1. Classification *INPE-COM.4/RPE* *C.D.U.: 523.3-853*	2. Period	4. Distribution Criterion internal [ ] external [X]
3. Key Words (selected by the author) *GEOMAGNETIC STORM* *F-REGION*		
5. Report Nº *INPE-1835-RPE/197*	6. Date *July, 1980*	7. Revised by *Y. Nakamura*
8. Title and Sub-title *IONOSPHERIC F-REGION RESPONSE TO GEOMAGNETIC STORMS, OVER BRAZILIAN LOW LATITUDE*		9. Authorized by *Nelson de Jesus Parada* *Director*
10. Sector *DME/DCE/DGA/GIO*	Code *30.371*	11. Nº of Copies *13*
12. Authorship *M.A. Abdu* *I.J. Kantor* *E.R. de Paula* *A.C. Giese* 13. Signature of the responsible		14. Nº of Pages *20* 15. Price

16. Summary/Notes

Ionosonde data from Cachoeira Paulista (22ºS, 45ºW), are analysed to study the response of the ionospheric F-region electron densities and heights to magnetic storm disturbances of moderate to strong intensity. It is found that the ionospheric response is highly variable from one storm to another, depending upon the intensity, duration and the definitions of the different phases of the magnetic storm. However, certain characteristics of the ionospheric response over Cachoeira Paulista seem to be typical, as follows: (a) in general, the ionosphere appears relatively more disturbed during the night than during the day; (b) during the main phase of the magnetic storm, the F-region maximum electron density generally presents significant enhancements and (c) significant depletion in the ionization occurs during the recovery phase of the storm. The changes in the height of the layer are not well defined, except in rare cases when it shows variations in opposite sense to that of the electron density. These results are interpreted interms of the extension, to low latitude, of the storm induced mid-latitude thermospheric disturbances in composition and transport.

17. Remarks *This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico (FNDCT)", Brazil, under Contract FINEP-537/CT. This work was submitted to the XXXII annual meeting of "SBPC".*

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1. INTRODUCTION

Response of the ionospheric F region to Geomagnetic storms has been investigated, some what extensively over mid-latitudes, and the results can be summarised broadly as follows: 1) An enhancement, lasting for a few hours, in the F-region peak electron density and in the total electron content occurs within a few hours after the onset of a moderate magnetic storm. This is believed to be caused by an equatorward thermospheric wind, produced by the thermospheric pressure gradient, set up in the initial phase of the storm energy absorption, over the high latitude upper atmosphere. This enhancement is known as the positive phase of the storm. 2) A negative phase, namely, a marked decrease in the ionization, occurs within a day or two of the storm onset and lasts for a few days, the ionization returning to quiet time values with the recovery of the storm disturbances. This negative phase is believed to be caused by thermospheric composition changes, namely an increase in the ratio $|N_2|/|O|$, brought about by an equatorward propagating disturbance front, as a second phase of storm energy absorption over the high latitude (Rishbeth, 1972, 1975; Seaton, 1956; Davies, 1974 and Von Zahn Prolss, 1976). However, there are significient departures from this average picture, in the case of individual storms, depending upon the local time of the storm onset, season, itc. (see for example, Mendillo, 1973; Kane, 1978).

Relatively, litle is known about the characteristic of the F-region storm over low latitude, where the presence of the equatorial ionization anomaly (or the fountain effect) complicates the picture. It is important to determine the factors that influence the low latitude F-region storm characteristic, whether they have equatorial or high latitude origin. In the present paper, we have attempted to carry out such a study, by analysing the F-region parameters, f_oF_2 and h_pF_2, over Cachoeira Paulista (45ºW, 22º 41'S), a low latitude station, during a few selected magnetic storm of moderate to strong intensity.

