P.4.110 **Evaluation of two QPE algorithms using S-band dual-polarization radar observations in Korea**

Kyotaek Hwang[1], Sanghun Lim[1, *], Dong-Ryul Lee[1], and Choong Ke Lee[2]
[1]Korea Institute of Construction Technology, 283 Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 411-712 Korea
[2]Han River Flood Control Office, Ministry of Land, Infrastructure and Transport, 328 Dongjakdae-Ro, Seocho-Gu, Seoul 137-049 Korea

1. INTRODUCTION

Accurate observation of precipitation is a key issue to predict and prevent natural disasters (e.g. flood, landslide, and heavy snow). Especially in Korea, flash flood in the mountainous and urban areas causes severe damages in life and property due to intensive rainfall. Traditionally, the flash flood warnings have been established by ground and single-polarization-radar-based rainfall. However, the methods have been found to expose serious limitations of spatial extrapolation and relatively high uncertainty in rainfall estimation. In the recent past, dual-polarization radar technology has been becoming an alternative method to implement over large areas with high reliability.

Technical advances in dual-polarization radars have finally enabled us to observe multiple hydrometeorological variables at various scales for a couple of decades. As becoming able to measure the differential reflectivity, specific differential phase, and cross-correlation coefficient, reliability has been significantly improved compared to the conventional reflectivity-based method (Ryzhkov et al. 2005a). Some of the polarimetric parameters have technical advantages that the specific differential phase is immune to radar miscalibration, attenuation in precipitation, and partial blockage of the radar beam, for example (Zrnic and Ryzhkov 1996).

There have been many studies all over the world to present reliable polarimetric Quantitative Precipitation Estimation (QPE) algorithms under various meteorological conditions. Based on the advantages of the specific differential phase, power-law relation between the specific differential phase and precipitation was adopted with regionalized coefficients (Bringi and Chandrasekar 2001; Gorgucci et al. 2001; Matrosov et al. 2002; Ryzhkov et al. 2005a). Given the simplicity, the power-law-based methods have a potential to be used as baseline products. Ryzhkov et al. (2005b) classified precipitation events by scales and types and suggested a synthetic algorithm for the Joint Polarization Experiment (JPOLE). Cifelli et al. (2011) developed a more sophisticated algorithm with different classification criteria. The reflectivity, differential reflectivity, and specific differential phase were employed as thresholds to categorize precipitation events into five groups. Five equations induced by different variables were adopted to make appropriate and accurate estimations.

In this study, polarimetric QPE algorithms developed by the institutions securing high level of technology were adopted and validated with ground rainfall observations for various environments. Korea is represented by complex topography with urban and mountainous areas that impacts of spatial scale was also examined. Based on the evaluation results, applicability of the QPE algorithms was fully investigated. This study would contribute to suggest proper application of the QPE algorithms in Korea.

2. MATERIALS AND METHODS

2.1 *Radar and Ground Observations*

Several government agencies in Korea have just started to adopt the cutting-edge technology and to apply over nationwide areas. As a pilot phase, Ministry of Land, Infrastructure and Transport (MOLIT) has installed and been operating two S-band radars at Mt. Biseul and Mt. Sobaek since June 2009 and November 2011, respectively to make a better prediction of extreme rainfall events and to therefore reduce flood-induced damage (Fig. 1). The radars were designed to cover Nakdong river watershed, which is the second largest watershed located in the southern-east part of Korean Peninsula. The government agency has further planned to set up four more S-band polarimetric radars and five X-band ones to cover the entire area of Korea. It is expected that the accuracy of rainfall prediction in Korea

* *Corresponding author address:* Sanghun Lim, Korea Institute of Construction Technology, 283 Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 411-712 Korea. e-mail: slim@kict.re.kr

including various scales of watersheds and urban districts will be greatly improve once all the radars are completely in operation.

In this study, polarimetric data from Mt. Biseul was used. Mt. Biseul is located in the southeastern part of the Korean Peninsula. The S-band radar at Mt. Biseul covers a range of 100 km and its spatial resolution is 125 m (Table 1). Scan speed in operation is currently 3 rpm and volume scan takes 2.5 minutes of each cycle (Table 1). In the radar coverage, 141 rainfall gauge stations of MOLIT and K water are located.

