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Polarimetric radar rainfall estimation

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ABSTRACT

Polarimetric estimation of rainfall provided more reliable and accurate data than that of conventional radars. This paper aims to provide the application of Polarimetric radar in the estimation of heavy rainfall by its conventional use, provides analysing technique, relate the algorithms to measure rainfall rates, compares its efficiency to conventional radars, gauges and analyses few examples observed before to provide a schematic view about its uniqueness in its behaviour. These examples provide a better view in the estimation of the rainfall by Polarimetric rainfall. The paper produces details about the rain drop size and shape, rain drop distribution, areal mean rate values, average drop sizes and various concordances are discussed here. Moreover the properties and parametric values of rain fall and its estimates, β and axis ratio relation are also described in this paper.

Keywords: Polarimetric radar, differential phase shift, backscattering, flash flood, dipolarisation, specific differential phase.

1. INTRODUCTION

Conventional radars transmit and receive horizontal pulses to and froth the target, whereas in contrast, the Polarimetric radars exhibit both horizontal and vertical pulses. This property enables the backscattering of pulses, thereby paving way for polarisation synthesis. Polarimetric radar measurements are based on parameters such as differential reflectivity (*Zdr*) and specific differential phase shift (*KDP*). These two factors rely upon the average drop size and shape relationship. Measurement provided through Specific differential phase technique, were not affected by the beam blockages and attenuation (Ryzhkov and Zrnic´ 1995a, b; Zrnic´ and Ryzhkov 1996; Ryzhkov et al. 1997; Vivekanandan et al. 1999; Brandes et al. 2001). Rainfall rate estimation depends upon the rain drop shape. The average drop shape determines the drop rate of the rainfall occurred. The mean drop shape also plays an importance in determining the algorithms, and content of water based on differential reflectivity and specific differential phase. The particles or the hydrometeors are not exactly spherical in shape. They possess different shape with respect to their axis aspects. Hence the backscattering waves are not as same for that of the horizontal and vertical polarised waves the precipitation paves a role in determining the strength of the backscattered waves. Theoretical studies of raindrop shaped had been pursued by Green (1975), Beard and Chaung (1987). Experimental studies ware also performed by Pruppacher and Beard (1970) and Chandrasekar et al. (1988) and Bringi et al. (1998).

2. RAINDROP MODEL

Through theoretical and experimental verifications, the general shape of a rain drop is designated approximately to be spherical as of smaller size. But, the shape changes with increase in size acquire an oblate model, or to possess an oblate spheroid structure. The raindrop model plays a prime role in determining the mean drop rate. The obliqueness is due to the phenomenon of backscattering by horizontal and vertical polarisations respectively. The axis ratio of the raindrop (*r*) is given by

$$r = \frac{b}{a} \qquad (1)$$

Where a is semi-major axis and b is semi- minor axis. Various drop model analysis is shown in the Fig.1 for various drop axis ratio to be considered , the β values is related to it in order to obtain the axis ratio bias relationship. The Fig.2 explains about the rain drop axis ratio to different values of β.

3. FACTORS AFFECTING RAINFALL ESTIMATION ACCURACY

There are various factors that are responsible in affecting the accuracy of rainfall rate, such as error that is created in measuring the backscattered power from the target. Rather, the atmospheric changes also accounts between the estimation level and that of the ground space. These variations produce high distortion and create error in the radar measurements. Also, faults in radar instruments may also be responsible for error measurements. The

