The morphology of Great Geomagnetic Storms recorded at Alibag for the period 1905 to 1945 : Part II—The Disturbance local time inequality, *DS* and the disturbance daily variation, *SD*

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ABSTRACT. In continuation of results of storm-time disturbance variations $D_{st}(H, E, Z)$ presented in Part I of the paper, the characteristics of disturbance daily variation, *SD*, and the disturbance local time inequality, *DS*, in the magnetic elements *H*, *E* and *Z*, as derived from 74 great sudden commencement storms recorded at Alibag during the period 1905 to 1945 are examined and discussed here. The *DS* (*H*) and *SD* (*H*) predominate over those in the elements *E* and *Z*. The magnitude of *DS*(*H*) during the main phase of the storm is large and decreases rapidly during the recovery phase. The phase angle of the first harmonic of *DS*(*H*) increases systematically with storm-time, especially during the first five 6-hour intervals of storm-time. The *DS* and *SD* variations for Alibag compare well with those for Honolulu and Zikawei given by Sugiura and Chapman, while the first harmonic of *DS* for Huancayo appears to be enhanced in a small measure. The *SD* variations are similar in magnitude and phase to those derived by Moos for Colaba (Bombay) for the period 1872 to 1904. The storm-time courses of D_{st} (*H*) and *DS*(*H*) for Alibag are about parallel to each other with a tendency for the minimum in *DS*(*H*) to be reached earlier than that of D_{st} (*H*) and their decay rates are about the same especially towards the later stages of their courses. Two decay rates are, however, noticed in the recovery phase of the average great storm. The decay rate of the earlier portion of the recovery phase is more rapid than that of the later portion, indicating the probability of two ring currents being associated with geomagnetic storms.

1. Introduction

In Part I of this paper (Yacob and Sastri 1965) the average storm-time disturbance variation (D_{st}) of 74 great storms, recorded at Alibag Magnetic Observatory during the period 1905 to 1945, has been given. Here the mean disturbance local time inequality (*DS*), for different intervals of storm-time and the mean disturbance daily variation (*SD*) for each of three local storm-days are presented. The great storms taken for analysis are the same 74 as listed in Part I for the derivation of the average D_{st} and are the same as those selected for analysis by Sugiura and Chapman (1958). The following elaboration will serve to clearly define D_{st} and *SD* and distinguish between *DS* and *SD*.

The magnetic storm field, *D*, at any station is both a function of storm-time (time reckoned from the hour of storm commencement; the hour during which the storm commences is termed 0^h storm-time) and a function of local time of the station. When a large number, *N*, of storms, whose commencement times are evenly distributed over the local day of the station, are considered and the hourly magnitudes of *D* for each storm are arranged according to storm-time and averaged for the *N* storms, the part of *D* at each hour of storm-time, *i.e.*, a function of local time, will be mostly averaged out. The mean hourly disturbance magnitudes so obtained constitute the type of disturbance variation, *i.e.*, a function of storm-time only. This is termed the storm-time disturbance variation, D_{st}, which has been derived in Part I of the paper for an average great storm at Alibag. On the other hand, when the hourly magnitudes of *D* of a storm-day are arranged according to the local time of the station and the mean for each local hour is taken for the *N* storms (*i.e.*, for *N* storm-days), the mean magnitude of D_{st} associated with the mean magnitude of *D* at each hour will be about the same. When, therefore, the average of the 24 mean hourly magnitudes of *D* is removed from each hour, the 24-hourly inequalities so obtained will constitute the type of disturbance variation, *i.e.*, a function of local time. This is termed the disturbance daily variation, *SD*.

Usually *SD* is obtained without particular reference to commencement time of storms, using the five international disturbed GMT days of each month. Moos (1910) was the first to make a departure and derive *SD* from specific storms, using the first 24-hourly values from the commencement of storms. He derived *SD* (*H*) (*SD* for the magnetic element *H*) from 113 sudden commencement storms of all intensities, recorded at Colaba (Bombay) during the period 1872 to 1904 and also from 134 great storms of both sudden commencement and gradual commencement types. For the group of 134 great storms he also derived *SD* for the magnetic elements *D* and *Z*. His results will be referred to later.

Chapman (1952) realised that the part of *D* which is a function of local time is not entirely independent of storm-time. He derived the disturbance daily variation for shorter intervals of storm-time than 24 hours, named it disturbance local time inequality and gave it the symbol *DS*. *DS* is essentially the same as *SD*, with the difference that the derivation of the former is based on short intervals of storm-time, while that of the latter is based on 24 hours of storm-time. The average of *DS* over 24 hours with respect to storm-time is *SD*. If, for instance, *DS* is derived for 6-hour intervals of storm-time, the average of the first four *DS*'s will constitute *SD* for the first day of storm and similarly the average of the next four *DS*'s will give *SD* for the second day of storm and so on. *DS* may be derived for any interval of storm-time, even for a particular hour of storm-time. *DS* is useful for studying the amplitude and phase of the disturbance daily variation at different phases of the average storm. Both *DS* and *SD* are functions of cyclic local-time hours and, therefore, they may be harmonically analysed with the fundamental mode having a period of 24 hours. Chapman (1952) first obtained *DS* variations and their harmonic components for four consecutive half-days of storm from 40 moderate storms and showed that the amplitude of *DS* (*H*) was greatest for the first half-day and steadily diminished from each half-day to the next, while the phase steadily increased. *DS* (*E*) and *DS* (*Z*) were also found to show similar changes.

Sugiura and Chapman (1956, 1957, 1958), in a series of studies, have derived *DS* (*H, E, Z*) for different intervals of storm-time as well as *SD* for each of three days of storm. These disturbance variations have been determined for an average weak storm, an average moderate storm and an average great storm for different latitudinal group of stations. Their method of analysis has been followed here, as in Part I of the paper, to derive for the case of an average great storm at Alibag the mean *DS* for quarter-day intervals of storm-time for the first two days of storm and one-third day intervals of storm-time for the third day of storm. *SD* for each of the three days of storm is determined by averaging the *DS* of the different storm-time intervals of the relevant storm-day.

2. Method of analysis

The method adopted in this investigation is exactly the same as that employed by Sugiura and Chapman (1955) and is briefly outlined here, as a continuation of the method of analysis given in Part I for the derivation of D_{st}. There it is stated that for the storm S_n we have the sequence of residuals $d_{n\,(-4)}, d_{n\,(-3)}, d_{n\,(-2)}, 0, d_{n\,0}, d_{n\,1}, d_{n\,2}, \ldots\ldots\ldots\ldots\; d_{n\,71}$, corresponding to -4^h to 71^h storm-time. The sequence of residuals $d_{n\,0}, d_{n\,1} \ldots\ldots d_{n\,71}$ for the storm S_n is divided into quarter-day intervals for the first two storm days and into one-third-day intervals for the third day of storm and the intervals are labelled 1, 2, 3, ... 11.

