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Study of Ionospheric Irregularities in the F-Region During Geomagnetic Storms

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I. Introduction

The Ionospheric disturbances associated with magnetic storms have been recognized and studied by many works all over the globe during the last 6 decades. Several mechanisms that are identified playing dominant role during magnetic storms include, heating of the neutral and ionized constituents of the ionosphere(Yonezawa,1963;Thomas and Norton, 1966),changes in the neutral composition (Seaton, 1958; King, 1962, 1966; Duncaul, 1969; Chandra and Habon,1969), movements of ionization into the magnetosphere(Balmer and Krishna Murthy,1968) and most importantly by electrodynamic movements of ionization (Martyn, 1953; Maeda and Sato,1959). According to Martyn's theory, the movements In F_2 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. In the following, a brief review of the studies on the effect of geomagnetic activity on drifts and anisotropy parameters is given.

Fooks (1961) 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 Jones (1961).All the results were presented together, as 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 ration 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.

A considerable increase in the magnitude of drift velocity was observed during storm conditions by Checha and Zelenkov (1959) at Tomsk (56^{0}38^{1}N., 84^{0}58^{1}E) in F region. An increase in drift speed was observed only after K=4 in the case of E-region by Chapman (1953) at Ottawa (45.4^0 N.,75.9^0 W) while a steady increase in the drift speed with K index from 0 to 5 was obtained by him in the case of F-region. Briggs and Spencer (1954) found that the drift speed for F region increases with K index for K>4 with little variation was found for values of K less than 4.

From a study of radio star scintillations at Jodrell Bank (53.2^{0}N., 2.3^{0}W), Maxwell and Little (1952), Maxwell (1955), Maxwell and Dagg (1954) and Dagg (1957) reported a systematic increase of the F_2 region drift at 500 km level with the K index, the increase being more rapid from K=3.

At Yamagawa (31.2^0 N.,130.6^0 E), a mid latitude station, Rao and Rao (1964) 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. For instance, at Waltair (17.7^0 N.,83.3^0 E) Rao and Rao(1964) found an increase in the F-region drift speed with magnetic activity, but a decrease with K_p index was noticed by Rao and Rao(1961) and this inconsistency was attributed to the differences in solar epoch.

Skinner et al.(1963) and later Rastogi et al.(1971),have found negative correlation between E and F region K_p index at Ibadan(3^{0}S) and at Thumba(0.3^{0}S) respectively. Later, Vyas (1980) reported negative correlation for another equatorial station, Tiruchirapalli (10^{0}49^{1}N., 78^{0}42^1 E). Patel(1982) studied the effect of

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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 35^0 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. (1974) 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 both E and F regions, 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.field (Rastogi et al., 1971). The other main conclusions reported by Rastogi et al.are 1) a decrease in the axial ratio during disturbed days in both E and F regions 2) irregularities are mainly field aligned, except E region irregularities during disturbed days aligned $\pm 30^0$ NS direction and 3) decrease in the semi minor axis during disturbed days.

Sardesai et al. (1982) found a negative correlation between apparent drift speed and K_p index in case of both daytime E-region and night time F-region, at Udaipur (Geomag.lat.14^0 55^1 N).The EW component of apparent drift velocity which is normally eastward in night time F region was found to be reduced with the increase of geomagnetic activity. 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 Rao (1964) at Waltair obtained slightly higher values under disturbed conditions for Va and V in E and F regions. In the E region, Rao and Rao (1966) found a positive correlation between apparent drift speed and K_p index.

Most of the studies 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 example, the E region drift speeds at Waltair (Rao et al., 1959) appear to increase with K_p index, while at Udaipur (Rai et al., 1982) a negative correlation was found between the apparent drift speed and K_p index. The F region drift speed at Waltair (Rao et al.,1958) showed an increase with K_p index initially but decreased under enhanced geomagnetic activity. Also, 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 Viz., 1959 and Chandra and Rastogi, 1974. Mitra and Viz found no significant change in the magnitude of the drift velocity during large magneti storms at Delhi(28^0 35^1 N.,77^0 5^1 E). Chandra and Rastogi, noticed daytime counter electrojet events during geomagnetic storms indicating an eastward electron drift and Esq. disappearance.

