Study of Geomagnetic Field Variations at Low Latitude of African Equatorial Region

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Abstract: *Hourly values of horizontal (H) field component of geomagnetic field at Mbour obtained from World Geomagnetic Data Centre – Kyoto (WDC-kyoto) and solar wind parameters obtained from OMNIWEB website during several storm events in 2004 and 2010 were used to investigate the influence of solar wind parameters on H-component at a low latitude station in Africa. The results show a close correspondence of rapid changes between H-component and solar wind parameters during initial phase, main phase and recovery phase of geomagnetic storm. Further investigation using spectral analysis techniques as well as regression analysis showed that solar wind parameters is a strong candidate in triggering geomagnetic storm which affects H-component of the geomagnetic field.*

Keywords: H-component, solar wind parameters, geomagnetic storm, geomagnetic field.

1. Introduction

The earth has a magnetic field known as geomagnetic field which extends from the inner core of the earth to a region referred to as the magnetosphere which is above the earth surface. The earth experiences magnetic storm which is a short-lived disturbance of the earth magnetosphere mainly caused by solar wind interaction with the earth magnetic field. During magnetic storm, electric current in the magnetosphere exerts a magnetic force which pushes out the boundary between the magnetosphere and the solar wind. This disturbance leading to geomagnetic storm may be due to coronal mass ejection (CME) of the solar wind which may have been originated from weak magnetic field region of the sun's surface Susan, (2006). The feature of the sun-earth interaction is shown in fig. 1 below.
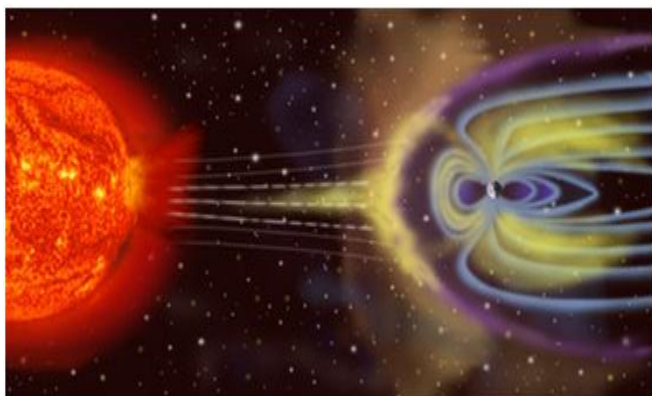

Figure 1: Sun-Earth interaction

The signature of ground magnetic storm is a measure of disturbance storm (Dst) index formed from the average of the deviation of northward (H) component of magnetic field near the equator from a long term average. Magnetic storm has three phases that are different from each other. The first is the initial phase which is a condition where the northern (H) component of the magnetic field increases from about +10nT to +50nT. After this stage, may commence a sudden sharp jump in the northward component of the earth's magnetic field. This is otherwise called sudden storm commencement (SSC). Some storms are not being associated with SSC (Tsurutani, 2001). Following the initial phase is the main phase. It is a situation where the strength of the ground magnetic field is reduced to 100nT or above. The last stage of storm is the recovery phase. The magnetic field returns to its ambient value at this last stage. This stage may be followed by intense storm or may just end there. Fig.2 show the different phases of storm.
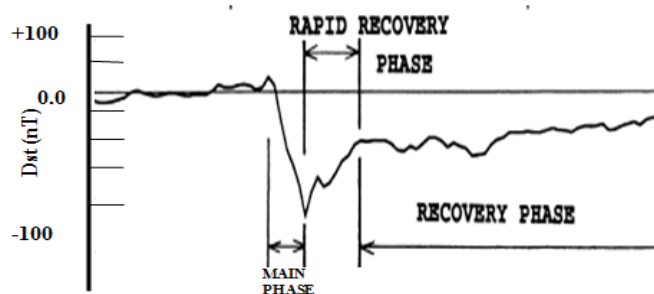

Figure 2: Dst index development during a geomagnetic storm

The horizontal component of geomagnetic field at low latitude exhibits a typical signature during geomagnetic storm period. The southward movement of interplanetary magnetic field (IMF) is signatory to ground magnetic storm recognized as the main phase as the ring current intensifies. When the IMF turns northward, the ring current begins to recover and the low latitude H-component begins to rise slowly back to its quiet time level called the recovery phase. The horizontal component of magnetic field at low latitude fluctuates during geomagnetic storm period.

However, it is observed that ground magnetograms also show some oscillatory structure during magnetically disturbed periods and this may be categorized as pulsation (Vichare and Alex, 2006). Pulsations are believed to some extent to be directly driven by density oscillation of solar wind (Kepto et al, 2002, Kepko and Spence, 2003) whereas Singer et al, (1977) result showed that pulsation activity is directly proportional to solar wind velocity.

The purpose of this research is to determine the effect of interplanetary magnetic field parameters on ground magnetic field measurements at equatorial low latitude stations.

