Equatorial Enhancement of SSC Magnitudes

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Storm sudden commencement (SSC) magnitudes are known to be generally larger in the equatorial electrojet region. This aspect is studied in detail and it is shown that the equatorial enhancement ratio fluctuates over a very wide range and is not always commensurate with the equatorial electrojet strength. Large ratios during weak or reverse (counter) electrojets are not uncommon. During nights when electrojet is very small, ratios greater than, lesser than or equal to unity are observed. During daytime too, ratios as low as unity (no equatorial enhancement) are sometimes observed even when the electrojet is strong.

1. Introduction

When irregularities in interplanetary plasma encounter the earth, a sudden change occurs in the components of the geomagnetic field resulting into storm sudden commencement (SSC). Geomagnetic SSCs are composed of a *Dst* component (zonal part) and a *DS* component (local-time inequality) (OBAYASHI and JACOBS, 1957). As the superposition of these two parts, the SSC usually exhibits a positive change in the *H* component at middle and low latitudes but could be preceded and/or followed by a negative impulse (SSC*). The first impact of enhanced solar wind on the earth's magnetopause causes hydromagnetic waves which travel through the magnetosphere towards the earth and their isotropic modes give the zonal part of the SSC. ARAKI (1977) terms this part as DL_{MI} , i.e., the main impulse originating as an abrupt increase of the magnetopause current and succeeding dynamical processes such as changes in the ring current and the tail current. There is also another part DP_{MI} due to a polar electric field transmitted along lines of force from the upper magnetosphere. The magnitudes of SSC can be a few gamma to several tens of gamma and the rise times can be one to several minutes due to arrival from different points of the magnetospheric boundary. At middle latitudes, larger SSCs have shorter rise times (PISHAROTY and SRIVASTAVA, 1962; SRIVASTAVA and ABBAS, 1973). At the equator, this relation is obscure (NATARAJAN, 1969). A very fascinating aspect of SSC is the enhancement of their magnitudes in the equatorial electrojet

region. SUGIURA (1953), FERRARO (1954), FORBUSH and VESTINE (1955) showed for the American zone that the SSC magnitudes were enhanced by almost a factor of 3 (or even more) near the dip equator specially near noon hours, almost in the same way as the equatorial H range (electrojet) increased. MAEDA and YAMAMOTO (1960) showed that the daytime enhancement was seen right up to $\pm 20^\circ$ dip, though the ratio was larger near the dip equator. SIVARAMAKRISHNAN (1956), SRINIVASAMURTHY (1960) and YACOB and KHANNA (1964) showed that similar equatorial enhancements were seen in the Indian zone also during daytime while in the night, there was no enhancement. RASTOGI *et al.* (1964) showed that the enhancements were larger for the American zone (Huancayo) than for the Indian zone (Trivandrum), which was compatible with the known stronger electrojet at Huancayo as compared to Trivandrum (RASTOGI, 1962).

For the nighttime, ONWUMECHILLI and OGBUHEI (1962) reported that there was an equatorial *enhancement* in the African and American zones. RASTOGI *et al.* (1966), BHARGAVA (1967), GUPTA (1967), TRIVEDI and RASTOGI (1968) and SASTRI and JAYAKAR (1970) showed that whereas there was nighttime enhancement of SSC at the equator in the American zone, the Indian zone showed no enhancement and sometimes even an equatorial decrease. In particular, the nighttime ratio of SSC magnitudes (Trivandrum/Alibag) was about 0.8 while the ratio (Annamalainagar/Alibag) exceeded unity (about 1.2). It may be recalled that Trivandrum is almost at the centre of the electrojet while Annamalainagar is at its edge and Alibag is far outside the electrojet region.

