GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES, VOL.7, NO. 4, SEPTEMBER 2001: 761-768

SPATIAL AND TEMPORAL DISTRIBUTIONS OF IONOSPHERIC CURRENTS-1. ALTITUDE-LATITUDE CROSS SECTIONS OF EQUATORIAL ELECTROJET AND WORLDWIDE PARTS OF Sq CURRENT DENSITY

C. AGODI ONWUMECHILI, P. O. EZEMA and S. O . OKO

(Received 12 January 2001 ; Revision accepted 9 May, 2001)

ABSTRACT

The first altitude-latitude cross section of worldwide part of Sq current density is reproduced. It is set at an altitude of 120 km and its current focus occurs at 35.7° latitude from the current centre. It depicts the tendency for most upper current layers observed by rockets to extend more below than above the altitude of peak current density. It also depicts the tendency of the return current streamlines of Chapman and Bartels (1940) to be equidistant towards the poles. The first altitude-latitude cross section of the equatorial electrojet (EEJ) current density on the continuous distribution of current density model based on a single data set is presented. It is set at an altitude of 106 km. It very much resembles the EEJ altitude-latitude cross section of Anandarao and Raghavarao (1979) from numerical model calculations using observed winds. The respective landmark values of the two EEJ cross sections are: peak current density j_0 at the current center 10.44 Akm^{-2} and 8 Akm^{-2}, at the altitude of 106 km the dip latitude w of current focus of 2.73° and 3°, the peak return current density j_m of −2.41 Akm^{-2} and −2.3 Akm^{-2} occur at dip latitude x_m of 5.13° and 6° and the latitudinal extent L_1 of return currents of 11.63° and 12° respectively.

Key words: Altitude-latitude cross sections, worldwide part of Sq (WSq), current density, dip latitude.

1. INTRODUCTION

The first presentation of the altitude-latitude cross section of the equatorial electrojet (EEJ) current density was done by Onwumechili (1965). However, owing to the lack of sufficient observed data for the determination of all the parameters of his continuous distribution of current density model, his altitude and latitude were in units of the scale lengths. This was followed by Sugiura and Cain (1966) who presented the altitude-latitude cross section of EEJ effective conductivity σ_{yy}.

Thereafter, a number of numerical model calculations (Untiedt 1967, Sugiura and Poros 1969, Krylov et al. 1973, Richmond 1973, Takeda and Maeda 1980,1981, Stening 1985, and Singh and Cole 1987) gave altitude-latitude cross sections of EEJ current density. The winds used in these calculations are hypothetical and some adopted arbitrary electric fields. As a result, only two of them showed some indication of the westward return currents on the flanks of the dip equator. However, when Anandarao and Raghavarao (1979, 1987) and Raghavarao and Anandarao (1987) used observed winds and electron density they reproduced the westward return current on the flanks. All its features are discussed here.

Davis et al. (1967) attempted altitude-latitude cross section of EEJ current density with altitude profiles of current density measured by rockets. This would have been ideal but unfortunately there were only 9 launching stations. More regrettably, there was no

C. AGODI ONWUMECHILI, 4813 Lackawanna St., College Park, MD 20740, USA
P. O. EZEMA, Department of Physics and Astronomy, University of Nigeria, Nsukka.
S. O. OKO, Department of Computer Science, University of Nigeria, Nsukka

measurement from about 240 km to 800 km dip distance. The region of westward return current and its interesting features were therefore omitted. The extrapolations into this region were therefore unrealistic.

Empirical models derived their parameters by fitting observations and then they proceed to extrapolate with the model. They are therefore anchored on observational data provided they fit observations well. Unfortunately, nearly all empirical models so far used are thin current shell models. They cannot provide altitude-latitude cross section because they take no account of the altitude distribution of the current.

However, the continuous distribution of current density model (Onwumechili 1965) provides for altitude distribution of current density and therefore has the capability to produce altitude-latitude cross section of current density. The altitude-latitude cross section of Onwumechili and Ozoemena (1989) based on this model, however derived the altitude parameters from rocket measurements and the latitudinal parameters from satellite magnetic variation measurements. Therefore the two sets of parameters do not refer to the same ionospheric current.

This paper presents altitude-latitude cross section of EEJ current density based on latitudinal and vertical parameters derived from an autonomous data set. The cross section therefore refers to an autonomous ionospheric current. The paper also presents the first altitude-latitude cross section of worldwide part of Sq (WSq) current density.

