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Longitudinal Morphology of the Morning Counter Equatorial Electrojet during Low Solar Activity

Abbas, M [a*], Mukhtar, I. F [b], Mohammad, B. K [a], Jusoh, M. H [c] and Yoshikawa A [d]

[a] *Department of Physics, Kebbi State University of Science and Technology, Aliero, Nigeria.*
[b] *Federal College of Education Technical, Gusau, Zamfara State, Nigeria.*
[c] *Applied Electromagnetic Research Group (AERG), Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia.*
[d] *International Center for Space Weather Science and Education (ICSWSE), Kyushu University, Japan.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The primary aim of this study is to investigate the longitudinal morphology of the Morning Counter-Equatorial Electrojet (MCEJ) during a period of low solar activity (specifically, the year 2008). The study employed a comparative longitudinal analysis of the Morning Counter-Equatorial Electrojet (MCEJ) during a period of low solar activity. The horizontal magnetic field data from four equatorial stations were collected using the Magnetic Data Acquisition System (MAGDAS). After data cleaning and processing, including hourly binning, baseline determination, and non-cyclic variation

**Corresponding author: E-mail: maphysik@yahoo.com;*

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correction, MCEJ events were identified based on the negative variations of the H component of the Earth magnetic field during the daytime hours (0600-1800 LT) hrs. The frequency of occurrence, intensity, and timing of these events were analysed across different longitudes and seasons to investigate their longitudinal and seasonal variations. Additionally, the impact of MCEJ events on the noontime equatorial electrojet was assessed. The study identified two categories of MCEJ events. The first type is associated to late reversal of the nighttime westward electric field. The occurrence of the MCEJ event decreases in the eastward direction. The second type is linked to late reversal of the abnormal nighttime eastward electric field and the occurrence frequency increases eastward. Both forms of MCEJ events influence the noontime electrojet, with the first type showing stronger seasonal dependence.

Keywords: Ionosphere; magnetosphere; electrojet (EEJ); morning counter-equatorial electrojet (MCEJ); westward electric field (WEF); eastward electric field (EEF).

1. INTRODUCTION

Magnetic field perturbations at the Earth's surface reflect electrodynamic changes of various current systems situated in the upper atmospheric region. During quiescence periods, the magnetic field exhibits a regular occurring pattern that changes with local time (LT) from one particular day to the other. At the magnetic equator, the field shows unique features due to a complex electrodynamic process within its confined region not exceeding ±3° dip latitude. One common noticeable feature is an abnormally enhanced eastward current situated in the E-region of the ionosphere during the daytime near the magnetic equator known as the equatorial electrojet (EEJ), [1,2]. The EEJ which is a consequence of the mutual orthogonality of electric and magnetic field at the equatorial dip latitude flows only during the absence or minimal solar-terrestrial magnetic disturbance periods, [1]. The EEJ is sometimes known to reverse its direction from the normal eastward current flow to westward during certain normal quiet days. This reversal was first identified by [3] and was later named Counter-equatorial electrojet (CEJ) by [4]. The visible manifestation of the reversal current is the obvious suppression or decrease of the northward (X) or horizontal (H) component of the Earth's magnetic field as a negative excursion below the baseline level [5-7,1].

Ever since the discovery of the CEJ phenomenon more than 6 decades ago, it has continued to gain the attention of several notable research workers due to its global dynamic influence not only within but also beyond its confined region, hence several impressive studies have emerged on the morphological characteristics, longitudinal variations and its causative mechanism [8-11]. Studies have generally shown that large-scale tidal winds generate substantial polarization electric fields at low latitudes that are directed eastward (westward) during daytime (night-time) hours. The switch in the direction occurs in the morning (0700 LT) and evening (2000 LT) hrs eg., [6]. This background field is the main driver of the eastward current known as EEJ during the daytime hours and is invariably responsible for the westward field of the horizontal magnetic field at night time.

The westward current which manifests during the normal eastward electrojet has been explained in terms of several factors by notable research workers. For example, [1,12] explained the occurrence of the daytime westward current in terms of atmospheric tidal effects. Earlier studies by [13,14] revealed that appropriate combinations of atmospheric tidal modes are capable of generating the dayside westward current at the magnetic equator [15].

Several studies have also been extensively conducted to unravel the characteristics and features of the CEJ mechanism such as solar cycle, seasonal, longitudinal, day-to-day variability and their dependence on lunar phase using ground-based and satellite observations. These studies revealed that the phenomena are more frequent or dominant in the morning and late afternoon hours [5,16,9,2,11]. An independent study by [4] revealed that morning CEJ occurrences are more frequent at the equinoxes and dominant afternoon CEJ events occur during the local summer solstice.

An earlier effort by [9] gave us some insight into the morphological features and the longitudinal dependence of the CEJ phenomenon. Later, [17] identified two categories of CEJ events; one that shows systematic changes in its diurnal pattern which seems to be controlled by the lunar tide and the other that changes abruptly instantaneously associated to South-North changes in the interplanetary magnetic field (IMF). He further explained that the CEJ events associated with lunar tide seem to persist for several days over a wider longitudinal width. All these studies to a large extent gave us a clearer understanding of the causative mechanism and other features of the CEJ events such as its day-to-day variability. To the best of our knowledge, no study has been conducted on the morphological characteristics of the morning counter electrojet (MCEJ) apart from its widely reported dominance over other local time (LT) events in some regions and occur more frequently especially during high solar activity but the detail feature of the MCEJ is not elusive. Hence, this present study seeks to explore for the first time detailed longitudinal morphology of the MCEJ during low solar activity. Because of this, the data and method of analysis are described in section 2, the results are presented in Section 3 and discussion of the findings is given in Section 4.

