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Inter-comparison of radar rainfall rate using Constant Altitude Plan Position Indicator and hybrid surface rainfall maps

Soohyun Kwon [a], Sung-Hwa Jung [a], GyuWon Lee [a,b,*]

[a] Center for Atmospheric REmote sensing (CARE), Kyungpook National University, Republic of Korea
[b] Department of Astronomy and Atmospheric Sciences, Research and Training Team for Future Creative Astrophysicists and Cosmologist, Kyungpook National University, Republic of Korea

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SUMMARY

Ground clutter and beam blockage caused by complex terrain deteriorates the accuracy of radar quantitative precipitation estimations (QPE). To improve radar QPE, we have developed a technique for radar rainfall estimation, the Kyungpook National University Hybrid Surface Rainfall (KHSR), based on a two-dimensional hybrid surface consisting of the lowest radar bins that are immune to ground clutter, beam blockage, and non-meteorological echoes. The KHSR map is a composite of a ground echo mask, a beam blockage mask, and a rain echo mask, and it was applied to an operational S-band dual-polarimetric radar that scans six PPIs at a low elevation angle every 2.5 min. By using three rainfall estimators, $R(Z_H)$, $R(Z_H, Z_{DR})$, and $R(Z_H, \xi_{DR})$, this technique was compared with an operational Constant Altitude Plan Position Indicator (CAPPI) QPE of the Korea Meteorological Administration during a summer season from June–August 2012. In comparison with CAPPI, KHSR shows improved rainfall estimates for three algorithms, and it was more effective with dual-polarimetric rainfall algorithms than with single polarimetric rainfall algorithms. Error increased with increasing range from radar, but this increase was more rapid using CAPPI than using KHSR. KHSR using the $R(Z_H, Z_{DR})$ algorithm was the most accurate long range (>100 km from the radar) estimator.

1. Introduction

Radar observations in complex terrains suffer from severe beam blockage and ground clutter, resulting in inaccurate estimates of radar rainfall. Many techniques have been developed to detect and remove ground clutter and anomalous propagation (AP), including ground echo maps, signal processing filters, the Bayesian approach, and fuzzy logic (e.g., Berenguer et al., 2006; Cho et al., 2006; Harrison et al., 2000; Hubbert et al., 2009; Rico-Ramirez and Cluckie, 2008; Steiner and Smith, 2002). Blocked regions have also been corrected using a vertical profile of reflectivity (e.g., Andrieu et al., 1997; Creutin et al., 1997; Kucera et al., 2004), a digital elevation model simulation of the beam blocked fraction (e.g., Bech et al., 2003; Kabeche et al., 2011), and using the self-consistency between dual-polarimetric parameters (e.g., Lang et al., 2009; Zhang et al., 2013).

The radar quantitative precipitation estimation (QPE) technique for operational use was developed in Switzerland (e.g., Germann, 2000; Germann and Joss, 2001, 2002; Germann et al., 2006; Lee et al., 1995), and resulted in significant improvements of radar rainfall over complex terrain. The technique utilizes the vertical profile of reflectivity at the mesobeta scale to correct the reflectivity in beam blockage at low elevation angles. It then eliminates ground clutter using dynamic clutter maps (e.g., Lee et al., 1995), and fills in the holes of the clutter elimination by interpolating from neighboring reflectivity. However, the usefulness of this method depends on the representativeness of the profile in time and space. Furthermore, it is difficult to expand the profile correction method into dual-polarimetric measurements (e.g., Z_{DR}) due to an insufficient scheme to correct Z_{DR} in partially blocked areas.

The hybrid scan surface method, which uses multiple elevation angles to avoid contamination by ground clutter and beam blockage, was developed to improve radar QPE over complex terrain. The standard "terrain-based" hybrid scan method has been widely used for operational radar (Fulton et al., 1998; Maddox et al., 2002; O'Bannon, 1997). These algorithms consist of beam simulations based on standard terrain data, such as digital elevation models (DEM) and standard beam propagation. Chang et al. (2009)

* Corresponding author at: Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Daehakro 80, Buk-gu, Daegu 702-701, Republic of Korea. Tel.: +82 53 950 6361; fax: +82 53 950 6359.
E-mail address: gyuwon@knu.ac.kr (G. Lee).

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developed an algorithm to mitigate ground clutter caused by radar side-lobe by comparing the differences in the occurrence of radar reflectivity and gauge-based rainfall.

Most dual-polarimetric radar in Korea is located on top of high mountains, with elevations up to 1,408 m, in order to avoid beam blockage. However, the high radar elevation causes rainfall error due to the height difference between the radar and the ground. The scanning strategy employs negative elevation angles to overcome this height difference, resulting in increased ground clutter. Thus, using multiple elevation angles is useful for improving the accuracy of rainfall estimation over complex terrains, such as the Korean peninsula.

In this study, we aimed to develop a technique for radar rainfall estimation to replace the existing Constant Altitude Plan Position Indicator (CAPPI) used for operational radar QPE by the Korea Meteorological Administration (KMA) for complex terrains. The Kyungpook National University Hybrid Surface Rainfall (KHSR), uses the lowest radar elevation angles which are not affected by beam blockage, ground echo, and non-meteorological echo, using an operational S-band dual-polarization radar. The technique uses dual-polarimetric parameters to classify the non-meteorological echo. We evaluated the method by comparison with operational radar CAPPI QPE data from KMA, calculated during a summer season (June–August 2012). In addition, we also examined the discrepancies between the KHSR and CAPPI rainfall estimates using both single and dual-polarimetric parameters.

