GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES, VOL. 12 NO. 2, MARCH, 2006: 251-258
COPYRIGHT (C) BACHUDO SCIENCE COL. LTD. PRINTED IN NIGERIA. ISSN 1118-0579.

GEOMAGNETIC AND GEOELECTRIC VARIATIONS IN THE WEST AFRICAN LONGITUDES OF THE EQUATORIAL ELECTROJET (EEJ).

P.O.EZEMA

(Received 3 November, 2004; Revision Accepted ,1 February,2005)

ABSTRACT

Ten electromagnetic stations were set up as a coordinated programme for the International Equatorial Electrojet Year (IFEY) between November 1992 and November 1994 by a French Team. The stations occupied covered a distance of 1200 km from Lamto 6.2°N, 5.02°W in the South to Tombouctou 16.7°N, 3°W in the North. The stations are listed in Table 1 and Fig .1a. Similar experimentations were carried out in American and Asian sectors and over 200 stations were occupied across the dip equator. Simultaneous recordings of H, D, Z, E_x and E_y for the quiet days of May 1st and 2nd 1993 (A_p <7) have been analyzed for:

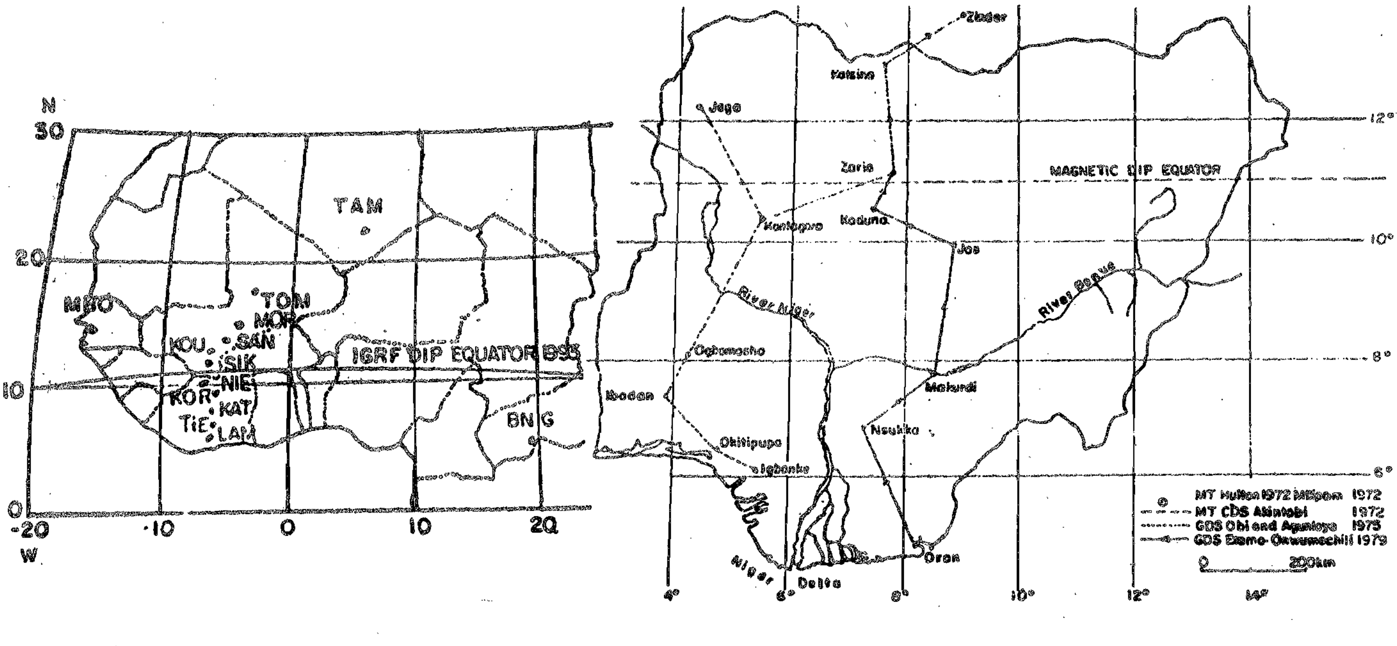
(i) The solar quiet daily variations Sq (H), Sq (D) and Sq (Z);
(ii) Day to day variability of hourly amplitudes.
(iii) Crustal and mantle MT-resistivity for SAN and NIE stations.

