# Characterization of Radar Measured Rainfall Parameters and Effects of Specific Attenuation on Radio Wave Propagation in Akure, Nigeria

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***Abstract*** **- In this work, three years data (2008 to 2010) of rainfall parameters using a vertically looking Micro rain radar (MRR) located the tropical region of Akure, South-western Nigeria was considered. Rainfall parameters were measured from the ground level to a height of 4.8 km above sea level with a vertically looking MRR having a resolution of 0.16 km and a total of 30 range gates. The rain events were classified into Stratiform and convective types depending on the values of rain rates. The drop number concentrations with drop diameter, yearly cumulative distribution of rain rates and the rain induced attenuation derived based on the different rain types were also analyzed in this work. The drop size distribution results show that drop sizes measured varies from 0.25 mm in diameter to about 5.26 mm and the drop size concentration decreases with an increase in the rain drop diameter and the rain attenuation shows a consistent increase in the specific attenuation value from drizzle rain type to thunderstorm rain type with value as high as 80 dB/km for thunderstorm rain type. The higher dB/km may lead to total signal outage if the decision of communication system. Also, the specific attenuation reaches a critical stage at frequencies ranging from 31-100 GHz, and thereafter decreases slightly before reaching saturation level at 100 GHz.**

**Keywords:** ***Specific attenuation, radar, rain rates, drop size distribution, drop diameter and drop concentration.***

## I. INTRODUCTION

Demand for more communication services is increasing daily and more access to higher frequencies up to super high frequency (SHF) and extremely high frequency (EHF) bands are now being proposed for satellite services. Allocation towards higher end of electromagnetic spectrum especially above 10 GHz is increasing on a daily basis, hence the need to meet the demand for higher data rate for various communication and multimedia requirements. It is important to note that rain which can cause several decibels of attenuation has been identified to be a major cause of visual impairment at millimetre wave frequencies (above 10 GHz) and is the limiting factor in satellite / terrestrial link design, especially for tropical and equitorial regions which experience heavy rainfall [1] and [2]. To further compound the problem, the quality of signals received in tropical regions (Sub- Saharan Africa) is often hampered by very intensive rainstorms that are characterized by large size raindrops along the path of communication satellite.

Radar precipitation measurements often referred to as vertical profile reflection (VPR) do not necessarily represent surface condition of precipitation. Hence, its reliability and effectiveness over other equipments such as the rain gauge and disdrometer in the prediction of attenuation due to rain over different heights. In this research work, using a vertically looking Micro Rain Radar (MRR) we focus more on a feature of VPR which was never considered much in this part of the world. According to [3] and [4], significant gradient of radar reflectivity are well known in and above the melting layer with constant reflectivity generally between the surface and the melting layer. It was also observed that the height of the measuring volume increases with increasing distance from the radar due to the earth curvature. Hence, measurements of high resolution profiles obtained with a vertically pointing Doppler radars showing a significant shape transformation of drop size distribution (DSD) and Z-R relation is reported for years 2008, 2009 and 2010.

The main aim of this paper is to show attenuation of different height dependence rain rates using vertically looking MRR and to deduce their effect on radio wave propagation. While the objectives are to measure and analyze rainfall parameters such as rain rates (RR), Liquid water content (LWC or M), Radar reflectivity (Z) and Falling velocity (W) for a period of three years (2008, 2009 and 2010). Also, to determine how the drop sizes distribution (DSD) of the back scattered signals from rain drops varies with the drop diameters for various rain types.

Several attenuation measurements has been done by various researchers with Advanced Communication Technology Satellite (ACTS) also using the Olympus satellites at 30/20 GHz. However, the method generally used is to estimate the rain induced attenuation from the knowledge of rain DSD. From this study, and various other studies done on DSD it is established that the distribution of the drop sizes falling at particular rain rates varies according to the meteorological conditions and so is the attenuation at a particular frequency.

## II THE MICRO RAIN RADAR

Radar is a system that uses electromagnetic waves to identify both location, direction, and / or speed of both moving objects like motor vehicles, aircrafts, ships, weather formations and terrains.

The micro rain radar (MRR) is a unique radar that measures the vertical profile of rain rate (RR), liquid water content (LWC or M), radar reflectivity (Z), drop size distribution (DSD) and the corresponding falling velocity of drops (W). It provides information for now – casting of precipitations i.e. it will detect the start of rain from ground level to high above the radar several minutes before the sense of rain at the ground level.