2. Data

Volumetric data from the Mt. Bisl S-band dual-polarimetric (BSL) radar (Table 1), collected between June and August 2012 (summer season) were used in this study. This radar has a beam width of 0.95°, a bin spacing of 125 m, and scans six elevation angles (−0.5°, 0.0°, 0.5°, 0.8°, 1.2°, and 1.6°) for every 2.5 min. The radar elevation angle contains a negative elevation angle to obtain radar data close to the ground surface, which can improve radar QPE and detect low level precipitation and the onset of shallow convection in surrounding valleys (Brown et al., 2002, 2007). However, the measurements at low elevation angles from the BSL radar suffer from severe ground clutter and beam blockage, especially at −0.5° and 0.0°.

Data from 165 KMA rain gauges within the BSL radar observation range (150 km) were used to verify the radar QPE (Fig. 1). Rain gauge rainfall was collected by a tipping bucket, with a tip resolution of 0.5 mm, every 1 min. The 1-min rainfall amounts were calculated from the daily-accumulated rainfall measured each minute. Hourly rainfall rates were calculated by averaging the 1-min rainfall rates for an hour. Almost 40 rain days, including monsoon and typhoon events, were recorded during the June–August 2012 summer season. Total rainfall recorded at the rain gauges ranged from 450 to 700 mm.

For each rain event, the biases in reflectivity (Z_H) and differential reflectivity (Z_{DR}) were individually calibrated by post-processing using the self-consistency constraint method and vertically pointing observations, respectively (Kwon et al., 2015; Lee and Zawadzki, 2006). The averaged Z_H calibration bias is 1.35 dB, and the standard deviation of the Z_H bias is 0.78 dB. The Z_{DR} bias varied from 0.11 to 0.27 dB. The individual calibration bias was applied to each event with vertically pointing observations. If a vertically pointing observation was not available, an average Z_{DR} bias of 0.16 was used.

Table 1
Characteristics of the S-band dual-polarization radar at Mt. Bisl (BSL).

Parameter	Value
Frequency (wavelength)	2,785 MHz (10 cm, S-band)
Location	35°41′38″N, 128°32′6″E
Height	1,085 m
Beam width	0.95°
Bin spacing	125 m
Moments	Filtered Z_H, unfiltered Z_H, Vr, SW, Z_{DR}, ρ_{HV}, Φ_{DP}, K_{DP}
Elevation angle	−0.5°, 0.0°, 0.5°, 0.8°, 1.2°, 1.6°

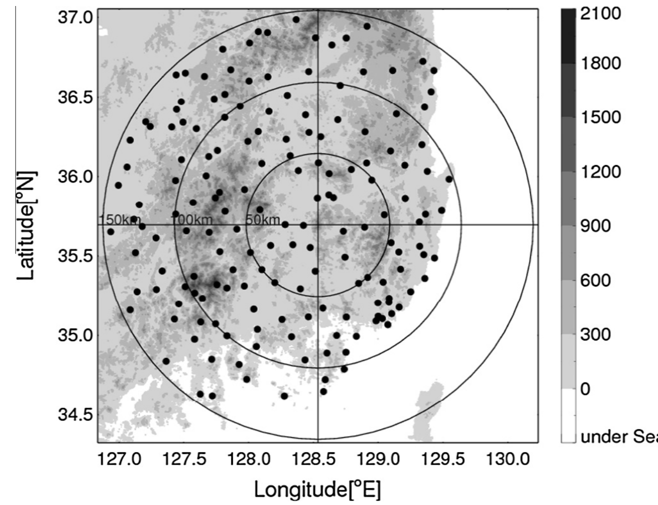

Fig. 1. Geographical distribution of terrain and rain gauges (closed circles) within the radar observation range of the BSL radar. The terrain elevation is shaded in gray, as shown in the scale bar.

3. Methodology

3.1. KHSR development

The KHSR radar rainfall estimates are based on the KHSR mask, which consists of radar bins with the lowest elevation angles that are immune to beam shielding, ground echoes, and non-meteorological echoes. The KHSR mask uses the lowest elevation angle that satisfies the criteria of the selected threshold. The rainfall rate is estimated using Z_H, and Z_{DR} at the KHSR mask. The estimated rainfall rate at polar coordinates is converted to Cartesian coordinates for comparison with CAPPI (Fig. 2). The details are described in the following sections.

3.1.1. Construction of the beam blockage mask

To avoid the effect of radar beam shielding, radar beam blockage (BK) is simulated at each elevation angle of the BSL radar using DEM CGIAR-CSI 2015, which has a horizontal resolution of 3″ (~90 m), the two-way perfect Gaussian beam pattern, and a beam geometry by standard refraction (e.g., Kucera et al., 2004). The fractions of unblocked power are quantified to the beam blockage index (QI_{BK}) using a range from 0 to 1 (Fig. 3). A value of 0 (gray in Fig. 3) represents a completely blocked region, while a value of 1 (black in Fig. 3) represents an unblocked region. From the BSL, for an elevation angle of −0.5°, the western region is fully blocked, while areas >50 km from the radar are partially blocked (Fig. 3a). In addition, the western and southeastern regions are partially blocked at 0.0° (Fig. 3b). No beam blockages exist above 0.8° (Fig. 3c).

The BK mask is made up of the lowest elevation angle radar bins with QI_{BK} greater than BK threshold (0.9), achieved by comparison with QI_{BK} for each radar bin in the vertical dimension. The threshold of 0.9 corresponds to beam shielding of 10% and to a power loss of 0.5 dB. This power loss is smaller than the reflectivity calibration