Investigation of the Influence of Distant Parameters on Horizontal Component of Ground Magnetic Field

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ABSTRACT

The influence of distant parameters on the horizontal component of magnetic field was investigated for two years within two locations in Africa. The measure of storm occurrence (Dst-index) was used to select successful storm days. The effect of distant parameters on residual field was investigated using filter analysis. This study was considered on both time domain and frequency domain. The results showed very close correspondence of rapid changes in amplitudes between residual H-component and the selected IMF parameters especially the solar wind velocity, proton density and Bz. The correlation analysis between the distant parameters and residual H-component completely revealed effective dependence of the depression of residual field on the selected parameters. The value of the correlation coefficient (r) with solar wind velocity, proton density and Bz showed significant values of the range of 0.5 and above. This is direct evidence that Solar wind velocity, proton density and Bz are more effective in causing geomagnetic fluctuations at equatorial low latitude stations.

Keywords: geomagnetism, geomagnetic storm, IMF parameters, magnetosphere, residual field

I. INTRODUCTION

Geomagnetism is the study of the magnetic field of the Earth [1]. The Earth has a magnetic field known as geomagnetic field. This geomagnetic field extends from inner core to a region referred to as magnetosphere. Geomagnetic field experiences magnetic storm which is a short-lived disturbance on the Earth’s magnetosphere. This effect is suspected to be caused by the interaction of interplanetary magnetic field (IMF) parameters with geomagnetic field [6]. Some of the characteristics of the effects are the creation of ring-current in the Earth system; it could also cause ionisation [9], [11].

Magnetic storm basically is of three phases. The first phase is the initial phase which is a condition where the north component (H) of the magnetic field increases from about +10 to +50nT. The initial phase may commence with what is called sudden storm commencement (SSC). This is a sudden sharp jump in the northward component of the Earth’s magnetic field at the start of the initial phase. The cause of this sharp increase may be attributed to the sudden introduction of extra-pressure of the solar wind into the Earth’s magnetospheric environment [5].

However, it is clear that some storms are not associated with sudden commencement, perhaps if it does, the initial phase may be absent [10]. After the initial phase comes the main phase which is the point of maximum depression of the horizontal component of geomagnetic field (i.e. the magnitude of the field of magnet is reduced by 100 nT or above).

Magnetic storms have severe effects in our civilized generation. These problems associated with intense or super storms can ordinarily be remedied by meteorological forecast or prediction of space events before time. Apart from the remedy, high energy radiating particles can cause cancer of the skin and electronic damages, etc. The effect of storm is most effective when interplanetary magnetic field (IMF) moves in southward direction. The last stage of storm is the recovery phase which usually lasts for days. This is a phase where the magnetic field returns to its average value [2].

[7], studied the effect of interplanetary parameters on geomagnetic activities. Solar wind velocity (V) was the first one to be explored for such a relationship with geomagnetic activity. The paper examined the relationship between solar wind velocity alongside other parameters with linked data sets. This paper revealed that V can cause geomagnetic irregularities but VB is more effective to cause geomagnetic
storm. [12], examined the effect of the pressure experienced by ground magnetic field which is suspected to be coming from charged particles from the weak surface part of the sun’s surface. The paper examined activities of storm using minute values of the components selected. In the paper, significant quantitative relationship was found between the IMF parameters and ground horizontal magnetic field during the phases of sampled storm events. Despite their several analyses in different successive storm days, IMF parameters significantly correlated with ground horizontal component of magnetic field. The result explains that solar wind parameters are responsible for the fluctuations at the ground geomagnetic field.

[9], studied the influence of solar wind on horizontal component of geomagnetic field during storm. This paper shows the disturbance storm time of steady geomagnetic storm as well as change in horizontal component including IMF concurrently. The magnitude of changes of the horizontal component of ground magnetic field and interplanetary magnetic field (IMF) show slight change before sudden storm commencement. Thus, after SSC, there was observed changes on horizontal component. The analyses were done considering other days and corresponding depression recorded which confirms that IMF and disturbed storm-time are actually responsible for the fluctuations on H-component.

Expansion of knowledge concerning the space environment surrounding the Earth has become one of the vital focuses for research. This is mainly due to the fact that the adverse conditions in near-Earth space cause significant damage to technological systems and considerable economic losses [13], however, some researchers argued that the fluctuations at the geomagnetic field are only the primary cause of local effect whereas some, such as [12] established that external sources are only responsible for the variation of ground magnetic field, hence our motivation to quantitatively investigate the source of the fluctuation of ground horizontal magnetic field outside equatorial electrojet within two stations in Africa [4], [3].

II. ANALYSIS

The two sets of data used on this research were obtained from World Geomagnetic Data Centre website in Kyoto Japan (Dst-index and ground horizontal magnetic field component) and OMNIWEB website (IMF parameters). The horizontal components corresponding to the days of storm occurrences for each of the stations MBO and TAM were selected. The selected data were in minutes but were averaged to hours to have the same time interval as the Dst index as well as the solar wind parameters. Universal time (UT) was employed.

