# Rainfall estimation for the first operational S-band polarimetric radar in Korea

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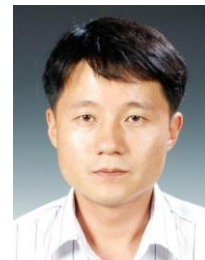
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1 Introduction

There have been many researches on polarimetric radar to implement it into operational usage. The particle identification algorithm for improving data quality control and rainfall estimates by the discrimination of non-meteorological artifacts such as anomalous propagation, birds, insects, second trip echo, and melting layer detection were developed (Vivekanandan et al., 1999; Ryzhkov and Zrnic, 1998; Giangrande and Ryzhkov, 2008). Improvement of quantitative precipitation estimation (QPE) accuracy is one of major points of polarization radar (Ryzhkov and Zrnic, 1996; May et al., 1999; Bringi and Chandrasekar, 2001; Brandes and Zhang, 2002; Ryzhkov et al., 2005). Ciffelli et al. (2011) compared the two rainfall algorithms, CSU-HIDRO (Colorado State University-Hydrometeor IDentification of Rainfall) and JPOLE (Joint Polarization Experiment)-like, in the high plains environment.

The specific differential phase is a very important factor for rainfall estimation, because it is not susceptible to radar calibration, beam attenuation or beam blockage. It is also closely related to rain intensity, even in the presence of dry, tumbling hail (Balakrishnan and Zrnic, 1990; Aydin et al., 1995). Recently, Ryzhkov et al. (2013) found out that the R(A) method yields robust estimates of rain rates and totals at S band and X band polarimetric radar. They also explained that it had better performance on the rainfall estimation especially in beam blockage region and radar networking than other relations.

There is no single relation of polarimetric relations which is optimum for the whole range of rainfall. Therefore, rainfall relations could be optimized by combining each advantage of polarimetric relations. Ryzhkov et al. (2005) used only reflectivity thresholds and Bringi et al. (2004) used more than one criterion that is based on both reflectivity thresholds and the values of the polarimetric variables in order to combine the relations. Peppler et al. (2011) proposed the weighted combinations of estimators on the basis of their error characteristics at various rainfall rates.

Polarimetric rainfall relations using long period disdrometer data were calculated and the assessment of each relation after applying a very simple quality control for differential phase shift was done (You et al., 2013). The accuracy of rainfall estimation using $R(K_{DP})$ is worse than that of $R(Z, Z_{DR})$, since DSD data were interpolated for scattering simulations and very simple quality control algorithm was applied. You et al. (2013) applied more robust quality control algorithm and compared the accuracy of $R(K_{DP})$ relations obtained by using DSD data observed at Busan and Oklahoma with different rain drop shape assumptions. In this study, the optimum rainfall estimation relations will be discussed to integrate each polarimetric rainfall relation and three rainfall cases were used to assess their performance.

2 Rainfall relation

2.1   Disdromter data

It is required DSD data and scattering simulation to get polarimetric rainfall estimation relations. DSD data obtained by POSS (Precipitation Occurrence Sensor System) were used in this study. The POSS, a kind of disdrometer, was installed at Pukyong national university around 82 km away from Bislsan radar site (Fig. 1). The disdrometer has a low power, continuous wave, X-band, and bistatic system. The transmitter and receiver are housed separately and mounted on a frame 45 cm apart to determine the 1-min DSD for drop diameters ranging from nearly 0.34 mm to 5.34 mm (Sheppard 1990). 1-min DSD obtained from March 2001 to September 2004 were used and processed to remove the unreliable data as shown in You et al. (2013). DSD data for calculations of relationships were 84,574 samples after quality control. Most of the data are distributed in a wide range with a maximum rain rate of about 199 mm h^{-1}.

2.2   Calculations of rainfall relations

Polarimetric variables were calculated using by T-matrix scattering techniques derived by Waterman (1971) and later developed further by Mishchenko et al. (1996). In the scattering simulation, rain drop shape is required to calculate polarimetric parameters. Three rain drop shape assumptions were used same as shown in Ryzhkov et al. (2005). An equilibrium axis ratio derived from the numerical model of Beard and Chung (1987), which is in good agreement with the results from wind tunnel measurements (here after DS1) was used. Oscillating drops appear to be more spherical on average than the drops with equilibrium shapes as shown by Andsager et al. (1999) in laboratory studies. Brngi et al. (2003)

suggested different relation with diameter size (DS 2). Another shape-diameter relation that combines the observations of different authors was proposed by Brandes et al. (2002, here after DS3). Another required parameter of the T-matrix simulation is the temperature which is assumed as 20 ℃ in this study. The distribution of canting angles of rain drops is Gaussian with a mean of 0 degree and a standard deviation of 10 degree, which have been used the previous studies (Ryzhkov et al., 2002, Keenan et al., 2001).

