Z-R RELATIONS OF MICRO RAIN RADAR DURING CYCLONES, MONSOON AND CLEAR SKY CONDITIONS AT COASTAL LOCATION OF ANDHRA PRADESH

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ABSTRACT

To oversee the research on precipitation a portable, compact Frequency Modulated Continuous Wave (FM-CW) System said as the Micro Rain Radar (MRR or MRR2) is used which operates at 24 GHz. It’s a low-cost, often radar system that requires minimum maintenance and supervision. In this paper we derive and compare the Z-R relations from a low-power, low-cost vertically pointing FM-CW System Micro Rain Radar (MRR) operating at 24.1 GHz at different rain fall events. Here the rainfall data is recorded continuously by a vertical profile Doppler radar Micro Rain Radar MRR2. Z-R relation of the form $Z = A R^b$ is derived from coastal location of Andhra Pradesh of Cyclone period Rain events, clear-sky mode and monsoon period rain events are collected from the vertically profiling Doppler radar Micro Rain Radar (MRR2) installed at K L University (16.440N, 80.620E) 29 meters above the sea level (ASL) in Centre for Applied Research in Electromagnetics (CARE) lab. The coefficients $A$ and $b$ of Z-R relation varies from place to place. Data recordings collected under different climatic condition like clear sky, monsoon and cyclone are evaluated and sketched. By this seasonal rainfall and reflectivity intensities with variations in coefficient $A$ and exponent $b$ is observed.

Keywords: MRR, Radar Reflectivity (Z), Rain rate (R), vertical profile, Doppler radar.

I. INTRODUCTION

In the current days the remote sensing instruments are largely used for meteorological, Cloud physics. The signals are backscattered due to the precipitation present in the atmosphere that affects the day-day communications of wide wireless and cellular systems [1]. Micro Rain Radar (MRR2) is used to measure the Radar reflectivity (Z) and Rain rate (R) that is given by Marshall and Palmer as $Z = A R^b$ which is a power equation and varies from place-place with time. A vertical profiling K-band radar (MRR2) and X-band (POSS-Precipitation Occurrence and Sensor System) radar is used [2], to study the Snowfall characteristics and Z-R relation of graupel and snowflake events with the particle image by using Electric balances and Image System and vertical radar reflectivity is obtained by MRR. In Kolkata region Z-R relationship [3], of monsoon (stratiform) period and post-monsoon (convective) periods are carried out by Doppler radar (Micro Rain Radar), where power relation used by this radar for Rainfall rate (RR) and Radar Reflectivity (Z) obtained from DSD is $Z= A R^b$. The variation in coefficient 'A' and exponent 'b' is observed differently for different locations and time of Remote sensing instruments using for rainfall estimation. The precipitation measurements and categorization of rainy season relations [4], are made from France with three weather radars of distinct locations X-band Radar, Spatial resolution weather radar and vertical profiling radar MRR2 (Micro Rain Radar). The high variations of Z-R relations are seen from different rain events of X-band radar and MRR2 based on reflectivity intensity of Increasing, Decreasing and Stagnating for reliable rainfall
estimation and advancing the application of Z-R relation by the rainfall classification. The Radar reflectivity (Z) and Rain rate (R) studies are carried out over 60 years which is more important for radar meteorology and [5] the measurements taken from Singapore area using S-band MDWR and Disdrometer at Changi airport. Z-R relations are plotted and varied with utmost accuracy by deriving and categorizing the different rain types such as Stratiform, Convective and Transition rains. NASA Wallops Flight Facility(WFF) [6], at United States is having a tipping rain gage. a Disdrometer and two radars one is S-band and other is K-band (MRR) radar which are vertical profiling, with in the area of 32 meters range for observations of every storm of mid-Atlantic coastal location. Here the Z-R relations are done for every rain event for each range gate of MRR at distinct heights and says that above 500m from ground the reflectivity value >1 dB is not agreed. The Z-R measured values are highly agreed with Disdrometer, S-band radar and MRR. The rainfall measurements [8], are taken from YVU, YSR Kadapa with Parsivel Disdrometer of two Cyclones JAL (2010) and NILAM (2012) and relation of radar measured reflectivity Z, rain rate R, given by Marshall and Palmer derived from Raindrop Size Distribution (DSD) is Z = A R b and classified the type of rainfall based on Reflectivity values and Rain rates.