TABLE I: Stations, codes and geomagnetic coordinates

| Station      | Code | Latitude   | Longitude |
|--------------|------|------------|-----------|
| Mbour        | MBO  | 14.42°     | 16.97°    |
| Tamanrasset   | TAM  | 22.79°     | 5.52°     |

The Dst-index was examined and it was observed that there were signatures of storm occurrences in 2004 and 2010. Days of successive storm occurrences were identified as shown in Table II and quiet days in Table III as below.

TABLE II: Selected days of storm in 2004 and 2010

| S/N | Storm days | Month | Year |
|-----|------------|-------|------|
| 1   | 8 - 11     | November | 2004 |
| 2   | 6 - 7      | April  | 2010 |

TABLE III: Selected quiet days in 2004 and 2010

| S/N | Quiet days | Month | Year |
|-----|------------|-------|------|
| 1   | 3rd - 6th  | November | 2004 |
| 2   | 10th and 26th | April  | 2010 |

The baseline values of disturbed and quiet time of H-component and selected IMF parameters were calculated as the average of the values of the hours flanking the midnight. This is done to eliminate other extraneous effects fluctuating the data. The calculations are outlined below.

\[ W_0 = \frac{w_0 + w_{01} + w_{23} + w_{22}}{4} \]

where \( w_0, w_{01}, w_{23} \) and \( w_{22} \) are values of recorded data at 0000, 0001, 2300, and 2200 hours respectively. \( W_0 \) = baseline value [8].

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

\[ \Delta W = w_t - w_0 \]

where \( t = 0, 1, 2…23 \) hours.

The residual horizontal geomagnetic field was determined by the expression \( (\text{Disturbed} - \text{Quiet}) - \text{Dst} \cos \lambda_m \). Where \( \lambda_m \) represents the magnetic latitude of each station. These procedures were followed in order to eliminate diurnal variations and local factors from the H-component. The components were examined in time domain using MATLAB software. A better way of viewing the results is frequency domain which is referred to as spectral analysis. This was done using MATLAB software. The basis of spectral analysis is the Fourier series;

\[ f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \]

\[ y(t) = A_n \sin (2\pi ft + Q_n) \]

However, the correlation analysis between each of the IMF parameters and the residual H-component was carried out. This was to further reveal the rate of fluctuation caused by any of the selected parameters.

III. RESULTS AND DISCUSSIONS

A. Observation for the Event of 8th – 11th November, 2004.

The four days of storm event were observed from ground magnetic observatories at both stations under study. The plot of the amplitude of residual H-component against time at MBO and TAM stations are shown in figures 1b and 1c.
respectively. The measure of storm occurrence for the four days of storm was also plotted as shown in figure 1a. The IMF parameters of solar wind velocity, proton density, total B-field, Bx, By and Bz respectively were equally plotted for the same days of storm event and are shown in figures 1d, 1e, 1f, 1g, 1h and 1i respectively.

It is very noticeable on the amplitude of the residual H-component that there is observed downward slope at both stations which is also in-line with the Dst-index for the same period. The solar wind velocity and proton density are seen to have more similar structural pattern in their amplitude with the residual field of H-component. The rest of the selected IMF parameters were observed to oscillate similarly during the same period with H-component though does not show complete structural pattern in-line with what is observed in the H-component. A more cursory look at figure 1a above reveals absence of initial phase of storm. This means that there was sudden storm commencement (SSC). This event started at about 0000 hrs of the first day and this is seen to be a common occurrence at residual H-component as well as the selected parameters.

The main phase of this storm as observed on Dst index being the measure of storm event is observed to have its maximum downward peak around 1500 hrs of the first day (6th April, 2010). The residual horizontal components at both stations and IMF parameters of solar wind velocity and proton density have similar fluctuating structures with the Dst index at the same hour. The Z–component of IMF respectively.

B. Observation for the Event of 6th – 7th April, 2010

Figs. 2b and 2c show the diurnal variations of H-component at MBO and TAM for the disturbed and quiet days respectively. The corrected H-component following from the subtraction of quiet time from disturbed time of H-component is shown in Fig. 2d. The measure of storm for the same two days storm is shown in Fig. 2a whereas the residual of H-component at both stations are shown in Figs. 2e and 2f. The solar wind velocity, Bz, total B-field and proton density are shown in Figs. 2g, 2h, 2i and 2j respectively.

The main phase of this storm event as observed on Dst index being the measure of storm event is observed to have its maximum downward peak around 1500 hrs of the first day (6th April, 2010). The residual horizontal components at both stations and IMF parameters of solar wind velocity and proton density have similar fluctuating structures with the Dst index at the same hour. The Z–component of IMF respectively.
picked up to match with the activities of other parameters in response to storm. The three phases (initial, main and recovery) of storm as noticed on H-component were also observed on most of the selected IMF parameters.

Fig. 2. Time series of hourly Dst index and processed horizontal component field along with the selected parameters during 6th – 7th April, 2010.

