Classification of tropical convective and stratiform rains using a Micro Rain Radar and its effect on microwave radio signals in Akure

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Abstract

Micro Rain Radar (MRR-2) positioned at Federal University of Technology Akure ($7^o15^/ N, 5^o15^/ E$)was used for the measurements of rainfall parameters like the liquid water content , radar reflectivity, rain rates and the corresponding falling velocities. It was done for heights ranging from 0   4800m with 30 different range gates of height steps 160m above sea level. The rain types were classified into Drizzle, widespread Shower and Thunderstorm depending on the values of rain rates in mm/h.

Data collected for the monsoon period of two years were used to determine the vertical profile of the Z-R relationship using the power law: $Z = aR^b$ for all the rain types. Result shows that the values of the correlation coefficients were all above 0.64 (except for thunderstorm 2010) suggesting a good Z-R relationship. Values of coefficients a and exponents b so obtained are very useful in predicting attenuation and the study of radar meteorology.

Keywords: *Micro rain radar, Drizzle, Widespread, Shower, Thunderstorm and attenuation.*

1. Introduction

Radar (in its general term) is a system that uses electromagnetic waves to identify the location, direction, and / or speed of both moving and fixed objects like aircrafts, ships, motor vehicles, weather formations and terrains.

Micro rain radar is a very unique instrument that measures all the rainfall parameters like the drop size distributions (DSD), rain rates (RR), Liquid water content (LWC), the fall velocity (W) and the 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. It has the transmitter and a receiver typically in the same location. The transmitter emits radio waves that are reflected by the targets and detected by a receiver. Due to the fact that returned radio signal are usually weak, radio signals are easily amplified. Hence, radar can detect objects at ranges where other emissions like sound or visible light would be too weak to detect.

Rains are droplets in water or precipitation from clouds in the sky that are bigger than 0.5mm. Droplets of water that are about 0.2mm to 0.5mm big are called drizzle [1].

The main objective of this work is to classify rain activities into stratiform and convective based on measured parameters and also to determine the relationship of these parameters as it impaired radio propagation.

Various authors have done similar work using the conventional rain gauge to measure the rain rates and at heights resolutions of 50m to 100m and about 30minutes time resolution. Most of this works were carried out in temperate regions. However, [2] in Ile-Ife, West Africa measured rainfall parameters using a disdrometer over a time interval of one minute for 21 rain events. Similarly, considerable effort has gone into the various methods for classification of tropical precipitation such as [3. Since according to [4], the mass field respond to latent heating profiles in convective and stratiform precipitation differently, more methods have been employed in classifying this rainfall types. Also, [5]Ali Tokay et. al. worked on the comparison of Dropsize Distribution measurements (DSD) by impact and optical Disdrometers. Here the observation were designed to test how accurately the instruments measure DSD. Similarly [6] shows the Z-R relationship for a weather radar in the Eastern coast of North Eastern Brazil and obtained values for coefficients a and exponents b and compared with other values obtained in similar regions for all the classes of rain fall types.

Classification of rain events into convective and stratiform rain is very important this is due to different nature of contribution of latent heat released to climate. When weighted mean diameter (D_o) and RR decreases simultaneously following convective period, the rain is classified as transition. The stratiform rain is characterised by approximately steady having RR 10mm/hr and usually with higher value of D_o (mm) and rain events having RR greater than 10mm/hr are referred to as high rain otherwise called convective rain. High rains consists of nearly 10% of total rainfall observation [7].

2. Instrumentation / Experimental Site

This typical MRR-2 used for this work operates with an electromagnetic radiation at a frequency of 24GHz with a modulation of 1.5- 15 MHz depending on the height resolution. Here the height is resolved to a total of 30 range gates from 160m to 4,800m. The radiation is transmitted vertically to the atmosphere and a small portion of it is scattered back, by rain drops or other forms of precipitations at those height, to the antenna all in the same point.
As a result of the falling velocity of the rain drops relative to the stationary antenna, there is a frequency deviation (called the Doppler frequency) between the transmitted and received signal. This frequency is a measure of the falling velocity of the rain drops.

The radar also has an electronic unit which determines this spectrum with an 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.

