GEOMAGNETIC RESEARCH IN PHYSICS: THE JOURNEY SO FAR.

BY

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Mr. Vice-Chancellor sir,
Members of the governing council,
Distinguished colleagues,
Lions and Lionesses,
Ladies and gentlemen

PREAMBLES:

I fill highly elated and honoured standing here before you today, to deliver my inaugural lecture. May God take all the glory. A little digression into some aspects of my life that contributed to the choice of my field of research will be necessary to highlight, before delving into the main body of this lecture.

Going back memory lane, I can vividly recall how my father and mentor, Chief Patrick Okoye (elias Okoye Washington), of blessed memory, laboured and inspired my love for

sciences in general, and Mathematics in particular. This love for Mathematics later metamorphosed into a special love for Physics.

It was my late father, who planted and watered the seed of my academic excellence which we are celebrating today. For this, and many other reasons, he will always be my all time hero. I equally remember my secondary school days at Queen of the Rosary College (QRC) Onitsha, with fond memories. I recall how Mr Ohaezukosi, my mathematics teacher, would most times asked me to come forward to the board to solve mathematical problems, because, I would shout "I have seen it" while he was still solving the problem. I would successfully solve the problems and without batting an eyelid, I would write "QED". Equally, the ease with which I solved additional Mathematical problems, endeared me to my classmates. Being a disciplined student, I did not allow the praises I got to derail me, but I remained focused in my studies.

I excelled in my school certificate examination; I made distinction in both Physics and Mathematics, and was therefore employed and posted to Onitsha Girls Secondary

School as an auxiliary teacher to teach Physics to final year students then, (class five students). I quickly accepted and took up the challenge. The first assignment given to me by the students was to solve a challenging problem from a past WAEC question paper. With God on my side, and beyond all expectations, I solved a problem that graduate teachers of both Dennis Memorial Grammar School (DMGS) and Christ the King College (CKC), Onitsha, could not solve. It is worthy to note that finding a solution to the problem which started on a Sunday night, took me to the wee hours of the next day, around 1.00 am when I got break-through. My scream of joy disturbed my father's sleep, who ran straight to my room, anxiety written all over his face. "Papa, I have solved the disturbing problem", was my reassuring response. He smiled and said, "My daughter, I did the same in my own days".

Vice- Chancellor, Sir, this problem which I solved that was based on Archemedes principles and Hooke's law combined, was the starting point of this journey that led to where I am today. Permit me not to go into details of what happened in the school as I came into the class and unfolded the solution

to the problem. It was after that incident, that I made a bold resolution to become a physicist one day. It should be noted that my desire to become a physicist did not start when I got married to the love of my life, P. N. okeke. Rather, the ease with which I saw him solve his Ph.D problems, when I got married to him, made me to redoubled my efforts and took my dream of becoming a physicist to the next level, by making it a reality. His encouragement and support can not be quantified or measured, it was but second to none.

I got admission into the University of Nigeria, Nsukka, in the Department of Physics 1976, and had the privileged opportunity to be taught by eminent then Professors; and lecturers Prof F. N. Ndili, Prof C. A Onwumechili, Prof A. O. Animalu Prof S.E. Okoye, Rev. Sr. Prof M. Heeram and other wonderful lecturers, then, Dr. C.E. Okeke, Dr. P.N. Okeke, Dr. J. Ododo, Dr. B.A. Oli, Dr. Singh, Dr. S. Pal, Dr. C. Macgruda Dr. Huq . It is important to note that, then, in a class of twenty seven, we were only two ladies, myself and now Dr (Mrs) Ogwo, the wife of the past Vice Chancellor of Abia State University, Okigwe. I graduated from this department in 1980 with Second Class honours upper division. I was posted to St Theresa's Secondary school

Nsukka, as a youth corper, I was there till 1981. Thereafter, I took appointment with the State School Education Commission, and taught Physics in three secondary schools in Nsukka. I am proud today to say that in each of these schools, I distinguished myself and kept a wonderful record in physics WAEC/SSCE results. I am equally proud to say that some of my students from secondary schools are consultant medical doctors, Professors, Engineers, architects and lecturers in this University, I cite but a few, Dr (Mrs) J. N. Nwodo, Dr (Mrs) N Odo, and Dr (Mrs) Francisca Ogbonna, all in Faculty of Pharmacy, U.N.N. Dr Paul Asogwa the HOD of GS (Natural Science). Dr. C. Nwadinigwe, of the Orthopedic hospital Enugu.

My MSc work was in solid earth geophysics, which was supervised by the Prof K. M. Onuoha, the immediate past DVC Academics. His thorough supervision has contributed to the solid academic foundation laid. I express my sincere gratitude to him.

My PhD work was in upper atmospheric geophysics, which was supervised by Prof. C. A. Onwumechili, then Vice-

Chancellor of Ife and Prof. Emeritus. This slight movement from solid earth to geophysics of the upper atmosphere came as a result of the conference I attended in Uppsala in 1990. There I met with many upper atmospheric geophysicist and after listening to their various presentations, particularly that of Prof. C. A. Onwumechili, I went to him and indicated my burning interesting in his field. He turned to me and said, “I need to test your capabilities for some months”. He did exactly that, and at the end of three months, he opened up and said to me “ You are a research material, but I want you to note that you will make it and excel, if only you have to talk physics, smile physics, walk physics, work physics, sleep physics wake physics, live and die physics”. After which he burst into laughter, at this juncture, Vice Chancellor, sir, permit me to testify that it pays heavily to work with seasoned academic that is authority in an area. Professor C. A. Onwumechili really taught me, drilled me and exposed me to academic world; a world of serious research. Before then, little did I know that the solid earth geophysics was completely related to the geophysics of the upper atmosphere. His work centered mainly on (EEJ) and worldwide solar quiet day (WSq) current system. I am glad to say that my various

research activities have taken me to various part of the world, including Japan, USA, Uk, Brazil, South Africa, Australia, India and the rest of them.

Vice-Chancellor, Sir, this is a brief summary of the first phase of the journey. I am now going into the actual journey, which is the beginning of the research work.

An inaugural lecture is supposed to x-ray ones work, from past to present, indicating contributions to knowledge that definitely led one to the position of a Professor, as well as the research leadership one demonstrates after being a Professor. The lecture is planned as follows: I will start by defining some important parameters used in this presentation. Then I will briefly discuss the totality of my research activities, introduce interludes at necessary points, followed by conclusion and appreciation.

Definition of terms

Geophysics: The scientific study of the physics of the earth. This could be, studying its magnetism or earth's atmosphere.

Magnetism: The study of properties and effects of magnetic substances.

Meteorology: The scientific study of the earth's atmosphere and its changes.

Geomagnetism: Is the magnetic field of the earth.

Earth's Dynamo: Comprises of dynamo action in the earth's core and atmospheric dynamo action.

