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Characterization of Equatorial Electrojet Current in Africa Sector Using Two Approaches

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Authors' contributions

This work was carried out in collaboration between the authors. Author AOI designed the study, managed the literatures, performed the statistical analysis and wrote the first draft of the manuscript. Author IAA managed the analyses of the study, the literature searches and corrected the final manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Variations in the Equatorial Electrojet (EEJ) ground strength is estimated in three stations (Addis-Ababa - AAB, Ilorin - ILR and Lagos - LAG) in the Africa sector using MAGDAS data collected from September to December, 2008. Hourly data of the horizontal magnetic field component was used in the study. The EEJ strength was studied using the observed and model simulation approach to determine the correlation and error in their results. The EEJ strength in the stations was estimated with respect to Maputo located off-dip equator. The maximum strength of magnetic effect of the EEJ at the ground level was observed in AAB with a value of 62.98 nT in December, followed by ILR with 57.51 nT in November, and LAG with 46.76 nT in December. The model simulation presented higher values compared to the observed EEJ values with the highest peak variation of 130 nT in AAB (October), 103 nT in ILR (December), and 79.32 nT in LAG (December). Correlation analysis and Root mean square error (RMSE) was carried between the two methods. Lagos (LAG) presented the best correlation and the least RMSE (0.85 and 0.18) in November, while the least suitable fit was noticed in September with RMSE of 8.15 in Addis Ababa (AAB).

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Keywords: Equatorial electrojet; dip equator; MAGDAS; fambitakoye model; e-region; solar quiet.

1. INTRODUCTION

Stewart [1] suggested that solar daily variations of the geomagnetic field are a result of the movement of the conducting upper atmosphere across the vertical component of the Earth's magnetic field, which is due to the solar heating influence of the atmosphere. During magnetically quiet conditions, dynamo currents driven by winds and tidal motions in the E- region of the ionosphere results in daily variations in the geomagnetic fields at the Earth surface [2]. Also, on quiet days when the geomagnetic disturbance is small the significant part of the observed variation depends on the solar time and it is called Solar Quiet daily variation (Sq) [3]. At the magnetic dip equator, Hall current is generated by the midday eastward polarization field, which is a result of global-scale dynamo. A vertical polarization field is set up which opposes the downward flow of current due to the presence of non-conducting boundaries. This field gives rise to the intense Hall current which is called the Equatorial Electrojet (EEJ; Chapman 1951). The EEJ represents an intense current flowing in east-west direction over the dip equator with a latitudinal extent of ±3º on either side of the dip equator within a latitudinal range of 100-120 km. Several studies have examined the various aspect of the EEJ using different equipment such as satellite measurement [4] rocket measurement [5] and ground measurements [6].

A study of geomagnetic field variations from some equatorial electrojet stations using 10 MAGDAS (Magnetic Data Acquisition System) stations by Adimula*et al*. [7] shows that there could be a substantial day to day variability in the EEJ strength along the dip equator. Variations of greater than 80 nT are found in pairs of stations on the same day with analysis showing a correlation between pairs of stations decreasing as a function of increasing distance between them. Abbas*et al.* [8] investigated the variability of the EEJ strength along the magnetic equator using MAGDAS data of some selected stations along the 96ºMM. The results obtained revealed that the amplitude of dH (Horizontal component of magnetic field) has diurnal variability which peaks during the day at about local noon. They attributed the diurnal variation of H component to the enhancement dynamo action in this region. The study shows that the EEJ strength at Addis Ababa with respect to Khartoum is stronger than that with respect to Nairobi. It is worthy of note that, although various works have been done in the investigation of EEJ strength in using different methods but examining the morphology of the different methods over Africa has been limited. In this work, the variation of EEJ current in the Africa sector using two approaches (the inferred from SqH and the Fambitakoye Model) is investigated to determine the suitability of each approach in the Africa sector. This study also compares the variation pattern of EEJ occurrence along the three equatorial stations and Model Simulation results was examined in each of the stations.