2. RESULTS

Quarter hourly values of f_oF_2 and h_pF_2 on quiet days, immediately preceding and following the storm interval, were used to determine a representative quiet time diurnal variation of these parameters, $\overline{f_oF_2}(t)$ and $\overline{h_pF_2}(t)$, which are then used to determine the deviations of these parameters as a function of local time, namely, $\Delta f_oF_2(t) = f_oF_2(t) - \overline{f_oF_2}(t)$, during selected periods of magnetic storms. To have and idea of the degree of variations of a relatively quiet time F-region, we have presented $\Delta f_oF_2(t)$ and $\Delta h_pF_2(t)$ for a few quiet days in Figure 1, so that the degree of variations in these parameters, due to magnetic disturbance, to be presented below, may be seen in comparison with this quiet time picture.

Figure 2 presents $\Delta f_oF_2(t)$ on 4-8 April, 1978, following a storm that started on 3 April, with the corresponding Dst variations shown in the same figure. During the Dst main phase the changes in the f_oF_2 is predominantly positive, charactering the positive phase of the ionospheric storm. During the recovery phase, significant reduction in the F-region peak electron density is observed, characterising the negative phase of the storm. In the present event the negative phase seems to be confined mostly to night hours only. The $\Delta h_pF_2(t)$ did not presents any well-defined modification during this storm.

Another event envolving a somewhat more intense magnetic storm is presented in Figure 3(a) and 3(b). Probably due to the occurence of several successive storms, the main phase disturbances lasted for about four days, during which the Δf_oF_2 variations showed predominantly positive values, similar to that observed in the previous example. The recovery phase of this storm is characterised by a negative phase in the ionospheric storm. It is interesting to note that the negative phase in this example is mostly a night-time phenomenon as was noted also in the previous example.

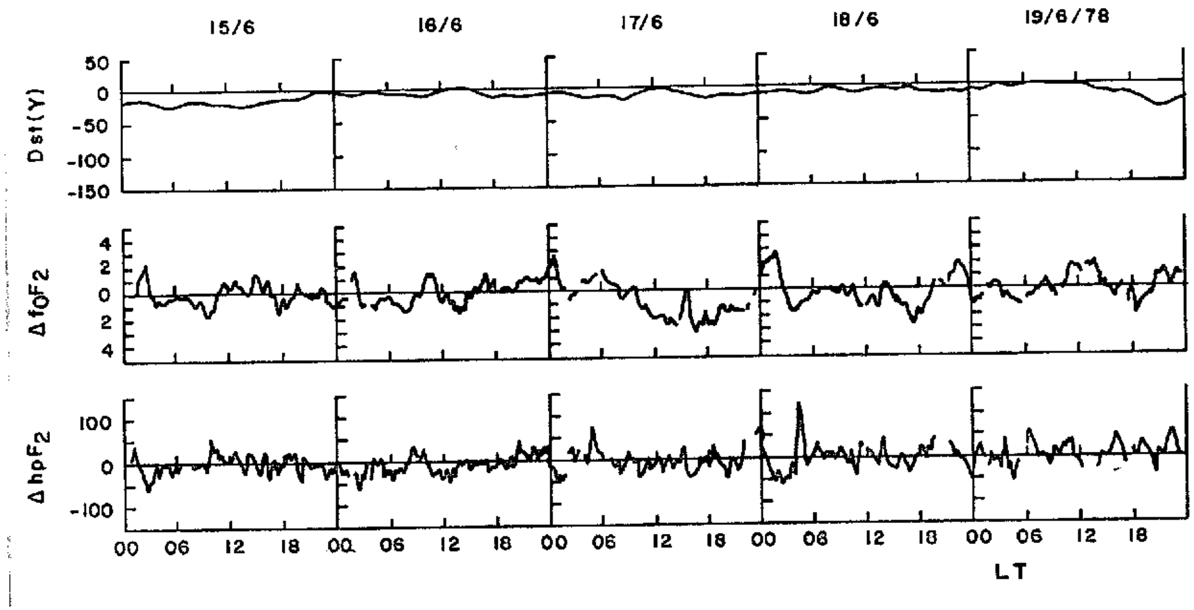

Fig. 1 - Variations in the critical frequency of the F - layer and in the height of the layer, with respect to their quiet time mean values, namely, $\Delta f_0 F_2(t)$ and $\Delta h_p F_2(t)$ ploted for a few quiet days.

