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Diurnal variation of enhancement of sudden fluctuations in *H* in the region of the Indian magnetic equator

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ABSTRACT. For the Indian region of the magnetic equator the diurnal variation of enhancement of amplitudes of sudden impulses and fluctuations of development time less than 10 minutes is studied with the observations at Trivandrum, Annamalainagar and Alibag for the period of I.G.Y. and I.G.C. The expected day-time enhancements at Trivandrum and Annamalainagar are found to exist, but the diurnal variation of the enhancements does not exactly follow the $S_q(H)$ trend. Nor do the magnitudes of the enhancements for the different hours of the day strictly correspond to enhancements in $S_q(H)$ hourly inequalities, as derived from the night level. During the night hours there is definitely no enhancement of fluctuations close to the Indian magnetic equator. Actually night-time fluctuations at Annamalainagar are a little larger than those at Trivandrum (station closest to the magnetic equator) and Alibag. Night-time enhancements of fluctuations near the Nigerian and South American magnetic equators found by Onwumechilli and Ogbuehi (1962) are not seen for the region of the Indian magnetic equator. The difference is attributed to differences in the internal electrical conductivities at the different localities.

1. With the finding of very high $S_q(H)$ ranges in the magnetic equatorial region and the postulation of an ionospheric 'electrojet' to account for the observed effects, the question, whether magnitudes of geomagnetic disturbances, especially of the short-period fluctuations, are also large in the equatorial region has received much attention. It has been shown that the day-time SSC's and SI's occurring in the equatorial regions are very much enhanced compared with those occurring simultaneously outside the equatorial zone of a few degrees width. Ferraro and Unthank (1951) found that the diurnal variation of SSC amplitudes was similar to the $S_q(H)$ diurnal variation. Sugiura (1953) showed that the ratio of the amplitudes of SSC's at Huancayo to those at Cheltenham increased in the morning, reached a maximum at about 11 hrs local time and decreased in the afternoon. Forbush and Vestine (1955) examined SSC amplitudes in detail in relation to $S_q(H)$ hourly inequalities and came to the conclusion that the diurnal variation of sizes of SSC's simulated the $S_q(H)$ diurnal variation, thus indicating the large measure of dependence of SSC sizes on $S_q(H)$ magnitudes. A similar analysis has been carried out by Srinivasamurthy (1960) in the case of SSC's and SI's occurring at Kodaikanal during the period 1949 to 1957 to show the existence of a positive correlation between day-time SSC amplitudes and the diurnal range in H. Sugiura and Chapman (1956) examining the sizes of SSC's at Huancayo for the period 1922—47 find a sharp peak in the interval 8^h to 9^h (almost the local time) and high amplitudes between 8^h and 14^h. The size of SSC's rises very sharply from 6^h and fall very sharply from 14^h. When the sizes of SSC's are normalised with those at Cheltenham they find that the ratio curve begins to rise steeply at about 6^h, reaches its maximum near noon and then decreases rapidly. Maeda and Yamamoto (1960) have shown that the day-time enhancement at equatorial stations occurs not only in amplitude of SSC's but also in amplitudes of SI's and that the character of daily variation in amplitude at equatorial stations is almost the same for both SSC's and SI's. A detailed study of fluctuations in H has been made by Onwumechilli and Ogbuehi (1962) who have shown that the amplitude of fluctuations in the region of the magnetic equator is extremely sensitive to the strength

TABLE 1

Station	Geographic		Geomagnetic		Magnetic Dip	Mean quiet-day range for IGY and IGC in		
	Lat.	Long.	Lat.	Long.		H γ	Z γ	D
Alibag	18° 38′N	72° 52′E	9° 28′N	143° 36′E	24° 38′	69	36	49
Annamalainagar	11° 22′N	79° 41′E	1° 32′N	149° 22′E	5° 25′	110	44	34
Trivandrum	8° 29′N	76° 57′E	0° 54′S	146° 18′E	—0° 36′	145	49	25

of S_q current. In addition, they find that the amplitude of fluctuations occurring during the night-time is also enhanced in the equatorial region. This latter finding is entirely new and it will be interesting to see if this is true everywhere in the equatorial belt, which is one of the aims of the present investigation.