2 THEORETICAL CALCUALTIONS.

(a) ALTITUDE-LATITUDE CROSS SECTION

For the continuous distribution of current density model. The eastward current density j(x, z) at the point (x, z) is given by:

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

where x is northwards, y is eastwards and z is downwards; the origin is at the center of the current x = 0 = z; a and b are constant scale lengths along x and z respectively; α and β are dimensionless constants controlling the current distribution latitudinally and vertically respectively; and j_o is the peak current density at the current center.

In geocentric spherical polar coordinators [(R + r), ϕ, λ] the model is

$$j = j_0 \frac{a^2(a^2+\alpha\varphi^2)}{(a^2+\varphi^2)^2} \frac{b^2(b^2+\beta r^2)}{(b^2+r^2)^2} \qquad 2$$

where R is the radial distance to the center of the current, ϕ is southward latitude from the center of the current, λ is eastward longitude, and a is a constant scale latitude.

Since Eqs.(1) and (2) are essentially the same, we may in general use Eq.(1). When a and x are in degrees, it refers to geocentric polar coordinates but when a and x are in km, it refers to Cartesian coordinates.

The cross section is presented as contours of equal current density j Akm^{-2} on the (x, z) plane at a given local time. We therefore need expressions for the coordinates of the point with current density j.

We may rewrite Eq.(1) as

$$p = \frac{(1+\alpha r^2)}{(1+r^2)^2} \frac{(1+\beta s^2)}{(1+s^2)^2} \qquad 3$$

where $p = j/j_o$, $r = x/a$ and $s = z/b$.

For points along the x axis, s = 0 = z. The solution for r and x from the resulting equation.

$$p = \frac{1 + \alpha r^2}{\left(1 + r^2\right)^2} \quad 4$$

is: $$x^2 = a^2\left[(\alpha - 2p) \pm \sqrt{(\alpha - 2p)^2 - 4p(p-1)}\,\right]/2p. \quad 5$$

For points along the z axis, r = 0 = x. The solution for s and z from the resulting equation

$$p = \frac{1 + \beta s^2}{\left(1 + \alpha r^2\right)^2} \quad 6$$

is: $$z^2 = b^2\left[(\beta - 2p) \pm \sqrt{(\beta - 2p)^2 - 4p(p-1)}\,\right]/2p \quad 7$$

For the general case we rewrite Eq.(3) as

$$q = p\frac{\left(1 + r^2\right)^2}{1 + \alpha r^2} = \frac{1 + \beta s^2}{\left(1 + s^2\right)^2} \quad 8$$

We choose r or x = ar and calculate q for given p. Then the solution for s and z is

$$z^2 = b^2\left[(\beta - 2q) \pm \sqrt{(\beta - 2q)^2 - 4q(q-1)}\,\right]/2q \quad 9$$

Some landmark positions also help. At the current foci

$$j = 0 = p, \quad x^2 = w^2 = -a^2/\alpha. \quad 10$$

At x_m where the return current peaks as j_m we have

$$j_m = j_o\,\alpha^2/4(\alpha - 1). \quad X_m^2 = a^2(\alpha - 2)/\alpha. \quad 11$$

From the above analysis, the altitude-latitude cross section is easily constructed provided we know the values of the parameters: j_o, a, α, b and β. These are obtained from least square fitting of observational data with the model for the selected local time. Then choosing a current density like 2 Akm^{-2} or −1 Akm^{-2}, its contour is calculated from the above equations.

The current intensity J Akm^{-1} and the total forward current I_F amperes are independent of altitude. Therefore, they cannot have altitude-latitude cross section.

(b) ALTITUDE-LATITUDE CROSS SECTION OF WORLDWIDE PART OF Sq (WSq) CURRENT DENSITY

So far there is no determination of j_o, a, α, b and β from the same data set of worldwide part of Sq (WSq). We are therefore compelled to combine the latitudinal parameters a and α from ground-based geomagnetic variation observations with the vertical distribution parameters j_o,b and β from rocket measurement for the purpose of producing the first **altitude-latitude** cross section of WSq current system. Onwumechili (1967) obtained five concordant values of each parameter a and α from the recordings of worldwide distribution of observatories. Their means are a = 63° and α = -3.11. Their worldwide origin makes them preferable to the a = 63° and α = -3.14 ± 0.17 from the Indian sector alone.

