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ARTICLE

Ionospheric Currents in the Equatorial and Low Latitudes of Africa

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ABSTRACT

The magnetometer data obtained for 2008 from geomagnetic stations installed across Africa by magnetic data acquisition set (MAGDAS) have been used to study the ionospheric Sq current system in the equatorial and low-latitudes of Africa. The aim of this work is to separate the quiet-day field variations obtained in the equatorial and low latitude regions of Africa into their external and internal field contributions and then to use the paired external and internal coefficients of the SHA to determine the source current and induced currents. The method used involved a spherical harmonic analysis (SHA). This was applied in the separation of the internal and external field/current contribution to the Sq variations. The result shows that the variation in the currents is seen to be a dawn-to-dusk phenomenon with the variation in the external currents different from that of the internal currents both in amplitude and in phase. Furthermore, the seasonal variation in the external current maximizes during the March equinox and minimizes during the December solstice. The maximum current observed in AAB and ILR is due to the Equatorial Electrojet Current present in the AAB and ILR stations. Seasonal variation was observed in the geomagnetic component variations as well as in the currents. This is attributed to the position of the sun with respect to the earth at different months of the year. The equinoctial maximum is observed in external current intensity which occurred mostly during the March Equinox.

Keywords: Equatorial; Low latitudes; Africa; Ionospheric Sq; Currents

1. Introduction

The magnetic field can be divided into three distinct parts as seen on the earth's surface: The observed magnetic field is made up of three compo-

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nents: The Main Field, the External Magnetic Field, and the Crustal Field. The Main Field is the largest component of the magnetic field and is thought to be produced by electrical currents in the fluid outer core of the Earth. The External Magnetic Field is thought to be produced by interactions between the Earth's ionosphere and the solar wind. Electric currents are comparable to those fluctuating in the atmosphere of the Earth flow in the conducting Earth below the source current. The characteristics of the source currents and the distribution of electrically conducting materials in the Earth affect the size, direction, and depth of penetration of the induced currents. Magnetometers detect the composite of external (source) and interior (induced) field components from the currents at observatories on the surface of the Earth. The amplitudes and phase connections were demonstrated to be helpful in calculating the conductivity of the deep earth when these currents were divided into their component portions using Spherical Harmonic Analysis (SHA) or other integral techniques [1]. The period of fluctuation of the source current and the distribution of electrically conducting materials in the area of the earth beginning to be explored determine the depth of penetration of the induced current into the deep earth [2].

Campbell and Schiffmacher [3] established equivalent ionospheric source currents representing the quiet-day geomagnetic variations for a half-sector of the Earth that induced Australia. They used a spherical harmonic separation of the external and internal fields for the extremely quiet condition existing in 1965. According to their result, the month-by-month behavior of the current system indicated a clockwise vortex source with a maximum of 12.8×10^4 A in January and a minimum of 4.4×10^4 A in June.

Takeda [4] noted that the intensity of the Sq currents in high solar activity was about twice as large as it is in low solar activity. By comparing the amplitude of the Sq for the same value of conductivity, Takeda [5] pointed out that solar activity depends on the Sq amplitude. He noted that the seasonal variation is seemingly due to differences in neutral winds or due to the magnetic effect of the field-aligned current (FAC) flowing between the two Hemispheres generated by the asymmetry in the dynamo action.

The aim of this work is to separate the quiet-day field variations obtained in the equatorial and low-latitude regions of Africa into their external and internal field contributions and then to use the paired external and internal coefficients of the SHA to determine the source current and induced currents.

2. Data source

The average hourly geomagnetic data used in this study were obtained from geomagnetic stations established in parts of the region (Ilorin (8.5°N, 4.68°E), Lagos (6.4°N, 3.27°E), Addis Ababa (9.04°N, 38.77°E) and Hermanus (34.34°S, 19.24°E)) by magnetic data acquisition set (MAGDAS), Japan for the year 2008 as presented in **Figure 1**.

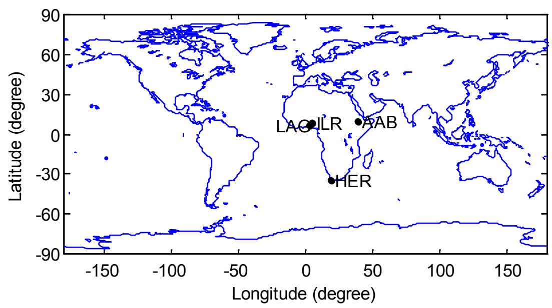

Figure 1. Geographical map showing the study area.

