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Geomagnetic Storm Effects on Drift and Anisotropy Parameters of Ionospheric Irregularities in the E-region at Waltair

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Abstract

The variation of drift and anisotropy parameters of Ionospheric irregularities in the E-region at Waltair (dip 17.7°N; 83.3° E) during 3 geomagnetic storms has been studied mainly to resolve the controversy that has been reported in the literature about the effect of magnetic activity on the drift and anisotropy parameters. E-region spaced antenna drift records taken on frequency 2.4 MHz during the period September 1983-May 1984 at Waltair are used in the present study. In the E-region, the true drift velocity during storm period appears to be larger than the control day values. The ratio of V_a/V shows a gradual decrease during storm period and random velocity during storm time is quiet less compared to the control day values. No significant variation is observed in the apparent drift direction and structure size on storm days with respect to the control days. The orientation of the semi-major axis mostly lies in the range of 120° – 150° N of E, both on storm days as well as on control days but the average value of the axial ratio shows a higher value compared to the average on control days.

Key words: Close spaced receivers, Ground diffraction pattern, Geomagnetic activity, Ionospheric irregularities and Geomagnetic storms.

1. Introduction

The Ionospheric disturbances associated with magnetic storms have been recognized and studied by many works all over the globe during the last six decades. Several mechanisms that are identified playing dominant role during magnetic storms include, heating of the neutral and ionized constituents of the ionosphere, changes in the neutral composition^{1,2}, movements of ionization into the magnetosphere and most importantly

by electrodynamic movements of ionization^{3,4}. According to Martyn's theory³, the movements in F₂ region are caused by the current system in the E region (lower ionosphere) and hence it is to be expected that the F-region movements and the magnetic activity are interdependent. This has led to a systematic study of the effect of geomagnetic activity on drift and anisotropy parameters of ionospheric irregularities, extensively, by several workers, at different observatories, covering almost all the latitude regions and even over a couple of solar epochs.

Fooks⁵, made a study of the drift and anisotropy parameters of the E and F region irregularities under magnetically disturbed conditions and compared them with those obtained under quiet conditions by Fooks and Jones⁶. No significant difference between either E and F region results or between the day and night results was observed. It was found that while the median value of the axial ratio for both the conditions of observation was not appreciably altered, but the length of the semi-major axis was considerably reduced under magnetically disturbed conditions.

2. Literature Review :

In the following, a brief review of the studies on the effect of geomagnetic activity on drift and anisotropy parameters is given.

Harang and Pederson⁷ observed high drift speeds during storm conditions but no systematic variation with K in the case of E region. Rao and Rao⁸, at a mid latitude station, found that the E region drift speed increased on disturbed days. The results reported from low altitude and equatorial belt region suggested that drift speed decreases with magnetic activity index. Kelleher⁹, noticed an increase in the Es drift at Slough (51.5°N, 0.6°W) with the increase of K index.

Rastogi *et al.*¹⁰, reported negative correlation between E and F region ionospheric irregularities with K_p index at Thumba (0.3°S). Later, Vyas¹¹ reported negative correlation for another equatorial station, Tiruchirapalli (10°49' N, 78° 42' E). Patel and Chandra¹², studied the effect of magnetic activity on drift speed at various stations and found a negative correlation between drift speed and magnetic activity index in both E and F regions at all stations located between equator and 35° N geog. latitude. They have also reported that a positive correlation at high latitudes beyond Sq. focus and almost no effect at midlatitude stations.

Rastogi *et al.*¹³ at Thumba (magnetic equator) made a comparison of the drift speeds on international quiet and disturbed days and studied the daily variations of the apparent drift speed during the years 1964 and 1967-68. There was a reduction in the drift speed on disturbed days in E region, the reduction being most significant around noon hours. The reduction in the drift speed with K_p was explained as due to the electric field of magnetospheric origin increasing with the geomagnetic activity, opposing the equatorial S_q field¹⁰. The other main conclusions reported by¹⁰ are 1) a decrease in the axial ratio during disturbed days in E region 2) irregularities are mainly field aligned, except E region irregularities during disturbed days aligned ± 30° NS direction and 3) decrease in the semi minor axis during disturbed days.