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2. Observations

In this paper, we analyse geomagnetic storm events of hourly values of ground horizontal (H) component magnetic field at Mbour (MBO) geomagnetic observatory and IMF parameters from OMNIWEB Website as well as Dst-index of same website station.

2.1 Observation for the Event of 3rd- 4th April, 2004.

Two days of occurrence of storm were observed from ground magnetic observatories at MBO station and the plot of the amplitude of storm against time using MATLAB software is shown in fig. 3b. The Dst index for the two days of storm were also plotted and is shown in fig.3a. Interplanetary magnetic field (IMF) parameters of proton density, solar wind velocity, Z – component of IMF and total B – field of IMF respectively were also plotted for the two days event of the storm and are shown in figs. 3c, 3d, 3e and 3f.
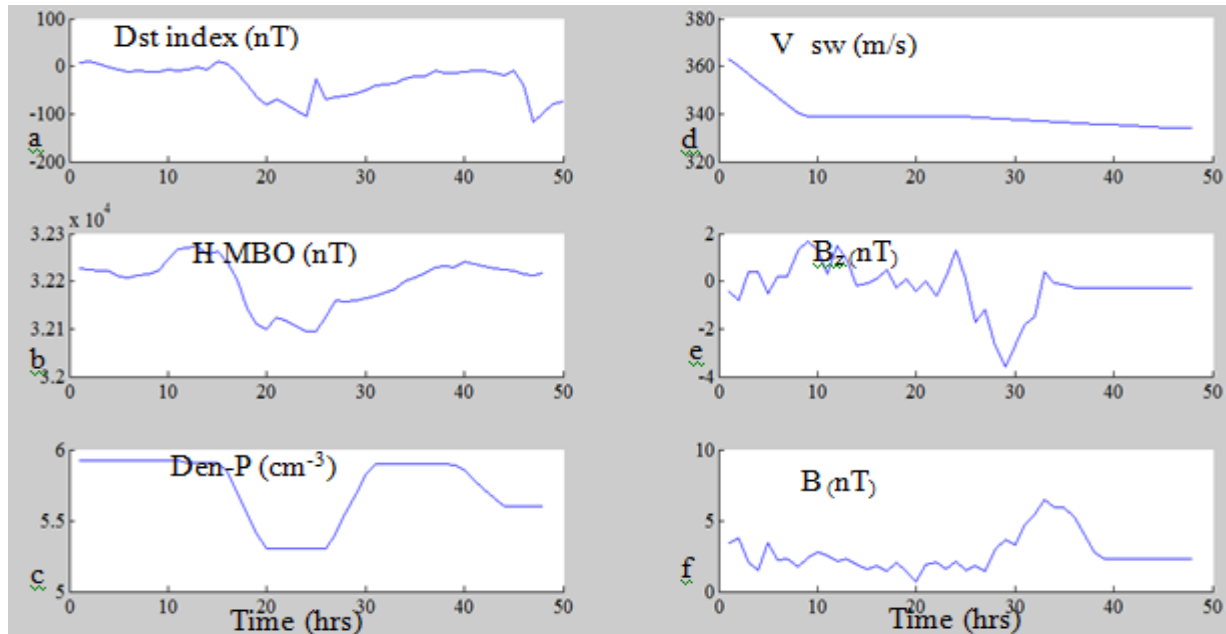

Figure 3: Variation of (a) Dst index, (b) H component at MBO and (c) proton density, (d) solar wind velocity, (e) Z – component of IMF and (f) total B – field of IMF for the storm days of 3rd – 4th April, 2004

It is clearly shown that between 1200hrs – 1400hrs universal time (UT) on the 3rd April, 2004 as in fig. 3b, there is an observed sudden increase in amplitude of H – component in MBO station which is in-line with the initial phase of the storm as observed in fig. 3a which is the measure of storm occurrence (Dst index). Thereafter, the fluctuations in the H – component decreased between the hours of 1500hrs – 20000hrs of the first day of the storm. These downward fluctuations of H component were also observed to occur in the Dst index (fig. 3a) which is referred to as main phase of storm. The slow recovery phase of the storm as observed in Dst index (fig. 3a) were also observed in the H – component of the MBO observatory station (fig. 3b). A close look at the variations observed in the IMF parameters shows that it is only the proton density that has similar observed features in the H – component. Usually magnetic records are masked with magnetospheric and quiet day ionospheric currents. As a result, it becomes necessary to remove these effects by subtracting the quiet day diurnal variation as well as the magnetospheric current from the disturbed H – component.

