P3.2

MONITORING DROP-SIZE DISTRIBUTIONS WITH POLARIMETRIC RADAR

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1. INTRODUCTION

Dual-polarization radars typically transmit horizontally and vertically polarized electromagnetic waves and receive backscattered signals. Because illuminated hydrometeors are not exactly spherical and not similarly oriented, their radar backscatter cross-sections are not the same for the different polarizations. Waves propagating through precipitation are subject to scattering, differential attenuation, differential phase shifts, and depolarization. Signal properties change continuously as the waves propagate yielding information that can be used to estimate particle size, shape, orientation, and thermodynamic phase. The measurements can be used to estimate the governing parameters of gamma drop-size distributions (Ulbrich 1983) and associated rainfall rates. The retrieval technique described here, an adaptation of that proposed by Zhang et al. (2001), is based on measurements of radar reflectivity at horizontal polarization and differential reflectivity and an empirical constraining relationship between the drop-size distribution (DSD) shape factor and slope parameter.

2. DSD RETRIEVAL METHOD

It is assumed that raindrops are represented by the gamma size distribution

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D) \qquad (1)$$

where N_0 (mm $^{-\mu-1}$ m^{-3}) is a number concentration parameter, μ is a distribution shape parameter, and Λ (mm^{-1}) is a slope term. Note that the DSD is described by three parameters and that their determination requires three measurements or relationships. Radar reflectivity, differential reflectivity, and specific differential phase are all related to rain rate; but for several reasons the specific differential phase is deemed a poor choice for closing the system. Instead, we close the system with a constraining relation between μ and Λ and the radar reflectivity and differential reflectivity measurements. The radar reflectivities at horizontal and vertical polarization are given by

$$Z_{H,V} = \frac{4\lambda^4}{\pi^4 |K_w|^2} N_0 \int_0^{D_{\max}} D^{\mu} \exp(-\Lambda D)[(1-2\sigma_{\phi}{}^2) \, |f_{a,b}(D)|^2 + 2\sigma_{\phi}{}^2 \, |f_a(D) f_b(D)|]dD \qquad (2)$$

where H and V indicate horizontal and vertical polarization states, λ is the radar wavelength, K_w is the dielectric factor for water, f_a and f_b are backscattering amplitudes along the major (a) and minor (b) drop axis, and σ_ϕ is the standard deviation of the drop distribution canting angle. In the absence of information regarding drop canting, we assume for this study that σ_ϕ=0^o. The differential reflectivity is defined as the ratio of reflectivity at horizontal and vertical polarization when expressed in mm^6 m^{-3}

$$Z_{DR} = \frac{Z_H}{Z_V}. \qquad (3)$$

Another relation is needed to compute the three parameters in (1). The procedure makes use of the correlation between μ and Λ. The relationship for disdrometer observations made in Florida and having drop counts greater than 1000 min^{-1} and rain rates greater than 5 mm h^{-1} is shown in Fig. 1. The fitted empirical relation is

$$\Lambda = 1.935 + 0.735\mu + 0.0365\mu^2 . \qquad (4)$$

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It has been argued that relations between DSD governing parameters such as Eq. (4) could be due to statistical error in the estimated moments of the DSD. Our analysis (Zhang et al. 2002) shows that errors in the moments cause a linear relation between μ and Λ and not the curvature seen in Fig. 1. Consequently, we believe the relation captures the behavior of natural DSDs.

A useful parameter is the median volume diameter (D_0) defined as

$$\int_0^{D_0} D^3 N(D)dD = \int_{D_0}^{D_{\max}} D^3 N(D)dD$$

where D_{max} (mm) is the equivalent volume diameter of the largest drop. One half of the liquid water content is contained in droplets smaller and one half in drops larger than D_0. A DSD parameter with more physical importance than the concentration parameter is the total drop concentration (N_T, m^{-3}) computed from

$$N_T = \int_0^{D_{\max}} N(D)dD\,.$$

The computational procedure to find the DSD parameters is to use the definition of Z_{DR} [Eq. (3)] expressed in terms of the DSD parameters and the backscattering amplitudes and Eq. (4) to retrieve μ and Λ by iteration, and then use the radar reflectivity at horizontal polarization [Eq. (2)] to find N_0. The drops are assumed to have radar-apparent mean axis ratios (r) given by (Brandes et al. 2002)

$$r = 0.9951 + 0.02510D - 0.03644D^2$$
$$+0.005030D^3 - 0.0002492D^4$$

where D (mm) is the drop equivalent volume diameter.

For this study we estimate D_{max} from radar reflectivity with

$$D_{\max} = 0.9468 - 0.006811Z_H + 0.004247Z_H{}^2$$
$$-0.0001116Z_H{}^3 + 0.000001246Z_H{}^4 + D'$$

where D_{max} and Z_H have units of mm and dBZ, respectively, and D' (set to 1 mm) is an adjustment to account for the likelihood that the true maximum diameter exceeds that observed. This expression was determined with disdrometer observations.

