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Solar flare effects (SFE) on geomagnetic fields across latitudes

Obiageli Josephine Ugonabo*, Francisca Nneka Okeke and Benjamin Ikechukwu Ugwu

Department of Physics and Astronomy, University of Nigeria, Nsukka, Nigeria.

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A comprehensive study of Solar Flare Effects (SFE) across latitudes has been carried out using an extensive data set of two geomagnetic elements H and Z selected from 1997 to 2005. The X (intense) and M (medium) solar flares were examined under quiet conditions. Nine stations extending from equatorial to high latitudes were used in the study. Data employed in this work include minute data of geomagnetic field, solar flare and hourly data of geomagnetic field. On the whole, about one hundred and fifty four (154) solar flares were selected. Each of these flares was critically studied and analyzed to see its response on the geomagnetic H and Z components. Only fifteen to thirty four flares showed the signature in the different stations. The study revealed that pre-solar flare and solar flare amplitude variations are least in the mid latitude stations, followed by the equatorial and low latitude stations and the highest in the high latitude stations. The pre-solar flare amplitude variations and solar flare amplitude variations of Z failed to show any clear pattern. Correlation existed between the solar flare amplitude variations of H and the pre-solar flare amplitude variations. The ratios of $\Delta H_{SFE}/\Delta Ho$ and $\Delta Z_{SFE}/\Delta Zo$ were greater than zero for all the stations used in the study. This implies that the solar flare effects enhance geomagnetic field across latitudes.

Key words: Solar fare, geomagnetic component, variation, latitude, amplitude.

INTRODUCTION

The effects of solar flare and other solar activity phenomena on geomagnetic components and lives, communication, navigation systems as well as power distribution system have been studied.

Solar flare affects the geomagnetic field by increasing ionization mainly in the E region, partially in the D region and occasionally in the F regions. Rastogi et al. (1997) argued that the dense plasma clouds from the sun are stopped at the magnetopause when the magnetic pressure of the earth's magnetic field balances dynamic pressure of the plasma and there is a sharp rise in H component of the earth's magnetic pressure as the magnetosphere is compressed. Lorentz force deflects the charged particles making them to travel around the planet instead of entering it.

A flare is a sudden, rapid, intense and violent explosion in a sun's atmosphere leading to intense variation in brightness. Solar flares are produced when the magnetic energy that has built up in the solar atmosphere is suddenly released. Around sunspots are active regions

*Corresponding author. E-mail: obiageli.ugonabo@unn.edu.ng.

where intense magnetic fields build up and penetrate the photosphere linking the corona to the solar interior. Solar flares are produced mainly in two preferred longitude ranges; the active regions (Zhang et al., 2011). The energy released is as high as 6×10^{25}J, ~millions of 100-megaton H-bomb exploding at the same time; it takes about eight minutes to reach the earth. Radiations are emitted across the entire electromagnetic spectrum and affect all the layers of the solar atmosphere, heating up plasma to tens of millions of kelvin; accelerating electrons, protons and heavier ions to near the speed of light. There are three stages in the production of a solar flare. At the first stage magnetic energy is released. Soft x-rays are detected here. The second stage involves accelerating electrons, protons and heavier ions to energies above 1 MeV. At this stage, radio waves, hard x-rays and gamma rays are released and could be detected. The third stage involves the gradual build up and decay of soft x-rays. Large flares are less frequent than small flares. Usually, there is an increase in the number of solar flares as the sun approaches the maximum part of its eleven year cycle.

Baker and Martyne (1953) reported that the prevailing current system in the dip latitudes is the equatorial electrojet current and that the basic reason for the existence of the electrojet is the high cowling conductivity at the dip equator. But many authors argue that the day-to-day variability in the solar quiet (Sq) variation in low latitudes is mostly due to the variation in the dynamo electric fields rather than the conductivity (Dunford, 1970; Onwumechili and Ezema, 1976; Okeke and Hamano, 2000).

Onwumechili and Ogbuehi (1962) studied the diurnal characteristics of fluctuations in the horizontal intensity H at Ibadan and compared them with the characteristics of solar flares. They thus suggested that the fluctuations under quiet conditions are caused by fluctuations in the quality and quantity of ionized wave radiation from the sun.

Rishbeth (1969) explained that additional current exists under quiet conditions. This is confirmed by Campbell (1982) and Campbell (1987) who showed great enhancement of the 24 h component of the daily geomagnetic field occurred with strong summer time maxima in the annual variation of the variation of the H, D and Z components above 70° latitude. Campbell (1982) showed that in the mid latitudes occur the lowest values of Sq geomagnetic variations. In high latitudes, the Sq variation does not correspond to simple current systems like the electrojet.

