A Rain Drop Size Distribution (DSD) Retrieval Algorithm for CASA DFW Urban Radar Network

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Overview

The raindrop size distribution (RSD) is a fundamental descriptor of rain microphysics, and hence extensive effort has been under way to measure RSD through both in-situ sampling devices as well as remote observations. The raindrop size distribution along with shape information, essentially determines the behavior of dual polarization observations of precipitation. A remote estimator of RSD from radar measurements can significantly enhance the area over which RSD is observed.

The Dallas-Fort Worth urban weather radar network is being developed by the NSF ERC for Collaborative Adaptive Sensing of Atmosphere (CASA), as a demonstration of the X-band radar networking concept in a metropolitan region. *(More information about the DFW network can be found in Poster: **P190**.)* Though it is an operational radar network, it provides great opportunity to study the RSD variability over different types of storms for scientific applications. This poster will perform a radar data quality control (QC) process for further estimation of RSD parameters. A couple of dual-polarization based RSD retrieval algorithms will then be implemented using data collected from NEXRAD in DFW region as well as the dual-frequency CSU-CHILL radar. The results from this research will be used for development of Quantitative Precipitation Estimation (QPE) system and urban flash flood forecasting model for the DFW region.

RSD and Its Implications for Dual-pol Radar Measurements

The raindrop size distribution (RSD) describes the probability density distribution function of raindrop sizes. A good knowledge of the RSD in the precipitating system is necessary for accurate radar QPE and QPF. Generally, the gamma distribution model can adequately represent many of the natural variations in the shape of the raindrop size distribution (Ulbrich 1983), which can be formed as:

$$N(D) = N_0 D^{\mu} e^{-\Lambda D} \tag{1}$$

where N_0 is the intercept parameter in $\mathrm{m^{-3}mm^{-1-\mu}}$, μ is a distribution shape parameter, Λ is a slope term in $\mathrm{mm^{-1}}$, and D is the volume equivalent diameter in mm. The raindrop size distribution model used in this study is the "normalized" gamma distribution (Testud et al. 2000) that can be described as:

$$N(D) = N_w f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp\left[-(3.67+\mu)\frac{D}{D_0}\right] \tag{2}$$

where N_w is the scaled version of N_0 defined as:

$$N_w = \frac{N_0}{f(\mu)} D_0^{\mu} \tag{3}$$

$$f(\mu) = \frac{6}{(3.67)^4} \cdot \frac{(3.67+\mu)^{\mu+4}}{\Gamma(\mu+4)} \tag{4}$$

The dual-polarization radar measurements, namely, reflectivity at horizontal polarization (Z_h) and vertical polarization (Z_v), differential reflectivity (Z_{dr}), and specific differential phase (K_{dp}), can be related to the integral form of drop size distribution as:

$$Z_h = \frac{\lambda^4}{\pi^5 |K_w|^2} \int \sigma_h(D) N(D) dD \tag{5}$$

$$Z_v = \frac{\lambda^4}{\pi^5 |K_w|^2} \int \sigma_v(D) N(D) dD \tag{6}$$

$$Z_{dr} = 10log_{10}\frac{Z_h}{Z_v} = 10log_{10}\left(\frac{\int \sigma_h(D)N(D)dD}{\int \sigma_v(D)N(D)dD}\right) \tag{7}$$

$$K_{dp} = \frac{180}{\pi}\lambda\, Re \int [f_h(D) - f_v(D)] N(D) dD \tag{8}$$

where λ is the radar wavelength, σ_h and σ_v are the radar cross section at horizontal and vertical polarization, respectively, K_w is the dielectric factor of water given by $K_w = (\varepsilon_r - 1)/(\varepsilon_r + 2)$, ε_r is the complex dielectric constant of water, f_h and f_v are the complex forward-scatter amplitudes at horizontal and vertical polarizations, respectively.

RSD Parameter Retrieval Algorithm

- Retrieval Algorithm for S-band Radar

This algorithm is a modified version of the "β" method proposed by Gorgucci et al. (2002), which takes account of three dual-polarization measurements, including Z_h (in dBZ), Z_{dr} (in dB), and K_{dp} (in deg/km).

