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Dual polarization spectral retrievals of the effective raindrop shapes

D. Moisseev[1], **C. Unal**[2], **H. Russchenberg**[2], **and V. Chandrasekar**[1]

[1]Dept. of Electrical Engineering, Colorado State University, Fort Collins, CO, USA
[1]IRCTR, Delft University of Technology, Delft, The Netherlands

Abstract. Use of dual polarimetric spectral measurements for the retrieval of the slope, β, of the assumed linear dependence of the axis ratio on the equivolumetric diameter was investigated. It is shown that dual polarimetric Doppler power spectra can be used for a joint retrieval of DSD parameters and the slope of the mean raindrop size-shape relationship. This procedure is not sensitive to the rain rate and allows for accurate analysis of parameter β behavior for different precipitation events.

1 Introduction

Polarimetric weather radar measurements depend on mean raindrop shapes. It is common to use the equilibrium raindrop shapes (Beard and Chuang, 1987) that are attributed to the steady air flows. Turbulent, unsteady airflows, however, are commonly present during the precipitation events. For that reason, the effective raindrop shapes are expected to vary from the equilibrium ones as a result of oscillations of raindrops induced by turbulent motion of the air. To accommodate for the raindrop oscillations, Gorgucci et al. (2000) has introduced an additional parameter into polarimetric rain rate retrieval algorithm that represents the slope of the size-shape relationship, if the linear dependence (Proppacher and Beard, 1970) of the axis ratio on the equivolumetric diameter is assumed. Several other studies such as (Brandes et al., 2002; Bringi et al., 2003; Ryzhkov and Shuur, 2003) have also used similar approach to solve this problem.

The proposed technique, however, have two limiting factors that restrict ones need to study fine structure variation of the raindrop shape changes in different types of rain. For example, it is important to know how the β parameter depends on meteorological conditions. The above mentioned techniques, for estimation of β, use Z_h, Zdr and Kdp measurements. Use of Kdp restricts applicability of proposed techniques to rain events with rain rates larger than 7 mm/hour (Ryzhkov and Shuur, 2003). Moreover, use of Kdp implies reduction of the range resolution, and therefore results in range averaged estimates of β.

In this study we use measurements of spectral differential reflectivity (sZDR) (Unal et al., 2001), which is a measurement of the differential reflectivity per Doppler velocity bin, to investigate relationships between size of raindrops and their shapes. Generally speaking if there will be no turbulent or cross-wind spectrum widening the observed values of sZDR would be directly related to the scattering properties of raindrops and will not depend on a drop size distribution (DSD) of them. Therefore, observations of sZDR provide an attractive technique for studying shapes of raindrops. In reality this measurement would weakly depend on the DSD, and the relative concentrations of raindrops at different diameters will play a role. However, even in case of light rain we should be able to observe different shapes of raindrops.

The proposed dual polarization spectral analysis is illustrated on the data collected by the S-band Transportable Atmospheric Radar (TARA) of the Delft University of Technology. These measurements were carried out on Sept 19^{th}, 2001 during a stratiform rain event (see Fig. 1).

2 Dual polarization spectral measurements of precipitation

Doppler radar spectral measurements at a non-zero elevation angle have raindrops fall velocity components, therefore one may use them to discriminate between particles of different size. Combination of these measurements with dual polarimetric capabilities gives one a unique opportunity to observe polarimetric properties of raindrops separately for different drop diameters. In this case the spectral Zdr measurement, that is ratio of *hh* to *vv* power spectra, represent Zdr measurements for every velocity resolution bin. In the absence of turbulence this measurement would directly define the axis ratio of rain drops. But in case of turbulent spectral broadening the

Correspondence to: D. Moisseev
(dmitri@engr.colostate.edu)

