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Investigation of Rain Drop size Distribution and Specific Attenuation using Micro Rain Radar in Tropical Region.

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Abstract
The measurement of the vertical profiles of rainfall parameters such as drop size distribution, rain rate, liquid water content, fall velocity and radar reflectivity were carried out by using Micro Rain Radar in 2006 and 2008 at Akure (Lat 5°15'E, long 7°15'N) in South-Western Nigeria. The vertical distributions of these parameters with heights are presented for 0 - 4800 m.The range gates for the measurement are 30 with a height step of 160 m. The variation of the drop size distribution, rain rate and liquid water content with height were evaluated. The highest rain rate and liquid water content were observed within the height range 0-160 m. For the all cases considered, the largest concentration of drop size with a diameter of 0.246 mm occurred in the height range 0-160 m.
Empirical relations in the form have been obtained for the rainfall rate, the radar reflectivity factor Z, and liquid water content using the least square power law regression. The results show that the relationship obtained for height range 0-160 m for the two years were in good agreement with the values available in the literatures. For all cases considered, there is a good correlation between the parameters. The measured rainfall rates were divided into classes using the criteria; for stratiform rain type, rain rate R < 50mm/h and convective rain type, rain rate R > 50 mm/h. Results of the rain attenuation shows consistent increase in the specific attenuation from stratiform to convective rain type which may lead to total signal loss.
Keywords: *Stratiform rain; Convective rain; Micro Rain Radar; Rain rates, Radar reflectivity, Attenuation and Tropical region.*

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I. Introduction

Measurements of rain drop size distribution (DSD) have a broad list of applications in telecommunication, meteorology, hydrology, and related sciences. The performance of communication links in frequencies above 5 GHZ are affected by rain attenuation. Attenuation is one of the most crucial factors to be considered in the link budget estimation. *(Marzuki et al 2013).*

The rain attenuation is a function of raindrop, and consequently can be predicted when the DSD data are available. In addition, weather radar operation also requires the information on the DSD. *(Renggono et al 2001.)* The radar only provides the radar reflectivity (Z) and we need to convert it to rainfall rate (R) by using an equation which is commonly known as the ($Z - R$)relation. The equation relates the measured (Z)and the estimated $R$and can be derived traditionallyfrom long-term observations of DSD. *(Vonnisa et al 2014).*

Knowledge of the DSD is also important in cloud physics, soil erosion study, and harvesting energy from raindrop. The DSD has a broad list of applications, and the study of the DSD in Indonesia is still limited to few locations. A pioneering study on the DSD was conducted at Bogor, west Jawa, Indonesia, by using a rain drop camera.

Regional variability alongDSD in the equatorial Indonesia has also been observed through a network of Parsivel disdrometer observation at Kototabang, Pontianak, Manado and Biak . The aforementioned studies mostly deal with the surface DSD. The evolution of rain drops before reaching the ground surface may have a significant effect on the DSD application. For example, the radar reflectivity is an inherent property of the DSD which is proportional to the 6th power of the drop sizes.

The Micro Rain Radar (MRR)is operating at 24.1 GHZ and is a frequency-modulated continuous-wave ($FM - CW$) radar pointed vertically with a$0.6M$ offset antenna 2 $beamwidth$ (Peters, G., 2002.).The ability of MRR at resolving small drops and successful investigations have been reported in many literatures . However, it's accuracy has been questioned due to several problems such as strong rain attenuation at the frequency of 24.1 GHZ and the vertical wind that affects the fall speed of the drops , particularly in heavy rain. Thus, some correction techniques have been proposed to improve the MRR standard processing method.

II. Description of the Experiment

The MRR used for this work was manufactured by Meteorologist Messtechnik GmbH (Metek),is a pointing Frequency Modulated Continuous Wave (FMCW) radar operating at a frequency of 24 GHz . It uses a 60 cm offset antenna and a low power (50mW) solid state transmitter. *(Gerhard et al.,2002).* This leads to a very compact design and a low power consumption of approximately 25 W. To avoid snow accumulation on the dish, a 200W dish heating system has been installed. The measuring principle of the Micro Rain Radar is based on electromagnetic waves of a frequency of 24 GHz. In contrast to normal rain-radar devices, the signals are emitted vertically into the atmosphere where a part of the emitted signal is scattered back to the parabolic antenna by the rain drops and the output signal is transmitted continuously.

Due to the falling velocity of the rain drops relative to the stationary antenna there is a frequency deviation between the transmitted and the received signal known as Doppler frequency which is a measure of the falling velocity of the rain drops. Since rain drops of different diameter have different falling velocities, the backscattered signal consists of a distribution of different Doppler frequencies.The Radar electronics determines this spectrum with a high time resolution of 10 seconds and sends it to the connected control and data acquisition system, where the drop spectrum is calculated from the Doppler spectrum considering the transfer function of the radar module. The integration over the entire drop spectrum, considering further correction terms, followed by an averaging for 30 seconds, results in the actual rain rate and the liquid water content. *(Crane, R. K., 1982).*

According to Diederich et al 2004, the Micro Rain Radar measures the Doppler spectrum from 0 to 12 m/s and the standard real-time processing uses the relation given by Atlas et al., (1973) to attribute drop diameters to Doppler velocities. The MRR has the indoor and outdoor components as shown in Figure 1.

