz in the second event, respectively. The electron densities in the E_s layer during the maximum of the 1500 LT event were a factor of 5 greater than the diurnal maximum in the regular E_s layers. A similar enhancement was present in the nighttime case as well. The height of the E_s layer was nearly constant at 100 km during both events. At the times of these events the magnetic disturbance index had returned to normal ($Kp \leq 3$), and the local magnetograms (presented for all four cases in Figure 3) show almost complete recovery in the magnetic field with only minor fluctuations (weaker than those in the October 16-17 event) present in the H component of the field. We may note that in the present two events f_bE_s reached maximum values in ≤15 min, the time resolution of the observation.

In the third case presented in Figure 2 the magnetic storm, not accompanied by an sc, started near midday on November 24, 1973, and the largest disturbance occurred on November 25. The first E_s enhancements after the storm were observed around 1400 and 1900 LT on November 27 (no E_s data were available from 0500 LT on November 25 until 1045 LT on November 26). The local magnetic field had almost recovered from the storm time disturbance and showed small-scale fluctuations in the H component more conspicuously during the 1400 LT event than during the 1900 LT event (Figure 3). E_s enhancements took place at 1900 LT on November 28 with features similar to those on the previous day. The E region electron density enhancements for these events would be nearly of the same order of magnitude as the enhancement in the October 16-17 midnight event. However, the delay with respect to the storm commencement is considerably more in this case.

The last case presented in Figure 2 corresponds to the storm that occurred with an sc near 2000 LT on November 21, 1975. The first E_s enhancement appears to have occurred around midnight of November 22-23, when f_tE_s showed some increase with no appreciable change in the plasma frequency of the layer. More pronounced E_s enhancement took place around 1400 LT on November 23, when f_tE_s and f_bE_s reached 10 and 8 MHz, respectively. Magnetic disturbance had almost subsided during the enhancements, and as in the previous cases, the H component of the field showed minor fluctuations. A careful examination of the E_s data for November 22 shows that at the time of high magnetic activity the E_s occurrence was somewhat reduced, a feature that resembles the mid-latitude cases of negative correlation between the two [Layser, 1972]. More data will be needed to confirm the existence of any such negative correlation over our station with simultaneous values of Kp (or preferably with local K values).

The E_s parameters plotted on November 21 before the ssc also seem to be high in comparison with the monthly mean diurnal maximum of 6 and 5 MHz for the f_tE_s and f_bE_s, respectively. Though the magnetic disturbance which preceded this enhancement took place on November 17 with $Kp > 4$, the daily sum of Kp for that day (22) was considerably smaller than that for the other cases discussed before. Also, the enhancements observed during the daytime are in the c-type E_s at virtual heights of 115-120 km, decreasing gradually to 105 km during the enhancement around 1800 LT (an execption to all other events for which the virtual heights were near 100 km).

For the four cases of E_s enhancements shown in Figure 2 the peak deviation of f_tE_s and f_bE_s and the rms deviation for the month at the respective hours are presented in Table 1. The magnetic storm association of these events is borne out by the fact that the observed deviations in the E_s parameters are many times the standard deviations. In the course of the operation of the ionosonde at Cachoeira Paulista for some months in 1973-1975 a few more such events have been observed. A superposed epoch analysis taking zero time as that of the peaks in the E_s enhancements is presented in Figure 4 for seven events for which reasonable coverage of data for 4 days before and after the events existed (separate curves for f_tE_s and f_bE_s are presented; also, 15-min values are plotted for ±10 hours from the peak of the event, while hourly means are plotted for the rest of the time). The Kp values appear significantly higher for 3 days before the E_s enhancement, with the majority of the points lying above twice the standard deviation referred to a

