Characterization of seasonal and annual variation of horizontal component of magnetic field in Africa and Asia regions

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Abstract. This study considered the horizontal component of the magnetic field, H, which is a characteristic of Equatorial Electrojet (EEJ). Using Magnetic Data Acquisition System (MAGDAS) data preserved for the year 2009, variations in H strength were determined in 10 stations in Africa and Asia sector. The seasonal and annual fluctuations in the H-component of the Earth's magnetic field were studied using hourly data of the horizontal magnetic field component. For the hourly fluctuation, the baseline values of H were estimated using the average values around local midnight hours between 2300 and 0200 local-time (LT) and subtracted from other hourly values; for seasonal and yearly analysis, the monthly and annual averages were computed. In all seasons, seasonal variations were higher in equatorial stations than in anti-equatorial stations, while maximum values of SqH were recorded in the equinocial season, with an annual highest peak value of 70.96 nT in Langkawi (LKW; 6.30°S, 99.78°E) and the lowest peak value of 27.45 nT in Cooktown (CKT; 15.48°N, 145.25°E) both at 1300 LT.

1. Introduction
The equatorial electrojet (EEJ) is a short strip of current that flows eastward at the diurnal ionospheric equatorial expanse of the earth. Bruni et al., [1] emphasized that the conductivity peak heights shift as one moves to higher altitudes, as expected for weaker field configurations, due to the anisotropic character of the ionospheric electrical conductivity. The E-region features a global-scale ionospheric circulation that institutes a solar quiet (Sq) Pedersen current system with an eastwards electric field and a horizontal and northwards magnetic field at an altitude of 100 km to 130 km. At lower ionospheric latitudes, where the geomagnetic field is nearly horizontal, the effective ionospheric conductivity is particularly high.

The current strength of around 100kA at about 110 km height supports a day-side electrojet magnetic-field increase. At a geomagnetic observatory near the dip-equator, the amplitude of the daily variation of horizontal magnetic intensity (ΔH) is higher than the variation of data from other locations of Earth. The EEJ is distinguished by a steep negative V-shaped curve in the H field that reaches its minimum within 0.5° of the magnetic dip equator. Magnetic data from satellite missions like the Ørsted satellite (1999–present) and CHAMP (2000–present) has significantly advanced our understanding of the EEJ [2].
The combination of lunar tide variability in the equatorial electric field and solar-driven variability in the E-region conductivity, as established by Gasperini et al., [3], adds complexity to the EEJ. Denisenko et al., [4] found that the electric field penetration is inversely related to the integral ionospheric Pedersen conductivity and approximately proportional to atmospheric conductivity near the ground. Also, this penetrated electric field is a hundred times larger at night than during the day, and its penetration of electrostatic fields is dependent on various conductivity distribution features. In this study, we looked at the features of the EEJ ΔH at 10 different stations, demonstrating seasonal and annual fluctuations in 2009. At mid-latitudes, Obiekezie and Obiadazie [5] discovered a persistent overnight change in the horizontal magnetic field component and attributed it to distant magnetospheric sources.

2. Materials and Methods
The study examined a year's worth of data (2009) from ten (10) observatories' Magnetic Data Acquisition System (MAGDAS) equipment. According to the classification of the planetary magnetic index, Kp, the five (5) most magnetically quiet days from the Internationally Quiet Day (IQD) in each month for the year 2009 were chosen. The baseline value of H (H₀) was calculated as the average value of the H component near local midnight between 2300 LT and 0200 LT.

\[ H_0 = \frac{H_{2300} + H_{2400} + H_{0100} + H_{0200}}{4} \]  

(1)

Where H_{2300}, H_{2400}, H_{0100}, H_{0200} represent the hourly values of H at 23, 24, 01 and 02 hours LT, respectively. The midnight baseline values were subtracted from the hourly values to get the hourly departures from midnight for a particular day. Thus,

\[ dH = H_t - H_0 \]  

(2)

where t=1 to 24, Hₜ is hourly values of magnetic element H, dH gives the measurements of the hourly amplitude of the variation of the horizontal component of the earth magnetic field H i.e SqH. Figure 1 and Table 1 show the MAGDAS stations and coordinates of stations used in the study. The seasonal variations were investigated by dividing the months into four seasons: December Solstice (November, December, January), March Equinox (February, March, April), June Solstice (May, June, July), and September Equinox (August, September, October). Annual variation was investigated by averaging monthly values of dH for the entire year under examination, while each season was approximated by averaging monthly values on each hour under that season [6].