Onwumechili (1992a) determined the vertical parameters j_o, b and β from altitude profiles of WSq current density measured by rockets. The peak current density j_o = 2.37 ± 0.38 Akm^{-2}.

He determined two sets of the parameters b and β because the profile is not symmetrical about the altitude of the peak current density. For the lower part of the profile below the altitude of the peak current density b_1 = 6.59 ± 2.18 km and β_1 = 0.234 ± 0.32, and for the upper part of the profile above the altitude of the peak current density b_2 = 7.09 ± 2.47 km and β_2 = 0.021 ± 0.35.

Onwumechili (1992b) showed that the altitude of the peak current density of WSq was higher close to the dip equator than elsewhere. The rockets found that from 7° to 77° latitude, the mean altitude of the peak current density of WSq was 118 ± 7 km with a median of 118 km. When weighted by the range of latitude in which an altitude occurs, the mean from 0° to 77° latitude is 117.6 ± 5.5 km. For the purpose of constructing the altitude-latitude cross section of WSq current density we adopt a peak current density of j_o = 2.5 Akm^{-2} at an altitude of h = 120 km.

With the above parameters the altitude-latitude cross section of the WSq current system shown in Fig. 1 was calculated and plotted as described in section 2 above. It may be noted that the latitudes are full scale latitudes measured from the current axis. It is also noted that the contours extend more below than above the altitude of 120 km. This is due to the differences of b_1 and β_1 from b_2 and β_2, which thus preserves the lack of symmetry of the altitude profile of current density about the altitude of the current density peak. Ultimately, this arises from the interaction of the upper current layer (WSq layer) and the eastward lower current layer (EEJ layer) which often stretches the lower part of the upper current layer.

Contours are given for the current densities of 2, 1.5, 1, 0.5, 0.1, -0.1, -0.5, and −1 Akm^{-2}. The total altitude extent of the 0.5 Akm^{2} contour is about 17 km, in accord with the total altitude extent of 18 ± 3 km for the upper current layer observed by rockets (Onwumechili 1992b). The rocket may not easily detect less than 0.5 Akm^{-2}. The forward current decreases to zero at the focus, 35.7° latitude from the current center. From there the return current grows from zero to a peak of about −59 percent of the peak of forward current at the current center. This ratio is about double the ratio for EEJ because the return current in Fig. 1 covers about