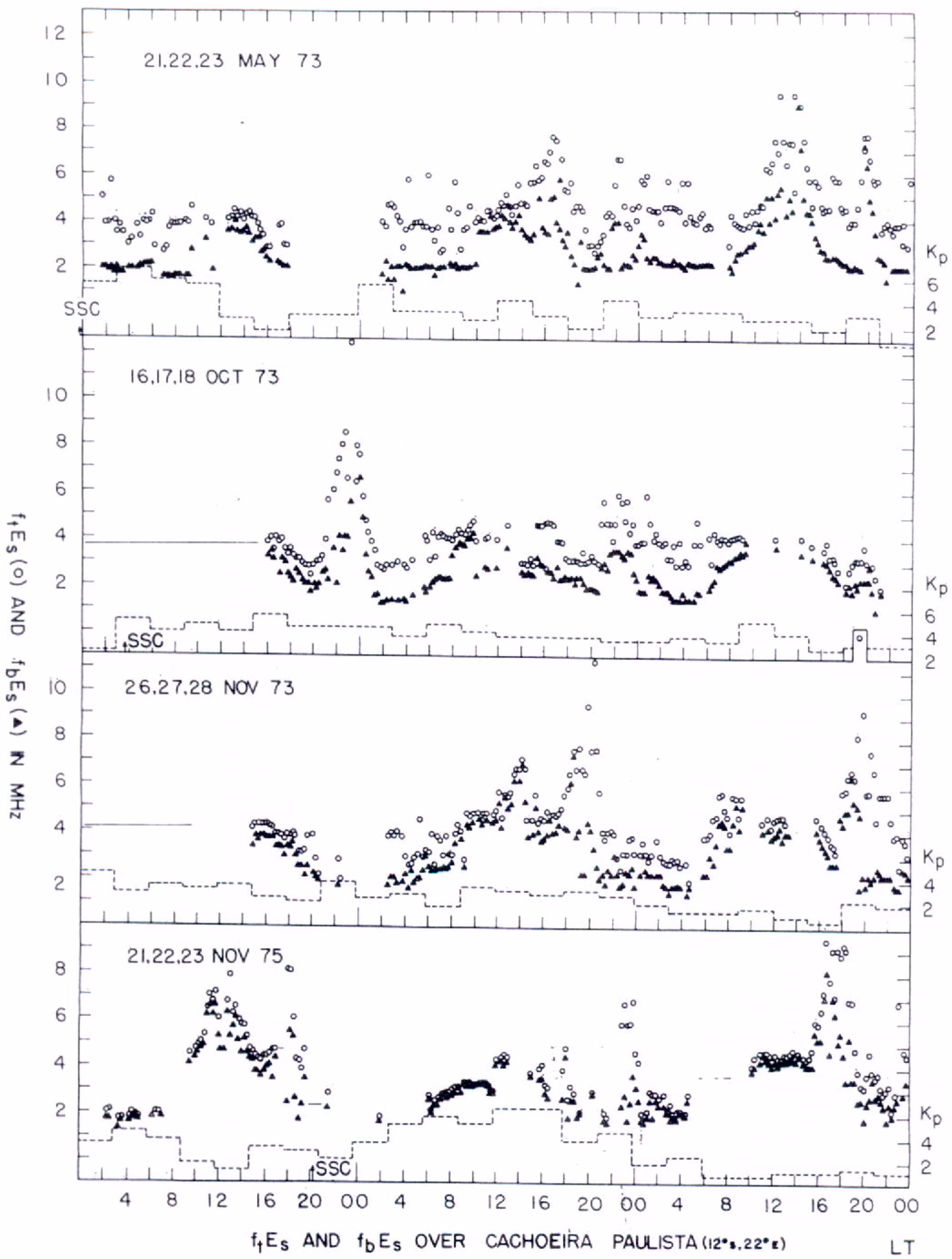
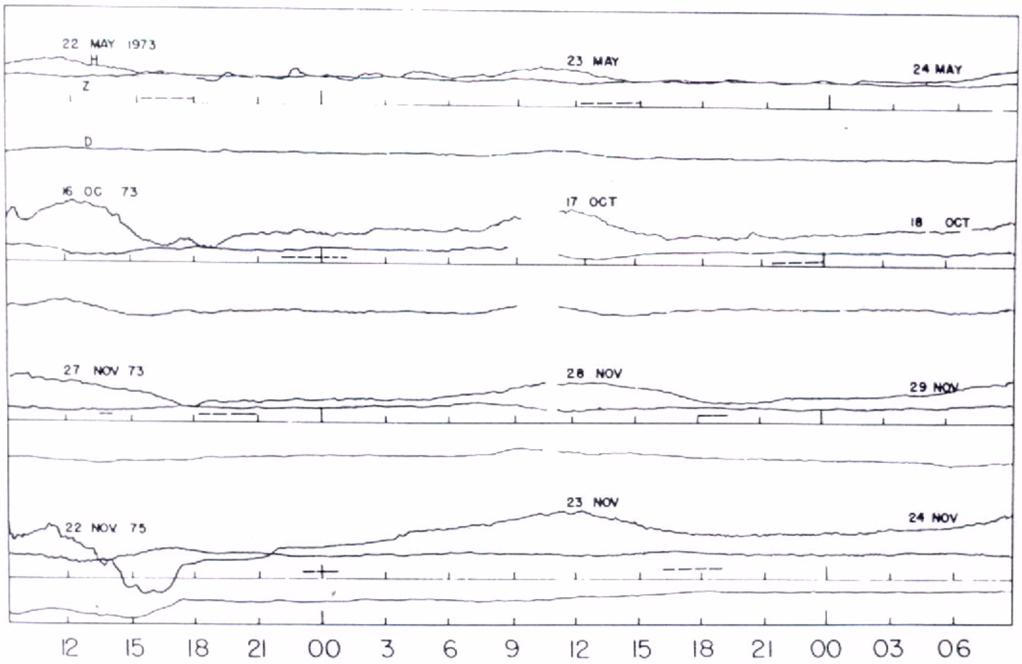