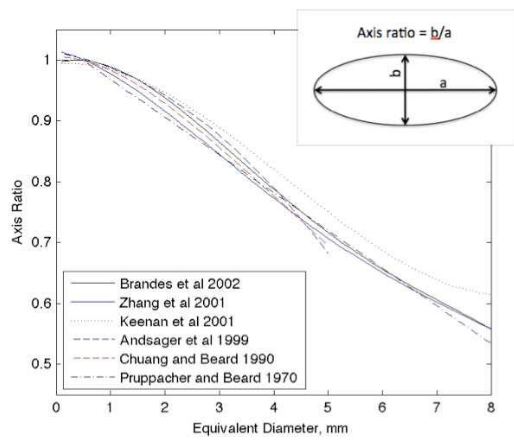

Figure 1
Axis ratio vs. equivalent diameter

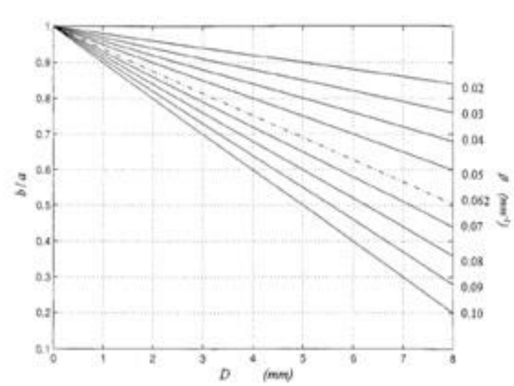

Figure 2
Axis ratio vs. Diameter plot

Bharathan Iyer et al.
Polarimetric radar rainfall estimation,
Indian Journal of Engineering, 2012, 1(1), 8-11,

electronic assembly inside the radar may fail to produce the desired result due to the various atmospheric conditions prevailing in the environment.

4. MEASUREMENTS USED FOR RAIN ESTIMATION

The most commonly used measurement parameters are here in to account in the rainfall estimation. Differential reflectivity (*Zdr*) is a ratio of the reflected horizontal and vertical power returns. It is a good indicator of drop shape, enables good estimate of average rain drop. Correlation Coefficient is a statistical correlation between the reflected horizontal and vertical power returns. It is a good estimator of regions of precipitation types, such as rain and snow. Specific differential phase (*KDP*) is a returned phase comparison between the horizontal and vertical pulses. The phase difference occurs by the difference in number of wavelength along the path in horizontally and vertically polarised waves.

5. ANALYSIS OF RAINFALL TECHNIQUE

A rainfall is analysed through radar using the following techniques:

1. *R*: unadjusted radar rainfall estimates obtained by using Marshall-Palmer Z-R relation.
2. *Rh, adj*: Marshall-Palmer *Z-R* relation by applying corrections for occlusion and an adjustments for attenuation, based on rain-gauge measurements.
3. *RKDP*: Based on a linear relation between *R* and *KDP*.
4. *RZPHI*: Radar rainfall estimates, obtained by using differential phase shift technique for attenuation process.

6. ALGORITHMS AND MEASUREMENT TECHNIQUES USED

The various algorithms that are used during the rain fall rate determination are as follows,

- Rainfall Estimates given by Marshall-Palmer Relationship,

$$z = aR^b \quad (2)$$

DROP SIZE	QUANTITY	Z	WATER VOLUME
1mm	4096	36 dBZ	17,160 mm3
4 mm	1	36 dBZ	270mm3

Where a and b are constants and R is the reflectivity factor,

6.1. Polarimetric Rain rate

Specific Differential Propagation Phase,

$$K_{DP} = \frac{\partial \Phi_{DP}(r)}{2\partial r} \approx \frac{\Phi_{DP}(r_2) - \Phi_{DP}(r_1)}{2(r_2 - r_1)} \quad (3)$$

By Marshall Palmer relation,

$$z = aR^b \Rightarrow R = a'z^{b'} \quad (4)$$

K_{DP}

$$R = a(K_{DP})^b \quad (5)$$

Z_h - Z_{DR}

$$R = c(Z_h)^b 10^{(0.1aZ_{DR})} \quad (6)$$

K_{DP} - Z_{DR}

$$R = c(K_{DP})^b 10^{(0.1aZ_{DR})} \quad (7)$$

6.2. Efficiency of polarimetric radars in rainfall estimation

The Polarimetric radar estimates are better than conventional radars in the factors of reduced bias and better correlation. *ZH* and *ZDR*, constituting bias errors can affect the estimate of bias (*β).* In conventional radars, *(ZH)* is based on absolute power measurements whereas (*KDP)* depends upon phase measurement and henceforth they are immune to biases, is explained by the Fig.3. The above shows bias in the estimate of β as a function of bias in *ZH* and *ZDR*. The line marked 1 indicates no bias, and lines marked different from 1 indicate overestimation (.1) and underestimation (1). Typically in a well-maintained system, bias error in *Z*DR is less than 0.2 dB and bias in *Z*H is less than 1 dB. Therefore, β can be estimated within 10% accuracy under those biases of *ZH* and *ZDR.* Another graph enlisted below, Fig.4, shows reduced bias of Polarimetric radar, based on hourly calculation of areal mean rain rate.

