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Variations of Horizontal Component of Geomagnetic Field Over Lagos and Ilorin Stations in Nigeria

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Abstract

This study presents a detailed investigation of Solar Quiet day horizontal geomagnetic field variations, Sq (H), observed at Lagos and Ilorin geomagnetic stations during 2008 from September – December. The data obtained was in minute type from Space Research Environment Center (SERC) for the two stations in Nigeria. The solar quiet (Sq) variation was derived through spherical harmonic analysis of hourly values of the horizontal (H) component of the geomagnetic values. Quantitative analysis of diurnal Sq(H) profiles reveals clear daytime enhancements linked to ionospheric dynamo action, with Ilorin station exhibiting highest peak amplitude in the local noon hours around (11:00 – 14:00 LT), with peak amplitudes of about 20–35 nT at Lagos and 40–80 nT at Ilorin. This enhanced amplitude reflects enhanced E-region conductivity and equatorial electrojet activity in Ilorin station. Morphological analysis revealed similar Sq (H) curve patterns for both stations, except for an anomalous irregularity observed at Ilorin in September 2006, possibly caused by local disturbances in the Sq current system. The study concludes that the Sq variation is superimposed on magnetic disturbances of a non-ionospheric origin and also demonstrate strong latitudinal control of Sq(H) over Nigeria and provide insight into equatorial ionospheric electrodynamics during quiet geomagnetic conditions.

The diagram above illustrates the concept of geomagnetic field within the atmosphere, a key compenent of the Earth's geomagnetic environment.

- These curved lines represent magnetic field lines that originate near the South Magnetic Pole and enter near the North Magnetic Pole.
- The bright, rainbow-like colors are used to visually emphasize the strength and structure of the geomagnetic field (not actual colors in nature).
- The bright, rainbow-like colors are used to visually emphasize the strength and structure of the geomagnetic field (not actual colors in nature).
- Earth is shown against a space background, highlighting its interaction with the surrounding space environment.
- The glowing arcs extending outward demonstrate the magnetosphere, which protects Earth from charged particles.
- The bright region near the Sun's direction symbolizes the influence of solar wind interacting with Earth's magnetic field.

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1. Introduction

The Earth's geomagnetic field exhibits regular daily variations even under magnetically quiet conditions. These variations, known as Solar Quiet (Sq) variations, are primarily driven by ionospheric dynamo currents generated through the interaction of solar radiation, thermal- tidal winds and the Earth's main magnetic field Chapman [1]. The Sq current system flows predominantly in the E-region of the ionosphere (approximately 90–130 km altitude) and produces measurable perturbations in the horizontal (H) component of the geomagnetic field at the Earth's surface. According to Campbell, geomagnetic field patterns change annually due to ionization fluctuations driven by solar radiation. Diurnal changes in the position of the focal latitude during quiet magnetic conditions would influence the pattern of the Sq current Emenike [2,3].

In equatorial and low- latitude regions, Sq (H) variations are strongly influenced by the equatorial electrojet (EEJ), an intense eastward current confined to a narrow band around the magnetic equator. Nigeria, located within the African equatorial ionospheric region, provides a unique opportunity to investigate these current systems using ground- based magnetometer data. Lagos and Ilorin stations, situated at different geomagnetic latitudes, are particularly suitable for examining the latitudinal structure of Sq (H) and the contribution of the EEJ. The method used to analyze geomagnetic variations in their global scale is the spherical harmonic analysis method, which enables one to separate the total field into external part and internal part. The aim of this work is to study solar quiet day horizontal component of the geomagnetic field variation for Lagos and Ilorin stations in the year 2008 during quiet conditions and to discuss the underlying ionospheric processes responsible for the observed features.