MRR is a compact 24.1 GHz FM-CW radar used for the measurements of vertical profiles of drop size distribution (DSD), for

The MRR-2 used for this work operates with electromagnetic radiation at a freq of 24.1 GHz with a modulation of approx 1.5 – 15MHz depending on the height. The radiation is transmitted vertically into the atmosphere where a small portion is scattered back to the antenna from rain drops or other forms of precipitation. The advantages of this type of radar is the small required transmitter power for a given radar sensitivity. That is the small transmitting power (50mW) of MRR antenna ensures that no beam overlap problems need to be considered.

## III DATA ANALYSIS / PROJECT SITE

The data from MRR is stored as Raw data, instantaneous data and average or real data each in separate folders. The raw data are stored in an unprocessed form. Here the values of Z, LWC, RR and W are not yet calculated.

Datasets for this work was obtained with a vertically pointing MRR located at the Federal University of Technology, Akure south western Nigeria. A map of the radar sites is shown in Fig. 1. The file format showing how all the data obtained were arranged as recorded by evaluation computer (the in-door component) is as shown in Table 1.

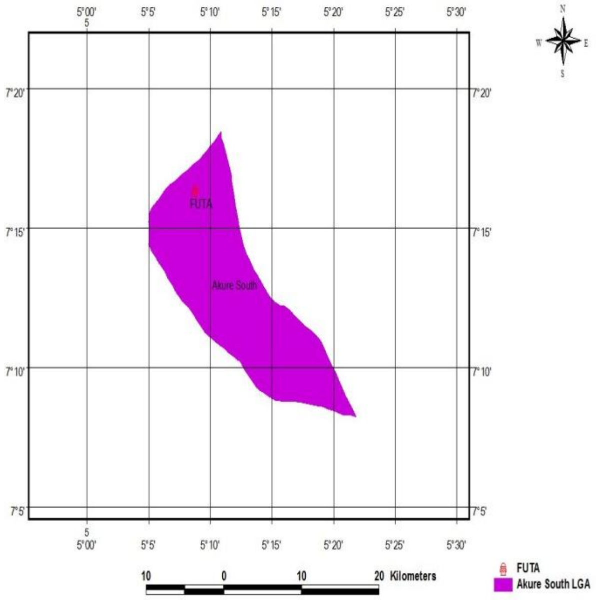


Fig 1: Map of the project site.

Fig 2: Outdoor component of MRR at Akure

Data in an Average data folder contains processed values of Rain rate (RR), Liquid water content (LWC), Radar reflectivity (Z), Falling velocity (w) of drops and some other parameters like the spectral drop densities and spectral reflectivity using one minute integration time. Files containing data are stored in separate folders on a monthly basis. The data format is human readable and each set consists of line. The order of line and the used identifiers are as listed in the table below:

## IV MICROPHYSICAL PARAMETERS IN MICRO RAIN RADAR.

Log-normal distribution are usually characterized in terms of the log-transformed variable using as parameters the expected values, or means, of its distribution and the standard deviation. Log-normal distributions are symmetrical again at the log level [5].
Log-normal representation is suitable for a broad range of applications and can facilitate interpretation of the physical processes that control the shape of the distribution.

[6] expresses Lognormal distribution as:

$$N(D)=\frac{N_t}{(2\pi)^{0.5}\ln D} X \exp[-\frac{\ln^2(D/D_g)}{2\ln^2\delta}] \quad (1)$$

$N_t$ is the total number of drops im m-3
$D_g$ is the geometric mean of the drop diameter in mm.
δ is the standard deviation of D.
The mass weighted mean diameter Dm or the diameter at mid range is given by:

$$D_m = \frac{M_4}{M_3} \quad (2)$$

M3 and M4 are the third and the fourth moment of rain drop size distribution spectra.

## V. ATTENUATION

Attenuation is caused by scattering and absorption of e.m. waves by drops of liquid water. The scattering diffuses the signal while absorption involves the resonance of the wave with individual molecules of water. The specific attenuation can be obtained using the emperical scaling procedure between specific attenuation, phase shift and rain rate [1].
The specific attenuation calculated from the imaginary part of the effective propagation constant $K_{V,H}$, while the phase shift was from the real part of $K_{V,H}$ in the rain medium for the path length (L) taken as 1km.