2. MATERIALS AND METHODS

The magnetic data obtained from MAGDAS instrument for year 2008 was used. Three equatorial stations which include, Ilorin (ILR, Geogr. Lat. 8.50º N, Long. 4.68º E, Geomag Lat. -1.82, Long. 76.80); Lagos (LAG, Geogr. Lat. 6.45º N, Long. 3.27º E, Geomag Lat. -3.04, Long. 75.33) and Addis-Ababa (AAB, Geogr. Lat. 9.04º N, Long. 38.7º E, Geomag Lat. 0.18, Long. 110.47), as well as a reference station, Maputo (Geogr. Lat. -25.57ºS, Long. 32.26 º E, Geomag Lat. -35.98, Long. 99.57) located off-dip equator, are used in the study. Highlighted in Fig.1 is the map of Africa showing the geographical location of ILR, LAG, AAB and MPT. Records of the horizontal magnetic field intensity H measurements were taken in the year 2008. However, we were only able to obtain data from September to December, 2008 for the four stations. Table 1 shows the coordinates of the stations. Five (5) most magnetically quiet days from the Internationally Quiet Day (IQD) in each month for the year were selected according to the classification of planetary magnetic index, Kp (see Geoscience Australia) [9]. The baseline value of H (H_0) was calculated as the average value of H component near local midnight between 2300 Local Time (LT) and 0200 LT.

$$H_o = \frac{H_{2400}+H_{2300}+H_{0100}+H_{0200}}{4} \quad (1)$$

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

$$dH = H_t - H_o \quad (2)$$

Where,

t=1 to 24, H_t is hourly values of magnetic element H, dH gives the measure of the hourly amplitude of the variation of horizontal component of the Earth magnetic field H i.eSqH [10].

2.1 Obtaining Electrojet Current

2.1.1 From the Sq observation

Generally, signatures of EEJ have been deduced using the equ. (2) by subtracting dH values of station located outside the electrojet region from station located within the region. i.e

$$dH_{EEJ} = dH_{insidedip} - dH_{offdip} \quad (3)$$

2.1.2 From the fambitakoye model

The equatorial electrojet is considered as a current ribbon flowing eastward along the magnetic equator at a fixed altitude (h=105km) according to Fambitakoye and Mayaud [11].

The EEJ current distribution will then be represented by the following expression;

$$I(x,t) = I_o\left(1 - \frac{(x-c)^2}{a^2}\right)^2 . exp\left(-\frac{(t-T)^2}{{t_m}^2}\right) \quad (4)$$

Where,

x is the northward distance from the EEJ centre and is defined as c-a < x ≤ c+a; c is the position of the EEJ center and a is the half width, (I_o) is the current intensity, T is the local hour of the maximum of ΔH in the daily variation under the EEJ, T=12LT on average, t_m is a fitting parameter that controls the time interval of the Guassian-like shape of the diurnal variation in ΔH, t_m=4. The quadratic current distribution is used in this study because it satisfactorily accounts for the observed magnetic effects of the EEJ.

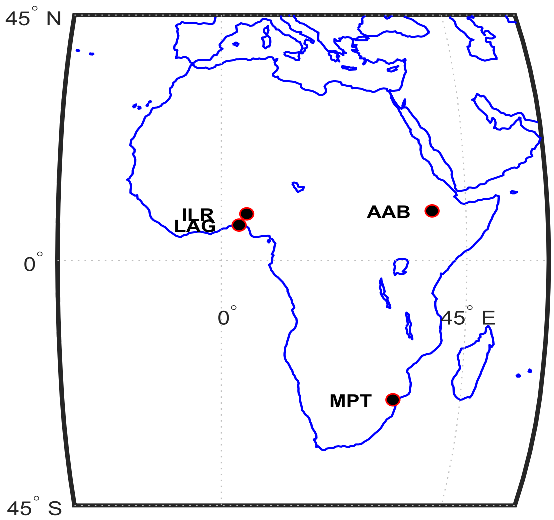

Fig. 1. A geographical location of MAGDAS stations used

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
Ilorin	Ilr	Nigeria	8.50	4.68	-1.82	76.80
Addis ababa	Aab	Ethiopia	9.04	38.77	0.18	110.47
Lagos	Lag	Nigeria	6.45	3.27	-3.04	75.33
Maputo	Mpt	Mozambque	-25.57	32.36	-35.98	99.57