Fig. 2. Quarter-hourly plots of f_tE_s (circles) and f_bE_s (triangles) for 3 days, corresponding to four magnetic storm events described in the text. Three-hourly magnetic indices Kp are also plotted as dashed line histograms.

mean (shown by the dashed line together with the 98% confidence width of the mean) taken from a group representating ±20 days plotted in the lower part of the figure. If we take means of Kp for groups of 3 days before and after the E_s enhancement, it is seen that the value immediately before the E_s enhancement is the highest in the group and has a deviation twice the standard deviation of the group. Thus the probability that the occurrence of high Kp values for 3 consecutive days before these enhancements is a random phenomenon is very small.

Discussion

The ionization enhancements in the E region during these events appear quite significant considering, particularly, the evening and midnight cases. The ambient E region electron densisities, for example, during the midnight event of October 16-17 and the 2000 LT event of May 23 could be shown to be of the order of 10^5 cm^{-3} or higher from considerations of winds, recombination coefficients, and diffusion coefficients, for these heights. Estimation based on different criteria



MAGNETOGRAMS FOR VASSOURAS, R DE JANEIRO

Fig. 3. Magnetograms for Vassouras, Rio de Janeiro, for 2 days, covering the E_s events corresponding to the four cases shown in Figure 2. The times of the E_s events are indicated by patches of dashed lines.

also would lead to similar values for the ambient densities. As an example we consider the event of 2000 LT on May 23 during which the f_bE_s enhancement of up to 7.5 MHz took place in ≤15 min (the time resolution of the observation). It seems that a wind system which could produce blanketing -type E_s layers is unlikely to undergo changes with such short time scales [see Layser, 1972]. Further, the fact that the virtual height of the E_s layer (which was around 100 km) did not change during the course of the event implies that the observed f_bE_s enhancement resulted from a corresponding increase in the source of ionization over the observing station with a time scale of the order of 15 min or less. If we consider metallic ion E_s layers, then it would be necessary to assume that the conditions for the E_s layering were already prevailing at these times and that molecular ions were produced by an enhanced source of ionization such that sufficient numbers of them were converted to metallic ions by a charge transfer mechanism with a time constant, $\{k([O_2^+] + [NO^+])\}^{-1}$, which did not exceed 15 min. (This time constant corresponds to the conversion of metal atoms to metal ions by the reaction $M + X^+ \rightarrow M^+ + X$, where $X^+ = O_2^+$ or NO^+, and the