For each of the intervals 1, 2, 3, ... 11, a table is formed containing 24 columns corresponding to $0^h - 23^h$ local-time and 74 rows, corresponding to the total number of storms used in this analysis, to which the residuals in each interval are transcribed and arranged according to the corresponding local times. In the case of interval 1 for *H* a departure is made from this straightforward transcription. In this case

$$\frac{1}{N} \sum_{n=1}^{N} d_{nh}$$

is subtracted from each of the residuals d_{nh} ($h=0, \ldots\ldots\; 5$) and only the remainder is entered in the table. This is done because initially D_{st} (*H*) on the basis of hour to hour differences changes rapidly with a reversal in sign.

For each table the columnar means are formed and 24 such means are obtained and are denoted by $u_0, u_1, u_2, \ldots\ldots\; u_{23}$, the subscripts referring to local hours. The mean, $\bar{u}$ of these 24 u's represents the mean linear change per hour averaged over the particular interval of storm-time. Each of the values $u_0, u_1, u_2 \ldots\ldots\; u_{23}$ is then freed of this mean linear change by subtraction to give the mean local time disturbance magnitude on an hour to hour difference basis, for the interval concerned, *i.e.*, $u_0'\,(=u_0-\bar{u})$, $u_1'\,(=u_1-\bar{u})$, ... $u_{23}'\,(=u_{23}-\bar{u})$. These values are cumulatively summed to give the actual mean local time disturbance magnitudes, $v_0\,(=u_0')$, $v_1(=u_0'+u_1'), \ldots\ldots v_{23}\,(=u_0'+u_1'+\ldots+u_{23}')$. The hourly inequalities formed after subtracting the mean, $\bar{v}$ of the 24 values $v_0, v_1, \ldots\ldots\ldots\; v_{23}$ from each of these hourly values constitute the mean disturbance local time inequality, *DS*, for the particular interval of storm-time, for the *N* number of storms and for the station considered.

In this way 11 sets of *DS* are obtained for each of the elements *H*, *D* and *Z* for the eight quarter-day intervals of the first two days of storm and for the three one-third day intervals of the third day. The *DS* variations for the four intervals 1, 2, 3 and 4 are then averaged to give the disturbance daily variation SD^1 for the first day of the storm. Similarly SD^2 and SD^3 for the second and third days of storm are determined by averaging *DS* variations for storm-time intervals 5, 6, 7 and 8 and 9, 10 and 11 respectively.

The mean *DS* variation for each interval and each of the elements *H*, *D* and *Z* are analysed

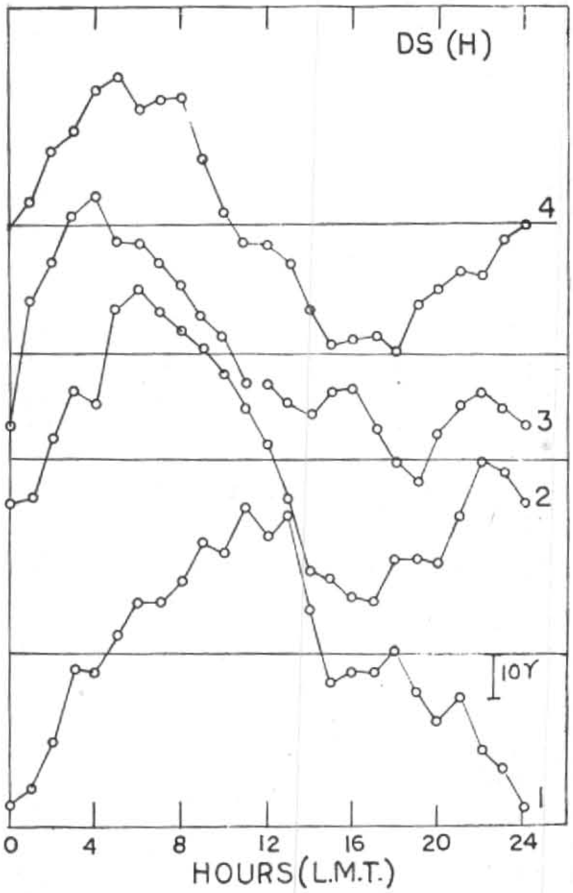

Fig. 1(a). *DS* **in the horizontal force** *H*, **for the storm-time intervals** $0^h - 5^h(1), 6^h - 11^h$ (2), $12^h - 17^h$ (3), $18^h - 23^h$(4), **for the average great storm at Alipore.**

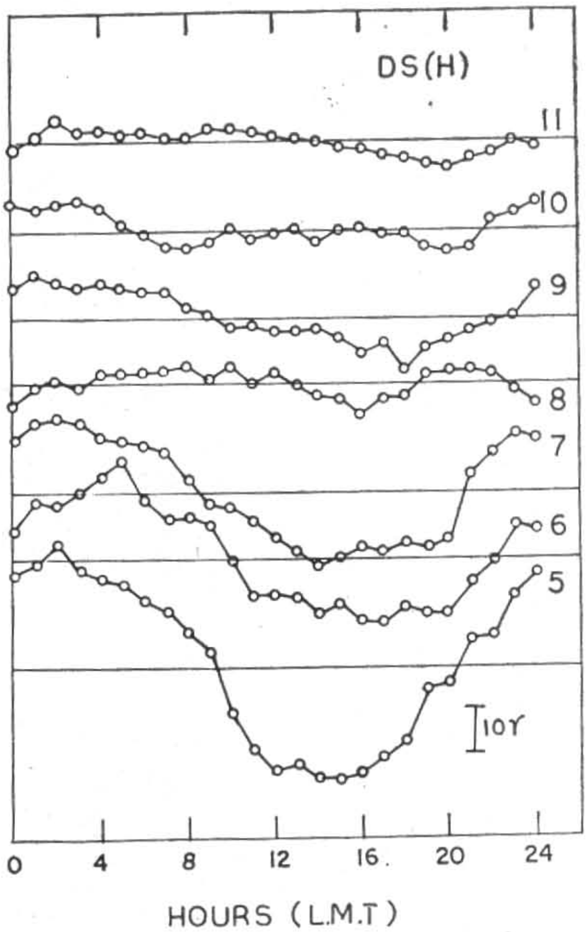

Fig. 1(b). *DS* **in the horizontal force** *H*, **for the storm-time intervals** $24^h - 29^h$ (5), $30^h - 35^h$ (6), $36^h - 41^h$ (7), $42^h - 47^h$ (8), $48^h - 55^h$ (9), $56^h - 63^h$ (10), $64^h - 71^h$ (11), **for the average great storm at Alibag.**

harmonically and expressed as

$$\sum_{n=1}^{4} (a_n \cos n\lambda + b_n \sin n\lambda)$$

$$\text{or} \quad \sum_{n=1}^{4} C_n \sin (n\lambda + \phi_n)$$

where C_n [$C_n = \sqrt{(a_n^2 + b_n^2)}$] is the amplitude in γ and ϕ_n the phase angle in degrees, of the nth harmonic. λ is reckoned at the rate of 15 degrees per hour from local midnight. Similarly the mean *SD* variations for each of the three storm days are also analysed harmonically.

