AN EXPOSITORY STUDY ON THE EQUATORIAL ELECTROJET

Agha S. O. & Agbo G. A.
Department of Industrial Physics
Ebonyi State University
Abakaliki, **NIGERIA**

ABSTRACT

The equatorial electrojet has been reviewed. The dip equator in comparison with other equators was considered. There have also been some highlights on the E-region ionosphere. It was noted that both the dip equator and the E-region are prerequisite concepts in electrojet studies. It is observed that the phenomenon of the equatorial electrojet has very strong dependence on the ionospheric activities in the E-region height and on the dip equator location.

Keywords: Electrojet, Dip equator, ionosphere, E-region**.**

INTRODUCTION

According to Chapman [1], the equatorial electrojet is defined as a high concentration of electric current flowing from west to east in a narrow belt flanking the dip equator on the sunward hemisphere. This current is unique by virtue of its restricted location, magnitude and effects. Generally, the field of equatorial aeronomy has been studied for many years by many researchers but numerous problems remain to be investigated as is the case for that matter in all aeronomical research [2]. This work tends to give an expository information about the phenomenon of the equatorial electrojet with highlights on the prerequisite concepts like the dip equator and the E-region ionosphere. Although the equatorial conditions are reflected in ionizations in other regions of the ionosphere, the degree of this effect in other regions is low compared with that of the daytime E-region.

Matsushita and Campbell [2] had earlier suggested that there was an increasing field in the daytime E-region which is due to the location of a strong current within this region. Their suggestion followed the direct proof of the existence of ionospheric currents determined with magnetic field sensors aboard rockets which had been sent through the ionoshpere. Bandyopadyay and Montes [3] noted that the H - components of the field due to this strong current was large and positive in a very narrow latitude region about the dip equator. According to Onwumechili [4], the enhanced east-west conductivity which occurs in a narrow strip flanking the dip equator decrease with distance from the equator. Martyn determined the half-width of the strip at 3^o latitude [5].

Chapman [6] noted that the height integrated conductivity at the magnetic equator was $2x10^{-7}$ emu. cm. Several investigations have been carried out on studies on the equatorial electrojet, some of which are mentioned here. Before reviewing the works of some of these researchers, a review of the concepts of the dip equator and the E-region ionosphere is imperative.

REVIEW ON THE DIP EQUATOR AND THE E-REGION IONOSPHERE

The Dip Equator

Sir Isaac Newton had argued that the shape of the Earth should be that of an oblate ellipsoid, as opposed to that of sphere; it should be somewhat flattened at the poles and should bulge outward around the equator [7]. This inference was made on logical grounds, the details of which are not presented here. The flattened poles (North and South) were called the geographic poles and the bulging equator,

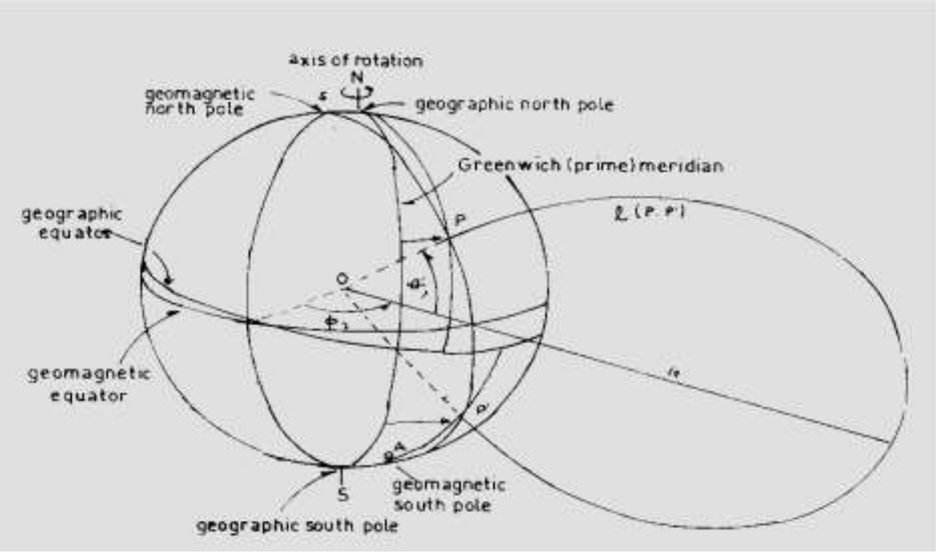

Fig.1:Geomagnetic locations based on a spherical coordinate system aligned with respect to the dipole field with latitude ø$^{'}$ and longitude $\theta^{'}$; P and P$^{'}$ are conjugate points on a dipole field line of length, L [8].