If $Z_h \geq 35$ dBZ, $Z_{dr} > 0.2$ dB, $K_{dp} > 0.3$ deg/km, D_0 and N_w are retrieved as:

$$\beta = 2.08 Z_{hL}^{-0.365} K_{dp}^{0.38} Z_{drL}^{0.965} \tag{9}$$

$$D_0 = a_1 Z_{hL}^{b_1} Z_{drL}^{c_1} \tag{10}$$

where $Z_{hL} = 10^{Z_h/10}$ and $Z_{drL} = 10^{Z_{dr}/10}$ are reflectivity and differential reflectivity in linear unit. And the coefficients are $a_1 = 0.595\beta^{0.0353}$, $b_1 = 0.0242\beta^{-0.359}$, $c_1 = 0.103\beta^{-0.91}$.

$$\log_{10} N_w = a_2 Z_{hL}^{b_2} Z_{drL}^{c_2} \tag{11}$$

where $a_2 = 3.12\beta^{0.0201}$, $b_2 = 0.176\beta^{0.376}$, $c_2 = -0.101\beta^{-0.897}$.

If $Z_h < 35$ dBZ, $Z_{dr} \geq 0.2$ dB,

$$D_0 = 1.81 Z_{dr}^{0.486} \tag{12}$$

$$N_w = \frac{21 Z_{hL}}{D_0^{7.353}} \tag{13}$$

If $Z_h < 35$ dBZ, $\mathrm{Z_{dr}} < 0.2$ dB,

$$D_0 = 1.81 * \gamma^{0.486} * Z_{hL}^{0.136} \tag{14}$$

$$N_w = \left(\frac{1.513}{1.81 * \gamma^{0.486}}\right)^{7.35} \tag{15}$$

where $\gamma = \frac{<Z_{dr}>}{<Z_{hL}^{0.37}>}$.

- Retrieval Algorithm for X-band Radar

For RSD retrieval using X-band radar observations, we calculate the β as:

$$\beta = 0.536\left(K_{dp}/Z_{hL}\right)^{0.276} Z_{drL}^{1.212} \tag{16}$$

Then, D_0 and N_w will be retrieved as:

$$D_0 = a_1\left(\frac{Z_{drL} - 0.8}{\beta}\right)^{b_1} \tag{17}$$

$$\log_{10} N_w = a_2 Z_{hL}^{b_2}\left(\frac{Z_{drL} - 0.8}{\beta}\right)^{c_2} \tag{18}$$

where $a_1 = 0.201$, $b_1 = 0.884$, $a_2 = 7.030$, $b_2 = 0.083$, $c_2 = 0.581$.

Radar Data Quality Control

Radar signal processing and data quality control (QC) are critical for meteorological product generation. Instead of directly taking the radar measurements to compute the RSD parameters, we first apply a data QC process because it is not an easy work to get the intrinsic values that radar should measure, especially at higher/attenuating frequency such as X-band.

The principle of this QC process is based on the microphysical characteristics of precipitation with relatively high co-polar correlation and relatively smooth radial behavior of differential propagation phase. A data quality flag is generated based on the thresholds of ρ_{hv}, standard deviation of Φ_{DP}, and signal-to-noise ratio (SNR) (Wang and Chandrasekar, 2009). The quality controlled data is well suited for mitigation of non-meteorological clutter contamination. Fig. 1(a)(b) are sample fields of Z_h, Z_{dr} from KFWS radar for the rainfall event occurred in the DFW region on June 9th, 2013.

In addition, a hybrid rainfall estimation algorithm is developed to measure the rainfall rate using the upgraded dual-polarization NEXRAD data. The K_{dp} field and rainfall rate map corresponding to the data shown in Fig.1 are shown in Fig. 2(a)(b). Nevertheless, the relation between rainfall rate measurements and raindrop size distribution is beyond the scope of this poster.

