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Influence of non-recurrent geomagnetic activity on ionospheric scintillations†

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ostract We have quantified the effect of geomagnetic storms on ionospheric scintillations observed at a few Indian low latitude stations. Total eventy-three storms were studied and classified into different categories to see the type of activity in the ionosphere on, before or after each category l storm To show the effect of geomagnetic storms in each category on the occurrence of scintillations, we selected five individual non-recurrent eomagnetic storms, mostly severe ones, having different sudden storm commencement times It is noted that for intense geomagnetic storms, both cintillation and ionosphere data yield identical results which demonstrate that spatial irregularities of electron density in the ionosphere may be attributed to magnetic storms and associated perturbations A study of storm time N_MF_2, h'F and scintillation, was carried out to understand the Physics behind the triggering / suppression of scintillation activity. It is found that during the main phase, N_MF_2 shows peak values while it decreases sharply during the recovery phase Any enhancement during recovery time in N_MF_2 along with a rise in h'F, implies either an irregularity formation or strong possibility of occurrence of scintillation. It is also found that during solar maximum years, equatorial scintillations are totally inhibited during recurrent eomagnetic storms for all seasons while no such rule holds good for non-recurrent storms. The study reveals that F-region response to geomagnetic torms is interplay of the electromagnetic drift and rise in h'F associated with storm time electric field.

Keywords Non-recurrent geomagnetic storms, ionospheric scintillations

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Introduction

dio waves coming from a radio star or a satellite radio beacon nsmitter when pass through a medium containing electron nsity irregularities cause fluctuation of signal parameters like plitude or phase. These fluctuations are popularly known as intillations. It is in analogy to twinkling of a star caused by ospheric irregularities. Study of scintillations provides a lot information about the irregularities *i.e.*, intensity of scintillation 4) as a function of density, scale size, drift, anisotropy and the atial extent of the irregularities. An excellent review of the illation theories has been done by Yeh [1].

The equatorial region is unique in scintillation as well as nagnetic studies because in this region, the earth's magnetic lines of forces are nearly horizontal. The charged particles thrown outwards after the outbreak of a flare either be directed towards the earth or any other planet in the solar system. The investigations of scintillation activity during stormy conditions will thus be useful in understanding the behavior of ionosphere regularities under such conditions. The storm time variation in ring current (Dst) slowly returns to normal levels indicating that the ring current dies away less rapidly than the polar disturbance.

Koster [2] used the planetary magnetic index (K_p) to show that for lower values of $K_p(\Sigma K_p < 30)$, there is no clear correlation between magnetic activity and scintillation; however for larger values of $K_p(\Sigma K_p > 30)$, there is a strong negative correlation. Aarons *et al* [3] found that pre-midnight scintillations are inhibited by magnetic activity, based on K_p values and that during the post-midnight period, increased magnetic activity

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increases scintillation activity under moderate solar flux conditions. Aarons [4] suggested that during magnetic storms, the ring current plays a leading role by either directly or indirectly establishing the conditions necessary for equatorial F-layer irregularity generation or inhibition. Vijayakumar *et al* [5] pointed out that increased magnetic activity might inhibit growth of the Rayleigh-Taylor instability and hence occurrence of scintillations, especially during high solar activity.

Kelley and Maruyamma [6] presented a diagnostic model for equatorial spread–F detailing the effect of magnetic activity. Pathan *et al* [7] showed that VHF radio wave scintillations at low latitudes are greatly reduced during geomagnetic active nights in the Indian sector. Extensive studies on the morphology of storms have been made through various experimental techniques and storm time variations of the electron content depending on the stages of storm development, location, season and local time of occurrence [8-10]. It is noted from early studies [11-14] that the storms with D_{st} – 75 nT are found to be more effective in scintillation activity. The influence of magnetic activity inhibition of spread-F during sunspot maximum years has been reported in Refs. [15-17] and that for minimum years has been reported in Refs. [18-20].

