ATMOSPHERIC DYNAMICS AND THE REGIONAL CONTRIBUTIONS TO THE EARTH'S ENERGY BALANCE AND GLOBAL WARMING

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UNIVERSITY OF IBADAN

ATMOSPHERIC DYNAMICS AND THE REGIONAL CONTRIBUTIONS TO THE EARTH'S ENERGY BALANCE AND GLOBAL WARMING

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost of the College of Medicine, Dean of the Faculty of Science, Dean of the Postgraduate School, Deans of other Faculties and of Students, Directors of Institutes, Distinguished Ladies and Gentlemen.

Introduction

Thanks to God. He created the earth with the theory of connectivity at the back of His mind. Today, we know that the different parts of, and processes taking place on earth, are connected by more than the electromagnetic waves. In this lecture we will examine these connections using a very thin layer of the earth's atmosphere called the troposphere.

Atmospheric Dynamics

Atmospheric dynamics involves observational and theoretical analyses of all motion systems of meteorological significance, including such diverse phenomena as thunderstorms, tornadoes, gravity waves, tropical hurricanes, extra-tropical cyclones, jet streams, and global-scale circulations. The immediate goal of dynamical studies is to explain the observed circulations on the basis of fundamental physical principles. The practical objectives of such studies include improving weather prediction, developing methods for the prediction of short-term (seasonal and inter-annual) climate fluctuations, and understanding the implications of human-induced perturbations (e.g., increased carbon dioxide concentrations or depletion of the ozone layer) on the global climate.

The Department of Physics is well known for studies of thunderstorms. The research in this area started in 1959 through the efforts of Prof. A.I.I. Ette. We have since expanded the frontiers of knowledge in this area after the icon retired from the department. I shall be dealing with the area in greater detail.

Research on global-scale problems includes many topics related to climate change and climate variability, stratospheric dynamics, and the general circulation. We have benefitted from our cooperation with other research centres which had enabled us access to satellite data. Such results will also be presented.

Atmospheric Physics

In order to be able to provide a quick overview of the content of this lecture, it will be profitable to explain the following topics that are included in the discipline called atmospheric physics.

Atmospheric Chemistry, Cloud and Aerosol Researches

The atmosphere is chemically complex and evolving due to natural events, biological and anthropogenic activities; it has fundamental chemical links to the oceans, the solid earth and the biota. Anthropogenic perturbations such as land-use and industrial activities have profoundly modified the chemical composition of the troposphere and stratosphere, with potentially important consequences on future climate and living organisms. Examples of such changes include the formation of an ozone hole over Antarctica since the late 1970s, the observed trends in long-lived greenhouse gases, the changes in the concentrations of tropospheric ozone in the subtropics (especially Lagos), and acidic deposition due to growing emissions of hydrocarbons, nitrogen oxides and sulfur dioxide in industrialized regions.

The laboratory and field research deals with atmospheric gas measurements, and the physical and optical properties of tropospheric particles (Oladiran 1979; Oladiran and Nymphas 2004; Akinyemi 2005; Olatona 2008; and Ogunsola). Cloud and Aerosol Research on the other hand is concerned with three broad areas of research that overlap in many important ways: atmospheric aerosols and trace gases, the physics and chemistry of clouds and precipitation, and mesoscale and microscale processes associated with cloud and precipitation systems. The atmospheric aerosol and trace gas studies are concerned with the origins of various particles and gases in the air and their effects on the atmosphere on local, regional and global scales. This has involved the group in studies of the emissions of particles and gases from industries.

For many years, the Department has been engaged in studies of the structures of clouds and the various processes that can lead to precipitation and/or lightning. Although rooted in field observations, this work includes conceptual and numerical model developments. Current studies include the effects of clouds on the radiative balance of the earth and climate as well as mesoscale studies of cloud and precipitation systems. The research has enjoyed funding from the International Science Programme of the Uppsala University, Sweden. One of the unique aspects of these studies is the blending of synoptic, mesoscale and microscale analyses, an aspect for which the Ibadan group enjoyed the assistance of the Nigerian Meteorological Agency in form of data and technical support. The studies have led to new conceptual models.

Boundary-Layer Research

The structure and dynamics of the lowest layer of the atmosphere which comprises the planetary boundary layer (PBL) are of vital importance for the understanding of weather and climate, the dispersion of pollutants, and the exchange of heat, water vapor, and momentum with the underlying surface. Processes of special interest within the PBL include the vertical transfer of momentum, heat and water vapor by turbulence, and the absorption and emission of radiation at the surface and within the atmosphere. One focus of the research efforts is on measuring the turbulent fluctuations of velocity components, temperature and humidity. Another focus is on the theoretical analysis and interpretation of turbulent statistics and flow dynamics. The importance of instabilities, secondary flows, and coherent structures has been an essential part of this study. Present emphasis is on the role of the boundary layer in energy transfer, and satellite capabilities in ocean and land measurements, with a view to developing appropriate algorithms to determine accurate ground truths with satellite measurements.

Staff and students are engaged in a variety of field and theoretical projects including the study of surface fluxes, mesoscale variations in boundary-layer structure, and effects of variable terrain and variable vegetation. Observations are being made from fixed towers, and satellites (NIMEX, Otunla, Jegede et al. Adeniyi, etc).

Departmental researchers have participated in many international research programmes in many parts of the globe, from the Tropics to the Arctic region (CARBO AFRICA, WAMEX, NORTH-SOUTH COOPERATION, etc,). In all these participations, we have enjoyed the help of various granting bodies, notable among them ISP, Uppsala, Sweden.

Climate Change

As human activity begins to alter atmospheric composition and climate on a global scale, the challenge of understanding the global system—comprised of atmosphere, ocean, ice and land vegetation, takes on a heightened sense of urgency. Climate research is also motivated by the hope of substantial economic benefits to be realized from improved weather and climate prediction on time scales ranging from weeks to seasons or longer.

In the Department, we are engaged in a number of projects directed towards a better understanding of climate variability and long-term climate change, including:

- dynamics of atmospheric variability on time scales of weeks or longer and its relation to extreme events such as droughts and unseasonable warmth or cold;
- the El Nino phenomenon in the equatorial region and its effects on global climate;
- the effects of human activities;

- the determination of the optimal time for the commencement of the planting season; and
- food security.

(Adeniyi and Oladiran 2000; Nymphas, Adeniyi, Ogolo and Oladiran 2004; Oladiran and Aina 1987; Oladiran 1987; Oladiran 1998c; Akinyemi and Oladiran 2004; Adeniyi, Nymphas, Ogunsola and Oladiran 2007).

The Atmospheric Ozone

The earth's atmosphere has layers, which are actually characterized by how the temperature of the atmosphere changes with altitude (figs. 1 and 2).

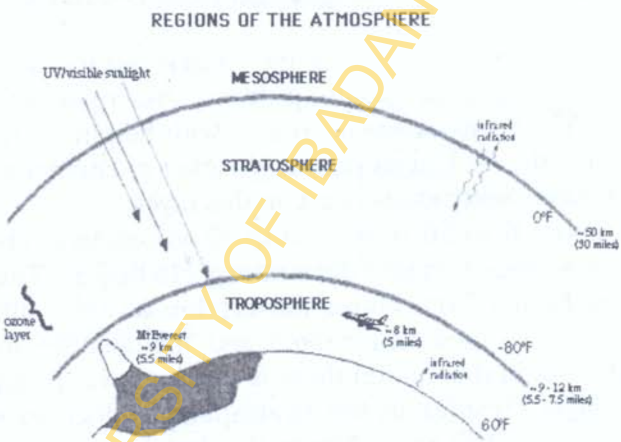


Fig. 1. Regions of the atmosphere (*http://www.ozonelayer.noaa.gov/science/atmosphere.htm*, last updated on 20 March 2008 by *Karin.L.Gleason@noaa.gov)*

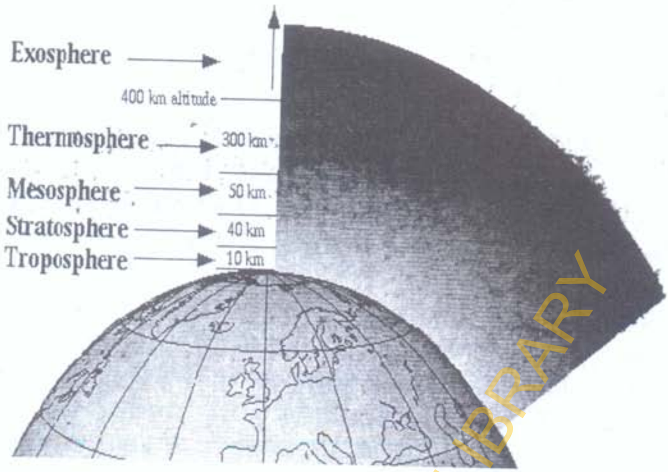


Fig. 2: General Atmospheric Structure (After NASA, 2008)

The troposphere begins at the earth's surface, which acts as a source of heat resulting from absorption of visible sunlight. The temperature decreases with height in the troposphere, and the air is well mixed. Weather phenomena such as thunderstorms and clouds occur in this layer.

At about 6 to 10 miles (10 to 17 kilometers) above the earth, a new region called the stratosphere begins. The stratosphere is heated from above (absorption of solar ultraviolet radiation by oxygen and ozone) and temperature increases with altitude. In this region there is much slower mixing. The "ozone layer" resides in the stratosphere, which extends to about 30 miles (50 km). Above this height the temperature begins to decrease with altitude again and the layer called mesosphere begins.

Both the stratosphere and the troposphere have important direct and indirect effects on the well-being of humankind. In this century, it has become increasingly clear that humans are influencing the chemical composition of the troposphere and stratosphere in ways that can have impact on the conditions at the earth's surface. Some of the most challenging environmental issues of our time have arisen, and thus the need for ozone research and monitoring has become very important.

Ninety percent of atmospheric ozone resides in the stratosphere and is produced by active chemical processes in the presence of solar energy, by the absorption of UV-B. It increases by a feedback chemical process described by the Chapman equations (Chapman 1930; Hunt 1966a, b). Ozone on the other hand, absorbs the UV-B component of the solar radiation, resulting in the stratospheric temperature increasing with height. The distribution of ozone in the atmosphere is shown in figure 3.

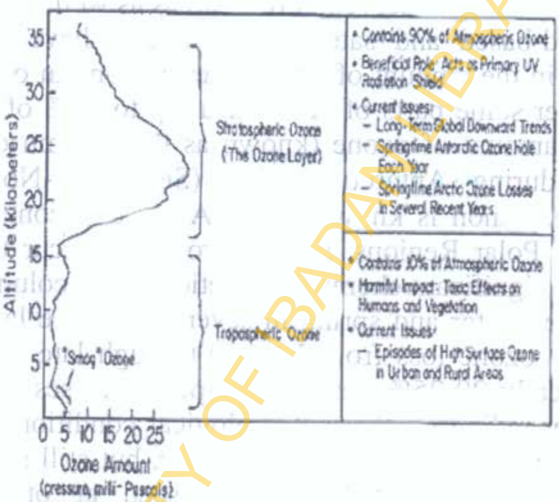


Fig. 3. Distribution of ozone in the atmosphere (Adapted from the WMO Global Ozone Research and Monitoring Project Report 1999)

The Ozone layer provides protection against the UV-B that would otherwise be harmful to both animals and plants when absorbed in large quantities by regulating the amount that reaches the troposphere. It also acts as a tracer of atmospheric motion (Brewer and Wilson 1968; Newman 2003). Without the filtering action of the ozone layer, more of the Sun's UV-B radiation would penetrate the atmosphere and would reach the earth's surface. Many experimental studies of plants and animals, and clinical studies of humans, have shown the harmful effects of excessive exposure to UV-B radiation (Jacobson 2000; Parker 2000).

