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Inter-relationships between the thickness, width and intensity of the equatorial electrojet in Indian sector

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Abstract. The temporal variations of the thickness, width and current intensity of equatorial electrojet over Indian sector have been evaluated from a thick current shell format of continuous current distribution model of equatorial electrojet on quiet condition. The thick current shell model takes into account the vertical ionospheric currents; permits both the width and the thickness of the jet to be determined simultaneously. The EEJ intensity increases from dawn reaches the peak at about local noon and thereafter decays towards sunset. The thickness and width of equatorial electrojet EEJ exhibit consistent diurnal variations. The thickness decreases from about 0.06642° at dawn to the minimum at about 1100 hr LT and then begins to increase towards the dusk. The width increases with the sunrise, reaches maximum at about 1100 hr LT and then begins to decrease towards the dusk. The mean annual half-thickness and half-width for the solar minimum year 1986 (Sunspot number R = 13.4) is 0.0625 ±0.0037° and 2.68 ±0.23° respectively. The dynamics of the variation of electrojet intensity and thickness shows that electrojet shrinks as its intensity increases. The thick current shell model is shown to give better hourly representation of jet behaviour than thin shell format hitherto being used. The thin current shell model best fits only the near local noon jet observation. The transient variation of the jet thickness is explained in terms of the wind shears in consistency with the electrodynamics of the dynamo region.

Keywords : Earth – solar-terrestial interactions – magnetic field

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1. Introduction

The observed enhanced horizontal magnetic field intensity at the magnetic equatorial neighbourhood is ascribed to an intense ionospheric current flowing east-west within the narrow strip flanking the dip equator. This effect was named equatorial electrojet EEJ by Chapman (1951) and he proposed a model to represent the phenomenon. Ever since then a number of improved models have been employed in describing EEJ (Onwumechili 1966a, b, c; Untiedt 1967; Richmond 1973a,b; Suzuki 1973; Fambitakoye & Mayaud 1976). Some of these models operate on some assumptions which results in approximation of the EEJ to a thin sheet flowing current. Forbes & Lindzen (1976) convincingly demonstrated the defects and inconsistency in using a thin shell approximation in the vicinity of the equatorial magnetic equator.

Onwumechili (1966a,b,c; 1967) presented a two dimensional model of the continuous current distribution responsible for EEJ. It is a meridional plane model which in this simple form has to be applied to specific longitudes or local times. The model is a realistic model having both width and thickness. Electrojet models computed under the thin-shell approximation have been shown to be inadequate by Untiedt (1967), Sugiura & Poros (1969), and Richmond (1973) due to the neglect of vertical currents.

The present work made use of the thick current shell format of Onwumechili's current model to estimate the width, thickness and intensity of the equatorial electrojet over the Indian sector from a set of ground geomagnetic data. We then investigated the inter-relationship between the current parameters and propose a suitable mechanism responsible for the observed interplay. The model is briefly represented in the methodology section alongside the procedure for evaluation of the current parameters as well as the results. The results are discussed in Section 3. The summary of the results are presented in section 4.

2. Methodology

2.1 Model

According to the Onwumechili model, the eastward current density at any point (x, z) is given by

$$j = \frac{j_0 a^2 (a^2 + \alpha x) b^2 (b^2 + \beta z^2)}{(a^2 + x^2)^2 (b^2 + z^2)^2} \tag{1}$$

where j (μA m^{-2}) is the eastward current density at the point (x, z). The origin is at the centre of the current, x is northwards, and z is downwards. The model is extensible to three dimension by introducing the coordinate y or longitude ø or eastwards local time t. j_0 is the current density at the centre, a and b are constant latitudinal and vertical

Table 1. Coordinates of the geomagnetic observatories.

		Geog.		Dip latitude
Station	Code	Lat. (°N)	long (°E)	(°N)
Trivandrum	TRD	8.29	76.57	0.20
Ettaiyapuram	ETT	9.10	78.00	0.50
Kodaikanal	KOD	10.23	77.47	2.14
Annamalainagar	ANN	11.4	79.7	3.28
Hyderabad	HYB	17.42	78.55	9.33

scale lengths respectively, α and β are dimensionless parameters controlling the current distribution latitudinally and vertically respectively.

Onwumechili (1966c) used the Biot-Savart law to obtain the northwards X and vertical Z components of the magnetic field variation with latitude on the horizontal plane ($v =$ constant) as a result of the current distribution in (1). He derived the half thickness p *km* or *degree* at half of the peak current density as:

$$p^2 = b^2[(\beta - 1) + \{1 + (\beta - 1)^2\}^{1/2}] \tag{2}$$

Half of the latitudinal width or the focal distance of the current w km or degree is given by:

$$w^2 \;=\; -\frac{a^2}{\alpha} \tag{3}$$

Evaluation of current parameters: Simultaneously recorded hourly horizontal H and vertical Z field values for the solar minimum year 1986 (Sunspot number R = 13.4) were obtained from 5 Indian stations whose coordinates are shown in Table 1. These hourly horizontal and vertical field values were treated for hourly departures, non-cyclic and Dst variations to ensure absolute quiet condition as required. The electrojet index was obtained by subtracting the hourly values of worldwide Sq as obtained at Hyderabad, a station just outside the electrojet, from the other four stations that fall within the electrojet influence.

