Ionosphere over Africa: Results from Geomagnetic Field Measurements During International Heliophysical Year IHY

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Abstract: Space Environment Research Centre of Kyushu University, Japan, installed 13 units of Magnetic Data Acquisition Systems MAGDAS over Africa during the International Heliophysical Year IHY. Magnetic records from 10 stations along the African 96° Magnetic Meridian (Geographical 30° – 40° East) were examined for Solar quiet daily Sq variations in the two geomagnetic field components H and D. Latitudinal variations of Sq in the geomagnetic components were examined. Signatures of equatorial electrojet and worldwide Sq were identified and studied in detail. H field experienced more variation within the equatorial electrojet zone. Diurnal variations of the geomagnetic variations in the two components were discussed. Sq H is expectedly consistently maximum within the electrojet zone as a result of EEJ. Sq D has maximum values at about -20є (sunrise), -10є (noon time) and +10є (sunset). Levels of inter-relationships between the Sq and its variability in the two components were statistically derived and interpreted in line with the mechanisms responsible for the variations of the geomagnetic field. Data from 2 magnetic observatories within equatorial electrojet EEJ strip and 2 stations outside the EEJ strip were employed to evaluate and study the signatures of the Equatorial electrojet over the African sector. The transient variations of the EEJ at two almost parallel axes using Lagos-Ilorin (West Africa) and Nairobi-Addis Ababa (East Africa) pairs were examined. The eastern electrojet appeared stronger than the western. The latitudinal and longitudinal profiles of the Sq were examined and inferences drawn from observed results were discussed.

Keywords: Solar Quiet Daily Sq Variations, Equatorial Electrojet, Ionosphere Introduction

The upper region of the atmosphere, known as the ionosphere, is a medium of propagation of radio waves. Ever since the discovery of the ionosphere [1], it has continued to be object of study using different techniques and probes. Rabiu [2] observed that ionosphere has continued to attract interest due to its increasing applications in radio-communication.

It has since been observed that the geomagnetic field intensities vary from one sector to another even within the equatorial zone. Patil et al.,[3,4] estimated the ratios of the EEJ strength at high solar activity to low solar activity at Indian and American sectors and found a discrepancy between the values at the two sectors. Doumouya et al., [5] studied the longitudinal variation of geomagnetic field intensities at equatorial zone using surface magnetic data recorded at 26 stations located in six different longitude sectors that were set up or augmented during the international Equatorial Electrojet Year IEEY; the nature of the longitudinal inequalities in the EEJ strength indicates that the equatorial electrojet was strongest in South America (80є–100єW) and weakest in the Indian sector (75єE) with a secondary minimum and a maximum centered, respectively, in the Atlantic Ocean (30єW) and in western Africa (10єE) [5].

Wilkinson [6] observed that variability is possibly one of the most interesting and least explored properties of the ionosphere. Both spatial and temporal variability has attracted scientific attention [6, 7]. Hitherto, it has been impossible to conduct spatial variability of the ionosphere obviously due to unavailability of adequate observational instruments. International Heliophysical Year program of the United Nations which actually commenced in 2005 enabled deployment and distribution of observational facilities to Africa [8, 9]. MAGDAS, an acronym of the Magnetic Data Acquisition System, is a project of the Space Environment Research Centre of the Kyushu University, Japan, that has distributed about 15 Magnetometers over Africa up to date. Details of MAGDAS, its deployment, instrumentation, and research capability are documented in Yumoto and the MAGDAS group [10, 11, 12]; Uozumi, et al, [13]; Maeda et al, [14]; and Rabiu et al., [15]. This work reports the results obtained from probing the ionosphere along African 96єMM using MAGDAS data. More specifically we attempt to investigate the transient and spatial variations of the solar quiet daily Sq variation in the Earth's magnetic field along the African 96є magnetic meridian. A comparative analysis was also performed between the equatorial electrojet observed at the Eastern- and western- Africa.

