



Magnetospheric and Ionospheric Sources of Geomagnetic Field Variations

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Abstract

This study investigated the magnetospheric and ionospheric sources of geomagnetic field variation using the data set that consists of the hourly values of the geomagnetic element: horizontal intensity H , recorded at the geomagnetic observatory of the Department of physics, university of Ilorin, Ilorin (Long 4.670 and Lat. 8.50, dip 4.1°S) Nigeria for the months of august, October and December in the year 2008. The study attributed the daytime variation to the ionospheric sources while various reasons were given to explain these night-time variations, which include convective drift currents in the magnetosphere and the asymmetric rings currents in the magnetospheric currents; this variation due to disturbances indicates possible non-ionospheric origin and a partial ring current in the night side magnetosphere. The mean monthly hourly variation showed seasonal variation with the $Sq(H)$ maximizes in equinox with least variation in June solstice. Moreover, the mean ration of seasonal contributions of magnetospheric to ionospheric sources revealed that the E season has more contributions from both magnetospheric and ionospheric sources than other seasons with the least occurring during the J season.

Keywords

$Sq(H)$, Geomagnetic Observatory, Magnetospheric and Ionospheric Sources, Geomagnetic Field Variation and Asymmetric Rings Currents

Subject Areas: Atmospheric Sciences, Geophysics

1. Introduction

The geomagnetic field varies on a huge range of time scales: from milliseconds to millions of years. The slower changes, occurring over time scales of a few years to thousand years, are related to the dynamo processes acting within the Earth and are generally referred to as geomagnetic secular variation. On the contrary, the short-term variations are primarily of external origin arising from currents flowing in the ionosphere and magnetosphere [1].

Currents flowing in the magnetosphere are responsible for the occurrence of geomagnetic storms and substorms (*i.e.* of irregular variations), while currents flowing in the ionosphere are associated with a more or less regular daily variation of the geomagnetic field. Among the possible short-term geomagnetic variations, the smoothest and most regular is that observed on magnetically quiet days, and it is known as “solar quiet daily variation”. This variation mainly arises from the ionospheric current system flowing in the so-called dynamo region. This current system, which can be quite well approximated by a 2-D current flowing in the ionospheric E-region between 90 and 130 km [2] and [3], is driven by different processes. This current is indeed related with the expansion and contraction of the atmosphere as the Sun rises and falls daily through the year, with the global scale horizontal upper-atmosphere winds, with the lunar tidal forces upon the region, and with variations of the sun electromagnetic emissions responsible for extra photoionization of the region. As a result, the solar daily variation is a function of latitude, local time, season and solar activity level [4]. However, on days characterized by normal geomagnetic activity, or even days with only minor disturbance, in addition to the solar quiet daily variation, there is the solar disturbance variation, whose intensity varies with the intensity of the general disturbance. The solar daily variation fluctuates in both amplitude and pattern even on very quiet days [4]; these changes are known as “day-to-day variation” and are ascribed to irregularities in the winds at E-region height and to solar-activity-related changes in the ionospheric conductivity and wind system. The night-time geomagnetic variation has also been noticed in Sq, even when [5] used only 37 of the quietest days of the solar activity minimum year of 1965, the variation still persisted at midnight [6]. Hence it is not generally accepted that ionospheric currents do not flow at night outside the aurora and polar regions. [7] found a consistent nighttime variation in horizontal magnetic field component at mid latitudes and attributed same to distant magnetospheric sources after [8]. The variability of the nighttime field may thus be as a result of the variability of the nighttime distant currents. Moreover, ground magnetometers are capable of detecting fields due to distant magnetospheric sources such as the magnetotail current, the partial ring current, the substorm current wedge and the dayside current wedge. The contribution coming from these magnetospheric sources is not entirely negligible. Indeed, they physically contribute to the daily variation even on relatively quiet days.

2. Dataset and Analysis

The data set used in this study consists of the hourly values of the geomagnetic element: horizontal intensity H , recorded at the geomagnetic observatory of the Department of Physics, University of Ilorin, Ilorin for the months of August, October and December in the year 2008. The geographical coordinates of this observatory are long. 4.67° and lat. 8.5°. The geomagnetic observatory at Ilorin benefited from the cooperation of the MAGDAS project of Space Environment Research Center (SERC), Kyushu University (KU) Hakozaki 6-10-1, Higashi-ku, Fukuoka 812-8581, Japan. The data were analyzed for all the 15 international quiet days of months of the year.

