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Empirical Determination of the Effect of Rainfall on Radio Communication (The Case of the Aviation Industry) in Nigeria

Eke J.[1], Ohaneme C.O.[2], Onoh G.N.[1]

Department of Electrical/Electronic Engineering, Enugu State University of Science and Technology, Enugu, Enugu State, Nigeria[1]

Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria[2]

ABSTRACT*:* Despite the presence and use of modern aviation equipment and instrumentation, there are still regular occurrences of air wish ups with very grave consequences. Often this has been attributed not only to equipment failures but to the inability of the operators to read or understood the role of nature in air navigation. These natural effects are the cloud cover, rainfall (both the volume and rate) as well as temperature. This paper uses empirical information of some of these meteorological conditions on radar signal reception to predict weather conditions. The work was carried out at Akanu Ibiam International Airport situated in Enugu, one of the old regional capitals of Nigeria, Enugu (6.42^{o}N, 7.61^{o}E). This was because of its strategic position and weather variations. It is neither of the heavy rainfall area nor of the hot dry zone of the country. It also has some hills around it which gave its name, Enugu, meaning on top of a hill. Using simple model, it was found that as the rainfall rate ($\mathbf{R_f}$) increased the value of the return power $\mathbf{P_r}$ is only significantly noticeable at higher frequencies of 30GHz and above but for lower $\mathbf{R_f}$ the backscatter echo signal $\mathbf{P_r}$ is negligibly small irrespective of the values of the frequency. The results show that for communication in Enugu, radar frequency of between 10 and 30 GHz are recommended.

KEYWORDS: Meteorological conditions, radar, attenuation, target, echo signal rainfall rate, cloud cover, backscatter.

I. INTRODUCTION

With the global breakdown of the banking industry some years past, each nation has sought for ways of boosting her economy. They have done this by trying to diversify their economic base. Increase in agricultural yields, industrial outputs, mineral mining etc have received budgetary allocations. While in the developed economies where these are yielding positive results, the developing nations have looked inwards and have included tourism as a serious source of economic growth. This is why many international airports are springing up in these countries.

In Nigeria, approval has been given for about four new international airports to be built. These are either upgraded or new ones built. While the Ibom airport at Uyo, Akwa Ibom State has been completed, the ones at Katsina and Asaba are at various levels of completion. The Akanu Ibiam International Airport at Enugu, the capital of the old eastern region of Nigeria is being upgraded from local to international status. One very important factor which will facilitate the use of these airports is the safety of the planes. A few years past, the available records show that the performance of aviation industry in Nigeria has been negative. This must not have been unconnected to the adverse effect of weather conditions especially rainfall on the poor visibility of airplane during rainy seasons. This study equally shows that improving the visibility of the airbus will in no small measure encourage the use of our airports in Nigeria, thereby enhancing the economic base of the nation through tourism. However in the last few months the international airports in the country has received the USA Grade A status. It is therefore important that this status be maintained. One way to do this is to ensure that the planes are well monitored and directed accordingly, hence the present work. Therefore, this work x-rays the effect of rainfall on the safety of lives and properties of Nigeria aviation industry using Akanu Ibiam International Airport Enugu, South-East Nigeria as a case study.

Nigeria has two main climate seasons – the rainy and the dry seasons. The harmattan period though very pronounced especially in the Northern part of the country occurs with the dry season. The rainy season occurs from March to September while October to February is the dry season with harmattan occurring in December and January. These

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periods however vary from region to region. This paper uses Enugu as the case study. Enugu is presently the capital of Enugu State and equally served as capital of the defunct old Eastern Region of Nigeria. It is situated approximately at 6.42^{o}N latitude and 7.61^{o}E longitude. The mean temperature range of Enugu in rainy season is between 26^{o}C and 31^{o}C, dry season between 29^{o}C and 32^{o}C, and harmattan season between 24^{o}C and 25^{o}C.

The role of the RADAR in guiding planes cannot be overemphasized. Radar as an acronym for Radio Detection and Ranging uses radio waves which is part of the electromagnetic radiation.

Radio waves can be made to carry information by varying a combination of the amplitude, frequency and phase of the wave within a frequency band. As an electromagnetic radiation, when it impinges upon a conductor, it couples to the conductor, travels along it and induces an electric current on the surface of that conductor by exciting the electrons of the conducting material.

Radio waves use atmosphere for their transmission especially through troposphere, stratosphere, mesosphere and ionosphere. Fig. 1 shows the nature of the atmospheric layers.

