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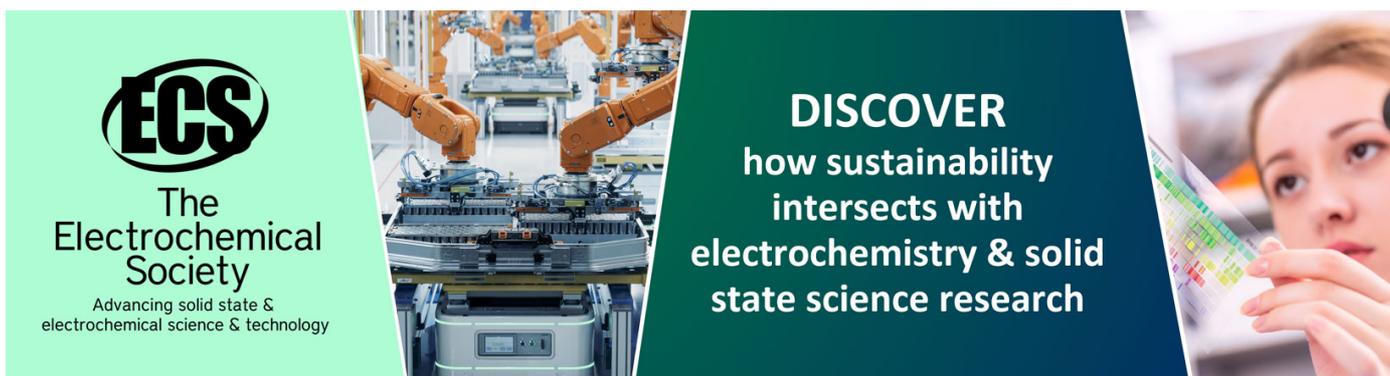
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# Longitudinal Variation of EEJ Current during Different Phases of Solar Cycle

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**Abstract** - The equatorial electrojet (EEJ) is an eastward current flow around the dip equator in E-region of the ionosphere within the range of 90 to 120 km altitude. The longitudinal variation of EEJ was studied using the ground-based measurement from six different longitudinal sectors. The ground magnetometer data were provided by magnetometer networks such as those from Magnetic Data Acquisition System (MAGDAS) /Circum-pan Pacific Magnetometer Network (CPMN), Indian Institute of Geomagnetism (IIG) and International Real-time Magnetic Observatory Network (INTERMAGNET). The EUEL index used in this study was calculated from geomagnetic northward H component. The H-component was normalized to the dip equator using the CM4 model. This study present results of the longitudinal variation of EEJ during the three phases of solar cycle 24: solar minimum (2008), inclination phase (2011) and solar maximum (2014). Results show that EEJ current is higher in the American sector and lowest between African and Indian sector in 2008 and 2011. On the other hand, during the year of solar maximum, this current component is comparable in American and Southeast Asian sector.

## 1. Introduction

Ionospheric current at E layer at the altitude of 90-120km consist of two main current which is the Equatorial Electrojet (EEJ ) and Solar-quiet (Sq) currents. The former is driven by the eastward electric field that generated by local winds [1] within the latitude of  $\pm 3^\circ$  at dip equator. On the other hand, Sq current is a global current system that flows counter-clockwise in Northern hemisphere and clockwise in the Southern hemisphere [2]. Both current overlap at the dip equator which give the total current that affects the ground-based magnetometer measurement. Previous studies carried out using satellite measurement found out that both EEJ and Sq vary with longitude [3,4]. Another approached by previous study using ground-based magnetometer by [5] where the EEJ current is stronger in South America at longitude  $77^\circ\text{W}$  and weakest in India between longitude  $70^\circ\text{E}$  and  $90^\circ\text{E}$ . However, their study does not use the normalization technique and their results might contain some uncertainty in order to get the longitudinal profile. A study by [6] found EEJ to be higher at about longitude  $93^\circ$  than longitude  $77^\circ$ . They use normalization of the ratio of the range of Sq at off-dip equator station for 10 quiet days. Their longitudinal profile is limited to 10 months data and focused on Indian region only. The longitudinal variation of EEJ was also studied by [7] using the simultaneous data during solar minimum. The present study adopts the technique of [8] to investigate the longitudinal variability of EEJ during different phases of solar cycle 24.