3 Rainfall estimation and validation

3.1 Rainfall cases

The first case was selected from 0000 LST on June 25 to 1400 LST on June 26. The second one was from 0000 LST on July 9 to 2000 LST on July 10 and the final one was from 2100 LST on August 7 to 0300 LST on August 8 in 2011. Figure 1 shows the time series of total rainfall amount observed on the ground rain gages in each case. Total rainfall amount refers to those obtained by adding the amount of rainfall observed by rain gages within the radius of the radar. As shown in case 1, there were two peaks of rainfall, the first peak was caused by Changma front and the second one was due to the influence of the typhoon. There were three peaks which were the impact of Changma front in case 2. The third case was also precipitation system caused by typhoon but maintained for relatively short time period. The rainfall data from 130 rain gages distributed from 5 km to 100 km within radar coverage were used to evaluate the accuracy of radar rainfall.
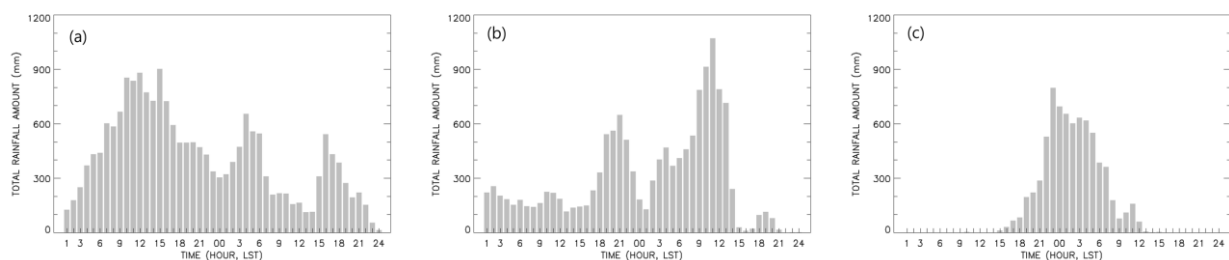

Figure 1: Time series of total rainfall amount from all rain gages within radar coverage for (a) case1, (b) case 2, and (c) case 3.

3.2 Validations

In order to validate each rainfall relation, the normalized error (NE), root mean square error (RMSE), and correlation coefficients (CC) were used. Above statistical variables were calculated by using 1 hour rainfall amount of radar and gage at the point. The point rainfall of radar was obtained by averaging rainfall over a small area (500 m × 1 °) centered on each rain gage. For the assessment of each relationship, polarimetric rainfall relations using the formula obtained DSDs observed in Busan city and $R=200R^{1.6}$ were used. The gages recorded rainfall greater than 0.0 mm were selected and the number of samples for each case are 2891, 3051, and 423 pairs, respectively.

Figure 2 (a) shows the histogram with 5 mm interval of rainfall observed from gages for case 1. The frequency of rainfall of less than 5 mm h^{-1} and more than 10 mm h^{-1} were occupied about 70% and 13 % of the total rainfall, respectively. NE, RMSE, and CC were distributed from 0.34, 3.2, and 0.59 to 1.05, 6.2, and 0.83, respectively. The R(K_{DP}) relation with DS 3, R(K_{DP}, Z_{DR}) with DS 1, and R(Z, Z_{DR}) with DS 1 assumption had the best score among relations. The accuracy of R(Z) relation was better than that of all R(K_{DP}, Z_{DR}) relations. R(Z,Z_{DR}) with DS 1 assumption had the best performance in all relations of case 1.