From a study of SSC changes in the various geomagnetic components observed at different latitudes, WILSON and SUGIURA (1961) concluded that the transmission of the hydromagnetic waves from magnetopause towards earth was via longitudinal waves at low latitudes and by transverse waves at higher latitudes. To explain the peculiarities of SSC behaviour, JACOBS and WATANABE (1963) proposed that the electric field associated with the isotropic hydromagnetic waves causes a downward drift of the ionisation in the upper ionosphere, thus increasing the ionospheric E region electron *densities* and hence electrojet current. However, SCHUTZ *et al.* (1974) measured the electric *field* in the ionospheric E region during a sudden impulse (SI) and noticed an increase in the electric field. Thus, during an SSC, either the electron density or the electric field or both are likely to increase in the electrojet region. The currents to generate SSC at the equatorial region are composed of magnetospheric currents, ionospheric currents and currents induced underground or ocean effects (SCHUMUCHER, 1969). Whereas the magnetospheric currents are greatest at the equator and decrease slowly towards higher latitudes (ARAKI, 1977), the ionospheric currents would be generally proportional to the Sq current system and

would show the usual equatorial electrojet enhancement, provided the induced currents, which can often be complicated, are at least proportional to the overhead currents. In this communication we examine this aspect critically.

2. Analysis

We use data for SSC magnitudes of the H component of geomagnetic field at the equatorial stations Trivandrum (dip 0.7°S), Kodaikanal (dip 3.6°N), Annamalainagar (dip 5.4°N) and the low latitude station Alibag (dip 24.7°N), all at about 75°E longitude, for the 12-year period 1958–1969. A total of 275

Fig. 1. The average daily variation of H at Trivandrum (dip 0.7°S) and Alibag (dip 24.7°N) and their difference (Triv.—Alib.) for years 1958–69. The bottom plot shows the average *ratio* of SSC magnitudes at Trivandrum and Alibag for a total of 275 events in this period. The number of events in each LT interval is indicated and the vertical bars indicate *extreme* values of the ratios.

events are studied, distributed in various years and UT intervals. Since all UT intervals were not adequately represented in every year, data for all years for the same UT interval are combined.

Figure 1 shows the average daily variation of H at Trivandrum and Alibag and their difference. Thus, the extra electrojet (Triv. minus Alibag) occurs from about 0600 LT to 1800 LT with a maximum strength at about 1100 LT. The lowest curve shows the *average* value of the ratios of SSC magnitudes at Trivandrum and Alibag. For night hours, the ratio is almost unity (slightly less) while for sunlit hours, the ratio is above unity from 0600 LT to about 1800 LT, in general agreement with the finding of SUGIURA (1953). Thus, the enhancements of electrojet and the SSC amplitude ratios do seem to be in general parallel. However, for any particular LT interval, the ratios of SSC magnitudes were found to vary greatly from event to event. The extreme range is shown by the vertical bars. We propose to examine this aspect. Another interesting aspect is the phenomenon of counter-electrojet when sometimes during the morning or afternoon hours the H values in the equatorial region drop below even the night level, thus indicating *reversals* of the normal electrojet current directions (GOUIN and MAYAUD, 1967). What happens to the ratio of SSC

Fig. 2. Trivandrum SSC versus Alibag SSC (right half) and Kodaikanal and Annamalainagar SSC versus Trivandrum SSC (left half) for 0000-0700 LT. CEJ indicates a possible counter-electrojet. Different symbols indicate different LT. The lines are similar magnitude (45°) loci.

magnitudes at Trivandrum and Alibag when such a *counter-electrojet* is operative? We propose to examine this aspect too.

Figure 2 is a plot of SSC (H) magnitudes at pairs of stations for the mid-night-dawn period 0000–0700 LT. The plot on the right is for Trivandrum versus Alibag. Different hourly intervals are shown by different symbols. Surprisingly, there are more points below the 45° line than above it. This indicates that during these hours when electrojet does not exist, the SSC at Trivandrum is sometimes *smaller* than the SSC at Alibag as noticed earlier too by RASTOGI *et al.* (1964), BHARGAVA (1967) and GUPTA (1967). Some of these events (notably Aug. 29, 1960) were during counter-electrojets. On the other hand, there are some other odd events when Trivandrum magnitudes were much *larger* than the Alibag magnitudes. Thus, even during nighttime, the Trivandrum/Alibag ratio deviates considerably from unity *both ways*. Whereas some of these could be due to errors of measurement, many of the events seem to show genuine deviations. On the left in Fig. 2, the upper plot is Kodaikanal versus Trivandrum and the lower plot is Annamalainagar versus Trivandrum. Data for Kodaikanal were rather meagre, but for the few events that the plot represents, magnitudes at Kodaikanal and Trivandrum are almost similar. However, in the Annamalainagar-Trivandrum plot, most of the events indicate larger amplitudes at Annamalainagar. GUPTA (1967) and TRIVEDI and RASTOGI

Fig. 3. Same as Fig. 2, for 0700–1400 LT.

