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Effect of solar disturbances on the geomagnetic H, Y and Z fields in American equatorial electrojet stations I Solar Flare Effects

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ABSTRACT
The paper describes the solar flare effect (sfe) in horizontal (H), vertical (Z) and eastward (Y) components of the geomagnetic field at the equatorial electrojet station over the years 1958-1977. It is supplemented by similar study of magnetograms at others equatorial station Yauca, Chimbote, Chiclayo, Talara and Fuquene for the years 1957-1959. The amplitudes of sfe in both H and Y fields at any of the stations are enhanced at about two hours before noon but the effect on Z field are small. This is shown to be in contrast to large sfe in Z and small sfe in Y at Trivandrum, the electrojet station in India. The abnormal variation of sfe in Z are suggested as due to induction of conductive regions below the Andes. The difference in the induction effects Indian and American longitudes may be due to different orientations of the subsurface conducting regions.

INTRODUCTION

The solar quiet day, Sq, variations of the horizontal, H, eastward Y and vertical Z fields at low and middle latitudes are assumed to be the effect of the electric currents in the ionospheric E layer during the daylight hours. The current is the product of the ionization (Ne) produced by the solar radiations and the electric field (E) produced by the motion of these ionized regions across the vertical component of the earth's geomagnetic field due to the gravitational tides of the moon and sun. The abnormal enhancement of the daily range of Sq H at stations close to the magnetic equator has been attributed to enhanced electrical conductivities due to the orthogonality of the electric and magnetic field near the dip equator. Rastogi (1983) showed that the long term like solar cycle variation of the range of Sq H at equatorial latitude is controlled mainly by corresponding variation of sunspots while the seasonal variation of Sq H is controlled by the electric field. The daily variation of H at electrojet station was shown to be the product of Ne and E. The daily variation of the geomagnetic field is shown to be affected by the apparent rotation of the earths magnetosphere together with the sun with respect to the station fixed on the solid earth (Olson 1989).

Besides the regular radiations from the sun, occasionally transient burst of radiation comes from the sun following the eruption of solar chromosphere, known as solar flare. There are also bursts of solar charged particles reaching the earth causing sudden storm commencements (ssc). The solar flare effect (sfe) is due to a pure ionization enhancement without any change of electric field, but ssc is associated with the electric field effect without any change of local ionization. These transient events of solar disturbance can be a good diagnostic for studying the direction of ionospheric current vector and for understanding the important solar terrestrial relationship.

During the 1GY – 1GC (July 1957 – December 1959) period, Carnegie Institution of Washington USA had established four temporary geomagnetic observatories at Talara, Chiclayo Chimbote and Yauca besides the permanent observatories at Huancayo, Peru and Fuquene, Columbia. Forbush & Casaverde (1961) described some preliminary results of the analysis of these data, but most of the data has remained without any detailed analyses. Copies of original magnetograms are available from the World Data Centre A for Geophysics in Boulder, Colo, U.S.A. These stations together with their geographic and geomagnetic coordinates are listed in Table 1.

Table 1. List of stations whose data is used together with the geographic and geomagnetic coordinates.

Stations	Code	Geographic		Inclination	Declination
		Lat.	**Long.**	°N	°E
Teoloyucan	TEO	19.8	260.8	29.0	7.7
Sanjuan	SJG	18.1	293.9	29.6	-9.6
Fuquene	FUQ	5.5	286.3	33.0	-2.3
Talara	TAL	-4.6	278.7	14.2	4.4
Chiclayo	CCL	-6.8	280.2	10.6	4.1
Chimbote	CMB	-9.1	281.4	6.6	4.0
Huaneayo	HUA	-12.1	284.7	2.1	2.7
Yauca	YAU	-15.5	285.3	4.6	3.3
Trivandrum	TRD	8.5	77.0	-1.7	2.8

The microfilm copies of the magnetograms from all these stations were acquired by the authors through the Arthur Day Awards Fund. The amplitudes of sfe and ssc in the H, D and Z compounds at all the stations were scaled by the author himself. This paper describes the features of the solar flare effects and the accompanying paper describes the ssc at these stations in the equatorial electrojet region in American longitude sector.

SOLAR FLARE EFFECTS AT HUANCAYO

First of all we examine the sfe events observed at Huaneayo over the extended period of 1957 to 1977. In Fig.1 (a) and (b) are reproduced the magnetogram traces at Huaneayo showing solar flare effects on normal electrojet and counter electrojet periods respectively.

The amplitudes of sfe in ΔH, ΔY and ΔZ together with Hα index are shown in each case. Because of varying scale values of different component, the amplitude of sfe in H, Y and Z can not be estimated by direct viewing. The impulses in H, Y and Z due to solar flare are indicated for each of the events. During normal EEJ periods the impulse in any of the components H, Y and Z is always positive. The largest crochet in H during the period of study was on 7 August 1972 at 10 34 L.T. with Hα index of +64. The amplitude of sfe was 230 nT for H, 35 nT for Y and only 20 nT for Z. Even during the other strong flares ΔZ was only between 5 and 15 nT.