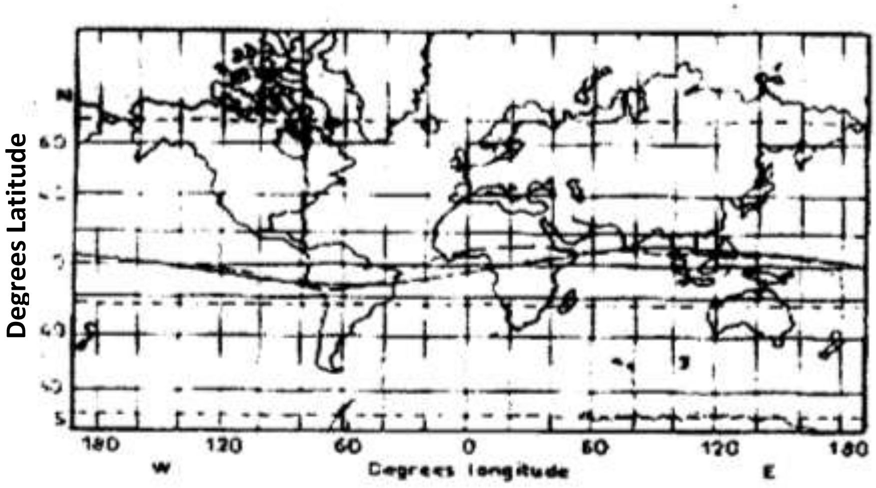

Fig. 2: A world map showing the geographic equator, the dip equator (broken line) and the dipole equator (solid line) [2].

the geographic equator. In the study of geomagnetism, the poles and the equator appear to be unique locations on the globe. But the geomagnetic poles and the equator do not coincide with the geographic poles and equator, respectively. Campbell [8] described the geomagnetic poles as the intersections of the I = 0^o obtained from local measurements of H and Z. Presently, these poles are inclined at about 11^o to the Earth's spin axis. Fig.1 illustrates the locations of the geomagnetic poles and equator. The geomagnetic dipole is the trace along the Earth's surface for which the dipole inclination, I = 0^o. This however is a different location from what is described as the dip equator corresponding to the axis of the dipole field at the Earth's surface. Schuster [9] suggested that in the absence of direct measurements the dip equator should be given by the location where the complete IGRF model field values show an inclination of 0^o. Lowrie [7] observed that the discrepancy between the geomagnetic and the dip equators is very large in the African continental region and small in the South American region. Making allusions to the Earth's field elements, Chapman [10] defined the dip equator as the line along which the vertical component of the geomagnetic field is zero. He noted also that when the geomagnetic field is developed into spherical harmonic series, the first order term is the major term and corresponds to the field that a dipole at the centre of the Earth would produce. He described the line along which the magnetic field of this equivalent dipole had no vertical component as the dipole equator. According to Onwumechilli [11], the degree to which the dip, the dipole and the geographic equators affect ionospheric current fluctuations and consequently geomagnetic field variations defines a region known as the equatorial region. An illustration of the three equators is shown in Fig. 2.

THE E-REGION OF THE IONOSHERE

Owing to the peculiar nature of the E-region ionosphere, the attentions of a lot of researchers have been attracted to it, since the past few decades [12]. The ionosphere is divided into regions and each region has its own unique behaviour. The E-region appears to be more significant perhaps because of its role in the ionospheric dynamo action. It is divided into a nighttime layer and a daytime layer [13]. Nikola [14] observed that the E-region ionization was mainly due to soft x-rays (1-10mm) and far ultraviolet radiation. He noted that the region can reflect radiowaves having frequencies less than 10 MHz and that its height-range is between 90 and 120km above the Earth's surface.

Newell [15] and Bordeau [16] revealed the possibility of observing both electron density and ion density profiles in the E-region. Very useful data have been published by Elling [17] and Hough [18] concerning the penetration frequencies of the nighttime E-layers. Elling recognized two layers- the middle layer of Watts and Brown [19] of higher density and the nighttime E-layer with a somewhat lower density. Robinson (20) noted from observations of the physical mechanism going on in the E-region ionization that the day-time E-layer was the best known of all ionospheric layers. He asserted that the E-layer maximum electron density measured by ground-based ionosondes is quite regular in its temporal and geographical variations.