2. Results of previous investigations have shown that in the region of the magnetic equator all types of geomagnetic fluctuations in H are augmented during the day-time, more or less in the same manner. A similar finding for the region of the Indian magnetic equator has been reported by Yacob (1959) and Yacob and Pisharoty (1963). The present investigation is confined to examining sizes of SI's and suddden changes in H (hereafter referred to as sudden fluctuations) to find the mode of diurnal variation in their enhancements in the region of the magnetic equator in south India and the measure of dependence of their sizes on the $S_q(H)$ amplitudes. The sudden fluctuations considered are of short duration, the development time being less than 10 minutes. Some examples of sudden fluctuations that have been studied are shown in Fig. 1. The data are from the three magnetic observatories Alibag, Annamalainagar and Trivandrum covering the I.G.Y. and I.G.C. periods. Trivandrum and Annamalainagar are close to the magnetic equator while Alibag is very remote from it. All the three observatories are within a narrow belt of longitudes whose extent is less than 30 minutes of time. This latter fact greatly facilitates a study of relative magnitudes of magnetic parameters depending on local time, in particular the sudden fluctuations occurring simultaneously at all three observatories. The exact geographic and geomagnetic locations of these three observatories as well as some of the magnetic parameters pertaining to them are given in Table 1.

3. In all, 630 sudden fluctuations in H occurring simultaneously at the three observatories and at different hours of the day and night were scaled. The sudden fluctuations were both negative and positive and they were from quiet as well as disturbed days. No definite criterion was followed in their selection except their prominence and simultaneous occurrence at the three observatories. The least magnitude of the sudden fluctuations considered was of the order of $\pm 4\gamma$. Since the development times of the sudden fluctuations were very small (less than 10 minutes) it was not considered necessary to free their amplitudes of the $S_q(H)$ mixture, which if at all will only be very small parts of amplitudes. For each fluctuation (1) the ratio of the amplitude at Trivandrum to the amplitude at Alibag, (2) the ratio of the amplitude at Annamalainagar to the amplitude at Alibag and (3) the ratio of the amplitude at Trivandrum to the amplitude at Annamalainagar were computed. The mean of the ratios for each of the cases (1), (2) and (3) was then worked out for each IST hourly interval. Examination of the mean ratios for the positive and negative sudden fluctuations separately for

Fig. 1. Some examples of sudden fluctuations in H occurring at Trivandrum (TRV), Annamalainagar (ANG) and Alibag (ALB)

The scale values are not the same for the three stations. The last row indicates the procedure for scaling the amplitude of fluctuations

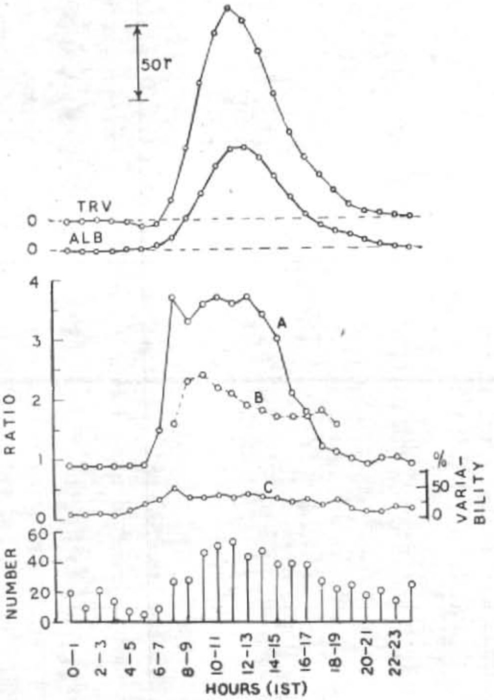

Fig. 2. Top-most two curves—Mean $S_q(H)$ variation for Trivandrum and Alibag as determined from the mid-night level

Curve A —Hourly ratios of amplitudes of sudden fluctuations at Trivandrum by those at Alibag

Curve B —Hourly ratios of $S_q(H)$ inequalities at Trivandrum by those at Alibag

Curve C —Hourly variability of ratios of amplitudes of sudden fluctuations from the hourly mean ratio

