Preliminary result of hail detection using an operational S-band polarimetric radar in Korea

Mi-Young Kang[1], Dong-In Lee[1,2], Cheol-Hwan You[2], and Sol-Ip Heo[3]

[1]Department of Environmental Atmospheric Sciences, Pukyong National University, 608-737 Busan, Korea
[2]Atmospheric Environmental Research Institute, Pukyong National University, 608-737 Busan, Korea
[3]National Institute of Meteorological Research, KMA 697-845 Jeju-do, Korea

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Miyoung KANG

1 Introduction

Three major agencies in Korea; the Ministry of National Defense (MND), the Ministry of Land, Infrastructure and Transport (MLIT), and the Korea Meteorological Administration (KMA) use radars for monitoring and forecasting of severe weather and flash floods operationally. The MND and KMA plan to install their own dual-polarization radars in a few years. The MLIT already has deployed two S-band dual-polarization radars (hereafter S-DPOL) for operational usage and will install four more radars. The KMA has installed one S-DPOL at the most north-western of Korea in this year. The expected final DPOL radar network in Korea is shown in Figure 1. A DPOL has much better performance of data quality control, hydrometeor classification, and rainfall estimation than Single POL has (Ryzhkov et al., 2005; Brandes et al., 2001).

There were many researches on classifying hail using DPOL in many countries, because hail is one of hydrometeors plays a much important role not only in meteorology but also in agriculture. A hail detection algorithm using DPOL is based on the assumption that differential reflectivity (Z_{DR}) of hail is low due to the random orientation and the combination of low Z_{DR} and high reflectivity (Z) is clue to the presence of hail (Bringi and Chandrasekar, 2001). The advantage of the polarimetric variables is that it provides better quality of hail detection and pinpoints the location of hail in the storm including its height above ground (Heinselman and Ryzhkov (2006).

It was very difficult to monitor the hail event only using conventional radar before installation of DPOL in Korea. Bislsan radar (BSL) with polarimetric capability installed at the eastern part of Korea in 2009 by MLIT. In this study, Hydrometeor Classification Algorithm (HCA) developed by NCAR (National Center for Atmospheric Research) and hail detection algorithm will be tested by combination of Z and Z_{DR}, named by Hail Differential Reflectivity (H_{DR}). And the comparison of performance between H_{DR} and HCA will be done using ground based observation of hail events.

2 Data

2.1 BSL S-band DPOL

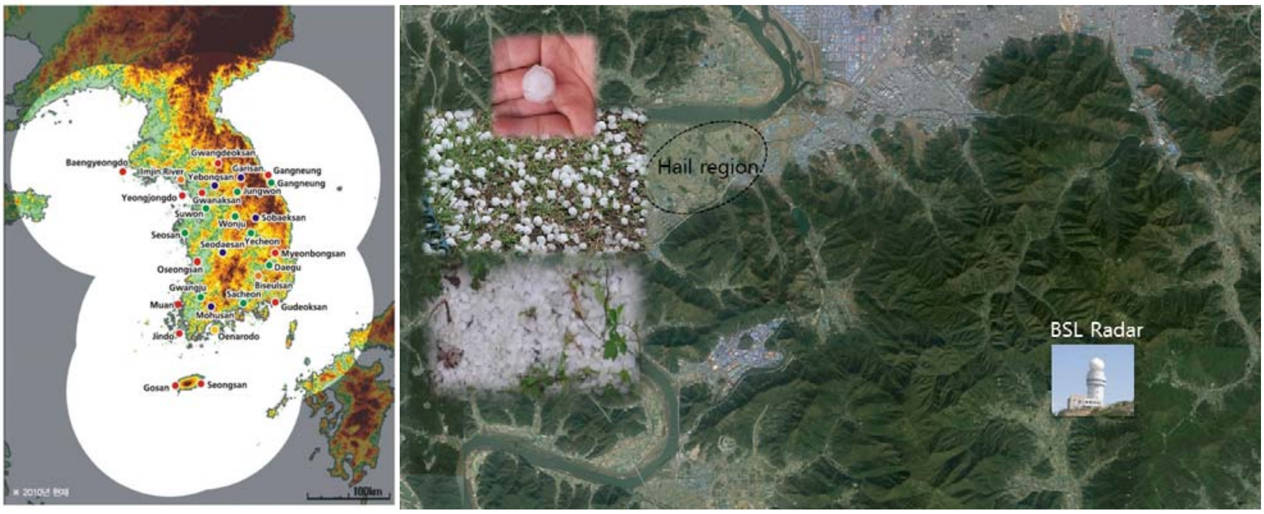

Figure 1: Final dual polarization radar network in Korea. It is adopted from the KMA report (left panel). Right panel is BSL S-band POL station and Hail stones collected at industrial complex of rural areas, in Daegu on 08 May 2012.

