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Vertical Profiles of Rain Drop-Size Distribution over Tropical Semi-Arid-Region, Kadapa (14.47° N; 78.82 ° E), India

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Abstract:* South-West and North East monsoon are the two important periodic winds, which show high impact on the rain. In general, the South-West (SW) monsoon spreads over the state from June to September and North-East (NE) monsoon from October to December. In this paper we present the details of vertical profiles of rainfall measured with Micro Rain Radar (MRR) deployed at Kadapa (14.47° N; 78.82 ° E), a semiarid tropical site in Andhra Pradesh, India for the period from 2009 to 2010. This paper discusses the relation between various rain drop size distribution properties such as Rain Reflectivity (Z), Rain Rate (RR), Liquid Water Content(LWC) of the rain in these two monsoons. In the present study, the Z-R relationship is obtained using linear regression. The Strati form and Convective precipitations are found to occur at different rates of rainfall.
Keywords: Rain Rate, Radar Reflectivity, Liquid Water Content, Linear Regression

I. Introduction

The Rainfall measurement is one of the most important metrological parameter for cloud classification studies. An important characteristic of clouds and precipitation is the raindrop size spectrum. The nature of clouds means it is necessary to use techniques such as remote sensing. One instrument which uses remote sensing, more precisely electromagnetic waves in order to study precipitation, is Micro Rain Radar (MRR). This is a very useful device, capable of analyzing the distribution of raindrop sizes in a vertical column with an acceptable temporal and spatial resolution. The remote detection of rainfall using radar is parameterized through the reflectivity factor, which depends on the number of drops and the distribution of sizes. The technical details and limitations of MRR technology have been described in previous studies, along with some applications [1–5]. In addition, the Ground based MRR is very much useful to validate satellite data.

These days cloud precipitation measurement is carried out by Digital Recording Rain Gauges (satellite data).. Almost from the year 1900 onwards the Rainfall measurements are being carried out by Indian Metrological Department (IMD) from many parts of the country. The rain rate estimation from the MRR measurements is based on empirical model such as the Z-R Relation [1]. Measurement of accurate rain rate requires in depth knowledge of rain DSD (Drop Size Distribution) [2]. Generally, the heavy Rainfall occurs during the monsoon seasons. All the rain parameters are integral parameters of rain DSD [3]. The study of rain DSD is also very useful for different domains like cloud physics, microwave communications, soil erosion. The radar reflectivity Z is the 6th moment of rain DSD. The back scattered signal is not only dependent on rain rate but also depends on number and size distribution of rain drops. Reflectivity factor should be derived from rain DSD.A wide range of Z-R relation has no one-to-one relation far so. To estimate the Rainfall, the common technique used is to develop the relation between Radar Reflectivity Z and Rainfall Rate R. In recent research several scientists have examined the applicability of separate Z-R relations for rain originated from Stratiforrn and Convective clouds. Lee et al presented an analytical solution for single rain drop evaporation and results showed reflectivity is more sensitive than differential reflectivity [4]. So ZDR-Z-R formula is more robust and more accurate than Z-R formula. In general, the Z-R relation shows clear differences between NE and SW monsoon seasons. [5] Normally the drop size is bigger during SW monsoon precipitation than NE.

II. Experimental setup

The Micro Rain Radar deployed in the premises of Yogi Vemana University, Kadapa (***14.47°N; 78.82°E***) is shown in Fig (1)

Fig (1) Micro rain radar deployed at Yogivemana University Kadapa

MRR retrieves the vertical profiles of the rain such as Rain Rate, Reflectivity and other rain parameters. The specification of MRR is as follows in Table 1.

S.No	Parameter	Range
1	Frequency	24 GHz
2	Modulation	05-15 MHz
3	No.of height steps	31
4	Transmit power	50 mW
5	Average Time	1 Minute
6	Power Supply	DC

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III Comparative Study of the Rain Measurements

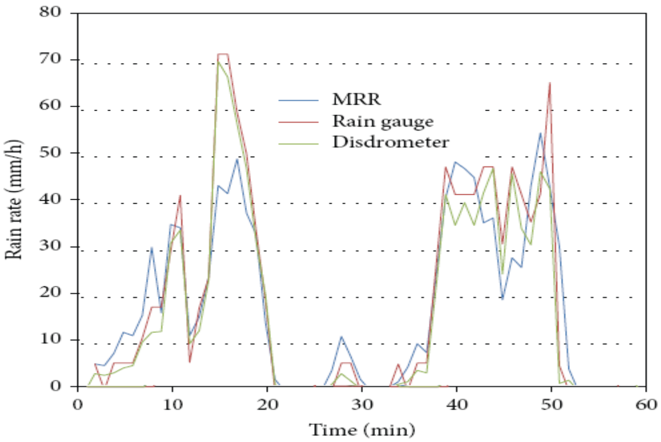

Fig (2) Comparison of the different precipitation intensities measured with the three instruments.