3. Results and Discussion

The mean disturbance local time inequality DS^n (H), DS^n (E) and DS^n (Z), (n=1, ... 11), for Alibag as derived from 74 great storms recorded during the period 1905 to 1945 are shown in Figs. 1 (a and b), 2 and 3 respectively. The disturbance daily variation SD^n (H), SD^n (E) and SD^n (Z), (n=first, second and third day of storm) are given in Figs. 4, 5 and 6 respectively. The quite-day variation S_q (H), S_q (E) and S_q (Z) at Alibag for the months in which the storms occurred have also been given in Figs. 4, 5 and 6. For comparison the curves of *SD* and S_q for geomag. lat. -1° (Huancayo) and for geomagnetic latitude 21° (mean of Honolulu and Zikawei) have been reproduced in the above figures from the results of Sugiura and Chapman (1958). The hourly magnitudes of the variations *DS* for the eleven intervals of storm-time and of the variations *SD* for the three storm days have been given as an appendix to the paper.

DS variations

It is immediately seen that variations in *DS* (H) are much larger compared with *DS* (E) or *DS* (Z) at Alibag. The maximum range in *DS* (H) is of the order of 140γ, while for *DS* (E) or *DS* (Z) it is hardly 30γ. Another striking feature is the prominent regularity in the *DS* (H) variations especially for the intervals 1 to 7. Some semblance of regularity of variations in *DS* (E) and *DS* (Z) is seen only for the intervals 3 to 7.

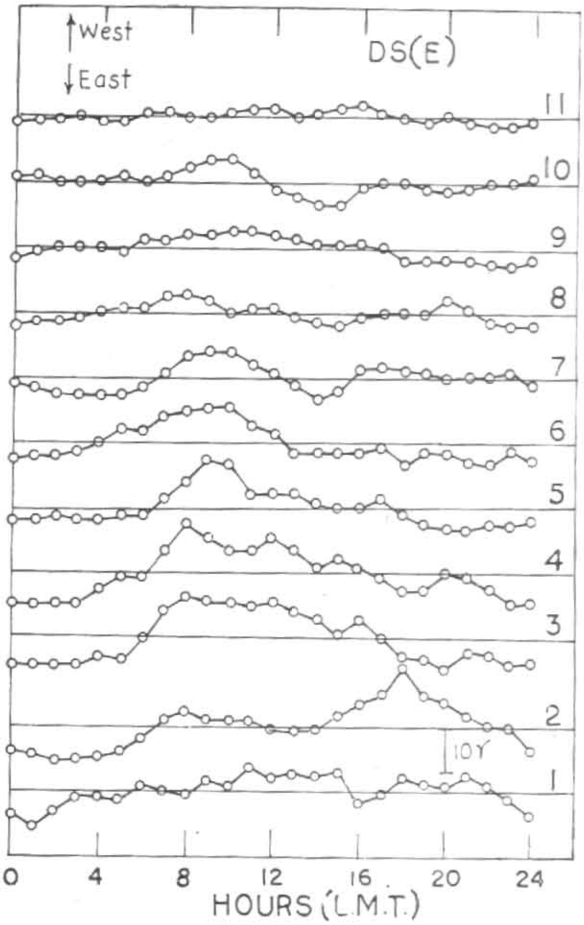

Fig. 2. *DS* **in the east declination** E**, measured in the force unit, for the storm-time intervals 1 to 11, for the average great storm at Alibag**

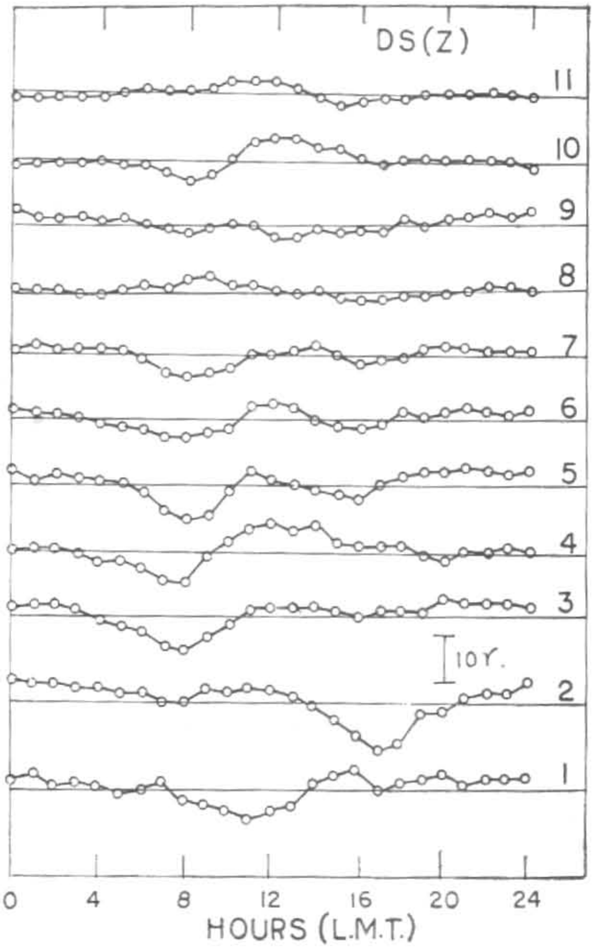

Fig. 3. *DS* **in the vertical force** Z**, for the storm-time intervals 1 to 11, for the average great storm at Alibag,** Z **being measured positively toward Nadir**

The DS (H) for the first interval, *i.e.*, for storm-time 0^h to 5^h is distinctly different from the $DS(H)$ for other intervals. The epoch of maximum of the variation occurs at about local noon and that of the minimum is seen to be at midnight whereas for the other intervals, especially intervals 2 to 7, the epoch of maximum varies from midnight to early morning, and the minimum occurs during the afternoon hours. The interval 0^h to 5^h storm-time largely corresponds to the preliminary positive phase of storm, when solar plasma stream is envisaged to 'compress' the geomagnetic field lines. The particular phase of DS (H) of the first interval indicates that the solar plasma pressure is maximum for the noon meridian and minimum for the midnight meridian. It appears that the source of DS for the first interval is the magnetospheric boundary and not ionospheric currents which are usually postulated for DS and SD variations (Chapman 1935, Vestine *et al.* 1947). The phase of DS will be examined in greater detail later in the paper.

DS (H) range is seen to be large during the main phase of storm and rapidly decreases during the recovery phase. The e.m.f. set up in the auroral regions to drive the DS electric currents in the ionosphere evidently decreases with the progress of storm.

S_q and SD variations

The mean S_q (H) at Alibag is similar to those for geomagnetic latitudes $-1°$ (Huancayo) and $+21°$ (Honolulu and Zikawei) though the magnitudes differ widely. The SD (H) variations too are similar at these three latitudes with comparable ranges for all the three days. The magnitude of enhancement in S_q (H) range seen at Huancayo is, however, not apparent in its SD (H), though the range is about a third more than SD (H) range at Alibag or Honolulu and Zikawei. The SD ionospheric currents appear to be enhanced only in a small measure in the region of the magnetic equator. The SD (E) and SD (Z) variations of Alibag are similar to those of Honolulu and Zikawei. They are reverse of those for Huancayo.

