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THUS SPOKE THE GOOD SHEPHERD: GO FORTH AND EXPLAIN THE STORMS

BY

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73RD INAUGURAL LECTURE

OLABISI ONABANJO UNIVERSITY
AGO-IWOYE

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THUS SPOKE THE GOOD SHEPHERD:GO FORTH AND EXPLAINTHE STORMS

The Vice Chancellor,
The Deputy Vice Chancellor,
The Registrar,
The Librarian,
The Bursar,
Provosts here present,
The Dean of Faculty of Science,
Deans of Faculties here present,
Distinguished Academic Colleagues,
Distinguished Non-Academic Colleagues,
Distinguished Guest and Friends,
My Dear Students,
All protocol observed.

1.0 Introduction

1.1 Preamble

Mr Vice Chancellor Sir, it is with a deep sense of gratitude to the Almighty God, the Alpha and the Omega that I stand here today to present my inaugural thesis: Thus Spoke the Good Shepherd: Go Forth and Explain the Storms. I am also grateful to the University for approving my request to give a narrative of my major contributions to the body of scientific knowledge. In this light, I will assert upfront that these contributions which are in the main on the explanation of the mechanisms responsible for equatorial ionospheric radio wave absorption and the ionospheric storm phenomena are steeped in the twin phenomena of fertility and birth which give life through love and pain. But let me begin with Psalm 23: "The Lord is My Shepherd "and a homily from it, as well as the poem:"Autumn" by Rainer Maria Rilke.

Psalm 23

The Lord is my shepherd, what more do I need?
In green pastures he lets me rest.
To quiet streams of water he leads me,
And revives my failing spirit.
He leads me along the right paths
ever true to his name.
Even though I walk through the valley of the shadows of death,
No harm would I fear, for you are there by my side.
With your rod and your staff you give me comfort.
You prepare a banquet for me
In the presence of my foes.
You anoint my head with oil;
my cup is overflowing.
Only goodness and kindness will follow me
all the days of my life,
I shall dwell in the house of the Lord
for ever and ever.

The homily: A Soprano and an Old Catholic Monk were invited to individually give rendition of Psalm 23 at a Christmas carol. Taking the lead, the soprano rendered Psalm 23 to a standing ovation. And at his turn, the Monk sang the Psalm in a coarse voice; when he finished, there was dead silence in the hall. In the midst of this silence, the soprano rose to his feet and said to the audience: I understand the reason for your earlier standing ovation and this your overwhelming silence. The motivation is that I only touched your ears with my knowledge of the lyrics of Psalm 23, while the Monk touched your hearts because he knows the good shepherd; I now know that it is only the good shepherd that can touch our hearts". And I must add here that this homily is at the heart of my narrative. And let me wager that for a scientist, there is an eternal struggle between the vision of the good shepherd that is unbounded and the vision of men that is imperfect. It is his choice to submit his talent to the vision of the good shepherd or that of man.

Now the poem:

Autumn

The leaves are falling, falling as if from far up,
as if orchards were dying high in space.
Each leaf falls as if it were motioning "no."

And tonight the heavy earth is falling
away from all other stars in the loneliness.
We're all falling. This hand here is falling.
And look at the other one. It's in them all.

And yet there is Someone, whose hands
infinitely calm, holding up all this falling.

Mr Vice Chancellor Sir, I needed the poem Autumn to resonate here today because at the beginning of my career I found solace in the words of this inherently "mystical" work of Rainer Maria Rilke—the Bohemian-Austrian poet and novelist because it invoked unforgettable metaphors that gave me indescribable hope in times of profound anxiety while I longed for the good shepherd;for I believed with the hymnist in "Come Lord Jesus" that:

The clouds shall send a Saviour
Like a softly falling rain,
Yet mighty in his power,
To free us from chains,
His shield will be compassion,
His weapon liberty

Indeed his weapon is liberty because the good shepherd in his own chosen time, one morning in mid-1999, led me out of Egypt into the Journal Section of the University of Lagos Library, and as I walked along the isle, a Journal fell at about four metres behind me. As I looked back, a thought came upon me to go back, pick and return it to its place on the shelf. I accepted the thought, pick it up but found out from the Journal's Call Mark that its shelf position is about four metres from where it was on the floor; much more than that, I also found that the journal was a new library acquisition- a donation from the World Bank. At this point, the mysterious happened as at my first attempt, the journal opened onto a seminal work on geomagnetic storms in the mid latitudes of the Earth that used high frequency radio absorption data, and of which I had corresponding data for the equatorial region of Africa. This singular ineffable encounter, which I believe was in resonance with the vision of God as I was filled with the message: "*Go forth and explain the storms*" thereafter placed in my hands tools to address one of the unsettled problems in ionospheric phenomena studies- the influence of geomagnetic storms on radio wave absorption in the equatorial ionosphere, and eternally changed my research direction as well as career as a University teacher, and made this day possible.

Now, let me bring us to speed with the images from my research direction, and which are at the heart of my major contributions: Space Weather.

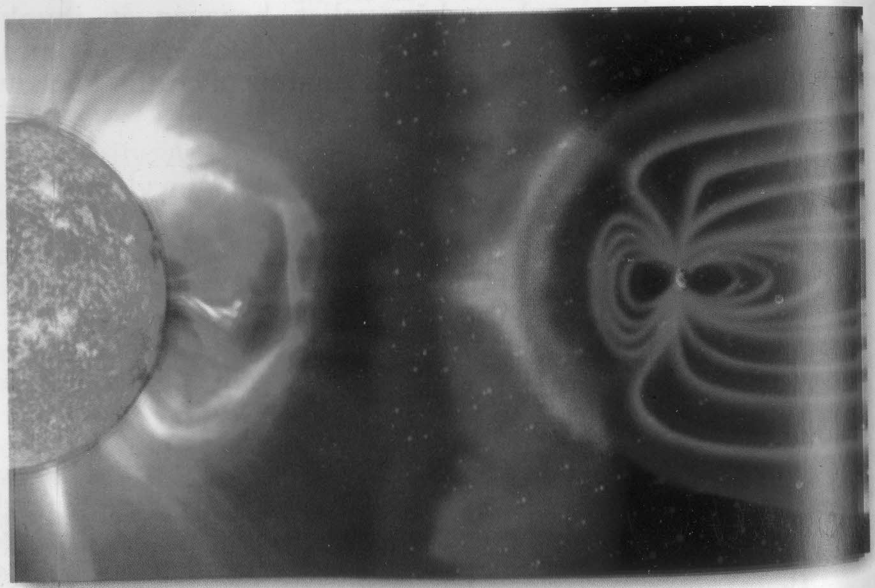


Figure 1.1: Origin of Space Weather: The space weather environment ©NASA

Figure 1.2. Top: Aurora during the aftermath of a large geomagnetic storm on November 20, 2003 © Stan Solomon. Bottom: Aurora on October 30, 2003© Tom Eklund

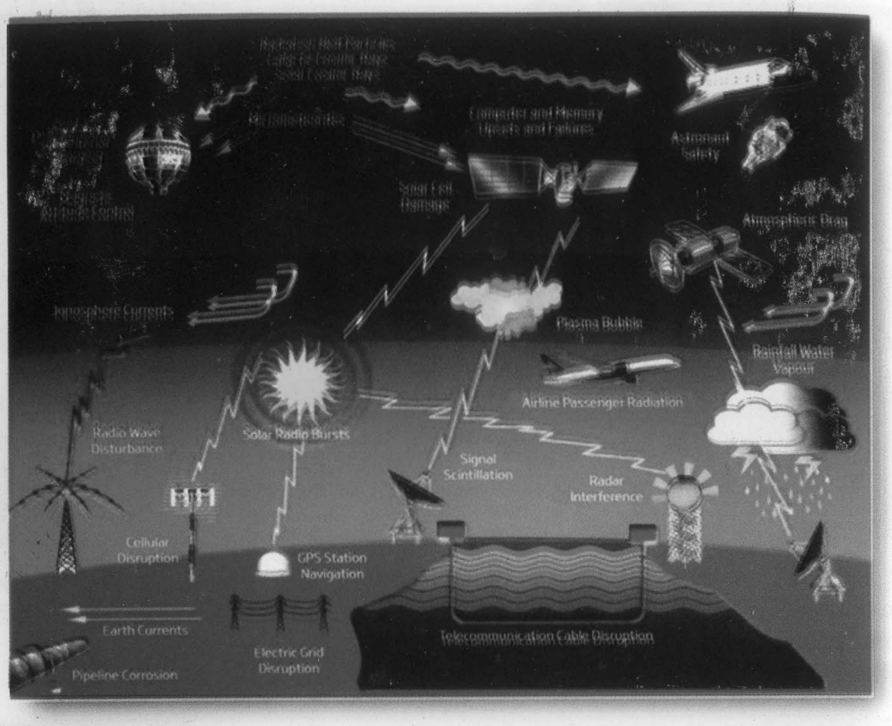


Figure 1.3: Impacts of space weather © L. J. Lanzerotti, Bell Laboratories, Lucent Technologies, Inc.

1.2 The Background Information

Mr Vice Chancellor Sir, my field of research is ionospheric physics and radio wave propagation while my specialization is mainly in the area of space weather (Figures 1.1, 1.2 and 1.3). Space weather encompasses the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground- based technological systems and can endanger human life or health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses (United States of America's National Space Weather Program Strategic Plan, FCM-P30-1995).

The definition of space weather that covers changes in the space environment and the effects that those changes have on an array man's activities on Earth highlights the importance of studying space weather which is twofold: One is academic as it is considered a central part of space science. The other is technological as it represents a concern to man especially in the developing countries were various national development efforts are increasingly dependent on space-borne and ground-based technological systems which are susceptible to space weather. This aspect of space weather compels the need for a full understanding of the behaviour of the ionospheric storm phenomena with regards to the latitudinal and longitudinal dependence of the ionosphere-thermosphere system's response to major solar events. This need constitutes the driving concept of my research efforts.

Mr Vice Chancellor Sir, in a world of astonishing changes, the most critical duty of any Government remains the security of its people. This is because national security is an important pre-condition for sustainable development. And an important vehicle for governments towards achieving national security is the engagement of people through propaganda and persuasion which can be cost-effectively done through radio communication on long distance high frequency (HF) (3-30 MHz) point-to-point broadcasting (often referred to as shortwave). Pertinently, this mode of communication is dependent on the ionosphere (Figure 1.4) for the propagation of radio signals beyond the horizon. Furthermore, the military worldwide rely on High Frequency (HF) radio systems for coordinating soldiers in times of peace, war or terrorists' strike. This is because communications by satellite are vulnerable to jamming and physical damage. Also, the availability of satellite channels for the military is limited and their supporting infrastructure are expensive to procure as well as sustain.

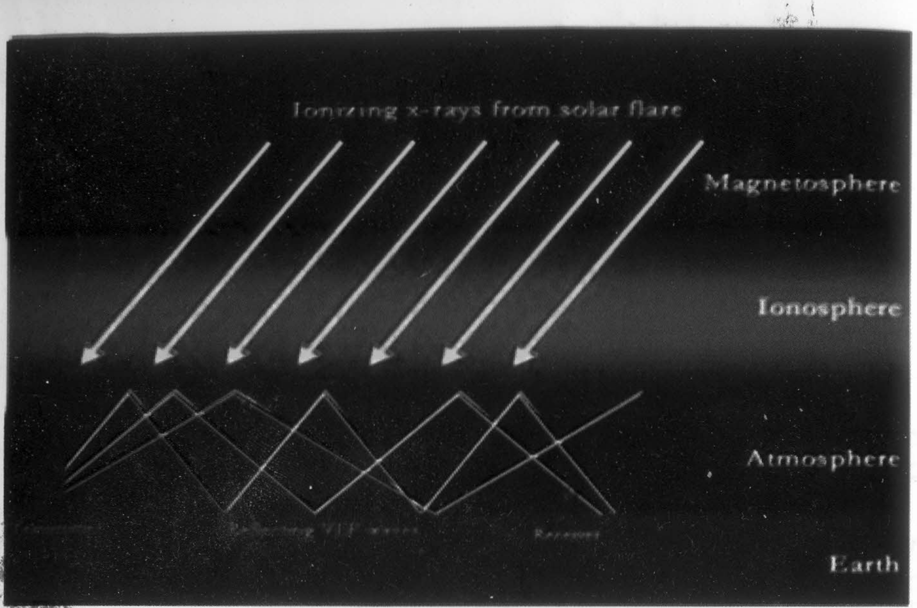


Figure 1.4. The Ionosphere ©http://solar-center.stanford.edu/SID/activities/images/image012.jpg

This situation leaves the ionospheric HF radio communication a reliable communication backbone but with the requirement of commendable knowledge of the propagation characteristics of the ionospheric phenomena; this is because the operational efficiency of radio communications systems is largely dependent on the detailed knowledge of the diurnal and seasonal variations of radio wave absorption. These phenomena are crucial in frequency allocation by both international and local regulators on the one hand and planning of broadcast timetables on the other hand by broadcasting services such as the BBC World Service, Voice of America (VOA), Voice of Nigeria (VON) and Federal Radio Corporation of Nigeria (FRCN), as well as the military worldwide. Otherwise there will be chaos and radio communication operations would be grossly inefficient due to interference and excessive ionospheric radio wave absorption.

Table 1.1 shows the BBC World Service broadcast frequency schedule for West Africa. Observe that the broadcast frequencies vary with the time of the day in order to avoid excessive radio wave absorption that will arise from inappropriate frequencies. Table 1.1 and Figure 1.5 which presents the real time Ionospheric map of the world underscore the importance of the knowledge diurnal and seasonal variation of radio wave absorption in any region of the world.