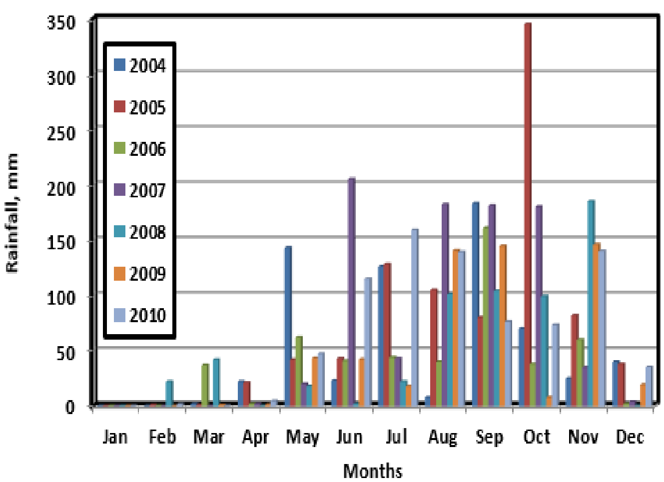

Fig (3) Rainfall information during from 2004 to 2010 year over kadapa as per IMD

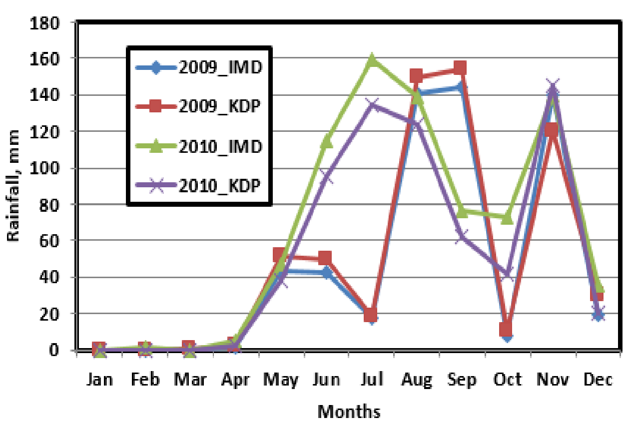

Fig (4) Comparison of Rainfall during 2009 and 2010 over kadapa

This section compares the data provided by the three different instruments used in the study for collecting rain samples. each instrument uses a different method and thus measures rain on different sampling volumes (the Rain gauge and the disdrometer measure at ground level, and the MRR measures in a column of 3,000m at 30 height levels). However, the differences should be explicable from this perspective, as they all measure precipitation intensities. Figure 2 shows the precipitation intensities registered by each of the three devices: the rain gauge and the disdrometer at surface level and theMRR,where an average has been used of the precipitation intensities at the levels of 200 and 300m above surface level.

Rainfall data was collected by India Meteorological Department (IMD) for seven years from 2004 to 2010, i.e. in SW and NE monsoon seasons, respectively. The following graphs [Fig (3) & Fig (4)] illustrate the Rainfall information over Kadapa. Comparison of Rainfall from rain gauge and MRR during 2009 and 2010 over kadapa is shown good agreement between to measurements and that indicates MRR can be used for precipitation studies.

IV. Z-R Relationship

The Z-R relation is very useful for studying the classification of clouds. Radar does not measure rate of rainfall directly, but estimates back scattered energy from the rain drops using a parametric relation

$Z=\alpha R^{b}$ ------------------ (1)

Where Z is Radar Reflectivity (dBZ), R is rainfall rate (mm/hour), and α and b are constants.

