"ENERGY-BUDGET OF THE EARTH-ATMOSPHERE SYSTEM: WHAT ROLE FOR PARTICULATES?"

BY

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1 INTRODUCTION

It is my utmost pleasure to deliver the Second Inaugural Lecture in Physics in this University.

Physics concerns the formulation and study of the laws that govern the working of the Universe. The word "Universe" means everything; ranging from the most tiny sub-nuclear particles (about 0.00001 atomic radius in size) to the largest agglomeration of matter in space, called galaxies (about 150 trillion earth radii).

First, let us take a bird's eye-view of the history of the Universe, the **everything**. Research studies by space and planetary scientists (i.e. astrophysicists, astronomers, geophysicists, geologists and archaeologists) have unfolded to us that we are in an ever-expanding Universe. The beginning of everything is the so-called **Big-Bang**, that horrendous primordial explosion which occurred some 18 billion years ago. The attendant fireball radiated enormous quantities of lethal gamma-rays and X-rays at that time. This suggests that, shortly after the explosion, primordial matter must have been in a state of uniform gas at extremely high temperatures. Continuous expansion of the primordial matter led to gradual rarefaction, cooling and, eventually, to the so-called cosmological critical point ($T = 50K$, $\rho = 3 \times 10^{-33}$ kgm^{-3}) at which gravitational influence of matter became larger than that of radiation. At that point gravitational instabilities, supported by the creation of turbulent eddies with non-uniform density distribution, had facilitated condensation of matter into individual spheres of radius as large as 10^{21}m (or 100,000 light years). These were giant clouds of cool air drifting away from each other. These were the so-called **protogalaxies.** Upon creation, these protogalaxies would spin about randomly-oriented axes, becoming denser and hotter. In the next few hundred million years, the luminous bodies now known as stars had evolved. Kant-Laplace cosmological hypothesis says that the planets were formed from the gaseous ring surrounding the sun. Since this gaseous ring was very massive, gravitational forces acting between different parts of the ring were great enough to cause condensation of the ring material into planets. These original condensation were called **protoplanets**, being much larger than the planets of today. Chemically, they comprised hydrogen and helium with a mere 1% of the terrestrial elements. Shortly upon the birth of the protoplanets, the interstellar dust particles (iron oxides, silicates, etc.) settled towards the central region of the protoplanets, forming solid cores surrounded by hydrogen-helium atmosphere. The process most probably occurred before the sun itself had condensed enough to be hot and luminous. Transformation to the present Sun took millions of years later; after which the radiation pressure of sunlight blew off the hydrogen-helium envelopes of the inner planets, exposing their rocky central cores in the process. This was 4.5 billion years ago.

At that point in time, the inner planets of our solar system (i.e. Mercury, Venus, Earth and Mars) were devoid of atmospheres for a long period of time. Then, how did our Earth, devoid of an atmosphere about 4.5 billion years ago, develop an atmosphere of the type and structure we have today?

2. THE EVOLUTION OF THE ATMOSPHERE

A planetary atmosphere is defined as the envelope of gas surrounding that planet and sustained there by the grativational pull of that planet. About 99 per cent of the Earth's atmosphere lies within the first 90 km from the Earth's surface; its mass being a mere one part in a million of the mass of the earth. It should be mentioned that a planetary atmosphere is not made of gases only, it contains both liquid and solid matter, all suspended within the air mass.

The Earth's atmosphere had evolved over a period of 4.5 billion years, following the formation of the crust. As stated earlier, the initial hydrogen-helium atmosphere of the Earth was blown off during the period of heating. The present one was constituted by effluents from the Earth's interior, that is, by gases such as hydrogen, water vapour, carbon monoxide, carbon dioxide, nitrogen, hydrogen sulphide and hydrogen chloride given off during volcanic activity. Degassing of the Earth is followed by photo dissociation by sunlight and thereafter chemical reactions in which methane (CH_4) and ammonia (NH_3) were formed. Simultaneously, water vapour condensed on CO_2 while hydrogen chloride and ammonia dissolved in it. With its present mean surface temperature of between 280 and 300 K and its gaseous chemical composition, consisting virtually of Nitrogen and Oxygen, the Earth is the only planet of our Solar system that can sustain life. The chemical evolution of the Earth's atmosphere is best illustrated through a cursory look at the build-up process of atmospheric oxygen over time. Oxygen build-up in the atmosphere is of particular interest, partly because of the dependence of the partial pressure of several other atmospheric gases on the partial pressure of oxygen and partly because it is a necessary ingredient in the complete evolution of air-breathing animals.

