Solar flare effects in geomagnetic field at Indian stations—Part I: Trivandrum, the centre of equatorial electrojet

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The paper describes the solar flare effects (SFEs) in horizontal (H), eastward (Y) and vertical (Z) components of the geomagnetic field at Trivandrum for the period 1957-1982. The impulse in H and Z fields shows a maximum at 1030 hrs LT, significantly before noon. The SFE impulse in Y shows a maximum in forenoon and minimum in afternoon hours. The ratio ΔZ/ΔH is abnormally large (=1.2) and is almost constant for any time of the day. The individual values of ΔZ/ΔH are larger for faster growth of the flare. The abnormal SFE (Z) is suggested to be due to the concentration of general induced current over wide latitude zone both sides of the equator through Palk Strait, besides the electromagnetic induction of ionospheric current in the narrow band of conducting graben in Palk Strait between India and Sri Lanka. The induction is shown to be directly proportional to the growth time of the flare impulse in H field.

1 Introduction

The solar flares cause a temporary increase of solar ionizing radiation and have been considered to cause a simple augmentation of the S4 current1. Nagata2 studied these geomagnetic crochets at Huancayo, Kakioka and Watheroo and found good time-correlation in the development and decay of the product at these stations. The availability of large data during IGY period enabled the computation of the current system for individual solar flares3,4.

Nagata5 in his study of the global distribution of 15 typical SFE during the IGY, found that there was a perfect simultaneous relationship between optical and radio geomagnetic solar flares and the absorption of radio waves in the ionosphere.

Forbush and Casavere6 showed that the enhancement of the amplitude of H field at Peruvian stations varied in a manner similar to the S4(H) itself. Rajaru and Rao7, Rastogi et al.8 and many others9,10 have described extensive studies of solar flare effects in H at Indian stations. Studying the magnetograms at Annamalainagar over the period 1969-1976, Rastogi11 concluded that the solar flare produced meridional current flow in the same region of the ionosphere as that of the zonal component of electrojet current. Describing the effect of solar flare in H, Y and Z fields due to the extraordinarily strong crochet at 1311 hrs LT on 15 June 1991, the impulses in Z were found to be strong positive at the equatorial stations Trivandrum, Etaiyapuram and Annamalainagar12. If the SFE is due to the intensification of the normal equatorial electrojet current then the impulse in Z should have been strong negative at the northern fringe region of the electrojet current belt. After critical study of solar flare effects at the equatorial electrojet station in American sector, Huancayo, Rastogi13 concluded that there were very small impulses in Z field during solar flares. Rastogi et al.14 described the solar flare effects in H, Y and Z at stations in Indo-USSR chain of magnetic observatories extending from the magnetic latitudes 0° to 45°N. During normal electrojet conditions, the impulse of SFE in Z was shown to be positive at all the four equatorial stations Trivandrum, Etaiyapuram, Kodiakanal and Annamalainagar, but at all other stations, SFEs in Z were negative. Rastogi15 scaled the amplitudes of SFE in H, Y and Z at the equatorial electrojet stations around the world during IGY. It was found that SFEs in H were positive and maximum at around noon at any of the stations. The SFE in Y were small and no diurnal pattern was noticed. The SFEs in Z were very small at Huancayo and Addis-Ababa. The SFEs in Z were positive at Koror, the ratio ΔZ/ΔH being about 0.5. The ΔZ impulses at Trivandrum were positive and significantly larger than the corresponding ΔH, and

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the average $\Delta Z/\Delta H$ varied between 1.0 and 2.0. This abnormal effect in $Z$ field was suggested to be due to the electromagnetic induction in the conducting graben in the Palk Strait in between southern tip of India and Sri Lanka. A closer scrutiny of the magnetograms at Annamalainagar showed some impulses in $Z$ to be positive and some others to be negative.

Hence, a study of the solar flare effects in $H$, $Y$ and $Z$ at Trivandrum, Annamalainagar and Alibag covering an extended period of observations was undertaken and the present paper is the result of these investigations. The occurrences of the solar flare effects were identified from the Bulletins Series 12 of the International Association of Geomagnetism and Aeronomy (IAGA). The amplitudes of impulses in $H$, $Y$ and $Z$ components were scaled from the microfilm copies of the magnetograms itself. The period of study covered is 1957-1982. The large and small flares were identified from the large and small impulse in the $H$ field. Further, the slow and fast flares were identified on the basis of the temporal variation of the impulse in $H$ field. No comparison has been made in this paper between the magnetic crochet and UV or X-ray fluxes of the solar flares.