Histogram at bottom of figure —Hourly frequency of sudden fluctuations taken for consideration

each of the day-time hourly intervals showed that they were not significantly different, indicating that there was not much error involved in not freeing the fluctuations of the $S_q(H)$ mixture. The mean ratios in the case of Trivandrum/Alibag for the hourly intervals 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15 and 15-16, for the positive and negative sudden fluctuations were respectively 3·1 and 4·3, 2·9 and 3·4, 3·5 and 3·6, 3·7 and 3·7, 3·1 and 4·1, 3·6 and 3·7, 3·5 and 3·4, 2·7 and 3·4, and 2·1 and 2·0. The percentage variability of the ratios from the mean for each hourly interval was also derived. In Figs. 2, 3 and 4 are shown the diurnal variation of the ratios for the cases (1), (2) and (3) as well as the curves of variabilities of the ratios at the different hours and the $S_q(H)$ variation for the different pairs of stations Trivandrum, Annamalainagar and Alibag for the years 1958-59 as derived from the mid-night level (mean for the hours 22-23, 23-24, 0-1 and 1-2 IST). In addition, the ratios of the hourly $S_q(H)$ inequalities (determined from the night-level) for the day hours for the cases (1) (Trivandrum/Alibag), (2) (Annamalainagar / Alibag) and (3) (Trivandrum/Annamalainagar) are also shown. The number of sudden fluctuations considered for each hourly interval has also been depicted in each of the figures.

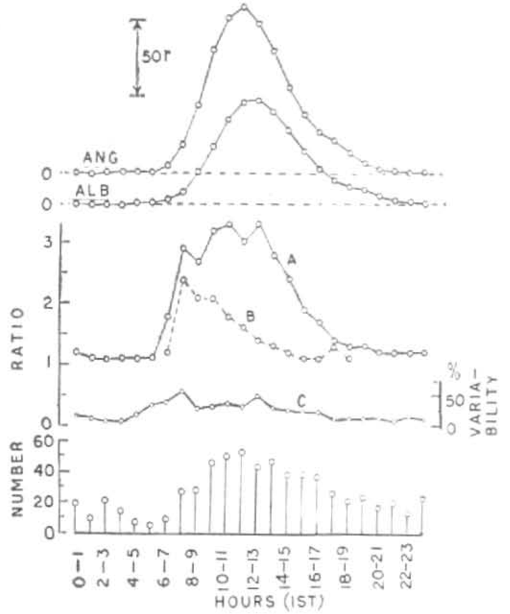

Fig. 3

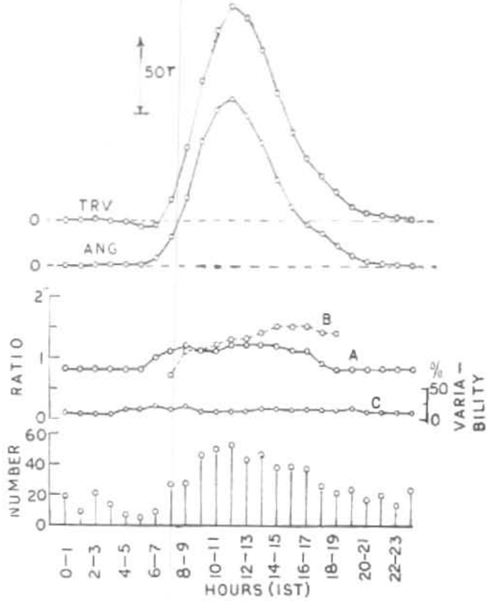

Fig. 4

Top-most two curves—**Mean** $Sq(H)$ **variation for Annamalainagar and Alibag (Fig. 3)/for Trivandrum and Annamalainagar (Fig. 4) as determined from the mid-night level**

Curve A—**Hourly ratios of amplitudes of sudden fluctuations at Annamalainagar to those at Alibag (Fig. 3)/at Trivandrum to those at Annamalainagar (Fig. 4)**

Curve B—**Hourly ratios of** $Sq(H)$ **inequalities at Annamalainagar to those at Alibag (Fig. 3)/at Trivandrum to those at Annamalainagar (Fig. 4)**

Curve C—**Hourly variability of ratios of amplitudes of sudden fluctuations from the hourly mean ratio**

Histogram at bottom of figure—**Hourly frequency of sudden fluctuations taken for consideration**

4. The following features may be observed in Figs. 2, 3 and 4.

(*a*) The hourly frequency distribution of the sudden fluctuations has a prominent minimum during the interval $5^h - 6^h$ IST and a broad maximum around noon, a feature observed by many investigators for SSC's, SI's and other fluctuations.

(*b*) The variability of the ratios of the amplitudes of sudden fluctuations for all cases of (1), (2) and (3) is higher during the day-hours (average about 35% of mean) than the night-hours (average about 15% of mean).