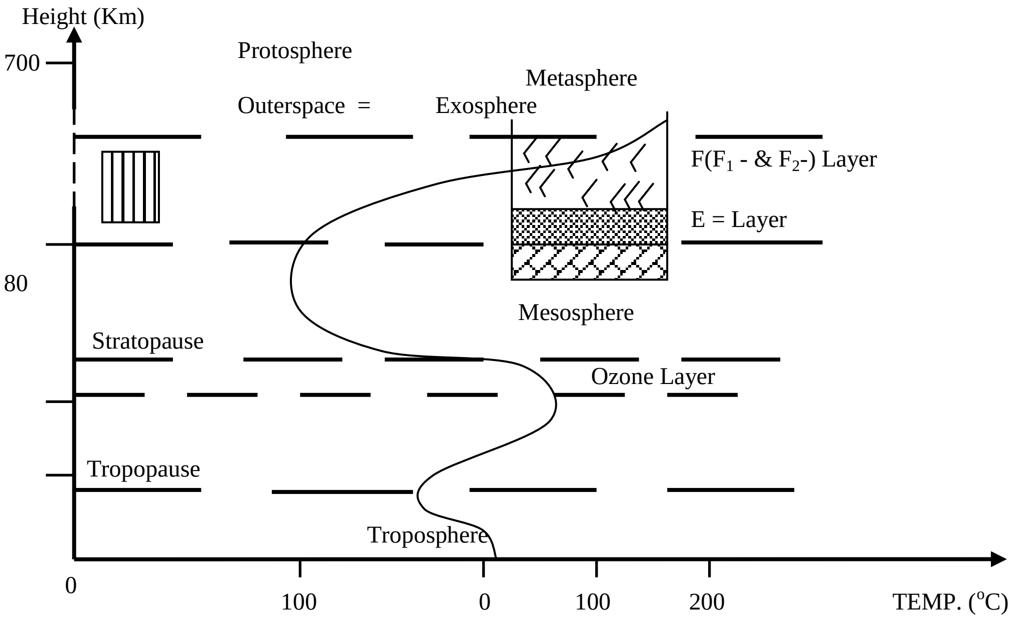

Fig. 1: The atmosphere layers

II. SYSTEM MODELS FOR RADIO WAVES (RADAR) PROPAGATION

The earth's surface and the medium (atmosphere) in which radio-waves propagate can significantly affect the behaviour of radio (electromagnetic) signals. This is because the atmosphere is made up of gases, water vapour e.t.c, whose structures vary according to the solar activities and these affect the prevailing meteorological conditions. Equally affecting the meteorological condition is pollution due to emissions of gases. The atmospheric gases plus other pollutants which exhibit different refractive indices give rise to variety of phenomena such as refractions, reflection, scattering, absorption, ducting and fading of radio signals. This is because as the radio-waves transverse the atmosphere, they suffer amplitude and phase distortions which vary with the frequency of signal and the atmospheric refractive indices of the medium encountered. Attenuation due to rain is an important factor in communication system design and has been proved by [1] and [2], to be not only a strong function of frequency but also of the microphysical structures of the rain. Rain also affects radar signal due to its scattering actions. The scattering could be forward-or backward-scattering. The history of radio scattering from turbulence induced refractive index fluctuation has been discussed by [3].

The principle of operation of radar system is such that an electromagnetic wave at a given frequency generated from a transmitter is sent out in form of pulses for pulsed modulation radar. This signal is intercepted by the target, sent back either by scattering or reflection to the transmitting antenna. Information such as the transmitter-to-target and target-to-receiver distance (location of target), size and shape of target and radar reflectivity can be obtained; while the speed of

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target can be obtained by observing the Doppler frequency shift between transmitted and received waves. In monostatic radar, the time delay, T_d, or propagation delay of the received energy relative to that transmitted is given as:

$$T_d = \frac{2R}{C} \quad (1)$$

where C is the speed of electromagnetic wave (m/s), and R is the radar range (m)

The return power density of echo signal as given by [4] is

$$P_r = \frac{PG^2\lambda^2\delta}{(4\pi)^3 R^4} \quad (2)$$

where G is the gain of antenna, λ is the wavelength of radar signal, δ is the cross sectional area of target.

There is a relationship between the average power, P_{av}, the peak power, P_t, and duty cycle, τ/T_p, of the radar system given by [5] as

$$P_{av} = \frac{P_t\tau}{T_p} \quad (3)$$

where τ is the pulse width, T_p is pulse repetition period, f_p is the pulse repetition frequency and τ/T_p is the duty cycle which is also equal to τf_p. Therefore, Eq.(3) now becomes

$$P_{av} = P_t\tau f_p \quad (4)$$

Also, the work of [5] has shown that

$$G = \frac{\pi^2}{\theta_B \emptyset_B} \quad (5)$$

where θ_B is the vertical beamwidth and $\emptyset_B$ is the horizontal beamwidth. For Reyleigh scattering region, the radar cross-sectional area δ can be written as.

$$\delta = \frac{\pi^5 D^6 |k|^2}{\lambda} \quad (6)$$

where $|k^2| = \frac{\in -1}{\in +2}$, ∈ is the dielectric constant of the scattering particles and D is the scattering particles' diameter.

For rain scattering,

$$D = aR_f{}^b \quad (7)$$

where R_f(mm/h) is the rainfall rate, a and b are empirical constants that depend on the type of rain.

As it will be obvious, rain will cause attenuation of radar signals which will vary according to the frequencies and rain drop size distributions. According to classical theory, as a wave propagates through a medium in the x direction, the transmitted intensity is given by this Lambert law [5] as

$$I = I_o exp^{mx} \quad (8)$$

where I and I_o are the wave intensity at x and $x = 0$ respectively, m is the total cross sectional area per unit volume which is related to the attenuation. According to [6], for a wave passing through a rain medium of thickness 1km, the attenuation, A, is given as

$$A(dB/km) = 4.343N\theta^3 \times \partial i(r)n(r)dr \quad (9)$$

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where N is the radio refractivity, θ is the beamwidth in m , δ_i is the radar cross sectional area in m^2, r is the rainfall rate in *mm/h*, n is the refractive index of rain, and d_r is the rain drop diameter.

III. EXPERIMENTAL DETAILS AND ASSUMPTIONS

The observation of cloud and the estimation or measurement of its thickness and height of their bases above the earth's surface are important for many purposes, especially in aviation and other operational applications of meteorology. The meteorological data obtained is based on experimental weather observations carried out in 2004, 2005 and 2006 from the Meteorological Service, Federal Ministry of Aviation, Akanu Ibiam International Airport Enugu, Nigeria. Instruments used are rainguage: used for measuring the average amount of rainfall at a particular place/area; thermometer- used for measuring the temperature of an area/environment; and sight observations used to observe the intensity of the cloud cover. The meteorological data collated from the experiments are:

(a) Samples of rainfall per hour on three occasions for each of the year under study.

(b) The rainfall rates (mm/h) for the period.

(c) Cloud cover (oktas or eights)

(d) Temperature (^oC)

The mean temperature for each year is obtained from the temperature reading for the number of days that make up each month of the year using thermometer. Also, the amount of the rainfall is measured using raiguage. Besides, the amount of cloud cover was by mere observation as the instrument such as ceilometers or cloud mirror was unavailable to be used by the meteorological monitoring personal in the airport.