A universal Z-R relationship does not hold in all conditions. Reflectivity depends on the back scattered energy by target. When Rainfall rate increases the back scattered energy decreases, because of attenuation of the signal by Rainfall.

$$RR \ \alpha \ \frac{1}{Reflectivity(R)} \text{ --------- (2)}$$

Hence at high Rainfall rate a conventional Z-R relation may not be valid. Moreover at high Rainfall rate, the rain events consist of various drop sizes [6]. The shape of the rain drop size distribution show bi or tri model peaks.[7] reflectivity depends on DSD at high Rainfall rates. Concepts of single Z-R relationships may not be appropriate [8] in Z-R relationship instantaneous surface and upper air metrological elements (pressure, temperature etc.) will not consider the back scattered signal surfaces bending due to variations of refractive index in atmosphere.[9] pointed out that large data set of over 10,000 samples is required to obtain valid estimates of Z-R parameters. In [10] the stratiform precipitation has small drops (lower reflectivity) or some large drops (high reflectivity) dominated rain rate produced by a drop spectrum. The specific Z-R relations are usually established based on Rain data versus radar reflectivities [11].From the previous studies the Rainfall decreases for a given radar reflectivity as the precipitation form changed from convective to Stratiform. In Z-R relation normally the region, Coefficient ‘ α ‘ increased downward with height in each category .Exponent ‘b’ showed a small decrease for Stratiform and no change for convective or a small increase for mixed convective and Stratiform. In Stratiform region the Coefficient ‘α’ increases by ~37% with decrease in height and exponent ‘b’ decreases slightly.

In the previous literature [12] the Z-R relation is obtained Z= 315 $R^{1.20}$ for all data, Z=139 $R^{1.43}$ for Convective, and Z= 367 $R^{1.30}$ for Stratiform. [13] Z for Stratiform is larger than that for Connective. Stratiform precipitation falls from nimbostratus clouds and convective from cumulus and cumulonimbus clouds. [14] Z-R relation was Z= 407 $R^{1.26}$ for a particular event, where as it was Z = 431 $R^{1.25}$ for all events.. The exponent B (Coefficient A) found to be smaller(larger) in case of Stratiform(convective) than in convective (Stratiform). Considered effect of heights in the range 200 m - 2000 m , and found that 'b' reduced from 1.3 to 0.9 . The co-efficient 'α' was also found to decrease with height and has a range between 60 and 210 for light and moderate rain, but exceeding 500 at lower altitudes during heavy rain. In our research work, where the highest rainfall of about 150 mm/ hour was recorded on 16-11-2010, with the radar reflectivity ranging to 200 dBZ at different heights as shown in Fig (5). Where as in Fig (6) Scatter graph for Rain Rate vs Radar Reflectivity pertaining to data recorded on 7-11-2010 as 55mm/h the Rainfall show on x-axis and it’s radar reflectivity recoded around 142 dBZ.