3. Method of analysis

The method employed in this work involves the Spherical Harmonic Analsysis (SHA) devised by Guass (1838) in solving the magnetic potential function *V*. It was Guass [6] who showed that the potential has two parts: the external (source) and internal (induced) parts of the potential function. He expressed the magnetic potential of the Sq field, *V* measured from the daily mean values at the universal time, *T* comprises of both the internal (induced) current and the external source current as a sum of spherical harmonics as:

$$V_n^m = C + a \sum_{n=1}^{\alpha} \sum_{m=0}^{n} \left\{ \left({}_{an}^{me} \left(\frac{r}{a} \right)^n + {}_{an}^{mi} \left(\frac{a}{r} \right)^{n+1} \right) \cos(m\phi) + \left({}_{bn}^{me} \left(\frac{r}{a} \right)^n + {}_{bn}^{mi} \left(\frac{a}{r} \right)^{n+1} \right) \sin(m\phi) \right\} {}_{p_n}^{m}(\theta) \quad (1)$$

where C, θ, a, r *and* ϕ denote a constant of integration, the geomagnetic colatitude, the earth's radius and the local time of the observatory respectively. a_n^{me}, a_n^{mi}, b_n^{me} and b_n^{mi} are Legendre polynomial coefficients, e and i represent the external and internal values, respectively. P_n^m are Legendre polynomials and are functions of colatitude θ only. The integers, n and m are called degree and order respectively. Following Campbell [7] the equivalent current function, J(φ) in Amperes for an hour of the day, φ/15 (the longitude divided by 15^o) is obtained from:

$$J = \sum_{m=1}^{4} \sum_{n=m}^{12} [U_n^m \cos(m\phi) + V_n^m \sin(m\phi)]\, P_n^m \quad (2)$$

With 4 for the maximum value of m, and 12 for the maximum value of n. For the external current representation, we have:

$$U_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right) a_n^{me}\left(\frac{a}{R}\right)^n \quad (3)$$

$$V_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right) b_n^{me}\left(\frac{a}{R}\right)^n \quad (4)$$

And the internal current representation, we have:

$$U_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right) a_n^{mi}\left(\frac{R}{a}\right)^{n+1} \quad (5)$$

$$V_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right) b_n^{mi}\left(\frac{R}{a}\right)^{n+1} \quad (6)$$

where, R is the radius of the Earth in kilometers.

The value of a is the radius of a sphere whose surface is located where a current could flow to give the fields described at the Earth's surface by the SHA, hence the name "Equivalent Current". It is believed that the dynamo current sources are in the ionospheric E-region (near 100 km altitude). Because there is other evidence that the dynamo current source is in the E-region ionosphere, near 100 km altitude, the value of a ≈ R and the ratio $\left[\frac{a}{R} - 1\right]$ may be omitted from the current computations [8].

However, the equivalent external current intensity I of latitudinal component Θ and longitudinal component ø can be determined (in amperes) from J by:

$$I_\theta = \frac{1}{r\sin\theta}\frac{\partial J}{\partial \emptyset} \quad (7)$$

$$I_\emptyset = -\frac{1}{r}\frac{\partial J}{\partial \theta} \quad (8)$$

Therefore, the total current intensity (internal and external) can be given by:

$$I = I_\theta + I_\emptyset \quad (9)$$

4. Results and discussion

Figure 2 shows the external currents for the four African stations: ILR, LAG, AAB and HER while **Figure 3** shows the contour map for the external current in Africa. The variation in the external currents occurred in all hours of the day from dawn to dusk. The external current curves for all the stations are seen to increase gradually from midnight values to a maximum intensity around 10:00 for AAB, 11:00 for LAG, 11:00 for Lagos and 13:00 for HER and a gradual decrease to midnight values. This effect is also observed in the contour maps for the external current shown in **Figure 3**. The contour lines of the contour map are seen to be increasing inwards which indicates a positive variation pattern.

It is observed that the nighttime values are minimal. This is due to the disappearance of the sun which is the main source of ionization in the ionosphere. Takeda [4] noted that the intensity of the Sq currents in high solar activity was about twice as large as it is in low solar activity. Moldwin [9] also noted that the ionospheric ionization at any given position depends on the position of the sun in the sky and on its absolute output.

At night, the amount of sunlight goes to zero and production due to photoionization ceases. However, the currents are not observed to be zero. This therefore suggests that the observed nighttime currents are from sources different from the ionospheric sources. Moldwin [9] noted that these currents are from other sources like the magnetospheric and ring currents. Obiekezie [10] pointed out that these currents filter into the ionosphere at night even during magnetic quiet periods. This non-zero current at night is reported by other researchers such as Campbell [11], Okeke and Rabiu [12], Rabiu [13], and Obiekezie, et al. [14].

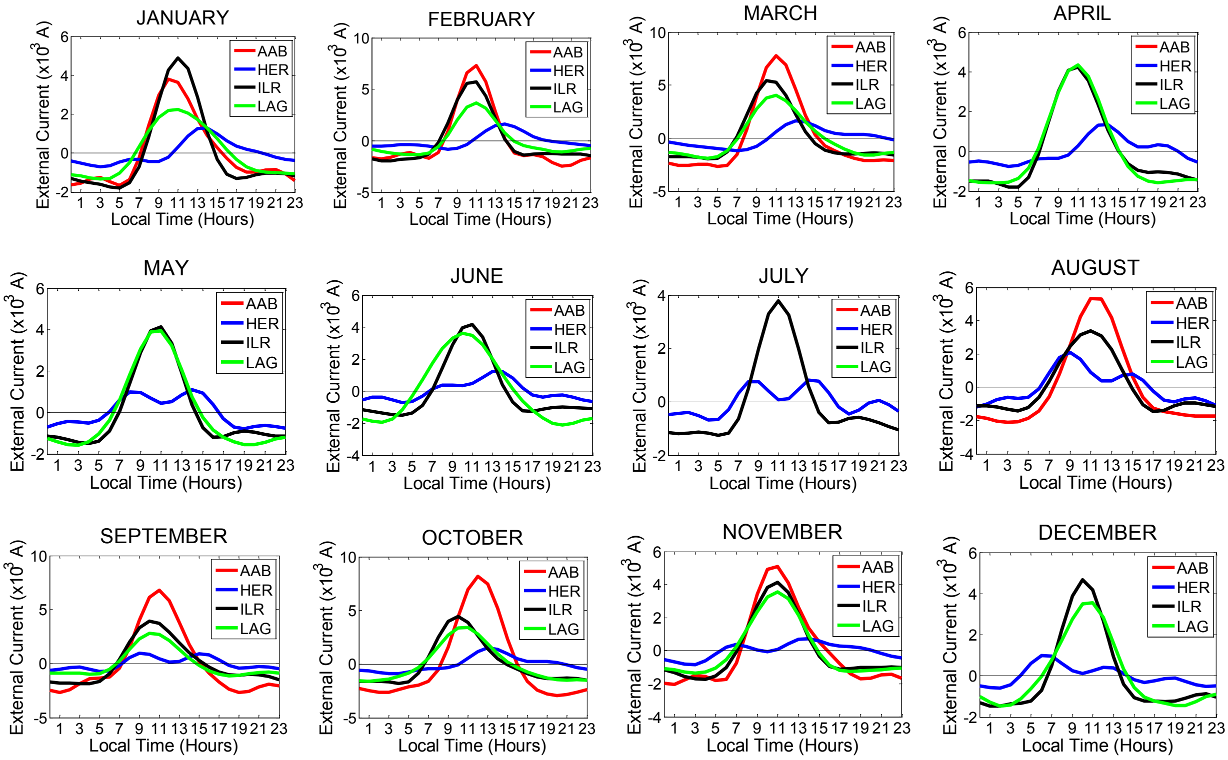

Figure 2. External Sq current across Africa (ILR, LAG, AAB, HER).

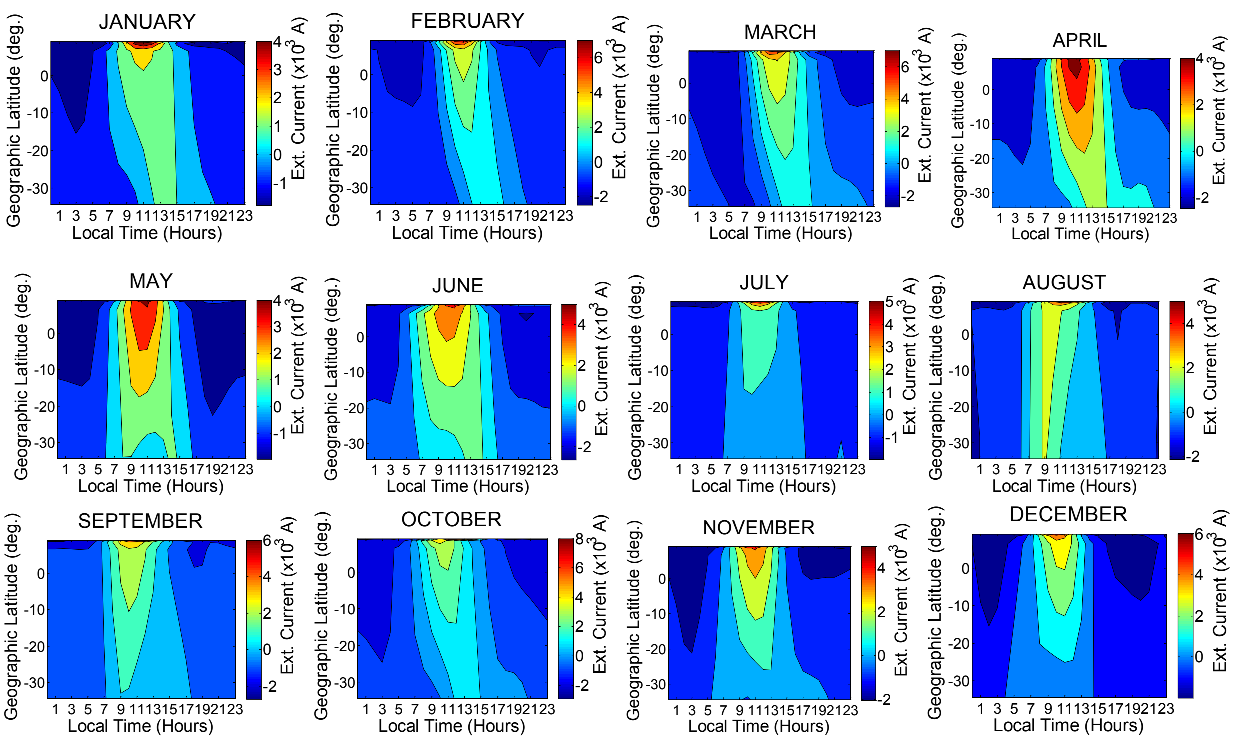

Figure 3. Contour map of external current for equatorial, low and mid latitudes of Africa.

The maximum current was observed in ILR in January and in AAB in almost all the months. AAB and ILR are equatorial electrojet stations located at latitude 0.18° of the dip equator. The equatorial electrojet is a narrow belt of intense electric current in the ionosphere confined to about ±3° of the dip equator. This result is in agreement with the work of Rastogi [15] who observed a maximum diurnal and semi-diurnal variation in X over the dip equator indicative of EEJ. Obiekezie et al. [14] also observed a maximum Sq (H) variation at the AAB station indicative of the EEJ.

The external current pattern in HER station which is in the Southern hemisphere shows a crest-like pattern just like the other three stations in Africa in the Northern hemisphere. This is not in line with the suggested pattern of the ionospheric current system. The ionospheric currents typically form two global horizontal current vortices at the sunlit side of the Earth, one flowing clockwise in the Southern hemisphere and the other flowing counterclockwise in the Northern hemisphere. The HER is expected to have a current pattern opposite that of ILR, LAG and AAB because of the hemispherical differences between them, however, it was observed that HER was having a crest also. This behavior could be attributed to the position of the station with respect to the Sq focus in the southern hemisphere. Hence, it is suggested that within the equatorial and low latitudes, the ionospheric current pattern is the same in both hemispheres.

Maximum external currents were obtained in March equinox for all the stations: ILR, LAG, AAB and HER with a value of approximately 4.8×10^3 A for ILR, 4.2×10^3 A for LAG, 8×10^3 A for AAB and 1.5×10^3 A for HER. This equinoctial maximum in the external currents is in agreement with Obiekezie and Okeke [2]. The minimum external current was observed in June Solstice in ILR, and HER with a value of 3.8×10^3 A, 5×10^3 A and 8×10^3 A respectively. At LAG and AAB, minimum variation was observed during the December Solstice and September equinox with a value of 2.85×10^3 A and 2.5×10^3 A respectively.

As can be seen in **Figure 4**, the variation in the internal currents occurred in all hours of the day

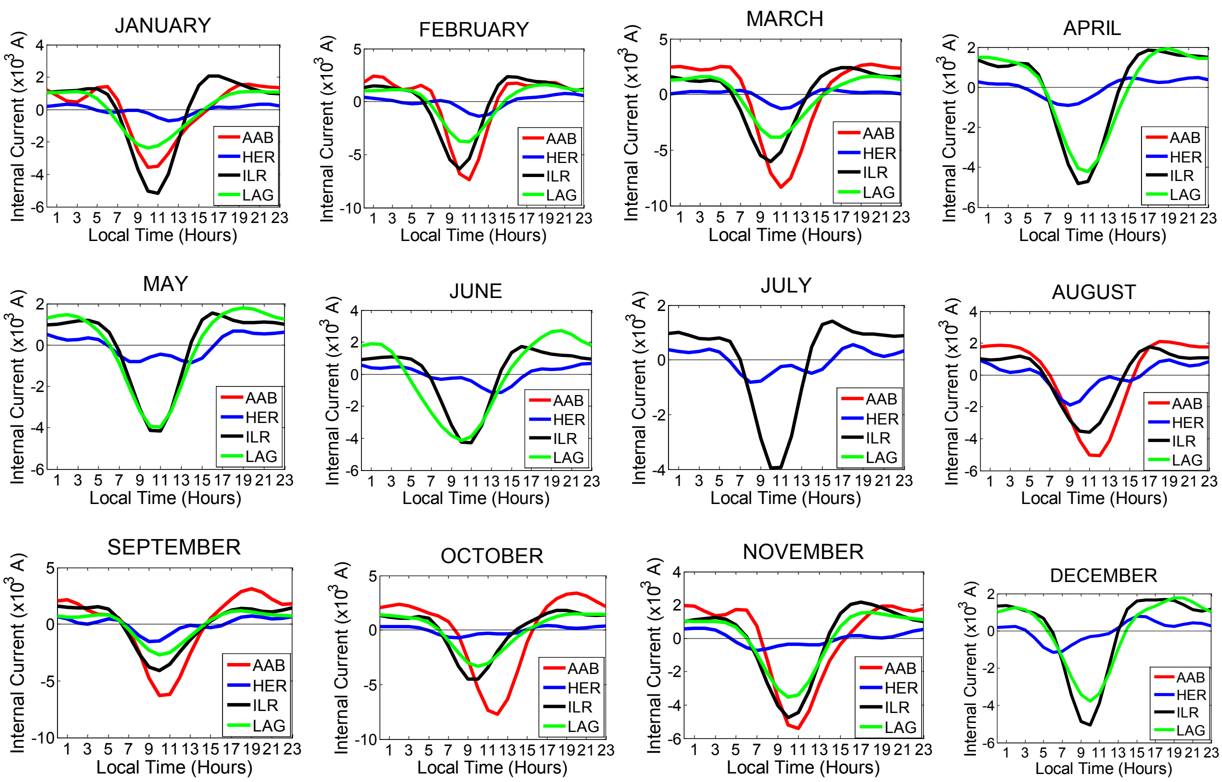

Figure 4. Internal Sq current across Africa (ILR, LAG, AAB, HER).