Sardesai *et al.*¹⁴ found a negative correlation between apparent drift speed and K_p index in case of daytime E-region, at Udaipur (Geomag. lat. 14° 55' N). During day time the relationship between EW component of E region drift velocity and K_p index is found scattered. Thus no definite conclusion could be drawn. Rao and Rao⁸, at Waltair obtained slightly higher values under disturbed conditions for V_a and V in E region. Darshan Singh and Gurm¹⁵, reported that the E region drift speed increases significantly with an increase in K_p index at Patiala (Dip 43.8N) during winter. However, during summer and equinoxes, they noticed a decrease in drift speed with K_p.

Rezende *et al.*¹⁶ analyzed the effects of two intense magnetic storms over ionospheric irregularities using GPS signal scintillation data from the stations of Sao Luis in the equatorial region and other stations. They analyzed storms occurred on October 28-31, 2003 and November 7-11, 2004. Both storm periods presented two main phases. They observed that in the main phase of the storm, TEC over Sao Jose dos Campos reached higher values than the TEC for the magnetically quiet days. Guzhu Li *et al.*¹⁷ using a set of in Situ satellites and ground-based GPS total electron content and scintillations receivers VHF radar, found that the irregularities occurred over a wide longitudinal range, extending from around 300°E to 120°E on storm days 25 and 27 July 2004. They showed that under complex storm conditions, besides the long duration or multiple penetrations, the combined effect of PPEFs and DDEFs could result in a wide longitude extent of ionospheric irregularities at times.

Rastogi and Chandra¹⁸ studied the effects of super geomagnetic storm of 6 April 2000 on E and F-regions of the ionosphere at Thumba (India) and at Jicamarca (Peru). They reported that the geomagnetic storm of the April 2000 resulted in both the prompt penetration electric field and later in the disturbance dynamo field and affected both the dayside and night side ionosphere. The sudden large turning of the IMF-Bz imposes a prompt penetration electric field at low latitude ionosphere globally. The effect on the E-region irregularities during dayside (Es-q) is simultaneous both in the F-region, irregularities during night side is delayed by an hour or so.

3. Research Problem and Significance :

Earlier investigations reviewed above were based on either looking into the dependence of the drift parameters on K_p index or the variation of these parameters during quiet and disturbed days. As such the average values of these parameters studied, sometimes appear to be mutually contradictory, even within the same latitude regions. For instance, the E region drift speeds at Waltair¹⁹, appear to increase with K_p index, while at Udaipur¹⁴ a negative correlation was found between the apparent drift speed and K_p index. In addition to, it appears that very few studies were made about the variation of drift and anisotropy parameters during magnetic storms, except for the studies of Mitra and Vij²⁰ and Rastogi *et al.*¹³. Mitra and Vif¹⁷, found no significant change in the magnitude of the drift velocity during large magnetic storms at Delhi (28° 35' N., 77° 51' E). Rastogi *et al.*¹³, noticed daytime counter electrojet events during geomagnetic storms indicating an eastward electron drift and Esq. disappearance. Therefore, the authors have undertaken a study, particularly to investigate how the drift and anisotropy parameters of the E-region irregularities vary during the course of geomagnetic storms, to gain a better insight into the influence of geomagnetic activity on drift and other irregularity parameters.

4. Research Methodology

4.1. Experimental Technique :

The experimental method was originally proposed independently by Mitra²¹ and Krautkramer²², essentially involves a pulse radio wave, on a chosen frequency, to illuminate the ionosphere containing a large number of small scale moving irregularities. Due to their movement the irregularities cast a moving diffraction pattern on the ground, which is seen as the amplitude variation of the reflected radio signal, termed as fading. A spaced array of antennas located at the three corners of right angled triangle samples the time varying diffraction pattern on the ground and from simple triangulation method, apparent movement of the irregularities could be estimated.

4.2. Experimental Procedure :

The experimental arrangement comprises three horizontal dipoles (receivers), oriented along the EW direction, placed at a height of 12' above the ground and is situated at the 3 corners of a right angled triangle. The arm length was 140 m in EW and NS directions. E region spaced antenna drift records taken on frequency of 2.4 MHz during the period September 1983-May 1984 at Waltair (Visakhapatnam) are used in the present investigation. Night time records on 2.4 MHz frequency mostly correspond to Es region and these records are included in E region data. Geomagnetic storm data has been taken from Solar Geophysical Data Bulletins Published by U.S. Dept. of Commerce (Boulder, Colorado, U.S.A., 80 303). Only those storms are selected, for which continuous drift data was available for at least 3 days following the onset of the geomagnetic storm. In all, E region continuous drift records were available for 3 storms. The details of the magnetic storms that are selected for the present study are given in table 1. For making a comparative study, 3 control days are also selected – the two successive days just before the commencement of each storm and one after the end of the storm (as indicated in the storm data bulletins). Finally records obtained both storm as well as on control days are then subjected to full correlation analysis to obtain the drift and anisotropy parameters.