(i) Dynamo action within the core: This refers to, the motion of the conducting liquid core relative to the magnetic field, which is generated within its molten iron core through a combination of thermal movement, the earths daily rotation and electrical forces within the core. Magneto-hydrodynamic phenomenon-summarizes the above, this implies the motion of electrons in the fluid core which generates flow of current and in turn, magnetic field is set up which again, as the flow continues, induces magnetism along the neighboring rocks.

(ii) **Ionospheric dynamo action** could be regarded as electric current system, that flows in the ionosphere, where source of magnetic field exists, hence, ionospheric dynamo is produced by

movement of charged particles of the ionosphere across earth's main field**.**

Dip Equator: Over most of the northern hemisphere, the north seeking end of the dip-needle dips downwards (inclination or dip {I} is positive), while over most of the southern hemisphere the south- seeking end is the lower one (I is negative). Then, the regions of positive and negative I are separated by a curve- called dip equator or magnetic equator. Along this dip equator, I is zero (0).

Ionosphere: Is the uppermost part of the atmosphere that is ionized by solar radiation, and electron density is sufficiently high to affect the propagation of electromagnetic waves at radio frequencies.

Geomagnetic storms: This refers to dynamic processes on the sun which ejects plasma and charged particles, mainly, protons and electrons and associated field to the earth's environment, causing geomagnetic disturbances on the earth's surface.

Magnetic elements: From Fig 1, at any point O, the vector magnetic field intensity, is given by F or B. The quantities B, H, D,I, X, Y, Z are called magnetic elements. They are thus interconnected as follows: **$H = B\cos I$, $X = H\cos D$, $X^2 + Y^2 = H^2$**

$Z = B\cos I = H\tan I$, $Y = H\sin D$, $H^2 + Z^2 = B^2$ or F^2

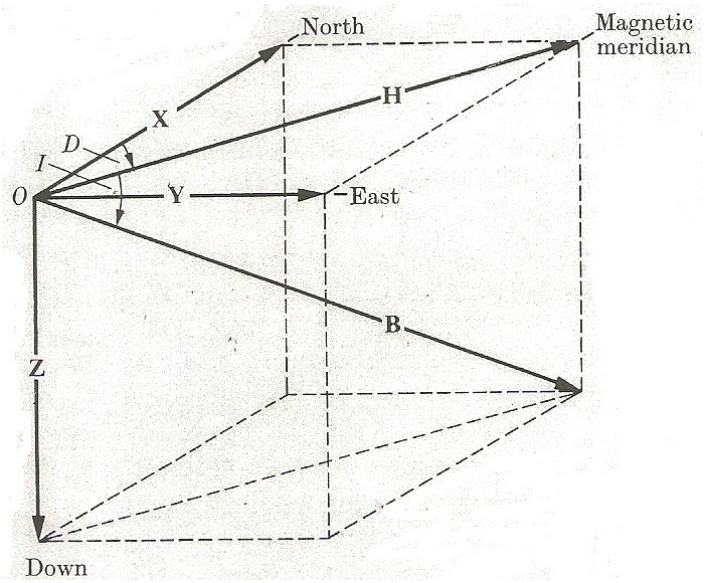

Fig. 1. The geomagnetic force B, its rectangular components X, Y, and Z, and the elements H, D, and I.

Atmospheric Angular Momentum:

This is a fundamental geophysical parameter that measures the intensities of zonal circulation. It exchanges relatively large proportion of its momentum with the solid earth below.

Equatorial Electrojet (EEJ): – At the dip equator; where the magnetic dip angle I, is equal to zero, the midday eastward polarization field generated by global scale dynamo action gives rise to a downward Hall current. A strong vertical polarization field is set up which opposes the downward flow of current due to presence of non-conducting boundaries. The field in turn gives rise to the intense Hall current which is called the EEJ. The basic reason for the existence of the EEJ is as a result of large value of Hall polarization and hence large value of Cowling conductivity at the dip equator where the earth's field is horizontal.

Geomagnetic Research Works

Geomagnetic research in physics span across the entire earth, (from earth interior to the very upper atmosphere of the earth).

The first kind of this research work started with the study of the earth interior. In our analysis, five graphical techniques were employed in determining the depth from aeromagnetic profiles taken across the lower Benue trough of Nigeria. It was discovered that the methods of RamBabu and RaO were recommended because of its advantages over others, and particularly when applied to isolated and non-interfering anomalies. This was later adopted by many research workers, who worked after us.

Before going into the discussion of further work, it is pertinent to note that, geophysics of the earth interior and geophysics of the upper atmosphere are inter-related and non can be isolated from the other. Two parameters control ionospheric dynamo, these are distribution of winds and electrical conductivity in the ionosphere. Invariably, these parameters are influenced by several other factors; the solar cycle, solar flares, solar eclipse, the orbital parameters of the Earth, the Sun and Moon. The above is necessary as they constitute the backbone of the research work to be discussed from now.

EEJ Research: Onwumechili, (1977), noted that the manifestation of EEJ include; the spatial structures of its very high current density, configurations and regular temporal variations of the EEJ current systems, the magnetic fields of the EEJ current system, the ionopheric plasma density irregularities, generated by the turbulent flow of the EEJ current, the electric fields and ionospheric plasma drifts in the dip equatorial zones, the quiet time counter electrojet (CEJ), and the temporal variabilities of the above phenomena. Hence, a lot of challenges were thrown open for researchers in this active area of research.

In work of Okeke and Onwumechili (1992), we used;

$$SV_H = \frac{1}{n}\sum_{i}^{h} (h_{\alpha i} - h_{\alpha i+1}) \quad \ldots\ldots\ldots\ldots 1$$

i = 1 to 365, α = 1 to 24, to establish the relationship between EEJ and WSq, and found that employing the sequential variability (SV) in measuring the D-D variations in equatorial zone, the D-D of EEJ and that of WSq are not in phase and consequently combine somewhat destructively within the EEJ zone. It was remarkably noted that it was the very first time

the SV was used in determining D-D variation in the equatorial zone.

The result of the above work sprang our interest further, (F.N. Okeke, C.A. Onwumechili & A.B. Rabiu) decided and looked at the changes of geomagnetic hourly amplitude at low latitudes in 1998. This work discovered for the first time, that inclusion of the magnetic element D revealed that EEJ current system has not only an east-west component, as earlier predicted by several authors but also a north-south component. It also revealed that the meridional component of the EEJ current intensity evidenced at the kodaikanal and Annamalainagar stations is an integral part of the zonal component at Trivandrum. Our results suggest that ionosopheric conductivity mainly controls the magnitude, while the electric field and ultimately winds mainly control the phase and randomness of the D-D variability of the hourly amplitudes of Sq. The random component is attributed to local and/or regional atmospheric winds, probably of gravity wave origin. An interesting and exciting result that raised controversy.

In 1998, I received the research fellowship award and visited University of Natal Durban, South Africa, where I worked with Prof. W.A. Walker. The work carried out was on observation of magnetospheric substorm. When I made the observation and reported, he was excited and asked me to carryout all the analyses, which I did and generated a paper which was published in a reputable journal; Irish Astronomical Journal (IAJ). This ended the first phase of my research, little did I know that God was preparing me yet for a bigger award. After my visit of South Africa, I then warned another fellowship award; Fellow, Japanese Society for Promotion of Science (FJSPS) in the University of Tokyo, Japan, where I did my post doctoral work from 1999 to 2000.