3. Theoretical Background / Methodology

Radar reflectivity factor is a function of the size, dielectric property, shape and aspect of the target.

It is measured by this equation:

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

($mm^6 m^{-3}$) 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.

While the liquid water content is given by:

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

ρ_w is the density of water

The differential rain rate rr (D) is equal to the volume of the differential drop let number density

$$\left(\frac{\pi}{6}\right) . N(D) D^3$$

Hence, rain rate is obtained by integration over the drop size:

$$RR = \frac{\pi}{6} \int_0^\infty N(D) D^3 v(D) dD ---------- (4)$$

The relation between the radar reflectivity and rain rate depends on the structure of the drop size distribution. Gerhad Peters et al.

4.1 Z-R Relationships

Equation $Z = aR^b$ was used to determine the relationship between rainfall rate (*R*), radar reflectivity factor (*Z*). Natural logarithm is applied to both sides of the equation resulting in:

$$LnZ = Lna + bLnR$$

Making Y = lnZ; س= ln a; س= b; X = ln R

a straight-line function is obtained:

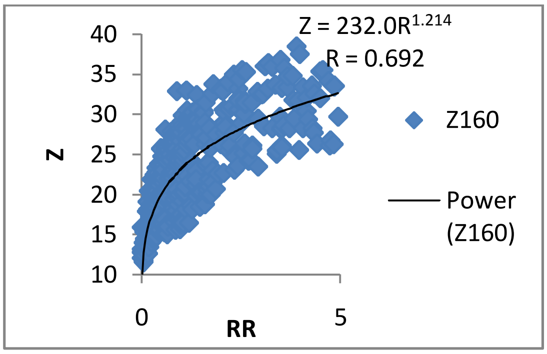
$Y = \alpha + \beta X$ -- (5)

where سand سare the y-axis intercept and the slope respectively. The coefficients a and b of equation ($Z = aR^b$) were estimated by linear regression for Z versus R.

4.2 Categorization of Rainfall Types

There are two main classifications of rain, they are the convective and stratiform rain. The two can be further classified into Drizzle, Widespread, Shower and Thunderstorm.
In this work the rain types are classified into Drizzle, widespread, shower and thunderstorm. They are classified as follows: Drizzle 0<R 5; Wide spread 5<RR 10mm/hr; Shower 10<RR 40mm/hr; Thunderstorm RR>40mm/hr.

5. Results



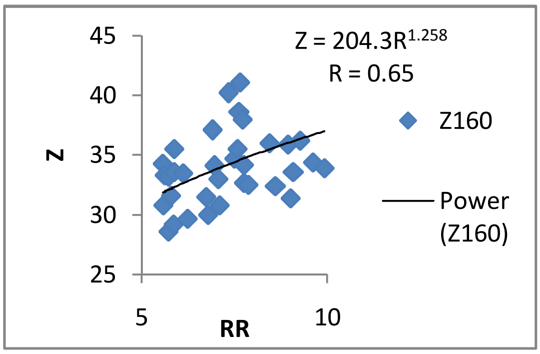
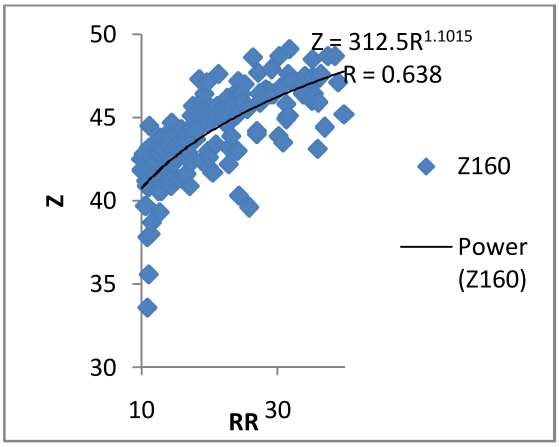


Fig. 1a: Z-R relation at height 160m for Drizzle (2009) Fig. 1b: Z-R relation at height 160m for Widespread (2009)