Figs. 4b and 4c show the diurnal variation of the H components at MBO for the disturbed and quiet days. Figs. 4d is 4b – 4c (i.e. disturbed H – Sq (H). Fig. 4e is then referred to as the residual field following from the subtraction of the magnetospheric and ionospheric currents. The residual H – component is placed along with the change in the average level of the proton density and that of solar wind velocity as in figs. 4f and 4g.
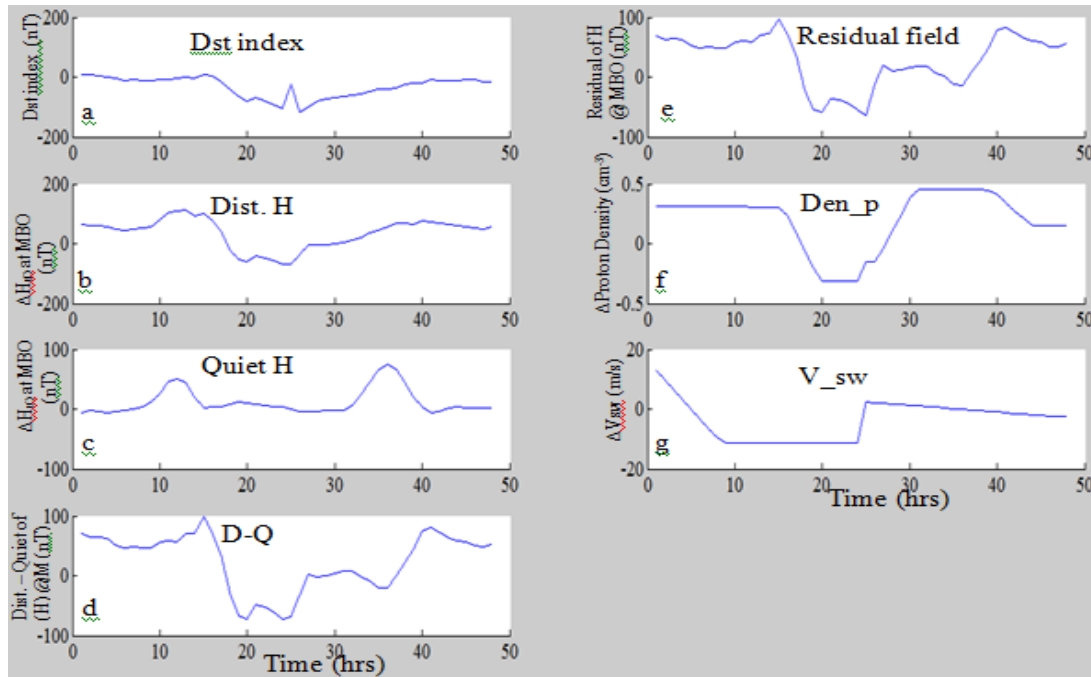
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Figure 4: Time series of hourly Dst index, H component of geomagnetic field after successive removal of each component along with solar wind parameters during 3rd – 4th April, 2004.

The observation between the residual fields and solar wind parameters (proton density and solar wind velocity) show great similarities of storm event.

However, some scientists had argued that the cause of geomagnetic field disturbance is as a result of local sources. Thus, this similarity of events between residual H component and solar wind parameters is an interesting evidence for further studies. The data were then transformed from time domain to frequency domain using fast Fourier transform (fft) technique. This is to reveal the power spectra that could have been superimposed on time domain and the calculations were done using MATLAB software. Quantitative relationship between the horizontal (H) component of geomagnetic field and solar wind parameters were also calculated.

2.2 Observation for the Event During 2nd - 3rd May, 2010

Fig. 5b shows the storm-time variation of magnetic field horizontal (H) component at MBO for the two days magnetic storm which picks up at about 1000hrs and lasted till 2000hrs on the first day of storm (2nd May, 2010). The Dst index for the same two days of storm event is shown in fig. 5a with a downward maximum peak of – 80nT. Figs. 5c, 5d, 5e, 5f, 5g and 5h respectively present the hourly mean variation of interplanetary magnetic field parameters of solar wind velocity, proton density, and total B – field, X – component of IMF, Y – component of IMF and Z – component of IMF.
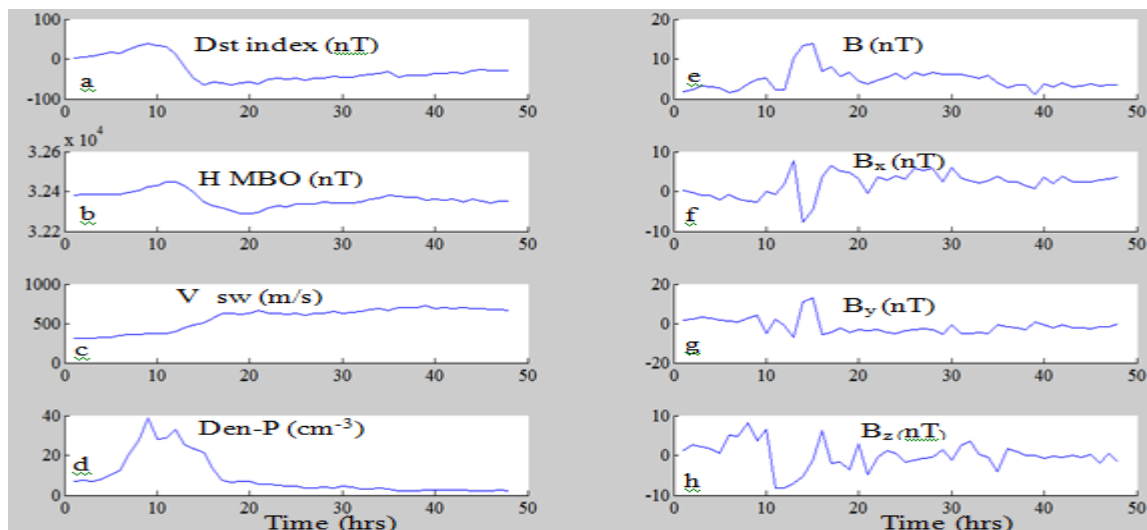