Thus, $A_{V,H} = 8.686\ln(K_{V,H}L)$ (3)

Table 1: Data format for instantaneous and averaged data

| IDENTIFIER | MEANING | UNIT |
|---|---|---|
| MRR | Header line | n. A |
| H | Height | M |
| TF | Transfer function | Dimensionless |
| $F_{nn}$, $F_{00}$-$F_{63}$ | Spectral reflectivity | dB |
| $N_{nn}$, $N_{00}$-$N_{43}$ | Spectral drop densities | $m^{-3}mm^{-1}$ |
| Z | Radar reflectivity | dBZ |
| RR | Rain rate | $mmh^{-1}$ |
| LWC | Liquid water content | $gm^{-3}$ |
| W | Fall velocity | $ms^{-1}$ |

## VI. RESULTS

### CONTRIBUTION TO Z, ΔZ VS DIAMETER AT MID RANGE ($D_m$)

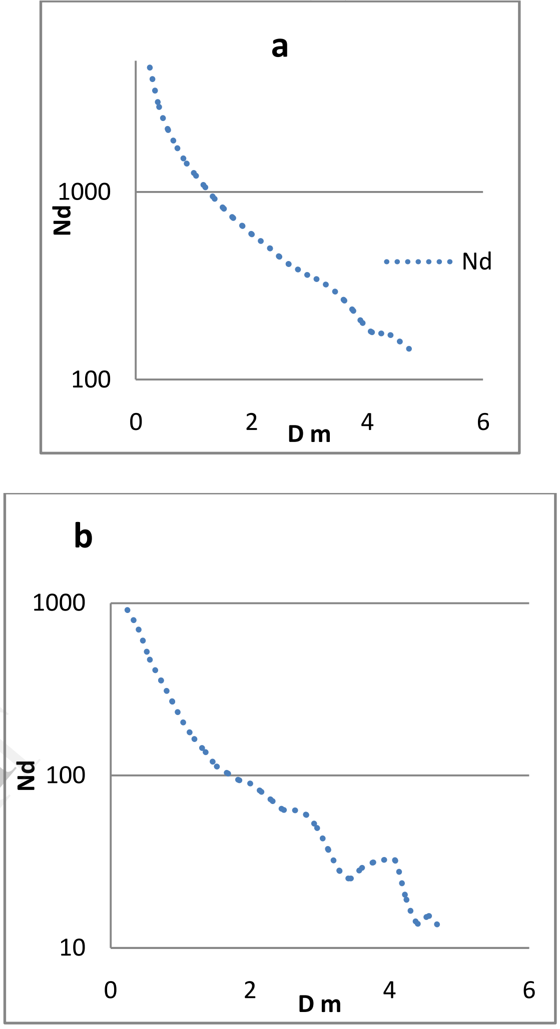
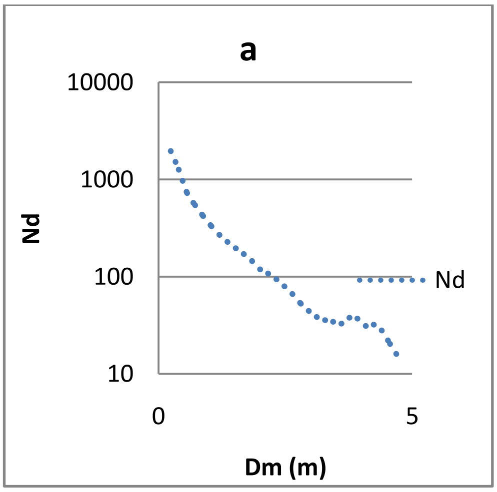


Fig 3.1: Rainfall DSD at Akure, Nigeria for stratiform rainfall type- for (a) Drizzle (b)Wide spread YEAR 2008



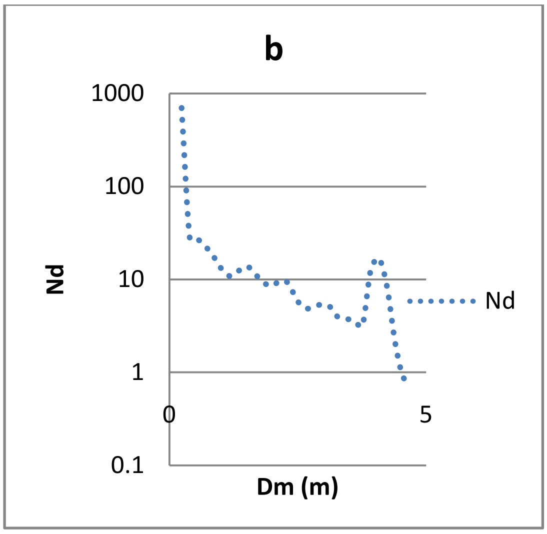


Fig 3.2: Rainfall DSD at Akure, Nigeria for convective rainfall type-for (a) shower(b) thunderstorm spread  YEAR 2008