There are two main mechanisms for the production of oxygen throughout geologic time:

(i) photosynthesis, and
(ii) photodissociation

of water vapour in the upper atmosphere followed by the escape of hydrogen to space, characterized by the reaction:

* $H_2O + 2h\nu \rightarrow 2H + O$

The former is far more effective than the latter. It should be noted that simultaneously with oxygen production processes, the following destruction processes are on:

* O_2 and O_3 oxidation of surface
* Decay and decomposition
* O_2 in H_2O solution.

It is the net balance of the production (pluses) and destruction (minuses) that gives the oxygen growth. The probable course of the growth of the partial pressure of oxygen in the atmosphere over time can be summarized into three stages (Holland, 1964) (Figure 1): Stage I refers to the period lasting from the formation of the Earth's crust, some 4.5 billion years ago (taken at time t = 0, for the purpose of this aspect of our discussion) to about 4 billion years ago.

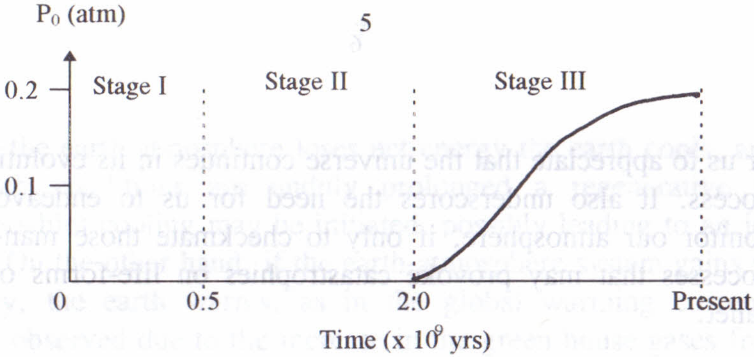


Figure 1. Possible course of oxygen partial pressure in the atmosphere over time (After Holland, 1964).

This period is characterized by, at best, a very tenuous atmosphere made up of methane (CH_4), ammonia (NH_3) and some hydrogen (H) ejected as highly reduced volcanic gases, if these were in existence in the crust and/or upper mantle; otherwise no atmosphere existed (as there would have been no native iron to serve as oxidation buffer).

During Stage II oxidation of the atmosphere is almost completely determined by photosynthesis. It is not definite when photosynthesis began but, in Stage III, oxygen is produced more rapidly than the reduced gases ejected into the atmosphere. Build up of oxygen partial pressure to its present level lasted about 3 billion years: It progressed from the Pre-Cambrian age (about 2.8 billion years ago) when the partial pressure of oxygen was 0.001 of the present atmospheric level (PAL) (Brancazio and Cameron, 1963); through the Silurian period (440 to 400 million years ago) when marine photosynthesis pushed atmospheric oxygen level to 0.1 PAL to sustain the first air-breathing animals; through the ice-age and finally to the recent age (10,000 years to present), the epoch of man's development.

All the aforementioned facts serve to underpin the need for us to appreciate that the universe continues in its evolutionary process. It also underscores the need for us to endeavour to monitor our atmosphere, if only to checkmate those man-made processes that may provoke catastrophies on life-forms on our planet.

3. EARTH-ATMOSPHERE ENERGY: SOURCE, SINK, BALANCE OR LACK OF IT

The primary source of the energy of the earth-atmosphere system is the Sun. This energy is essentially shortwave, being almost equally divided between the ultraviolet and visible, on the one part, and the near infrared, on the other. About 30 per cent of the solar energy arriving at the top of the earth's atmosphere is reflected back to space, the rest being absorbed by the atmosphere, the ocean, ice, land and, indeed, the biosphere. The earth-atmosphere system re-radiates a good portion of the shortwave energy it had intercepted. This re-radiation is in the form of long waves (i.e. mid-infrared and far-infrared waves). In order to avoid abrupt (and undesirable) changes in the biosphere, it is necessary that radiative equilibrium exists in the earth-atmosphere system; this means that the solar energy absorbed from the sun by the earth-atmosphere system over a long period must be balanced by that emitted by that system. In other words, it is desirable to balance the energy-budget of the earth-atmosphere system.

3.1 GREEN HOUSE GASES

In the history of the earth-atmosphere system, a state of perfect radiative balance of the type stated above has not been observed; instead, imbalances have been reported. That is, when the earth-atmosphere loses net energy the earth cools, and, if such conditions are unduly prolonged a regenerative (or irreversible) cooling may be initiated, possibly leading to an ice-age! On the other hand, if the earth-atmosphere system gains net energy, the earth warms, as in the global warming currently being observed due to the increase in the green house gases from anthropogenic sources and valued at about 0.5^{0} C over the last century. The green house gases are, in order of importance:

(i) water vapour,
(ii) carbon dioxide,
(iii) methane,
(iv) sulphate, emitted from burning fossil fuels, and
(v) Ozone.