Rastogi (1996) discovered that during the normal electrojet period, a solar flare produced a positive change in H, a negative change in Y and Z, the effect on ΔY (negative) increased linearly with increasing value of ΔH. This suggested that the solar flare effects on all the three geomagnetic components were plainly the augmentation of the ionospheric current over station in agreement with the conclusion of Saben (1968).

Rastogi et al. (1997) explained that the solar flare effects are associated with the arrival of enhanced electromagnetic radiations from the sun, which while traversing the ionosphere, generate additional ionizations mainly in the E, partially in the D- and sometimes in the F-region. They discovered that the solar flare effects registered on the magnetograms are augmentation of the ionospheric current and equally discovered an equatorial enhancement in ΔH due to solar flare effects which is observed to be similar in nature to the latitudinal variation of Sq (H) at low latitudes.

Okeke et al. (1998) suggested from their study that ionospheric conductivity mainly controls the magnitude of the day to day variability of geomagnetic hourly amplitude at low latitudes, while electric field and wind systems controls the phase and randomness.

Okeke and Okpala (2005) in their study of the solar flare effect of 6th May 1998 in a section of the Euro-African zone observed that every geomagnetic SFE is unique and characterized by abnormal signature of the event, and the current system of the geomagnetic SFE is not a simple augmentation of the Sq currents as there exist phase difference between the two current systems. The phase difference between the SFE and the Sq field suggests that the current system maybe flowing at different layers of the ionosphere whose cause and the contribution of the ionosphere layers need to be studied.

Okeke and Ichoja (2011) studied the impact of severe solar flare effects (SFE) and sudden storms commencement (SSC) on geomagnetic fields, in dip equator, low and mid latitude stations. The results of the analyses revealed a positive enhancement of the horizontal intensity (H) in the dip equator and negative excursions of the vertical intensities (Z) in low and mid latitude stations. Strong correlation was found to exist between the vertical intensities of the solar flare and sudden storm commencement (Z_{SFE} and Z_{SSC}), while the horizontal intensities of SFE and SSC (H_{SFE} and H_{SSC}) were poorly correlated.

Qian et al. (2012), used model simulations to investigate possible additional contributions from electrodynamics, and found that the vertical E×B drift in the magnetic equatorial region plays a significant role in the ionospheric response to solar flares.

Ugonabo et al. (2013) analyzed solar flare effects on geomagnetic H component at equatorial and low latitudes and the results revealed that pre-solar flare and solar flare amplitude variations of H are high in equatorial and low latitude stations. Correlation existed between the solar flare amplitude variations of H and the pre-solar amplitude variations. The ratios of $\Delta H_{SFE}/\Delta Ho$ were greater than zero for the three stations used in the study. Hence, solar flare effects enhance the geomagnetic field in the equatorial and low latitudes.

This study seeks to investigate the effects of solar flares on geomagnetic fields across latitudes using X and

M solar flares occurring on quiet conditions from 1997 to 2005.

Sources of data

The minute data of the geomagnetic field were collected from the INTERMAGNET website, the solar flare data were accessed from the National Geophysical Data Centre of the National Oceanic and Atmospheric Administration, Boulder, USA, the hourly data of the geomagnetic field and the international quiet days were accessed from World Data Centre for Geomagnetism, Kyoto, Japan. M and X solar flares that occurred mostly on the international 10 quietest days for each month from 1997 to 2005 were selected.

Pre-solar flare and solar flare effect amplitudes

The amplitude variations in H and Z components just before the start time of the flare with respect to 0000 h value on the same day were computed. These will enable us understand the effect of the solar flare on these components. The amplitude variations were defined as ΔH_o and ΔZ_o after Okeke and Okpala (2005) and Ugonabo et al. (2013) as:

$$\Delta H_0 = H_{bf} - H_{00} \quad (1)$$

$$\Delta Z_0 = Z_{bf} - Z_{00} \quad (2)$$

where H_{bf} and Z_{bf} are the values of field components recorded just before the start time of the flare and H_{oo} and Z_{oo} are the values at 0000 h UT.

Okeke and Okpala (2005) also defined the enhancements due to solar flare on the components H and Z are defined as ΔH_{sfe} and ΔZ_{sfe} and were obtained as:

$$\Delta H_{sfe} = H_{pf} - H_{bf} \quad (3)$$

$$\Delta Z_{sfe} = Z_{pf} - Z_{bf} \quad (4)$$

where H_{pf} and Z_{pf} are the values of the geomagnetic H and Z fields at the peak (time) of the flare.

THEORETICAL ESTIMATION OF SFE CURRENT

According to Okeke and Okpala (2005) and Ugonabo et al. (2013) as in Volland and Taubenheim (1958), relative portions of the solar flare effect current flowing in the E-layer can be drawn as the following.

