

Counter Electrojet Events using Ilorin Observations during a Low Solar Activity Period

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The horizontal magnetic field intensity (S_qH) values are deduced from the 2009 record of Magnetic Data Acquisition System (MAGDAS), at Ilorin (8.47°N, 4.68°E), Nigeria. Around 1000-1200 local time (LT) on March 6, 2009, diurnal S_qH (DS_qH) variations have a maximum value of about ~ 90 nT and a minimum value of about ~ 66 nT on December 28, 2009. Monthly mean maximum values of S_qH (MS_qH) were observed at 1100 LT in all months with the exception of December and January, when they peak at 1200 LT. The higher numbers of daily counter electro-jet (DCEJ) events in the early and late morning are a consequence of the late reversal of westward to eastward currents and sudden generation of CEJ during pre-sunrise hours. There is no DCEJ event observation between 1000 LT and 1300 LT in all months, which indicates that intense eastward electric field, which is the equatorial electro-jet (EEJ) was dominant during the period. Exceptions to higher DCEJ in the evening as compared to morning period for all months were observed in March and October. The longest hour of DCEJ duration did not exceed 4-hours, mostly during evening period, which contrasts Mayaud (1977) works. The seasonal equatorial lunar effect is insignificant at Ilorin, since the higher number of seasonal CEJ was observed in June solstice.

1. Introduction

Daily variations of the magnetic field on Earth's surface during geomagnetic quiet conditions are known to be associated with solar dynamo currents driven by winds and thermal tidal motions in the E-region of the ionosphere. The solar quiet (S_q) daily variation that resulted from the dynamo current in the E region of the ionosphere was driven by the atmospheric tidal wind mainly (1, -2) mode and flows as two current whorls at both the Northern and Southern hemispheres [1-3]. On magnetically quiet or less-disturbed days, this S_q daily variation exhibits regular variation at middle and low latitudes [2,4-6]. The S_q daily regular variation of the horizontal (H)-field (S_qH) is expected to increase with sunrise, reaches a maximum value near noon hours and return to the base level by sunset [7,8]. Despite this acclaimed regular

variation of S_qH suggested by many authors (Chapman and Bartels [4], Matsushita [2], Campbell [5,6]) abnormal variations were also observed at the equatorial region either by an increase or decrease in the values of S_qH daily variations during daytime hours (0600-1800 LT). Egedal [9]; Onwumechilli [10] found an unexpected increment on the values of S_qH daily variations at stations around $\pm 3^\circ$ within the magnetic equator. Chapman [11] explained that this increase is due to a belt of strong eastward current, known as equatorial electro-jet (EEJ), flowing within the ionosphere at E-region heights due to an enhance conductivity created there by the inhibition of the vertical Hall polarization field. The abnormal decrease, which resulted in the depression of daily variation of S_qH beyond the base level (zero value), has been detected at equatorial stations by Onwumechilli [12], Hutton and Oyinloye [13], Fambitakoye [14], Onwumechilli and Akasofu [15], and Rastogi [16].

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Gouin and Mayaud [17] suggested that this decrease in the value of S_qH beyond zero on a quiet day is due to a narrow band of currents flowing westward against the normal eastward equatorial electro-jet currents and named it counter equatorial electro-jets (CEJ). Sizova [18] and Sizova and Pudovkin [19] examined about ten CEJ events within and outside of the equatorial electro-jet stations in the Asian zone at Trivandrum (8.29°N, 76.59°E) and Hyderabad (17.31°N, 78.27°E), Davao (7.30°N, 126°E) and Baguio (16.26°N, 120.34°E) and American zone (Huacanyo (69.2°N, 53.5°W) and Fuquene (5.25°N, 73.49°W)). They suggested that CEJ formation and life-time are associated with the reversal of the interplanetary magnetic field (IMF) of the Bz-component from South to North, and that its intensity was determined by the solar wind electric field.

Rastogi [20], Gouin and Mayaud [17], Maynard [21], and Alex and Mukherjee [22] suggested that the number of S_qH CEJ events during morning hours is relatively low as compared to evening hours during minimum solar activity periods. However, Rao and Rajarao [23] reported no case of CEJ from their results within the period of 1958-1962. Mayaud [24] found that CEJ event in the morning is frequent in Africa and India such that their duration could take about 5 to 6 hours and sometimes, lasts for a day.

He also reported that at any station where the CEJ event in the morning period is almost a regular feature, its intensity would correlates the solar cycle to the planetary regular daily magnetic field intensity. Otherwise, it would obviously anti-correlates with the solar cycle. Rastogi [7] reported that the occurrence of mid-day (1200 LT) depression in S_qH has been rare at most of the equatorial stations. He found that the total number of such CEJ events observed between 1100 and 1300 LT were as follows: 6 at Davao over 6 year period; 10 at Kodaikanal over 18 year period; 17 at Addis Ababa over 9 year period; 11 at Freetown over 7 year period; and 8 at Huacanyo over 24 year period. He further suggested that such S_qH CEJ events near noon hours were observed during years of minimum solar activity.

The seasonal S_qH variability reported by [8,10,25-29] showed a semi-annual signature and equinoctial maxima at equatorial stations. Onwumechili and Ogbuechi [30] and Chandra et al. [26] attributed equinoctial maximum to an intense S_qH that is narrower at the equinoxes.

Campbell [27] found that the S_qH semi-annual changes followed the seasonal ionization pattern. This indicates that a semi-annual variation is a component within the range of seasonal variation of S_qH , which depicts characteristic of EEJ. Hutton and Oyinloye [13] and Mayaud [24] showed that the seasonal morning CEJ events at Zaria and Addis-Ababa is higher during equinoctial months as compared to December and June solstices. During afternoon period, they observed higher number of CEJ events during December solstice as compared to other seasons. RajaRao and Sivaramani [31], Onwumechilli and Alexander [32], Gouin [33], Onwumechilli and Akasofu [15], Gupta [34], Rastogi [35], and Mayaud [24] attributed this higher number of CEJ recorded in the afternoon period of December solstice to seasonal variations of the equatorial lunar effect. They reported that this seasonal variation of the equatorial lunar effect was significantly modulated by the new Moon and initiates higher number of CEJ at any longitude during December solstice.

As mentioned earlier, a number of researchers have studied and reported the variability of S_qH that is characterized by CEJ events at equatorial regions during low solar activity period. The closest period when CEJ events were reported over the Nigeria ionosphere was in the years 1963 and 1970. These CEJ events were detected by Onwumechili [12] and Hutton and Oyinloye [13] on a day at Ibadan and Zaria, respectively. The solar cycle variability over a century has shown that year 1901 has been the most magnetically quiet year. However, an investigation on CEJ events during such a similar geo-magnetically quiet period is a not available. The year 2009 (a year of deep minimum) presents itself as an exceptional year, being the next most quiet magnetic year since 1901. Therefore, it will be interesting to analyze the morphological features of CEJ events in 2009 at Ilorin, Nigeria, and also to update older results of CEJ events.