In view of the above considerations, in this paper, the author has made an attempt to study the variation of the horizontal drift and anisotropy parameters of the F-region ionospheric irregularities during 6 geomagnetic storms to gain a better insight into the influence of geomagnetic activity on drift and other irregularity parameters.

II. Data and Method of Analysis

a) Principle of D_1 technique of measuring drift and anisotropy parameters of the ionospheric irregularities

This method originally proposed independently by Mitra (1949) and Krautkramer (1950) 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.

Figure 1 depicts the configuration of the three receiving aerials, which are horizontal dipoles. They are oriented along the EW direction, placed at a height of 12' above the ground and are situated at the 3 corners of a right angled triangle. The arm length was 140 m in EW and NS directions.

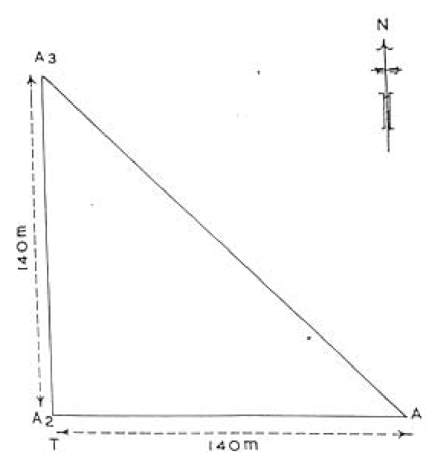


Figure 1: Relative disposition of the aerials

b) Scaling of amplitude fading records

Typical spaced aerial fading records for the F region is shown in Figure 2. In the present investigation 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.

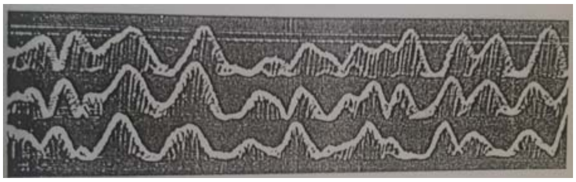


Figure 2: Typical fading record of drift in F region

c) Criteria for the selection of 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.

F region spaced antenna drift records taken on frequency 5.6 MHz during the period September 1983-May 1984 at Waltair are used in the present investigation. 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. Continuous drift records were available for 6 storms at Waltair. 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.

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 analysis(Briggs, Phillips and Shin, 1955). 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 300 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 ∑Kp
			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*

III. Results

a) Drift parameters

i. *True drift velocity*

Figure 3 Shows the 4 hourly average storm time variation of the true drift velocity for 3 consecutive days following the commencement of the storm. It can be seen from the figure that the true drift velocity appears to decrease gradually with the progress of the storm. The increase noticed after 24 hours of the commencement of the storm may, perhaps be associated with the diurnal variation of the true drift velocity.

Also shown in Figure 3 is the 4 hourly average of the control day variation (continuous line) of the true drift velocity. This variation is plotted with respect to local time(IST) and the comparison could only be made with the overall average values, instead of individual 4 hourly values, as the time scales being different. The control day variation shown in the figure is repeated for the three storm days to make the comparison easy. As can be seen from the figure, the true drift velocity during the entire storm period is smaller than the average value of the control day true drift velocity at any hour, indicating a slight but definite decrease in the storm time value of the true drift velocity.

Average $\sum K_p$ values (average of all the six storms) indicated in the Figure 3 are mostly found to be maximum on the 2nd day of the storm, i.e., about 20 hours after the commencement of the storm. The gradual decrease in the true drift velocity during storm days does seem to be affected by day to day $\sum K_p$ variation.

