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Impact of Severe Solar Flare Effects (SFE) and Sudden Storm Commencement (SSC) on Geomagnetic Fields, Across Latitudes

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Abstract
The influence of severe solar flare effects (SFE) and sudden storm commencement (SSC) on geomagnetic fields, in dip equator, low and mid latitude stations, have been studied using the five internationally accepted quietest days for the months in the year 2000. The results of the analysis 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. Also, the results of the correlation analysis showed that a strong correlation exists 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. The results from our study have revealed that SFE and SSC have quite significant influence on H and Z components of magnetic field in all the stations studied. The pronounced enhancement of H at station near the dip equator was attributed to both geomagnetic storms, which are as result of dynamical processes on the sun that deliver plasma of charged particles and associated fields to the earth environment.

Keywords: solar flare, storm commencement, geomagnetic field, dip equator, geomagnetic storms

INTRODUCTION

The importance of studying solar flare effects and geomagnetic storms on Earth's atmosphere is very crucial. This is because, they cause power cuts, tripping of circuit breakers and transformer damage, communications are distorted during storm-time, and satellite life-times are shortened. Geomagnetic storms could also cause malfunctioning of human nervous system, and it has been recorded that large number of sudden deaths from cardiovascular diseases occurs within the first few hours of geomagnetic storms. Hence, the need for this study cannot be overemphasised. Geomagnetic variation caused by solar flares has been analyzed by several workers.
In the analyses of the effect of Geomagnetic disturbances on socio-economic development in Nigeria, Okeke and Ifepe (2005), pointed out that geomagnetic storms and sub storms that commence most often after intense solar flares, adversely and negatively affect socio-economic development in Nigeria as in other parts of the world.

Okeke and Okpala (2005) in the study of the solar flare 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 system..

Rastogi (1996), described the results of an extensive study of SFE on H and D at the equatorial station Anamalunagar over the period 1967. He discovered that during the normal electrojet period a solar flare produced a positive change in H, a negative change in Y and a negative change in Z

Rastogi et al. (1997) reported that SSC amplitude in the H component was fairly constant with latitude, whereas the Z component showed large positive excursions at station within the electrojet belt.
Wang et al. (2006), made a statistical survey of interplanetary (IP) shocks and storm sudden commencements (SSCs) observed between 1995 and 2004, and found that 75% of SSCs are associated with shocks.

Okeke (1999) utilized several sets of observations in an attempt to identify the characteristics of the magnetospheric sub storm of April 1997 and concluded that the 29 April sub storm was probably not triggered externally since it was localized. The characteristics of the ground magnetic perturbations and energetic electron fluxes of this storm exhibited typical signature of the onset of a magnetospheric sub storm.

Wang (2007) examined the cosmic ray variation, solar wind speed, ion density, interplanetary magnetic field and geomagnetic disturbances storm time index (D_{st}) around 14 solar cosmic ray ground level enhancement (GLE) events in solar cycle 23. He found that all but one of GLE_s are always followed by a geomagnetic storm with D_{st} -50nT within 15 days later. Phenomenae that affect the Earth's atmosphere and magnetosphere have direct impacts or

consequences on human existence. This study therefore, becomes very necessary as the Earth's atmosphere and magnetosphere help in absorbing harmful solar radiation and hence protect life on the Earth. We intend to see in this our work the level of responsiveness of the horizontal (H) and the vertical (Z) components of the geomagnetic fields to the solar flare effects and the geomagnetic storms using the quietest days. Equally, we also aimed to establish a relationship (if any) between the geomagnetic field components of the solar flare effects (SFE) and the sudden storm commencement (SSC) using correlation analysis across the stations.

SOURCES OF DATA

The solar flare data used in this work were obtained from Burst and Transient Source Experiment (BATSE) and NASA GEOS satellite database. The NASA GOES satellite records bursts of solar X-ray radiation in the range 05-4A and 1-8A range of wavelengths.

Storm Data

The storm data used in this work were obtained from World Data Centre (WDC) for geomagnetism, Kyoto, Japan.

Geomagnetic Field Data

The data used in this work were gotten from World Data Centre (WDC) for geomagnetism 1 Kyoto, Japan and the Space Physics Interactive Data Resources Centre (SPIDR), Bouder, USA. Three geomagnetic stations were used, one station each from dip equator, low latitude and mid-latitude stations respectively as shown in the table 1 below.

