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Study of Equatorial Electrojet using Chain of Stations along the Dip Equator

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STUDYOFEQUATORIALELECTROJETUSINGCHAINOFSTATIONSALONGTHEDIPEQUATOR

Strictly as per the compliance and regulations of:

Study of Equatorial Electrojet using Chain of Stations along the Dip Equator

G. A. Agbo [α], A. C. Onugwu [σ] & E. A. Ibanga [ρ]

Abstract- This study examined Equatorial electrojet (EEJ) in four longitudinal zones namely; Addis-ababa (AAE) in East African sector, Huancayo (HUA) in South America, M'boh (MBO) in West African sector and Guam (GUA) in Pacific Ocean. The study shows that EEJ is higher in the South American Sector than any of the longitudinal sectors studied. It was interestingly shown that all the stations had their peaks in the noontime. These results suggest that in the entire longitudinal sectors the EEJ has its maximum in the noontime. The result also shows that EEJ is mostly observed during March and April, reduces in strength in the months of May, June, July, August and resurfaces again between September and October. Seasonal variation shows that the E-season is higher than D-season and J-season in all the stations studied.

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I. Introduction

Dip equator is a region with utmost importance due to its complex nature that is associated in this area. This is due to the parallel flow of the magnetic field lines through the region unlike the other parts. It was discovered that current flowing through the dip equator is responsible for the changes that occur in the area; the name given to such current is known as equatorial electrojet (EEJ) (Chapman, 1951; Onwumechili, 1997). The flow of ions and electrons inside the ionosphere and magnetosphere forms the current systems which cause variation in the intensity of the earth's magnetic field that has effects on the earth where human being depends for survival. The ionosphere can be defined as the ionized layer of the atmosphere, comprising free electrons and positive ions, generally in equal numbers, in a medium that is electrically neutral, Agbo (2008). Most importantly the ionosphere influences the propagation of radio wave signals through it; as such the study of EEJ is significant in radio wave propagation through the equatorial region.

Many researchers have used data from different areas to study the intensities of EEJ; for instance, Stewart, (1989) used POGO Satellite data to determine the time and longitudinal variations of the intensities of the EEJ. The study carried out by (Furbush and Casaverde, 1961) had shown the relationship between the vertical drift velocity of day time E×B in the ionospheric region and the day time strength of the EEJ (Rabiu, *et al*., 2007). The existence of seasonal variation in EEJ intensities has also been widely reported in several longitude sectors using both ground and satellite based measurements (Rabiu, *et al*., 2017).

On the other hand, previous studies on longitudinal dependence of EEJ tend to focus their analysis in a certain sector or area for instance Okeke, *et al.,*(1998) and Alex, *et al*., (1992) which compared east and west coast of South American sector. Despite previous researches, some characteristics of the EEJ still remain to be investigated. Such research gaps led to an open and pending question such as; the seasonal variation of EEJ current in the dip equator as changes occur during the flow of current along the equator, the relative magnitudes of EEJ at the different stations along the chain of stations under the study, the monthly variation of EEJ current along the dip equator. All these motivated the current study. Although the longitudinal variation of EEJ has been studied by Bolagi, *et al.,* (2013) but did not subtract the contributions of the global Sq from their EEJ magnetic effect due to the absence of dip equator station at certain longitudinal sectors.

II. Materials and Methods

The dataset used in this study consists of the hourly mean values of the geomagnetic field horizontal component from four observatories. The observatories data were made available by Geomagnetic data service-World Data Center-kyoto, Japan. The observatories used are Huancayo (HUA), Fuquene (FUQ), M'Bour (MBO), Guimar (GUI). The distribution of the geomagnetic observatories used for the dissertation is shown in figure 1.

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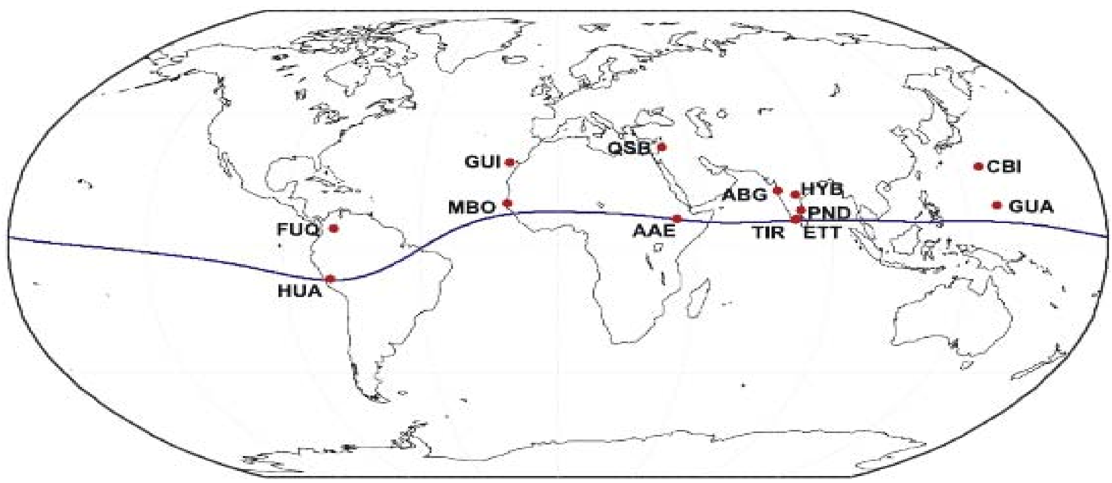

Figure 1: Distribution of the geomagnetic stations used for the study. The dip equator is represented by the blue line

In recent years most of these observatories have problems ranging from instrument failure to weather effects. As a result record data were no longer consistent. The year, 2011 were observed to contains data of all the stations used hence 2011 is taken as the year of study and therein referred to as year of interest. These stations include the four observatories within the influence of EEJ which are HUA, MBO, AAE, GUA and four observatories outside the EEJ influence which are; FUQ, GUI, HER, CBI. This means that we have four pairs of observatories for the purpose of this study. The reason for this is to obtain the EEJ indices of the geomagnetic element.