However, there were observed maximum negative peaks on the amplitudes of Dst-index which shows signature of storm. In line with this, there were also observed maximum negative peaks on the amplitudes of H-component at MBO and TAM in time domain which is seen to correspond with the amplitudes of the selected interplanetary magnetic field (IMF) parameters of solar wind velocity, proton density, Bx, By, Bz and B in almost all the events. Dst-index for all the events indicates clearly that there were occurrences of storm for each of the event periods and the trend of amplitudes at each time align with the residuals of H-component at both stations. Normally ground magnetic field data are usually mixed with unwanted signals and after removing the noise interference, diurnal variations from the H–components, 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 was seen to be very visible. The amplitude of H–component at both stations maintained the same amplitude shape. It is also observed that solar wind velocity, proton density and Bz have more common regular amplitude structure with the residual H–component at both stations than the other selected IMF parameters. Sudden storm commencement (SSC) was observed to occur on a storm event as experienced on the first day of the event of 8th – 11th November, 2004 and this is suspected to be as a result of sudden sharp intrusion of solar wind into the ground magnetic field. The results of the components as examined in time domain were also transformed into frequency domain for further investigation. This was done to expose every spectrum for clearer visual inspection. It is obvious to observe that the maximum rise in the amplitudes of residual H–component in the frequency domain is observed to have corresponding features with Dst-index and the IMF parameters of solar wind velocity, proton density, Bx, By, Bz and B. The storm effect was observed to be more rapid in the noon hours and sometimes recovers late in the night.

However, some researchers have argued that the course of geomagnetic storm is only traceable to inherent parameters whereas few others such as [12], stated that the effect can only come from distant parameters. The method used in this research helped to clear this disparity. This is because the results showed signatory of storm with the presence of local factors. Furthermore, the local factor was eliminated from the result and further observation also showed signatory of storm. The research has revealed that geomagnetic storm can either be caused by inherent parameters or solar wind parameters. The magnitude of the effect caused by each of the sources is dependent on the strength of force generated by the field.

The correlation analysis between the IMF parameters and residual H–component completely revealed effective dependence of the depression of residual H–component on the selected IMF parameters. The value of the correlation coefficient (r) between residual H-component and some of the selected IMF parameters such as solar wind velocity, proton density and Bz show significant values of the range of 0.5 and above. This simply means that they are more effective in causing fluctuation of the geomagnetic field.

The power spectra of the residuals of ground magnetic field of the events of 2004 and 2010 are shown in figs. 3 - 11 below. The residuals of ground magnetic field together with selected solar wind parameters were then transformed from time domain to frequency domain using fast Fourier
transform (fft) technique with time window of 48 hours and 72 hours depending on the duration of each storm. This gave the opportunity for the display of discrete frequencies occurrence for each of the respective events. The calculations were done using MATLAB software. It was observed that the maximum amplitudes of the residual H–component at both stations were seen to correspond with most of the IMF parameters.

![Residual (MBO)](image1)

Fig. 3: Time domain and frequency spectra showing residual of horizontal component of MBO observatory during 8th – 11th November, 2004.

![Residual (TAM)](image2)

Fig. 4: Time domain and frequency spectra showing residual of horizontal component of TAM observatory during 8th – 11th November, 2004.

![ΔV_sw](image3)

Fig. 5: Time and frequency domains showing solar wind velocity during 8th – 11th November, 2004.

![ΔDEN_P](image4)

Fig. 6: Time domain and power spectral density show proton density during 8th – 11th November, 2004.
Fig. 7: Time series and frequency spectra showing $B_z$ during 8th – 11th Nov., 2004.

Fig. 8: Time domain and frequency spectra showing residual of horizontal element of MBO observatory during 6th – 7th April, 2010.

Fig. 9: Time domain and frequency spectra of residual horizontal element of TAM observatory during 6th – 7th April, 2010.

Fig. 10: Time series and frequency domain showing solar wind velocity during 6th – 7th April, 2010.
IV. SUMMARY AND CONCLUSION

Geomagnetic storm was investigated using hourly observations of horizontal component of geomagnetic field, solar wind parameters and Disturbed storm time (Dst) index in 2004 and 2010. The coherency of change on the amplitude of H-component with associated solar wind parameters revealed that IMF parameters contribute to the geomagnetic field disturbances as observed in time and frequency domains. The correlation analysis equally revealed that solar wind velocity, proton density and Bz contributes effectively to geomagnetic field measurements.

However, the purpose of this investigation was to find out the effect of inherent parameters and distant parameters on Horizontal component of geomagnetic field. From the results, there were observed clear and significant evidence that each of the factors can cause fluctuation of geomagnetic field. This study showed great revelation that both local factors and distant parameters are capable of causing geomagnetic storm. Based on the observations from time domain, frequency domain and the quantitative analysis; it was deduced that the activities of distant parameters significantly fluctuate the horizontal component of geomagnetic field especially the solar wind velocity, proton density and Bz.

Thus, this research confirms without doubt that geomagnetic disturbance is associated with the activities of solar wind parameters as well as Dst index. In absence of storm, the geomagnetic field will be at its quiet time except for some local or external effects.

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Fig. 11: Time and frequency domains showing proton density during 6th – 7th April, 2010.
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