4.3. Method of Analysis :

Spaced aerial fading records for the E region are shown in Fig. 1. The scaling interval for the evaluation of the correlation coefficients is varied from 0.24 to 0.40 seconds for the different sets of records as per the situation and the number of ordinates chosen for each of the three fading tracks of a record are 200.

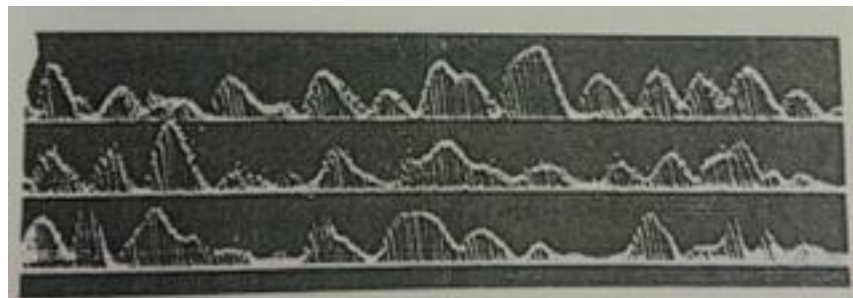


Fig. 1. Typical fading record of drift in E region

Selection of the fading records :

1. The fading records remain statistically stationary at least within the length of the sample used for analysis and that it contains at least eight or more fading cycles. The criterion is believed to provide a reliable estimate of the correlation coefficients.
2. The three fading tracks in each record possess a relatively high degree of similarity, pertaining to the nature of their variation of amplitude, revealing a steady horizontal drift of irregularities. It is to be clarified here that the implementation of the above condition does not mean biasing the determination of random changes relative to pure horizontal drift, as the records rejected on the ground of exhibiting highly dissimilar variation of amplitude on the three fading tracks are quite a few in number.
3. Records exhibiting the fading of a closely split echo, are not used as the fading is produced by a process of interference between the two components of the split echo, and hence vitiates the results.

The present analysis essentially consists of taking the onset time of each storm as the zero hour, and obtained the drift and anisotropy parameters for every hour following the storm, for all the storms using full

correlation method of analysis²³. Four hourly average values are then obtained, as the representative values. The storm time variation of drift and anisotropy parameters is then plotted, from the zero hour of the storm, i.e., the commencement of the storm to the end of the storm at 4 hourly intervals. Similarly, the control day average values of drift and anisotropy parameters are obtained. In all about 270 hourly drift records during storm time and about 200 records during control days are analyzed.

Table 1. Geomagnetic storm data

Storm	Date of commencement	Onset time hrs(I.S.T)	Recovery		Type of storm	Range in ΔH at Hyderabad (Gamma)	Average daily indices ΣKp
			Date	Time, hrs			
1	15 Sept.83	0644	17 Sept.	2330	SC	123	21,26,25
2	03 Jan.84	1230	06 Jan.	0030	GC	108	20,30,26
3	25 Jan.84	1030	27 Jan.	0930	GC	135	10,16,8
4	21 Mar.84	1730	24 Mar.	0230	GC	157	7, 21, 18
5	4 Apr.84	1010	06 Apr.	0530	GC	118	54, 57, 12
6	09 May.84	1030	13 May.	0930	GC	147	19, 27, 10

GC = Gradual commencement SC = Sudden commencement

5. Results

5.1. Drift Parameters

5.1.1. True drift velocity

Fig. 2 depicts the 4 hourly average storm time variation of the E region drift velocity. The true drift velocity shows a marginal increase with the progress of the storm, reaching maximum values after 24 hour of the storm commencement. It can also be noticed that the true drift velocity throughout the storm period showed higher values compared to the control day values, at least until 40 hours of the commencement of the storm, and after that the true drift value appears to be reaching the control day average value of the true drift speed.