2. MATERIALS AND METHODS

The horizontal component of the Earth's magnetic field measured over Four (4) equatorial stations across the globe acquired using Magnetic Data Acquisition system (MAGDAS) are used to study the longitudinal morphology of morning counter equatorial electrojet (MCEJ) during quiet days of the year 2008. Table 1 provides the list of the stations and their coordinate systems used in the study. The diurnal variations of the MCEJ were generated from the International Quiet Days (IQDs) published in the World Data Centre catalog. The days used were carefully selected based on the magnetic activity index $A =\leq 6$ and the concept of local time (LT) was employed throughout the analysis.

Each day, the MAGDAS records minute average values of the H-component of the Earth's magnetic field. The 1440 minute average values were binned to hourly values and this reduced the data to 24 hourly values. The baseline which define if a counter-electrojet occurred or not was obtain by simply taking an average of two hours flanking the local midnight (0000 LT and 0100 LT). The daily baseline values for the element used in the study are given as;

$$H_{\circ} = \frac{H_{0000}+H_{0100}}{2} \quad (1)$$

Where H_{0100} and H_{0000} are the hourly values of H at 0100 and 0000 LT respectively. The hourly departure approximately equal to the hourly solar quiet of H- component was estimated by simply subtracting the baseline values of a particular day from each hourly value of that same day. The hourly departure is further corrected for non-cyclic variation to eliminate the difference between the value of a field at the 24th LT and 1st LT hour as earlier established by [18,19]. This was achieved by making linear adjustment on the daily hourly values of the Sq. Hence, the corrected non-cyclic hourly departures give the solar daily variation of the H-component of the Earth's magnetic field during magnetically quiet days. For comprehensive data processing routine see [5].

Table 1. List of magnetic observatories and their coordinate system used in the study

Stations Name	Station Code	Geographic		Geomagnetic	
		Latitude (°N)	Longitude (°E)	Latitude (°N)	Longitude (°E)
Ilorin,	ILR	8.50	4.68	-1.82	76.80
Langkawi	LKW	6.30	99.78	-2.32	171.29
Yap Island	YAP	9.50	138.08	1.49	209.06
Ancon	ANC	-11.77	-77.15	0.77	354.33

3. RESULTS AND DISCUSSION

Fig. 1 (panels a and b) depicts the longitudinal profile of the quiet time H-field at some selected stations across the globe on January 30, 2008 and January 31, 2008 respectively. It is evident that a conspicuously daytime depression known as counter-electrojet of the H-field is readily observed during the morning hours (MCEJ) on January 30, 2008 (panel a). The MCEJ appeared exceptionally strong (38 nT) in the American sector (ANC), very feeble in the West Africa (ILR) and East Asian sector (LKW) and surprisingly absent at YAP just separated by about 2 hours from the eastern side of LKW. Similar MCEJ events were also observed on January 31, 2008 (panel b) at LKW and YAP separated by a narrow longitude with no traces of the MCEJ at ILR and ANC separated by more than

6 hours. These results are in agreement with earlier findings of [17, 20] who independently observed in their respective studies that CEJ events may not necessarily occur on the same day at two stations even if they are separated by about 30° longitude or less, suggesting that the variability in occurrence pattern at observatories may be due to the neutral wind patterns which are confirmed at longitudinal zone. The MCEJ appeared weak (25 nT) at LKW and stronger (45 nT) progressively with longitude seen at YAP.

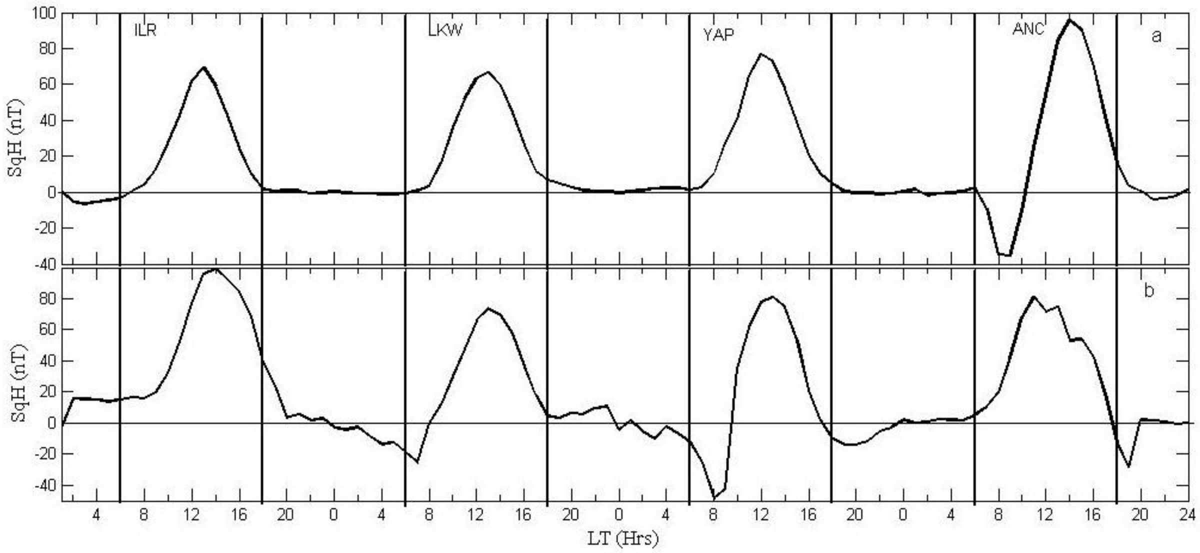

Fig. 1. Longitudinal variation of solar quiet Sq H at some selected equatorial stations across the globe on (a) 30 January, 2008, (b) 31 January, 2008