The hail reported by citizens and KMA and could be observed by S-DPOL in Daegu located at the south-eastern part of Korea on 8 May in 2012. The trough of atmospheric pressure was located near Daegu area and locally strong thunderstorm was passed through there with hail. Hail report of KMA, sounding and BSL radar data were used for this study. BSL radar is S-band, which has simultaneous transmission, 0.95 beam width and located at the top of 1,085 m height Mountain. Figure 1 shows the location of BSL DPOL and hail region.

2.2 Hail event on 8 May 2012.

The downtown of Daegu city has rare hail storm climatologically. However, industrial complex of rural areas located a few kilometers away from Daegu has many hail cases. Some strong hail storm was recorded from 1610 LST to 1630 LST on 08 May 2012.

This hail was occurred by strongly localized storm and the duration was about 1 hour. Accumulated rainfall amount at the area was less than 5 mm for 1 hour. However, the maximum value of reflectivity was 63 dBZ and above 58 dBZ at the hail region. The maximum hail size was around 2cm and was within 2cm mostly.

3 Results

3.1 A new H_{DR} relation

The most commonly used algorithm for hail detection using polarimetric parameters are combined - measurements of Z_H and Z_{DR}. Aydin et al. (1986) suggested that H_{DR} greater than 0dB indicates the presence of hail. And higher H_{DR} means larger hail. The H_{DR} parameter proposed by Aydin et al. (1986) is calculated by Equations (1) and (2).

In this study, a similar relation was calculated by Drop Size Distribution (DSD) data observed in Busan of Korea for four years . The Z and Z_{DR} were calculated using by T-matrix scattering techniques derived by Waterman (1971) and later developed further by Mishchenko eta al. (1996). The total number of DSDs was 122,909 after quality control. The axis ratio of rain drops was assumed equilibrium axis ratio derived from the numerical model by Beard and Chung (1987). Another required parameter of the T-matrix simulation is the temperature which is assumed as 20 °C and wavelength is S-band. A new relations are shown in Equation (3).

$$H_{DR}=Z- f(Z_{DR}) \qquad \text{when } H_{DR}>0\text{, it's hail} \tag{1}$$

where,

$$\begin{aligned} f(Z_{DR})&=27 \text{ if } Z_{DR}\le 0\text{dB} \\ f(Z_{DR})&=19Z_{DR}+27 \text{ if } 0\le Z_{DR}\le 1.74\text{dB} \\ f(Z_{DR})&=60 \text{ if } Z_{DR}\ge 1.74\text{dB} \end{aligned} \tag{2}$$

$$\begin{aligned} f(Z_{DR})&=40 \text{ if } Z_{DR}\le 0\text{dB} \\ f(Z_{DR})&=13.82Z_{DR}+40 \text{ if } 0\le Z_{DR}\le 1.23\text{dB} \\ f(Z_{DR})&=57 \text{ if } Z_{DR}\ge 1.23\text{dB} \end{aligned} \tag{3}$$