This paper (Part I) describes the results for Trivandrum. The coordinates and other specifications of Trivandrum are given as follows:

- Geographic latitude: 8° 29’ N
- Geographic longitude: 76° 57’ E
- Geomagnetic latitude: 0° 54’ S
- Geomagnetic longitude: 148° 18’ E
- Inclination ($I$): -0° 36.3’ (1959), -0° 4.9’ (1982)

### 2 Daily variations of $H$, $Y$ and $Z$ fields

First, the daily variations of $H$, $Y$ and $Z$ fields are studied at Trivandrum, averaged for International Quiet (IQ) days of a year of maximum solar activity (1958) and a year of minimum solar activity (1964). These are shown in Fig.1.

The $\Delta H$ during any of the years showed a single peak around 1100 hrs LT, the peak value being about 150 nT in 1958 and about 80 nT in 1964. During 1964, the $\Delta H$ decreased to base value by 1600 hrs LT; but in 1958, $\Delta H$ decayed slowly to the base value by midnight. The eastward field ($\Delta Y$) showed a small maximum between 0700 and 0800 hrs LT and a minimum during 1100-1200 hrs LT. The $\Delta Z$ showed a strong positive peak during 0900 and 1000 hrs LT and a flat minimum in the afternoon hours. It is to be noticed that the minimum occurred significantly at later times in 1958 than in 1964. The daily variation of $\Delta Z$ appears to be closely represented by the time-gradient of corresponding daily variation of $H$ field. The abnormal variation of $\Delta Z$ at Trivandrum, situated almost at the magnetic equator, is generally attributed to the electromagnetic induction in sub-surface conducting region. Then, one has to conclude that the induction is related to the temporal gradient of $\Delta H$ rather than the scalar value of $\Delta H$ itself.

### 3 Results of solar flare effects at Trivandrum

In Fig.2 are reproduced the tracings of $H$, $Y$ and $Z$ magnetograms for few days when solar flare had occurred. On 3 Feb. 1983, there was a solar flare at 1200 hrs LT.
1058 hrs LT with an impulse $\Delta H$ of 108 nT, $\Delta Z$ of 72 nT, and $\Delta Y$ of insignificantly small magnitude. The solar flare at 1232 hrs LT on 9 July 1982 had produced $\Delta H = +122$ nT, $\Delta Z = 82$ nT and $\Delta Y = -8$ nT. There was a very sharp and strong solar flare on 15 June 1991 at 1311 hrs LT producing $\Delta H = 187$ nT, $\Delta Z = 180$ nT and $\Delta Y = -14$ nT. On 13 April 1974, there were three solar flares at 0918 hrs LT, 1025 hrs LT and 1251 hrs LT. In each of the cases, $\Delta Z$ values were positive and comparable in magnitude to the corresponding $\Delta H$. The impulses in $Y$ field were too small to be recorded. On 5 June 1982, there were

Fig. 2—Reproduction of $H$, $Y$ and $Z$ magnetograms at Trivandrum on some days when solar flare effects were observed.
three flares—one at 0627 hrs LT during counter electrojet condition and two at 1115 hrs LT and 1230 hrs LT during the state of a strong normal electrojet. Strong positive $\Delta Z$ values recorded during midday flares were larger than the corresponding $\Delta H$ values. This conforms to the earlier results that the solar flare impulses in Z field at Trivandrum are anomalously large.

In Fig.3 are shown the temporal variations of the mean amplitudes of $\Delta H$, $\Delta Y$ and $\Delta Z$ as well as of $\Delta Z/\Delta H$. The daily variation of the SFE in $H$ was very similar to that of $S_0 (H)$ itself except that the peak of crochet in $H$ occurred significantly before noon. The daily variation of SFE in $Z$ is similar to that of $H$ and thus differs from the $S_0 (Z)$ shown in Fig.1. The diurnal variation of SFE in $Y$ field was small, but had a peak in the morning and a minimum in the afternoon hours similar to the $S_0 (Y)$ variation. The ratio $\Delta Z/\Delta H$ varied between 1.1 and 1.3 and had statistically no diurnal variation.