The S_q current i_0 is made up of i_{0E} which flows in the maximum level of the E region and the remaining portion i_{oR} flowing in other regions. This means that total S_q current is giving by:

$$i_o = i_{oE} + i_{oR} \text{ (Sq current)} \quad (5)$$

Equally, additional current i of geomagnetic SFE is made up of i_E in the E-region maximum and a portion i_D in other regions. Therefore, we have:

$$i = i_E + i_D \text{ (SFE current)} \quad (6)$$

Hence, total current flowing during the SFE is given by:

$$i_o + i = i_{oE} + i_E + i_{oR} + i_D \quad (7)$$

That is,

$$i_0\left(1 + i/i_0\right) = i_{0E}\left(1 + i_E/i_{oE}\right) + i_{oR} + i_D \quad (8)$$

But magnetic horizontal intensity is proportional to the current, we can therefore write:

$$i/i_0 = \frac{\Delta H_{SFE}}{\Delta H_0} = \frac{i_E}{i_{oE}} \quad (9)$$

Hence,

$$\Delta H_{SFE} = \frac{\Delta H_0 i_E}{i_{oE}} \quad (10)$$

Equation 10 can be written in a more general form as:

$$\Delta H_{SFE} = K\Delta H_o + \varphi \quad (11)$$

where $K \approx \frac{\Delta H_{SFE}}{\Delta H_0}$ is the slope and φ is the intercept, which is theoretically zero as could be inferred from Equation 10.

Equation 11 therefore suggests a correlation between ΔH_{SFE} and ΔH_o for any location where SFE signature has been observed. Thus, in a linear regressed ΔH_{SFE} - ΔH_o plot, the slope (≈K) is a statistical measure of enhancement or reduction in the geomagnetic H-component. It is an enhancement if K>0, in which case, a positive correlation is envisaged, otherwise K<0 and a negative correlation is envisaged.

METHOD OF DATA ANALYSIS

The solar quiet (Sq) field base line is the field average of the value

Table 1. Stations used and their geographic positions.

STATION	IAGA	COUNTRY	GEO. LAT. (°N)	GEO. LONG. (°E)
Bangui	BNG	Central African Rep.	4.33	18.57
Addis Ababa	AAE	Ethiopia	9.03	38.77
Tamanrasset	TAM	Algeria	22.69	5.53
Tihany	THY	Hungary	46.90	17.54
Nagycenk	NCK	Hungary	47.63	12.72
Belsk	BEL	Poland	51.84	20.79
Niemegk	NGK	Germany	52.07	12.68
Nurmijarvi	NUR	Finland	60.51	24.66
Abisko	ABK	Sweden	68.36	18.82

of the hours flanking local midnight and calculated using Equations 12 and 13.

$$H_{00} = \frac{1}{3}\left(H_{23} + H_{24} + H_{1}\right) \qquad (12)$$

$$Z_{00} = \frac{1}{3}\left(Z_{23} + Z_{24} + Z_{1}\right) \qquad (13)$$

H_{23}, H_{24}, H_1, Z_{23}, Z_{24} and Z_1 are the values of the H and Z components at the twenty-third and the twenty-fourth hours preceeding the day and the first hour of the day, respectively. H_{00} and Z_{00} are the average values of the H and Z components respectively.

The deviation from the midnight at a particular hour (t) was calculated using Equations 5.3 and 5.4.

$$H_{t0} = H_{t} - H_{00} \qquad (14)$$

$$Z_{t0} = Z_{t} - Z_{00} \qquad (15)$$

H_t and Z_t are the values of H and Z, respectively at the time, t.

The pre-solar flare amplitude variations were thus computed using Equations 1 and 2. The enhancements due to the solar flare on the components H and Z were computed using Equations 3 and 4. The S_q current i_0 is sum of i_{0E} and i_{oR} as seen in Equation 5.

As already seen and discussed in Equation 6, additional current i of geomagnetic SFE is sum of i_E in the E-region maximum and a portion i_D in other regions. Hence, total current flowing during the SFE is given by Equation 7 that yielded Equation 8.

Also, as seen in Equation 9, magnetic horizontal intensity is proportional to the current hence the ratio $\frac{\Delta H_{SFE}}{\Delta H_0}$ was calculated and tabulated for all the nine stations. Ratios greater than zero imply that SFE is enhancing the geomagnetic field and vice versa.

RESULTS AND DISCUSSION

Table 1 shows the nine stations used in the study with their geographic positions. Figure 1a to d shows some sample plots of H against the Universal Time for flares that occur on 30th May, 2002 at AAE, 27th November, 1999 at BNG and TAM and 16th May,1999 at THY. The same Figure 1e and f also shows two sample plots of Z against the universal time for flares that occurred on the 27th November, 1999 at BNG and NGK. Each of the plots shows the flare signature (the starting period, the peak and the end period). Tables 2 and 3 show the computed values of $\Delta H_{SFE}/\Delta H_o$ and $\Delta Z_{SFE}/\Delta Z_o$, respectively for the different stations. Figure 2a to i shows the plots of the ratios of ΔH_{SFE} to ΔH_o for all the stations, while Table 4 gives the summary of the regression analyses result as drawn from Figure 2.