Data analysis

Solar Quiet daily variation Sq in geomagnetic field

Hourly profiles of horizontal component (H) and declination (D) taken on 29th December 2008 (Ap index = 1) at 10 MAGDAS stations along 96° Magnetic meridian 'MM' in Africa were analysed for regular solar quiet daily variation. Coordinates of the stations engaged in this work are shown in Table 1; Figure 1 presented the distribution of the stations. The solar quiet daily variation Sq in H (Sq H) and D (Sq D) were obtained by correcting the hourly departures, obtained from the difference between the hourly values and the midnight baseline values, for non-cyclic variation. Details of this method were explained in Rabiu et al [16].

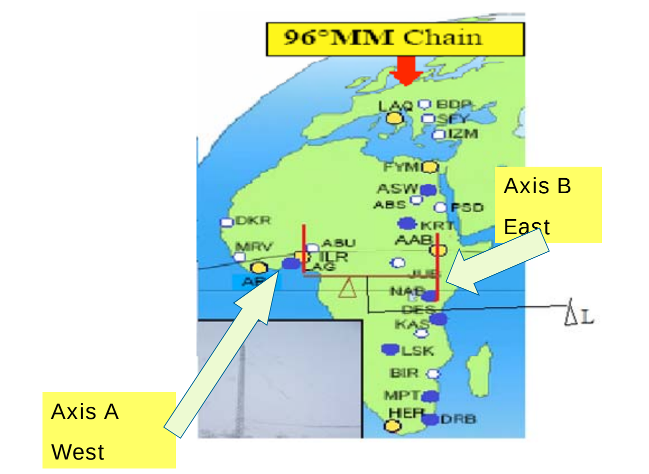

Fig. 1. Map of Africa showing stations along 96° Magnetic Meridian and equatorial chain

Contour maps showing local time variation of Sq(H) and Sq(D) across the geomagnetic latitudes are shown in Figures 2 and 3 respectively. Figure 4 shows the latitudinal variation of the noon-time Sq (H) across the stations.

TABLE 1. Coordinates of the Stations along 96° Magnetic Meridian

Station	Geographical Latitude (°)	Geomagnetic Latitude (°)
AAB	9.04	0.18
NAB	-1.16	-10.65
ASW	23.59	15.2
DES	-6.47	-16.26
DRB	-29.49	-39.21
FYM	29.18	16.1
HER	-34.34	-42.29
KRT	15.33	5.69
LSK	-15.25	-26.06
MPT	-25.58	-35.98

Equatorial electrojet along African longitudes

Two pairs of stations were engaged in studying the electrojet along the African longitudes. It is widely approved that in order to estimate the strength of the intensity of equatorial electrojet in nanotesla, two stations along very close longitudes are always selected; such that one lies within the electrojet strip while the other is outside (for examples [3], [4], [15], [17], [18]). So for this aspect of study, the MAGDAS stations engaged are illustrated in Figure 1 and coordinates shown in Table 2.

ILR and AAB are stations within electrojet strip while LAG and NAB are outside the electrojet strip. Sq(H) in the four stations were estimated as explained in section 2.1; EEJ were evaluated by subtracting Sq at the outside EEJ stations from the one under the EEJ influence. ILR-LAG pair constitutes the western axis pair, while AAB-NAB pair the eastern axis pair. For example the EEJ effect at ILR was obtained by subtracting the Sq at LAG from Sq at ILR at any time. The distance of separation ΔL between the two axes is 3744.585 km (33.735°). Fig 5 shows the diurnal variations of Sq at ILR, LAG, AAB, and NAB, as well as the EEJ at ILR and AAB. Figure 6 plots the EEJ at ILR, the station on the western axis, against that of ADD on the eastern axis.