From	To	Days	Frequency (kHz)
05:00	06:00	Daily	5875
05:00	07:00	Daily	6005
06:00	07:00	Daily	7355, 15105
06:00	08:00	Daily	12095
07:00	08:00	Daily	11770, 13660, 17830
16:00	18:00	Daily	17830
17:00	18:00	Daily	17780
17:00	20:00	Daily	15400
18:00	20:00	Daily	13660
18:00	21:00	Daily	11810
20:00	21:00	Daily	9915, 12095
21:00	22:00	Mon-Fri	9915, 11810, 12095

Table 1.1: BBC World Service - Radio Frequency Guide for West Africa ©(www.bbc.co.uk/worldservice/schedules/frequencies)

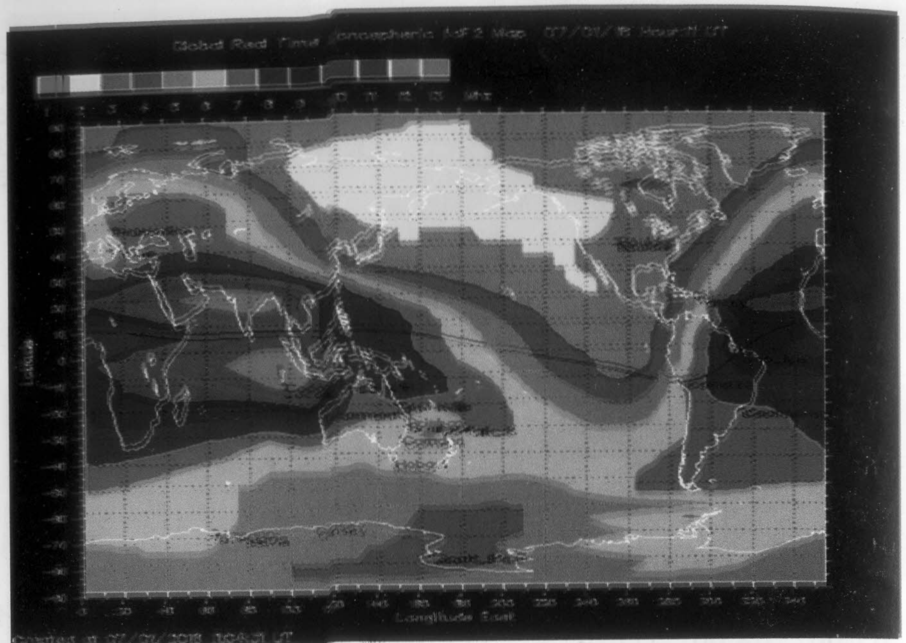


Figure 1.5. Real Time Ionospheric Map ©Australian Government Bureau of Meteorology Weather Services http://www.sws.bom.gov.au/HF_Systems/6/5

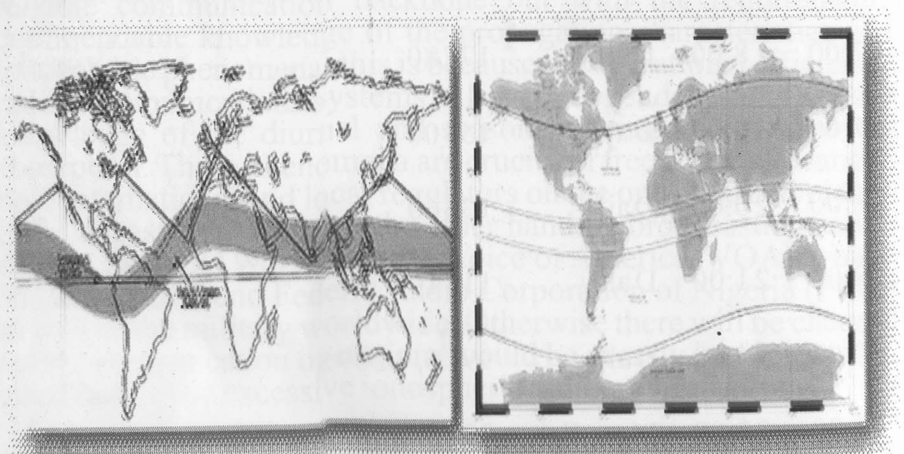


Figure 1.6 The Geomagnetic Low Latitude/Equitorial Region. Left Picture ©uksmg.com Right Picture©wcflunatall.com

However, there existed, at the beginning of my career, paucity of this knowledge in the equatorial region of Africa (Figure 1. 6) where Nigeria is located. This dearth of scientific knowledge of the equatorial ionosphere was due to on the one hand the near non-availability of such facilities as rocket-borne experiments and incoherent scatter radars and on the other hand limited number ionosonde and GPS receiver stations. While in the middle and high latitudes, most of the complexities of ionospheric HF radio wave absorption appear mostly resolved due to the fact that the lower ionosphere in these regions have been the subject of extensive studies using vast arrays of ground-based and rocket-borne experiments. Figure 1.7 while presenting a maps of SPIDR ionospheric stations underscores my point.

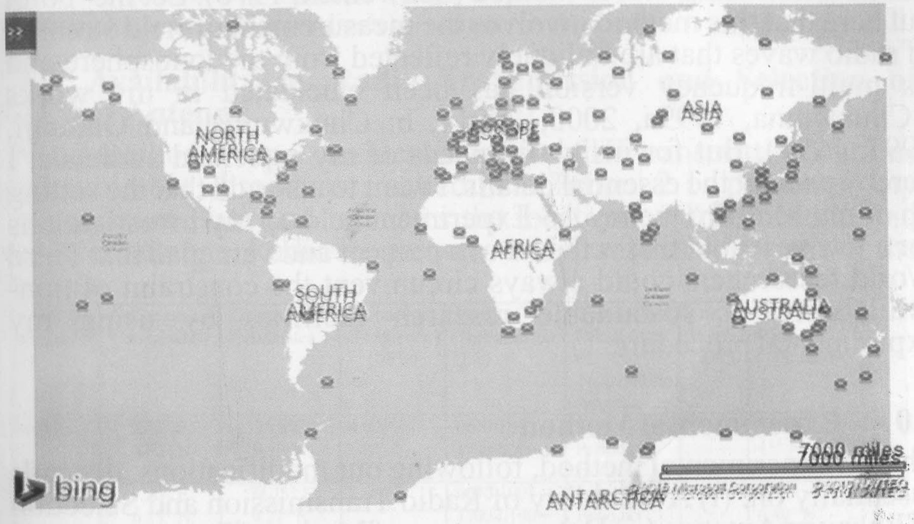


Figure 1.7. SPIDR Ionospheric Stations during 1980-2014. © http://spidr.ngdc.noaa.gov/spidr/

According to Chukwuma (2000a), these studies in the mid and high latitudes have provided valuable information concerning ionospheric structures, processes and formation which has resulted in the improvement of long distance HF communication and frequency management in these regions.

In this regards, the improvement of the operational efficiency of radio communications systems in the equatorial region of African, I insisted then, demanded a detailed study of the ionospheric radio wave absorption at the equatorial region in order to unravel the phenomena of (i) frequency and seasonal dependency of HF radio wave absorption, and (ii) geomagnetic storm after-effects, on radio wave absorption in the equatorial region. The results of these investigations, I argued, would provide the users of the HF systems in the equatorial region in general and Nigeria in particular requisite scientific knowledge for technological innovation and optimal performance of their radio communication hardware in the form of effective and power saving radio communication.

My vision implied innovation: firstly, I had to overcome the constraint of unavailability of sustainable research facilities by building and using the A3 method (Schwentek, 1976). Let me point out here that this method involves the measurement of field strength of radio waves that are obliquely reflected from the ionosphere and its multi-frequency version has been elucidated in my works ((Chukwuma, 1999a, 2000, 2001a, b; Chukwuma and Olatunji, 1997, 1999). But for insightful needs of my esteemed audience, I hereby present the essential details. I want to also add that the setting up of my Multifrequency A3 Experiment held up my investigations for a few years but that is the lot of a pioneer and I am glad that Third World researchers could always circumvent the constraint of non-availability of sustainable research facilities by using my experimental procedure.

2.0 Experimental Method

The A3 experimental method, following our modifications, depends essentially on: (i) Availability of Radio Transmission and Selection of Receiver Antenna (ii) Determination of Modes of Propagation and (iii) Determination of Absorption and Data Analysis.

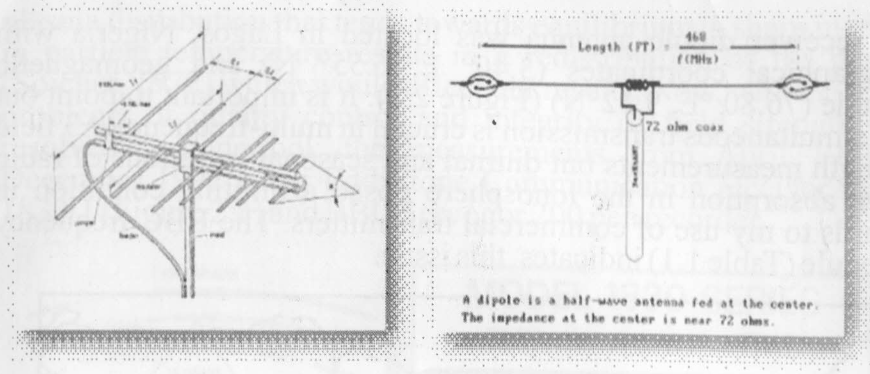


Figure 2.1.Transmitting Antenna (Log-periodic) ©all-antennas. Inform; Right: Receiving Antenna (Half-wave dipole) © radiosurvivalist.com.

2.1 Availability of Radio Transmission and Selection of Receiver Antenna

The A3 method compels an identification of HF transmitting stations with reliable broadcast schedule. Table 2.1 presents my Transmission Data and indicates the location of Transmitting and Receiver antenna, Radio frequencies and Transmission hours of the Stations.

Transmitter Location	Geographical Coodinates	Geomagnetic Coodinates	Transmitter Frequency (MHz)	Hours of Transmission (LT)	Type and Orientation of Transmitting Antenna	Out Power (KW)	Ionospheric Point coordinates
Cotonou	2.43° E, 6.35° N	75.8°E 9.10°N	4.87	0600-1005 1700-0100	Log Periodic Horizontal	50	2.90° E, 6. 45° N
Lomc	1.20° E. 6.27° N	74.13° E 9.21° N	5.047	0600-1005 1700-0100	Log Periodic Horizontal	50	2.30° E, 6.40° N
Kaduna	7.5° E, 10.50° N	81.60°E 12.26°N	6.09	0530-2305	Half wave Non-directional	100	5.45° E, 8.52° N 4.43° E, 7.54° N
Libreville	9.45°E, 0.38° N	81.23° E 1.99° N	9.60	0530-2305	Half wave	200	6.43° E, 3.47° N 4.92° E, 5.01° N
Ascension Island	-14.37° E, -7.95° N	56.80°E -2.15°N	15.40	0800-0915 1000-1230 1600-2400	Half wave	200	-5.45° E, 0.70° N -1.05° E, 2.93° N

Table 2.1. Transmission Data (Chukwuma and Olatunji, 1999)

My receiver dipole antenna was located in Lagos, Nigeria with geographical coordinates (3.40° E, 6.55° N) and geomagnetic latitude (76.80 °E, 9.12°N) (Figure 2.2). It is important to point out that simultaneous transmission is crucial in multi-frequency A3 field strength measurements but diurnal and seasonal variations of radio wave absorption in the ionosphere posed a limiting condition in regards to my use of commercial transmitters. The BBC frequency schedule (Table 1.1) indicates this issue.

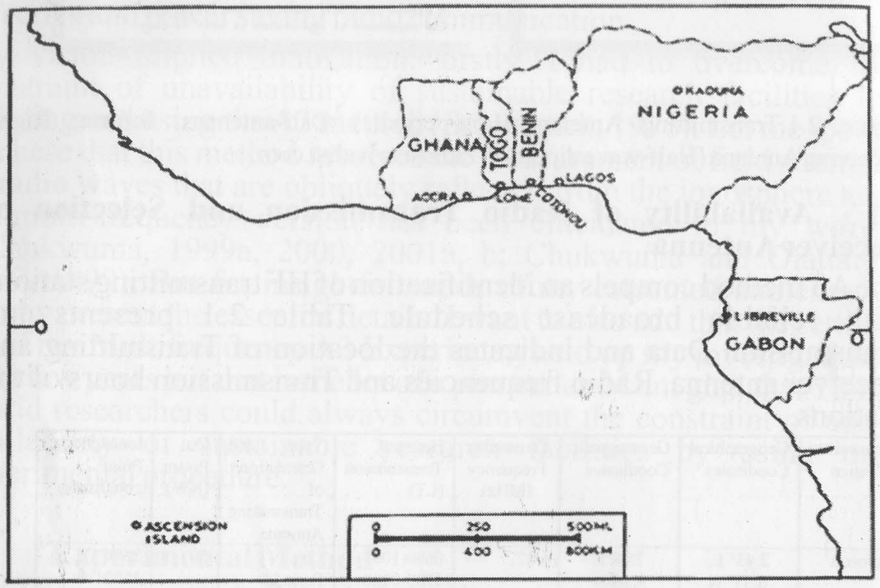


Figure 2.2. A map showing transmitter and receiver locations for the A3 method circuits in West and Central Africa (after Chukwuma V. U., 2001a)

However, as shown in Table 2.I, a small window of time around 1000 LT was the only period when it was possible for me to carry out the multi-frequency absorption measurements. I want to remark at this point that the discovery of the1000 LT window for field strength measurement was remarkable in that the 1000 LT period being outside sunrise was capable of indicating real changes in electron density due to external drivers. It is known that sunrise period is manifested by a rapid increase in electron temperatures and a less rapid increase in ion temperatures at all altitudes. In a plasma distribution that tends towards equilibrium, a sharp increase in particle temperature results in a redistribution of the plasma (Soicher, 1972) which would affect our results. Now, with the initial problems of quality control and integrity of field strength data resolved, I undertook the measurements from April 1991 to December 1992 using Eddystone Communication receiver model 1830/1 (Figure 2.3) and BBC Servògor 200 pen recorder.

