In situ investigation of Rain drop size distribution (DSD) using Micro Rain Radar Data and its effect on microwave radio signals in tropical region

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ABSTRACT

Three years (2008, 2009 and 2010) data of Rain drop size distribution and some associated rain parameters such as the rain rates (R), radar reflectivity (Z), liquid water content (M), and the falling velocities (W) were observed and analysed using a vertically pointing Micro Rain Radar (MRR) at the Department of Physics, Federal University of Technology Akure (7º15´N, 5º15´E), a tropical location in Nigeria. The parameters were measured from the ground level to a height of 4.8 km above sea level with a vertical resolution of 160 m and over a total of 30 range gates with 1-minute integration time. Data collected from the monsoon period were used to determine the vertical profile of Z-R relationship for all the rain types. The study established relationships between all the parameters and the results shows typical values for negative exponential rain drop size distribution (DSD) similar to that of Marshall-Palmer for both stratiform and convective rain. At 0.01% of time, the measured rain rate was underestimated by 35% when compared with the ITU-R recommendation for this region and it was observed that over 85% of the total rainfall in this part of the world is stratiform while the remaining 15% are convective except for the month of October which is the peak of the rainy season in the year where a high number of convective rain is observed. The results of this study may assist to improve the design and planning of terrestrial and satellite radio communication system in this location, this may also be useful for understanding rain structures over this region. Results of radar reflectivity versus rain rate indicate that the exponent is lower and the intercept is higher for stratiform rain types than in the convective classification.

Keywords:*Micro rain radar, Rain microstructure, Drop size distribution, Stratiform and Convective.*

1. Introduction

Generally, rain refers to precipitation in liquid state and it consists of drops of water falling from clouds if when very small they are collectively termed as stratiform and when the drops are large they are convective (Burton *et al.*, 1997)**.** Clouds which contains huge numbers of tiny droplets of moisture gives rise to raindrops and are formed when these tiny droplets grow, first by moisture from the surrounding air condensing on them and then by coalescing with other droplets. It is therefore important to note that in order to have rain we must have a cloud – a cloud is made up of water in the air (water vapour) and along with this water are tiny particles called condensation nuclei – for instance, the little pieces of salt leftover after sea water evaporates, or a particle of dust or smoke. Condensation occurs when the water vapour wraps itself around the tiny particles. Each particle (surrounded by water) becomes a tiny droplet between 0.0001 and 0.005 centimetre in diameter. (The particles range in size, therefore, the droplets range in size.) However, we can call the growing droplet a raindrop as soon as it reaches the size of 0.5 mm in diameter or bigger (Diederich, 2004).

The size of raindrops can vary considerably from diameters of .1 mm to 5 mm for stratiform while, they vary from about 0.5 mm to as much as 8 mm in thunderstorms. There is a natural limit for the size of raindrops. Large drops falling through air break up into smaller drops when they attain a velocity of about 30 km/hr. Raindrops are often large enough to have a size dependent shape that cannot be characterized by a single length, so there are difficulties in describing the size spectra of rain drops. The conventional solution used to describe rain spectra is in terms of the equivalent drop diameter D_o defined as the diameter of a sphere of the same volume as the deformed drop (Harikumar, 2009).

In addition to equivalent diameterD_0, there are three other quantities commonly used to characterize rain. (1) The size distribution n(D_o) expressed here in terms of the number of drops per unit size interval per cubic metre of air, (2) liquid water content (LWC) and (3) the Rain rate (R). Rainfall plays a very important role in hydrological cycle, which is a key unit in driving energy circulation in the atmosphere and hence, is the most dominant impairment for the propagation of radio waves (Das *et al.*, 2010). Rain water may seriously affect the performance of microwave links operating at frequencies greater than 10 GHz (Kamakar *et al*., 2011 and Ojo*et al.,* 2013).Thus, rain drop size distribution (RDSD) is one of the most widely used parameters for better understanding and complete description of rain phenomenon. Various RDSD models such as: Lognormal, Gamma, Weibull, Marshall and Palmer are employed to parameterize the RDSD.