Table 1: Geographical and Geomagnetic Coordinates

No	Stations	Code	Geographical		Geomagnetic	
			Latitude	Longitude	Latitude	Longitude
1	FUQUENE	FUQ	5.4ON	73.73W	15.72N	357.99W
2	HONOLULU	HON	21.32N	158.0W	21.64N	269.74W
3	IRKUTSK	IRK	52.30N	104.20E	41.93N	176.90E

Pre-Flare Amplitude Variation

In order to understand the SFE on H,Y and Z the changes in these components just before the start of the flare and after the flare with respect to the 0000h value on the same day were also noted and referred to as the pre-flare values H_0, Y_0 and Z_0.

$$H_0 = (H_1 + H_{24})/2 \quad (1)$$

$$Y_0 = (Y_1 + Y_{24})/2 \quad (2)$$

$$Z_0 = (Z_1 + Z_{24})/2 \quad (3)$$

Where H_1, Y_1 and Z_1 are the values of field components recorded just before the start time of the flare and H_{24}, Y_{24} and Z_{24} are the values at 24.00Hours UT.

Solar Flare Effect Amplitude Variation

The enhancements due to solar flare on the component H, Y, Z were defined as:

$$\Delta H_{bf} = H_1 - H_0 \quad (4)$$

$$\Delta Y_{bf} = Y_1 - Y_0 \quad (5)$$

$$\Delta Z_{bf} = Z_1 - Z_0 \quad (6)$$

$$\Delta H_{af} = H_2 - H_0 \quad (7)$$

$$\Delta Y_{af} = Y_2 - Y_0 \quad (8)$$

$$\Delta Z_{af} = Z_2 - Z_0 \quad (9)$$

Where ΔH_{bf}, ΔY_{bf}, ΔZ_{bf}, and ΔH_{af}, ΔY_{af}, ΔZ_{af} are the values of the geomagnetic H, Y, Z field before and after the flare respectively. The equations above are as used in Okeke and Okpala (2005)

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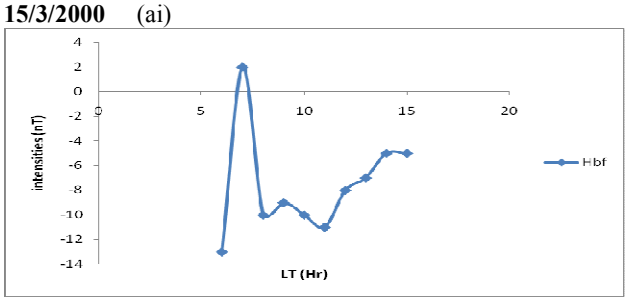

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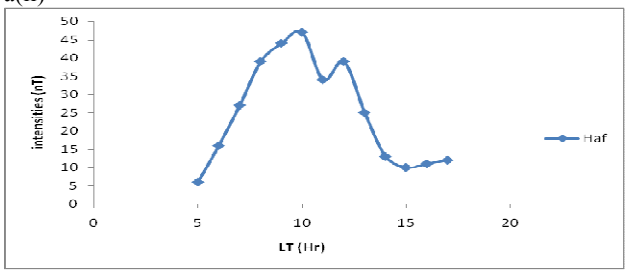

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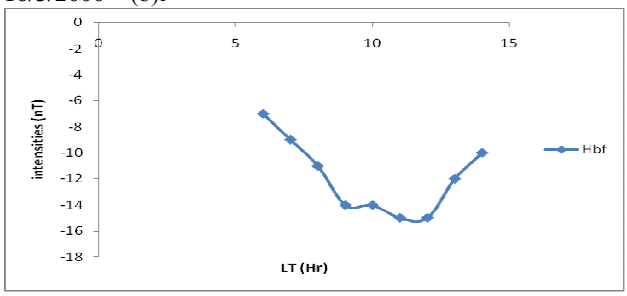

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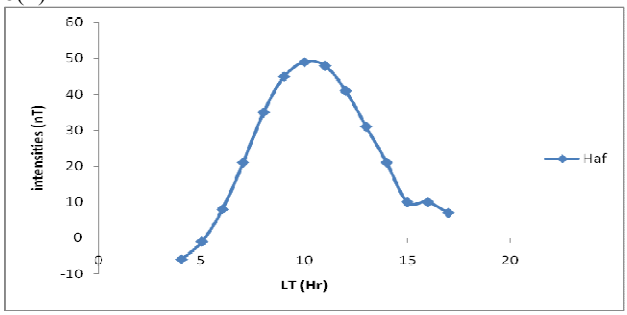