In Fig. (1b) are shown some negative crochets in H at Huancayo. These occurred mostly in the morning and evening hours during the counter electrojet period when the H field was lower than the night time levels, the impulse in Y and Z were negative suggesting the reversed electrojet current during these periods. On few occasions negative impulse was recorded in H field when the mean H field was well above the night time level. On 3 January 1960 two flares occurred at 1240 LT with Hα index of +7 and with ΔH = +22 nT, ΔY = +3 nT and ΔZ =

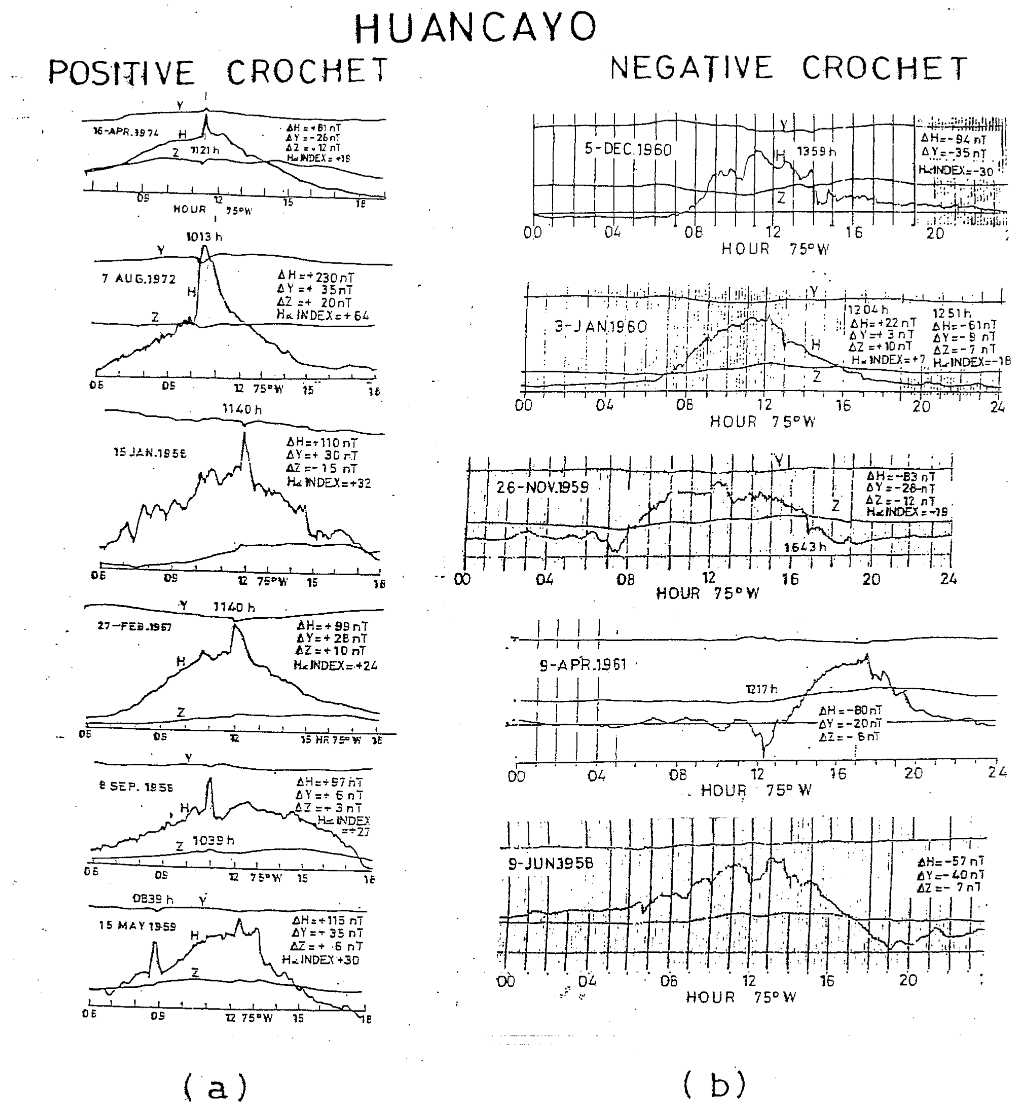

Figure 1(a,b). Traces of magnetograms at Huancayo showing examples of positive and negative crochets in H field.