1.1 Objectives of the study

The objective of this study is to determine the variation of external current for Lagos and Ilorin stations. The specific objectives are:

I. To select the ten international quiet days for each month to minimize the effects of magnetic disturbances.

II. To obtain the Sq (H) amplitudes of the geomagnetic field.

III. To determine the (SqH) variation of the geomagnetic field.

IV. To determine the seasonal variation in the two stations.

1.2 Organization

This paper is structured into five sections namely: Section 1 contains the Introduction of the geomagnetic field variation in the Ionosphere, Section 2 contains the related work of solar quiet variation of the horizontal component, Section 3 contains the total procedure followed in carrying out the analysis (Materials and Methods), Section 4 explains the Results and Discussion and Section 5 contains the Conclusion.

2. Related Work

The variability of Sq (H) of the geomagnetic field has been a subject of study for many decades due to its significant impact on ionospheric dynamics and its practical implications for space weather forecasting and technology dependent systems. Suzuki studied the geomagnetic solar quiet field [4]. He observed that universal time variability are made up of two parts; which are the regular variations during quiet period (Sq) and the irregular variation during very disturbed period. Fukushima proposed an additional source of the geomagnetic variations where he suggested that a large scale electric field of magnetospheric origin would result to ionospheric currents systems and corresponding ground magnetic variation patterns similar to the ionospheric dynamo [5]. Rastogi and Onwumechili studied the geomagnetic field variation of Sq of horizontal component at India stations, a low latitude sector and they observed maxima magnitudes of Sq of horizontal component during equinoctial months and the lowest magnitudes of Sq of horizontal component at noon hours during June season which indicates a semi-annual variability [6,7]. James worked on day-to-day variability in Sq (H) at thirteen stations confined within a narrow longitude belt along Indo-Russian using the correlation coefficients of Sq (H) between each pair of stations [8]. They identified three latitude zones where correlations were very high as the equatorial electrojet latitudes, latitudes midway between equator and Sq focus. They suggested that the observed solar daily range in H field for each day was the result of the interactions of the current systems over the three different zones. Okeke and Hamano worked on the daily variations of geomagnetic H, D and Z field at equatorial latitudes [9]. Their research led to the study of the variations in three components H, D and Z at new equatorial electro jet regions. The results of the analysis were carried out, revealed that the amplitude of H has diurnal which peaks during the day at about local noon in all the three equatorial electrojet regions. This diurnal variation in H with Sq enhancement in all the three regions is attributed to the enhanced dynamo action at these regions. Diurnal variation as observed in D indicates that the equatorial electrojet current system has both east – west and north – south components. Okeke worked on Sq (H) variation over equatorial electrojet regions [10]. The diurnal variation of the monthly means of Sq (H) on the five international quiet days showed mostly expected diurnal variation of equatorial electrojet regions. Obiekezie and Agbo observed the day to day variability of the Sq (H) variation in the Indian sector [11]. It revealed that the variations are a dynamic phenomenon, showing significant random fluctuations in both amplitude and phase daily, not having a fixed pattern. Obiekezie and Okeke worked on variations of the geomagnetic H, D and Z field intensities on quiet days of the west African latitudes [12]. They observed the patterns of variations observed in H element, which peaks around noon, was attributed the effect of equatorial electrojet current. A reverse variation was noticed on some days which were seen to be the effect of counter electrojet current. Agbo worked on variability of daily horizontal components of geomagnetic field at low and middle latitudes [13]. The study confirms that the daily horizontal component of the geomagnetic field shows significant day to day variability Sq (H) low and middle latitudes, primarily driven by ionospheric currents, peaking around local noon and varying in amplitude and phase with night time variations attributed to non- ionospheric origin. Obiekezie worked on geomagnetic field variations at dip equatorial latitudes of west Africa [14]. The findings emphasize that geomagnetic variations in west Africa are complex, reflecting the intricate dynamic processes in the equatorial ionosphere and provides insights into space weather impacts. Obiekezie and Obiadazie worked on the variability of the horizontal component of geomagnetic field at the African sector [15]. The variability of the night time is believed to be from sources other than ionosphere. The observation in Addis Ababa showed that the station was attributed to the influence of equatorial electrojet. Obiekezie and Ezeakudo worked on the variability of solar quiet ionospheric currents in Nigeria using Lagos and Ilorin stations [16]. They observed that the variations were seen to be a function of the induction medium.