Figure 5: Variation of Dst index and raw H component at MBO station along with solar wind Parameters for 2nd – 3rd May, 2010

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It is visually clear that there is observed similarities of events between the H – component and IMF parameters. There is observed downward amplitude which started at about 1000hrs UT and showed a slow recovery till late in the night of 2nd May, 2010. This claims the main phase of the storm. In order to eliminate the fluctuations coming from internal sources, it became necessary to subtract the local effects from the disturbed horizontal component before comparison with the IMF parameters.

Dst index is the measure of storm event as recorded in fig. 6a. The mean of H component of geomagnetic field at MBO station is shown in fig. 6b and 6c for the disturbed H – component and Sq (H) day. Fig. 6d is the result that follows from the subtraction of quiet time diurnal variation from the disturbed H - component. The residual field is shown in fig. 6e whereas the IMF parameters of solar wind velocity, proton density and Bz are shown in fig. 6f and 6g respectively.
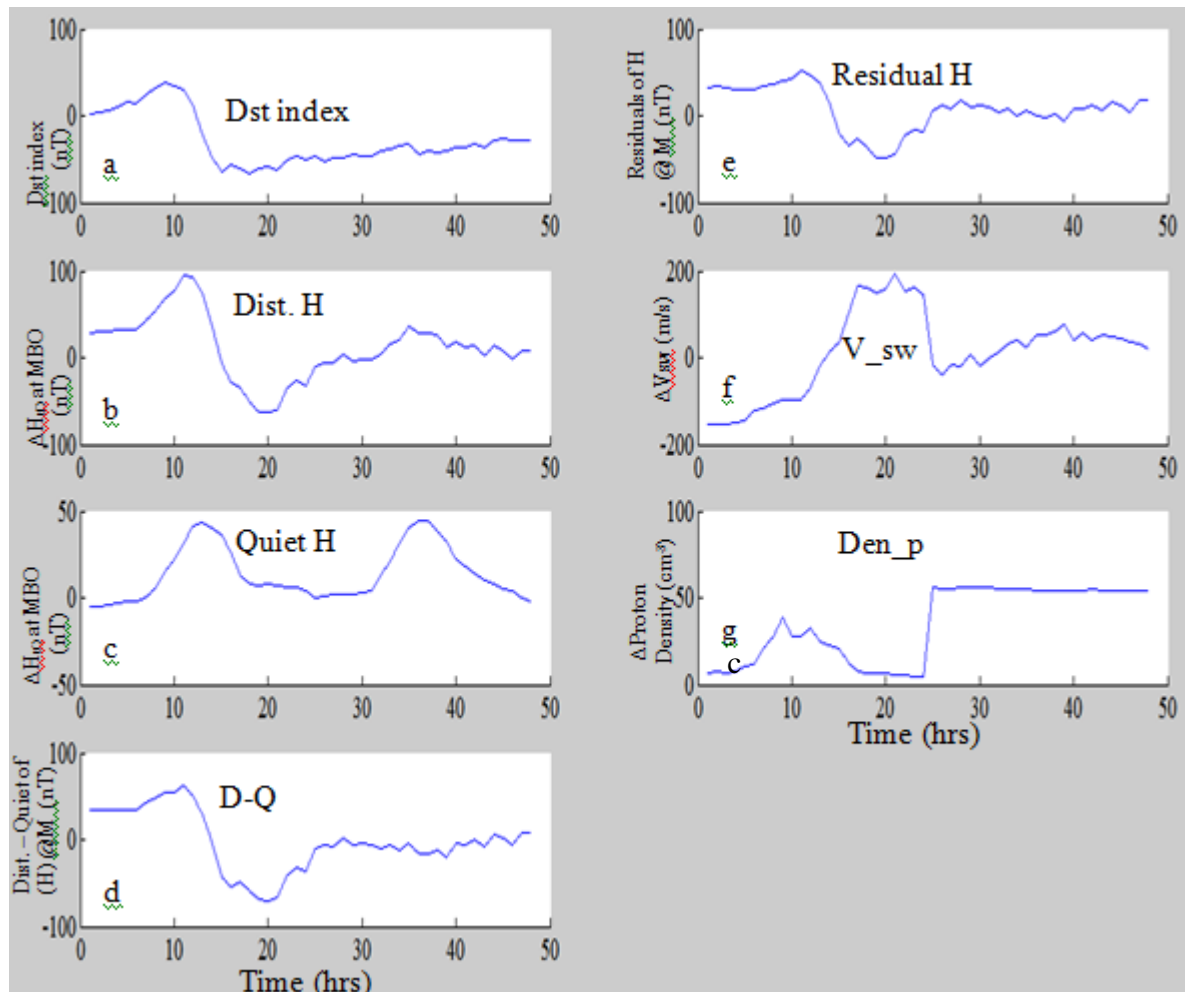