Results show an abnormal Sq (H) variation for MOP station which has a higher Sq(H) hourly values than those closest the dip equator. Sq (H) should be maximum at the dip equator and decreases on either side progressively. Day to day variability of hourly amplitudes in H is higher in the African longitude when compared with the results of the Indian sector. Z variation has lower day to day variability than the results of the Indian sector. The MT-resistivity reveals a conductive sedimentary top layer with a highly resistive material, presumably crystalline basement rocks at depths of 1305 km and above.

KEYWORDS: Geomagnetic and geoelectric variation, diurnal variations, day to day variability, impedance

INTRODUCTION

The name equatorial electrojet (EEJ) was fashioned by Chapman (1951) to describe the enhancement of the magnetic diurnal variation which was discovered at Huancayo observatory near the dip equator in 1922. It is an electric current that flows within a narrow band of ± 3° latitude around the geomagnetic equator. Since its discovery, many researchers have carried out measurements consisting of a net work of stations to study its magnetic effects (Chapman, 1951; Forbush and Casaverde, 1961, Fambitakoye and Mayaud, 1976a, b, and Hesse, 1982). Magnetic measurements made by rockets (Cain and Sweeney, 1973) Onwumechili and Agu, 1980; 1981) have enabled scientists to study the EEJ on a global scale. Ezema and Onwumechili (1984); Ogunade, (1995); Oni and Alabi (1972); Hutton (1972a); Akintobi (1972); Oni and Agunloye, (1973, 1976) have all done work to characterize the electrojet parameters such as its height, width, intensity and density.



(a) (b)

Figure.1(a): Geographical position of stations occupied across the dip latitude stretching 1200 km. Stations are represented by their three letters (After Doumouya et al 1998)
(b) Induction studies in Nigeria (After Ezema and Onwumechili, 1984).

P.O.EZEMA, Department of Physics and Astronomy, University of Nigeria, Nsukka Nigeria

Figure 1b shows areas where work has been done in Nigeria and putting the site of the present work together, we can say that the West African longitude is fairly being covered. The present coverage is the first comprehensive survey of MT work in West Africa. (Doumouya et al, 1998)

Table 1: Stations occupied for the electromagnetic induction work.

S/N Stations	Symbols of stations(°N)	Latitudes (°N)	dip-Latitudes from	distances (km) dip equator	Longitudes (°W)
1 Tombouctou	TOM	16.733	5.56	611.98	3.000
2 Mopti	MOP.	14.508	3.32	365.00	4.087
3 San	SAN	13.237	2.04	223.91	4.879
4 Koutiala	KOU	12.356	1.15	126.11	5.448
5 Sikasso	SIK	11.344	0.125	13.75	5.706
0 Dip equator	DEQ	11.20	0.0	0.0	5.0
6 Nielle	NIE	10.203	-1.03	-112.85	5.636
7 Korhogo	KOR	9.336	-1.90	-209.17	5.427
8 Katiola	KAT	8.183	-3.06	-337.1	5.044
9 Tiebissou	TIE	7.218	-4.04	-444.28	5.241
10 Lamto	LAM	6.233	-5.03	-553.61	5.017

Data Treatment

Data was supplied by ORSTOM, Bondy on CD Rom and consist of computed hourly mean values of H, D, Z components of the earth's magnetic field; the N-S telluric current (E_x) and E-W telluric current (E_y) measured in mv/km in each of the stations in Figure 1a. A total of 240 magnetically quiet days (Ap < 7) were selected from November 1992 to November 1994 out of which only six groups of days had simultaneous valid recordings in at least six of the ten stations. Recorded values for 1st and 2nd May 1993 were used in the analysis.

The stations in the EEJ zone are under the upper WSq and lower Sq current layers and their combined intensities contribute to the solar quiet daily variation Sq in such a way that:

$$Sq\ (H) = \text{observed}\ \Delta H = EEJ\ (\Delta H) + WSq\ (\Delta H). \qquad (1)$$

In the next presentation attempt will be made to separate Sq (ΔH) into EEJ (ΔH) and WSq(ΔH).

The Sq (H), Sq (D) and Sq (Z) diurnal variations were obtained by subtracting the average of the hourly mean value at midnight from the recorded hourly mean values of H_t

$$Sq\ (H) = H_t - (H_1 + H_{24})/2 \text{ for } t = 1, 2, \ldots\ldots\ldots 24. \qquad (2)$$

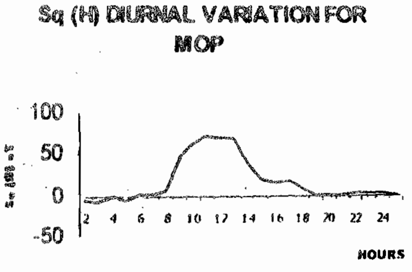
The midnight average is so taken because both current layers, WSq and Sq, are virtually non-existent at night.

