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Systematic Variation of Rain Rate and Radar Reflectivity Relations for Micro Wave Applications in a Tropical Location.

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Abstract: *Understanding the detailed structure and behavior of rainfall parameters is important for improving the efficiency of signals over an Earth-space transmission links. The use of data from weather radar is an efficient way of observing the characteristics of rainfall. The attenuation due to rain has been recognized as one of the major causes of unavailability of radio communication systems operating at frequencies above 10 GHz (Ojo et.al, 2008). In this study, Two years of profile measurement of rainfall parameter using vertically-pointing micro rain radar sited at the Department of Physics, the Federal University of Technology, Akure, (7°15'N, 5°15'E) has been analyzed to develop empirical model of rain rate and radar reflectivity over some heights and their effects on radio wave propagation in Akure South-West, Nigeria. The rain parameter was observed within the heights range of 160 to 4800 m at an interval of 160 m height based on the stratiform and convective rain type. Empirical relations in the form* $Z = aR^b$ *were obtained for the rainfall (R) and the radar reflectivity factor (Z) using the least square power law regression.*

Keywords: *Rain rate, Radar reflectivity, Micro Rain Radar, Tropical Location*

I. Introduction

In the design of Earth-space links for communication systems, several factors must be put into consideration. These factors include absorption by atmospheric gases, scattering and depolarization by hydrometeors such as clouds and precipitation (Freeman, 2007).

Precipitations (or hydrometeors) are known to be a major concern to link budget engineers particularly with respect to bandwidth availability and efficiency. In past research work involving the study of precipitation effects on signal transmission, rainfall has been identified as the active phenomena responsible for signal outages and losses during transmission. Instances of outages (either short or long) due to rainfall in packet-oriented networks often result in irreplaceable loss of time and resources. Hence, it is necessary to reduce these losses by embarking on corrective schemes which will eliminate to a great extent the effects of rainfall on communication systems link.

All these effects must be considered, as they are the causes of signal impairment for both terrestrial and Earth-satellite systems; with rainfall being the most crucial especially at frequencies above 10 GHz. The effect of rainfall is more severe in tropical regions which are characterized by heavy rainfall intensity and the presence of large raindrops (Ojo et al., 2008), Moupfouma and Martins (1995), observed that raindrop size distribution changes with geographical location and it can strongly influence rain specific attenuation and consequently, total rain attenuation.

In this paper, the systematic variation of rain rate and radar reflectivity factor for microwave application in a tropical environment is presented based on the in-situ measurement of rainfall parameters for a period of two years.

II. Measurement Details And Analysis

The experimental site is located at the Department of Physics, Federal University of Technology Akure, Ondo State Nigeria, (7°15'N, 5°15'E). Figure 1 presents the map showing the experimental site while Figures 2(a) and (b) are the outdoor and indoor unit of the MRR set up.

Fig 1: The map showing the experimental site.

The measurement was taken for a period of two years 2007 and 2008. The profile measurements were carried out by means of a vertically-pointing Micro Rain Radar (MRR) with a vertical resolution of 160 m and an integration time of 1 minute during an intensive measurement campaign that spanned two years at the site. The maximum measuring height was 4800 m. The height was set to give room for the rain height region at this location (Ojo, et al; 2014). For ground based comparison, measurements from a height of 160 m were used based on the altitude of the location to the sea level.


Figure 2: Experimental set up showing (a) the outdoor unit and (b) indoor unit of the MRR.

The equipment is capable of measuring raindrop diameter between 0.16 to 4.8 mm with an accuracy of $\pm$ 5 % error limit. Other details characteristics of the set up is available in the work of Peter et al, 2002 and are not reiterated here. The data were collected for 30 different range gates from 160 – 4800 meters above sea level (sea level height in Akure is (358 m) in a step of 160 m up to 4800 m.

III. Rainfall Parameters

This section discusses some rainfall parameters as applicable to this study.

3.1 Rain rate, *R*

This is a measure of the intensity of rainfall and it is obtained by calculating the amount of rain that would fall in a given location over a given interval of time if the rainfall intensity were constant over that time period. The rate is typically expressed in terms of length (depth) per unit time, for example, millimeters per hour, or inches per hour (AMS, 2007). The rain rate for each one minute drop size sample was computed using the relation:

$$R = 6\pi \times 10^{-4} \times \int_0^\infty N(D)D^3\, V(D) dD \qquad (1)$$

where R is the rain rate (mmhr^{-1}), D is the rain drop diameter (mm), V (D) is the terminal velocity of the drop in (m/s).