In this paper we are presenting the Z-R relations of Cyclones, Monsoon and Clear air mode for the year 2018-2019 and the data is taken from the Micro Rain Radar (MRR2) located at K L University, 29m ASL with respect to 30 range gates the radar reflectivity and rain rates are calculated accurately.

II. EXPERIMENTAL LOCATION AND PROCEDURE

![Micro Rain Radar.](image1)

(a) Micro Rain Radar.

![MRR PC.](image2)

(b) MRR PC.

In this present study the measurements are taken from coastal location of Andhra Pradesh at K L University 16.4418oN, 80.62oE at the height of 29m ASL, Guntur, India with a vertical profile Doppler Radar Micro Rain Radar (MRR2) for all the precipitation measurements of this location. MRR transmits 24.23 GHz Doppler frequencies of Electromagnetic waves into the atmosphere where EM signals are scattered due to rainfall/precipitation conditions. This FMCW system (MRR) provides the data of total 30 range gates with 64 spectral bins of time resolution 10s with 200m step variation up to 6000m.

For many years the power relation of Z = A*R^b given by Marshall and Palmer is used for classification of the rainfall events and snowflakes with the measured Reflectivity and Rain rate of the MRR data. The empirically derived constants Coefficient 'A' and exponent 'b' vary from place to place and in distinct rain events.

Here the data of MRR2 K-band radar is analysed during the Cyclone time, Monsoon time and Clear air modes of 2018-2019 years. Data is collected as, in the year 2018 coastal location of Andhra Pradesh is affected with two Cyclones PHETHAI and DAYE in the months of December and September respectively, Monsoon period data is collected in the month of August. Finally, Clear air mode data is taken in the year 2019 of February month.

The main theme of this knows the Rainfall Reflectivity Intensity whether it is increasing, decreasing and stagnating for the measured reflectivity and rain rates collected. The reflectivity values are measured for every range gate (30 range gates) of MRR with the 200m step variation where the Coefficient A and exponent b values are varied with respect to time/seasons is seen/ observed.
i. Equations
Reflectivity Z and Rain rate R equation: Reflectivity Z depends on RR (Rain Rate) and DSD (Drop Size Distribution). Radar Reflectivity (Z) property says that, Z is directly proportional to the sixth power of rain drop size diameter 'D' and radar reflectivity Z of rainwater is greater than ice or snow.

\[ Z = \Sigma_i \frac{D_i^6}{\text{unit volume}} \]  

So, \( Z = Z(\text{RR, DSD}) \)

According to Marshall and Palmer DSD is given as

\[ N_d = N_0 e^{-\lambda D} \]  

by assuming the unknown values of DSD

\[ N_d = \frac{8000}{m^3/mm} e^{-4.1R^{-0.21}D} \]  

Finally, we get,

\[ Z = A \cdot R^b \]  

where A and b are empirical derived constants which always varies seasonally from time to time and place to place along with Z and R values.