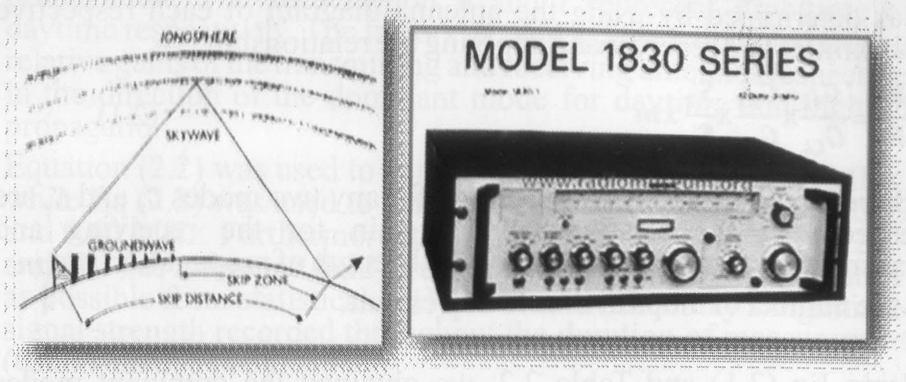


Figure 2.3. Left: A3 Radio wave propagation ©reivilo.co.za; Right: Eddystone Communication Receiver ©Radiomuseum.org

2.2 Determination of Modes of Propagation

Circuit	Frequency (MHz)	Mode	Elevation Angle	Rx Antenna Gain (db)	Tx Antenna Gain (db)	fCos α (MHz)
Cotonou-Lagos	4.87	1E	63.4	70.0	9.0	4.37
		1F	75.0	90.0	7.2	4.72
Kaduna-Lagos	6.09	2E	34.93	26.0	0.64	3.49
		2F	62.60	88.0	0.84	5.41
Libreville-Lagos	9.60	1E	14.80	10.0	0.18	2.35
		1F	34.92	26.0	0.64	5.50
		2E	26.80	28.0	0.54	4.33
		2F	54.39	78.0	0.80	7.80
As Island-Lagos	15.40	2E	10.76	6.0	0.04	2.88
		2F	27.76	14.0	0.56	7.17

Table 2.2. Possible modes of radio wave propagation on the circuits (Chukwuma and Olatunji, 1999)

Crucial to a reliable field strength measurement for HF radio wave absorption investigation is the determination of the dominant modes of propagation of radio wave from a number of possible modes of propagation of radio wave on the circuits. Table 2.2 shows the possible modes for the circuits at 1000 LT. From these possible modes, the dominant mode for a circuit, which is defined as the mode that has a higher relative antenna gain among the possible modes, was determined by using the antenna diagram of each respective transmitter and receiver and applying the relationship:

$$\frac{E_1}{E_2} = \frac{G_{t1}}{G_{t2}} \times \frac{G_{r1}}{G_{r2}} \times \frac{S'_2}{S'_1} \, x m \qquad (2.1)$$

where E_1 and E_2 are signals received for any two modes G_r and G_t are respectively the relative antenna gain for the receiving and transmitting antenna. s' is the half path length of propagation and m is the number of hops in a multi hop circuit.

Using Eq (2.1) and Table 2.2, we obtained the dominant modes (Table 2.3) for the A3 circuits that are under consideration.

A3 Circuits	Frequency (MHz)	Mode
Cotonou-Lagos	4.87	1F
Kaduna-Lagos	6.09	2F
Libreville-Lagos	9.60	2F
As Island-Lagos	15.40	2F

Table 2.3. Dominant modes of propagation on the circuits (Chukwuma and Olatunji, 1999)

2.3 Determination of Absorption and Data Analysis

The absorption of HF radio wave for any HF circuit, when the height of reflection of the radio wave is the same for both daytime and nighttime propagation is:

$$L\,(t) = 20 Log_{10} \frac{E_n}{E_t} dB \qquad (2.2)$$

when the heights of reflection are different for daytime and nighttime propagation is:

$$L(t) = Log_{10} \left[E_n S'_n k_a k_b \quad E_t S'_t\right] dB \qquad (2.3)$$

where E_n is the nighttime field strength when there is no absorption field, E_t is the daytime field strength S' is the half path length of propagation, The subscription n and t represent nighttime and daytime respectively. The factors K_a and K_b are calculated from the relative gains of the transmitting and receiving antennas respectively in the direction of the dominant mode for daytime and nighttime propagation.

Equation (2.2) was used to determine absorption for 15.40 MHz while Eq (2.3) was used to determine the absorption at 4.87, 6.09 and 9.60 MHz. Furthermore, the values of E_n used in Eqs (2.2) and (2.3) as reference field strength are determined as accurately as possible from statistical analysis of individual day's nighttime signal strength recorded throughout the duration of measurement (Chukwuma, 2000).

2.1 Initial Results

Radio wave absorption, L in the ionosphere, whose knowledge is crucial for radio communications, can be related to the solar zenith angle by the expression (Appleton and Piggott, 1954)

$$L = A\, Cos^n \theta \qquad (2.4)$$

where $n = index$ $\theta = solar\ zenith\ angle$ and $A = constant.$

It is pertinent to note that the only fact that is certain in regards to Equation 2.4 is that at first approximation, optimal radio wave absorption in the ionosphere occurs when the solar radiation is at right angles to the centre of the region being irradiated. That is when the Sun is overhead at local noon. Beyond this point, the physics becomes complex, and it's noteworthy that radio wave absorption measurements are diurnal and mostly outside noon.

Now at low latitudes (Equatorial region) where there is paucity of valuable information concerning ionospheric structures, earlier investigations using vertical sounding (A1 Method) found that the absorption index, n in Equation (2.4) has a value 1.0 for the diurnal variation of absorption and a value of 1.7 for seasonal variation (Skinner, 1965; Gnanalingam, 1969). Also using a single frequency A3 data, Shamsi (1986) found a value of about 2.1 for the seasonal index. Now, these results were respectively found to predict higher values of absorption than are actually observed during the months of May-September (Skinner and Wright, 1956; Mbipom, 1971; Gnanalingam, 1974; Shamsi, 1986), and as such are of limited technological value.

Inspired by the failed attempts to explain the discrepancy between empirical predicted and observed values of absorption on the basis of seasonal modification of the electron density profile caused by changes in atmospheric composition (Gnanalingam, 1974) and changes in the ionizing solar flux and seasonal variation of solar zenith angle, I now set out to explain the underlying phenomena of the equatorial radio wave absorption using my A3 data. The results (Figure 2.4) of this effort, unlike the earlier ones, showed clearly that though seasonal variation of HF radio wave absorption may be semiannual at low frequencies, it is not semiannual at higher frequencies. This result implied the modification of extant theories.

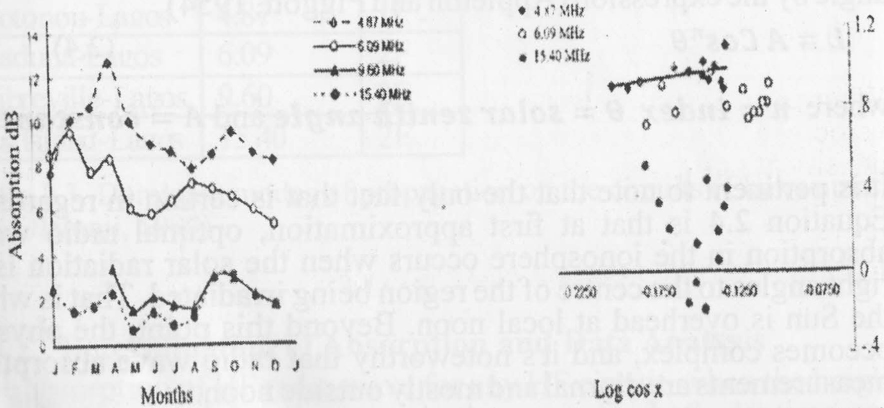


Figure 2.4 Left: Seasonal variation on different radio wave frequencies; Right: Determination of seasonal index n (after Chukwuma, 1999a).

Correspondingly, I found that the law, $L = A\,Cos^n\theta$, did not appear to adequately explain seasonal variation in the equatorial region (Chukwuma, 1999a, Chukwuma and Olatunji, 1997). Furthermore, we also found that absorption at higher frequencies are less amenable to theoretical interpretation than the lower frequencies (Chukwuma and Olatunji, 1997). It is noteworthy that I had to rely on an earlier seminal work which had reported that in trying to explain the seasonal behavior of absorption, the variation of absorption with height of the recombination coefficient cannot be neglected (Nicolet, 1951). And according to Takar and Friedrich (1988), theoretical models of ion chemistry predict a decrease of effective electron recombination with increasing ion production. At low altitude, this is due to a shifting away from cluster ions that have large recombination coefficient towards the primary molecular ions with significant smaller recombination coefficient. This would result in high radio wave absorption in the equatorial region (Chukwuma and Olatunji, 1997). This was good thinking.

On the issue of frequency dependency of HF radio wave absorption, I noted that according to Appleton (1937), the total absorption suffered by HF radio waves which have travelled through a Chapman layer, and have been reflected without deviative losses from higher layer, is given as:

$$L = 4.3\left(\frac{4\pi e^2}{mc}\right)(Cos\chi)^{\frac{3}{2}} N_0 \nu_0 H/\omega^2 \qquad (2.5)$$

Where e and m are the electronic charge and mass respectively, c the velocity of light, χ the Sun's zenith angle, N_0 the maximum electron density at noon, ν_0 the electron collisional frequency at the height of maximum ionization at noon for $\chi = 0$, ω the angular frequency of the radio wave and H is scale height.

Equation (2.5) could be written in the generalized empirical form:

$$L = Af^n \qquad (2.6)$$

At constant χ; where A is a constant

According to the magneto-ionic theory $n = 2$ in Equation (2.6), but in the equatorial region, using observed data, Skinner and Wright (1956) and Gnanalingam (1974) showed that n is nearly 1.0 while Oyinloye (1975) concluded that n has a value of 2.4. In the light of the discrepancies between theory and experimental results on the one hand and among experimental results themselves, it was obvious to me that the frequency dependence of HF radio wave absorption is a research problem that required a detailed solution which I need to provide from the analysis of my multfrequency absorption data.

Interestingly, the preliminary analysis of my data gave the frequency index a range of values $0.8 \leq n \leq 2.4$ (Chukwuma, 2000a) which appeared to simultaneously validate the earlier results of Skinner and Wright (1956), and Gnanalingam (1974) on the one hand and Oyinloye (1975) on the other hand. This result while authenticating my A3 experimental protocol did not to me fully answer my research problem and necessitated a further analysis of my absorption data which this time showed that the ionospheric absorption in the equatorial region appear to follow the law:

$$L = B + Af^{-2} \qquad (2.7)$$

where B and A are constants

The result as indicted in Eq (2.7) implies that ionospheric absorption consists of a component which is independent of radio wave frequency. Furthermore, the results showed that solar activity did not affect frequency dependency in the equatorial region (Chukwuma, 2000). It was heartwarming that these results were hailed at that time as one of the best work coming out of contemporary Africa. These results are presented in Figures (2.5) and (2.6).

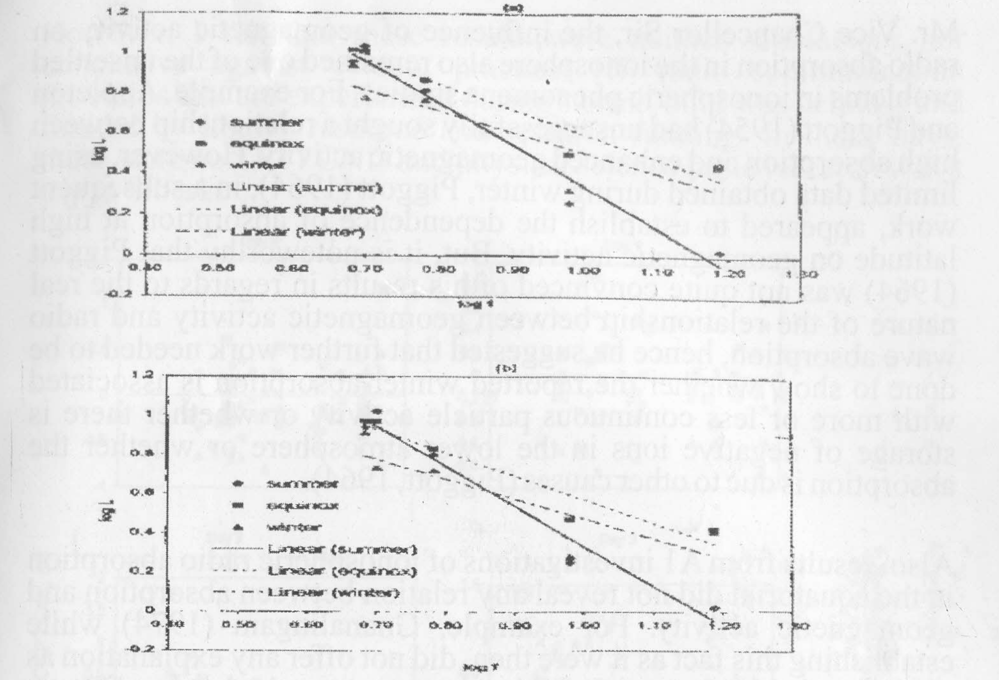


Figure 2.5. Top: Variation of absorption with radio frequency; Bottom: Variation of corrected absorption with radio frequency (After Chukwuma, 2000)

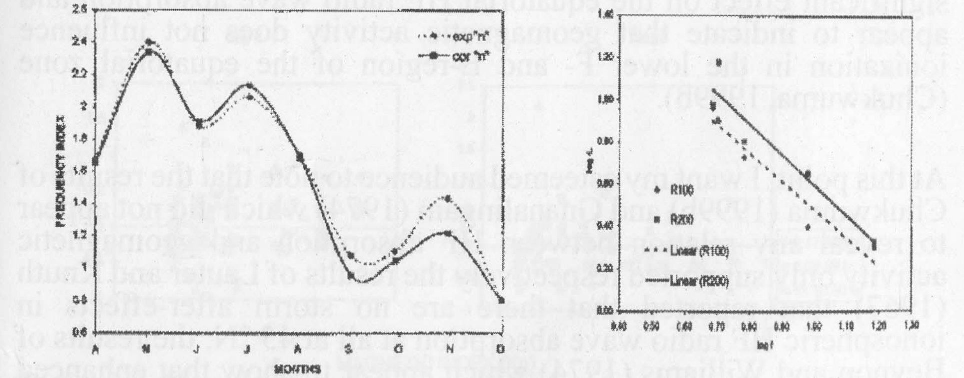


Figure 2.6. Left: Monthly values of frequency index; Right: Solar activity control of frequency dependence (after Chukwuma, 2000).

Mr. Vice Chancellor Sir, the influence of geomagnetic activity on radio absorption in the ionosphere also remained one of the unsettled problems in ionospheric phenomena studies. For example, Appleton and Piggott (1954) had unsuccessfully sought a relationship between high absorption and enhanced geomagnetic activity. However, using limited data obtained during winter, Piggott (1964), in a subsequent work, appeared to establish the dependence of absorption at high latitude on geomagnetic activity. But, it is noteworthy that Piggott (1964) was not quite convinced of his results in regards to the real nature of the relationship between geomagnetic activity and radio wave absorption, hence he suggested that further work needed to be done to show whether the reported winter absorption is associated with more or less continuous particle activity or whether there is storage of negative ions in the lower atmosphere or whether the absorption is due to other causes (Piggott, 1964).

Also, results from A1 investigations of ionospheric radio absorption in the equatorial did not reveal any relation between absorption and geomagnetic activity. For example, Gnanalingam (1974) while establishing this fact as it were then, did not offer any explanation as to the probable cause it of this phenomenon. And to proffer an explanation, I examined my A3 absorption data for any possible influence of geomagnetic activity and the results (Figures 2.7 and 2.8) I obtained went on to confirm that geomagnetic activity has no significant effect on the equatorial HF radio wave absorption and appear to indicate that geomagnetic activity does not influence ionization in the lower F- and E-region of the equatorial zone (Chukwuma, 1999b).