2. Materials and Methods

Records of Magnetic Data Acquisition System (MAGDAS) for each month of the year 2009 at the University of Ilorin, Ilorin (Geographic coordinates: 8.47°N, 4.68°E, Geomagnetic coordinates: 1.84°S, 76.80°E), Nigeria were analyzed. These records are made-up of the horizontal (H), declination (D), vertical (Z) and total (F) field component. For this work, magnetic field intensity data-set of the H-field components

are employed to investigate CEJ. The year 2009 is a low solar activity year with an average sunspot number of 3.1. Table 1 show the geomagnetic conditions for the year 2009, which was retrieved from the Kyoto data catalogue of the World Data Centre at <http://wdc.kugi.kyoto-u.ac.jp/>. It depicts maximum values of Disturbance storm time (Dst) and Planetary magnetic (Kp) indices in each month with their corresponding days and hours when these disturbances occurs. This table showed that disturbed periods in the year 2009 are not strong. The year 2009 has 81 spotless days, which indicates that 81 days within year 2009 are without sunspot (<http://www.spaceweather.com/glossary/spotlessdays.htm>). Highest magnitudes of Dst and Kp values was observed on the 22nd July, 2009, which represents a moderate storm (Dst = -78 nT, Kp = 4.3).

Table 1: Geomagnetic conditions for 2009.

Months	Days	Hours (UT)	Dst values (nT)	Kp values
January	26	1500	-32	3.3
February	4	1800	-48	3.0
March	13	0900	-31	3.0
April	9	2000	-31	2.3
May	8	0800	-25	1.7
June	24	0500	42	3.0
July	22	1000	-78	4.3
August	6	0800	-38	4.0
September	21	1000	-22	1.3
October	23	0300	-45	3.3
November	26	1800	-30	1.7
December	14	0900	-18	1.3

A base line value of geomagnetic field intensity of H-component (BaseH) was deduced from MAGDAS geomagnetic records of 1-minute value and converted to 1-hour local time bins for each day in every month. The BaseH on each day was defined as the average value of H-component near local midnight (i.e., between 2400 LT and 0100 LT).

$$BaseH = \frac{BH_1 + BH_{24}}{2} \quad (1)$$

Here, BH_1 and BH_{24} are the hourly values of H-component at 0100 and 2400 LT, respectively. The hourly departures (ΔH), which are approximately equal to S_qH are the residual values after

subtracting the BaseH value from the H-component values for each hour of each day.

$$\Delta H_t = BH_t - BaseH \quad (2)$$

Where, $t = 1$ to 24 hours. These analyses were carried-out on the entire days for each month under investigation.

2.1. Daily, monthly mean, annual and seasonal variations of S_qH

The hourly variation of S_qH over a day is the diurnal variation denoted by DS_qH . This overall variation of DS_qH in each month is further used to estimate their monthly mean values (MS_qH).

The annual variation was plotted using daily values of DS_qH from the first day of January to the last day of December, 2009 over all hours. In order to complement this, seasonal variation was further analyzed using three seasonal groups of 4-month that will be described in the next subsection. Each season was estimated by averaging the MS_qH values on each hour under a particular season.

2.2. Daily, monthly and seasonal counter electrojet events

The number of counter electro-jet (CEJ) events observed from all DS_qH variations during the daytime hours (0600-1800 LT) is noted. These CEJ events are noted within accuracy of one hour and are sub-divided into four cases of events with respect to times separated into four periods; early morning (0600-0800 LT), late morning (0900-1100 LT), noon/afternoon (1200-1400 LT) and evening (1500-1800 LT) hours. This similar classification of CEJ events was repeated for the monthly and seasonal events. Although, the year under investigation has an average sunspot number of 3.1, but days with magnetic disturbances were further excluded from the analysis. The months are also divided into three seasonal groups of 4-month each. They are: December season (November, December, January and February); Equinox season (March, April, September and October); and June season (May, June, July and August). The seasonal CEJ events were counted from the daytime hours (0600-1800 LT) within each season separately in the early morning, late morning, noon/afternoon, and evening hours.

3. Results and Discussions

The S_qH hourly values deduced from the observed ΔH_t values, where $t = 1$ to 24 hours (as described in the previous section), have been computed for all days of 2009 from the data at Ilorin. As a result of power interruptions, all the records of the daily values for the year 2009 could not be retrieved from the MAGDAS. Therefore, the number of days of data that have been used in each month is shown with bar graph in Fig. 1. From Fig. 1, February had fifteen days data. Twenty-one and twenty-two days data are available in January and August, respectively. In April and May, twenty days data are plotted, the remaining months data are greater than twenty-two days. The DS_qH CEJ (DCEJ) events are classified into: time CEJ events begins, number of CEJ event at each hour, duration of CEJ events, maximum amplitude of CEJ event, time, and the day with maximum amplitude of CEJ events in all months during early morning, late morning, noon/afternoon, and evening hours (Tables 2, 3, 4 and 5). The time series plots (Fig. 2

panel a-l) illustrate DS_qH variation during all days and their corresponding monthly mean (MS_qH) on y-axis with local time (LT) on x-axis. These MS_qH variations are given in red lines with downward-pointing triangle while DS_qH are given in green lines. From each month of Fig. 2 on panel a-l, a black line was drawn at zero value on y-axis along the x-axis, which indicates the base level that show CEJ events during daytime hours. The bar-charts in Fig. 3 panel a-l depicts the number of CEJ events, time CEJ event begins, duration of CEJ events, period with no CEJ event, and period with highest CEJ events during daytime hours in all months of the year 2009. The magnitude of CEJ observed from DS_qH variation during daytime hours is shown with Fig. 4. The annual variation of DS_qH from all hours of the day throughout the year 2009 was shown with Fig. 5 and Fig. 6 shows the seasonal variation of DS_qH determined from monthly mean estimates.

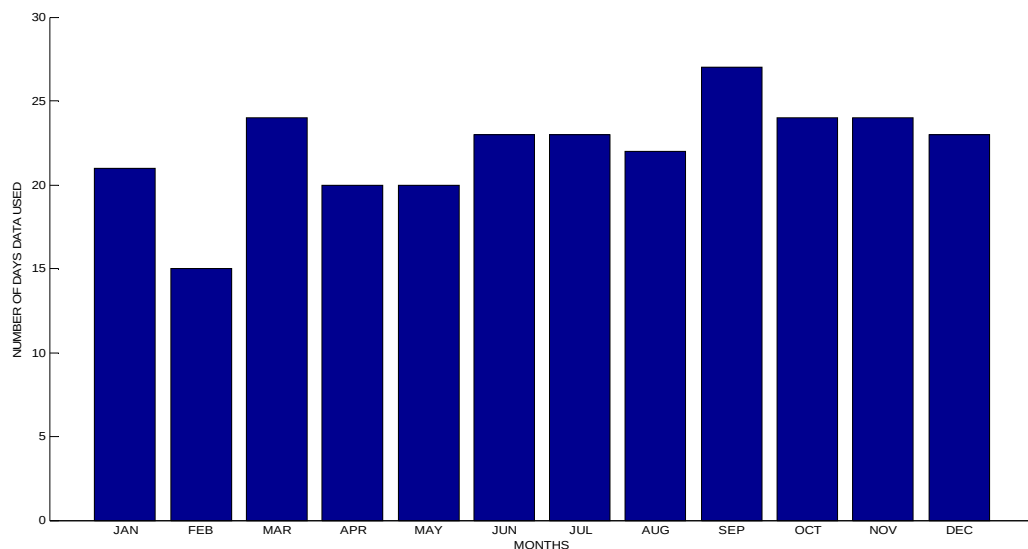


Fig.1: Histogram of the number of days in each month with available data.