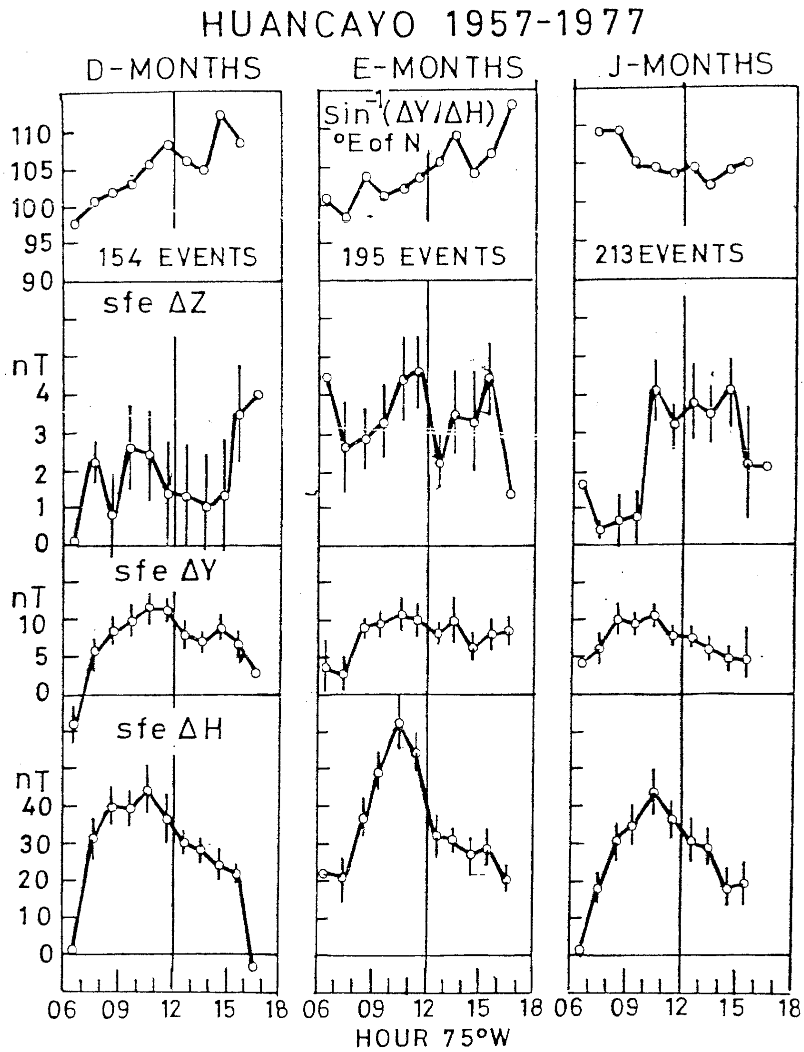

Figure 2. Diurnal variations of the amplitudes of sfe in H, Y and Z fields at Huancayo and the direction of flare current vectors given by q = $\sin^{-1}$ (DY/DH) averaged for the three seasons of the years 1957-1977.

+ 10 nT; at 1251 LT there was another flare with ΔH = -61 nT, ΔY = -9nT and ΔZ = -7 nT and Ha index was –18. The cause of these few abnormal negative erochet needs further investigation.

Fig.2 shows the daily variations of the amplitudes of sfe in H, Y and Z components averaged for these seasons of the years 1957 – 1977. The daily variations of the direction of the current vector due to the solar flare $\theta = \sin^{-1} \Delta Y/\Delta H$ are also shown for the three seasons.

The daily variations of sfe in H showed a maximum about two hours before noon. The maximum day time value of sfe in H was largest in E months. These features are similar to the daily and seasonal variations of the Sq (H) itself.

The daily variations of amplitude of sfe in Y field also indicate a maximum in the pre-noon hours. The sfe in Z were small and randomly distributed with time.

The sfe current vector was around 100-110°E of north, i.e. 10-20° south of east. This is in agreement with the results of an earlier study (Rastogi 1999). The direction of Sq current vector at Huancayo has been shown to be on the average = 13°S of east (Rastogi & Chandra 2002). Thus the flare current vector is generally in the same direction as that of normal electrojet current vector.

The Solar Physics Observatory at Huancayo have been computing the Hα flux index of the solar flare observed by them. In Fig.3 are shown the relationship between the ΔH due to sfe against the Ha index. The number noted against each point indicates the number of observations. A linear relation between ΔH and Hα index is clearly seen.

In Fig.4 are shown the yearly mean of the amplitude of ΔH due to sfe and the yearly mean sunspot number. A direct relationship between the amplitude of sfe ΔH and sunspot number is clearly seen.

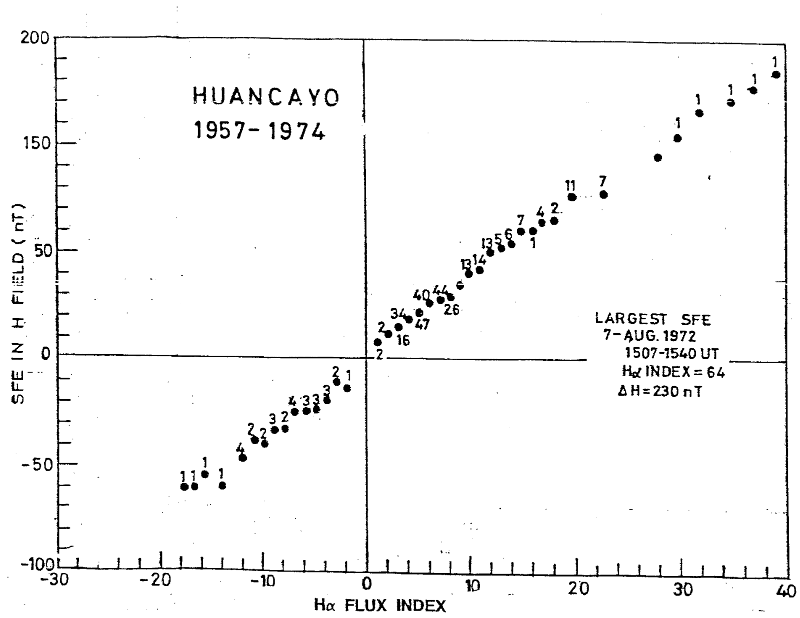

Figure 3. The relation between the amplitude of sfe in H at Huancayo and the Ha solar flux index of the solar flares.