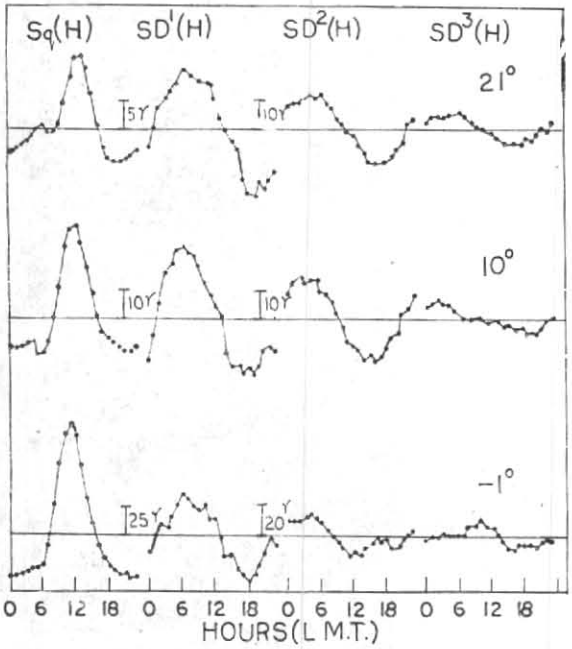

Fig. 4. $SD(H)$ **at three geomagnetic latitudes −1°, 10°, 21°, for the average great storm**

$SD^1(H)$, $SD^2(H)$, and $SD^3(H)$, refer to the first, second and third days of storm, respectively. The mean Sq (H) for the months in which the 74 great storms occurred is shown in column 1

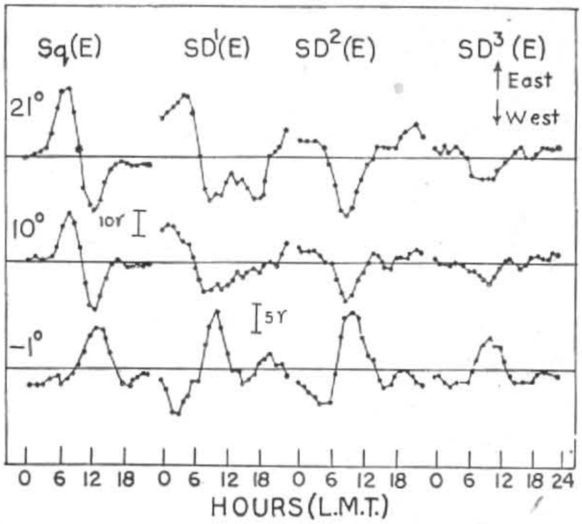

Fig. 5. SD **in the east declination** E**, measured in the force unit at the three geomagnetic latitudes −1°, 10°, 21°, for the average great storm**

The three columns for SD, *i.e.*, the second, third and fourth from the left, refer to the first, second and third days of the storm, respectively. The mean $Sq(E)$ for the months in which the 74 great storms occurred is shown in column 1

It is interesting to compare the SD variations for the first day of storm with those obtained by Moos (1910) for Colaba (Bombay). The true average disturbance daily variations for the period 1872 to 1904 given in plate 73 of Part II of his monumental volume strikingly agree with the SD variations obtained here for Alibag for the period 1905 to 1945. The range in $SD(H)$ of 40γ obtained from the 113 sudden commencement storms by Moos compares with 45γ obtained for Alibag. In both cases $SD(H)$ is maximum at about six hours LMT (*i.e.*, epoch of least disturbance) and minimum at about 18 hours LMT (*i.e.*, epoch of maximum disturbance). The $SD(H)$ for Colaba (Bombay) obtained from 134 great storms of both sudden commencement and gradual commencement types is seen to have a greater range (57γ) in variation. There is also striking similarity in both magnitude and phase in SD (E) and SD (Z) obtained by Moos from the 134 great storms for Colaba (Bombay) and those derived here from 74 great sudden commencement storms for Alibag.

First Harmonic of DS

The results of harmonic analysis of DS and SD variations of Alibag are given in Tables 1 and 2. In Fig. 7 are given the harmonic dials for $DS(H)$, $DS(E)$ and $DS(Z)$ of Alibag together with those for Huancayo (1°S) and for Honolulu and Zikawei (21°N). These indicate the variation of amplitude and phase of the first harmonic component of DS from storm-time interval, 1 to 11. The predominance of $DS(H)$ for the regions shown is easily seen. The larger magnitude of the harmonic dial for $DS(H)$ for Huancayo definitely indicates a certain amount of enhanced effects for the region of the magnetic equator. Both the amplitude and phase of the first harmonic component of $DS(H)$ show a fairly systematic change with storm-time interval, for all the three latitudinal regions. This is especially striking for the first five intervals in the course of which the phase shift is of the order of 90° (6 hours) for all the regions; the epoch of maximum $DS(H)$ changes from about local noon to about early morning in the course of the first two intervals of storm-time. From the intervals 5 to 11 the amplitude of the 24-hour component of $DS(H)$ steadily decreases with the phase angle showing only a small decrease. The magnitude of $DS(H)$ thus steadily decreases with storm-time after the first day of storm but the phase indications are such that the epoch of maximum continues to be about the early morning hours.

Higher Harmonics of DS and SD

The variations with storm-time interval of amplitude and phase of the second harmonic component of DS for Alibag are shown in the harmonic dials of Fig. 8. It is seen that not only the amplitudes are small, but there is also no regularity in phase or amplitude change from interval to interval. With a view to eliminate

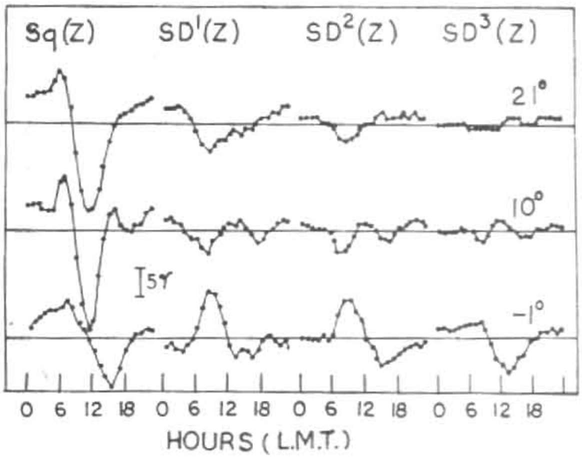

Fig. 6. *SD* in the vertical force *Z*, at the three geomagnetic latitudes —1° 10°, 21°, for the average great storm, *Z* being measured positively toward Nadir

The three columns for *SD*, *i.e.*, the second, third and fourth from the left, refer to the first, second and third days of the storm respectively. The mean *Sq*(*Z*) for the months in which the 74 great storms occurred is shown in column 1

TABLE 1

Harmonic data for the first component of *DS* in *E*, *H* and *Z* for the average great storm

(10° Alibag)