At this point, I want my esteemed audience to note that the results of Chukwuma (1999b) and Gnanalingam (1974) which did not appear to reveal any relation between HF absorption and geomagnetic activity only supported respectively the results of Lauter and Knuth (1967) that reported that there are no storm after-effects in ionospheric HF radio wave absorption at all at 45 °N, the results of Beynon and Williams (1974) which appear to show that enhanced absorption has a rather low latitude limit of about 37 °N and the work of Marcz (1983) that showed that storm related enhanced absorption can be traced only to a geomagnetic latitude of 25 °N.

However, I felt that these results were neither satisfactory nor conclusive against evident practical HF radio communication problems that are experienced during storm, but I was helpless and limited by library resource and research funding. In those days, there were no TETFUND and physical science basic research was a trip to Siberia.

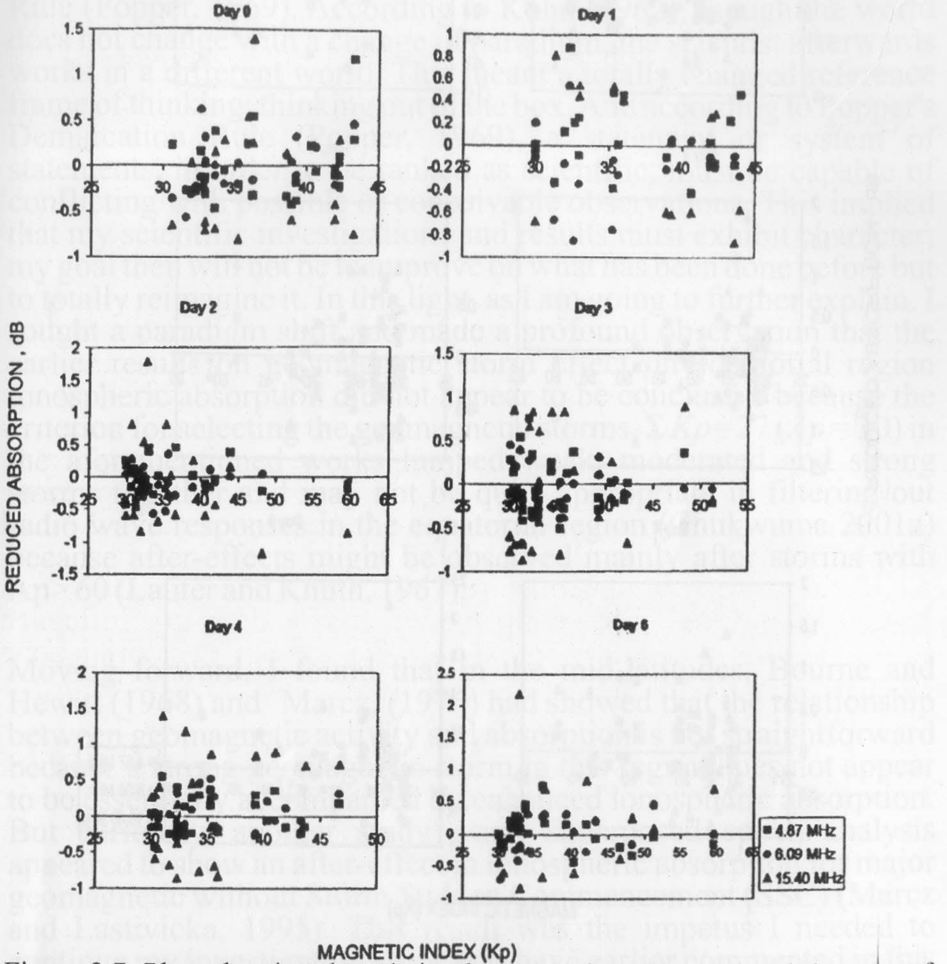


Figure 2.7. Plots showing the relation between absorption (*L*) and the sum of eight of three-hourly mean planetary magnetic index (K_p) (after Chukwuma, 1999b).

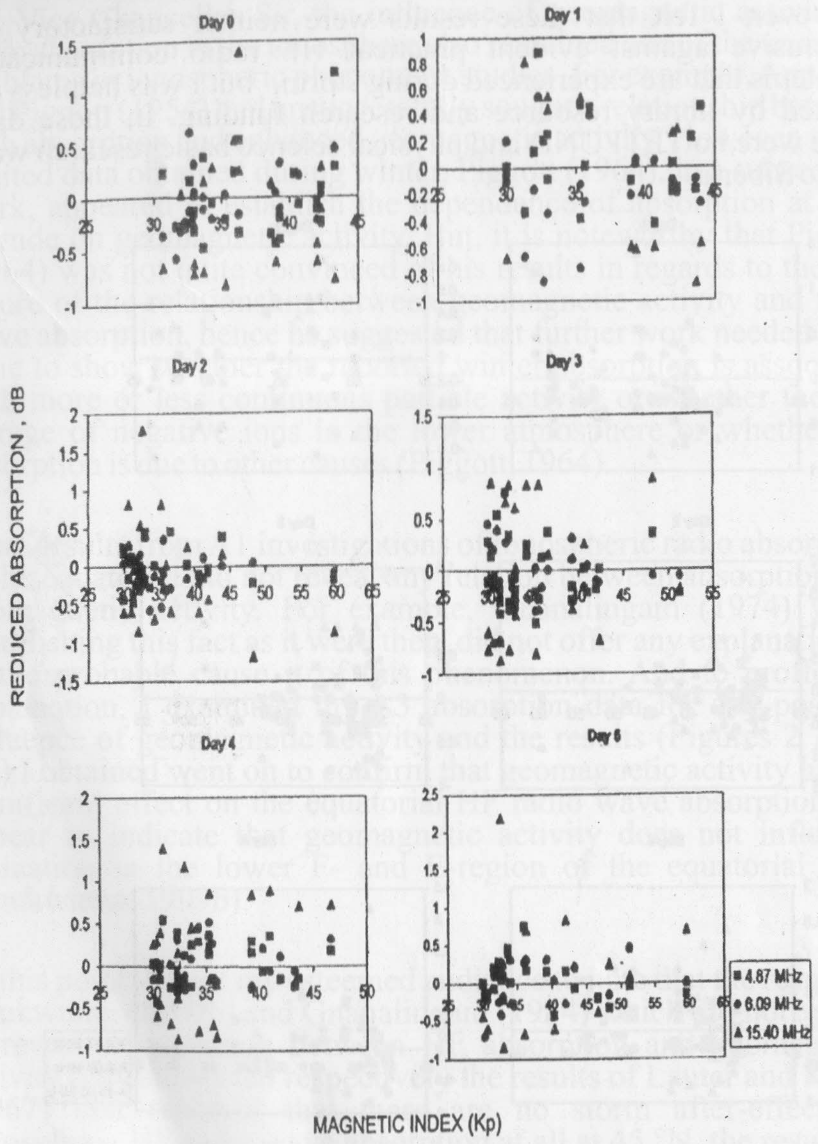


Figure 2.8. Plots showing the relation between the reduced absorption and the sum of eight of three-hourly mean planetary magnetic index (Kp) (after Chukwuma, 1999b).

2.2 Coming of Age: Geomagnetic Storms

My esteemed audience, permit me to remark at this point that following my divine encounter at the Journal Section of the University of Lagos Library, the philosophical underpinning of my research work in the equatorial region became embedded in the philosophical works of Kuhn (1962), and Popper's Demarcation Rule (Popper, 1969). According to Kuhn (1962), though the world does not change with a change of paradigm, the scientist afterwards works in a different world. This meant a totally changed reference frame of thinking; thinking out of the box. And according to Popper's Demarcation Rule (Popper, 1969), a statement or system of statements, in order to be ranked as scientific, must be capable of conflicting with possible or conceivable observations. This implied that my scientific investigations and results must exhibit character; my goal then will not be to improve on what has been done before but to totally reimagine it. In this light, as I am going to further explain, I sought a paradigm shift and made a profound observation that the earlier results on geomagnetic storm effect on equatorial region ionospheric absorption did not appear to be conclusive because the criterion for selecting the geomagnetic storms, $\Sigma Kp=27$ ($Ap=30$) in the aforementioned works lumped weak, moderated and strong storms together and may not be quite appropriate in filtering out radio wave responses in the equatorial region (Chukwuma 2001a) because after-effects might be observed mainly after storms with $Ap>60$ (Lauter and Knuth, 1967).

Moving forward, I found that in the mid-latitudes, Bourne and Hewitt (1968) and Marcz, (1976) had showed that the relationship between geomagnetic activity and absorption is not straightforward because a strong geomagnetic storm in this region does not appear to be essentially accompanied by enhanced ionospheric absorption. But curiously, another study using superposed epoch analysis appeared to show an after-effect in ionospheric absorption for major geomagnetic without Storm Sudden Commencement (SSC) (Marcz and Lastivicka, 1995). This result was the impetus I needed to continue my investigation since as I have earlier commented in this lecture that I was not satisfied with my earlier results, and still felt that more work needed to be done to unravel this equatorial ionospheric phenomenon. This urge for further investigation was more so because I had in Chukwuma (1999b) sought a direct relationship between planetary geomagnetic activity and radio wave absorption without taking into account an earlier observed deficiency (Chaman- La,l.2000; Svalgaard, 1976) in the planetary index of geomagnetic activity.

Now settled in my new paradigm, I reanalyzed my HF absorption data. Considering this time variations in HF absorption within five days of marked change in geomagnetic activity. In the hope of obtaining the clearest possible relationship between geomagnetic activity and ionospheric radio wave absorption, severe storms were selected in favour of weak and moderate storms with days of *Ap*> 54 chosen as key days. The key days were also chosen with an additional criterion that ensured that the key days were preceded by relatively magnetic quiet condition (Oyinloye, 1988), and this resulted in a selection of well separated storms reaching distinct peak values (Marcz, 1983). Thereafter, following Bourne and Hewitt (1968), Lauter and Knuth (1967) and Marz (1983), I applied the superposed epoch technique on my HF absorption data that were obtained on the key days and the respective five days before and after the key days. The results of my effort this time are presented below.

2.2.1 Results

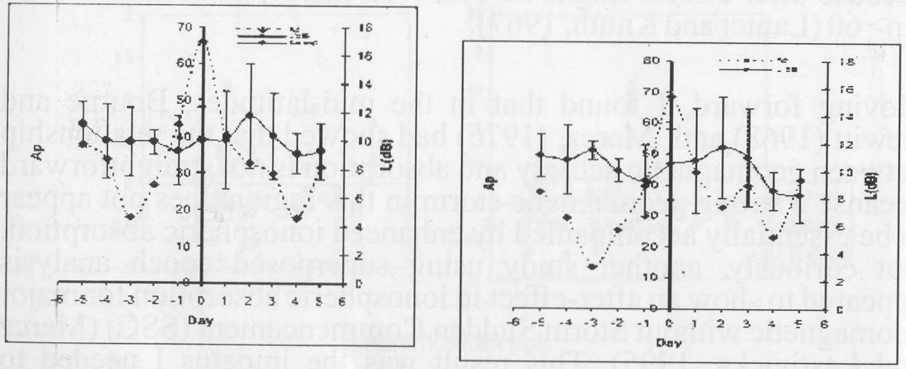


Figure 2.9.Left: Variations in geomagnetic activity and ionospheric absorption around all server storms (ASS); Right: Variations in geomagnetic activity and ionospheric absorption around severe storms with storm sudden commencement (SSC) (after Chukwuma, 2001a)

Figure 2.9 (left panel) shows the result from superposed epoch analysis of mean changes in geomagnetic activity and HF absorption around all severe storms. It is evident that the result appears to indicate HF absorption in the equatorial ionosphere increasing on the second day following severe geomagnetic storm. Figure 2.9 (right panel) represents the result of another superposed analysis of geomagnetic activity and ionospheric HF absorption, but in the case of selected major storms with SSC. Presently, the result also shows that equatorial ionospheric absorption increases on the second day following the highest geomagnetic activity.

The results presented in Figure 2.9 went against the results of previous investigations in the equatorial region. The differing results arose, as I had earlier remarked, because the previous criterion of selecting storms was prominently in favour of weak storms (K_p 30). According to Vats (1992), geomagnetic storms are caused by two kinds of fast streams; the flare associated fast streams consisting of dense magnetized plasmoids produce stronger disturbances than the coronal associated streams which, have similar high speeds and, are composed of relatively lower plasma density (Chukwuma, 2001a). This fact validated my method of analysis.

The increase in absorption (Chukwuma, 2001a), which occurred on the second day, appear to suggest that the origin of the enhancement in absorption may be the same as that of the middle European latitudes which do not occur on the key day but after 2-4 days (Bourne and Hewitt, 1968; Lauter and Knuth, 1967). This increase in absorption may be due to direct and / or secondary effects of particle precipitation (Marcz, 1976) because Maih (1989) had reported the precipitation of low energy particles at low altitude in the equatorial region. Furthermore, the absorption of solar wind energy, which is responsible for geomagnetic activity, has the same phase all over the globe (Chaman-Lal.2000).