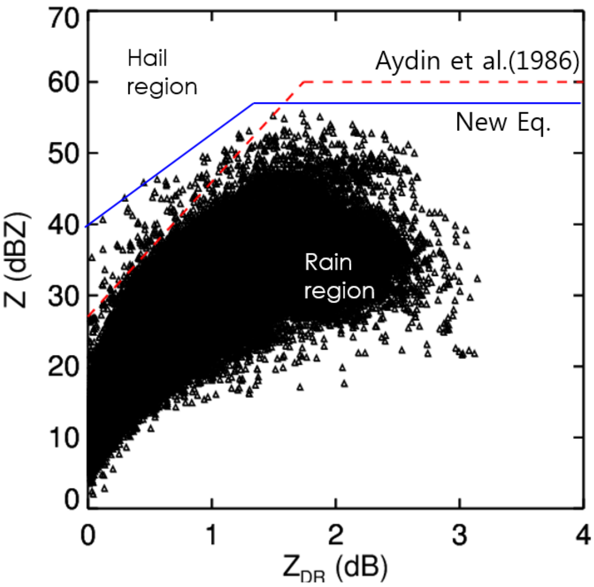

Figure 2: Rain-hail region in the Z_H-Z_{DR} plane as defined by Aydin's formula (red dot line) and new formula (blue solid line). The blue curve shows the rain-hail boundary by Equation (3)

Figure 2 shows the rain-hail boundary in the Z_H-Z_{DR} plane as defined by Aydin's and new relation. Aydin's line intersects rain regions which Z_{DR} is less than 1.5 dB and Z_H is 30 dBZ to 53 dBZ. We calculated the new relation not overlapped with each region.

3.2 HCA result

The National Institute of Meteorological Research (NIMR) developed hydrometeor classification algorithm through joint research with the NCAR from 2009 to 2011 (NIMR 2009). NCAR algorithm decides the hydrometeors using maximum value of membership function and 2 weighting classification of 14 hydrometeors in total without non-meteorological echo (Vivekanandan, J. et. al, 1999). The horizontal distribution of reflectivity, differential reflectivity and result of HCA are shown in Figure 3. The black polygon shows the suspected hail location. The reflectivity was above 55 dBZ and Z_{DR} was low value from -0.5 to 0 dB.

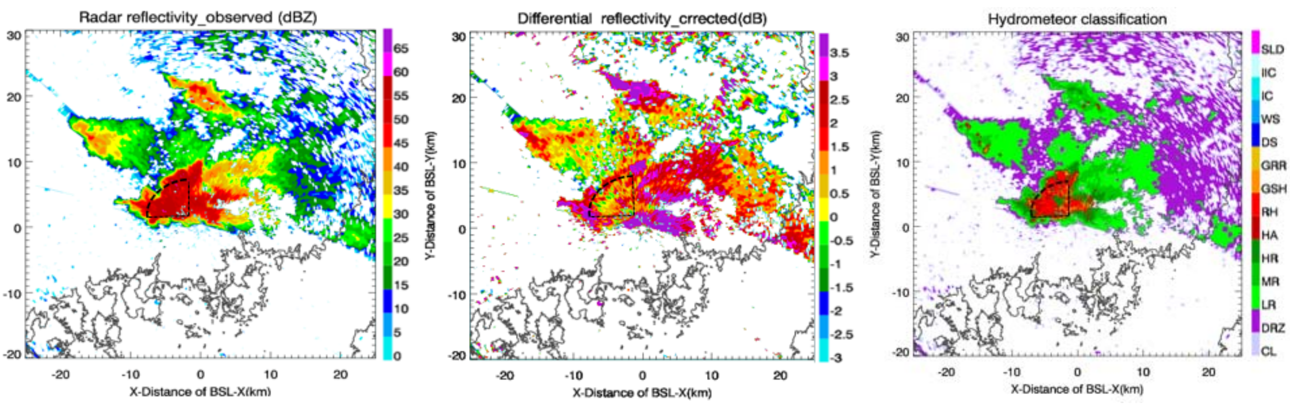

Figure 3: PPIs of Z_H, Z_{DR}, and HCA at 1620LST 08 May, 2012, obtained with 0.02 elevation angle of BSL DPOL. The dark diagram shows the area where the dark red color and red color which indicate rain/hail and hail, respectively.

The time series of polarimetric parameters at industrial complex of rural areas was reported with hail occurrence were shown in Figure 4 to evaluate H_{DR}. The pink shading area shows good signature of hail, high reflectivity, lower Z_{DR}, high cross correlation coefficients from 1610 LST to 1625 LST. This is one of clues for NCAR HCA algorithm's reliability but we do not know if the whole area was hail or not.