(*c*) The fluctuation-ratios for the night-hours are consistently less for case (1) (Trivandrum/Alibag) than for case (2) (Annamalainagar/Alibag). The fact that the amplitudes of night-time fluctuations are always higher at Annamalainagar than at Trivandrum is clearly brought out in Fig. 4. The mean fluctuation-ratio for the night-hours for cases (1), (2) and (3) are respectively 0·9, 1·2 and 0·8. It is evident that not only there is no appreciable augmentation of the amplitudes of fluctuations at night in the region of the Indian magnetic equator but there appears to be a diminution in their sizes very close to the magnetic equator.

(*d*) The variation in the mean fluctuation-ratio for the different hourly intervals during the day-time is very interesting in cases (1) and (2). The ratio rises very sharply after sunrise and reaches almost the average day-time level in just two hours. From the interval $7^h — 8^h$ to $12^h — 13^h$ the ratios remain at a

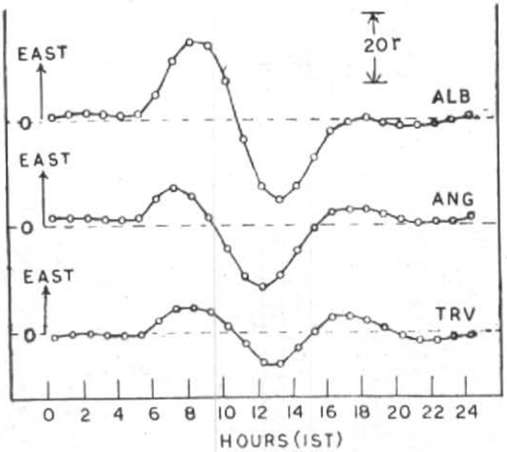

Fig. 5. Mean $S_q(D)$ variation for Trivandrum, Annamalainagar and Alibag for the IGY and IGC period

fairly constant level, at the average of 3·6 for case (1) (Trivandrum/Alibag) and 3·1 for case (2) (Annamalainagar/Alibag). In both the cases (1) and (2) the ratios decrease very rapidly from about 13 hours towards the night level of about 1.

(*e*) For all the day-time hourly intervals except 6^h —7^h the mean fluctuation-ratio is higher for case (1) than for case (2). For the interval 6^h —7^h the ratio for case (2) is significantly higher than for case (1).

(*f*) There does not appear to be any peak value for the hourly fluctuation-ratios corresponding to the peak of $S_q(H)$ variation curves, when the W-E S_q current strength is at its maximum. Only a broad maximum of fluctuation-ratio between the intervals 7^h —8^h and 12^h —13^h is in evidence for all the cases (1), (2) and (3).

(*g*) A comparison of the day-time portion of the curve of ratio of fluctuations (curve A) with that of ratio of $S_q(H)$ hourly inequalities (curve B) clearly shows the lack of similarity between them. Curve B in Figs. 2 and 3 reaches its maximum at 7—8 hours in the case of Annamalainagar/Alibag and at 8—9 hours in the case of Trivandrum/Alibag. Thereafter the tendency is to decrease steadily till about the time of sun-set.

(*h*) An interesting feature regarding fluctuation-ratios is the day-time broad maximum between the intervals 7^h —8^h and 12^h —13^h. This period of broad maximum coincides roughly with the duration of W-E component of S_q current system over any one station. This is apparent from Fig. 5 where the mean $S_q(D)$ variations for the years 1958-59 are shown for the three observatories. Two prominent turning points are seen in each of the $S_q(D)$ curves one between 7^h and 8^h and another between 12^h and 13^h IST (13^h and 14^h IST for Alibag). Their turning points actually represent the axis of the N-S branch and S-N branch of the S_q current system. Thus the interval between $7^h - 8^h$ and $12^h - 13^h$ very closely represents the duration of the W-E branch of the S_q current system over any one observatory. It may be inferred that fluctuation-ratios are maximum during the period when the W-E branch of the S_q current system as bounded by the axes of the N-S and S-N branches is over the station.