On First April, 1999, I landed at Narita Airport Japan, and was received by my host, Professor Yozo Hamano. On my way to the University, he turned to me and said to me “In the next two days you will let us know why you are here, in Japan”. I looked at him in amazement and he said to me again “I mean what you have done, what you are doing and what you have planned to do, research wise”. I then breathed deeply and said “thank God”. On that next two days, I gave a

brief lecture on my research program and my future research plans. They revealed to me that they saw my interesting publications and that was why they invited me. They again fixed 15th May 1999 as the day I would address the entire Faculty on same issue, I phoned my husband, Prof. P.N. Okeke and he encouraged me and asked me to leave no stone unturned. It was after fifteen of May, 1999 that my tremendous work in geomagnetic research commenced. I started by learning MatLab programme, a very powerful software for both analyses and plotting. I stayed, worked in my office, some times from morning till morning.

Geomagnetic research in Japan

With the establishment of the new geomagnetic field observatories in the Ocean Hemisphere Network Project (OHP) in Japan, the minute values of geomagnetic components, H, D and Z were converted to hourly mean values and were used in studying the variations in these components. The striking results from our analyses were that the pronounced magnitude of Z variation as we observed in Christmas Island was attributed mainly to sea induction. Abnormal features were observed on 23rd of January 1997, at

Huancayo in the geomagnetic components. It is very interesting to inform you that, this result from our published paper into Journal of EPS, Japan generated academic dispute that ended in our favour (See Appendix 1-3). Prof. Rastogi, who raised the dispute, later wrote me requesting that I should visit his research institute in India, but then, I was at CPTEC Brazil as a visiting associate. I am happy to announce that after the Tsunami events, I have received several mails requesting for the reprints of our paper. It is an achievement to note that what we predicted in 2000 came to light in 2004 during the Tsunami events.

Work on AQDs

In our work (Okeke, F.N. & Hamano Y. 2000) on some features of abnormal quiet days (AQD's), one of the findings revealed that both the vertical and the horizontal components of the geomagnetic field at one of the EEJ stations showed maximum value around local noon hour. This is an abnormal new feature, very rare, that has not been observed by previous workers. Features of constant dH amplitudes were suggested to be associated with substorms. The pre-noon and afternoon

maximum in dH were attributed to the counter electrojet (CEJ).

Several workers have studied the causes and forms of ADD's, for example, (Brown 1981; Butcher, 1982; Gouin and Mayaud, 1967; Stening, 1977, Last, et al. 1976; Fambitakoye and Mayand, 1975; Sastri, 1981 and Rastogi, 1997) from their works, controversy still exists as of the correct causes(s) of AQDs. Good enough, results from our work has categorized types of AQDs with possible causes, and since then, most workers are adopting our categorized types and causes.

Since then, our geomagnetic research has extended from earth interior to upper atmosphere and now incorporating the intermediaries between interior and upper atmosphere. Hence, several studies have been carried out covering the above.

INTERLUDE I (LIFE & PHYSICS)

Let me remind you of the importance of laws of physics in our lives: Your ability to sit down, listen to my lecture, work about, eat and swallow, fly about in an airplane, drive in a car, are all governed by laws of physics.

First, is the Newton's laws of motion. (Examples: of passengers in a moving vehicle or standing vehicle). Then, again, if there is no friction we will not be able to walk without slipping or while is motion unable to stop. Tree, plants crops are in existence because of friction, vehicles, planes, trans etc can move for the same reasons. Could we imagine life without applications of laws of physics? It is not possible.

Research Integrating Earth Interior and Upper Atmosphere

For the past decades, studies on Sq analysis have been carried out intensively, but not so much has yet been done on applications of external currents to the earth interior. Hence, Suziki (1978), using the method of spherical Harmonic Analysis in his work, found that the internal currents seem to flow much more freely than was earlier suggested by other researchers. Campbell (1989), suggested from his work that there may be detectable lateral differences in the electrical conductivity structure of the sub-continental mantle. From several works of (Matsushita, 1973, Hobbs and Dawes, 1979; Beamish et al. 1980, 1983; Takeda 1985; 1991; Campbell and

Schiffmacer 1988; Malin and Gupta 1977 and Campbell 1989) it was obvious that application of the external Sq currents in the mapping of the upper mantle conductivity had not be considered. Hence, in 1998, Campbell first carried out such work in the Australian "hemisphere". Okeke (2000), while still in Japan, carried out extensive review work on the use of Sq current in mapping out the upper mantle conductivity. The result of this work has yielded novel results today, as we shall soon see. This was soon followed by a work carried out by my first PhD student, Dr. Stanley Agha. In his Ph.D problem; we assumed that the Sq variations measured from daily mean values at L' Aquila observatory were derived from a magnetic potential V, expanded by Schimidt's functions $p_n^m(Cos\theta)$ with coefficients e_{na}^m and $\mathrm{e}_{\mathrm{nb}}^{\mathrm{m}}$ for part of external origin and $\acute{\imath}_{na}^m$ and $\acute{\imath}_{nb}^m$ for the part of internal origin.

$$V = C + R\sum_{n=1}^{\infty}\sum_{m=0}^{n}\left\{(a_{ex})_n^m\left(\frac{r}{R}\right)^n + (a_{in})_n^m\left(\frac{R}{r}\right)^{n+1}\right\}\mathrm{cosm}\,\phi$$

$$+\left\{(b_{ex})_n^m\left(\frac{r}{R}\right)^n + (b_{in})_n^m\left(\frac{R}{r}\right)^{n+1}\right\}\mathrm{sinm}\,\phi\ \ ]p_n^m(\theta).....2$$

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where $(a_{ex})_n^m$ & $(b_{ex})_n^m$ are coefficients for part of external origin & $(a_{in})_n^m$ and $(b_{in})_n^m$ are coefficients for part of internal origin.