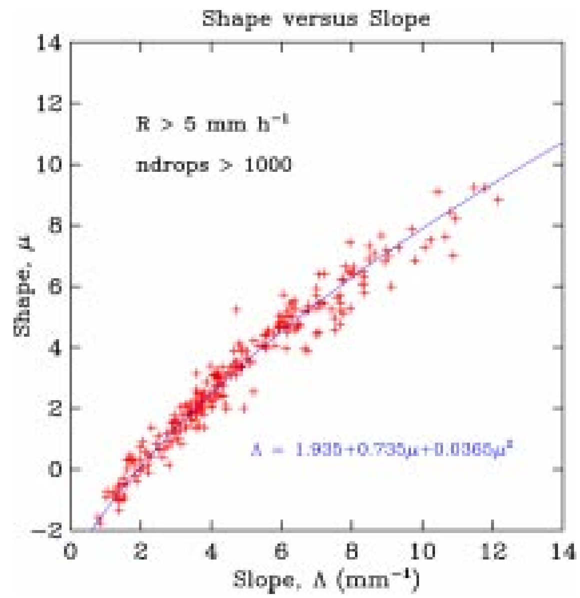

Fig. 1: The $\mu - \Lambda$ relation for Florida DSD observations.

3. VERIFICATION

The constrained-gamma retrieval method was applied to S-band polarimetric radar measurements collected in Florida during the summer of 1998. One minute observations from a video disdrometer were available for comparison. The disdrometer was located 38 km from the radar. Radar measurements were made at 0.5^o antenna elevation. The beam center was roughly 400 m above the disdrometer. Observations and computations for a long-lived event occurring on 17 September are presented in Fig. 2 and Table1. Radar reflectivity values, as measured by radar and computed from the observed drops, are closely matched (Fig. 2a). For data points matched in time the mean difference is 0.3 dB (Table 1). Some differences are readily explained by precipitation gradients and the advection of hydrometeors. The DSD retrieval method is highly dependent on the differential reflectivity measurement. From Fig. 2b it's clear that the radar and disdrometer values are highly correlated. The mean radar and disdrometer Z_{DR}s are 0.82 and 0.84 dB, respectively.

Figures 2c and 2d present comparisons for the physical parameters N_T and D_0. The retrieval for the total drop concentration is excellent except for a few outliers and a brief period near 2100 UTC. Differences here are due to the N_T dependence on reflectivity. Using the disdrometer observations as a standard, drop concentrations are underestimated with the constrained-gamma method (Table 1). Mean logarithms of the

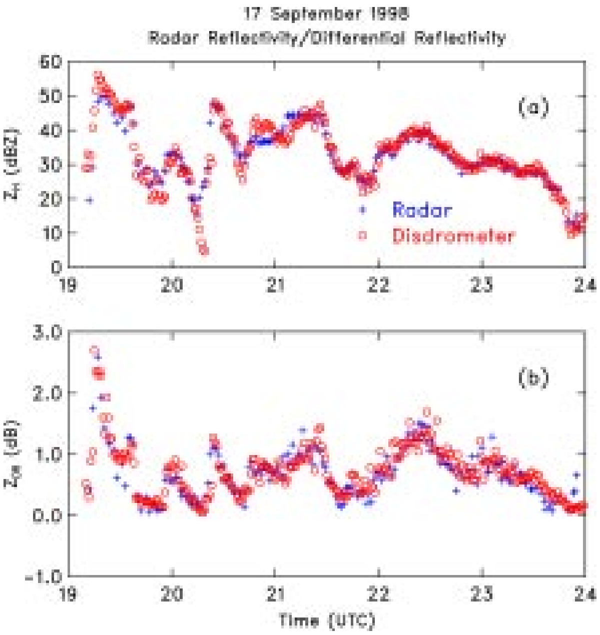

Fig. 2a,b: Radar-disdrometer plots of (a) radar reflectivity and (b) differential reflectivity.

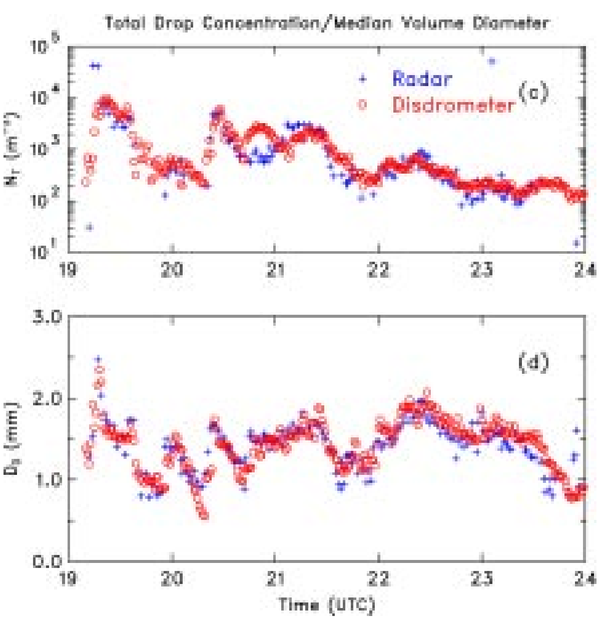

Fig. 2 continued: (c) total drop concentration and (d) median volume diameter.