(1968) have reported an average ratio of 0.8 for (Trivandrum/Annamalainagar) at night. Thus, for some reason SSC magnitudes very near the dip equator are *reduced* in magnitude as compared to SSC magnitudes farther away. A plot of Annamalainagar versus Alibag (shown later) indicated slightly higher values at Annamalainagar.

Figure 3 shows similar plots for 0700–1400 LT when the equatorial electrojet is in full swing. Here, Trivandrum magnitudes are considerably larger than those at Alibag; but the slopes vary widely from event to event even for the same hourly LT interval (depicted by any one symbol). Surprisingly, magnitudes at both Kodaikanal and Annamalainagar are almost similar to those at Trivandrum, though one would have expected that Annamalainagar which is in the weaker part (edge) of the electrojet (5.4° dip) would show magnitudes much less than those at Trivandrum. The extra electrojet (excess of H range at station over H range at Alibag) at Annamalainagar is only about 25% of the extra electrojet at Trivandrum (KANE, 1973b), while Kodaikanal is about 95% of Trivandrum. The *average* SSC ratios of Alibag, Annamalainagar and Kodaikanal vis a vis Trivandrum are 0.48, 0.89 and 0.91 (TRIVEDI and RASTOGI, 1968). If excess of SSC magnitude over Alibag is calculated, the excess at Annamalainagar and Kodaikanal would be about 80 and 83% of excess at Trivandrum. Thus, for some reason, either SSC magnitudes at Kodaikanal and Trivandrum are *less* than what they should have been in lieu of their being near

Fig. 4. Same as Fig. 2, for 1400–1700 LT.

the centre of the electrojet, or, SSC magnitudes at Annamalainagar are unduly large.

Figure 4 shows similar plots for 1400–1700 LT, an interval when electrojet strength is subsiding and may become zero or even reverse (counter-electrojet). Thus, ratios from unity upwards are expected and observed. However, Annamalainagar again shows magnitudes similar to Trivandrum which would imply either that SSC magnitudes are the same throughout the $\pm 5^\circ$ dip belt of the electrojet region, or there is some inhibiting factor operative very near the dip equator which does not allow Trivandrum SSC to be very much higher than Annamalainagar SSC.

Figure 5 shows similar plots for the dusk-midnight period 1700–2400 LT. The plots are similar to those in Fig. 2 for 0000–0700 LT and here again, Trivandrum magnitudes are often *less* than those at Alibag and Annamalainagar indicating an inhibition effect very near the dip equator.

In the plots in Figs. 2–5, different hourly intervals were depicted by different symbols. However, even for the same hourly interval, the electrojet may not be equally strong on different days as the day-to-day variability of the equatorial electrojet strength is well known and is related to ionospheric dynamical upheavals (KANE, 1972). Could it be then that the ratio of SSC magnitudes (Trivandrum/Alibag) is proportional to the actual electrojet strength at Trivandrum at the moment when the SSC event occurred? To check this,

Fig. 5. Same as Fig. 2, for 1700–2400 LT.

1200 LT, the ratios are generally larger than unity but there is a very large scatter, indicating that the SSC magnitude amplification at Trivandrum is not proportional to the strength of the electrojet. For example, for an electrojet of 100 gamma the SSC magnitudes at Trivandrum seem to be anything from 1.0 to 3.5 times SSC magnitudes at Alibag. Figure 6(c) refers to 1200–1700 LT and includes events of afternoon counter-electrojets (negative ΔSd_I). Here again, scatter is large. Figure 6(d) refers to dusk-night hours and ΔSd_I are near zero and ratios are near unity; but a few deviations are seen.

Could this scatter be because we have mixed up data for high and low sunspot years? In Fig. 6(c) we have put the dates for some events. Three events in 1959 seem to be scattered wide apart. Thus, solar activity is not the cause of the scatter.

