Retrieving Rain Microstructure from C-Band Polarimetric Radar with Added Information from 2D Video Disdrometer

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Abstract

Rain microstructure parameters such as size, shape and orientation angles are required not only for improving polarimetric radar-based forecasting/nowcasting prediction tools but also for evaluating radiowave propagation effects on satellite and terrestrial communication systems. In this paper we consider how such parameters could be retrieved from C-band polarimetric weather radar data, with additional information from 2D video disdrometer, either co-located or situated nearby. Examples from Ontario, Canada, and from Alabama, USA, are presented, the two locations being very different rain climate regimes.

1. Introduction

Polarimetric weather radars typically measure 4 quantities, namely, (1) co-polar reflectivity (Z_h), (2) differential reflectivity (Z_{dr}), (3) differential phase Φ_{dp} and (4) co-polar correlation coefficient ρ_{hv}. For radars capable of making cross-polar measurements, an additional parameter, the linear depolarization ratio (LDR), is also determined. Definition of all these parameters can be seen in [1].

Of the above, only the first three parameters (Z_h, Z_{dr} and Φ_{dp}) are used for quantitative estimation of rainfall rates (see again [1]).The polarimetric data based algorithms based on these three quantities make certain fundamental assumptions regarding the rain microstructural properties, such as drop shapes, orientation angles and size distributions. Typical assumptions are : (i) drops are oblate in shape and their axis ratios are given by a monotonically dependent formula on the equivalent diameter, D_{eq}, (ii) that the drop orientation angles are described by a Gaussian distribution for the drop polar (or zenith) angle with zero degree mean and 5 degree standard deviation, and uniform distribution for the azimuth angle between 0 and 2π and (iii) that the size distribution follows a Gamma function, described by 3 parameters, including Dm the mass weighted mean diameter and μ the shape parameter.

Such assumptions, though based on a variety of data/measurement sources, have not been tested or validated thoroughly with in-situ measurements in natural rain on a long-term or statistical basis. With the advent of high quality imaging devices such as the 2D video disdrometer [2], it is now possible to obtain information on each individual drop and derive their statistical variations. It has been shown recently that the combined use of polarimetric radar and a highly-calibrated 2D video disdrometer (2DVD) gives rise to better retrieval techniques than those using polarimetric information alone.

Here we present two examples from two different rain climate regimes to demonstrate this, the locations being Ontario, Canada, and Alabama, USA. In both cases, simultaneous measurements have been made using C-band polarimetric radar and 2DVD located nearby. The first example indicates that the co-polar correlation coefficient ρhv could be additionally used to improve the DSD estimates in certain cases whilst the second shows how the drop-by-drop information from the 2DVD could be used to calculate the five parameters mentioned above, so that retrieval algorithms could be more 'tuned' to the specific event being considered.

2. The Two Examples

Several events recorded by the King City C-band polarimetric radar [3], together with simultaneous measurements from a 2DVD located 33 km away have shown that broad DSDs can produce a measurable decrease in ρ_{hv} [4]. Fig. 1 shows a long duration rain event where this is evident. Panel (a) shows the time series of measured ρ_{hv} (averaged) over the 2DVD site whilst panel (b) shows mean diameter of the 1-minute DSD from the 2DVD measurements, together with the DSD 'width' (as given in eq. (7.50a) in [1]). The increase in the DSD mean and the width at around 11;00 can be seen to produce a reduction in the measured ρ_{hv}. The lowest panel reconfirms this decrease which shows the calculated ρ_{hv} using the 2DVD data.