From above equation, three components H, D and Z of magnetic variation on the earth's surface (r = R) are obtained, hence

$$H = \sum_n \sum_m (a_n^m \cos m\phi + b_n^m \sin m\phi) X_n^m(\theta) \quad \ldots\ldots\ldots\ldots 3$$

$$D = \sum_n \sum_m (-b_n^m \cos m\phi + a_n^m \sin m\phi) Y_n^m(\theta) \quad \ldots\ldots\ldots\ldots 4$$

$$Z = \sum_n \sum_m (a_n^m \cos m\phi + b_n^m \sin m\phi) p_n^m(\theta) \quad \ldots\ldots\ldots\ldots 5$$

where all symbols retain their usual meanings. The Schimdt's function P_n^m was computed, also the intermediate coefficients related to the quiet day SHA coefficient, both for the external and internal SHA were equally calculated. Finally the depth to a conductive layer was derived as;

$$d_n^m = Z - P, \text{ where;} \quad \ldots\ldots\ldots\ldots 6$$

$$Z = R \frac{\left\{A_n^m \left[n(a_{ex})_{nn}^m - (n+1)(a_{in})_n^m + B_n^m \left[n(b_{ex})_n^m - (n-1)(b_{in})_n^m\right]\right]\right\}}{n)n+1)\left[(A_n^m)^2 + (B_n^m)^2\right]} \quad \ldots\ldots\ldots 7$$

and

$$P = R\frac{\left\{A_n^m\left[n(b_{ex})_n^m - (n+1)(b_{in})_n^m - B_n^m\left[n(n(a_{ex})_n^m - (n+1)(a_{in})_n^m\right]\right\}\right.}{n(n+1)\{(A_n^m)^2 + (B_n^m)^2\}} \quad \ldots\ldots\ldots\ldots 8$$

Our analytical method, involved a situation in which the currents and conductivity for an earth half sector were explored. In compensation for the full sphere, which was needed for application of Gauss method for separating the external and internal currents, the hemisphere was cloned by the transformation of 24 hours in time to 360^o in longitude. The flow chart in Fig I demonstrates the data processing routine employed in the analyses.

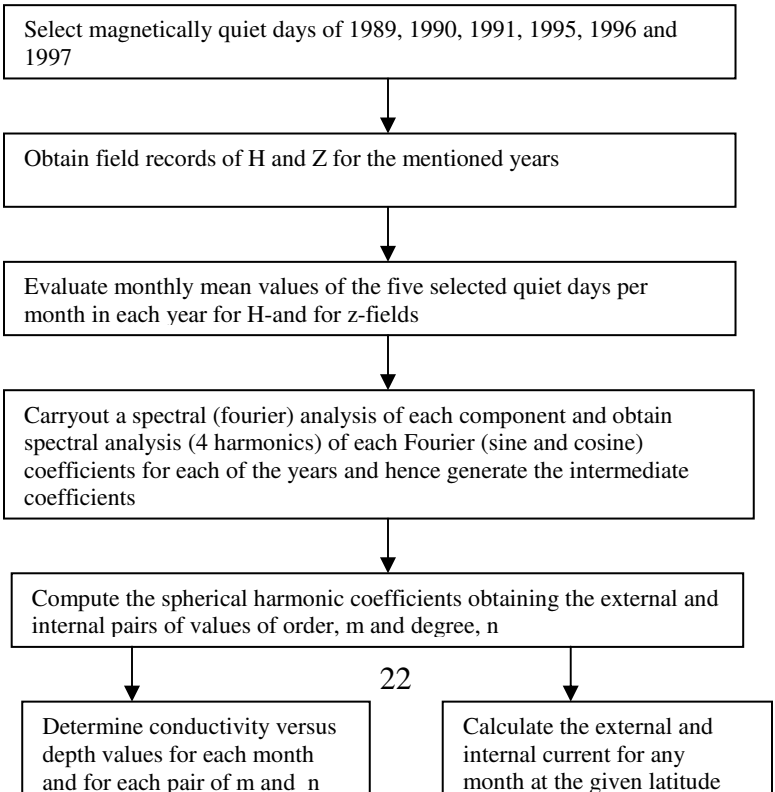

Fig. 2. Data processing routine

The results of this study indicate that the average electrical conductivity of the upper mantle in L' aquila rose from very low sub-crustal value to 0.1751m at about 290km depth and dropped to a value of about 0.16s/m at a mean depth of approximately 389km and again rises sharply to a value of about 0.28s/m at 705km. This results were compared with regional seismic wave velocity models, which revealed a correspondence between high conductivity and low velocity layers. The rapid increase in conductivity between the depth of 380 and 800km in this work, is almost in agreement with the global model given by Schutz and Larsen (1990). The enhanced conductivity values obtained in this study was attributed to the complicated structure of the crust and upper mantle which result in large lateral variations in electrical conductivity.

As a result of the above interesting and exciting result, another PhD study of mine Dr. Theresa Nkechi Obiekeze, took up another challenge. It is really obvious that the electrical depth structure of the earth has been achieved in the past, using the magnetotelleric (MT) and the Geomagnetic Deep Sounding (GDS) method. Having observed that the above two methods fail to resolve the conductivity-depth structure of the earth beyond 200km from the crust, calls for urgent need for a different method, which is Sq method.

This Sq method having been applied to some other regions, but never in West African region, we quickly addressed this problem. More interesting still, is the failure of Vassal et al. (1998) to get any result, using the data obtained during the International Equatorial Electrojet Year (IEEY) experiment in West African region, applying MT and GDS method. They, then, concluded that the MT and GDS methods for probing the conductivity of the upper mantle at this region were not suitable.

This prompted our quick action and decision to apply the Sq method, a most recent technique in this West African region where no such work applying Sq method has been carried out.

The solar quiet day ionospheric current variations observed at a line of tensions that are located in the West African sub region were used in determining the upper mantle conductivity structure. Applying almost same analysis as Dr. Agha did, but using chain of stations and one year. Thus, it is exciting and interesting to note that the application of the solar quiet day ionospheric current variation has enabled us to determine the conductivity depth structure of the upper mantle in the West African sub region, where no result was produced by methods of MT and DGS. Since then, some scientists, particularly in geophysics of earth interior have indicated much interest in our results. We have started with them, it is encouraging as well as exciting.

Ionospheric Geomagnetic Research

Challenges still continue in geomagnetic research in physics, and the journey progresses. The ionsphere is a very important part of the earth, it acts as a conducting medium, with induced

current flowing. The current produces magnetic variations at the surface of the earth, and the current flow results in the movement of the atmosphere. In the past and recent works, it has been seen that ionosphere has always been regarded as a thin layer, and that the vertical component of the ionospheric conductivity is insignificant and as such, is negligible. But from various indications and phenomena of the ionosphere, we thought it wise to investigate the authenticity of the above statements. This resulted in another exciting Ph.D project, which was carried out by Mr. G.A. Agbo, now Dr. G.A. Agbo. He investigated whether vertical component do exist, and if so, is ionosphere thin or thick layer?

The work was approached, by first addressing the basic microscopic Ohm's law $J=\sigma E$, where J is current density, E is electric field vector and σ is medium conductivity. Having regarded the ionosphere as thick layer and therefore three dimensional current density, in which the vertical current flow is not neglected.