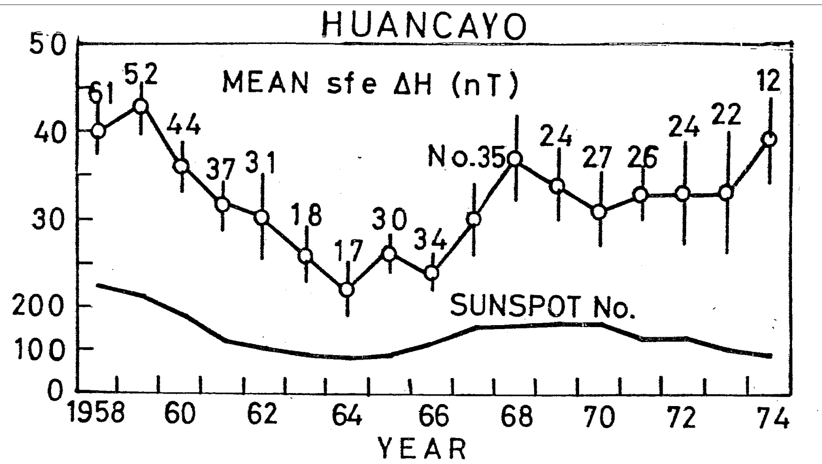

Figure 4. Solar cycles variations of the yearly average amplitude of midday sfe in H at Huancayo.

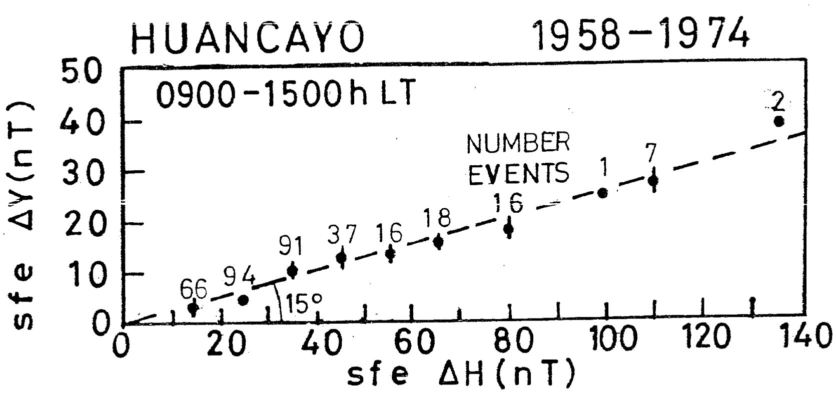

Figure 5. Relation between the sfe in Y against sfe in H at Huancayo for the years 1958-1974.

In Fig.5 are shown the relationship between the midday amplitudes of sfe ΔY against sfe ΔH. A linear relation indicates that the meridional component of the flare induced current is an integral part of the electrojet current itself.

In Fig.6 are shown the diurnal variations of sfe in H, Y and Z averaged over the years 1957-1977. Only other equatorial electrojet station for which similar data are available is Trivandrum and therefore the averaged diurnal variations of sfe in H, Y and Z averaged over the years 1957-1982 are also shown for comparison. Because of the large number of flares data used here it is expected that the characteristies of individual flares are eliminated in the averaging process and the curves indicate genuine diurnal variation. The amplitude of sfe in H field are maximum at both HUA and TRD around 1030 LT. The amplitude of sfe in H at any particular hour is larger at HUA than at TRD but the difference is not very large.

The amplitude of sfe in Z at HUA are very small being less than +5 nT and is as expected of the Chapman's model of equatorial electrojet for a station very close to the magnetic equator. The amplitudes of sfe in Z at TRD are extraordinarily large and have been suggested to be due to electromagnetic induction in the subsurface conducting region anomalies (Rastogi 2001).

The sfe in Y field at HUA are significantly large being around 10 nT during 08-11 LT in a similar way in the daily variations of Sq Y itself. The sfe in Y at TRD are small and always between 2 nT. Thus there are significant regional anomalies in sfe as in the case of the electrojet itself.

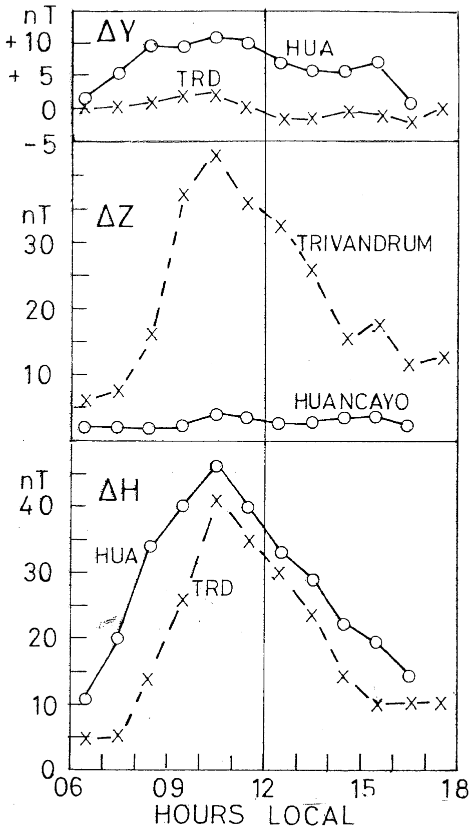

Figure 6. Annual average local time variations of the solar flare amplitudes in H, Y and Z fields at Huancayo and Trivandrum.