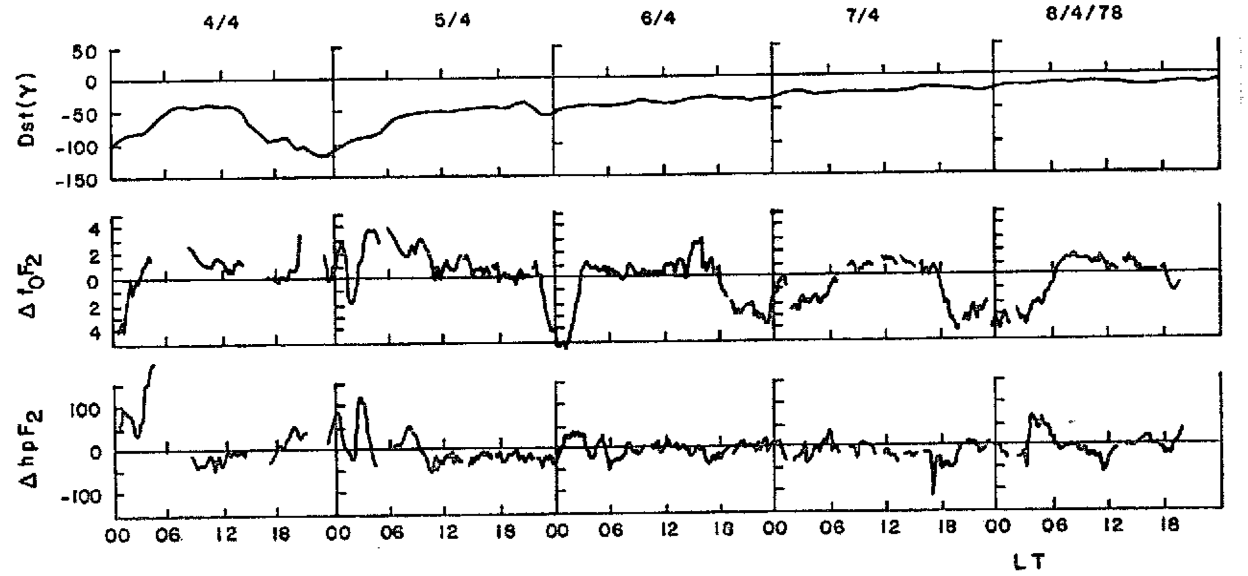

Fig. 2 - $\Delta f_0 F_2(t)$ and $\Delta h_p F_2(t)$ and the Dst variation on 4 - 8 April, 1978, ploted for the Case of a magnetic storm that started on 3 April,1978.