The components of the current density J is expressed as;

$$\begin{pmatrix} J_x \\ J_y \\ J_z \end{pmatrix} = \begin{bmatrix} \sigma_o \cos^2 I + \sigma_1 \sin^2 I & \sigma_2 \sin I & (\sigma_o - \sigma_1)\cos I \sin I \\ -\sigma_2 \sin I & \sigma_1 & \sigma_2 \cos I \\ (\sigma_o - \sigma_1)\cos I \sin I & -\sigma_2 \cos I & \sigma \cos^2 I + \sigma_1 \sin^2 I \end{bmatrix} \ldots\ldots\ldots 9$$

Good to note that quantity σ, in three dimensions is given by;

$$\sigma \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

Hence,

J_x $-\sigma_{xx}Ex + \sigma_{xy}Ey + \sigma_{xz} Ez$

$J_y = \sigma_{yx}Ex + \sigma_{yy}Ey + \sigma_{yz} Ez$……………………11

$J_z = \sigma_{x}Ex + \sigma_{zy} Eyt\ \sigma_{zz} Ez$,

We then have that the elements of the three-dimensional conductivity is given as;

$\sigma_{xx} = \sigma_o \cos^2 I + \sigma y \sin^2 I$

$\sigma_{xy} = -\sigma yx = \sigma_2 \sin I$

$\sigma_{xz} = \sigma zx = (\sigma_o - \sigma_1)$ CosI SinI…………………12

$\sigma_{yy} = \sigma_1$

$\sigma_{yz} = =\sigma zy = \sigma_2 \cos I$

$\sigma_{zz} = \sigma_o \sin^2 I + \sigma_1 \cos^2 I$

These last equations were employed in studying the ionospheric conductivity in 3-dimensions. A Matlab software was applied in the analysis. The major discovery from our analysis is that vertical components of the ionospheric conductivity is neither zero nor negligible, since reasonable and meaningful values were obtained. Interestingly, this result is invariance with results of several authors, for example; (Baker and Martyn, 1953, Onwumechili, 1997, Tsunomura, 1999, Rastogi, 2000. etc). By their application of two-dimension ionospheric conductivity, they concluded that there is zero or very negligible vertical component of current density. Having published this paper in international journal, it has since then raised some interesting academic dispute, which is still ongoing and I am happy to say that it is ending in our favour. Other workers could not discover the result because computer software necessary to handle the complex mathematics involved, were not in existence.

Remarkable, is the discovery of the existence of the vertical ionospheric conductivity in 3-D ionosphere, we attributed this

to the upward drift of particles that connect the ionosphere and magnetosphere, thereby causing current to flow in the magnetosphere, and hence, dragging the geomagnetic field which causes changes in the density and motion of the ionosphere, and invariably current flow in the ionosphere, hence there is little or no shielding between the ionosphere and the magnetosphere. With this discovery, the dynamic coupling of the vertical ionospheric conductivities with other ionospheric conductivity components aids in further understanding of the complexity of the ionosphere.

The results from this work have yet suggested more valuable research work, as the newly discovered 3-D ionosphere has effects on plasma density, plasma irregularities and many other dynamical processes in the ionosphere, hence the study of solar terrestrial interactions becomes crucial.

INTERLUDE 2

There is a saying in the bible “He who is down needs fear no fall”. This is also experienced in physics in the laws of equilibrium and stability and Centre of gravity (C.G). A tall person has his or her C.G very high while a short person has

his/her C.G very low, so when these two individual are given a slight push, a vertical line drawn through the C.G of a tall person will fall outside his/her base and he topples while for the short person a vertical line through her C.G. will fall within her base and she balances. "*Akwa Akwulu*". It is also very dangerous to over take a highly loaded lorry at corners because of the same reason. For the same reason, sports cars are made to be very low to the ground, so that no matter the speed with which they round corners the line through the C.G will always fall within the base of the tyres.

(i) The results from our previous work led another Ph.D of mine, now Dr. (Mrs.) B.C. Isikwue, to carry out work on solar dynamical process effect on ozone variation in Nigeria. This work was based on the following realization: Theoretical investigations and astronomical observations proved that the earth's rotation is variable. It has also been ascertained that the variability of earth's rotation vector is caused by the gravitational torque exerted by the sun, moon and some planets and also by dynamical processes due to mass redistribution and conservation of the total angular momentum of the entire earth in different parts of the earth system, and by some other excitation in mechanism such as the hydrosphere (Ma and Han,

2006). We strictly noted that this AAM is a fundamental geophysical parameter that measures the intensity of the zonal circulation. Hence, the global zonal winds in the troposphere and stratosphere are the main contributions to the axial AAM components. The dynamical processes reflect the rate of transportation of ozone by winds in regions of the atmosphere. It has been found that the strength of atmospheric dynamics over the tropics is mostly influenced by extra tropical suction pump ETSP. Ozone variation, transportation and depletion have been a major concern to most scientists. Nigeria is in the tropical region where zonal winds are considered to be weak, research work involving these dynamical processes have long been neglected and ignored, hence, there is need for research work in this area. The work carried out in this research involved employing the relationship between AAM and LOD to determine their contributions on depletion and variation of ozone.

Following the equations of Jadin (1999) and Abarca del Rio et al. (2000, 2003), given by;

AAM

$$\frac{2\pi r^3}{G}\int_{p_b}^{p}\int_{-\pi/2}^{\pi/2}\int_{o}^{2\pi} u\cos^2\phi\partial\lambda\partial\phi\partial p + \frac{\mathrm{R}^4}{\mathrm{g}}\int_{-\pi/2}^{\pi/2}\int_{o}^{2\pi} p_s\cos^3\phi\partial\lambda\partial\phi \quad ..13$$

Where R is the earths radius, g is the acceleration due to gravity, u is the zonal wind and P_s is the atmospheric surface pressure. The second term in AAM equation above is dropped, because it is related to the changes in the mass distribution of the atmosphere which plays no significant role in global AAM budget. Since Nigeria is the area of study and being in equatorial belt, then the equation for AAM becomes

$$AAM = \frac{2\pi R^3}{g}\int_{p_b}^{p}\int_{\partial}^{\pi/2}\int_{\partial}^{x} u\cos^2\phi\partial\phi\partial\lambda\partial p \quad \ldots\ldots\ldots\ldots\ldots\ldots 14$$

The solution of the problem is based on the assumption that the solid earth and atmosphere form a closed dynamic system, hence, the ΔLOD variability is directly proportional to AAM. Then we can write;

$$\Delta LOD \cong R3/_{c\Omega g}\int_{p_b}^{p}\int_{\pi/2}^{\pi/2}\int_{o}^{2\pi} u\cos^2\phi\partial\lambda\partial\phi\partial p + \frac{0.7oR^4}{c_g}\int_{-\pi/2}^{\pi/2}\int_{o}^{2\pi} ps\cos^3\phi \ldots 15$$

C is the principal moment of inertia of the earth's mantle plus crust ≈ 1.45 x 10^{-14}kgm^2,Ω is the mean rate of rotation of the earth ≈ 7.29 x 10-^{15} radians/second. Finally, the relationship between AAM and LOD is given as;

ΔLOD = 1.68 x 10^{-29}ΔAAM. …….. 16

Our work has established the fact that ozone is transferred by means of zonal wind from the upper trosposphere to the lower stratosphere in Nigeria (tropics), caused by the variation in AAM as a result of the variation of LOD. The ozone variations are more pronounced in the higher latitude regions than in low latitude regions. Further discovered, is the strong effect of pressure levels of atmosphere on ozone variation arising from its effect on the AAM and LOD. Our work confirms results of previous researchers (Fandel, 1988, Holten et al., 1995; and Abarca del Rio et al. 2003) who used different analytical approaches. Hence we deduced that the influence of atmospheric dynamics is a major factor in the variability of stratospheric ozone distribution over the tropic. Consequently, the transportation of ozone by zonal wind, which is latitudinal and seasonal dependant could cause ozone depletion in Nigeria. Since increase in ozone variations is found to be associated with magnetic storm, it is then suggested that another study relating magnetic storm with variation in ozone be carried out in tropics, since the effect of magnetic storm was found to be very strong.