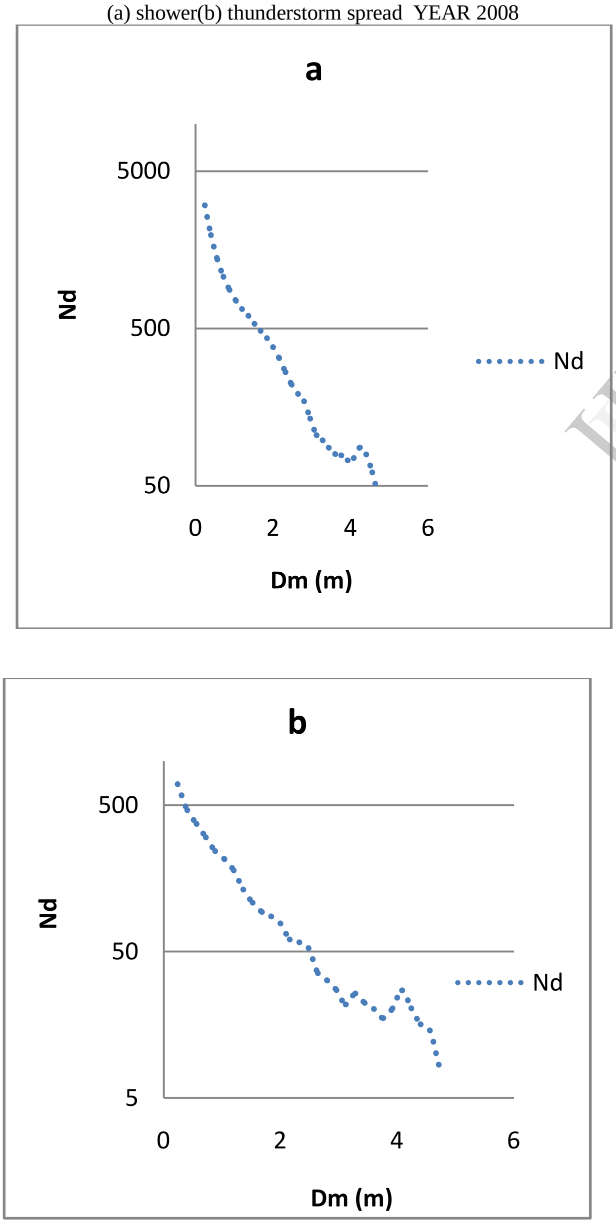


Fig 3.3: Rainfall DSD at Akure, Nigeria for stratiform rainfall type- for (a) Drizzle (b) Wide spread  YEAR 2009

