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Storm-time disturbance field and the computed equatorial D_{st} index

S Mukherjee, S Alex & G K Rangarajan
Indian Institute of Geomagnetism, Colaba, Mumbai 400 005

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The geomagnetic disturbance field (D) is a composite of both universal time component (D_{st}) and the local time-dependent part (SD) of the field. The equatorial D_{st} index is an accepted measure to quantify the strength of the magnetic storm, defining the contribution from the symmetric magnetospheric ring current. A new approach is made to compute the D_{st} index with a less cumbersome process using observed horizontal field intensity at low latitudes, which incorporates certain normalization factors for removing the part associated with the quiet-time ionospheric current and the elimination of the secular trend. Systematic correspondence between the conventional equatorial D_{st} index [$D_{st(cv)}$] and the computed D_{st} [$D_{st(cal)}$] is shown to exist. Since the spacing of stations used for the calculation of $D_{st(cv)}$ is non-uniform, too large and far from ideal, an attempt is made to compute the D_{st} index by the inclusion of an additional station Alibag (lat.18.38°N ; long.72.52°E) in the Indian longitude, covering a wide gap. Progressive change in the asymmetric component after the inclusion of the station Alibag in the computation of D_{st} is brought out from the analysis.

1 Introduction

Large-scale disturbances in the magnetosphere originate in the solar plasma streaming towards the earth. Injection of charged particles in the magnetosphere, under favourable interplanetary conditions, gives rise to the geomagnetic disturbance fields. Horizontal component of the magnetic field recorded on the ground at low and middle latitudes shows clear signature of the enhanced energy transfer from the interplanetary space into the inner magnetosphere. Chapman[1] described this disturbance field as a combination of an axially symmetric part (D_{st}) and an asymmetric part (SD), i.e. $D = D_{st} + SD$. In other words D_{st} will be UT-dependent while the SD component will depend on local time.

During the main phase of a magnetic storm, a major portion of the D field can be attributed to the symmetric ring current encircling the earth at a distance of 3-5 R_E. Initially it was thought that the SD (asymmetric) component had its origin in the auroral ionosphere[2], but later observations of concurrent variations in phase between geostationary altitudes and ground clearly indicated that the asymmetric component could be of magnetospheric origin[3]. It is now attributed to the currents in the ionosphere or magnetosphere or both[4]. To quantify the strength of the magnetospheric ring current in the equatorial plane, the equatorial D_{st} index was proposed during the *International Geophysical Year*[5,6]. It is derived from the hourly observations of the H field at a network of four low latitude stations, viz. San Juan, Honolulu, Hermanus and Kakioka (see Table 1) well away from both the equatorial and auroral electrojet belts. According to Mayaud[7] the equatorial D_{st} index is one with a direct physical significance as an indicator of the strength of the ring current. In deriving the index, care is taken to eliminate long term secular trend and the seasonal and diurnal quiet day variation through a suitable harmonic representation. The derivation of the D_{st} index by the method adopted by Sugiura[6] involves the following steps:

(i) Long term secular variation is eliminated through polynomial fitting to the annual mean values of the International Quiet (IQ) days.

(ii) Hourly values of the S_q variations are synthesized from the Fourier analysis of the mean monthly hourly values of quiet days for each month for individual stations.

(iii) A final correction to normalize the variations to the dipole equator by multiplying the hourly

D_{st} value by secθ_m factor, where θ_m is the dipole latitude of the station[7, 8].

In the derivation of the equatorial D_{st} index it is tacitly assumed that $\Sigma \sin \lambda_i = 0$, where λ_i is the longitude of the selected station used in averaging, and also that the distribution is uniform. But the present network of stations (Kakioka, Honolulu, San Juan and Hermanus) indicates a huge gap between Hermanus (19°E) and Kakioka (140°E). Rostoker[9] and Mayaud[7] suggested that the inclusion of a station from near-equatorial latitudes, away from the equatorial electrojet influence, would upgrade the disturbance pattern in a greater detail. Stations like Alibag or Hyderabad fill in the slot excellently. In this paper, we attempt to evaluate the equatorial D_{st} index using five instead of four stations, incorporating Alibag to cover up the longitude gap. In addition, we also compute the index leaving out one or more of the conventional D_{st} stations to see the effect on the derived index. Comparisons are made between the IAGA approved D_{st} index, $D_{st\,(conventional)}$, herein after symbolized as $D_{st(cv)}$, and the other equivalent indices computed by us for different levels of magnetic disturbance. A simplified method in contrast to the rigorous computational procedures used in the derivation of standard D_{st} index is evolved from the observed values of the H-component during disturbed days incorporating the method of elimination of quiet-day variation and the baseline correction to account for any average secular trend of the location.