The ozone residing in the stratosphere is beneficial, but, we must note here that a high level of ozone near the earth's surface acts like a toxic element. There must therefore be a balance. The moment man changes the natural balance or the natural concentration, there is bound to be a great problem, some of which we are already experiencing—photochemical smog—a familiar problem in the atmosphere of many cities around the world. Higher amounts of surface-level ozone are increasingly being observed in rural areas as well.

Ground-based and satellite instruments have measured decreases in the amount of stratospheric ozone in our atmosphere. Over some parts of Antarctica, up to 60% of the total overhead amount of ozone (known as the column ozone) is depleted during Antarctic spring (September-November). This phenomenon is known as the Antarctic ozone hole. In the Arctic Polar Regions, similar processes occur that have also led to significant chemical depletion of the column ozone during late winter and spring in seven out of the last eleven years. The ozone loss from January through late March has been typically 20-25%, and shorter-period losses have been higher, depending on the meteorological conditions encountered in the Arctic stratosphere. Smaller, but still significant, stratospheric decreases have been seen at other, more populated regions of the earth. Increases in surface UV-B radiation have been observed in association with local decreases in stratospheric ozone, from both ground-based and satellite-borne instruments.

Man has continued to produce chemicals that lead to ozone depletion in the stratosphere through the process of atmospheric circulation. The ozone-depleting compounds contain various combinations of the chemical elements: chlorine, fluorine, bromine, carbon, and hydrogen and are often described by the general term halocarbons.

The compounds that contain only chlorine, fluorine, and carbon are called chlorofluorocarbons, usually abbreviated as

CFCs. CFCs, carbon tetrachloride, and methyl chloroform are important human-produced ozone-depleting gases that have been used in many applications including refrigeration, air conditioning, foam blowing, cleaning of electronics components, and as solvents. Another important group of human-produced halocarbons is the halons, which contain carbon, bromine, fluorine, and (in some cases) chlorine and have been mainly used as fire extinguishers.

CFCs are mixed worldwide by the large-scale motions of the atmosphere and survive until (after 1-2 years) they reach the stratosphere and are broken down by ultraviolet radiation. The chlorine atoms within them are released and directly attack ozone. In the process of destroying ozone, the chlorine atoms are regenerated and begin to attack other ozone molecules... and so on, for thousands of cycles before the chlorine atoms are removed from the stratosphere by other processes (see fig. 4).

Fig. 4. Simplified cycle of reactions in which chlorine (Cl) destroys ozone (O_3)

Naturally, ozone forms a layer in the stratosphere, thinnest in the tropics (around the equator) and denser towards the poles even without depletion. Any proportionate depletion will be felt more in the tropics. Thus, we know that the problem is not that of the developed world but critically our own.

The results of studies at Ibadan are summarized below.

Ibadan Results

For the tropical region, the study of the atmospheric ozone gives the following results (Akinyemi and Oladiran 2003, 2006, 2007; Akinyemi 2005; Akinyemi et al. 2006):

- The monthly ozone concentrations from 1997 to 2006 over the latitude range 30°S to 30°N over Africa showed a gradual decrease of the mean ozone concentration towards the equator (280DU to 263DU at the equator). (Note that normally, there are 3 molecules of ozone for every 10 million molecules of air (WMO 1998). So this decrease is not minor).
- The quasi-biennial oscillation of ozone concentration was observed over Lagos and Dakar.
- The maximum ozone concentration over the latitude zone 5° – 15° north occurred between July and August, while the minimum for the same zone occurred between December and January with the respective values of 278DU and 242.6DU. Nigeria is situated in this zone.
- Temporal oscillation periods range from 2 to 6 days, while seasonal oscillation periods range from 120 to 380 days over Lagos, Dakar, Kinshasa, and Nampula. There is very close similarity in the characteristic behavior of ozone over Lagos and Dakar, possibly because they lie on the same latitude.
- The stations exhibited annual variability of 14.1% 15.1%, 9.8%, and 10.9% at Lagos, Dakar, Kinshasa, and Nampula respectively.
- The vulnerability of the four stations to surface UV-B exposure is higher at the southern stations (Kinshasa/Brazzaville and Nampula), than at the

northern stations (Lagos and Dakar), i.e., equal hours of exposure to sunlight at these stations will result in different dose assimilation of UV-B—this is merely a statistical comparative result and should not give us any false sense of security. It shows that global regulation is not enough; we need local as well as regional regulation.

- A model for the prediction of the current ozone concentration based on the local weather has shown at least a 75% agreement and needs to be further developed.

The Ozone Depletion (and the attendant creation of Ozone Hole), often gets directly equated to the problem of global warming in the popular press and by the general public. Whilst there is a connection because ozone contributes to the greenhouse effect by a feedback process, the Ozone Depletion is a separate issue. It is more of a health and ecological issue than global warming. However it is another stark reminder of the effect of man's activities on the environment. Figure 5 is the plot of ozone depletion obtained by the Atmospheric Group of the Cambridge University, and emphasizes the reality of Ozone Depletion.

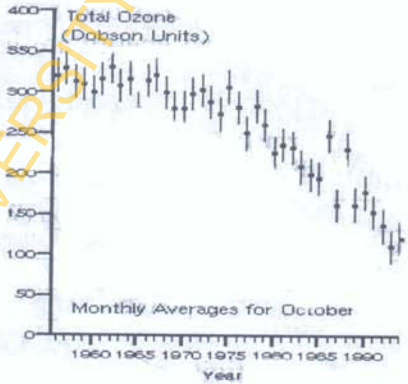


Fig. 5. The trend of ozone concentration in the atmosphere.

Earth's Energy Balance

A spherical simplification of the planets and an assumption of circular orbits round the sun (heliotropic consideration) yield a radiative energy balance whereby the solar radiation is balanced by the infrared radiation:

$$(1 - r)S/4 = \sigma \gamma T_E^4 \qquad (1)$$

And the net temperature, T_E, of the earth as

$$T_E = [(1 - r)S/(4\gamma\sigma)]^{1/4} \qquad (2)$$

Where r = planetary albedo ≈ 0.3;

ϵ = relative emissivity of the earth;

S = solar constant ≈ 1353Wm^{-2} ; and

σ = Stefan's constant.

The term $\sigma \gamma T_E^4$ is the average rate at which energy is absorbed and subsequently radiated by each square metre of the earth's surface as long-wave radiation (≈ 237Wm^{-2}) which is about the strength of four 60 Watt bulbs. The balance between the incoming and the outgoing radiation is called energy balance. This situation exists under normal conditions. Some minor sources of thermal energy are indicated in table 1.

Table 1: Minor Thermal Energy Sources Contributing to Radiative Energy Balance

Source	Contribution (W/m^{-2})
Radioisotope Decay	0.06
Fuel Consumption	0.018
Tidal Friction	0.005

A decrease in the reflectivity of the earth, r, or the relative emissivity, γ, will result in an increase in the average temperature of the earth. It is primarily the properties of the gases that make up the earth's atmosphere that affect these quantities. The absorption of thermal radiation by the constituent gases of the atmosphere is frequency dependent. Some atmospheric gases absorb thermal radiation, at the long-wave regime but transparent to short waves from the sun and vice versa. Oxygen and nitrogen are transparent to the long-wave thermal radiation.

The analyses above are for the earth and its atmosphere as a body. When the radiation enters the earth's atmosphere, part of it is absorbed by air and the other gases present, another part is absorbed by water vapour, while the rest goes into the solid earth as ground flux to be conducted to the colder parts. Separating the sensible and latent heats is a major problem.

The latent heat is not purely due to absorption by water vapour only, but is affected by other condensates. It is also affected by the chemical decomposition of the aerosols in the atmosphere. The sensible heat, on the other hand is affected by pollution and the other particulate effluents into the atmosphere. The Bowen ratio is the ratio of the sensible heat flux to the latent heat flux.

In a study carried out at Ibadan (Ogolo 2002), Bowen ratio was used as an index of variation, expressing it in terms of directly measurable quantities using the thermodynamic equations of the atmosphere. The resulting equation is of the form

$$B = \gamma \, \Delta T / \Delta e; \qquad (3)$$

where γ = psychrometric constant; ΔT = vertical temperature gradient; and Δe = vertical vapour pressure gradient. The equation was found to be accurate to within 95%. Latent heat is easily determined from meteorological parameters, so that the sensible heat flux and the net radiation can be predicted from measurements of the ground flux. The fit between the measured and the predicted net radiation is about 98%, using the eddy correlation technique. An empirical relation of the form

$$T = Be + c; \qquad (4)$$

was obtained for this locality, and we found that B = B{wind speed, cloud cover, fog}; while c = c{wind speed, fog}.

Some gases, such as water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide, hydro-fluoro-carbons (HFCs), per-fluoro-carbons (PFCs), and sulfur hexafluoride are transparent to solar (shortwave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface. This way, they continue keeping the temperature of the earth and its atmosphere sufficiently high for life to subsist on it. Hence, carbon dioxide, water and other naturally occurring greenhouse gases (trace gases), perform the God-given duty of a warm blanket for the earth. This blanketing effect is called greenhouse effect.

Just as in the case of ozone, man is adding more of these gases to the atmospheric loading, and by the nature of their duty as dictated by God, they keep trapping more heat, and the earth and its atmosphere is warming up. Man is gradually converting the earth's environment to that of the Venus environment where the predominant gas is CO_2 (and its heat trapping associates). CO_2 has increased the Venus temperature to 525°C compared to the 5°C it would have had if it contained air.

The question is: Are we ready for this type of phenomenal increase in temperature?

Production of Greenhouse Gases

Contemporary levels of atmospheric CO_2 are being influenced by the combustion of fossil fuels and the net result of biomass accumulation or destruction. Analysis of the CO_2 levels at various locations and the global average indicate that there is a steady increase: 280 ppmv (parts per million by volume) in 1750 compared to the current average value of 350ppmv - a 25% increase!

$$C + O_2 \rightarrow\rightarrow CO_2 \qquad (5)$$

Combustion of hydrocarbon fuels, petroleum, and natural gas produces a similar effect, also creating water vapour by the oxidation of the hydrogen of the fuel. It is a cascaded process. Every year approximately 5.0×10^{12} kg of carbon in the form of CO_2 is released to the atmosphere as a result of global consumption of fossil fuels.

Energy-related carbon dioxide emissions account for about 98 percent of U.S. CO_2 emissions. The vast majority of CO_2 emissions come from fossil fuel combustion, with smaller amounts from other uses (non-fuel) of fossil fuels, as well as from electricity generation using geothermal energy and non-biomass waste. Other sources of CO_2 emissions include industrial processes, such as cement and limestone production. Appendices 1 and 2 are estimates for the U.S. CO_2 emissions from energy consumption. (Unfortunately, we have no such estimates in Nigeria. A pointer to the need to arrest the current situation is the erratic weather behaviour of the last two years, which will be discussed briefly later. The value cannot be small since domestic and commercial energy requirements are now derived from oil using unregulated exhaust engines).

Global Warming

The average global temperature has already increased by about 0.74K since 1900. Over the last 100 years, the average temperature of the air near the Earth´s surface has risen a little less than 1° Celsius (0.74 ± 0.18°C, or 1.30 ± 0.32° Fahrenheit). Though it does not seem all that much, it is responsible for the conspicuous increase in ***storms***, ***floods*** and ***raging forest fires*** we have seen in the last ten years.