Table 2: $DS_q H$ counter electro-jet (DCEJ) events during early morning (0600-0800 LT) period.

	Months	Time CEJ event begins/number of CEJ event at each hour			Duration of CEJ events	Maximum amplitude, time and day of CEJ events
		0600 LT	0700 LT	0800 LT		
1	January	7 events	6 events	1 event	3-hours	-6.08 nT (0800 LT), 1st January
2	February	9 events	7 events	2 events	3-hours	-10.04 nT (0700 LT), 2nd February
3	March	10 events	9 events	2 events	3-hours	-15.80 nT (0700 LT), 10th March
4	April	12 events	11 events	3 events	3-hours	-11.03 nT (0700 LT), 6th April
5	May	6 events	2 events	No event	2-hours	-4.80 nT (0600 LT), 5th May
6	June	8 events	1 event	No event	2-hours	-3.63 nT (0600 LT), 1st June
7	July	7 events	4 events	1 event	3-hours	-6.10 nT (0700 LT), 30th July
8	August	7 events	6 events	3 events	3-hours	-11.28 nT (0600 LT), 5th August
9	September	9 events	8 events	2 events	3-hours	-8.37 nT (0700 LT), 23rd September
10	October	13 events	8 events	1 event	3-hours	-6.75 nT (0700 LT), 2th October
11	November	4 events	2 events	No event	2-hours	-5.44 nT (0600 LT), 18th November
12	December	6 events	5 events	1 event	3-hours	-4.54 nT (0600 LT), 26th December

Table 3: $DS_q H$ counter electro-jet (DCEJ) events during late morning (0900-1100 LT) period.

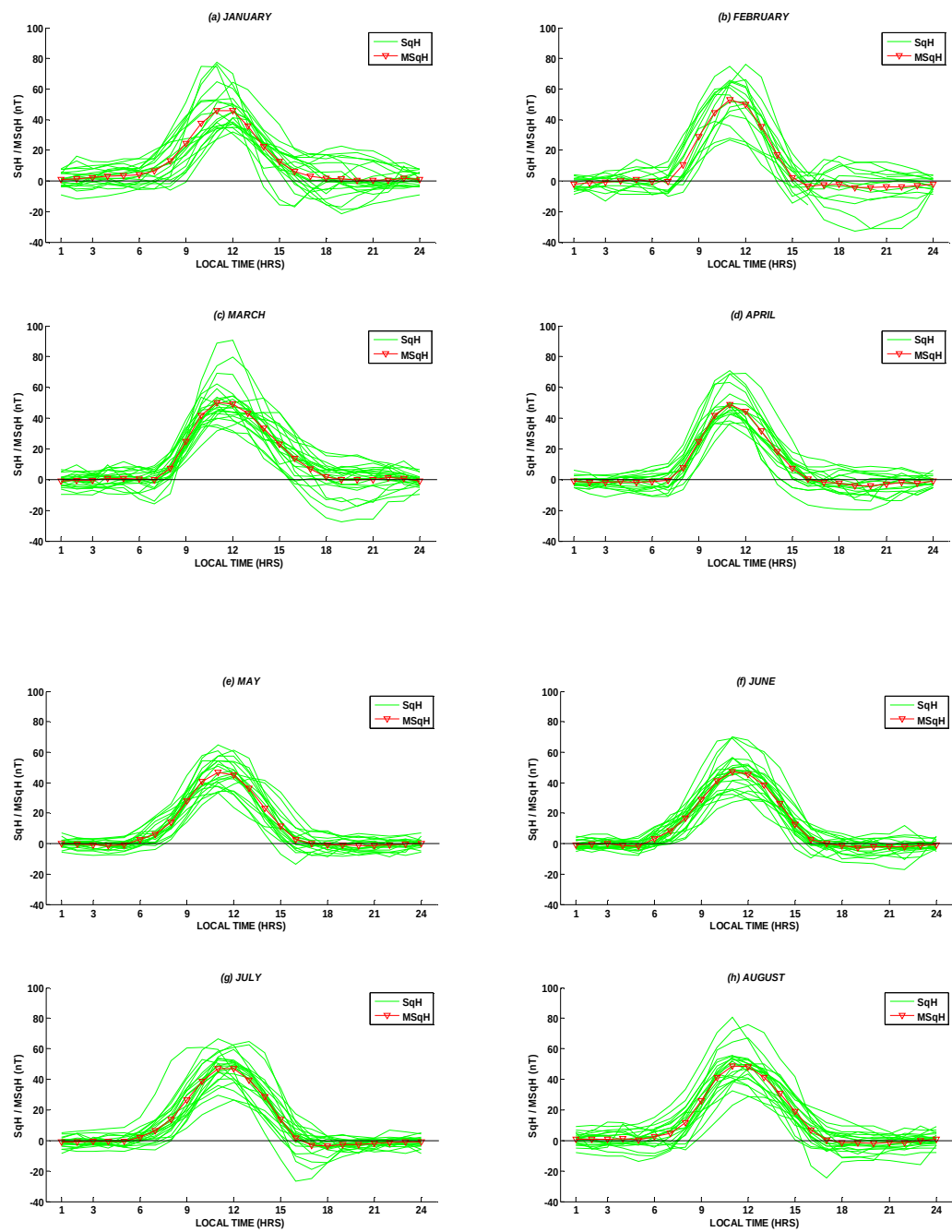
	Months	Time CEJ event begins/number of CEJ event at each hour			Duration of CEJ events	Maximum amplitude, time and day of CEJ events
		0900 LT	1000 LT	1100 LT		
1	January	1 event	No event	No event	1-hour	-0.80 nT (0900 LT), 1st January
2	February	No event	No event	No event	No duration	Nil
3	March	No event	No event	No event	No duration	Nil
4	April	No event	No event	No event	No duration	Nil
5	May	No event	No event	No event	No duration	Nil
6	June	No event	No event	No event	No duration	Nil
7	July	No event	No event	No event	No duration	Nil
8	August	No event	No event	No event	No duration	Nil
9	September	No event	No event	No event	No duration	Nil
10	October	No event	No event	No event	No duration	Nil
11	November	No event	No event	No event	No duration	Nil
12	December	No event	No event	No event	No duration	Nil

Table 4: DS_qH counter electro-jet (DCEJ) events during noon/afternoon (1200-1400 LT) period.