2 Database

The analysis is confined to geomagnetic disturbances recorded in 1992 as we could get high resolution (1 min) definitive data for three stations presently operating under the 'INTERMAGNET' system network[10], so that in case of large discrepancies in our result we could look at the fine structure of the departures. These were supplemented with the published hourly values of Alibag and Hermanus. Table 1 gives the coordinates of the low latitude stations whose horizontal intensity data are utilized for the computation of the D_{st} index in the present study.

The storm days in 1992 selected for the study are based on different strengths of the D_{st}, e.g. (i) on 10 May 1992, $|D_{st\ max}| \sim 300$ nT; (ii) on 9 Feb. 1992, $|D_{st\ max.}| \sim 200$ nT; (iii) on 20 Feb. 1992, $|D_{st\ max}| \sim 150$nT; (iv) on 9 Nov. 1992, $|D_{st\ max}| \sim 100$ nT; and (v) on 4 Nov. 1992, $|D_{st\ max}| \sim 50$nT. The disturbance field values of the H-component for respective stations are referred to as H_d hereafter. Hourly values of D_{st} index are obtained from the *Solar Geophysical Data* bulletins.

3 Method of derivation

In the first step, we derive, using the present proposed method, the D_{st} index [$D_{st(cal)}$] from the same set of stations as used by Sugiura for deriving the equatorial D_{st} index [$D_{st(cv)}$]. After establishing the extent of compatibility between $D_{st(cal)}$ and $D_{st(cv)}$, we next assess the effect of inclusion of Alibag and further the elimination of one of the four standard stations used for the computation of $D_{st(cv)}$. The parameter D_{st} has to be expressed as a global contribution of the geomagnetic disturbance after the removal of the part associated with the overhead quiet-time ionospheric current prevailing over the individual location. This is achieved by subtracting the appropriate hourly mean (H_q) values for the corresponding month of the respective storms. Since the index, related to the ring current parameter D_{st}, is assumed to be normalized with reference to the equatorial plane, the disturbance field expressed by (H_d – H_q) for each station is

Table 1—Coordinates of the magnetic observatories of the D_{st} network (after *Report UAG* 86, NOAA, Boulder, Colorado)

Station	IAGA code	Geographic		Dipole	
		Latitude	Longitude	Latitude (deg.)	Longitude (deg.)
Honolulu	HON	21.32°N	158.00°W	21.36	267.97
San Juan	SJG	18.12°N	66.15°W	29.41	4.65
Hermanus	HER	34.42°S	19.23°E	–33.59	81.99
Alibag	ABG	18.38°N	72.52°E	9.24	144.58
Kakioka	KAK	36.23°N	140.18°E	26.31	207.25

divided by the term cos θ_i, where θ_i is the dipole latitude for the respective station.

The next step is an attempt to eliminate the secular trend. For each storm, the quietest day of the month is taken as the control day. The mean departure of the hourly values of the H-component for this control day (H_c) from the computed D_st [$D_\mathrm{st(cal)}$] for the day is taken as an estimate of the baseline value (H_b) for individual storms to eliminate the secular trend; i.e. $H_\mathrm{b} = H_\mathrm{c} - D_\mathrm{st(cal)}$. In order to assess the contribution to $D_\mathrm{st(cal)}$ by the inclusion of the low latitude station, Alibag, in the Indian longitude, away from the equatorial electrojet influence or by the omission of any of the stations used for computing the conventional D_st, the analysis was performed in the following manner.