Figure 1: **Outdoor unit of the MRR** **Figure 2: Indoor unit of MRR**

The outdoor component is made up of the following:

a. Offset parabolic dish antenna with 0.5m efficient aperture diameter and 24.1 GHz FM-CW transmit frequency cord

b. Radar front end (electromagnetic field)

c. Transmitter control electronic housing; 26cm x 16cm x 10cm

d. Recorder unit and digital signal processor unit for FFT (Fast Fourier Transform)-analysis for derivation of Doppler spectra (10s sampling time)

e. Data transmission with R5232 interface for system control

f. 25m-junction cable for data transfer and power supply of outdoor components.

The indoor component consist of

a. Power supply 220VAC/24VDC/25W

b. Evaluation computer

User can use either mains or 24VDC, as both are available

III. Project Site

The measurement site chosen for the study is the Department of Physics, Federal University of Technology Akure Ondo State Nigeria (7°15'N, 5°15'E). The measurement was taken for a period of two months (August and September) in the year (2006). Ondo State is composed of lowlands and rugged hills with granitic outcrops in several places. In general, the land rises from the coastal part (less than fifteen metres above sea level) in the south, to the rugged hills of the north eastern area.

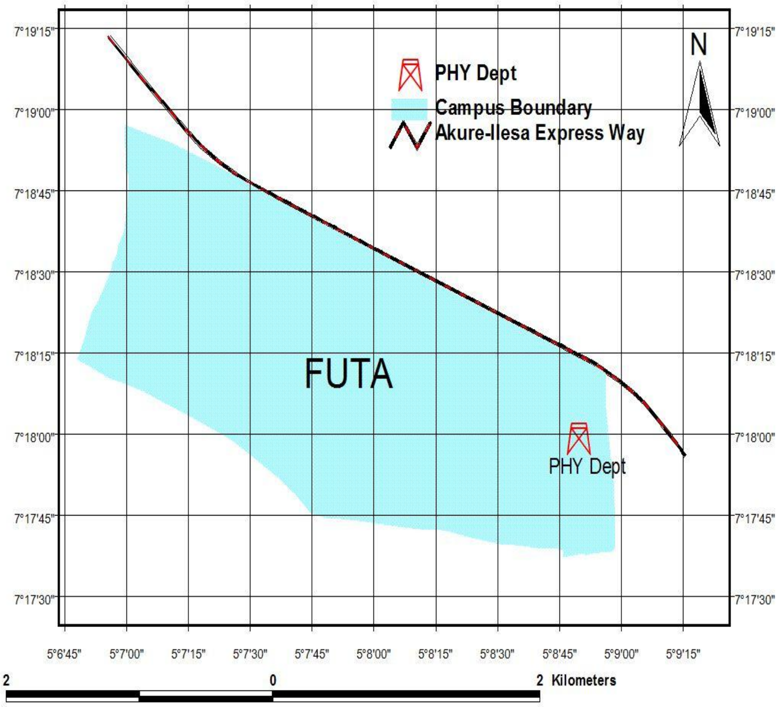

Figure 3: Map of Physics Department of Federal University of Technology, Akure

IV. Some Theoretical Concepts

The MRR used in this work is a profiling Frequency Modulated Continuous Wave (FM-CW) Doppler radar which operates at frequency 24.1 GHz. It measures the backscattered signal from the rain drops to calculate different microphysical parameters at different heights. The measured Doppler spectra are converted into drop diameters to provide Information on the DSD using different known relationship. Rain microstructure of rain rate (R), liquid water content (LWC) and radar reflectivity (Z) are estimated from the DSD, while the average fall speed of the drops (V_m)is calculated from the measured Doppler spectrum.

Shengjie et al (2010) and Gerharard P. et al (2002) shows that the integral parameters from the DSD are expressed for each of the rain microstructures as:

$$R = \frac{\pi}{6}\int_0^\infty N(D) D^3 v(D) dD \quad (1)$$

$$Z = \int_0^\infty N(D) D^6 dD \quad (2)$$

$$LWC = \frac{\pi}{6}\rho_w \int_0^\infty N(D) D^3 dD \quad (3)$$

$$D_m = \int \frac{DN(D) dD}{N(D) dD} \quad (4)$$

where R is the rain rate in mm/h, Z is the radar reflectivity in dB, LWC is the liquid water content in mg/m^3, D_m is the mean drop diameter in mm, N(D) is the number of drops with the size D to D + ΔD in $mm^{-1}m^{-}3$, D is the diameter of the drops in mm, v(D) is the fall velocity of the drops with size D to D + ΔD in m/s, ρ_w is the density of water.