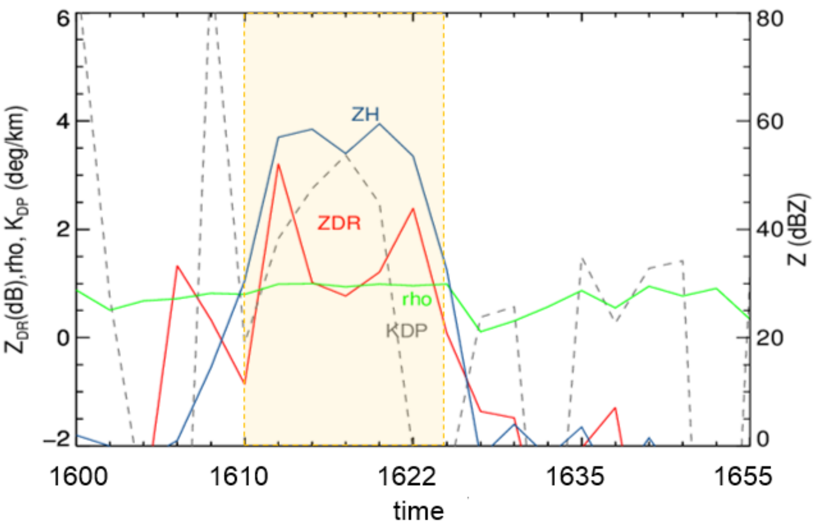

Figure 4: Time series of polarimetric parameter along a portion of a ray (294 ° azimuth) Fig.3 at the elevation angle (0.02°) scan at 1620 LST, May 08, 2012 in Daegu, Korea

3.3 Comparison of H_{DR}

Figure 5 shows the horizontal distributions of H_{DR}, computed from Equations (2) and (3). "A" character on the Figure 5 is a location recorded hail. H_{DR} is generally an indicator of intensity or size of hail. In the regions with strong reflectivity, it could discriminate hail from rain region with a greater certainty. In this case, H_{DR} detected hail region in coincident with the area of 53dBZ designated as hail in the current rainfall algorithm of WSR-88D. There is larger area above 30 dB of H_{DR} calculated from Equation 2 than that of new H_{DR} value obtained from Equation (2). Comparing H_{DR} and HCA, both Adyin et al. and new relation has a little different size of above 20 dB region. It is considered that new H_{DR} has more similar to HCA hail category.

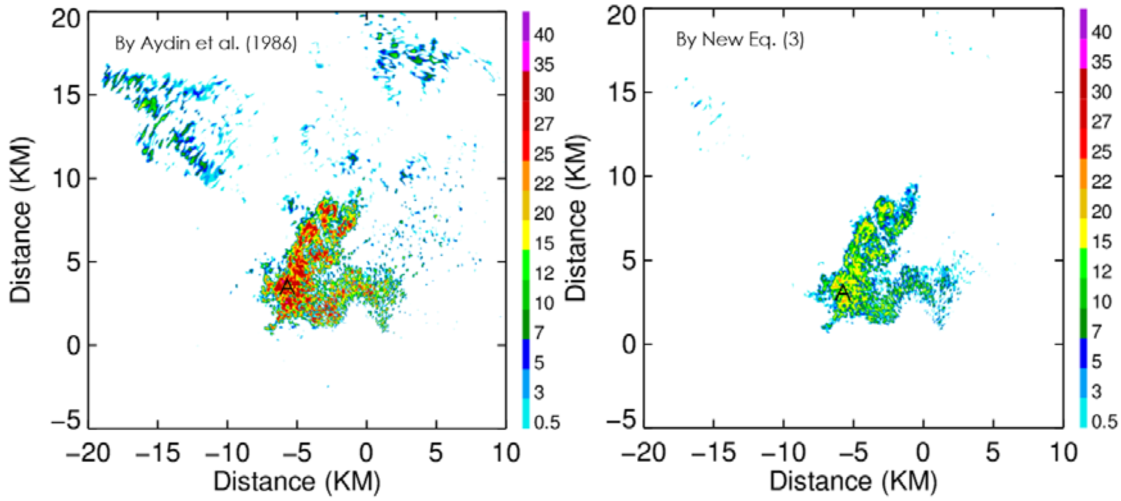

Figure 5: 0.02 degree PPI of H_{DR} on 08 May 2012 (a) obtained from Aydin et al. and (b) new relation. Hail was reported by ground observers at point A from 1610 LST to 1630 LST

Figure 6 shows the radial plots of Z and Z_{DR} along with a single ray through the point A as shown in Fig 5. It is presumed that this sharp gradient of Z and Z_{DR} could give information about hail location. It is very good coincidence with H_{DR} value has larger than 0 dB. And there is the difference of intensity of H_{DR} value between Aydin et al. and new method.