(a) The Green House

In its modern form a green house is a building with glass sides and roof used for the production of fruits, vegetables, flowers and any other plants that require special conditions of temperature.

The mechanism by which the house functions is that white light (short waves) penetrates through the glass into the green house, thereby supplying radiant energy to the interior of the green house. The constituents of the interior, in turn, reradiate part of the short waves absorbed as long waves (i.e. infrared or heat waves) to which glass is opaque. The heat is therefore trapped in the green house and, unless it is ventilated, the interior of the green house will remain permanently hotter than its outside.

(b) **Green House Effect:** a warming of the Earth's surface and lower atmosphere that tends to intensify with an increase in atmospheric carbon dioxide and other green house gases. The mechanism is as follows: The atmosphere allows a large percentage of the rays of visible light from the sun to reach the Earth's surface and heat it up. A part of the energy is reradiated by the Earth's surface in the form of long wave infrared radiation, much of which is absorbed by the green house gases in the atmosphere and which is reflected back to the surface as heat. This is analogous to the effect produced by the glass panes of a green house described earlier.

The trapping of the infrared radiation causes the Earth's surface and lower atmospheric layers to warm to a higher temperature than would otherwise be the case. Without the green house heating, the Earth's average temperature would be only - 73°C and the oceans would have frozen up.

It should be mentioned, however, that simultaneously, various constituents of the earth and its atmosphere manage to reflect energy back to space, thereby tending to cool the atmosphere, preventing a thermal runaway situation.

Indeed, "thermal runaway" occurs on planet Venus where green house warming is much more than thermal cooling by molecular emission to space; and surface temperatures are as high as 500°C.

On the balance it appears fair to say that while most naturally occurring green house gases tend to behave as global thermostats, regulating the temperature of the earth to within habitable ranges, the human-induced ones tend to destroy the regulating roles of the natural green-house gases, thereby continuously warming the atmosphere.

3.2 THE SUSPENDED PARTICULATE MATTER (SPM) AND THE RADIATIVE TRANSFER

Contemporary alarm over the increase of the green house gases has virtually suppressed the fundamental role of the non-gaseous atmospheric constituents, the suspended particulate matter (SPM), otherwise called aerosol. The atmospheric aerosol is the class of liquid or solid particles with radii between 0.05 and 50 μm dispersed within the atmosphere (See Table 1).

3.3 WHY STUDY AEROSOLS?

Late 1976, a couple of years after I obtained a Ph.D., I got attracted to atmospheric energy budget studies, as a major research field. How did it begin? By chance, I attended the International Radiation Symposium (IRS) in Girmisch-Partenkirchen, Germany in August 1976. The IRS holds once every four years. It is therefore not surprising that it is always a beehive: usually between 400 and 500 scientists from all the continents of the planet Earth attend each Symposium. For being able to attend, I thank the University of Lagos for its policy of actively encouraging young academicians to attend International Conferences. At the IRS-76, I interacted with world leaders in the new field and thence perceived the need not only to understand the structure/morphology as well as pollution effects of atmospheric aerosols but also their interactions with atmospheric gases and electomagnetic radiation to influence climate, vegetation and agricultural processes.

Table 1: The Atmospheric Aerosol

Type	Mechanism of Formation	Source	Portion of the Atmosphere where type is prevalent
Gas-to-particle conversion (GPC)	Formed by chemical reactions of a variety of trace gases.	Anthropogeic: industry, construction processes	Troposphere
Maritime	Evaporation residue of the sea spray	Natural	Troposphere
Mineral dust	Wind erosion of soils of arid and semi-arid regions	Natural: Deserts, continental region	Troposhere
Organic	Biological pollens or spores	Natural	Troposphere
Smoke particles	Forest fires, fires from humid incinerators, domestic fires	Anthropogenic	Troposphere

Following IRS-76, I got linked with such notable scientists as Dr. Vernon Derr, then Head of the Atmospheric Spectroscopy Group of the Wave Propagation Laboratory (WPL), National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado, U.S.A. and Dr. Frederick Volz of the Cambridge Air Force Research Laboratory, Hanscom Fields, Massachussetts, U.S.A. My visits to their laboratories and our long mutual interaction gave great impetus to my very modest efforts in Lagos.

To underscore the importance of this kind of study, we note the following:

(a) Some aerosols (e.g. volcanic dust or ash) are capable of inducing short-period climate perturbation of the order of a few years.
(b) The Scientific community will continue to need reliable and economical global-scale or satellite data for the understanding of global climate systems.