Data from current studies showed that an increase of one degree Celsius makes the earth warmer now than it has been for at least a thousand years. Out of the 20 warmest years on record, 19 have occurred since 1980. The three hottest years ever observed have all occurred in the last ten years. In 2007 alone, the disasters associated with weather are depicted in table 2.

Table 2: Weather Related Disasters in 2007

Location	Type of Disaster	Casualty and/Period
Britain	Flooding. England and Wales's wettest May-June since record keeping in 1766	350,000 affected. Worst in 60 years.
West Africa	Floods	800,000 affected in 14 countries
Lesotho	High temperature and drought	Crops destroyed
Sudan	Torrential rain	150,000 without shelter; at least 500,000 received aids
Madagascar	Cyclones and heavy rains	33,000 affected; 260,000 farmers displaced.
North Korea	Flood, land and mud slides	960,000 people affected
Bangladesh	Flooding	3,000 killed; 1.25million animals killed; 1.5million homes destroyed or damaged
India	Flood	30million people affected
Pakistan	Cyclonic rains	377,000 people affected; several hundreds dead.
Bolivia	Flooding	350,000 affected; 25,000 displaced.
Mexico	Regional flooding	>500,000 homeless; >1million affected
Dominican Republic	Prolonged heavy rain resulting in flooding & land slides	65,000 displaced
United States of America	Fire across tinder dry forest across southern California	>500,000 people fled from their homes.

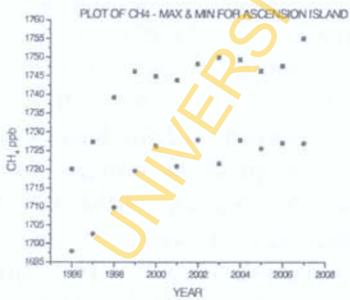
2010 is on track to becoming the warmest year ever! It was reported on June 2, 2010, that figures from US scientists showed that the arctic sea ice is at a record low, while land temperatures are likely to hit new heights. Heat waves have already killed many.

In 2005, the UNO office for the coordination of Human Affairs issued 10 emergencies, while in 2007, it issued 14 emergencies. Apart from the data displayed in table 2, other confirmation of global warming includes:

- The Northwest passage was fully open to ships in 2007, for the first time in recorded history.
- The harmattan in West Africa is becoming folklore to those less than 12 years of age and may extend to those over 40 years in the next 20 years.
- The sea level and sea surface temperature is rising—some low-lying countries may become non-existent in the near future.

Rising temperature may foster the spread of diseases by enabling mosquitoes, ticks, and other disease carrying organisms, including fungi, to spread farther afield.

The opinion of many is that "The dangers of global warming are nearly as dire as those posed by nuclear weapons" and are occurring faster than expected. The tragedy is that the greenhouse gases keep increasing and are being uniformly distributed round the earth via atmospheric circulation. The trends of greenhouse gas variations in New York, Lagos, Beijing, and the remote Ascension Island are the same and is as depicted in figure 6 (After Ogunsola 2010, private communication).



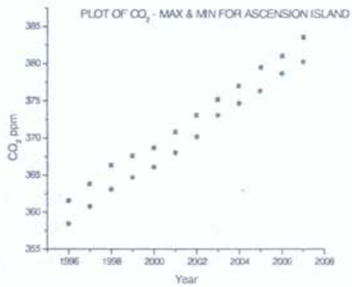


Fig. 6. The trends of variations of methane and carbon dioxide over Ascension Island.

Aerosol Studies

Starting from 1979, comprehensive studies of the aerosol characteristics of the West African region were undertaken, including the peculiar harmattan dust. Sources of aerosol in the atmosphere include oceans (53%); soil and weathering (14%); biosphere, evaporation and trace sources from volcanoes (11%); chemical and photo-chemical sources (12%); and anthropological sources that act as perturbations and can vary the atmospheric dust loading by up to 10%. The harmattan dust enhancement falls under the latter four groups and can contribute up to 33% of the net increase in the ambient aerosol at its peak. The intercontinental meteorological connections are borne out by the characteristics of the radioactivity of the harmattan dust with enhanced activity coinciding with nuclear accidents in far away Europe and Russia (Sanni 1973; Oladiran 1979, 1988b). Aerosol is an active agent for the transport of emissions from one region to another.

For this region, the index of cumulated atmospheric pollution I_k is of the form:

$$I_k = \sum_{i=0}^{n} \left(\frac{Ci}{Ki}\right), \qquad (6)$$

where C_i = mean value of the calculated concentration of the i^{th} substance; K_i = sanitation standard for the mean concentration(or its recommended value) of the i^{th} substance. For this period, the predominant constituents are solid particles and can be regarded in broad terms as dust. For the harmattan period, the value of I_k varies from 3.6 to 16.4, the modal value coinciding with the peak period of the harmattan. The maximum deduced SO_2 concentration ranges from *0.22mg/m³* to *0.98mg/m³* (three- to twenty- fold of the acceptable level). This is very much higher than the accepted sanitation level of 0.*04mg/m³* (Hesek 1989). The non-harmattan concentration ranges from *0.013mg/m³* to *0.067mg/m³* in Ibadan (Oladiran 1991, 1994; Oladiran and Nymphas 2004). The question is: From where does this large concentration come? The answer is: Everywhere!

The control of emission can only be achieved if all countries cooperate to regulate the emission. Nature will redistribute the emitted pollutants, for example;

- aerosols are nutrition sources for many ecosystems, e.g. it was suggested that dust originating from West Africa and deposited into the Atlantic ocean are a major source of iron used by phytoplankton that may capture excess CO_2 (Young 1991);
- they are sources of top soils in the Atlantic islands (Prospero and Neels 1986); and
- the atmospheric aerosol particles are the transport vehicles for radionuclide particles, and harmattan dust (Oladiran 1988b; Washington and Todd 2005).

Another interesting aspect of the study is the optical effects of the dusts. Olatona (2008) used the aerosol optical thickness to characterize the dusts in the African continent, with special emphasis on West Africa. Aerosol optical thickness measures the degree to which aerosols prevent the transmission of solar radiation. This is crucial to the understanding of aerosol impact on climate, agriculture, transportation, communication and health (Miller and Tegen 1998; Oladiran 1979). The TOMS satellite data over 38 locations in West Africa and 20 other locations in Africa were studied. The ground-based Aerosol Robotic Networks (AERONET) located at Ilorin showed a 0.95 correlation between ground and satellite data, so that the reliability of the satellite data is assured.

The aerosol optical thickness, τ, showed a seasonal variation (0.3 in October, and 2.23 in March for Ibadan); decreases from the coast landwards (2.50 for Lagos and 1.08 for Niamey). While τ is correlated positively to wind speed, it showed a negative correlation with rain (Oladiran 1994; Oladiran and Nymphas 2004; Olatona 2008). The Angstrom-parameter further confirmed that the soil dust dominated the aerosol from February to June, while carbon aerosols dominated from July to January over Ilorin (Olatona 2008). The trend of temporal variations at various locations within a narrow latitude zone, are similar (see fig. 7(a-e) (after

Olatona 2008), but their magnitudes are affected by the local weather.

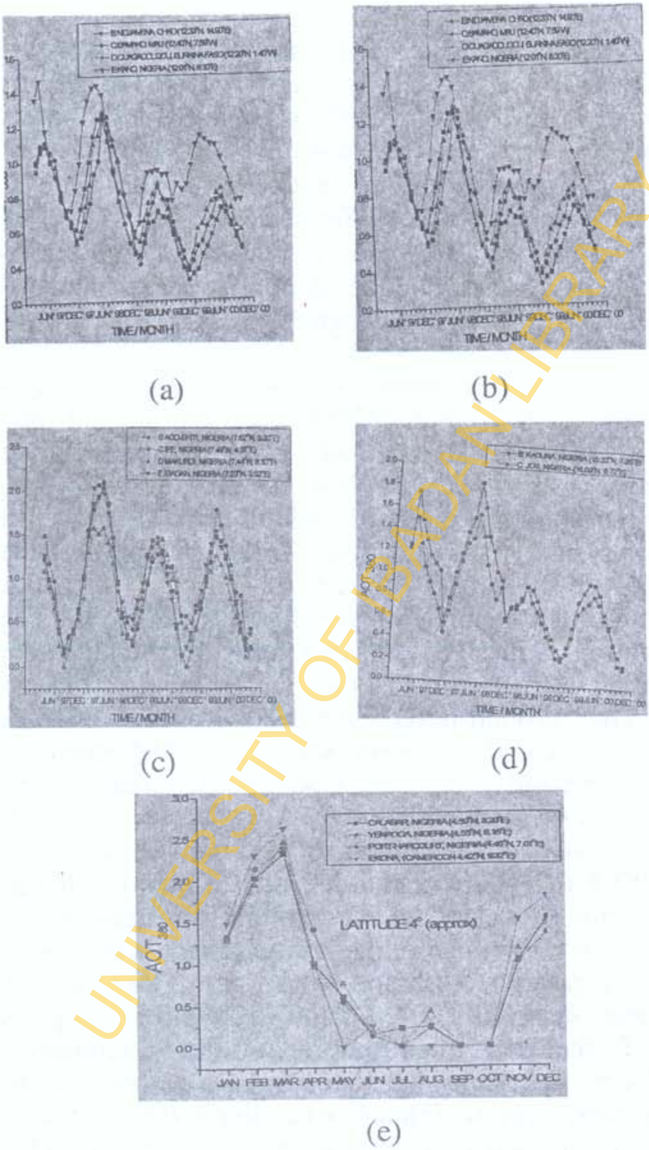


Fig. 7. Variations of optical thickness: (a) & (b) for locations around 12°N (c) & (d) for locations around 7°N (e) for locations around 4°N

Atmospheric Circulation

Atmospheric circulation is the large-scale movement of air by which heat is distributed on the surface of the Earth. The excess heating at the tropics leads to the rising motion of air. The heated air rises until it reaches the tropopause where its density becomes the same as the surrounding air, whereupon it moves polewards. This is the engine that distributes **all** materials injected into the atmosphere round the globe. In principle then, a single cell would be set up, which is known as Hadley cell. Due to the rotation of the Earth and to the large temperature differences with such a single cell, the Hadley cell is confined to low latitudes, less than about 30°.

As the equatorial air rises, air from higher latitudes moves towards the equator to take its place (trade winds). However, trade winds do not blow directly to the equator. The Earth's rotation induces a fictitious force, the Coriolis force, that results in the deflection of all moving objects not at the equator, to the right of the direction of motion in the northern atmosphere and to the left in the southern Hemisphere. Hence, the trade winds on the northern and southern hemispheres blow from the northeast and southeast, respectively. They are not coming together (converging) exactly at the equator but at a region called the Inter Tropical Convergence Zone (ITCZ). Moist air from the trade wind zone, where evaporation exceeds precipitation, is drawn into the areas of rising motion. The strong upward motion of air in the ITCZ is characterized by heavy precipitation in convective thunderstorms. On the other hand, the amount of water vapour a parcel of air can hold increases as the parcel descends, so the relative humidity in a descending parcel decreases. Hence, the regions with subsiding air (and as such with diverging surface winds) are dry, and include in particular the desert regions between latitudes 20° and 30° (fig. 8).

