Accurate Characterization of Rain Drop Size Distribution Using Meteorological Particle Spectrometer and 2D Video Disdrometer for Propagation and Remote Sensing Applications

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***Abstract*—Accurate measurements of rain drop size distributions (DSD), with particular emphasis on small and tiny drops, are presented. Measurements were conducted in two very different climate regions, namely Northern Colorado and Northern Alabama. Both datasets reveal a combination of (i) a drizzle mode for drop diameters less than 0.7 mm and (ii) a precipitation mode for larger diameters. Scattering calculations using the DSDs are performed at S and X bands and compared with radar observations for the first location. Our accurate DSDs will improve radar-based rain rate estimates as well as propagation predictions.**

***Index Terms*—rain drop size distribution, rainfall remote sensing, rain attenuation predictions.**

I. INTRODUCTION

Accurate characterization of rain drop size distribution (DSD) is required for propagation predictions for systems operating in the microwave and millimeter wave frequency bands, as well as for rainfall estimates from polarimetric radar measurements at S, C, and X-bands, and for higher frequency bands. An extensive amount of DSD measurements is available in the literature from surface disdrometers, but very few accurately characterize the full size spectrum which needs at least two instruments and an overlapping size range to ensure that instrumental errors are low (i.e., ensure consistency and continuity of concentration measurements in the overlap size range). In this paper we describe DSD data collected with 'side-by-side' collocation of the Meteorological Particle Spectrometer (MPS, [1]) with a 3rd generation, low-profile, 2D-video disdrometer (2DVD, [2]) to enable us to characterize the concentration of the tiny drops with very high resolution (50 µm) provided by the MPS, and the same for larger drops (with resolution of 170 µm) from the 2DVD. Our objective then is to combine the MPS and 2DVD data to form a composite DSD with high resolution at the small drop end provided by the MPS and good resolution provided by the 2DVD for moderate-to-large drops. So far, measurements at two locations have been carried out, namely Greeley, