EXTERNAL Sq CURRENTS IN THE WEST AFRICAN REGION

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(Received 3 February 2009)

Abstract

The external Sq currents for quiet days in 1993 were studied for the West African region using the magnetic data obtained in the course of the French participation in the International Equatorial Electrojet Year (IEEY). Spherical Harmonic Analysis technique was used to separate the internal and external contributions of the quiet field variations. The external current range provided a simple way of viewing a full year's change in the external Sq current system. The maximum range was found in March with a value of 34.4×10^6 A and the minimum found in December with a value of 1.7×10^6 A. The seasonal variation was found highest in March (equinox) with a value of 16.6×10^6 A followed by June (summer solstice) 9.42×10^6 A; the least was found in December (Winter solstice) 7.76×10^6 A.

1. Introduction

The current sources of Sq are known to arise primarily from thermal-tidal motions in the ionosphere and they induce a secondary current that flows in the conducting earth. The depth of this induction depends upon how rapidly the source varies and the conductivity patterns within the earth. At the earth's surface, magnetometers measure the sum of the fields from the source and induced currents.

By using Gauss Spherical Harmonic Analysis (SHA) method or other integral methods one can separate this current into its component parts. The authors of [1, 2] used this SHA method to show that the daily quiet-time geomagnetic field variations came mostly from sources of current external to the Earth; this finding led to the discovery of the ionosphere. Recent investigations of the external source currents for the India-Siberia region [3-5] and Australian region [6] are the latest example of this Gauss SHA method.

The aim of this work is to analyze the quiet-time geomagnetic fields for the year 1993 in the West African region using the SHA method to separate the Sq ionospheric source currents from the induced currents within the Earth and examine how these external currents change through the months and seasons in the year.

2. Data and analysis

The geomagnetic data set used in this study consists of hourly mean values of H, D, and Z Fields obtained from the International Equatorial Electrojet Year (IEEY) record in the West African sub-sector. The data were collected during the intensive, coordinated, and pluridisciplinary investigation of ionospheric dynamics in the equatorial region of the African sector [7, 8]. The network consists of ten stations which operated from November 1992 to November 1994 along a 1200 km long North-South profile across the magnetic dip equator. The sites are located between Ivory Coast in the south and Mali in the North with approximately 150 km space between sites. Table 1 shows the geographic location of the stations.

Table 1. Geographic positions of the magneto telluric stations operating during the IEEY West African experiment.

	stations	symbols of stations	latitudes (°N)	Dip-latitudes (°N)	distances (km) from dip-equator	Longitudes (°W)
1	Tombouctou	TOM	16.733	5.513	611.98	3.000
2	Mopti	MOP	14.508	3.288	365.00	4.087
3	San	SAN	13.237	2.017	223.91	4.879
4	Koutiala	KOU	12.356	1.136	126.11	5.448
5	Sikass	SIK	11,344	0.124	13.75	5.706
6	Nielle	NIE	10.203	-1.017	-112.85	5.636
7	Korhogo	KOR	9.336	-1.884	-209.17	5.427
8	Katiola	KAT	8.183	-3.037	-337.1	5.044
9	Tiebissou	TIE	7.218	-4.003	-444.48	5.241
10	Lamto	LAM	6.233	-4.988	-553.61	5.01

The method of analysis for this work involves the spherical harmonic analysis (SHA) devised by [9] in solving the magnetic potential function V, in which it was shown that the potential has two parts—the external (source) and internal (induced) parts of the potential function. The magnetic potential V at geocentric distance r is expressed as

$$V = C + R\sum_n \sum_m \{ \left[a_n^{me} + a_n^{mi}\right] Cosm\phi + \left(b_n^{me} + b_n^{mi}\right) Sinm\phi \} P_n^m(\theta), \quad (1)$$

where $C, \theta, R, and \phi$ denote the constant of integration, the geomagnetic colatitude, the earths radius, and the local time of the observatory. The $a_n^{me}, a_n^{mi}, b_n^{me}$ and b_n^{mi} are the Legendre polynomial coefficients, where e and i represent the external and internal values, respectively. p_n^m are the Legendre polynomials and functions of colatitude θ only. The integers n and m are called degree and order, respectively; n has a value of 1 or greater, and m is always less than or equal to n.

On the other hand, the surface magnetic variation fields, H, D, and Z are analyzed in the form

$$H = \sum_{n=m} \sum_{m=1} \left[a_n^m Cos(m\phi) + b_n^m Sin(m\phi)\right] \frac{\partial P_n^m(\theta)}{\partial \theta}, \quad (2)$$

$$D = \sum_{n=m} \sum_{m=1} \left[- b_n^m Cos\,(m\phi) + a_n^m Sin\,(m\phi)\right] m \frac{P_n^m(\theta)}{Sin\,\theta}, \quad (3)$$

$$Z = \sum_{n=m} \sum_{m=1} \left[a_n^m Cos\,(m\phi) + b_n^m Sin\,(m\phi)\right] P_n^m(\theta), \quad (4)$$

where

$$a_n^m = \left(a_n^{me} + a_n^{mi}\right) \text{ and } b_n^m = \left(b_n^{me} + b_n^{mi}\right). \quad (5)$$

The equivalent current function $J(\phi)$, in amperes, for an hour of the day is obtained from

$$J(\phi) = \sum_{m=1}^{4} \sum_{n=1}^{12} \left(U_n^m Cos(m\phi) + V_n^m Sin(m\phi)\right) P_n^m(\theta), \quad (6)$$

$$U_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right)a_n^{me}\left(\frac{a}{R}\right)^n, \tag{7}$$

$$V_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right)b_n^{me}\left(\frac{a}{R}\right)^n. \tag{8}$$

For the internal current representation

$$U_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right)a_n^{mi}\left(\frac{R}{a}\right)^{n+1}, \tag{9}$$

$$V_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right)b_n^{mi}\left(\frac{R}{a}\right)^{n+1}, \tag{10}$$

where a is the geocentric distance of the current sheets [10].

The analysis was started with the selection of magnetically quite days from the five internationally quite days (IQDS) in each month for the year 1993. The base line for this analysis is taken as the average for the mean of the five quite days for the month. The base line removal was followed by the Fourier analysis of the three components of the magnetic field, then came the polynomial fitting of the latitudinal variation of the station field Fourier components and the computation of the Legendre polynomial coefficients. To avoid noise that is common in high harmonics, the SHA coefficients were computed to degree 12 and order 4.

3. Results and discussion

Figure 1 illustrates the separated currents; external, internal, and total (external + internal) currents in the West African region for the month of March in 1993. The station Mopti is used to represent the northern stations while Katiola represents the southern stations. The internal currents are seen to be different from the external currents both in amplitude and in phase. These phase and amplitude differences are a function of the Earth conductivity (4).

The external current pattern is seen to be different in the northern and southern stations. The external current pattern in the northern stations is seen to be exactly opposite that in the southern stations.

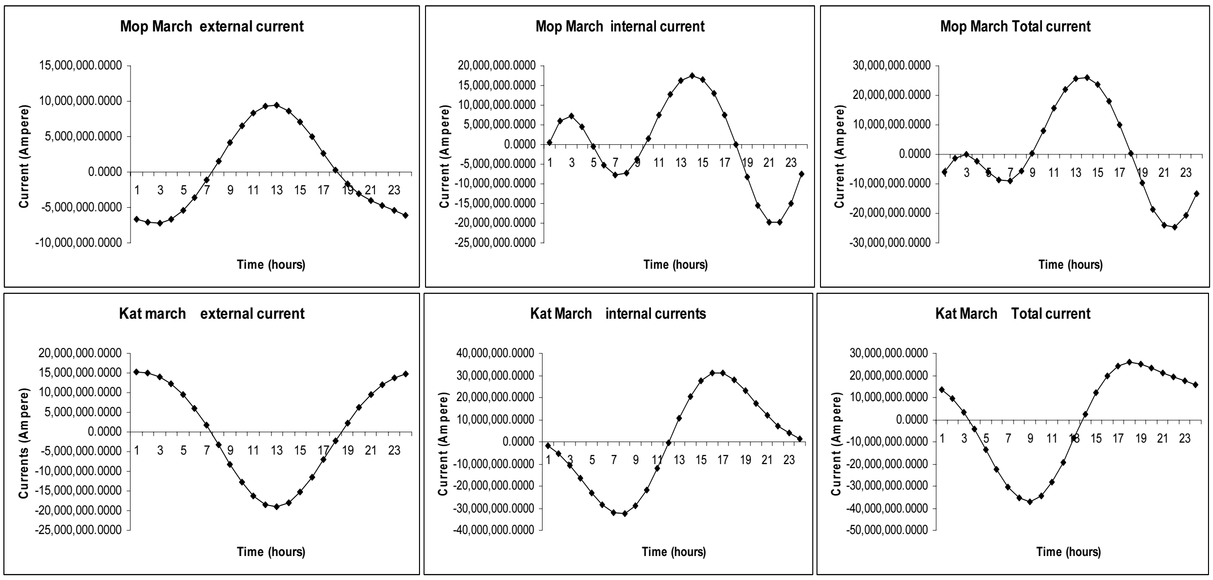

Fig 1. Separated external, internal, and total currents for Mopti (MOP) and Katiola (KAT) for the month of March.

For the northernmost stations (Tombouctou, Mopti, and San), it is seen to be negative in the early morning hours and positive in the afternoon; then turns negative again in the late noon hours with a shape of an anticline, while for the southernmost stations (Katiola, Lamto, and Tiebissou), it is seen to be positive in the early morning hours, negative in the afternoon; then it turns positive again in the late noon hours, having a shape of a syncline. The midday increase at the northernmost stations is matched by a midday decrease in the southernmost stations.