The table 1 shows the names, code, geographic and altitudes of the stations that were used in the study.

Table 1: Geographic and Geomagnetic Locations of the Observatories Used in the study

			Geographic	Geographic	Geomagnetic	Geomagnetic	
	Station	code	Latitude	Longitude	Latitude	Longitude	Dip Latitude
1	Fuquene	FUQ	5.47	286.27	15.92	357.77	17.06
2	M'Bour	MBO	14.39	343.04	20.26	57.32	4.59
3	Guimar	GUI	28.32	343.56	33.91	60.49	23.04
4	Addis Ababa	AAE	9.02	38.77	5.23	111.57	0.95
5	Guam	GUM	13.58	144.87	5.1	215.43	6.19
6	Chichijima	CBI	27.1	142.18	18.28	211.39	20.79
7	Huancayo	HUA	12.04	284.67	2.23	356.32	0.59
8	Hermanus	HER	34	38.28	34.121	108.43	7.34

a) *Data Treatment*

Geomagnetic data values were not reported in all the days of the months and at all the stations due to some certain factors. This means that the geomagnetic data is not a continuous data set. The cause of this discrepancy might be battery discharges and also meteorological factors. This technical problem takes time to be corrected and thus this prompted our selection of data used in this work. The 2011 is chosen because it has recorded H, hourly mean values from January to December in all the four pairs of stations used.

b) *Base line values*

The geosciences (upper atmospheric) researches have challenge on the data in respect of geomagnetic quiet day, but according to Onwumechili, the night time values have been favoured because ionospheric E-region which provide the dynamo current is absent at night (Onwumechili, 1997). For this reason, the midnight values or mean between the proceeding and subsequent midnight values are taken as the zero reference which is also called the base line for the diurnal variations. So we define our base line as the average of the four hours flanking the local midnight (23, 24, 01, 02 hours).

Therefore the daily baseline value of the geomagnetic field component, H, used in this work is

$$H_0 = \frac{H_{23}+H_{24}+H_{01}+H_{02}}{4} \quad (1)$$

Where H_{01}, H_{02}, H_{23} and H_{24} are the hour values of H at 01, 02, 23 and 24 LT (hrs) respectively.

c) *Midnight departure*

The hourly departure of H from midnight baseline is obtained by subtracting the midnight baseline values for a particular day from the hourly values for that particular day. Therefore, for time "t" in hours (local time, LT)

$$\Delta H_t = H_t - H_0 \quad (2)$$

Where t = 01, 02, ... 24 (hours).

d) *Correction for non-cyclic variation*

A process whereby the values of ΔH at 01:00 LT is different from the values of ΔH at 24:00 LT is called non-cyclic variation. This is in accordance with (Okeke, *et al*., 1998) and Rabiu (2000). Then the hourly departure is further corrected for the above reason. This is done by making linear adjustment in the daily hourly values of ΔH. $V_1, V_2, \ldots V_{24}$. A way of achieving this is to consider the hourly departure values of ΔH at 01 LT, 02, ... 24 LT such that

$$\Delta = \frac{V_{01} - V_{24}}{23} \quad (3)$$

Then the linearly adjusted values at these hours are:

$$V_1 + 0\Delta,\ V_2 + 1\Delta,\ V_3 + 2\Delta \ldots V_{23} + 22\Delta,\ V_{24} + 23\Delta \quad (4)$$

The hourly departure corrected for non- cyclic variation gives the solar quiet daily variation of H.

e) *Estimating EEJ strength*

Consider observation point A (Figure 2) within EEJ strip and another observation point B outside the influence of EEJ or outside the EEJ strips. A is under EEJ + Sq but B is only under Sq. Therefore, the EEJ at A is

$$\text{EEJ at A} = Sq_A - Sq_B \quad (5)$$

One should note that the point of station must be along or very close to the same meridian.
This is illustrated in figure 2.