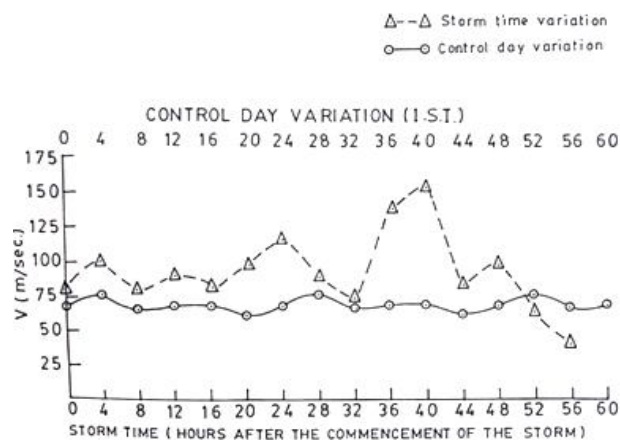


Fig. 2. Storm time variation of true drift velocity [v]

5.1.2. Apparent velocity :

Figs.3. (a) and 3(b) show respectively the apparent velocity (V_a) and the ratio of apparent velocity to the true drift speed (V_a/V) variations during the storm days as well as on control days. It can be seen from the Fig. 3 (a), that V_a shows an oscillatory variation with increasing and decreasing values throughout the storm period. The horizontal lines shown in the figure represent the control day average values. No significant variation could be seen between the storm time variation and control day variation of the true drift velocity. However, the ratio V_a/V , which gives a measure of departure of the apparent velocity with respect to the true drift velocity, shows a gradual decrease during the storm, at least, till about 32 hours. This result indicates that during storm period, no significant variation could be found between true drift and apparent drift velocities. The oscillatory nature found in the variation of the apparent drift velocity could also be seen in the ratio V_a/V . Perhaps this variation might be due to the predominance of the diurnal component present in the true drift direction.

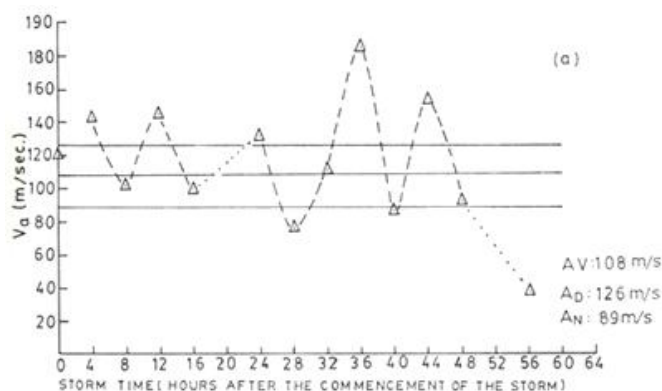


Fig. 3 (a) Storm time variation of Apparent drift velocity [V_a]

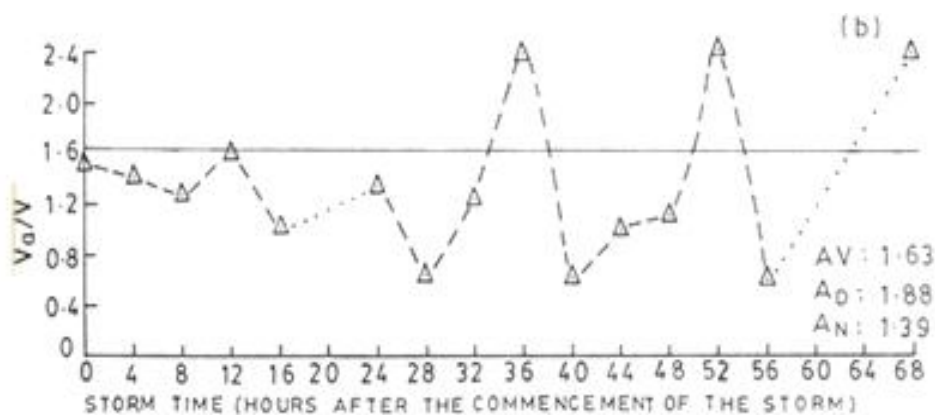


Fig. 3 (b) Storm time variation of Ratio [V_a/V]

5.1.3. Random velocity :

The variation of random velocity (V_c), which is a measure of irregular, motions within the amplitude pattern of the small scale irregularities, during magnetic storms is shown in fig. 4. It can be seen from the figure, that the random velocity shows a gradual increase with the progress of the storm. However, its value is quite

comparable with the control day value of the random velocity, indicating, no significant difference in the variation between the storm and control day values. It can be readily seen that during the initial period of the storm time, the random velocity is smaller than the control day values. Storm time values are higher during the latter period of the storm.