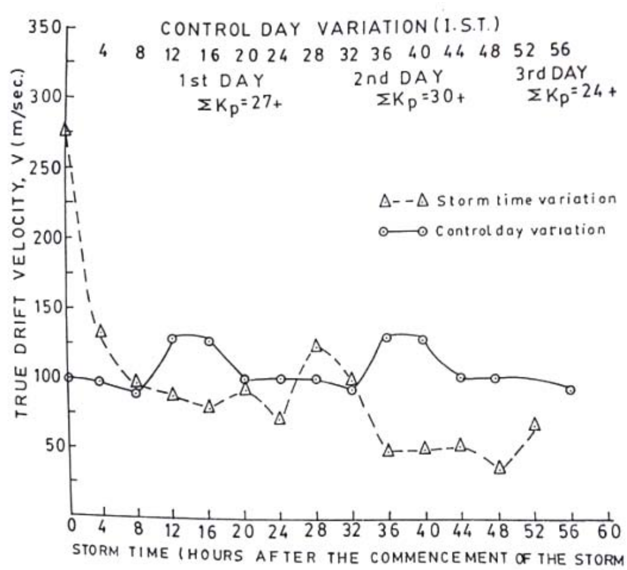


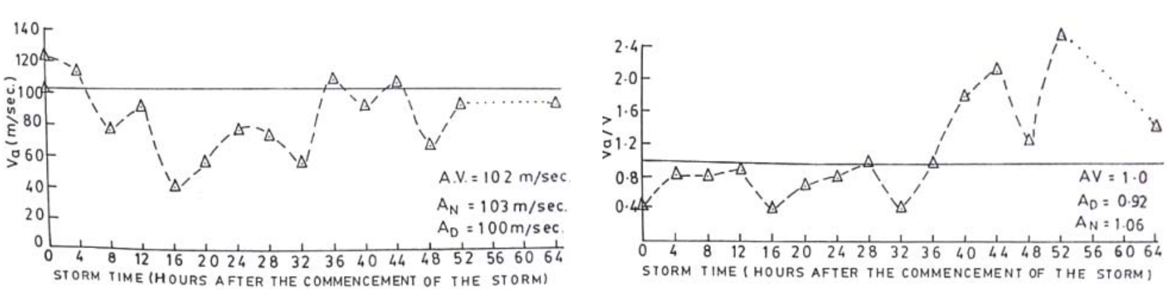
Figure 3: Storm time variation of true drift velocity [v]

ii. *Apparent velocity*

The apparent velocity of small scale irregularities could be identified with the velocity obtained by Mitra's similar fades method of analysis. The ratio of Va/V of the apparent to true drift velocity obtained by correlation method of analysis gives the relative departure of the apparent velocity from the true drift velocity of the irregularities. Hence, the variation of apparent velocity and apparent direction during geomagnetic storm are also studied. Figure 4 (a) & (b) depict the variation of the 4 hourly average value of the apparent velocity and the ratio of Va/V during the geomagnetic storm.

The line that was drawn parallel to the time axis in Figure 4 (a) is the average value of the apparent velocity on the control days. The day and night time average values of the apparent velocity on control days are also indicated in the fig. It can be seen from the Figure 4 (a) that most of the time during the storm the apparent velocity is much below the average value on the control days, indicating a decrease in the apparent velocity on storm days.

The ratio of Va/V during storm as seen from Figure 4 (a) to be also quiet less during the first 32 hours of the storm and after 36 hours of the storm the ratio of Va/V is observed to be of quiet a large value.



(a) (b)

Figure 4: Storm time variation of (a) Apparent drift velocity [Va] and (b) Ratio [Va/V]

iii. *Random velocity*

The variation in the 4 hourly average values of the random velocity (Vc) during geomagnetic storm as well as the control day variation is shown in Figure 5.It can be seen from the figure that the random velocity increases as the storm progressed, reaching quite large values after about 16 hours of the commencement of the storm. As can be seen from the figure, that the random velocity, during the storm time appears to be larger when compared to its value on control days, at least, till about 40 hrs of the commencement of the storm. From then onwards, the random velocity falls gradually below the control day average value. The trend of diurnal variation in the random velocity on control days seems to be quite apparent even on storm days.

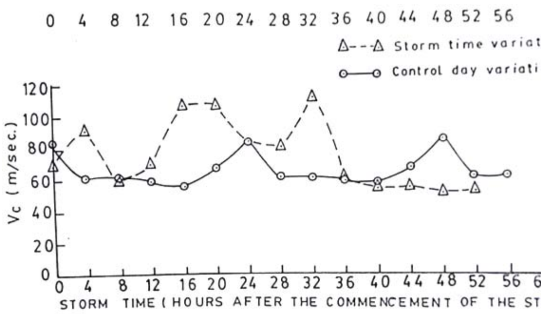


Figure 5: Storm time variation of random velocity [Vc]