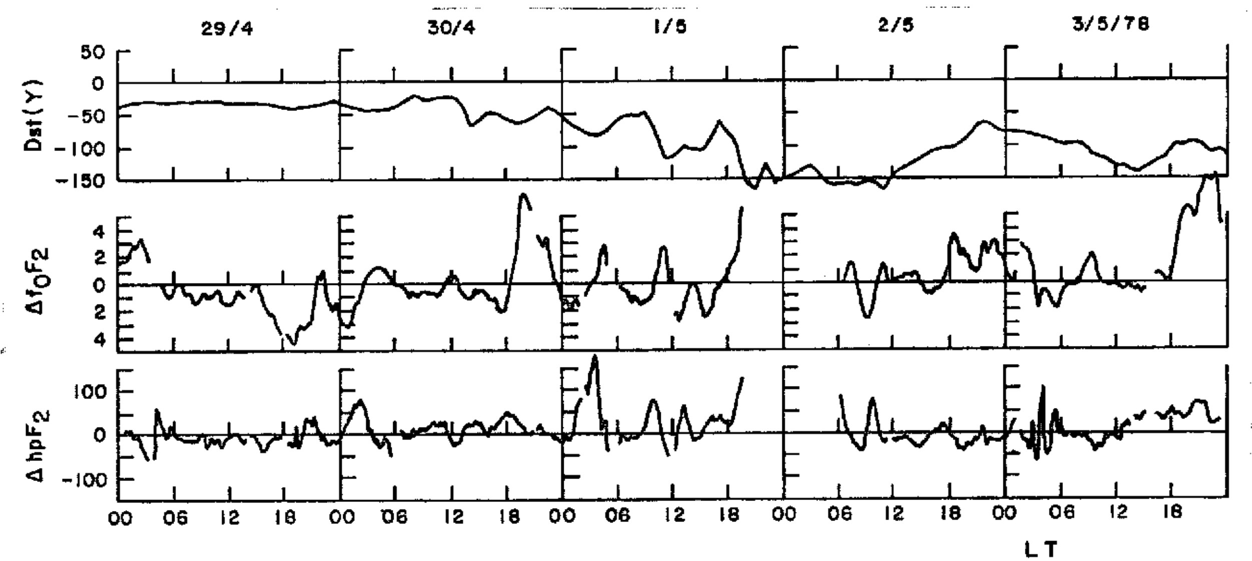

Fig. 3a - $\Delta\ f_0F_2(t)$ and $\Delta\ h_p\ F_2(t)$ and Dst variations corresponding to a long lasting magnetic disturbance that started on 30 April, 1978.

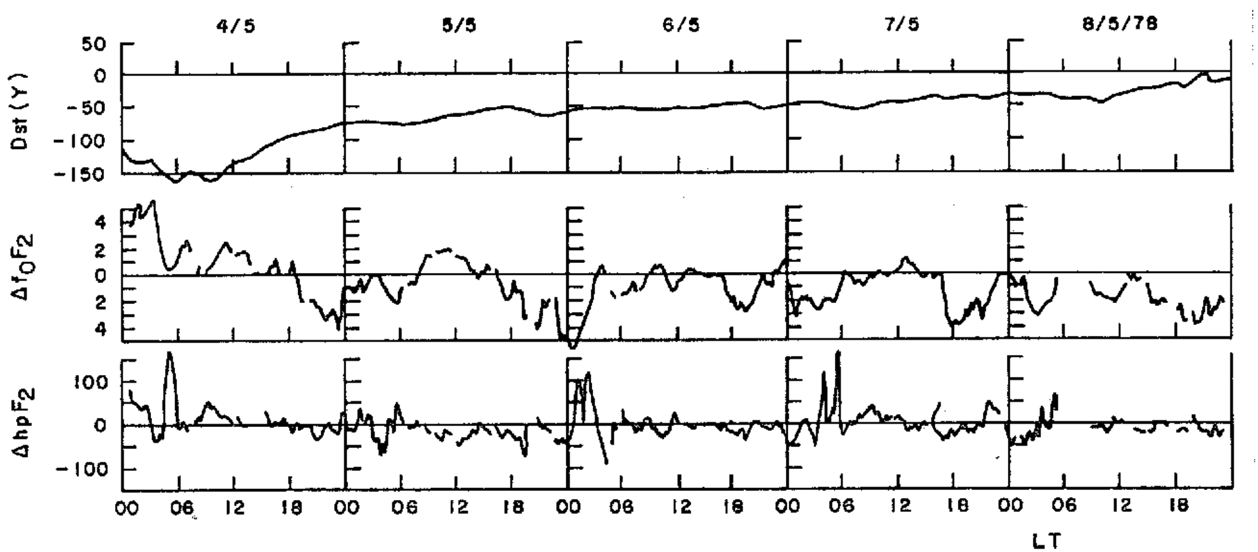

Fig. 3b - Continuation of the plot in 3a, till the recovery of the storm on 8 May, 1978.

In the case of a magnetic storm, which does not present well defined main phase and recovery phase, the phases in the ionospheric storm development do not appear clearly defined either. In the example presented in Figure 4, the ionospheric storm shows a significant negative deviation near the Dst minimum around the midnight of 26-27 March, 1978. However, ionization enhancements were observed during the two following nights, when the Dst values indicated continuing disturbances which caused a slow down of the recovery phase of the storm.