	Months	Time CEJ event begins/number of CEJ event at each hour			Duration of CEJ events	Maximum amplitude, time and day of CEJ events
		1200 LT	1300 LT	1400 LT		
1	January	No event	No event	1 event	1-hour	-3.91 nT (1400 LT), 29th January
2	February	No event	No event	1 event	1-hour	-1.11 nT (1400 LT), 9th February
3	March	No event	No event	No event	No duration	Nil
4	April	No event	No event	1 event	1-hour	-3.15 nT (1400 LT), 7th April
5	May	No event	No event	No event	No duration	Nil
6	June	No event	No event	No event	No duration	Nil
7	July	No event	No event	No event	No duration	Nil
8	August	No event	No event	No event	No duration	Nil
9	September	No event	No event	No event	No duration	Nil
10	October	No event	No event	No event	No duration	Nil
11	November	No event	No event	No event	No duration	Nil
12	December	No event	No event	No event	No duration	Nil

Table 5: DS_qH counter electro-jet (DCEJ) events during evening (1500-1800 LT) period.

	Months	Time CEJ event begins/number of CEJ event at each hour				Duration of CEJ events	Maximum amplitude, time and day of CEJ events
		1500 LT	1600 LT	1700 LT	1800 LT		
1	January	2 events	5 events	9 events	7 events	4-hours	-17.06 nT (1600 LT), 30th January
2	February	6 events	11 events	7 events	8 events	4-hours	-29.37 nT (1800 LT), 23rd February
3	March	No event	4 events	4 events	5 events	3-hours	-24.86 nT (1800 LT), 14th March
4	April	2 events	10 events	12 events	13 events	4-hours	-19.14 nT (1800 LT), 7th April
5	May	1 event	7 events	11 events	13 events	4-hours	-13.57 nT (1600 LT), 9th May
6	June	1 event	7 events	14 events	12 events	4-hours	-12.04 nT (1800 LT), 25th June
7	July	1 event	7 events	13 events	15 events	4- hours	-26.61 nT (1600 LT), 20th July
8	August	No event	4 events	11 events	13 events	3-hours	-24.59 nT (1700 LT), 19th August
9	September	1 event	5 events	10 events	13 events	4-hours	-7.64 nT (1600 LT), 1st September
10	October	No event	3 events	4 events	9 events	3-hours	-16.17 nT (1700 LT), 30th October
11	November	2 events	5 events	9 events	10 events	4-hours	-24.84 nT (1800 LT), 24th November
12	December	3 events	6 events	8 events	10 events	4-hours	-17.75 nT (1800 LT), 18th December



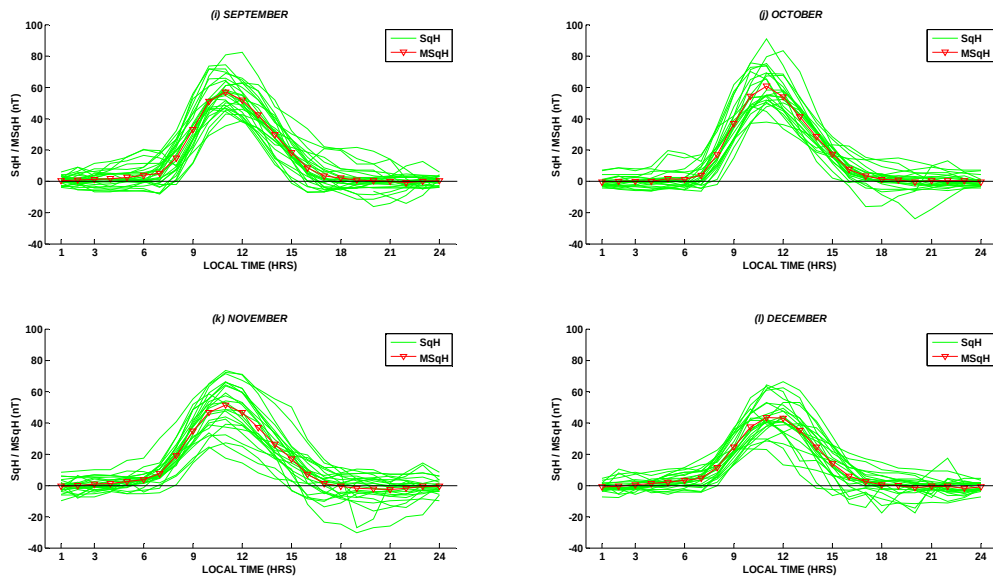


Fig.2: Diurnal and monthly mean variations of S_qH in each month during January-December 2009.

During the daytime hours (Fig. 2 panel a-l), DS_qH variations have a maximum value of ~ 90 nT on March 6, 2009 and a minimum value of ~ 66 nT on December 28, 2009. Also, in Fig. 2 panel a-l, maximum values of MS_qH was observed near noon hours (1100 LT) in all the months with an exception in January. In January, the MS_qH maximum value was observed at midday (1200 LT). A maximum value of about ~ 59 nT was observed during the daytime hours on MS_qH variations in October and a minimum value of ~ 41 nT was observed in January.

The variability of DS_qH and MS_qH variations show that there is no DCEJ event between 1000 LT and 1300 LT simultaneously across all the month (Fig. 2 panel a-l). Further effort that shows that DCEJ event is absent from DS_qH variations around 1000-1300 LT is presented with bar-charts in Fig. 3.0 panel a-l. This effort from Fig. 3.0 shows 7-hours absence of DCEJ events between 0900 LT and 1500 LT in March, August and October, and from 0800 to 1400 LT in May, June and November. The shortest period (4-hours) of DCEJ absence was observed in January (1000-1300 LT). In February and April, no DCEJ event was observed from 0900 LT to 1300 LT (5-hours). The absence of DCEJ event for 5-hours in February and April was observed to have extended to 1400 LT in December (6-hours).