Assumptions

It is assumed that stratiform type of rain exists in Enugu because Enugu experiences conventional and stratiform pattern of rainfall, and also because of easy evaluation of the experimental results. With these assumptions, the radar reflectivity factor, Z, due to stratiform rainfall [6] is

$$Z = 200{R_f}^{1.6} \qquad (10)$$

where R_f is the rainfall rate. It has been established that the meteorological (rain) return signal or echo is derivable from the basic radar equation given as

$$P_r = \frac{P_t G \lambda C_t}{1024(In2)R^2} \sum_I \partial_t \qquad (11)$$

where $\sum_I \partial_t = \eta = \frac{\pi^5 D^6}{\lambda^4} |K|^2 = \frac{\pi^5}{\lambda^4} \left|\frac{\epsilon - 1}{\epsilon + 2}\right| Z$ (12)

Hence, $Z = \sum_t D^6 = 200{R_f}^{1.6}$, for stratiform rainfall.

$|K|^2$ varies with temperature and frequency. However, the characteristic relationship between the complex refractive index, ϵ, and the frequency at temperature of 25^0C has been shown by [7]. For wavelength of 10.48cm (2.86GHz) at temperature of 25^0C, the complex refractive index is $\epsilon = \epsilon_r + \epsilon_j = 90 - 7j$ which is 89.7. Table 2 shows that its yearly mean temperature is about 25.84%. Table 2 also shows a gradual increase in average temperature due to the so called global warming.

Equations 13 and 14 are based on the basic radar equation to calculate the back-scatter echo signal, P_r, and rain attenuation, A, under the influence of meteorological clutter which include

$$P_r = 32.06 \times 10^6 \left(7.33 f^4 R_f^{1.6} \times 10^{-12}\right) watts \qquad (13)$$

$$A(dB/km) = 4.343 \times 10^3 \times 7.33 f^4 R_f^{1.6} \qquad (14)$$

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IV. METEOROLOGICAL DATA PRESENTATION AND ANALYSIS

Table 1 shows the rainfall rates for 2004, 2005 and 2006 while Tables 2 and 3 show the mean temperature and amount of cloud cover and temperature for the same period. The cloud cover is measured in oktas (eights) as used in meteorology to show the amount of cloud cover in geographical area or environment.

Table 1: Amount of Rainfall per hour and Rainfall Rate for 2004, 2005 and 2006

Amount of rainfall per hour and rainfall rate for 2004					Amount of rainfall per hour and rainfall rate for 2005				Amount of rainfall per hour and rainfall rate, R_f (mmh) for 2006			
Months	**Mean samples of Rainfall per hour for three occasions**			**Rainfall Rate, (R_f) (mm/h)**	**Mean samples of Rainfall per hour for three occasions**			**Rainfall Rate (R_f) (mm/h)**	**Mean Samples of Rainfall Per Hour for Three Occasions**			**Rainfall Rate, (R_f) (mm/h)**
January	0.0	0.0	0.3	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.9	0.30	0.8	2.2	2.31	1.77	0.1	0.1	0.0	0.07
March	0.9	0.0	0.6	0.50	4.4	3.2	2.6	3.04	1.0	1.4	2.0	1.47
April	8.4	9.5	12.3	10.07	6.6	5.2	9.2	7.0	5.0	3.4	8.4	5.6
May	3.5	8.4	6.6	6.16	10.3	9.2	10.4	9.97	0.0	15.5	7.2	7.55
June	6.7	6.4	6.9	6.72	13.9	14.0	14.4	14.10	6.3	4.2	2.2	4.24
July	5.0	6.2	7.0	6.06	14.7	14.2	14.0	14.30	4.0	4.1	4.0	4.0
August	6.8	8.8	10.4	8.63	15.5	13.5	14.6	14.53	3.8	3.6	3.7	3.70
September	8.30	7.8	7.0	7.72	8.60	4.4	5.42	6.14	5.3	5.3	5.3	5.3
October	5.54	6.2	8.6	6.78	5.50	4.0	5.0	4.83	0.0	0.0	12.7	4.23
November	0.0	1.3	1.4	0.90	0.50	0.0	1.0	0.50	0.0	1.8	0.0	0.6
December	0.0	0.1	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2: Mean temperature (^oC) for 2004, 2005 & 2006

Mean Temperature (Combined Data Viewing)			
	Mean temperature (o^C)		
Month	2004	2005	2006
Jan.	27.20	25.60	27.40
Feb.	27.30	26.50	27.30
Mar.	26.30	29.20	26.40
Apr.	25.50	26.00	26.50
May	24.60	25.30	26.00
Jun.	24.80	25.20	25.00
Jul.	24.60	25.40	25.30
Aug.	25.00	26.00	24.30

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Sept.	25.80	26.00	25.60
Oct.	26.60	27.00	26.00
Nov.	27.00	27.30	27.00
Dec.	25.40	24.00	27.20
Avg.	25.84	26.13	26.17

Table 3: Cloud Cover for 2004, 2005 and 2006

Cloud Cover (Combined Data Viewing)			
Amount of Cloud (Oktas)			
Month	2004	2005	2006
Jan.	1.50	2.00	2.60
Feb.	4.20	4.30	4.90
Mar.	4.40	4.60	5.60
Apr.	6.50	5.50	6.60
May	6.60	6.50	6.80
Jun.	6.70	6.80	6.90
Jul.	6.90	7.00	7.30
Aug.	7.20	7.10	7.00
Sept.	6.70	6.40	6.50
Oct.	5.90	4.40	5.40
Nov.	5.40	4.20	4.30
Dec.	2.30	2.50	3.20

V. RESULTS AND DISCUSSIONS

From the empirical data obtained as shown in Tables 1, 2 and 3, several computations are done to evaluate the effect of rainfall on radio communication in aviation industry in Nigeria. The evaluations were done by deploying the models that were developed to estimate the rainfall rate, the rainfall backscatter (R. Back sc.), the rain echo signal, (R. Echo (P_r), and wave attenuation A(dB/km). Using equations 13 and 14, and the parameters in Tables 1, 2 and 3, the results shown by Tables 4, 5 and 6 are obtained for three different conditions for different years.