Figure 6: Time series of hourly Dst index, horizontal (H) component of geomagnetic field after successive removal of each component along with mean of solar wind parameters during 2nd – 3rd May, 2010

An observed maximum downward peak of about -80nT is measured on the measure of storm occurrence (Dst index) which occurred between 1500hrs – 2100hrs of the first day of storm (2nd May, 2010). The structure of the trend of the amplitude against time as observed on Dst index is seen to be similar with the H - component. Even after removing the local sources, the residual field still retained similar storm feature. Therefore, Dst index cannot be said to be responsible for the fluctuation on residual H component since its effect had been eliminated. The maximum decrease of residual field at MBO station is - 60nT. The solar wind velocity rose up to match with the decreased peak observed at the residual field while proton density maintained same similar downward peak with the residual H - component. Their correlation coefficient is seen to be positive.

3. Analysis

The values of H-component was recorded in minutes but was converted to hours since other parameters are hourly recorded data within the period under study. These data were recorded based on the days that storm occurred according to the classification of Dst-index. The baseline averages of the components for each of the storm days selected within the month in 2004 and 2010 were taken to be the average of the four hours flanking the midnight of the day and is thus shown as

$$W_0 = \left(\frac{w_{00} + w_{01} + w_{23} + w_{22}}{4} \right) \qquad 3.1$$

Where w_{00}, w_{01}, w_{23} and w_{22} are values of recorded data at 0000, 0001, 2300, and 2200 hours respectively, W_o = base-line of the component.

The difference between an hourly value of the variable and the base-line is thus;

$$\Delta W = w_t - w_0 \qquad 3.2$$

Where $t = 0,1,2\ldots23$ hours,

The days of geomagnetic field disturbances were carefully selected. The international quiet and disturbed days were selected based on the planetary magnetic index as published by the Australian Geosciences Website. The solar quiet days were averaged before subtracting it from the averaged disturbed days under study. The change in H-component was determined by the expression {(Disturbed − Quiet) − Dst $\cos\lambda_m$} to remove magnetospheric and ionospheric currents as local sources associated with Dst index. Each of the components is calculated in time domain using MATLAB software. The hourly values of the averaged Solar wind velocity (ΔV_SW), Total field (ΔB), ΔB_x, ΔB_y, ΔB_z and Proton density ($\Delta DEN\text{-}P$) respectively of corresponding days were all sorted and examined in time domain. This showed the similarities between solar wind parameters and residuals of H component. MATLAB software was as well used to run the Fourier series in terms of fast Fourier transform (fft). Figs. 7 - 13 show the power spectra of residual field of H component and IMF parameters for the two storm events which actually revealed the presence of discrete frequencies. Regression analysis was applied to find the quantitative relationship between H - component of geomagnetic field and that of solar wind parameters.
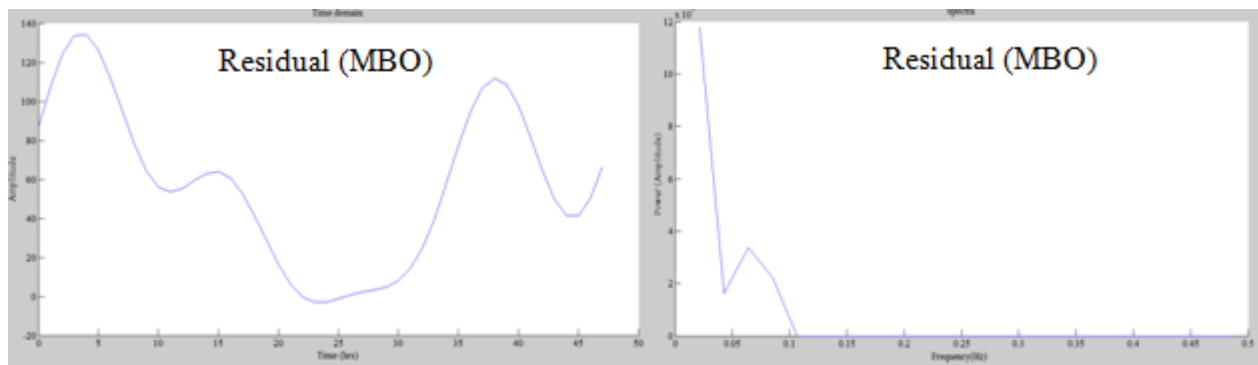