3. RESULTS AND DISCUSSION

3.1 Variation of Horizontal Magnetic Component, dH

Diurnal variation of magnetic field component dH over four stations in September-December, 2008 is shown in Fig. 2. The field strength peaks are seen at noon in all the stations except Maputo (MPT) which peaks at 1100 LT in September and October, and around 0800 LT in November and December which could be attributed to latitudinal position as geographical latitude and Sun's positioning largely determine both the ionization and tidal motion in the ionosphere. On the average, the highest peak field strength was observed in October, while the least was recorded in November. The SqH variation rises at sunrise (0500-0600 LT) in each of the stations with the increase in solar radiation reaching the peak around noon. This could be observed in each of the stations from the equatorial region. Also, the noon amplitude was observed to be higher when the station is closer to the magnetic equator as this is evident in the equatorial stations. The diurnal variation began to rise around 0800 LT in all the months, reaches its peak at local noon and gradually falls to a lower value in the evening. Variations during the daytime in all the months are observed to be higher than nighttime. It is worthy to note that, apart from these peak values of SqH observed in all the stations in Fig. 2, the plots are also characterized with Counter Electrojet (CEJ) observations which presents negative values. This CEJ could be clearly identified with a black line drawn on the baseline (zero) value of each plot. Similar results have been reported by Rabiu*et al*. [10], while investigating the variability of equatorial ionosphere inferred from geomagnetic field measurement. However, Obiekezie and Obiadazie [12] had observed that nighttime variation of dH, when no solar radiation is present could be a result of other sources than the ionosphere (e.g magnetosphere). Generally, the higher daytime dH magnitude observed in all the stations have been attributed to the variability of the ionospheric processes and physical structures (conductivity and wind structure) as well as enhancement dynamo action [13].