Due to the important role of water in the atmosphere it is therefore very important for the understanding of its dynamic processes in the atmosphere for weather prediction and other forms of climate research. Thus, there is great interest to measure atmospheric water in all its phases as it occurs in many different forms in the atmosphere. In its gaseous phase it occurs as cloud ice, dry snow or hail. Furthermore there exist some mixed forms where liquid water and ice are combined e.g. wet snow or graupel. Today, atmospheric water can be measured in many different ways: Directly in the atmosphere by balloon or aircraft soundings, from space by satellite and from the ground by rain sensors, rain radars or radiometers.

With rainfall measurements making their importance felt, rain drop size distribution (DSD) has become another important parameter. In calibrating the radar and also for understanding the attenuation and other effects of rainfall on communication, knowledge of DSD has become very essential. With satellite measurements of rainfall becoming a reality, measurements of rain rate and DSD at the surface to serve as ground truth for satellite data have gained importance and accurate rain rate estimation requires detailed knowledge of rain DSD (Tokay *et al.*, 1995).Micro Rain Radar (MRR) is a very unique instrument that measures all the rainfall parameters like the drop size distributions, rain rates, Liquid water content, fall velocity and radar reflectivity from the ground level to heights as high as 4800m. It operates at a time resolution of as low as 10sec or 1min as the case might be.

2. Instrumentation / Experimental Site

The Micro rain radar used for this study has an electronic unit which determines the spectrum with a high time resolution of 10sec or less and sends it to a connected control and data acquisition system where the drop spectrum is calculated and this ultimately leads to the values of the actual rain rate and the liquid water content at various heights above the ground level from 160m to, 320,……4800m. The time resolution used for this work is 1minute. It operates with an electromagnetic radiation at a frequency of 24.1 GHz. The parameters used for this work were measured with a vertically pointing Micro rain radar located at the Federal University of Technology Akure, Ondo State, Nigeria (7°15`N, 5°15`E) which is in South-western Nigeria. The measurements were taken for a period of four (4) years of 2008, 2009, 2010 & 2014.

3. Theoretical Background / Methodology

The existence of melting layer is a definite signature of stratiform type of rain and the reason behind this is the fact that melting layer can only form when there is no strong up-drift, which is only satisfied in stratiform rain condition (Saurabh Das et al. 2010). This method has been utilized with MRR data using time series of vertical radar reflectivity profile up to 4.8 km to classify the rain (Kunhikrishnan*et al.*, 2006., Cha *et al.*, 2007).

$$Z = \int_0^{\infty} N(D) D^6 dD \qquad (1)$$

(mm^6m^{-3}) and the equivalent radar reflectivity factor.Where D is the falling diameter of the rain drops.N(D) is the number of drop per unit volume and diameter.

The relationship between the radar reflectivity and rain rate depends on the structure of the drop size distribution, (Gerhad*et al.*, 2005).

The Reflectivity factor is related to the rain rate as

$$Z = aR^b \qquad (2)$$

where a and b are constant parameters,

Linearizing the equation (2.3) we have:

$$\ln Z = \ln a + b \ln R \qquad (3)$$

4.1 Marshall and Palmer Distribution

The DSD is well represented by an expression developed by Marshall and Palmer and found out that it follows function of the form:

$$N(D) = N_O \exp(-\Lambda D) \qquad (4)$$

where N(D) is the concentration of raindrops per diameter interval ΔD in mm, D is the rain drop diameter.

N is the intercept parameter with fixed value of $8x10^3 mm^{-1}m^{-3}$, ∧ (mm^{-1}) the slope parameter

$$\wedge = 4.1R^{-0.21} \ mm^{-1}$$

R is the rainfall rate (mm/h).

Marshall-Palmer discovered that Rain Drop size Distribution (RDSD) for several rain rates, the exponential function does not fit the observation. Hence, it is sometimes necessary to consider the Marshall –Palmer curves applicable at diameter greater than 1-1.5mm. (Battan, 1973).

4.2 Lognormal Distribution

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 (Eckhard*et al.*, 2001).

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.