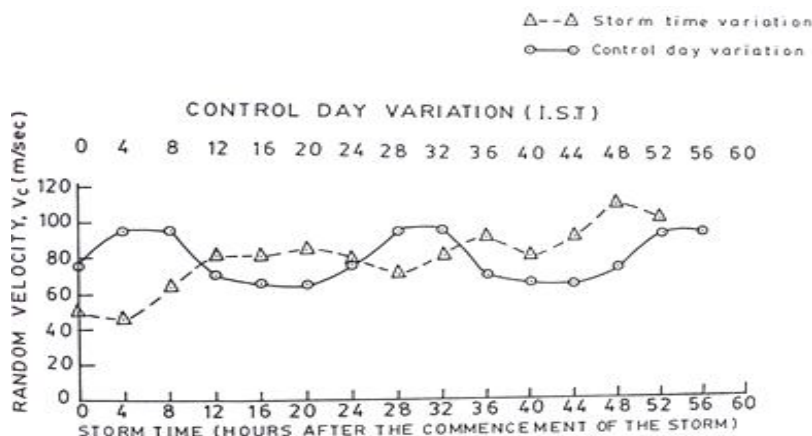


Fig. 4. Storm time variation of Random velocity [V_c]

5.1.4. True drift direction, ϕ (Deg. N. of E.):

The four hourly storm time variation of E region true drift direction is plotted in fig. 5. It can be seen from the figure that the true drift direction varies from westward direction at the commencement of the storm towards the southward direction gradually during the first 20 hours of the storm. The true drift direction again appears to gradually shift towards westward direction during the next 16 hours of the storm. This directional change from westwards to southwards can also be seen on control days; from fig. 5, perhaps this variation is associated with the diurnal variation of true direction. In order to find whether there is any variation in the % occurrence of the true drift direction on storm days with respect to control days, the percentage occurrence of true drift direction is plotted in the polar histogram (fig. 6a & b). There seems to be a change in the maximum percentage occurrence of in that, it is in the **SW** quadrant during quite days compared to **SE** quadrant during storm days. This shift can be indicative of the reversal of the electric field during storm time.

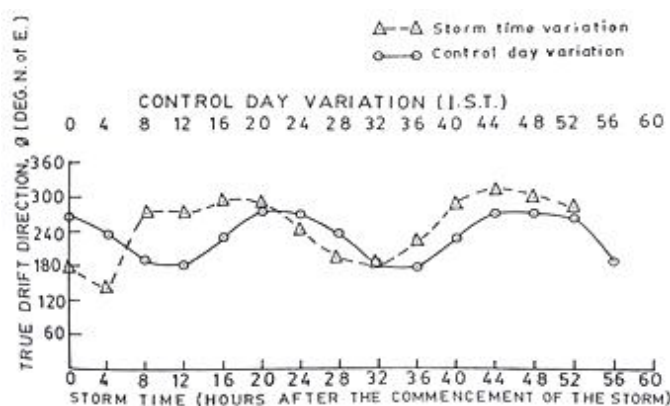


Fig. 5 Storm time variation of true drift direction [ϕ]

It can be seen from the figure that the true drift direction on storm days lie mostly in the range of $270^{\circ} - 330^{\circ}$ N of E. On control days, about 50% the true drift direction lies in the range of $210^{\circ} - 300^{\circ}$ N of E, indicating a slight change from south-east to south direction. There does not seem to be any significant change in the direction of apparent drift direction (ϕ_a) on storm days with respect to the direction on control days as seen from fig.7. (a&b).