Fig. 1 established the fact that the occurrence of MCEJ does not depend entirely on global mechanism occurring at different longitude but regional factor also make significant contribution. The absence of MCEJ at some of these longitude sectors may likely to be due stronger local mechanisms over the global phenomena. The prominent MCEJ that extended to about 1000 LT hrs at ANC shifted the noontime peak to later hours (1400 LT) seen in Fig. 1 (panel a) and other sectors with feeble MCEJ had their noontime EEJ intensity around 1200 LT hrs. In a different study and different local time [17] observed cases whereby the daytime CEJ events in the H-field is quite different or differ greatly between two longitude stations (AAB and KOD). He observed that afternoon CEJ (ACEJ) is fairly localized in longitude. We assert that the MCEJ events in this study also follow suit fairly localized in longitude which in some occasions may not occur on the same day even if they are separated by a narrow longitude of 2 hours as the case between LKW and YAP in Fig. 1 (panel a).

Moreover, careful observation of the MCEJ on these days revealed some outstanding features and thus indicates that the events exhibit varying characteristics. For instance, the MCEJ events that occurred across all the longitudes were found to be associated with the late reversal of night-time westward electric field (WEF) except ANC which is unconnected to the late reversal of the WEF. The MCEJ associated to the late reversal of nighttime WEF signals the superposition of highly westward normal night-time current that extended to early morning hours over the equatorial region. Another interesting aspect of these exceptionally or pertinent MCEJ associated with the late reversal of WEF seen in YAP in Fig. 1 (panel b) and the one not connected to late reversal of night-time WEF obvious at ANC in Fig. 1 (panel a) that extended well beyond 0900 LT shift the noontime EEJ peak to latter hour (1400 LT hrs) of the day. This thus, indicates that both forms of MCEJ events possess the characteristics to shift the EEJ intensity to later hours. This result is in sharp agreement with earlier efforts by [5] that examined various causes of CEJ events at different longitude sectors and observed that the events exhibit varying natures even if they are separated by limited longitudinal extent. The diurnal variations of ΔH (YAP) with no traces of MCEJ and ΔH (LKW) with feeble MCEJ associated with late reversal of night-time WEF seem not to have any significant influence on the diurnal trend at these longitudes strictly following the strong electrojet characteristics. The incredible enhancement of the daytime EEJ in the West African sector (ILR) and the systematic reduction in the EEJ as it flows eastward (see Fig. 1, panel b) is clear evidence of the modification of the entire current system associated with the Sq field and the electrojet. The mechanism is more conspicuous with a step-like decrease in the American sector (ANC). We assert that the modification of the EEJ is a characteristic of counter electrojet (CEJ) not strong enough to cause the EEJ to go beyond the night-time baseline.

Fig. 2 shows the diurnal variations of the EEJ at Ilorin (ILR), Langkawi (LKW), Yap Island (YAP) and Ancon (ANC) on May 10, 2008. This day is characterized by MCEJ conspicuously seen at all the stations for LKW with evening CEJ (ECEJ) which is not the concern of this study. The absence of MCEJ at LKW on this day may likely be attributed to the prevalence of local effects over the global mechanisms. For example, the MCEJ at ILR that extended to 08:00 LT hrs is associated with the late reversal of night-time WEF and this shifted the noon peak to about 13:00 LT hrs.

Also from Fig. 2, the MCEJ that occurred around 08:00 LT hrs at ANC that is not associated with late reversal of night-time WEF In fact, the MCEJ at this longitude sector (ANC) is associated with the late reversal of abnormal night-time eastward electric field (EEF). The effect of this MCEJ event shifted the noontime EEJ peak to the latter hours (1400 LT). This further clearly indicates that the MCEJ associated with late reversal of normal night-time WEF and those connected to late reversal of abnormal nigh-time eastward electric field tend to shift the noontime EEJ peak to latter hours under certain ionospheric conditions.

The variation of the EEJ index at YAP in Fig. 2 does not show negative values during the morning hours but exhibits some form of depression around 1000 LT hrs which is different than the normal EEJ variation. This feature becomes more obvious when compared with the expected normal electrojet current pattern. This may likely indicate the presence of the westward current in addition to the normal eastward current system. This event takes place when the normal eastward current is strong; hence the superposed westward current was not sufficiently strong enough to cause a net negative excursion hence we observed only a slight depression in the EEJ index around 1000 LT hrs and reduced the noontime EEJ peak instead of a proper MCEJ with negative values. Even this situation can be considered a characteristic of the CEJ phenomenon and thus indicator of a weak MCEJ event.

Extending this description further, we thus suggest that the reversal of the equatorial electrojet seems to be due to some mechanism which when stronger than the normal eastward current caused an overlapping of westward current or complete reversal of the eastward current at the vicinity of the magnetic equator. The overall results seem to indicate that the extended local time of daytime WEF of MCEJ associated with the late reversal and those not related to the late reversal of WEF play a significant role in determining the noontime peak and magnitude of the EEJ depending on the strength of the EEJ.