Mahen*et al.*, (2006) expresses Lognormal distribution as:

$$N(D) = \frac{N_t}{(2\pi)^{0.5} \ln D} * \exp[-\frac{\ln^2(D/D_g)}{2\ln^2 \delta}] \qquad (5)$$

whereN_t is the total number of drops in m^{-3}, D_g is the geometric mean of the drop diameter in mm, δ is the standard deviation of D.

5 Results

Rain Drop Size Distribution (DSD) Characteristics

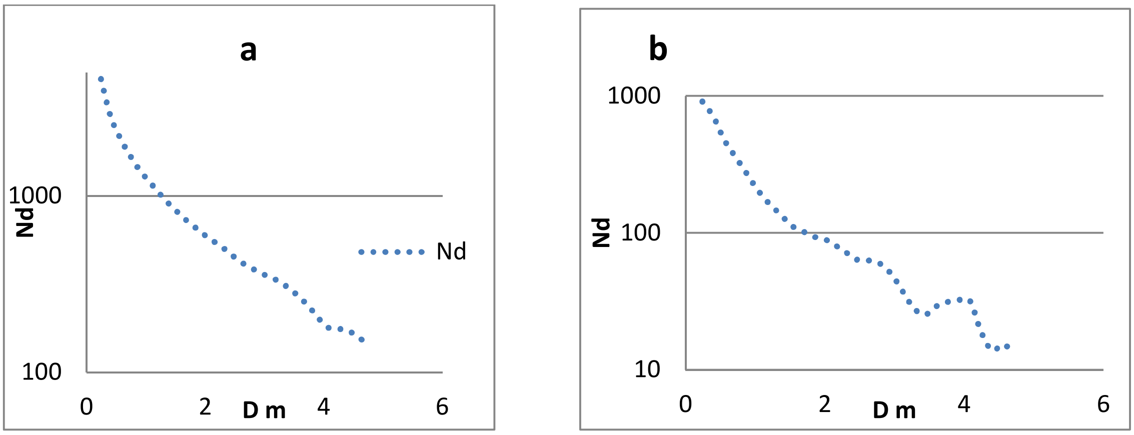

Figure 1: Rainfall DSD for stratiform rainfall type- for (a) Drizzle (b)Wide spread YEAR 2008

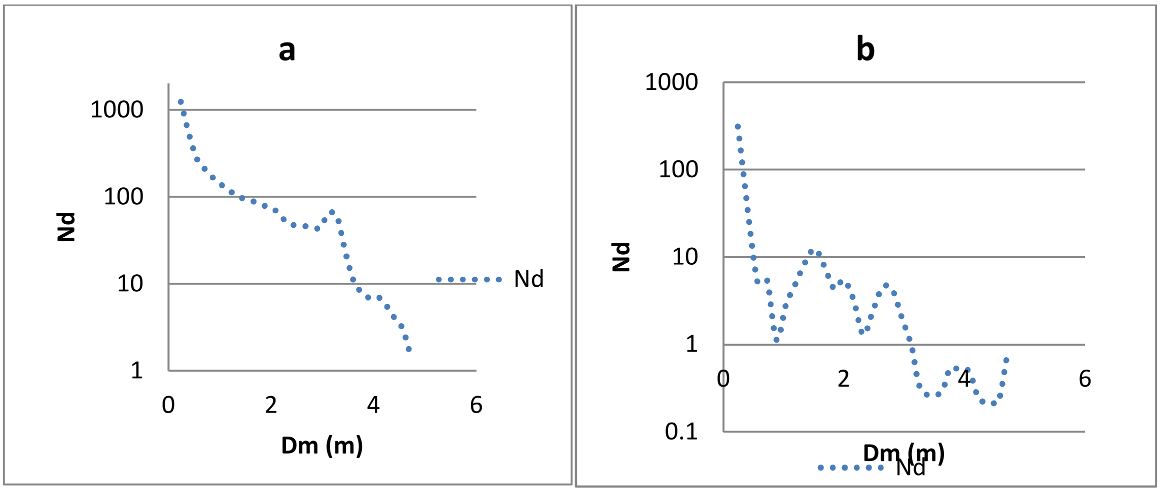

Figure 2: Rainfall DSD for convective rainfall type for (a) shower (b) thunderstorm YEAR 2010