Despite the absence of DCEJ event within this period (1000-1300 LT), DCEJ events were observed during the early morning, late morning, noon/afternoon and evening period over all the month investigated. In all months, DCEJ events in the early morning begin at 0600 LT and were observed for 3-hours (0600-0800 LT) with exception of May, June and November, when DCEJ events were observed for 2-hours (0600-0700 LT). At 0600 LT in all month, the number of DCEJ event is always highest compare to the DCEJ events observed at 0700 LT and 0800 LT. For example, 14 DCEJ events were observed in January, 7 DCEJ events at 0600 LT, 6 DCEJ events at 0700 LT, and 1 DCEJ event at 0800 LT. In the remaining months (February, March, April, July, August, September, October, and December), DCEJ events recorded at 0600 LT are 9, 10, 12, 7, 7, 9, 13 and 6, respectively. In the next hour (0700 LT), DCEJ events were observed to have gradually reduced to 7, 9, 11, 4, 6, 8, 8 and 5 and significantly reduced to 2, 2, 3, 1, 3, 2, 1 and 1 at 0800 LT, in that order (Table 2 and Fig. 3 panel a, b, c, d, g, h, i, j and l). Considering the case when DCEJ events in the early morning were observed for 2-hours (0600-0700 LT), 6, 8 and 4 DCEJ events were recorded at 0600 LT and later reduced significantly at 0700 LT to 2, 1 and 2 events in May, June and November, respectively. A late morning DCEJ event in January begins at 0900 LT and disappears before 1000 LT. There is no record

of DCEJ event from all other months (Table 3 and Fig. 3 panel a-l). During the noon/afternoon (1200-1400 LT) period, 1 DCEJ event with one hour duration (1400 LT) was observed in January, February and April. In other months, no DCEJ event was recorded (Table 4 and Fig. 3 panel a-l).

The DCEJ events were recorded for 4-hours during the evening period (1500-1800 LT) in all months, with the exception of March, August and October, when DCEJ events were recorded for 3-hours (1600-1800 LT). Table 5 shows that 2, 6, 2, 1, 1, 1, 2 and 3 DCEJ events begin at 1500 LT in January, February, April, May, June, July, September, November and December, respectively. At 1600 LT, there are 5, 11, 4, 10, 7, 7, 4, 5, 3, 5 and 6 DCEJ events that were significant with higher amplitude in January-December. As can be seen from our results, a number of DCEJ events around 1800 LT is significantly increasing such that it almost double the DCEJ events recorded during 1400 LT (Table 5 and Fig. 3 panel a-l).

On the examination of DCEJ events on monthly basis (Fig. 3 and Table 2), the number of DCEJ events observed during the evening hours are always higher than the early morning, late morning and noon/afternoon hours. The exceptions to these examinations were observed in March and October. The total numbers of DCEJ events accounted for in the early morning are 21 and 22 in March and October, respectively. Their corresponding number of DCEJ events during the evening hours for March and October are 13 and 16, respectively. The highest number of DCEJ events during the early morning (26) and evening (37) periods was recorded in April. The lowest DCEJ events were seen in November (6) during early morning and March (13) during evening hours (Tables 2, 3, 4, 5 and Fig. 3 panel a-l).

The MS_q CEJ (MCEJ) events cases observed in February, April, June, July and August show few MCEJ events with slight intensity during the evening period. As can be seen from our results, no significant case of MCEJ event was recorded during the early morning, late morning and noon/afternoon period. During the evening period, 1 MCEJ event recorded has slight intensity (SMCEJ) and was observed for 1-hour (1800 LT) in June and August. Also, 2 SMCEJ events were observed for 2-hours (1700-1800 LT) in April and July, and 3 SMCEJ events were observed for 3-hours (1600-1800 LT) in February. The highest magnitude of SMCEJ was observed around 1800 LT in July with a value of ~ -2 nT. Our results show that these observed SMCEJ were fluctuating

around zero, which indicates that their magnitudes are extremely weaker.

As expected, maximum values from S_q of the horizontal magnetic field intensity near noon hours were observed almost on all day throughout the year. These results share similar characteristics with the results of Rastogi [7] and Bolaji et al. [8]. Also, Rastogi and Iyer [36] used American (Huacanyo) and Asian (Trivandrum) geomagnetic horizontal field data and reported that the diurnal variations of the horizontal field at these equatorial stations reached maximum values between 1100 and 1130 LT during low solar activity, and at 1200 LT during high solar activity. They attributed this maximum value near noon hours to an increase in solar dynamo currents driven by winds and thermal tidal motions in the E-region of the ionosphere.

Our results around 1000-1300 LT that depict no record of DCEJ event simultaneously in all months share similar characteristics with the work of Rastogi [7]. Although, our result shows longer period (1-hour) regarding absence of DCEJ events as compared to results reported by Rastogi [7]. He recorded no CEJ event around 1100-1300 LT and reported that it rarely occurs at equatorial stations and could take closer to 6 years to record about 5 CEJ events in a single equatorial station. He further suggested that these absences of CEJ events are commonly observed during a low solar activity year. We therefore suggest a complete absence of westward electric field during this period and increasing dominating strength of the eastward electric field.

The maximum duration of 3 to 4-hours observed from our results during early and late morning DCEJ events contrasts Mayaud [24] results. He reported that CEJ event duration during morning hours at equatorial stations in Africa and India could take 5 to 6 hours and sometimes, lasts for a day. The possible mechanism responsible for this shorter duration during morning hours from our results as compared to that of Mayaud [24] are as follows:

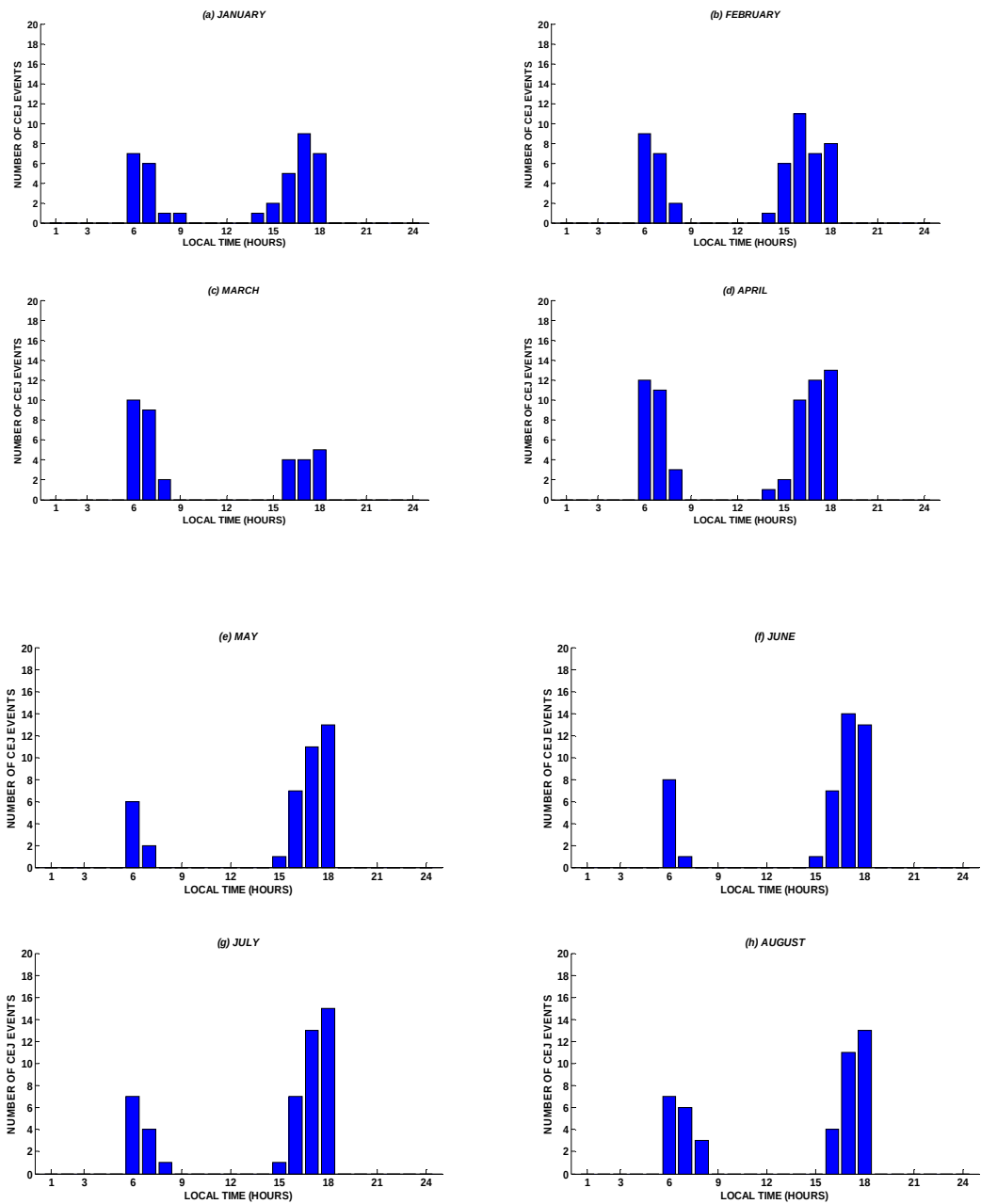
- (1) The DCEJ events observed in the early morning strongly confirm that the westward electric field has higher intensity and reverses late to become an eastward electric field. This higher intensity of westward currents spans from the nighttime through pre-sunrise to sunrise period. Despite that this westward electric field reverses lately, it decays faster during the early morning period. Apart from the late reversal of the westward electric field, a striking sudden generation of DCEJ event was observed between pre-sunrise (0600 LT)