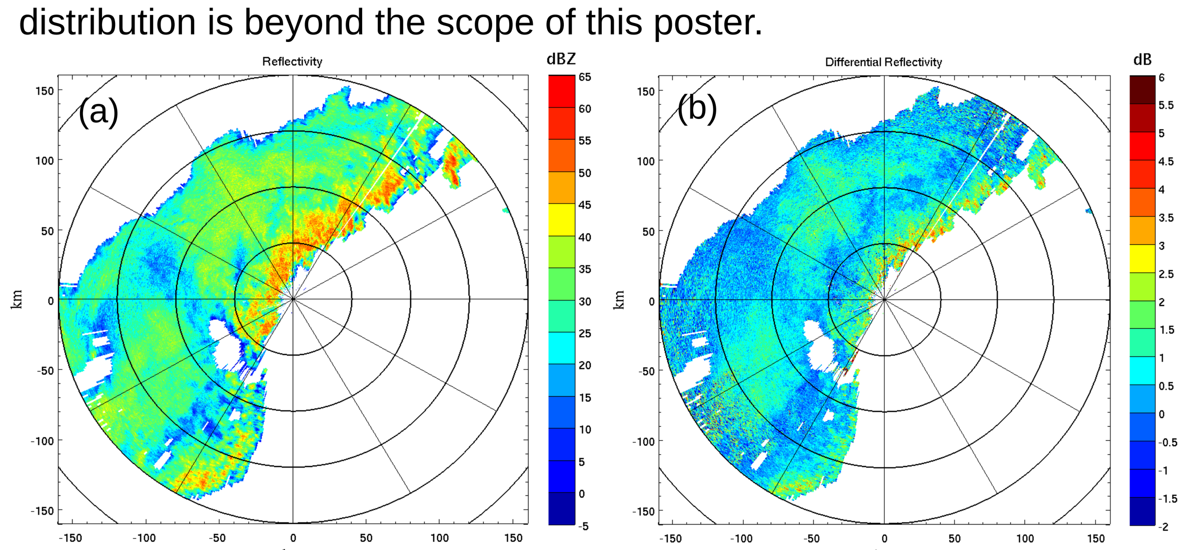

Fig. 1. (a) Z_h (b) Z_{dr} field for KFWS at 11:00:59UTC, June 9th, 2013.

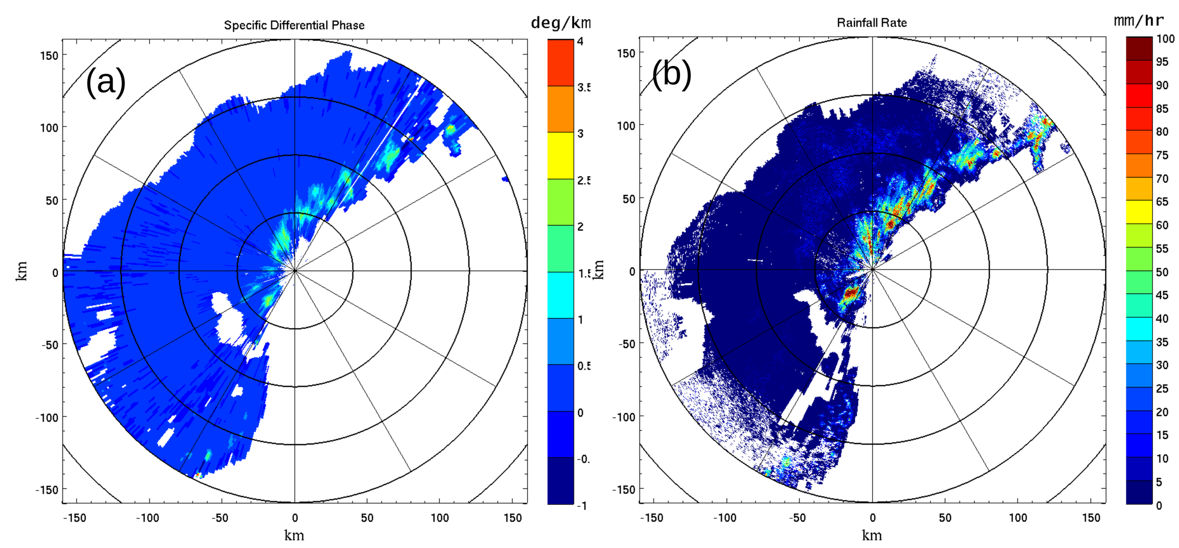

Fig. 2. (a) K_{dp} and (b) rainfall rate field for the same data as shown in Fig. 1.