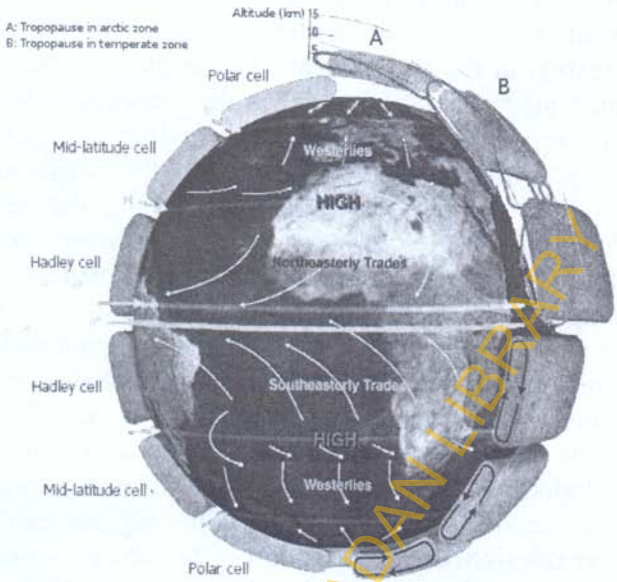


Fig. 8. Idealized atmospheric circulation

Also both poles are referred to as (polar) desert areas because air descends, and moves towards lower latitudes at the surface. The Coriolis force deflects these surface winds westwards, and these are therefore called polar easterlies.

In mid-latitudes, the picture is quite different. Because of the rotation of the earth, the motion produced by the horizontal density gradients is mainly West-East, and there is relatively little meridional circulation. This relative strong horizontal temperature gradient at mid-latitudes is referred to as polar front and separates the relative cold polar air from the warm subtropical air. However, the situation is not a stable one, and large transient disturbances (which appear as anticyclones and cyclones or depressions on the weather map) develop. How efficient the atmosphere is in redistributing energy strongly depends on the various mechanisms of atmospheric circulation. Cyclones and anticyclones at mid-latitudes are most effective at transporting heat polewards.

The wind belts and the jet streams girding the planet are steered by three convection cells: the Hadley cell, the Ferrel cell, and the Polar cell. While the Hadley, Ferrel, and Polar cells are major players in global heat transport, they do not act alone. Disparities in temperature also drive a set of longitudinal circulation cells, and the overall atmospheric motion is known as the zonal overturning circulation.

Atmospheric Electric Charge Transfer and its Studies at Ibadan

In a public lecture as this, every interest must be catered for. This is especially very important for a topic that is strongly related to divinity. The topic is sometimes referred to as the location of the atmospheric dynamo.

Some Traditional Beliefs about Lightning

Most people associate thunder and lightning with divinity. In North America, the Cherokee Indians speak of their cosmic friend, Thunder, whose two sons, the Thunderboys, wear the beautiful clothes, Rainbow and Lightning. These three are involved in the origins of corn and game—the food of the people. The Cherokees (and Nigerians) believe lightning strikes wicked people (and trees); these people (and trees) struck and killed by lightning are buried in the corn fields—to ward off other wicked people and to fertilize the corn (Kilpatrick et al. 1964; Idowu 1962).

The Pueblo Indians in Arizona use lightning "stones" made of quartz. When the two parts of such stones are rubbed together electrical discharges are emitted and are used in rain ceremonies (Switzer 1972). Among the Pueblo Indians, a person who survives a lightning strike is given the title "Lightning Doctor".

The Iroqois divided the world into the Upper `World of benevolent spirits, and the Lower World of malevolent spirits. The two worlds are in constant war. The Upper World uses lightning as its weapon. The Navajos call thunder the voice of the thunderbird associated with war, healing and blessing. In South America, the concept of the Thunderbird is also found. The Incar associated thunder with the god of war, trade and death, such that after the forcible Christianization of South America, the St. James' *Boarnergers* cult sanctified a son of Thunder under the guise of a Catholic saint. The cult of St James is still very active in the Northern Bolivian Altiplano (Evans-Pritchard 1967, 1972).

In Africa, the viewpoint is not very different, only the embellishments vary. Among the cattle rearing Nuer of Southern Sudan, to be struck by lightning is to be transformed into a god, joining the other gods. If the lightning strike leaves a survivor, he becomes a spiritual leader. During thunderstorms, people desirous of this status hold up their staffs so as to attract lightning. Also among the Nuer, children are encouraged to throw burning tobacco fragments into the storm as an invocation to the god of lightning to manifest itself gently.

In Nigeria, lightning and thunder are associated with the vengeance of the gods, especially *Sango*, against wrongdoers (Idowu 1962). Among the Yoruba, however, during severe thunderstorms, cooking fires are put out, sending long trails of smoke into the sky. Rain-makers and *Sango* priests burn herbs to prevent rain or to cause rain to fall. *Sango* priests are believed to have the ability, when offended, to call down lightning on others. The instrument used is a thunderstone, often a meteorite. The ancient Egyptians also associate lightning with meteoric thunderstones. An actual stone is also believed to be thrown down to earth in thunderstorms.

In Asia, the thunderbolt is the emblem of Bhudism. The dominance of Bhudism over Hinduism is symbolized by a mythical battle, during which Buddha wrested the thunderbolt from Indra (Blankenburg 1911). The lightning priest is called a "lord of rocks", referring to the use of thunderstones (Paul 1982; Slausser 1982, Sachel 1962) and to the belief that during a thunderstorm, actual stones are thrown down to earth by a god.

In Europe, the traditional concepts of lightning are not very different from those of elsewhere in the world. Lightning is the attribute of the most powerful deities. The ancient

Greeks and Romans depicted Zeus/Jupiter, 'father of the gods', as the hurler of the lightning bolt. Among the ancient Scandinavians, Thor, the blacksmith god, fought the enemies of man, including the demons of drought, with thunderbolts and spears of fire—lightning. Reference to lightning is also found in the Bible, in Exodus 9:24-26, 1 Samuel 7:10, Deuteronomy 32:41, etc.

The summary above shows that all over the world, ancient traditions regarding lightning exist, and these traditions are very similar.

The Pragmatic Basis of the Traditional Customs

Lightning is associated with rain and therefore with life and fertility of soil and/or animals. Lightning is also associated with the nitrification or nitrogen-fixing in the ground which enhances soil fertility.

Quartz has piezo-electrical properties which are utilized by the Pueblo-Indians; they clearly recognize the kinship between the discharges of the lightning stones and the electrical discharge of lightning.

Lightning usually strikes the highest point, for the electric field of a charged cloud overhead releases ions from the pointed edges which serve as paths for the lightning to ground. There is a Yoruba warning: "Don't point a stick to the sky during a thunderstorm, it is an invitation to Sango's anger, who might regard it as an insult" (The same is true of an umbrella which has a pointed edge). On the other hand, the Nuer elder desiring deitification, holds up his staff inviting lightning to strike him. In either case, all over the world, it is recognized that lightning will strike the highest point. The Nuer children who throw burning bits of tobacco into the storm and the Yoruba housewife extinguishing her cooking fire, are both creating streams of smoke which releases charges, thus reducing the likelihood of a very violent strike. They have inadvertently created lightning "protectors" as we know it now.

A modelled comparison of meteorites and metals exploded by the passage of an electric current shows almost identical characteristics (>99% similarity) (Rolf et al. 1976). Thunderstones priguated by lightning, do exist and have been found. They are usually very small, whereas meteorites are bigger. It is natural that an onlooker of as awesome an event as a lightning strike would tend to look for a larger rather than a smaller cause. It should also be recognized that a meteorite in flight would produce similar and sound manifestations to lightning, and would also cause damage, but in the absence of high electric field and rain.

The Yoruba rain makers are now known to burn plants that contain a very high concentration of silver iodide, of potent condensation nuclei (*oshunshun*). The clouds are seeded in the same way as meteorologists do now to produce artificial rain (while the traditionalists will depend on wind dispersing the seeding, the modern meteorologist will use instrumented airplanes) (Bruer 1976). This science now is a potent instrument of warfare!!

The scientific mind should never reject out of hand, the traditional beliefs as they are usually based on observations. They are similar to our scientific hypothesis, which remains a hypothesis until proved to become a law. Newton's law of gravitation remained the 'apple' hypothesis until it was proved and has since become the pillar of science.

The Science of Lightning

The earth always carries a negative charge. In the atmosphere and during fair weather, there is always an electric current flowing from a highly electrified layer some 9 – 12 km up in the atmosphere. The layer is an equipotential layer, which varies spatially. It is called the tropopause, with an average potential of +300,000 volts relative to the earth. The mean electric current flowing to the unit square metre of the earth is estimated at $3.6 \times 10^{-12} Am^{-2}$, giving an integrated electric current over the earth as 1800A, with an integrated earth-electrosphere resistance of 200Ω. [This does not contradict our knowledge of the air in the atmosphere as a bad conductor as this net resistance can be conceived as a large number (5.4×10^{14}) of high resistances in parallel].

The earth-electrosphere system behaves like a spherical capacitor. Without a constant charging of this capacitor it will become completely discharged in approximately 30 minutes. The complete discharging will lead to catastrophic effects on the earth—plants will die for lack of nutrients which are absorbed as ions. Without the plants, life will cease.

The mechanism of continuous charging, and hence, maintenance of life, is the thunderstorm activity. It does this through precipitation currents, lightning discharges, point-discharge currents, displacement currents, and convection currents to some extent. Point discharge currents are the most predominant (Wilson 1920; Schonland 1964; Ette and Oladiran 1980a).

The lightning conductor is a point discharger. The association of lightning with fertilization of the soil traditionally may be due to the conception of production of ions as a result of the presence of the earth-charge, and/or fixation of nitrogen which forms nitric oxide due to the high temperature in the lightning channel or the production of nitrates (C_{NO3}) during point discharges (Reiter 1968; Reiter and Reiter 1959; Visser 1961; and Ette and Udoimuk 1980). Unless these ions are produced, plant growth is impossible. (Call it fact 1 from tradition). Ette and Udoimuk (1980), obtained a relationship of the form:

$$E/C_{NO3} = A\,R^{0.45}\,f_E^{\,-0.53}\,; \qquad (7)$$

where E is the electric field, C_{NO_3} is the nitrate concentration, R is the rate of rainfall, f_E is the frequency of electric field reversal and A is a locality constant.

I AM SURE BY NOW YOU ARE CONVINCED THAT RESEARCH ON LIGHTNING IS CRUCIAL TO LIFE.

Gish and Wait (1950), from measurements of currents above thunderstorm clouds, deduced that the net current outflow from above a typical cloud is 0.5A, so that an estimated 3,600 storm centres must be in existence at any time for the earth-electrosphere capacitor to be continuously charged.

Satellite photograph results have confirmed this estimate to within a percentage accuracy of 95%. ***All these assume the existence of a charged cloud.***

From 1966, extensive investigations of the electrostatic, electromagnetic (low frequency, high frequency and optical) and acoustic fields of lightning discharges were carried out at Ibadan by Aina (1969), Ajayi (1970), McKoy (1968), Oladiran (1981, 1982a, 1985a,b); Oladiran et al. (1988a,b); Oladiran and Israelsson (1990); Oladiran (1995); and Nymphas et al. (2010) amongst others. A comprehensive review of the results obtained up to 1980 is contained in a paper by Oladiran (1982b) and need not be repeated here, but is cited for completeness. The results below constitute our journey from that time to date.

Charge Generation Mechanisms in the Cloud

All of about 18 theories of cloud charge generation can be grouped into two: Self-polarizing mechanisms and charging by extraneous influences.

Self-polarizing Mechanisms

In these mechanisms, the sign and magnitude of the separated charges are independent of the ambient electric fields and the separation proceeds at a uniform rate. Among these processes is the Lennard (1892) effect which is the process of charge separation by splashing of liquids on a surface or on collision with each other or other particles. The smaller particles carry a negative charge while the bigger ones carry a positive charge. These processes will give rise to a cloud of negative polarity (Sartor and Atkinson 1967; Latham and Mayers 1970; Jennings and Latham 1974; Oladiran and Ojo 1996; amongst others).

