SOLAR FLARE EFFECTS AND STORM SUDDEN COMMENCEMENT EVENT IN GEOMAGNETIC H, Y AND Z FIELDS AT EURO-AFRICAN OBSERVATORIES.

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Abstract

Variations in the three components of geomagnetic field were observed at the twenty-two geomagnetic Euro-African Observatories during the solar flare that occurred on the 6 May, 1998 at 0080UT and storm sudden commencement that took place on May 8, 1998 at 15.00 UT. The geomagnetic field on 6 May, 1998 was quiet. Strong correlation exists between the solar flare amplitude of the Z component (dZsfe) and the monthly mean of the Sq variation. Strong responses of Z and Y fields to solar activity were noted. From the estimation of the contributions of D and E-layers to the geomagnetic SFE, it was inferred that both of these layers contribute to geomagnetic SFE almost equally with ratio of D-layer current to E-layer current being approximately 1.21.

Keywords: *Solar flare, Storm sudden commencement, Variation, Sq current, correlation.*

Introduction

It has long been established that Solar Flare is related to several atmospheric phenomenon. Hence Afraimovich et al. (2001) and Wayne & Thompson (2004) determined the electron density variations due to solar flare in the D-region. Different methods have been employed in investigating the solar flare effects at different altitudes of the ionosphere, which have been carried out by several authors (Thome and Wagner 1971, Afraimovich, et al., 2002; Wayne and Thompson, 2004). These include the use of cosmic radio noise recorders, VHF radio beacons, broad based geostationary satellites, incoherent scattering methods, and more recently the GPS system. The relationship between solar flares and ionospheric phenomena is most clearly evident in the case of prompt ionospheric disturbances that occur in good time coincidence with the appearance of a visible flare on the solar disc. Some ionosopheric disturbances associated with solar flare include: Short Wave Fade out (SWF), Sudden Cosmic Noise Absorption (SCNA), Sudden Frequency Deviation (SFD), Sudden Phase Anomaly (SPA), Sudden Enhancement of Atmosphere (SEA). Two prominent features of the geomagnetic field variation include: Sudden Storm Commencement (SSC), and Solar Flare Effect (SFE).

Solar flares could potentially cause wide spread power cuts, tripping of circuit breakers and transformer damage. It has since been recorded that the most pronounced effect of solar flares on the ionosphere is observed in the D-and E-regions. Solar flares perturb the ionosphere leading to fading of signals received due to increased ionization in the ionosphere, hence affecting communications. Ionospheric currents are often associated with geomagnetic responses, hence solar flares are mainly observed through their effect on the earth's geomagnetic fields. This paper aims at investigating the geomagnetic solar flare effect (SFE) which occurred on 6 May, 1998 in a section of the Euro-African zone, and the storm sudden commencement that took place after. The day, 6 May, 1998 is an international accepted solar quiet day and as such gives us the advantage of studying SFE without consideration of inputs from ring currents and other forms of geomagnetic disturbances associated with disturbed day variations. This study will enrich our understanding as of the nature of augmentation of current systems prevalent during the period of the flare in the Euro-African zone, which has long been neglected.

Data Sources

The solar flare of 6 May, 1998 was obtained from the GEOS-8 X-ray flux, courtesy of the US NASA database. The rest of the data used in this work are from the World Data Centre (WDC) for geomagnetism 1 Kyoto, Japan and the Space Physics Interactive Data Resource Centre (SPIDR), Boulder, USA. The observatories all lie within geographic longitude 10°E to 20°E and geographic latitude of 0°N to 80°N corresponding to the eastern section of the Euro-African zone. The geographic and geomagnetic coordinates are summarized in Table 1.

Analysis of Data

The occurrence of solar flare of 6 May, 1998 is seen in Fig 1, as having taken place at 0800UT.

Mean hourly amplitude variation:

The monthly Sq HYZ geomagnetic field superposed on the 6 May, 1998 field variation for the observatories, from low, mid and high latitude station were considered, and the plots provide a fair representation of field variations in the stations around the Euro-African zone. In comparing the daily geomagnetic variation for 6 May 1998, with Sq geomagnetic field variation, we first define the baseline of the mean hourly amplitude values as the average of the four hourly values for 0000-0200UT and 2200-2400UT.