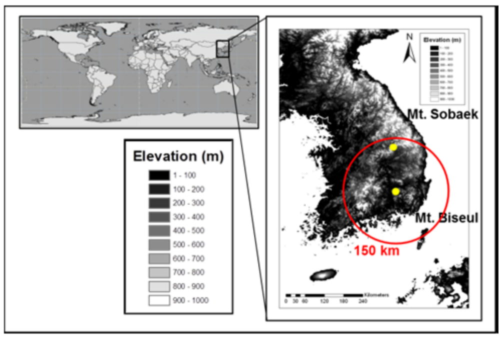

Fig. 1. Geographic location and digital elevation model of the study area

Table 1. Geographic and operational profiles of the radar at Mt. Biseul

Type	Profile
Longitude	128.48°E
Latitude	36.96°N
Elevation	1074 m
Scan speed	3 rpm
Observation range	150 km
Spatial resolution	125 m
Temporal resolution	2.5 min
Beam width	0.95°

2.2. *QPE Algorithms*

2.2.1 *JPOLE Algorithm*

Ryzhkov et al. (2005a) developed a synthetic QPE algorithm based on the equilibrium raindrop shapes in steady airflow, which is defined as relationships between the raindrop axis ratio and its equivolume diameter. The standard Weather Surveillance Radar-1988 Doppler (WSR-88D) $R(Z_h)$ formulation was used to select the most optimized method during the JPOLE. Flowchart of the JPOLE algorithm is shown in Fig. 2.

The equation follows the WSR-88D parameters that

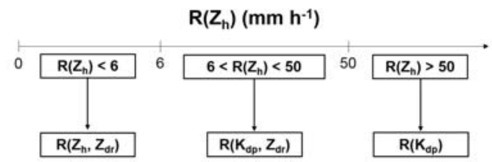

Fig. 2. Flowchart of the JPOLE algorithm

$$R(Z_h)=0.0170(Z_h^{0.714}) \quad (1)$$

where Z_h is in mm^6 m^{-3} and limited to 53 dBZ to apply in the algorithm because of hail contamination. R is in mm h^{-1}. As $R(Z_h)$ is calculated, three equations are employed as follows

$$R=R(Z_h)/(0.4+5.0|Z_{dr}-1|^{1.3}) \quad (\text{if } R(Z_h)<6) \quad (2)$$

$$R=R(K_{dp})/(0.4+3.5|Z_{dr}-1|^{1.7}) \quad (\text{if } 6<R(Z_h)<50) \quad (3)$$

$$R=R(K_{dp})=44.0|K_{dp}|^{0.822} sign(K_{dp}) \quad (\text{if } R(Z_h)>50) \quad (4)$$

where Z_{dr} is a linear scale value and K_{dp} is the one-way differential propagation phase value (° km^{-1}).

2.2.2 *CSU Algorithm*

Colorado State University (CSU) algorithm uses polarimetric variables (i.e. Z_h, Z_{dr}, and K_{dp}) as thresholds to classify a scale of rainfall amount (Cifelli et al. 2011). Other than the WSR-88D relationship (Eq. (8)), physically based equations (Eq. (5-7)) are employed. Flowchart of the CSU algorithm is shown in Fig. 3.

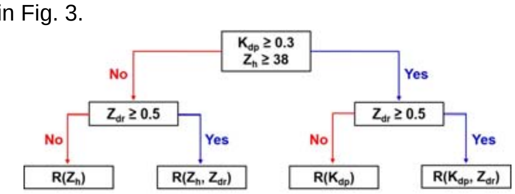

Fig. 3. Flowchart of the CSU algorithm

In the algorithm, rainfall is estimated by four equations that

$$R(K_{dp},Z_{dr})=90.8(K_{dp})^{0.93}10^{(-0.169Z_{dr})}$$
$$(\text{if } K_{dp}\geq 0.3,\ Z_h\geq 38,\text{ and } Z_{dr}\geq 0.5) \quad (5)$$