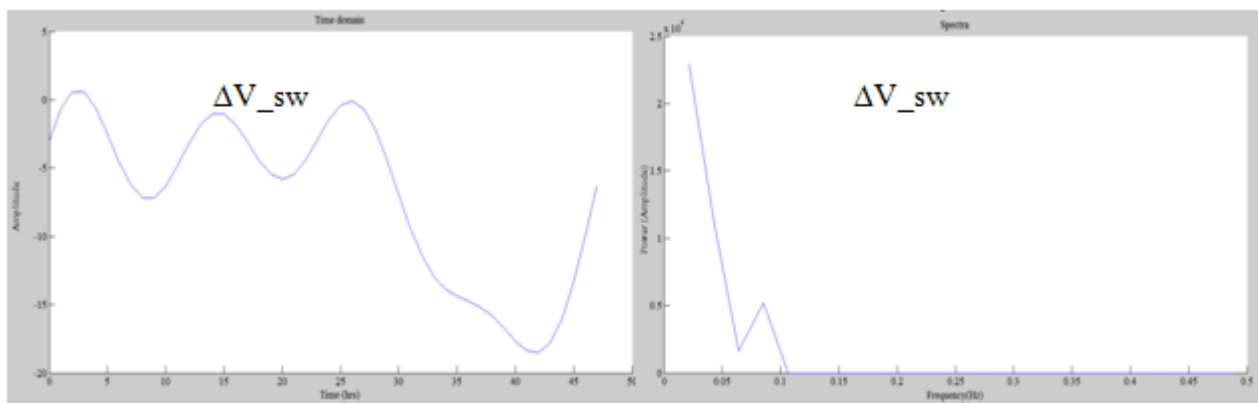**Figure 7:** Time domain and power spectra density of residual of H component at MBO station during $3^{rd} - 4^{th}$ April, 2004

Figure 8: Time domain and power spectra density of solar wind velocity during $3^{rd} - 4^{th}$ April, 2004.
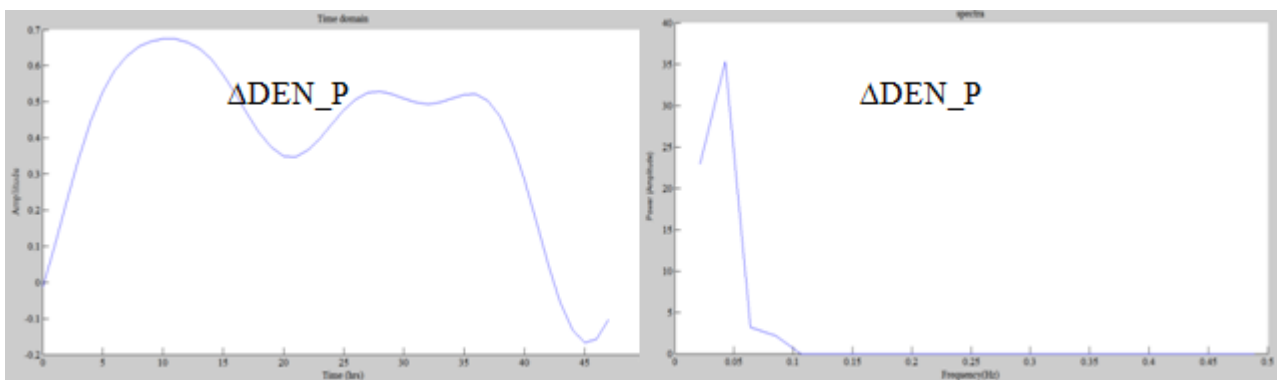

