551.515.1:551.515.2(54)

Sudden Commencement amplitudes and Storm ranges in the Indian equatorial belt

B. N. BHARGAVA

Colaba Observatory, Bombay

(*Received 19 October 1966*)

ABSTRACT. For the highly active period of solar cycle 19, amplitudes of storm sudden commencements (SSC) at the three stations in the Indian equatorial region are examined. Storms with a large main phase are found to accompany sudden commencements occurring during the day time. The equatorial enhancement in SSC amplitudes in the horizontal force is found to be almost uniform from 2·7° magnetic latitude to the dip equator except for a few hours centred on local noon. In the vertical force, the enhancement at Trivandrum near the dip equator is found to be extremely large. The occurrence of storms with large ranges in the vertical force and the seasonal characteristics of the ranges are also investigated. An unexpected quasi-periodic variation in ranges in the vertical force has been found at Kodaikanal. Probable causes of large amplitudes of SSCs and storm ranges in the vertical force are discussed.

1. Introduction

The phenomenon of storm sudden commencement (SSC) and of subsequent main phase and recovery of the horizontal force of the earth's magnetic field has been extensively studied in the past few decades. Considerable information has been gathered on the principal characteristics of SSCs such as their shape, amplitude, rise time, local time and latitudinal dependence and day-time enhancement near the magnetic equator. It is now fairly well known that the SSCs are due to the impact of solar plasma on the earth's magnetosphere and consequent generation and transmission to the earth of a hydromagnetic wave. The SSC amplitudes in the horizontal force are not related to the importance of the source flare on the sun or to the magnitude of the following magnetic storm. In the vertical component, both the SSC amplitudes and the ranges of the following storms are usually small. However, at Trivandrum near the magnetic equator, in addition to the large S_q range in Z, the amplitudes of SSCs as well as the main phase of storms are also noticed to be much larger than at similar location in the South American equatorial region. Using data collected during the major part of high solar activity period of solar cycle 19 at the three magnetic stations in south India the amplitudes of SSCs and ranges of storms have been studied in the present investigation. The stations, their co-ordinates, magnetic latitudes and the period for which data were available are given in Table 1.

2. Local time occurrence of SSCs and ranges of associated storms

Following Matsushita's classification (1957) the SSCs at the three stations are predominantly of the shape referred to as SC with a main positive impulse. On a few occasions the type designated as SC with a negative impulse preceding the main positive impulse has also been observed. The distribution in local time of SSCs by Ferraro, Parkinson and Unthank (1951) and Matsushita (1962) indicated a slight tendency of SSC occurrence with a larger frequency during early afternoon hours. In the Indian equatorial region 130 SSCs, observed at Kodaikanal, were grouped according to time of their occurrence. No definite indication of their occurrence with higher frequency during any part of the day was, however, observed. SSCs preceding 'severe' storm (range in H, $R_H \geqslant 400\gamma$) did, however, appear to occur with larger frequency during day time. Of the 25 SSCs preceding severe storms, 20 occurred between 0000 and 1400 UT or about three times as frequently as those which were recorded during the remaining 10 hours. While the number of SSCs is inadequate for a precise determination of occurrence in local time there is an indication that conditions for a storm to develop with a large main phase are favourable in this region when the preceding SSC occurs during day time. In the earlier part of the active period of the solar cycle 19 (1957-58), of the 8 SSCs, 7 occurred between 0300 and 1400 UT or during an eleven-hour interval centred at 0830 UT. During the later part of the cycle (1959-62), 13 of the 17 SSCs preceding severe storms occurred between 2300 and 0900 UT or during a ten-hour interval centred at 0400 UT. It would, therefore, appear that large main phase development of storms was associated with SSCs which occurred about 4½ hours earlier during the later part of the solar cycle.