As if to establish the occurrence of radio wave absorption beyond doubt, I in the work Chukwuma (2001b) found that enhancement in absorption following major storms could be traced to the low latitude of 3.40 °N. This observed enhancement of HF absorption that was reported for first time by me, was according to Chukwuma (2001b), due to direct and/ or secondary effects of particle

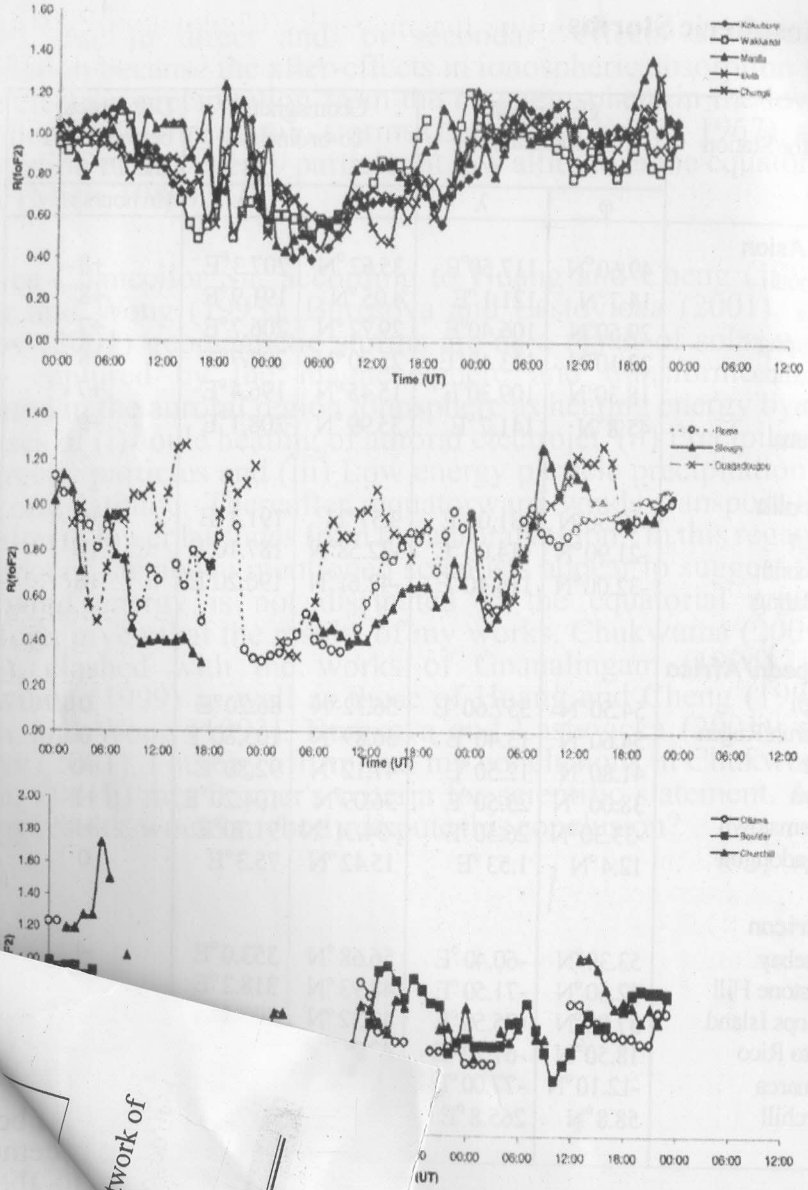
(2001b), due to direct and/ or secondary effects of particle precipitation because the after-effects in ionospheric absorption are due to electron precipitation from the magnetosphere in the lower ionosphere following certain storms (Lauter and Knuth, 1967), and precipitation of low energy particles at low altitude in the equatorial region (Maih, 1989).

Mr. Vice Chancellor Sir, according to Huang and Cheng (1993), Walker and Wong (1993), Buresova and Lastovicka (2001), and Danilov (2001) geomagnetic storms are as a result of solar wind energy captured by the magnetosphere and transformed and dissipated in the auroral region ionosphere as heating energy by the processes of (i) Joule heating of auroral electrojet, (ii) Precipitation of energetic particles and (iii) Low energy particle precipitation of subauroral latitude. Thereafter, equatorward winds transport this ionization to lower latitudes from the auroral region. In this regards, the works of the above mentioned scientists appear to suggest that solar wind energy is not dissipated in the equatorial region. Therefore, given that the results of my works, Chukwuma (2001a, 2001b), clashed with the works of Gnanalingam (1974) and Chukwuma (1999) as well as those of Huang and Cheng (1993), Walker and Wong (1993), Buresova and Lastovicka (2001), and Danilov (2001), I hereby affirm that my conclusions in Chukwuma (2001a, 2001b) met Popper's criteria for scientific statement. And with my results, would anybody dispute this conclusion?

3.0 Ionospheric Storms

Sector/Station	Geographic coordinates		Geomagnetic co-ordinates		Difference between LST and UT
	φ	λ	φ	λ	(in hours)
East Asian					
Manzhouli	49.60°N	117.50°E	35.62°N	207.3°E	+8
Manila	14.7°N	121.1°E	4.05°N	191.9°E	+8
Chongqing	29.50°N	106.40°E	29.72°N	206.7°E	+7
Guangzhou	23.10°N	113.40°E	25.70°N	206.7°E	+8
Hainan	18.30°N	109.30°E	15.45°N	196.4°E	+7
Wakkanai	45.8°N	141.7°E	35.99°N	208.1°E	+9
Australia					
Darwin	-12.50°N	131.00°E	3.57°N	191.1°E	+9
Learmonth	-21.90°N	114.00°E	-32.58°N	187.10°E	+8
Mundaring	-32.00°N	116.40°E	-42.61°N	190.20°E	+8
European/Africa					
Slough	54.50°N	357.60°E	56.72°N	86.20°E	0
Juliusruh/Rugen	54.60°N	13.40°E	56.89°N	103.80°E	0
Rome	41.80°N	12.50°E	47.12°N	92.80°E	+0
Athens	38.00°N	23.50°E	36.09°N	104.20°E	+1
Grahamstown	-33.30°N	26.50°E	-34.31°N	91.70°E	+1
Ouagadougou	12.4°N	1.53°E	15.42°N	75.3°E	0
American					
Goosebay	53.30°N	-60.40°E	56.68°N	353.0°E	-4
Milestone Hill	42.60°N	-71.50°E	48.93°N	318.2°E	-5
Wallops Island	37.80°N	-75.50°E	42.32°N	302.4°E	-5
Puerto Rico	18.50°N	-67.20°E	42.32°N	302.40°E	-4
Jicamarca	-12.10°N	-77.00°E	-0.98°N	355.70°E	-5
Churchill	58.8°N	265.8°E	68.44°N	326.5°E	-6

Table 3.1.SPIDR (Space Physics Interactive Data Resource) global network of ionosndes



storm for March 13-15, 1989; indicating
hukwuma, 2003a)

etwork of

Mr. Vice Chancellor Sir, given that myworks (Chukwuma, 2001a, 2001b) which examined geomagnetic storm after-effect on radio wave absorption in the equatorial region found that that radio wave absorption in the low latitudes increased after major geomagnetic storms as has been observed in the mid- and high latitudes (Bourne and Hewitt, 1968; Marcz, 1976, 1983; Marcz and Lastovicka, 1995; Piggot, 1964), it did appear to me that major geomagnetic storms could adversely influence the performance and reliability of ground-based technological systems and can endanger human life or health in our region. In this respect, I sought to show if there existed some degree of simultaneity in global response of the ionosphere to major geomagnetic disturbances. This I did by investigating F2 region global structure response to geomagnetic storms using hourly values of *foF2* data obtained during the very intense geomagnetic storm (D_{st}= -600 nT) of March 13-15, 1989 from SPIDR ionospheric stations (Table 3.1). Remarkably, results of this investigation, as presented by Fig. 3.1 (Chukwuma, 2003a), showed that all the stations under study indicated some high degree of simultaneity in global response of the ionosphere to major geomagnetic disturbances. Furthermore, the results, by the geographical reach of the ionospheric stations (as shown in Table 3.1) indicated that global ionospheric response extended to a latitude as low as 12.4° N. This was a profound discovery.

Insightful as the results of Chukwuma (2003a) were, its characterization as a seminal work required a validation using the data of another intense storm. This I did with the storm of October 20-21, 1989 (D_{st} =-266 nT); the result of analysis of the *foF2* data of this particular intense storm as reported in Chukwuma, (2003b) showed that global response of the ionosphere was restricted to the mid- and high latitude, and lacked simultaneity but confirmed the suggestion of Chukwuma (2003a) that the F2 region global structure response during the super storm of March 13-15, 1989 may be due to the very intensive nature of that particular storm. It is noteworthy that the geomagnetic storm of March 13-15, 1989 is one of the largest storms in last 50 years and had profound effects on earth and in space. Power systems in Canada and Sweden failed as large electric currents were induced in power lines and tripped protective relays (Bolduc, 2002; Cliffswallow, 1993: Czech et al., 1992;

1992; Kappenman and Albertson, 1990). Increased atmospheric drag resulting from the expansion of the Earth's outer atmosphere during the disturbance altered the orbits of many satellites with the result that NASA lost track of some of them for a short period. Satellite navigation systems failed to operate and High Frequency (HF) communication systems were also out of action (Cliffswallow, 1993). And aurorae were sighted at quite equatorial latitudes. Figure 3.2 presents the impacts the geomagnetic storm of March 13-15, 1989.

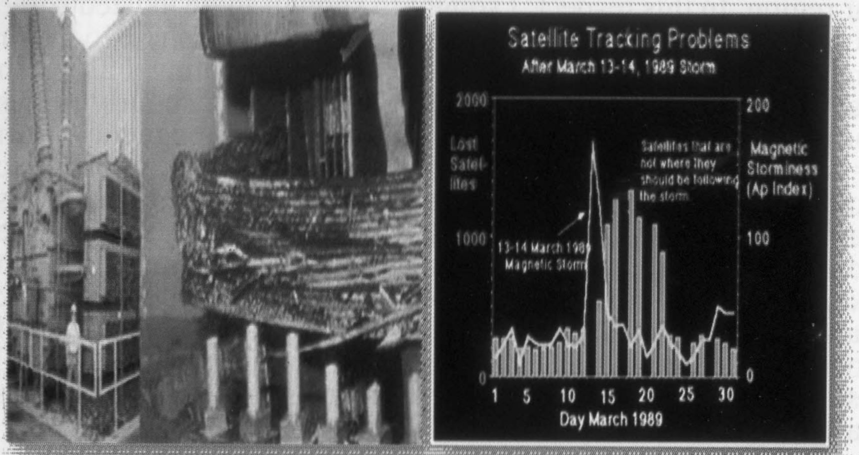


Figure 3.2. Impact of Space Weather:Left- Severe Internal damage of the PJM Public Service Step-Up Transformer by March 13,1989 Geomagnetic Storm © mordernsurvivlablog.com Right-Satellite Tracking Problem © ccar.colorado.edu

3.1 The Pre-storm Ionospheric Phenomena

Mr. Vice Chancellor Sir, the F region response to a geomagnetic storm that is known as ionospheric storm consists of positive and negative phases. According to Danilov (2001), the principal features of the positive and negative phase distribution and variations have been explained on the basis of the principal concept: during a geomagnetic disturbance there is an input of energy into the polar atmosphere, which changes thermospheric parameters such as composition, temperature and circulations. Composition changes

The circulation spreads the heated gas to lower latitudes. The conflict between storm-induced circulation and the regular one determines the spatial distribution of the negative and positive phases in various seasons (Chukwuma, 2003b). However, there are still some unresolved problems; two of the acute ones, according to Danilov (2001), are the appearance of positive storm before the beginning of a geomagnetic storm in the mid latitudes and the occurrence of negative phase at the equator. These problems are now known as pre-storm phenomena. However, these phenomena that appear to be rare geophysical events could be classified as potentially high impact, but low probability natural hazard.

To study the validity of the existence of the pre-storm phenomena, I did a community analysis of the intense geomagnetic storms of April 1-2, 1973(D_{st} =-211) whose resulting ionospheric storm was worldwide and extended to very low latitudes, the very intense March 13-15, 1989 storm (D_{st}= -600 nT) and the storm of October 20-21, 1989 (D_{st} =-266 nT). The last two storms occurred during two remarkable periods of the maximum phase of solar cycle 22 and whose geomagnetic and ionospheric phenomena are of considerable interest for the understanding of the morphology of ionospheric storms, as well as solving of technological problems.

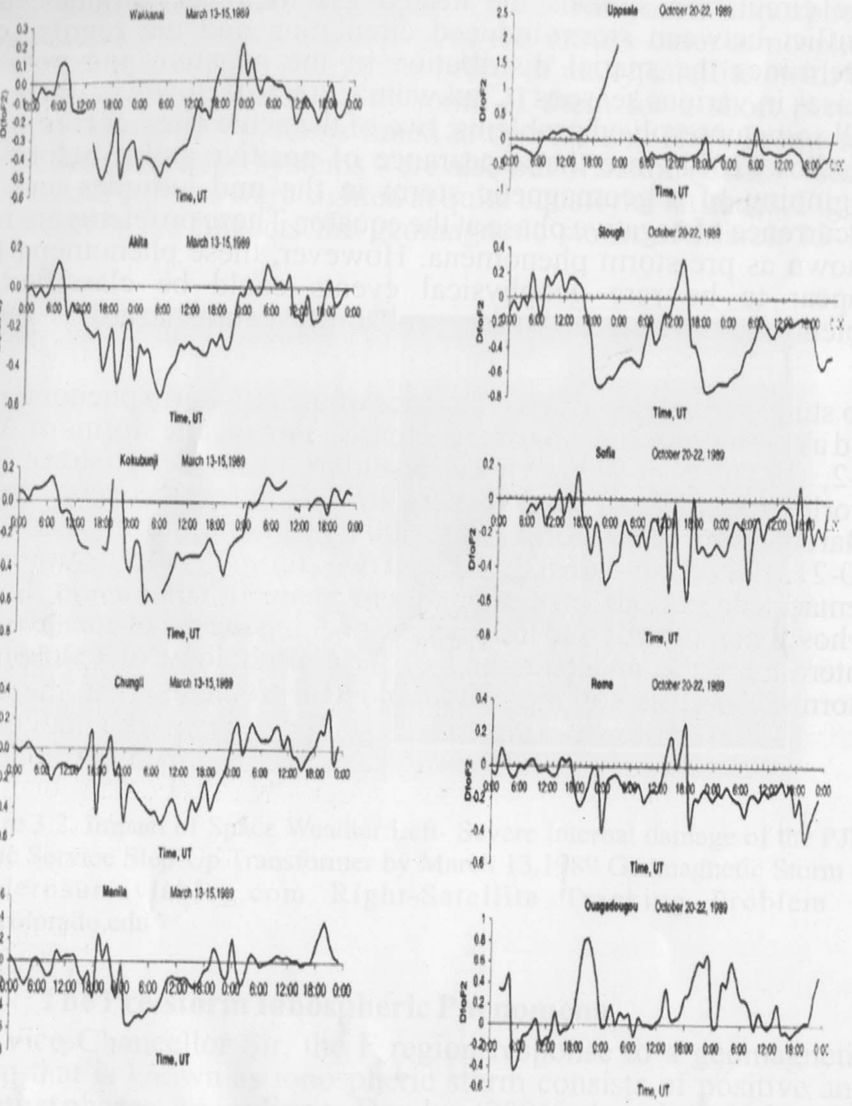
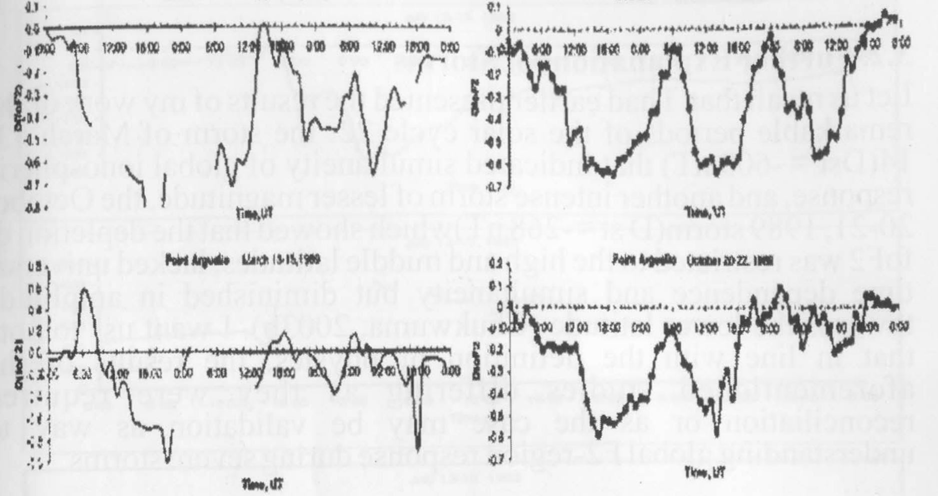