Table 4: Amount of Rainfall per hour and rainfall rates in 2004

Samples of Rain per hour, for three occasions							
					Frequency in GHZ:	2.86	
	Samples of Rain Per Hour						
Month	01	02	03	R_f(mm/hr)	R.Backsc	R.Echo (P_r)	Atten. A(dB/km)
Jan.	0.00	0.00	0.30	0.10	1.23E + 25	3.77E + 19	5.35E + 28

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Feb.	0.00	0.00	0.90	0.30	7.14E + 25	2.19E + 20	3.10E + 29
Mar.	0.90	0.00	0.60	0.50	1.62E + 26	4.95E + 20	7.03E + 29
Apr.	8.40	9.50	12.30	10.07	1.97E + 28	6.04E + 22	8.57E + 31
May	3.50	8.40	6.60	6.17	9.01E + 27	2.76E + 22	3.91E + 31
Jun.	6.70	6.40	6.90	6.67	1.02E + 28	3.12E + 22	4.43E + 31
Jul.	5.00	6.20	7.00	6.07	8.78E + 27	2.69E + 22	3.81E + 31
Aug.	6.80	8.80	10.40	8.67	1.55E + 28	4.75E + 22	6.74E + 31
Sept.	8.30	7.80	7.00	7.70	1.29E + 28	3.93E + 22	5.58E + 31
Oct.	5.54	6.20	8.60	6.78	1.05E + 28	3.21E + 22	4.55E + 31
Nov.	0.00	1.30	1.40	0.90	4.14E + 26	1.27E + 21	1.80E + 30
Dec.	0.00	0.10	0.00	0.03	2.12E + 24	6.50E + 18	9.22E + 27

Table 5: Amount of Rainfall per hour and rainfall rates in 2005

Samples of Rain per hour, for three occasions							
				Frequency in GHZ: 2.86			
	Samples of Rain Per Hour						
Month	01	02	03	R_f(mm/hr)	R.Backsc	R.Echo (P_r)	Atten. A(db/km)
Jan.	0.00	0.00	0.00	0.00	0.00E +00	0.00E + 00	0.00E + 00
Feb.	0.80	2.20	2.31	1.77	1.22E + 27	3.74E + 21	5.31E + 30
Mar.	4.40	3.20	2.60	3.40	3.47E + 27	1.06E + 22	1.51E + 31
Apr.	6.60	5.20	9.20	7.00	1.10E + 28	3.38E + 22	4.79E + 31
May	10.30	9.20	10.40	9.97	1.01E + 28	3.10E + 22	4.40E + 31
Jun.	13.90	14.20	14.40	14.10	7.21E + 27	2.21E + 22	3.13E + 31
Jul.	14.7	14.0	15.1	14.61	6.86E + 27	2.10E + 22	2.98E + 31
Aug.	15.50	13.50	14.60	14.53	2.89E + 28	8.83E + 22	1.25E + 31
Sept.	8.60	4.40	5.42	6.14	8.95E + 27	2.74E + 22	3.89E + 31
Oct.	5.50	6.00	5.00	5.50	7.50E + 27	2.30E + 22	3.26E + 31
Nov.	0.5	0.00	1.0	0.50	6.94E + 27	2.12E + 22	3.02E + 31
Dec.	0.0	0.00	0.0	0.0	4.21E + 27	1.29E + 22	1.83E + 31

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Table 6: Amount of Rainfall per hour and rainfall rates in 2006

	Samples of Rain Per Hour			Samples of Rain per hour, for three occasions — Frequency in GHZ: 2.86			
Month	01	02	03	R_f(mm/hr)	R.Backsc	R.Echo (P_r)	Atten. A(db/km)
Jan.	0.00	0.00	0.90	0.30	0.10E + 26	1.05E + 21	1.49E + 30
Feb.	0.10	0.10	0.00	0.07	6.44E + 24	1.97E + 19	2.80E + 28
Mar.	3.00	1.40	4.00	2.80	2.55E + 27	7.79E + 21	1.11E + 31
Apr.	5.00	3.40	8.40	5.60	7.72E + 27	2.36E + 22	3.35E + 31
May	0.00	15.50	7.20	7.57	1.25E + 28	3.82E + 22	5.43E + 31
Jun.	6.30	4.20	2.20	4.23	4.93E + 27	1.51E + 22	2.14E + 31
Jul.	4.00	4.10	4.00	4.03	4.57E + 27	1.40E + 22	1.98E + 31
Aug.	3.80	3.60	3.70	3.70	3.98E + 27	1.22E + 22	1.73E + 31
Sept.	5.30	5.50	5.30	5.37	7.21E + 27	2.21E + 22	3.13E + 31
Oct.	0.00	0.00	12.70	4.23	4.93E + 27	1.51E + 22	2.14E + 31
Nov.	0.00	9.80	0.00	3.27	3.26E + 27	9.97E + 21	1.42E + 30
Dec.	0.00	0.00	0.00	0.00	0.00E + 00	0.00E + 00	0.00E + 00

However, it had earlier been established by [7] that the equation to evaluate the effects of meteorological phenomena such as hydrometeors (e.g., rain) on radar waves is as shown in equations 13 and 14. For attenuation due to rain, from Eqns. (13) and (14), f is the frequency of the radar system and R_f is the rainfall rate (mm/h).

It is observed that both the rain backscatter echo and the attenuation and the rate of rainfall depend on the radar frequency(f). This dependency indicates the influence of these parameters on radar system behaviour under the rain medium. This dependency of rainfall rate on the radar frequency of the propagating waves as depicted by equations 13 and 14 gives the results shown in Table 7.