3. Principal features of Sudden Commencement amplitudes and ranges of storms

The sudden commencement arises from the impact of an ionized cloud from the sun on the earth's geomagnetic field (Chapman and Ferraro 1940). The hydromagnetic wave generated by the impact of solar plasma transmits the effect to the surface of the earth (Piddington 1959, Dessler and

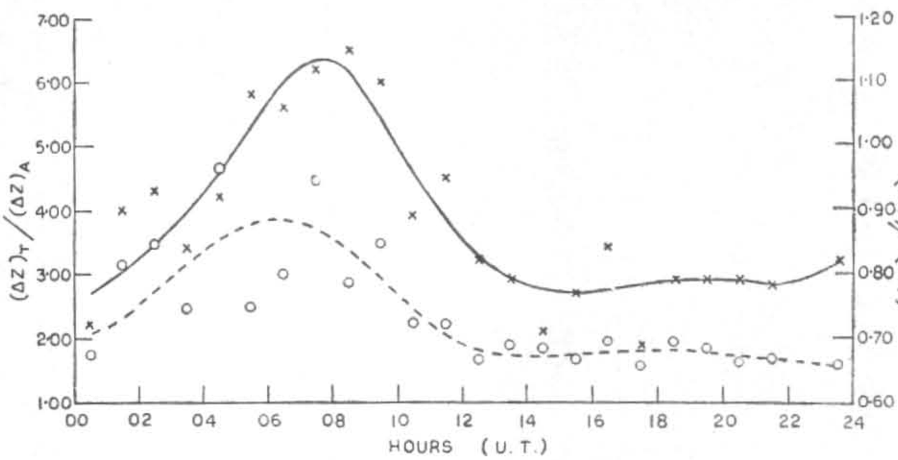

Fig. 1. Local-time variation of the ratios of SSC amplitudes

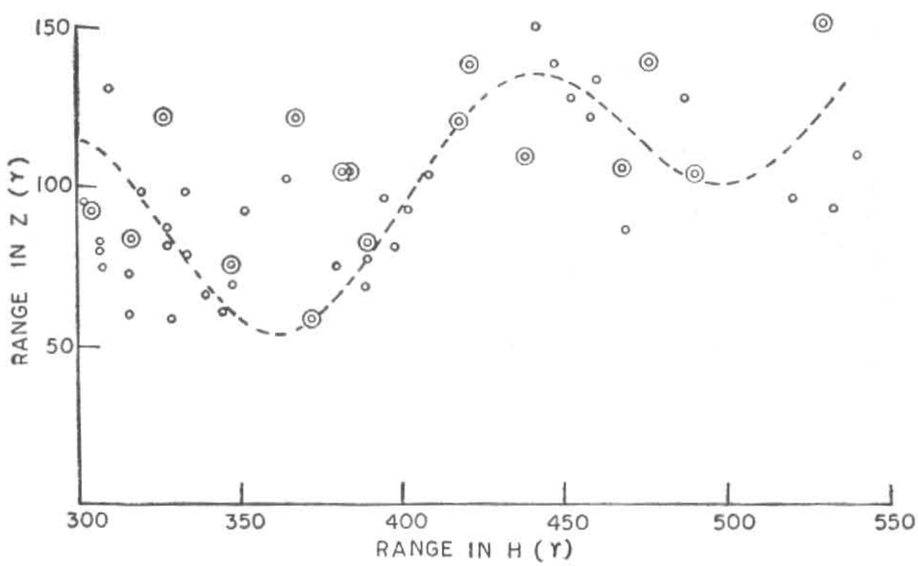

Fig. 2. Kodaikanal storm ranges in Z for moderately severe and severe storms

Parker 1959). The perturbation (Wilson and Sugiura 1961) is propagated to the lower latitudes by longitudinal and to the high latitudes by transverse hydromagnetic waves. The main deviation in the vertical force is small compared to horizontal force. For 30 sudden commencements observed at a number of stations, Matsushita (1960) computed the ratios of the deviation in Z to the positive deviation in H and found that the ratios varied from 0 to about 0·3. The signs of the ratios were found to be peculiar to the stations and were independent of the local time of occurrence or of the type of SSC. The day-time enhancement of the amplitude of the sudden commencement near the magnetic equator is believed to be associated with high Cowling conductivity at a height of about 100 km. For examining the characteristics of SSC amplitude and to determine the relative enhancement at Trivandrum on the magnetic equator the data of this station were compared with those of Annamalainagar at 2·7°N magnetic latitude. 114 SSCs in horizontal force and 106 in vertical force registered simultaneously at both the stations were grouped according to local time of occurrence and ratios of SSC amplitudes in H and Z at Trivandrum to the corresponding SSC at Annamalainagar were obtained and averaged for each hour. The local-time variation of the ratios in $(R_H)_T / (R_H)_A$ and $(R_Z)_T / (R_Z)_A$ in horizontal and vertical force respectively are shown in Fig. 1 (Subscripts T and A are for Trivandrum and Annamalainagar). The ratios in amplitude in HF are surprisingly smaller than unity for the major portion of a day. The relative enhancement of SSC amplitudes in HF at the magnetic equator is confined to a period of about 5½ hours centred around 1300 hrs local time. During the night time the SSC amplitudes in H at Trivandrum were only 80 per cent of those at Annamalainagar. In the vertical force, however, the relative enhancement at Trivandrum is found to be exceedingly large ranging from 170 per cent at night to about 400 per cent at about 1100 hours local time.

4. Storm ranges in the horizontal and vertical force