6.3. Conventional (r) estimation

$$R = a'z^{b'}$$

The comparison between the conventional radar and the Polarimetric radar in estimation level is given below. The conventional radar algorithm and the horizontal reflectivity phenomenon provided data with many disturbances since contaminated through hail, affected through beam blockages, attenuation factors and distances above the ground. Whereas the Polarimetric radar estimates using the differential phase shift propagation method provided much efficiency free from attenuation and with better correlation property (Fig.5 and 6).

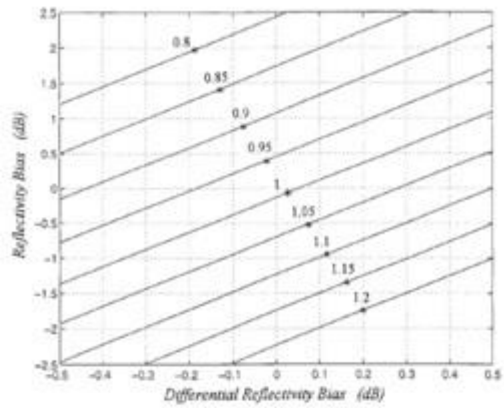

Figure 3
Reflectivity bias vs. Differential reflectivity

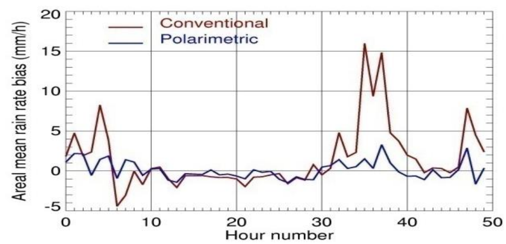

Figure 4
Areal mean rainfall rate

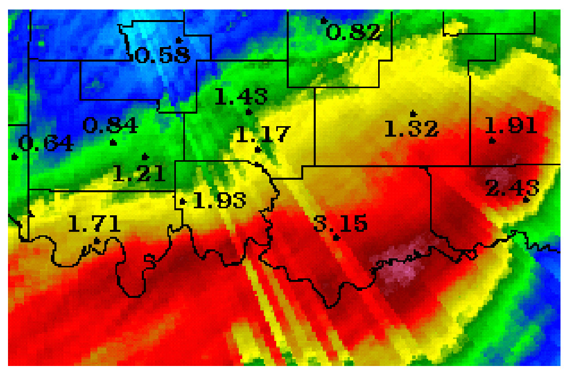

Figure 5
Conventional estimation of rainfall

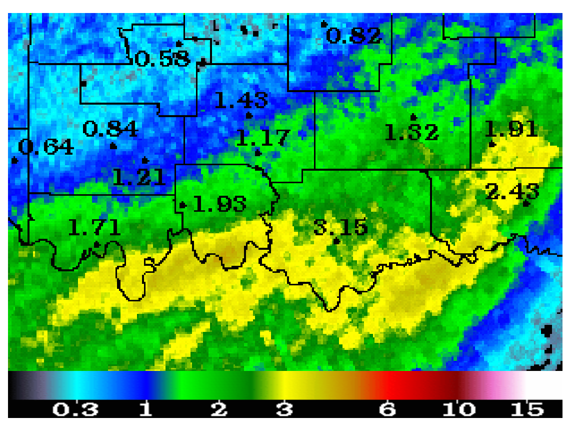

Figure 6
Polarimetric estimation of rainfall

Bharathan Iyer et al.
Polarimetric radar rainfall estimation,
Indian Journal of Engineering, 2012, 1(1), 8-11,