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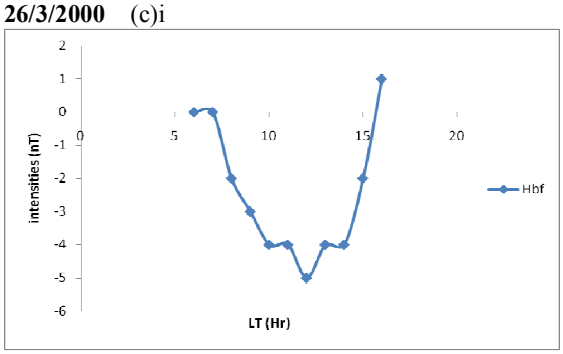

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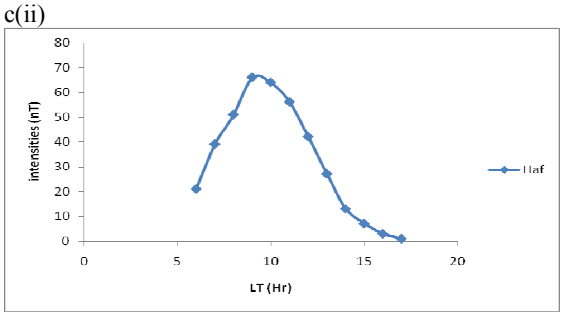

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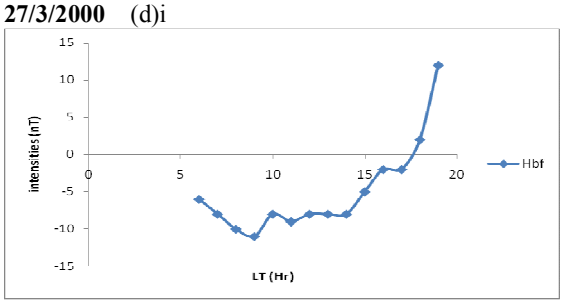

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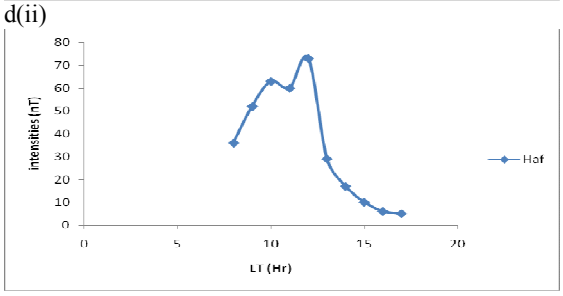

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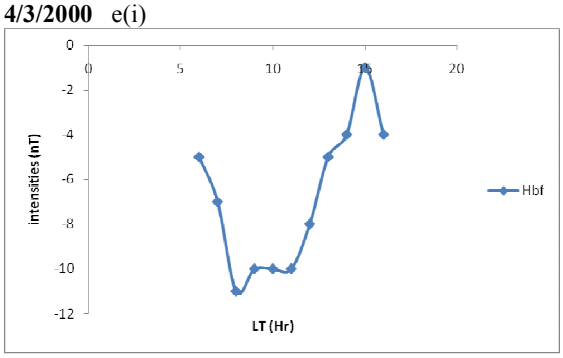

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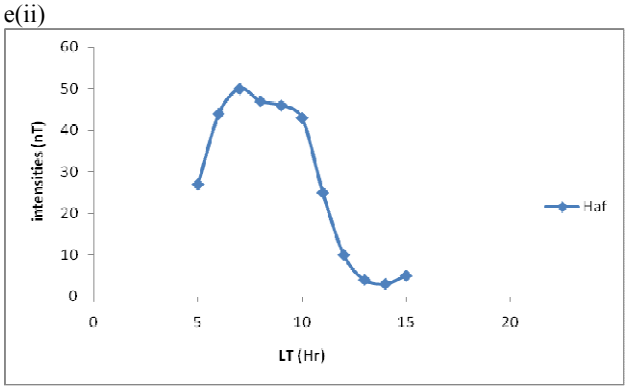