To check whether the parameter ΔSd_I used above as a source of the electrojet strength is faulty for some reason and whether the use of ΔH directly would perhaps bring more order, Fig. 7 shows a similar plot using ΔH of Trivandrum as abscissa. The scatter is similar in Figs. 6 and 7. In addition, nighttime ΔH values at Trivandrum deviate considerably from zero, indicating that ΔH is a less satisfactory parameter of the electrojet strength as compared to ΔSd_I , mostly due to storm-time contamination and/or long-term trends.

Fig. 7. Same as Fig. 6, with ΔH at Trivandrum as abscissa.

Instead of the parameter ΔSd_I defined above we also tried out the simpler parameter $\Delta(H_{\text{TRI}} - H_{\text{ALI}})$ considering deviations from pre-dawn level (FAMBITAKOYE *et al.*, 1973). Results were similar to those for ΔSd_I and hence are not shown here.

Figure 8 shows the plots of hourly values of ΔSd_I for a few selected days when SSC events occurred at times marked by the arrows during counter-electrojets in the morning hours (left half) and afternoon hours (right half), some post-dusk events included in the latter. The actual magnitudes of SSC observed at Trivandrum (numerator) and Alibag (denominator) in gamma and their ratio are indicated for each event as also the year, month, and date. For all these events, the ΔSd_I at the time of SSC is very near zero and sometimes significantly negative, indicating clear counter-electrojets. However, the ratios have a very wide range, from as low as 0.4 to as high as 4.3. Even allowing

Fig. 8. Daily variation plots of ΔSd_I at Trivandrum on selected dates (dates indicated) when SSC occurred at times (marked by arrows) in the morning (left half) and evening (right half). The SSC magnitudes in gamma at Trivandrum (numerator) and Alibag (denominator) and their ratio are indicated for each event.

for a possibility that the SSC magnitudes may have an error of about ± 2 gamma, the ratios are still in a very wide range. Thus, inhibition of SSC magnitudes at Trivandrum (low ratios) as well as their accentuation (large ratios) are often noticed and are not at all commensurate with the electrojet strength then existing.

Figure 9 shows actual plots of H values at Trivandrum and Alibag for a few selected events in 1966 which were included in Fig. 8. There is nothing unusual about the profiles of these events except that even though the electrojet strength was very small in each case, the ratios (Trivandrum/Alibag) for SSC magnitudes are 1.6, 0.7, 1.4 and 1.5, all different from unity.

To check whether such discrepancies are observed at other longitudes, the published records of SSC magnitudes at Huancayo and San Juan (American zone) were used. Figure 10 shows a plot of Huancayo (dip 2°N) versus San Juan (dip 48°N) for various LT intervals for 1958–69. The scatter is obvious

Fig. 9. Actual plots of H at Trivandrum and Alibag for a few hours around SSC events on Jan. 20, 1966 (SSC 0700 LT, TR/AL=1.6); Aug. 29, 1966 (SSC 1816 LT, TR/AL=0.7), Aug. 30, 1966 (SSC 1612 LT, TR/AL=1.4); Oct. 15, 1966 (SSC 1455 LT, TR/AL=1.5).

Fig. 10. Huancayo (equator) SSC versus San Juan (low latitude) SSC for 1958-69 for (a) 0000-0700 LT, (b) 0700-1200 LT, (c) 1200-1700 LT, (d) 1700-2400 LT (75°W).

with ratios as low as 1.0 or less and as high as 6 or more (even in early morning or late evening); and on two occasions (July 13, 1968 and May 1, 1967) the Huancayo magnitudes were *less* than those at San Juan, perhaps due to counter-electrojets. During night, the ratios deviate considerably from unity and can be as high as 2.0 though occasionally ratios less than unity are observed (e.g., Oct. 31, 1968, ratio 0.5).