Since a satellite signal consists of an aggregate of (electromagnetic) radiances emanating from the various objects within the solid angle covered by the satellite sensor, the information contained within the signal is only retrievable upon the application of physical/statistical model(s) based on the interaction of energy and matter. These are done through algorithms or computer codes. Data thus retrieved can, in turn, be coupled to general circulation models (GCMs) to simulate the effects of land surface processes on global climate systems. In the process, a few feedback effects may be unfolded. A typical scheme has been recommended by "ISLSCP" 1988. The applicability of algorithms is limited by the underlying assumptions, physics and the approximations relating to the atmospheric correction techniques. The latter (i.e. **the atmospheric corrections**) which involve the **clouds**, **aerosols** and the **mixed gases** can lead to different end-products when different algorithms are used for the same set of desired parameters. In many cases, therefore, a local or **ground based** independent **validation** procedures or an appropriate parameterization may be necessary for specific problems.

Indeed when, in 1983, the United Nations Environment Programme (UNEP) supported by the International Council of Scientific Unions (ICSU), the World Climate Research Programme (WCRP) within the World Meteorological Organization (WMO) sponsored the International Satellite Land Surface Climatology Project (ISLSCP) to develop methologies for deriving quantitative information concerning land-surface climatology variables from satellite observations, the need soon became obvious to have adequate understanding of the physical structure and spatial and temporal variabilities of the atmospheric aerosol.

Specifically, ISLSCP was aimed at accurately evaluating the following radiative transfer parameters from satellite data:

3.3.1. The Surface Radiation and Heat Budget

This is made of two components:

(a) Surface radiation budget, a measure of the radiation absorbed by land surface;
(b) Surface heat budget which provides information on

what proportion of absorbed radiation goes into ground flux.

3.3.2. Insolation

(A substantial part of the incoming solar radiation is absorbed by the atmosphere, heating it up in the process; the rest is either transmitted to land or sea surface or multiply scattered, the scattered radiation being absorbed by the atmosphere or earth and possibly sent back to space).

Insolation, $\phi_s^{\downarrow}$ is the shortwave radiation reaching the ground. It relates to the solar flux $\phi_{s0}^{\downarrow}$ the shortwave absorbed by the atmosphere $\phi_{s,atm}$, radiated back to space $\phi_{s,ref}$ and the surface albedo α as

$$\phi_{s0}^{\downarrow} = \phi_{s,atm} + \phi_{s,ref} + \phi_s^{\downarrow}(1 - \alpha)$$

or

$$\phi_s^{\downarrow} = \phi_{s0}^{\downarrow} - (\phi_{s,atm} + \phi_{s,ref}) / (1 - \alpha)$$

$$= \phi_{sb} + \phi_{sd}$$

3.3.3. Albedo α

The albedo α, of a surface is the ratio of the radiation reflected by a surface to that incident on it. That is,

$$\alpha = \phi_s^{\uparrow} / \phi_s^{\downarrow}$$

so that

$$\phi_{s,net} = \phi_s^{\downarrow} (1 - \alpha)$$

$$= \phi_s^{\downarrow} - \phi_s^{\uparrow}$$

Of great importance is Planetary albedo: the integrated albedo of the land, ocean and the biosphere for the earth's surface.

3.3.4. Upward Longwave Flux and Surface Temperature

The first part is also termed the Outward Longwave Radiation (OLR). Radiation at the top of the atmosphere (TOA) is given by

$$\phi_{L,TOA} = \phi_L - \phi_{L,atm} + \phi_{L,e}^{\uparrow}$$

where

$\phi_L^{\uparrow}$ = Longwave upward flux from the surface

$\phi_{L,am}$ = amount of $\phi_L^{\uparrow}$ absorbed by the atmosphere

$\phi_{L,e}^{\uparrow}$ = contribution of OLR emitted by the atmosphere

Land surface temperature T_{sg} is got from the expression which incorporates Stefan's law:

$$\phi_L = \varepsilon\sigma T_{sg} + (1-\alpha)\phi_{Le}^{\downarrow}$$

or

$$T_{sg} = \sqrt[4]{\frac{\phi_L^{\uparrow} - (1-\varepsilon)\phi_{L,e}^{\downarrow}}{(1-\alpha)}}.$$

where

ε = emissivity
σ = Stefan-Boltzmann constant
$\phi_{L,e}^{\downarrow}$ = downward (counter radiation) longwave flux.

3.3.5 Downward Longwave Flux

The longwave radiation emitted towards the surface by the atmosphere

$$\phi_L^{\downarrow} = f(T(p), q(p))$$

where

$T(p), q(p)$ = profiles of temperature T and water vapour mixing ratio q in the atmosphere as functions of pressure p.

Since the absorptance of the land surface is near unity practically all of ϕ_L is obtained from satellite soundings.