Hence the base line $C_b = \frac{1}{4}(C_{24} + C_{23} + C_{01} + C_{02})$ (1)

where C_{01}, C_{02}, C_{23} and C_{24} are the geomagnetic component hourly means for 0100UT, 0200UT, 2300UT and 2400UT respectively of the same day. Hence for the different geomagnetic components we have:

$$Z_b = \frac{1}{4}(Z_{23} + Z_{24} + Z_{01} + Z_{02}) \quad (2)$$

$$H_b = \frac{1}{4}(H_{23} + H_{24} + H_{01} + H_{o2}) \quad (3)$$

$$Y_b = \frac{1}{4}(Y_{23} + Y_{24} + Y_{01} + Y_{02}) \quad (4)$$

The S_q hourly amplitude, $\Delta C = C_t \; C_b$ (5)

where C_t is the value of the geomagnetic field component at time t.

Pre-flare amplitude variation

In comparing the response of the different components of the geomagnetic field during the flare, we define the pre-flare amplitude as ΔH_o, ΔY_o and ΔZ_o, given by;

$$dH_o = H_{bf} - H_{oo} \quad (6)$$

$$dY_o = Y_{bf} \; Y_{oo} \quad (7)$$

$$dZ_o = Z_{bf} - Z_{oo} \quad (8)$$

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

Solar Flare Effect (SFE) amplitude variation

The solar flare amplitude could be defined as;

$$dH_{sfe} = H_{pf} \; H_{bf} \quad (9)$$

$$dY_{sfe} = Y_{pf} \; Y_{bf} \quad (10)$$

$$dZ_{sfe} = Z_{pf} \; Z_{bf} \quad (11)$$

where H_{pf}, Y_{pf} and Z_{pf} are the field component values at the peak of the solar flare. The values of the above where computed and employed in plotting graphs.

Table 1: Geographic and geomagnetic coordinates of stations

Station name/code	GG lat.	GG long	GM long.	GM long
Belsk/BEL	51.83	20.80	50.19	105.24
Brorfelde/BFE	55.62	11.67	55.49	98.74
Budkov/BDV	49.07	14.02	48.82	97.64
Chambon-la-foret/CLF	48.02	2.27	50.06	85.71
Dourbes/DOU	50.10	4.60	51.60	88.99
Eskdalemuir/ESK	55.32	-3.20	58.04	84.06
Furstenfeldbruck/FUR	48.17	11.28	48.48	94.62
Hartland/HAD	50.98	-4.48	54.17	80.28
Hel/HLP	54.60	18.82	53.19	104.80
Hurbanovo/HRB	47.87	18.18	46.89	101.07
Lerwick/LER	60.13	-1.18	62.15	89.55
Lov/LOV	59.35	17.83	57.84	106.75
Manhay/MAB	50.30	5.68	51.59	90.14
Nagcenk/NCK	47.63	16.72	46.93	99.59
Neimegk/NGK	52.07	12.68	51.94	97.77
Tihany/THY	46.90	17.90	46.01	100.41
Tromso/TRO	69.67	18.95	67.01	117.17
Wingst/WWNG	53.75	9.07	54.22	95.21
Valencia/VAL	51.93	-10.25	56.15	74.79
Bangui/BNG	4.55	18.57	4.35	90.31
Tamanrasset/TAM	22.79	5.53	24.56	4.45
Hornsund/HRN	77.00	15.55	73.50	127.54

Correlation Analysis

Correlation analysis was carried out among the mean monthly Sq variation and the pre-flare and solar flare amplitude of the three geomagnetic field components used in this work to verify the relationship between the pre-flare/SFE components variations and the monthly mean.

The result of the correlation at 5% confidence level is as follows:

$r(dH_{sfe}, dH_{mv}) = 0.285$

$r(dY_{sfe}, dY_{mv}) = 0.565$

$r(dZ_{sfe}, dZ_{mv}) = 0.938$

$r(dH_{o}, dH_{mv}) = 0.427$

$r(dY_{o}, dY_{mv}) = 0.098$

$r(dZ_{o}, dZ_{mv}) = 0.057$

Estimation of respective contributions of D and E layer to the geomagnetic SFE.

An approximate contribution of E and D layer was studied using simple calculation by Volland and Taubenhiem (1958). The Sq current $í_o$ is composed of a portion $í_{oE}$ flowing in the maximum level of the E region