$$R(K_{dp})=40.5(K_{dp})^{0.85}$$
$$(\text{if } K_{dp}\geq 0.3,\ Z_h\geq 38,\text{ and } Z_{dr}<0.5) \quad (6)$$

$$R(Z_h, Z_{dr}) = 6.7\times10^{-3}(Z_h)^{0.927}10^{(-0.343Z_{dr})}$$
$$(\text{if } K_{dp}<0.3,\ Z_h<38,\ \text{and } Z_{dr}\geq0.5) \tag{7}$$

$$R(Z_h) = 0.0170(Z_h)^{0.7143}$$
$$(\text{if } K_{dp}<0.3,\ Z_h<38,\ \text{and } Z_{dr}<0.5) \tag{8}$$

3. RESULTS AND DISCUSSIONS

Two QPE algorithms were employed to estimate and represent distributions of rainfall in multiple summer rainfall events. Fig. 4 shows radar-induced daily rainfall maps using the CSU (left panels) and JPOLE algorithm (right panels). Both models similarly simulated the amount of daily rainfall in the three cases. The CSU algorithm estimated slightly less, generally several tens of millimeters a day and this quantitative trend was distinguishable especially in amount of more than 100 mm d^{-1}. For two cases in August and September, 2012, this algorithmic characteristic can be found in wider spatial ranges and more distinguishable reddish areas (Fig. 4). To figure out the spatial differences, further studies in specific verification of major parameters over large areas in Korea and comparison of the results within the other adjacent areas are required.