6.4. Polarimetric R (K_{DP}) estimation

$$R = a\left(K_{DP}\right)^b$$

7. DROP SIZE DISTRIBUTION

The drop size distribution plays a vital role in calculation of rain variable and that of radar variables. The Fig.7, schematically explain about various drop size distribution that has been analysed by a disdrometer. Three various factors are being analysed here such as drop size distribution, water content distribution and the 6th moment of drop size distribution. They analyse the various types of large drop particles, strong conventions as well as weak conventions. DSD examples of five typical types (From Cao et al. 2009): a) DSD; b) water content distribution; c) 6th moment of DSD. Rows from top to bottom indicate rain types of "big drop", strong convection, weak convection, stratiform rain, and bimodal DSD, respectively.

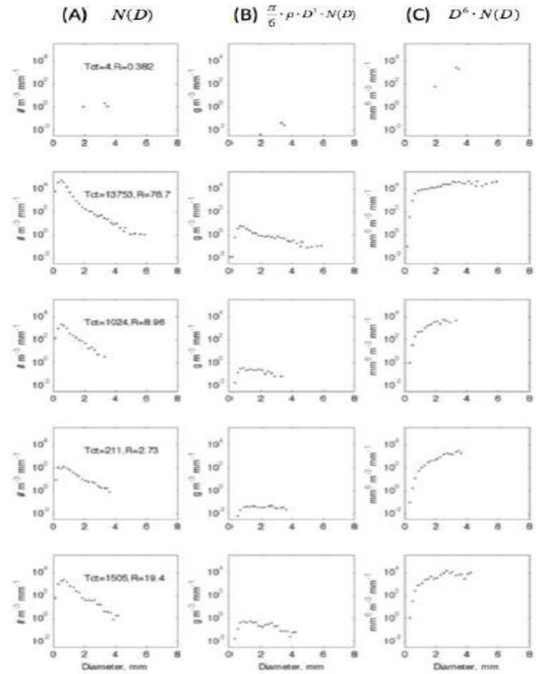

Figure 7

Various drop size distribution by a disdrometer

8. ANALYSIS OF VERIFED CASES

There are two cases taken here as examples, the first case is an example of a flash flood event and another is a natural rainfall account. The salient features of these analysis are provided here as point of examples of rainfall analysis.

8.1. EXAMPLE 1: FLASH FLOOD EVENT

16th AUGUST 2006, *Liguria Apennines.*

*Roberto Cremonini * and Renzo Bechini (2008)*

- A low pressure trough centred over north-western Britain moved south along Atlantic coast.
- Another African anticyclone expanded in north-east, caused intensification of wet south-westerly winds above *Liguria Apennines.*
- The rainfall intensities were observed between 01:00 and 04:00 UTC.
- Algorithms of *R, Rh, adj, RZPHI, RKDP* were utilised for this purpose.

Fig.8 shows the comparisons between the algorithms and the rain gauge. The investigations rely on different precipitation accumulation factor. In the graph, as observed, RH algorithm shows poor correlation and severe underestimation. The rain rate analysis for a specific beam is shown in Fig.9. The attenuation became an important factor for consideration. Estimates *Rh, adj* obtained matched with other algorithmic factors and provided better correlation.

ZPHI algorithm, of the both factors in which the differential phase shift *ΦDP* is used to account for the signal attenuation, and the *RKDP* algorithm, where the rainfall rate is linearly related to *KDP*, performed better than the algorithm depending on single polarisation. Comparisons with the rain gauges show a great under estimation of *Rh* ranges. But in case of Polarimetric estimation, they provided with a data of reduced bias value and better correlation.

8.2. EXAMPLE 2

September 13, 2008

- Caused severe storms in western Alps.
- The minimum pressure centre became deeper.
- A cold front approached alps with low trough over France
- Entire Piemonte strong instability and severe storm activity.