The average fall velocity V_m obtained from the measured Doppler spectrum follows the form:

$$v_m = \frac{\lambda}{2} \frac{\int_0^\infty f.P(f)df}{\int_0^\infty P(f)df} \quad (5)$$

whereλ is the wavelength and p(f) is the spectral Doppler power as related to Doppler frequency. Equation (5) is related to DSD weighted by D^6 as:

$$v_m = \frac{\int_0^\infty N(D)D^6 v(D)dD}{\int_0^\infty N(D)D^6 dD} \quad (6)$$

According to Saurabh *et al.*,(2010), rain is the most dominant impairment for the propagation of radio waves. Rain attenuation models are based on the properties of rain drops and interaction between raindrops and electromagnetic waves. Drop size distribution is a very important parameter for calculating rain attenuation which vary for different rain types of similar intensity. Rain attenuation can therefore be said to depend on the vertical extent of rain up to the rain height.

Attenuationis the reduction of intensity of electromagnetic wave along its path and it is caused by scattering and absorption of electromagnetic waves by drops of liquid water (Robert, 2000). The scattering diffuses the signal while absorption involves the resonance of the wave with individual molecules of water.

Since attenuationrefers to the reduction in the signal power, the reduction of the backscattered power is defined by the equation:

$$d\overline{P_r} = 2K_L \overline{P_r} d_r \quad (7)$$

where $d\overline{P_r}$ is the incremental reduction of the backscattered power $\overline{P_r}$ due to absorption and scattering of the medium between the radar set and the target, K_L is the attenuation coefficient, the factor 2 indicates radar power transverses the same path twice.
Integrating equation (6) over the range zero to r we have:

$$\overline{P_r} = \overline{P_{r_o}} e^{2\int_o^r K_L dr} \quad (8)$$

$$10\ Log \frac{\overline{P_r}}{P_{r_o}} = -2\int_0^r Kdr \quad (9)$$

$\overline{P_{r_o}}$ is the power which would be recovered had there been no attenuation, $\overline{P_r}$ is in decibel K is in decibel per length, Attenuation of microwaves can be caused by atmospheric gases, clouds and precipitation. Equation (9) can be written as:

$$10\ \log \frac{\overline{P_r}}{P_{r_o}} = 2\int_0^r (K_g + K_c + K_p)dr \quad (10)$$

Attenuation by radar waves is as a result of (i) absorption (ii) scattering. Gases, cloud droplets and rain drops acts only as absorber when large snowflakes and rain drops are present along the radar path both absorption and scattering must be considered and the specific attenuation can be obtained using the emperical scaling procedure between specific attenuation, phase shift and rain rate as used by Ajewole *et al*., (1999).Also, according to Achmad *et al.*, (2007) and Saurabh *et al.*,(2010), rain is the most dominant impairment for the propagation of radio waves and rain attenuation models are based on the properties of rain drops and interaction between raindrops and electromagnetic waves. Drop size distribution is therefore an important parameter for calculating rain attenuation which vary for different rain types of similar intensity. Rain attenuation can therefore be said to depend on the vertical extent of rain up to the rain height.

V. Data Acquisition

Data used for this study was collected by the high resolution Micro Rain Rader located at the Federal University of Technology, Akure, Ondo State. (7°15' 0"N /5° 12' 0" E).
The rain rate collected was from August 1st to September 30th, 2006 at 1minute sampling time. This falls within the peak of the rainy season in the locality.
We considered the highest rain rate value in each of the month.

- August -24mm/hr
- September- 32mm/hr

The radar gave a rain height of 0-4800m at steps of 160 m for a total 30 range gates for each of the months.