Charging by Extraneous Influences

In the presence of an electric field, probably set up by the Lennard effect or the effect of cosmic rays, falling and colliding drops would become polarized and selective capture of the surrounding ions by the falling drops can take place, or the charges can be separated due to some of the cloud droplets carrying away part of the charge on the underside of the polarized drops after a rebounding collision (Wilson 1920; Whipple and Chalmers 1944; Ette and Oladiran 1980(b); Latham 1969). Oladiran (1990) has shown that these drops can be set into vibration which would become quantized depending on the magnitude of the existing field and so lead to disruption and eventual charge separation. The amount of charge separated in these processes depends on the magnitude of the electric field, and can lead to electric fields of up to 250,000Vm^{-1} and an ambient charge of $7.0 \times 10^{-8}C/m^3$ in a cumulative feedback process.

The two mechanisms would in fact complement each other and eventually increase the electric field within the cloud to high values within limited small regions of the cloud by streamer propagation as demonstrated by Oladiran (1980a,b; 1983; 1985a,b; 1990;1995). These results further demonstrated that the occurrence of lightning does not depend on solid precipitation but can occur in warm clouds (Oladiran 1985a,b). The debate for the need of the existence of a very high ambient electric field of up to 700,000V/m for lightning to occur was laid to rest, as only a small fraction of this is required, of the order of 180,000V/m or less. The governing equation (Oladiran 1985) is shown below and has been confirmed by other workers.

$$E_s(Po) = \frac{200}{R^{0.3}} \{1 - (\Delta P/P_o)^{0.7}\} \qquad (8)$$

By virtue of the result in the above equation, we deduce that if breakdown occurs at -230kV/m for a droplet distribution at 1000mbar, the same droplet distribution, precipitating at the rate, will break down at -130kV/m at 700mbar and at -88kV/m at 500 mbar. Further reduction in the values of the breakdown fields will be enhanced by the increase in the effective path length of streamers in actual clouds.

Convection within the cloud will cause a further reduction as this will have the net effect of increasing the precipitation rate. Since the electric field needed for field intensification by streamer propagation is lower than the breakdown value, we conclude that the production of lightning in warm clouds containing pockets of a large population density of droplets will require much lower fields than have been assumed. If this droplet region is oriented to the ambient field beyond a certain angle, the effective electric field along its axis will be too small to produce the dipole effect for streamer intensification. A situation like this is common, especially in regions of very strong wind shear, and lightning will not be observed in such warm clouds.

Figures 9 – 13 represent the laboratory demonstrations of these processes; the results of which have been confirmed by radar observations in the cloud.

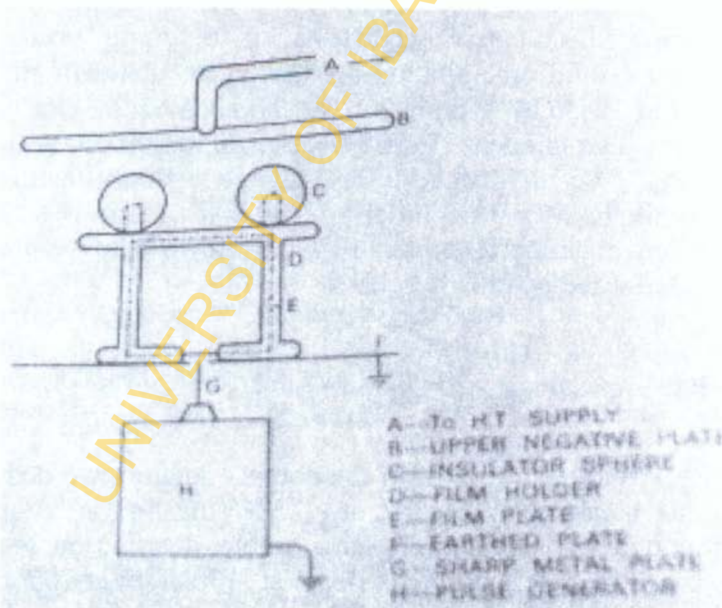
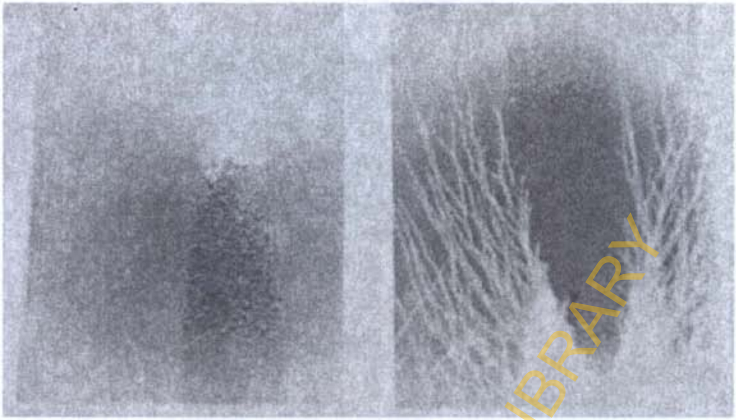
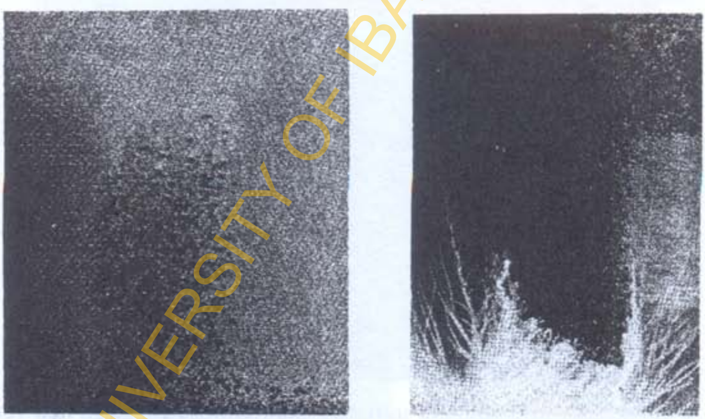


Fig. 9. Schematic diagram of the experimental arrangement



(a) (b)

Fig. 10. (a) The top, and (b) the bottom of the vertical prolate in discharging droplet region sprayed onto photographic film.



(a) (b)

Fig. 11. (a) The top, and (b) the bottom, of a vertical cross-shaped discharging droplet region sprayed on film

Fig. 12. Streamers to the prolate-shaped droplet region inclined to the electric field at about 48°

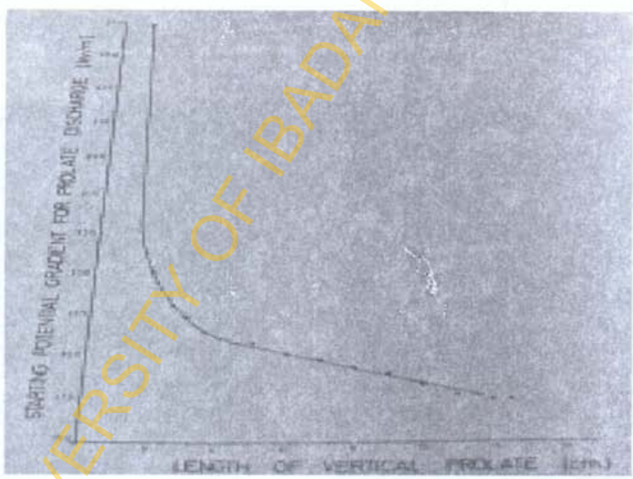


Fig. 13. The potential gradient initiating continuous discharge in a vertical prolate droplet region as a function of the vertical length of the rolate.

With the results above, a detailed understanding of the micro-physical charging processes in the cloud were elucidated. The summary of the results are as follows:

(a) When streamers interact with uncharged drops, they were either absorbed without re-emission; absorbed and re-emitted, depending on the size of the drops (fig. 14a & b, after Oladiran 1981), suffer temporary deflection of their path (fig. 15a) or branches were sent to the drops from the main streamer channel (fig. 15b).

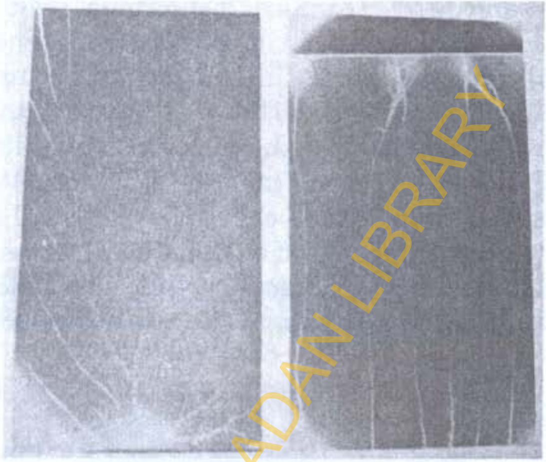


Fig. 14. (a) The top, and (b) the bottom of a positive streamer.

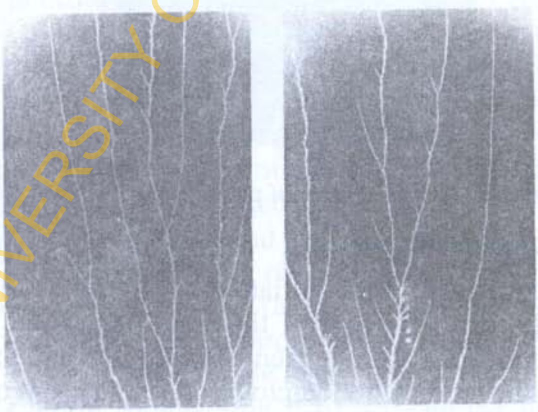


Fig.15. (a) The temporary deflection of positive streamers caused by interaction with drops; (b) The branching of positive streamers channels to drops.

(b) The channel of the streamers after interaction with the droplets is narrower than the channel of the incident streamers before interaction and gets narrower as the number of interactions increases until it is completely absorbed (fig. 16). Since the channel radius decreases as the net streamer charge decreases (Phelps 1974), this result confirmed that the drops acquired charges from the streamers. The implication of this result is that though the charging mechanisms earlier discussed would be effective initially, and that Wilson ion-capture theory would only give very small charging to the droplets, the main charging mechanism is through the streamer interactions. Charge intensification would follow the normal electrostatic processes.

Fig. 16. Multiple interaction of positive streamer branch with drops.

(c) Streamer propagation has been suggested to be responsible for the initiation of the stepped-leader of a lightning discharge through repetitive streamer production, which eventually builds up the electric field within thunderclouds to values required for negative leader propagation (Loeb 1966, 1968); Latham 1969; Smith 1976). The results confirmed these theories, and unified and simplified them through the streamer intensification processes.

(d) The missing link between the lightning flash and the accompanying gush of rain is the streamer interaction with cloud droplets (Latham and Saunders 1970; Moore and Vonnegut 1973; Brazier-Smith, Jennings and Latham 1973; Oladiran 1981, 1982).

Characteristics of Lightning and Related Parameters

The results presented above were going on in parallel with field measurements of rain current, point discharge current, lightning density and its effects on installations, meteorological parameters, and modelling. We have come to realize that there is neither pure experimental investigation in atmospheric physics, nor a pure theoretical atmospheric physics. You must be able to model your results if you would be able to interpret them. Otherwise, you will just be planting for others to reap.