Okeke [21] noted that the quiet field variations at observatories come from the dynamo current in the ionospheric E-region. According to the author solar radiation ionizes the ionosphere and wind carries the ionised particles with velocity V across the lines of the Earth's magnetic flux, B. This constitutes a conductor cutting the magnetic lines resulting in an induced emf (V x $\mathbf{B}$). The Author asserted that in a given region, the direction of **B** is fixed.

Therefore, for the current to make up its flow, the wind has to blow in closed curves, but contrary to expectation, the wind progresses, making the current divergent and incapable of completing its circuit. This leads to the establishment of a polarization field given by:

$$\boldsymbol{E} = -\nabla\phi \qquad (1)$$

Meanwhile there are two possible origins of electric field E whose sum is given by:

$$\boldsymbol{E}' = \boldsymbol{E} + (\nabla \times \boldsymbol{B}) \qquad (2)$$

The above resultant field maintains a current that completes the circuit. Because this current does not diverge,

$$\nabla.\boldsymbol{J} = \boldsymbol{0} \qquad (3)$$

and

$$\boldsymbol{J} = \sigma \boldsymbol{E}' \qquad (4)$$

Here, **J** is the current density and σ the tensor conductivity.

The illustration above reveals that to drive a current that completes the circuit, the dynamo induced field in the E-region must be aided by a polarization electrostatic field, E. Campbell [8] suggested that the E-region dynamo current is given that special name because the ionospheric plasma (a conductor) that is moved through the Earth's magnetic field is similar in a way to the current that is generated in the wires of a hydroelectric plant dynamo as these wires are moved by water turbines through the field of a large permanent magnet.

THE EQUATORIAL ELECTROJET

There has been a lot of evidence of a dynamo current flowing in the ionosphere especially at the E-region. The most convincing proof of ionospheric currents comes from magnetic field sensors aboard rockets that have been sent through the ionosphere. According to Ptaff et al [22] an increasing field in the day-time E-region (Fig.3) always show the location of a strong current as the rocket approaches the critical Sq altitude and the H equivalent component of the field becomes large and positive in a very narrow latitude region about the dip equator. The physics of the ionosphere requires that a special current condition be established at the magnetic dip equator, where the Earth's field is directed magnetic south to north in a horizontal plane [23]. There, the hall current inhibited by the ionospheric boundaries perpendicular to the flow, causes a polarization field to be established in opposition to the flow. Under these equatorial conditions, the effective conductivity parallel to the boundary (at right angle to the Earth's magnetic field) is increased above the normal Pedersen conductivity. The net result is a considerable enhancement of the east-west conductivity that concentrates the flow of any arriving E-region ionospheric current. This observation is described as the equatorial electrojet. The width of this fountain at the magnetic equator is about 450-550 km and the latitudinal spread is in the range, $\pm 20^0$.

The phenomenon of the equatorial fountain was first noted in 1922 by the department of Terrestrial magnetism of the Carnegie institution, Washington from a geomagnetic observatory established at Huancayo, Peru. The actual nature of Huancayo increased Sq (H) field was greatly investigated but prior to the investigation, Egedal [24] had observed that the diurnal range at six stations near the equator showed a sharply peaked curve symmetrical about the dip equator and smoother than a plot against dipole latitude [2]. Later experiments by Pontier [25] in Togo, Giesecke [26] in Peru, Madwar [27] in Sudan and Gulatee [28] proved that the increase in the H-component of the Earth's magnetic field may be found anywhere on the Earth near the dip equator. Investigators such as Onwumechili [11], Cahill [29] and Forbush and Casaverde [30] have examined the height, width and current intensity of the electrojet. Cowling and Borger [31] noted that in the ionosphere, hall current leading to polarization easily leaks away along the lines of force of the geomagnetic field except at the dip equator, where the geomagnetic field is entirely horizontal. This observation has been investigated by many researchers such as [6]. It is presently apparent that the consequent enhancement in ionospheric conductivity is enough to account for the total Sq field variation observed. Campbell, et al [36] discovered that even though the geomagnetic latitude distribution best organizes Sq data at most locations, near the equator, the dip latitude dominates the equatorial electrojet processes. Thus in their analysis of the external Sq currents in the India-Siberia region, three equatorial station latitude assignments were altered by about 1^o or less. Two was done to allow the strong Sq electrojet field to appear at 0^o latitude location. Such an electrojet adjustment according to them was typical for Sq studies and had no effect upon the major conclusions of their own work.