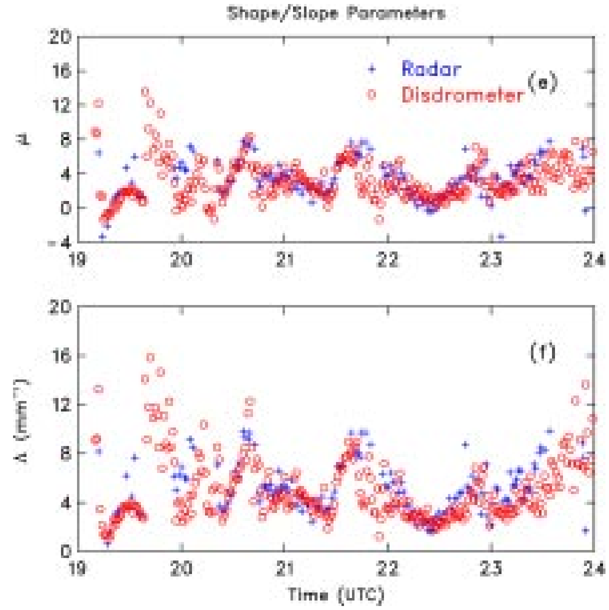

Fig. 2 continued: (e) DSD shape parameter and (f) DSD slope parameter.

concentrations differ by 0.10 (~25%). [Computations assuming that the drops are distributed exponentially (μ=0) yields drop concentrations that average a factor of 6 too large.] Trends in D_0 are well matched. For the entire data segment estimated median drop diameters retrieved with the constrained-gamma method are 0.10 mm too large. Differences are greatest for the more convective stage of the event (1910–2130 UTC).

Gamma DSD shape and slope parameters are compared in Figs. 2e and 2f. For significant precipitation ($Z_H \geq 25$ dBZ) trends and magnitudes show good agreement. Disdrometer-derived values tend to be less than their radar counterparts. This could be due to sample volume differences such that the disdrometer observes smaller D_{max} values than the radar. Correlations between the radar-retrieved and disdrometer-observed values are relatively low. This result stems in part from the considerable scatter and large magnitudes in the 1 min disdrometer observations at lower rain rates.

4. SUMMARY AND CONCLUSIONS

The method of Zhang et al. (2001) for estimating the governing parameters of gamma drop-size distributions and rain rates from polarimetric measurements has been improved and evaluated. The three parameters of the DSD are obtained from radar reflectivity, differential reflectivity, and a constraining empirical relation between the DSD shape factor and slope parameter. Observed trends in radar-retrieved total drop concentrations and median drop diameters showed good agreement with disdrometer observations. Agreement also was found for retrieved DSD shape and slope parameters. Differences from disdrometer-based parameters were minor and often appeared related to sampling issues in regions of precipitation gradients. The capacity of the constrained-gamma method to retrieve DSD parameters affirms the utility of the method and the enabling μ - Λ relation.

Further improvement in the DSD retrievals may come from refinement of the empirical representations for radar-apparent drop shape, maximum drop size, and perhaps the raindrop distribution itself. Although trends in the retrieved DSD parameters agreed with those from the disdrometer, correlations between the one-minute samples were only moderate. Plans call for expanding this work to radar disdrometer comparisons at shorter distances to reduce sampling affects and investigating potential benefits of filtering to reduce noise levels at the lower rain rates.

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REFERENCES

Brandes, E. A., G. Zhang, and J. Vivekanandan, 2002: Experiments in rainfall estimation with a polarimetric radar in a subtropical environment. *J. Appl. Meteor.*, **41**, (In press).

Ulbrich, C. W., 1983: Natural variations in the analytical form of the raindrop size distribution. *J. Climate Appl. Meteor.*, **22**, 1764-1775.

Zhang, G., J. Vivekanandan, and E. Brandes, 2001: A method for estimating rain rate and drop size distribution from polarimetric radar measurements. *IEEE Trans. Geosci. Remote Sensing,* **39**, 830-841.

Zhang, G., J. Vivekanandan, and E. Brandes, 2002: The shape slope relation in gamma raindrop size distributions: Statistical error or useful information? (In preparation)

Table 1: Comparison of radar reflectivity (in dBZ), differential reflectivity (dB), and DSD parameters as determined by radar and disdrometer. The units for D_0 and Λ are mm and mm^{-1}, respectively. RMSE is the root-mean-square error. Based on 153 common data points.

	Z_H	Z_{DR}	$\log N_T$	D_0	μ	Λ
Radar	35.3	0.82	2.74	1.53	3.4	5.0
Disdrometer	35.6	0.84	2.84	1.43	2.8	4.4
Corr. Coef.	0.94	0.81	0.81	0.61	0.48	0.52
RMSE	2.7	0.22	0.39	0.22	1.2	1.2