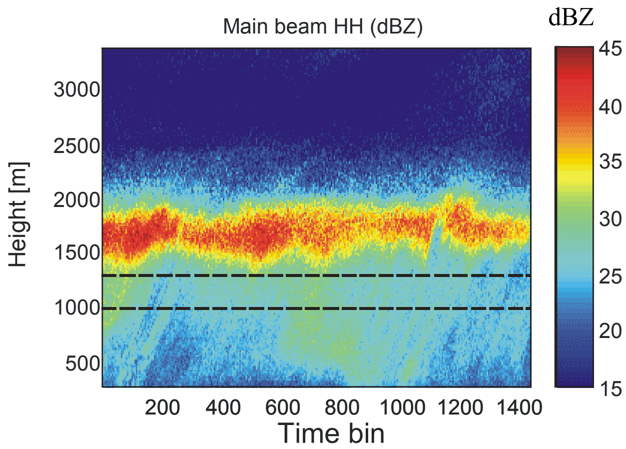

Fig. 1. Measurements of the stratiform rain event on September 19th, 2001 at Cabauw, The Netherlands. Every time bin represents 0.6 s. The dashed lines show the boundaries of the measurements selection used for this study. The lower line was selected to mitigate the wind shear effect on Doppler spectra. A wind shear of more that 5 m/s was present on that day at the height of around 800 m. The top line is selected to avoid inclusion of melting snowflake into the analysis.

neighboring velocity cells would affect each other and therefore the DSD of the rain event would influence this measurement. Therefore, to retrieve size-shape raindrop relationship from dual polarimetric spectral measurements, one should know corresponding DSD, turbulence broadening and an ambient air velocity. We should note that a vertical wind shear would affect observed Doppler spectra, and therefore one should mitigate this influence.

To simulate Doppler power spectra we have assumed that DSD has a gamma distribution. We have used the normalized gamma distribution (Testud et al., 2001; Bringi and Chadrasekar, 2001). The effect of the turbulent and cross-wind spectrum broadening was simulated using gaussian shaped kernel. The scattering properties of raindrops were calculated using the Rayleigh-Gans approximation (Bringi and Chadrasekar, 2001). We have assumed that there is no canting of raindrops. The axis ratio was assumed to have the linear form after (Ryzhkov and Shuur, 2003):

$$a/b = (1.0 + 0.05\beta) - \beta D_e$$

In Fig. 2 the simulated Doppler power spectra for 45 degree elevation angle are shown for different values of the DSD parameters and width of the turbulence kernel. We should note that changes in β values have a negligible effect on the power spectra. In Fig. 3 the spectral Zdr is plotted. We should note that contrary to the Fig. 2 the β values have a non-negligible effect on sZdr. The other unknown that one encounters when compares measured Doppler spectra with the model one is the ambient air motion. It manifests itself as a shift along x-axis and should be taken into account.

3 Inverse problem solution

As we have observed it is possible to separate retrieval of the DSD parameters, spectral broadening and ambient air velocity from the retrieval of β. Similar to Williams (2002) we use nonlinear least-squares method (Rust, 2003) to fit log values of modeled and observed power spectra. From this fit we have estimated DSD parameters, spectral broadening and ambient air velocity. Then using these retrieved values we have estimated β by fitting modeled sZdr to the measured one. In Fig. 4 an example of the resulting fit is shown. We can see that this procedure gives a rather accurate estimate of β. The initial variance of sZdr is compensated by using several spectral points to estimate β. In our case we have used 128 point FFT to estimate power spectra. Moreover, 5 consecutive spectra were averaged to reduce the variance of the power spectra. Prior to the averaging all spectra were shifted to the same mean velocity to reduce the effect of the ambient air velocity variations on power spectra calculations. After clipping of the noisy parts of Doppler spectra, 67 velocity bins were kept and used for our retrievals.

4 Results and discussion

For this study we have analyzed measurements of a stratiform rain that took place on September 19, 2001 at Cabauw, The Netherlands. That was a light rain event with reflectivities not exceeding 35 dBZ. Our retrieval has resulted in mean D_m value of 1.76 mm, and mean μ value of -0.26. The standard deviations of these values were 0.2 and 0.5 respectively. We also have observed that raindrops have more spherical shapes than it is expected from equilibrium theory. In Fig. 5 the histogram of the retrieved β values is shown. We can see that the retrieved β values vary between 0.035 and 0.065, with the median value of 0.051.

In Fig. 6 the scatter plot of the retrieved β values versus the turbulence broadening width is shown. We can see that there is a clear dependence of the retrieved β on the retrieved σ. One would expect that raindrop oscillations increase with the turbulence strength, and as a result parameter β should decrease. On the other hand, fitting errors would result in the opposite trend, because underestimation in the turbulence broadening would result in underestimation of β.

It is interesting to see this behavior for larger values of turbulent broadening that are observed in convective rains. That, however, is the topic for the future studies.