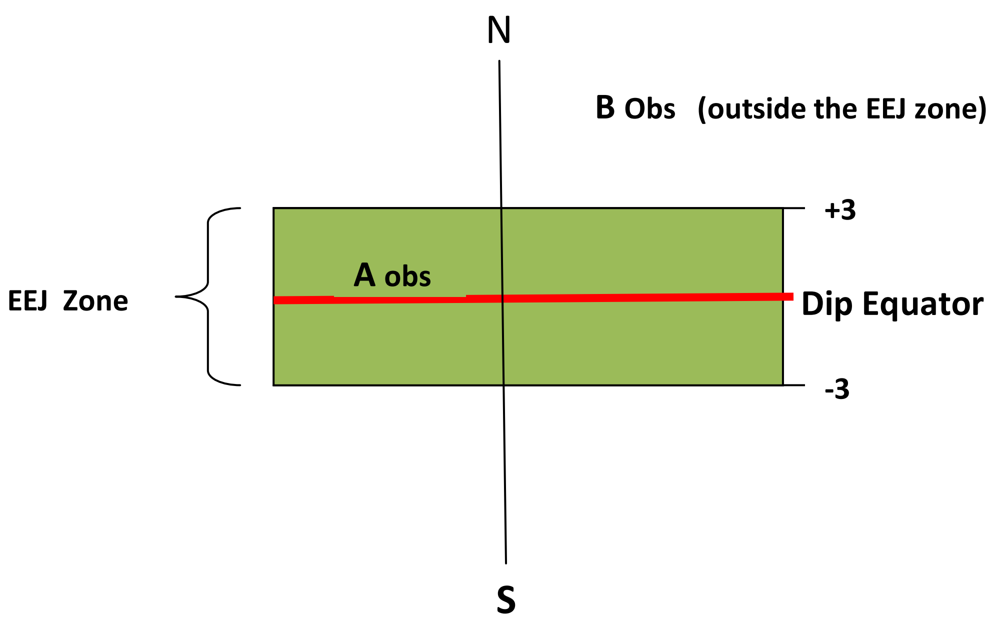

Figure 2: Illustration on how to get EEJ current from solar quiet current

III. Results and Discussion

In this part, we present the results of EEJ current in the chain of stations along the dip equator. We used the recorded geomagnetic component of H, which were obtained from the observatories located along the magnetic dip equator. In chapter three, we pointed out that data passed through different processing stages. Now, we present the results obtained at each of the stages. Due to the volume of data involved we present some as a sample for the year 2011. Some of the values are even approximated to the nearest whole numbers or closest decimal places so as to fit into the tables.