The external current range for each month and station is identified as the difference between the maximum and the minimum current levels for the individual month and station. This range is a single value for a given month and station and provides a simple way to view a full year's change in the external Sq current system. Table 2 shows the calculated monthly ranges for the different stations. The maximum range is found in March with a value of 34.3×10^6 A and the minimum range is found in December with a value of 1.7×10^6. The yearly averages of March, June, and December are used to represent the equinoxial, summer and winter solsticial variation of these external currents. We found from Table 2 the maximum value in March (equinox) with a value of 16.6×10^6 A followed by June (summer solstice) 9.42×10^6 A; the least is found in December (Winter solstice) 7.76×10^6 A. Our representation of the quite external currents can be compared to several regional Sq studies. The two most comprehensive ones are that of [11, 12].

The authors of [11] analyzed the international Geophysical year (IGY) 1958 records by dividing the seasons into three month groups of D, E, and J months. Their computed current vortices from the Euro-African sector (they called it zone 1) showed maximum amplitudes of 12.9×10^4, 22.5×10^4 and 26.4×10^4 for the D, E, and J months, thus having a maximum occurring at the J months. If we followed [11] three months grouping we would get 11.13×10^6, 13.27×10^6, and 8.58×10^6 A for D, E, and J months having a minimum in the J months, a maximum for the E months. This is in disagreement with [11], who reported their zone 1, northern hemisphere (Euro-African region) J month currents to be larger than their E month current. A part of the discrepancy may be due to this decision to average together recordings of two different continents. The stations in this study are located very close to the equator; in effect, we are dealing with equatorial stations, so it is not surprising that we got our maximum at the equinox, when the sun is overhead at the equator. This is understood since one of the critical features affecting the Sq field pattern is solar ionization.

Table 2. Monthly range of external current intensity in Ampere.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
		CURR	ENT		INTE	NSI	TY	X	10^6			
Tom	3.8	7.8	11.3	13.2	10.4	8.0	3.6	8.9	7.8	6.3	4.6	3.6
Mop	4.3	3.9	16.5	18.8	5.3	5.6	6.0	6.2	6.0	4.7	3.3	2.5
San	9.5	2.6	3.0	3.4	3.7	4.1	4.6	4.6	4.1	3.1	1.9	1.7
Kou	4.9	6.1	8.6	17.0	2.8	3.2	3.6	3.4	3.0	2.1	2.4	2.5
Sik	7.9	9.5	5.5	5.6	4.2	2.7	2.3	2.2	3.7	5.5	5.9	5.4
Nie	17.5	26.0	25.8	19.8	15.7	12.6	4.2	5.2	7.8	10.3	10.3	9.3
Kor	20.2	23.0	12.6	21.4	18.1	16.8	6.1	7.4	10.6	13.4	13.0	11.3
Kat	23.7	13.5	34.3	27.8	25.5	17.3	8.9	10.5	21.2	28.6	22.3	13.2
Tie	20.9	29.0	29.2	16.7	14.1	11.7	10.7	12.3	15.8	18.0	16.5	14.0
Lam	16.3	20.7	19.2	16.2	14.2	12.2	11.4	12.9	15.3	17.8	16.3	14.1
Yearly Average	12.9	14.21	16.6	16	11.4	9.42	6.14	7.36	9.53	10.98	9.65	7.76

The authors of [12] analyzed the International Quite Sun Year (IQSY) 1965 quite days and found their African external current intensities in winter, equinox, and summer to be 3.0×10^4, 10.2×10^4, (8.6×10^4 for spring and 11.8×10^4 for fall equinox), and 13.7×10^4, thus having a maximum value in summer and a minimum in winter. This is also in disagreement with our result of a maximum in equinox. The discrepancy here could be due to the fact that their stations were located in the southern hemisphere, so that at their summer time when the sun is over head they had their maximum.

Our result may be compared with the one obtained in [13], where it is found that the temperature in the upper atmosphere estimated from satellite drag on geomagnetically quite days is higher during equinox than during summer, although this claim needs to be re-verified before the relationship between the two effects can be definitely determined.

4. Conclusions

The External Sq current for the West African region for 1993 has been obtained from magnetometer data obtained during the IEEY experiment in Africa by the application of the method of Spherical Harmonic Analysis. From the results obtained the following deductions can be made.

(1) The stations located on the Northern side of the magnetic dip equator have the external current pattern exactly opposite than in the southernmost stations.

(2) The external current intensity is maximum during the March Equinox and minimum during the June solstice. This is in contrast with other regional results but could be ascribed to our station being an equatorial station and the sun being over head at the equator during equinox.

(3) The external currents varied both in amplitude and in phase with the internal currents; the variation is seen to be a function of the induction medium (the Earth).

We therefore suggest that more work should be done on this variation of external and internal currents to better elucidate the relationship between the source current and the induction medium (the Earth).

Acknowledgments

The IEEY experiment carried out in the African sector was possible because of the funds provided by: Ministère de la Coopération, Département de la Recherche et des Formations, ORSTOM, Département TOA (Terre Océan Atmosphère), CNET Centre Lannion, Ministère de la Recherche et de la Technologie, Centre National de la Recherche Scientifique, Département SDU (Sciencesde l'univers), CEA, Commissariat à 1Énergie Atomique the Université Paris-Sud; Abidjan University, Ivory Coast; Dakar University, Senegal. The efforts of the different individuals and groups who participated in the IEEY studies are greatly acknowledged.

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