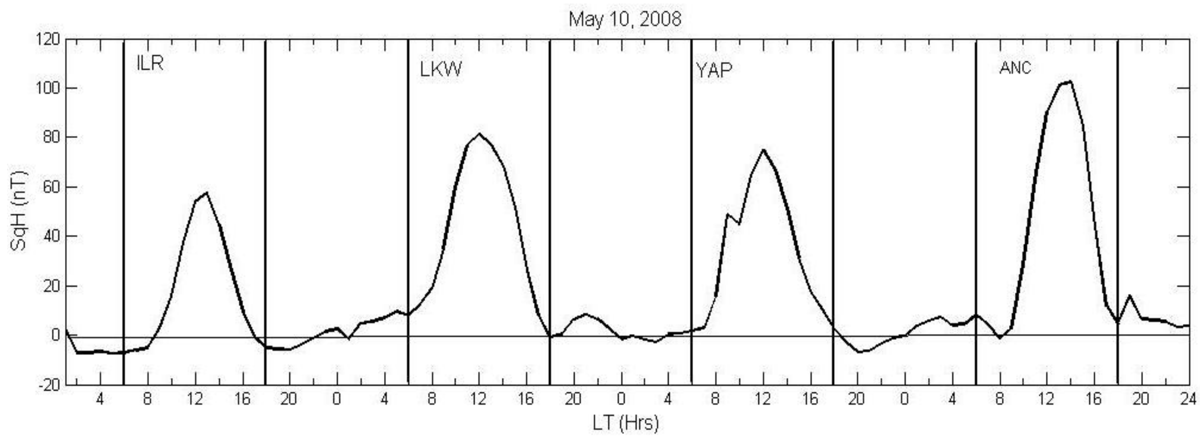

Fig. 2. Longitudinal variation of the equatorial electrojet current the quiet day of May 10, 2008

Fig. 3 shows the diurnal variations of the H-field on a series of days in September 2008. Interestingly, MCEJ associated with the late reversal of night-time WEF could be seen in all the days in the West African sector (ILR), this feature is completely absent at any longitude sector except for ANC seen on September 24, 2008. On each of these days, the magnetic activity index Ap≤ 6 and this thus makes these days to be considered magnetically quiet. The MCEJ seen in the American sector (ANC) is not associated with the late reversal of night-time WEF indication that the MCEJ on this day at this longitude sector exhibits different features to the West African sector (ILR) that is associated with the late reversal of normal night-time WEF.

The frequent or dominant occurrence of MCEJ associated with the late reversal of night-time WEF in the West African sector (ILR) could signal the presence of weak EEJ or eastward current strength to overcome the normal night-time westward current that extended beyond 0600 LT hrs at this longitude sector. To determine the local time effect of the MCEJ associated/not associated with the late reversal of night-time WEF, Fig. 4 is plotted. These MCEJ events were found during 0700-0800 LT hrs. Two categories of MCEJ can be identified on this day. The MCEJ not associated with the late reversal of WEF that occurred in the West African sector (ILR) and the one associated with the late reversal of WEF is seen in the American sector (ANC). These MCEJ were observed to extend to around 0800 LT but had strong influence on the EEJ having its peak at 1100-1200 LT hrs respectively. This noontime EEJ peak despite the MCEJ are a normal phenomenon and expected owing to the weak MCEJ that does not go beyond 0700 LT to cause any significant influence on the EEJ intensity. On the other hand, the diurnal variation of the H-field in the Asian sector with a complete absence of MCEJ, in fact an abnormal enhancement of ΔH that started building up from midnight (0100 LT) hrs and progressively enhanced with local time (LT) resulting in an early peak of EEJ around 1100 LT hrs. This is in agreement with earlier effort of [9] who opined that EEJ reaches its peak intensity around 1100 (1200) LT hrs during low (high) solar activity periods.

Generally, the MCEJ events were found to decrease as the electrojet current flows from the West African sector (ILR) to the East American sector (ANC). The higher occurrence of MCEJ events 122 days occurred in the West African sector (ILR) and progressively dropped with longitude to about 59 days seen in the American sector (ANC) as shown in Table 2. This seems to point to the fact that as the jet flows eastward, there seems to be extra input energy that tends to reduce or minimize the occurrence of MCEJ.