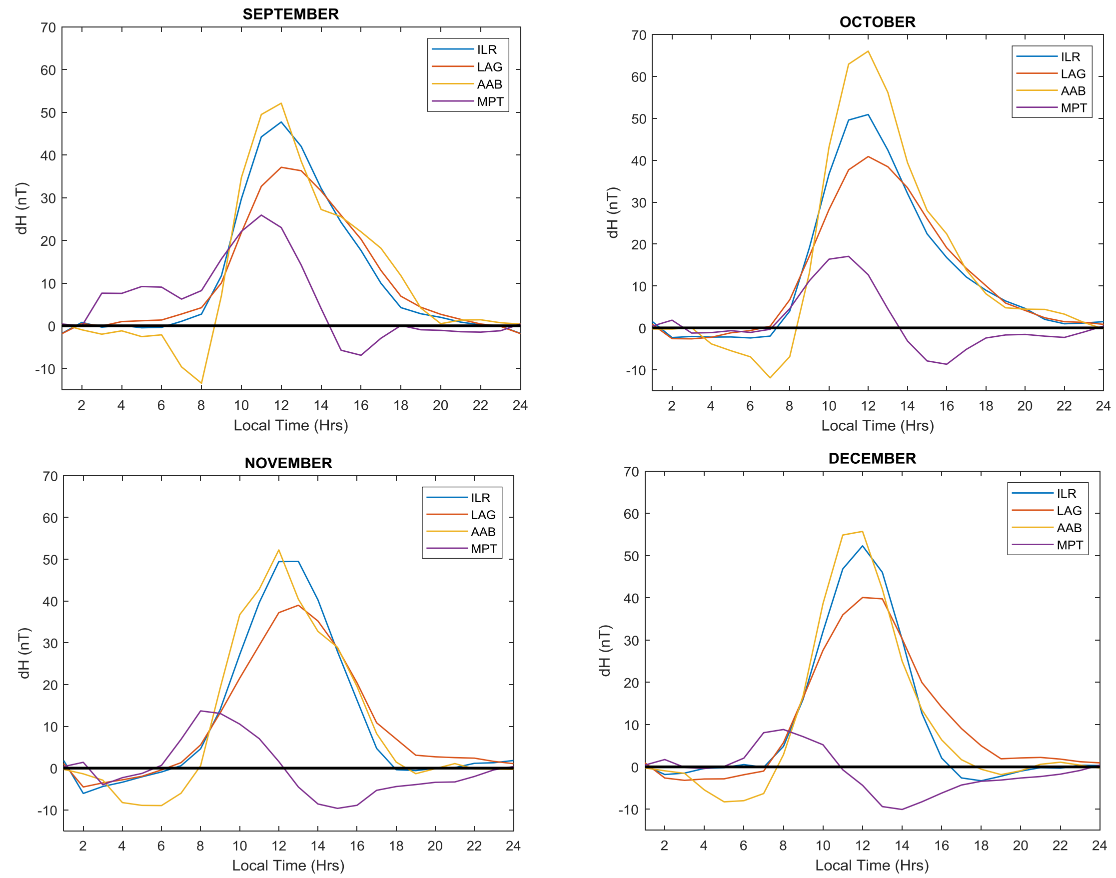

Fig. 2. Diurnal variations in horizontal magnetic field component (dH) over the four stations

3.2 Diurnal Variation of EEJ Current

Fig. 3a illustrates the pattern of EEJ current in September over the four stations. The figure shows the EEJ strength peaks in AAB at 1600 LT with a value of 38.22 nT; ILR and LAG had peak values of 30.87 nT and 31.27 nT, respectively at 1500 LT. The variation pattern in October is shown in Fig. 3b with AAB having the highest magnitude of 53.72 nT, followed by ILR with a value of 38.23 nT, while LAG had the least peak value of 36.56 nT. Highest peak value was observed at 1300 LT in ILR while the lowest peak value of 43.78 nT was recorded in LAG in November. Generally, the highest variation pattern of EEJ in the three stations were seen in December at 1200 LT with a value of 62.98 nT in AAB, 56.4 nT in ILR and 46.76 nT in LAG.