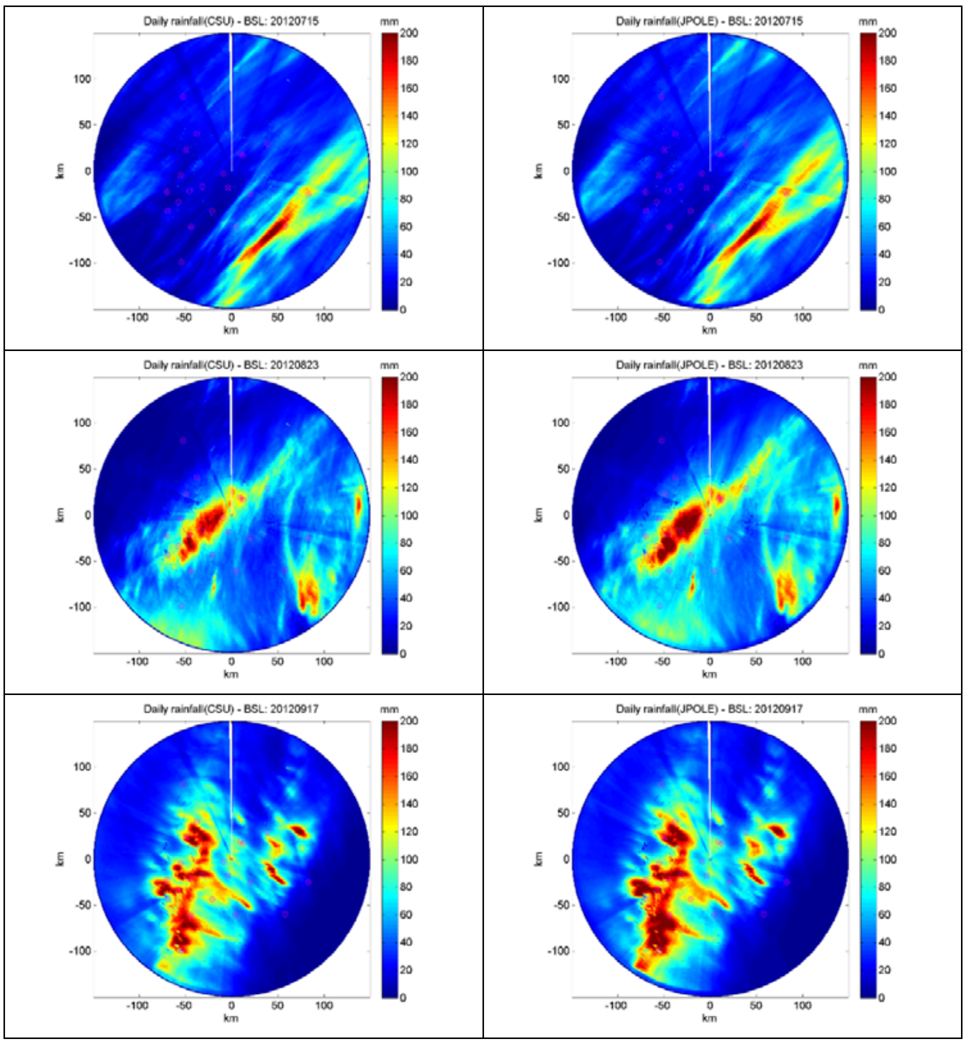

Fig. 4. Radar based daily rainfall (mm) for July 15, August 23 and September 17, 2012. Left panels are for the CSU algorithm (Cifelli et al. 2011) and right panes are for the JPOLE algorithm (Ryzhkov et al. 2005). Top panels are for July 15, middle for August 23, and bottom for September 17, 2012. ⓧs indicate the locations of Korea Meteorological Administration (KMA) Automated Weather Stations (AWSs).

Radar estimations by the two models were also compared with the ground measurement data to evaluate model reliability. A comparison graph of the ground observations and radar estimations is suggested in Fig. 5. Both models followed the observation well in various rain scales (0–300 mm d^{-1}). Normalized bias (NB) and normalized absolute error (NAE) were also computed to quantitatively evaluate the models (Fig. 5). While both models reasonably reproduced daily rainfall in an acceptable level, the JPOLE showed more conservative results. The statistics of the JPOLE showed a little deviation having a value of -13.89 and a similar NAE of 18.7. NAE of the CSU was slightly higher, which means the model also reasonably estimate precipitation at multiple sites. However, NB of the CSU (-22.22) was apparently higher than the JPOLE: the JPOLE seemed to more robustly make estimations. Reliability of the models was yet fully verified from these results. More case studies at multiple sites under various environments should be accompanied.

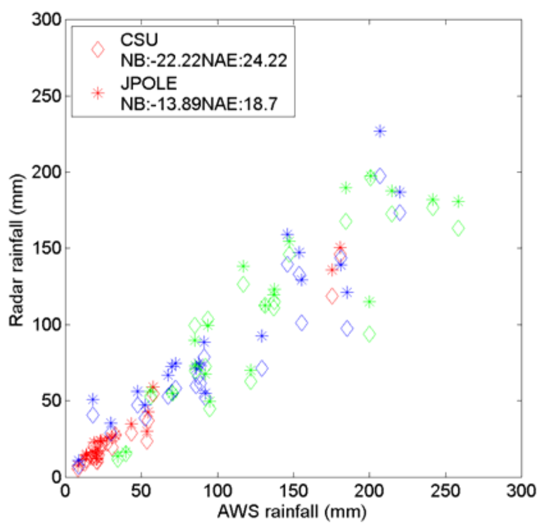

Fig. 5. Comparison of KMA AWS gauge rainfall and radar based daily rainfall for July 13, August 23 and September 17, 2012. Red: July 15, Blue: August 23, and Green: September 17, 2012.

4. CONCLUSION

Exploitation of polarimetric radar in hydrometeorology is at the initial stage in Korea. This study aimed to figure out regional applicability of the radar-induced precipitation estimations in Korean Peninsula. Two algorithms, the CSU and JPOLE, were adopted and both tended to reasonably reproduced daily precipitation in multiple rainfall cases during summer of 2012 at multiple sites. In model comparisons using ground observations, the JPOLE algorithm showed conservative performance with a narrower range of deviation. In order to fully verify the models and their applicability over the East Asia monsoon climate, additional studies under various cases and environments should be further conducted.

5. ACKNOWLEDGEMENT

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