Table 1: Sample Data

MRR	6.1E+10	UTC+02	AVE		60	STP	160	ASL	360	SMP	1.25E+05	NF0	0.857	NF1	0	SVS	4.1	DVS
H	160	320	480		640	800	960	1120	1280	1440	1600	1760	1920	2080	2240	2400	2560	
Z	14.6	16.4	16.7		16.3	17.8	17.9	15.7	10.8	5.4	3.8	5.8	7.4	0.5	3.1	4.6	2.3	
RR	0.33	0.8	1.07		1.37	2.42	2.79	1.87	0.55	0	0	0	0	0	0	0	0	
LWC	0.04	0.12	0.17		0.27	0.49	0.58	0.42	0.14	0	0	0	0	0	0	0	0	
W	4.15	3.46	3.34		2.47	1.71	1.59	1.53	1.22	1.11	1.54	1.76	1.68	3.06	4.12	4.31	2	
Z	17.1	19.4	19.8		19.6	19.5	18.7	17	12.4	4.8	4.2	5.8	4.3	4.5	3.9	2.1	3.5	
RR	0.6	1.56	1.92		1.87	2.08	1.87	1.29	0.47	0	0	0	0	0	0	0	0	
LWC	0.09	0.26	0.32		0.29	0.34	0.31	0.22	0.09	0	0	0	0	0	0	0	0	
W	4.52	3.71	3.43		3.18	3.18	2.37	1.88	1.33	1.37	2.04	2.33	1.28	2.12	2.72	2.16	2.88	
Z	10.5	10.4	9.8		9.7	8.8	7.4	7.5	6.4	5.8	4.8	4.8	4.4	2.9	4.9	1.6	2.9	
RR	0.13	0.16	0.15		0.13	0.14	0.1	0.07	0	0	0	0	0	0	0	0	0	
LWC	0.02	0.03	0.03		0.02	0.02	0.02	0.01	0	0	0	0	0	0	0	0	0	
W	4.39	2.49	3.01		2.53	2.63	2.49	2.14	1.97	1.39	1.87	2.3	2.71	3.29	2.39	3.21	1.85	
Z	7	8.1	7.4		7.1	8.5	8.1	4.6	5.4	4.4	4.3	1.3	4.5	1.6	4.3	1.2	2.3	
RR	0.05	0.09	0.06		0.07	0.18	0.07	0	0	0	0	0	0	0	0	0	0	
LWC	0.01	0.01	0.01		0.01	0.04	0.02	0	0	0	0	0	0	0	0	0	0	
W	3.78	3.18	2.71		2.47	1.86	1.55	1.66	1.48	1.72	1.84	4.11	2.37	2.1	2.94	2.52	1.67	
Z	5.1	7.5	8		7.4	6.4	6	3.8	-0.3	1	1.7	2.4	3.5	1.2	3.7	2.3	5.1	
RR	0	0.05	0.17		0.03	0.03	0	0	0	0	0	0	0	0	0	0	0	
LWC	0	0.01	0.04		0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	
W	1.56	1.48	2.04		2.17	2.55	2.32	1.63	1.93	2.13	3.29	2.86	2.32	2.21	3	2.02	1.73	
Z	10.8	13.1	12.7		10.9	8.3	6.5	5.8	2.2	3.2	5.2	4.2	5.7	4.5	1.6	5.4	1.6	
RR	0.4	1.01	1.1		0.63	0.15	0	0	0	0	0	0	0	0	0	0	0	
LWC	0.08	0.26	0.31		0.17	0.04	0	0	0	0	0	0	0	0	0	0	0	
W	1.56	1.24	1.07		1.24	1.91	2.19	2.3	2.19	2.23	1.4	1.87	2.07	1.25	2.68	2.86	2.81	

Table 2:SAMPLE OF PROCESSED DATA

H	Z	RR	LWC	W	Z	RR	LWC	W	Z	RR	LWC	W	Z
160	14.6	0.33	0.04	4.15	17.1	0.6	0.09	4.52	10.5	0.13	0.02	4.39	
320	16.4	0.8	0.12	3.46	19.4	1.56	0.26	3.71	10.4	0.16	0.03	2.49	
480	16.7	1.07	0.17	3.34	19.8	1.92	0.32	3.43	9.8	0.15	0.03	3.01	
640	16.3	1.37	0.27	2.47	19.6	1.87	0.29	3.18	9.7	0.13	0.02	2.53	
800	17.8	2.42	0.49	1.71	19.5	2.08	0.34	3.18	8.8	0.14	0.02	2.63	
960	17.9	2.79	0.58	1.59	18.7	1.87	0.31	2.37	7.4	0.1	0.02	2.49	
1120	15.7	1.87	0.42	1.53	17	1.29	0.22	1.88	7.5	0.07	0.01	2.14	
1280	10.8	0.55	0.14	1.22	12.4	0.47	0.09	1.33	6.4	0	0	1.97	
1440	5.4	0	0	1.11	4.8	0	0	1.37	5.8	0	0	1.39	
1600	3.8	0	0.00E+00	1.54	4.20E+00	0	0	2.04	4.8	0	0	1.87E+00	
1760	5.8	0	0	1.76	5.8	0	0	2.33	4.8	0	0	2.3	
1920	7.4	0	0	1.68	4.3	0	0	1.28	4.4	0	0	2.71	
2080	0.5	0	0	3.06	4.5	0	0	2.12	2.9	0	0	3.29	
2240	3.1	0	0	4.12	3.9	0	0	2.72	4.9	0	0	2.39	
2400	4.6	0	0	4.31	2.1	0	0	2.16	1.6	0	0	3.21	
2560	2.3	0	0	2	3.5	0	0	2.88	2.9	0	0	1.85	
2720	5.8	0	0	1.87	1.4	0	0	3.08	0.3	0	0	3.04	
2880	6.1	0	0	2.17	6.3	0	0	3.18	1.9	0	0	1.65	
3040	4.1	0	0	2.47	7	0	0	3.24	4.6	0	0	2.39	
3200	7.2	0	0	2.33	4.8	0	0	2.87	6.7	0	0	2.22	
3360	5.9	0	0	2.06	4.6	0	0	3.77	3.4	0	0	1.83	
3520	0.6	0	0	1.77	-1.3	0	0	2.77	5.2	0	0	1.93	
3680	3.3	0	0	2.87	6.7	0	0	2.46	1	0	0	4.75	
3840	6.9	0	0	2.62	10.4	0	0	2.59	5.6	0	0	2.79	
4000	10.7	0	0	2.16	12.8	0	0	2.27	9.2	0	0	2.01	
4160	13.5	0	0	2.29	12.5	0.31	0.05	2.2	12.1	0.16	0.03	1.93	

SAMPLE DATA FOR THE MONTH OF AUGUST, 2016.

