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A statistical approach to radar rainfall estimates using polarimetric variables

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ABSTRACT

To improve the accuracy of radar rainfall estimates, this study examines rainfall relationships derived from polarimetric variables calculated from Drop Size Distributions (DSDs) measured by POSS (Precipitation Occurrence Sensor System) and PARSIVEL (PARticle Size and VELocity) disdrometers for eight different rainfall events in Korea associated with the Changma front, low pressure systems, typhoons, or the indirect effects of typhoons.

Analysis of the correlation coefficients between polarimetric variables as independent parameters shows that multicollinearity is expected for Z–K_{DP}, Z–A_H, and K_{DP}–A_H. Of these, R(Z, K_{DP}) is the only relationship that had too low an accuracy for application to radar rainfall estimation. R(Z, Z_{DR}, K_{DP}) and R(Z, K_{DP}, A_H) were also omitted from this analysis because their intercept coefficients were too large.

Analysis of the sensitivity of radar rainfall estimation to DSDs variation shows that the latest observed DSDs perform well, as much as 2.4 mm h^{-1} for RMSE (Root Mean Square Error) and 0.23 for NE (Normalized Error) in maximum. The statistical scores of each radar rainfall estimator vary between different rainfall events. This paper examines a new approach to radar rainfall estimation that is similar to the ensemble technique widely used in numerical prediction models. The ensemble members were chosen based on the average and standard deviation of their RMSE and NE for eight rainfall events. Two different weighting schemes were applied to each ensemble and the members were weighted equally or, alternatively, weighted based on their statistical scores. The performance of eight ensemble sets was examined using four independent rainfall events. There is little difference in the accuracy of each ensemble with respect to the weighting scheme applied. An ensemble composed of R(Z,Z_{DR}), R(Z), and R(K_{DP}), all given an equal weighting, was the most accurate.

1. Introduction

Weather radar is a useful instrument for estimating rainfall amounts, as well as monitoring and forecasting severe storms, due to its high spatial and temporal resolution compared with other remote sensing instrumentation. Regarding radar rainfall estimation, the Z–R relationship (hereafter R(Z)) is required to convert reflectivity (Z) to rain rate (R). The drop size distributions (DSDs) observed by disdrometers have been widely used to measure both Z and R values associated with different rainfall types (Campos and Zawadzki 2000; You et al. 2004). However, the accuracy of radar rainfall estimates can be reduced due to signal contamination by non-meteorological targets, signal attenuation, poor hardware calibration, and partial beam filling (Wilson and Brandes 1979; Austin 1987). Since the advent of polarimetric radar, these problems can be mitigated by using polarimetric parameters such as Z, differential reflectivity (Z_{DR}), the differential phase shift (Φ_{DP}), the cross-correlation coefficient (ρ_{hv}), and the specific differential phase (K_{DP}) (Ryzhkov and Zrnic 1998; Vivekanandan et al. 1999; Giangrande and Ryzhkov 2008). An improvement of radar rainfall accuracy is one of the major points of polarimetric radar (Ryzhkov and Zrnic 1996; May et al. 1999; Bringi and Chandrasekar 2001). There have been several studies of polarimetric radar rainfall estimation; for example, use of a synthetic algorithm in Oklahoma (Ryzhkov et al. 2005a), and a comparison of two different rainfall algorithms in Colorado (Cifelli et al., 2011). Recently, Ryzhkov et al. (2014) introduced specific attenuation (A_H) for rainfall estimation and found that the R (A_H) relationship provides accurate rainfall estimates, even at S-band wavelength where attenuation is small compared with shorter wavelength radars. There are three main agencies in Korea that operate radars to monitor and forecast extreme rainfall events: the Ministry of National Defense (MND); the Ministry of Land, Infrastructure and Transportation (MoLIT); and the Korea Meteorological Administration

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(KMA) are replacing their single polarization radar network with a dual polarization radar network. MoLIT installed the first S-band polarimetric radar in Korea, and KMA will have installed 10 S-band polarimetric radars by 2019. NMD replaced three C-band Doppler radars with C-band polarimetric radars in 2017. To operate so many polarimetric radars successfully, studies investigating polarimetric radar applications, such as rainfall estimation, hydrometeor classification, and DSD retrieval are required. There have been few studies of rainfall estimation and polarimetric radar data quality in Korea. You et al. (2014a) derived polarimetric rainfall relationships using long-period DSDs measured using a POSS (Precipitation Occurrence Sensor System; Sheppard 1990) disdrometer. They found rainfall estimates using R (Z,Z_{DR}) obtained by DSDs measured in the Busan area of Korea were more accurate than those obtained in Oklahoma, USA. A quality control algorithm for removing non-weather echoes, and a separate algorithm for unfolding Φ_{DP} to obtain more accurate K_{DP} values, was applied to the rainfall estimation using $R(K_{DP})$ (You et al. 2014b). A relationship combining available variables has been obtained from polarimetric radar of the form $R(Z,Z_{DR},K_{DP},A_H)$ and this was examined by comparing it with other rainfall relationships such as R(Z), $R(Z,Z_{DR})$, and $R(K_{DP})$ (You and Lee 2015a). All possible rainfall relationships based on combined polarimetric variables, including A_H, should be examined to measure radar rainfall estimation and evaluate the performance of rainfall estimation with respect to the temporal variations of rainfall. None of the rainfall relationship will consistently generate the most accurate rainfall estimates, and this is because R(Z) is more accurate for light rainfall and $R(K_{DP})$ is more accurate for heavy rainfall (Ryzhkov et al. 2005a). As such, the ensemble technique, which is widely used in numerical weather prediction modeling (Lorenz 1965), and the blending method, which combines the radar and numerical prediction models, can be used to achieve more robust and accurate rainfall estimates. Use of polarimetric radars provides many rainfall relationships, meaning each can be used as an ensemble member. Polarimetric radar rainfall relationships obtained from DSDs with different time periods should be examined because they are largely dependent on data from the specific region and time.