(ii) Another Ph.D of Mine, Sivla William Tafon took off and started with the investigation of thermospheric wind response to geomagnetic activities. This is imperative, since mobility of

charged particles is greatly affected by the presence of the geomagnetic field. The data was grouped in seasons, solar flux and geomagnetic activity levels. Fig. 3 shows block diagrams illustrating the data processing.

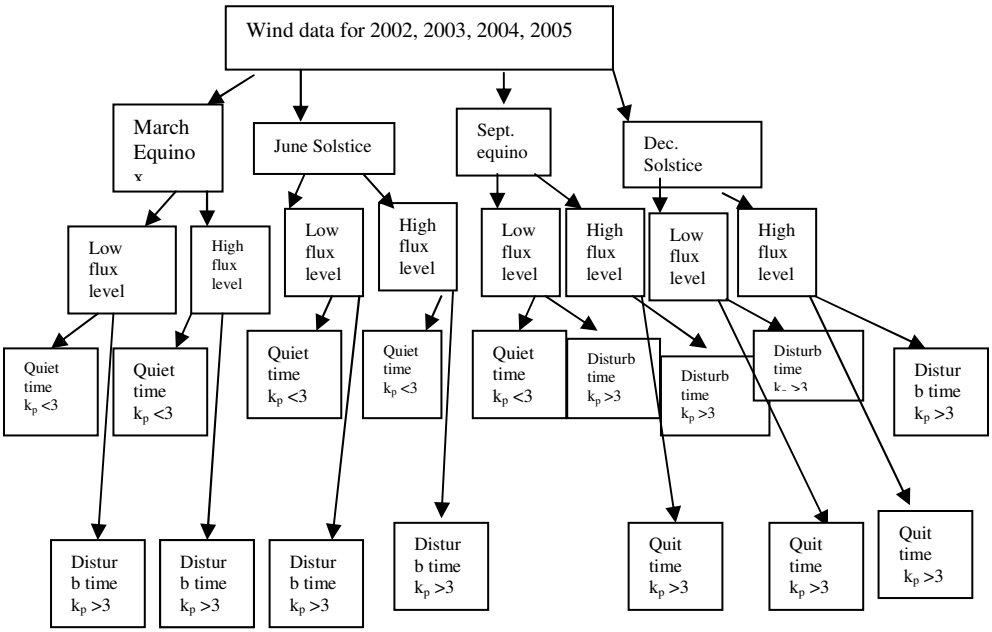

Fig. 3 Data processing at two different solar flux levels

The study was carried out in quest to seek solution to many unresolved issues, inclusive is the solution to complexity of the response of thermospheric wind to geomagnetic and solar activities.

The work was successful carried out, employing the most recent thermospheric wind data, derived from STAR accelerometes on board and the challenging mini- satellite payload (CHAMP). The results of work consolidate the fact that wind moves the ions in the atmosphere, in effect, creates necessary conditions for a dynamo action. The current systems formed, exhibit magnetic effect which is observed on the ground at observatories. The observed disturbance in the solar wind, and the current systems within magnetosphere are found to increase, resulting in magnetic disturbances and storms. The results from this work have helped in clarifying some of the pending issues and have thrown more light to the complex phenomena in the geomagnetic field worldwide.

I will briefly mention the projects of five other Ph.D students of mine:

(i) Mr. K.C. Okpala (a lecturer II in Department of Physics & Astronomy, UNN, who just recently came back from University of Delaware USA, where he did part of his Ph.D work), is currently rounding up his Ph.D entitled; study of the effect of cosmic rays on atmospheric and geomagnetic parameters. It is strongly hoped that results from this work will settle the existing controversies on the nature of galactic cosmic ray (GCR) – solar radiation cloud forcing mechanism;

(ii) Miss E.C. Okoro (a lecturer in Department of Physics and Astronomy, is also currently carrying out detailed research work (Ph.D) on; Influence of Zonal Winds and Magnetics Storms on Ozone variations in the Tropics.

(iii) Mr. E.B. I. Ugwu (a lecturer in G.S., U.N.N), is also currently working on 'Dependence of solar flare on solar wind and combined effects on geomagnetic field: an observational studies in Nigeria. With the installation of Nigeria Environmental Climatic and Observing Programme (NECOP) and solar flare monitor at the Centre For Basic Space Science, (CBSS), University of Nigeria Nsukka, at new permanent site, new researches have erupted, we are able to obtain data on solar flares, wind pressure and accurate climatic variables in 20

stations in Nigeria. We are grateful to Prof. P.N. Okeke (Director of CBSS), who attracted these equipment/instruments, at no cost to the University.

(iv) Mrs O.J. Ugonabo, is currently working on "Magnetic storms and geoeffectiveness of solar wind.

(v) D.N. Obiora (a Senior Lecturer in the Department of Physics and Astronomy) is working on "Application of solar quiet day current to investigate the Niger Delta subsurface structure. This is infact an innovative work in this area. It is our hope that the results from this work will not only result to more academic dispute but possibly a noble prize. This is the first of its kind, and very exciting.

Three new students have just reported to be assigned topics and many more students are warming up to join my research group. Without any exaggeration, I am proud to inform you that my research group is very vibrant and I thank God for this. We can see that as the journey advances, research progresses. I have no doubts that one day we might hit a noble prize, this is our ambition. The journey so far is encouraging and challenging. I thank God who has given us the strength and wisdom to face the challenges.

Question:

I know many people will ask, "after these results of research work, what are the relationship of geomagnetism to life"

Answer:

Geomagnetism has applications in many aspects of life, which make it relevant to sustainability and development of life.

Examples:

(i) **Magnetic Irregularities (MIs)**: are caused by crustal deposits. These MIs are usually determined by an area survey at quiet geomagnetic periods. Hence, magnetic anomaly maps showing these changes are used in the exploration of energy and mineral resources through any of the magnetic methods, such as geomagnetic depth sounding and aeromagnetic survey.

(ii) **Communications:** Geomagnetic storms enhance the ionospheric currents and induce voltage on telegraph lines such that the information/signal on transfer are distorted. Modern communication systems rely solely on radio wave links, oceanic and land-based

cables, microwaves transponders, telephone-line connections, and fibre-optic cables. Geomagnetic storms can cause disruption throughout the network of these facilities. Geomagnetic storms upset the high frequency (HF) radio waves as they propagate through the ionosphere, and are also responsible for phase changes in very low frequency navigation systems, fade outs of HF communication links at low latitudes.