We have classified seventy-three storms that occurred during 1988–1993 on the basis of origin and their association with various interplanetary parameters and minimum negative excursion of Dst, during the high and moderate solar activity period of observation. The simultaneous scintillation observations of geomagnetic storm time response at anomaly crest region and that of equatorial region showed that scintillation activity in general, is suppressed during geomagnetic disturbances. However, at equatorial stations, scintillations seemed to be unaffected by those storms which occurred during lower solar activity periods. The above result is almost in agreement with Rastogi's suggestions that during high sunspot-years, scintillation occurrence is suppressed for all seasons by magnetic disturbances, while it is not so during low sunspot years at the magnetic equator [21]. One of our findings is that for certain types of non-recurrent geomagnetic storms, the above thumb rule do not hold good, even during the years of a solar maximum.

2. Acquisition of data and method

The solar data was obtained from the Central Institute of Astrophysics, Solar Radio Observatory (Potsdam). Scintillation data of Thiruvananthapuram (Geo. Lat. 8.3°; Geo. Long. 76.9°; Dip angle 0.6°; Dip angle of sub-ionospheric point at 400 km, – 0.6°); Thiruchendur (Geo. Lat. 8.3°; Geo. Long. 78.1°; Dip angle –0.7°; Dip angle of subionospheric point at 400 km, – 0.5°) and Bhopal (Geo. Lat. 23.2°; Geo. Long. 77.6°; Dip angle 33.8°; Dip angle of sub-ionospheric point at 400 km, 30.7°) were analysed for this study. The geomagnetic storm, maximum electron density of F_2 layer (N_MF_2) and Virtual height of F-layer (h'F) data were from the Space Physics Laboratory (VSSC), Thumba and Physical Research Laboratory (PRL), Ahamadabad (for Bhopal). A_p and K_p values were noted from geomagnetic data bulletin of Worl[illegible] Data Center. Because of spread-F, we were unable to use f_0F and h'F data from Thiruvananthapuram; the data were used from Kodaikanal.

3. Classification of storms

Equatorial ionospheric responses to seventy-three geomagnetic storms were investigated. They are grouped into two main categories : recurrent and non-recurrent during the period 1988-1993. Some important events for each year are illustrated which occurred due to an interaction of the inter planetary magnetic clouds with the Earth's magnetic field. Ionospheric response during different phases of geomagnetic storms, their association with various interplanetary parameters and local time dependence has been analyzed for grouping the geomagnetic storm. The storms are also classified on the basis of varying range of equatorial Dst values, starting time of recovery, and solar maximum and solar moderate periods; the details of which are given in Table 1.

Table 1. Geomagnetic storms considered for this validation study January 1988 to June 1993

Type of storms	1988	1989	1990	1991	1992	19[illegible]
Non-recurrent	3	9	8	4	3	
Recurrent	5	6	8	10	6	[illegible]
Unknown origin	1	2	2	2	1	0
Dst<–250 nT	1	3	2	2	1	
–250<Dst<–150 nT	2	6	4	3	2	1
–150<Dst<–75 nT	6	13	10	7	6	[illegible]
Sudden commencement	3	15	10	7	3	2
Gradual commencement	6	7	6	6	7	1
Category I	6(50%)	9(36%)	5(50%)	8(53%)	5(46%)	[illegible]
Category II	2(22%)	6(25%)	3(30%)	3(23%)	2(20%)	
Category III	2(27%)	9(36%)	2(20%)	3(23%)	3(33%)	1