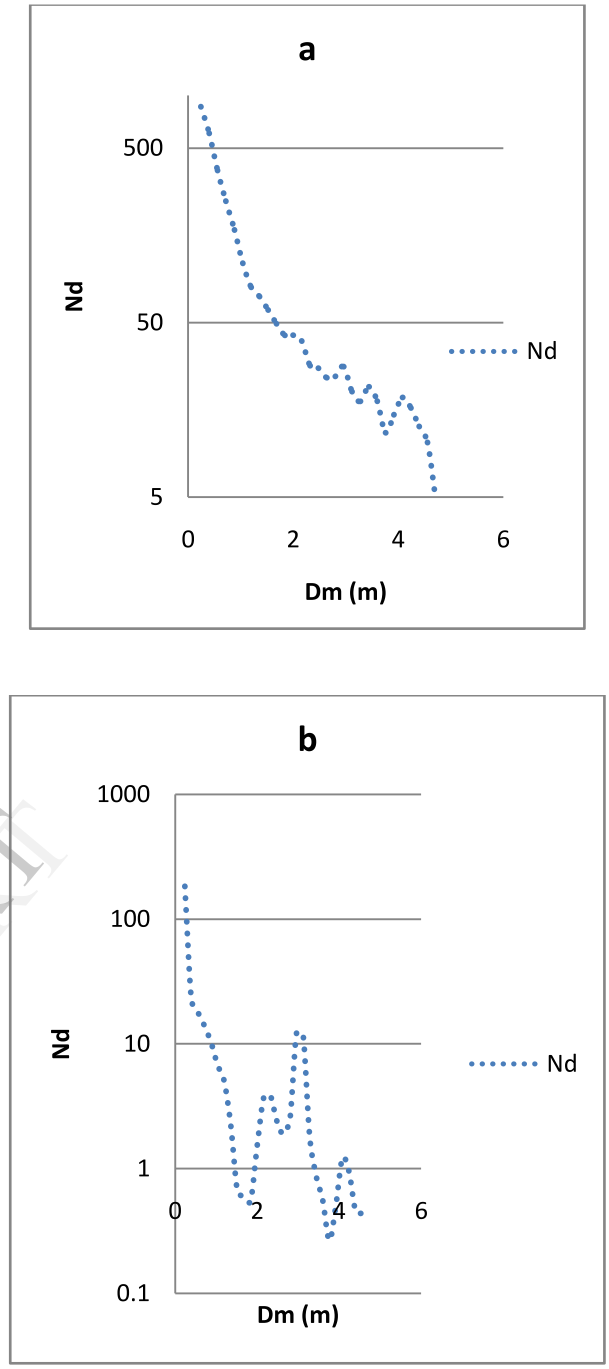


Fig 3.4: Rainfall DSD at Akure, Nigeria for convective rainfall type- for (a) shower (b) thunderstorm spread  YEAR 2009

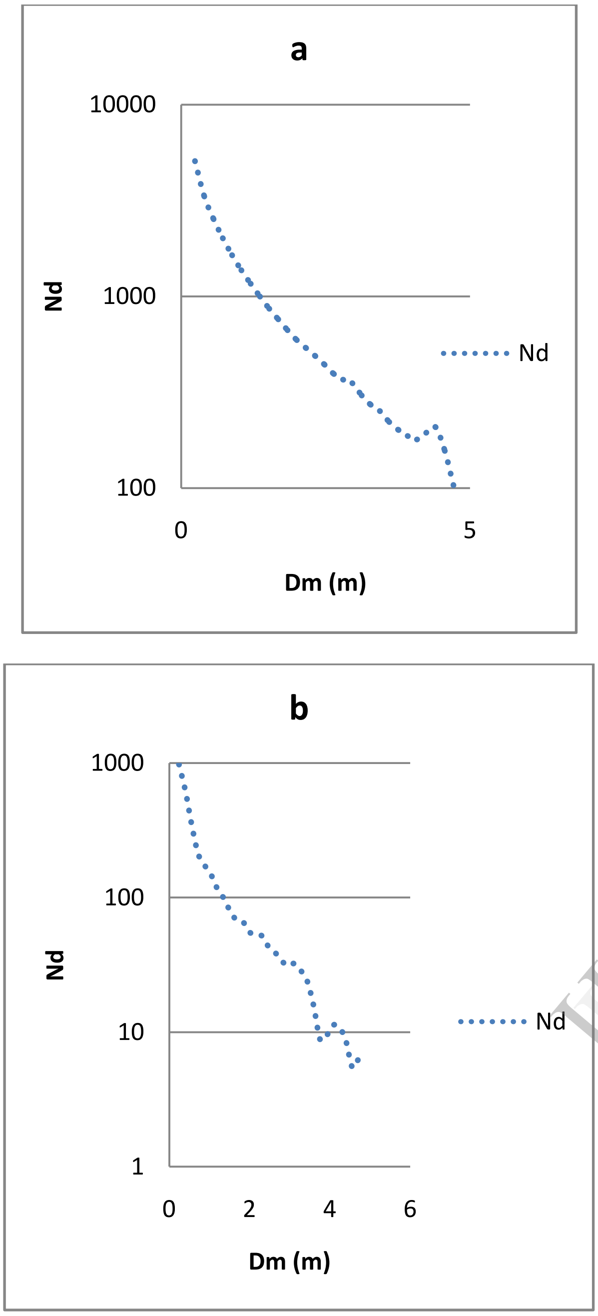


Fig 3.5: Rainfall DSD at Akure, Nigeria for stratiform rainfall type- for (a) Drizzle (b) Wide spread YEAR 2010