3.3.6 Net Radiation

$$R_n = \phi_s^{\downarrow} - \phi_L + \phi_{Le}^{\downarrow}$$
$$= \phi_{s,net} + \phi_{L,net}$$

where

$$\phi_{L,net} = \varepsilon \phi_{Le}^{\downarrow} - \phi_L^{\uparrow}$$

3.5 EL NINO/SOUTHERN OSCILLATION (ENSO)

Any discussion on the earth-atmosphere energy balance or atmospheric heating rates will be incomplete without mention of an important regional climate phenomenon which provokes global-scale responses, the ENSO. This is because the climatic effects of the EL NINO/Southern Oscillation (ENSO) are contemporaneous with those of the green house gases and the particulates, making it difficult to unambiguously associate cause and effect in relation to globally observed climate changes.

3.5.1 EL NINO

Occasionally, a Peru current sweeps northward along South American Coast from Southern Chile towards the equator. In certain years (1891, 1941, 1957-58, 1982-83, 1986-87, 1997) there has been a general weakening of atmospheric circulation and the usually strong South-East Trade Winds off the West Coast of South America have faded. This has been accompanied by movement of the cold Peru Current westward, away from the land. These were first reported in the mid nineteenth century but it is only recently that Oceanographers discovered that the low sea surface temperature along the Peruvian coast arose from the "upwelling" of cold water from below the surface.

The westward movement of the cold Peru Current is accompanied by a halt of the upwelling of the cold water along the shore. These conditions have allowed a stream of Pacific Equitorial counter current, usually from the Gulf of Panama to latitude 2^{o} - 3^{o} S (i.e. in the area of Guayaquil, Ecuador (2^{o} 10' S) to continue down the coast as far as latitude 14^{o} S (i.e. South of Lima Peru (12^{o} 03' S). As this warm highly saline water arrived around Christmas season, it was named "Currente del Nino" by the local fisherman who first observed it. It was observed by residents that the annual ocean warming was variable in effect, being intensely so every few years. Over time, the current was simply termed EL NINO the child'. A remarkable ecological consequence of the El Nino is that it either kills or drives the anchovies deep beneath the surface or swept far off-shore. This then provokes a scarcity of the school of fish which normally thrive in cold waters. As the anchovies disappear a disaster comes in the wakes: the birds and tuna which are predators of the small fish either die or begin to leave. It is so serious that the gas from the decaying fish and birds can blacken the paint on ships passing by.

The commencement of the El Nino is marked by torre ıtial rains on the normally arid South American Coast, with attendant floods and immense soil erosion of the unvegetated surfaces.

3.5.2 THE SOUTHERN OSCILLATION

It has been established that the oceans and the atmosphere are coupled dynamically. For instance, changes in surface winds affect Sea Surface Temperature, SST, (Wyrtki, 1975) while wind variations are a manifestation of atmospheric responses to changes in SST (Rasmusson and Carpenter, 1982). Changes can be "triggered" by westernly wind bursts over the western Pacific or by a host of ocean waves that are superposed, causing an atmospheric instability. If the system is sufficiently unstable an atmospheric oscillation may be generated and sustained over a considerable period.

It has been confirmed that the tropical Pacific sea surface temperature (SST) variations were ultimately coupled to a global pattern of climate anomalies discovered by Sir Gilbert Walker early in this century. A feature of this oscillation is a see-saw pattern of atmospheric surface pressure between the Indian Ocean and Central Pacific. The linking of the coastal warming near Peru with the much larger scale warmings over the equatorial Pacific and the linking of tropical Pacific sea surface temperature variation to Walker's Southern Oscillation meant that the coastal warmings were simply one regional aspect of a much larger climate involving both atmosphere and ocean (WMO, 1995). This global pattern of variability is called El Nino/Southern Oscillation (ENSO) cycle. El Nino refers to the warm phase of ENSO while La Nina (meaning "little girl") is the cold phase of ENSO. The interannual variabilities have periods of between a few months and some 3 years.

As a result of the global-scale responses to tropical Pacific sea surface temperature anomalies, we have such recorded ENSO-related phenomena in other parts of the world, the so-called ENSO Teleconnection, e.g. (a) ENSO-like events in Tropical Atlantic (Alexander et al 1992) such as the North Atlantic Oscillation (NOA), and (b) ENSO-Monzoon linkages (Verma, 1991).

4. SOME HIGHLIGHTS OF THE RADIATIVE TRANSFER STUDIES DONE IN LAGOS

At the outset, I faced the bane of most experimental sciences in the third World - unavailability of primary data. This bug pervades all aspects of the atmospheric sciences.

I then pioneered in Nigeria multispectral data on atmospheric turbidity (Oluwafemi 1978, 1979, 1980) leading to the first set of results on the annual variations of such primary data as the aerosol optical depth, the Angstrom wavelength exponent α , the background aerosol extinction coefficient and precipitable water.