Furhter example of the superimposed storm disturbances, resulting in poorly defined main and recovery phases in the Dst variations, are presented in Figure 5, 6 and 7, together with the corresponding $\Delta f_oF_2(t)$ and $\Delta h_pF_2(t)$. In Figure 5 the $\Delta f_oF_2(t)$ shows mixed characteristics, namely, both enhancements and decrease in the F-region peak ionization, during the few days following the main phase on 9 May, 1978. The first well defined negative storm effect was seen on the 4^{th} day, from the storm onset, and well into the recovery phase. This delay in the occurence of the negative phase, as compared to those in the previous examples, is due probably to the Dst enhancement that took place on 11 March, 1978. Figure 6 also presents predominantly positive storm effect in f_oF_2 from 2 to 4 June, 1978, during which the Dst values indicated characteristics of extended storm main phase disturbances, and only on the 4^{th} day, from the storms onset, when the Dst values indicated recovery, did the negative ionospheric storm effect occur. Similar arguments may as well apply also for the results given in Figure 7. It may be tentatively concluded that recurring magnetic disturbances, following the main phase of a storm, prevent, or cause delay, in the occurence of a negative phase in storm induced F-region ionization time variations.

Based on the few examples of the F-region response to magnetic storm over Cachoeira Paulista, presented here, it seems possible to draw the following tentative conclusions:

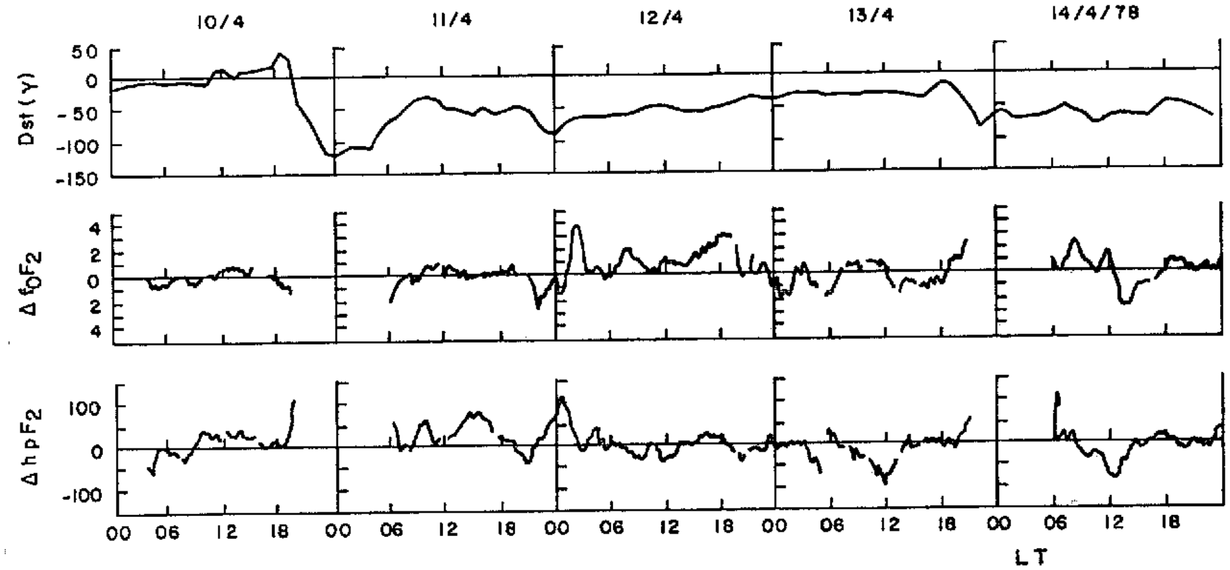

Fig. 4 - $\Delta f_0 F_2(t)$, $\Delta h_p F_2(t)$ and Dst variation during the magnetic storm disturbances that started on 10 April, 1978.