Interval	a_1	b_1	c_1	φ_1	
1	−3·0	−1·2	3·2	248	*E*
2	−2·8	−4·7	5·5	210	
3	−7·1	+1·9	7·4	284	
4	−6·3	+1·4	6·5	282	
5	−4·5	+2·0	5·0	294	
6	−3·2	+3·5	4·7	318	
7	−2·0	−0·3	2·0	261	
8	−1·0	+1·1	1·5	317	
9	−2·8	+1·9	3·4	304	
10	+0·3	+1·8	1·8	8	
11	−1·5	−0·2	1·5	263	
1	−24·5	+8·5	26·0	289	*H*
2	−1·4	+29·7	29·7	357	
3	+3·9	+23·9	24·3	9	
4	+5·6	+27·6	28·2	11	
5	+20·4	+15·8	25·8	52	
6	+7·7	+14·3	16·2	28	
7	+12·2	+11·1	16·5	48	
8	+0·3	+2·0	2·0	7	
9	+3·7	+6·8	7·7	28	
10	+2·9	+1·3	3·2	65	
11	−0·7	+3·4	3·4	348	
1	+2·6	−1·6	3·1	122	*Z*
2	+1·6	+4·0	4·3	21	
3	+1·5	−3·2	3·5	154	
4	−1·8	−2·3	2·9	218	
5	+2·4	−2·2	3·2	132	
6	+0·5	−1·7	1·8	162	
7	+1·5	−1·3	2·0	132	
8	−0·1	+1·1	1·1	356	
9	+1·9	−0·1	1·9	94	
10	−1·3	−1·3	1·8	225	
11	−0·9	+0·7	1·1	308	

a, *b* and *c* are in gammas and φ in degrees

TABLE 2

The harmonic coefficients for the first four components of *SD*

Average Great Storm (Alibag)

	Storm day	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
SD (*H*)	1	−4·1	+22·5	−3·1	−1·7	−3·2	−0·9	0·9	−0·6
	2	+10·2	+10·8	−0·1	−0·5	+0·5	−0·4	0·4	+0·1
	3	+1·9	+3·8	+1·6	+1·8	+0·4	+0·3	0·0	−0·2
SD (*E*)	1	−4·8	−0·7	−0·7	−2·1	+0·2	−0·2	−0·3	+0·2
	2	−2·7	+1·6	−0·5	−2·0	+0·8	+1·0	−0·3	−0·3
	3	−1·3	+1·2	0·0	−0·3	+0·4	+0·7	−0·1	−0·3
SD (*Z*)	1	+1·0	−0·8	+1·9	+0·6	−0·7	−0·3	−0·1	0·0
	2	+1·1	−1·0	+1·2	0·0	−1·4	0·0	+0·4	−0·3
	3	−0·1	−0·2	+0·7	−0·2	−1·0	−0·1	+0·4	−0·4

a_n and b_n are reckoned in gamma

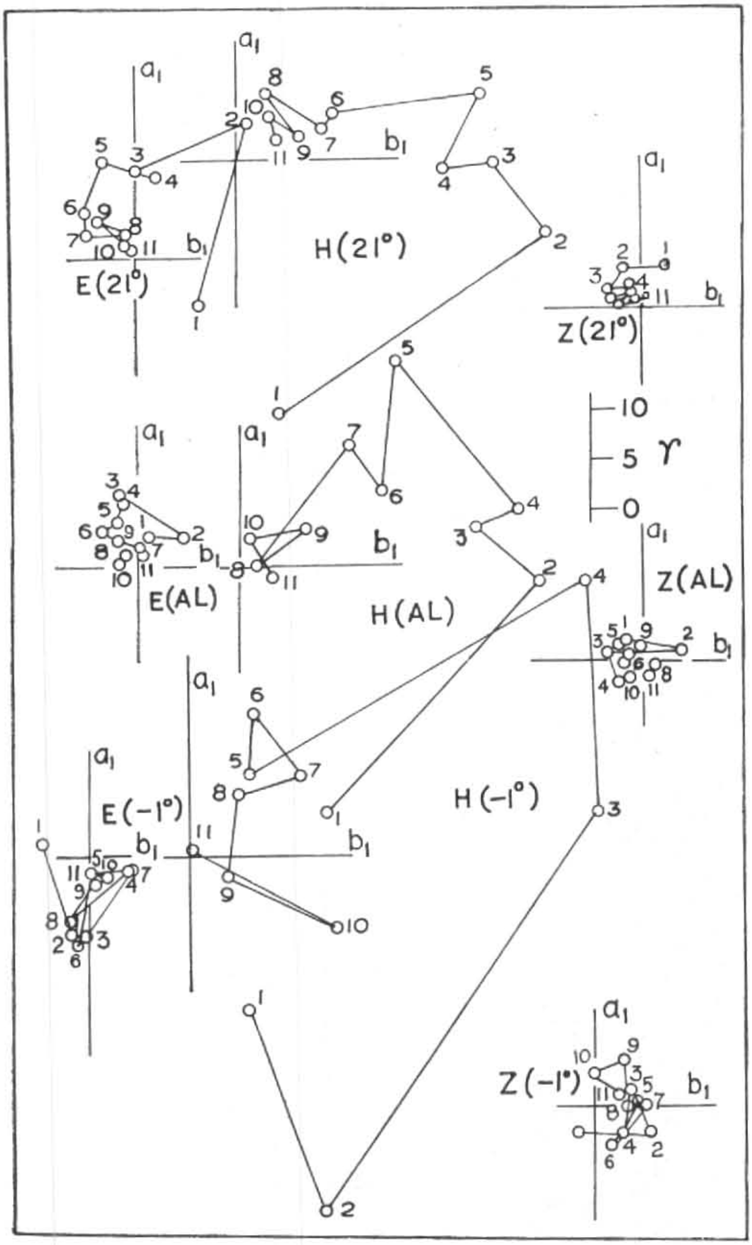

Fig. 7. Harmonic dials for the first component of *DS* in *H*, *E* and *Z* for the average great storm for the geomagnetic latitudes —1°, 10°, 21°

The eleven points refer to the first eight 6-hour intervals of storm-time and the following three to the three 8-hour intervals

these irregular variations the harmonic coefficients of the mean *DS* variation for each of the three storm days, that is for SD^1, SD^2 and SD^3 are obtained (Table 2) and the harmonic dials for the elements *H*, *Z* and *E* are shown in Fig. 9. In addition, the dials for the other higher harmonics, namely, the third and fourth harmonics are also shown in Fig. 9. It is evident that the magnitudes of the higher harmonics of the mean *DS* or *SD* variations are very small with no clear regularity, indicating that the first harmonic has a high degree of predominance in the *DS* or *SD* variations of Alibag, confirming the earlier findings of Sugiura and Chapman.