As could be seen from the longitudes in Table 1, most of the stations used in the study are 1 h ahead of GMT (example BNG, THY, NCK, BEL, NGK and ABK), NUR is 2 h ahead and AAE is 3 h ahead. Therefore, conversion to local times did not yield any appreciable differences. Furthermore, most of the flares used were noon flares.

In the equatorial and low latitude stations, AddisAbaba station having nineteen solar flare events depicted four flares whose ratios of $\Delta H_{SFE}/\Delta H_o$ ranged between 0.62 and 0.67, only one flare with ratio equal to one. The rest of the fourteen flares had ratios between 1.07 and 52.50. At Bangui station, fifteen solar flare events recorded six flares with ratios of $\Delta H_{SFE}/\Delta H_o$ ranging between 0.34 and 0.58 and nine flares depicted ratios between 1.03 and 2.50. At Tamanrasset station, twenty-three solar flare events recorded eight flares with ratios ranging between 0.10 and 0.96, while the rest of the fifteen flares depicted ratios between 1.06 and 2.60.

In the mid latitudes, four stations were used, Tihany, Nagycenk, Belsk and Niemegk. In Tihany station, thirty-five solar flare events showed only seven flares with ratios of $\Delta H_{SFE}/\Delta H_o$ ranging between 0.57 and 0.92, two flares with ratios equal to one and the rest of the twenty-six flares had ratios between 1.03 and 7. At Nagycenk station, thirty-one solar flare events recorded five flares whose ratios of $\Delta H_{SFE}/\Delta H_o$ ranged between 0.76 and 0.9, two flares with ratios equal to one, while