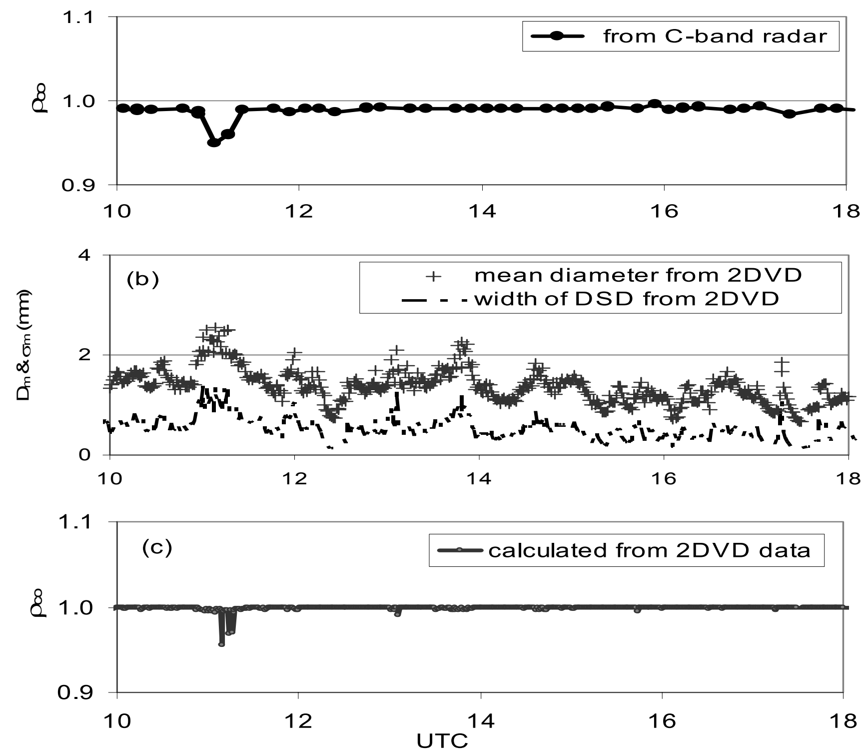

Fig. 1: (a) Time series variation of ρ_{hv} extracted from the King City radar data averaged over the 2DVD site, for the 1 Dec 2006 event; (b) D_m and width derived from the 2DVD DSD data; (c) ρ_{hv} calculated using the 2DVD DSD.

Fig. 2 shows ρhv measured from the radar (shown as open circles) at the 2DVD site versus the width of the DSD from the 2DVD data (circles) and compares with the calculated ρ_{hv} (shown as gray diamonds) from the 2DVD DSDs. The two sets of data agree with each other in that they both show the decrease in ρ_{hv} with increasing width. The dotted curve superimposed on the measurements represents the best-fitted equation. This together with other equations calculated using the 2DVD measurements have been used to derive the DSD characteristics for typical rain events in Ontario. Fig. 3 shows the relative frequency of $\log_{10}(N_w)$ versus Dm estimated for these regions, where N_w represents the normalized intercept parameter for an equivalent gamma DSD. Most cases have N_w in the 1000 7000 mm^{-1} m^{-3} range (i.e. below the Marshall-Palmer value of 8000) and D_m in the 1.25 to 1.75 mm range. It is also noticeable that N_w decreases with increasing D_m, a trend which has been observed in previous studies, for example, by Bringi et al. [5], who separated their events into stratiform and convective rain and further into maritime and continental clusters from a large database of averaged DSDs from many locations world wide. The variation given in Fig. 3 appears to be dominated by stratiform rain as opposed to convective rain as is typical when one uses data from all range gates from an entire PPI sweep, i.e., the area of stratiform rain far exceeds the area of the compact highly convective cells in the event analyzed. The relevant data from Bringi et al. [5] are superimposed on the grey scale contours in Fig. 3 for comparison. The agreement is reasonably close.

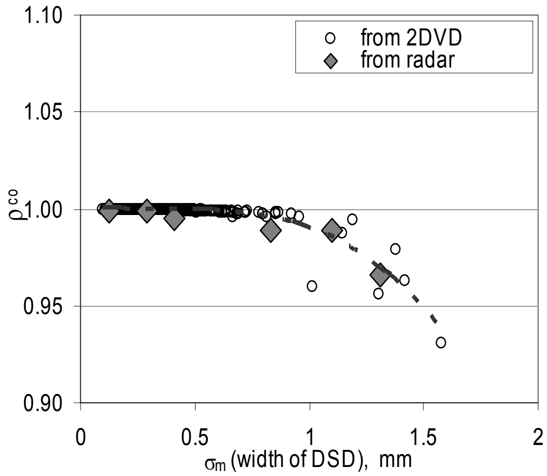

Fig. 2: Calculations of ρ_{hv} versus σ_m using the 2DVD data (using 1 minute integrated DSDs) from 2 events compared with the radar measured ρ_{hv}.

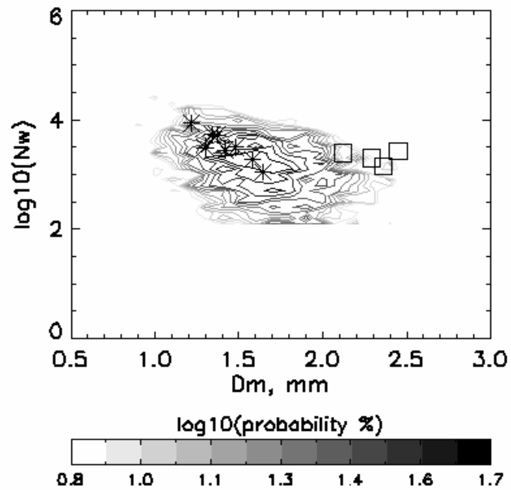

Fig. 3: Contour plot showing the relative frequency $\log_{10}(N_w)$ versus D_m variation calculated from a PPI scan taken during a more severe and widespread event. Superimposed on the grey-scale contours are the $\log_{10}(N_w)$ versus D_m from [7] for stratiform rain (stars) and continental cluster (squares).