iv. *True drift direction,∅ (Deg.N.of E)*

Figure 6 depicts the storm time variation in the true drift direction of the F-region irregularities. The true drift direction can be seen to be changing from about 251222^0 N of E during the first 24 hrs of the storm period, i.e., from southwards to northwards. It again retraced its direction to about 256^0 N of E in the next 24 hrs of the storm period, before changing again towards northward direction. The diurnal variation trend that is seen during the storm period in the true drift direction can also be seen in the control day variation of the true drift direction. It can be seen from the Figure 7 that while there is a broad maximum for the direction ∅ during control days, the polar histogram shows a maximum in the north of N-E quadrant and may perhaps be taken as indicative of the reversal of electric field during storm time.

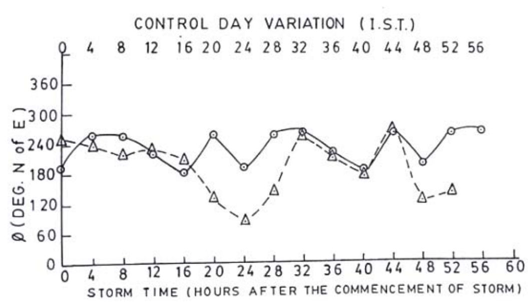
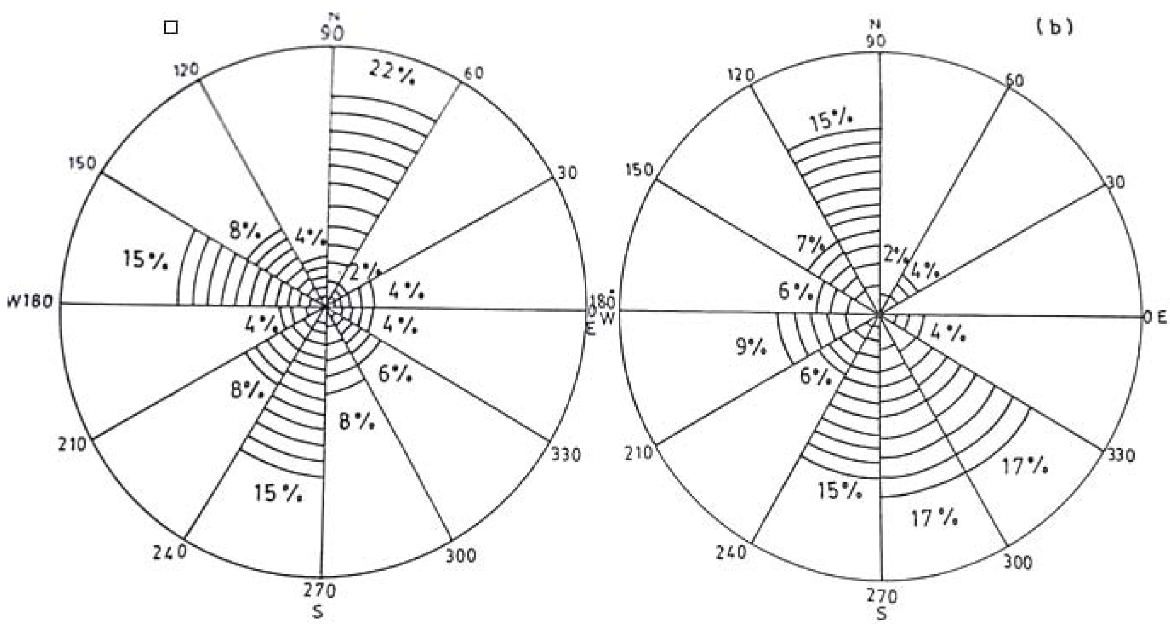


Figure 6: Storm time variation of true drift direction [∅]

It can be seen from Figure 7 (a) that the percentage distribution of the direction of true drift on storm days is not indicating any preferential direction, but has a tendency to orient in the NS direction. The true drift direction can be seen to be about 22% in the 60^0 – 90^0 N of E and about 15% in the 150^0 – 180^0 and 240^0 – 270^0 N of E. The control day distribution (Figure 7(b) of the direction of the true drift also does not show any preferential direction except that nearly 50% of the values lie in the range 240^0 – 330^0 N of E indicating again a preferential NS direction. It can also infer from the two figures that there does not seem to be significant effect of geomagnetic storms on the true drift direction in the F region of the ionosphere.