In (Oluwafemi, 1981), we reported a modest advance when, with the cooperation of the helicopter crew of the Nigerian Air Force, we obtained the first, in West Africa, of experimentally measured profiles of three crucial parameters in the Earth's planetary boundary layer (i.e. within the first 1 kilometer of the Earth's atmosphere). Squadron Leader Law Uvem Iyoho kindly piloted the air-craft for all the sets of cruises (Figure 2).

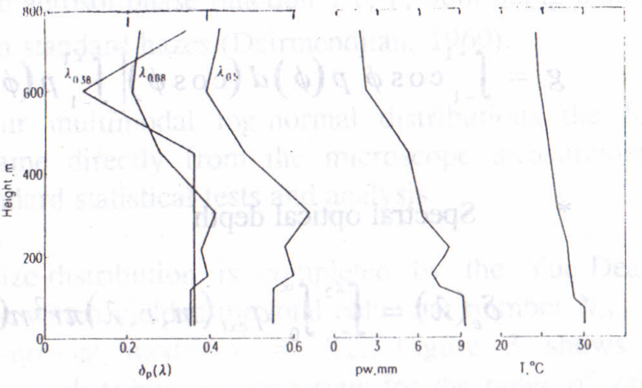


Figure 2
Height variations of aerosol optical depths, $\delta_p(\lambda)$, at 0.38, 0.5 and 0.88 μm, precipitable water and temperature for the helicopter flight of 13 February 1979. Time: 0950–1047 (GMT + 1). Relative humidities 63–70%.

Filter samples of particulates collected both on ground and aloft were processed with optical and electron microscopes for size counts.

In the determination of almost every radiative property of the atmospheric aerosol, the size distribution n(r) is a fundamental feature. For example, in the following key radiative quantities n(r) features:

* The spectral extinction coefficient

$$\sigma_e(\lambda) = \int_0^{\alpha} Q_{ext(m,r,\lambda)} \pi \; r^2 n(r) dr$$

* The aerosol scattering phase function

$$p(\varphi) = \frac{4\pi}{\sigma_{sc}} \int_0^{\infty} n(r) \sigma_j(r,\varphi) dr$$

* Asymmetry factor

$$g = \int_{-1}^{+1} \cos\phi \; p(\phi) d(\cos\phi) \left[\int_{-1}^{+1} p(\phi) d(\cos\phi) \right]^{-1}$$

* Spectral optical depth

$$\delta_e(\lambda) = \int_{z_1}^{z_2} \int_0^{\infty} q_{ext}(m,r,\lambda) \pi r^2 n(r) dr \, dz$$

Yet *n(r)* is about the most involving parameter to measure experimentally. Theoretically, in the retrieval of particulate size distribution from multispectral irradiance measurements, one needs invert the Fredholm integral of the first kind

$$g(\lambda) = \int_{r_1}^{r_2} k(r,\lambda) n(r) dr$$

which, by quadratures (Twomey, 1976), yields

$$n = (A^* A)^{-1} A^* g$$

A complete numerical inversion proc edure for size distribution from multispectral transmittance data must give the

* "form-parameter" and
* total number.

Underlying this is the need for proper representation of the extinction efficiency parameter $Q(m,r,\lambda)$ which is somewhat sensitive to the complex index of refraction

$$m = n - in'$$

where n , n' are respectively, the real and imaginary components of the refractive index. The latter is obtained from a careful combination of the raw experimental fractional distribution and the normalized aerosol phase function $P(\varphi)$; both being matched with data from standard hazes (Deirmendjian, 1969).

For our multimodal log-normal distributions the form parameters came directly from the microscope measurements, following standard statistical tests and analysis.

The size-distribution is completed by the Yue-Deapak (1983) scheme which yielded the total columnar number $N_{cT,i}$ for the two log-normal modes $i = 1,2$. Figure 3 shows the experimental size distribution appropriate for the range of values of the imaginary component of the complex index of refraction. Thereafter, it became possible to produce our first of regional models of atmospheric heating rates epresentative of the land masses immediately around the Gulf of Guinea and extending up to about the Southern Sahel. These models refer the middle to the far infrared region of the electromagnetic spectrum. Table 2b refers to the reduced data, from one model for the atmospheric surface layer.

hr^{-1} under severe harmattan; and

* the radiative effect of the dust is to reduce the normal evaporative cooling in the air by up to 18% (near the coast) and 16% to the North (South of the Sahel).