4. Results and discussion

A comparative study of nocturnal scintillation has been ma[illegible] for the equatorial stations and anomaly crest region w[illegible] American Geostationary Satellite FLEETSAT positioned at [illegible] E at a frequency of 244 MHz from 1988 to 1991 and 250 M[illegible] from 1992 to 1993. The storms were studied to see what acti[illegible] preceded them in the ionosphere, under the equatorial [illegible] anomaly crest zones. To show the effect of geomagnetic stor[illegible] on the occurrence of scintillations, we selected five individ[illegible] geomagnetic storms mostly severe ones, having differ[illegible] sudden storm commencement times. It was found that the num[illegible] of sudden–commencement storms were maximum during [illegible] solar maximum years (1989-91). Based on Aarons hyp[illegible] the storms were further classified on the basis of the time of occurrence of the maximum excursion of Dst, in the generation or inhibition of ionospheric irregularity formation. For *category I*, recovery phase of the three storms started during daytime, well before sunset. For *Category II*, it was around midnight whereas in the *Category III*, recovery started during post-sunset hours and before midnight.

Figure 1 depicts the storm of Cateogry II, of November 17 thru 18, 1989. The storm occurred at 1455 IST (0925-UT) on November 17th and the recovery started at 2308 hours IST on the same day. Scintillations at Thiruvananthapuram were observed on the same night during 0215-0835 hours IST. Scintillation patches of long duration were the general characteristic before the commencement of the storm. The equatorial N_MF_2 showed an enhancement compared to the monthly median value during the main phase of the storm. However, during the recovery phase, N_MF_2, h'F showed a low and a high altitude respectively. During the time of scintillation, h'F data was interrupted. It is a characteristic that when the recovery starts after post midnight time, irregularity may generate and a hike in h'F can be observed. A number of non-recurrent storms, showed little effect on scintillations during this period. Certain type of ion may be responsible for storm time instability formation

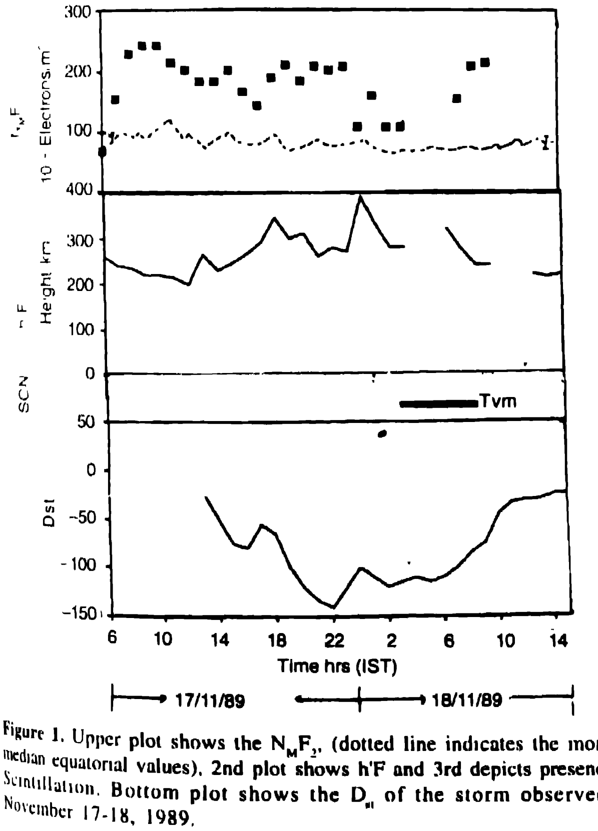

Figure 1. Upper plot shows the N_MF_2, (dotted line indicates the monthly median equatorial values), 2nd plot shows h'F and 3rd depicts presence of Scintillation. Bottom plot shows the D_{st} of the storm observed on November 17-18, 1989.

Figure 2 shows another Category II non-recurrent geomagnetics torm; its influence lasted four to five days. It was due to an 1B flare which occurred at 1630 IST (1100 UT) on December 28, 1989. D_{st} showed a long zigzag variation due to sub-storm events. Scintillation as well as spread-F, were suppressed throughout these days ; scintillations were noted prior to this storm. At the time of recovery, N_MF_2 showed a sharp decrease. However, after 16 hours may be due to sub-storms effects, an enhancement in N_MF_2 occurred. While comparing N_MF_2 values at anomaly crest and at equatorial region, it was found that storm time anomaly crest peaks are higher than the equatorial values.