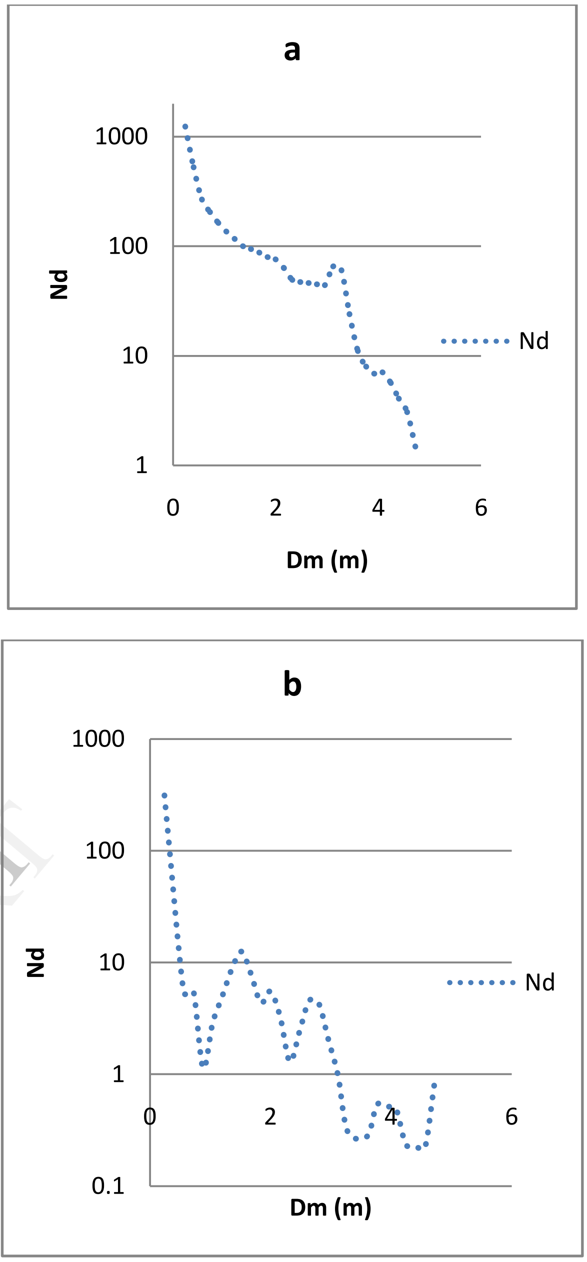


Fig 3.6: Rainfall DSD at Akure, Nigeria for convective rainfall type for (a) shower (b) thunderstorm YEAR 2010

*Implications of the DSD results*

The DsD results show that drop sizes measured varies from 0.25 mm in diameter to about 5.26 mm, with the larger concentration of the diameter around 0.250 - 0.559 mm (with an average diameter interval of 0.04 mm). As the rain drop diameter increases the drop size concentration decreases [7]. Rain drops in the diameter bin of 0.25 mm which represent the drop spectrum N04 contributed most to the rain fall event throughout this period over each of the rain types.

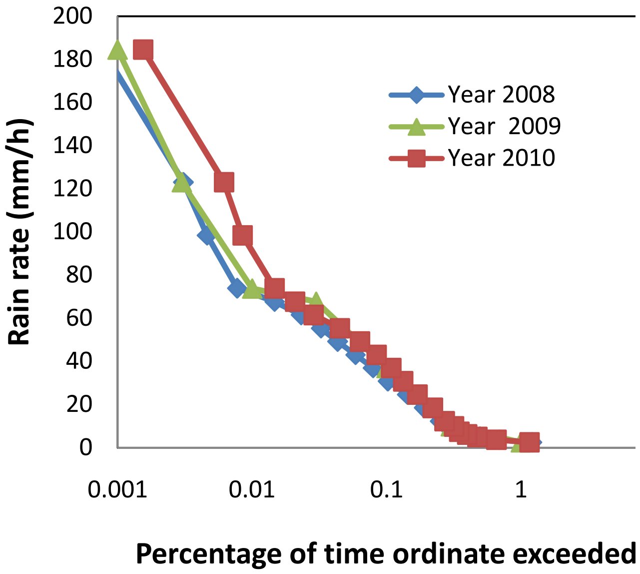


Fig. 4: Yearly cumulative distribution of rain rate

The yearly cumulative shows that Akure with an average annual rainfall accumulation of 1599 mm recorded about 78, 74 and 81 mm/h at 0.01% of time in the first , second and third year respectively (Fig. 4). Year 2010 recorded more rain than the other two years considered in this work. This shows the dynamic pattern of rain rate over the location.

The cumulative distribution of measured rain rate (fig. 5) compared with ITU-P. 837-5 (2007) model is also presented in Fig. 27. The higher the rainfall rate the lower the corresponding percentage of time recorded while the lower the rainfall rate the higher the percentage of time. It could further be observed that the recent ITU-R P.837-5 (2007) model underestimated the rain rate values in this region. At 0.01% of time the measured rain rate was about 35% under estimated.