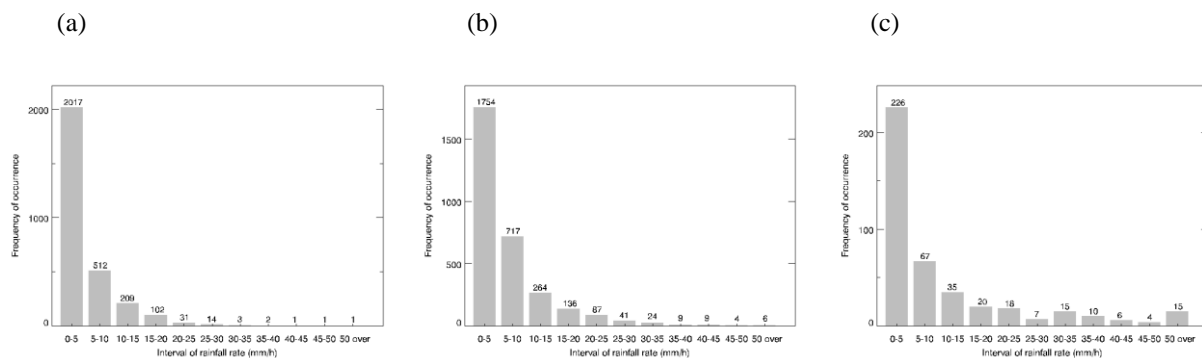(a)   (b)   (c)

Figure 2: Histogram with 5 mm bin of rainfall observed at gages for (a) case 1, (b) case 2, and (c) case 3. The number on each bar shows the frequency of certain rainfall occurrence.

Figure 2 (b) shows the histogram with 5 mm bin size of rainfall observed from gages for case 2. The frequency of rainfall of less than 5 mm h^{-1} and more than 10 mm h^{-1} were occupied about 57% and 19 % of the total rainfall, respectively. NE, RMSE, and CC were distributed from 0.3, 4.4, and 0.73 to 1.04, 8.7, and 0.87, respectively. The R(K$_{DP}$) relation with DS1, R(K$_{DP}$, Z$_{DR}$) with DS 1, and R(Z, Z$_{DR}$) with DS 2 assumption had the best score among relations. The accuracy of R(Z) relation was also better than that of all R(K$_{DP}$, Z$_{DR}$) relations. R(Z,Z$_{DR}$) with DS 2 assumption had the best performance in all relations of case 2.

Figure 2 (c) shows the histogram with 5 mm bin size of rainfall observed from gages for case 3. The frequency of rainfall of less than 5 mm h^{-1} and more than 10 mm h^{-1} were occupied about 53% and 31 % of the total rainfall, respectively. The ratio of the stronger rainfall to the total is the highest in three cases, even the samples were the smallest. NE, RMSE, and CC were distributed from 0.4, 6.7, and 0.9 to 0.71, 13.5, and 0.93, respectively. The R(K$_{DP}$) relation with DS2, R(K$_{DP}$, Z$_{DR}$) with DS 1, and R(Z, Z$_{DR}$) with DS 2 assumption had the best score among relations. The accuracy of R(Z) relation was also better than that of all R(K$_{DP}$, Z$_{DR}$) and R(Z, Z$_{DR}$) relations. R(K$_{DP}$) with DS 2 assumption was the best performance in all relations for case 3. All R(Z, Z$_{DR}$) relations had the worst result in this case which had the highest portion of stronger rainfall.

3.3 Accuracy of relations with drop shapes and polarimetric parameters

As described above, it was found that depending on the precipitation cases, the performance of the relations along the drop shape assumptions is different. To examine the errors more detail, the RMSE with rainfall rate of rainfall obtained by each relation were shown in Figure 3. The triangle with solid line, the rectangle with solid line, the cross with dashed line, and the circle with dashed line represents M-P, DS 1, DS 2, and DS 3, respectively. In case of R(K$_{DP}$), rainfall obtained from DS 1 and DS 3 assumption were better than that of DS 2 in the range of less than 15 mm h^{-1}. In higher than 15 mm h^{-1}, DS 2 is superior to others (Fig. 3 (a)). The R(K$_{DP}$, Z$_{DR}$) with DS 1 had the best performance in all rain range (Fig. 3 (b)). R(Z, Z$_{DR}$) with DS 2 is better than other two relations (Fig. 3 (c)). As mentioned in many researches, a single relation does not have good performance than that of combined ones.
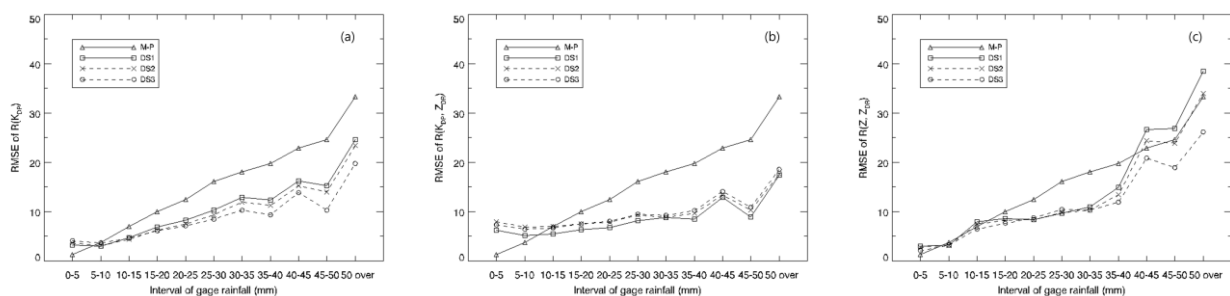