(iii) **In satellite operations:** It is discovered that solar panel powering the satellite becomes degraded because of exposure to solar-terrestrial environment during storm-time, due to increased high energy fluxes. Also, during storm-time, the changes in thermospheric wind and density modify the dray on satellites which (Maynard, 1995) found to be the cause of transitory tracking loss and hence satellite lifetimes are shorten.

It has been long observed that the secondary currents induced from ionospheric currents, mostly from the magnetic disturbances could cause pipe corrosion, which, if not controlled

can lead to bursting or leaking of fuel pipe lines. This is disastrous.

It has been ascertained that magnetite exist in mammals, these are surrounded by nervous tissue indicating the possibility of interaction between the brain and the magnetic particles. Many researchers, (eg Pyvkin 1977; Gnevyshev, 1977), have reported geomagnetic disturbance effects on man. A large number of sudden deaths from cardiovascular disease occurred within the first few hours of a geomagnetic storm. Also these exist correlation between convulsive seizures and geomagnetic activity also positive correlation between human hallucinations and geomagnetic activity. There could also be malfunctioning of human nervous system as a result of high tension cable or storms.

Finally, the atmospheric disturbance affects meteorology of a given place and hence the seasonal weather conditions, because climatic elements are solar cycle dependent.

INTERLUDE 3

Aeroplanes and ships are possible because of the discovery of laws of floatation and Archmodes principle in physics. At this

point, let us look at all inventions in the world based on fundamental laws and research in physics, let us name but a few, X-rays nuclear weapons, discovery of radio waves-this has led to radio communication by phone. Discovery of satellite further led to wireless communication we are all enjoying today. Application of sound waves (echoes) is relevant in the oil companies. We also note that the law of electromagnetic induction has led to the discovery of transformers which play prominent part in power distribution. The study of crystals and electrons have resulted to production of chips that perform miracles today. What keeps the earth rotating and revolving around the sun without falling into space? It is as a result of simple physics law of gravitation. The gravitational force between the earth and the sun is responsible for holding the earth in position. Concluding, the five integrating teams that make up physics include; **motion**, **energy**, **quanta**, **conservation laws** and **wave**. Without motion, there will be no life, no energy implies no work if no work is done there is no life, if energy is destroyed not conserved, it will be disastrous to life on earth. Then wave is responsible for most of the invented modern technology. In summary, we live and die physics.

Conclusion:

It is clearly obvious that between 1989 to 2009, we have carried out extensive research in the area of geomagnetism, that covers the entire earth, starting from interior to the upper atmosphere. So much research work have been carried out and some have raised several disputes and controversies which ended in our favour. The research team is growing stronger and stronger. Our results have revealed and have unfolded hidden or still undiscovered phenomena. We are in a dynamic and not a static world, as such more current and future research work in the area of geomagnetism, which has been noted to encompass the entire earth, should be intensified. At this point, we must pray that we do not escape into space. The solar terrestrial interaction research, is a wide and exciting one, we hope that with some break-throughs and new findings that we will one day earn a noble price.

Acknowledgments

Mr. Vice-Chancellor Sir, to end this lecture, I will like to express my appreciation to all who contributed in one way or the other to my success today. I am highly indebted to God Almighty, whose blessings, protection, and guidance cannot be quantified, glory be to Jesus, honour to our Mother Mary.

I sincerely thank the Vice-Chancellor, Ven. Prof. C.O. Nebo, who has made the Inaugural lecture in this University so exciting (appetizing), no wonder, the highest number of Inaugural Lecturers has been recorded in his own time.

I thank my father Chief Patrick Okoye of the blessed memory for being my mentor. My mother Mrs. Margret Okoye, my brothers and sisters for all their cooperation and love.

Then, I turn to my immediate family, I have already mentioned in the beginning that my husband's encouragement is second to none. It is not an overstatement to say that, his love for me and the entire family is something to be reckoned, May God continue to bless and protect you for us, you are one in a million. To all my children and in-laws for their special love and obedience, I am proud of you all. A special thanks to my son-in-law Ik Ezechi, who helped in proofreading part of this work.

I equally thank all my friends and lecturers for their contributions. I am sending special greetings to my Ph.D supervisor, Prof. C.A. Onwumechili, who is in USA, who tried his best to be here but could not. I equally send special greetings to Prof. Yazo Homano of the University of Tokyo, for hosting

me and guiding me through Matlab Software. My thanks also to Prof. W.A. Walker of S.A., Prof. J. Marengo and Prof. C. Carlos of CPTEC Brazil. To Prof. M.O. Oliver of Morgan State University of Baltimore, USA, Prof. D. Waugh of Johnhopkins University Mary Land, USA. Prof. J.M. Forbes of University of Colorado, Boulder, USA and many others who allowed my free access to their facilities and supported my visits to their various institutions. They have contributed immensely to the position I am today.

I thank my colleagues in the Department for their cooperation, I equally thank all staff of Faculty of Physical Sciences for their support. I seize this opportunity to thank all my students, right from secondary school, undergraduate to graduate level. I thank in particular my Ph.D students that are now Doctors, and those yet to complete their work, my various MSc students who are now warming up to register for their Ph.D, to God be the glory. I also thank Miss Chinyere Ngwu, for typing neat work.

Finally I thank the audience for their sacrifices and patience. May God lead you all safely back home. We have seen that we live and die physics; hence it is not an overstatement to conclude that physics is life and life is all about physics.

THANK YOU ALL FOR LISTENING.

APPENDIX I

Subj: **Fwd: EPS0804**
Date: 13/02/02 08:42:08 Romance Standard Time
From: hamano@eps.s.u-tokyo.ac.jp (yozo hamano)
To: EPSEELON@aol.com
CC: pokeke@cfassp39.harvard.edu, pokeke@cfa.harvard.edu

File: Kiritimaticomments.zip (3183378 bytes)
DL Time (32000 bps): < 28 minutes

Dear Francisca,

How are you doing? I just received the following message and the attached files from EPS editor. As written by Prof. Honkura (Editor in chief to EPS), If you can submit a reply, please let me know or send e-mail to yhonkura@geo.titech.ac.jp.

With best regards,

Yozo

□-

Dear Prof. Hamano,

We received the following paper and after reviews we accepted this paper for publication in EPS. Please see the attached files for details.

Comments on the paper entitled "Daily variations of geomagnetic H, D and Z-fields at equatorial latitudes" by F. N. Okeke and Y. Hamano

This paper is infact a comment paper on the above paper. So I am now asking the authors whether they intend to submit a reply to this paper. If submitted, the reply will be subject to brief reviews and the reply will appear, if accepted, together with the comment in the same issue of EPS.

Could you talk with Dr. Okeke and inform me wether he can submit a reply within a few weeks? If I do not receive any reply, the above comment paper will appear in the latest issue of EPS.