LATITUDINAL VARIATION OF THE SOLAR FLARE EFFECTS IN X,Y AND Z

Before discussing the effect of solar flare on H, Y and Z fields at different stations, the normal Sq variations of H, Y and Z are computed and are shown in Fig.8 for stations YAU, HUA, CMB, CCL and TAL. As expected the daily variation of H at any of the stations maximizes about an hour before noon. The maximum daily value of H is largest at HUA, less at YAU and then decreases progressively with increasing distance from the Huaneayo. The amplitude of SqH normalized to that at Huancayo was 0.85 for YAU, 0.69 for CMB, 0.58 for ECL and 0.54 for TAL. The SqZ showed midday minimum at HUA and all northern stations, the magnitude of the minimum being largest at CMB. The SqZ at YAU showed exceptionally large value being about half of the SqH at the same place. The Sq Y at YAU and HUA showed a maximum around noon, and its variation was small at other stations. The Sq current vector a southerly direction in forenoon and northerly direction in the afternoon hours for stations north of equator but YAU indicated northerly direction at both the prenoon and afternoon hours.

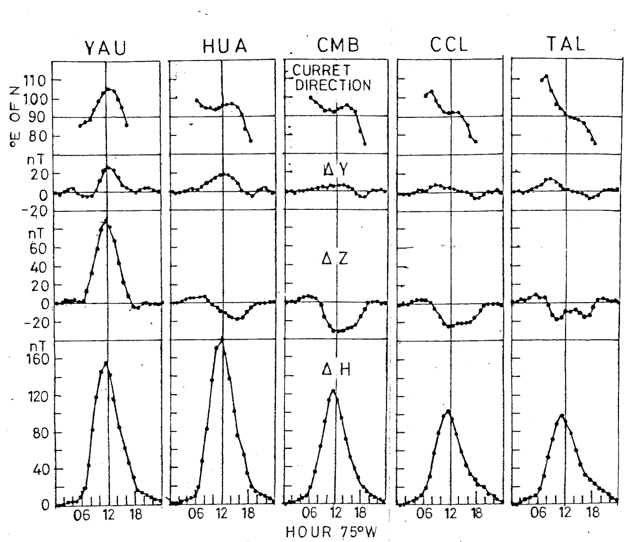

Figure 7. Daily variations of the H, Y and Z components of the geomagnetic field and of the direction of current vector q = $\sin^{-1}$ (DY/DH) at electrojet stations in Peru averaged for the years 1958-1959.

a)