III. RESULTS AND DISCUSSION

The vertical profile of MRR2, Z-R relations has its own practical importance for high range of distances which is having up to 6 km of 30 range gates. Here the Z-R relationship is made from three periods of collected data that is Monsoon Period, Cyclone Period and Clear Air Mode Period. Totally 9 days of events are collected and analysed the Reflectivity intensities with the variation in the reflectivity, coefficient and exponent numerical values.
From above Fig. 2, the monsoon period rainfall data is evaluated for the August month on 10th 2018 where the rain rate observed is about 30mm and RADAR reflectivity is observed at the altitudes of 200m, 1200m and 2200m. Here the Reflectivity is about 45 dBZ constant with variations in exponent and coefficient values slightly as ± 0.03 and ± 0.88 respectively.
As shown in the above Fig.3., the monsoon period rain data is evaluated for the August month on 11th 2018 where the rain rate observed is about 40mm and RADAR reflectivity is seen at different altitudes of 200m, 1200m and 2200m. Here the Reflectivity is about 48 dBZ constant with variations in A and b values are ± 0.50 and ± 0.01 respectively.

From below Fig.4., the monsoon rainfall data for the August month on 12th 2018 is evaluated where the rain rate is 28mm and its RADAR reflectivity at the altitudes of 200m, 1200m and 2200m is 43 dBZ constant with variations in coefficient and exponent values slightly as ± 0.33 and ± 0.01 respectively.
Fig. 4 Z-R relation (a) @ 200m, (b) @ 1200m and (c) @ 2200m On 12-08-2018
Fig. 5 Z-R relation (a) @ 200m, (b) @ 1200m and (c) @ 2200m On 13-08-2018

From Fig.5., the Z-R relation of Monsoon period is taken with height variation of 200m, 1200m and 2200m respectively as plotted above. It can be seen that the RADAR Reflectivity 40 dBZ with respect to the rainfall rate as 10mm, also the variations in the 'A' and 'b' values of 'Z' are ± 0.80 and ± 0.01 respectively.

Table 1. Z-R Relation of Monsoon period from 10-08-2018 to 3-08-2018.

<table>
<thead>
<tr>
<th>EVENTS HEIGHT (m)</th>
<th>10-08-2018</th>
<th>11-08-2018</th>
<th>12-08-2018</th>
<th>13-08-2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>20.7</td>
<td>19.9</td>
<td>19.8</td>
<td>21.4</td>
</tr>
<tr>
<td>1200</td>
<td>0.29</td>
<td>0.29</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>2200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

From below Fig.6., Z-R relations for a Cyclone (DAYE) period at distinct range gates (September 20, 2018) of 200m, 1200m and 2200m variation is observed with the Reflectivity of about 34dBZ and variations in coefficient A and exponent b are ± 2.2 and ± 0.8 respectively.
Fig. 6 Z-R relation (a) @ 200m, (b) @ 1200m and (c) @ 2200m On 20-09-2018
From above Fig.7., the Cyclone rainfall data for the September 21st, 2018 is evaluated where the rain rate is 35 mm and its RADAR reflectivity at the altitudes of 200m, 1200m and 2200m is 48 dBZ constant with variations in coefficient and exponent values slightly as $A = \pm 0.40$ and $b = \pm 0.15$ respectively.
The rainfall event of Cyclone (PHETHAI) of December 16, 2018 is evaluated as shown in above Fig.8., with the rain rate of 3mm and have the Reflectivity of 25 dBZ. Here the rain fall very less but reflectivity is observed due to continuous formation of rain with constant falling rain drops. The values of $A = \pm 3$ and $b = \pm 0.01$ are varied here.
For heavy rain rate of about 50 mm during Cyclone (PHETHAI), the reflectivity is very high of about 50 dBZ at the heights of 200m, 1200m and 2200m height as shown in Fig.9. Variations in A and b values are ± 1.01 and ± 0.01 respectively is observed. As Reflectivity (Z) and Rain rate (RR) of Z-R relation, values changes from location to location with respect to time and we observe the values of coefficient A and b exponent also varying between for 10-08-2018 to 13-08-2018, and are ±3 and ±0.10 respectively.

Table 3.Z-R Relation of period from 16-12-2018 to 17-12-2018.