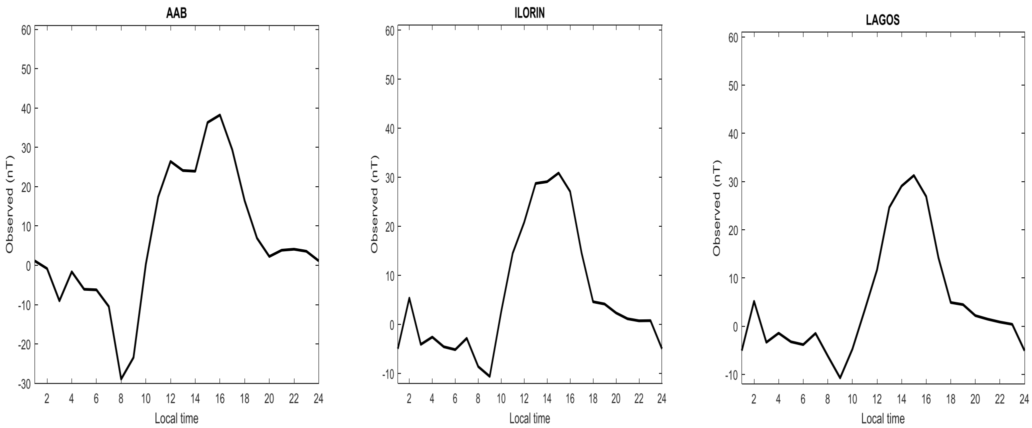

Fig. 3a. Variations in EEJ current over AAB, ILR AND LAG in September

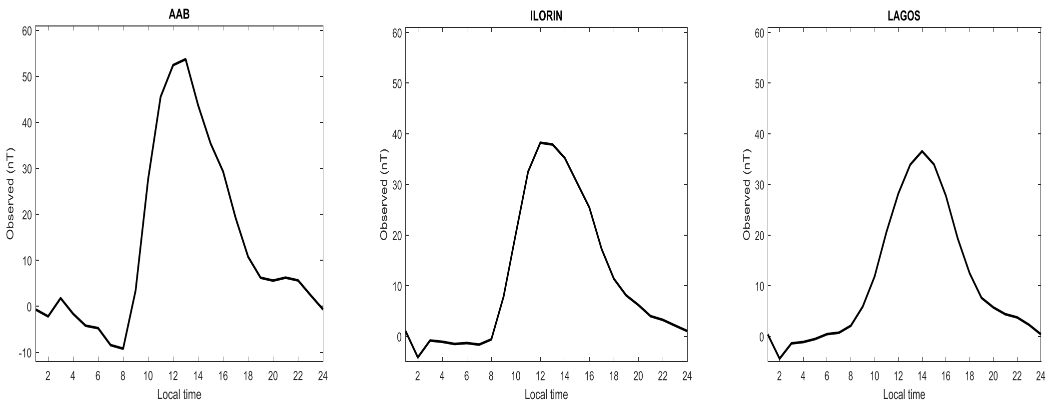

Fig. 3b. Variations in EEJ current over AAB, ILR AND LAG in October

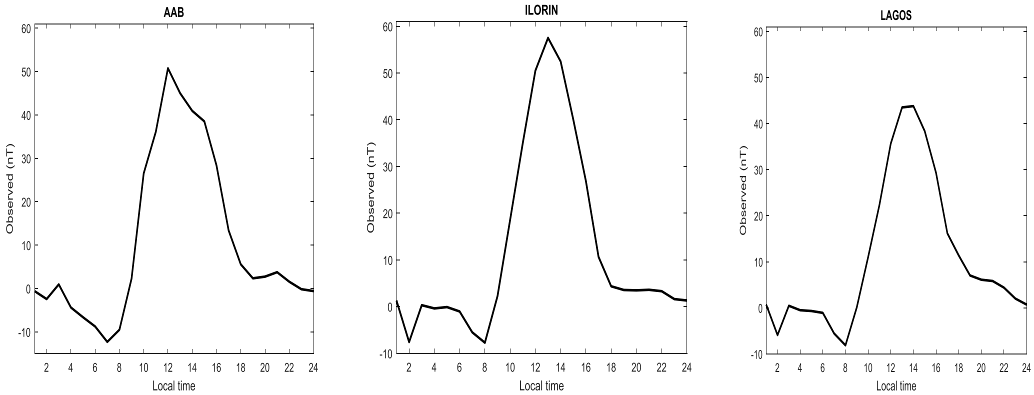

Fig. 3c.Variations in EEJ current over AAB, ILR AND LAG in November

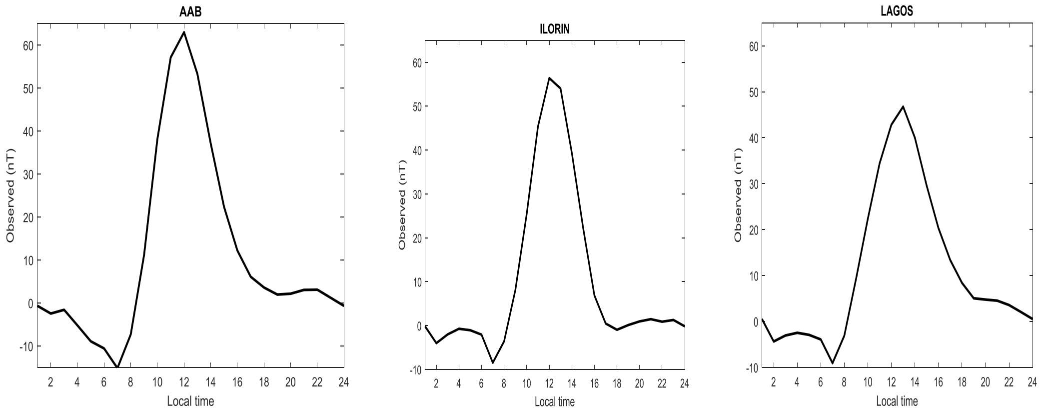

Fig. 3d. Variations in EEJ current over AAB, ILR AND LAG in December

the disparity in the occurrence of the peak period of EEJ current across all the stations in the months could be attributed to combined effects of the peak electron density and electric field (Chandra *et al*., 2000).