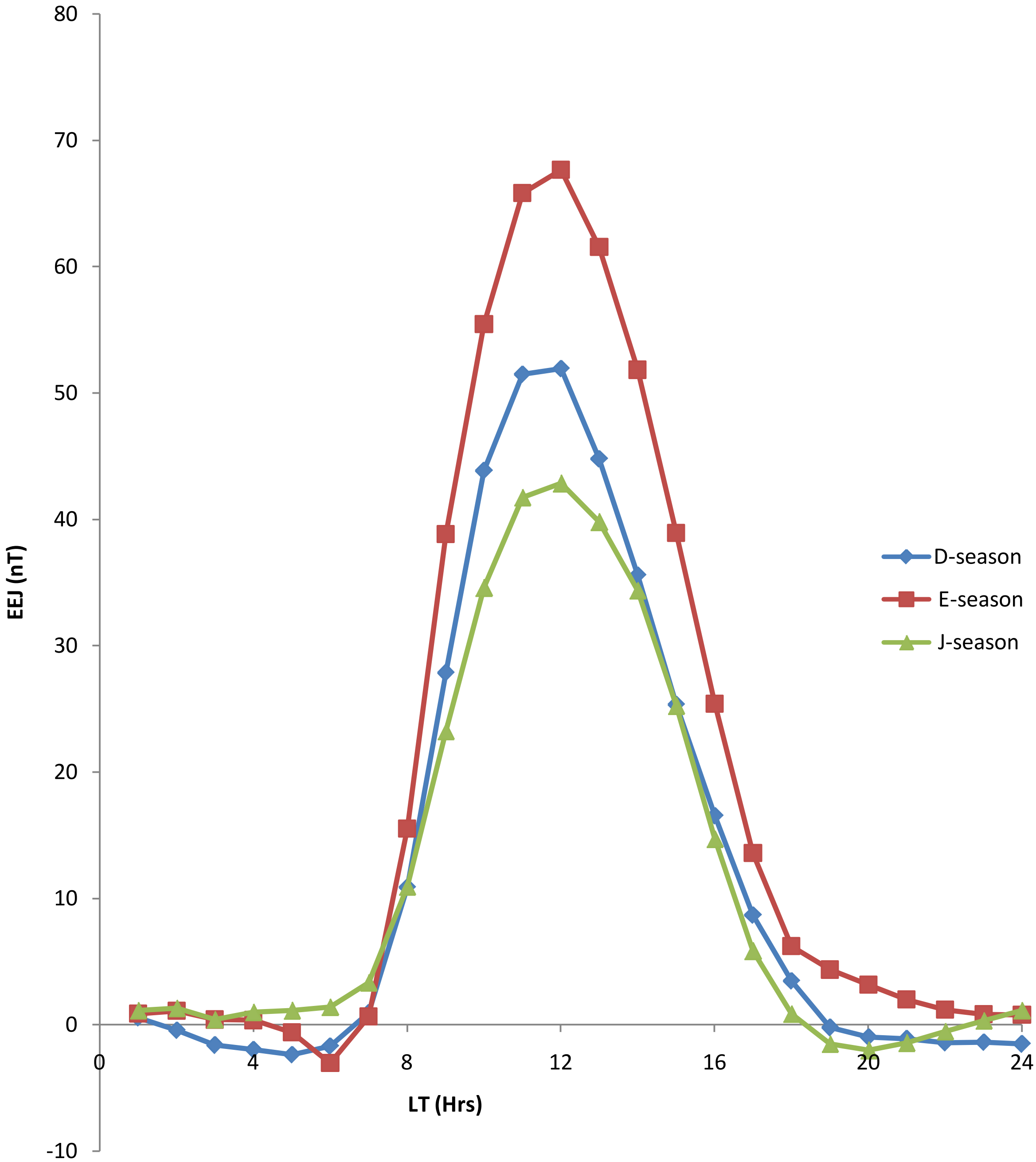

Figure 2: Seasonal variations of EEJ with time in 2011

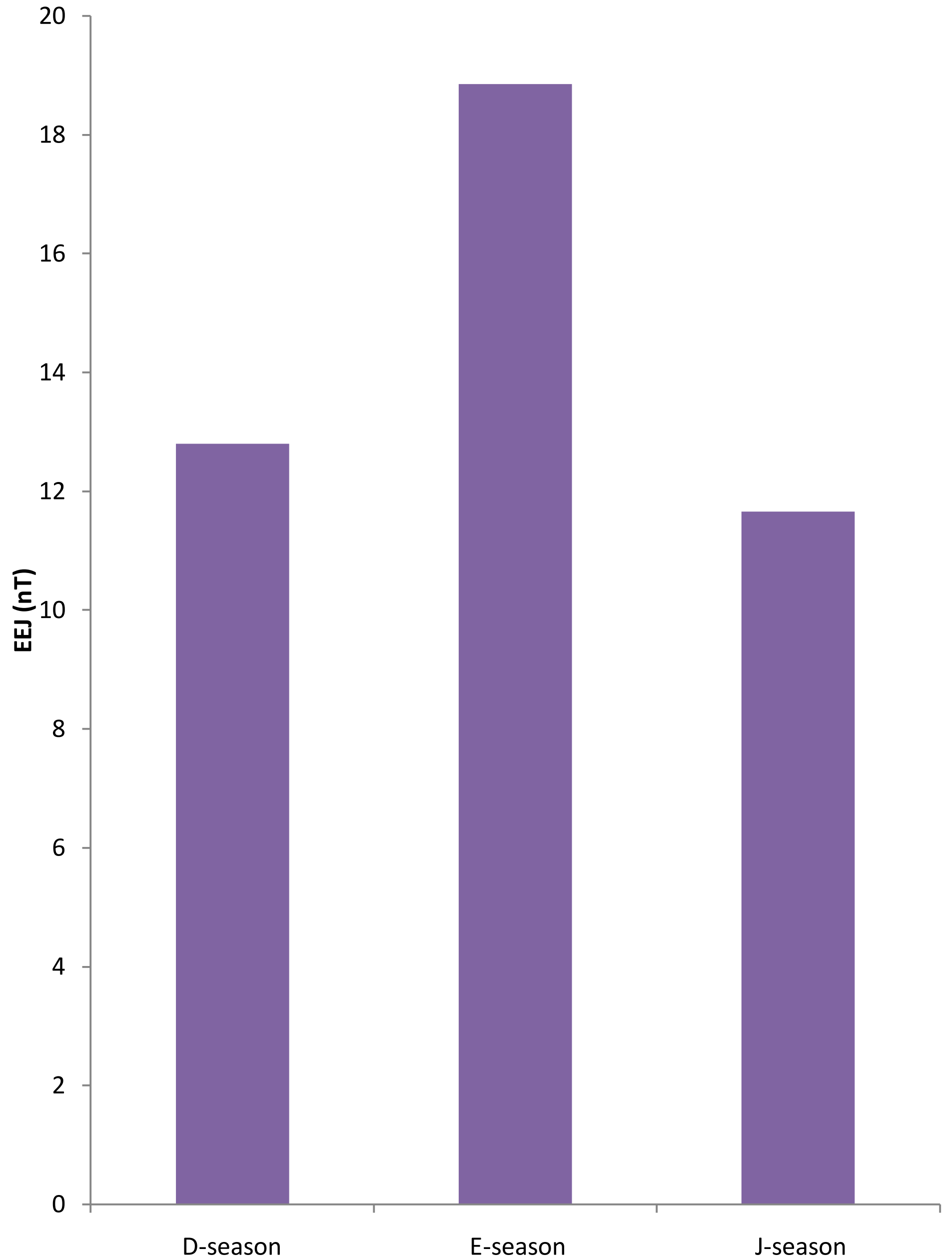

Figure 3: Seasonal variations of EEJ in 2011

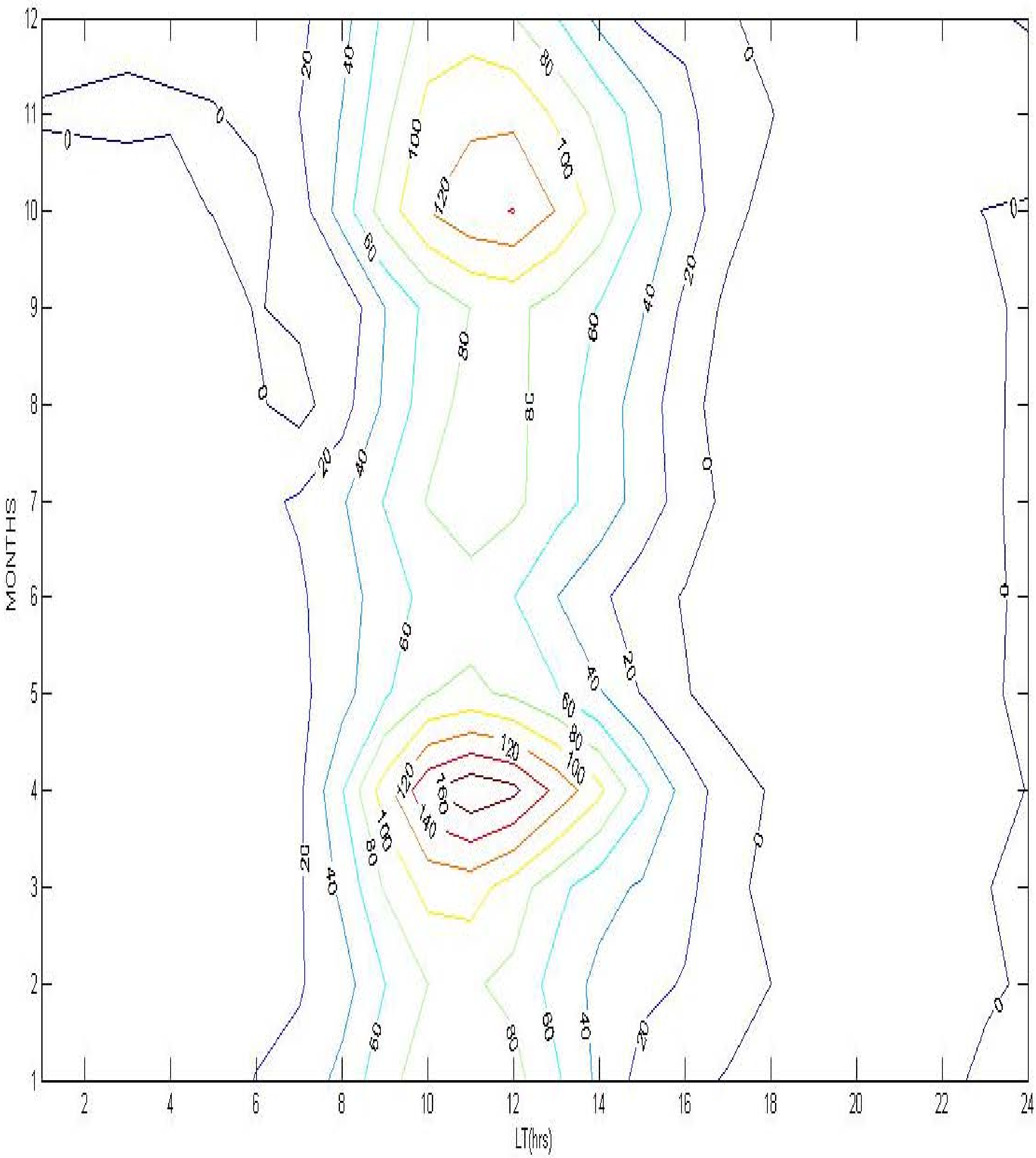

Figure 4: Contour plot of the EEJ current at HUA station in 2011

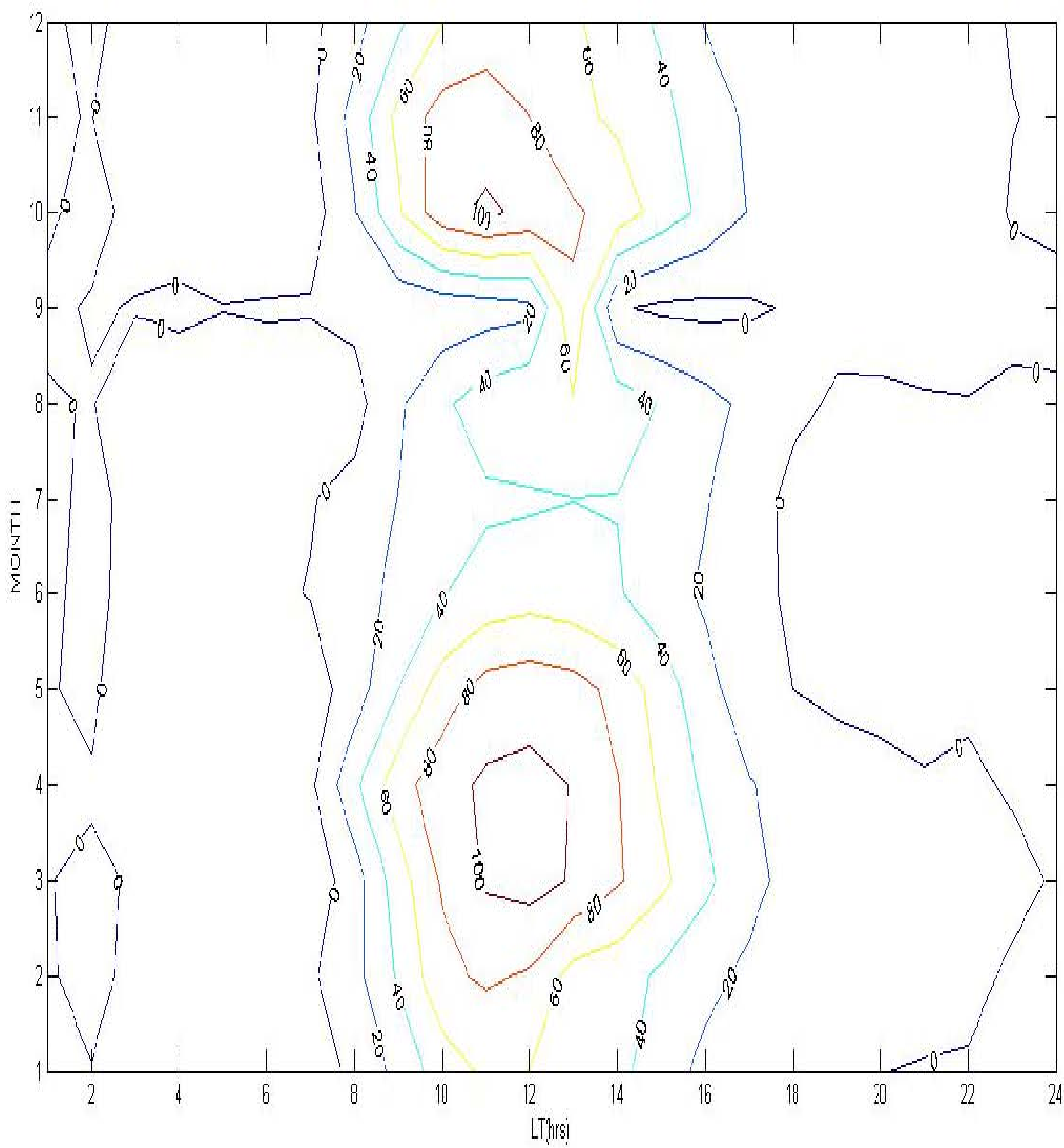

Figure 5: Contour plot of the EEJ current at AAE station in 2011

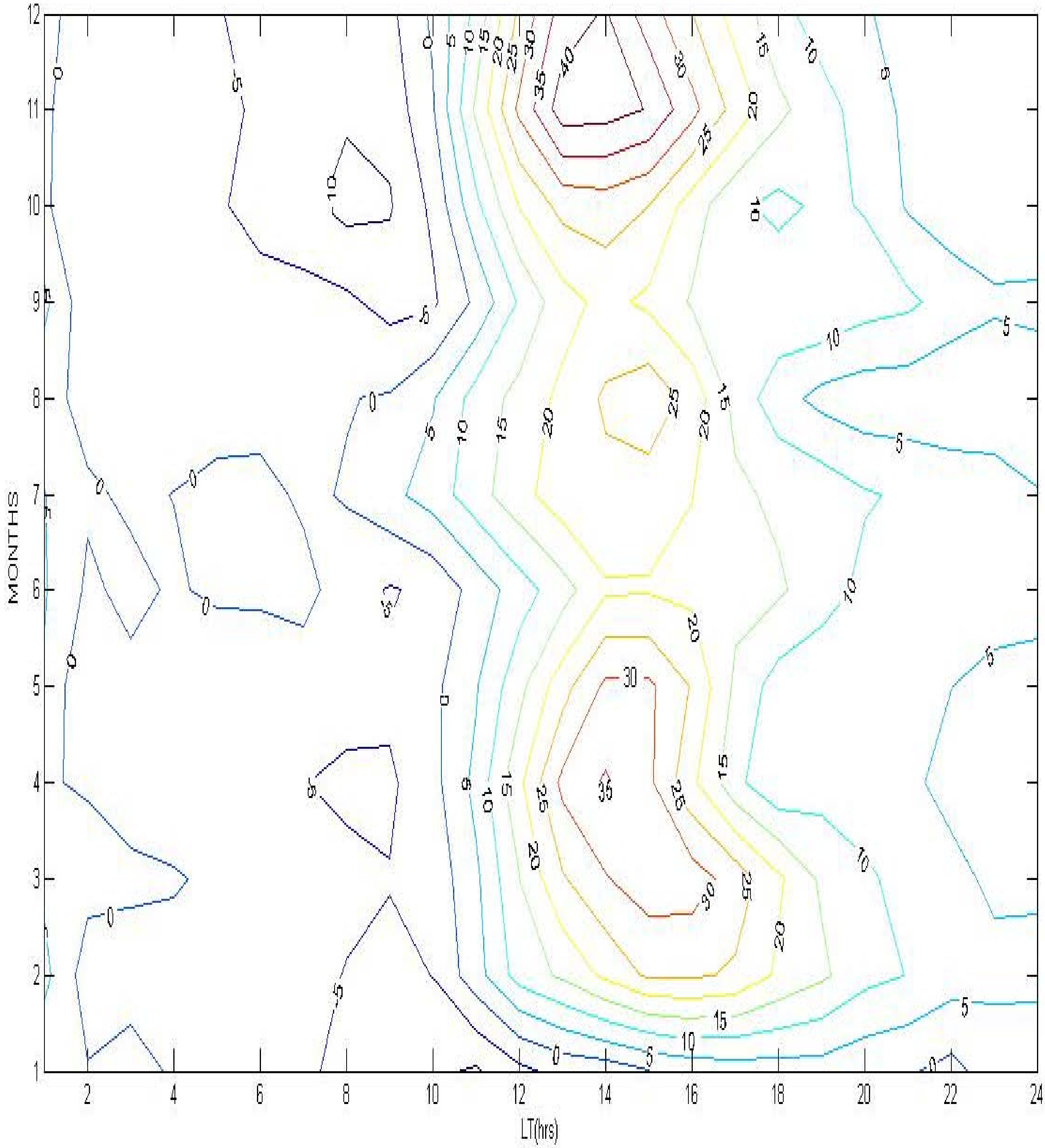