5. This investigation has revealed that the day-time sudden fluctuations in H are very much enhanced with sunrise in regions close to the magnetic equator and that the enhancement increases towards the magnetic equator. The fact that the fluctuation-ratio for the interval 6^h —7^h is seen to be greater for Annamalainagar/Alibag than for Trivandrum/Alibag (ref. para 4*e*) does show the dependence of the ratio-magnitude on S_q current strength. Sunrise at Annamalainagar occurs about 13 minutes earlier than at Trivandrum and to this extent the early morning S_q current strength is weaker at Trivandrum than at Annamalainagar. As a result, though Trivandrum is closer to the magnetic equator than Annamalainagar, the mean fluctuation-ratio for the interval 6^h —7^h turns out to be greater. This finding is in conformity with that of Onwumechilli and Ogbuehi (1962). It is on this feature they base their main inference that the day-time augmentation of fluctuations in the magnetic equatorial region is sensitively dependent on the S_q current strength. In this investigation no further evidence can be had for the sensitive dependence

of augmentation on the strength of the S_q current. Though it may be seen from the $S_q(H)$ variation curves that S_q current strength for any one station continues to increase steadily till about noon, a corresponding steady increase in the fluctuation-ratios is not evident after the interval 7^h —8^h IST. As pointed out in para 4(*d*) and 4(*f*) there is only a broad maximum between the intervals 7^h —8^h and 12^h —13^h. Neither is fluctuation-ratio dependent sensitively on the ratio of $S_q(H)$ inequalities, that is, on the ratio of S_q current strengths at the different pairs of observatories. Thus from the results for the region of the Indian magnetic equator it is not possible to say that the fluctuation-amplitudes have sensitive dependence on the strength of the S_q current, once the *E*-layer ionization sets in.

6. However, it is seen that the fluctuation-ratios are very high for the period when the W-E branch of S_q current system as bounded by the axes of the N-S and S-N branches is over the station in question. It appears that what is needed for the occurrence of day-time sudden fluctuations in *H* is the *E*-layer with the W-E branch of the S_q current system coming over the station. As long as this branch of the S_q current system is over the equatorial station the amplitude of fluctuation is high. It follows, therefore, that the sudden fluctuations in *H* are the result of currents superposed in the branch or sudden changes in one of the three parameters connected with the ionospheric dynamo current, *viz.*, (1) ionospheric wind, (2) strength of the magnetic field normal to the ionospheric wind and (3) the state of the ionization in the *E*-layer and that such currents are enhanced close to the magnetic equator on account of the higher total effective *E*-layer electric conductivity there. Onwumechilli and Ogbuehi (1962) have considered changes in the state of ionization of the *E*-layer and currents flowing from auroral regions as the most probable causes of fluctuations in *H*. They do not think that the fluctuations of the type they have studied are caused by hydromagnetic waves since maximum amplitudes are found at the magnetic equator and not at the geomagnetic equator. The possibility of refraction of hydromagnetic waves by the ionospheric layers may also have to be considered in this connection. This effect, though complicated by the several ionospheric layers, may have a consolidated focussing result at the magnetic equator. Perhaps, a good number of sudden fluctuations considered in this investigation are caused by hydromagnetic waves from the interface between the solar wind and the geomagnetic field so that the major portion of the fluctuation is not associated with S_q currents. This may be the reason why the fluctuation amplitudes were not found to depend sensitively on S_q current strength once the *E*-layer was established.

7. Coming to the question of night-time sudden fluctuations in *H*, it is definitely seen that there is no appreciable enhancement in the region of the Indian magnetic equator. Actually the observed effect is a diminution close to the magnetic equator. This finding is not in conformity with that of Onwumechilli and Ogbuehi (1962), who have reported appreciable night-time enhancement for the Nigerian dip equator as well as for Huancayo and other regions. The *E*-layer being absent during the night, there is no possibility of electric currents, that can be associated with geomagnetic fluctuations, flowing at heights comparable with the *E*-layer. Any associated electric currents should be confined to the higher *F*-layer, where, not much "electrojet" effect can be expected to produce localised enhancements of fluctuations. Unless focussing of hydromagnetic waves by the night-time *F*-layer is taken to be effective in producing the night-time enhancements of fluctuations in the magnetic equatorial region, a plausible cause of night-time enhancements may be the differences in electrical conductivity within the earth at different localities. The fact that the amplitudes of sudden fluctuations at night are a little larger at Annamalainagar than at

Alibag or Trivandrum suggests that the earth conductivity at Annamalainagar is a little higher than at Alibag or Trivandrum. The night-time enhancements of fluctuations near the magnetic equator in Nigeria and other regions noticed by Onwumechilli and Ogbuehi may perhaps be accounted for by possible differences in earth conductivities at Ibadan and the equatorial regions considered by them.

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