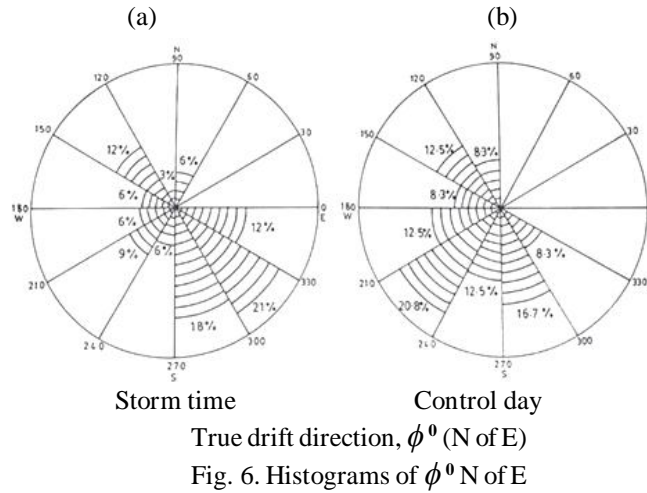


Fig. 6. Histograms of ϕ^0 N of E

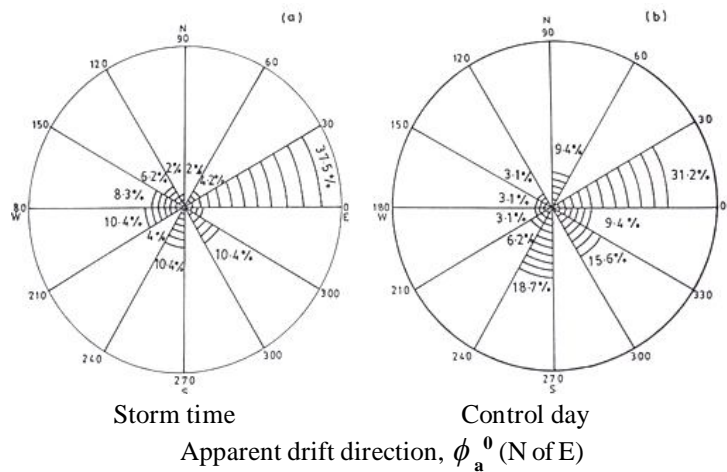


Fig. 7. Histograms of ϕ_a^0 N of E

5.2. Parameters of Ground Diffraction Pattern :

5.2.1. Size of the irregularities :

Fig. 8 describes the variation of the structure size, a , of the E region irregularities during magnetic storm. Also seen in the figure is the control day variation of a . It can be seen from the figure, that the size of the irregularities during storm time does not show significant variation during the progress of the storm. The diurnal variation that is seen on the control days with relatively larger value during night time compared to the day time does not seem to be apparent during storm time. However, the average value of a , calculated for the entire period ($a = 214$ m) appears to be significantly smaller compared to the control day value ($a = 278$ m), indicating a definite effect of the magnetic storm activity on the structure size of E region irregularities.

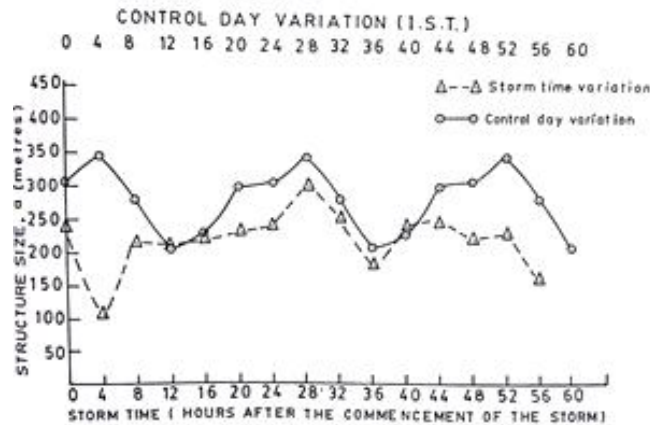
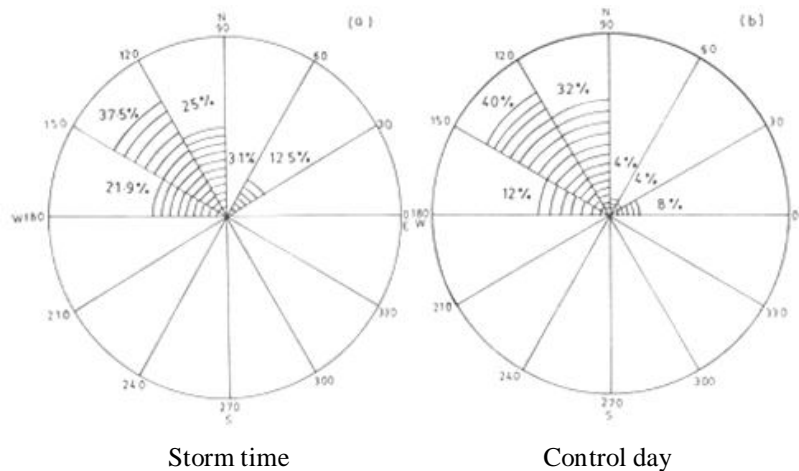


Fig. 8. Storm time variation of the size of the irregularities [a]