A more ambitious model of atmospheric heating rate (also for the middle to the far infrared) is typified in Oluwafemi (1996) where the major result is as given in Figure 4. Here, we notice a warming close to the earth's surface and a cooling aloft. From a term-by-term analysis of a form of the radiative transfer equation:

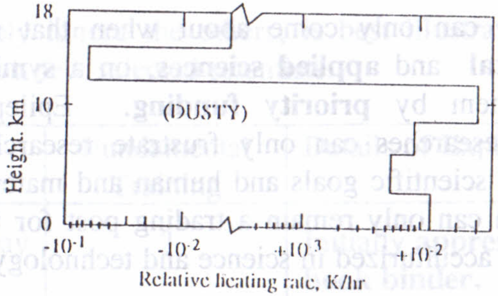
$$\Delta F = [(F\downarrow(z+\Delta z) - F\uparrow(z+\Delta z)) - (F\downarrow(z) - F\uparrow(z))]$$

where

$$F\downarrow(z) = 4\sigma\int_{T(z_1)}^{T(z_2)} \overline{A}\{u(T') - u[T(z)], T'\}T'^3 dT' + 4\sigma\int_0^{T(z)} \overline{A}\{u(T(z_1) - u[T(z)], T'\}T'^3 dT'$$

$$F\uparrow(z) = 4\sigma\int_{T(z_1)}^{T(z_2)} \overline{A}\{u(T') - u[T(z)], T'\}T'^3 dT' + \varepsilon T^4(z_1)\overline{A}\{u[T(z_1)] - u[T(z), T(z_1)\}$$

for a two-stream flux model, it was deduced that the observed warming is traceable to the downwelling thermal emissions of the particles which have peak concentrations around the 700 mb (~3.5km) level. The pattern of our modelled atmospheric heating rates agrees largely with the independent work of Carlson and Benjamin (1980).



Estimates of relative (Dusty minus dust free) longwave heating in the Harmattan

Figure 4

5. WHAT LESSONS TO LEARN?

1. That two of the publications generated from these researches, viz, Atmos. Environ. 13, 1611-1615 (1979) and AJST Series B 1-4, 1996, were lead (or star) articles in these two journals gave the work tacit international recognition.

But the object lesson is that the fruits of science are prone to unfeterred access; they are available to everyone, irrespective of colour, creed or race. Any scientist need only apply himself and consistently obey the universal rules underlying his chosen scientific career. Mr. Vice-Chancellor, in this regard my humble counsel to budding academicians based in the less developed world like our own is that it is intellectually rewarding to cultivate the habit of competing for journal spaces with other workers located in the developed parts of the world. This is *sine quo non* for proper academic growth and development.

2. In the modern setting, economic and industrial progress of any nation can only come about when that nation embraces **fundamental** and **applied sciences**, on a **symbiotic basis** and nurtures them by **priority funding**. Epileptic funding of scientific researches can only frustrate researchers, leading to unachieved scientific goals and human and material waste. Any such nation can only remain a trading post for the nations that are already acculturized in science and technology.

3. Building a science culture is a slow and painful process. Therefore, at the individual level, any pioneering effort requires absolute dedication and tenacity if expectations are to be realized. (For example, accumulating primary regional data as precursors for modest regional climate models took the first eight years of my unceasing efforts).

At the National level, it is wise not to expect immediate large-scale practical rewards from investments in fundamental science research. Yet, no technological breakthrough can come about without resort to fundamental scientific investigations.

4. No aspect of knowledge is an island onto itself. We illustrate this with a few instances.

(a) This lecture, willy-nilly, involved not only Physics and the complimentary dose of Mathematics, but also contained smatterings of astrophysics, geology, geography, archeology, chemistry, meteorology, oceanography, ecology, computer science/numerical methods and, necessarily, history.

(b) That different aspects of knowledge are always criss crossing one another and that any aspect cannot completely ignore the others, is best illustrated with the career of a few selected scientists:

Scientist	Fundamental Training	Details of Exploits
Michael Faraday British (1791–1867)	?	Initially **apprentice to a book binder.** Attended informal **lectures** by Humphry Davy, the **famous Chemist**. Later he was appointed laboratory assistant to Davy at the Royal Institution; and ultimately succeeded Davy as Director of the laboratory. Switched interest to electricity and magnetism. His systematic experimental (no mathematics) investigation led to his **discovery of electromagnetic induction.**
Karl Friedrich Gauss. German (1777 - 1855)	Mathematician, Physicist and Astronomer	**One of the greatest mathematicians** of all time; most remarkable for his work in modern times; renowned for performing enormously complicated calculations, without using computers. Briefly, he was

		interested in **geodetic survey**. Later became interested in electric and magnetic phenomena, leading eventually to the **invention of the electric telegraph.**
Sir Earnest Rutherford, British. (1871-1937)	Experimental Physics	He founded nuclear physics with the discoveries of the nuclear transmutation of the elements by radioactive decay; produced the first artificial nuclear reaction. Received the **Nobel Prize** in **Chemistry** in 1908.
Marie S. Curie, Polish. (1867-1934)	Experimental Physics	Shared the **1903 Nobel Prize in Physics** with her husband, Pierre Curie, French (a Chemist) and Henry Becquerel. Received a second **Nobel Prize in Chemistry** later.
Rosalyn S. Yalow, American.	Nuclear Physics	A full-fledged Physicist, having obtained a Ph.D. in Nuclear Physics in 1945 from the University of Illinois. Two years after her Ph.D. she went into Medical Physics, almost fortuitously. She