Real Data Implementation of the RSD Algorithms

The testing of RSD retrieval algorithms has been performed with radar data collected by KFWS and dual-frequency CSU-CHILL radar.

RSD retrieval results corresponding to the data in Fig. 1 and Fig. 2 are shown in Fig. 3.

A strong storm passing CSU-CHILL radar observing range on August 12th, 2013 is also used to demonstrate the data quality control process and test the RSD retrieval methodologies. Fig. 4 and Fig. 5 show the observations and RSD parameters for S- and X-band data, respectively.

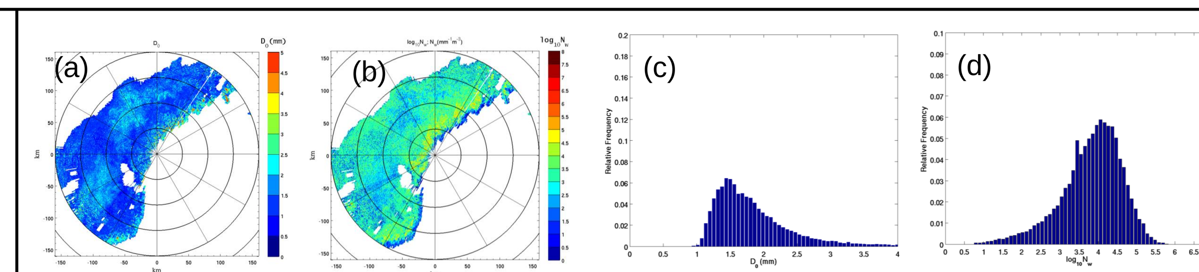

Fig. 3. RSD retrieval results for data shown in Fig. 1 and Fig. 2. (a) and (b) are PPI plots for D_0 and $\log10(N_w)$, whereas (c) and (d) are histograms of the distribution of D_0 and $\log10(N_w)$ in the region where rainfall rate is higher than 10 mm/hr.