and sunrise (0800 LT) period (PSP). This sudden generated DCEJ event around PSP decays slowly. Comparing sudden generated DCEJ and DCEJ event from late reversal, it is obvious that the magnitude of a sudden generated DCEJ event is considerably higher during the early morning period. For example, sudden generation of DCEJ events have higher magnitudes of -6.08 nT (0800 LT), -10.04 nT (0700 LT), -15.80 nT (0700 LT), -6.10 nT (0700 LT) and -8.37 nT (0700 LT) on the 1st January, 2nd February, 30th March, 30th July, 5th August, and 23rd September, 2009, respectively, as compared to the gradually decaying DCEJ events (Table 2). One of these evidences is obvious during the morning period on 1st January, 2009 when the sudden generated DCEJ event at 0800 LT decays slowly and become insignificant at 0900 LT despite the strongest eastward electric field in-place.

(2) The expected interplay from these aforementioned activities during the early morning is that the EEJ from intense eastward electric field would become wane due to influence of the late reversal of westward electric field that initiated increased CEJ event with significant intensity. However, as can be seen from our results (Fig. 2 panel a-l), DS_qH variations in all months irrespective of the number of DCEJ events coupled with higher intensity during early morning hours rise progressively. This indicates that an enhanced and stronger solar dynamo current driven by winds and thermal tidal motions within the E-region that resulted to eastward currents are becoming stronger during the early morning and strongest when closer to the late morning hours. Hence, the competition in the early morning hour between the late westward electric field and dominating EEJ currents result to reducing DCEJ events and increasing DS_qH variability as one approaches late morning period.

(3) A significant improvement of eastward current was observed during the late morning and noon/afternoon hour in all months coupled with insignificant westward electric field. The insignificant westward electric field initiates a slight DCEJ event observed around 0900 LT on 1st January, 2009 during late morning period. Similar slight DCEJ event was observed on the 29th January, 9th February and 7th April, 2009 around 1400 LT during noon/afternoon period. Otherwise, any occurrence of DCEJ event irrespective of the daytime period indicates that daytime eastward ionospheric currents have been significantly suppressed by stronger narrow band of currents, which are flowing westward.

The number of DCEJ events around 1800 LT that almost double that around 1400 LT indicates that the eastward electric field in-place has significantly subside such that the westward electric field become stronger. It is also evident that the CEJ events results obtained here are more frequent during the evening hours as compared to all other hours investigated. These are in good agreement with existing CEJ results of [17, 20-22]. However, DCEJ events in March and October contrast these results. It is obvious that the westward electric field in March and October in the morning reverses faster to eastward electric field when compared to other months.



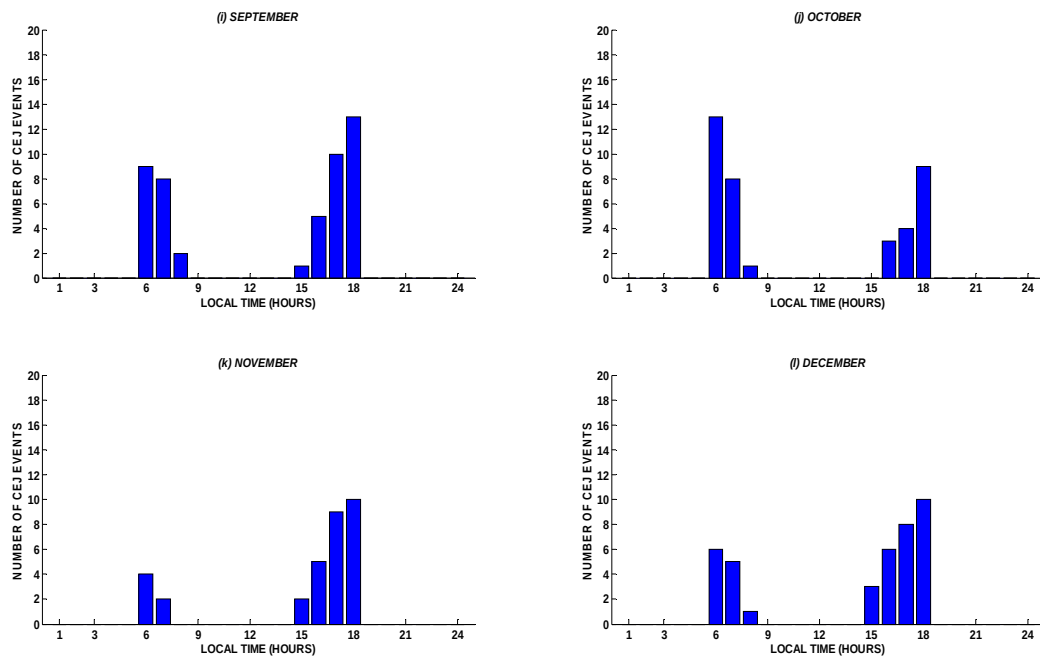


Fig.3: Number of CEJ events and their period of observations during daytime hours from January to December 2009.