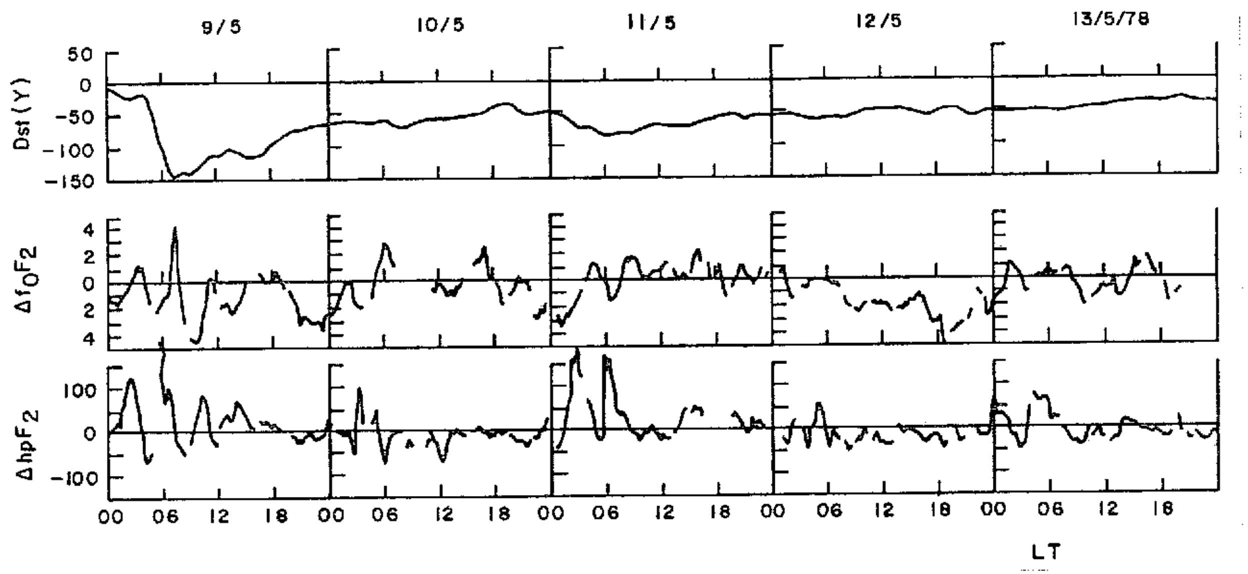

Fig. 5 - Δf_0 $F_2(t)$, Δh_p F_2 and Dst variations during the magnetic disturbances that started on 9 May, 1978.