DISCUSSION OF RESULTS

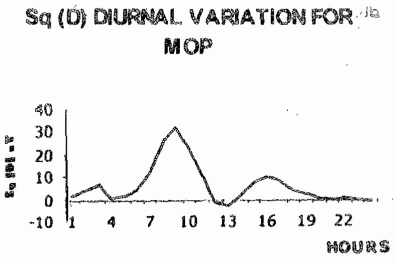
Sq diurnal variations in H, D, Z.

The diurnal Sq variation in H has the same shape in all the stations, increasing from night level to attain maximum at noon, and then regularly decreasing to its night level. The jet effect is prevalent from 8h in the morning to 18h in the afternoon (Fig. 2a). The noon amplitude should be higher closer to the dip equator but one particular case at MOP station contradicts this empirical evidence. The stations were normalized to SIK which is at the dip equator (0.12°N). While the values of Sq (H) decreased on both sides of the dip equator, Sq(H) at MOP was 13% higher than SIK at the dip equator. The Sq (D) maintained the same shape and constant variability in all the stations (Fig 2b). Its value north or south of the dip equator never changed which shows that it is independent of both Sq and WSq.Fig 2 shows Sq diurnal variations in H, D, Z.

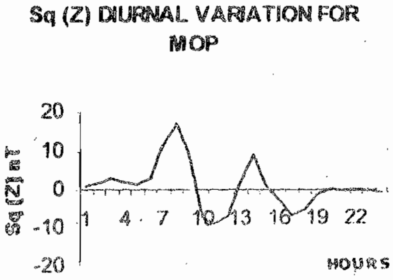
a



b



c



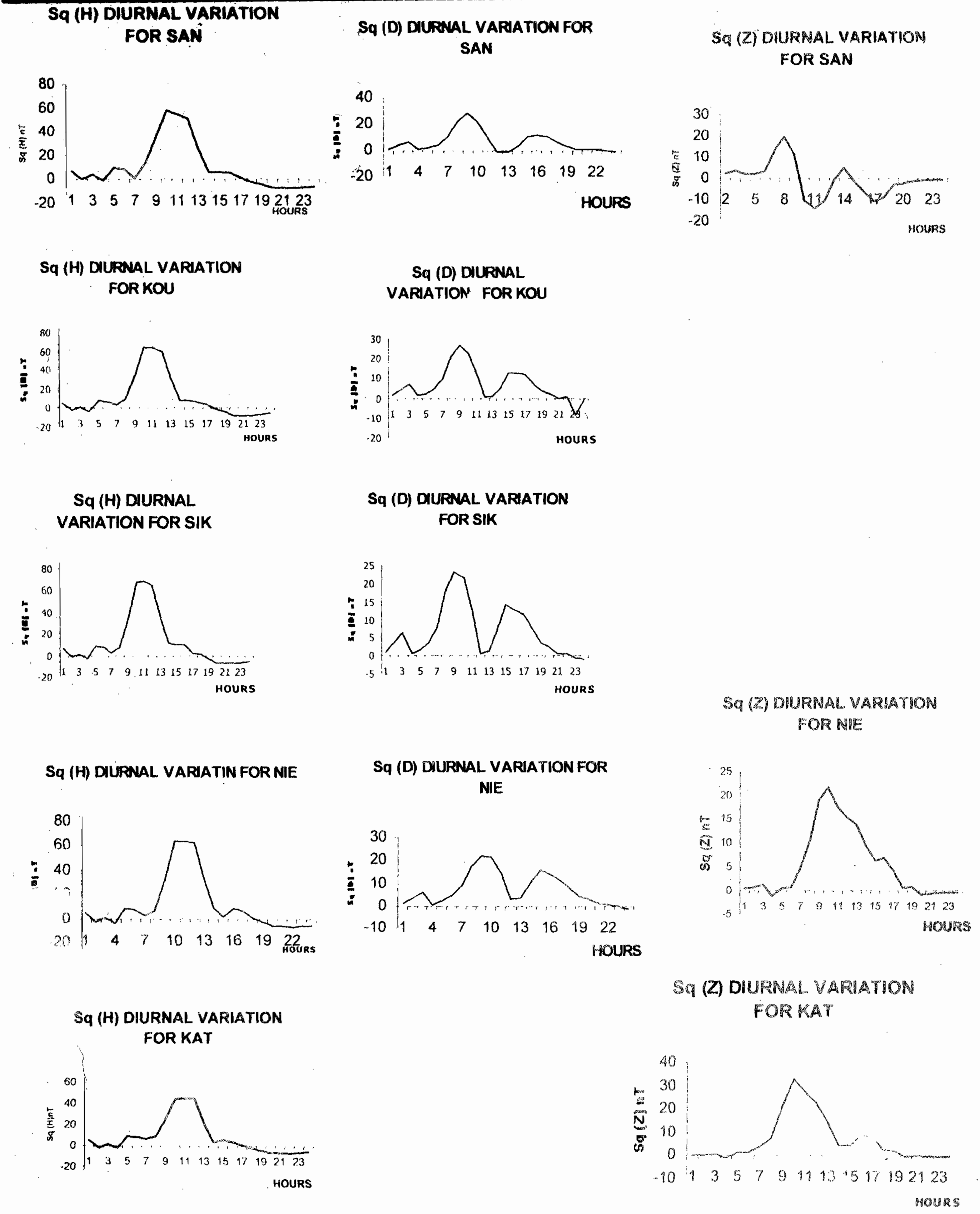


Fig. 2 (a) Sq (H), (b) Sq(D) and (c) Sq (Z) diurnal variations

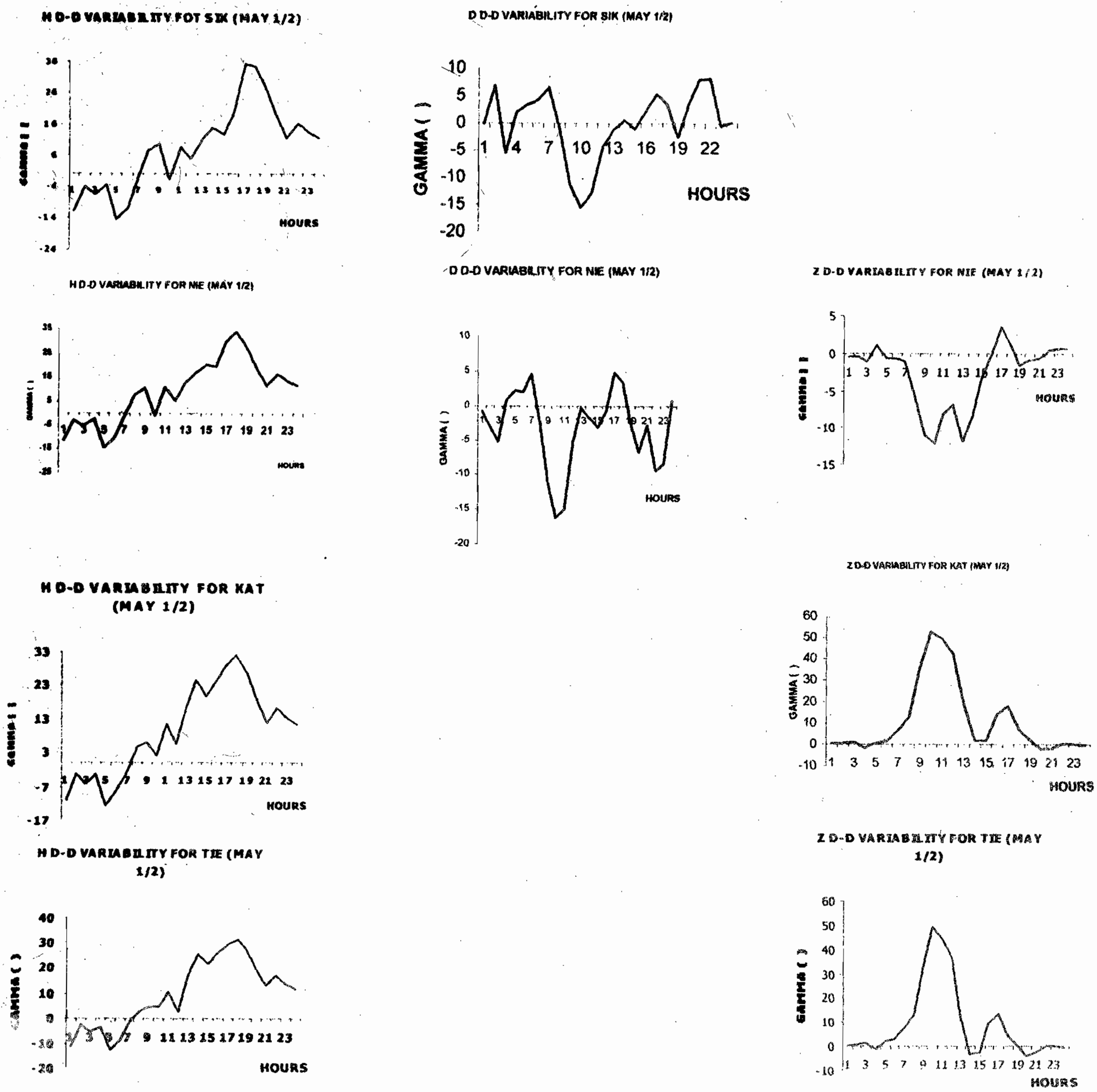


Fig. 3: Day to day variability of (a) H, (b) D, (c) Z for 1st & 2nd May, 1993

The variability of the Z field of EEJ at the five stations under study resemble the diurnal variation of the observed Z field at the stations, which shows that the day to day variability of the field typical of EEJ resembles the day to day variability of the EEJ contribution to the field.