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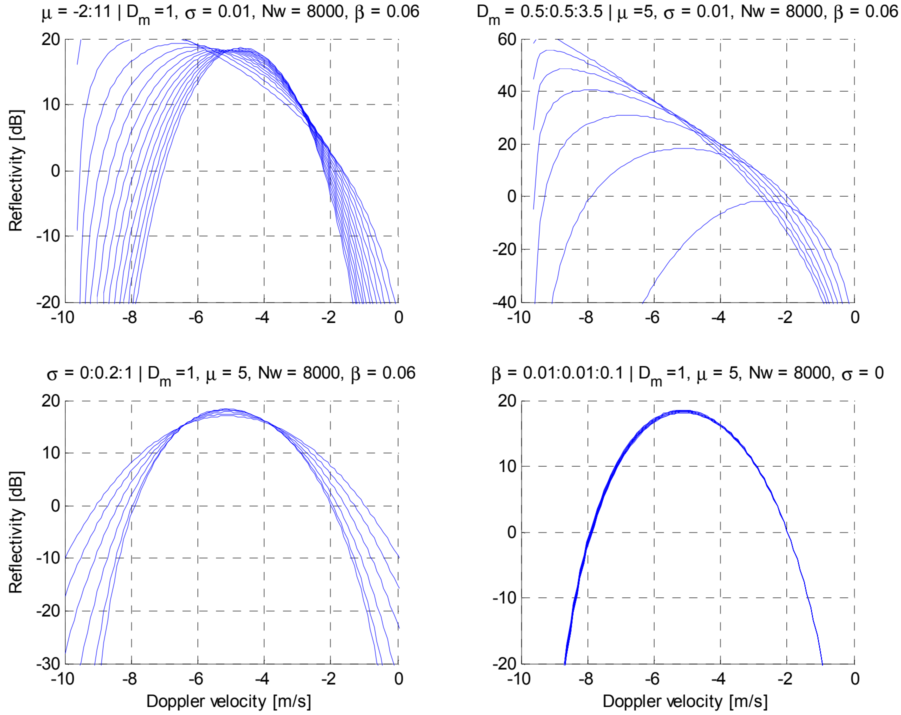

Fig. 2. Simulated Doppler power spectra (*hh* – polarization) for different values of the DSD parameters, turbulent broadening and β. Elevation angle is assumed to be equal 45 degrees.

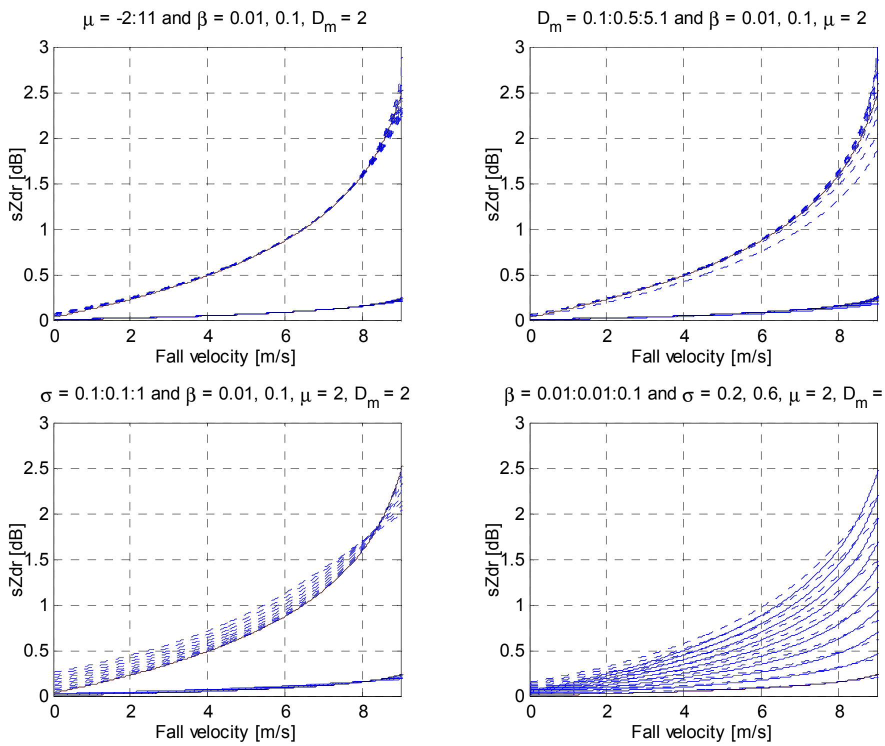

Fig. 3. Simulated ratio of co-polar Doppler power spectra (spectral Zdr, sZdr) for different values of the DSD parameters, turbulent broadening and β. It should be noted that in the absence of turbulence sZdr values are directly related to a size-shape relation.