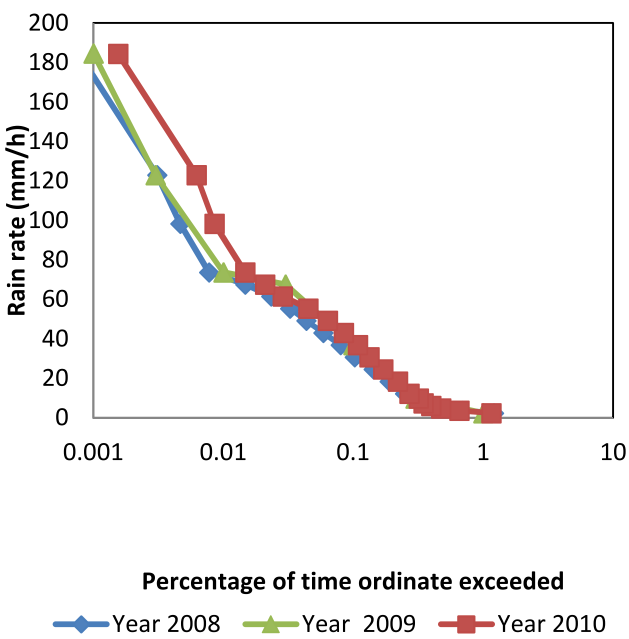

Figure 3: Yearly cumulative distribution of rain rate

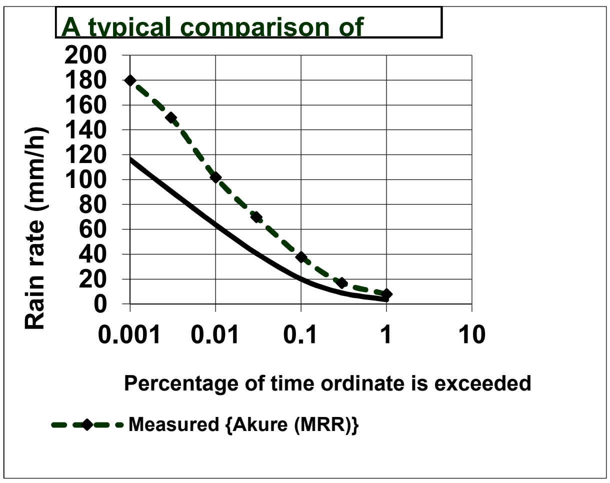

Figure 4: 3 years Average cumulative distribution of rain rate with ITU

5.1 Rain Drop Size Distribution (DSD) Characteristics

Figures 1 and 2 shows the DSD results for years 2008 and 2010 indicating 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. This is in agreement with the work of Ali Tokay *et al*. (2001). 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.The distributions above are typical Marshall and Palmer Models which is in agreement with the work of Adimula (1997).

Figures.3 and 4are the plots of rain rates versus percentage of time for years 2008, 2009 and 2010. The result shows that Akure with an average annual rainfall accumulation of 1599 mm recorded about 78, 74 and 81 mm/hr at 0.01% of time in the first, second and third year respectively (Figure 3). Year 2010 recorded more rain than that of 2008 and 2009 considered in this work and this shows a dynamic pattern of rain rain rate over the location.

The cumulative distribution of measured rain rate compared with ITU-P model is also presented in Figure 4. Results of the plot indicate that the corresponding percentage of time recorded while the lower rainfall rate has higher 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.

6 CONCLUSION

Rain events for years 2008, 2009, 2010 and 2014 collected using a Micro Rain Radar were used for this research. They were classified into high and low rains according to the values of rain rates. The high rains were further classified into shower and thunderstorm, while the low rain were classified into drizzle and widespread. It was observed that most of the rain events in this part of the world is the low rain (stratiform) i.e. rain rates below 10 mm/hr. This is evident in the various plots of DSD results which shows that the drop diameter increases as the drop-size concentration decreases. From the plot of the yearly cumulative distribution of rain rate for years 2008, 2009 and 2010, it was observed that year 2010 recorded more rain than the other two years and the percentage of time decreases as the rain rate increases.

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