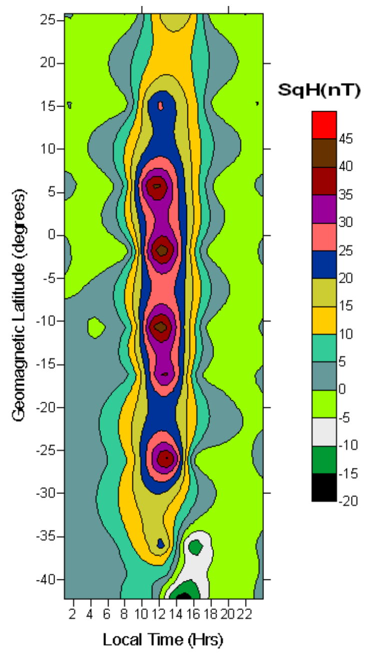

Fig. 2. Latitudinal and diurnal variation of Sq (H)

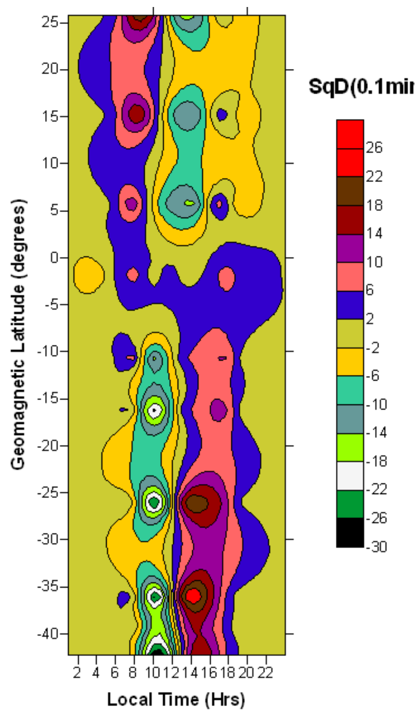

Fig. 3. Latitudinal and diurnal variation of Sq (D)

TABLE 2. Coordinates of the Stations for EEJ studies

Stations	Geomagnetic Latitude (◦)	Geographic Longitude (◦E)	Geographic Latitude (◦)
Ilorin ILR	-1.82	4.67	8.50◦N
Lagos LAG		3.43	3.42◦N
Adiss Ababa AAB	0.18	38.77	9.04◦N
Nairobi NAB		36.80	1.16◦S

The measure of variance in the EEJ strength with respect to the distance of separation of the two axes is defined as EEJ gradient and obtained from equation (1) as follows:

$$EEJ \quad gradient = \frac{ILR_{EEJ} - AAB_{EEJ}}{\Delta L} \qquad (1)$$

The EEJ gradient was obtained at each minute and its diurnal variation is illustrated in Figure 7.

Discussion of Results

Figure 2 clearly show that there is diurnal variation of Sq (H) and Sq (D) along 96°MM across the latitudes. Generally, for both H and D, daytime Sq is greater than night time. Sq in H maximizes in daytime at about local noon; this is obviously due to ionospheric augmentation by solar activity in consistency with atmospheric dynamo theory [15,19].

Sq H is expectedly consistently maximum within the electrojet zone as a result of equatorial electrojet EEJ phenomena. Sq H at about local noon, when the sun is vertically overhead and solar activity is maximum on any day at any location, as shown in Figure 4 has one outstanding peak almost at magnetic equator. Enhanced Cowling conductivity along the dip equator has been described as a major cause of the EEJ [17, 18, 20].

At about local noon Sq in D has strongest focus at below 0° geomagnetic latitude. It is noted that, unlike Sq in H, Sq in D doesn't maintain a consistent maximum along at local noon across the latitudes. Rather there is variability in the period of maxima with latitudes. Interestingly maxima values of Sq D migrate with latitudes along the 96 MM and attain maximum values the following latitudes with respective solar regimes: 15є (sunrise), -2.5є (noon time) and -25є (sunset). It is clear that declination follow the rotation of the earth with Sun. Figure 5 clearly shows an enhancement in Sq field at ILR and AAD as against the values at LAG and NAB. This is obviously due to EEJ field at along the EEJ strip. Rabiu and Nagarajan [21] has confirmed that the width of the electrojet is about 3° on either side of the magnetic equator in the Indian sector. ILR (geomagnetic latitude -1.82) and AAD (geomagnetic latitude -0.18) are within the equatorial electrojet strip while LAG and NAB are outside the EEJ influence. The equatorial intensification of the magnetic field is due to equatorial electrojet.