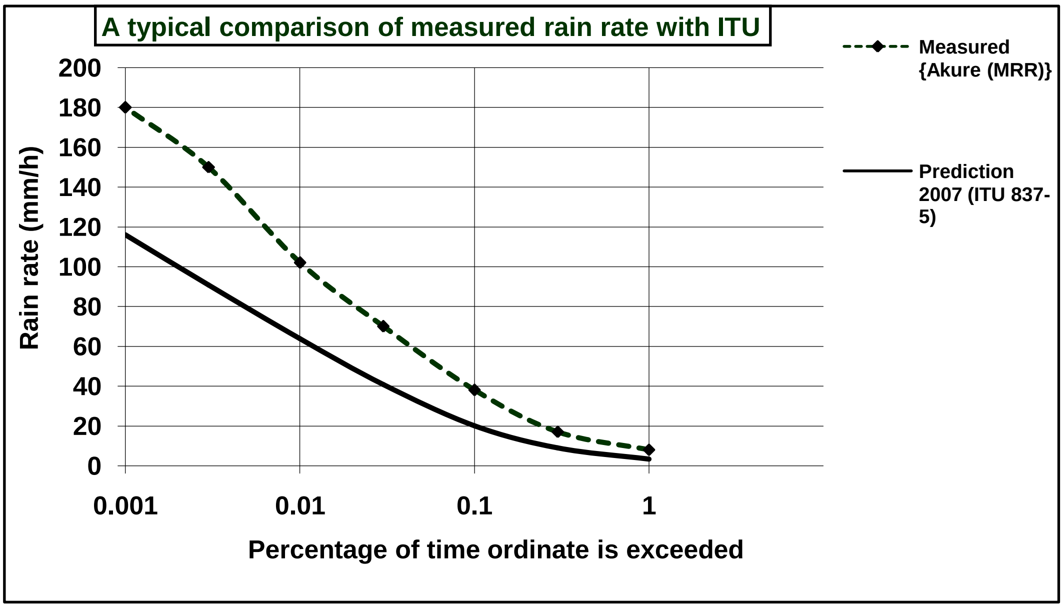


Fig. 5:. 3 years Average cumulative distribution of rain rate

## SPECIFIC ATTENUATION FOR DRIZZLE, WIDESPREAD , SHOWER AND THUNDERSTORM

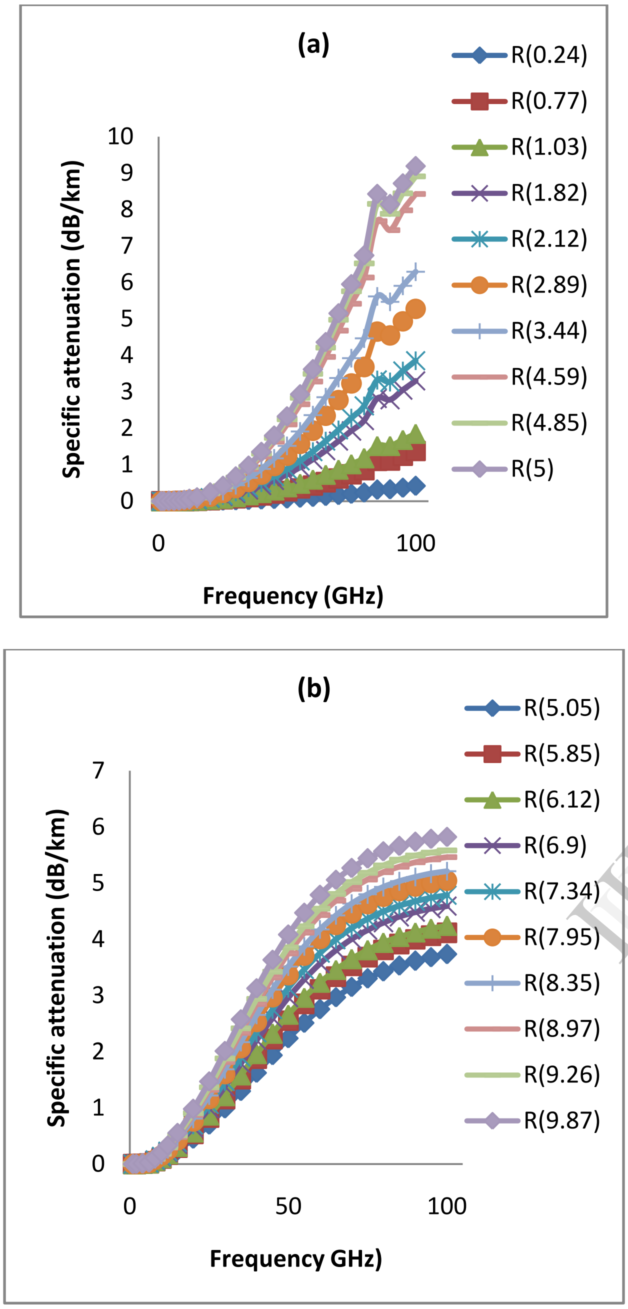


Fig.6: Specific attenuation for (a) Drizzle (b) Wide spread

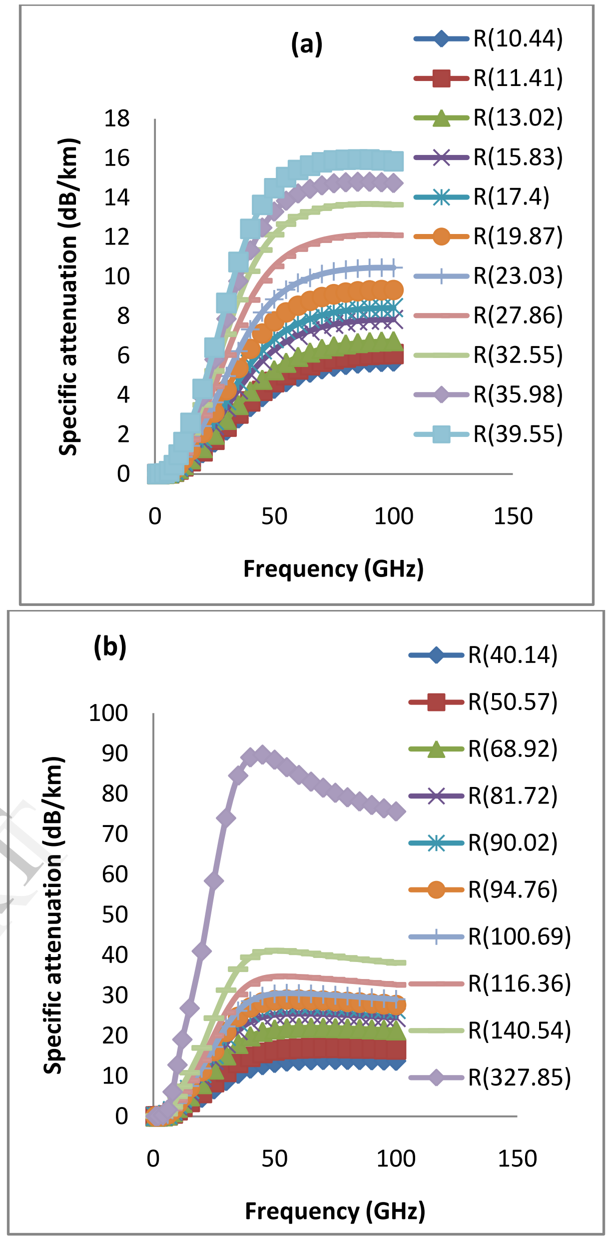


Fig 7 (a) Shower (b) Thunderstorm at different rain rates

The specific attenuation was evaluated (Fig. 6 and 7) for frequencies of 1-100 GHz to give room for future satellite systems design. In general, specific attenuation increases with increasing frequency for stratiform and convective rain types. At a critical frequency, which ranges from 31-100 GHz, the specific attenuation decreased slightly and reaches saturation at 100 GHz. We also observed a consistent increase in the specific attenuation value from drizzle rain type to thunderstorm rain type. The specific attenuation can be as high as 80 dB/km for thunderstorm rain type. The higher dB/km may result into total signal outage if not properly compensated for in the systems design. This is also in perfect agreement with earlier prediction that in tropical countries rain can induce as large as 85dB attenuation on a 5km 30 GHz link [8].

## VII CONCLUSION

Vertical profiles of rain parameters such as rain rate, drop size distribution, liquid water content and average fall velocity have been analyzed for different rain types based on the propagation point of view. Using an MRR, some case studies of tropical rain over Akure south western part of Nigeria are presented. From the MRR observation, rain is classified into two different types based on the different microphysical parameters mentioned above. The observation shows that the drop size distribution at different height gives an insight of the physical process associated with rain in this region. Results from this work provided further insight into the tropical rain structure and the applicability for satellite communication links designs at high frequencies for tropical sites. Finally, we observed a consistent increase in the specific attenuation value from drizzle rain type to thunderstorm rain type. The specific attenuation can be as high as 80 dB/km for thunderstorm rain type. The higher dB/km may result into total signal outage if not properly compensated for in the systems design.

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