For the second location-based example, we consider an intense event which lasted for over 2 hours, producing significant amount of 'large drops'. Fig. 4 shows the measured DSD from the 2DVD data. From the 2DVD images of individual drops for this event, orientation angle for each drop as well as its shape were derived, which in turn were used as input to an enhanced version of the T-matrix method to compute the forward and back scatter amplitudes of each drop at C-band. The polarimetric radar variables were then calculated from the individual drop contribution over a finite time period, for example 30 seconds. The calculated Z_h, Z_{dr}, K_{dp} and ρ_{hv} were compared with measurements from th C-band polarimetric radar, ARMOR [6], located 15 km away. A K_{dp} based attenuation correction method was applied to the Z_h and Z_{dr} data from the C-band radar, after ensuring accurate radar calibration. Time series comparisons, given in Fig. 5, show very good agreement for all four quantities. The agreement is significantly better than computations using bulk assumptions on rain microstructure (not shown here). It was found that the agreement is particularly improved in the case of ρ_{hv}, this parameter being very sensitive to variation of shapes as well as orientation angles.

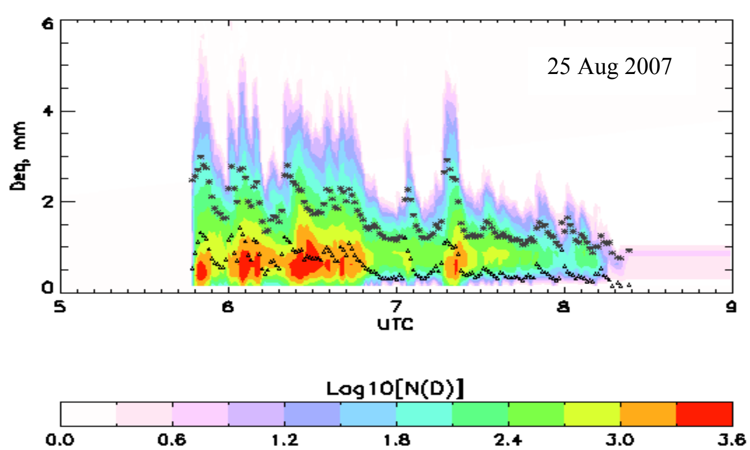

Fig. 4: 1-minute DSD for an intense rain event in Alabama. The color shows the number of drops on a $\log_{10}$ scale.

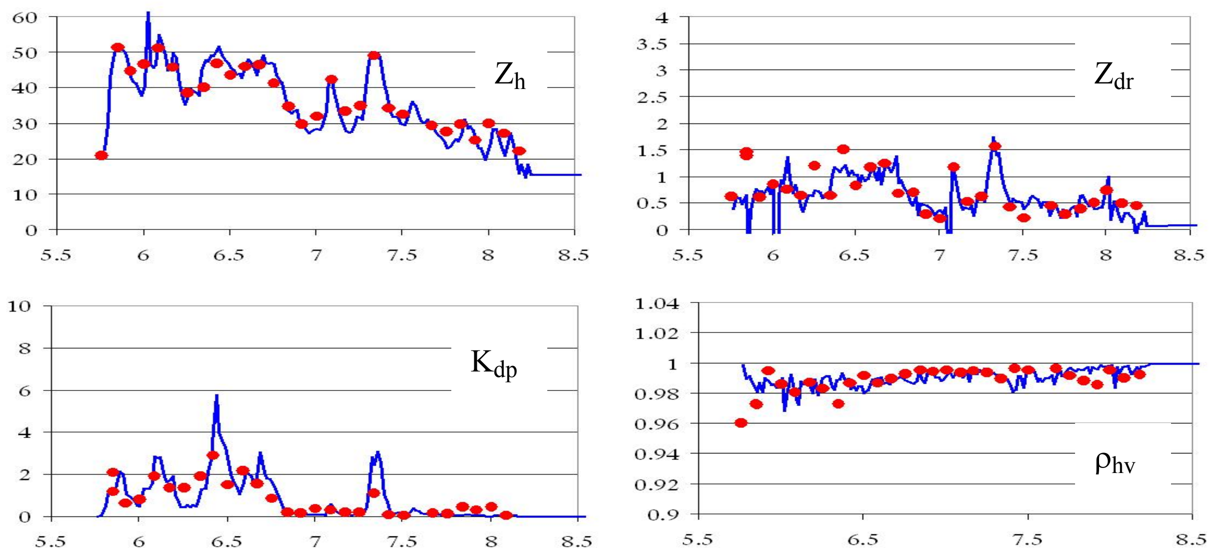

Fig. 5: Time series comparisons between the 2DVD data based calculations (on a 'drop-by-drop' basis) in blue and the C-band polarimetric radar measurements (after attenuation correction) as red points.

3. Summary

The above examples have clearly demonstrated the merit in using polarimetric radar data, together with 2DVD measurements, to derive better information on rainfall microstructure. Such information is valuable in other areas too, such as evaluating propagation effects in rain for satellite and terrestrial communication systems.

4. Acknowledgements

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5. References

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