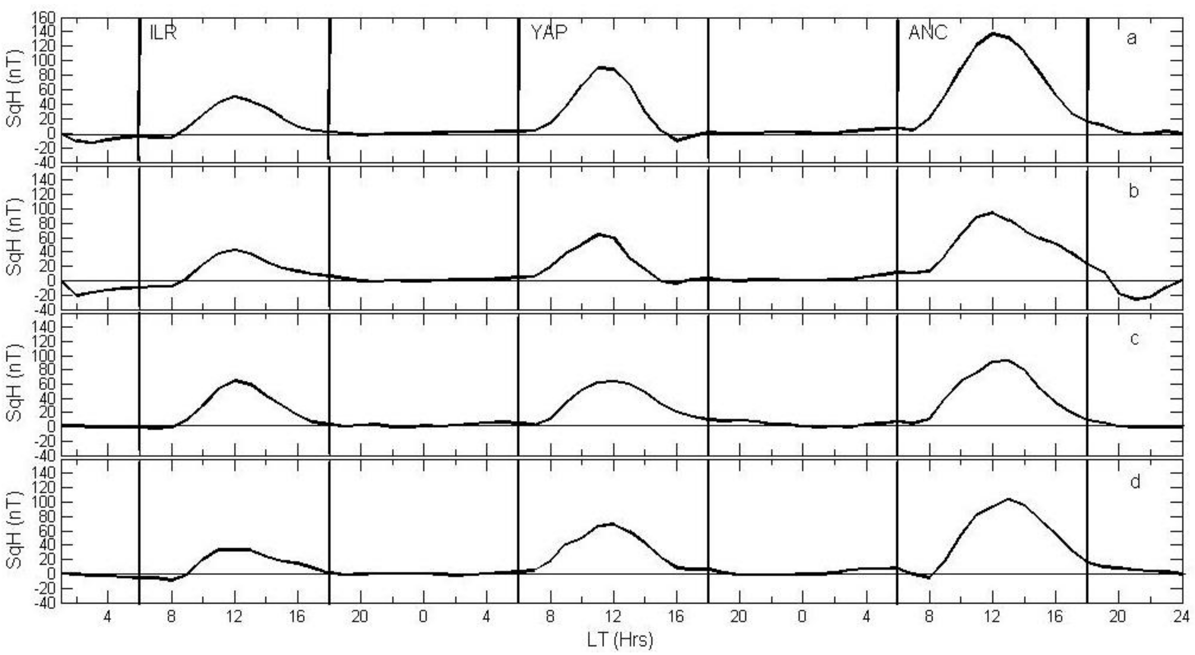

Fig. 3. Diurnal variation of H-field on series of days (a) September 20, 2008 (b) September 22, 2008, (c) September 23, 2008 and (d) September 24, 2008 respectively

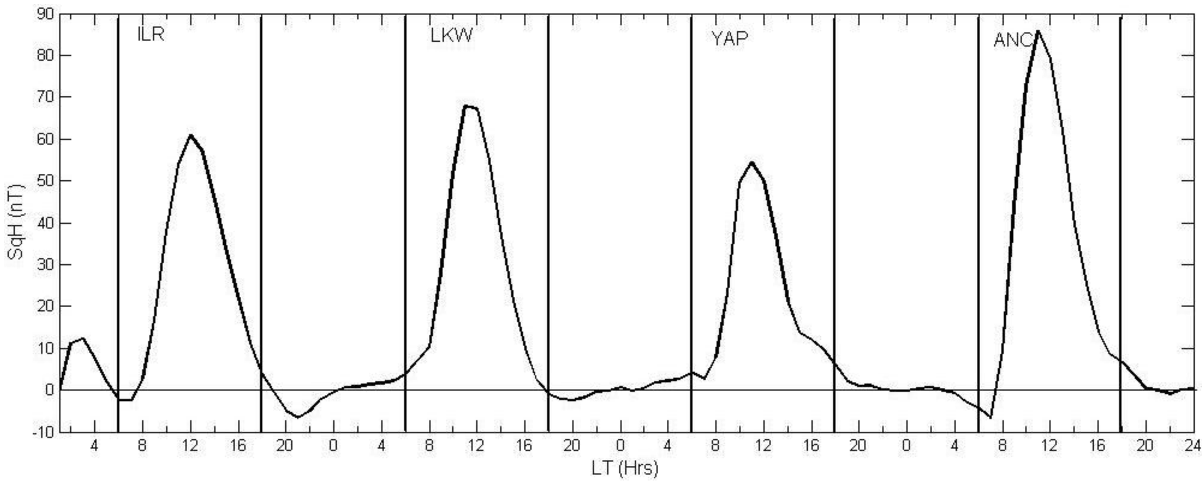

Fig. 4. Diurnal variation of H-field on November 4, 2008

Table 2. Total occurrence of morning CEJ events in the year 2008

ILR	LKW	YAP	ANC
122	81	74	59

In some days, the MCEJ events were reliably observed to be associated with the late reversal of the normal night-time westward electric field (WEF). These MCEJ events associated the late late reversal of WEF were found to decrease progressively as the EEJ flow eastward with a higher occurrence of 105 days observed in the West African sector ILR and dropped to about 22 days in the American sector (ANC) as shown in table 3. This indicates the progressive increase in the intensity of the eastward current with longitudes which tends to reduce the effect of the late reversal of the night-time WEF during the morning hours. We assert that the occurrence of MCEJ associated with the late reversal of normal night-time WEF signals weaker morning EEJ strength, hence, MCEJ associated with the late reversal of night-time WEF seems to thrive in a region or longitude with weaker build-up EEJ current intensity. Extending this description further, it is expected that the background E-field is still pointing westward before 0600 LT hrs dominating the current direction (westward). During the subsequent hours (0700 LT), the large-scale electric field should switch direction and drift eastward gaining more momentum to overcome the night-time westward electric field thereby establishing an eastward current responsible for the positive magnetic field variations. The dominance of MCEJ events associated with the late night-time WEF at the West African sector (ILR) could signal the prevalence or extension of the night-time WEF beyond 0600 LT hrs at this longitude sector. On average, MCEJ associated to late reversal of WEF were observed to occur at all longitudes but predominantly in the West African sector (ILR). This is consistent with the earlier report of [7] that found CEJ events at all the longitudes considered in their study. During the subsequent hours (after 0700 LT hrs), the large-scale eastward field gained more momentum and overcame the westward field, hence resulting in the enhanced noontime peak of the EEJ intensity reliably observed in Figs. 1-4.

