Merging Single and Dual-polarization Radar Rainrates to Improve the Accuracy of Quantitative Rainrate Estimation

Jae-Kyoung Lee, Ji-Hyeon Kim, Hye-Sook Park, Mi-Kyung Suk, Jae-Won Lee

Korea Meteorological Administration, Weather Radar Center, Seoul 156-720, Korea

Jae-Kyoung Lee

1 Introduction

Quantitative Precipitation Estimation (QPE) system based on 11 single-polarization radars has been operated by the Korea Meteorological Administration (KMA). Furthermore, radar rainrates can be estimated accurately if various variables observed by the dual-pol radar in operation are utilized(Vulpiani, *et al*., 2009; Oh *et al*., 2010; Cifelli *et al*., 2011; Kang *et al*., 2011; Kwon, et al., 2011). Therefore, this study applied several merging methods to the QPE system using single-pol radars and S-band dual-pol radar in order to improve the accuracy of the rainrate estimation of the QPE system.

2 Merging methods

In QPE systems, generally, a certain model is not superior to others all the time. If results of several systems are aggregated into one result reflecting strengths and weaknesses for each model, the more accurate rainrate estimation is obtained (Clemen *et al*., 1995). This study dealt with multiple merging methods as follows:

Simple Average and Maximum Value methods

The easiest methods are the Simple Average (SA) method which assigns the equal weight to all of models and the Maximum Value (MV) method which selects the largest value among them.

Weighted Average method

The Weighted Average (WA) method assigns different weights to models according to the model errors. This study dealt with the Variance-Covariance method (Bates and Granger, 1969) to merge the multiple rainrates. Weights of models are as follows (Jeong et al., 2009):

$$w_1 = \frac{\sigma_2^2 - \sigma_{12}}{\sigma_1^2 + \sigma_2^2 - 2\sigma_{12}}, \quad w_2 = \frac{\sigma_1^2 - \sigma_{12}}{\sigma_1^2 + \sigma_2^2 - 2\sigma_{12}} \tag{1}$$

Where, σ_c^2 is error variance of merged rainrates, σ_1^2 is error variance of model R_1 $(= E(e_1^2))$, σ_2^2 은 error variance of model R_2 $(= E(e_2^2))$, σ_{12} is covariance of model R_1 and R_2 $(= E(e_1, e_2))$, the sum of weights is 1.

Sum of Square Error method

Sum of Squared Error (SSE) method assigns weights which are proportional to the reciprocal of error variance in each model to the multiple rainrates. Weights of models are as follows (Jeong et al., 2009):

$$w_1 = \frac{1/\sigma_1^2}{1/\sigma_1^2 + 1/\sigma_2^2} = \frac{\sigma_2^2}{\sigma_1^2 + 1_2^2}, \quad w_2 = \frac{\sigma_1^2}{\sigma_1^2 + 1_2^2} \tag{2}$$

Time-Varying mergence method

The Time-Varying mergence (TV) method assigns weights which are different according to the merging time to the several QPE rainrates. This study dealt with the Time-Varying SSE (TVSSE) (Granger and Newbold, 1977) to aggregate the multiple rainrates to one. Weights of models are as follows:

$$\hat{\sigma}_i^2 = \sum_{s=t-v}^{t-1} (e_{s,t})^2 \tag{3}$$

Where v is the range of used observational error.

3 Merging rainrates of single- and S-band dual-pol radars

This study carried out the QPE system (called RAR-AWS Rainfall calculation system, RAR system) based on 11 single-pol radars which is operated by the KMA in work-site. In the RAR system, every 10-minute reflectivity from radars and observed rainrates are inputted into the Window Probability Matching Method (WPMM) (Rosenfeld et al., 1993) to obtain parameters of the Z-R relation, thereby estimating real-time radar rainrates. For rainrate estimation of the dual-pol radar, the Bislsan S-band dual-pol radar which was launched by the Ministry of Land, Infrastructure and Transport in 2009 was utilized to estimate radar rainrates using the Z-R relation (Bringi and Chandrasekar, 2001) with the reflectivity (Z_H) and specific reflectivity (Z_{DR}). The rainrate estimator is as follows:

$$R(Z_H, Z_{DR}) = 0.0067 \times (Z_H^{0.93}) \times (10^{(0.1\times -3.43\times Z_{DR})}) \tag{4}$$