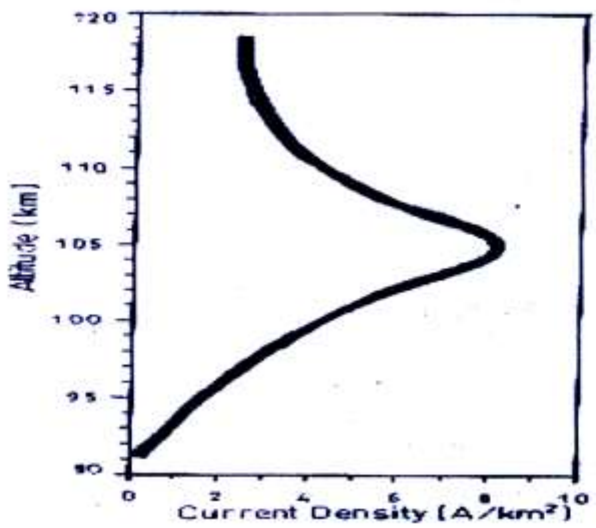

Fig 3: Ionospheric current density observed for rocket flight near the equinox and close to the dip equator; maximum E-region current detected near 106-km altitude [22].

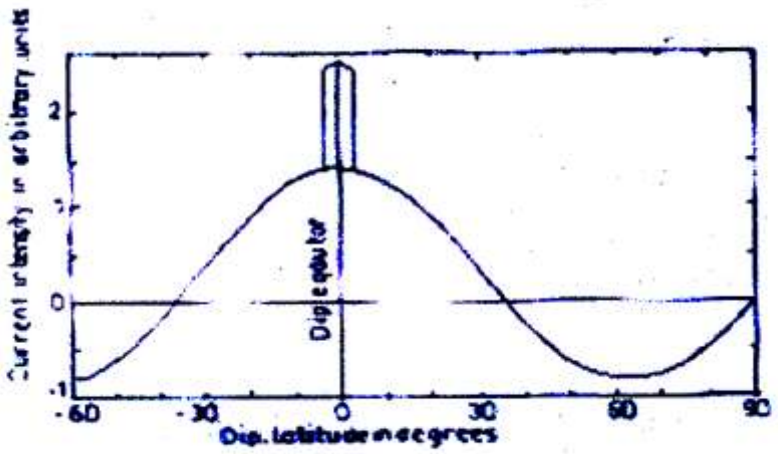

Fig 4 Amplitude of the intensity of the Eastward component of the dynamo current as a function of dip latitude [37]

Baker and Martyn (37) had suggested that the enhanced east-west conductivity occurring in a narrow strip flanking the dip equator decreases with distance from that equator, and that the current in the equatorial strip has a daytime value given by:

$$I_y = KCK_3 \begin{bmatrix} (10\sin^3 \theta\text{-}7.88\ \mathrm{cosec}\theta)\sin 2\phi + \\ 1.31\mathrm{cosec}\ \theta\cos^2 2\phi \end{bmatrix}$$

……………………………………………..(5)

They added that the eastward component of the dynamo current in every other place was given as:

$$I_y = KCK_3 \begin{bmatrix} 2.67\sin \theta\text{-}4\sin^3\theta - 0.085\tan^2) \\ 1/2\theta\mathrm{cosec}\theta)\sin 2\phi \\ \text{-}0.14\tan^2 1/2\theta\mathrm{cosec}\theta\cos 2\phi \end{bmatrix}$$

…………………………………………… (6)

where the values of the constants vary with location. C is almost M/r^3 where M is the magnetic moment of the Earth and r is the radial distance of the current from the Earth centre and K$_3$ is the height integrated effective conductivity whereas k is an amplitude factor in the velocity potential.