Figure 6: Contour plot of the EEJ current at MBO station in 2011

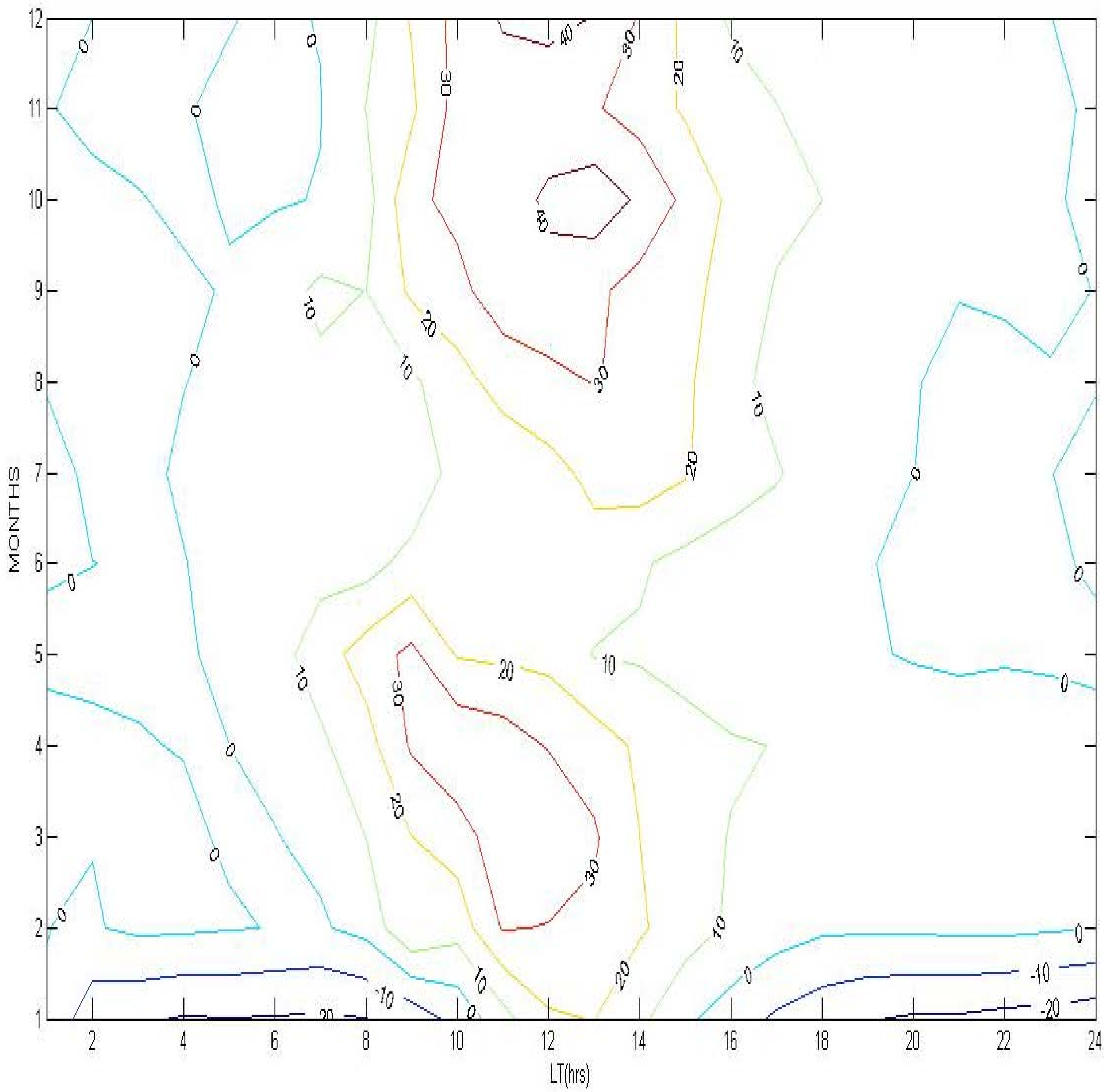

Figure 7: Contour plot of the EEJ current at GUA station in 2011

a) Seasonal variation of EEJ in 2011

The mean variations for different seasons are studied. Figure 17 shows the annual seasonal variation of EEJ. The amplitude of EEJ was highest in E-season with values of about 70 nT. This was followed by D-season with about 50 nT, and finally the J-season with about 40 nT. All the seasons peak at about the noontime. This was illustrated using bar chart as in Figure 3. One can infer from the above that the EEJ was stronger in the E-Season compared to the other remaining seasons.

b) Contour of the EEJ current at HUA station 2011

The contour diagram in Figure 4 shows the annual variation of the monthly values of EEJ plotted as a function of local time (LT) for the year 2011.The variation is plotted using the EEJ values from January to December, 2011 over all the hours in HUA. From the contour diagram of Figure 4, it was noticed that the line gap used at HUA station shows a difference of 20 nT from each other. An interesting thing here is that the flow of EEJ at the station is similar to the field surrounding a bar magnet. But here, it was shown clearly that the flow of the current was between 05.00LT and 17.00LT.

