DIURNAL VARIATION OF THE CENTER OF EQUATORIAL ELECTROJET FROM A THICK CURRENT SHELL MODEL

A.B. RABIU[1,2,+] and N. NAGARAJAN [1]
[1]National Geophysical Research Institute, Uppal road, Hyderabad 500 007, India.
[2]Department of Physics, Federal University of Technology, Akure, Nigeria.

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Abstract

The central anomaly in the equatorial ionosphere is the equatorial electrojet, an intense current flowing eastward in the low latitude ionosphere within the narrow region flanking the dip equator. A composite thick current shell model format of equatorial electrojet have been employed to determine the diurnal variation of the dip latitude of the equatorial electrojet center at the Indian sector. The equatorial electrojet center is observed to migrate northwards towards the dip equator from the dawn such that it is closer to the dip equator at about local noon and then reclined southwards towards the dusk. The model result wholly confirmed the satellite observational results and partly contradicted the results hitherto obtained from approximate thin shell model.

Keywords: Equatorial electrojet; Ionosphere; Model.

1. Introduction

Chapman (1951) baptized the intense ionospheric current flowing east-west within the narrow strip flanking the dip equator, responsible for the observed enhanced horizontal magnetic field intensity at the magnetic equatorial neighbourhood, equatorial electrojet. The variability of the jet center, as well as other structural properties of the jet, have since been observed and studied by several workers. For examples, Oko *et al.* (1996); Okeke, *et al.*, (1998); and Jadhav (2002a, b).

As rightly observed by Oko *et al.* (1996) most of studies on electrojet were focused on noon time period as the ranges of the magnetic field intensities were fitted into models in order to evaluate the electrojet characteristics. This usual practice was improved on when they - Oko *et al.* (1996)- evaluated a thin shell of Onwumechili (1966a,b,c) continuous current model of equatorial electrojet to obtain the diurnal variation of electrojet center at Indian sector. Our results using thick shell format (Rabiu and Nagarajan, 2005a,b) confirmed the expectation of the numerical computation of Forbes and Lindzen (1976) that the thin shell approximation has some defects and inconsistency in the vicinity of the equatorial magnetic equator. We therefore seek to explore the thick shell format of the same continuous current distribution to evaluate the local time hourly values of jet center at the India sector.

2. Model Evaluation

Onwumechili (1966a, b, c; 1967) presented a two dimensional model of the continuous current distribution responsible for EEJ as:

$$j = \frac{j_o a^2 \left(a^2 + \alpha x^2\right) b^2 \left(b^2 + \beta z^2\right)}{\left(a^2 + x^2\right)^2 \left(b^2 + z^2\right)^2} \qquad (1)$$

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 $\O$ or eastwards local time t. j_0 is the current density at the centre, a and b are constant latitudinal and vertical scale lengths respectively, α and β are dimensionless parameters controlling the current distribution latitudinally and vertically respectively. 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.

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) as follows:

$$\left(sg.z\right)P^4 X = \tfrac{1}{2}k \begin{bmatrix} \left(1+\beta\right)\left(v+\alpha v+2\alpha a\right)\left(u+b\right)^2 + \\ 2\left(1-\beta\right)\left(v+\alpha v+4a-2\alpha a\right)\left(u+b\right) \\ +\left(1+\beta\right)\left(v+\alpha v+2a\right)\left(v+a\right)^2 \end{bmatrix} \qquad (2)$$

+ *corresponding author* (email:tunderabiu@yahoo.com)

$$-(sg.x)P^4 Z = \tfrac{1}{2}k\begin{bmatrix}(1+\alpha)(1+\beta)(u+b)^3+(1+\alpha)(1+\beta)(u+b)^2+\\(1+\beta)(v+\alpha v+3a-\alpha a)(v+a)(u+b)-\\(1-\beta)b(v+\alpha v+3a-\alpha a)(v+a)\end{bmatrix} \qquad (3)$$

$$where\ \ P^2 = (u+b)^2+(v+a)^2 \qquad (4)$$

$$k = 0.1\pi^2 abj_o \qquad (5)$$

$$u = |x|\ and\ v = |z| \qquad (6)$$

$$sg.x = sign\ of\ \left(x/u\right)\ and\ is \pm 1\ when\ x = 0 \qquad (7)$$

$$sg.z = sign\ of\ \left(z/v\right)\ and\ is \pm 1\ when\ z = 0 \qquad (8)$$

Equations 2 and 3 give the horizontal and vertical magnetic field variations respectively, due to thick current shell format.

In the neigbourhood of dip equator northwards component X and horizontal component H are approximately equal as the inclination is very small, therefore “X H•H. “Z and H are measurable field components at observatories, where *v* is the current altitude taken to be 106 km (0.96°) as determined by rocket and satellite measurements (Onwumechili, 1997), *u* is the dip latitude of the point of observation. Equations 1-8 were as presented by Onwumechili (1997). It has been observed that 0° dip latitude does not coincide with the center of the electrojet (Oko, et al., 1996). Therefore we chose to write an expression for the electrojet axis x_0, in terms of the dip latitude,δ, as:

$$u = \delta - x_o \qquad (9)$$

where x_0 is the dip latitude of the current center, that is, the electrojet center.