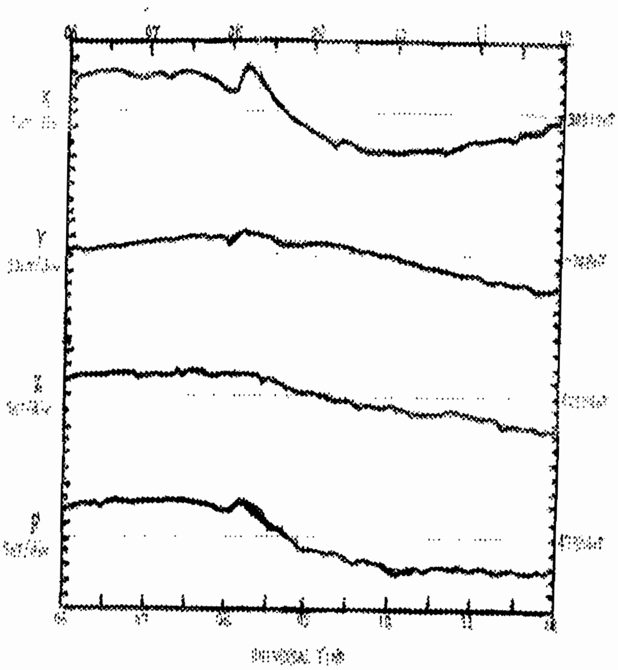

Fig.1: Geomagnetic Solar flare effect on the 6th of May, 1998

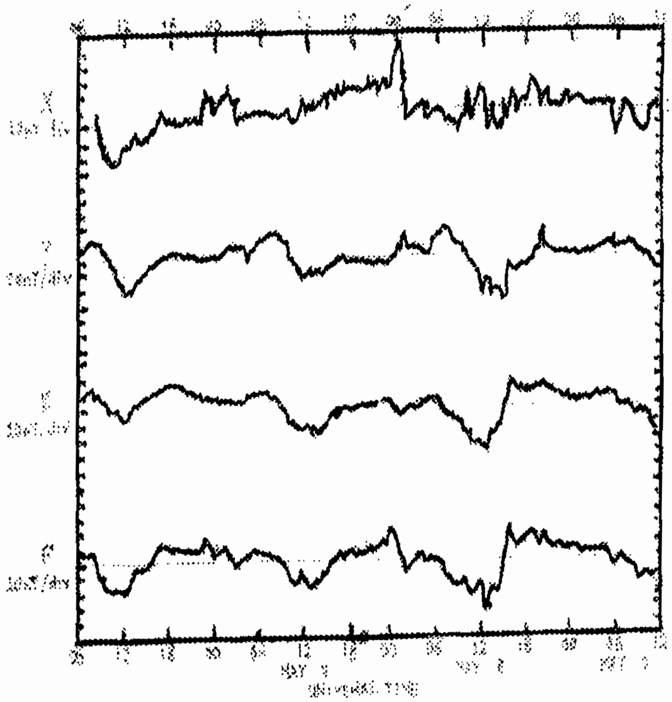

Fig. 2: Sudden storm commencement of 8th May, 1998

and the remaining portion i_{oR} flowing in other regions, i.e.

$$i_o = i_{oE} + i_{oR} \text{ (Sq current)} \quad (12)$$

Also, the additional current i of the geomagnetic SFE is composed of a portion i_E in the E region maximum, and a portion i_D in other region, so that

$$i = i_E + i_D \text{ (SFE current)} \quad (13)$$

Then whole current flowing during SFE is then

$$i_o + i = i_{oE} + i_E + i_{oR} + i_D \quad (14)$$

$$\text{or } i_o(1 + i/i_o) = i_{oE}(1 + i_E/i_{oE}) + i_{oR} + i_D \quad (15)$$

Since the magnetic horizontal intensity is proportional to the current, we have that

and the E-layer current is approximately proportional to the E-layer maximum electron density, so that

Both $\Delta H/\Delta Ho$ and $\Delta N_E/N_{oE}$ are given for a number of SFE, following same assumption by Volland and Taubenhiem (1958) that the Sq current is flowing only in the E-region, so that $i_{oE} \equiv i_o$. In avoiding the negative values of i_D that should have arisen from eqn.(15) if the assumption now is that within the E-region about half of the Sq current is flowing, then

$$i_{oE} \approx i_{oR} \approx \tfrac{1}{2} i_o \quad (16)$$

Putting (18) in (15) yields

We employed eqn. (19) in our work and approximately calculated the respective contribution of the E region to D region to the SFE current as 1.21.

This slightly differs from being exactly equal, but approximately equal.