As the time approaches local noon, the intensity of the current increases such that the maximum values of EEJ were observed between 10.00LT and 12.00LT at the station. In most hours of the entire months, it was observed that from night time till pre-sunrise hours there was a record of minimum values of EEJ which represented the westward current named counter electrojet (CEJ). The maximum values of EEJ at peak period form two closed loops where EEJ were much enhanced with values between 120 nT and 160 nT at about 12.00LT in October and April. The maximum EEJ values were seen in April with values of about 160 nT, followed by October with 120 nT. Other months have high values of EEJ at peak period but not as much as those mentioned. This indicates that EEJ are enhanced during the months of April and October compared to other months in 2011 at HUA station.

c) Contour plot of the EEJ current at AAE station in 2011

The contour plot in Figure 5 shows the monthly variation of EEJ plotted as a function of local time (LT) in the 2011. The values of EEJ from January to December 2011 were used for the study over all the hours at AAE station. It was clearly noticed that in the contour diagram of Figure 5, the line difference of 20 nT from each contour line were used. The flow of EEJ at AAE station shows a similar display like that of HUA but the HUA station was more intense compared to AAE showing that the EEJ had more effect at the HUA than AAE. Notwithstanding, the flow of the EEJ at AAE was between 08.00LT and 16.00LT as shown.

The rate of the flow of the current was shown to increase as it was approaching the peak at the station under discussion. It was observed that throughout the night time till pre-sunrise hours, the minimum values of EEJ current were observed on the most hours of the entire months. As the currents flow, they formed two closed loop during the peak time within the months of March, April and May at the first loop and September, October and November at the second loop. These months were shown to record high flow of EEJ current which varies from about 80 nT to 100 nT around 11:00 LT and 12:00 LT.

The maximum EEJ values were seen in April with about 100 nT, and also in October the values of EEJ reappeared again to the values of about 100 nT. Another months that recorded high values of EEJ at AAE station were March and September. It was clearly shown that within the months of the higher enhanced EEJ current varies from about 80 nT to 100 nT around 11.00LT and 12.00LT. The maximum EEJ values were seen in October and April with 100nT in each month, follow by September and March with 80nT in each month. Though, other months had high values of EEJ at peak period but not as much as those months mentioned. Hence, at AAE station the EEJ are enhanced during the months of October, April, March and September compare to other months in 2011.

d) Contour variation of the EEJ current at MBO station

The contour plot in Figure 6 shows the monthly variation of EEJ plotted as a function of local time (LT) in 2011. The values of EEJ obtained from January to December were employed for the study over all the hours at MBO station. Unlike the HUA and AAE stations, the line difference of 5 nT from each contour line were used as shown in Figure 6. It was noticed that the flow of EEJ varies from 11.00LT to 18.00LT.

The variation of EEJ became more intense as it approaches the peak. At about 14.00LT which is the peak hour at MBO station, the variation forms three loops of current, though two was more intense than the third one. Unlike the HUA and AAE that peaked about local noontime, the MBO station peaked at 14.00LT. The difference in time of peak might be due to the influence of dynamical forcing and tides which are generated in the lower atmosphere and grow in amplitude as they propagate upward. The maximum values of EEJ were noticed in November with 40 nT of EEJ, followed by April with 35 nT. Notwithstanding, other months have high values of EEJ at peak period but not as much as the mentioned months. This means that at MBO station the EEJ current are enhanced during the months of November and April compare to other months.

e) Contour of the EEJ current at GUA station in 2011

The contour diagram in Figure 7 shows the variation of the monthly values of EEJ plotted as a function of local time (LT) for the year 2011. The variation is plotted using the EEJ values from January to December, 2011 over all the hours of the GUA station. The line gap used at GUA station shows a difference of 10 nT from each other as clearly shown in Figure 7. The flow of EEJ was between 10.00LT and 14.00LT. As the peak hour was approaching, the flow of the current became intense such that at the peak time, the current forms two close loops at the months of high enhancement of the EEJ current. The maximum values of EEJ were observed at peak period in October with about 40 nT, follow by April, March and September with 30 nT at each month. It was clear that other months have high values of EEJ at peak period but not as much as those mentioned. This means that at GUA station, EEJ current are enhanced during the month of April, March, October and September compared to other months in 2011.

IV. Conclusion

The present study has yielded some new observational results on the variations of EEJ current. Data of hourly profiles of 60 quiet days from four stations (Huancayo; HUA), (Addis Ababa; AAE), (Mbor; MBO) and (Guam; GUA) within the Equatorial electrojet sectors were analysed for its monthly and seasonal variability as well. EEJ is found to be stronger on the South America than on the African sector irrespective of solar intensity condition in Africa. During local mid night EEJ are at times assumed to be almost in a straight line but not always. CEJ is a local phenomenon because it does not occur in all the station at the same time. Based on Lloyd pseason, EEJ is strongest during equinox which is E season than D and J season. Most of the stations observed counter electrojet in the morning period and some times during evening time. It therefore suggested that it may be due to the late reversal of the westward night time electric field to its day time. The seasonal variation is attributed to seasonal shift in the mean position of the EEJ current system and the electrodynamics effect of local winds. April recorded the highest value of EEJ at the HUA station in the year of interest with about 160 nT EEJ current. The annual mean of the EEJ amplitude in HUA station is higher in 2011 than any other stations while the MBO station is the least.

We are recommending further study on the; Night time enhancement of EEJ. The effect of EEJ in radio wave propagation through the equatorial region.

V. Acknowledgments

The authors wish to express their gratitude to World Data Center (WDC) Kyoto Japan for making available hourly mean values of observatories used in this work. We wish also to acknowledge all the authors whose works were cited in this work.

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