Fig.1 (a-e) above: graphs of daily sfe (h_{bf} & h_{af}) for March 2000 quietest days, fuquene station

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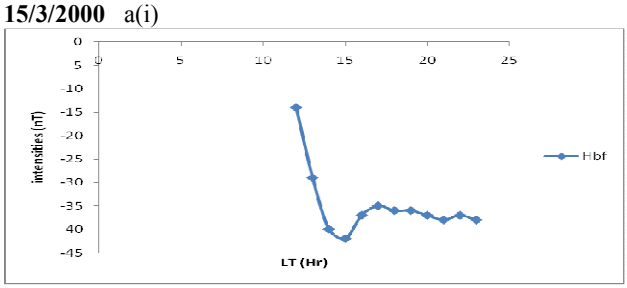

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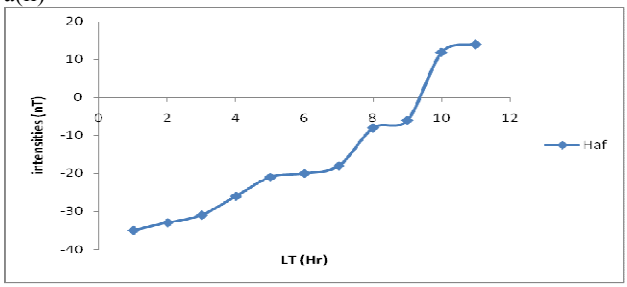

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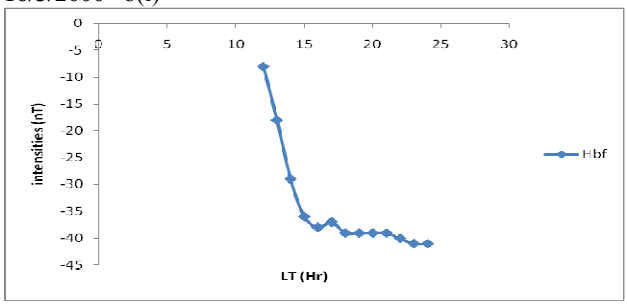

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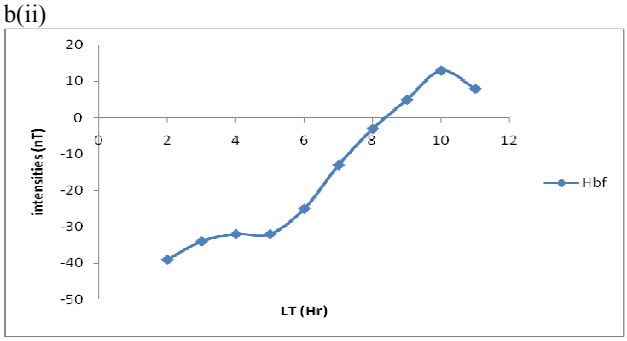

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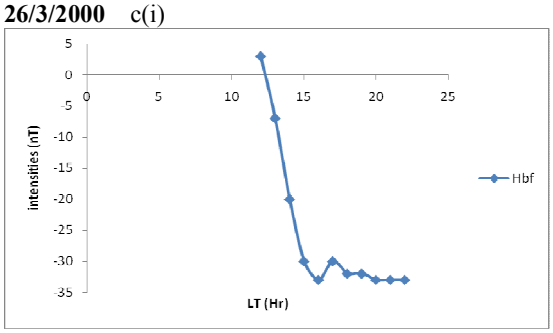

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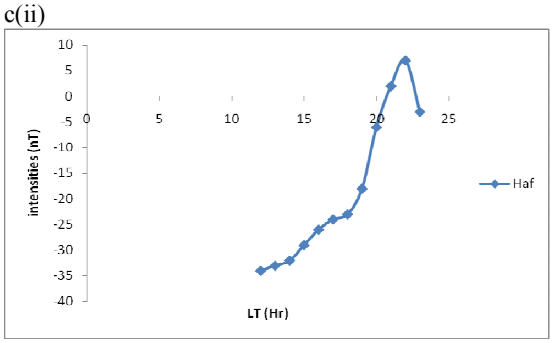