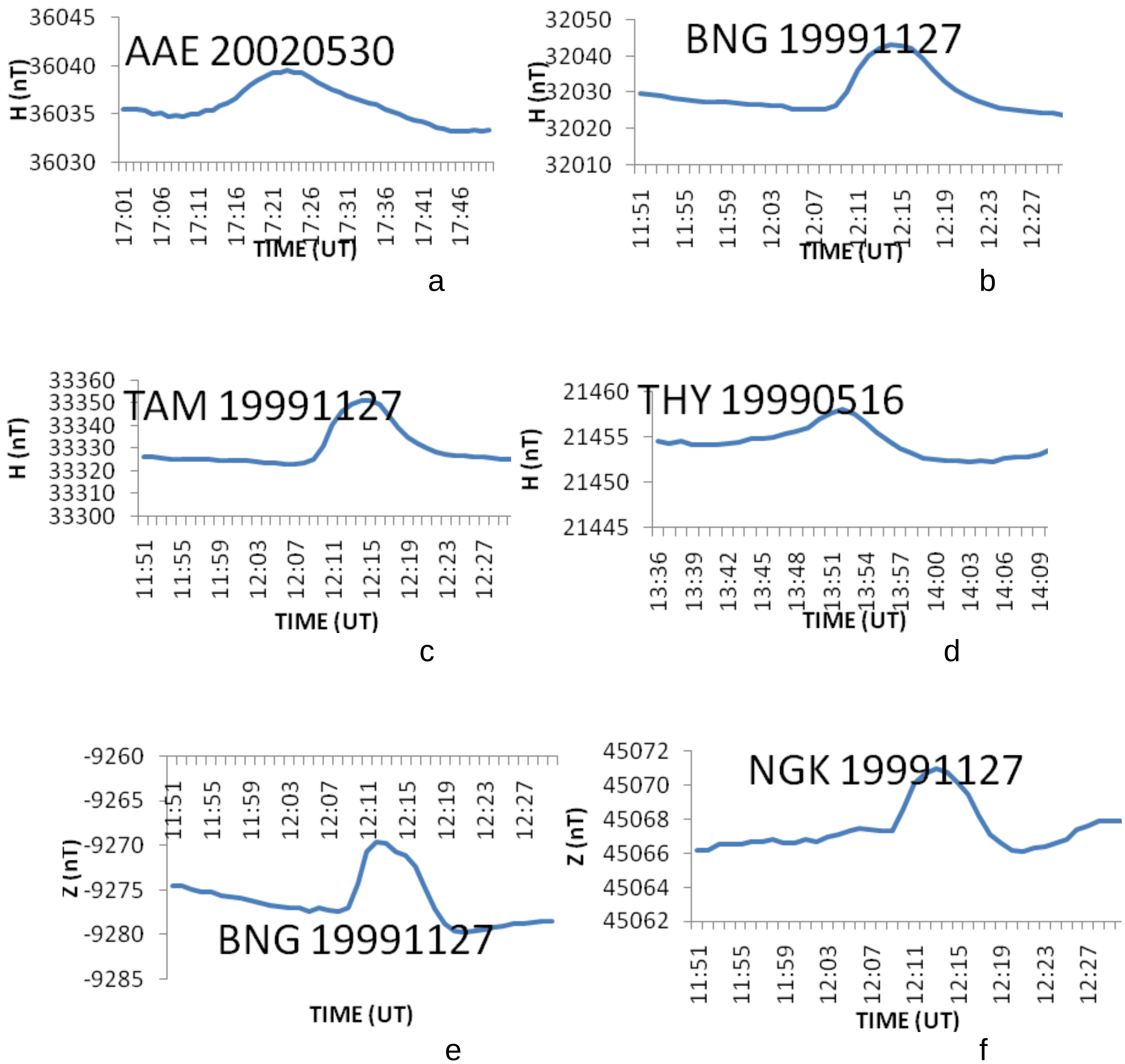

Figure 1. (a-f) Sample plots of H and Z against T for some flares.

twenty-four flares depicted ratios between 1.06 and 6.50. At Belsk station, twenty-eight solar flare events depicted four flares with ratios ranging between 0.43 and 0.93, three flares with ratios equal to one and twenty-four flares with ratios between 1.1 and 5.70. Finally, at Niemegk station, twenty-seven solar flare events recorded only three flares with ratios ranging between 0.5 and 0.96, two flares with ratios equal to one and twenty-two flares with ratios between 1.03 and 5.20.

In the high latitudes, only two stations were used, Nurmijarvi and Abisko. At Nurmijarvi station, nineteen solar flare events recorded eight flares whose ratios of $\Delta H_{SFE}/\Delta H_o$ ranged between 0.12 and 0.92 and eleven flares with ratios between 1.09 and 2.83. At Abisko, seventeen solar flare events depicted five flares with ratios between 0.17 and 0.74 and twelve flares with ratios between 1.08 and 6.00.

Table 4 gives a clear correlation between ΔH_{SFE} and ΔH_o with a positive slope in all the stations. The results are statistically significant at 95% confidence. It could be observed from the distribution of slope that the degree of enhancement of the H-component by SFE is highest at high latitudes (ABK and NUR) stations and lowest at mid latitudes (THY, NCK, BEL and NGK) stations. The same Table 4 also depicts that the intercepts deviate significantly from the theoretical prediction of zero. This could arise as a result of the coarse approximations of the local times and minor effects of longitudinal variations (Okeke and Okpala, 2005). The results therefore suggest

Table 2. Computed values of $\Delta H_{SFE}/\Delta H_o$ in all the stations.

Date (YYMMD)	Time (UT)	$\Delta H_{SFE}/\Delta H_o$								
		AAE	BNG	TAM	THY	NCK	BEL	NGK	NUR	ABK