Forbush and Vestine (1955) have shown that in the equatorial region not only the amplitude of SSC is enhanced but the initial phase of a storm is also enhanced. For investigating the storm time phenomena, it is usual to confine the data to horizontal force variation at lower middle latitudes where the disturbance daily variations and polar storm effects are small. However, in view of abnormal amplitudes in SSC (Z) at the Indian stations the horizontal and vertical force absolute ranges for all storms during the major part of solar cycle 19 were examined for characteristics of ranges at these stations.

TABLE 1

Station	Geographic co-ordinates Lat. (°N)	Geographic co-ordinates Long. (°E)	Magnetic latitude (°N)	Period for which data available
Annamalai-nagar	11·4	79·7	2·7	1 Oct 1957 to 31 Dec 1962
Kodaikanal	10·2	77·5	1·7	1 Jan 1956 to 31 Dec 1962
Trivandrum	8·7	76·9	0·3	1 Oct 1957 to 31 Dec 1962

(a) Seasonal shift in storms with large range in Z

The number of magnetic storms shows an equinoctial maxima everywhere. Thus, at Kodaikanal the number of severe storms ($R_H \geqslant 400\gamma$) is largest during E months. However, if ranges in Z are considered and storms classified as severe when range in Z is greater than 100 γ a surprising feature is noticed. The number of such storms shows a considerable increase in J months. For a comparison, the seasonal distribution of 26 severe storms ($R_H \geqslant 400\gamma$) and of 32 storms ($R_Z \geqslant 100\ \gamma$) is shown in Table 2. There is a distinct shift of storms to J months when ranges in Z are considered as criteria for the classification as severe.

(b) Storm ranges and SSC amplitudes at the magnetic equator during northern summer

In the horizontal force, the storm ranges also are generally largest during E months. In vertical force, however, the largest ranges at Trivandrum are found to occur during J months. The average ranges based on 125 SSC storms are shown in Table 3.

In sudden commencements the average amplitudes for the season for all the three stations, shown in Table 4, are largest, both in H and Z, during the J months and smallest during the D months. The increase from D months to J months in amplitudes of V. F. of the SSC is largest at Trivandrum.

(c) In general, the storm ranges in Z increase with ranges in H. However, it is found that it is not always so and often the ranges in vertical force for certain storms are disproportionately large. In order to find how the ranges in Z varied with those in H for moderately severe and severe storms, all storms with $R_H \geqslant 300\ \gamma$ were considered and the ranges in Z were plotted against those in H. The plot for Kodaikanal is shown in Fig. 2.