Table 7: Effect of Frequencies for different Rainfall Rate R_f (mm/hr)

(a)

Freq (GHZ)	R_f (mm/hr)	R.BackSc	R.Echo (P_r)	Atten. A(dB/Km)
5	0.10	1.15E + 26	3.52E + 20	5.00E + 29
10	0.10	1.84E + 27	5.63E + 21	8.00E + 30
20	0.10	2.95E + 28	9.01E + 22	1.28E + 32
30	0.10	1.49E + 29	4.56E + 23	6.48E + 32
40	0.10	4.71E + 29	1.44E + 24	2.05E + 33
50	0.10	1.15E + 30	3.52E + 24	5.00E + 33

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(b)

Freq (GHZ)	R_f (mm/hr)	R.BackSc	R.Echo (P_r)	Atten. A(dB/Km)
5	1.77	1.14E + 28	3.50E + 22	4.96E + 31
10	1.77	1.83E + 29	5.59E + 23	7.94E + 32
20	1.77	2.92E + 30	8.95E + 24	1.27E + 34
30	1.77	1.48E + 31	4.54E + 25	6.43E + 34
40	1.77	4.68E + 31	1.43E + 26	2.03E + 35
50	1.77	1.14E + 32	3.50E + 26	4.96E + 35

(c)

Freq (GHZ)	R_f (mm/hr)	R.BackSc	R.Echo (P_r)	Atten. A(dB/Km)
5	12.75	2.69E + 29	8.23E + 23	1.17E + 33
10	12.75	4.30E + 30	1.32E + 25	1.87E + 34
20	12.75	6.89E + 31	2.11E + 26	2.99E + 35
30	12.75	3.49E + 32	1.07E + 27	1.51E + 36
40	12.75	1.10E + 33	3.37E + 27	4.79E + 36
50	12.75	2.69E + 33	8.23E + 27	1.17E + 37

(d)

Freq (GHZ)	R_f (mm/hr)	R.BackSc	R.Echo (P_r)	Atten. A(dB/Km)
5	10.10	1.85E + 29	5.67E + 23	8.05E + 32
10	10.10	2.96E + 30	9.07E + 24	1.29E + 34
20	10.10	4.74E + 31	1.45E + 26	2.06E + 35
30	10.10	2,40E + 32	7.35E + 26	1.06E + 35
40	10.10	7.59E + 32	2.32E + 27	3.30E + 36
50	10.10	1.85E + 33	5.67E + 27	8.05E + 36

Figs. 2, 3 and 4 illustrate the variations of rainfall rate R_f (mm/h) yearly for the three years. It is observed from the graph that the rainfall rate – rain rate – which is an indication of the amount of rainfall per hour follows a fluctuating pattern within the period (2004 – 2006) under investigation. The highest amounts of rainfall rate for the three years are, 10.07 mm/h in 2004, 14.61 mm/h in 2005 and 7.57 mm/h in 2006. See Tables 4, 5 and 6. The variations of the rainfall rates within the years are due to the fluctuating meteorological conditions which cause rainfall such as cloud cover formation profiles, solar radiations and other atmospheric processes to vary.

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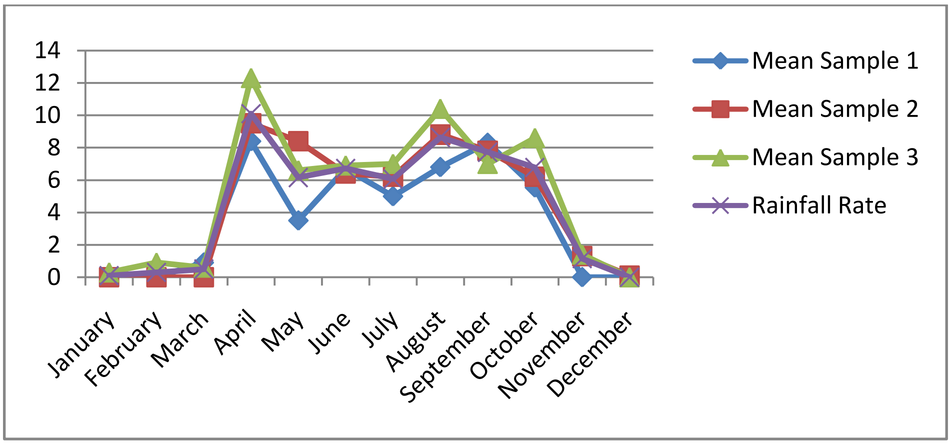