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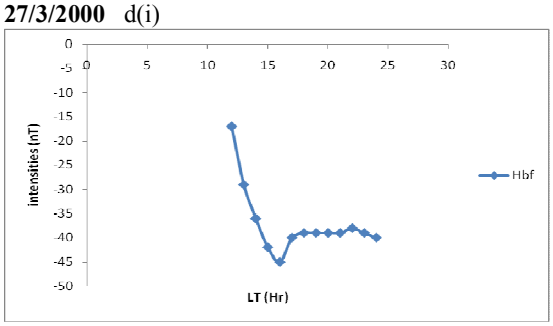

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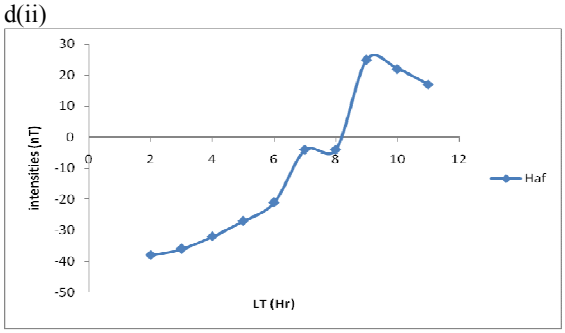

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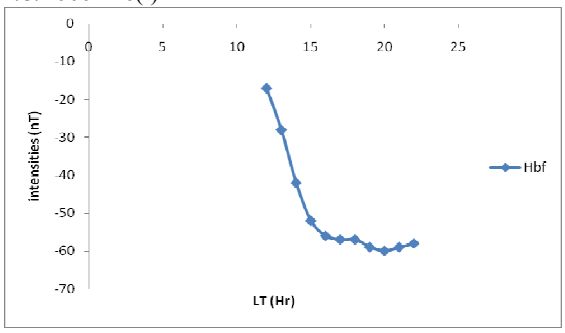

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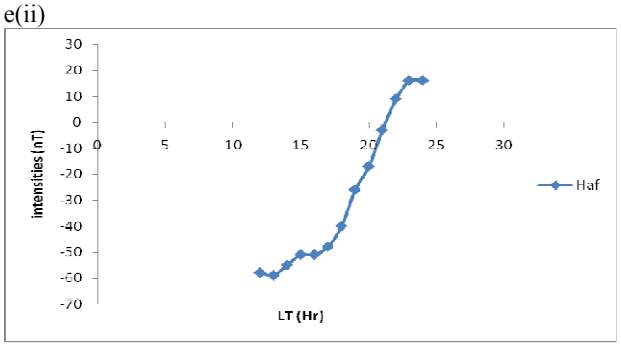

Fig. 2(a- e) above: graphs of daily sfe (h_{bf} & h_{af}) for March 2000 quietest days, Honolulu station

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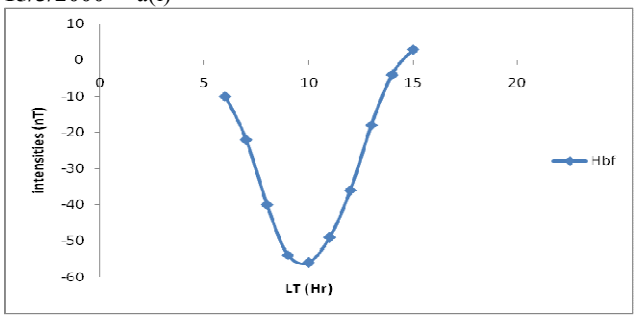

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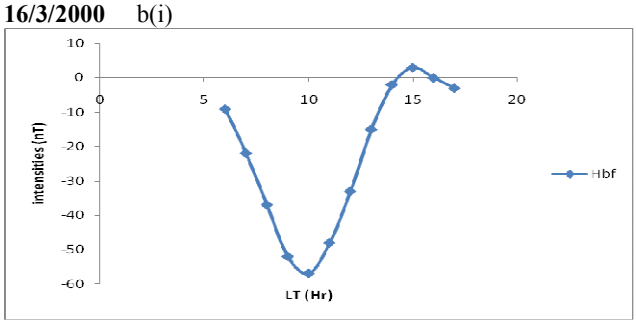