## 2. Method and analysis

We are using the EUEL index that was derived from the northward component. In order to calculate the EUEL index, the median value of the northward component  $H$  is subtracted from the original data to obtain  $E_r$ . The equatorial disturbance in storm time ( $EDst$ ) is subtracted from the  $E_r$  to get the EUEL index. The  $EDst$  index represents the magnetic disturbance at the equatorial region particularly from ring current and sudden storm commencement (SSC) [8,9]. In order to avoid the latitudinal variation effect at off-dip equator stations, we subtracting  $EDst * \cos(\varphi)$  where  $\varphi$  is the geomagnetic latitude of station [10]. This technique is to ensures that the EUEL index are free from any part of magnetosphere disturbances.

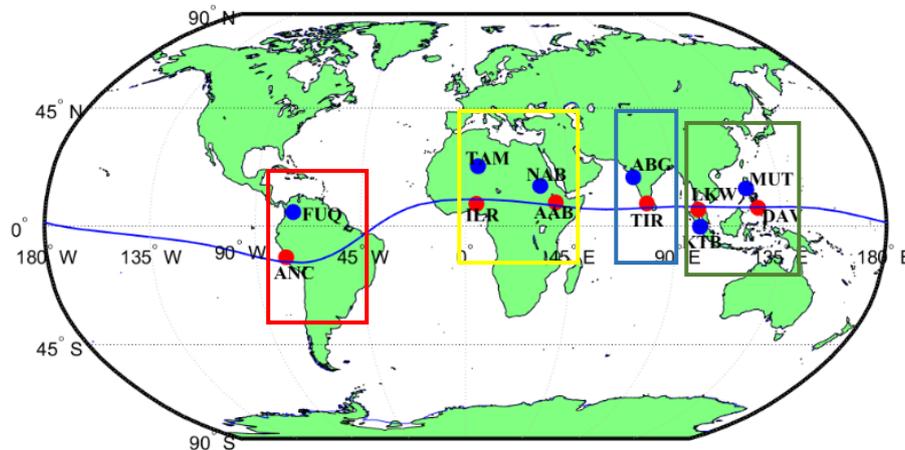
The magnetometer data was taken from the six longitude region that located at South American sector, Indian sector and Southeast Asian sector. The station pairs are including the station located at dip equator and off-dip equator. The station pair includes ANC-FUQ at South America sector, TAM-ILR and AAB-NAB located at Africa, TIR-ABG located at Indian sector, while DAV-MUT and LKW-KTB located at Southeast Asian sector. Station details are presented in Table 1 and location of the observatory stations used are illustrated in Figure 1. We analysis data period to cover the three phases of solar cycle 24: 2008 (solar minimum), 2011 (inclination phase) and 2014 (solar maximum). Figure 2 is the P parameter that shows the solar activity level from the year 2005 until 2015. In order to avoid counter electrojet effect (CEJ) we consider data at noontime for selected days with  $Kp < 3$  are taken. The same normalization technique from [7,8] is applied. The difference between EUEL of total current and EUEL Sq current will get the EEJ current, as shown in this formula:

$$EEJ = EUEL_{total\ current} - EUEL_{Sq\ current} \quad (1)$$

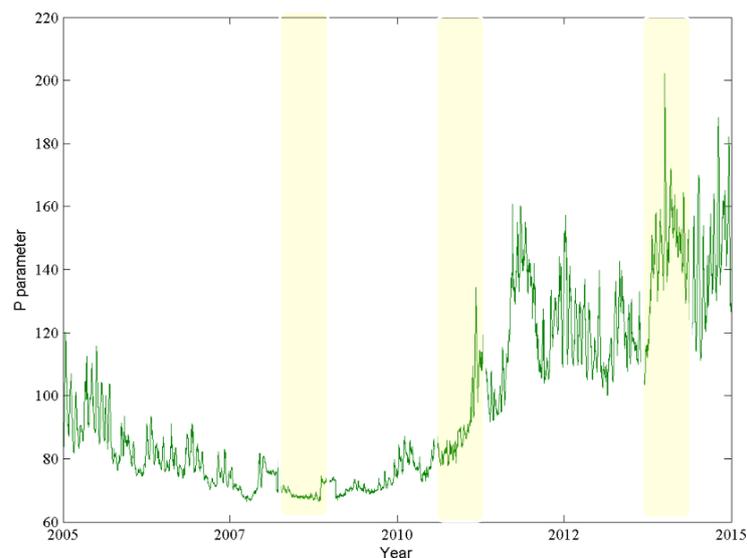
The longitudinal profile of EEJ was obtained using the spline interpolation and linear interpolation fittings.