Figure 3: The RMSE with rain rate obtained from each relation with different drop shape for all cases (a) R(K$_{DP}$), (b) R(K$_{DP}$, Z$_{DR}$), and (c) R(Z, Z$_{DR}$).

Fig. 4 shows the distribution of RMSE as determined by the best relation corresponding to the gage rainfall. The triangle with solid line, the rectangle with solid line, the cross with dashed line, and the circle with dashed line represent M-P, R(K$_{DP}$), R(K$_{DP}$,Z$_{DR}$), and R(Z,Z$_{DR}$), respectively. The performance of R(Z) and R(Z,Z$_{DR}$) were better in the range of rainfall less than 10 mm h^{-1}, the error of R(K$_{DP}$) relation is the lowest between 10 to 20 mm h^{-1}, and R(K$_{DP}$, Z$_{DR}$) relation had better result in the range of rainfall stronger than 20 mm h^{-1} than that of others.
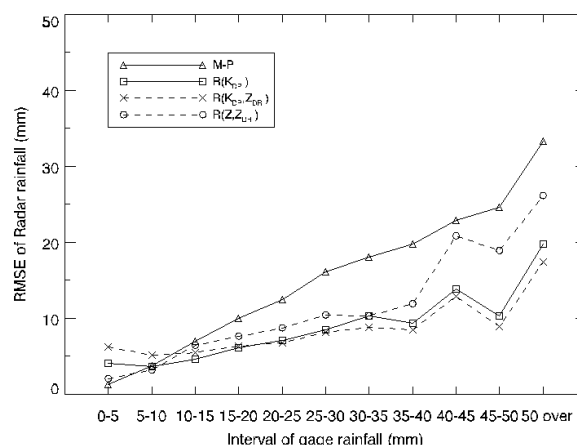

Figure 4: The RMSE with rain rate of rainfall obtained from the best relation for all cases.

4 Summary

Polarimetric radars will play an important role in monitoring and predicting high impact weather within several years in Korea. To prepare it, rainfall estimation relations with different drop shape assumptions were obtained using by long period disdrometer data and their accuracy using polarimetric variables observed from Bislsan radar which is the first polarimetric radar in Korea was evaluated. Three rainfall cases caused by different conditions, which are Changma front and typhoon, Changma front only, and typhoon only, occurred in 2011 were analyzed.

The combined relations would be proposed according to the error analysis as one of optimum algorithm of rainfall estimation as follows;

$$R=0.0364Z^{0.625}, \qquad \text{rain rate} < 5 \text{ mm h}^{-1}$$

$$R=0.0081Z_{0.095}Z_{DR}^{-4.96}, \qquad 5 \text{ mm h}^{-1} < \text{rain rate} < 10 \text{ mm h}^{-1}$$

$$R=61.4K_{DP}^{0.833}, \qquad 10 \text{ mm h}^{-1} < \text{rain rate} < 20 \text{ mm h}^{-1}$$

$$R=139.1K_{DP}^{0.949}Z_{DR}^{-2.41}, \qquad \text{rain rate} > 20 \text{ mm h}^{-1}$$

The rainfall calculated from all polarimetric relations would be set to the rain rate in the above equations. More research would be required to define the relation as reference rain rate because each polarimetric relation has uncertainties at certain range of rain rate. However, the results of this study are expected to contribute to various fields such as hydrometeor classification and improving rainfall estimation accuracy for operational use of polarimetric radar in Korea.

Acknowledgement

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