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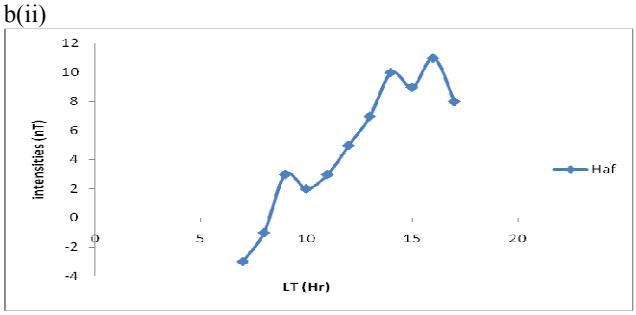

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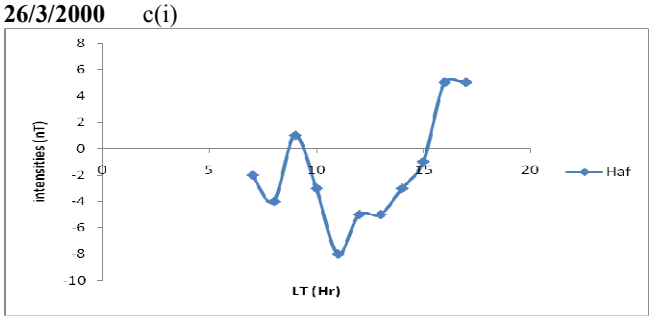

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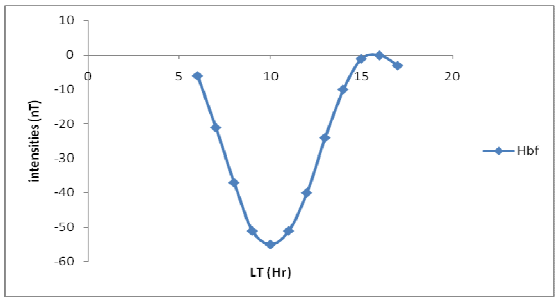

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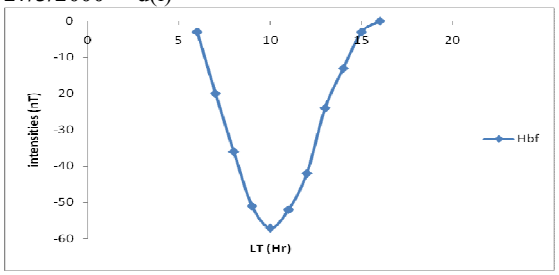

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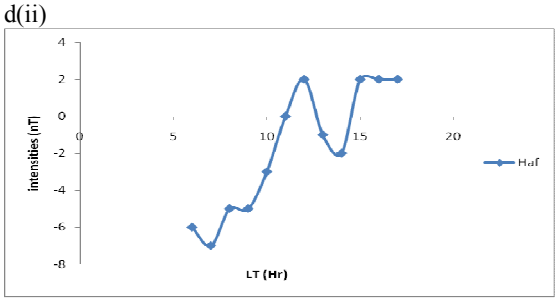

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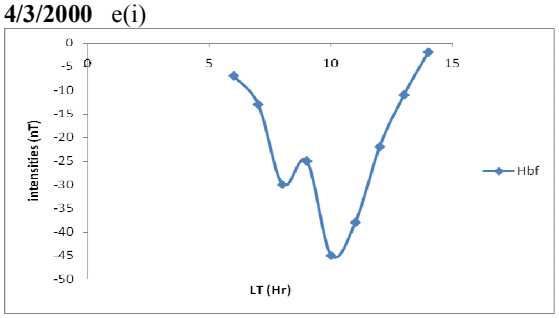

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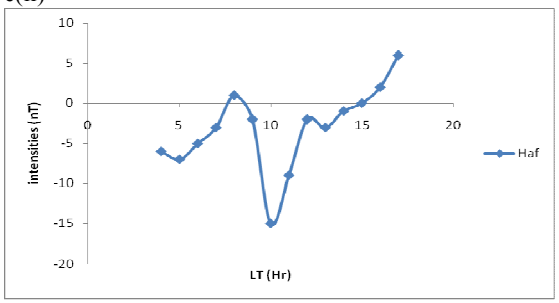

Fig. 3(a-e) above: graphs of daily sfe (h_{bf} & h_{af}) for March 2000 quietest days, Irkutsk station

Correlation Analysis

A correlation was carried out between the geomagnetic field components of the solar flare (H_{SFE} and Z_{SFE}) and the geomagnetic field components of the storm sudden commencement (H_{SSC} and Z_{SSC}) to ascertain if there any relationship between them. The equation for the correlation here is;

$$r(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

where x andy are the sample mean avearge.