**Table 1.** Geographic and Geomagnetic coordinates of the observatories used in the study

Stations	Code	Geographic		Geomagnetic	
		Lat. (°)	Lon.(°)	Lat. (°)	Lon.(°)
Ancon	ANC	-11.77	-77.15	0.77	354.33
Fuquene	FUQ	5.40	-73.73	15.72	357.99
Ilorin	ILR	8.50	4.68	-1.82	76.80
Tamanrasset	TAM	22.8	5.5	25.4	80.6
Adis Adaba	AAB	9.04	38.77	0.18	110.47
Nairobi	NAB	-1.16	36.48	-10.65	108.18
Tirunelveli	TIR	8.70	77.80	0.21	149.30
Alibag	ABG	18.62	72.87	10.36	146.54
Langkawi	LKW	6.30	99.78	-2.321	171.29
Kototabang	KTB	-0.20	100.32	-10.63	171.93
Davao	DAV	7.00	125.40	-1.02	196.54
Muntinlupa	MUT	14.37	121.02	6.79	192.24



**Figure 1.** The location of the observatory station. Red dots show the stations at dip-equator while the blue dots show off-dip equator stations. The red box, yellow box, blue box and green box represents South American, African, Indian and Southeast Asian sector respectively.



**Figure 2.** P parameter that indicates the level of solar activity from the year 2005 to 2015. Yellow box represents 2008, 2011 and 2014.

### 3. Results And Discussions.

#### 3.1 Longitudinal Variation

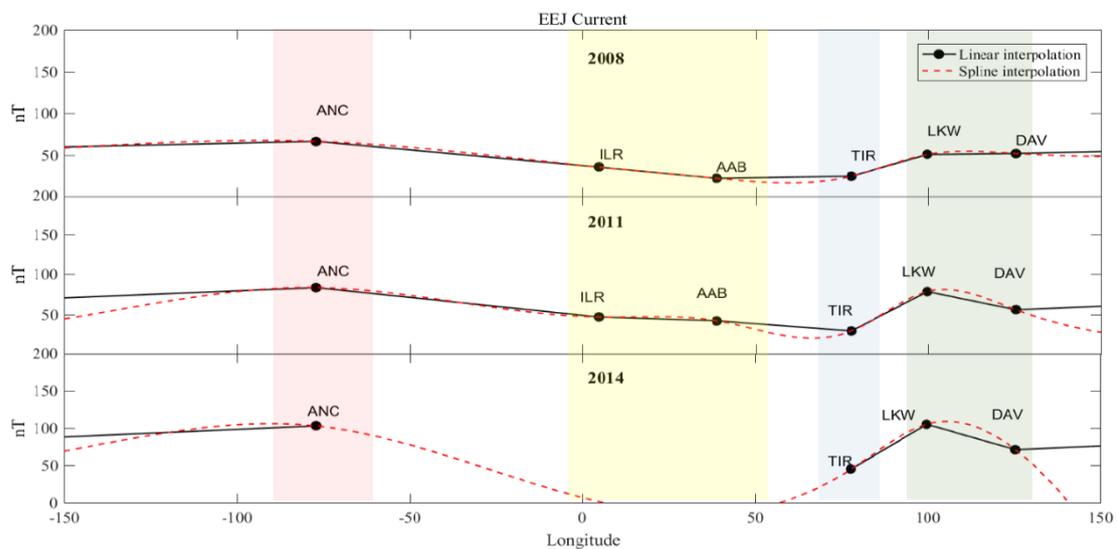
The EEJ data at each longitude sector is calculated using average data for year 2008, 2011 and 2014. The spline interpolation is used to obtain the longitudinal variation and comparison is made with linear fitting as shown in Figure 3. Results show that the magnitude of EEJ is higher at ANC-FUQ stations pair which is in the South American sector in 2008 and 2011 and lowest between AAB-NAB and TIR-ABG which is in African and Indian sector respectively. Table 2 shows the average magnitude of EEJ. During 2008, EEJ value between LKW station and DAV station does not show any significant difference. The similar results obtained at station TIR and AAB in 2008 and station ILR and AAB in 2011. However, LKW and DAV show the significant result in 2011 and 2014. Apparently, our results also specify that the value of EEJ in 2014 between ANC and LKW are comparable. Possible factors that can be related to the differences on longitudinal dependence are atmospheric tides, gravity and planetary wave [6, 12]. Since it is the first time we discover this

behaviour, further study is needed to explain the parameter that contribute to the difference of EEJ intensity at these longitude sector.