3. Materials and Method

The data used in this study consist of the horizontal component (H) of the geomagnetic field recorded at Lagos and Ilorin stations during 2008. Magnetically quiet days were selected based on standard geomagnetic indices to ensure minimal disturbance from magnetospheric currents. For each selected day, a nighttime baseline was established, and deviations from this baseline were computed to obtain Sq (H) values expressed in nanotesla (nT).

According to the fourier theorem, a function f(x) having a fundamental period 2 and satisfying the dirichlet conditions can be represented by the following infinite Fourier series [17].

$$f(x)=a_0+\sum_{m=1}^{4}\left(a_m\cos mx+b_m\sin mx\right) \quad (1)$$

Many practical cases involving physical oscillations, the independent variable is time (t) and the periodic interval normally denoted by T. and each cycle is therefore completed in seconds.

If

$$x=\omega t \quad (2)$$

$\omega=2\pi$ f, Angular velocity, m= order (ranging from 1-4), m 0 because Sq is cyclic in 24 hours.

f= Frequency; the number of oscillation completed in a cycle and is measured in hertz.

$$\text{f}=\frac{1}{T} \quad \text{and} \quad \omega=\frac{2\pi}{T}$$

Therefore putting equation (2) into equation (1), we have;

$$f(t)=a_0+\sum_{m=1}^{4}\left(a_m\cos m\omega t+b_m\sin m\omega t\right) \quad (3)$$

Considering geophysical analysis, t = 1 to 24 hours and total time (T) = 24

Therefore, $\omega=\frac{2\pi}{T}=\frac{2\times180}{24}=15\deg ree/hr$ and equation (3) becomes

$$f(t)=a_0+\sum_{m=1}^{4}\left(a_m\cos 15mt+b_m\sin 15mt\right) \quad (4)$$

Where the Fourier coefficient becomes

$$a_m=\frac{1}{12}\sum_{t=1}^{24}f(t)\cos 15mt \quad (5)$$

$$b_m=\frac{1}{12}\sum_{t=1}^{24}f(t)\sin 15mt \quad (6)$$

Where $f(t)$ is the H component of the geomagnetic field.

The data procedure follows the steps shown below.

The local time (LT) for the stations was employed throughout the analysis. The data was in minute type and was converted to hourly values by finding the average per hour. The ten quiet days was selected and mean of the hourly values was used to obtain the monthly values. Taking the mean hourly values of the 10 quietest days of every month;

$$\bar{Q}(nT)=\frac{Q_1+Q_2+Q_3+\ldots\ldots\ldots\ldots+Q_{10}}{10} \quad (7)$$

$\bar{Q}$ = Mean of hourly value for each month

For H, D and Z components, the baseline values for the analysis is given as the average of the hours flanking in the midnight plus the midnight values, which is given as;

$$\left.\begin{aligned} H_b &= \frac{H_{22}+H_{23}+H_{00}+H_{01}}{4}\\ D_b &= \frac{D_{22}+D_{23}+D_{00}+D_{01}}{4}\\ Z_b &= \frac{Z_{22}+Z_{23}+Z_{00}+Z_{01}}{4}\end{aligned}\right\} \quad (8)$$

Where H_{00}, H_{01}, H_{22}, H_{23}, D_{00}, D_{01}, D_{22}, D_{23}, Z_{00}, Z_{01}, Z_{22}, Z_{23} represents the hourly values at 00, 01, 22 and 23 local time (LT) respectively.