Table 2. Pairs of correlation for the H, Z fields at 5% confidence level.

Stations	Elements correlated	Correlation coefficient
Fuquene	H_{SFE}, H_{SSC} Z_{SFE}, Z_{SSC}	0.527 -0.402
Honolulu	H_{SFE}, H_{SSC} Z_{SFE}, Z_{SSC}	0.215 0.983
Irkutsk	H_{SFE}, H_{SSC} Z_{SFE}, Z_{SSC}	0.637 -0.742

DISCUSSION OF RESULTS

The observations and analyses made in this study have enabled us to carry on with the following discussions, having studied the aspects of SFE and associated SSC and their related changes as regards across the latitudes.

Analysis of Effects of Solar Flare on Respective H and Z Components

The solar flares were observed at Fuquene station (Fig. 1a-e) at 11.26 UT which corresponds to 16.00hr LT on one of the most quietest days, the 15th day of March 2000. The H_{bf} for the above day was at its maximum of 2nT at 7.00hr LT and minimum of -13nT at 6.00hr LT, while the H_{af} which increases from 5.00hr LT, started decreasing at the 13.00hr LT with its maximum value of 47nT at 10.00hr LT and minimum value of 6nT at 5.00hr LT for the same quietest day. Also, the 16th day of March recorded its maximum and minimum values of H_{bf} of -7nT at 6.00hr LT and -15nT at 11.00hr LT respectively, while the maximum and minimum values of H_{af} for the same quietest day is 49nT at 10.00hr LT and -6nT at 4.00hr LT respectively. However, it was clearly observed at this station that the negative values of H before the occurrence of the solar flares conspicuously turned to positive values of H after the solar flares. Equally, on the 15th day of March, the positive values of Z_{bf} at the station also turned negative at the arrival of the solar flares on the quietest day of the month, with maximum and minimum values of Z_{bf} being 7nT at 8.00hr LT and 4nT at 6.00hr LT while the Z_{af} for the same quietest day has its maximum and minimum values of 20nT at 6.00hr LT and -19nT at 12.00hr LT. These results are in total agreement with the findings of (Rastogi et.al.;

1997), that the geomagnetic disturbances have greatest intensity and longest duration at lowest latitude in the day side hemisphere.

The solar flares at the Honolulu station (Fig. 2a –e) occurred at 13.00hr UT corresponding to the 12.00hr LT. The maximum and minimum values of H_{bf} were observed to be -14nT at 12.00hr LT and 38nT at 23.00hr LT respectively, while H_{af} maximum and minimum values for the same 15th of March record 14nT at 11.00hr LT and -35nT at 1.00hr LT. The 16th day of March has H_{bf} maximum value of 8nT at 12.00hr LT and minimum value of -41nT at 23.00hr LT, while the H_{af} has its maximum and minimum values of 13nT at 10.00hr LT and -39nT at 2.00hr LT respectively. Although, there were no remarkable changes in the values of Z_{bf} , there was consistency in the increase in its variation, while Z_{af} recorded variations that are erratic. The negative excursion of Z_{af} in this low latitude station is consistent with observations of (Rastogi 1998), that negative amplitude of Z_{sfe} was seen at Annamalainagar which is a low latitude station.

The variations of H_{bf} and H_{af} of the solar flares at the Irkutsk station (Fig. 3a –e) followed almost the same pattern with that at Honolulu station except that these values were almost all positive. Both values of H_{bf} and H_{af} in this station depict a consistent increase in their values with H_{af} on the 15th quietest day of March most distinguished. The H_{af} of the solar flares recorded reduced values. In this station too, maximum and minimum values of H_{bf} recorded 3nT at 15.00hr LT and -57nT at 10.00hr LT respectively, while that of H_{af} maximum and minimum values remain 9nT at 17.00hr and 0nT at 5.00hr LT. On the 16th day of March, the highest value of H_{bf} is 3nT at 15.00hr LT and the lowest value at -5nT at 10.00hr LT, while the H_{af} maximum and minimum values are 3nT at 16.00hr LT and -57nT at 11.00hr LT. Z_{bf} and Z_{af} show similar characteristic with that of H_{bf} and H_{af}. While the Z_{bf} shows a little positive increase on the first three hours of the quietest days, the Z_{af} shows no defined pattern of increase or decrease in values. This is attributed to latitude and local time of occurrence (Rastogi 1998). The understanding of SSC in general, involves a complex current system that develops in the magnetosehere-ionosphere domain as a result of sudden magnetospheric compression (Sastri 1975) and (Bhaskara 2008).