TABLE 1. Enhancement Features of Some of the E_s Events Discussed in Text

Time, LT		Maximum Value during Enhancement, MHz	Monthly Mean, MHz	rms Deviation, MHz	Maximum Deviation During Enhancement
			May 23, 1973		
1400	f_tE_s	13.0	4.36	1.14	8.64
	f_bE_s	9.0	3.18	1.07	5.82
2000	f_tE_s	6.7	3.80	0.88	2.90
	f_bE_s	5.0	2.31	0.78	2.69
			October 16-17, 1973		
0000	f_tE_s	13.0	3.53	1.49	9.47
	f_bE_s	6.5	2.21	0.98	4.29
			November 27, 1973		
1400	f_tE_s	7.2	4.66	0.46	2.54
	f_bE_s	6.7	4.05	0.60	2.65
1900	f_tE_s	12.5	3.99	1.54	8.51
	f_bE_s	6.5	2.59	0.94	3.91

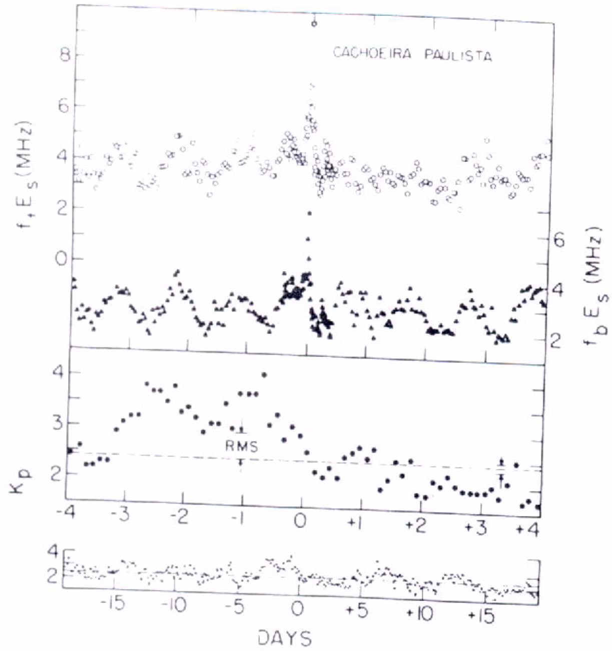


Fig. 4. A superposed epoch analysis of seven events showing means of f_tE_s and f_bE_s for four days before and after the events, taking zero time as that of the maximum of the E_s event. The corresponding mean Kp values and their standard deviations are shown in the lower part of the figure. Mean Kp variation for ±20 days from the E_s event is shown at the bottom of the figure.

metal atom production rate being ignored during this period.) Assuming a value for the charge transfer coefficient k of 6×10^{-9} cm^3 s^{-1}, as deduced by Narcisi [1968], the ambient molecular ion density $[O_2^+] + [NO^+]$ should be at least of the order of 2×5 cm^{-3} for explaining the observed rise time of ≤15 min. If, on the other hand, we assume molecular ion E_s layer, the ambient density required to produce the observed f_bE_s could be still higher. In fact, at such high ambient densities the E_s layering by the wind shear mechanism might not be very significant, unless winds were very strong. In the case of the midnight event of October 16-17 the source of ionization seems to have intensified more slowly. Based on monthly mean f_bE_s values for some months in 1973, Abdu and Batista [1977] have shown that an ambient nighttime E region ionization of around 5×10^4 cm^{-3} might be present regularly during that period. Our present results demonstrate that the nighttime ionization undergoes significant enhancement associated with magnetic disturbances, a fact that might suggest a particle origin for the source of ionization. Positive correlation, observed between Kp and nighttime E region ionization changes derived from analysis of rocket profiles of intermediate layers, has been attributed by Geller et al. [1975] to possible presence of energetic electron pricipitation over mid-latitude night E region. In an earlier work based on a riometer absorption event [Abdu et al., 1973], evidence for a particle precipitation in the D region over the geomagnetic anomaly, following an sc of a severe magnetic storm, has been presented.