19971104	0552-0602	-	-	-	1.20	0.75	1.41	1.03	0.12	2.00
19980406	1623-1655	-	-	-	1.45	1.50	1.20	0.96	0.92	-
19980528	1343-1400	-	-	-	0.57	1.42	1.00	5.20	-	-
19981122	2140-2235	-	-	-	1.23	1.06	1.27	2.13	1.19	1.09
19990516	1345-1353	0.62	-	1.06	1.45	5.00	0.77	2.20	-	0.17
19990716	1542-1554	-	-	-	1.00	1.00	5.70	2.33	-	-
19991127	1205-1216	-	1.70	0.96	1.45	1.11	1.50	2.00	1.40	4.17
19991221	1712-1722	-	-	-	1.14	0.80	-	35.00	0.31	-
20000415	1437-1453	-	2.20	0.85	0.92	2.00	1.55	-	-	-
20000707	1056-1127	-	0.54	-	1.10	1.06	-	1.77	-	-
20000707	1810-1833	-	-	1.15	1.03	1.50	2.50	1.75	0.89	1.08
20000721	1430-1443	-	0.58	1.06	1.20	1.57	-	-	-	-
20000825	1421-1446	-	-	0.23	1.00	0.90	2.13	-	2.83	2.27
20010309	0151-0200	1.00	2.50	1.43	1.60	1.00	1.10	1.00	1.36	1.28
20010520	0912-0923	1.10	1.17	1.32	1.91	1.11	2.25	2.13	1.09	1.58
20010829	1242-1307	1.64	-		2.90	-	-	-		
20010909	1510-1521	0.65	-	1.11	1.23	-	-	-	-	-
20010917	1544-1554	-	0.46		1.90	1.71	1.80	-	-	-
20011017	1116-1128	52.50	1.78	1.16	0.70	6.50	1.86	2.00	0.19	6.00
20020102	1248-1255	1.91	1.18	2.60	1.08	1.80	0.93	1.50	1.21	0.56
20020530	1711-1739	0.63	1.54	0.85	1.00	1.50	1.73	1.67	1.41	1.45
20020711	1444-1457	1.07	-	1.53	1.09	0.67	3.00	-	-	-
20020824	1112-1141	-	0.58	0.58	7.00	3.00	1.81	2.77	0.79	0.67
20020828	1645-1709	1.17	0.42	0.53	0.85	5.00	0.38	0.40	0.91	0.39
20030317	1850-1916	2.06	-	0.10	1.23	2.00	1.55	-	-	-
20030319	0934-1000	5.61	-	-	0.73	1.37	-	-	-	-
20030527	2256-2313	0.67	1.24	1.24	1.60	1.46	1.68	2.23	-	-
20030611	1621-1650	-	-	-	1.90	0.76	2.24	1.47	1.10	0.74
20030805	1243-1251	2.16	1.03	0.62	1.05	2.80	-	-	-	-
20031004	1542-1549	1.21	0.34	1.15	1.27	1.25	1.90	3.40	1.32	1.72
20031023	1049-1055	1.09	-	2.26	0.64	1.00	1.86	2.50	0.22	
20040306	1208-1241	1.48	-	1.21	4.00	1.38	0.51	0.47	1.21	1.53
20040815	1234-1243	2.50	-	1.29	1.07	1.16	1.40	9.40	2.08	2.26
20050506	1111-1135	-		1.29	1.23	-	-	-	-	-
20050908	1649-1711	2.50	-	-	-	-	-	-	-	-