Best regards,

Y. Honkura
Editor-in-Chief of EPS

Earth Planets Space, 54, 421–422, 2002

Comments on the paper entitled "Daily variations of geomagnetic H, D and Z-fields at equatorial latitudes by F. N. Okeke and Y. Hamano"

R. G. Rastogi

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(Received July 30, 2001; Revised February 12, 2002; Accepted February 13, 2002)

Okeke and Hamano (2000) have described the daily variations of geomagnetic field H, D and Z at the equatorial station Kiritimati. Some conclusions by the authors are not correct according to my views and I would like to clarify these points here.

The first conclusion the authors have made is "The pronounced magnitude of Z variations observed in Kiritimati is mainly due to sea induction." Any model of the equatorial electrojet current belt indicates that the latitudinal profile of ΔH during the daytime should show a maximum over the dip equator while the profile of ΔZ would show a minimum around the latitude of the northern fringe and a maximum around the southern fringe of the electrojet belt. Assuming the electrojet to extend between $\pm 3°$ dip latitude, the minimum of ΔZ should occur around 3°N dip latitude or 6°N inclination. Fambitakoye (1971) has clearly shown the simultaneous growth and later decay of the ΔH peak over the dip equator and of the ΔZ peaks at the two fringe regions during the course of the day using data from the central African longitude sectors. Doumouya *et al.* (1998) have described geomagnetic field measurements at a chain of observations stretching across both sides of the dip equator at West African longitudes. A maximum of ΔH was clearly seen close to the dip equator around 1100 local time. The contours of ΔZ showed a minimum around 3°N dip latitude slightly before noon, and a corresponding maximum around 3°S dip latitude. The ΔH and ΔZ values near the northern edge of the electrojet belt were 80 nT and −50 nT respectively. Thus $\Delta Z/\Delta H$ was large near the fringe regions of the electrojet. The geomagnetic latitude of Kiritimati given in the paper is 3.09°N; the inclination estimated from IGRF coefficients is 6.4°N giving the dip latitude as 3.2°N, which is the latitude close to the northern fringe of the electrojet belt. The diagrams of ΔH, ΔD and ΔZ in the paper give a confused impression due to different scale values and a large offset at midnight for ΔZ in some diagrams. A composite diagram showing ΔH, ΔD and ΔZ at Kiritimati with a uniform scale is presented in Fig. 1 constructed from the original diagrams. It is clearly seen that the curves for ΔH and ΔZ for all months are in inverse phase with their peaks occurring at the same time. During October 1998 when ΔH was large, the values of the ranges of H and Z were 128 and −96 nT respectively. The ratio $\Delta Z/\Delta H$ was large similar to that observed in the West African region. Thus the variation of Z at Kiritimati is as expected of a normal eastward flowing electrojet current and there is no abnormality in the data.

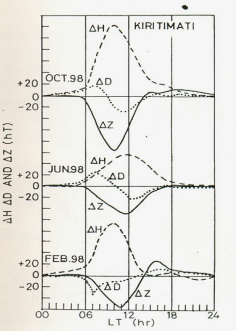

Fig. 1. Diurnal Sq variations of at Kiritimati during February 1998, June 1998 and October 1998 (after Okeke and Hamano, 2000).

The second comment is the statement "Seasonal variations with more pronounced equinoctial maxima observed in H than in Z is due to enhanced electron density at equinox." Rastogi (1993) has discussed the relative importance of the ionosphere electron density and electric field based on a long series of data of ΔH and of the peak electron density in the E region (NmE) at Huancayo and Kodaikanal. It was shown that long-term variations of ΔH, like the solar cycle variation, are dictated by the corresponding variation of NmE. But the seasonal variation of ΔH even after correction due to NmE still shows equinoctial maxima and is due to the seasonal variation of the local electric field, not the elec-

tron density. Chandra *et al.* (2000) after a coordinated study of the rocket and ground based data of the electrojet have reached the same conclusion that the equinoctial maxima of the electrojet strength are due to the electric field at the electrojet region of the ionosphere.

The daily variation of ΔD is also very normal for equatorial stations where the variation was as expected at a northern hemisphere station with a morning maximum and a midday minimum. During December solstices the variation is reversed as seen at other equatorial stations in Asian Pacific sectors. (Rastogi and Stening, 2002).

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R. G. Rastogi (e-mail: parvs@prl.ernet.in)

APPENDIX III

Earth Planets Space, 54, 423, 2002

Reply to "Comments on the paper entitled 'Daily variations of geomagnetic H, D and Z-fields at equatorial latitudes by F. N. Okeke and Y. Hamano'"

F. N. Okeke[1] and Y. Hamano[2]

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1. It is not correct to rule out the possibility that the pronounced variation of Z observed in Kiritimati could be due to sea induction. See page 242 of Okeke and Hamano (2000) for detailed explanation.

2. There is no doubt in that ΔZ and ΔH should respectively show the minimum and the maximum values. We are merely claiming that the minimum value in Z variation is more pronounced at Kiritimati than those at Huancayo and Pohnpei. See figures for clarification.

3. We are very familiar with the studies of Fambitakoye (1971) and Doumouya *et al.* (1998), as can be seen from our references to these papers, and Rastogi's explanation on ΔZ has been taken into consideration in our paper. See Fig. 4 in page 241.

4. The remark on the scale used is not relevant. We have used the same scale for plotting all the ΔH diagrams and different scales for plotting all the ΔD and ΔZ diagrams. Since we are not comparing the different elements, the use of the same scale for all the elements is unnecessary, and we think no confusion will be generated.

5. Another weak point in Rastogi's argument is his tendency to draw conclusions from a single or a few persons' work. For example, we have observed that in Fig. 13(c) of Doumouya *et al.* (1998), the maximum value of ΔH, which Rastogi claims to have appeared close to the dip equator at around 11:00 local time, appeared in fact at around 11:00 universal time.

6. Even though the ratio $\Delta Z/\Delta H$ is approximately 0.63 as Rastogi quoted from Doumouya *et al.* (1998) and approximately 0.75 in Okeke and Hamano (2000), the fact remains that the pronounced variation was observed.

7. Rastogi seems to have been confused and the abnormality in the behaviour of variation ΔZ in Okeke and Hamano (2000) is taken as the abnormality in the data. In fact, the abnormal feature we referred to was seen on 23rd January when the Z component of the geomagnetic field showed the maximum value around local noon hours at Huancayo.

8. It is surprising to find that although D has deviated from the normal known variation such as the morning trough and the afternoon crest, as evident from Fig. 1(a), Rastogi termed it normal. We remark that it is common in research for some observations to deviate from the expected theoretical results.

9. Finally, we remark that the seasonal variations with more pronounced equinoctial maxima as observed in H than in Z could be a contribution from both the electric field as well as the enhanced electron density at equinox.

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Okeke, F. N. and Y. Hamano, Daily variations of geomagnetic H, D and Z-fields at equatorial latitudes, *Earth Planets Space*, **52**, 237–243, 2000.

F. N. Okeke (e-mail: okekef@infoweb.abs.net) and Y. Hamano

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