![Figure 1: Map of the World Showing Locations of Geomagnetic Observatories used in the study](image_url)
Table 1: The geographic and geomagnetic coordinates of the stations used in the study

| STATION NAME | STATION CODE | COUNTRY     | GEOGRAPHIC LATITUDE | GEOGRAPHIC LONGITUDE | GEOMAGNETIC LATITUDE | GEOMAGNETIC LONGITUDE |
|--------------|--------------|-------------|---------------------|----------------------|----------------------|-----------------------|
| COOKTOWN     | CKT          | AUSTRALIA   | -15.48              | 145.25               | -24.62               | 218.38                |
| DAVAO        | DAV          | PHILIPPINE  | 7                   | 125.4                | -1.2                 | 196.54                |
| LANGKAWI     | LKW          | MALAYSIA    | 6.3                 | 99.78                | -2.32                | 171.29                |
| ASWAN        | ASW          | EGYPT       | 23.59               | 32.51                | 15.2                 | 104.24                |
| YAP ISLAND   | YAP          | FSM         | 9.5                 | 138.08               | 1.49                 | 209.06                |
| FAYUM        | FYM          | EGYPT       | 29.18               | 35.5                 | 25.76                | 112.65                |
| LAGOS        | LAG          | NIGERIA     | 6.45                | 3.27                 | -3.04                | 75.33                 |
| ADDIS ABABA  | AAB          | ETHIOPIA    | 9.04                | 38.77                | 0.18                 | 110.47                |
| MAPUTO       | MPT          | MOZAMBIQUE  | -25.57              | 32.36                | -35.98               | 99.57                 |
| ILORIN       | ILR          | NIGERIA     | 8.5                 | 4.68                 | -1.82                | 76.8                  |

3. Results and Discussion

3.1 Seasonal Variation of Horizontal Magnetic Field Component

Seasonal fluctuation of SqH is shown in Figure 2 (a-d) for stations where data is available. Seasonal variation was higher in equatorial stations than in sites outside the equatorial belt region in all seasons, according to the statistics. In comparison to the solstice time, the equinoctial season has higher values. ILR reported maximum values of 48.62 nT and 52.43 nT in March and September equinoxes, respectively, while minimum values of 44.31 nT and 32.75 nT were recorded in June and December solstices, respectively. YAP reached a maximum of 84.89 nT during the March equinox and a minimum of 70.99 nT during the June solstice. Similarly, DAV revealed the greatest variance of 82.39 nT in the March equinox, with the least change in the (June and December) solstice, with values of 54.19 nT and 65.91 nT, respectively. LKW had a maximum variance of 75.89 nT (March equinox) and a minimum variation of 43.92 nT (June solstice). SqH variation in AAB reached a high of 74.71 nT at the March Equinox and a low of 35.29 nT during the December solstice.

LAG also displays a minimum value of 39.7 nT during the December solstice and a minimum value of 54.05 nT during the September equinox. However, other stations along the magnetic equator's northern and southern hemispheres showed opposite seasonal variability, with maximum and minimum values reported throughout the solstice season. FYM, for example, measured a maximum of 18.19 nT at the June solstice and a minimum of 11.31 nT at the December solstice. Similarly, at the September equinox, ASW displayed the greatest variance of 27.64 nT and the least variation (19.4 nT). MPT measured a maximum of 30.94 nT during the September equinox and a minimum of 7.99 nT during the December solstice. For the stations studied, the range of seasonal fluctuation in March equinox is 75.55 nT, whereas the range in June solstice is 60.15 nT.