Sq amplitude (ΔH, ΔD, ΔZ) is obtained from the difference between the mean value and baseline for any hour t, which is;

$$\left.\begin{aligned}\Delta H &= H_t - H_b \\ \Delta D &= D_t - D_b \\ \Delta Z &= Z_t - Z_b\end{aligned}\right\} \quad \text{Where t = 0 to 23 hours} \tag{9}$$

For non-cyclic variation , this is corrected with the use of the hourly departures. This non-cyclic variation is defined as a phenomenon in which the value at 00 LT is different from the value at 23 LT [18,19].

$$\Delta C = \frac{V_{00} - V_{23}}{23} \tag{10}$$

Where V represents the H, D and Z components, multiplying equations (10) by T ranging from 0 to 23 hours, we have;

$$T\Delta C = \left(\frac{V_{00} - V_{23}}{23}\right)T \tag{11}$$

The linearly adjusted values at these hours are;

$$\text{Sq}(V) = V_0 + 0\Delta C, V_1 + 1\Delta C, V_2 + 2\Delta C + \text{.........}, V_{23} + 23\Delta C \tag{12}$$

In order words

$$\text{Sq}(V) = V_t + t\Delta C \quad \text{Where t = 0 to 23 hours} \tag{13}$$

Therefore, the hourly values corrected for non-cyclic variation on the quiet days give rise to solar quiet daily variation for H, D and Z. The Sq variation for each of the components H, D and Z are denoted as Sq (H), Sq (D) and Sq (Z) which was obtained for the 10 quietest days of the year.

4. Results and Discussion

Figure 1 illustrates the diurnal Sq (H) variation for Lagos station during magnetically quiet days in 2008. The Sq (H) values remain near the nighttime baseline from 00:00 – 05:00 LT, typically within ±2 nT, indicating minimal ionospheric current activity during pre-dawn hours and also could be due to local irregularities in Sq current. Following sunrise (≈06:00 LT), Sq (H) begins a steady increase associated with enhanced E-region ionization [12].

The daytime maximum occurs between 12:00 and 14:00 LT, with peak amplitudes generally in the range of 20–35 nT. After local noon, Sq (H) gradually decreases as ionospheric conductivity weakens toward sunset, returning to near-baseline values by 18:00 – 20:00 LT. The moderate amplitude observed at Lagos reflects the dominance of the global Sq current system.

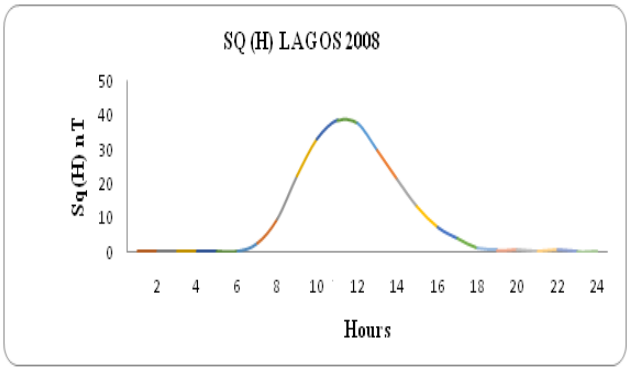

Figure 1: Variation of Sq (H) of the Geomagnetic Field

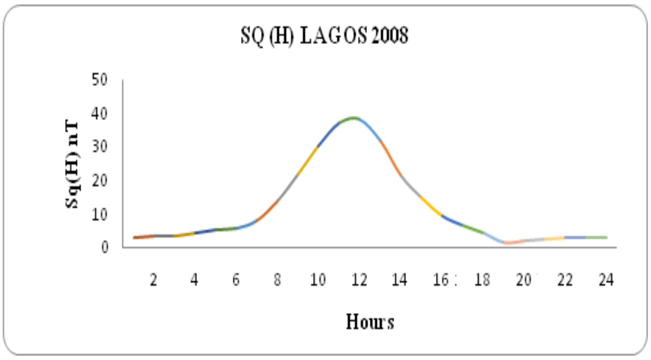

Figure 2: Variation of Sq (H) of the Geomagnetic Field

Figure 3 illustrates a sharp decrease between noon and post noon hours at 13: 00 LT. This pattern of variation observed in fig. 3 which more or less deviated from the expected normal variation could be attributed the effect of counter electrojet and also the atmospheric tidal winds may influence the Sq field, causing fluctuations in the Sq amplitude and distortion in the Sq shape.