The computed D_st in the present study is defined as

$$D_\mathrm{st(cal)} = \sum_{i=1}^{4} \left\{ \left[\left(H_{\mathrm{d}_i} - H_{\mathrm{q}_i} \right) / \cos\theta_i \right] - H_{\mathrm{b}_i} \right\} \quad \ldots (1)$$

where i = 1-4 refer to the four stations, namely, San Juan, Hermanus, Honolulu and Kakioka, H_{d_i} and H_{q_i} represent the observed hourly values of the storm day and the mean of IQ days for station 'i' with dipole latitude θ_i, respectively. The parameter H_{b_i} defines the secular trend for respective stations. Further, the calculation of the parameter $D_{\mathrm{st}*}$ is obtained by modifying Eq.(1) by including Alibag along with the aforesaid four stations, which expresses D_st as

$$D_{\mathrm{st}*} = \sum_{i=1}^{5} \left\{ \left[\left(H_{\mathrm{d}_i} - H_{\mathrm{q}_i} \right) / \cos\theta_i \right] - H_{\mathrm{b}_i} \right\} \quad \ldots (2)$$

4 Results and discussion

Figure 1 presents a comparative study of the various parameters computed for the four storms. Curves (A) [10 May 1992], (B) [9 Feb. 1992], (C) [20 Feb.1992] and (D) [9 Nov.1992] are shown in the descending level of the absolute magnitude of the strength of D_st, namely, $|D_{\mathrm{st\ max}}|$. The $D_\mathrm{st(cal)}$–H_d(SJG) and $D_\mathrm{st(cal)}$–H_d(HER) curves represent the D_st variation after the omission of the H-component data of San Juan and Hermanus, respectively. Referring to the curve (a) for all the storms shown, the striking feature noticed is that the $D_\mathrm{st(cal)}$ and $D_\mathrm{st(cv)}$ almost overlap for most period of the storm. Thus, irrespective of the strength of D_st, the $D_\mathrm{st(cv)}$ and $D_\mathrm{st\ (cal)}$ seem to match during the main phase as well as the recovery phase with the exception of a slight departure in the initial phase. This strongly supports the authenticity of the method of calculation of D_st index adopted in this study. The dashed curve representing the computed D_st [$D_\mathrm{st\ (cal)}$] is shown with all the curves in Fig.1 for comparison. The $D_{\mathrm{st}*}$ depicted by the full line curve in Fig.1 defines the modified $D_\mathrm{st(cal)}$ after the inclusion of the disturbance variation H for the station Alibag as given in Eq. (2). The comparatively large negative values of $D_{\mathrm{st}*}$ during the main phase of all the storms shown in Fig.1, clearly suggest the increase in the D_st strength with the inclusion of the station Alibag. The magnitude of depression seems to follow a monotonic increase with the intensity of storms. The maximum intensification of the ring current intensity is found at 1500 hrs UT. The rapid depression in respect of the local time influence of the disturbance H variation at Alibag (75°E) indicates the resultant effect of the asymmetric injection of the energetic charged particles in the evening quadrant [11]. This asymmetry is a function of the longitude with reference to the position of the sun with largest effects in the local dusk-midnight sector due to the asymmetric injection of the energetic charged particles in the evening quadrant[12,13]. The omission of the H-component data of San Juan, a station at 66.15° W longitude, from $D_\mathrm{st\ (cal)}$ modifies the main phase pattern as shown in Fig.1[A(b)], giving rise to a deficit in the D_st component during the initial stage of the main phase (0600 –1200 hrs UT). However, the removal of the H-component data of Hermanus (19.23° E) from $D_\mathrm{st(cal)}$ does not seem to influence the variation pattern profoundly as seen in Fig.1[A(c)]. This is probably due to the fact that the contribution from Hermanus to the asymmetric component at this local time is minimal.