2.1. Evaluation of Solar Daily Variation

The concept of local time (LT) was used throughout the analysis. The observatory is 1 hour ahead of the Greenwich Mean Time and thus, when it is 12 noon universal time UT, the LT is 1.00 p.m. The baseline is defined as the average of the 4 hours flanking local midnight (23, 24, 1, 2, hours). The daily baseline values for the elements used in this research are:

$$H_0 = \frac{H_{23} + H_{24} + H_1 + H_2}{4} \quad (1)$$

H_0 was corrected to the nearest whole number, where (H_1) , (H_2) , (H_{23}) and (H_{24}) are the hourly values of H at 01, 02, 23 and 24 hours LT respectively.

2.2. The Midnight Departure Values

The hourly departures of H from midnight baseline, (ΔH) were obtained by subtracting the midnight baseline values for a particular day from the hourly values for that particular day. Thus for “ t ” hour LT:

$$\Delta H_t = H_t - H_0 \quad (2)$$

where $t = 1$ to 24 hrs.

2.3. Non Cyclic Variation Analysis

The hourly departure is further corrected for non-cyclic variation, a phenomenon in which the value at 01 LT is different from the value at 24 LT, after [9] and [10]. This is done by making linear adjustment in the daily hourly values of (ΔH) . A way of doing this is to consider the hourly departures (ΔH) at 01 LT, 02 LT, 24 LT as V_1, V_2, \dots, V_{24} , and take

$$\Delta c = \frac{V_1 - V_{24}}{23} \quad (3)$$

After [16], the linearly adjusted values at these hours are:

$$V_1 + 0\Delta c; V_2 + 1\Delta c; V_3 + 2\Delta c; \dots; V_{23} + 22\Delta c; V_{24} + 23\Delta c \quad (4)$$

In other words:

$$S_t(V) = V_t + (t - 1)\Delta c \quad (5)$$

where t is the local time ranging from 01 to 24.

The hourly departures corrected for non-cyclic variation gives the solar daily variation in H . $Sq(H)$ denote the solar quiet daily variation in H . A set of hourly profile of $Sq(H)$ was obtained for the 15 quiet days of the year 2008.

2.4. Monthly Means

The monthly means for the quiet daily variation were evaluated for every month for the quiet days, each month having five (5) quiet days. This was done by averaging the hourly quiet days in each month.

2.5. Seasonal Variation of H Element

Following Lloyd's seasons [11], the months of the year are classified into three seasons; December or D-Season (January, February, November, December), Equinox or E season (March, April, September, October), June Solstice or J-Season (May, June, July, August). The seasonal mean were evaluated by first choosing one month in the different season to represent that season and finding the average of the $Sq(H)$ for that month means.

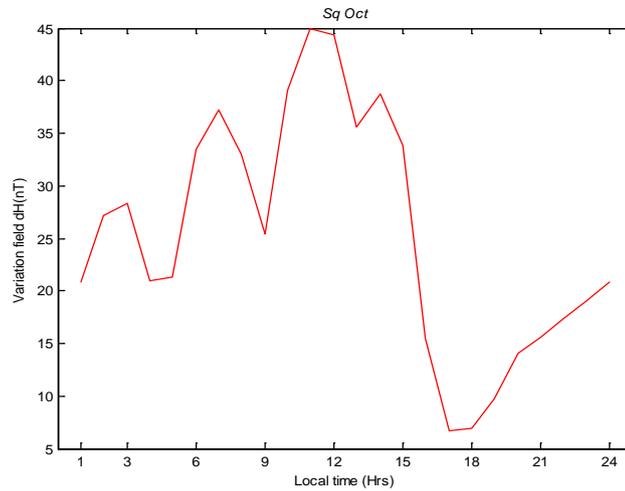
3. Results and Discussion

Figures 1(a)-(c) shows that the diurnal variations of solar quiet daily variation, Sq , exist in element on quiet days in each of the season. The daytime is taken to be from 06:00 hrs LT reaches the peak at about 12 noon, and reclines to low level at 18:00 hrs LT. While the night time was taken as the time from 18:00 hrs LT to 06:00 hrs LT. This is quite in agreement with the diurnal variation pattern of Sq in the earlier works of [12] and [13], which showed that the maximum intensity of Sq occurs around the local noon. [14] reported a similar diurnal variation pattern of Sq in H , $Sq(H)$ for 1958-1973 in Addis Ababa.