Fig.9 shows the rainfall from 6:00 to 18:00 UTC estimated by Bric Della Croc radar. Flash flood accumulated an area of 19.3 km2. The overall estimation of the ZPHI was better. The significantly distinguished the efficiency of rain gauge and rainfall measurements. These scale mapping clearly gives the view about the radar estimation with that of rain gauges. It shows that the Polarimetric with ZPHI algorithm estimation shows up a better correlation and clearer values.the rainfall analysis between the distance and that of the speed measurement that is taken in to account and as well as from the Fig 10, clearly shows the distinguished rate analysis of the mean rainfall rate, provided the values of average measurements. Accumulated precipitation estimated by radar (colour) and measured by regional rain gauges since 06:00 to 18:00 UTC on 13 September 2008.

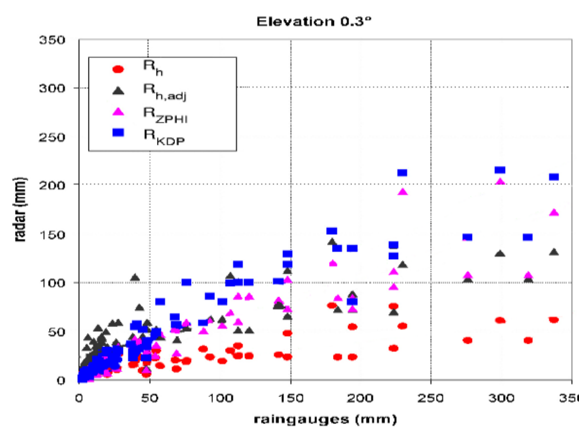

Figure 8

Comparisons of algorithm between Rh, Rh, adj, Rzphi,, Rkdp

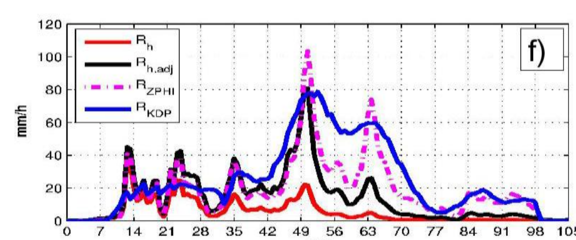

Figure 9

Distance vs. Speed measurements of polarimetric analysis

9. CONCLUSION

Even though we use conventional radars and rain gauges still, flash floods, and sudden precipitation phenomena can be missed or inaccurate. Polarimetric radars are unique in monitoring these circumstances. Their advantages are that they are immune or resistible to beam blocking, attenuation and absolute calibration. The two examples provided here were taken in order to distinguish the efficiency of the Polarimetric radars to that of the conventional ones. In the first example for the purpose of signal attenuation, both the ZPHI algorithm and differential phase shift were used and the RKDP algorithm. The rainfall linearly based on KDP, performed better than that of single Polarimetric algorithms. The comparison with that of rain gauges showed large underestimation, in case of the Rh algorithmic estimations. Polarimetric radar showed better biasing (reduced biasing). In the second example, the ZPHI algorithm proved to be strong for estimation, while still providing quite accurate rainfall estimates even in presence of strong attenuation.

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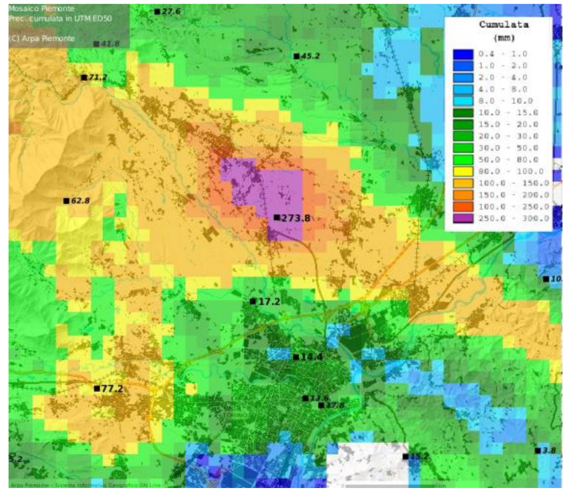

Figure 10

Distinguished rate analysis of the mean rainfall rate

Bharathan Iyer et al.
Polarimetric radar rainfall estimation,
Indian Journal of Engineering, 2012, 1(1), 8-11,