Figure 3.3. Pre-storm Phenomena. Top Panel:.Left- Variation of $D(f_oF2)$ in East Asia for March 13-15, 1989. Right: Variation of $D(f_oF2)$ in Euro-Africa for October 20-22, 1989. Bottom Panel:Variation of $D(f_oF2)$ in America sector respectively for March 13-15, 1989 (Left) and October 20-22, 1989 (Right) (Chukwuma, 2007a)



The results of my effort (Fig. 3.3) (Chukwuma, 2007a), confirmed the existence the pre-storm as a geomagnetic phenomenon. In the light of my results, and in regards to the suggestion by Danilov (2001) that pre-storm phenomena are still some unsolved problems, I went on to profoundly report in Chukwuma (2007a) that the non-explanation of pre-storm phenomena is because in the studies of ionospheric storms, it is assumed that the beginning of the disturbance is defined by storm sudden commencement or main phase onset (MPO) which as a scheme restricted the geoeffectiveness of the solar wind to post onset time thereby fore-closing the explanation of any aspect of the morphology of ionospheric storms whose origin precede the onset reference time. It is important to note, I argued, that the use of sudden storm commencement (SSC) as a reference time constitute a poor choice (Prolss, 1995) because these impulse-like disturbance of the magnetic field are not associated with any significant energy deposition and are also observed after the onset of a magnetic storm, as indicated, for example, by the decrease in the Dst index (Akasofu, 1970); also the use of the main phase onset (MPO) for fixing the beginning of magnetic and ionospheric storms is fraught with problems that render a determination of the exact onset time difficult (Prolss, 1995). And permit me Mr, Vice Chancellor Sir, to add that this postulation of mine still stands, but my work was not yet done.

3.2. Further Explanations of Storms

Let us recall that I had earlier presented the results of my work of the remarkable periods of the solar cycle 22: the storm of March 13-14(Dst ≈ -600 nT) that indicated simultaneity of global ionospheric response, and another intense storm of lesser magnitude, the October 20-21, 1989 storm(D st ≈ -268 nT)which showed that the depletion of foF2 was restricted to the high and middle latitudes, lacked universal time dependence and simultaneity but diminished in amplitude towards the lower latitude (Chukwuma, 2003b). I want us to note that in line with the definition of physics, the results of the aforementioned studies differing as they were required reconciliation or as the case may be validation as way to understanding global F2-region response during severe storms.

Now in other to explain global F2-region response during severe storms, I undertook a further investigation into global ionospheric responses during intense geomagnetic activity using a set of scientific criteria (Chukwuma, 2007b) that led to the choice of the intense storm of July 13-15, 1982 (D_{st} ≈ -325 nT). And my results some of which are presented below in Figures 3.4 and 3.5 proved that that an intense storm was caused primarily by large increases in solar wind dynamic pressure. This is evident in the fact that the depletion of *foF2* during the main phase of the storm was strongly dependent on the solar wind dynamic pressure. Furthermore, the simultaneity of *foF2* depletion at the mid and low latitudes was not consistent with the previously held view that the mechanism for depletion of F2-region plasma density was changes in neutral composition resulting from neutral wind which is produced predominantly in the region of Joule heating in the aurora zone, but rather suggests that particle precipitation could account for the composition changes that caused the abrupt depletion at the ionospheric stations. My esteemed audience, these are insightful conclusions that have contributed immensely to the understanding of geomagnetic storms.

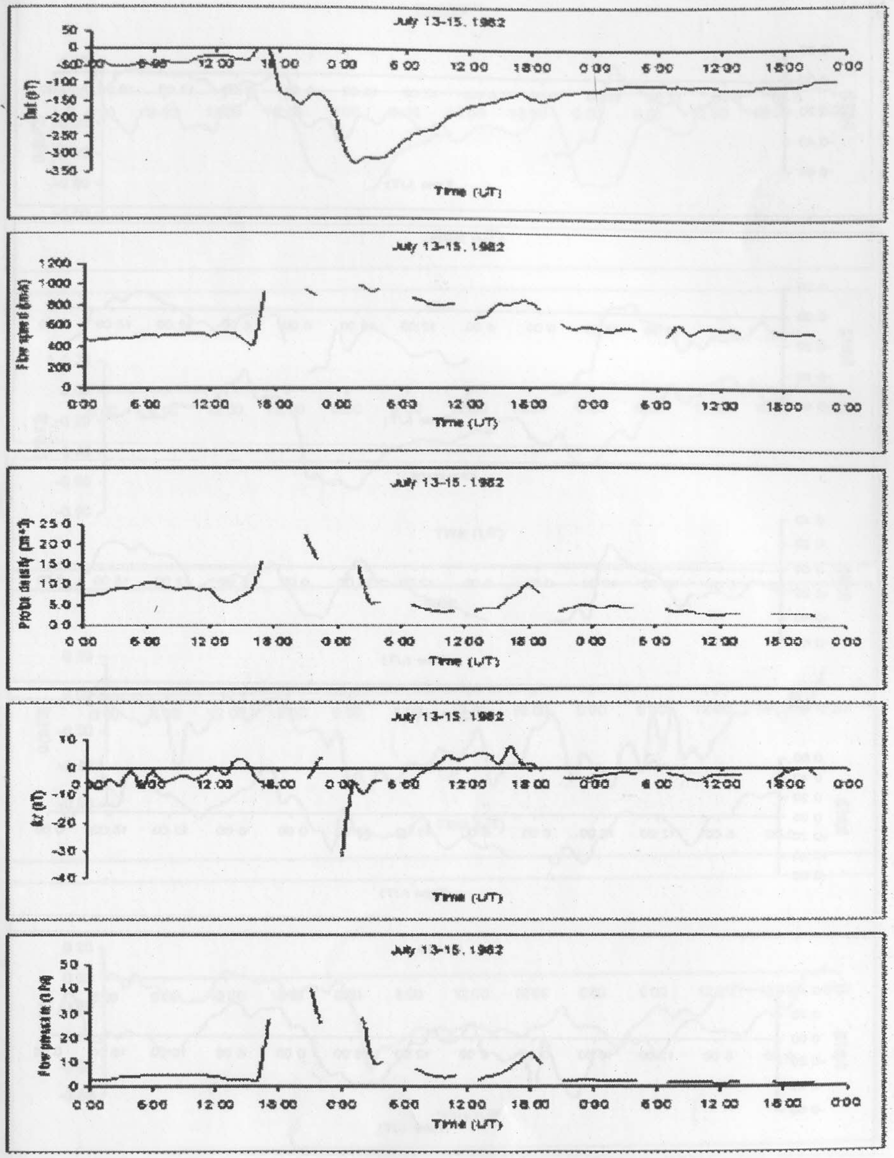


Figure 3.4 Composition of interplanetary and geomagnetic observation for July 13-15, 1982 (Chukwuma, 2007b).

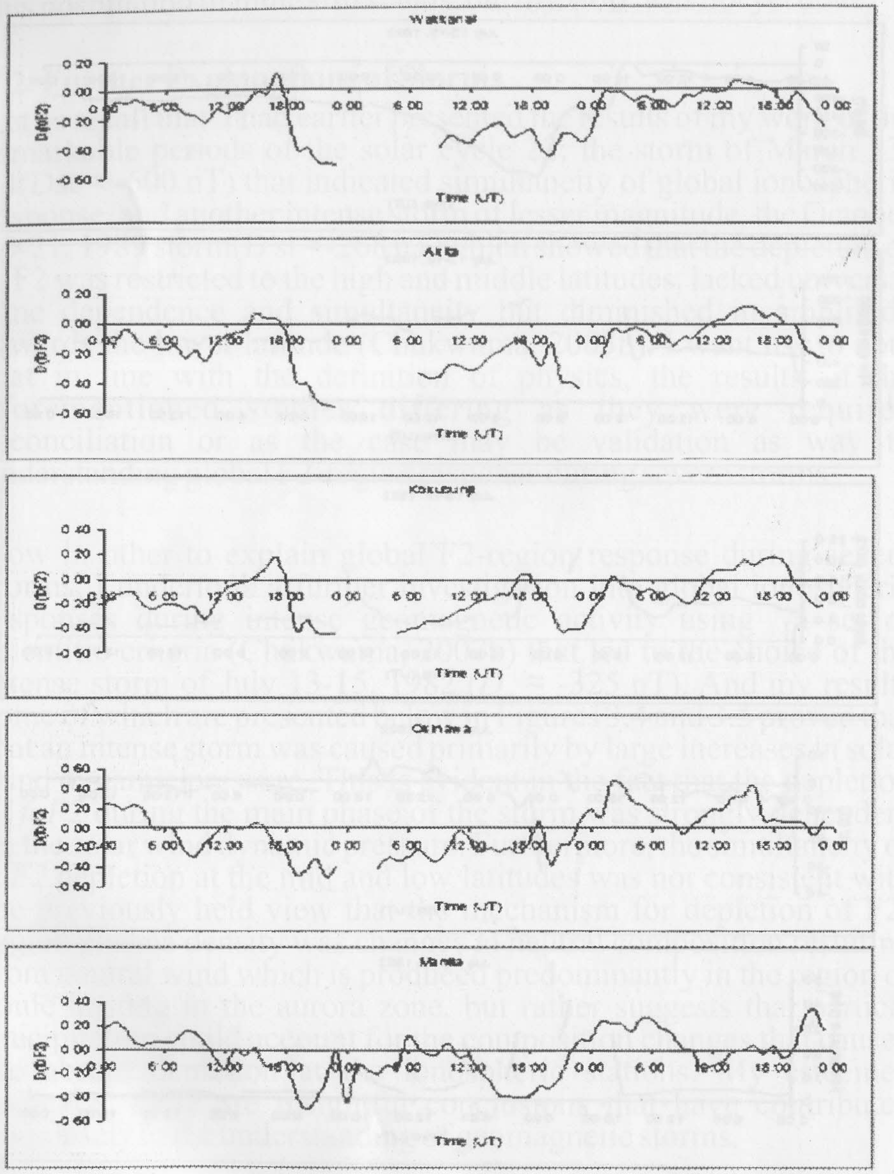


Figure 3.5 (a): Variations in$D(f_oF2)$) in East Asian sector for July 13-15, 1982 (Chukwuma, 2007b).

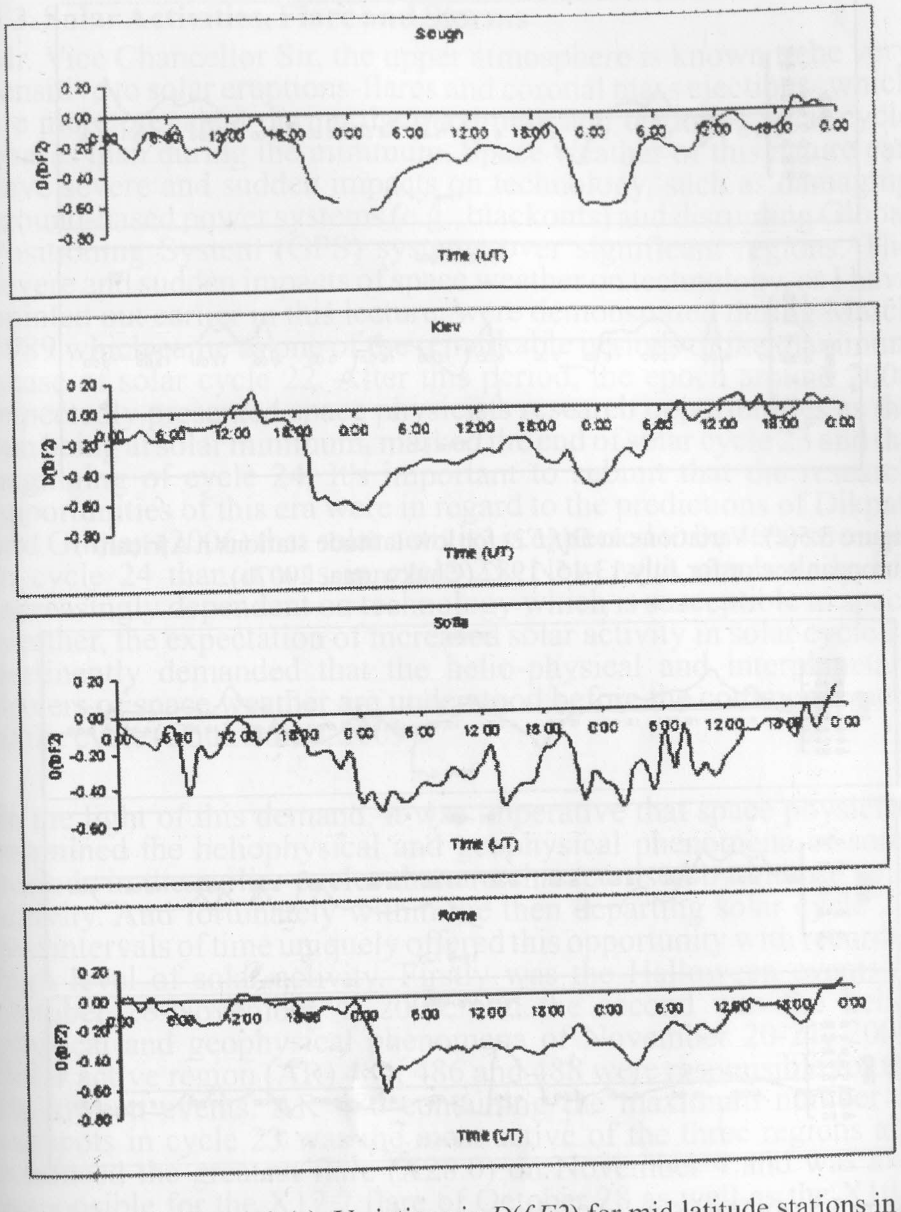


Figure 3.5(b): Figure 3 (a): Variations in $D(f_oF2)$ for mid latitude stations in African/ European sector for July 13-15, 1982 (Chukwuma, 2007b).