Figure 9: Time and power spectra density of proton density for $3^{rd} - 4^{th}$ April, 2004
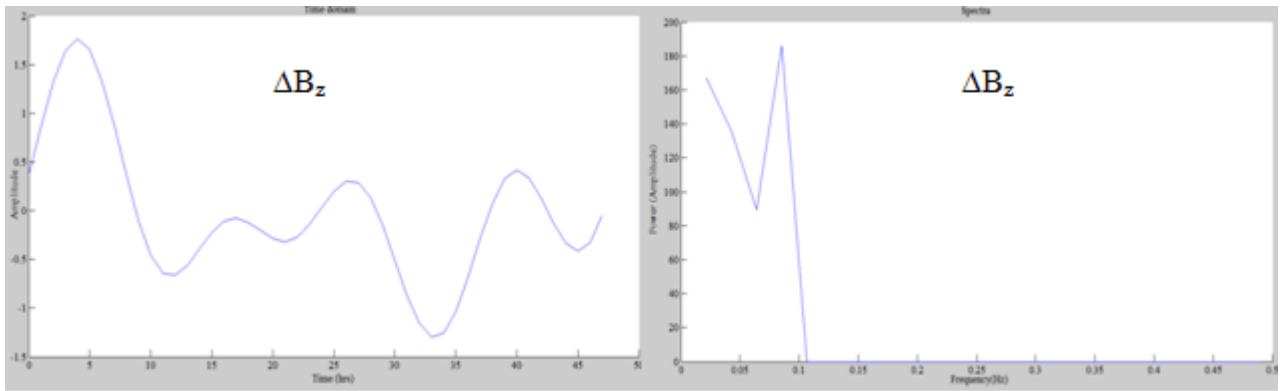
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Figure 10: Time and power spectra of B_z for $3^{rd} – 4^{th}$ April, 2004.
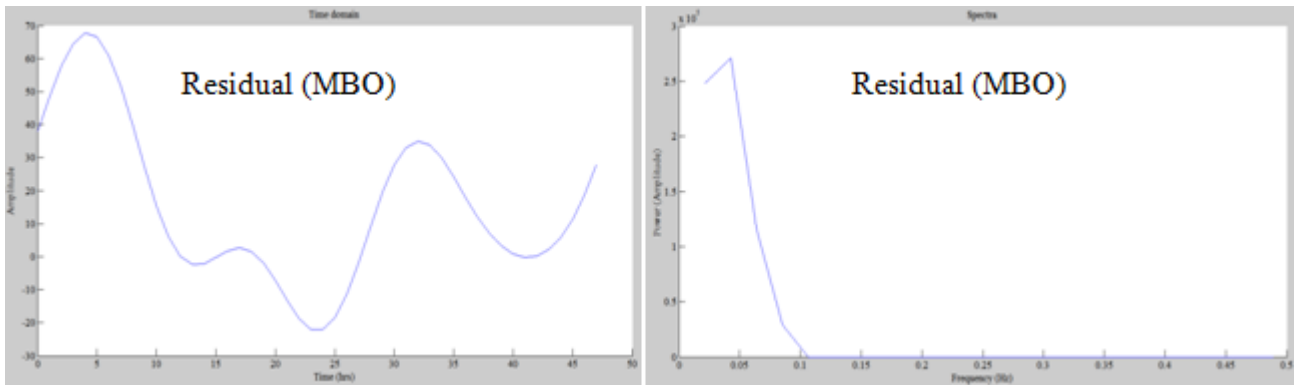

Figure 11: Time domain and power spectra density of residual of H component at MBO station during $2^{nd} – 3^{rd}$ May, 2010.
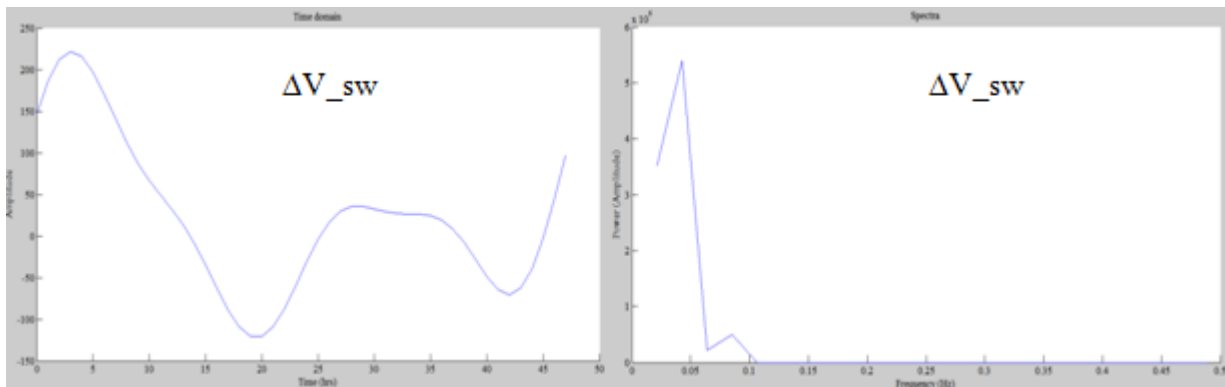