Table 3. MCEJ events associated with the late reversal of WEF in the year 2008

ILR	LKW	YAP	ANC
105	59	33	22

Apart from the MCEJ associated with the late reversal of night-time WEF, there are other MCEJ that are not associated with the late reversal of WEF, these MCEJ are associated with unusual night-time eastward electric fields (EEF). These MCEJ increase linearly with longitude in the eastward direction as the electrojet flow, except at **ANC** where it slightly dropped to about 37 days as shown in Table 3. the West African sector (ILR) with the highest number of MCEJ associated with the late reversal of night-time WEF recorded the least number of days (18) with MCEJ associated with the reversal of abnormal EEF and this progressively increase in the eastward direction as the electrojet gained momentum. This established the fact that as the electrojet flows eastward during the daytime it gain more momentum that increases the frequency of the occurrence of MCEJ events that are associated with the late reversal of unusual night-time eastward electric field at the same time enhances the occurrences of MCEJ that are associated to night-time reversal of normal WEF. Hence, this study for the first time established the categories of MCEJ events that decrease or increase with longitude in the eastward direction depending on the night-time electrical conductivity of the E-region.

Table 4. MCEJ events associated with the late reversal of EEF in the year 2008

ILR	LKW	YAP	ANC
18	22	41	37

From Fig. 5, it is obvious that MCEJ events were generally observed to be most frequent in August with the highest 15, and 12 days in Africa (ILR) and Asian (LKW) sectors respectively. In the American sector (ANC), the highest frequency (13 days) occurred in December. These are solstice months identified with weak electrojet current intensity and widely reported CEJ occurrences.

This result is consistent with [21] who observed that the occurrence of CEJ events maximizes during the solstice months. This result established that the MCEJ exhibits longitudinal variability just like the afternoon and noon CEJ events earlier reported by research workers e.g., [22,23,9,24,25]. The frequent occurrence of MCEJ phenomena at ILR could be explained in terms of the fact that at low solar magnetic activity period, the lower solar flux level causes significant decrease in the build-up level of atmospheric ionization rate and this lowers the ionospheric conductivity hence reducing the build-up of EEJ during the morning hours. The reduced EEJ intensity creates a conducive condition for MCEJ to prevail during the early morning hours as observed in the West African sector (ILR).

Fig. 6 shows the occurrence frequency of MCEJ associated with the late reversal of night-time WEF observed in each month during the solar quiet year 2008. These MCEJ events exhibit higher magnitudes in all the months through the year in the West African sector (ILR) except for February, April and August respectively. During these periods, the highest occurrence frequency of 12, 9 and 5 days were recorded in July at the African sector (ILR), August at the Asian sector (LKW) and November and December with an equal number of days in the American sector (ANC). On average, lowest occurrence frequency of MCEJ associated with the late reversal of night-time WEF was observed in each month through the year at the American sector (ANC) except November and December.

Fig. 7 shows the monthly occurrence of MCEJ associated with the late reversal of the unusual night-time eastward electric field (EEF). On average, the occurrence of the CEJ phenomenon is less frequent in the West African sector (ILR) and occurrence more frequent in the American sector (ANC) with its peak amplitude in October. In the Asian sector, it appeared more frequent in YAP than in the East Asian sector (LKW). This higher occurrence of late reversal of the abnormal night-time eastward electric field could be attributed to the local longitudinal gradient effect over the global mechanism.

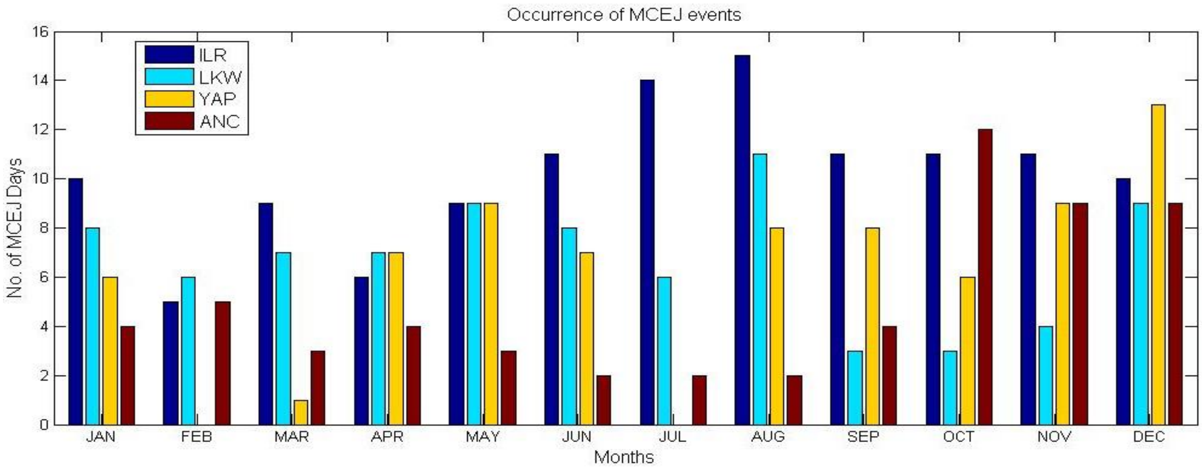

Fig. 5. Monthly occurrence of morning counter-equatorial electrojet (MCEJ) in year 2008