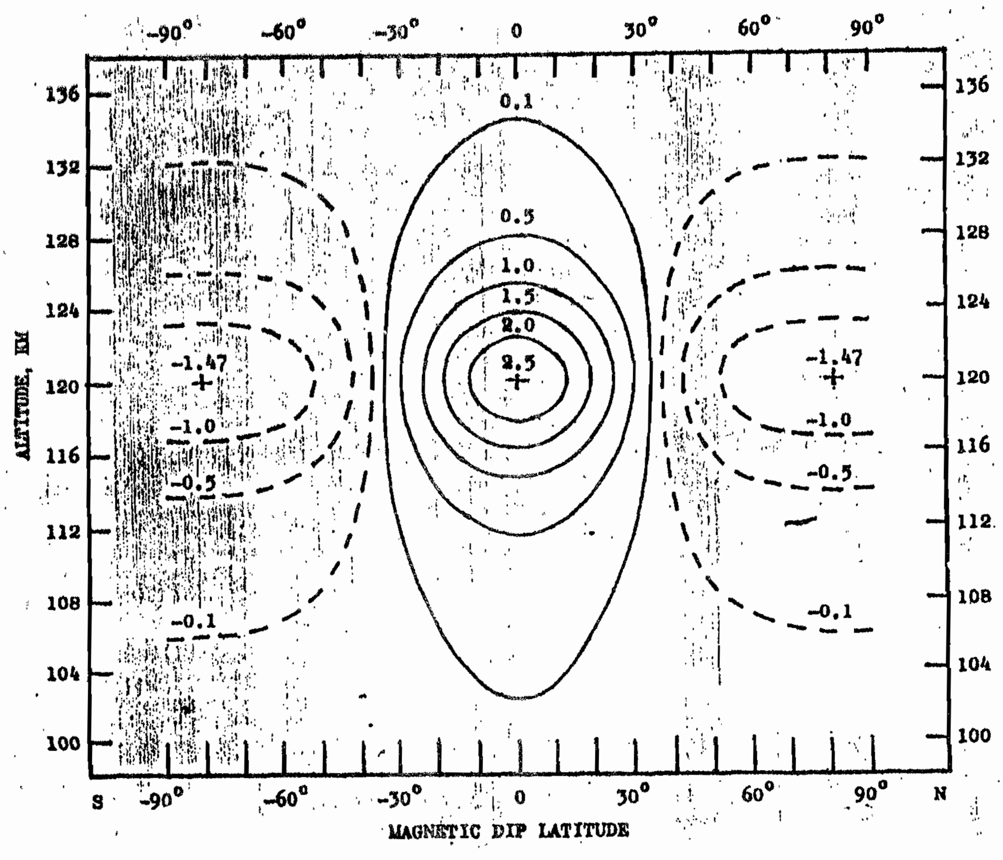

Fig. 1 Altitude-latitude cross section of worldwide part of Sq current density j Akm^{-2}. Continuous contours are for forward current densities of 2.0, 1.0, 0.5 and 0.1 Akm^{-2}, and broken contours are for return current densities of −1.0, -0.5 and −0.1 Akm^{-2}. Crosses mark the peak forward current density of j_o = 2.5 Akm^{-2} and the peak return current density of j_m = -1.47 Akm^{-2}.

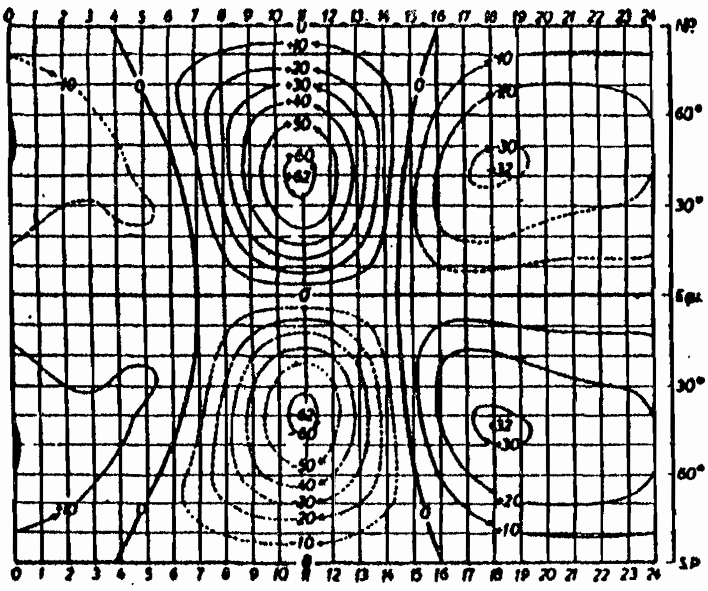

Fig. 2. Worldwide map of the ionospheric current systems corresponding to the solar daily geomagnetic variations in the equinoxes of the sunspot minimum year 1902. The meridians refer to local time, 12 = noon. Between consecutive streamlines, 10,000 A flow. Solid lines are for counter-clockwise and broken lines are for clockwise directions. After Chapman and Bartels (1940). p.229)

twice the area of the forward current whereas in the case of the EEJ the return current covers about four times the area of the forward current.

The return current contours rise quickly in altitude and then tend to maintain fairly steady altitude. This fairly steady altitude explains the tendency for return current streamlines to appear equidistant from shortly after the focus towards the poles. This may be seen in Fig. 2 from Chapman and Bartels (1940). The current terminates in latitude when all the forward current returns. At this latitude, all the return current density contours need not close. This explains why the return current density contours remain open in fig. 1

(c) ALTITUDE – LATITUDE CROSS SECTION OF EQUATORIAL ELECTORJET (EEJ) CURRENT DENSITY

Fortunately, in the case of the equatorial electorjet (EEJ), Onwumechili and Ezema (1992) have determined the necessary parameters: j_o, a, α, b and β from an autonomous data set. For the altitude-latitude cross section of the EEJ current density at local noon we adopt their values of j_o = 10.44 Akm^{-2}, a = 3.37^0, α = -1.5274, b = 8.845 km, β = 0.5253. Rockets determined the altitude of the EEJ peak current density as h = 106 km (Onwumechili 1992c). With these values the altitude-latitude cross section of the EEJ current system in fig. 3 was calculated and plotted as described in section 2 above. The continuous contours are for the eastward current densities of 10, 8, 6, 4, 3, 2, 1, 0.5 and 0.1 Akm^{-2}, and the broken contours are for the westward return current densities of –2, -1,-0.5 and –0.1 Akm^{-2}. For hours outside local noon the cross section has the same pattern as Fig. 3 but the current density is normally lower everywhere.