For quantitative analysis of day to day variability we used Onwumechili's (1997) sequential variability (SV) where

$$SV_{k}\cdot(H) = \frac{1}{24}\sum_{K=1}^{24}\left|H_{i(K+1)} - H_{iK}\right| \qquad (4)$$

with similar expressions for D and Z.

The SV for H is on the average 21.64 ± 0.05 for all the stations, that of D is 6.69± 0.15 while that of Z is 4.60± 0.23.

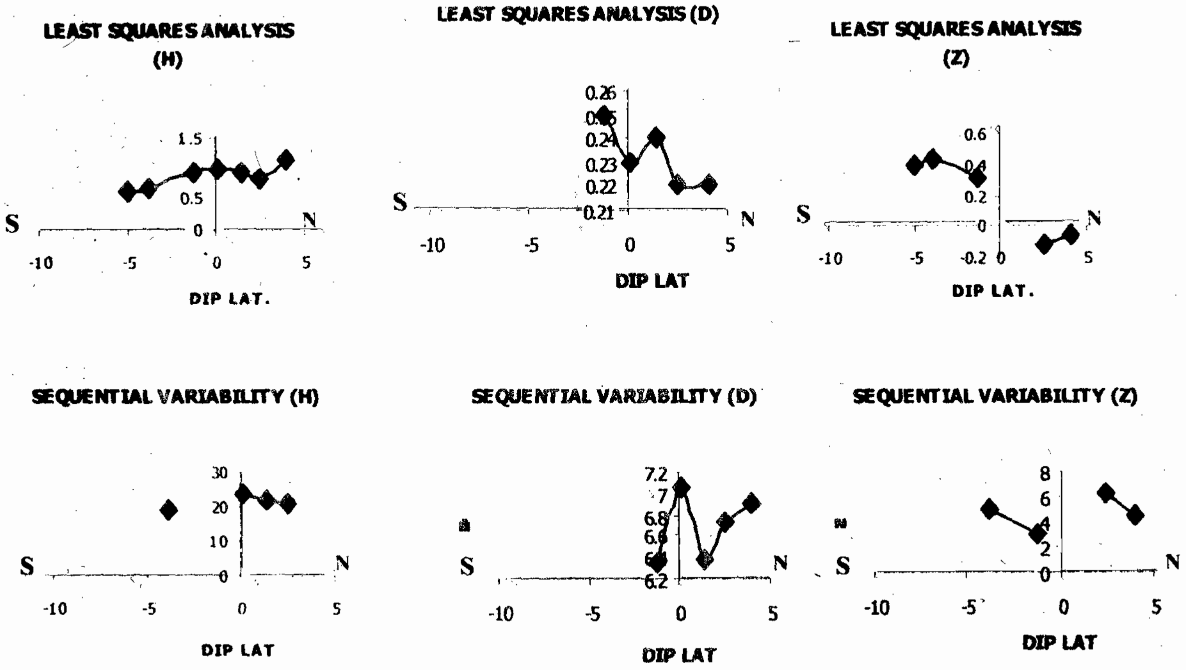


Figure 4. (a) Sequential variability for H,D,Z. and (b) Least squares analysis for H,D,Z

On the sequential variability H is very strong at 21.64 ± 0.05. Okeke and Onwumechili (1993) showed values of SV (H), SV (D) and SV (Z) for three Indian stations of Trivandrum, Kodaikanal and Annamalaina under EEJ. None had such high SV(H). The SV (Z) in the Indian sector is however much higher than that found in the West African sub region.