The E_s trace in the ionogram of 0015 LT on October 17, 1973 (Figure 5), shows almost complete blanketing of the F trace and also significant spread in the range of the E_s echoes. This resembles the a-type E_s known to occur over auroral latitudes during magnetic disturbances. Some degree of spread is generally present on most nights, but intensification, of which the figure represents a typical case, takes place following magnetic disturbances in all the cases that we have examined so far. In the daytime example for 1345 LT on May 23, 1973, the spread is relatively less pronounced, probably owing to the ionospheric absorption of the weak spread echoes. (The variation in the degree of the spread with frequency, seen in these ionograms, is most likely caused by a corresponding variation in the transmitted power of the sounder.) A comparison with the ionogram of 1345 on May 22, also shown, illustrates that the virtual height of the E_s trace during significant storm effects had decreased to 100 km or sometimes even less. In view of the well-known association among magnetic activity, particle precipitation, and a-type E_s over auroral latitude (see, for example, Reddy et al. [1969]), the appearance of an E_s trace in our ionogram resembling the a-type E_s might lend direct support to our suggestion of a particle origin for the source of ionization. However, unlike auroral latitudes, winds over our station should be sufficiently effective in producing blanketing-type layers; thus the blanketing traces in our ionograms that also exhibit large range spread seem to be an interesting phenomenon that merits more detailed investigation.

Over the Brazilian geomagnetic anomaly, no investigation of E_s behavior during magnetic disturbances has been reported before. The E_s response observed is, with a time delay that varies from one event to the other, of 1-3 days with respect to the initiation of the storm. Such delayed response of the E region to magnetic disturbances is hitherto unknown and is difficult to fit with any established class of E region disturbances. Two aspects of delayed ionospheric response to magnetic storms seem pertinent to mention here: (1) 'storm aftereffect' in the mid-latitude D region is a recognized phenomenon [Belrose and Thomas, 1968; Lauter and Taubenheim, 1970; Beynon and Williams, 1974] and has been interpreted as being caused by precipitation of energetic electrons that radially diffuse into the inner radiation zone following their injection into the outer zone in the initial phase of a storm [Spjeldvik and Thorne, 1975]; (2) equatorward propagating disturbances carrying changed thermospheric composition, initiated by the electrojet heating of the auroral E region, have been invoked [see Rishbeth, 1974; Davies, 1974] to explain F region negative storm effects over middle and low latitudes. This latter aspect seems very unlikely to contribute to the delayed E_s enhancements under discussion, because (1) the observed delay of around 3 days, in some cases, is too long for the speed of propagation of such disturbances; (2) rapid increase in f_tE_s, such as those observed at 1400 and 2000 LT on May 23, 1973, cannot be explained; (3) night enhancement in the E region electron densities may not be explained by composition changes; and (4) the effect of neutral atmospheric propagation disturbances in the E region should be observable at other low- and middle-latitudes stations as well. Since our observation presents definite cases of ionization enhance-