Instrumentation

For any successful research in Atmospheric Physics, design, construction, and adaptation of instruments is a must. Because of the random nature of the occurrence of disturbed weather, and in order to have a continuous data, an automatic switching and timing device was designed, constructed and operated (see fig. 17). The instrument activates various equipment as soon as rain starts to fall or the atmospheric potential gradient reaches a pre-determined level, whichever occurs first. Transient effects were eliminated in the design. This circuit was used for uninterrupted collection of data during thunderstorms for four years and the data collected formed the first comprehensive data on rainfall electrification, point discharge, potential gradient and rate of rainfall in this region. The device is in fact a thunderstorm warning device and it was so used at the Obudu cattle ranch for warning on the approach of a storm by enabling it to activate car horns so that the cattle were driven under a Faraday cage (Ette, Aina and Oladiran 1978; Oladiran 1979).

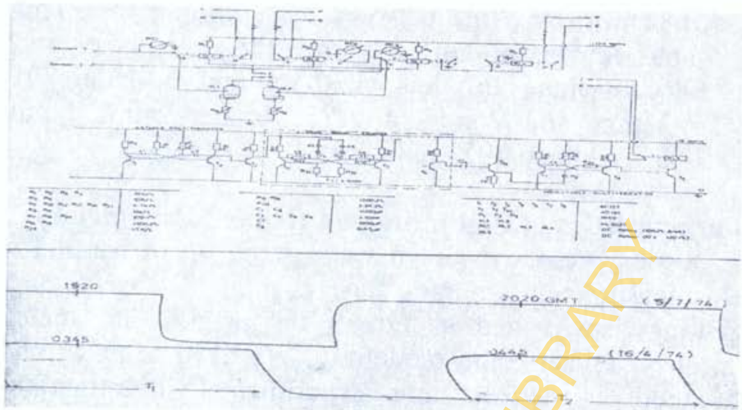


Fig. 17. Automatic switching and timing device circuit for disturbed weather recordings.

The condition of electrical energy supply in Nigeria has only worsened, but the scientific trend has not changed. Even in 1973 we had to couple a power converter to this device.

Up to 1988, lightning monitoring circuits were calibrated on the assumption that signals from lightning were sinusoidal in nature. A circuit which reproduces a lightning signal, the double exponential pulse generator (see fig. 18), was constructed by us. The CIGRE counter was therefore modified using active elements for discrimination of cloud and ground discharges (see figs. 19, 20 & 21), and the superiority of the design was demonstrated through a complex analysis of the circuit and comparison with earlier designs. This is now the accepted lightning density monitoring circuit (Oladiran et al. 1985; 1988). It can be used by both the vertical, plate or wire antennae.

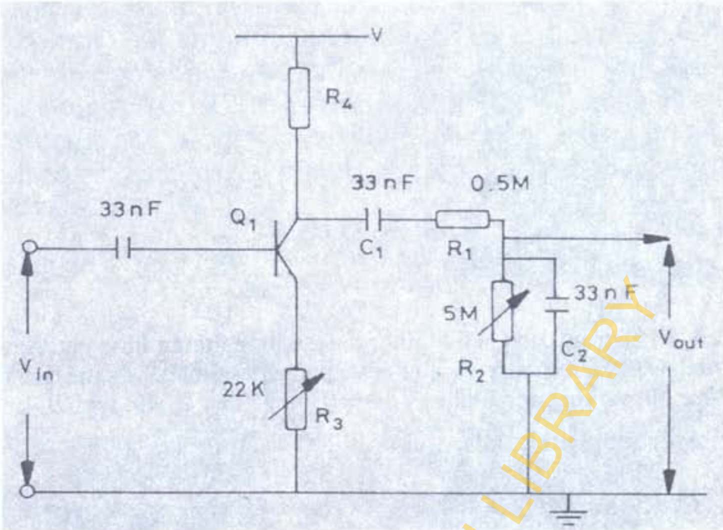


Fig. 18. Double exponential pulse generator

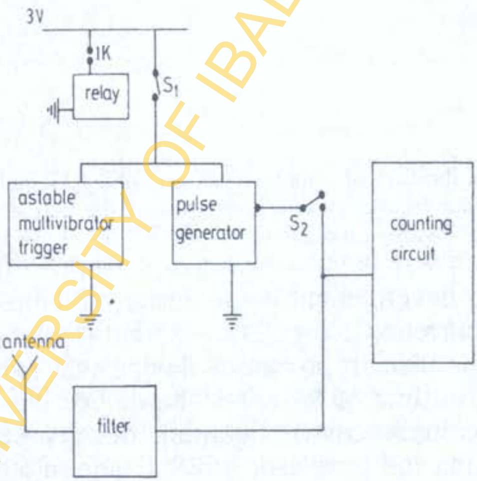
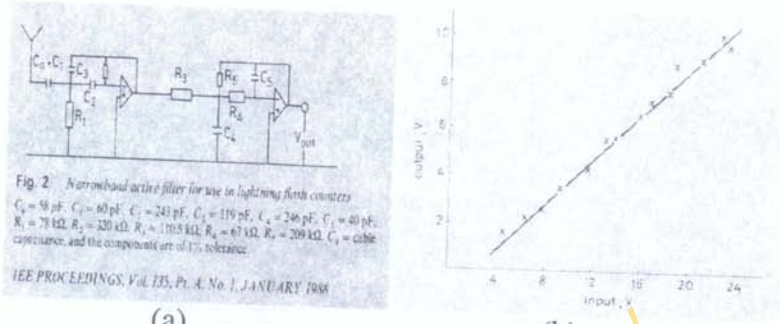
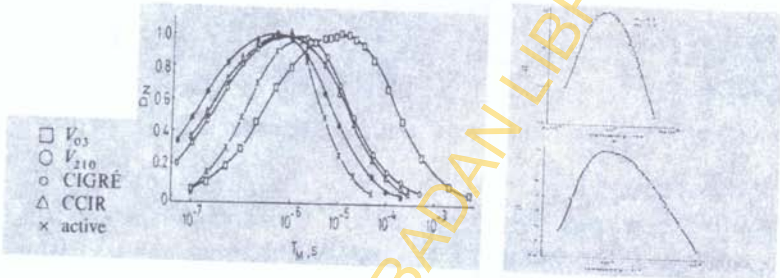


Fig. 19. Schematic diagram for in-situ calibration check of the Lightning Flash Counter (LFC)



(a) (b)

Fig. 20. (a) Narrow band active filter for use in lightning flash counter (b) Active filter response to double exponential pulses of constant rise time but varying amplitude [Vout = 0.445; Vin = 0.049; r = 0.99].



(a) (b)

Fig. 21. (a) Calibration of counters using double-exponential pulses; (b) Experimental frequency characteristics of the active filter (a – with gain = 1; b – with gain = 2).

A further development is the design of Time Registration of Event Occurrence using SDK – 85 Kit (Pisler and Oladiran 1985). This is a microprocessor device that can store up to 4000 events in time of 8 digits. The device was deployed in Ibadan for comprehensive lightning density determinations (Oladiran, Aina and Israelsson 1988; Oladiran 1995).

The next experimental challenge that we faced was the decomposition of the lightning signal into its spectral components. The design is simple, but the analysis is complex. The characteristics of the output signals obtained from a network depend on the response of the network to the input signal. For an accurate characterization of the input signal from a lightning discharge into a probe, the transfer function of the probe must be fully understood. A modified antennae coupling (fig. 22) was designed so that simultaneous signal storage and counting was done using a transient double-beam storage oscilloscope and microprocessor SDK-85 respectively.

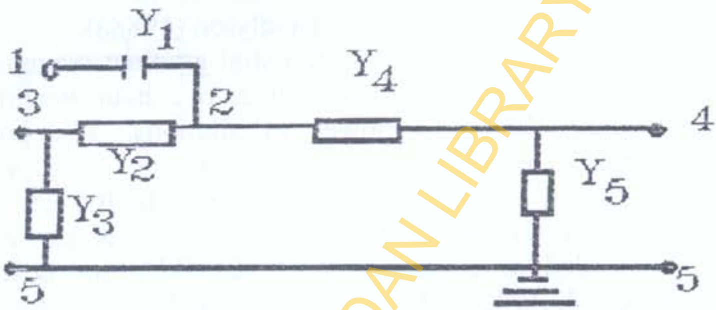


Fig. 22. Coupling network

The Pivotal Condensation Technique was used for network analyses and the following results were obtained:

(a) The recorded lightning signals are of four types (1) a positive or negative hump; (2) a positive fast rise followed by a negative excursion without a return to the positive ambient field existing before the flash; (3) a positive fast rise followed by a negative excursion with a final positive hump; and (4) the reverse of (2) and (3) above. This characterizes the various types of flashes (ground (negative or positive), cloud, or inter-cloud).

(b) The power spectrum indicates that the frequency of maximum power does not only depend on the rise time of the incident signal but on other factors characterizing the signal, such as (i) the ratio of the positive peak voltage to the negative peak voltage;

and (ii) the time lapse before the signal crosses the zero line.

(c) The range of frequencies to which the Lightning Flash Counter (LFC) responds ranges from 6.5 kHz to 22.7 kHz with strong dependence on the signal amplitude. The weather dependence of the above results is depicted in (table 3).

(d) The cloud to ground discharge ratio lies in the range 8:1 and 15:1 with a mean value of 11.2:1 as earlier reported by Oladiran and Israelsson (1988a).

(e) Viewed in terms of the potential gradient magnitude, thunderstorms lasting less than one hour would do more damage to power installations. The power spectral analysis showed that maximum peak power occurred at a frequency of 13.8 kHz for negative ground flashes, while a maximum peak power is recorded at a frequency of 52.5 kHz for positive ground flashes. The maximum peak power for the positive ground flash is about 5 times that of the maximum peak power for negative ground flashes. The power spectral regime is shown in table 4.

Table 3: Weather Characterization of Lightning Signals

Storm duration (hr).	Max. & mean rain rate(mm/hr)	Peak freq range & mean	Average ground discharges per storm	Numb of signals studied	% Distribution of duration	Peak field(kV/m)
0 – 0.5	Max. = 186 Mean = 92	8.4 -14.2 Mean = 12.4	36	46	8	16
0.5 – 1.0	Max. = 138 Mean = 67	6.8 – 20.6 Mean = 8.9	148	183	26	108
1.0 – 1.5	Max. = 105 Mean = 52	10 – 15.3 Mean =13.6	302	198	31	63
1.5 – 2.0	Max. = 156 Mean = 43	9.3 – 21.8 Mean = 10.3	185	104	22	38
>2.0	Max. = 122 Mean = 29	6.5 – 22.7 Mean = 7.8	87	83	13	13

Table 4: Power Spectral Characterization According to Rise Times of Lightning Signals

Rise time(μs)	Freq. at peak power(kHz)	% distribution
< 0.4	251	
0.4 – 0.6	61.7	2.1
0.6 – 0.8	44.7	
0.8 – 1.0	38.0	2.3
1.0 - 2.0	20.4	
2. - 3.	13.8	9.8
3. - 5.	8.13	
5 - 10	4.17	
10 - 20	2.24	34.8
20 – 35	1.32	
35 - 100	0.83	51
100 - 150	0.34	

Atmospheric Radioactivity

The characteristics of the ambient electric field are affected by the existing radionuclides. Sanni (1973) and Oladiran (1988c) showed that there is enhanced radionuclide concentration/activity during the harmattan and following nuclear accidents in Europe and the Soviet Union (as it existed before 1991), via the NE trade winds. The Chernobyl accident of 1987 was first noticed through high ambient electric fields. Since then, concerted efforts have been made for continuous study of the radionuclide condition in Ibadan and relating it to ambient electric fields (electric field can be measured continuously using a fieldmil over a long period of time). The summary of the results of such efforts by Adeniyi under my supervision is depicted in table 5.