Least Squares Analysis.

The result of the Least Squares analysis for the hourly amplitudes of the diurnal variation is shown in Figure 4.b with SIK as reference station.

Onwumechili (1997) had shown that the amplitude of the EEJ part of Sq (Z) increases from near zero at the dip equator to the maximum values at about 2.5° dip latitude on either side of the dip equator (360 km from the dip equator).

However, the result of the analysis here shows that on the southern part of the dip equator, the situation is exemplified but not on the northern part.

MT resistivity for SAN and NIE stations.

Cagniard (1953) had defined apparent resistivity in magnetotelluric sounding as

$$\rho_a = \frac{1}{\omega u}\left(\frac{Ex}{Hy}\right)^2 = \frac{1}{\omega u}\left(\frac{Ey}{Hx}\right)^2 = 0.2T\left[\frac{E}{H}\right]^2 \qquad (5)$$

where ω is frequency in radians per second, μ is magnetic permeability, E is the electric field intensity and H is the orthogonal component of magnetic field intensity. His proposal was based on the fact that electromagnetic field is a plane wave propagating vertically into the earth and that the earth is laterally uniform.

For a plane magnetic wave propagating in the Z-direction, the electric component Ex is along x-axis (Ex, 0, 0) and the magnetic field is in the y-axis (0, Hy, 0).

From the four Maxwell's equations:

$$\text{Curl E} = \frac{-\partial B}{\partial t} = \frac{-u\partial H}{\partial t} \qquad (6)$$

$$\text{Curl H} = \sigma E + \frac{\varepsilon \partial E}{\partial t} \qquad (7)$$

$$\text{Div E} = 0 \qquad (8)$$

$$\text{Div H} = 0 \qquad (9)$$

We obtain two identical equations:

$$\nabla^2 E = u\sigma \frac{\partial E}{\partial t} + u\sigma \frac{\partial^2 E}{\partial t^2} \qquad (10)$$

$$\nabla^2 H = u\sigma \frac{\partial H}{\partial t} + u\sigma \frac{\partial^2 H}{\partial t^2} \qquad (11)$$

For sinusoidal waves, $E_{(t)} = E_0 e^{i\omega t}$ and $\frac{\partial E}{\partial t} = i\omega E.$

Similarly $H_{(t)} = H_0 e^{i\omega t}$ and $\frac{\partial H}{\partial t} = i\omega H$ with $\omega = 2\pi f$

The equations (10) and (11) reduce to

$$\nabla^2 E = i\omega u\sigma E - \omega^2 \varepsilon u E \qquad (12)$$

$$\nabla^2 H = i\omega u\sigma H - \omega^2 \varepsilon u H \qquad (13)$$

and are the governing equations for propagating electric and magnetic field vectors in isotropic homogeneous medium with conductivity σ, relative permeability u and dielectric constant ε.

Neglecting the displacement current which is the second term on the right hand side of equations (12) and (13) and considering only the displacement current which is the first term on the right hand side, we obtain:

$$\nabla^2 E = -i\omega u\sigma E \text{ i.e. } \frac{d^2 E}{dz^2} = -k^2 E \text{ and} \qquad (14)$$

$$\nabla^2 H = -i\omega u\sigma H \text{ i.e } \frac{d^2 H}{dz^2} = -k^2 H \qquad (15)$$

where k^2 is the square of the wave number ($k^2 = i\omega u\sigma$).

The solutions of equations (14) and (15) are

$$E_x = A_n e^{iknz} + B_n e^{-iknz} \text{ and}$$

$$H_y = \frac{1}{i\omega u}\frac{\partial E_x}{\partial z} = \frac{k_n}{\omega u} A_n e^{ik_n z} - B_n e^{ik_n z} \qquad (16)$$