To bring out the difference, if any, between the variation in true drift direction with respect to apparent drift direction during geomagnetic storms the % distribution of, $\emptyset_a$ the apparent drift direction. The apparent drift direction is plotted in Figure 8 (a and b) showed a preferential direction both during storm days [Figure 8 (a)] and control days [Figure 8 (b)], in that the direction is more preferably in the eastward direction (0^0 – 30^0 N of E).A comparison of the apparent drift direction with the true drift direction reveals (Figure 7a and 7b) that while the apparent drift direction shows a preferential EW, the true drift direction shows a preferential NS direction.

(a) (b)

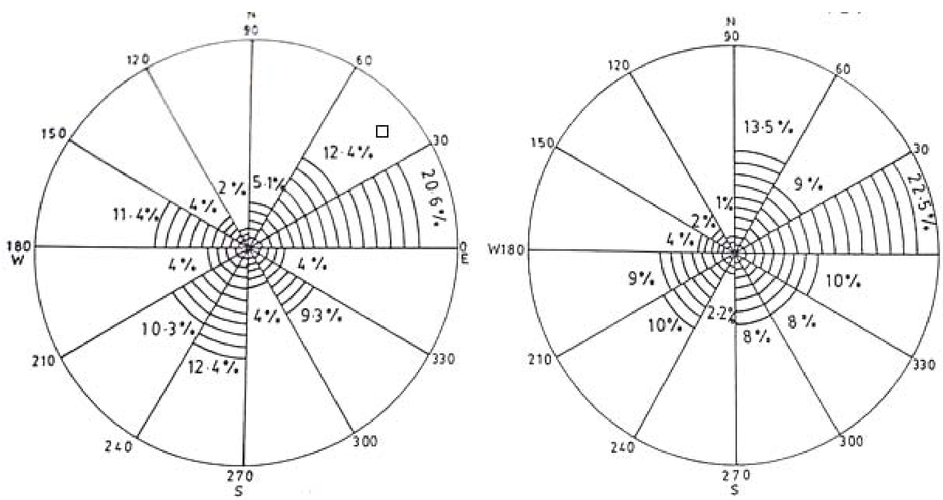


Storm time Control day

True drift direction, ϕ^0 (N of E)

Figure 7: Histograms of ϕ^0 N of E for F-Region

(a) (b)



Storm time Control day

Apparent drift direction, ϕ_a^0 (N of E)

Figure 8: Histograms of ϕ_a^0 N of E for F-Region

b) *Parameters of ground diffraction pattern*

i. *Size of the irregularities, a*

Figure 9 shows the average storm time variation of the size of the F region irregularities. The structure size a can be seen to be varying between a maximum value of 470 m to a minimum value of 125 m. Average control day variation of the structure size can also be seen to be varying between 325 m and 150 m. There seems to be significant diurnal variation in the average values of structure size on control days with higher values during night time hours and lower values during day time. Similar features can be seen in the average storm time variation of the structure size between as well. As can be noticed from the figure, no significant variation in the average value of the structure size 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) wherein the storm time average value is much smaller than the control day value.