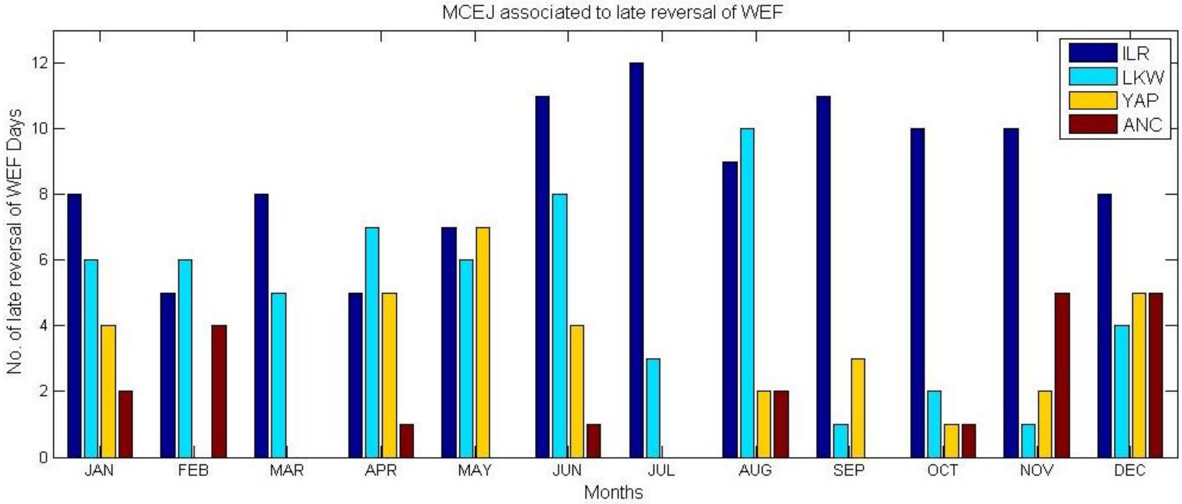

Fig. 6. Monthly occurrence of late reversal of morning westward electric field (WEF)

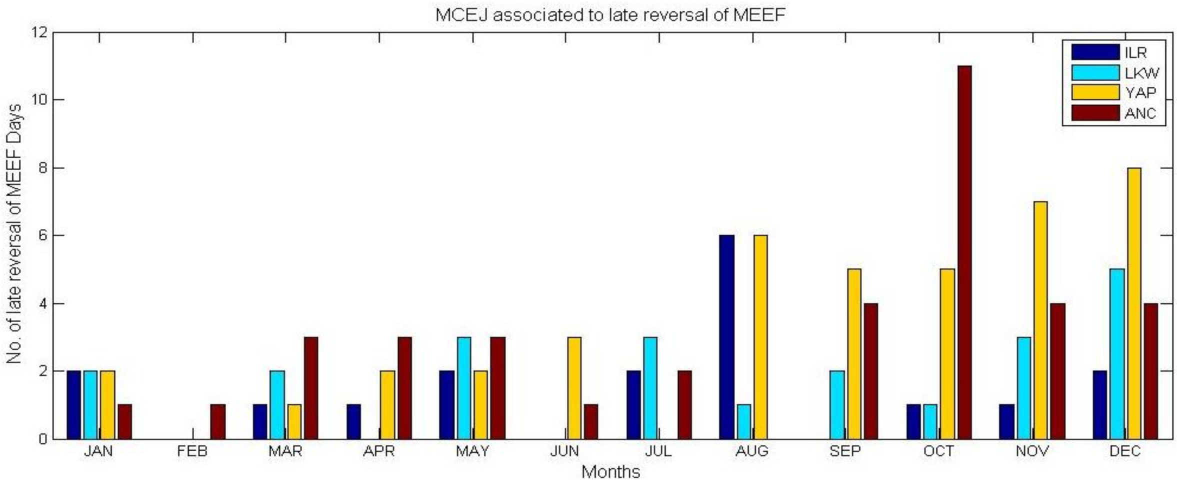

Fig. 7. Occurrence of late reversal of morning eastward electric field (MEEF)

This result further earlier confirms earlier report that night-time sometimes exhibits positive magnetic field variations indication the eastward electric field that extended to the early morning hours of this study. Amazingly these night-time positive variations were observed during solar minimum activity in contrast to earlier studies that reported the phenomenon mostly in the American sector during maximum solar activity. This further implies that at night-time when solar activity ceases to exist and the electrical conductivity of the E-region is minimal or shut down, some fundamental mechanisms either of ionospheric or non-ionospheric origin may play a significant role in generating and sustaining the electrical conductivity of the E-region ionosphere.

Fig. 8a shows the seasonal variations of MCEJ events that are associated with late reversal of WEF during the equinox, summer and December solstices. It is consistently seen that even the MCEJ associated with the late reversal of WEF consistently appeared higher in the West Africa sector (ILR) throughout the seasons and lowest in the American sector (ANC) seen in the equinox season. The higher (lower) occurrence of the seasonal MCEJ associated with the late reversal of WEF at the West African sector (American sector) is a strong reflection of weaker (stronger) morning equatorial electrojet current intensity at these longitude sectors as earlier mentioned.

The highest number of days (39) of the seasonal MCEJ occurred in the West African sector (ILR) in the summer solstice and shifted to the December solstice seen in the American sector (ANC). It is noteworthy to note that these