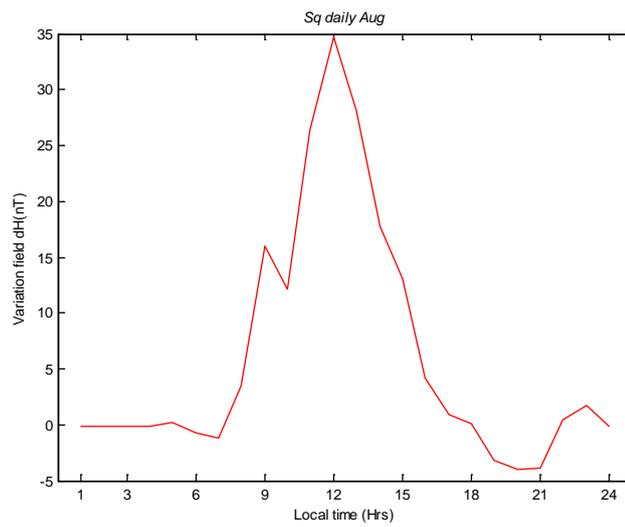
The diurnal variation of day-to-day variability, which followed the variation pattern of Sq , can be attributed to the variability of the ionospheric processes together with physical structure such as conductivity and winds structure, which are known to be responsible for the Sq variation. [15] noted after studying the variabilities in Indian equatorial electrojet sector that changes in the electric field control the phase and randomness of the variabilities, but the magnitude of the ionospheric conductivity controls the magnitude of the variabilities.

With a day in the E season having the highest value during the day and early hours of the day. With the lowest at night during the D season (as no absolute zero values at night showing the presence of little activities) on the day selected.

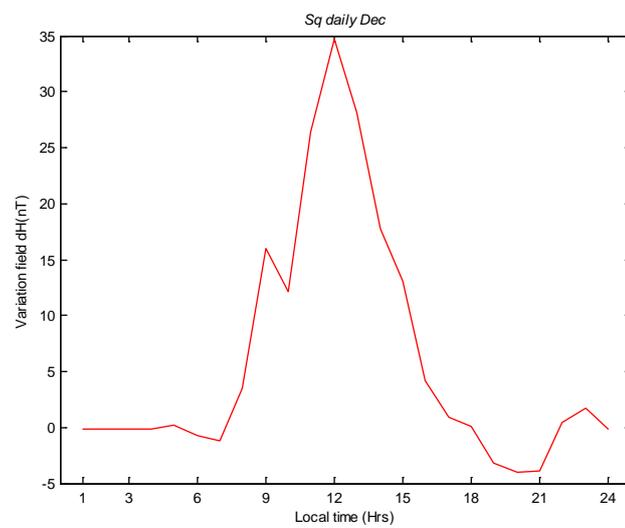
Figures 2-4 clearly reveal the seasonal variation of the solar quiet daily variation Sq , which varies with the magnetic components and prevailing ionospheric condition. $Sq(H)$ maximizes in equinox (71.9nT) with least variation in June solstice (15.1nT). [16] noted that the seasonal variability could be partially explained by the seasonal variation of lunar semi-diurnal tide. Seasonal change in the Sq variation is attributed to a seasonal shift in the mean position of the Sq current system of the ionospheric electrojet [17]. The electrodynamics effects of local winds can also account for seasonal variability, since the winds are subject to day-to-day and seasonal variability.



(a)



(b)



(c)

Figure 1. Solar quiet daily variation Sq in H on (a) the 7th Oct. 2008 at Ilorin (b) 7th of Aug. 2008 and (c) 7th of Dec. 2008.

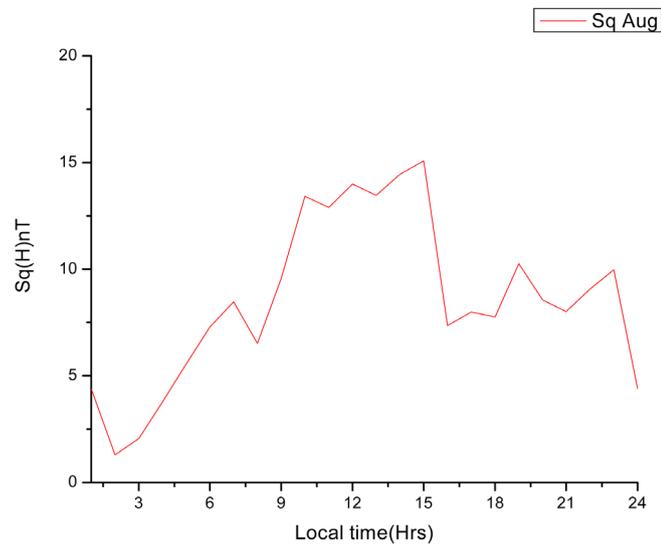


Figure 2. The mean monthly hourly variations of Sq for the month of August (J season).