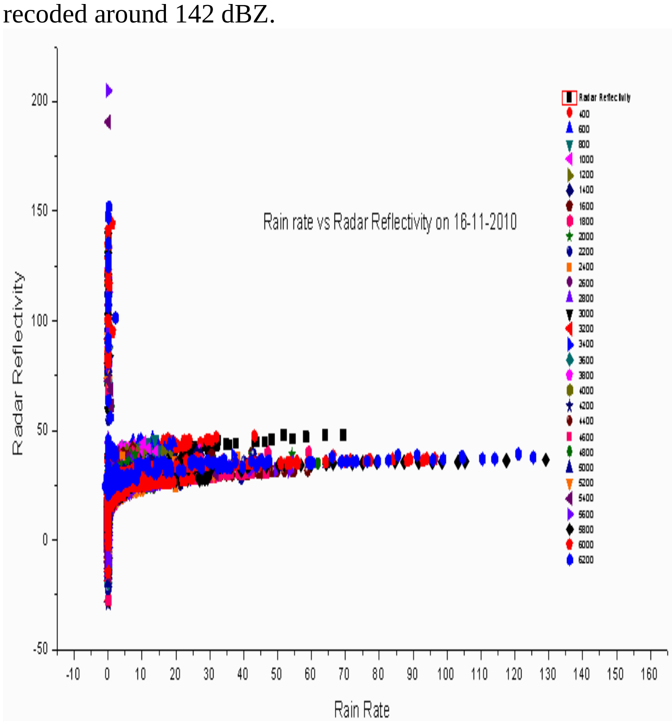

Fig (5) Scatter graph for Rain Rate VS Radar Reflectivity as on 16-11-2010

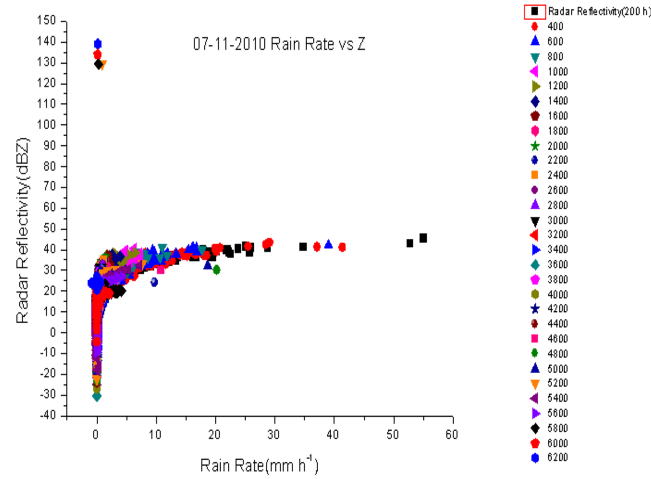

Fig (6) Scatter graph for Rain Rate VS Radar Reflectivity as on 07-11-2010

In the present work, rainfall data recorded on 7-11-2010 and 16-11-2010 was analyzed for threshold rainfall rates of R ≥ 50 mm/ hour for Convective and R < 50 mm/hour for stratiform rainfalls. Fig.8 shows a considerable difference in the rainfall on the two dates mentioned. A Radar Reflectivity of 40 dBZ and rainfall rate of 25 mm/ hour indicates stratiform precipitation. Whereas, high Radar Reflectivity of 49 dBZ and rainfall rate of 53 mm/ hour indicate convective precipitation.

Z-R relationship for convective and Stratiform Rainfall

The whole rain rate data is further divided into two one is convective and another is startiform Rainfall, by using threshold R ≥ 50 mm/h and R< 50 mm/h respectively. Fig (7) and (8) show the Stratiform and convective Rainfall ocuured at 16-11-2013 and 07-11-2013; Figure (9) shows the Stratiform Rainfall on two days ; Figure (10) represents the convective Rainfall for two days with height range from 0 to 6200 m. The Z-R relationship for above two days are represesnted in table (3) .

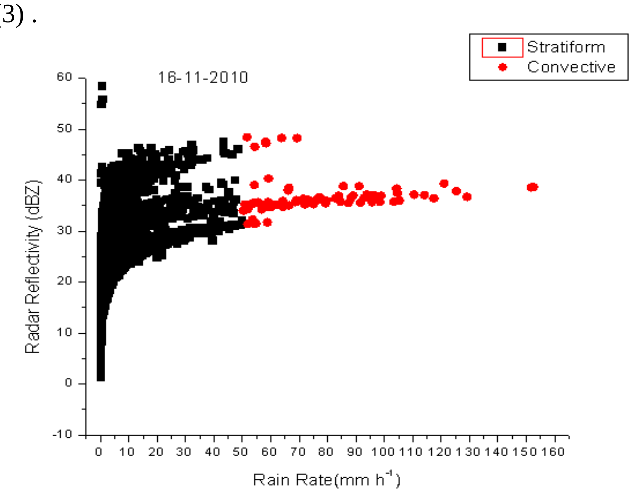

Fig (7) Stratiform and Convective Rainfall on 16-11-2010

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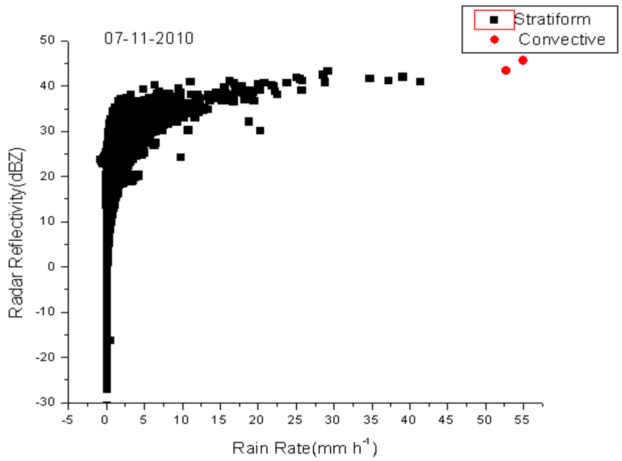

Fig (8) Stratiform and Convective Rainfall on 07-11-2010

The values of Z and R pertaining to the measurement years of 2009 and 2010 were used for establishing the general expression connecting Z and R. Heights in the ranges of 0 to 6200 m and 0 to 200 m above sea level were separately considered for comparison.