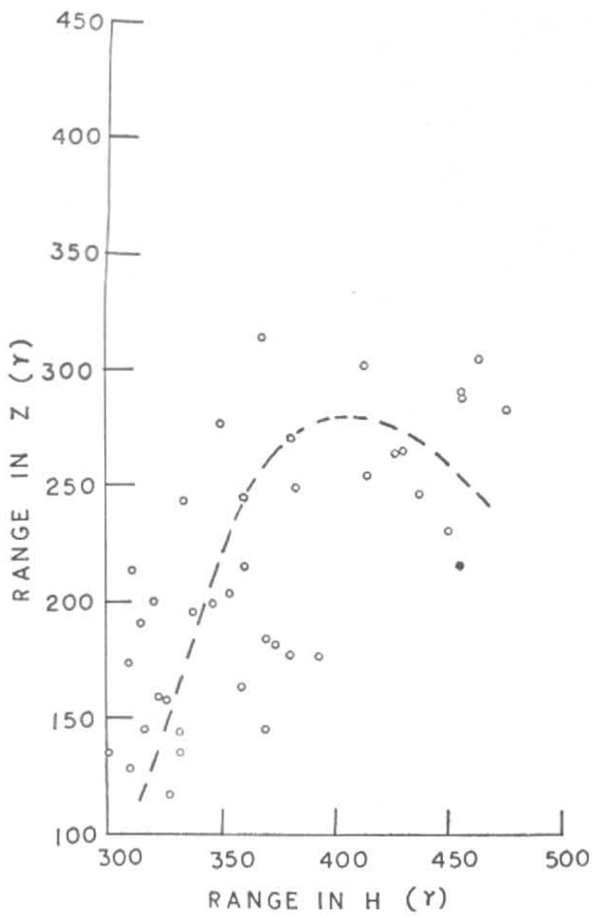

Fig. 3. Variation of the sto m ranges in Z with those in H at Trivandrum

TABLE 2

No. of storms with	J months	D months	E months
$R_H \geqslant 400\ \gamma$	5	6	15
$R_Z \geqslant 100\ \gamma$	12	5	15

TABLE 3

Average range (γ)	J months	D months	E months
H	278	225	287
Z	174	149	165

TABLE 4

Station	$(SC)_H$ ampl. (γ)			$(SC)_Z$ ampl. (γ)		
	J months	E months	D months	J months	E months	D months
Trivandrum	50·3	40·7	28·2	55·1	45·8	34·1
Kodaikanal	60·0	45·0	37·9	22·1	17·7	17·2
Annamalainagar	51·2	44·2	32·2	21·7	18·9	17·4

The ranges in Z are related to the ranges in H by —

$$R_Z = 0 \cdot 193\ R_H + 25$$

A surprising feature of the variation is that for storms with ranges in H between 325 and 550 γ a quasi-periodic change in Z range is observed. This has been indicated by a broken line in Fig. 2. The points enclosed by circles represent those storms which followed energetic particle solar events (PCA and GLE — events listed by Bailey 1964, and Obayashi and Hakura 1960). There is a general tendency for R_Z / R_H to be large following PCA events. The amplitude of the quasi-periodic variation indicates an effective variation in the inclination of the magnetic field at Kodaikanal of the order of 5 to 6 minutes.

Although the data available from the other two stations, *viz.*, Annamalainagar and Trivandrum are inadequate, these were examined for effects observed at Kodaikanal. There is no definite indication of this variation at Annamalainagar; at Trivandrum, however, there is some evidence of the quasi-periodic variation in Z. The plot for Trivandrum is shown in Fig. 3.

5. Discussion

In Sec. 2 it has been stated that most storms with large main phase followed SSCs which occurred in day time. This dependence of the magnitude of the main phase on the local time of SSC appears to indicate a diurnal enhancement of the early part of main phase of a storm in the equatorial region.

In this region the electrojet accounts for almost half the amplitude in the solar quiet-day variation in the horizontal force. If the enhancement in the quiet-day ranges and amplitudes of SSCs are only due to the effect of the electrojet, a systematic variation in these amplitudes should occur with respect to magnetic latitude at the three stations. Assuming an average half-width of the electrojet as 300 km and a height of 100 km, the maximum amplitudes in Z should be expected at a distance of about 316 km from the axis of the electrojet and the amplitudes in H should be largest near the axis. In the Indian equatorial region, however, they vary in a complex manner. The amplitudes at Annamalainagar in Z which should normally be the largest, are much smaller than those at Trivandrum. Even in the horizontal force, there is no evidence of any increase in the diurnal amplification of SSCs from 2·7° magnetic latitude as the magnetic equator is approached except for about 5½ hrs centred at noon. The figures in Table 4 indicate that the equatorial enhancement in SSC amplitudes is more or less uniform over a broad belt covering the three stations.