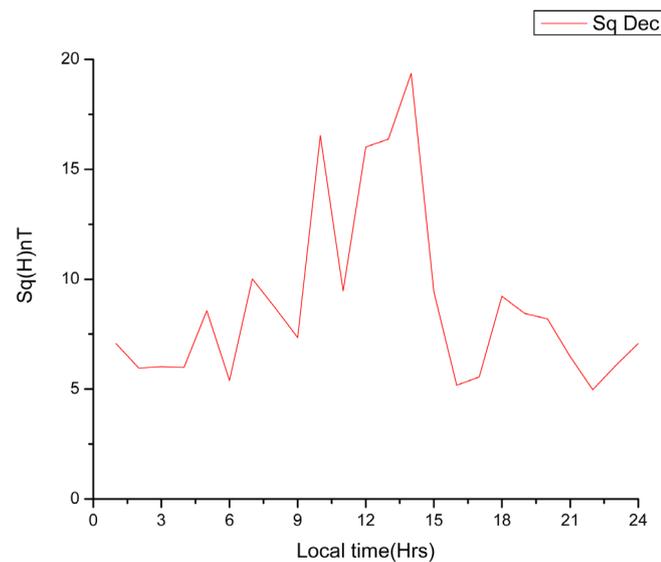


Figure 3. The mean monthly hourly variations of Sq for the month of December (D season).

Mean Ratio of Seasonal Contributions of Magnetospheric to Ionospheric Sources

The mean of Daytime and Night time contributions in E, J and D seasons were also calculated and the result can be seen in **Table 1**. The table was further transformed into **Figure 5** for easier comparison. The figure clearly shows that E season had the greatest contributions from both Magnetospheric and ionospheric sources. The J season also shows the least contributions from both magnetospheric and ionospheric sources. This is in agreement with [18] which showed that the magnetospheric contributions have variability with UT. The ratio of the mean nighttime contributions against the daytime contributions is also seen in **Table 2** and the corresponding column in **Figure 6** with the E season again showing the largest ratio as expected. However, the amplitude (or ratio) is more than what [13] showed (at least 0.5).

Figure 5 clearly shows that the magnetospheric contribution in the E season is greater than the ionospheric contributions while in the remaining seasons, the ionospheric contributions are greater than the magnetospheric contributions.

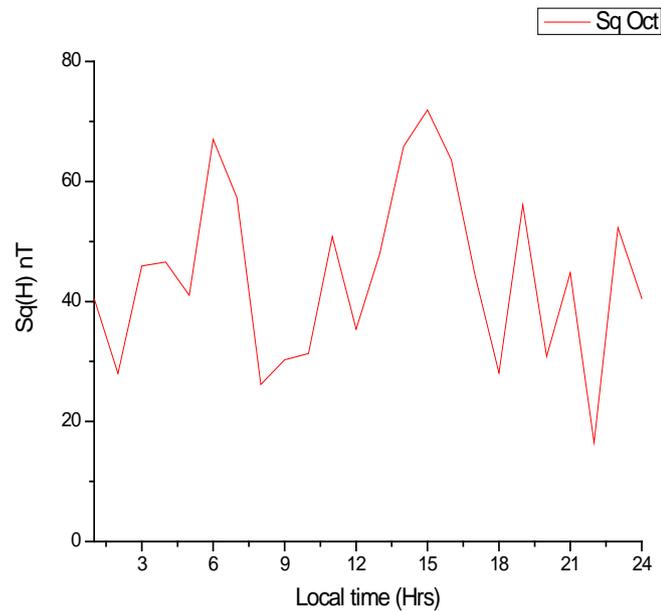


Figure 4. The mean monthly hourly variations of Sq for the month of October (E season).

Table 1. The mean of daytime and night time contributions in E, J and D seasons.