3.2 Radar reflectivity, Z

This is a measure of the efficiency of a radar target in intercepting and returning radio energy. The radar reflectivity of a meteorological target depends upon factors such as the number of hydrometeors per unit volume, the sizes of the hydrometeors, the physical state of the hydrometeors (ice or water), the shape or shapes of the individual elements of the group. It is usually expressed as:

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

where N (D) dD is the number of density of rain drops with equivalent diameter D in the interval dD. Equation (2) reveals that the variations of Z-R are strongly dependent on DSD variations (Kumur et al, 2011). The reflectivity factor is related to rain rate based on power law form by (Marsall and Palmer (1948).

$$Z = a\, R^b \qquad (3)$$

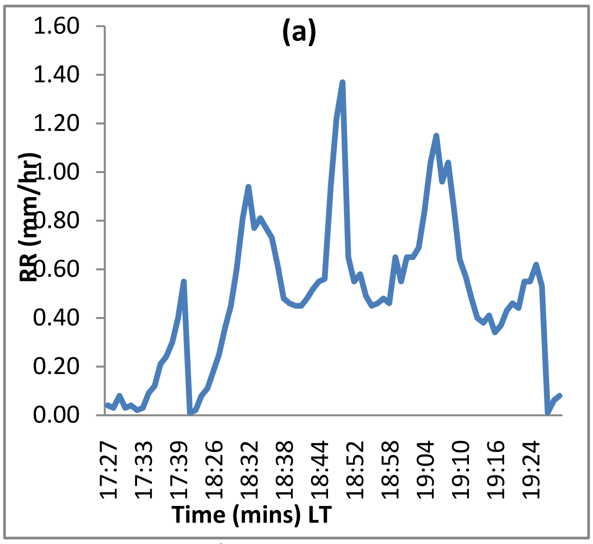
IV. Result And Discussion

Results observed in the analysis are presented in this section.

4.1 Time series of Rain event.

We have selected two rainy events to present the data obtained from the simultaneous measurement of the rain rate and radar reflectivity by the MRR over different heights. Figures 3 (a) and 3(b) present a recorded time series of rainfall rates for a short stratiform segment (approximately from 17:27 to 21:52 on the July 19, 2007) and from 16:06 to 17:41 on the July 21, 2008) higher intensity stratiform rain is presented at 160 m height. The variation of the stratiform segment is characterized by longer duration, lower and more stable intensity.

The first occurrence as presented in Figure 3 (a) shows a stratiform event with the presence of intense rain events from height 160 m. The rain events are characterized by an area-wide stratiform rain, with maximum rain rates of about 1.4mm h^{-1}observed in the half way of the rain event (18:32 – 18:50 mins LT). In Figure 3 (b), over the same height (160 m) the MRR displayed some typical widespread rainfall types with the peak of about 10 mmhr^{-1} at 16.50 hr LT.



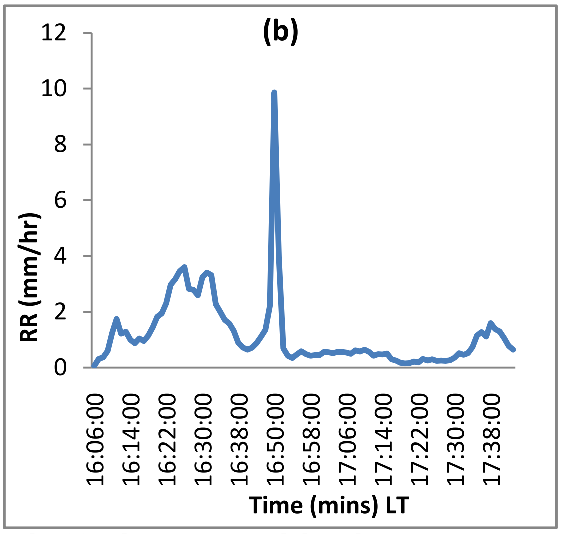


Figure 3: Time series of rain event observed at 160 m height on the (a) July 19, 2007 and (b) July 21, 2008.