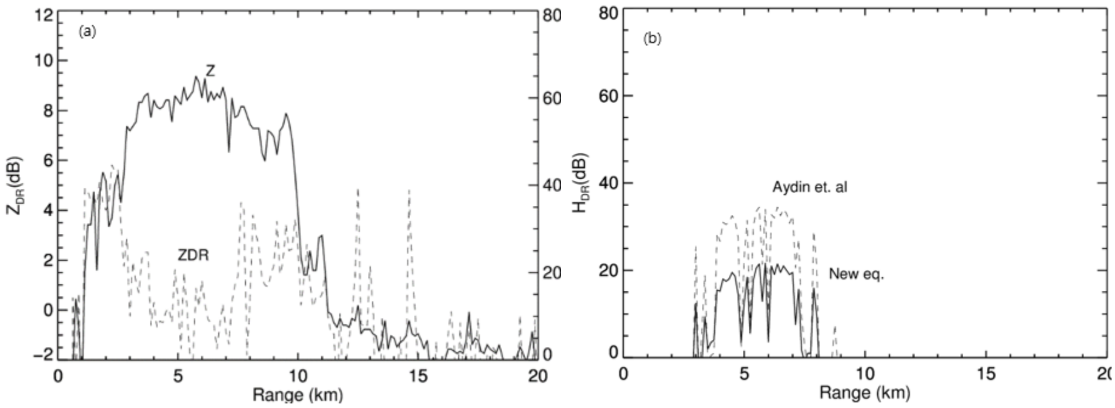

Figure 6: Radial profile of (a) Z_H and Z_{DR} and (b) H_{DR} along with a ray (294 ° in azimuth) in 0.02 elevation angle at 1620 LST 08 May 2012.

According to Depue et al.(2007) report on the polarimetric scheme for measuring hail size, H_{DR} value is above 20 at hail region. Hail stone size can be estimated from Depue et. al.' Graph (Figure 7).

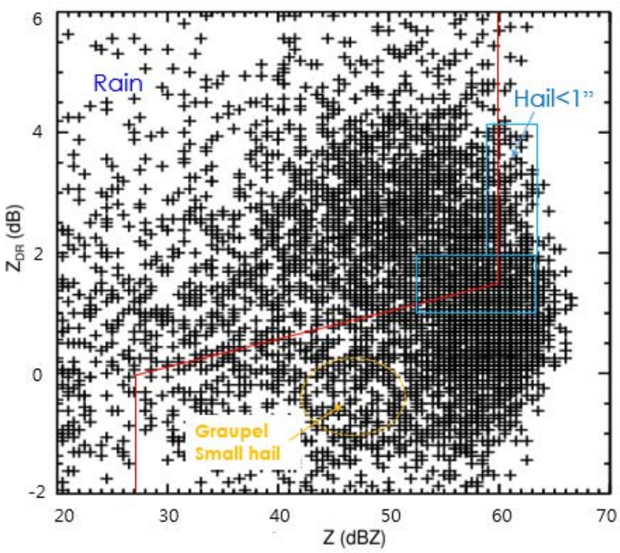

Figure 7: Scatter plot of Z_{DR}, Z from the radar PPI EL=0.02 deg of data that were denoted as dot fan shape region in Figure 3. Hail occurred on May 08, 2012. In the inverted L region hail is between 0.5 and 1inch (by Ryzhkov A. V. et al. (2010).

4. Summary

Hail signature of H_{DR} was calculated by DSDs data in Busan area and compared with some results between Aydin et al (1986). In addition, we also compared HCA and H_{DR} using hail case on 8 May in 2012. This study indicates that the H_{DR} parameter is useful for hail characterization. Even we use one case on hail in this study, we could know a new H_{DR} had better scores on detecting location and size of hail. More cases will be required to gain statistical confidence in its interpretations. If the H_{DR} value verification in other precipitation regimes are valid, they may also provide reference points for the evaluation of HCA based on NCAR Fuzzy membership function and categorization algorithms.

Acknowledgement

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