Figure 4 presents the Sq (H) variation observed at Ilorin station for the same period. Similar to Lagos, pre-dawn

Sq (H) values remain close to the baseline (within ±3 nT). However, after sunrise, Ilorin exhibits a much steeper morning enhancement, indicating stronger ionospheric current development. The Sq (H) peak at Ilorin typically occurs between 11:00 LT and 13:00 LT, slightly earlier than at Lagos, with amplitudes ranging from about 40 to 80 nT on quiet days [13]. In some months, peak values exceed 80 nT, reflecting intensified eastward currents associated with the equatorial electrojet. The post-noon decline is gradual, with Sq (H) values returning toward nighttime levels after 18:00 LT.

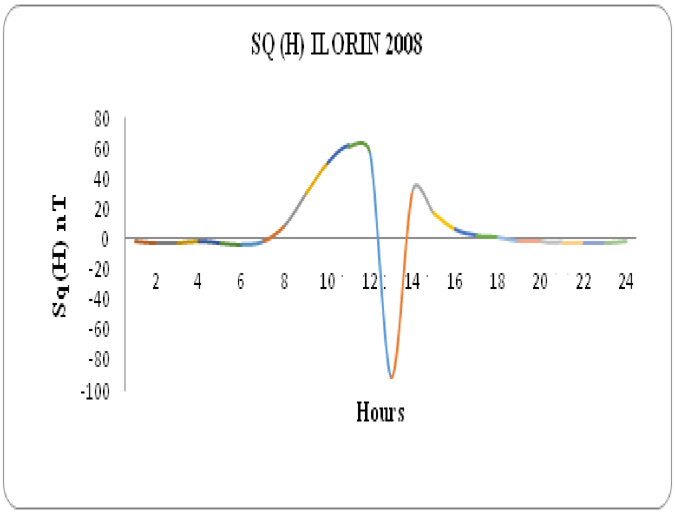

Figure 3: Variation of Sq (H) of the Geomagnetic Field

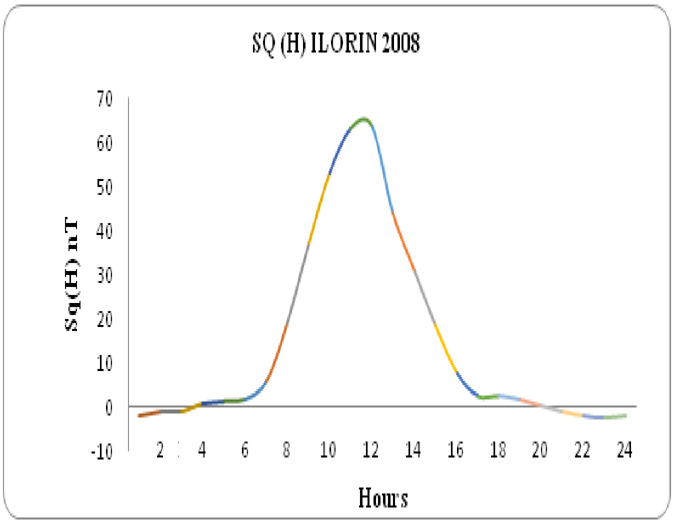

Figure 4: Variation of Sq (H) of the Geomagnetic Field

To further quantify the Sq (H) behavior, seasonal averages were evaluated by grouping months into March equinox (February–April), June solstice (May–July), September equinox (August–October), and December solstice (November–January). At Lagos station, mean seasonal Sq (H) peak amplitudes are approximately 32–35 nT during equinoxes, 20–25 nT during June solstice, and 22–28 nT during December solstice. This confirms stronger Sq currents during equinoctial periods compared to solstices. At Ilorin station, corresponding seasonal mean Sq (H) peaks are about 70–80 nT during equinoxes, 40–50 nT during June solstice, and 45–55 nT during December solstice. The equinoctial enhancement at Ilorin is significantly more pronounced, emphasizing the dominant role of the equatorial electrojet.