Introducing *equation 9* in *equations 2* and *3* results in a set of pair of non-linear equations. The non-linear model was applied to four data points, each with a pair of simultaneously measured horizontal H and vertical Z variation field components. The coordinates of the data points are listed in Table 1. The resultant system of eight non-linear equations with five unknown model parameters and one unknown physical parameter were subjected to non-linear least square optimisation method taking advantage of the robust Levenberg-Madquart optimisation subroutine of licensed MATLAB 6.0 version. Details of the method of evaluation of the five model parameters - j_o, a, α, b, β - and the jet center x_0 have been presented in Rabiu and Nagarajan (2005a).

3. Results and discussion

The diurnal variation of the dip latitude of the center of EEJ, x_0, is illustrated in Fig.1.This clearly demonstrates a consistent diurnal pattern, which described a northwards shift towards the dip equator from the rising of the jet at dawn and becoming closer to the dip equator at the peak intensity period of the jet after which it begins to recede southwards towards the dusk.

Magnitude wise this diurnal observation is in consistency with the Orsted satellite observational result of Jadhav et al (2002a) and contradicts Oko, et al. (1986) (-0.29 ± 0.02) result obtained from thin shell format. With mean value of -0.1911 ± 0.0031°, it is obvious that the center of EEJ is not necessarily at the dip equator in agreement with results of Srivastava (1992) and Onwumechili (1997) among others. This further implies that the equatorial electrojet axis does not coincide with the dip equator. Obviously the center of the jet is, however, close to the dip equator at about local noon (1000 LT) and always coincides with the hour of occurrence of the maximum peak forward current intensity, peculiar to the region of study, on any day.

Richmond (1973) showed that a meridional wind of 10 ms^{-1} shifts the jet center by 0.8 km. Anandarao and Raghavarao (1987) have found that a steady northward wind of 100 ms^{-1} is capable of shifting the center of EEJ southwards by 0.5°. Further calculations of the effects of zonal and meridional winds on the EEJ done by Anandarao and Raghavarao (1987) revealed that meridional winds shift the center of the jet either southwards or northwards depending upon whether the wind is northwards or southwards. Kane and Rastogi (1977) reported such a shift in the EEJ center from ground based magnetometer data from a chain of closely spaced stations in Africa. Forbes (1981) has concluded that shifting of electrojet axis can be responsible for day-today variability of electrojet intensity.

Diurnal variation of the jet center, x_0, follows the satellite observation of Jadhav (2002a), contradicts results reported in literatures based on thin shell format for EEJ current, and confirms the long term assertion of Forbes and Lindzen (1976) that thin shell approximation is only a representation of approximate noontime equatorial magnetic variations, and fail to take into account local time variations of the electrojet. This is further stressed by the fact that our electrojet center, x_0, is minimum and closer to the dip equator on the x-axis in Fig. 1., at about local noon. Forbes and Lindzen (1976) have demonstrated the defects and inconsistencies in using a thin shell approximation in the vicinity of the magnetic equator.

4. Conclusions

The diurnal variation pattern of the center of equatorial electrojet at the Indian sector has been studied using a thick shell format of continuous current distribution of Onwumechili (1966a,b, c). With mean value of -0.1911 ± 0.0031°, it is obvious that the center of equatorial electrojet is not necessarily at the dip equator and implies that the equatorial electrojet axis does not coincide with the dip equator. The equatorial electrojet center is observed to migrate northwards towards the dip equator from the dawn such that it is closer to the dip equator at about local noon and then reclined southwards towards the dusk. The model result wholly confirmed the satellite observational results and partly contradicted the results hitherto obtained from approximate thin shell model.

Table 1. Coordinates of the geomagnetic observatories

Station	Code	Geog.		Dip latitude (°N)
		Lat. °N	Long. °E	
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	11.40	79.70	3.28
Hyderabad	HYB	17.42	78.55	9.33

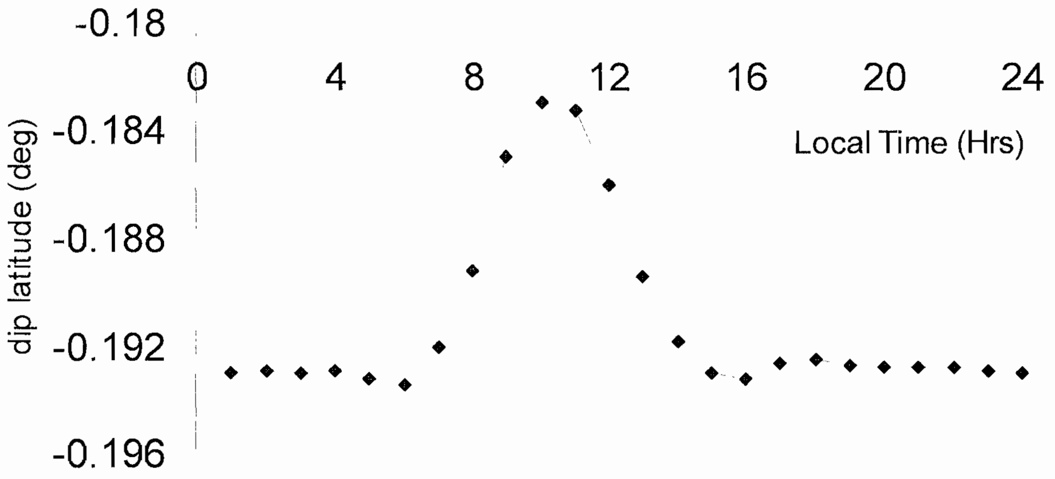

Fig.1. Diurnal variation of electrojet centre

Fig 1: Diurnal variation of the electrojet center for E-season of solar minimum year (Sunspot number R = 13.4) 1986 at Indian sector.

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