Examining the curves for the other three disturbance cases [Fig.1{(B),(C) and (D)}], departures of the asymmetry in $D_\mathrm{st(cal)}$, by the inclusion of Alibag hourly values, are found to reduce with the decreasing level of magnetic activity with the asymmetric strength changing from 20 nT to 10 nT approximately. During the recovery phase, when the energy injection has

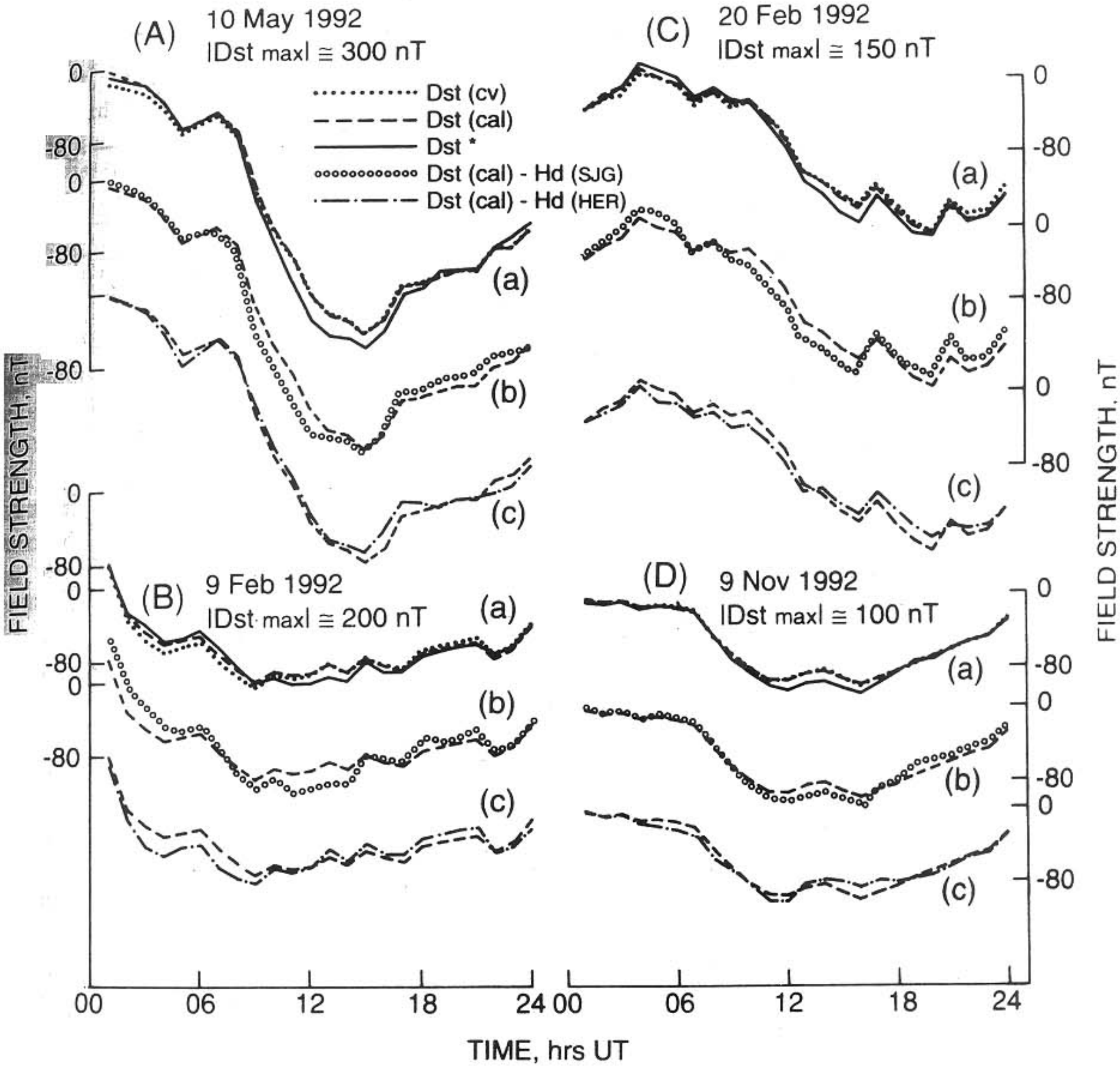

Fig. 1 — Inter comparison of the D_{st} index parameters for the four storms during 1992. [The dashed line curve is the computed D_{st} [$D_{st(cal)}$] and is shown against all the curves for comparison. The dotted line curve represents the conventional D_{st} [$D_{st(cv)}$]. The solid line curve (D_{st*}) as shown with the curve(a) of individual storms is the change in the D_{st} index by the inclusion of the station Alibag. The curves (ooooooo) and (– • – • –) show the variation after excluding San Juan and Hermanus, respectively.]

ceased and the asymmetric component weakens, the effect appears to diminish.