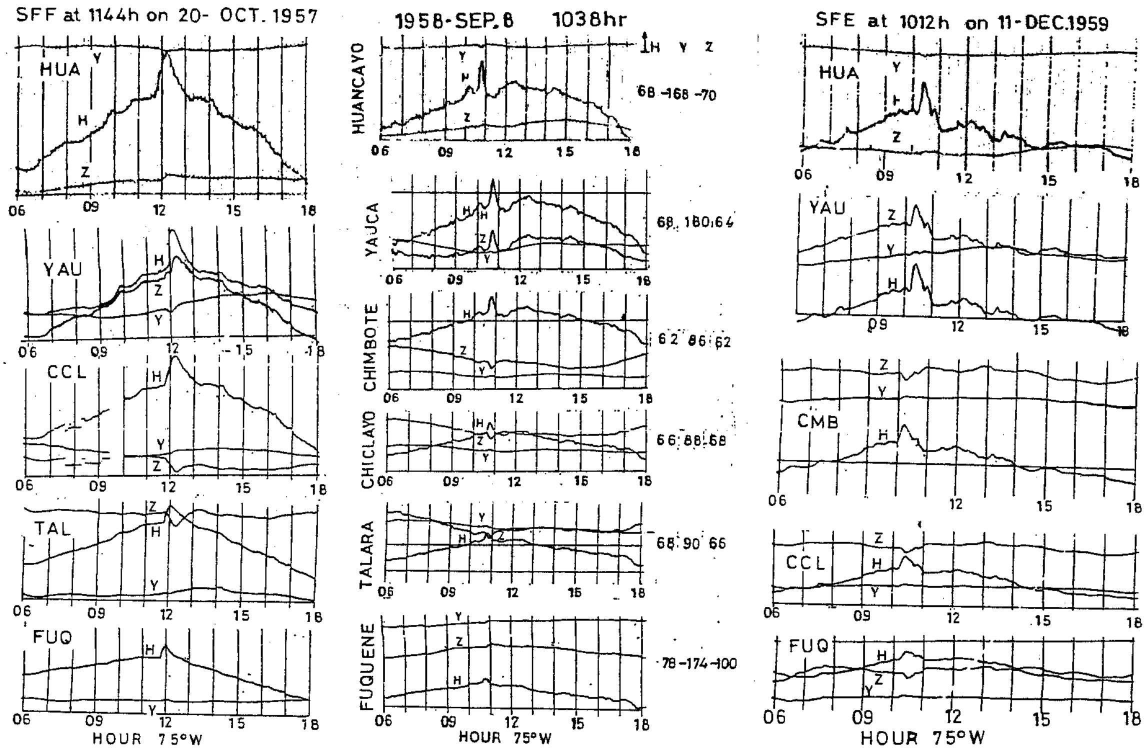

Figure 8(a). Magnetogram traces at the equatorial stations Huancayo, Yauca, Chimbote Chiclayo Talara in Peru and at low latitude station Fuquene in Columbia showing the solar flare effects for the three events in 1957-1959.

b)

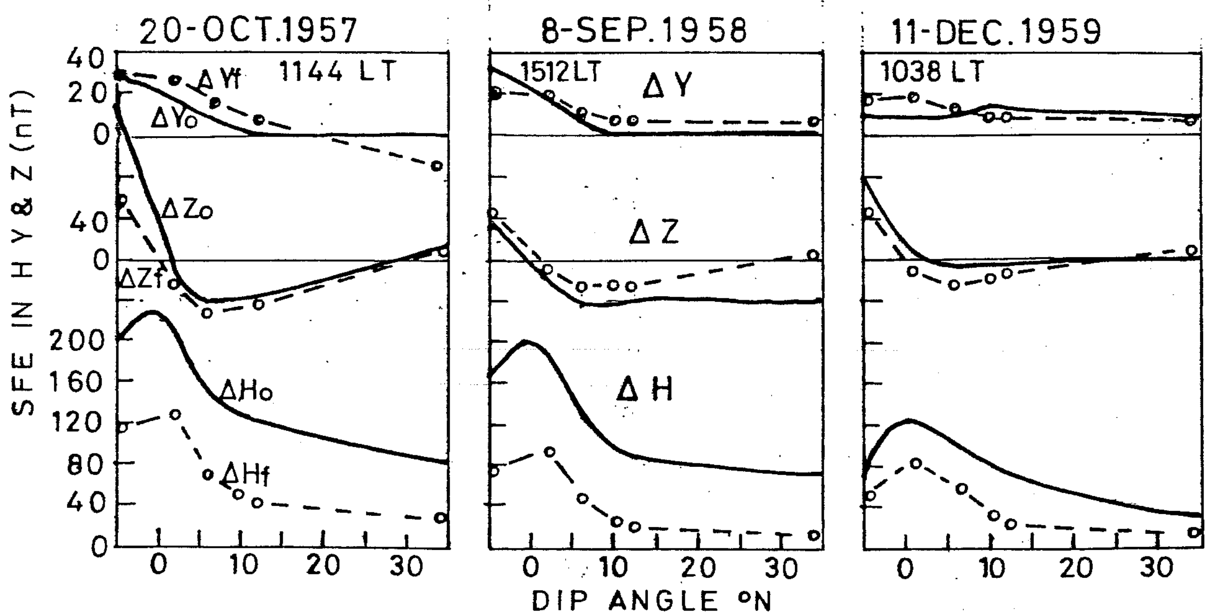

Figure 8(b). Diurnal variations of the amplitudes of sfe in H, Y and Z fields and the pre-flare amplitudes of H, Y and Z fields at the chain of stations due to the solar flares on 20 October 1957, 8 September 1958 and 11 December 1959.

In Fig.8 (a) are shown the magnetogram traces at all these stations during three solar flares at 1144 LT on 20 October 1957, 1038 LT on 8 September 1958 and 1012 LT on 11 December 1959. One feature which is most evident is that the Z trace at YAU is almost duplicate of corresponding H trace.

In Fig.8(b) are shown the latitude variations of pre-flare values and sfe impulses in H, Y and Z for each of the flares. The Sq ΔH as well as sfe ΔH were largest at Huancayo and decreased progressively with increasing latitude north or south of HUA. The Sq as well as sfe ΔZ were large positive at YAU and negative at any other stations being maximum at Chimbote. The ΔY due to Sq or due to sfe were maximum at YAU. Thus the anomaly in Sq Z and Sq Y at YAU persists in the amplitudes of sfe in Z and Y components.

In Fig.9 are shown the mass plots of sfe in H, Y and Z components at all the stations. There is definitely lot of scatter of points due to the nature of individual flare and not due to any ionosphere characteristics. The sfe H are strongest at HUA less at YAU and then in decreasing order at CMB, CCL, TAL and FUQ. At all equatorial stations there was a tendency of the higher amplitudes in the forenoon or in the morning hours. The sfe in Z are largest at YAU and again the amplitude tend to be larger in the forenoon than in the afternoon hours. The amplitude of sfe in Z at HUA are small but positive. The amplitude at all other equatorial stations are negative, while at FUQ these are again positive. The amplitude of sfe in Y component are comparatively larger at YAU and HUA than at other equatorial stations. At FUQ fairly large number of points show negative impulse in Y component.