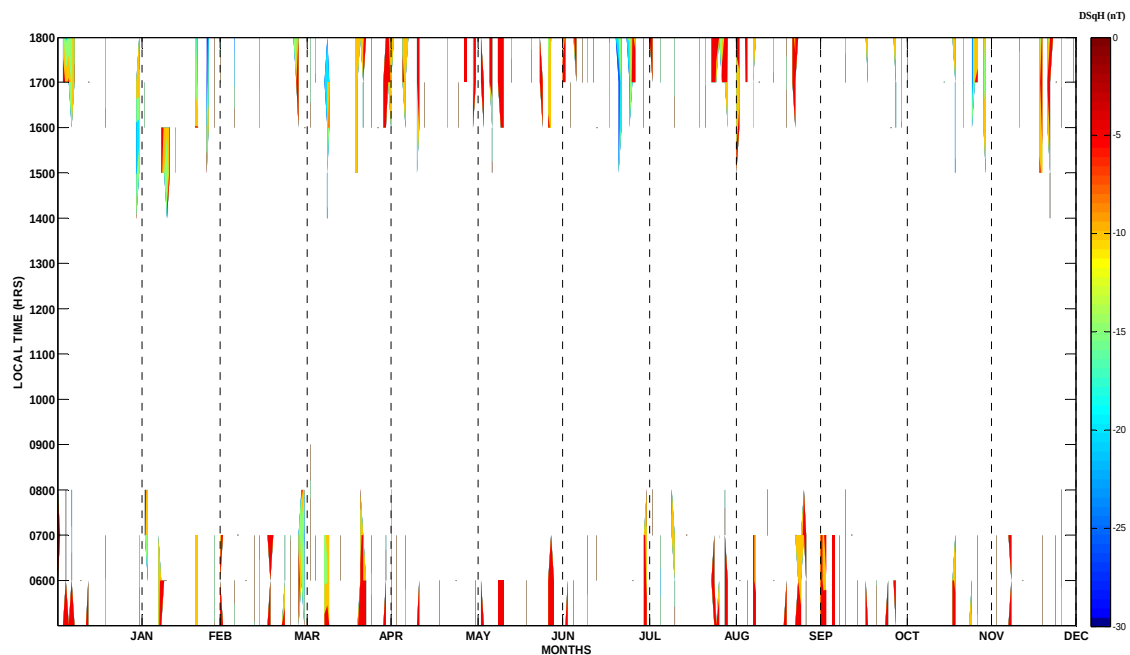


Fig.4: Magnitudes of CEJ from $S_q H$ observations during daytime hours in the year 2009.

The magnitudes of CEJ from $S_q H$ (DCEJ) observations for all the month during daytime hours of the year 2009 are shown with Fig. 4.0. The

color-bar besides the contour plot shows the intensity of the magnitudes. As can be observed from Fig. 4.0 during the early morning period, maximum amplitude of DCEJ events in all months

were observed at 0700 LT with a value of -10.04 nT (February), -15.80 nT (March), -11.03 nT (April), -6.1 nT (July), -8.37 nT (September), and -6.75 nT (October) with exceptions of January, May, June, August, November, and December. One of the exceptional cases (January) shows DCEJ maximum amplitude of -6.08 nT at 0800 LT, which is sudden and extends to 0900 LT before it subsides. This is the reason for the large amplitude of DCEJ observed around 0800 LT. For the remaining exceptional cases: May, June, August, November, and December, DCEJ were observed at 0600 LT with maximum amplitude of -4.80 nT, -3.63 nT, -11.28 nT, -5.44 nT and -4.54 nT, respectively (Table 2 and Fig. 4).

A late morning CEJ event in January at 0900 LT has slight amplitude of -0.80 nT (Table 3 and Fig. 4). During the noon/afternoon (1200-1400 LT) period, 1 DCEJ event was observed in January, February and April with a magnitude of -3.91 nT, -1.11 nT and -3.15 nT, respectively (Table 4 and

Fig. 4). During the evening period (Table 5 and Fig. 4), the maximum amplitudes of DCEJ in February, March, April, June, November and December at 1800 LT is -29.37 nT, -24.86 nT, -19.14 nT, -12.04 nT, -24.84 nT, and -17.75 nT, respectively. DCEJ events with significant amplitudes were also observed at 1600 LT in January (-17.06 nT), May (-13.57 nT), July (-26.61 nT), and September (-7.64 nT). Although, August and October have no record of DCEJ event at 1500 LT, but significant numbers were recorded at 1700 LT and have maximum magnitudes of -24.59 nT and -16.17 nT, respectively.

The results presented here support our earlier results that during the evening period when there is significant increase in the number of DCEJ events, it is obvious that significant increase in DCEJ magnitude in the evening as compared to other period is possible. This is an evidence of superimposed significant westward on the eastward electric field during the evening period.

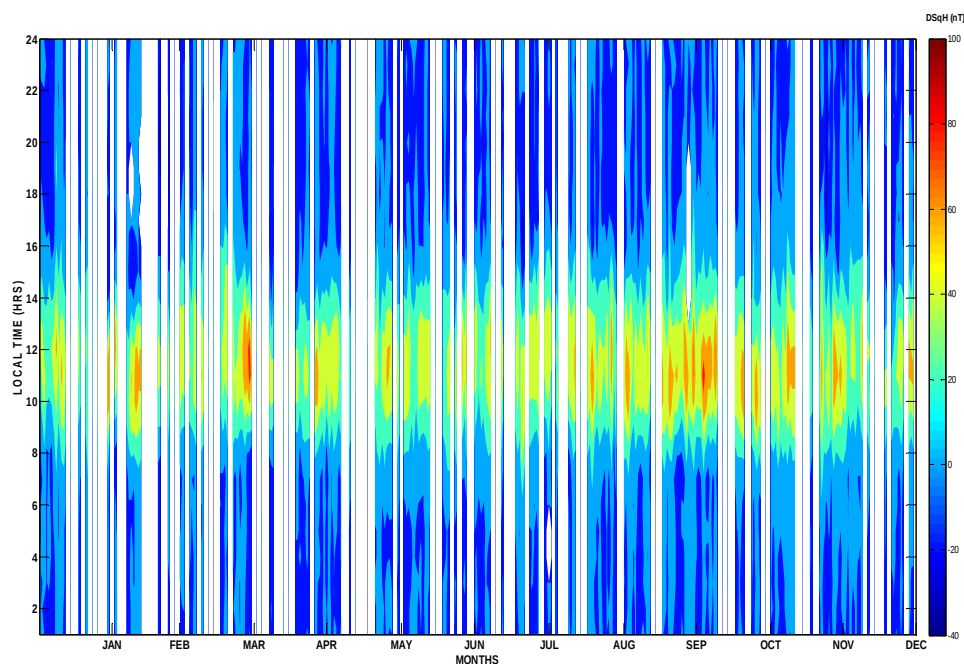


Fig.5: Annual variation of DS_qH for all the month over all hours of the day in the year 2009.