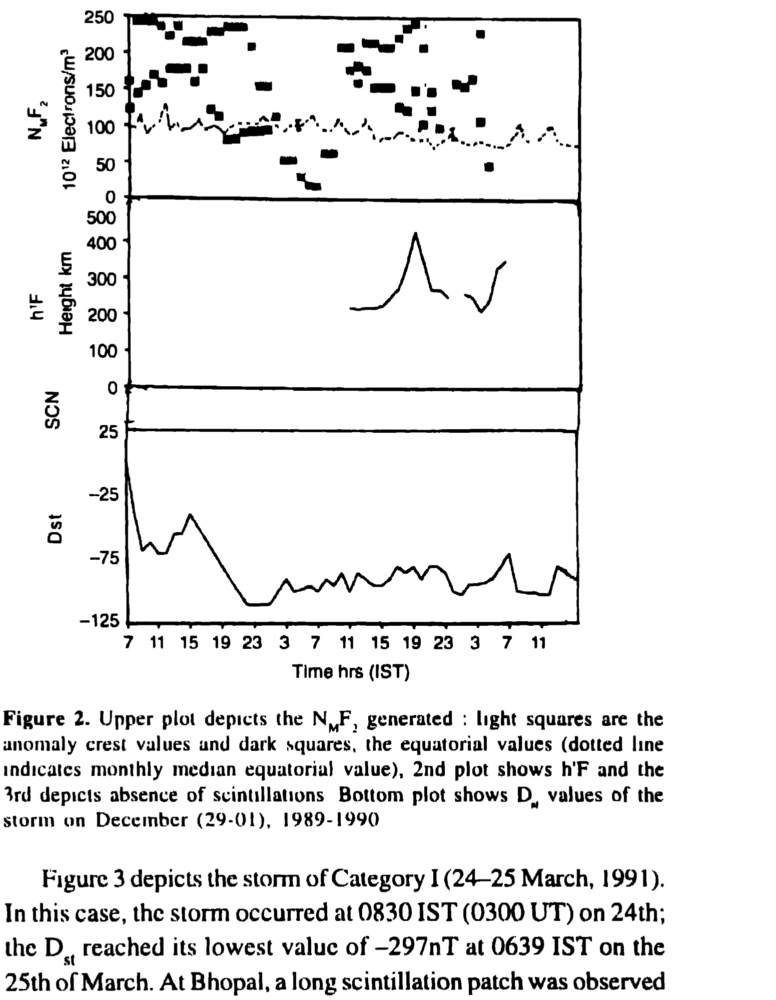

Figure 2. Upper plot depicts the N_MF_2 generated : light squares are the anomaly crest values and dark squares, the equatorial values (dotted line indicates monthly median equatorial value), 2nd plot shows h'F and the 3rd depicts absence of scintillations Bottom plot shows D_{st} values of the storm on December (29-01), 1989-1990

Figure 3 depicts the storm of Category I (24–25 March, 1991). In this case, the storm occurred at 0830 IST (0300 UT) on 24th; the D_{st} reached its lowest value of −297nT at 0639 IST on the 25th of March. At Bhopal, a long scintillation patch was observed during midnight hours and a short duration one during post-midnight hours. At Thiruvananthapuram, scintillations were comparatively less and occurred in two patches between 0118-0210 and 0508-0600 hrs IST. It is worth noting that scintillation occurred earlier at Bhopal than at Thiruvananthapuram. This is contrary to the normal behavior, since Thiruvananthapuram is one of the equatorial stations and may be assumed to be the seat of the R-T generation, while Bhopal is a station in the anomaly crest region. It clearly indicates a storm related irregularity formation at the low latitude or travelling ionospheric disturbances (TIDs). However, much effort is needed in order to understand the triggering of this type of plasma instability formation.