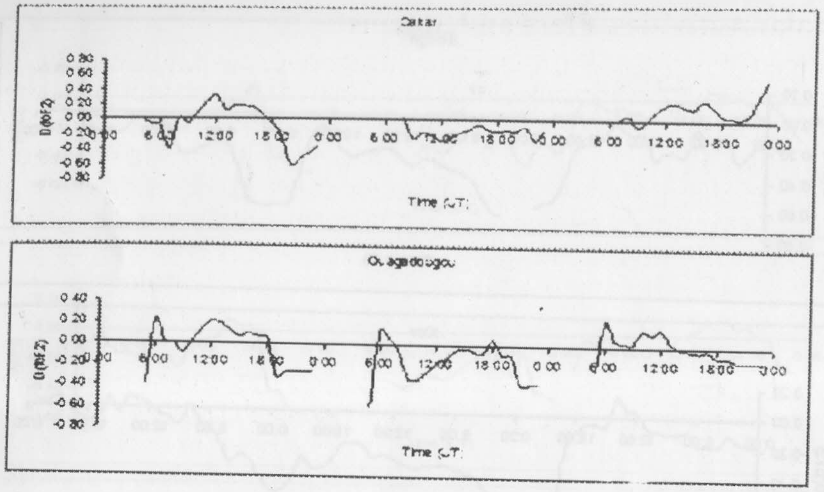


Figure 3.5(c): Variations in $D(f_oF2)$ for low latitude stations n African/ European sector for July 13-15, 1982 (Chukwuma, 2007b).

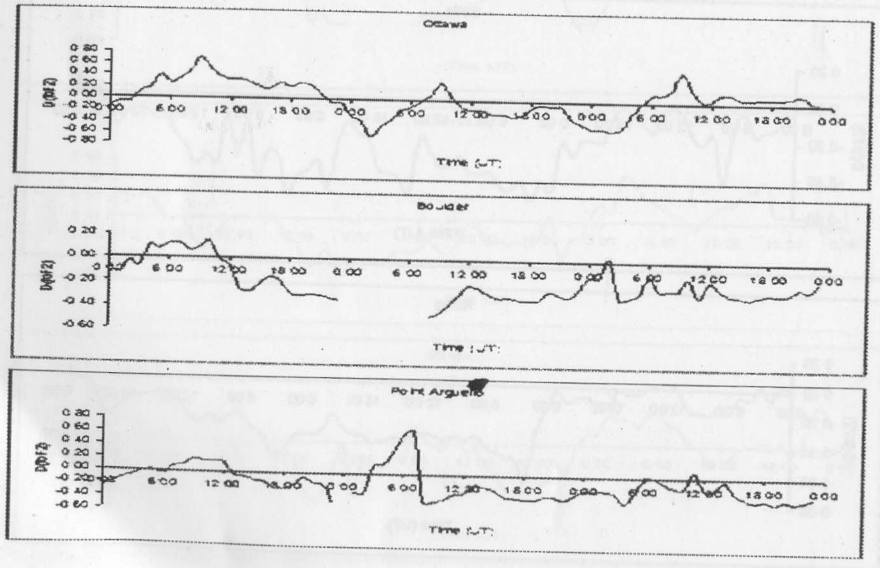


Figure 3.5 (d): Variations in $D(f_oF2)$ in American sector for July 13-15, 1982 (Chukwuma, 2007b)

3.3. Solar Activities, Flare and Storms

Mr. Vice Chancellor Sir, the upper atmosphere is known to be very sensitive to solar eruptions-flares and coronal mass ejections- which are more prevalent during the maximum and declining solar cycle phases than during the minimum. Space weather of this nature can have severe and sudden impacts on technology, such as damaging ground-based power systems (e.g., blackouts) and disrupting Global Positioning System (GPS) systems over significant regions. The severe and sudden impacts of space weather on technology, as I have pointed out earlier in this lecture, were demonstrated during March 1989 which came as one of the remarkable periods of the maximum phase of solar cycle 22. After this period, the epoch around 2008 expectedly presented space physicists research opportunities as the sun being at solar minimum, marked the end of solar cycle 23 and the beginning of cycle 24. It's important to submit that the research opportunities of this era were in regard to the predictions of Dikpati and Gilman (2006) that solar activity is expected to be 40% stronger in cycle 24 than it was in cycle 23. Now, with man's daily life increasingly dependent on technology which is susceptible to space weather, the expectation of increased solar activity in solar cycle 24 pertinently demanded that the helio-physical and interplanetary drivers of space weather are understood before the commencement of the cycle (Chukwuma, 2009).

In the light of this demand, it was imperative that space physicists examined the heliophysical and geophysical phenomena of some periods in the earlier cycles that are characterised by intense solar activity. And fortunately within the then departing solar cycle 23, two intervals of time uniquely offered this opportunity with recorded high level of solar activity. Firstly was the Halloween events of October 28-November 4, 2003, and the second was the helio-physical and geophysical phenomena of November 20-21, 2003. Solar active region (AR) 484, 486 and 488 were responsible for the Halloween events. AR 486 containing the maximum number of sunspots in cycle 23 was the most active of the three regions and produced the greatest flare (X28.0) on November 4 and was also responsible for the X17.2 flare of October 28 as well as the X10.0 flare of October 29, 2003. The solar activity during November 20-21 was due to active regions 501, 506 and 508 of which AR 501 was

21 was due to active regions 501, 506 and 508 of which AR 501 was most active producing the M9.6 and M5.8 flare of November 20. These flares caused the super storm of November 20. This storm is the greatest geomagnetic storm in solar cycle 23 and has number 5 in the list of 22 super-storms that occurred between 1957 and 2004 with minimum D_{st} respectively reaching -300 nT. Given that the Halloween 2003 events have been the subject of many studies (e.g., Blagoveshchensky, et. al., 2006; Brodrick, et. al., 2005; Gopalswamy, et. al., 2005a, Gopalswamy, al., 2005b), I accepted the challenge of investigating the helio-physical, interplanetary and magnetospheric structures and processes that are responsible for the super storm of November 20-21, 2003, as good knowledge of these structures and processes can help in the prediction of space weather conditions hours before they take place as is presently done with terrestrial weather.

Day	Time (UT)	Class	Location	NOAA Active Region
20	0119	C2.1	-	-
20	0212	M1.4	N03W05	501
20	0440	C4.3	S17E73	508
20	0728	C3.8	N03W22	501
20	0747	M9.6	N01W08	501
20	1018	C4.1	-	-
20	1237	C3.5	-	-
20	1442	C1.7	N09E59	507
20	1658	C1.7	-	-
20	1929	C8.6	-	-
20	2238	C1.5	-	-
20	2353	M5.8	N02W17	501
21	0233	C1.0	-	-
21	0943	C4.3	S23E36	506
21	1353	C1.0	-	-
21	1916	C3.4	-	-
21	2043	C1.1	-	508

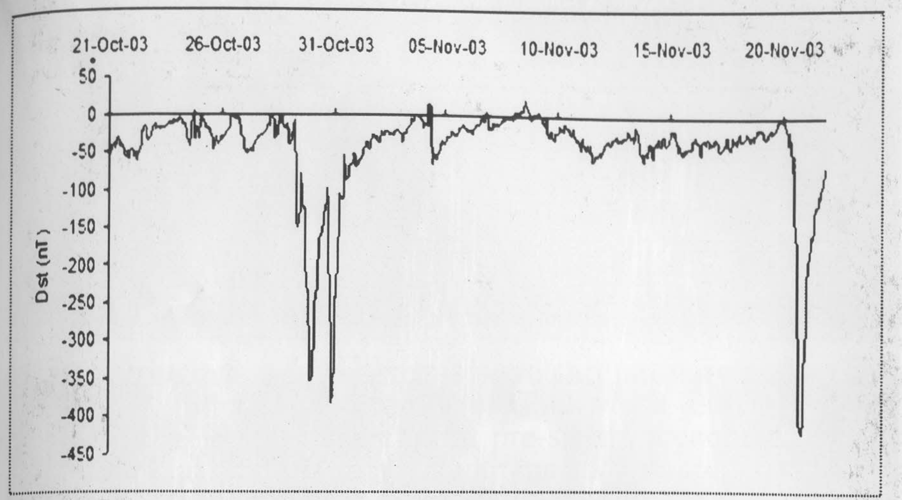
Top: Table 3.2 Characteristics of Solar X- rays flares during November 20-21, 2003. Below:: Table 3.3 Characteristics of Solar X- rays flares during October 28-31, 2003(Chukwuma, 2009).

Day	Time (UT)	Class	Location	NOAA Active Region
28	0045	C5.3	N08E08	488
28	0059	C6.7	N03W55	484
28	0133	C7.5	S19E15	486
28	0311	C7.7	N06W53	484
28	0339	C8.7	-	488
28	1110	X17.2	S16E08	486
29	0151	M1.1	-	486
29	0511	M3.5	-	486
29	0417	C6.2	-	-
29	1422	C9.2	S16W03	486
29	1657	C8.1	S19W07	486
29	1813	C7.8	N08W16	488
29	2049	X10.0	S15W02	486
30	0207	M1.6	N08W23	488
30	0837	C7.7	S21W55	492
30	1226	C7.6	-	-
30	1251	C7.3	-	488
30	1528	M1.5	-	486
30	1618	C5.7	-	488
30	1836	C5.8	-	488
30	1921	C3.6	-	-
31	0153	C5.5	N08W25	488
31	0243	C5.0	N08W33	488
31	0433	M2.0	N06W90	484
31	0616	M1.1	N08W28	488
31	1231	C8.5	-	-
31	1706	C5.3	-	486
31	2039	C5.1	N08W44	488
31	2311	C9.5	N08W44	488
31	2420	C4.4	-	-

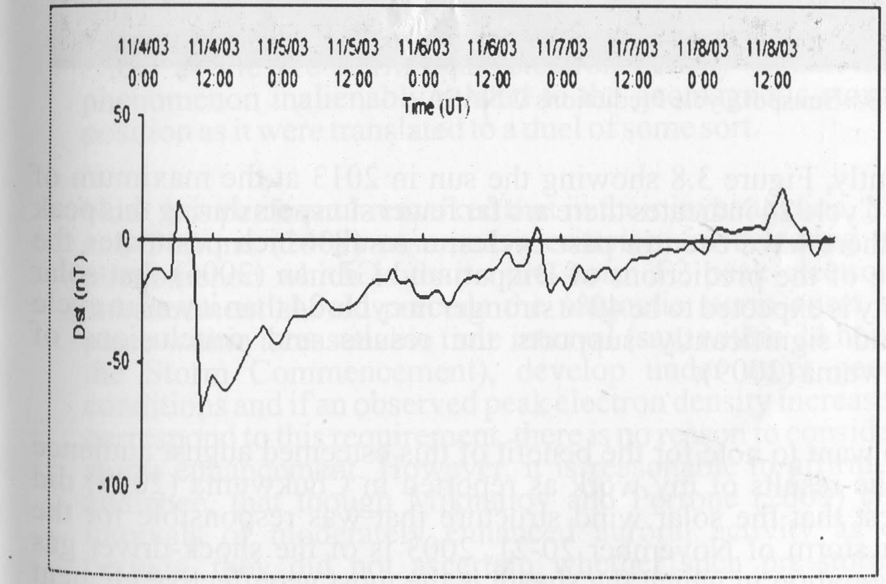
Day	Time (UT)	Class	Location	NOAA Active Region
4	0411	C3.0	-	-
4	0556	M2.6	-	-
4	0943	C2.8	-	486
4	1022	M3.0	-	488
4	1119	C3.7	-	486
4	1349	M2.1	-	486
4	1950	X28.0	S19W83	486
5	0241	M1.6	S18W89	486
5	0739	C4.7	-	
5	1052	M5.3	S16W90	486
5	1648	C1.9	-	-

Table 3.4: Characteristics of Solar X- rays flares during November 4-8, 2003 (Chukwuma, 2009).

And significantly, the results (Tables 3.2, 3.4 and 3.4; Figures 3.6 and 3.7) of my investigation of the heliophysical and geophysical phenomena during the high solar activity period in October-November 2003 (Chukwuma, 2009) showed that very large X class flares may not cause very intense geomagnetic storms as would flares of M importance, and underscore the fact that the initiation of a space weather events is a problem in the solar physics community which require distinct efforts focussing on flares and CMEs separately (Alexander (2007).



Top: Figure 3.6: *Dst* index variation for October 21-November 21, 2003. Below:3.7: *Dst* index variation for November 4-8, 2003(Chukwuma, 2009)



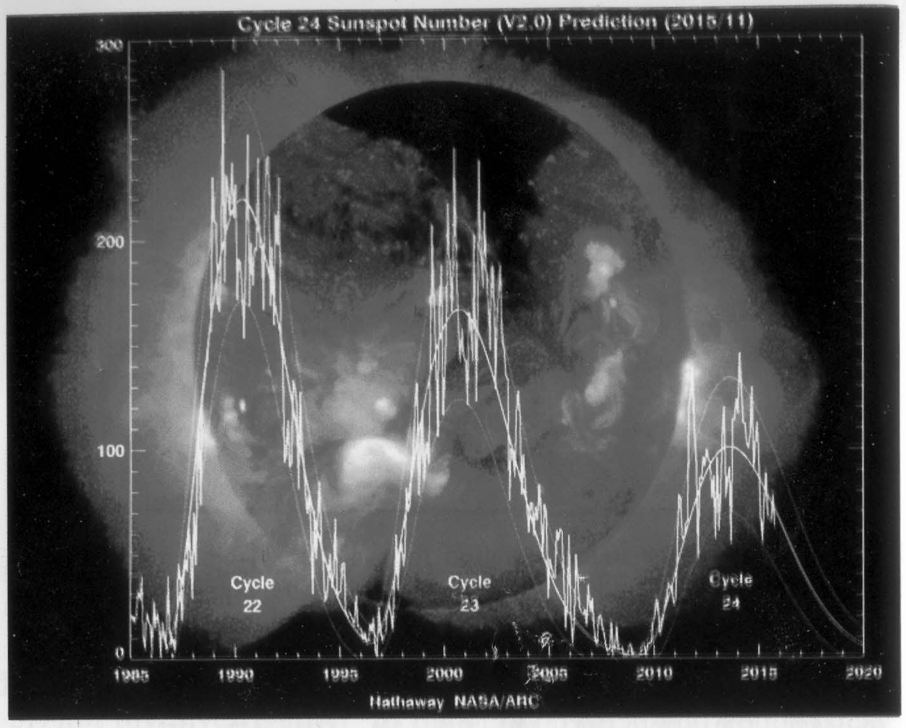


Figure 3.8 Sunspot Cycle Predictions © NASA

Presently, Figure 3.8 showing the sun in 2013 at the maximum of Solar Cycle 24 indicates there are far fewer sunspots during this peak than there have been in past cycles; a result which postulates the failure of the predictions of Dikpati and Gilman (2006) that solar activity is expected to be 40% stronger in cycle 24 than it was in cycle 23 and significantly supports the results and conclusions of Chukwuma (2009).