This paper discusses how to improve the accuracy of rainfall estimation using a selection of rainfall relationships, and proposes a new way to obtain more reliable rainfall estimates using measurements from a polarimetric radar in Korea. Section 2 describes the rain gauge, DSDs, and radar dataset, together with the calculation of polarimetric variables from DSDs and the validation methods. Section 3 introduces the polarimetric rainfall relationship, Z and Z_{DR} bias correction, the statistical results of rainfall estimation using all relationships, and a new method to obtain more accurate and robust rainfall estimates. Finally, Section 4 summarizes the results and provides the conclusions in Section 4.

2. Data and methodology

2.1. Dataset

The locations of all instruments used in this study, including rain gauges, radar, and disdrometers are shown in Fig. 1.

We used the 1-min DSDs measured by POSS over four years from 2001 to 2004, and by PARSIVEL during 2012 (You and Lee 2015a and 2015b) to obtain the polarimetric rainfall relationships. To screen for less reliable DSDs, estimates meeting any of the following criteria were removed: 1-min rain rates $< 0.1\ \mathrm{mm\,h^{-1}}$, total number concentrations of all channels < 10, and drop numbers counted only in the lower five channels (0.54 mm). Data were also removed if the difference in the amount of rainfall measured between PARSIVEL and the rain gauge was > 50% (You and Lee, 2015b).

Radar data were obtained from the polarimetric radar (hereafter BSL) operating with 750 kW of transmitted peak power, a beam width of 0.95°, and a frequency of 2.791 GHz. The polarimetric variables were estimated with a gate size of 0.125 km at six elevation angles every 2.5 min. Polarimetric variables at a 0.5° elevation angle and at every 2.5 min were selected to calculate rainfall. Data meeting the following criteria were excluded: those exceeding the standard deviation of Φ_{DP} (for nine gates) of 15°, or having $\rho_{hv} > 0.85$ to remove data contaminated by non-meteorological targets. K_{DP} was calculated from Φ_{DP} using 9 gates, or 25 gates if under $Z \geq 40$ dBZ or $Z < 40$ dBZ conditions. To reduce the radial fluctuation of Z_{DR}, a nine-gate moving

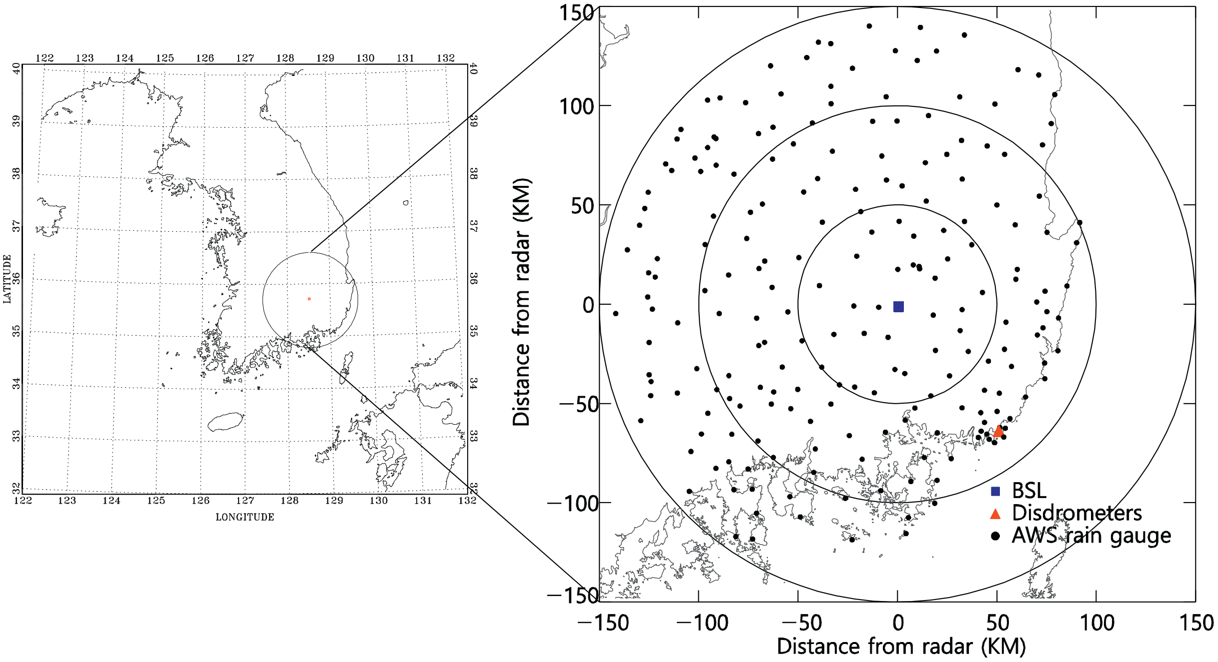

Fig. 1. The location of BSL radar (blue rectangle), the POSS and PARSIVEL disdrometer (red triangle), and the rain gauges (black circle). The BSL radar is located at the center of the right panel, and concentric circles increasing in radius by 50 km are drawn around this center. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)