Comparison of D_{st} and DS

For purposes of comparison the trends of D_{st} and *DS* for great storms recorded at Alibag have been shown in Fig. 10. D_{st} values for every hour of storm-time have been plotted together with the double amplitude, with negative sign, of the first harmonic of *DS* for each of the eleven intervals of storm-time. Smooth curves have

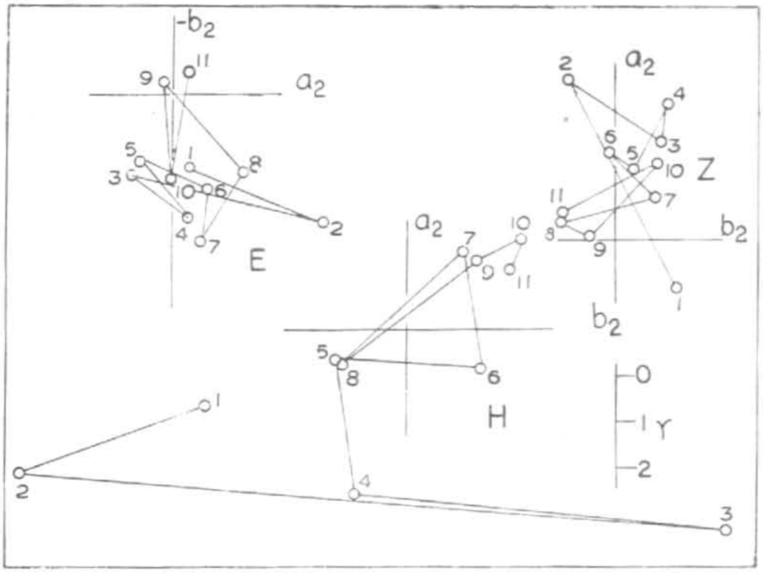

Fig. 8. Harmonic dials for the second component of DS in H, E and Z for the average great storm at Alibag

The eleven dial points refer to the first eight 6-hour storm-time intervals (in the first and second days) and the following three to the three 8-hour storm-time intervals (third day)

been drawn following the trend of the points for *DS*. A smooth curve has also been drawn to indicate the average trend of D_{st} (*H*).

The storm-time courses of *DS* as well as D_{st} for great storms at Alibag are very similar to those for the latitude of 21°N given by Sugiura and Chapman (1958), especially in the case of the horizontal component, *H*. There is a tendency for *DS* to attain its maximum a little earlier than that of D_{st} which conforms to the finding of Sugiura and Chapman (1958). From the storm-time trends for Alibag it cannot be inferred that the decay in *DS* is more rapid than in D_{st} for all elements. The courses of *DS*(*H*) and D_{st} (*H*) after the minimum epochs appear to be parallel to each other, especially towards the later stages of their courses, indicating that they decay at about the same rate. A feature to be noticed in the recovery phase of particularly D_{st} (*H*) is the existence of two different rates of decay. The earlier portion of the recovery phase decays more rapidly than the later portion. This feature is an indication that probably two ring currents, formed at different geocentric distances, are associated with magnetic storms. Similar inferences have been made by Akasofu *et al.* (1963) and Yacob (1964) while examining the recovery trends of individual magnetic storms.

4. Conclusion

The average *DS* and *SD* variations in the magnetic elements *H*, *E* and *Z* at Alibag have been derived from 74 great storms recorded during the period 1905 to 1945 and the following results have emerged —

(1) For the latitude of Alibag *DS*(*H*) and *SD*(*H*) predominate over *DS*(*Z*) or *DS*(*E*) and *SD*(*Z*) or *SD*(*E*),

(2) *DS*(*H*) range is large during the main phase of storm and rapidly decreases during the recovery phase,

(3) The phase angle of the first harmonic on *DS*(*H*) changes systematically in an anticlockwise direction with storm-time. This is specially striking for the first day of the storm,

(4) The amplitudes of the first harmonic of *DS* and *SD* are very much larger than those of the higher harmonics,

(5) The *SD* and *DS* variations obtained for Alibag compare well with those of Honolulu and Zikawei (geomag. lat. 21°N) given by Sugiura and Chapman, while a comparison with those for Huancayo (geomag. lat. 1°S) clearly shows a small measure of enhancement in the amplitude of these variations in the magnetic equatorial region, especially for the first day of storm,

(6) The magnitude and phase of the *SD* variations for Alibag are strikingly similar to those obtained by Moos for Colaba (Bombay) for the period 1872 to 1904,

(7) The storm-time courses of D_{st} (*H*) and *DS*(*H*) are about parallel to each other. The trends for Alibag indicate that both decay at about the same rate,

(8) The recovery phase of particularly D_{st} (*H*) has two distinct rates of decay. Initial portion of the recovery phase decays more rapidly than the later portion indicating the probable association of two ring currents with geomagnetic storms.

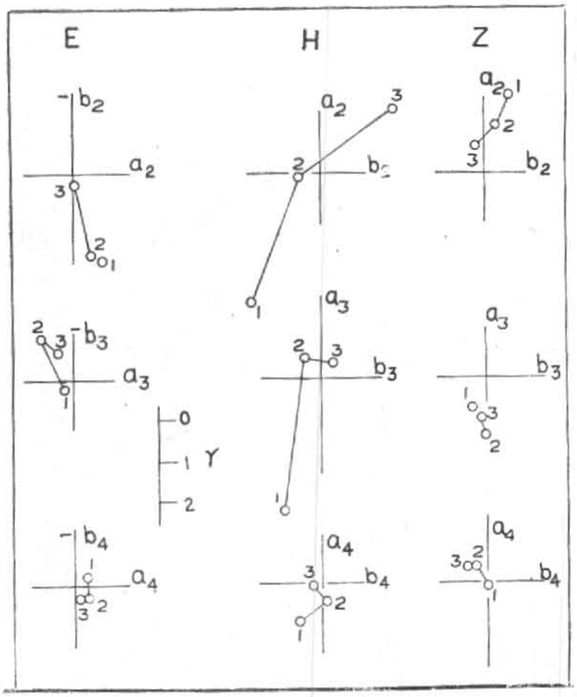

Fig. 9. Harmonic dials for the 2nd, 3rd and 4th components of *SD* (*H*, *E*, *Z*) for the average great storm at Alibag

The three dial points refer to the first, second and third days of the storm

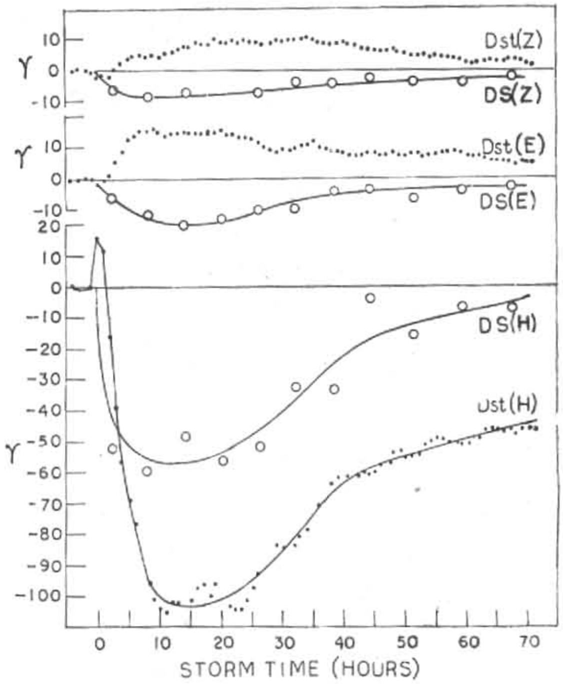

Fig. 10. D_{st} variations and the ranges (with negative sign) of the first harmonic component of *DS*, (2C1), for *H*, *E*, and *Z* plotted against storm-time at Alibag