strongly that SFE enhances the H-component of geomagnetic field.

The mid latitude stations showed lowest values of the pre-flare amplitude variations (ΔH_o) while the higher latitude stations revealed much wider variations. The mid latitude stations showed moderate amplitudes of ΔH_{SFE} compared to the equatorial, low and high latitude stations.

The pre-flare ΔZ_o variations were not high in all the stations. The ΔZ_o variations did not follow any particular pattern as regards the latitudes. Most stations revealed positive excursion.

The amplitude of the variations of Z as a result of the solar flare effect does not show a very clear pattern. The pre-flare ΔZ_o were generally larger than the SFE. Just like in the pre-flare ΔZ_o variations, all the stations exhibited positive variations of ΔZ_{SFE}.

The ratios of $\Delta Z_{SFE}/\Delta Z_o$ for all the nine stations have values greater than zero. The results confirm that the solar flare effects also enhance the Z components of the geomagnetic field.

Conclusions

The results of the study revealed that SFE consists

Table 3. Computed values of $\Delta Z_{SFE}/\Delta Z_o$ in all the stations.

Date (YYMMDD)	Time (UT)	$\Delta Z_{SFE}/\Delta Z_o$								
		AAE	BNG	TAM	THY	NCK	BEL	NGK	NUR	ABK
19971104	0552-0602	-	-	-	-	-	0.30	-	-	-
19980406	1623-1655	-	-	-	-	-	0.27	-	0.07	-
19981122	2140-2235	-	-	-	-	-	-	-	0.08	1.61
19990516	1345-1353	2.50	-	0.60	-	0.16	0.07	-	-	0.02
19990716	1542-1554	-	-	-	-	-	-	0.09	-	-
19991127	1205-1216	-	0.46	0.06	0.03	0.08	0.16	0.54	-0.13	2.14
19991221	1712-1722	-	-	-	-	-	-	-	0.27	-
20000415	1437-1453	-	-	-	-	-	0.09	-	-	-
20000707	1810-1833	-	-	-	-	-	-	-	0.27	-
20000825	1421-1446	-	-	-	-	0.18	-	-	-0.27	-
20010309	0151-0200	-	-	-	-	-	0.09	-	-0.24	0.28
20010520	0912-0923	-0.04	-	0.27	-	-	-	-	-0.07	0.07
20010829	1242-1307	-0.20	-	-	-	-	-	-	-	-
20010917	1544-1554	-	0.22	-	-	-	-	-	-	-
20011017	1116-1128	-	-	-	-	-	0.09	-	1.00	-
20020102	1248-1255	0.14	-	2.33	-	0.46	-	-	-	-
20020530	1711-1739	-1.75	-	-	-	0.18	0.11	-	0.27	-
20020711	1444-1457	0.26	-	-	-	0.06	0.09	-	-	-
20020824	1112-1141	-	-	-	-	-	-	0.50	-0.96	-
20020828	1645-1709	-0.47	-	-	-	-	-	-	13.25	-
20030317	1850-1916	-	-	1.50	-	-	-	-	-	-
20030319	0934-1000	0.01	-	-	-	0.06	-	-	-	-
20030527	2256-2313	0.01	-	-	-	-	0.11	-	-	-
20030611	1621-1650	-	-	-	-	-	-	-	0.16	-
20030805	1243-1251	0.01	-	0.05	-	2.00	-	-	-	-
20031004	1542-1549	0.00	-	-	-	-	0.10	-	3.00	-
20031023	1049-1055	0.00	-	-	-	-	0.01	2.33	0.15	-
20040306	1208-1241	-1.07	-	0.22	-	-	-	-	-1.07	-
20040815	1234-1243	-	-	0.33	-	0.41	0.17	-	-0.39	0.16
20050506	1111-1135	-	-	-	0.12	-	-	-	-	-
20050908	1649-1711	-0.20	-	-	-	-	-	-	-	-