Figure 2: Graph of rainfall and rainfall rate in the months of 2004

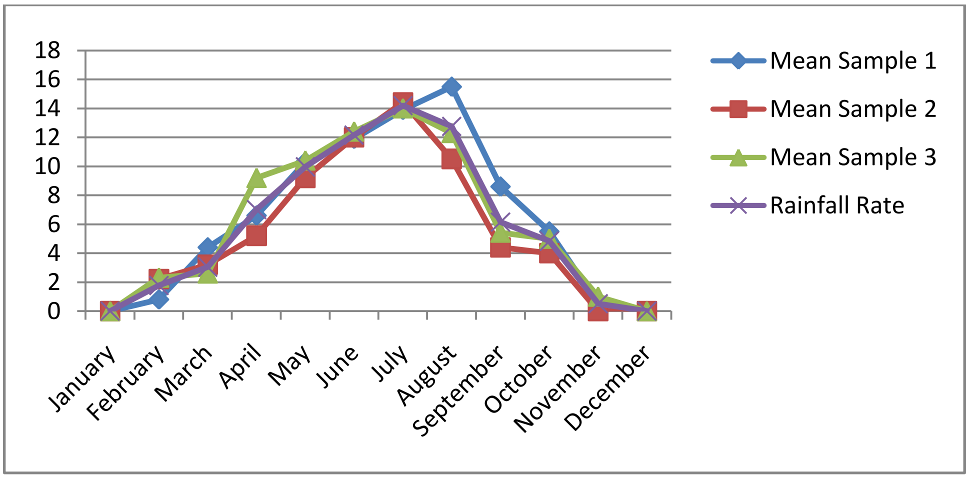

Figure 3: Graph of rainfall and rainfall rate in the months of 2005

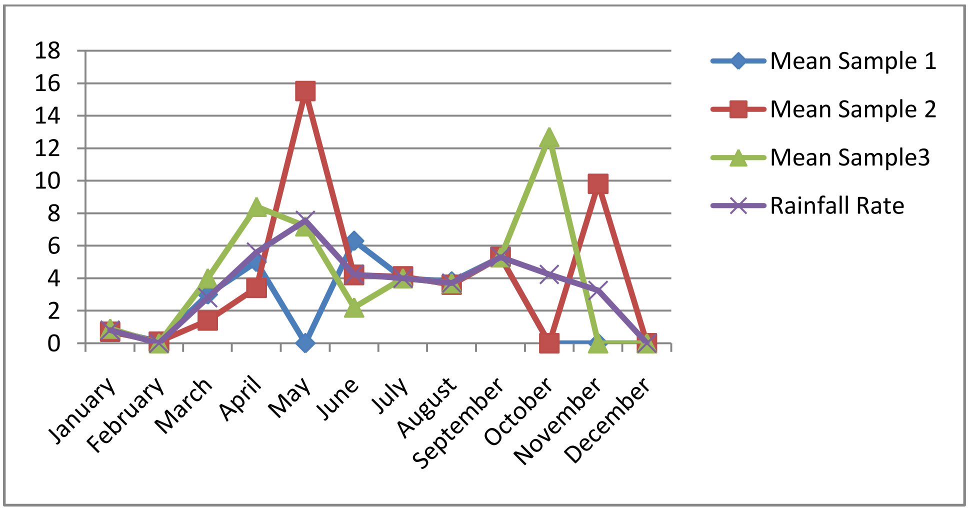

Figure 4: Graph of rainfall and rainfall rate in the months of 2006

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The pattern of variation of the rain backscatter echo signal, P_r with the months of the years under investigation is shown in Fig 3. This variation profile shows a near pattern with that in Fig. 2.

The highest rainfall rate in 2005 was in August and this produced the highest amount of backscatter echo signal for that year. This is also similar for 2004 and 2006. The radar return signals otherwise called the backscatter echo signal due to the rain vary according to the period of the year or seasons (See Tables 4, 5, 6).

Fig. 5 shows the graph of mean temperature for 2004, 2005 and 2006 while Fig. 6 shows the distribution of cloud cover for the years under review. They show the mean temperature and cloud cover are highest in March and July respectively.

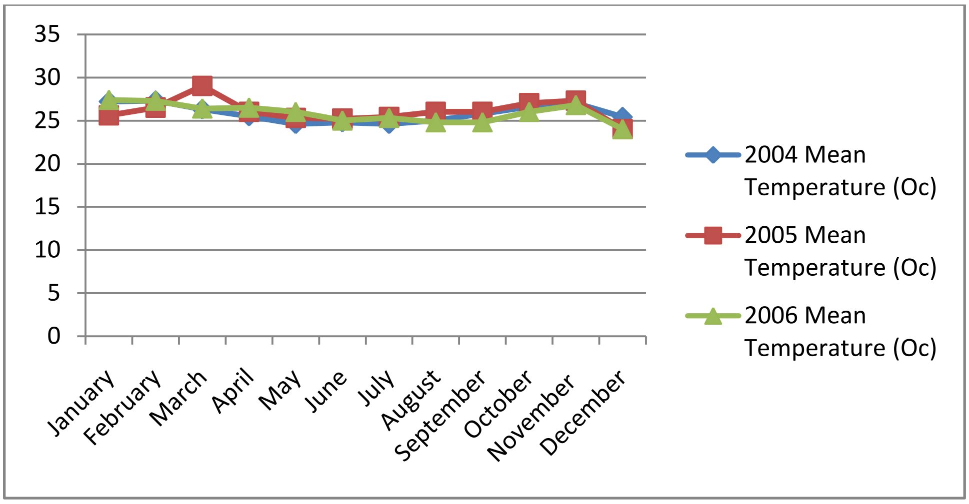

Figure 5: Graph of mean temperature for the years 2004, 2005 and 2006

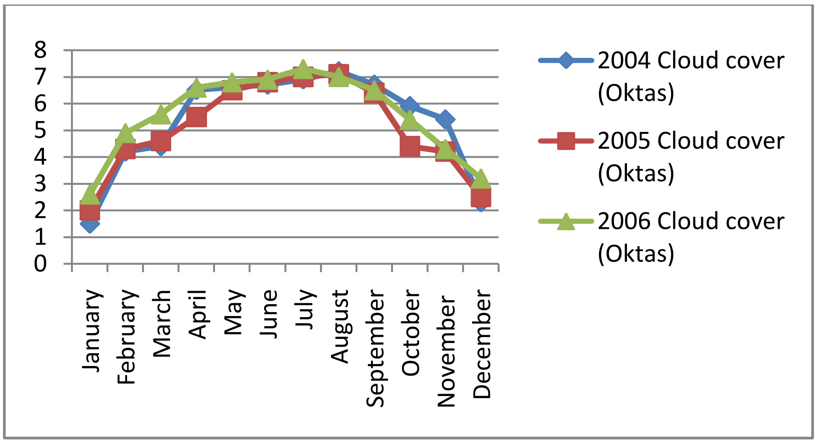

Figure 6: Graph showing the amount of cloud cover for the years 2004, 2005 and 2006

From Fig. 7, it can be deduced that rainfall varies through the years under consideration. For instance it shows the variation of rainfall for three occasions in 2004.