The values of b and β were evaluated using optimization method alongside other model parameters. Rabiu & Nandini (2006) report the details of the evaluation of the values of b and β using optimization method alongside other model parameters. The daytime hourly values of half-thickness p and half-width w were evaluated for different seasons and presented in Figs 1 and 2 respectively. Fig. 1 illustrates the diurnal variation of the half-thickness of the EEJ for winter season (D - top panel), summer (J - middle panel) and equinox (E - bottom panel). The larger diurnal variation of the half-thickness is observed during equinox (E) and the smaller one during summer (J). Fig. 2 illustrates

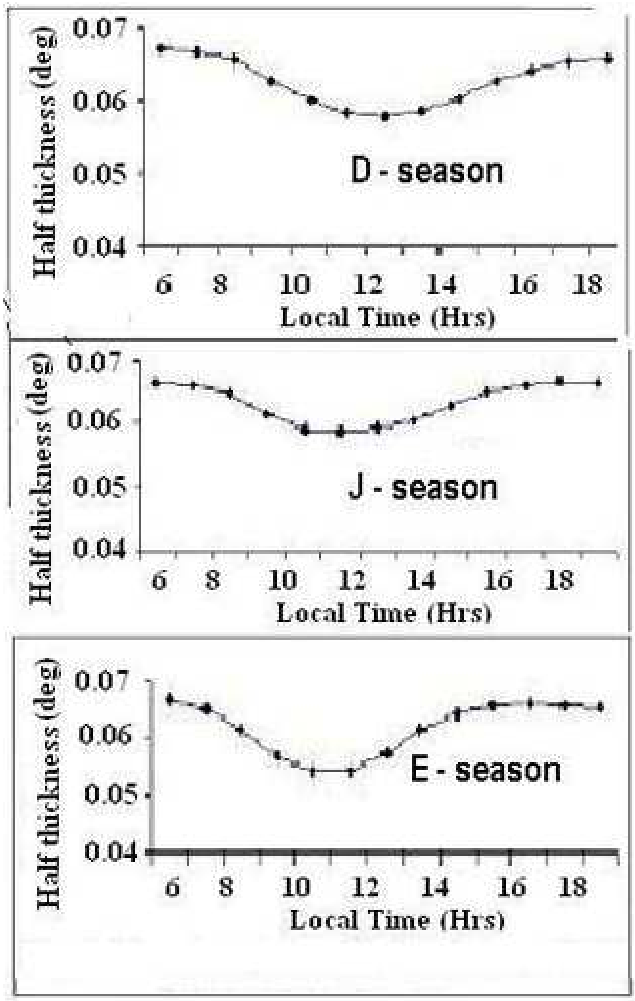

Figure 1. Diurnal variation of half-thickness of EEJ.

the diurnal variation of the half-width of the EEJ for winter season (D - top panel), summer (J - middle panel) and equinox (E - bottom panel). The diurnal variation of the half-width is greatest during equinox (E) and smallest during summer (J).

Table 2 reflects the mean values of half-thickness and width for the seasons as well as their mean annual values, in kilometers and degrees.

Fig. 3 illustrates the inter-relationships between seasonal and annual means of the half-width and thickness of equatorial electrojet. Half-thickness of EEJ has its greatest