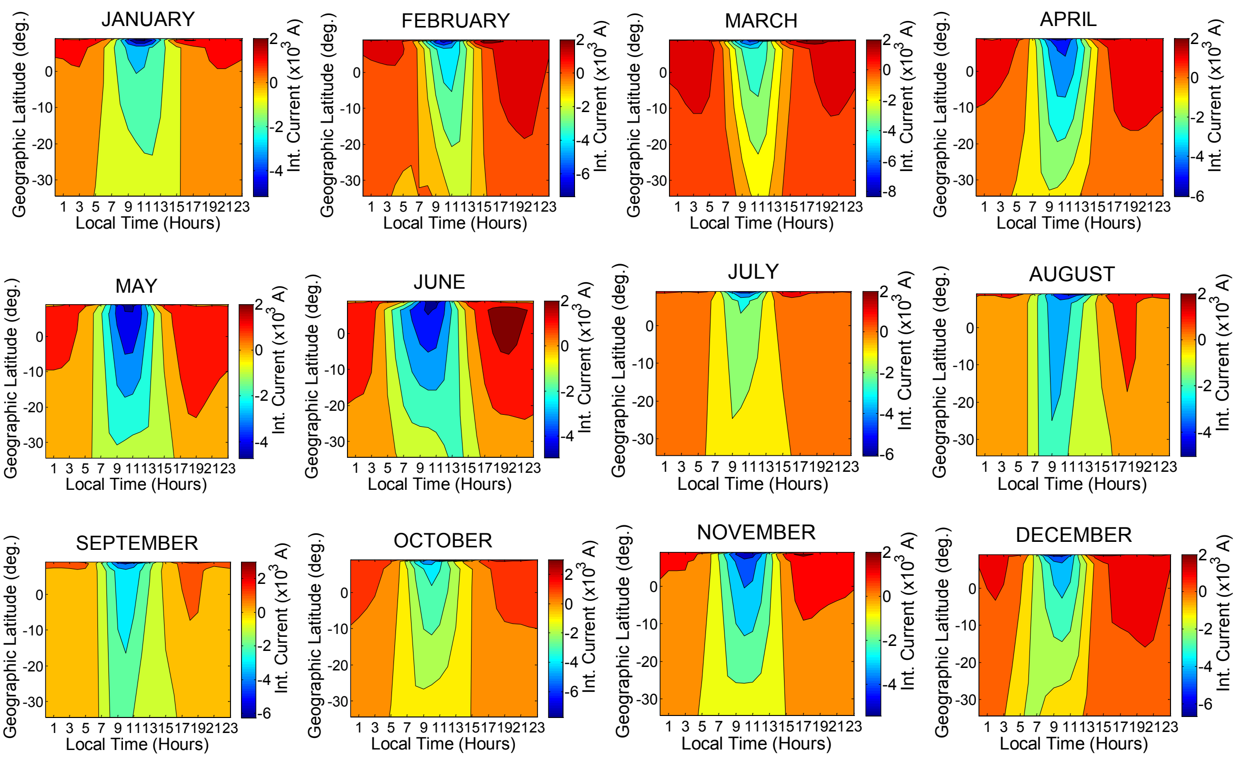

Figure 5. Contour map of internal current for equatorial, low and mid latitudes of Africa.

from dawn to dusk. The observed variation in internal currents is seen to be different from the external currents both in amplitude and phase. These differences observed in the phase and amplitude are a function of the Earth's conductivity. This is also reflected in the contour maps of the internal currents as shown in **Figure 5**. The calculated internal and external currents are seen to be lower than those of Campbell, et al. [16], and Obiekezie and Okeke [2]. Campbell et al. [16] observed external and internal currents in the order of 10^4 A while Obiekezie and Okeke [2] observed external and internal currents in the order of 10^6 A.

5. Conclusions

The application of the solar quiet day ionosphere current has enabled us to study the ionospheric Sq current system in the equatorial and low latitudes of Africa. The following deductions can be made from the results:

1) The maximum current observed in AAB and ILR is due to the Equatorial Electrojet Current present in the AAB and ILR stations.

2) Within the equatorial and low latitudes regions, the ionospheric current pattern is the same in both hemispheres.

3) The position of the station with respect to the Sq focus affects the external current pattern.

4) The source currents varied from the induced currents both in amplitude and phase.

5) Seasonal variation was observed in the geomagnetic component variations as well as in the currents. This is attributed to the position of the sun with respect to the earth at different months of the year.

6) The equinoctial maximum is observed in external current intensity which occurred mostly during the March Equinox.

Conflict of Interest

There is no conflict of interest.

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