3.3 Model Simulation of Equatorial Electrojet Current

Fig. 4 (a-d) illustrates the variation of EEJ current strength between the observed (left axis) and the model simulation (right axis) for each station in September-December, 2008. As earlier stated, Fambitakoye Model (1976) was analyzed using the equ (3) to estimate the EEJ current strength in this work. Table 2 shows the details of observed and model variation as well as the correlation coefficient and root mean square error (RMSE) between the two approaches in each station. The EEJ current strength over the three stations peaks at 1300LT in all the months using the Fambitakoye model. AAB had the highest peak of 130.1 nT, followed by 100.8 nT in ILR and the least peak of 62.96 nT for LAG in October. The peak value of 103.5 nT, 106.4 nT, and 79.32 nT were observed in ILR, AAB and LAG, respectively, in December. Generally, the month of September recorded the lowest variation of EEJ in the work with peak values of 94.46 nT, 98.82 nT and 50.83 nT in ILR, AAB, and LAG, respectively. Statistical indices- correlation coefficient and RMSE are used to investigate the morphology and suitability of each approach in the stations. The lower the RMSE, the better the correlation between the observed and model simulation in the station for the month. Also, the closer the value of the correlation coefficient is to 1, the better the correlation. From the Table 2, LAG presented the best correlation and the least RMSE (0.85 and 0.18) in November. Similarly, the two approaches performed well with RMSE (0.91) and correlation coefficient (0.86) in the month of December in LAG. The least suitable fit was noticed in September with RMSE of 8.15 in AAB, followed by a RMSE value of 6.91 in ILR. The observed and the model simulation show the best suitability in LAG for the four months, followed by ILR while the least suitability was seen in AAB.