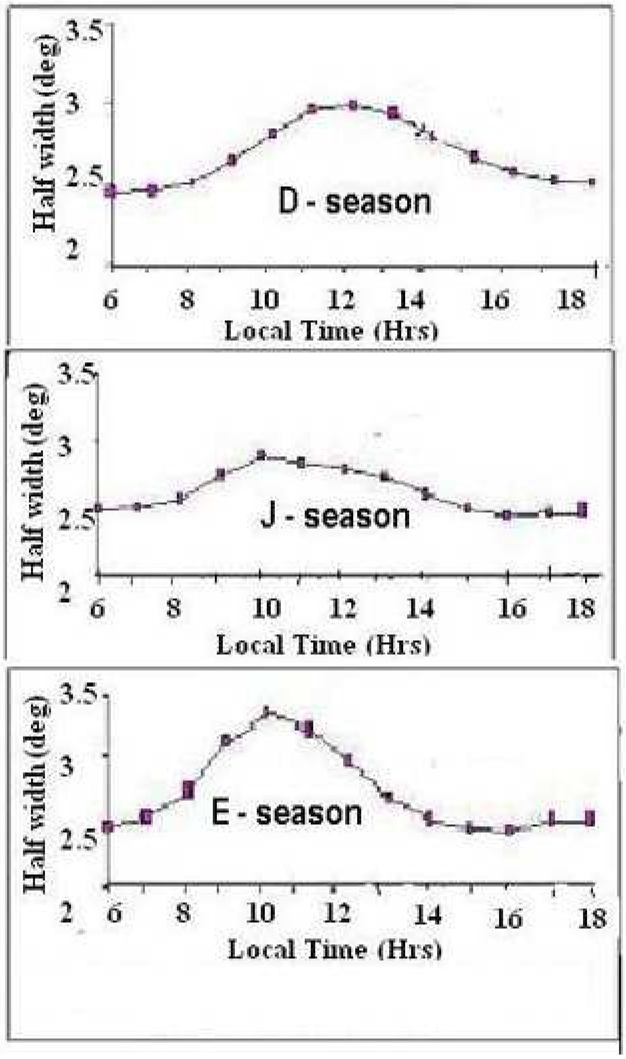

Figure 2. Diurnal variation of half-width of EEJ.

value in summer (J season) when the half-width has its minimum. The maximum value of half-width is observed in equinox (E) when the half-thickness is smallest.

3. Discussions

The thickness of equatorial electrojet EEJ exhibits a consistent diurnal variation throughout the seasons as illustrated in Fig. 1. It decreases from about 0.06642° at dawn to

Table 2. Mean values of half-thickness and half-width.

	Half-thickness		Half-width	
Seasons means	(km)	(°)	(km)	(°)
E – Equinox	6.8376	0.0616	304.14	2.74
	±0.5106	±0.0046	±35.52	±0.32
J – Summer	0.7.0152	0.0632	290.82	2.62
	± 0.3441	±0.0031	±17.76	± 0.16
D - Winter	6.9597	0.0627	297.48	2.68
	±0.3663	±0.0033	±22.1	±0.20
Annual means	6.9375	0.0625	297.48	2.68
	±0.4107	±0.0037	±25.53	±0.23

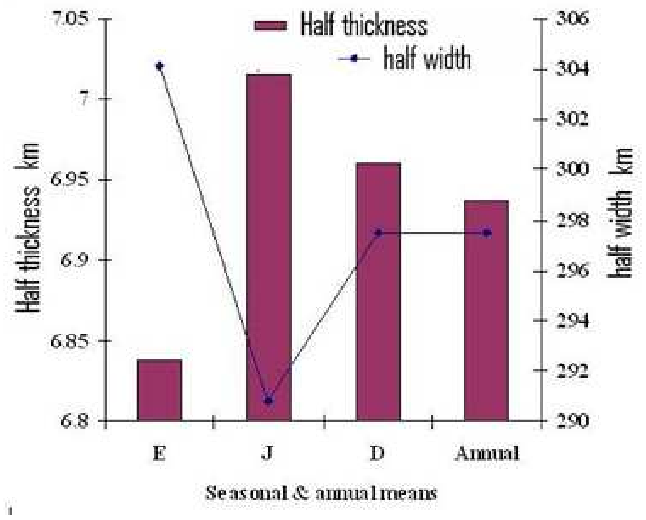

Figure 3. Seasonal and annual means of the half-thickness and width of equatorial electrojet.

the minimum in daytime at about 1100 hr LT and then begins to increase towards dusk. This is the first derivation of this diurnal variation of the thickness of the EEJ from the continuous current distribution model and so the result has no basis for comparison with others who have employed the thin current shell format of the model. Anandarao & Raghavarao (1987) noticed that a negative (positive) wind shear decreases (increases) the thickness of the jet. The fact that the thickness of the electrojet is minimum at about noon further shows that the model of the thin current shell is very suitable only for noon periods as noted by Forbes & Lindzen (1976).

Table 3. Comparison of our half-width values with others in literature at 1100 hr LT.

	(degrees)		(km)	
	mean	SD	mean	SD
Our results	2.83	0.3	314.13	33.3
Yakob & Khana 1963	2.61		289.71	
Anandarao & Raghavarao 1987	2.5		277.5	
Onwumechili & Ezema 1992	2.74	0.09	304.14	9.99
Oko et al. 1996	2.88	0.08	319.68	8.88
Jadhav et al. (2002a) OERSTED	2.0		222.0	

Generally the intensity of the EEJ increases from dawn towards noon when it maximizes and begins to decline towards the setting of the sun in consistency with the augmentation of the dynamo theory by the solar activity as observed by Onwumechili & Ezema (1977). The dynamics of the variation of electrojet intensity and thickness shows that electrojet shrinks as its intensity increases.