In Fig.4 are plotted individual values of $\Delta Z$ against the corresponding value of $\Delta H$ due to SFE at Trivandrum. It is very clearly seen that $\Delta Z$ increases consistently with increasing $\Delta H$. However, the points lie within a large range of the slope of regression line with $\Delta Z/\Delta H$ from 0.7 to 2.0. It is interesting to note that the negative values of $\Delta H$ due to the flare occurring at the counter electrojet period produce the negative impulse in the $Z$ field of magnitude comparable to or even exceeding the corresponding amplitude of $\Delta H$. These results are in conformity with the study of some individual flares by Rastogi et al.\textsuperscript{14}

In Fig.5 are shown the mass plots of individual ratio of $\Delta Z/\Delta H$ against the corresponding $\Delta H$. It is seen that the ratio $\Delta Z/\Delta H$ varies from a low value of 0.5 to as high a value as 2.0, both for flares during normal as well as the counter electrojet periods. There is no tendency of a definite relationship between the value of ratio $\Delta Z/\Delta H$ and the amplitude of SFE in $H$. Thus, it is not true that the larger flare produces larger $\Delta Z/\Delta H$. It was realized, while examining the magnetograms, that during fast flares, when the rising portion of the trace was sometimes too faint to be recorded in the photographic paper, the $\Delta Z$ was significantly larger than the corresponding $H$ indicating some increase of $\Delta Z/\Delta H$ with the rate of growth of SFE in $H$. During the counter electrojet events impulses in $H$ are, generally, small and negative. The corresponding impulse in $Z$ is also of the same magnitude and negative in sign.

In Fig.6 is shown the mass plot of $\Delta Z/\Delta H$ against the rate of growth of the flare in $H$. These data were scaled directly from the magnetograms, as it was rather difficult to use the microfilms for this purpose. The analysis was confined for the period Jan. 1980-Dec. 1982. It is clearly seen that the ratio $\Delta Z/\Delta H$ is linearly related to the growth rate of the flare.

4 Discussion

During the IGY period, the daily range of Z field at Trivandrum, Annamalainagar and Alibag was found
to be +58 nT, +54 nT and -46 nT, respectively. Srivastava and Sankaranarayan suggested this anomalous behaviour of $\Delta Z$ at Trivandrum and Annamalainagar as due to the coastal effect and such surface conductivity anomaly without any clear explanation. Rastogi showed that large positive value of the range of $S_q(Z)$ is observed at equatorial stations Kanyakumari, Trivandrum and Etaiyapuram. At Kodaikanal and Annamalainagar the daily range of $S_q(Z)$ is negative. The observed ratio of the daily ranges of $Z$ in relations to that of $H$ was shown to be between 0.3 and 0.4. It was also shown that the

induction of the overhead electrojet current in the sub-surface conductor at any depth could not explain the large positive value of the daily range of $Z$ at Trivandrum.

Rajaram et al. suggested channelling of the internal currents through a conductor in the upper mantle or in the lower crust between India and Sri Lanka. But again, no quantitative estimates are made. The large value of $\Delta Z/\Delta H$ exceeding 1.0 during storm sudden commencements (SSCs) as well as during solar flares cannot be, possibly, due to the deep-seated conductors.

Rastogi et al. have studied the latitudinal profiles of storm sudden commencement amplitudes in $H$, $Y$ and $Z$ at Indo-Russian chain of observatories for the daytime and nighttime events. An abnormally large positive impulse of $Z$ is recorded at the equatorial stations with a maximum at Trivandrum during the daytime as well as in nighttime. A prominent decrease of nighttime SSC($H$) over the equator was noticed and was explained as due to the concentration of induced currents from the source field extended in latitude.

The observed effect of SFE in $Z$ field at Trivandrum is suggested not to be directly due to the effect of the increase of the electrojet current during the solar flare. Most probably it is due to the electromagnetic induction in the narrow belt of the sub-surface conductor in the Palk Strait between India and Sri Lanka. The magnitude of the induction is directly proportional to the temporal variation of the

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Fig. 4—Solar flare effects on $\Delta Z$ plotted against corresponding $\Delta H$ at Trivandrum

Fig. 5—Ratio of $\Delta Z/\Delta H$ due to the solar flare effects plotted against the corresponding $\Delta H$ at Trivandrum
ionospheric current due to the flare. The source current being eastward, the induced current would produce large positive impulse in $Z$ field near the northern boundary, i.e. near the southern tip of Indian subcontinent. It is expected that any station in the western coast of Sri Lanka should experience large negative value of $\Delta Z/\Delta H$ due to solar flare.

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