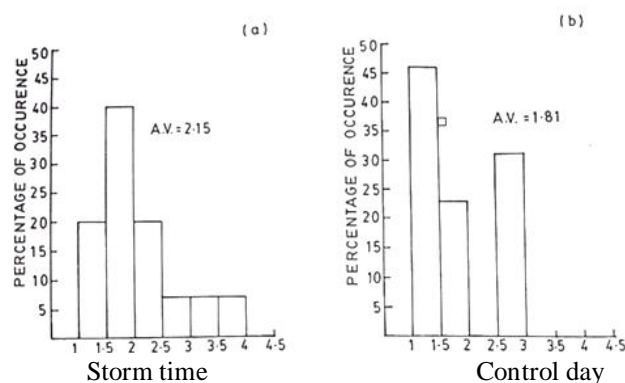
5.2.2. Orientation of the semi major axis, ψ^0 (N of E):

The orientation of the semi major axis, ψ lies mostly in the direction between $120^\circ - 150^\circ$, both during storm time as well as on control days, as can be seen from fig. 9 (a&b). As such, it can be concluded that the magnetic storm does not influence the orientation of the semi-major axis of the characteristic ellipse representing the small scale irregularities.

Orientation of the semi major axis, ψ^0 (N of E)Fig. 9. Histograms of ψ^0 (N of E)

5.2.3 Axial ratio, r

In fig. 10 (a&b), histograms of the percentage occurrence of the axial ratio r of the E region irregularities on storm days as well as on control days are presented respectively. It can be seen from the figures, while r is found to be mostly in the range of 1.5 to 2.0 on the storm days, it is on control days, mostly in the 1-1.5 range and 2.5 to 3.0 ranges. The average value on storm days shows a higher value (2.15) compared to the average value on the control days (1.81), indicating a slight elongation of the characteristic ellipse on storm days compared to control days.

Fig. 10. Histograms of axial ratio, r

The observed features of the drift and anisotropy parameters of E region irregularities presented above will now be discussed in the light of earlier investigations.

The present investigation essentially pertinent to the variation of drift and anisotropy parameters in the E-region during magnetic storms. So, these results could not be directly compared with other investigations made at Waltair or elsewhere, as those investigations were based on the studies of magnetic activity on drift and anisotropy parameters pertinent to different latitudes, seasons and solar activity periods. That is, these studies are based on either looking into the dependence of drift parameters on K_p index or the relative variation during magnetically quiet and disturbed days. Despite the above facts, the authors made an attempt to discuss the average variation of the drift parameters during storm days with earlier investigations of the variation of corresponding parameters with respect to magnetic activity. The present investigation revealed quite interesting variations in the E region drift parameters during geomagnetic storms. The E region drift speed was found to increase with the progress of the storm. Ratio of the apparent velocity to true drift velocity, during most of the storm time, in E region were noticed to be below the average value of the same on control days, indicating relative changes in the shapes of the ground diffraction patterns and also of the orientation of these patterns with respect to direction of movements, during storm and control day conditions. The same observation could be seen in the random velocity variation in E region irregularities, i.e. an increase in the average value with the progress of the storm while, no significant variation in the direction of the true drift velocity is noticed during storm time compared to control day.

The direction of the true drift in the confines to SE to SW directions. A significant decrease in the structure size (a), was noticed during storm conditions ($a=214$ m) compared to that on control days ($a=278$ m). The average value of the axial ratio r was found to be less during control days (1.81) compared to that on storm days (2.15). The orientation of the semi-major axis, ψ^0 (N of E) of the characteristic ellipse representing the irregularities, was found to be unaffected by magnetic storms. This interesting behavior might be attributed to the nature of variations in the E and F region electron densities, differences in the dynamical changes and ion-neutral coupling processes associated with magnetic storms. Jogullu²⁴, explained the opposite behavior of the drift parameters at low and high latitudes during disturbed conditions, in terms of changes in electron densities during magnetic storms. While the electron densities at low altitudes increase during storm conditions, at high latitudes electron density decreases. These changes must be related to storm time behavior of the ionosphere, in general, and to changes in the electron density in particular. For better understanding of the variations of the nature of the movement of the irregularities during geomagnetic storms, it is felt that a clear picture would emerge if a more detailed investigation by analyzing more storm time data together with electron density (Ionogram data) and categorizing each storm as positive or negative, depending upon increase or decrease in electron density respectively, associated with magnetic storms. The drift and anisotropy parameters are to be

studied separately during positive and negative storms respectively. Such a study perhaps would throw more light on some of the results reported above.