Figure 4 shows the ionospheric response to the storm of May 10–11, 1992 which is one of the severe Category II storms; its recovery started on the same day at 2149 hours IST. Scintillations were totally suppressed at Bhopal. At Thiruvananthapuram, scintillations were noted during the main phase, during 1810-2203 hours IST. Satellite signals were not properly received during this period making further observations difficult. However, spread-F was observed during the recovery phase. During this storm, we also note higher values of N_MF_2 at the anomaly crest region. In most of these cases, N_MF_2 showed a sharp rise along with the rise in h'F during the time of scintillations; obviously, it is an irregularity formation due to the abnormal reversal of the equatorial nighttime electric field from its normal westward to eastward directions.

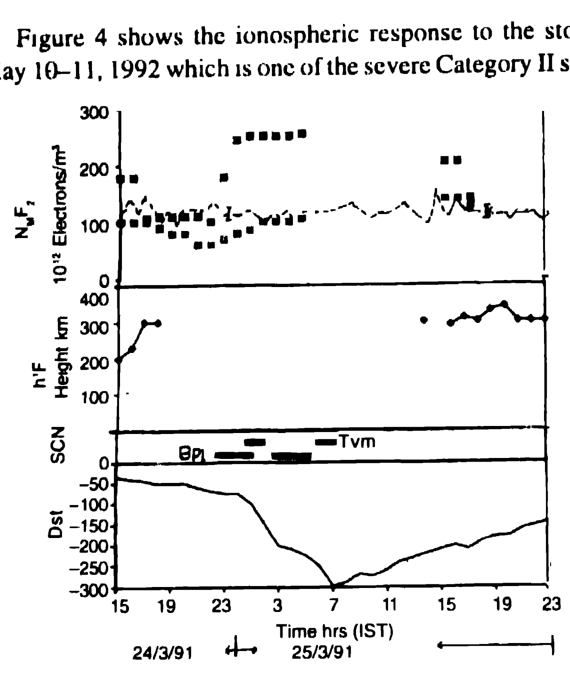

Figure 3. Upper plot shows the storm time response of N_MF_2, dark squares denoting the anomaly crest zone and light ones the equatorial region (dotted line-equatorial monthly median values), 2nd plot shows h'F and 3rd the presence of scintillations Bottom plot indiates D_{st} values of the storm observed on March 24-25, 1991

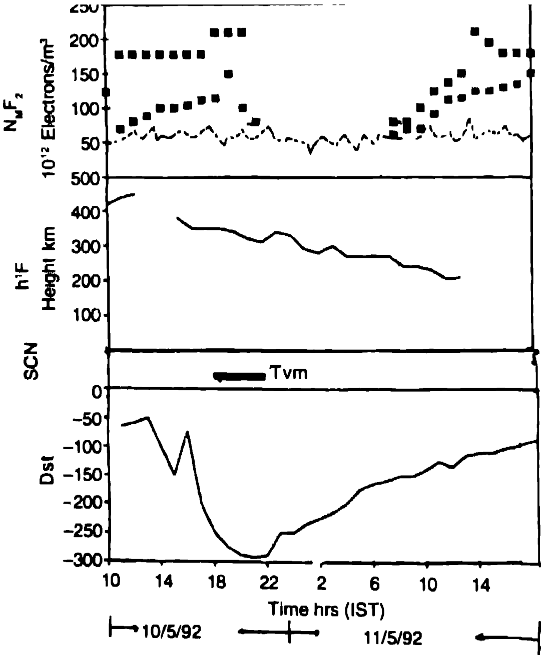

Figure 4. Upper plot depicts the generated N_MF_2 · dark square denoting the anomaly crest zone and light squares the equatorial zone (dotted line equatorial median value), 2nd plot shows the h'F at the equatorial region and 3rd plot shows presence of equatorial scintillation. Bottom plot indicates the D_{st} values of the storm on May 10–11th, 1992.