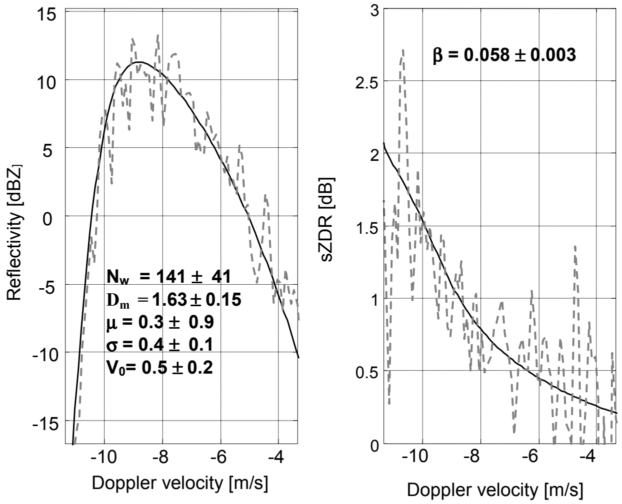

Fig. 4. An example of the fitting procedure. The left figure shows fit to the power spectrum and as a result the DSD parameters, ambient air velocity and spectral broadening are retrieved. The right figure shows retrieval of the β parameter. The errors are calculated based on the sum square residuals (Rust, 2003).

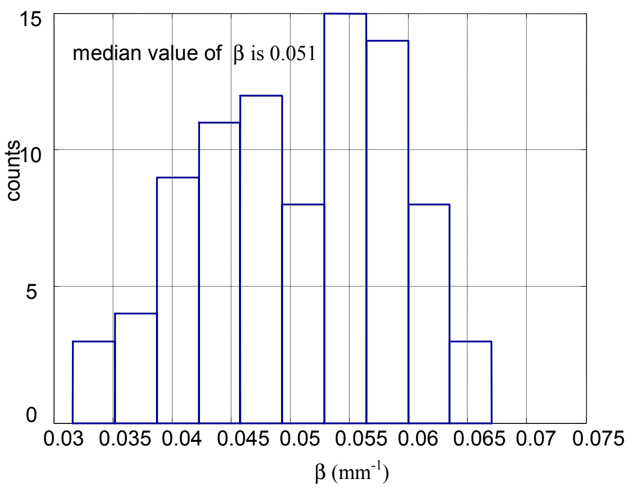

Fig. 5. The histogram of the retrieved values of β. Only retrieved values of β for that errors in D_m were less than 0.2, errors in σ were less than 0.11 and errors in β were less than 0.004 were kept.

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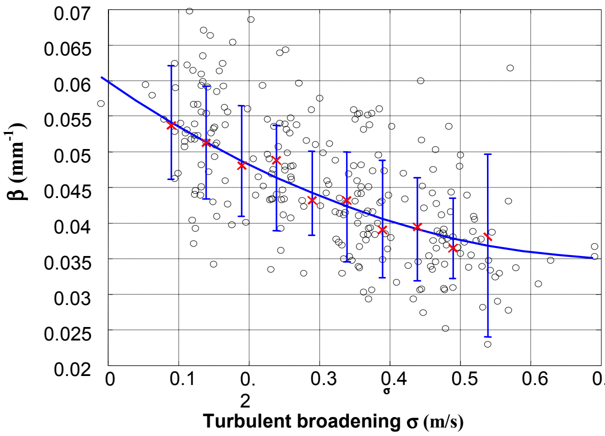

Fig. 6. Scatterplot of the retrieved values of β vs. retrieved values of turbulent broadening. To retrieve the values of turbulent broadening, the retrieved values of spectral broadening were corrected for the cross-wind spectral broadening. The circles represent scatterplot of the retrieved parameters. The crosses show mean values of β for spectral broadening values of [0.1, 0.15), [0.15, 0.2), [0.2, 0.25), [0.25, 0.3), [0.3, 0.35) , [0.35, 0.4), [0.4, 0.45), [0.45, 0.5), [0.5, 0.55), [0.55, 0.6). The solid line shows the second order polynomial fit to the averaged data. Similar to the Fig. 5 only the retrieved values that satisfy our accuracy requirement were kept.

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