VI. RESULTS AND DISCUSSION

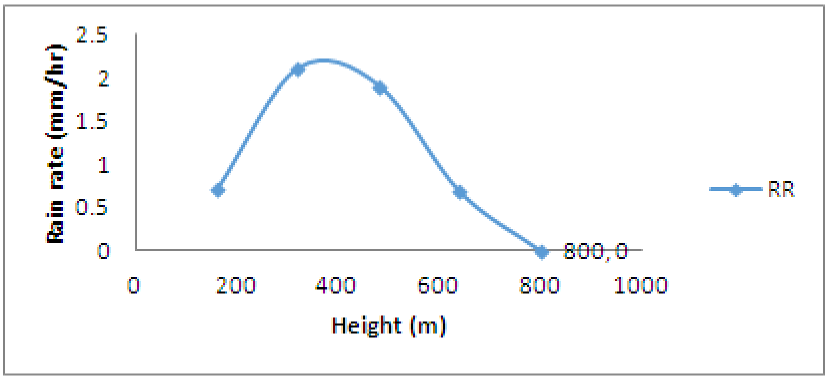

Figure 4: Drop size distribution at height 0-4800 m for 01-08-2006

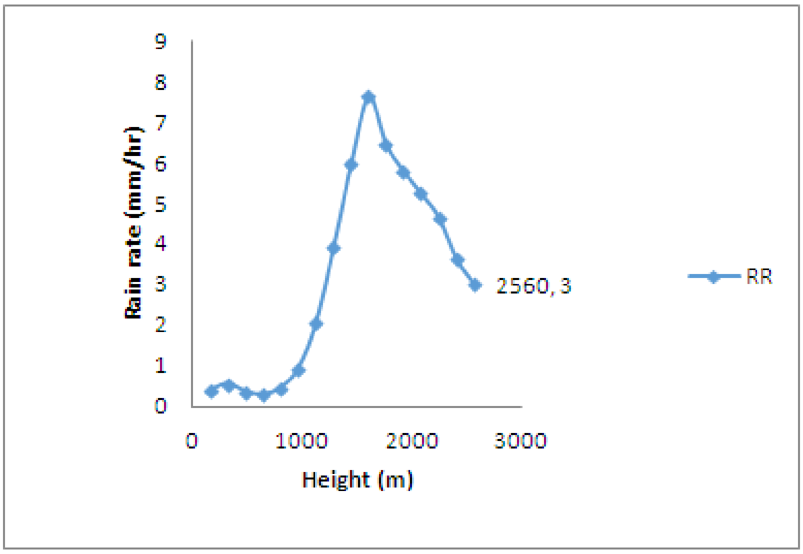

Figure 5: Drop size distribution at height 0-4800 m 02-08-2006

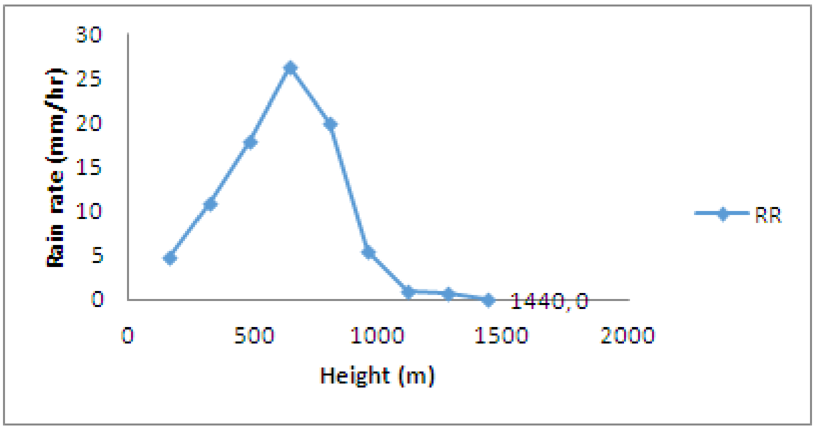

Figure 6: Drop size distribution at height 0-4800 m 03-08-2006

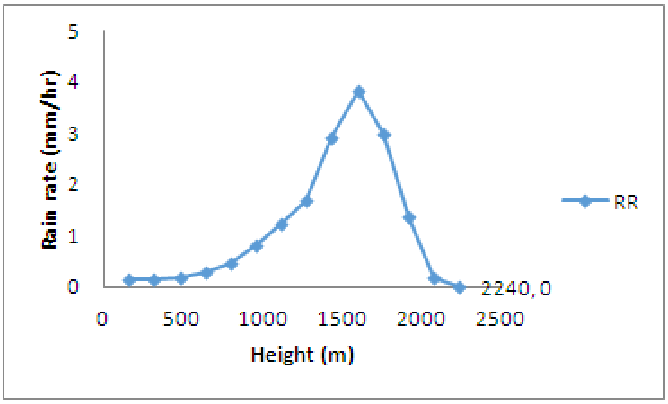

Figure 7: Drop size distribution at height 0-4800 m 04-08-2006

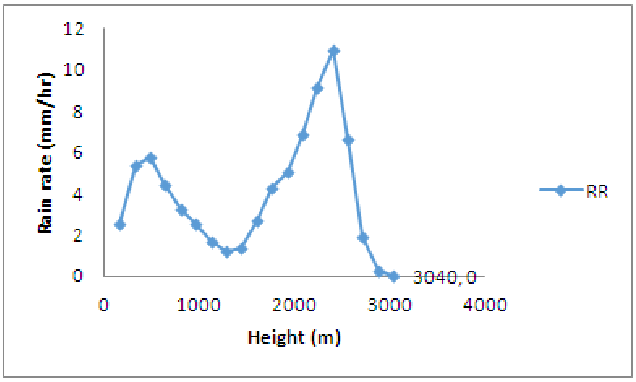

Figure 8: Drop size distribution at height 0-4800 m 05-08-2006

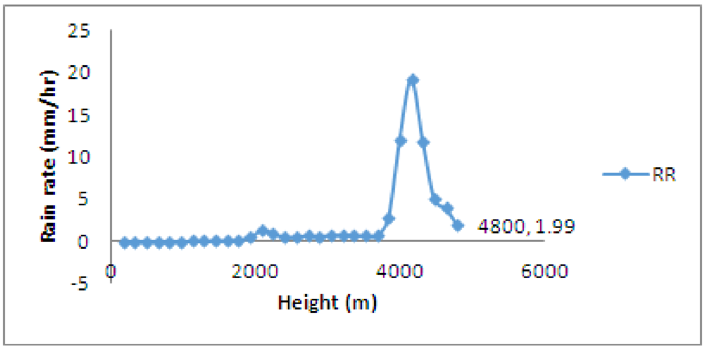

Figure 9: Drop size distribution at height 0-4800 m 06-09-2006

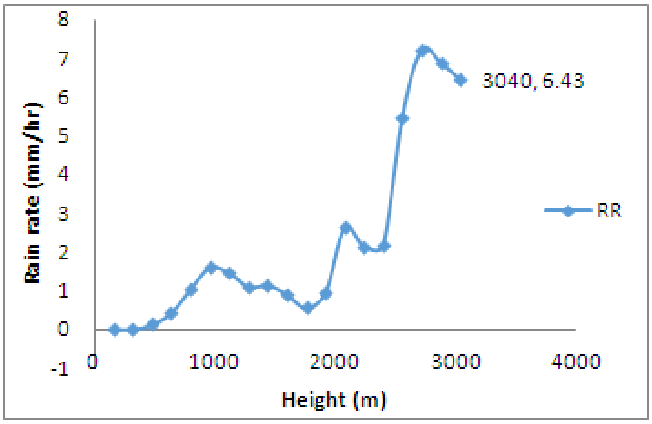

Figure 10: Drop size distribution at height 0-4800 m 07-09-2006

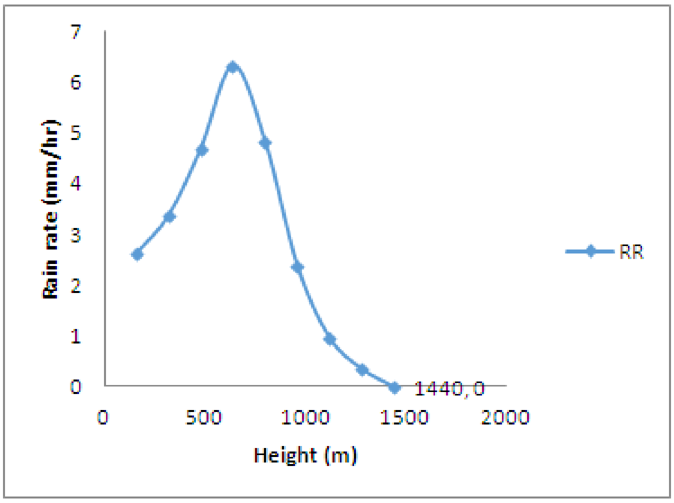

Figure 11: Drop size distribution at height 0-4800 m 08-09-2006

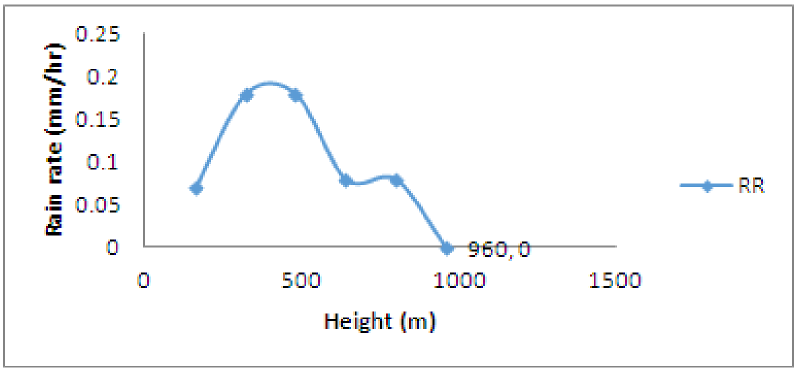

Figure 12: Drop size distribution at height 0-4800 m 09-09-2006