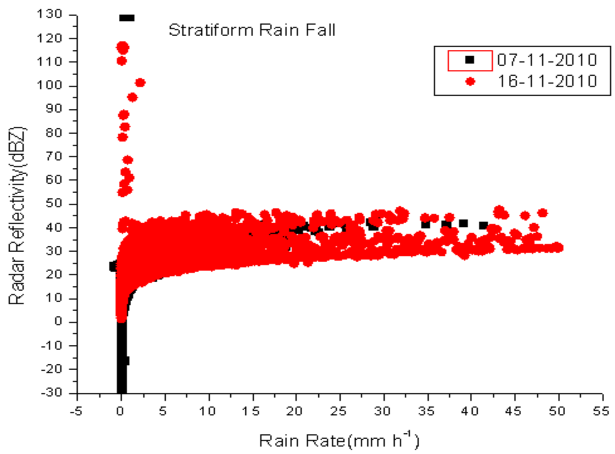

Fig (9) Stratiform Rainfall for Cyclone days

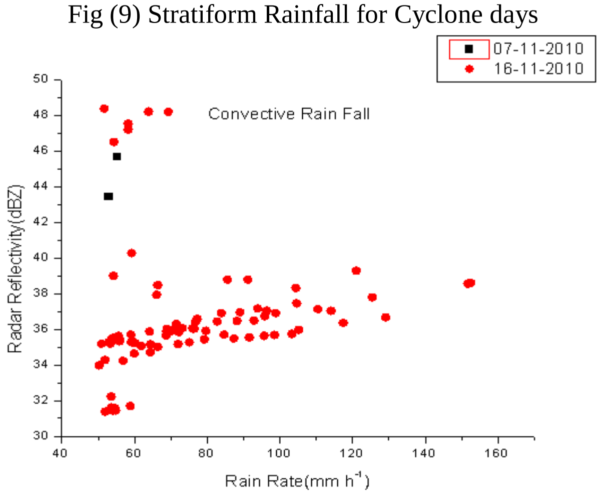

Fig (10) Convective Rainfall for Cyclone Days

Date	Stratiform	Convective
07-11-2010	Z = 94.68 $R^{1.32}$ (r = 0.90)	Z = 114.86 $R^{1.32}$ (r = 0.91)
16-11-2010	Z = 254.69 $R^{1.34}$ (r = 0.90)	Z = 229.46 $R^{1.4}$ (r = 0.8)

Table (3) Comparision Z-R relationship of Stratiform and convective rain during cyclone.

The Z-R relationships obtained for 2009 and 2010 are given below.
Range 0 to 6200 meters:
Stratiform Rainfall

Z = 108.86 $R^{1.16}$ (r = 0.81) (2009) -------- (3)

Z = 94.63 $R^{1.19}$ (r = 0.92) (2010) -------- (4)

Convective Rainfall

Z = 58.36 $R^{1.14}$ (r = 0.63) (2009) --------------- (5)

Z = 64.38 $R^{1.33}$ (r = 0.79) (2010) ----------- (6)

Range 0 to 200 meters:
Stratiform Rainfall

Z = 334.62 $R^{1.28}$ (r = 0.8) (2009) ----------- (7)

Z = 242 $R^{1.30}$ (r = 0.91) (2010) ----------- (8)

Convective Rainfall

Z = 684.53 $R^{1.29}$ (r = 0.92) (2009) ----------- (9)

Z = 498 $R^{1.33}$ (r = 0.90) (2010) ---------- (10)

The above expressions for Z indicate the following:

- Correlation coefficients for Convective rainfall are smaller than those for stratiform rainfall in the range 0 to 6200 meters.
- Correlation coefficients for Convective rainfall are larger than those for Stratiform rainfall in the range 0 to 200 meters.

V. Conclusion

The MRR rainfall parameters viz. Radar Reflectivity, Rain Rate and Liquid Water Content,were analyzed using the data observed by the tropical station at Kadapa, India for the years 2009 and 2010. From this data, empirical relations between Z, R, and LWC were obtained using the least square power law regression. Joss et al. classified R ≥ 50 as Convective rainfall and R < 50 as Stratiform rainfall. High Rain Rate of 159 mm/ hour and Radar Reflectivity of 200 dBZ were observed during the cyclone period. The LWC varied from 0.0 to 14.07 for different height ranges. Good correlation (r > 0.8) is observed among Z-R coefficients for stratiform rainfall for both 2009 and 2010. For Convective rainfall, good correlation is observed at lower heights but correlation is poor for large height span of 0 to 6200 meters.

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