The storm of April 4–5, 1993 is shown in Figure 5. The storm occurred on 4th April and recovery started at 1245 IST (0715 UT). Pre-midnight scintillations were observed at Bhopal on the 4th and 5th while there was no change in scintillation activity at Thiruvananthapuram which implies that during moderate solar activity years, storms have little affect on equatorial scintillations. Because of spread-F, ionospheric data at equatorial zone could not be obtained. Hence N_MF_2 of Ahmedabad is considered. A substantial suppression of h' F is noted, followed by the inhibition of scintillations at the anomaly crest region. The study reveals that equatorial scintillations get suppressed during geomagnetic storms (except for certain type of non-recurrent storms) during solar maximum years ; no much suppression however, exists during years of moderate solar activity.

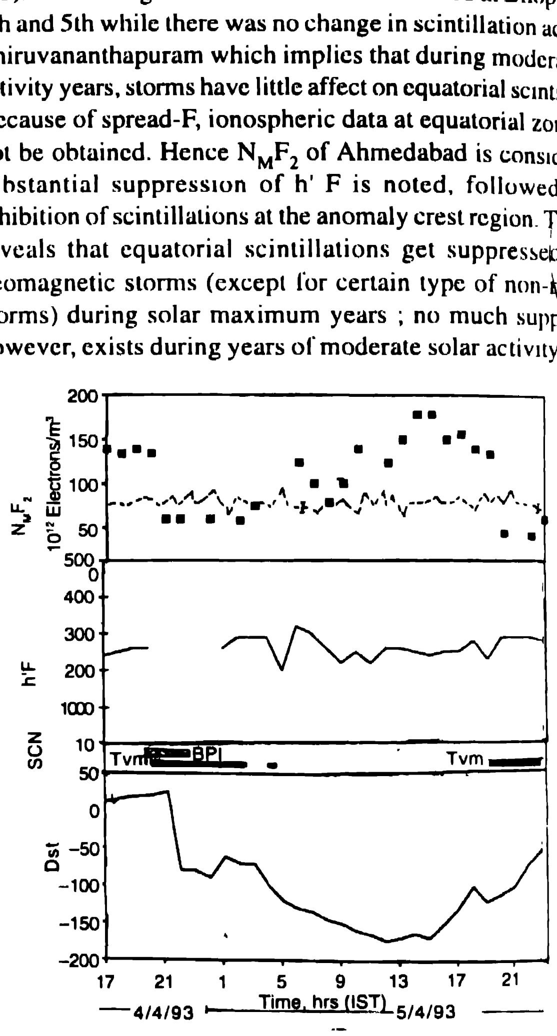

Figure 5. Upper plot depicts the storm time generated N_MF_2, dotted li anomaly crest monthly median 2nd plot depicts the h'F values Ahmedabad and 3rd presence of scintillations Bottom plot shows the I of the storm observed on April 4-5, 1993

Generally, the effect of geomagnetic disturbance is to inhibit scintillation at the anomaly crest region. However, the magnetic storms for which the D_{st} reaches below – 100 nT and recovery phase starts in local nighttime or in very early morning hours increase the scintillations greatly in post-midnight period. Hence time of recovery and lowest maximum excursion of the D_{st} are two important factors which play a crucial role in producing suppressing irregularities.

For intense geomagnetic storms, both scintillation and ionospheric data yield identical results which demonstrates that spatial irregularities of electron density in the ionosphere may be attributed to magnetic storms and associated perturbations.

The sharp increase in N_MF_2 along with rise in h'F during a recovery phase, following the onset of scintillation shows that F-region response to geomagnetic storm is an interplay of the electromagnetic drift associated with storm time electric fields; thermospheric circulation of wave and winds may either directly or indirectly play a leading role in establishing the conditions necessary for irregularity formation or inhibition.