Table 3 Parameters derived for each of the stations

STATION CODE	Angular difference (°)	$\lvert dH_{sfe}/dH_o \rvert$	$\lvert dY_{sfe}/dY_o \rvert$	$\lvert dH_{m.v.} \rvert$	$\lvert dZ_{m.v.} \rvert$	$\lvert dY_{m.v.} \rvert$
BEL	11.9	0.47	0.44	8.75	4.54	14.75
BFE	2.5	0.54	0.23	10.33	5.67	13.88
BDV	13.4	1.75	0.59	7.50	4.29	13.75
CLF	20.3	15.00	0.42	6.04	5.46	14.46
DOU	8.3	3.60	0.33	7.63	4.75	13.21
ESK	10.8	0.60	0.14	12.58	6.00	13.79
FUR	14.1	1.75	0.45	6.54	4.79	14.04
HAD	20.3	6.50	0.28	10.13	7.17	13.71
HLP	26.8	1.13	0.38	11.71	6.25	17.71
HRB	20.3	1.00	0.50	6.58	4.29	13.91
LER	14.8	0.58	1.00	13.67	6.86	14.08
LOV	6.8	0.45	0.13	11.21	5.96	13.96
MAB	19.5	2.33	0.35	7.71	5.00	14.38
NCK	13.8	1.30	0.52	6.33	4.42	13.58
NGK	10.6	1.09	0.50	9.08	4.46	14.04
THY	14.4	1.00	0.26	6.42	4.33	13.96
TRO	1.2	0.16	0.18	61.13	12.63	25.63
WNG	13.1	0.75	0.30	10.46	6.17	13.96
VAL	13.0	2 75	0.25	10.04	9.96	18.29
BNG	10.4	1.12	0.93	14.79	3.21	6.79
TAM	1.8	3.75	0.48	11.67	4.25	9.33
HRN	42.5	1.29	1.42	26.04	69.58	32.58

The result of correlation also reveals that dH_{sfe} is poorly correlated with monthly mean variation while dZ_{sfe} has a strong correlation with the monthly mean variation.

Estimation of respective contributions of D-and E-layers to the geomagnetic SFE shows that both of these layers contribute to the geomagnetic SFE in the ratio of approximately 1.21, implying that the contributions of the D-layer and E-layer are almost equal. This disagrees with earlier work by Lucas (1954), who concluded from his work that all currents flow above E-region in the ionosphere.

Conclusion

Geomagnetic solar flare effect is not a simple augmentation of the Sq current system prevalent at the time of the solar flare. A strong correlation exists between the dZ_{sfe} and the monthly mean of the Sq variation. Solar flare is characterized by abnormal geomagnetic signatures of the event. It was also estimated that the contribution of D-layer and E-layer to the geomagnetic SFE is approximately in the ratio of 1.21, indicating that they both contribute almost equally to SFE. The storm sudden commencement occurred on 8 May, 1600UT, as identified on fig.2. It is also suspected that there exists a possible independent current system for the solar effect at a level different from the Sq current system.

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Table 2 Parameters derived for each of the stations

STATION CODE	dYo(nT)	dHo(nT)	dZo (nT)	dY sfe (nT)	dH sfe (nT)	dZsfe (nT)
BEL	16	-17	-10	7	8	-6
BFE	22	-11	-14	5	-6	1
BDV	22	-8	5	13	14	-5
CLF	24	1	1	10	15	2
DOU	27	-5	-3	9	18	-4
ESK	28	-10	-5	4	6	-4
FUR	29	-8	-4	13	14	-4
HAD	25	2	-5	7	13	3
HEL	26	-15	-11	10	17	-3
HRB	22	-12	-6	11	12	-2
LER	7	-12	-8	-7	-7	-5
LOV	16	-20	-7	2	9	-2
MAB	26	-6	-1	9	14	-2
NCK	23	-10	-5	12	13	-5
NGK	24	-11	-5	12	12	-5
THY	43	-12	-5	11	12	-3
TRO	11	-25	-27	2	-4	4
WNG	26	-12	-8	8	9	-1
VAL	28	4	-3	7	11	3
BNG	14	17	-5	-13	19	-2
TAM	31	4	-7	15	15	-8
HRN	24	-31	-2	34	21	29

Storm Sudden Commencement

The Storm Sudden Commencement (SSC) occurred on the 8 May, 1998 at 15.00UT as registered on part of the magnetogram (Fig 2), with abrupt increase in the horizontal geomagnetic field H. This most likely is due to arrival of a dense plasma cloud made of charged particles from the sun, which are stopped at the magnetopause when the dynamic pressure of the charged particles is balanced by the magnetic pressure of the earth's magnetic field and the magnetosphere is compressed, invariably resulting in a sudden increase in H at these stations. The latitudinal variation of amplitudes of SSC in X & Y components have some sort of regular variation, while the SSC in Z has irregular variation across these stations.

Discussion of Results

The current systems as computed in this work is a fair approximation of real ionospheric current due to the fact that a considerable part of the magnetic disturbance may be due to currents flowing along the lines of force through the magnetosphere, between the northern and the southern hemisphere, Van Sabben (1968).

The correlation analysis carried out using the three geomagnetic components reveals relationship among solar flare elements and the daily monthly mean variation. This was carried out in order to ascertain if monthly mean variations show consistency, and if so, could serve as means of predicting the magnitude of SFE variations around the world.

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