To check relationship between individual observations in Fig.10 are shown the mass plots of sfe ΔH at YAU, CMB and TAL against corresponding ΔH at HUA. A linear relationships between sfe at HUA and other equatorial stations are clearly seen. On the average the ratio of the amplitude at sfe at different stations normalized with respect to the same at Huancayo was 0.80 for YAU, 0.50 for CMB and 0.35 for Talara. These values are similar to the ratio of Sq H at these stations suggesting that the intensification of sfe at the equator is similar to that of Sq H itself.

In Fig.11 are shown the relationship of ΔZ at CMB near the northern fringe of the electrojet and at YAU on the southern side of the electrojet center with respect to DH at Huancayo. With increasing value of ΔH sfe at HUA, the ΔZ at CMB decreases progressively while ΔZ at YAU increases progressively. These

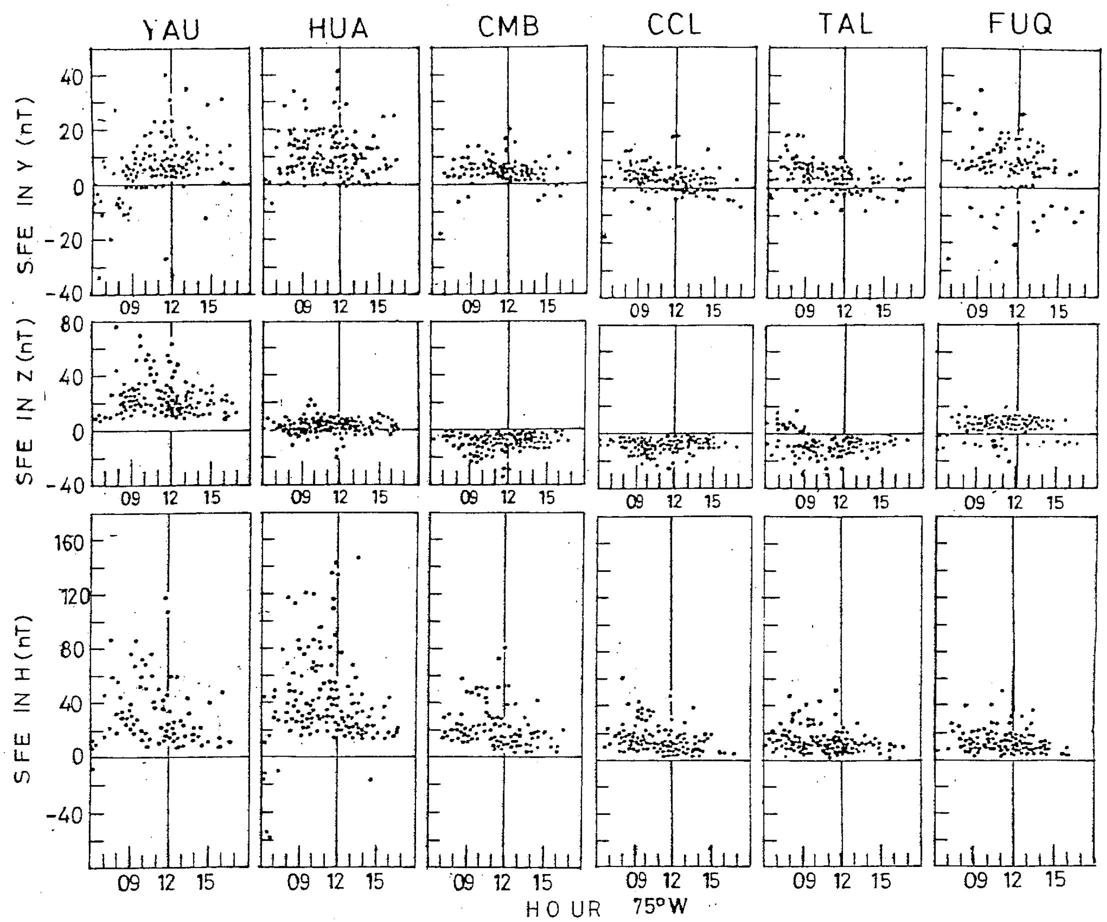

Figure 9. Mass plot showing the amplitudes of individual sfe in H, Y and Z fields during the period 1957-1959 at different stations.

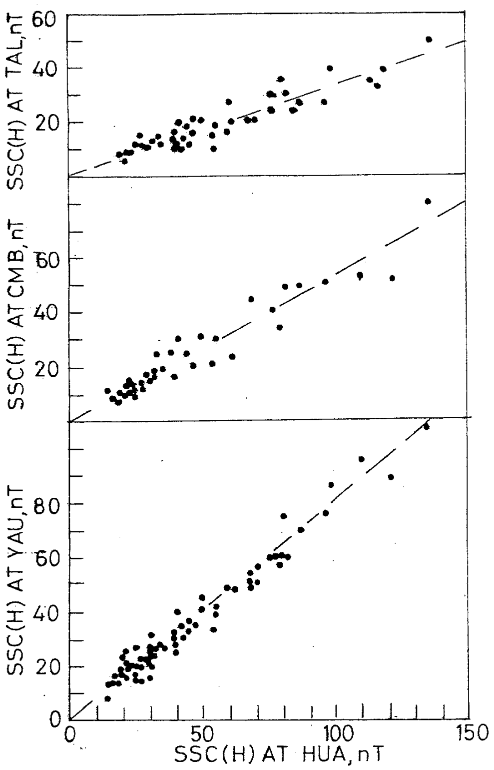

Figure 10. Mass plots of the amplitude of sfe in H at YAU, CMB and TAL against corresponding amplitude of sfe H Huancayo.