Figure 2 depicts (i) the magnitude of the asymmetric component (D_{st*}–$D_{st(cal)}$), in respect of the local time of Alibag for varying storm conditions, and (ii) a quantitative estimate of the magnitude of the difference between the computed D_{st} [$D_{st(cal)}$] and the conventional D_{st} [$D_{st(cv)}$] for various storm conditions. The difference in magnitude is of the order of ±5 nT for storms in the range with | $D_{st\ max.}$| ≥ 150 nT, whereas the departure is almost absent for storms with less intensity. The duration of each storm is given in Table 2 for reference. The time(UT) of occurrence of maximum main phase is indicated by solid arrows and the lined arrows indicated against the dashed curve represent the corresponding local time of the asymmetric component in $D_{st(cal)}$, for the longitude of Alibag (75°E). It is evident from the curves of asymmetric component that the magnitude of the southward field associated with the asymmetry depends on the intensity of

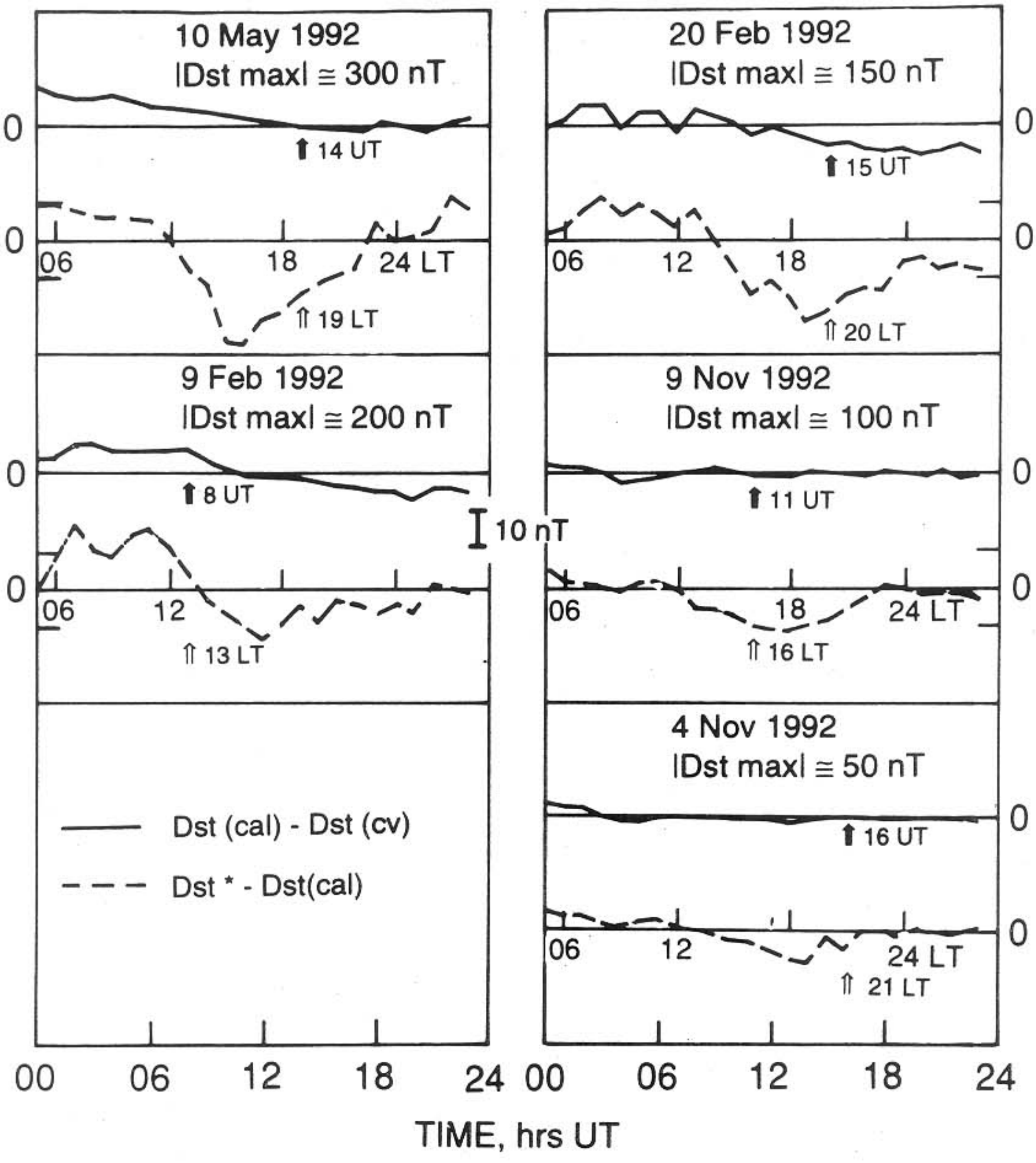

Fig.2 — Curves showing the difference between the computed D_{st} [$D_{st(cal)}$] and the conventional D_{st} [$D_{st(cv)}$] (depicted by the solid line) [The magnitude of the asymmetric component by the inclusion of Alibag is shown by the dashed line for different strengths of D_{st} ranging from 300 nT to 50 nT for five representative storms in 1992. The time (UT) of maximum mainphase is shown by solid arrows and the lined arrows represent the corresponding local time (LT) of Alibag.]

Table 2—Storm time period for the five selected days for the year 1992

Storm days selected	Start of storm		End of storm	
	Day	Time hrs UT	Day	Time hrs UT
10 May	9 May	1956	11 May	20 00
9 Feb.	08 Feb.	1427	10 Feb.	18 00
20 Feb.	20 Feb.	0109	21 Feb.	22 00
9 Nov.	09 Nov.	0400	10 Nov.	21 00
4 Nov.	04 Nov.	0400	05 Nov.	19 00

disturbance as well as the local time of the station. Thus, the inclusion of the low latitude station, Alibag (located in the east longitude zone), in the computation of D_{st} provides an idea of the intensity of the enhanced contribution of the asymmetric injection of the charged particles under various storm conditions with main phase in different local times. The results are in confirmity with the findings of Akasofu *et al.