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REFERENCES

Akasofu, S. I., Chapman, S. and Venkatesan, D.	1963	*J. geophys. Res.*, **68**, p. 3345.
Chapman, S.	1935	*Terr. Magn.* **40**, p. 349.
	1952	*Ann. Geofis.*, **5**, p. 1.
Moos, N. A. F.	1910	Mag. Observations made at the Government Observatory, Bombay, for the period 1846 to 1905 and their discussion, Part II. The Phenomenon and its Discussion, Bombay.
Sugiura, M. and Chapman, S.	1955	Sci. Rep. 1 (AFCRC-TR-55-406), AF 19 (604)—1048: Geophys. Inst. Alasksa.
	1956	Final Rep. (AFCRC-TR-56-450), AF 19 (604)-1048 Geophys. Inst., Alaska.
	1957	Final Rep. (AFCRC-TR-57-295, AD 117-256), AF 19 (604)—1732 : Geophys. Inst., Alaska.
	1958	Final Rep. (AFCRC-TR-58-266) AF 19 (604)—2163 : Geophys. Inst., Alaska.
Vestine, E. H., Lange, I., Laporte, L. and Scott, W. E.	1947	The Geomagnetic Field, its Description and Analysis, Carnagie Inst. Wash., Dep. Terr. Magn., Pu bl. No.580.
Yacob, A.	1964	*Indian J. Met. Geophys.*, **15**, p. 579.
yacob, A. and Sastri, N. S.	1965	*Ibid.*, **16**, p. 33.

APPENDIX

TABLE I. *DS* **and** *SD* **in** *E* **for the average great geomagnetic storm as derived from 74 great geomagnetic storms recorded at Alibag during the period 1905 to 1945**

DS (E) in tenths of gamma

Storm-time interval	0	1	2	3	4	5	6	7	8	9	10	11 (L.M.T.)
1 (0—5hr)	+55	−86	−46	−24	+18	+17	−5	−3	+8	−24	−9	−53
2 (6—11hr)	+57	+65	+81	+77	+68	+57	+35	−15	−27	−14	−11	−12
3 (12—17hr)	+63	+59	+57	+56	−42	+45	−2	−60	−85	−84	−84	−71
4 (18—23hr)	+65	+71	+68	+69	+38	+12	+6	−51	−112	−77	−55	−53
SD^1 (0—23hr)	+59	+70	+64	+56	+42	+33	+09	−32	−54	−50	−40	−46
5 (24—29hr)	+28	+26	+16	+29	+27	+16	+24	−19	−62	−114	−95	−32
6 (30—35hr)	+40	+28	+31	+18	+1	−26	−25	−56	−66	−84	−77	−42
7 (36—41hr)	+22	+33	+40	+42	+40	+37	+18	−12	−53	−57	−60	−29
8 (42—47hr)	+29	+24	+18	+8	−2	−9	−15	−38	−44	−30	−1	−11
DS^2(24—47hr)	+29	+28	+27	+25	+16	+4	+1	−31	−56	−71	−58	−29
9 (48—55hr)	+30	+11	0	−2	+3	+8	−23	−24	−33	−29	−37	−36
10 (56—63hr)	−11	−10	−4	+2	−1	−5	0	−8	−27	−48	−55	−19
11 (64—71hr)	+13	+13	+11	+4	+8	+8	−8	−9	+4	+3	−12	−21
SD^3(48—71hr)	+11	+4	+2	−1	+3	+3	−10	−13	−19	−25	−35	−25

Storm-time interval	12	13	14	15	16	17	18	19	20	21	22	23 (L.M.T.)
1 (0—5hr)	−26	−36	−31	−42	+32	+12	−23	−14	−10	−32	−11	+21
2 (6—11hr)	+14	+05	+12	−21	−49	−73	−129	−72	−45	−17	+2	+12
3 (12—17hr)	−76	−59	−40	−14	−37	+3	+43	+46	+68	+36	+39	+57
4 (18—23hr)	−76	−52	−12	−27	−11	+15	+36	+36	0	+6	+43	+71
SD^1 (0—23hr)	−41	−36	−18	−26	−16	−11	−18	−1	+3	−2	+18	+40
5 (24—29hr)	−30	−28	−8	−4	+2	−17	+17	+41	+46	+47	+37	+43
6 (30—35hr)	−15	+16	+16	+16	+17	+6	+49	+22	+22	+40	+46	+17
7 (36—41hr)	−15	+21	+51	+28	−24	−30	−24	−11	+4	+1	−2	−8
8 (42—47hr)	−11	+8	+18	+28	+15	0	+1	−3	−28	−9	+17	+33
SD^2(24—47hr)	−18	+4	+19	+17	+3	−10	+11	+12	+11	+21	+25	+22
9 (48—55hr)	−26	−22	−8	−11	−8	+3	+33	+35	+28	+26	+43	+44
10 (56—63hr)	+18	+31	+51	+45	+14	+3	+4	+9	+18	−5	0	−3
11 (64—71hr)	−16	+3	−6	−24	−27	−10	−2	+8	+3	+15	+23	+21
SD^3 (48—71hr)	−8	+4	+12	+3	−6	−1	+12	+17	+16	+15	+22	+21

TABLE II. *DS* **and** *SD* **in** *H* **for the average great geomagnetic storm as derived from 74 great geomagnetic storms recorded at Alibag during the period 1905 to 1945**

DS (*H*) in tenths of gamma

Storm-time interval	0	1	2	3	4	5	6	7	8	9	10	11 (L.M.T.)
1 (0—5hr)	—363	—316	—207	— 37	— 52	+ 40	+119	+119	+166	+262	+243	+341
2 (6—11hr)	— 98	— 93	+ 48	+162	+128	+346	+390	+344	+296	+264	+198	+116
3 (12—17hr)	—174	+119	+213	+324	+369	+257	+249	+215	+151	+82	+ 36	— 70
4 (18—23hr)	00	+ 55	+170	+210	+309	+342	+260	+287	+291	+153	+ 25	— 44
SD^1 (0—23hr)	—159	— 59	+ 56	+165	+189	+246	+255	+241	+226	+190	+125	+ 86
5 (24—29hr)	+212	+235	+277	+223	+204	+190	+146	+122	+ 79	+ 25	—107	—185
6 (30—35hr)	+ 56	+125	+121	+147	+184	+221	+129	+ 94	+ 89	+ 66	— 15	— 92
7 (36—41hr)	+121	+156	+170	+162	+128	+123	+112	+ 85	+ 24	— 33	— 39	— 69
8 (42h—47h)	— 45	— 5	+ 12	— 9	+ 17	+ 18	+ 19	+ 33	+ 40	+ 9	+ 38	— 1
SD^2 (24—47hr)	+ 86	+128	+145	+131	+133	+138	+101	+ 83	+ 58	+ 17	— 31	— 87
9 (48—55hr)	+ 71	+ 97	+ 82	+ 65	+ 79	+65	+ 58	+ 57	+24	+ 06	— 22	— 17
10 (56—63hr)	+ 59	+ 47	+ 57	+ 67	+ 48	+12	— 12	— 41	— 38	— 30	— 01	— 21
11 (64—71hr)	— 8	+ 12	+ 54	+ 33	+ 27	+20	+ 18	+ 6	+ 14	+ 31	+ 32	+ 20
SD^3 (48—71hr)	+ 41	+ 52	+ 64	+ 55	+ 51	+32	+ 21	+ 07	00	+ 2	+ 3	— 6