Figures 4 (a) and (b) also display the time series rainy event based on the selected days at 4800 m height. A periodic pattern is observed which follows same trend as earlier discussed although with different peaks (low and high) rain rates occurring at different time of the day.

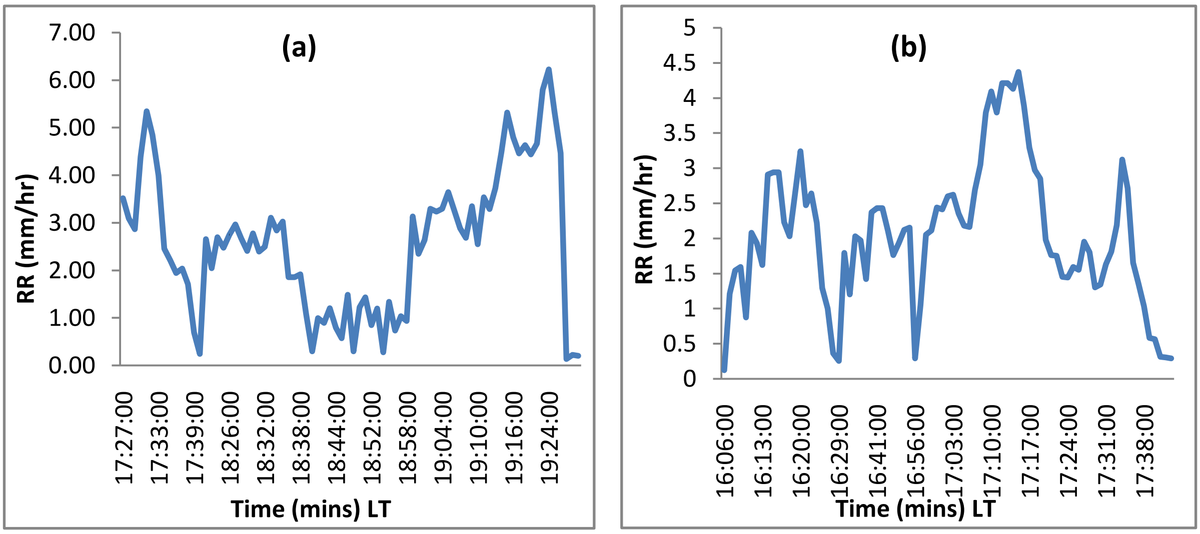


Figure 4: Time series of rain event observed at 4800 m height on the (a) July 19, 2007 and (b) July 21, 2008

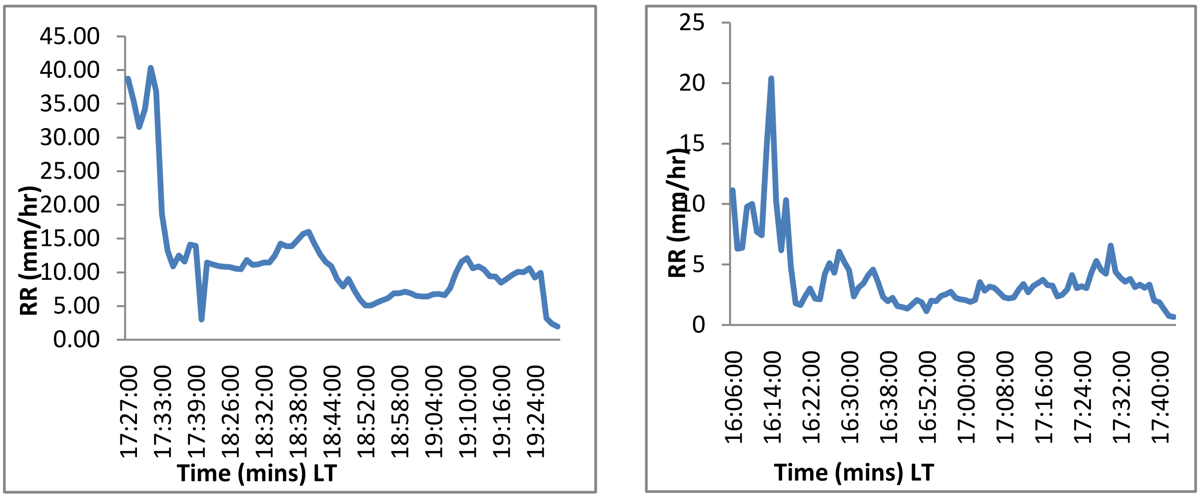
For the rain event shown in Figures 5 (a) and (b), at 4160 m height the events are characterized by an area-wide convective rain, which later on is interspersed with high rain rate or moderate rain rate up to 38 mm h^{-1}. For example in Figure 5 (a), the MRR recorded about 34 – 40 mm h^{-1} of rainfall in about 6mins. Thereafter, it reaches the peak of about 40 $mmhr^{-1}$in 6 mins at 17: 33 hr of the day. However at the same height on the 21st July, 2008 (Figure 5b) the rain events was convective, the MRR recorded up to about 22 mm h^{-1} on the same day followed by stratiform rain type. This trend is also continuous over the remaining heights (although not shown here for the sake of paucity of space).