<table>
<thead>
<tr>
<th>EVENTS→</th>
<th>16-12-2018</th>
<th>17-12-2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEIGHT(m)</td>
<td>200</td>
<td>1200</td>
</tr>
<tr>
<td>Coefficient A</td>
<td>23.51</td>
<td>19.73</td>
</tr>
<tr>
<td>Exponent b</td>
<td>0.559</td>
<td>0.454</td>
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</table>
Fig. 10 RADAR Reflectivity intensity during Clear Air Mode (a) @ 200m, (b) @ 1200m and (c) @ 2200m (February 2019)

From Fig.10., at Clear Sky condition a Reflectivity also seen due to presence of very tiny hydrometeors in air atmosphere of suspended particles, falling smog particles, particles raising from earth's surface due to winds etc., Various precipitation studies says that clear sky condition has the reflectivity of +28dBZ. Mainly this is seen due to absence clouds and precipitation particles, meanwhile the echoes of this clear sky are said to be as ghost echoes or angel echoes.
It is seen that, at low reflectivity the rain rate is minimum with respect to increase in height. At medium reflectivity rain rate is observed to be medium with respect to without change of altitude whereas at high reflectivity the rain rate is high at altitudes of 150-300m.

By this the data is evaluated for Nine events during Monsoon period, Cyclone period and Clear sky mode conditions at K L University to know the Z-R relationship with different altitudes of 200m, 1200m and 2200m. For Monsoon period Z-R relation of this coastal location is observed as $Z = 22 (\pm 2) \times R^{0.2}$, for Cyclone (two) period Z-R relation is seen as $Z = 27 (\pm 3) \times R^{0.5}$ and for Clear sky condition Z-R relation is $Z = 15 (\pm 2) \times R^{0.3}$ observed.

### IV. CONCLUSION

In this study we observe that the variation in Reflectivity intensity of increasing, decreasing and no changes shows the better improvement in the estimation of rain with the vertical profiler (MRR). Z-R relation of vertical profile radar at coastal location of Andhra Pradesh is significantly varied and it is very important parameter for estimation of rain rate (RR) from Reflectivity (Z). The coefficient 'A' and exponent 'b' of Z-R relation $Z = A R^b$ varied with respect to seasons of rainfall. This show the results are very useful in the estimation of rainfall from vertical profile radar, MRR data over coastal location of AP more precisely.

### V. ACKNOWLEDGEMENTS

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### Nomenclatures

<table>
<thead>
<tr>
<th>Z</th>
<th>Radar Reflectivity</th>
<th>Abbreviations</th>
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<tbody>
<tr>
<td>R</td>
<td>Rain Rate</td>
<td>MRR Micro Rain Radar-MRR2</td>
</tr>
<tr>
<td>$A$</td>
<td>Coefficient – Adjustable parameter</td>
<td>RR Rain Rate</td>
</tr>
<tr>
<td>$b$</td>
<td>Exponent -- Adjustable parameter</td>
<td>DSD Drop Size Distribution</td>
</tr>
<tr>
<td>D</td>
<td>Rain drop size Diameter</td>
<td>dBZ Decibel relative to ‘Z’ (Meteorology)</td>
</tr>
<tr>
<td>$N_d$</td>
<td>Number of rain drops with diameter D</td>
<td></td>
</tr>
</tbody>
</table>

### References

4. TRIDON, Frédéric, Joel VAN BAELEN, and Yves POINTIN. "Rain heterogeneity studies and specific ZR relationships determination with x-band and k-band radars to improve rain rate retrieval." Laboratoire de Météorologie Physique (LaMIP), CNRS/Université Blaise Pascal Clermont-Ferrand II (2008).
8. Kumar, N. P., et al. "Ranndrop size distribution variations in JAL and NILAM cyclones induced precipitation observed over Kadapa (14.47 o N, 78.82 o E), a tropical semi-arid region of India." 92.60. jf; 92.60. Qx (2014).
14. Suneetha, R. "Long-term observations of Bright band characteristics over Kadapa (14.47 N; 78.82 E) Semi-arid-region of tropical India.“

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