mostly of positive impulse in H. These could be attributed to the simultaneous existence of zonal and meridional currents that are responsible for Sq currents. More than half of the solar flares used in each of the stations depicted ratios of SFE current to Sq current ($\Delta H_{SFE}/\Delta H_o$) greater than zero. The results of the study imply that SFEs enhance geomagnetic field across all the latitudes (equatorial, low, mid and high). SFE on geomagnetic field is not a simple augmentation at the pre-flare ionospheric currents over these stations. The results are in agreement with Rastogi (1996).

The results revealed that pre-solar flare and solar flare amplitude variations of H are least in mid latitude stations and highest in the high latitude stations. The pre-solar flare and solar flare amplitude variations of Z did not show any clear pattern.

Positive correlation existed between the solar flare amplitude variations of H and the pre-solar amplitude variations and all the results are statistically significant at 95% confidence.

It is clearly obvious that SFEs enhances geomagnetic field across the latitudes studied. This is drawn from the result of the ratios of $\Delta H_{SFE}/\Delta H_o$ and $\Delta Z_{SFE}/\Delta Z_o$, being greater than zero in all the nine stations.

Conflict of Interests

The authors have not declared any conflict of interests.

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The authors are grateful to INTERMAGNET for supplying

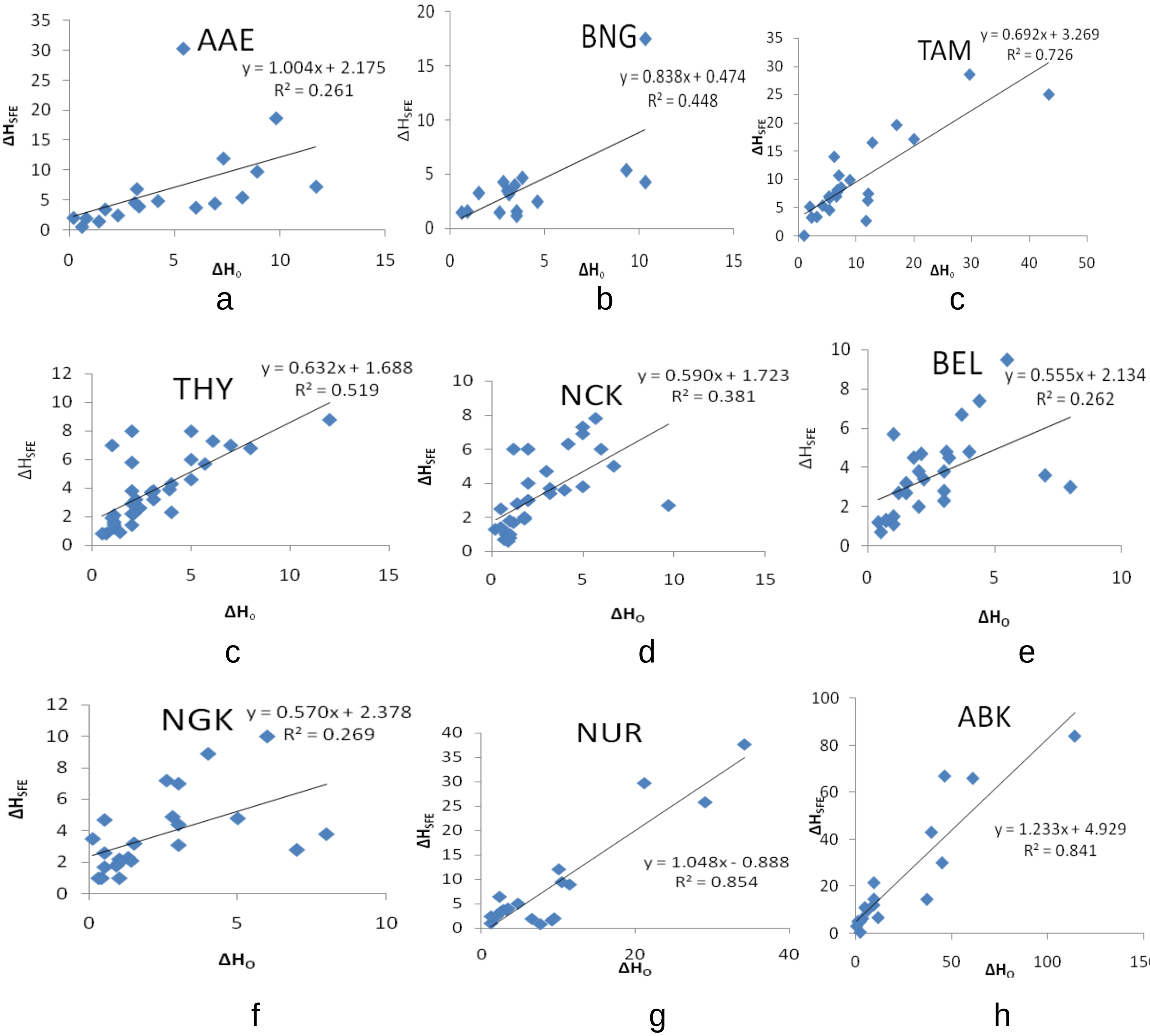

Figure 2. (a –i) Scatter plots of ΔH_{SFE} against ΔH_o for all the stations.

Table 4. Results of regression analysis.

Station	Slope, k	Intercept, φ	Correlation coefficient, r
AAE	1.004	2.175	0.48
BNG	0.838	0.474	0.67
TAM	0.632	3.269	0.85
THY	0.692	1.688	0.72
NCK	0.590	1.723	0.62
BEL	0.555	2.134	0.51
NGK	0.570	2.378	0.52
NUR	1.048	-0.888	0.92
ABK	1.233	4.929	0.92

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REFERENCES

Baker WG, Martyne DF (1953). Electric currents in the ionosphere, the conductivity. Phil. Trans. R. Soc. London A246:281-294.

Campbell WH (1982). Annual and semi-annual changes of the quiet daily variations (Sq) in the geomagnetic field at North American locations. J. Geophys. Res. 87:785-796.

Campbell WH (1987). Some effects of quiet geomagnetic field changes upon values used for main field modeling. Phys. Earth Planet Int. 48:193-199.

Dunford E (1970). Electric field and F-region electron densities over Peru. J. Atmos. Terr. Phys. 32:421.

Okeke FN, Ichoja A (2011). Impact of Severe Solar Flare Effects and Sudden Storm Commencement on Geomagnetic Fields, Across Latitudes. J. Emerg. Trends Eng. Appl. Sci. 2(2):219-225.

Okeke FN, Hamano Y (2000). Daily variations of geomagnetic HDZ-fields at equatorial latitudes. Earth Planet Space 52:237-243.

Okeke FN, Onwumechili CA, Rabiu AB (1998). Day to day variability of geomagnetic hourly amplitudes at low latitudes, Geophys. J. Int. 134:484-500.

Okeke FN, Okpala KC (2005). Geomagnetic Solar Flare Effect in H, Y, and Z fields in the Northern Hemisphere. NJSR 1:39-99.

Onwumechili CA, Ezema PO (1976). On the course of the geomagnetic daily variation in low latitudes. J. Atmos. Solar Terr. Phys. 39:1079-1086.

Onwumechili A, Ogbuehi PO (1962). Fluctuations in geomagnetic horizontal field. J. Atmos. Terr. Phys. 24(3):173-190.

Qian L, Burns AG, Solomon SC, Chamberlin PC (2012). Solar flare impacts on ionospheric electrodynamics. Geophys. Res. Lett. 39:L06101.

Rastogi RG, Pathan BM, Rao DRK, Alex S, Sastry TS (1997). An intense SFE and SSC events in geomagnetic H, Y and Z fields at the Indian observatories. Ann. Geophys. 15:1301-1308.

Rastogi RG (1996). Solar flare effects on zonal and meridional currents at the equatorial electrojet station, Annamalainager. J. Atmos. Terr. Phys. 58:1413-1430.

Rishbeth H (1969). On explaining the behavior of the ionospheric F-region. Rev. Geophys. 6:33-71.

Saben VD (1968). Solar flare effects on simultaneous magnetic daily variation, 1959-1961. J. Atmos. Terr. Phys. 30:1641-1648.

Ugonabo OJ, Okeke FN, Ugwu EBI (2013). “Preliminary analyses of solar flare effects on geomagnetic H component at equatorial and low latitudes”. Int. J. Recent Trends Sci. Technol. 9(2):235-237.

Volland H, Taubenheim J (1958). On the ionospheric current system of the geomagnetic solar flare effect. J. Atmos. Terr. Phys.12:258-260.

Zhang L, Mursula K, Usoskin I, Wang H (2011). Global analysis of active longitudes of solar x-ray flares. J. Atmos. Solar Terr. Phys. 73:258-263.