Figure 5: Time series of rain event observed at 4160 m height on the (a) July 19, 2007 and (b) July 21, 2008

4.2 Z –R Relation

It is possible to derive the Z – R relationship through regression analysis. Such relationships generally follow power laws of the equation (3). All values of Z and R were considered in establishing the general equation for the period under review. The study also characterized the tropical DSD's during the transition from the stratiform to convective rain by deriving the best fit of Z-R relations for the rain rate retrieval in these stages. The derived Z-R relations are compared with those reported in literature (Fujiwara, 1985, Joss et al, 1970, Marshall and Palmer, 1984, Ajayi and Owolabi, 1984 to mention but few).

Figures 6 (a) and 6 (b present the Z-R relationship during the year 2007 and 2008 respectively for the stratiform rain type while Figures 7 (a) and 7 (b) are for the convective rain type. It is evident from the results



that *a* is smaller in value while *b* is increased for stratiform rain type whereas *a* value is larger and *b* value is decreased for convective rain type. These results are in agreement with those observed by Kumar et al. (2011) in another tropical region. Although, both Singapore and Nigeria belongs to a tropical region, the results obtained are not the same, which further proved the dynamical nature of rain rate in the two regions which automatically influenced the radar reflectivity factor. The results of the coefficient obtained at different heights considered are presented in Table 1. Table 2 also presents the comparison of the result obtained in this study with those earlier obtained by some other researchers. The present result does not totally deviates from the previous results. However it is evident that Z-R relations are not a fixed value for any typical region as a result of the dynamical nature of rain rate.

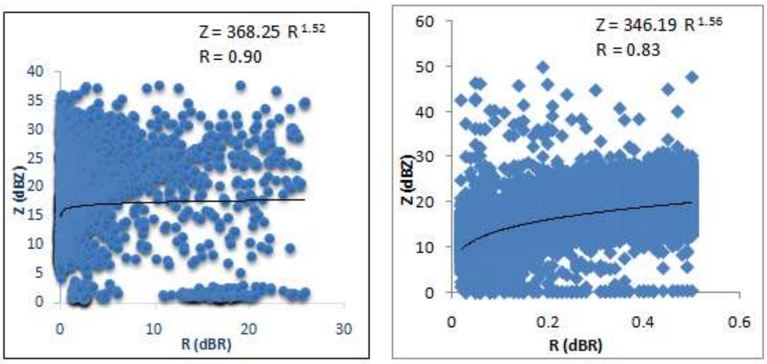


Figure.5: Z-R relation for stratiform rainfall at 160 - 4800 m heights for the year (a) 2007 and (b) 2008.

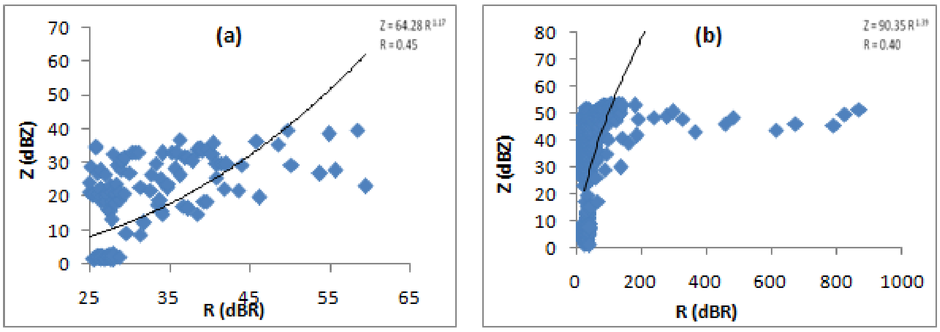


Figure.6: Z-R relation for convective rainfall at 160 - 4800 m heights for the year (a) 2007 and (b) 2008.