Simultaneous observations of storm time response at equatorial and anomaly crest regions showed scintillation activity is in general, found to be suppressed during geomagnetic disturbances ; however, at Thiruvananthapuram, scintillations seems to be unaffected by those storms which occurred during moderate activity periods. The result is in agreement with Rastogi *et al*'s suggestion [21]. However, our studies reveal that the association between equatorial scintillations and magnetic activity appears to have a functional dependence only during periods of high solar activity.

5 Conclusions

We have quantified the ionospheric response to different classes of geomagnetic storms, their association with scintillations and local time of dependence. From the results and discussions, we are led to believe that increased magnetic activity might inhibit the growth of scintillation producing instabilities except for certain types of non-recurrent magnetic storms which may play crucial role in initiating it. Rather than recurrent, non-recurrent activity is the best criterion for predicting disturbances during maximum solar activity period.

Generally during post-sunset hours, the equatorial F-region rises to higher altitude where ion-neutral collision frequency is quite small, thereby creating conditions favorable for Rayleigh-Taylor (R-T) instability. During stormy conditions, the normal F region electric fields are totally reversed by the superposed magnetospheric electric field. The study reveals that, F-regional response to geomagnetic storm is strongly affected by the electromagnetic drift and rise in h'F associated with storm time electric field.

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References

[1] K C Yeh and C H Liu *Proc. IEEE* **70** 324 (1982)

[2] J R Koster *Planet Space Sci. (GB)* **20** 1999 (1972)

[3] J Aarons, J P Mullen R F De Silva, J R Medeiros, R T Medeiros, A Bush by, J Pantoja, J Lanat and M R Paulson *J. Atmos Terr Phys* **42** 861 (1980)

[4] J Aarons *Radio Sci. (USA)* **26** 1131 (1991)

[5] P N Vijayakumar, J K Gupta, T R Tyagi, Lakha Singh and Y V Somayajulu *Indian J Radio Space Phys* **20** 50 (1991)

[6] M C Kelley and T Maruyama *J Geophys Res. (USA)* **97** 1271 (1992)

[7] B M Pathan, P V Korparkar, R G Rastogi and D R K Rao *Ann. Geophys (France)* **9** 120 (1991)

[8] S Basu, J P Mc Clure, Su Basu, W B Hanson and J Larons *J. Geophys Res. (USA)* **85** 5119 (1980)

[9] K N Iyer *Indian J. Radio Space Phys* **22** 277 (1993)

[10] B Jayachandran *(Personal Communication)* (1998)

[11] R S Dabas, D R Lakshmi and B M Reddy *Radio Sci (USA)* **24** 563 (1989)

[12] M A Abdu, I S Batista, G O Walker, J A A Sobal, N B Trivedi and E R de Panla *J Atmos Terr. Phys* **57** 1065 (1995)

[13] J H A Sobral, M A Abdu, W D Gonzlez, B T Tsurutani, I S Batista and A L Clande Gonzales *J Geophys Res. (USA)* **102** 14305 (1997)

[14] S Rangaswamy and K B Kapasi *J Atmos Terr. Phys (GB)* **25** 761 (1963)

[15] J H Sastri and B S Murthy *Ann. Geophys (France)* **31** 981 (1975)

[16] H Chandra and G D Vyas *Indian J Radio Space Phys.* **7** 263 (1978)

[17] S P Namboothiri, N Balan and P B Rao *J. Geophys Res* **94** 12055 (1989)

[18] J H Sastri, K Sasidaran, V Subramanyan and M Srisama Rao *Indian J. Radio Space Phys.* **7** 314 (1978)

[19] K S V Subharao and B V Krishnamurthy *Ann. Geophys. (France)* **39** 33 (1994)

[20] D Joymon, Sebastian Somi, T M George and S R Prabhakaran Nair *J Radio Space Phys.* **26** 213 (1997)

[21] R G Rastogi, P V Koparkar and B M Pathan *J. Geomag. Geoelectr (Japan)* **42** 1 (1990)