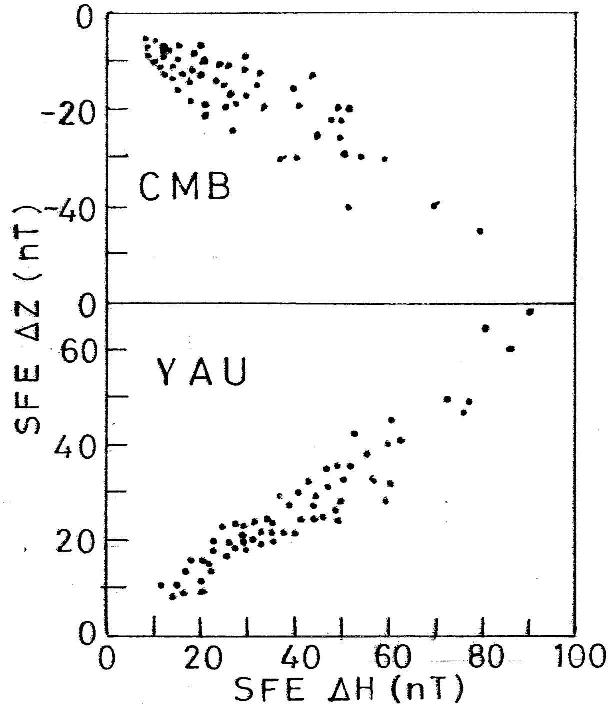

Figure 11. Mass plot of sfe in Z at CMB and YAU against corresponding sfe in H at Huancayo during 1957-89.

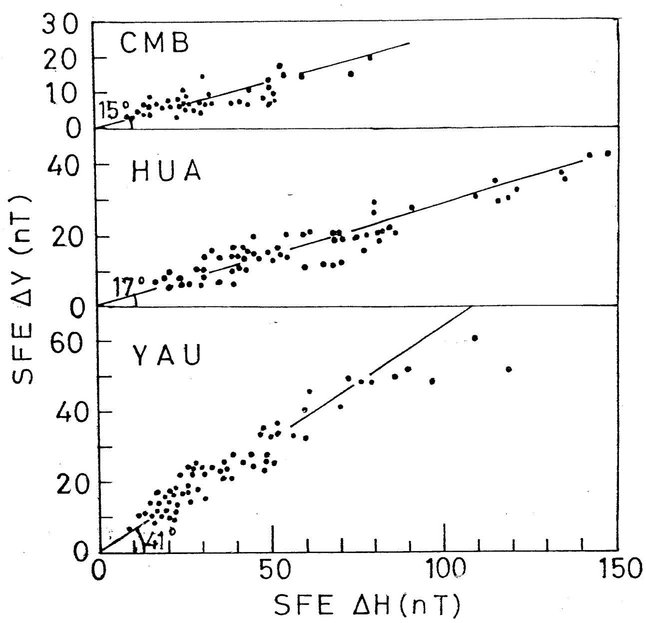

Figure 12. Mass plot of the amplitude of sfe in Y at YAU, HUA and CMB against the amplitude of sfe in H at Huancayo.

facts are also consistent with the idea that the solar flare effect is a temporary increase of the electrojet current.

In Fig.12 are shown sfe in Y component of YAU, HUA and CMB against corresponding ΔH at HUA. It is seen that with increasing ΔH at HUA i.e. with increasing strength of sfe the impulse at other equatorial stations increases progressively but fastest at YAU. The effect of increasing the amplitude of sfe in Y with increasing amplitude of sfe in H at Huancayo is strongest at YAU.

DISCUSSION

The study of solar flare effects on the three components of the geomagnetic field at equatorial stations along 75°W meridian clearly show that the flare induced current is just an intensification of the normal electrojet current with its anomalies in diurnal and seasonal variations.

The average amplitude of sfe in H are almost the same magnitude in the electrojet center in the American as well as in the Indian sector and maximizes two hours before noon. The indicates that the ionospheric electric field at both the places has its maximum value well before noon unlike the ionization which maximizes almost at noon.

Abnormally large amplitude of sfe in Z at Indian electrojet and its absence in American electrojet may be due to east west induced current due to under surface conducting region. In American longitude the geomagnetic stations are aligned such that the stations close to the magnetic equator are over the Andes mountains and other low latitude northern stations are close to the sea coast. Schmucker et al. (1966) have suggested large Z variations at southern electrojet stations in Peru due to an internal concentration of induction currents at shallow depth under the Andes. They estimated a superconductor 240 km deep east of Andes. The abnormal increase of DY in American sector is due to meridional extension of the conductor and the abnormal increase of DZ in Indian sector is due to the zonal extension of the conductor.

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