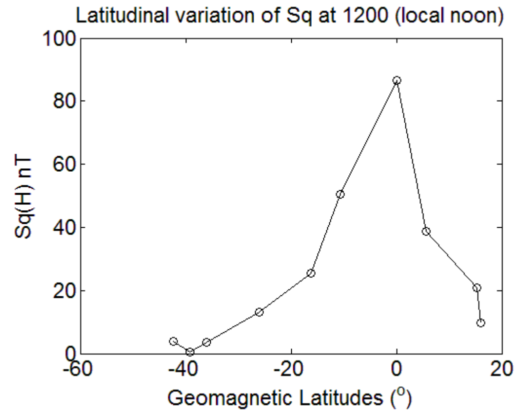

Fig. 4. Latitudinal variation of the noon-time Sq (H) across the stations

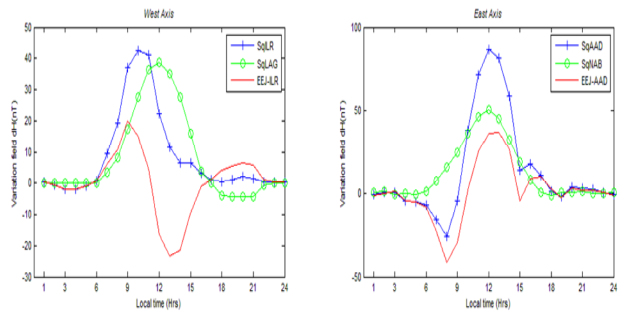

Fig. 5. Diurnal variations of Sq and EEJ. (Right panel shows the Sq at ILR and LAG as well as EEJ at ILR. Left panel shows the Sq at AAB, and NAB, as well as the EEJ at AAB).

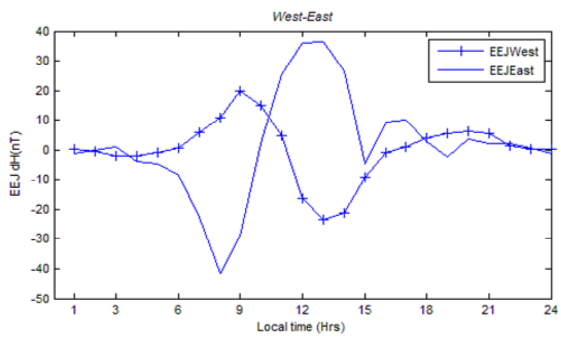

Fig. 6. Diurnal variation of EEJ at ILR (EEJ West) and ADD (EEJ East).

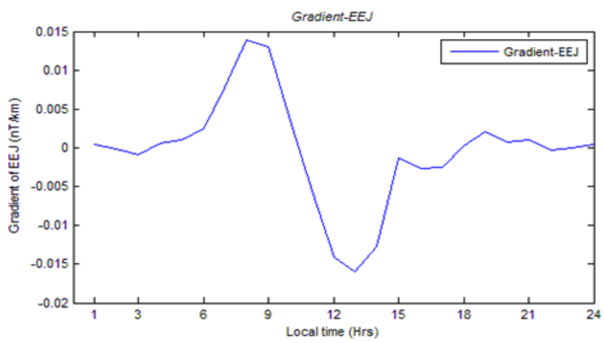

Fig. 7. Diurnal variation of EEJ gradient

The pattern obtained in Fig 6 clearly revealed that the western EEJ appears weaker than eastern EEJ. This discrepancy suggests that there is a process of re-injection of energy in the jet as it flows eastward. Figure 7 indicates a non-constant flow EEJ gradient with local time. The flow gradient does not follow a definite diurnal pattern. However drastic fluctuation is observed at the rising of the Sun/jet.

Conclusions

The following conclusions can be drawn from the investigation of the ionosphere over Africa using the geomagnetic field measurements taken, on 29th December 2008 (Ap index = 1) at 10 MAGDAS stations along 96° Magnetic meridian in Africa, during the International Heliophysical Year:

i. There is variability in the ionospheric processes over African even along same meridian.
ii. The enhanced field variation at equatorial region is due to the EEJ current
iii. There is a variation in the behaviour of EEJ at the West and East Africa
iv. The EEJ appear stronger in East than West Africa. It is suggested that it is as if there is a process of re-injection of energy as Jet flows eastward

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