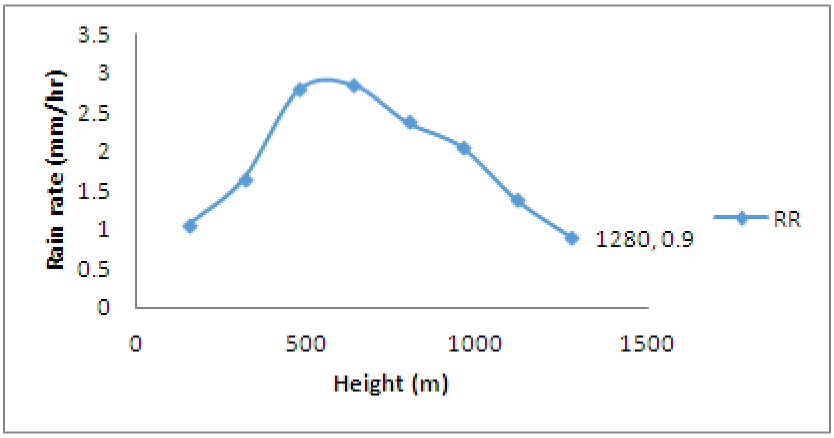

Figure 13: Drop size distribution at height 0-4800 m 10-09-2006

4.10: Results of Specific Attenuation for stratiform and convective

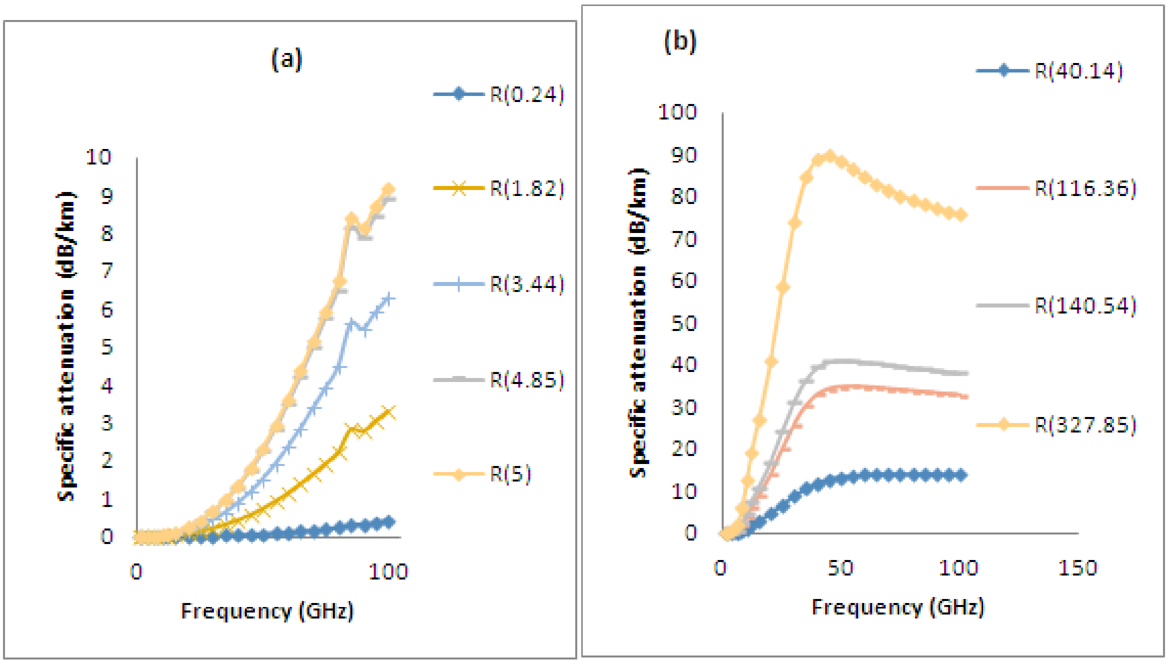

Figure14: Specific attenuation for (a) Stratiform (b) Convective at different rain rates

The variation of the rain rate with height was evaluated and presented in Figures 4 - 10 for August and September, 2006. The highest rain rate with height were observed along 0-160 m height for both cases considered.

The implication of this is that along this height, we expect to have more attenuation of radio wave due to rainfall compared with the other height bins. This is because wind and hydrodynamic forces are lower at this height than higher height levels. It is clear here that convective cell produce rain rate above 10mm/hr but for short duration not more than 15minutes between the peak. The plots of rainfall rate shows that most of the rainfall rates were mixed classes with rain coming from the Drizzle, widespread, shower and Thunderstorm clouds with the latter not well developed.

The absolute distribution of rain rates for the rainy periods of the day is 165 for rain rates ranging from 0-20mm/hr. Also for rain rates ranging from 20-40 the total rain distribution is 10 and 3 for rain rates ranging from 40 to 60 and is 1 for rain rates ranging from 100-120mm/hr.

The variation of the rain rate with height was evaluated for the two months data after being extracted from the raw data acquired as shown above.The highest rain rate and height content were observed along 0-4800m height for all cases considered. The implication of this is that along this height, we expect to have more attenuation of radio wave due to rainfall compared with the other height bins. This is because wind and hydrodynamic forces are lower at this height than higher height.