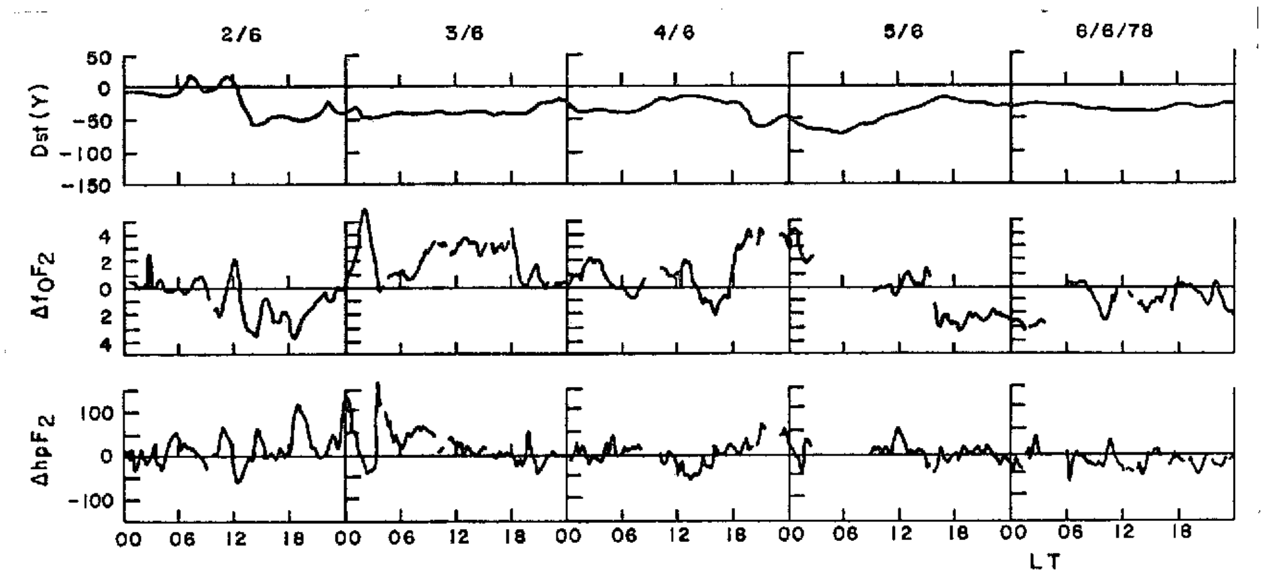

Fig. 6 - $\Delta f_0 F_2(t)$, $\Delta h_p F_2(t)$ and Dst variations during the magnetic storm disturbances that started on 2 June, 1978.

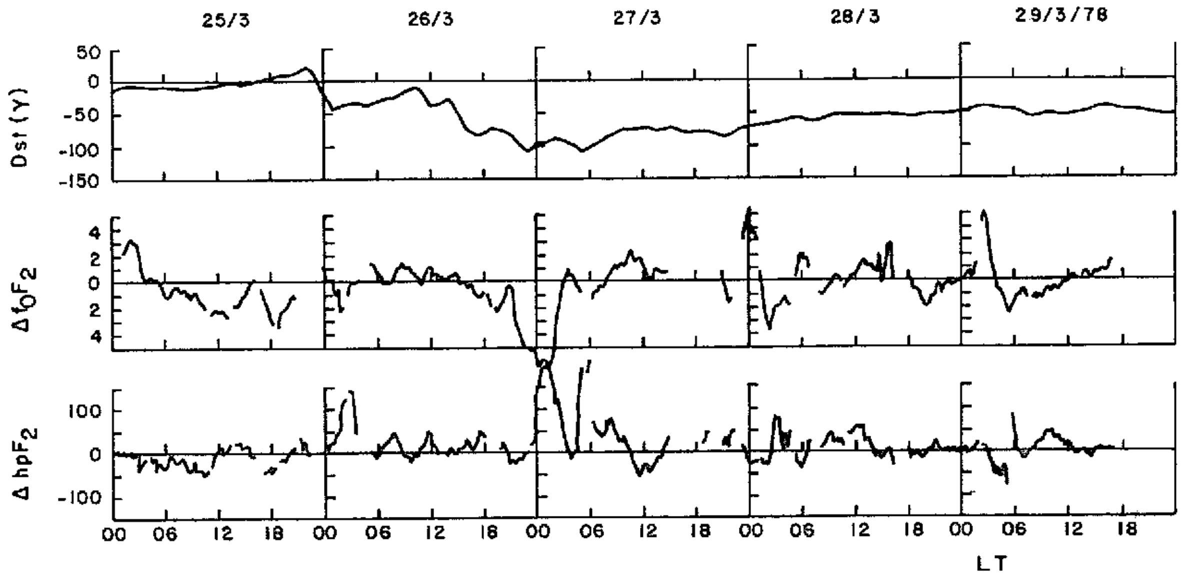

Fig. 7 - $\Delta f_0 F_2(t)$ $\Delta h_p F_2(t)$ and Dst variations during the magnetic storm disturbances, that started on 25 March, 1978.

1) The ionospheric F-region over Cachoeira Paulista undergoes significant changes in response to magnetic storms of moderate to strong intensity. The changes in the electron density are characterised by well defined enhancements, or decreases, with respect to the quiet time values. On the other hand, the height of F layers does not present well defined variations.

2) During the main phase of the magnetic storm, the F-region ionization often presents enhancements, similar to the positive storm effect observed over middle latitude (Evans, 1973; Matuura, 1972; Jones and Rishbeth, 1971). However, if the main phase is followed by recurring magnetic disturbances or by another storm, the resulting F-region response is not well defined. However, the ionization changes in this case seem to be more positive than negative.