With k_n as wave number for n^{th} layer; and neglecting Be^{-iknz} which increases with increasing z, we have for a uniform half-space

$$E_x = Ae^{ikz} \text{ and } H_y = \frac{k}{\omega u} Ae^{ikz} \qquad (17)$$

From which the wave impedance

$$Z_{xy} = \frac{E_x}{H_y} = \frac{\omega u}{k} = \frac{\omega u}{(i\sigma u\omega)^{\frac{1}{2}}} = \left(\frac{\omega u}{\sigma}\right)^{\frac{1}{2}} e^{-i\pi/4} = 2\pi\left(\frac{\rho}{5T}\right)^{\frac{1}{2}} e^{-i\pi/4} 10^{-3} \, ohm \qquad (18)$$

The magnetotelluric interpretation for SAN (2.02° dip lat.) and NIE (- 1.02°dip lat.) was done using the last term of equation 5. The period varied from one hour to ten hours starting from 20 h (8pm) to 05 h (5am). This period range eliminates the influence of the EEJ. The frequency is much less than 1 Hz (f << 1 Hz) ranging from 2.77×10^{-4} Hz to 2.77×10^{-5} Hz.

The plot of ρ_a vs. $\sqrt{T}$ gives a straight line on log-log graph paper rising approximately at a slope of 45° (Fig.5). The first layer conductance for a conducting layer covering an insulating basement is calculated from:

$$S = \frac{1}{[\omega u \rho_a]^{\frac{1}{2}}} = \frac{1}{1.12 \times 10^{-3}\sqrt{(\omega \rho_a)}} \text{ with thickness } h = S\rho_a \qquad (19)$$

The depth of conducting layer (sedimentary to basement rock) is 1301 km for SAN and 1535 km for NIE.

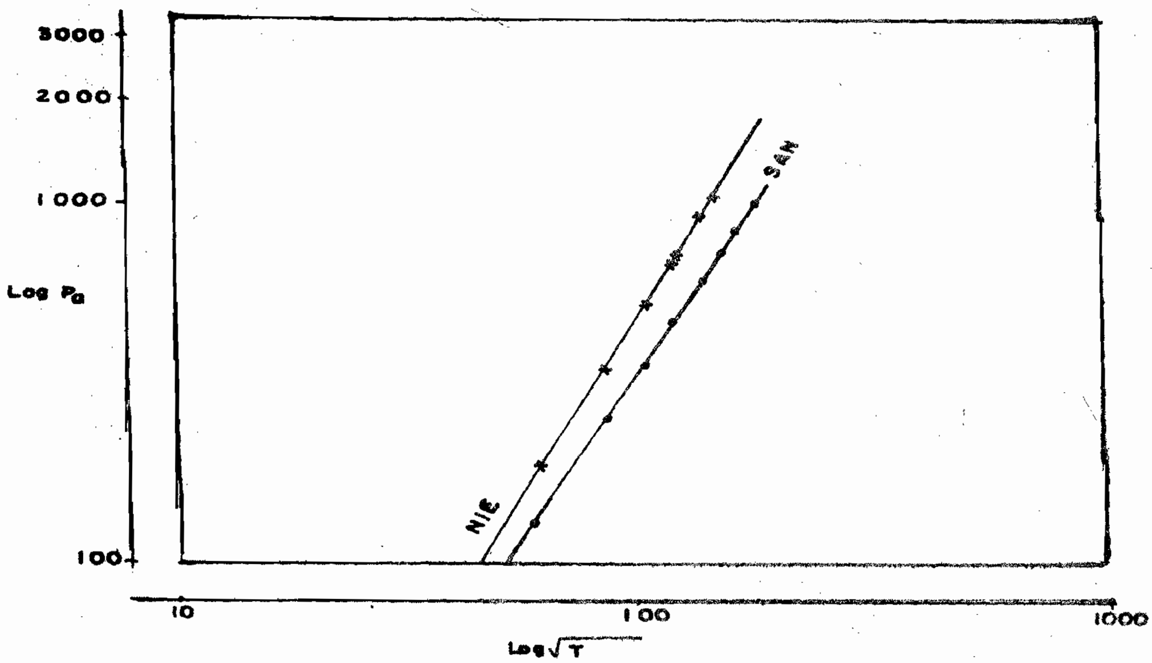


Figure 5: MT resistivity for SAN and NIE stations

CONCLUSIONS

Geomagnetic quiet daily variations for seven stations in the West African longitudes of EEJ were studied. There is an anomaly in Sq (H) variation for the station MOP which appears higher than it should be with respect to EEJ. The Sq (Z) which is minimal at the dip equator increases south of the dip equator without equivalent increase north of the dip equator as in Figure 4c.