*[13], wherein the longitudinal influence on the disturbance parameter at low and mid-latitudes is discussed. The influence of the solar wind-associated component in the low latitude diurnal variation under varied level of magnetic conditions and their local time dependence were dealt by many workers[11,14,15] who discussed the time profile and magnitude of the diurnally varying southward field of the asymmetric ring current with progressive increase in the level of disturbance. The strength of asymmetry seen at the time of large storm of 10 May 1992 (Fig.2) is in confirmity with the suggestion by Feldstein *et al.*[16], that the intensity of the asymmetric component of the ring current magnetic field is closely connected with the energy flow transferred from the solar wind to the magnetosphere. Feldstein *et al.*[17] computed the contribution to the D_{st} from the magnetospheric ring current (*DR*) and magnetopause current (*DCF*) for the intense magnetic storm of 31 Mar. - 3 Apr., 1973. The difference in *DR* and D_{st} observed before and during the main phase of the storm is mainly associated with the inclusion of the effect of the magnetospheric tail currents in the *DR* variation. According to them the role of the asymmetric current system in modifying the symmetric component during magnetic storms is rather significant and, hence, the importance of the inclusion of more representative longitudinal chain of magnetic observatories in calculating the D_{st} index is worth considering.

5 Conclusions

The D_{st} index parameter [$D_{st(cal)}$] computed using the hourly values from the four stations, incorporating the correction factor to account for the quiet-time as well as the secular trend for respective locations, is found to be a suitable index to match the conventional D_{st} and, hence, provide an alternative method to derive the equatorial D_{st} index easily. The inclusion of the hourly values of the *H*-component from the station Alibag in the computation has brought out the influence of the asymmetric component in modifying the index under different storm strengths. Depending on the occurrence time of the main phase of a storm, the effect of the asymmetric ring current will be largest at the station located in the late evening quadrant and, hence, a more proper and uniform longitudinal distribution of stations is emphasized. It is shown how Alibag in India can fill in this slot suitably.

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