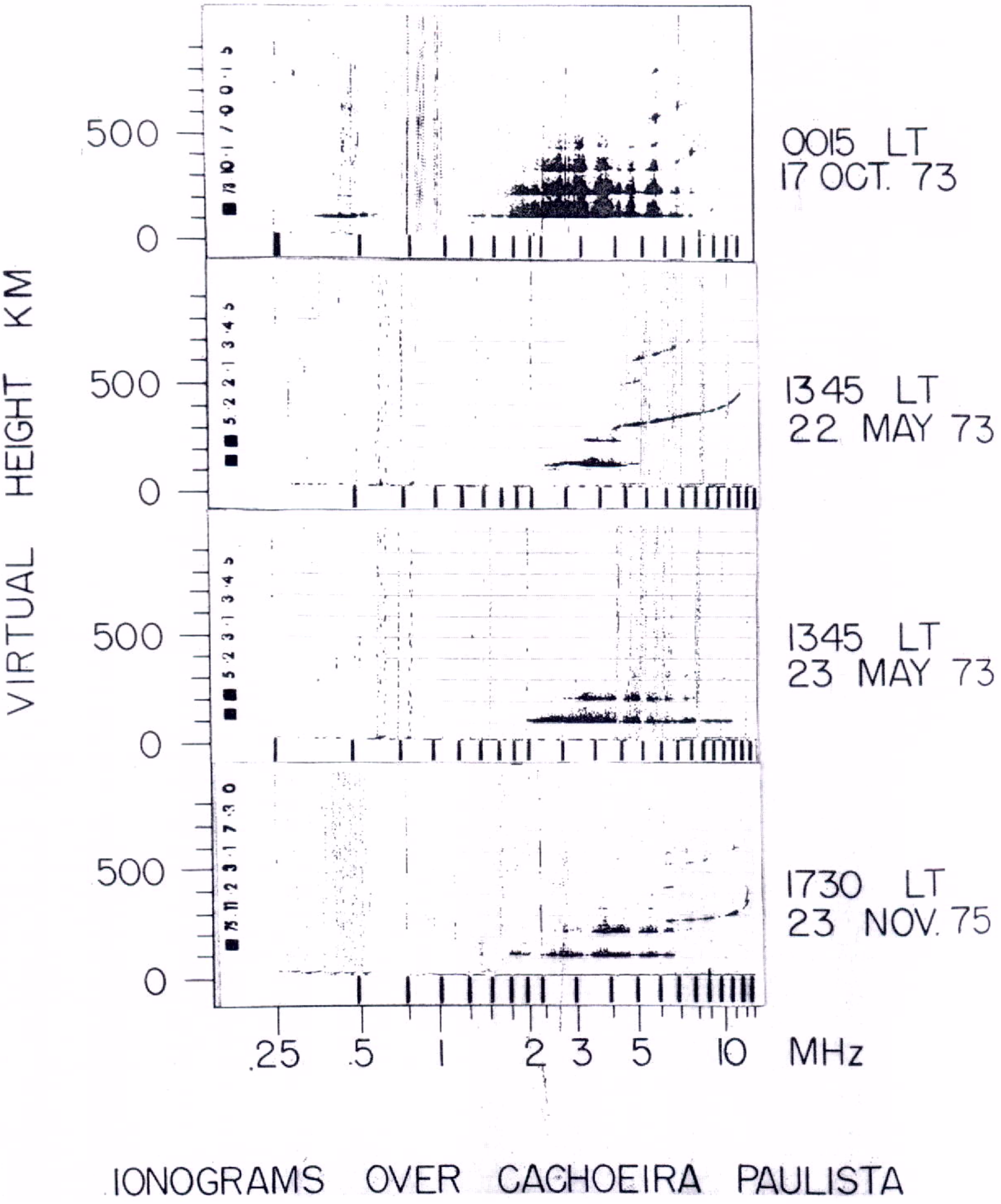


Fig. 5. Sample ionograms showing characteristics of the E_s traces during some storm effects. (The ionogram of 1345 LT on May 22, 1973, is shown for comparison with that of 1345 on May 23, when the storm effect was more significant.) The range spread in the E_s trace in the 0015 LT ionogram of October 17, 1973, may be noted.

ments with short time scales, irrespective of the delay factor, they would more likely fit in with the interpretation invoking particle precipitation in the geomagnetic anomaly. The observed delay of 1-3 days might be characteristic of the processes by which particles enter the lower L shells passing through the geomagnetic anomaly follwoing their injection into the outer zone in the initial phase of the storm. It might be pertinent to note, judging from the times of occurrences of most of these events, that they seem to have a tendency to occur around the dusk meridian rather than around the dawn meridian. These aspects also merit more detailed investigation.

Conclusions

The following conclusions may be drawn from the present study.

1. Enhancements in the E_s parameters f_fE_s and

f_bE_s take place in the Brazilian Geomagnetic Anomaly follwoing a magnetic storm of moderate intensity within 1-3 days after the initiation of the storm, and each enhancement lasts typically for 1-3 hours. During these events the local magnetogram shows near recovery from the storm effect, and the H component of the field generally exhibits minor fluctuations of periods of a few minutes.

2. The enhanced f_bE_s suggests significant increases in the ambient electron densities near 100 km, with nighttime enhanced densities often comparable to the regular E region daytime ambient densities.

3. The pattern and the magnitude of the night enhancements, together with the nature of the E_s trace exhibiting range spread of the echoes similar to the a-type E_s, observed over auroral latitude, would suggest a particle origin for the source of the observed ionization enhancements.

Mores detailed study on these types of E_s enhancements and related features will be undertaken as more data become available.

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