3) During a well defined recovery phase of a magnetic storm, the F-region ionization shows pronounced decreases on a few consecutive days, marking the negative phase of the ionospheric storm. This can be identified with the similar negative storm effect observed over mid-latitude (see, for example, Matuura, 1972; Rishbeth, 1975; Matsushita, 1959). Occurrence of further magnetic disturbances, or a subsequent storm, during the recovery phase of a storm under consideration, seems to inhibit the development of a negative phase in the ionospheric storm variations. However, when a recovery phase emerges after the last of the magnetic disturbances, the negative phase in the ionospheric response does seem to show up. This point however, has to be confirmed with a larger number of events.

From the above discussion, it turns out that the most consistent characteristics of the ionospheric storm morphology over Cachoeira Paulista is the depletion in the F-region ionization that occurs in the recovery phase of an isolated magnetic storm. However, the occurrence of this negative phase, being confined mostly to night hours, seems to be an interesting point since such a feature has not been reported for mid-latitude. The negative storm effect over mid-latitude has been observed at different time of the day, and in some cases the effect has been observed mainly as a day time phenomenon (see, for example, Prolss and Van Zahn, 1976).

3. DISCUSSION AND CONCLUSIONS

Over the low latitude, the ionospheric response to magnetic storm becomes somewhat complicated as it involves the following factors: (1) extension to lower latitudes, of the storm induced alterations in the mid-latitude thermospheric processes, namely, in the transport and in the composition, and (2) modifications in the electrodynamic coupling between the equatorial and low latitude ionospheres, namely, in the equatorial ionization anomaly.

The development of the equatorial anomaly gets inhibited due to a reduction in the vertical ionization drift velocities over the equator, resulting from the storm induced changes in the east-west electric fields (Woodman, 1970); consequently a positive storm effect in the F-region ionization over equator has been observed (see, for example, Rajaram, 1977). The low latitude ionosphere would, therefore, be expected to experience a negative storm effect at the local times corresponding to the regular appearence of the anomaly crest, which, over Cachoeira Paulista, occurs usually during the local time interval from afternoon to pre-midnight hours. However, the negative storm phase over Cachoeira Paulista continued well into the past-midnight and morning hours as can be seen in Figures 2 and 3b). Further, the ionization enhancements over the equator, arising from the inhibition of the fountain effect, seems to operate during intervals centered around the storm main phase disturbances only, where as the ionization decreases over Cachoeira Paulista are observed well into the recovery phase of the magnetic disturbances. Thus there does not seem to be any significant contribution in the negative storm effects observed over Cachoeira Paulista, as a result of the storm induced electrodynamic influences in the equatorial anomaly.

Hence it may be concluded that the negative storm effects observed over Cachoeira Paulista, in the events presente here, are produced by low latitude extension of the storm induced thermospheric disturbances. The morphology of these disturbances have been studies somewhat extensively by several authors (Seaton, 1956; Jones, 1973; Davies, 1974; Prolss and Von Zahn, 1976). Magnetospheric storm depositslarge amount of energy, in the form of particle precipitation and auroral electrojet enhancements, into the high latitude ionosphere. The resulting atmosphere heating causes enhanced mixing of the thermospheric constituents, raising the ratio of molecular to atomic species ($|N_2|/|O|$), and sets up disturbance fronts that propagate to lower latitude, bringing with it the changed thermospheric composition. Since the electron density in the F-region is inversely proportional to the ratio $|N_2|/|O|$, the arrival of the disturbances front over the ionosonde stations marks the onset of the negative phase in the ionospheric storm. Prolss and Von Zahn, 1976, have shown, from Satellite measurements of thermospheric composition, that the ionosonde stations, located within the disturbance zones, characterised by relatively higher $|N_2|/|O|$ ratio, are prone to experience the negative phase in the ionospheric storm. If would be interesting to know the circunstance under which the thermospheric disturbances extend to latitude as low as that of Cachoeira Paulista. It has been pointed out, in some recent studies (See, for example, Davies, 1974; Prolss and Von Zhan, 1976), that this would dispend upon the strenght of the storm, the season, the invariant latitude and the local time of the storm onset. Further studies are continuing, involving a larger number of events and also true height, analysis of the ionograms for some selected cases, in order to place, on a more quantitative basis, the cause-effect relationships that operate during ionospheric storms over low latitude.

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