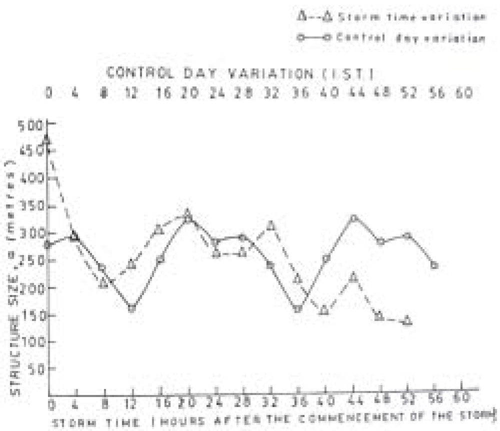
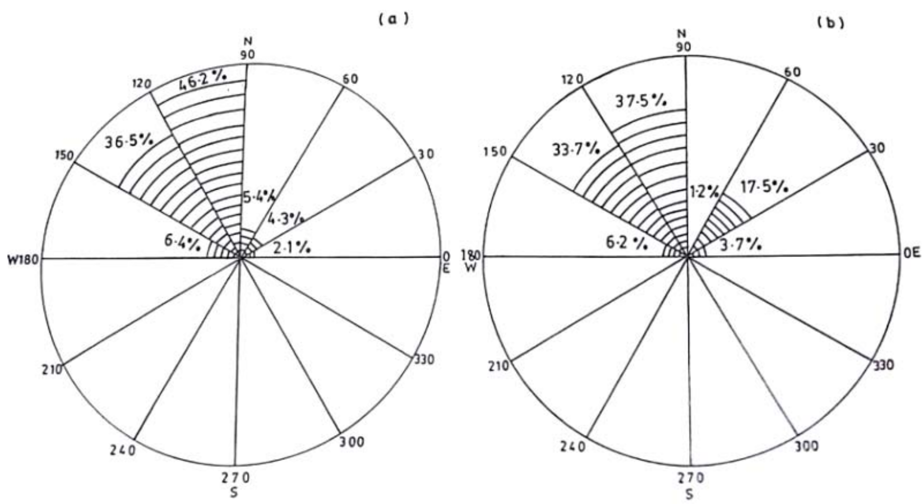


Figure 9: Storm time variation of the size of the irregularities [a]

ii. *Orientation of the semi major axis,* ψ^0*(N of E)*

The orientation of the semi major axis, ψ, of the characteristic ellipse both during storm time as well as on the control day is plotted in Figure 10. It can be seen from the polar histogram, that ψ mostly lies in the range of $90^0 - 150^0$ N of E, both on storm days as well as on control days, indicating no significant change during storm days.



Storm time

Control day

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

Figure 10: Histograms of ψ^0 (N of E) for F-Region

iii. *Axial ratio, r*

With a view to see whether there is any change in the axial ratio, r, of the characteristic ellipse of F region irregularities on storm days, the percentage occurrence of r is plotted in Figure 11. The percentage occurrence of r on control days is also shown in Figure 11(b) for comparison. It can be seen from the figures, while on storm days, the value lies in the range 2 to 2.5 on control days r lies in the range of 1.5 to 2.0. However, the average value of r appears to be less during storm days compared to the control day average value.