This study applied six merging methods (SA, MV, WA, SSE, Time-Varying WA, Time-Varying SSE) to the RAR system using single-pol radars and Bislsan S-band dual-pol radar in order to improve the accuracy of the rainrate estimation of the RAR system for 3 events in 2012 summer season. Merged radar rainrates was also compared with observed rainrates in 2 weather stations. As a result (refer to Table 1), the merging results of the WA and SSE methods which are assigned different weights due to the accuracy of the individual model, performed better than the popular merging method, the SA (Simple Average) method. Especially, the results of TVWA (Time-Varying WA) and TVSSE (Time-Varying SSE), which were weighted differently due to the time-varying model error and standard deviation, were superior to the WA and SSE. Among of all the merging methods, the accuracy of the TVWA merging results showed the best performance.

Fig 1 showed images of merged results on 0720 LST on 23 August in 2012. Results of the RAR system and MV method overestimated rain zones located the south-west to the north-east, SA results also was display excessively. The WA and SSE results were closer to the observed rainrates than previous results. Particularly, although bias of the TVWA and TVSSE were worse than the SA, WA, and SSE caused by underestimated partially, the TVWA and TVSSE were better than others in RMSE and correlation coefficient.

Table 1: Application results in each merging method for all events

Merging method	Bias (mm 10-min^{-1})	RMSE (mm 10-min^{-1})	Correlation Coefficient
RAR	1.465	2.856	0.324
MV	1.552	2.856	0.412
SA	0.695	1.455	0.449
WA	0.035	0.887	0.591
SSE	0.068	0.871	0.597
TVWA	0.198	0.692	0.629
TVSSE	0.184	0.722	0.609

** MV: Maximum Value; SA: Simple Average; WA: Weighted Average; SSE: Sum of Squared Error; TVWA: Time-Varying Weighted Average; TVSSE: Time-Varying Sum of Squared Error*

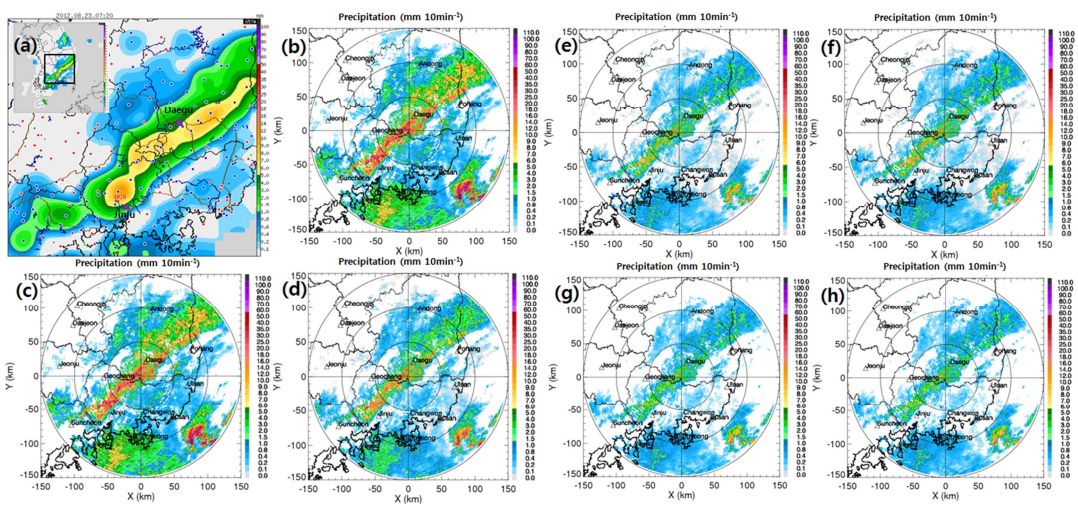

Figure. 1: Comparison of merging rainrate images on 0720 LST on 23 August in 2012: (a) AWS; (b) RAR system; (c) MV method; (d) SA method; (e) WA method; (f) SSE method; (g) TVWA method; (h) TVSSE method

4 Conclusion

This study focuses on aggregating the single- and dual-pol radars rainrates using several merging methods (SA, MV, WA, SSE, Time-Varying WA, Time-Varying SSE). It is proved that merging methods proposed by this study enables to improve the accuracy of the quantitative rainrate estimation of the RAR system. Moreover, this study is worthy of the fundamental research on the active utilization of dual-polarization radar for weather forecasts.

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