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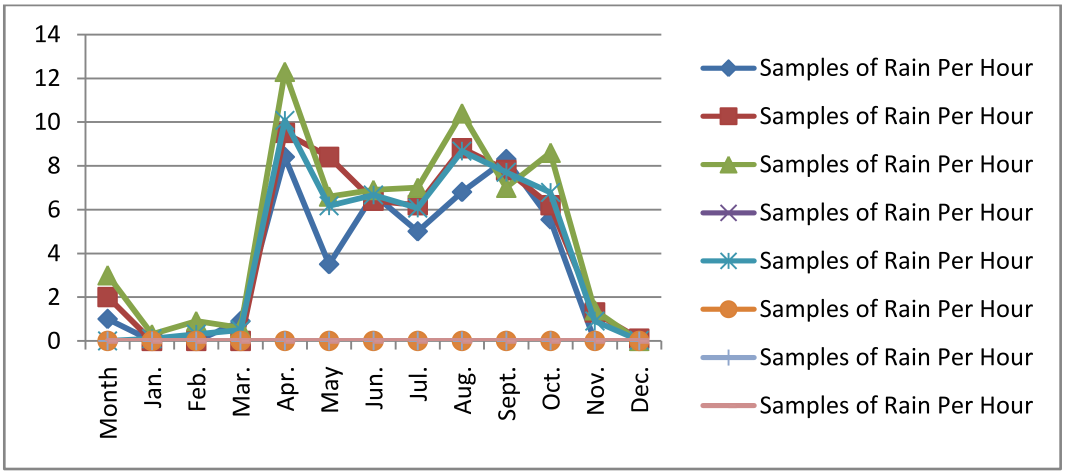

Figure 7: Graph showing variations of rainfall per hour for three occasions in 2004

This is a clear indication of the influence of the meteorological particles (such as rain) on radar performance. Fig. 8 shows the relationship between the rain backscatter signal, P_r and the rainfall rate R_f $\left(i.e., P_r\ vs\ R_f\right)$ for the three years under investigation. As shown in the graph, there is a direct relationship (almost linear at the beginning) between P_r and R_f. Consequently it is possible, theoretically, to obtain the value of one of the parameters P_r and R_f by measuring the values of the other. The graph is the curve of an equation of the form; $P_r = aR_f^b$(equation 7), where a and b are empirical constants while R_f is the rainfall rate. This is why radar systems are used in meteorology to determine the quantity of rainfall and its other microphysical properties at high frequency range of 10 – 30 GHZ or above.

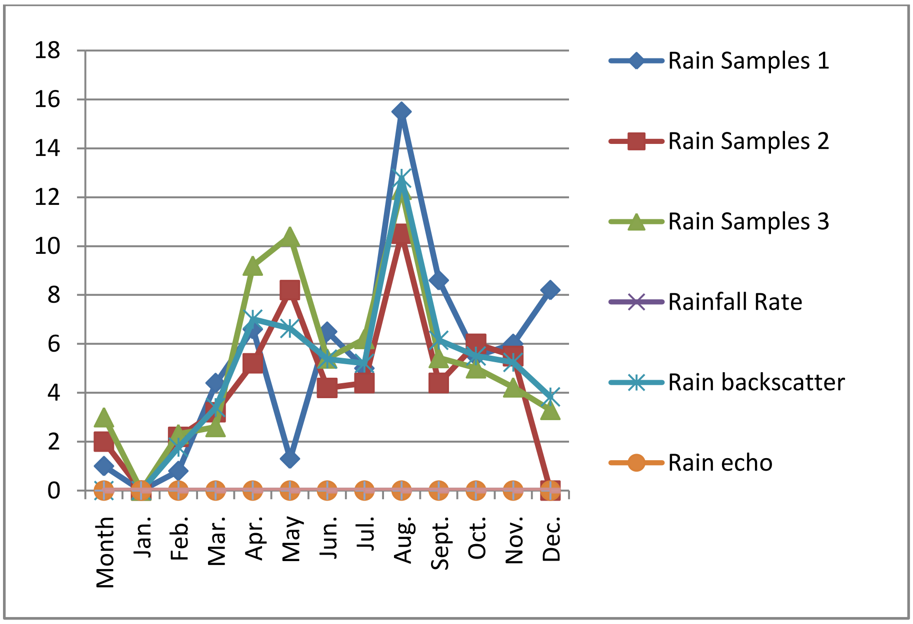

Figure 8: Graph showing variations of rainfall per hour for three occasions in 2005

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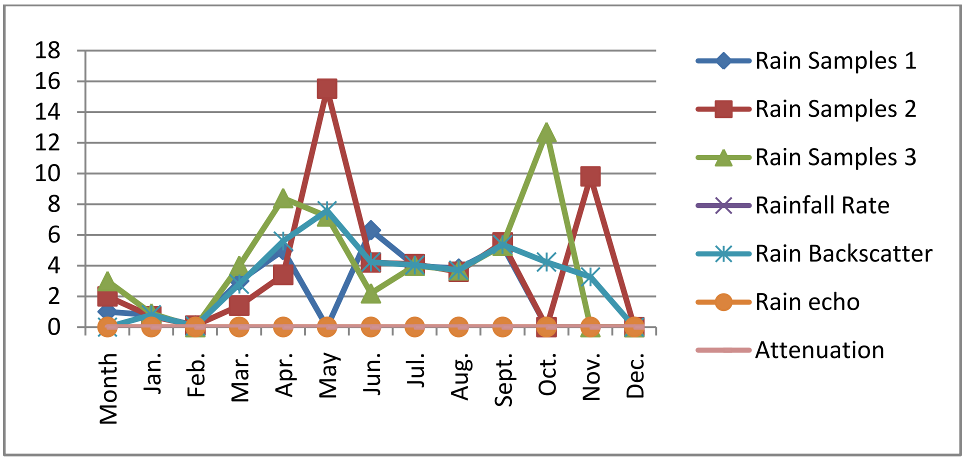

Figure 9: Graph showing variations of rainfall per hour for three occasions in 2006

The graph of attenuation, A(dB/km) against rainfall rate R_f for 2004, 2005, and 2006 is illustrated in Figs. 8 and 9 which is of the same shape and form as that in Fig. 4. From this graph, it is observed that attenuation is dependent on both the rainfall rate and the frequency of operation of the radar system. The dependency relationship is given as aR_f^b for a given radar frequency.