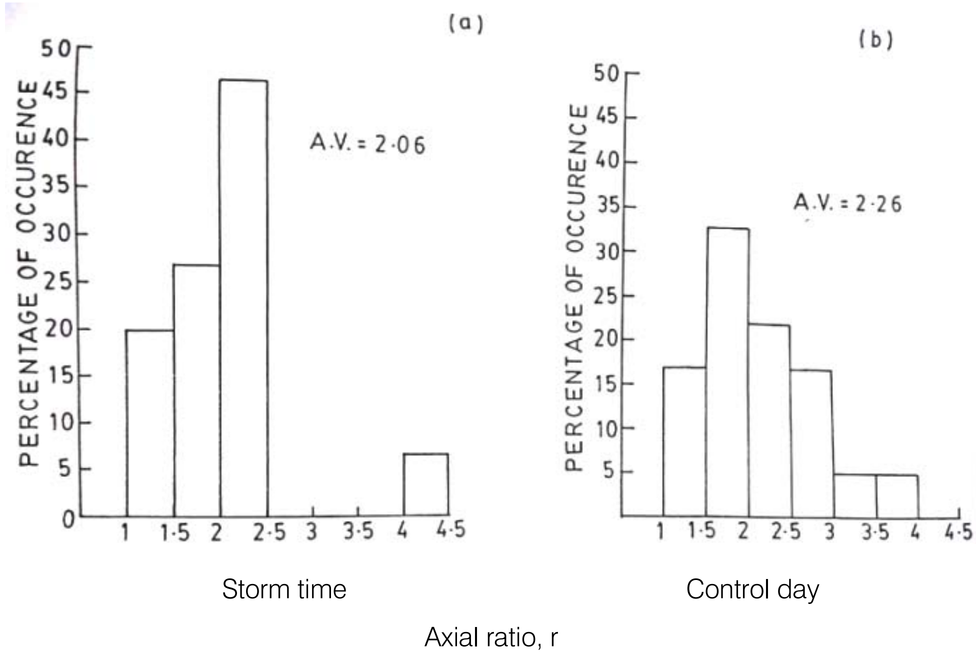


Figure 11: Histograms of axial ratio, r for F-Region

IV. Discussion

The present investigation essentially pertains to the variation of drift and anisotropy parameters during magnetic storms. As such 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. 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. However, an attempt has been made 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 F region drift parameters during geomagnetic storms. While the F region true drift velocity showed a decreasing trend with the progress of the storm, ratio of the apparent velocity to true drift velocity, during most of the storm time, in F region were noticed to be below the average value of the same on control days, indicating relative changes in the shape 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 the F 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 in the F region during storm time compared to control day. The direction of the true drift in the F region confines to northward and southward directions.

The present study revealed that practically there is no change in the average value of the structure size(a) of the irregularities in F region during storm time. Also, it is noticed that while the average value of r the axial ratio, in the case of F region on control days (r=2.26) was more than the average value on storm days(r=2.06). The orientation of the semi-major axis, ψ^0 (N of E) of the characteristic ellipse representing the irregularities, in the F region was found to be unaffected by magnetic storms.

An overview of the above results reveal that the effect of geomagnetic storms on the drift and anisotropy parameters of small scale irregularities might be attributed to the nature of variations in the F region electron densities, differences in the dynamical changes and ion-neutral coupling processes associated with magnetic storms. The decrease in the F region true drift velocity during disturbed days has been explained (Darshan Singh and Gurm, 1994) as due to increased electron densities, particularly at low latitudes, during magnetic storms. Jogulu and Rao (1970) 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.

It is believed that these changes must be related to storm time behavior of the ionosphere, in general, and to changes in the electron density in particular. However, 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 through more light some of the results reported above.

A perusal of the Table 2 reveals that the average value of the drift and anisotropy parameters during storm conditions obtained in the present investigations are in general consistent with the earlier investigations reported at Waltair under disturbed magnetic conditions.

Table 2

S.No	Station	Period of study	Result	References
1.	Waltair	Feb 1956 to Dec 1958	Drift speed in F_2 region decreases with increase of K index	Rao et all.
2.	Waltair	1964-1965	True drift velocity decreases during the disturbed conditions in the F region. No appreciable change in the case of r and a in the disturbed conditions	Jogulu and Rao
3.	Thumba	1964 and 1967-1968	Drift speed decreases increasing Kp index in the F region	Rastogi et all.
4.	Cambridge	-	Drift speed increases with the increase of magnetic activity in the F_2 region	Briggs and Spencer

V. Conclusions

The following conclusions are arrived at from a study of the Geomagnetic storm effects on drift and anisotropy parameters at Waltair.

1. The true drift velocity during the entire storm period is found to be smaller than the average value of the control day true drift velocity. The apparent velocity, Va during storm time is much below the average value on the control days. The ratio Va/V during storm time is quite less during the first 32 hours of the storm.
2. The random velocity, Vc during storm time is comparatively more than that observed on control days, at least for about 40 hours after the commencement of the storm.
3. The true drift direction is changing from about 252^0 N of E to about 86^0 N of E during the first 24 hours of the storm period i.e., from southwards to northwards and retraces its direction to about 256^0 N of E in the next 24 hours of the storm period, before changing again towards northward direction. The percentage distribution of the true drift direction on storm days does not show any preferential direction but has a tendency to orient in the NS direction. The control day distribution of the true drift direction also does not show any preferential direction except that nearly 50% of the values lie in the range 240^0 – 330^0 N of E indicating again a preferential NS direction.
4. The apparent drift direction showed a preferential direction both during storm days and control days in the eastward direction. A comparison of the apparent drift direction with the true drift direction reveals that while the apparent drift direction shows a preferential EW, the true drift direction shows a preferential NS direction.
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), where the storm time average value is found to be smaller than the control day value.
6. The orientation of the semi-major axis, ψ mostly lies in the range of 90^0 – 150^0 N of E,both on storm days as well as on control days, indicating no significant change during storm days.
7. The average value of the axial ratio, r is found to be less during storm days compared to the control day average value.

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