From the table 2, it is obvious that the average values of the parameters of the ionospheric irregularities during storm conditions obtained in the present investigation are consistent with the earlier investigations reported at Waltair and other stations under disturbed magnetic conditions.

Table 2. Earlier investigations reported at Waltair and other stations

S.No	Station	Period of study	Result	References
1.	Waltair	June.1957 to May.1959	E region drift speed increases with the increase of K index	Rao and Rao
2.	Waltair	1964-1965	True drift velocity (V) and random Velocity (Vc) show marked enhancement during disturbed conditions in the E region. The axial ratio (r) and the size of the irregularity (a) increases during the disturbed conditions	Jogulu and Rao
3.	Ahmedabad	1965-1966	E region apparent drift speed decreases With increase of magnetic activity. No significant change in the apparent drift direction with the change in the magnetic activity. True drift speed decreases with increase in Kp index. The axial ration increases with Kp index and Vc/V decreases with increase of Kp index.	Kaushika
4.	Tiruchirapalli	1978	E region midday apparent drift speed decreases significantly.	Vyas <i>et al.</i>
5.	Waltair	1964	V and V _a increases under disturbed conditions in the E region.	Rao and Rao
6.	Thumba	1964 and 1967-1968	E region drift speed decreases with increasing Kp index.	Rastogi <i>et al.</i>
7.	Patiala	1987-1990	1) Winter – E region drift speed increases with an increase in Kp index. 2) Summer and Equinox – E region drift speed decreases with the Kp index.	Darshan Singh and Gurm

6. Summary of results of our present study :

1. The true drift velocity, V during the storm period appears to be larger than the control day values, at least during the first 40 hours of the storm, and after that the true drift value appears to be reaching the control day average value of the true drift speed. The apparent drift velocity, a shows an oscillatory variation with increasing and decreasing values throughout the storm period. However, the ratio of V_a/V shows a gradual decrease during storm period, at least till the completion of initial and main phase of the storm.
2. The random velocity, V_c during the initial period of the storm is quiet less compared to the control day values. Storm time values shows higher values during the recovery phase of the storm.
3. The true drift direction, ϕ^0 (N of E) varies from westward direction at the commencement of the storm towards the southward direction gradually during the first 20 hours of the storm. After that ϕ shifts towards westward

direction during the next 16 hours of the storm. This directional change from westwards to southwards was also observed on control days. The true drift direction mostly lies in the range of $270^{\circ} - 330^{\circ}$ N of E on storm days, about 50% of the true drift direction lies in the range of $210^{\circ} - 300^{\circ}$ N of E on control days, indicating a slight change from south-east to south direction.

4. No significant variation is observed in the direction of apparent drift direction (ϕ_a) on the storm days with respect to the direction on control days.
5. No significant variation in the average value of the structure size (a) between the storm days and control days is found except towards the recovery phase of the storm (up to about 40 hours of the commencement of the storm) when the storm time value is much smaller than the control day value.
6. The orientation of the semi-major axis, ψ^0 (N of E) mostly lies in the range of $90^{\circ} - 150^{\circ}$ N of E, both on storm days as well as on control days, showing no significant change during storm days.
7. The average value of r on storm days is less during storm days compared to the control day average value.

7. Summary of results, Discussion and scope of future work :

A comparison of our present results with earlier studies at Waltair and at other stations distributed over various latitudes revealed that there is considerable influence of geomagnetic activity on the characteristics of drift and anisotropy parameters of small scale irregularities. These results indicate that the behavior of the ionosphere during magnetically disturbed conditions depend on the time of the day, latitude and intensity of the magnetic activity. This probably account for the differences in the variation of irregularity characteristics observed at various places all over the world. While magnetic activity studies give an average picture of the dependence of the irregularity parameters, our study revealed the importance of studying the behaviour of ionospheric irregularities during different phases of the geomagnetic storm, i.e. during the commencement (1 to 4 hours), maximum phase (next 12 to 20 hours) and recovery phase (next 24 -36 hours). An understanding of storm-time distribution of energy and how different regions of terrestrial atmospheres are coupled together. For this, a more coordinated approach by taking simultaneous observations of ionospheric irregularities at various stations located at different latitudes and longitudes and during specific geomagnetic storms are required. It is proposed to undertake such a study in the near future.

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