The $S(Q)$ field computations of Price and Stone (1964) indicate that during 1958 the quiet-day range in Z at Trivandrum varied from about 50 γ in winter to about 63 γ in the equinoxes. The data computed by them also show that at two of the low latitude stations, Trivandrum and Koror, there is a striking enhancement in $S_q\ (Z)$. The present investigation indicates that such an enhancement exists at Trivandrum both in Sudden Commencement amplitudes and in the magnitude of the main phase in the vertical component.

Parkinson (1961) has discussed the abnormal variation of the vertical component of the earth's magnetic field for coastal stations in relation to the shape of the continent and concentration of induced currents. The magnitudes of the short-period changes in Z are shown to depend on the relative depth of the ocean and the extent of reduction in the conductivity from the sea to the land. At stations close to the coast, the vertical component of the observed field is in the reverse direction to that of the inducing field (Ashour 1965). While the vertical force is enhanced at the coast, at sea just off the coast the horizontal force should be enhanced. The effect is very pronounced in rapid magnetic variations. Roden (1963) has discussed the effect of an ocean on the diurnal variation and his theoretical calculations for an idealized case indicate that even for magnetic variations with period as large as 24 hours an enhancement should be expected for a coastal station.

The magnetic observatory at Trivandrum is located at a distance of about 250 metres from the coast and the depth of the sea is 1000 metres within about 60 km of the coast. The magnitude of the induced currents can, therefore, be very large and appears to account for anomalously large quiet day variation, SSC amplitudes and storm ranges in the vertical component of the earth's field at this station.

The Annamalainagar magnetic station is also located close to the sea on the east coast at a distance of less than 20 km. Some enhancement should, therefore, take place in rapid fluctuations in Z at this station. Such an enhancement is observed if night-time data when electrojet effects are negligible are examined. The average night-time SSC amplitude in Z at this station was found to be 36 per cent greater than the amplitude at Kodaikanal for the corresponding SSCs. The magnitude of the enhancement is much smaller than at Trivandrum mainly because of relatively larger distance of the magnetic station from the sea. Roden has observed that in the case when the inducing field is a function of local time only, greater amplification of rapid magnetic variation in Z should be expected at the eastern edge of an ocean as compared to the western edge. The larger variations at Trivandrum which is located on the eastern edge of the ocean support this view.

6. Acknowledgement

The author is grateful to Shri A. Yacob for reading the manuscript and for his suggestions.

REFERENCES

Ashour, A. A.	1965	*Geophys. J.*, **10**, p. 147.
Bailey, D. K.	1964	Planet. Space Sci., 12, p. 495.
Chapman, S. and Ferraro, V. C. A.	1940	*Terr. Magn. Atmosph. Elect.*, **45**, p. 245.
Dessler, A. J. and Parker, E. N.	1959	*J. geophys. Res*, **64**, p. 2239.
Ferraro, V .C. A., Parkinson, W .C. and Unthank, H. W.	1951	*Ibid.*, **56**, p. 177.
Forbush, S. E. and Vestine, E. H.	1955	*Ibid.*, **60**, p. 299.
Matsushita, S.	1957	*Ibid.*, **62**, p. 162.
	1960	*Ibid.*, **65**, p. 1423.
	1962	*Ibid.*, **67**, p. 3753.
Obayasi, T. and Hakura, Y.	1960	*Ibid.*, **65**, p. 3143.
Parkinson, W. D.	1961	*Geophys. J.*, **6**, p. 441.
Pidington, J. H.	1959	*Ibid.*, **2**, p. 173.
Price, A. T. and Stone, D. J.	1964	Annals of the I.G.Y., XXXV, p. 63.
Roden, R. B.	1963	*Geophys. J.*, **8**, p. 375.
Wilson, C. R. and Sugiura, M.	1961	*J. geophys. Res.*, **66**, p. 4097.