The above are the scattered diagrams indicating the correlation coefficient and the regression line for the rain rate and the height for the various daily average precipitation of August and September in the year 2006. There is a high degree of correlation in all cases considered, the coefficients of correlation are better than 0.91 for most of the rain types. The power relationships obtained were comparable for all the rain types.

The specific attenuation was evaluated for frequencies ranging from 1-100 GHz which gives room for future satellite systems design. Figure 14 shows the plot of specific attenuation for ssstratiform and convective rainfall types. In general, specific attenuation increases with increasing frequency for all rainfall types and at a critical frequency between the rangeof 31-100 GHz, the specific attenuation decreased slightly and reaches saturation at 100 GHz. The specific attenuation can be as high as 80 dB/km for convective rain type. The higher dB/km may result into total signal outage (loss) if not properly compensated in the system design. This is also in perfect agreement with the earlier prediction of Acmad *et al.*, (2007) that in tropical countries rain can induce as large as 85 dB/km attenuation on a 5 km link at high frequency.

VII. CONCLUSION

The rainfall parameters measured for the two months considered have been analyzed for a tropical station, Akure in Nigeria. It was also observed that the rain rate below 5 mm/hr contributed the most to the rain event in the height range 0- 4800m. Hence stratiform rainfall was observed for two months (06/08 & 06/08) of painstaking observation and data acquisition, while the height range of 0-640m recorded the highest rain rate. The rainfall event on 06/08 was observed to be convectional having rainfall rate above 5 mm/hr for most of the observed and recorded data. The empirical relations obtained in this analysis are intended to provide useful information about the rainfall parameters among the rainfall rate, and height content for the rain types using the least square power law regression. The recorded rainfall rates were classified using the criteria described in Joss et. al. (1968), for Stratiform rain fall rate R < 5mm/h and convective rain R > 5 mm/h.

The correlation coefficients and graphs of rain rate, and height relationships for stratiform and convective rainfall for the various days and height range considered were observed good; the values are above 0.92, while that of convective rainfall type is also very good with correlation coefficient more than 0.85.

REFERENCES

[1]. Achmad M, Muriani L M, Gamantyo H and Akira M (2007), ''Preliminary results from the study of raindrop-sizedistribution and Rainfall Rate in Indonesia for the Development of Millimetre-wave systems in Tropical regions,''Proceedings of ISAP, Niigata Japan, pp. 1390-1393.

[2]. Ajewole, M.O, Kolawole, L.B and Ajayi G. O. (1999): Theoretical study of the effect of different types of Tropical rainfall on microwave and millimeter-wave Propagation. Radio science, volume **34**, Number 5, pp 1103-1124.

[3]. Crane, R.K. (1982). A two-Component rain model for the prediction ofattenuation statistics. Radio Science Journal.**17**; 153-15

[4]. Diederich M., Crewell S., Simmer C. and Uijlenhoet (2004): Investigation of rainfall Microstructure and variability using vertically pointing radar and disdrometer; Proceedings of ERAD, 80-86.

[5]. Gerhard, P, Bernd, F. and Tage, A. (2002), Rain Observation with a verticallylooking Micro Rain Radar (MRR), Boreal Environmental Research. **7** 353 – 362.

[6]. Marzuki, H. Hashiguchi, M. K. Yamamoto, S. Mori, and M. D. Yamanaka (2013), "Regional variability of raindrop size distribution over Indonesia," Ann. Geophys., Vol. 31, 1941–1948, 2013, doi:10.5194/angeo-31-1941-2013.

[7]. Peters, G., B. Fischer, and T. Andersson (2002), "Rain observations with a vertically looking Micro RainRadar (MRR)," Boreal Environ. Res., Vol. 7, 353–362.

[8]. Renggono, F., H. Hashiguchi, S. Fukao, M. D. Yamanaka, S.-Y. Ogino, N. Okamoto, F. Murata, B. P. Sitorus, M. Kudsy, M. Kartasasmita, and G. Ibrahim (2001), "Precipitating clouds observed by 1.3-GHz boundary layer radars in equatorial Indonesia," Ann. Geophys., Vol. 19, 889–897.

[9]. Saurabh Das, Ashish K Shukla and Animesh Maitra (2010), ''Investigation of vertical profile of rain micro structure at Ahmedabad in Indian tropical region'', Journal of Advance space research, Vol. 45, pp. 1235-1243.

[10]. Shengjie Niu and Xingcan Jia, Jianren Sang, Xiaoli Liu and Chunsong Lu, and Yangang Liu (2010), ''Distribution of Raindrop Sizes and Fall Velocities in a Semiarid Platue Climate: Convective versus Stratiform Rains'', vol. 49, pp 632-645.s

[11]. Vonnisa, M., T. Kozu, and T. Shimomai (2014), "Development of dual-frequency method to observe the vertical structure of raindrop size distribution at Kototabang," J. Ilmu Fisika (in Indonesian),Vol. 6, No. 2, 52–58.

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