Storm-time interval	12	13	14	15	16	17	18	19	20	21	22	23 (L.M.T.)
1 (0—5hr)	+267	+319	+ 99	— 69	— 44	—42	+ 13	— 94	—156	— 98	—232	—275
2 (6—11hr)	+ 36	— 89	—260	—284	—317	—329	—227	—235	—240	—133	0	— 27
3 (12—17hr)	— 71	—118	—147	— 93	— 87	—184	— 258	—299	—188	—121	— 85	—129
4 (18—23hr)	— 54	— 91	—202	—283	—268	—263	—299	—192	—146	—113	—122	— 27
SD^1 (0—23hr)	+ 45	+ 5	— 127	—182	—179	—205	—193	—205	—183	—116	—110	—115
5 (24—29hr)	—239	—235	—260	—256	—245	—220	—168	— 54	— 38	+ 59	+ 71	+162
6 (30—35hr)	— 92	—103	—129	—105	—151	—152	—117	—130	—135	— 59	— 12	+ 67
7 (36—41hr)	—111	—141	—174	—150	—131	— 136	—124	— 133	—108	+ 41	+ 87	+131
8 (42—47hr)	+ 16	— 15	— 31	— 37	— 69	—41	— 26	+ 18	+ 34	+ 30	+ 16	— 23
SD^2 (24—47hr)	—107	—123	—149	—137	—149	—137	—109	— 75	— 62	+ 18	+ 41	+ 84
9 (48—55hr)	— 27	— 26	— 33	— 54	— 76	—64	—117	— 74	— 52	— 32	— 7	— 2
10 (56—63hr)	— 11	— 4	— 29	— 4	— 4	—11	— 11	— 40	— 50	— 39	+ 20	+ 42
11 (64—71hr)	+ 14	+ 12	+ 2	— 8	— 19	—31	— 38	— 52	— 57	— 44	— 26	— 1
SD^3 (48—71hr)	— 8	— 6	— 20	—22	— 33	—35	— 55	— 55	— 53	— 38	— 4	+ 13

TABLE III. ***DS*** **and** ***SD*** **in** ***Z*** **for the average great geomagnetic storm as derived from 74 great geomagnetic storms recorded at Alibag during the period 1905 to 1945**

DS (*Z*) in tenths of gamma

Storm-time interval	0	1	2	3	4	5	6	7	8	9	10	11 (L.M.T.)
1 (0—5hr)	+ 21	+ 30	+ 6	+ 14	+ 1	— 8	+ 1	+ 13	— 34	— 40	— 49	—67
2 (6—11hr)	+ 48	+ 42	+ 38	+ 30	+ 31	+ 17	+ 22	— 1	+ 3	+ 31	+ 20	+ 32
3 (12—17hr)	+ 17	+ 24	+ 20	+ 6	— 11	— 27	— 42	— 70	— 80	— 55	— 21	+ 10
4 (18—23hr)	+ 2	— 2	— 4	— 8	— 33	— 29	— 37	— 69	— 72	— 8	+ 21	+ 45
*SD*¹ (0—23hr)	+ 22	+ 23	+ 15	+ 11	— 3	— 12	— 14	— 32	— 46	— 18	— 7	+ 5
5 (24—29hr)	+ 27	+ 12	+ 20	+ 15	+ 12	— 2	— 21	— 64	— 81	— 68	— 13	+ 25
6 (30—35hr)	+ 19	+ 8	+ 5	— 3	— 7	— 20	— 34	— 39	— 43	— 30	— 17	+ 32
7 (36—41hr)	+ 12	+ 18	+ 6	+ 8	+ 14	+ 15	— 15	— 42	— 53	— 43	— 25	— 2
8 (42—47hr)	+ 2	0	+ 2	— 6	— 7	+ 3	+ 14	— 1	+ 23	+ 33	+ 12	+ 8
*SD*² (24—47hr)	+ 15	+ 9	+ 8	+ 3	+ 3	— 1	— 14	— 37	— 39	— 27	— 11	+ 16
9 (48—55hr)	+ 26	+ 7	+ 9	+ 5	+ 14	+ 8	0	— 12	— 19	— 12	+ 1	— 2
10 (56—63hr)	— 16	— 12	— 13	— 5	— 2	— 6	— 8	— 35	— 50	— 37	— 4	+ 42
11 (64—71hr)	— 13	— 9	— 9	— 9	— 6	— 3	+ 8	+ 7	+ 6	+ 9	+ 26	+ 30
*SD*³ (48—71hr)	— 1	— 5	— 4	— 3	+ 2	0	0	— 13	— 21	— 13	+ 8	+ 23

Storm-time interval	12	13	14	15	16	17	18	19	20	21	22	23 (L.M.T.)
1 (0—5hr)	— 47	— 40	+ 12	+ 28	+ 44	— 2	+ 5	+ 19	+ 25	+ 13	+ 24	+ 21
2 (6—11hr)	+ 26	+ 7	— 6	— 44	— 78	— 110	—102	— 24	— 21	+ 12	+ 19	+ 19
3 (12—17hr)	+ 20	+ 21	+ 19	+ 15	— 4	+ 15	+ 13	+ 10	+ 38	+ 32	+ 33	+ 27
4 (18—23hr)	+ 61	+ 46	+ 57	+ 18	+ 14	+ 10	+ 11	— 8	— 17	— 2	+ 1	+ 6
*SD*¹ (0—23hr)	+ 15	+ 9	+ 21	+ 4	— 6	— 22	— 18	— 1	+ 6	+ 14	+ 19	+ 18
5 (24—29hr)	+ 11	+ 4	— 5	— 19	— 27	+ 4	+ 19	+ 26	+ 33	+ 42	+ 34	+ 24
6 (30—35hr)	+ 43	+ 31	— 1	— 12	— 17	— 8	+ 16	+ 8	+ 21	+ 29	+ 23	+ 5
7 (36—41hr)	+ 1	+ 14	+ 23	0	— 19	— 9	+ 4	+ 16	+ 23	+ 19	+ 15	+ 13
8 (42—47hr)	+ 1	— 8	— 3	— 19	— 18	— 17	— 13	— 12	— 11	+ 1	+ 14	+ 8
*SD*² (24—47hr)	+ 14	+ 10	+ 3	— 13	— 20	— 7	+ 7	+ 9	+ 17	+ 23	+ 21	+ 13
9 (48—55hr)	— 25	— 29	— 15	— 21	— 7	— 10	+ 8	+ 4	+ 9	+ 19	+ 28	+ 24
10 (56—63hr)	+ 55	+ 46	+ 34	+ 17	— 3	— 13	+ 1	+ 4	+ 3	0	— 1	+ 1
11 (64—71hr)	+ 26	+ 13	— 8	— 26	— 21	— 9	— 7	— 4	— 3	+ 4	— 1	— 2
*SD*³ (48—71hr)	+ 19	+ 10	+ 4	— 10	— 10	— 11	+ 1	+ 1	+ 3	+ 8	+ 9	+ 8