It may be worthwhile checking how SSC at Alibag (dip 24.7°N) compare with SSC at other nonequatorial stations. Figure 11(a) shows a plot of Alibag SSC versus Hyderabad SSC (dip 20.5°N), a location roughly at the same latitude but about 500 km east of Alibag. Even for the limited data (1967-69), the two show remarkably similar SSC magnitudes at all LT hours, giving us confidence that Alibag values are correct. Figure 11(b) shows Alibag SSC versus San Juan SSC. These two locations are separated by about 9 hr local time. The magnitudes of SSC at the two locations do not seem to tally well. The ratio deviates considerably from unity, with a large scatter. In particular during dusk-midnight (1700-2400 LT) for Alibag when San Juan is near noon (0800-1500 LT), San Juan SSC are consistently *smaller* than Alibag SSC, while at other hours, the two are comparable. It would thus seem that SSC magnitudes are larger during nights for middle latitudes. For Alibag, SASTRI and JAYAKAR (1969)

Fig. 11. Alibag SSC versus SSC at (a) Hyderabad, (b) San Juan, (c) Sabhawala, and (d) Annamalai Nagar for (I) 0000–0700 LT, (II) 0700–1200 LT, (III) 1200–1700 LT and (IV) 1700–2400 LT (75°E time).

have shown that the average SSC sizes are largest around midnight and smallest at about 04–06 LT. We compared San Juan SSC with SSC at Tucson (dip 59°N) and Honolulu (dip 39°N) but the correlations were not very good. This needs further scrutiny. Figure 11(c) shows Alibag SSC versus SSC at Sabhawala (dip 45°N), a location to the far north of Alibag. The data are scanty but Sabhawala SSC are consistently larger than Alibag SSC, probably because of the comparative proximity of Sabhawala to auroral regions. In the American zone too, Tucson SSC were generally larger than San Juan SSC. However, Sabhawala SSC were always larger than San Juan SSC, though both locations have about 45°N dip, albeit at very different longitudes (9 hr apart). Figure 11(d) shows Alibag SSC versus SSC at Annamalai Nagar, a location at the edge of the electrojet region. During nights, the ratio (Annamalai Nagar/Alibag) is slightly larger

than unity (about 1.1 to 1.2). During daytime, the ratios can be as high as 2 to 3 which is very surprising as the electrojet is certainly not so strong at Annamalainagar. Thus, SSC enhancements in the electrojet region are far too large and noncommensurate with the enhanced electrojet current.

3. Summary and Conclusions

The results of this study may be summarised as follows:

a) During night hours SSC magnitudes at equatorial and nonequatorial low latitudes are not always alike. On several occasions equatorial magnitudes are significantly *smaller* and on several others, these are significantly *larger*. This does not seem to be due to errors in observations. In the Indian longitudes (75°E), Annamalainagar which is at the edge of the electrojet region shows in general larger magnitudes than Trivandrum or Kodaikanal nearer dip equator. Thus, an *inhibitory* effect nearer the dip equator is indicated on some occasions. It is likely that the data in this region are affected by peculiar earth and/or ocean currents or conductivity anomalies. On some other occasions, equatorial enhancements are seen, even during night. In the American zone, nighttime equatorial enhancements are more frequent and larger.

b) During counter-electrojets, locations nearer the dip equator sometimes show less SSC magnitudes than those for locations outside the electrojet region. However, there are many occasions when similar circumstances produce a reverse effect (equatorial enhancement of SSC). Thus, at times when the H component is at the zero level (night time) or below it (counter-electrojet), the ratio (equator/non-equator) could be significantly higher than, lower than, or equal to unity.

c) During daytime, the equatorial SSC magnitudes are *in general* higher; but the enhancement ratio is not proportional to the strength of the electrojet. Ratios exceeding 2 or 3 during weak electrojets or ratios between 1 and 1.5 during strong electrojet are frequent.

These results are based mainly on data from the Indian zone and hence the conclusions too apply mainly to the Indian zone.

The exact mechanism of enhancement of SSC magnitudes in the equatorial electrojet region is not yet fully understood. SUGIURA (1971) suggested that a compressional hydromagnetic wave propagating from the magnetospheric boundary downwards into the ionosphere will create a polarisation electric field at the wave front when the wave hits the dynamo layer and the Hall current from the polarisation field will give rise first to a negative impulse and then a positive impulse. This would imply that the electrojet region enhancement of SSC should be roughly proportional to the electrojet strength, which is not at all borne out

by the present study. Larger ratios for small electrojet strength or vice versa are very common. It seems that the interaction between the hydromagnetic waves and the ionosphere is much more complex than envisaged above by SUGIURA (1971). This needs further scrutiny.

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