At a given altitude, the eastward current density peaks at the dip equator. From the peak the current density decreases to zero at a focus on either side of the dip equator. At the altitude of 106 km the focus occurred at w = 2.73° dip latitude. Beyond the focus, westward return currents commence tenuously and increase to a peak j_m at the dip latitude of x_m = 5.13°.

The percentage ratio of the peak return to the peak forward current density 100j_m/j_o = 23.12. The peak forward current density of 10.44 Akm^{-2} and the peak return current density of –2.41 Akm^{-2} are marked with crosses. Beyond that latitude the current density decreases towards zero. The current terminates at dip latitude of L_1 = 11.63°, by which latitude all the eastward current has returned. Therefore some return current contours are not closed as in the

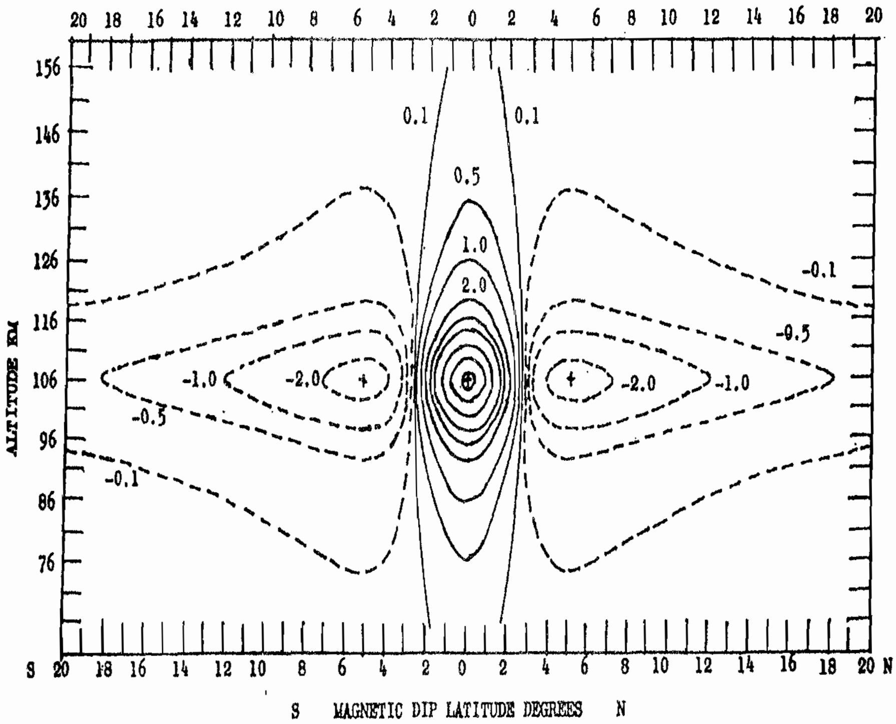

Fig. 3 Altitude-latitude cross section of equatorial electrojet current density j Akm^{-2} at local noon. Continuous contours are for the eastward current densities of 10, 8, 6, 4, 2, 1, 0.5 and 0.1 Akm^{-2}, and broken contours are for the westward return current densities of -2, -1, -0.5 and -0.1 Akm^{-2}. Crosses mark the peak forward current density of j_0 =10.44 Akm^{-2} at the centre and the peak return current density of j_m = -2.41 Akm^{-2} at x_m =5.13°dip latitude. The focus is at w = 2.73° dip latitude and the return currents extend to L_1 =11.63° dip latitude.