Therefore the prediction of the behaviour of radar or other radio wave on rain medium could be obtained by the knowledge of the type and microphysical properties of the rain or simply the rainfall rate and the frequency of the radio signal. The graph shows that the attenuation increases rapidly as the rainfall rate increases (for a fixed frequency). The attenuation pattern is important information for radar and satellite engineers to optimize their designs for rain environment.

The behavioural variation of the cloud cover for Enugu State is illustrated in Fig.6. The cloud cover formation has almost a bell shaped profile which implies constant cloud formation. This means that the atmospheric fluctuations are less than that in a city with sinusoidal pattern. This cloud cover pattern has direct effects on the frequency of occurrence of rainfall.

Fig. 7 illustrates the variations of P_r with frequency f $(i.e., P_r\ vs\ f)$ and with rainfall rate, R_f as signal, P_r is negligibly small irrespective of the values of the frequency. As the rainfall rate increase by 1.77mm/h, the values of P_r become noticeable and significant only at higher frequencies of 30GHZ and above. With higher rainfall rates of 10.1mm/h and 12.75mm/h, the variation of P_r with frequency become linear at lower frequency region of (5-10) GHZ but varies very rapidly and significantly as the frequency increases beyond 30GHZ.

These graphs and analysis clearly show that the effects of meteorological phenomena such as rain and cloud cover on radar and other radio wave communication system is dependent on the following factors.

(a) The meteorological medium – such as rain. In this case the parameter of interest is the rainfall rate, R_f

(b) The frequency of operations of the radio/radar system, f.

The graphs also show that, because of the relatively insignificant effect of rain and other hydrometers on radar and satellite communication systems at lower frequencies of 2-6GHZ, these frequency range is commonly used for space communications while at higher frequencies of 10-30GHZ and above, the radar is significantly used for meteorological and other environmental related studies.

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VII.CONCLUSION

This paper has successfully established the relationship between meteorological conditions in Enugu and the radar systems at S-band and beyond. Fundamentally it has revealed that the behaviours of radar signals depend on both the radar parameters (such as its output peak power, P_t, gain (g), frequency(f), range, R etc) and the meteorological conditions existing in the atmosphere through which it propagates.

The results of meteorological experiment on rainfall and temperature were used to model the equations for the analysis based on certain assumptions (such as Rayleigh scatter and stratiform rain etc). The equations are that of rainfall back-scatter echo power (P_r) and rainfall attenuation (dB/km). The analysis of the effects revealed that both the Rain back-scatter echo, P_r, and the attenuation (dB/km) are dependent on the rainfall rate, R_f (mm/h) and the radar frequency.

In each case, it was established that the relationship can be approximated to the form $aR_f^{\ b}$ for a given radar frequency or $C_f d$ for a given rainfall rate, R_f. The experimental data which were tabulated and plotted in graphical form equally revealed this form of relationship.

The tables show variations in the pattern and amount of rainfall measured for the same month of different years. These changes can be attributed to the so called greenhouse effect or global warming which is as a result of environmental pollutions accentuated by the depletion of the ozone layer.

This work is limited in scope and therefore did not include cross polarization due to rain, methods of polarization cancellation and various multiple or incoherent scattering effects on co polar and cross polar signals.

The analytical method was basically on rainfall effects. Harmattan haze presents equally disturbing effects on radar system. However, this was not covered in this research because of unreliability of the measurement done due to faulty instruments. Consequently further investigations are suggested to be carried out on harmattan haze, radiations and atmospheric wind profile in Enugu with a view to understanding their various dynamic components that affect weather fluctuations. This research has tried to provide information on the relationship of S-band frequency radar with meteorological elements such as rain. The information is important because S-band radar is not only used in civil aviation but also in agriculture to monitor soil moisture, crop yield etc.

It is important to note that the paper is based on S-band radar system in Enugu; however the analysis can be extended to other cities in Nigeria and for other bands of radar frequency for varying rain scatter diameter.

REFERENCES

[1] Cox D.C. et al. "Results from the 19 – and 28 GHz Cosmtar Satellite Propagation Experiments at Crawford Hill" (1982) Proceedings of IEEE vol. 70 No. 5 pp 458 – 488.
[2] Brown, S. et al. (1995) "An Imaging riometer for Ionospheric Studies" IEEE Electronics and Communication Engineering Journal Vol. 7. No. 55.
[3] Chadwick, R.B. et al. (1983) "Radar Remote Sensing of the Clear Atmosphere – Review and Applications" Proceedings of IEEE Vol. 71 No. 6, pp 738 – 744.
[4] Skolink M. (1980), "Introduction to Radar Systems", Second Edition Pavillion IV Books, 1980.
[5] Robert Jones, J.R., (1962), "The Radar Equation on Meteorology", Quarterly Journal of the Royal Meteorological Society, Vol. 88 pp. 485 – 495.
[6] Oslen R.L. et al (1978), "The aRb Relation in Calculation of Rain Attenuation", IEEE transactions: Antennas Propagations Vol. AP – 20, pp 318 – 329.
[7] Oguchi T. (1983) "Electromagnetic Wave Propagation and Scattering in Hydrometeors", Proceedings of IEEE Vol. 7 No. 9 pp 1029 – 1071.
[8] Wikipedia, "Electromagnetic Spectrum" (2010) Creative Commons Attribution Share Alike License.

BIOGRAPHY

1. **Eke James** is currently a lecturer in the department of Electrical/Electronic Engineering Enugu State University of Science and Technology Enugu, Nigeria. He holds PhD in Communication Engineering.
2. **Ohaneme Cletus O.** is a lecturer in the department of Electronic and Computer Engineering of Nnamdi Azikiwe University, Awka, Nigeria. He holds PhD degree in Communication Engineering in the department of Electrical/Electronic Engineering of Enugu State University of Science & Technology Enugu, Nigeria.
3. **Onoh Greg Nwachukwu** is currently a Professor of Communication Engineering in the department of Electrical/Electronic Engineering, Enugu State University of Science and Technology Enugu, Nigeria. He holds PhD in Communication Engineering.