A direct comparison of Lagos and Ilorin Sq (H) profiles reveals clear quantitative differences in both amplitude and seasonal dependence. While both stations show similar timing of the onset and decay of Sq (H), the maximum amplitude at Ilorin is roughly two to three times larger than that at Lagos across all seasons. The average difference in seasonal peak Sq (H) between the two stations is on the order of 25–45 nT. The time of peak Sq (H) at Ilorin consistently occurs slightly earlier than at Lagos, particularly during equinoctial months, consistent with strong confinement of the equatorial electrojet around local noon.

4.1 Summary of Monthly and Seasonal Sq (H) Peak Amplitudes

Table 3 summarizes the typical ranges of monthly and seasonal mean Sq (H) peak amplitudes for Lagos and Ilorin stations during 2008. The values represent average daytime maxima derived from quiet-day conditions and are expressed in nanotesla (nT).

Period	**Lagos Sq(H) Peak (nT)**	**Ilorin Sq(H) Peak (nT)**
January	22–26	45–55
February	26–30	55–65
March	30–35	70–80
April	30–35	70–80
May	24–28	50–60
June	18–22	35–45
July	18–22	35–45
August	24–28	50–60
September	30–35	70–80
October	28–33	65–75
November	22–26	45–55
December	24–28	45–55
March Equinox	**32-35**	**75-80**
June Solstice	**20-25**	**40-50**
September Equinox	**32-35**	**70-80**
December Solstice	**22-28**	**45-55**

Table 1: Monthly and Seasonal Mean Sq (H) Peak Amplitudes (nT) for Lagos and Ilorin (2008)

However, The Sq (H) variations observed at Lagos and Ilorin are controlled by several interconnected physical processes. Solar radiation governs ionospheric conductivity, while neutral winds drive the dynamo mechanism responsible for current generation. At equatorial latitudes, the geometry of the Earth's magnetic field further enhances eastward currents, giving rise to the equatorial electrojet.

The stronger Sq (H) response at Ilorin underscores the sensitivity of equatorial stations to changes in ionospheric electrodynamics. Variations in EEJ strength can be linked to factors such as tidal winds, seasonal effects, and solar activity level. Although 2008 corresponds to a period of relatively low solar activity, the persistent daytime enhancement observed in the data confirms that even during solar minimum conditions, ionospheric dynamo processes remain active. Understanding these variations is important not only for space physics research but also for practical applications. Geomagnetic field variations can affect ground based technological systems, including power networks and geomagnetic navigation, making regional studies such as this one highly relevant.

5. Conclusion

An extensive analysis of Sq (H) variations over Lagos and Ilorin stations for 2008 has been presented using quiet day geomagnetic observations. The following deductions were obtained from the results;

I. The Sq variation is dynamic, exhibiting strong day to day variability.

II. Both stations showed correlated variations in both amplitude and in phase.

III. Ilorin recorded higher Sq (H) amplitudes due to its location within the equatorial electrojet belt.

IV. Anomalous behavior seen in the morphological curve in fig. 3 was attributed to the magnetic disturbances of a magnetospheric origin.

V. The study confirms the latitudinal dependence of Sq (H) variations over Nigeria and emphasizes the importance of equatorial electrodynamics in shaping geomagnetic field behavior. These results provide a valuable reference for future investigations of seasonal, solar cycle, and longitudinal variations of ionospheric currents in the African sector.

Data Availability

The data generated is included in the manuscript

Conflict of Interest

The author declares no competing interests.

Funding Source

None

Author's Contributions

Theresa Obiekezie: Theory of method, reviewing and editing. Onyinye Ezeakudo: Calculations, manuscript writing with figures preparation.

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