Figure 12: Time domain and power spectra of solar wind velocity for $2^{nd} – 3^{rd}$ May, 2010.
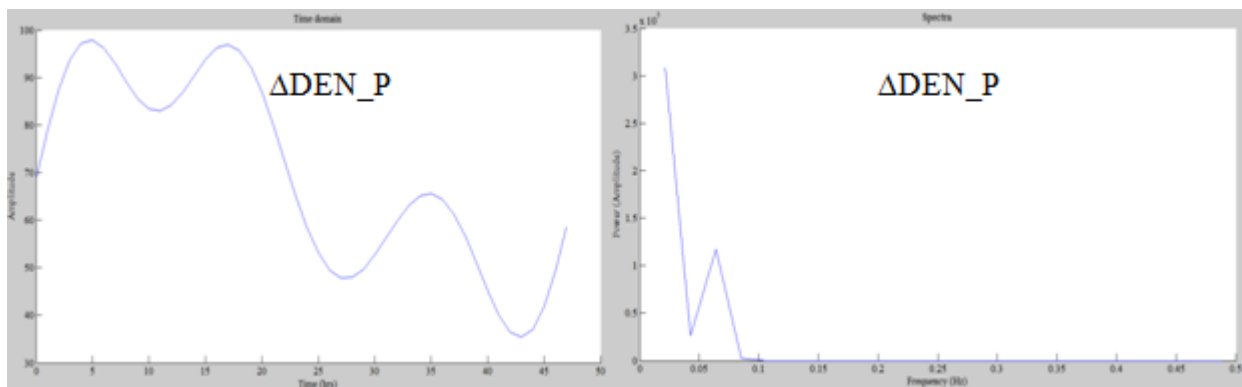

Figure 13: Time domain and power spectra density of proton density for $2^{nd} – 3^{rd}$ May, 2010

4. Results and Discussions

It is established that the fluctuations observed at the horizontal (H) component of geomagnetic field is a whole effect of magnetospheric activities (Kivelso and Southwood, 1986; Walker et al, 1992). Storm-time geomagnetic field variation is not completely as a result of local sources associated with Dst index but traced also to be associated with solar wind parameters (Vichare and Alex, 2006b). Kepko and Spence, (2002) equally shared similar view with strong argument using their result.

Generally, the observed maximum negative peaks on the amplitudes of H – component at MBO in time domain is seen to correlate with the maximum amplitudes of the interplanetary magnetic field (IMF) parameters of solar wind velocity, proton density and B_z in almost all the events. Dst index of all the events indicates clearly that there were occurrence of storm for each of the event periods as the trend of amplitudes at each time depicts similar features with the H – component. Normally ground magnetic field data are usually mixed with unwanted signals and after removing the noise interference from the H – component and IMF parameters, the amplitudes of signals still persistently displayed features signatory to storm. It is interesting to observe that initial phase, main phase and recovery phase of each of the storm events is seen to be more visible. It is observed that solar wind velocity, proton density and B_z have more common regular amplitude structure with the residual H – component than the other selected IMF parameters.

The time domain was transformed into frequency domain to see their relationship. Fortunately, it is observed clearly that the maximum rise in the amplitudes of H – component on frequency domain is observed to have corresponding features with IMF parameters of solar wind velocity, proton density and B_z as was also observed in time domain. The storm effect is observed to be more rapid in the noon hours and sometimes recovers late in the night. The regression analysis also revealed the effectiveness of IMF parameters in causing geomagnetic storm.

From the first considered storm event as shown in (fig. 3), there are similarities of storm event found between the H – component and IMF parameters which may be attributed to the activities of solar wind. The sudden storm commencement in H – component was observed to pick up at about 1500hrs universal time (UT) and the same trend of event is also observed to occur in IMF parameters. This feature is more common with solar wind velocity and proton density. The storm is observed to have lasted for approximately ten hours from the time of commencement to the recovery period. The measure of storm event (Dst) was also observed to have the same trend of event with the H – component within this same period. Only one maximum negative peak was observed to occur in this event and this took place during the afternoon time. The peaks of the discrete frequencies suggest the dependency of the magnitude of storm event on IMF parameters. Bz and total B-field does not show any observable feature relating to storm activity.

The residual record data at MBO station after removing the magnetospheric and ionospheric effects as in fig. 6 showed that there is still persistent sharp decrease in the H – component which is evidence of storm since the fluctuation seems to be partially in-line with Dst index. In this regard, it is however clear to say that Dst index is not completely responsible for the depression observed at the residuals of ground magnetic field. It is the light of the above reason that the residual event was subjected to comparison with IMF parameters by the method of spectral analysis to see if the cause of the fluctuation is coming from the internally generated disturbance within the Earth environment or as a result of IMF parameters. It is well observed that after removing the noise interference from H – component and IMF parameters in the frequency domain, their discrete frequencies were observed to show more clear similarities. The H – component have one maximum peak as well as the selected IMF parameters with each peaking at 0.1Htz.

The quantitative relationship between H component and solar wind parameters was calculated for the two events in 2004 and 2010 using excel software. Significant correlation between H component and proton density is found to be 0.77 for 3rd – 4th April, 2004. Moreso, significant correlation between H component and proton density is found to be 0.85, H component and solar wind velocity is 0.75 for 2nd – 3rd May, 2010.

This implies that the depression observed at horizontal component of geomagnetic field is not completely as a result of magnetospheric behaviour but can also be attributed to the activities of solar wind parameters especially proton density, solar wind velocity and B_z.

This result is in agreement with Singer, (1977), Walker et al, (1992), Rajni et al, (2008), Stephenson and Walker, (2002); Vichare and Alex, 2006.

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