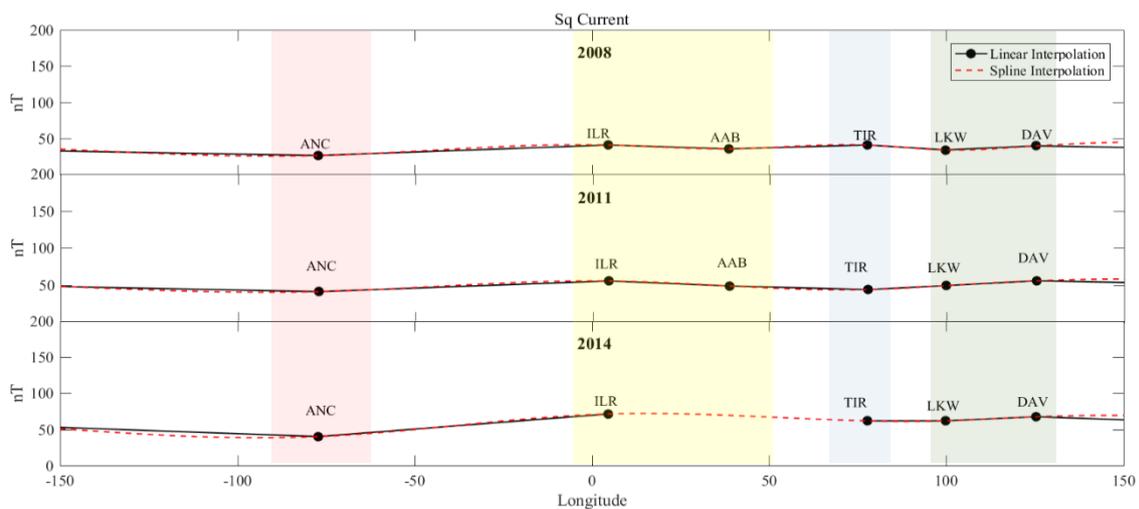
The results obtained agreed with the previous study by [5] where the EEJ is maximum in South America even though they are using a different approach. In their study, they only take data at dip-equator station or inside the EEJ band and they do not make any normalization technique. Our approach is better because by using the normalization technique we can make a comparison. The longitudinal variation of EEJ in this study also agrees with the study by [11,12] in which they separated the EEJ and Sq current at dip equator. By separating the EEJ and Sq it will give different results because of the contribution of Sq current that overlaps at dip-equator.

We continue the analysis by comparing the results in 2008 and 2011 with 2014 at Southeast Asian. This is due to the big difference longitudinal pattern at Southeast Asian sector in 2008 and 2011. The comparison is made between stations pair ILR-TAM, AAB-NAB and TIR-ABG. Unfortunately, data are not available in 2014 at stations ILR and NAB and it affects the normalization results. Therefore, future works using complete data with other station pair is recommended.

Apart from EEJ, we also perform spline interpolation to Sq data at all six sectors. The result is presented in Figure 4. Our result confirms that the Sq current does not show any longitudinal variation.



**Figure 3.** Longitudinal profile of EEJ from six different sectors for three different years (2008, 2011 and 2014). The black line indicates the linear interpolations while the dashed red line represents the spline interpolation.



**Figure 4.** Longitudinal profile of Sq current from six different sectors for three different years (2008, 2011 and 2014)

**Table 2.** Average for the magnitude of EEJ current for 2008 (solar minimum), 2011 (inclination phase) and 2014 (solar maximum).

Station	Average value of EEJ current (nT)		
	2008	2011	2014
ANC	66.43	83.86	102.55
ILR	35.49	46.61	NaN
AAB	22.40	40.99	NaN
TIR	24.63	28.72	44.55
LKW	50.64	78.66	104.81
DAV	51.91	52.25	70.79

#### 4. Conclusion

The longitudinal profile of EEJ has been constructed using yearly average data for 2008, 2011 and 2014 where six sectors have been considered in this study. Results show that the magnitude of EEJ current is higher at South America sector and lowest between African and Indian sector in 2008 and 2011. However, we found that in 2014 the value of EEJ is comparable between ANC and LKW. Due to the limitation of data in 2014, we could not compare the Southeast Asian sector with the 2008 and 2011 results. Magnitude of EEJ is higher during solar maximum due to increasing ionization in the ionosphere. Further study will be done in near future by changing the stations pair of AAB-NAB and TAM-ILR to other station and comparing ground-based magnetometer data with satellite data in order to find the discrepancy of longitudinal variations of EEJ.

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