Table 5: Comparative Analyses of Atmospheric Radioactivity with Meteorological Parameters

	α	β	Potential Gradient
Temperature	-0.49±0.06	-0.07±0.05	-0.84±0.1
Relative Humidity	0.44±0.05	0.12±0.05	0.57±0.09
Solar Radiation	0.40 ±0.06	-0.29 ±0.07	-0.52±0.09
Potential Gradient	0.96±0.01	0.87±0.04	

From these studies (Adeniyi and Oladiran 2005), a survey of the radioactive contamination of the harmattan dust showed a cumulative trend and is monotonically increasing gradually.

Rain Current

Solid precipitation is very rare in the tropics. Even in situations where solid hydrometeors are present aloft, melting usually takes place before the precipitation reaches the ground; and only occasionally does some graupel accompany rain. Routine measurements of rain current, made for the first time in this area with modified receptacle (see fig. 23, after Oladiran 1976), and associated parameters at Ibadan started in 1974 (Oladiran 1976). With the recording equipment arranged to be switched on automatically at the onset of rain or storm events (Oladiran 1979), all events during the period were monitored; and the resulting data are, therefore, likely to be fairly representative of the locality.

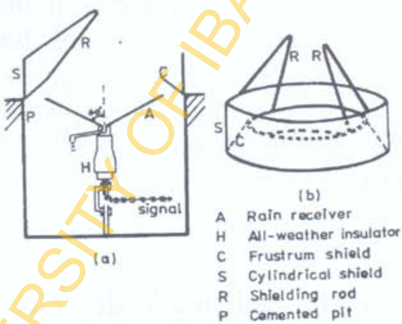


Fig. 23: (a) Rain receiver mounting and shielding arrangement (b) Exploded view of the shielding arrangement.

Analyses of the data revealed the following relations which may be of general nature (Ette and Oladiran 1980b):

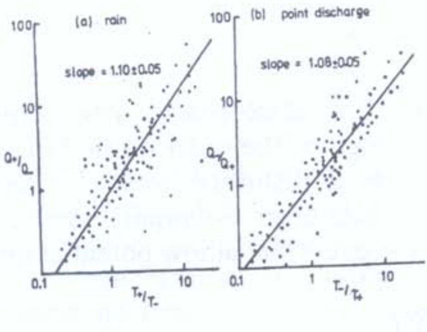
- On the average, the positive rain current bears a constant ratio to the negative rain current. A mean ratio of 1.1±0.2 was obtained for the locality.
- The mean ratio of positive rain duration to the negative rain duration is 1.9±0.2 (with a range of 0 to

20) for the locality. While the corresponding charge ratio also has a mean value of 1.9±0.3 and excluding instances of only positive rains, the range is from 0 to 98. These results showed that while the positive to negative charge and duration ratios for rain events here are on the average greater than unity—in agreement with results elsewhere—their quotient is not significantly different from unity. This can be interpreted to indicate that, for the locality, periods of positive and negative rains bring equally charged drops but that the differences in the charge magnitudes can be attributed to the observed higher rain drop number densities for the positively charged rains than for the negatively charged ones.

- The mean rain current density i_r is positive (downwards) and sensibly constant. The value for the locality is $1.0\pm0.1 \times 10^{-10}$ Am^{-2}.
- The similarity between rain and the point-discharge relations suggest a possible causal link between rain and point charges. On the basis of the Wilson (1929) theory, as worked out in detail by Whipple and Chalmers (1944), it is shown (Ette and Oladiran 1980b) that during periods of point-discharge currents of density i_p:

$$i_r = -\alpha(i_p - c) \qquad (9)$$

where α =0.25 is constant and c depends on the rainfall intensity R. This is demonstrated in figures 24 and 25.



(a) (b)

Fig. 24. Relations between charge and duration ratios for (a) rain events, and (b) point discharge events.

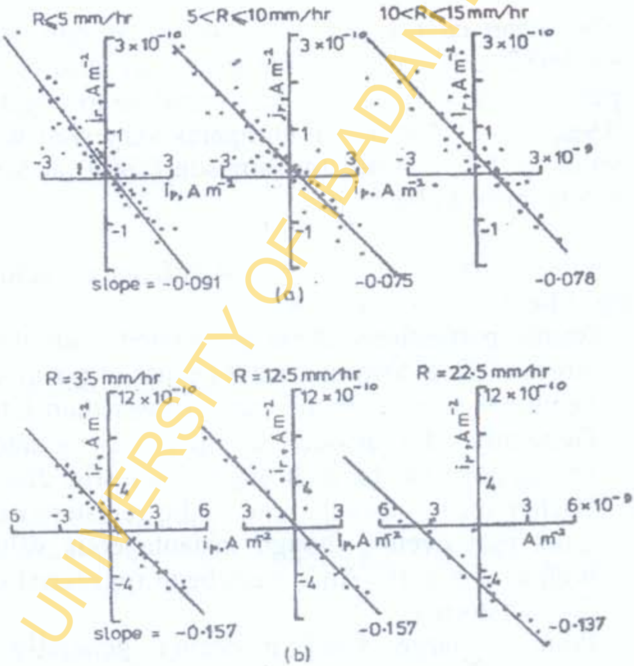


Fig. 25. Relation between ir and ip for (a) broad ranges of R, and (b) narrow ranges of R.

- At low potential gradients E,

$$i_r = -\lambda/2(E - E_o), \qquad (10)$$

where λ is the atmospheric conductivity, and E_o (≈154V/m) though of the order of the fair weather potential gradient, is a disturbed weather parameter. While equation (10) has been essentially verified experimentally, the data suggest that at low potential gradients,

$$i_r = - AR(E - E_o); \qquad (11)$$

Equation (11) shows that λ is proportional to R. This is the first of such results!

- The mean charge per unit volume of rain water is $+4.3\pm0.2 \times 10^{-5}$ Cm^{-3} while the mean ratio of charge per unit volume of rain water (positive to negative) is 0.9±0.1—a value which compares very well with the value of 1.1 obtained by Simpson (1909) at Simla in sub-tropical India.

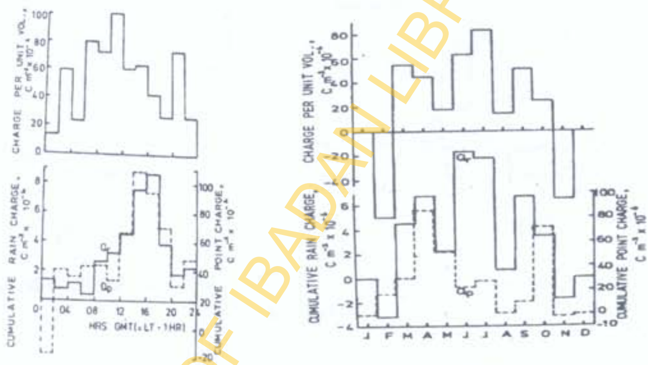
Observations, probably only of local significance, include the following (Ette and Oladiran 1980a):

(i) Rains, particularly those associated with thunderstorms, bring down a greater excess of positive over negative charges in the early stages than later on. Generally, the heavier the rain, the greater the excess positive charge brought down (fig. 26a & b).

(ii) Higher mean currents tend to be registered during quiet rain events, though instantaneous values as high as $\pm 5 \times 10^{-9}$ Am^{-2} have been registered during thunderstorms.

(iii) Point-discharge, when it occurs, generally starts soon after the onset of rain and continues well after cessation of rain. This may be attributed to the fact that, near the ground, the leading edge of the rain-bearing region of the cloud is blown ahead of the cloud by the downdraft (Byers and Braham 1953), so that rain falls before the cloud is close enough to initiate point-discharge.

(iv) The diurnal variations of the cumulative rain charge and the cumulative point charge are closely in phase with a minimum occurring between 1400 and 1800 GMT. The rains falling between the hours 0400 and 0600, 1800 and 2000, and 2200 and 0200 have a tendency to be predominantly negatively charged. Less than 10% of the rains in this locality fall during this time.



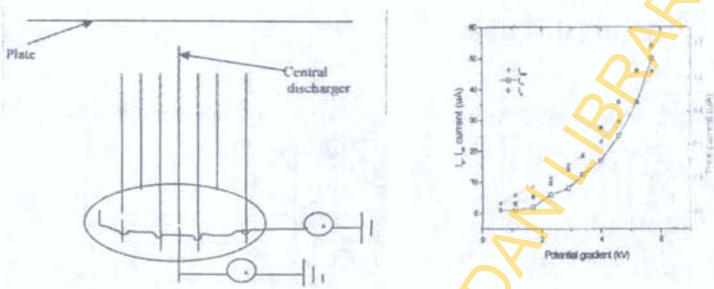
(a) (b)

Fig. 26: (a) Diurnal and (b) monthly variations of charge per unit volume of rain, cumulative rain charge surface density, and cumulative point charge surface density.

Lightning Density and Protection

Since 1752, when Franklin linked lightning to electrical discharges, efforts at protecting life and property from lightning has continued. The conventional lightning discharger is the lightning rod placed at the highest point of the installation to be protected. This arrangement gives protection over a 45° cone, and the area of coverage depends on the height of the point relative to the area to be protected. For a roof, with the standard 2 feet clearance from the roof, this area is approximately 25 square feet (or 2.335m^2), i.e.5 x 5 ft^2 or 1.52 x 1.52 m^2.

Recent research at Ibadan has shown that a multiple discharger with a central one increased the area of protection by a factor of 186 (Nymphas, Adeniyi and Oladiran 2010); and a typical one is shown in figure 27a & b. In figure 27b is the comparative discharge current for different types of multiple dischargers, with an increased discharge current of a factor of at least 6 for three discharger points.



(a) (b)

Fig. 27: Multiple lightning conductor and its characteristic curves (Nymphas, Adeniyi and Oladiran 2010)

With the current state of integrated circuits (IC), transients produced by lightning discharges have become a strong factor of consideration, bearing in mind that computer-related installations are the order of the day. Such IC's are usually protected from high voltage surges, but it is assumed that the main supply frequency lies within the range 50 – 60 HZ. We are working on this but preliminary results have shown that such transients can reduce the life-span of a computer by half.

For this locality the relationship between ground and cloud lightning discharges is of the form:

$$P = 0.05 + (\sin\lambda + on.05)/[(N_{TD} + 3)^{1/2}]; \qquad (12)$$

where $N_{TD} = N_c + N_g$; $P = 1/(1+N_c/N_g)$, N_c = cloud discharge number, N_g = ground discharge number; λ = latitude of the locality.

For Ibadan, $N_c/N_g = 14.4$; the annual ground flash density is 0.39 per km^2, while the cloud flash density is 5.7 per km^2.

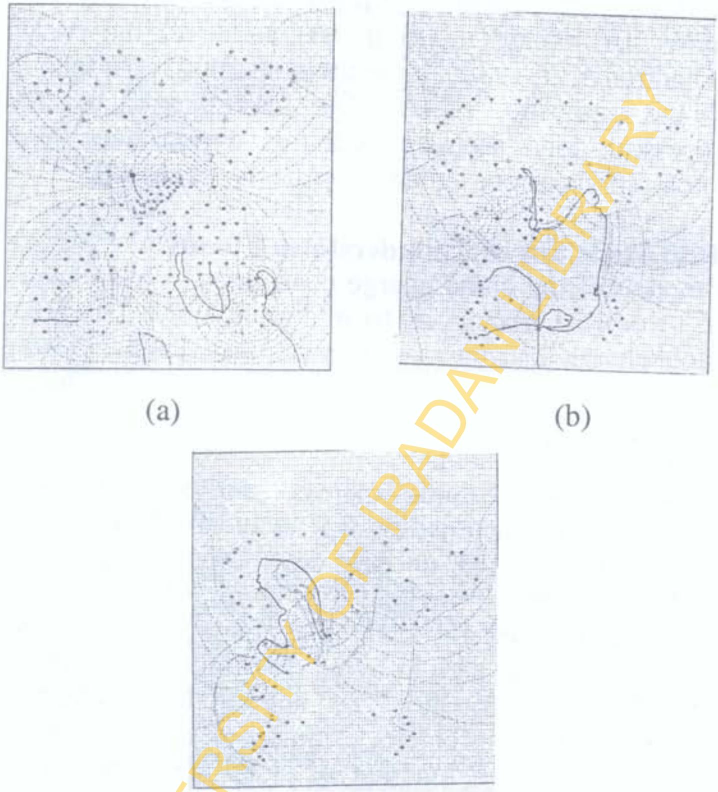
From the data accumulated in the last 28 years, we have found that three consecutive rains during which at least 5 lightning flashes are recorded and for which the time interval is not more than 4 days marks the beginning of the rainy season (Oladiran et al. 1988; Nymphas et al. 2004). We found that with the application of scientific determination of the planting season, food security measures during uncertain climatic con-ditions can be enhanced (Adeniyi et al. 2007).