Analysis of SSC across the Months

There was a huge record of severe geomagnetic storms across the quietest days for the months, except on 27th and 4th of March that recorded most minimal values. The maximum value of SSC in March was 8nT and minimum of -589nT while June has its maximum and minimum values at -27nT and -472nT respectively. It is evident from the table that the year 2000 recorded severe geomagnetic storms on 16th and 17th of March at the hours of 1.00 – 24.00, and 12.00 - 19.00 respectively, 26th of March at the hours of 1.00-14.00 while June 31st recorded severe SSC at the hours 12.00 – 24.00, 17th June at the hours of 1.00-18.00, 26th of June at the hours of 2.00-13.00, and 18th of June at the hours of 7.00 -24.00. It is also clearly seen that the severe geomagnetic storms -589nT ≤ -238nT on the 16th of March and -472nT ≤ -231 on the 18th of March showed severe disturbances and lasted for a long period of time which is in disagreement with the observations of many authors (Kokubum 1983) and (Rastogi 2007). Also, geomagnetic disturbances associated with high solar flares are generally believed to have moderate disturbances as obsvered by some researchers, but this statement is invariant with our observation in this work as the charged particles released are capable of causing ionization. Therefore, the changes observed in the geomagnetic intensities at the stations especially in Fuquene at the dip equator are greatly associated with this storm (Wang 2007) and (Wang et.al.; 2006). In this work, our observations are contrary to the observations of many authors who ascertained that at SSC the value of H is positively enhanced in mid latitude (Solovyev et.al.; 2008). The values of SSC observed on the 16th day of March and on the 18th day of June that accompanied the solar flares of 15th day of March and 17th day of June respectively, recorded an astronomical values for the months.

Correlation Analysis

Correlation analysis was carried out in the two geomagnetic components of the solar flare and the storm sudden commencement referred to as (H_{sfe}, H_{ssc}) and (Z_{sfe}, Z_{ssc}) to ascertain if there is any relationship between them. The analysis revealed that relationship exists between the solar flare elements and the storm sudden commencement elements. The analysis also showed that the H_{sfe} is poorly correlated with the H_{ssc} while Z_{sfe} showed a strong correlation with Z_{ssc}. Several authors have observed that the strong response of (Z) and the (Y) is attributed to variability of solar activities (Rastogi et.al.; 1997)

CONCLUSION

Our investigation shows that SFE and SSC have significant impact or influence on both the horizontal (H) and vertical (Z) components of the magnetic field in the three stations under consideration. These effects have much high consistency in the variation of magnetic intensities in Fuquene station located at the dip equator. Also, the sole cause of this change in magnetic activity is increase in solar activity, hence the variation in horizontal component of the magnetic field is highly related to geomagnetic storm, it could also be attributed to equatorial electrojet (EEJ) phenomena at the dip equator. The result of the correlation analysis carried out to establish if any relationship exists between components of SFE and

SSC shows that the vertical intensity Z_{sfe} and Z_{ssc} have a strong correlation while H_{sfe} and H_{ssc} are poorly correlated.

In conclusion therefore, this study has given us an indepth understanding of the behaviour of the geomagnetic field intensities (H & Z) as a result of solar flares that signal the arrival of magnetic storm and more importantly, the consequences that follow the compression of the magnetic field brought about by solar flares. The resultant effect is most pronounced in the dip equator than in low and mid latitude stations. In general, these results have revealed evidence of coupled interactions in the sun-earth system. It is seemingly interesting to note that both the Earth's atmosphere and magnetosphere help in absorbing the severe solar flares that can be injurious to human lives while astronauts in space and satellites can be badly affected and even cause malfunctioning of some sensitive parts. Our results have yet re-confirmed the enhanced amplitudes of H_{SFE} at equatorial latitude stations and also large negative excursions of Z at almost all the stations. This result is in agreement with work of (Rastogi et.al.; 1997)

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