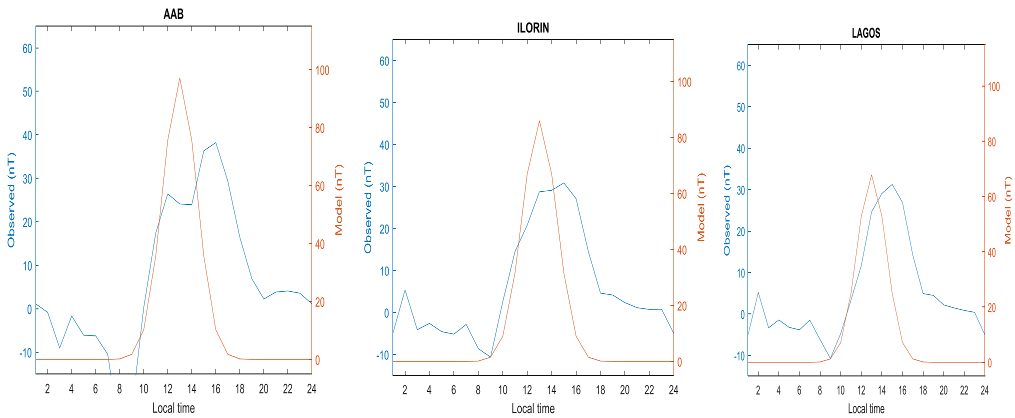

Fig. 4a. Plots of the relationship between observed and model EEJ in September

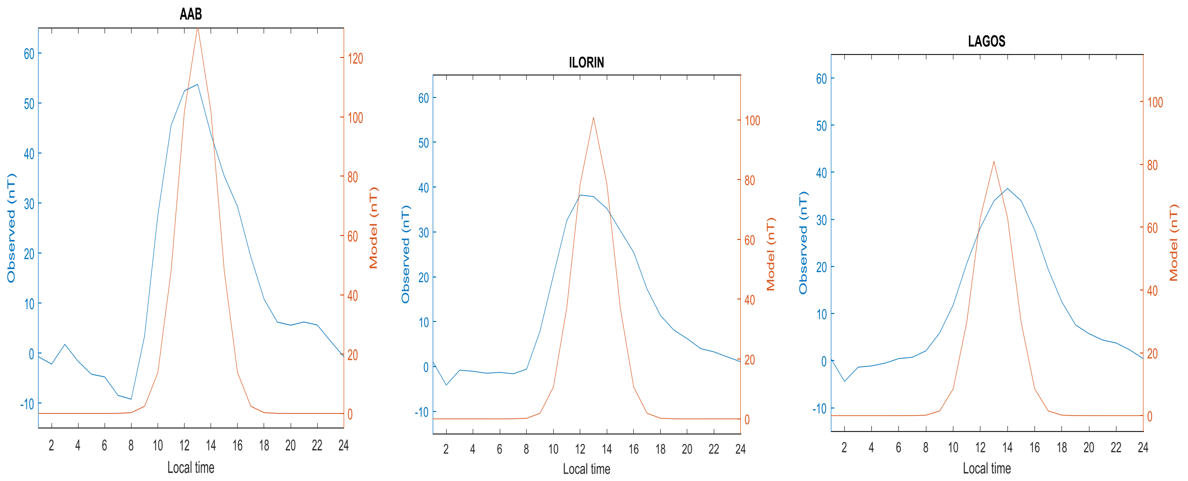

Fig. 4b. Plots of the relationship between observed and model EEJ in October

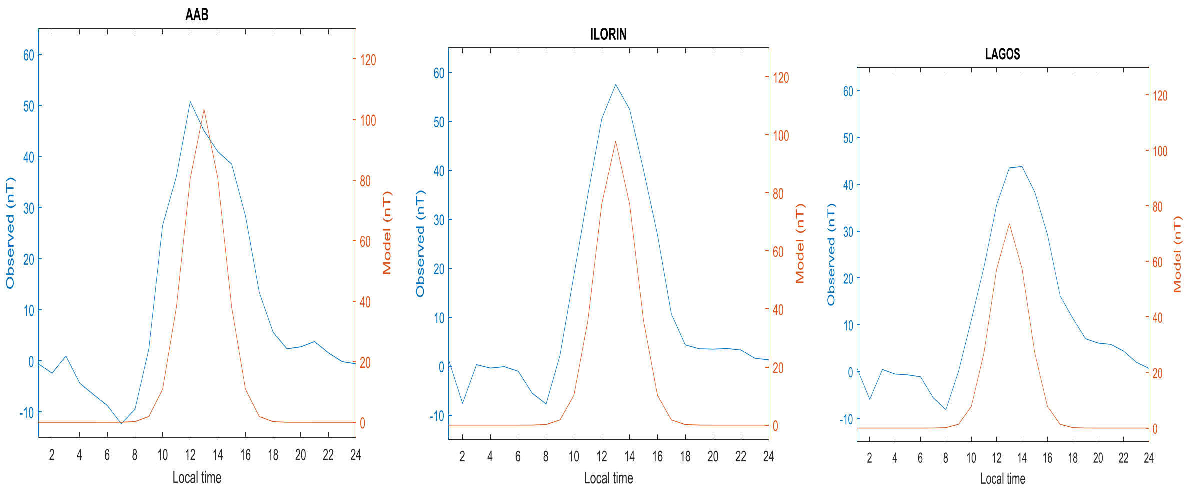

Fig. 4c. Plots of the relationship between observed and model EEJ in November

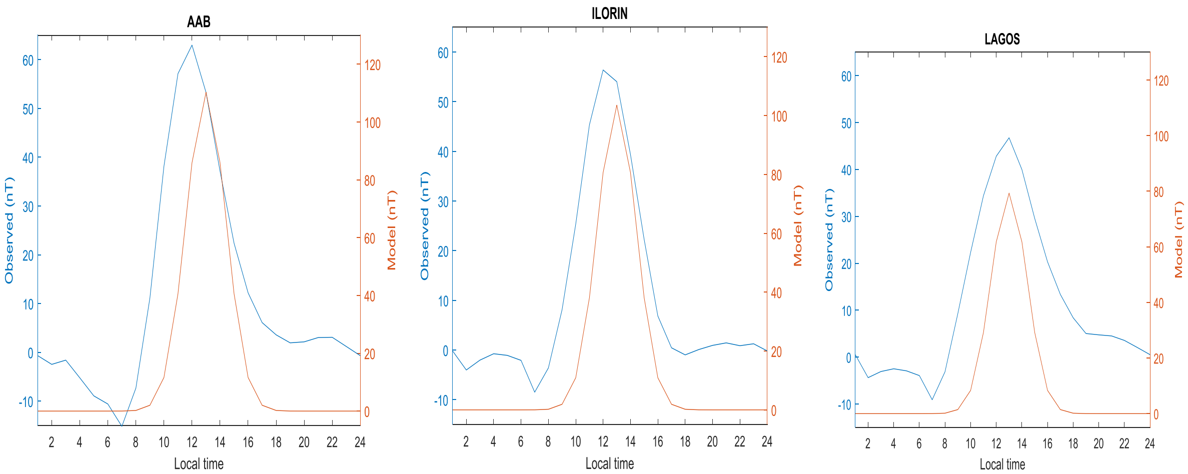

Fig. 4d. Plots of the relationship between observed and model EEJ in December

Table 2. Details of EEJ variation and the Statistical indices used

Month/ Station	Observed (nT)	Model (nT)	Corr. Coeff.	RMSE
September				
AAB	38.22	98.82	0.74	8.15
ILR	30.87	94.46	0.75	6.91
LAG	31.27	50.83	0.66	5.21
October				
AAB	53.72	130	0.83	6.09
ILR	38.23	100.8	0.79	3.59
LAG	36.56	62.96	0.74	1.49
November				
AAB	50.75	100.6	0.82	4.71
ILR	57.51	97.83	0.91	2.19
LAG	43.78	65.14	0.85	0.18
December				
AAB	62.98	106.4	0.83	5.33
ILR	56.4	103.5	0.88	5.31
LAG	46.76	79.32	0.86	0.91

4. CONCLUSION

The data presented in this work gave a comprehensive description of response of the horizontal magnetic field element during magnetic quiet condition (dH) and equatorial electrojet (EEJ) current strength, as well as the comparison between the observed EEJ and Model simulated EEJ using the Fambitakoye model. Consequently, the underlisted conclusions were drawn;

- Magnitude of variation of dH is affected by the latitudinal position of the stations.
- Sq variation rises from early morning, peaks around local noon and falls to lower values towards the evening. Variation in dH across the months during the daytime were higher than the nighttime period.
- Nighttime variations were deduced to be from sources different from the ionosphere i.emagnetospheric current and ring current.
- The different occurrence times for the peak EEJ strength across the month are linked to combined effects of the peak electron density and electric field. The highest observed peak EEJ was recorded in December in AAB and the least peak in ILR in September.
- The model simulation showed higher variation of EEJ compared to the observed values. Correlation coefficient and RMSE showed good fit between both approaches in LAG compared to other stations.