Massey and Boyd (38) showed that the longitudinal conductivity within the equatorial zone is given by:

$$\sigma_0 = \sum \frac{n_r e_r^2}{m_r v_r} \qquad (7)$$

Pedersen [39] also showed that the Pedersen conductivity is given as:

$$\sigma_1 = \sum \frac{n_r v_r e_r^2}{m_r (v_r{}^2 + w_r^2)} \qquad (8)$$

while the Hall conductivity σ_2 is given by:

$$\sigma_2 = -\sum \frac{n_r w_r e_r}{m_r (v_r^2 + w_r^2)} \qquad (9)$$

In equations (3), (4) and (5), r represents the type of charged particles, n_r, the number of the particles, m_r the mass, v_r the collision frequency of the charged particles with neutral particles and w_r the gyro-frequency.

From equations (3), (4) and (5) it can be shown that the effective conductivity σ_3 is greater than Pedersen conductivity and is given by:

$$\sigma_3 = \sigma_1 + \sigma_2^2 / \sigma_1 \qquad (10)$$

σ_3 is also referred to as the cowling conductivity and represents an enhancement over Pedersen conductivity. This is the major cause of the equatorial electroject. Forbush and Casaverde [30] noted however that the equatorial electrojet manifests as a great daytime increase in the H element of field that peaks prior to local noon and that near Huancayo, Peru, the main field is smaller than at other dip equator observatory locations. According to them, such a field alters the E-region gyro-frequency which generally produces larger than average electrojet effect at that location. They added that the dip equator moves with the westward drift of the main field so that its position was moving southward in Peru (and northward in India).

DIP EQUATOR IONOSPHERIC E-REGION AND THE ELECTROJET EFFECT

The location of the magnetic (or dip) equator is usually described as the locus of zero dip along the surface of the Earth. Egedal [24] noted that the dip latitude in general varies with longitudes and it also varies with height above the surface of the Earth. At a height between 90km and 120km is the ionospheric E-region where the net ionization is very high even though recombination takes place too [40]. It is also observed that the rate of change of ions (i) and electrons (e) at this height-region are respectively given as:

$$\frac{dn_i}{dt} = R_o \cos(\chi) - a_{ie} n_i n_e \qquad (11)$$

and

$$\frac{dn_e}{dt} = R_o \cos(\chi) - a_{ie} n_i n_e \qquad (12)$$

where $R_o \cos(\chi)$ is the production rate and α is the recombination coefficient; n_i and n_e are number of ions and electrons respectively [41]. χ is the angle from the zenith to the location of the sun. Chapman [42] noted that the E-region ionization varies as $(\cos(\chi))^{1/2}$. Mason [43] observed that the daytime E-region ionospheric current at the dip equator is very strong. He attributed the cause to be due to an enhanced conductivity at 100km height associated with the special magnetic field configuration characteristic of the location (Fig.4). Egadel [44] described this observation as the equatorial electrojet and suggested that the effect generates irregularities in electron density such that even at night, when the electrojet has subsided and there is little ionization in the equatorial E-region, fairly strong scattering irregularities usually remain in the neighbourhood of 100km (within the E-region).

CONCLUSION

The equatorial electrojet is a daytime phenomenon arising from the special mutually perpendicular configurations of the equatorial magnetic field and the Sq current system with respect to the vertical. The height interval in which the electrojet flows more or less coincides with the E-region heights (near 100km) at which various ionospheric irregularities are encountered [2]. The basic manifestation of the equatorial electrojet at ground level is the high daytime horizontal geomagnetic field strength variation observed at the magnetic (or dip) equator. It has however been realized that certain scatter – echo configurations noted on conventional ionograms were associated with the electrojet current variations [45]. Such ionograms of associated configurations at E-region heights are generally known as “sporadic E” (or E_s) and the configuration identified on equatorial ionogram as “equatorial sporadic E”. The irregularities that produce the equatorial sporadic E configuration have been shown by Ohen et al [46] to be situated within the equatorial electrojet, and an understanding of the physical characteristics of the irregularities is of interest, both for its own sake and for the purpose of studying the physics of the electrojet.

It is noted that through the study of ionograms, magnetograms and by the employment of ground backscatter, etc., many researchers have obtained some practical information of the physical characteristics of the irregularities related to the electrojet, the experiment nevertheless appear to reveal that the phenomena that occur are more complicated than those aspects that have already been explained by theory and further experimentation seems to be imperative. Future researchers are therefore recommended to consider such a phenomenon with a view to simplifying them.

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