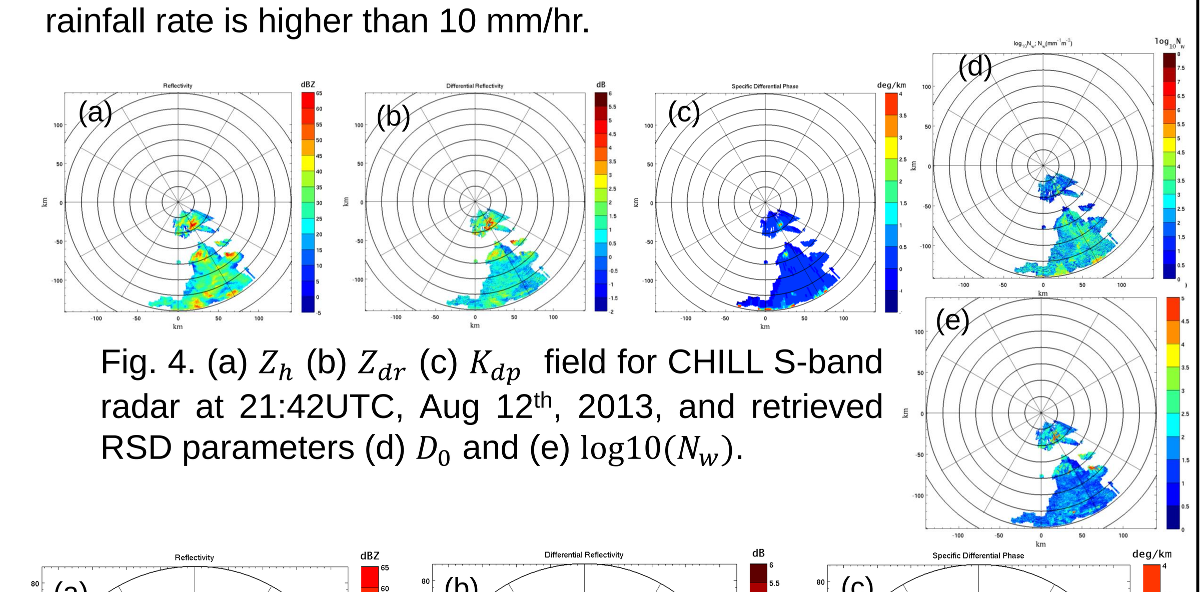

Fig. 4. (a) Z_h (b) Z_{dr} (c) K_{dp} field for CHILL S-band radar at 21:42UTC, Aug 12th, 2013, and retrieved RSD parameters (d) D_0 and (e) $\log10(N_w)$.

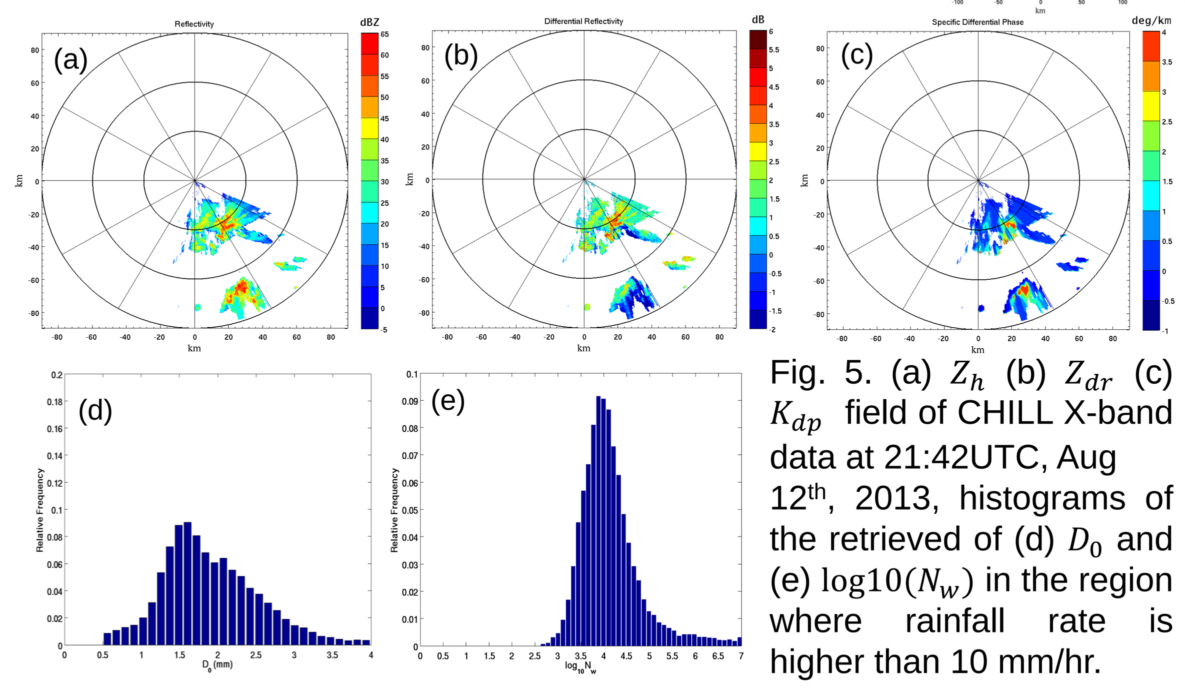

Fig. 5. (a) Z_h (b) Z_{dr} (c) K_{dp} field of CHILL X-band data at 21:42UTC, Aug 12th, 2013, histograms of the retrieved of (d) D_0 and (e) $\log10(N_w)$ in the region where rainfall rate is higher than 10 mm/hr.

Discussion

From the PPI plots and histograms of D_0 and $\log10(N_w)$, we can conclude that the two RSD retrieval algorithms work fairly well especially for heavy rainfall. However, these algorithms depend on a few assumptions on the rain drop shape mode, and the precipitation types. It is also greatly based on the data quality control process including the attenuation correction of reflectivity and differential reflectivity, and estimation of the specific differential propagation phase.

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