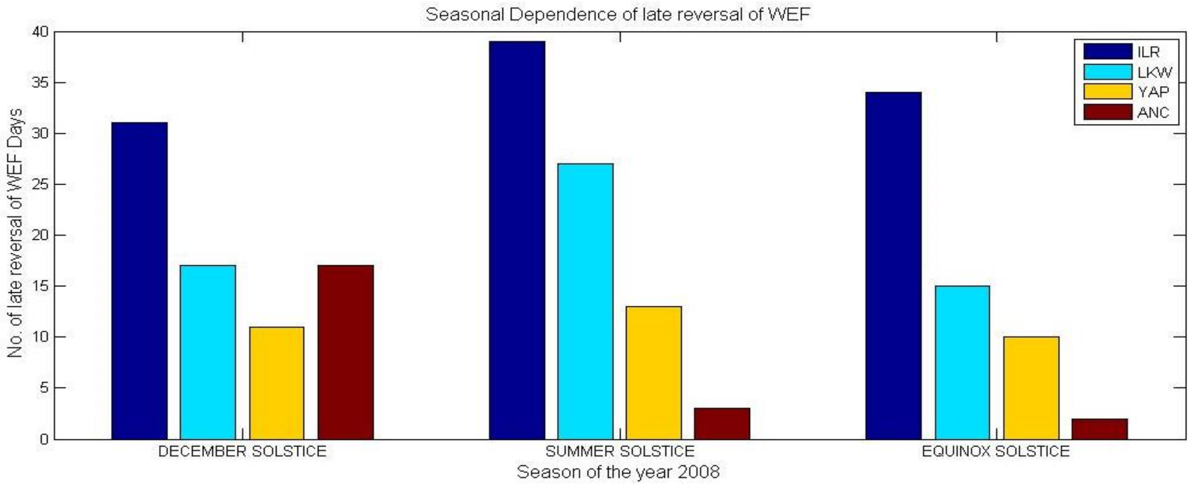

Fig. 8a. Seasonal variation of late reversal of WEF in the year 2008

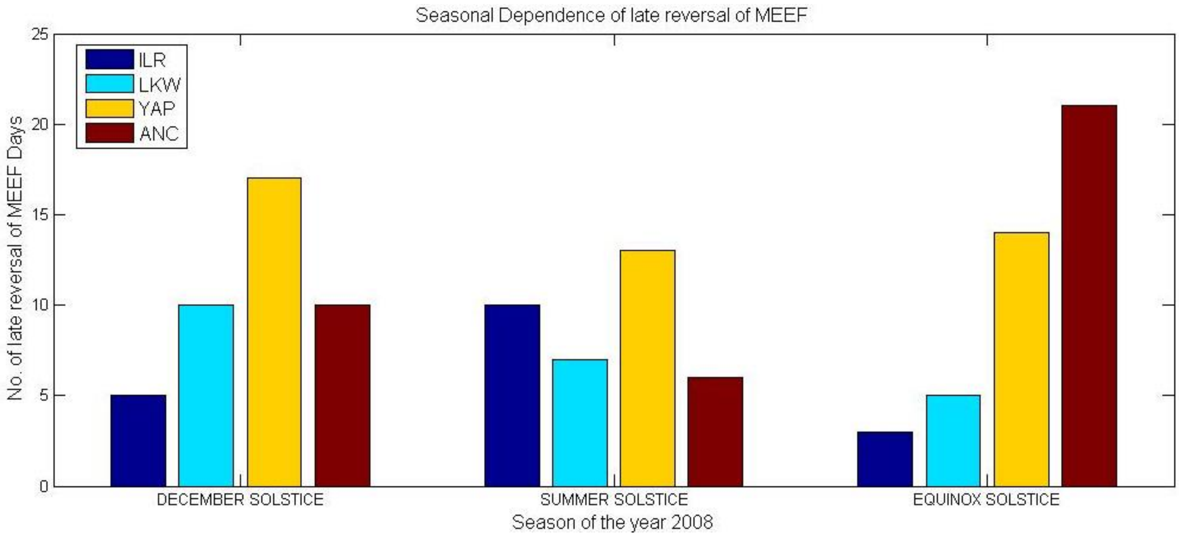

Fig. 8b. Seasonal variation of late reversal of MEEF in year 2008

are solstice seasons where the strength of the eastward current intensity is weak and thus suggest the occurrence of more CEJ events which are likely to take place at region and periods of weak normal electrojet current, hence could attributed to the observed higher MCEJ events on these seasons. Fig. 8b which depicts the seasonal variability of the late reversal of MEEF showed maximum occurrence (21) in the American sector seen in the equinox season. On average, the seasonal MEEF does not show any clear distinct variations but their magnitudes were observed to appear lower than their corresponding MCEJ magnitudes associated with the late reversal of WEF. This further clarifies or substantiates the fact that seasonal MEEJ does not show any longitudinal seasonal variation.

4. CONCLUSION

The study which examined for the first time the longitudinal characteristics of the MCEJ events identified two forms of CEJ:

1. MCEJ events that are associated with the late reversal of night-time westward electric field (WEF) that decreases progressively in the eastward direction from the West Africa (ILR) to South America (ANC) sector.
2. MCEJ phenomenon that is associated with late reversal of abnormal night-time eastward electric field (EEF). These CEJ events were found to decrease in the eastward direction in contrast to these associated to late reversal of the normal night-time WEF.

3. The higher (lower) occurrence of the seasonal MCEJ associated with the late reversal of WEF at the West African sector (American sector) is a strong reflection of weaker (stronger) morning equatorial electrojet current intensity at these longitude sectors
4. On average, the seasonal MEEF does not show any clear distinct variations but their magnitudes were observed to appear lower than their corresponding MCEJ magnitudes associated with the late reversal of WEF.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

SIGNIFICANCE OF THE STUDY

This study for the first time identify two categories of morning Counter-Equatorial Electrojet (MCEJ) phenomenon and significantly advances the understanding of those Mornings Counter-Equatorial Electrojet (MCEJ) by exploring there longitudinal seasonal behaviour and assessing their impact on the noontime equatorial electrojet. The findings provide valuable insights into the complex interplay of factors influencing MCEJ behavior and their role in shaping ionospheric dynamics and space weather phenomena.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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