- The result is good for use in Radio and satellite applications.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Stewart B. Hypothetical views regarding the connection between state of the sun and terrestrial magnetism in “Encyclopedia Brittanica”, 9th edition. 1882;16:181-184.
2. Chapman S. The equatorial electrojet as detected from the abnormal electric current distribution above Huancayo and elsewhere, Arch.Meteorl. Geophys. Bioclimatol. 1951;4:368-392.

3. Onwumechili CA. In: Eds. Matsushuita S. and Campbell, W. H. Physics of Geomagnetic Phenomena. Academic press, New York. 1967;1:425-507.
4. Luhr H, Maus S. Direct observation of the F-region dynamo currents and the spatial structure of the EEJ by CHAMP. Geophys. Res. Lett. 2006;33:24102.
5. Chandra H, Sinha HSS, Rastogi RG. Equatorial electrojet studies from rocket and ground measurements. Earth Planets Space. 2000;52:111– 120.
6. Manoj C, Luhr H, Maus S, Nagarajan N. Evidence for short spatial correlation lengths of the noontime equatorial electrojet inferred from a comparison of satellite and ground magnetic data. J. Geophys. Res. 2006;111:11312. Available:http://dx.doi.org/10.1029/2006JA011855.
7. Adimula IA, Rabiu AB, Yumoto Y. the MAGDAS Group. Geomagnetic field variations from some equatorial electrojet stations. Sun and Geosphere, 2011;1819-0839:6(2):39–43.
8. Abbas M, Joshua B, Bonde D, Adimula IA, Rabiu AB, Bello OR. Variability of Electrojet Strength along the Magnetic Equator using MAGDAS/CPMN Data, Journal of Information and Data Management. 2012;1(1):10-13.
9. Geoscience Australia: Tabulated IQD and IDD data; 2009. Available:www.ga.gov.au;
10. Rabiu AB, Mamukuyomi AI, Joshua EO. Variability of equatorial ionosphere inferred from geomagnetic field measurements. Bull. Astr. Soc. India. 2007;35:607-618.
11. Fambitakoye O,Mayaud PN. Equatorial electrojet and regular daily variation s_r- i. a determination of the equatorial electrojet parameters. Journal of Atmospheric and Terrestrial Physics. 1976;38:1-17.
12. Obiekezie TN,Obiadazie SC. The variation of H component of geomagnetic field at the Africa sector. Physical review & research international. 2013;3(2):154-160.
13. Onwumechilli CA. The Equatorial Electrojet. Gordon & Breach, Netherlands.1997;627.

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