Sastry (1970) studied the parameters of the EEJ by rocket-borne magnetometers and obtained a thickness of about 14-15 km. The bottom half and top half of EEJ thickness obtained, turned out to be 7 km (0.063°) and 8 km (0.072°) respectively; while Anandarao & Ragharavao (1987) model gives 8 km (0.072°) and 10 km respectively. Since our data is ground-based we chose to compare our results (6.9375 ± 0.4107 km) with the values of the bottom half-thickness reported by the duo and found relative consistency.

Anandarao & Raghavarao (1987) studied the effects of zonal and meridional winds on equatorial electrojet at 1100 hr LT, by solving electrodynamic equations, and found both the half-width and thickness of the EEJ to be at about 2.5° and 16-18 km (corresponding to half-thickness of 0.0721° - 0.0811°) respectively. These results are in excellent agreement with our result.

Our mean half-width w is 2.83 ± 0.30° at 1100 LT which is in accordance with the results of Onwumechili & Ogbuehi (1967) (3.81 ± 0.81°); Onwumechili & Ezema (1992) (2.74 ± 0.09°); and Oko et al (1996) (2.88± 0.08°); and Anandarao & Raghavarao (2.5°). Table 3 compares our half width values with those available from different sources in literatures. Table 3 set up together the half width of the equatorial electrojet in degrees (2nd column) and kilometres (4th column) as well as the standard deviation (3rd and 5th columns).

Anandarao & Raghavarao (1987) have found negative currents due to wind shears centred at about 6° on either side of the dip equator. This lends credence to the claims of the strong wind effects. Migratory tides have been invoked by Jadhav et al. (2002a).

Forbes (1981) and Anandarao & Raghavarao (1979) have explained the structural variability of equatorial electrojets in terms of wind effects.

The half-width of the electrojet as inferred from ground magnetometer data by Yacob & Khana (1963) is 290 km (2.61°), while the shear wind model of Anandarao & Raghavarao (1987) yields about 275 km ($\sim 2.45°$). These values tally so well with our estimation ($2.68 \pm 0.23°$). Anandarao & Raghavarao (1987) have shown that a positive (negative) wind shear decreases (increases) the width of the jet.

Hysell et al. (2002) carried out theoretical, computational, and experimental analysis of the effects of large winds on the low-latitude E region ionosphere and the equatorial electrojet in particular. Their model shows that the horizontal wind component drastically modifies the vertical polarization electric field in the electrojet and found out that strong winds and wind shears are present in the E region over Jicamarca. Forbes (1981) reviewed various studies that have been performed on the effects of winds on electrojets.

In agreement with Burrows (1970), Reddy & Devasia (1981) inferred that the wind-induced change in the width of the equatorial electrojet bears no simple relationship with the change in its intensity at the magnetic equator. Oko et al. (1996) does not really show any relationship between the width and intensity of the electrojet. The half-width obtained from the thin shell model in their figure 2 shows a decrease from around dawn towards dusk, while the current intensity demonstrates a rise from dawn towards a peak at about 1100 hr LT and then a decrease towards dusk. More recently Jadhav et al. (2002b) showed, in their figure 5 using Orsted satellite data, that the width of EEJ current system is largest in the American sector, and responsible for the strong peak in the EEJ strength at 270°E. Earlier Suguira & Poros (1969) worked on a meridional current model of EEJ and obtained a stronger EEJ at Peru with half-width of about 2.5° while India with weaker EEJ strength has smaller half-width of 2°.

One of the outstanding results we obtained using the thick current shell is the diurnal variation of the thickness of the EEJ which is opposite of the intensity. So the thicker the EEJ the weaker it becomes. Anandarao & Raghavarao (1987) noted that the zonal wind shears can decrease or increase the width of jet by as much as 100% depending upon their direction, strength and altitude, and concluded that if the width of the jet is increased, then the thickness would decrease and vice versa. This explanation fits our result as illustrated in Fig. 3.

Comparison of our results with the results of Oko et al. (1996) obtained for Indian sector using the approximate thin shell format shows a discrepancy outside the neighbourhood of local noon time. This further supports the mathematical deduction of Forbes & Lindzen (1976), who used a system of equations to show that EEJ becomes thinnest at local noon time and therefore expected that a thin shell model such as used by Oko et al. (1996) should only be appropriate to local noon time when the equatorial electrojet becomes thinnest.

4. Conclusions

The thickness of equatorial electrojet EEJ exhibits a consistent diurnal variation throughout the seasons such that it decreases from about 0.06642° at dawn to the minimum at about 1100 hr LT and then begins to increase towards the dusk.

The dynamics of the variation of electrojet intensity and thickness shows that electrojet shrinks as its intensity increases. The thin current shell model best fits only the near local noon jet observation, as the electrojet is thinnest at period of maximum intensity.

The transient variation of the jet thickness is explained in terms of the wind shears in consistency with the electrodynamics of the dynamo region.

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