The range values for the September equinox and December solstice are 53.25nT and 57.92nT, respectively. Table 2 shows a breakdown of peak variations by month for each station. The study found that the highest Sq values are found during the equinoctial season. Increased equatorial electron density, which enhances electrical conductivity when the sun is overhead at the equinox, as well as changes in the corresponding electric field, could explain the largest peak of Sq recorded during the equinox [7]. The seasonal shift could be related to a seasonal shift in the mean position of the ionospheric electrojet's Sq current system. Seasonal variation can also be explained by the electrodynamics influence of local winds. The maximum value of SqH obtained in this study could be due to the solar zenith angle's seasonal dependency. In seasonal variation investigations by Chandra et al., [8], Rabiu et al., [6], and Rastogi et al., [9], higher values of SqH were detected in the equinoctial season.
Table 2: Peak Values of Monthly Variation (nT) in some Stations for 2009

| MONTH  | DAV  | LKW  | YAP  | ILR  | LAG  | AAB  | CKT  | MPT  | FYM  | ASW  |
|--------|------|------|------|------|------|------|------|------|------|------|
| January| 65.91| 55.26| 49.73| 32.75| 26.6 | 35.29| 39.71| 4.5  | 8.88 | 21.28|
| February| 81.27| 63.29| 70.32| 55.67| 45.34| 74.71| 21.12| 6.6  | 7.87 | 13.79|
| March  | -    | 82.14| 100.9| -    | 41.52| -    | 30.49| -    | 26.6 | 33.05|
| April  | 84.87| 86.47| 67.48| 41.58| 42.4 | -    | 35.91| 22.65| 18   | 24.57|
| May    | 66.1 | 70.99| 56.04| 48.88| 44.69| -    | 21.37| 13.78| 23   | 29.55|
| June   | 49.62| -    | 31.79| 45.79| 42.99| -    | 21.66| 9.2  | 18.17| 22.76|
| July   | 46.76| -    | -    | 40.36| 39.88| -    | -    | 10.27| 10.85| 26.75|
| August | -    | -    | -    | 48.55| 40.92| 72.83| -    | -    | -    | 20.59|
| September| -   | -    | -    | 54.07| -    | 71.58| -    | -    | 13.82| 19.7 |
| October| -    | -    | -    | 54.67| 121.1| -    | -    | 30.94| 11.78| 22.88|
| November| -   | -    | -    | -    | -    | -    | 17.3 | 17.99| 21.83|
| December| -   | -    | -    | -    | -    | -    | 7.77 | -    | 19.87|

Figure 2: (a-d): The graphs of annual variation of dH for the year 2009
3.2 Annual Variation of Horizontal Magnetic Field Component

Figure 3 depicts the mean hourly fluctuation of the horizontal component of the magnetic field for 2009, with equatorial stations displaying greater variability than non-equatorial stations. This points to a significant concentration of electron density at the magnetic equator. In general, all of the stations' variation patterns followed a similar pattern, with early morning rises about 0700-0900 LT at all stations, peak values around noon (1100 LT-1300 LT), and then a steady fall due to decreasing photoionization. In all of the stations, the daytime magnitudes in dH are greater than the midnight magnitudes. The predominant wind system, which is strongest around midday, is the result of constant solar heating of the ionosphere. The strongest solar heating intensity during the daylight hours, together with the lowest possible loss rates, contributes optimally to their larger magnitudes [10]. The highest peak value of 70.64 nT was recorded at Langkawi (LKW) around 1300 LT and the lowest peak value of 9.38 nT at Maputo (MPT), which presents a range value of 61.26 nT for the year. Addis Ababa (AAB) and Davao (DAV) presented a value of 67.18 nT and 64.23 nT respectively at 1100 LT. Yap Island (YAP) recorded a value of 61.25 nT, Ilorin (ILR) had 46.6 nT at 1200 LT, while Lagos (LAG) recorded 42.79 nT at 1300 LT. The non-equatorial station, Cooktown (CKT), Aswan (ASW) and Fayum (FYM) recorded 26.74 nT, 21.09 nT and 14.91 nT, respectively at 1300 LT.

![Annual Variation of Horizontal Magnetic Field Component](image)

**Figure 3**: Mean hourly variation of dH in 2009

4. Conclusion

The horizontal component of the magnetic field in the stations studied exhibits latitudinal changes, as the position of the stations impacts the magnetic field strength reported, according to the results of the study. The magnetic field intensity recorded in the station increases as the station gets closer to the magnetic equator. The Sq variation is caused by the variability of ionospheric processes and physical structures such as conductivity and wind structure. Also, when there is no solar activity, the overnight fluctuations may be due to the variability of nighttime distant currents.
5. References

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