E SEASON		J SEASON		D SEASON	
DAYTIME_H	NIGHTTIME_H	DAYTIME_H	NIGHTTIME_H	DAYTIME_H	NIGHTTIME_H
38.6	45.8	10.9	6.2	11.1	6.7

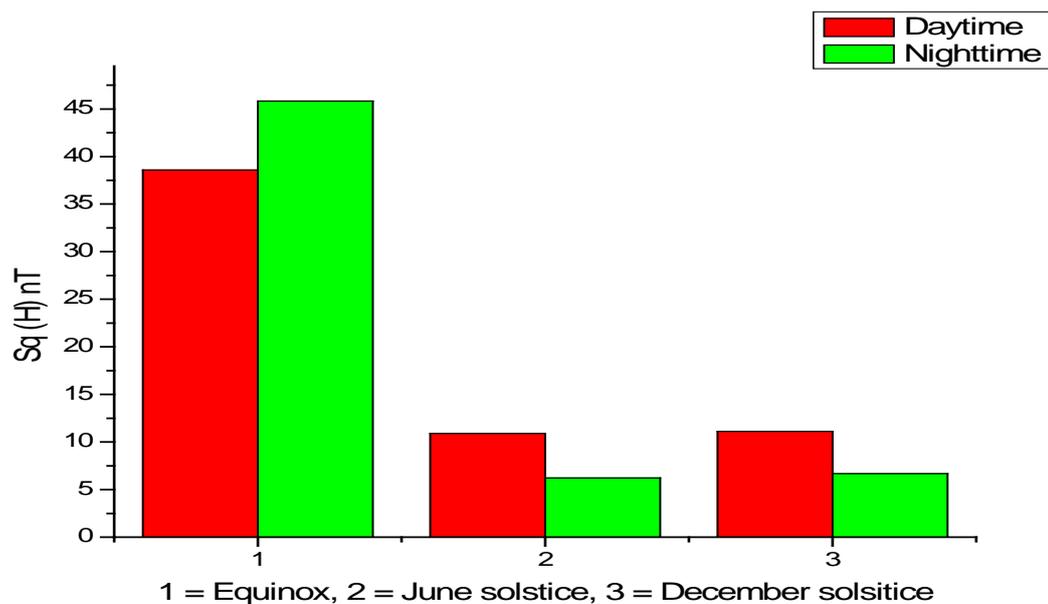


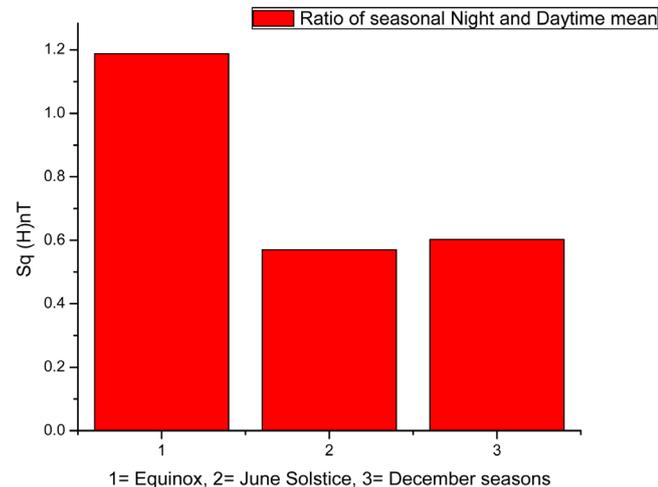
Figure 5. Seasonal contributions from magnetospheric and ionospheric sources.

4. Conclusions

The study of magnetic perturbations and their interpretation as current systems flowing in the Earth and in space is extremely complicated. The daily ground magnetic perturbations are a superposition of contributions from the

Table 2. The ratio of seasonal means of nighttime and daytime.

E SEASON NIGHTTIME/DAYTIME	J SEASON NIGHTTIME/DAYTIME	D SEASON NIGHTTIME/DAYTIME
1.2	0.6	0.6

**Figure 6.** The ratio of seasonal mean nighttime and daytime.

horizontal ionospheric currents, field-aligned currents, currents in the magnetosphere, and currents induced at the Earth's surface. However, investigation of the spatial variation of the daytime and nighttime solar quiet daily variation has been carried out using the data set that consist of hourly values of the Horizontal (H) component of Geomagnetic field intensity from MAGDAS station at Ilorin, Nigeria in the month of August, October and December 2008, which represent the J, E and D seasons. It was discovered that:

- The Solar quiet Sq showed a diurnal variation rises from 06:00 hrs LT, reaches the peak at about 12 noon, and reclines to low level at 1800 hrs LT. In general, the daytime magnitudes are much greater than the night time magnitudes for the months in each season of the year.
- The mean monthly hourly variation showed seasonal variation with the $Sq(H)$ maximizes in equinox (71.9nT) with least variation in June solstice (15.1nT).
- Mean ratio of seasonal contributions of Magnetospheric to Ionospheric sources revealed that the greatest contributions from both magnetospheric and ionospheric sources at the E season with the least at J season.
- The ratio of magnetospheric contributions to ionospheric contributions was greatest during the E season and the least was during the J season.

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