The day to day variability is higher in West African sub region than what Okeke and Onwumechili (1993) obtained for Indian stations in the same EEJ zone for the H component

The conductivity top layer of 1301 km for SAN and 1535 km for NIE are the best estimates for short periods of 10 hours. One requires longer periods of 30-40 hours to study the mantle.

Vassal et al (1998) created two models, one for the conductive sedimentary basin for the northern stations (from KOU to MOP) typical of SAN and the other for the continental shield structure of the southern zone (from LAM to NIE). For the craton he showed an insulating layer over a conducting layer (10,000 Ω m to a depth of 150 km and 1,000 Ω m to a depth of 350 km). While for the basin he had a conducting layer (10 Ω m to a depth of 5 km, 1000 Ω m to a depth of 150 km).

Both models are hypothetical; but the present estimation appears definitive.

REFERENCES

Akintobi, J. A ., 1972. Magneto telluric Variations in Nigeria. J. Geomag. Geoelectr., 24(2): 187-202.

Cagniard, I., 1953. Basic theory of the magneto - telluric method of geophysical prospecting. Geophysics, 18: 605-635.

Chapman, S., 1951. The equatorial electro jet as detected from the abnormal electric current distribution above Huancayo, Peru and elsewhere, Arch. Meteorol. Geophys. Bioklimatol., series A 4: 368-390.

Doumouya, V., Vassal, J., Cohen, Y., Fambitakoye, O. and Menville, M., 1998. Equatorial Electrojet at African longitudes: first results from magnetic measurements. Ann. Geophysicae, 16: 658 – 676.

Ezema, P. O. and Onwumechili, C. A.,1984. A Profile Study of Geomagnetic Variation In the Nigerian Equatorial Electrojet Region. Journal of Geomagnetism and Geoelectricity, 36: 98-111.

Fambitakoye, O. and Mayaud, P. N., 1976a. Equatorial electrojet and regular daily variation S_R – I. A determination of the equatorial electrojet parameters, J. Atmos. Terr. Phys., 38: 1 - 17.

Fambitakoye, O. and Mayaud, P. N.,1976b. Equatorial electrojet and regular daily variation S_R –II. The center of the equatorial electrojet, J. Atmos. Terr. Phys., 38: 19 - 26.

Forbush, S. E. and Casaverde, M., 1961. The equatorial electrojet in Peru, Carnegie Inst. Wash. Publ., No. 620, 135pp.

Hesse, D., 1982. An investigation of the equatorial electrojet by means of ground-based magnetic measurements in Brazil. Ann. Geophys. 38: 315 – 326.

Hutton, V. R. S., 1972a. Some problems of Electromagnetic Induction in the equatorial electrojet region – 11: The analysis of magnetic and telluric variations at Zaria, Nigeria. Geophys. J. R. astro. Soc. 28: 411 – 424.

Ogunade, S. O., 1995. Analysis of geomagnetic variations in South - Western Nigeria. Geophys. J. Int. 12: 162 –172.

Okeke, F. N. and Onwumechili, C. A., 1993. Preliminary analysis of geomagnetic day today variations in the equatorial zone, *Proc. UN-/ESA Conference on Basic Space Sciences*, Lagos,.

Oni, Ebun and Alabi, A. O., 1972. Preliminary results of the upper mantle conductivity structure in Nigeria. Phys. Earth planet. Int. 5: 179 - 183

Onwumechili, C.A.., 1997. The Equatorial Electrojet, Gordon and Breach Publishers,

Onwumechili, C. A. and Agu, C.E., 1980. General features of the magnetic field of the equatorial electrojet measured by POGO satellites, Planet, Space Sci, 28: 1125 – 1130.

Onwumechili, C. A. and Agu, C.E., 1981. Temporal variations of POGO equatorial electrojet parameters, J. Atmos. Terr. Phys., 43: 809-816

Oni, Ebun, and Agunloye, O., 1973. Further studies of subsurface electrical conductivity structure in Nigeria. J. Geomag. Geoelectr. 26: 191 – 202.

Oni, Ebun, and Agunloye, O., 1976: Results of recent studies of electrical conductivity of subsurface structure in parts of the Western and mid-Western states of Nigeria. Pure appl. Geophys. 114: 53 – 60.

Vassal, J. , Menvielle, M., Cohen, Y., Dukhan, M., Doumouya, V. Boka, K., Fambitakoye, O., 1998. A study of transient variations in the Earth's electromagnetic field at equatorial electrojet latitudes in Western Africa (Mali and Ivory Coast). Ann. Geophysicae 16: 677 – 697