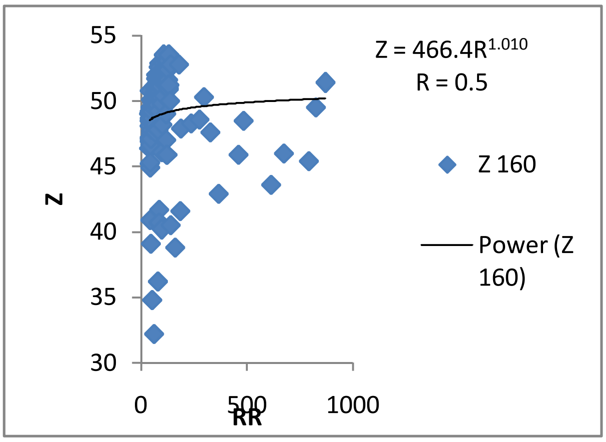


Fig. 1c: Z-R relation at height 160m for Shower (2010) Fig. 1d: Z-R relation at height 160m for Thunderstorm (2010)

Z-R RELATIONSHIP FOR DRIZZLE, WIDESPREAD, SHOWER AND THUNDERSTORM RAINFALL

There are two main classifications of rain, they are the convective and stratiform rain. The two can be further classified into: Stratiform: Drizzle and widespread; Convective: Shower and Thunderstorm.
In this work the rain types are classified into Drizzle, widespread, shower and thunderstorm. They are classified as follows: Drizzle 0<R 5; Wide spread 5<RR 10mm/hr; Shower 10<RR 40mm/hr; Thunderstorm RR>40mm/hr. 84% of rainfall events were classified as stratiform rain and the remaining as convective rain (Marcia ------).

Table 1 - **RDSD and Z-R coefficient and respective correlation coefficients for Drizzle, widespread, shower and Thunderstorm rain classes for years 2009 and 2010**

Year	RDSD					Z-R Relation and correlation coefficients (r)			
	Total	Drizzle	W.S	Shower	T.S	Drizzle	widespread	Shower	Thunderstorm
2009	12,188	9,374	1,240	1,432	141	$Z=232R^{1.21}$, r=0.69	$Z=204.3R^{1.26}$, r=0.65	$Z=249.2R^{1.16}$, r=0.71	$Z=380R^{1.06}$, r=0.86
2010	18,288	14,901	1,564	1,673	150	$Z=249.6R^{1.25}$, r=0.81	$Z=266.8R^{1.19}$, r=0.58	$Z=313.5R^{1.11}$, r=0.64	$Z=466.1R^{1.01}$, r=0.5

Table 1 shows the yearly RDSD as well as the a and b coefficients resultant from the Z-R regression technique. For stratiform class, the a coefficient is in the range 204 and 266 being highest in 2010. The b coefficient did not vary significantly, remaining in the range 1.19 and 1.26. The correlation coefficient were all well above 0.58. For the convective class the value of the a coefficient were high and varied widely from 249 to 466 being highest in 2010 whereas the b coefficient values were small from 1.01 to 1.16. The correlation coefficient were all above 0.64 (except for Thunderstorm 2010) suggesting a good Z-R relationship.

6. Conclusion

For the study of Z-R relationship for the MRR in the tropical region of Akure Ondo State Nigeria the rainfall rates were divided into two major classes using the criteria described by Mahen Konwar et al (2006) and further subdivided into Drizzle, widespread, shower and Thunderstorm. The values of coefficients a for Drizzle and Widespread for year 2009 were in the range of 204 and 232 whereas values of b coefficients in the range 1.21 and 1.26. For the convective class for year 2009 a varies from 289 and 380 and b varies from 289 and 380 and b varies from 1.06 and 1.16. Result obtained here are similar to what obtained in the literature but the convective ones were not. The fact that the Z-R general relationship had coefficients similar to the ones in stratiform (Drizzle and Widespread) this does not mean that stratiform rainfall predominated during the study period. The correlation coefficient for the two years is between ~0.6 and 0.8 meaning they have good relationship. For convective, they can be said to have fairly good Z-R relationship as the correlation coefficient r is 0.5 for Thunderstorm in 2010.

The plots of radar reflectivity and 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. This is evident in the plots in Figures 1 and the values of RDSD in Table 1 where the total RDSD during the monsoon periods in 2009 has convective rain of 1,543 and stratiform of 10,614. Also, for year 2010 the RDSD for stratiform is 16,465 and convective rain is 1,823.

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