Theoretical Modelling of Thunderstorm Clouds

Various models of the cloud charge configuration have been proposed—from the monopole, to multipole single charges, to multipole charge distributions. Though, these models have enhanced our knowledge of the bulk bahaviour of the cloud charge, limited knowledge of the microphysics of the cloud electrical behaviour is gained.

Model simulations at Ibadan incorporates various known models and cloud characteristics such as cloud shape, wind shear, charge configuration, up- and down-droughts, and the removal of charge from the cloud by lightning flashes. The only assumption was that the potential gradient at the position of the charge was put at zero to avoid division by zero when solving the Laplace's equation, i.e. solving the Laplace's equation as a singularity problem. Comparison of the number of flashes generated as a function of cloud size was made with experimental values. The agreement was greater than 75%. The variation of conductivity with height increases the flash rates, and combined with a weighted lightning initiation voltage, as earlier described, with pressure gives a closer agreement between observed cloud to ground lightning flash ratio and predicted values.

The current simulations show a marked superiority over the perforated sheared slices proposed by Ette and Olaofe (1982), which need to be modified to incorporate cloud development from single pole layer to multipole layers and to dissipate in the same way (Oladiran 1991). We have been able to simulate more than 90% of all types of observed lightning discharges. Some of these are shown in figure 28a, b & c (Oladiran 1991, 1992).



(a) (b) (c)

Fig. 28: Simulated lightning flashes – (a) Multiple ground flash; (b) Single ground flash with extensive cloud path; and (c) Cloud discharge.

Final Comment

Remember that whatever damage you do to mother earth anywhere in the world will be evenly distributed around the globe.

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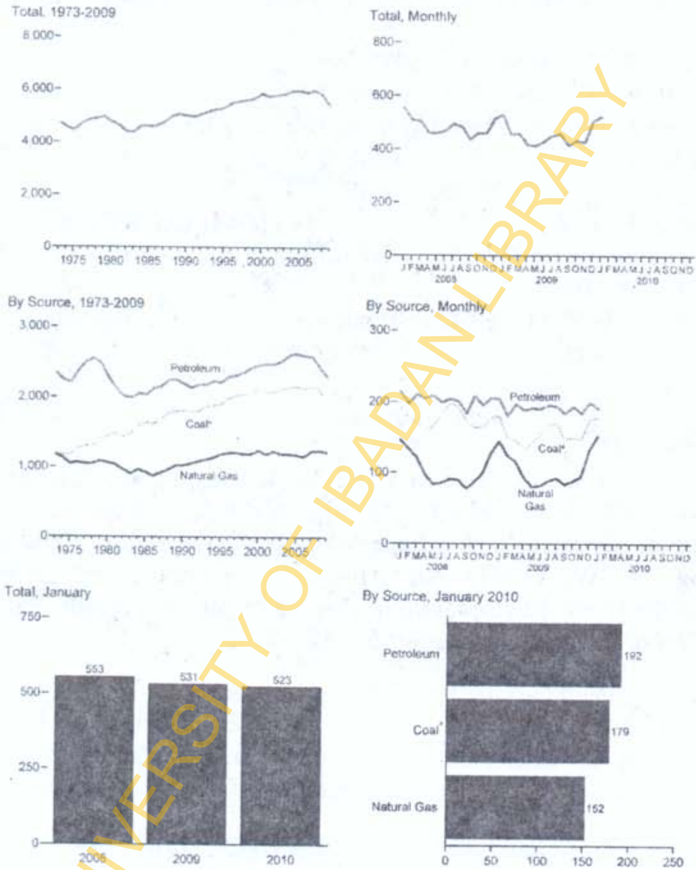
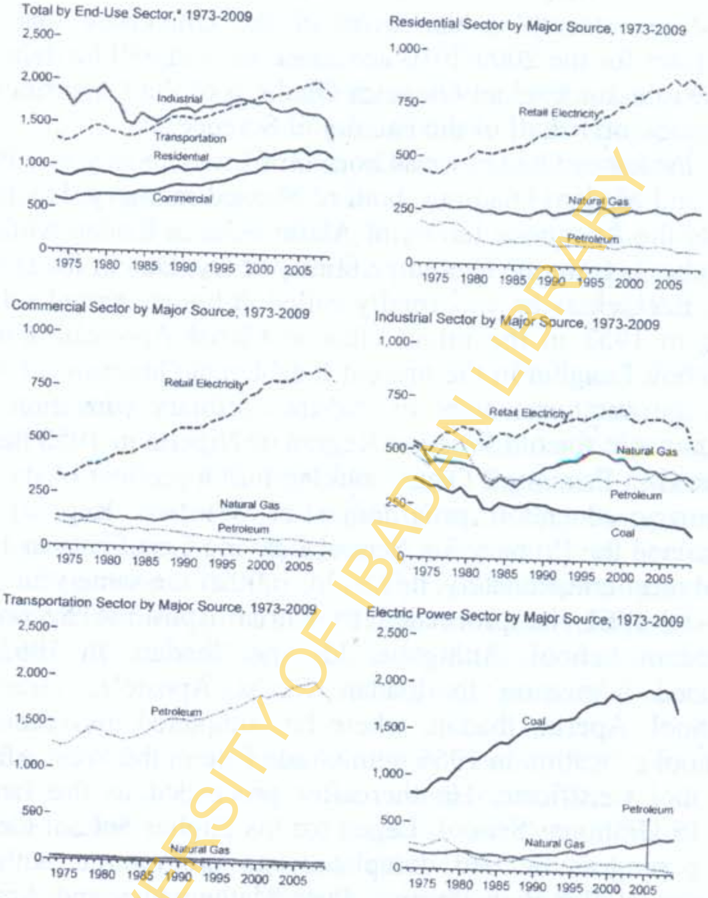
APPENDICES

Appendix 1
Carbon Dioxide Emissions from Energy Consumption by Source (Million Metric Tons of Carbon Dioxide)



Source: U.S. Energy Information Administration

Appendix 2
Carbon Dioxide Emissions from Energy Consumption by Sector (Million Metric Tons of Carbon Dioxide)



Source: U.S. Energy Information Administration

BIODATA OF PROFESSOR EZEKIEL OLUYEMI OLADIRAN

The seventeenth in the series of the University Inaugural lectures for the 2009/2010 academic session will be delivered by Professor Ezekiel Oluyemi Oladiran of the Department of Physics, on behalf of the Faculty of Science.

Professor Oladiran was born on Christmas day in 1949 to Pa and Madam Oladiran, both of blessed memory. His father is of the Abogunde family of Alafara-Oje in Ibadan while his mother is from the Ogundipe family of Oja Oba in Ibadan.

Ezekiel, as he was fondly called at home, started schooling in 1953 in the infant class at Christ Apostolic Church School, Langbin in the present Iddo Local Government Area. At the commencement of the free primary education programme in the old Western Region of Nigeria in 1955 he was placed in Primary 1 (Thus, making him a product of the free primary education programme of Western Region). He obtained the Primary Six School Leaving Certificate in 1960, and most unfortunately, he lost his mother the same year.

In 1961, he proceeded to Christ Apostolic Secondary Modern School, Anlugbua, Idi-Ape, Ibadan. In 1962, he gained admission to Ibadan Christ Apostolic Grammar School, Aperin, Ibadan, where he completed his secondary school education in 1966 with Grade One in the West African School Certificate. He thereafter proceeded to the famous CMS Grammar School, Lagos for his Higher School Certificate programme. He completed the programme with the grades of B,B,B in Physics, Pure Mathematics and Applied Mathematics; and A,A,B at the GCE A/L, London, in the same subjects, respectively.

Ezekiel preferred the University of Ibadan to the University of Ife by forfeiting his deposit at Ife to enter the University of Ibadan in 1969 for the B.Sc. (Hons.) degree course in Physics. A decision he has never regretted. He obtained an honours degree in Physics with Second Class Honours (Upper Division) in 1972.

The University of Ibadan offered him a postgraduate scholarship in 1972. He has ever since remained a native of the University of Ibadan, apart from short periods of travels when on leave. He obtained his Ph.D. in Physics from the University of Ibadan in 1976.

Professor Oladiran joined the services of the University on October 1, 1975 as a Graduate Assistant in the Department of Physics. He rose through all the ranks to become a Professor of Atmospheric Physics on October 1, 1991.

In 1978 he took a study leave to pursue the M.Sc. (Meteorology) degree at the University of Reading, England to broaden his knowledge in Atmospheric Physics and in the particular area of Metrology.

He has so far successfully supervised 9 Ph.D.s, 2 M.Phils and more than 20 M.Sc. candidates. Professor Oladiran has served the University of Ibadan in various capacities: Sub-Dean (Physical), 1987-1989; Director, Equipment Maintenance Centre, 1993-1998; Member, Central Appointment and Promotion Committee, representing the Faculty of Science; Head, Department of Physics, 2005-2008; Served on two Strategic Planning Committees under Professors Kayode and Adesogan; He is currently the faculty of Science representative on the Committee for the Appointment of Emeritus Professors.

He has visited many universities as Visiting Professor and Researcher, amongst which are: International Science Programme, Uppsala University, Uppsala, Sweden (1984-date); National University of Lesotho, 1990-1993, where he helped to establish the Honours Physics degree programme; University of Cape Coast, Ghana, where he also helped to establish the Masters programme in Meteorology and Atmospheric Physics.

He is actively involved in research projects of local, national and international scope and interests. He is currently involved in NIMEX and CARBOAFRICA projects for characterizing regional atmospheric parameters and the carbon dioxide fluxes.

Professor Oladiran has 78 publications to his credit as at June, 2010 (when the last paper came out), consisting of referred journal articles, proceedings, books, chapters in books and reports. He is an internationally recognized scientist both in the academic and administration of Science: Fellow of the Royal Meteorological Society, London (since 1979); He was an Executive Member of the International Commission on Cloud Physics and Precipitation from 1984 to 1992 (representing Africa); Consultant to World Meteorological Organization on Climate Monitoring (CLICOM), from 1984 to date; Member, and at some time Business Manager, and Acting Secretary of the Science Association of Nigeria; Member, Nigerian Institute of Physics; Consulting and Evaluating Sub-Committee Member of the ICCSU Grant Award Committee; Foreign Member, Zimbabwe Standard Organization (Lighting Protection); Foundation Member, Nigerian Meteorological Society; Foundation Member, Nigerian Society for Remote Sensing; He is on the Editorial Board or Associate Editor of 5 Journals.

Professor Oladiran is married to ever-young-looking Dr. (Mrs.) Comfort Oluranti Oladiran and they are blessed with children and grandchildren.