I also want to note for the benefit of this esteemed august audience that the results of my work as reported in Chukwuma (2009) did suggest that the solar wind structure that was responsible for the major storm of November 20-21, 2003 is of the shock-driver gas configuration in which the sheath is the most geoeffective element (even more geoeffective that the Coronal Mass Ejection (CME)

itself) that is responsible for storms. Another important result of Chukwuma (2009) confirmed earlier results that appear to show that pressure enhancement does not cause the direct injection of new particles into the ring current region; rather it causes a local adiabatic energization of the particles already within the ring current region.

My distinguished audience, I have earlier emphasised the importance of space weather research for scientific and technological innovations. However, a global review of literature on the mechanism responsible for the pre-storm and main phase global ionospheric phenomena during geomagnetic disturbance appeared to indicate that the phenomena were still not fully understood. For example, following the results of Chukwuma (2007a) where I had asserted the non-explanation of pre-storm phenomena, Mikhailov and Perrone (2009) disagreed with me and reported that there are no convincing arguments that pre-storm phenomena at middle and sub-auroral latitudes bear a relation to magnetic storms. According to Mikhailov and Perrone (2009), the ionospheric F2 peak electron density pre-storm enhancements were due to a previous geomagnetic storm, moderate auroral activity or they represented the class of positive quiet time events and as such there is no such effect as the pre-storm peak electron density enhancement as a phenomenon inalienably related to the geomagnetic storms. Their position as it were translated to a duel of some sort.

Now, it is pertinent I remarked that in their investigation, Mikhailov and Perrone (2009) assumed a criterion for selecting pre-storm phenomenon which is that a pre-storm F2 peak electron density enhancement should precede the magnetic storm onset and takes place within a reasonable time interval (say, within 24 hours before the Storm Commencement), develop under quiet geomagnetic conditions and if an observed peak electron density increase does not correspond to this requirement, there is no reason to consider it a pre-storm enhancement. However, it is reasonable to affirm, my dear audience, that though Mikhailov and Perrone (2009) considered intervals of moderately enhanced auroral activity as disturbed periods, they did not ascertain whether such pre-storm auroral activity is related to the following magnetic storm (Chukwuma, 2010). Hence, their postulation appeared to be lacking in phenomena physics which is by definition the logical explanation of the physical processes and phenomena of a particular structure.

Now clearly bothered by the lack of symmetry of the various investigations of mechanisms responsible for the pre-storm and main phase global ionospheric phenomena during geomagnetic disturbances, I began a study of these phenomena, especially with respect to the role of penetration electric fields. For this investigation, I used heliophysical, interplanetary, geomagnetic and ionospheric data from the November 20-21, 2003 storm. The choice of this particular storm was informed by the results of Chukwuma (2009) which have shown that the configuration and scale of the interplanetary magnetic field during the storm are indicative of strong penetration electric fields which have profound effects on the redistribution of the global ionospheric plasma that its field uplifts in the evening equatorial ionosphere (Huang, 2008). The results of this investigation (Figures 3.9 and 3.10), which I reported in Chukwuma (2010), showed that ionospheric responses in the main phase of the storm do not indicate prompt penetration electric fields as the main ionospheric storm driver. Furthermore, the results demonstrated that pre-storm phenomena's origin doesn't derive from local time effect. Also the simultaneous occurrence of foF2 enhancements at two widely separated longitudinal zones (Australian and American sectors) of the Earth appeared to suggest a role by the magnetospheric electric field. But the analysis of hmF2 at the Australian sector could not confirm these fields as main drivers of pre-storm phenomena. An investigation of flare effects on the pre-storm phenomena also revealed that solar flares are not the main drivers of these phenomena.

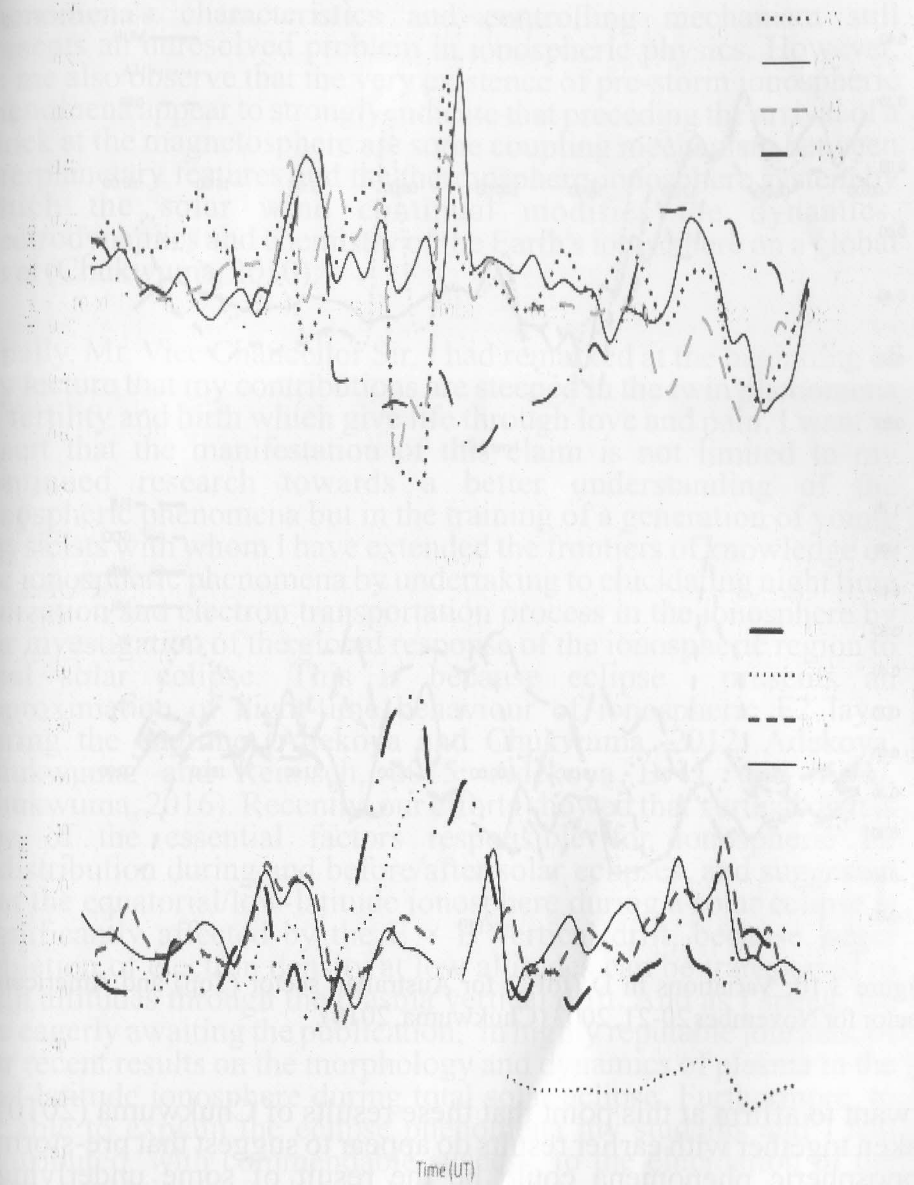


Figure 3.9: Variations in D (foF2) for East Asian sector (Top) and European/African sector (below) for November 20-21, 2003 (Chukwuma, 2010).

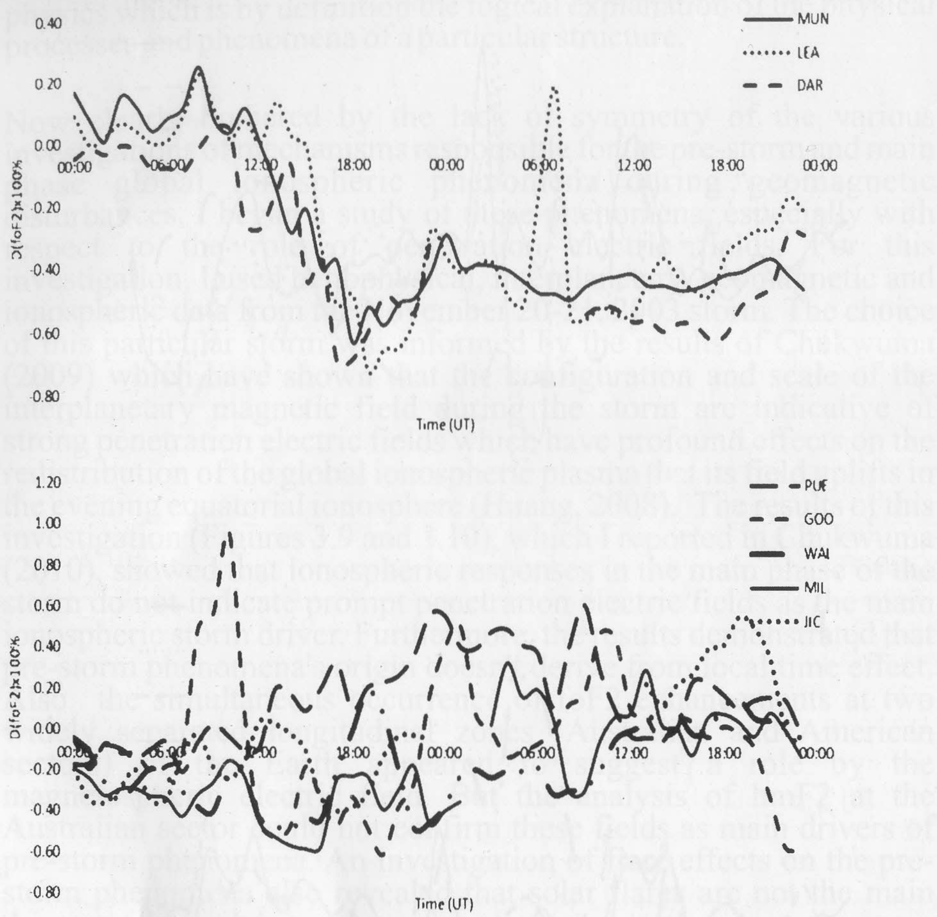


Figure 3.10: Variations in D (foF2) for Australian sector (Top) and American sector for November 20-21, 2003 (Chukwuma, 2010).

I want to affirm at this point that these results of Chukwuma (2010) taken together with earlier results do appear to suggest that pre-storm ionospheric phenomena could be the result of some underlying mechanisms that are working together to produce the observed storm effects, and their relative importance differs from case to case (Lei et al., 2008; Zhao et at., 2008). And as such, the real nature of the phenomena's characteristics and controlling mechanism still presents an unresolved problem in ionospheric physics. However, let me also observe that the very existence of pre-storm ionospheric phenomena appear to strongly indicate that preceding the arrival of a shock at the magnetosphere are some coupling mechanism between interplanetary features and the thermosphere-ionosphere system by which the solar wind continual modifies the dynamics, electrodynamics and chemistry of the Earth's ionosphere on a global level (Chukwuma, 2010).

Finally, Mr. Vice Chancellor Sir, I had remarked at the beginning of my lecture that my contributions are steeped in the twin phenomena of fertility and birth which give life through love and pain. I want to assert that the manifestation of this claim is not limited to my continued research towards a better understanding of the ionospheric phenomena but in the training of a generation of young physicists with whom I have extended the frontiers of knowledge on the ionospheric phenomena by undertaking to elucidating night time ionization and electron transportation process in the ionosphere by our investigation of the global response of the ionospheric region to total solar eclipse. This is because eclipse presents an approximation of night-time behaviour of ionospheric F2 layer during the daytime (Adekoya and Chukwuma, 2012; Adekoya, Chukwuma, and Reinisch, 2015; Adekoya B. J. and V. U. Chukwuma, 2016). Recently, our efforts showed that vertical drift is one of the essential factors responsible for ionospheric F2 redistribution during and before/after solar eclipses, and suggested that the equatorial/low-latitude ionosphere during a solar eclipse is significantly affected by the E × B vertical drift, because larger depletion of electron density at low altitudes can be transported to high altitudes through the plasma vertical drift. And as I speak, we are eagerly awaiting the publication, in highly reputable journals, of our recent results on the morphology and dynamics of plasma in the mid-latitude ionosphere during total solar eclipse. Furthermore, to be able to explain the eclipse phenomena my students and I had contributed, with commendable success, to the elucidation of the response of the ionospheric phenomena to geomagnetic storms in the following works: Chukwuma, V. U. (2005), Chukwuma, V. U. (2006), Chukwuma and Bakare (2006), Chukwuma and Lawal

(2007), Adebesin and Chukwuma (2008), Bakare, Chukwuma and Adekoya (2010), and David and Chukwuma, (2012).

Mr. Vice Chancellor Sir, I hope I have met with success in sustaining my theme by presenting a unified, and cumulative thesis in this lecture and therefore, hereby request you in your favourable consideration to discharge and acquit me of my academic debt.

Appreciation

My gratitude goes first to my late parents, Godfrey and Maria Oparaocha for their sacrifices, love and rod. To my uncle, Hyacinth Ekem for being there for me from the beginning.

I want to use this opportunity to once again thank my love, soul mate, awesome wife and counsellor, Ifeanyi for she is a great lady. I am also grateful to our lovely children, Ifeanyi, Chiburem, Onyinyechi, Somachi and Lotanna. They are individually amazing. My gratitude also goes to my sisters and brothers, Cecilia, Stella, Chioma, Ogechi, Comfort (Late), Kingsley, Jude, Godfrey and Collins.

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I want to now thank family, friends, colleagues and guests who honoured my invitation and are here for my inaugural lecture.

God bless you all.

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