		eventually pioneered the development of radio-immunoassay and received the 1977 **Nobel Prize in Medicine**. Explaining the success behind her revolutionary contribution to medical sciences, she wrote: "A multidisciplinary approach is necessary to weave the tools and concepts of physics into medicine. Maximal effectiveness is achieved only when each member of an interdisciplinary team makes a commitment to at least on-the-job training in the discipline of the other(s). I was fortunate to be joined in my work by a very talented physician, Solomon Berson. I learned medicine and he showed a remarkable talent in physics and mathematics. We **learned to talk the same hybrid language** - a major factor in our success as a research team".

Today, radioimmunoassay is a potent tool in the following biological investigations and clinical medicine:

(i) the measurement of hundreds of substances of biological interest - peptide hormones, steroid hormones, thyroid hormones, drugs, viruses, bacterial antigens etc.

(ii) a particularly significant application is in diabetes and the mass screening of underactivity of the thyroid of the new born. If untreated, the ailment is reported to manifest in irreversible mental retardation.

(d) Two bombs were detonated in Japan during the Second World War. They are offshoots of the celebrated Manhattan Project. But like all apparently evil things, there are some remote benefits; the "fall out of the Manhattan Project were nuclear medicine and the nuclear power.

(e) Similarly, the fall out of the Radiation Laboratory at MIT was radar.

(f) The German Physicist, Wilhelm Konrald Rontgen (1845 - 1923) discovered the X-rays in 1895 (for which he received the first Physics Nobel Prize in 1901). Within the last three decades, that medical diagnostic tool had gradually been upgraded to the new technique called "computerized tomography", also described as "computerized axial tomography", "transaxial tomography" and "reconstruction film projection". In it "a source and detector moving around the patient yield data that, processed by a computer, makes visible a two-dimensional slice of the living human body - at 2-millimeter recollection" - another indispensable medical tool.

The object lesson in all these is that an individual scientist can only chip at the body of knowledge: the more one studies the more one realizes how little one can know. Therefore **every scientist must be open-minded and humble.**

I should emphasize the intellectual beauty of humility with the carriage of one of the most remarkable minds that ever lived on planet Earth, Albert Einstein (1879-1955), the Jew, Swiss, German and American, all rolled in one. He was probably most known for his works on Special Relativity and General Relativity. But he made fundamental contributions in other branches of Physics. For example, in a review during the Einstein centennial, another accomplished physicist, Emil Wolf (1979), chronicled Einstein's exploits in the study of the nature of radiation and wave-particle duality and summarized as follows:

> "Thus the structure that Einstein built with his 1905 "photoelectric paper", his 1909 paper containing the first clear evidence for the wave-particle duality, his 1917 paper on elementary processes of interaction between molecules and radiation, and his 1924 and 1925 papers on the quantum theory of an ideal gas did not only elucidate the nature of light and radiation in general but also proved to

> be of fundamental importance to the formulation of wave mechanics."

Remarkably, and in characteristic humility and maturity, Einstein had down-played his own contributions in a comment he made four years to his death:

> "All the fifty years of conscious brooding have brought me no closer to the answer to the question, `what are light quanta?' Of course today, every rascal thinks he knows the answer, but he is deluding himself"
>
> Albert Einstein, 1951.

6. EPILOGUE

Mr. Vice-Chancellor, I thank God for sparing my life to see this day. Throughout my life, I have enjoyed the grace of God. This special grace has also put me in contact with several mortals, too numerous to mention here. I thank God for all of them.

I must not forget to mention the policy of your administration that has given concrete encouragement to indebted Professors to give their Inaugural Lectures. In these trying times, the bottom line is clear.

Mr. Vice-Chancellor, distinguished ladies and gentlemen, let me end this lecture by sharing with you a Bible quotation, the import of which was once unfolded to me by my academic mentor, Professor A.I.I. Ette, a most distinguished retired Professor of Physics and one-time President of the Nigerian Academy of Science. It is the expression of fulfilment by Simeon the righteous, Luke 2^{29-31}, who, upon the presentation of baby Jesus Christ to the Lord according to the Jewish Law rejoiced:

> "Lord, now lettest thou thy servant
> depart in peace,
> according to thy word;
> for mine eyes have seen thy salvation
> which thou hast prepared in the
> presence of all peoples"

Mr Vice-Chancellor, I came to the University of Lagos, I saw, and I have been fulfilled.

Thank you and God Bless.

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