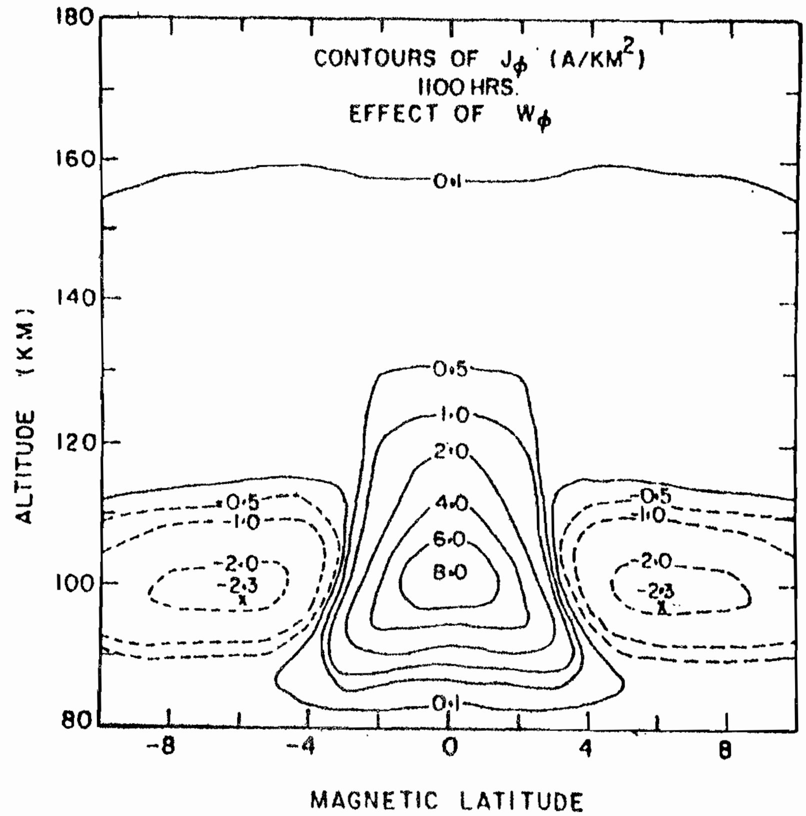

Fig.4 Altitude-latitude cross section of equatorial electrojet current density J_0 Akm^{-2} at 1100 hour local time calculated with observed east-west wind W_0. Continuous contours are for eastward current densities and broken contours are for westward current densities. The peak forward current density j_0 = 8Akm^{-2} at the centre and crosses mark the peak return current density of j_m =-2.3 Akm^{-2} at x_m =6° magnetic latitude. At the altitude of 106 km the focus is at w = 3°. The return currents extend to L_1 =12° magnetic latitude. After Anandarao and Raghavarao (1979)

case of WSq current contours. Indeed Fig. 3 has been extended far beyond the latitudinal extent of the return currents.

The numerical model calculations of Anandarao and Raghavarao (1979) using observed winds and electron density resulted in the altitude-latitude cross section of EEJ in Fig. 4. Within the same latitude range of ±10°, Fig. 3 resembles Fig. 4 Indeed, their features are very much in agreement. At the altitude of 106 km, the current focus of Fig. 4 is at 3° latitude. The peak return current j_m of =2.3 Akm^{-2} in Fig. 4 occurs at x_m = 6° latitude, Indeed Anandarao and Raghavarao (1979) say at 5° latitude. Their percentage ratio of the peak return to the peak forward current density is $100 j_m/j_0$ = -28.75. Raghavarao and Anandarao (1987) state that the return currents extend to latitude of L_1 = 12°. The comparison of the features of Figs. 3 and 4 above evidences their remarkable similarity.

3 CONCLUSIONS

The first altitude-latitude cross section of worldwide part of Sq (Wsq) current density has been reproduced with latitudinal parameters derived from ground-based geomagnetic variation measurements and vertical parameters derived from current density altitude profiles measured by rockets. The peak current density is at an altitude of 120 km and the WSq current focus occurs at 35.7° latitude from the current center. It depicts the current as extending more below than above the altitude of the peak current density as a result of interaction with the lower current layer. It also depicts the tendency of the return current streamlines of Chapman and Bartels (1940) to be equidistant towards the poles.

The first altitude-latitude cross section of the equatorial electrojet (EEJ) current density on the continuous distribution of current density model based on one data set has been presented with both latitudinal and vertical parameters derived from the POGO satellites data. It is set at an altitude of 106 km. The peak current density j_0 = 10.44 Akm^{-2} at the current centre and the focus occurs at w = 2.73°. The peak return current density j_m = -2.41 Akm^{-2} at x_m = 5.13° and the latitudinal extent of the current system is L_1 = 11.63° dip latitude.