TABLE 1: Z – R comparison over each of the heights considered

Z =aR^b				**Z = aR^b**		
HEIGHT (m)	YEAR = 2007		Correlation coefficient	YEAR = 2008		Correlation coefficient
	a	b	r^2	a	b	r^2
160	761	0.50	0.65	220	1.66	0.82
320	139	0.18	0.73	237	1.68	0.84
640	171	0.66	0.60	209	0.69	0.78
800	168	0.60	0.76	226	1.86	0.81
1760	198	0.74	0.59	188	1.17	0.71
1920	189	1.44	0.70	208	1.45	0.92
2080	152	1.37	0.71	187	1.40	0.73
2240	192	1.28	0.68	154	0.13	0.79
2880	202	1.17	0.72	206	1.44	0.84
3040	197	1.01	0.70	199	1.32	0.76
3360	192	0.89	0.72	195	1.06	0.93
4000	198	1.06	0.74	180	0.65	0.77
4160	181	1.09	0.78	171	0.96	0.97
4320	160	1.34	0.73	150	0.83	0.86

Table 2: Comparison of Z-R Relationship with height at some locations

Rain Type	Source	Location	*Z-R*	R
Stratiform Rain	Fujiwara (1965)	Miami, USA	$Z = 250 R^{1.48}$	
	Joss et al (1970)	Locarno – Monti	$Z = 220 R^{1.6}$	
	CCIR (1982)		$Z = 400 R^{1.4}$	
	Marshall and Palmer (1984)	Switzerland	$Z = 220 R^{1.6}$	
	Ajayi and Owolabi (1986)	Ile- Ife, Nigeria	$Z = 312 R^{1.35}$	
	Fundacao et al (2004)	Eastern Coast, Brazil	$Z = 167.8 R^{1.26}$	
	Present study (2007) (160 -4800 m) (160 m)	Akure, Nigeria	$Z = 368 R^{1.52}$ $Z = 350 R^{1.52}$	0.90 0.65
	Present study (2008) (160-4800 m) (160 m)	Akure, Nigeria	$Z = 346 R^{1.56}$ $Z = 325 R^{1.66}$	0.83 0.62
Convective Rain	Jones (1956)	Illinois, USA	$Z = 500 R^{1.5}$	
	Fujiwara (1965)	Miami, USA	$Z = 450 R^{1.37}$	
	Diem (1966)	Entebbe, Uganda Lwiro, Congo	$Z = 278 R^{1.3}$	
	Joss et al (1970)	Locarno – Monti, Austria	$Z = 500 R^{1.5}$	
	Sekhon and Srivastava (1971)	Cambridge, USA	$Z = 300 R^{1.35}$	
	Ajayi and Owolabi (1986)	Ile –Ife, Nigeria	$Z = 524 R^{1.27}$	
	Present study (2008) (160-4800 m) (160m)	Akure, Nigeria	$Z = 568 R^{1.32}$ $Z = 420 R^{1.27}$	0.76 0.62
	Present study (2006) (160-4800 m) (160 m)	Akure, Nigeria	$Z = 570 R^{1.37}$ $Z = 476 R^{1.34}$	0.82 0.65

Z is in $mm^6 m^{-3}$ and R in $mm h^{-1}$; r is the coefficient of correlation

V. Conclusion

In this report, we have presented the analysis Z-R relationship and their effects on radio wave propagation over Akure. The MRR data from 160 m to 4800 m height with a resolution of 160 m over two years have been used. The result of the time series of the two rain events over all the heights considered in this work shows that at heights below 3000 m, the rain events were characterized by stratiform rainfall types; however, at heights greater than 3000 m, the rain events were convective followed by stratiform rain at about 4800 m height above sea level.

Also, the result of the vertical profile of reflectivity of rainfall (Z - R) shows that the pre- factor takes values in the range 139 to 761 and the exponents ranged between 0.18 to 1.68, with correlation coefficients between 0.59 and 0.93. This relation shows that the Z – R relationships derived over each of the heights, were found to be very diverse and good correlation was obtained for the experimented result.

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