The annual variation of DS_qH is shown with two dimensional plot (Fig. 5) and shows that a maximum value of DS_qH occurs near noon hours (1000-1200 LT). The unfilled (white background) contours in Fig. 5 are as a result of interruptions in the data recording, which are due to inconsistent power supply. From these results (Fig. 5), it was

observed that from night time till the pre-sunrise hours (1900-0500 LT), minimum values of DS_qH with CEJ are observed on most hours of the entire months. The maximum value of DS_qH was seen in March (~ 91 nT), followed by October (~ 90 nT) and the lowest in September (~ 82 nT). Other months also have higher values of DS_qH at peak

period but not as much as those mentioned. The legend color bar besides the contour plot (Fig. 5) shows their magnitude differences. A semi-annual variation was observed in Fig. 5, there are two peaks of maximum values of DS_qH . These two peaks occurred around March and October at 1200 and 1100 LT, respectively. The consequence of a semi-annual variation is from the higher values of DS_qH , which are observed from the equinoctial months (March, April, September, and October) and the lower values observed during December solstice (November, December, January, and February) and June solstice (May, June, July, and August).

Our results reasonably correspond to the previous works of Chapman and Rajarao [25], Onwumechili and Ogbuechi [30], Chandra et al. [26], Campbell [27], Rastogi et al. [28], Rabiou et al. [29], and Bolaji et al. [8] at the equatorial stations. They observed semi-annual variation in their work. It was suggested that the variation of the intensity of EEJ obtained from the horizontal component observations is mainly responsible for the semi-annual variation. Rastogi et al. [28] reported that the semi-annual variation depicts characteristic of EEJ. This indicates that EEJ currents are stronger during equinoctial months compare to December and June solstices.

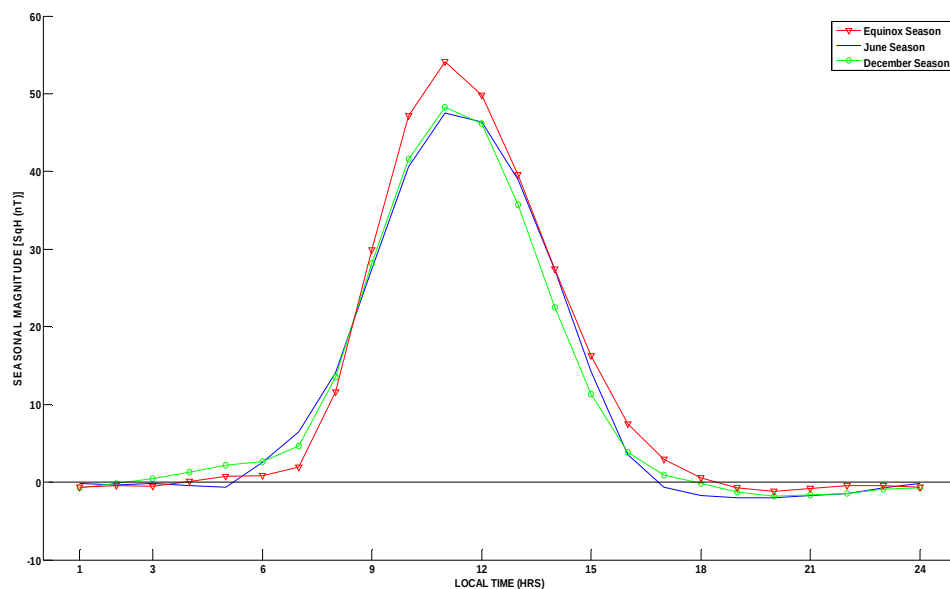


Fig.6: Different seasonal mean of DS_qH variations over Ilorin in year 2009.

The seasonal values maximize at 1100 LT (Fig. 6) with highest magnitude of ~ 54 nT observed during equinoctial months: March, April, September, and October. The solstices December (November, December, January and February) and June (May, June, July and August) magnitudes are lower compare to the equinoctial months. However, December solstice magnitude (48 nT) is greater than that of the June solstice (47 nT). Also, the seasonal variation shows a semi-annual pattern, maximum in equinoctials months and minimum in solstice's months. The possible mechanisms that could be responsible for this pattern have been previously discussed under annual variations on all hours of the day. Despite that, all the DS_qH seasonal variation reached their peak values at the

same period (1100 LT). The highest magnitude seen during the equinox shows that higher intensity of S_qH resulted from higher solar dynamo process. There is no observation of seasonal CEJ in the early morning, late morning and noon/afternoon periods. However, 2 cases of seasonal CEJ in the evening period has minimum range value of about ~ -1 nT to ~ -2 nT around 1700-1800 LT in June solstice. These reduce seasonal CEJ events with slight magnitudes during daytime hours in June solstice are results of higher number of CEJ events in May, June, July and August, which is a sub-division of June solstice.

Similar higher magnitude of S_qH during equinox season as compared to other seasons have

been reported by [8,25-30]. They attributed the equinoctial maximum to intense $S_q H$, which is narrower at the equinoxes. Our results regarding seasonal CEJ are in contrast with the works of RajaRao and Sivaramani [31], Onwumechilli and Alexander [32], Gouin [33], Onwumechilli and Akasofu [15], Gupta [34], Hutton and Oyinloye [13], Rastogi [35], and Mayaud [24]. Our results here show that a higher number of seasonal CEJ events is not reported at Ilorin during afternoon period of December solstice as reported by the above-mentioned researchers. Therefore, we cannot attribute the 2 cases of seasonal CEJ in July from our result to equatorial lunar effects, which cannot be modulated by the new Moon. We therefore suggest that the stronger influence of westward electric field during the evening period in May, June and July plays significant role in the 2 cases of seasonal CEJ reported during the period.

4. Conclusions

This paper investigates the occurrences of counter equatorial electro-jet (CEJ) events at daytime hours over Ilorin (8.47°N, 4.68°E), Nigeria, in the year 2009. The CEJ events are dominant around 0600 LT and 1800 LT when the magnitudes of ionospheric currents are minimal. In all months, CEJ events during the evening period are always higher than those in the morning period with the exception of March and October. This indicates that significant magnitude of westward electric field in March and October in the morning period is higher as compared to other months. Our results contrast that of Mayaud [24] because maximum duration of CEJ event observed here did not exceed 4-hours. In the same vein, the 2 cases of seasonal CEJ events were observed in June solstice and not in December solstice as reported. The reason could be that the year we investigated is a deep minimum year. Therefore, comparison of these results with other stations during a year of deep minimum to unveil if higher seasonal CEJ at any longitude will be found in December solstice and if the duration of CEJ event will exceed 4-hours in a day will be considered as the topic of a future.

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