The altitude-latitude cross section of the equatorial electrojet current density of Anandarao and Raghavarao (1979) from numerical model calculations using observed winds and selection density very much resembles the cross section described in 2 above. Its peak current density j_0 = 8 Amk^{-2} at the current centre and the focus at 106 km altitude occurs at w = 3°. The peak return current density j_m = -2.3 Akm^{-2} at x_m = 6° and the latitudinal extent of the current system is L_1 = 12° magnetic latitude.

REFERENCES

Anandarao B.C. and R.Raghavarao, 1979. Effects Of vertical sheers in the zonal winds on the electrojet, space Res., XIX: 283 -286.

Anandarao B.C. and R.Raghavarao 1987 Structural changes in the currents and fields of the equatorial electrojet due to zonal and meridional winds, J. Geophys. Res., 92: 2514 - 2526

Chapman S. and J. Bartels, 1940 Geomagnetism, vols 1 and 2, 1049pp., Oxford University Press, London.

Davis T.N., Burrows K., and J.D. Stolarik, 1967 A latitude survey of the equatorial elecctrojet with rocket-borne magnetometers, J. Geophys. Res., 72: 1845 - 1861

Krylov A.L., Soboleva T.N., Fishchuk D.I., Tsedilina Ye. And V.P. Shcherbakov, 1973 Structure of the equatorial electrojet, Geomagnetism and Aeronomy, 13: 400 -404, English Translation.

Onwumechili C.A., 1965 A three-dimensional model of density distribution of ionospheric current causing part of quiet day geomagnetic variations, Proc. Second International

Symposium on Equatorial Aeronomy, ed. F. de Mendonca, pp: 384 - 386, Brazilian Space Commission, Sac Paulo.

Onwumechili C.A. 1967 Geomagnetic variations in the equatorial zone, Volume 1, Chapter III-2, pp. 425 -507, in Physics of Geomagnetic Phenomena, ed. Matsushita S. and W.H. Campbell, Academic Press, New York,

Onwumechili C.A.1992a A study of rocket measurements of ionospheric currents -V- Modelling rocket profiles of low-latitude ionospheric currents, Geophys. J. Int., 108: 673 -682

Onwumechili C.A.1992b A study of rocket measurements of ionospherio currents -IV. Ionospheric currents in the transition zone and the overview of the study, Geophys. J. Int., 108: 660 -672

Onwumechili C.A.1992c A study of rocket measurements of currents -III. Ionospheric currents at the magnetic dip equator, Geophys. J Int., 108: 647 - 659

Onwumechili C.A. and P.O. Ezema, 1992 Latitudinal and vertical parameters of equatorial electrojet from an autonomous data set, J. Atmos. Terr. Phys., 54: 1535 -1544

Onwumechili C.A. and P.C. Ozoemena 1989 Contours of equatorial electrojet current density, J. Atmos. Terr. Phys. 51: 163 -168

Raghavarao R. and B.G. Anandarao, 1987 Equatorial electrojet and the counter-electrojet, Indian J. Radio Space Phys., 16: 54 -75.

Richmond A.D., 1973 Equatorial electrojet -1. Development of a model including winds and instabilities, J. Atmos. Terr. Phys., 35: 1085 -1103

Singh A. and K.D. Cole, 1987 A numerical model of the ionospheric dynamo - II. Electric current at equatorial and low latitudes, J. Atmos. Terrr. Phys. 49: 539 -547

Stening R.J., 1985 Modelling the equatorial electrojet, J. Geophys Res., 90: 1705 -1719,

Sugiura M. and J.C.Cain, 1966 A model equatorial electrojet, J Geophys. Res., 71: 1869 - 1877

Sugiura M. and D. J. Poros, 1969 An improved model equatorial electrojet with a meridional current system, J. Geophys. Res., 74: 4025 -4034

Takeda M and H Maeda, 1980. Three-dimensional structure of ionospheric currents - 1. Currents caused by diurnal tidal winds. J. Geophys. Res., 85; 6895-6899.

Takeda M. and H. Maeda 1981 Three-dimensional structure of ionospheric currents -2. Currents caused by semidiurnal tidal winds, J. Geophys. Res., 86: 5861 -5867,

Untied J., 1967 A model of the equatorial electrojet involving meridional currents, J. Geophys. Res., 72: 5799 -5810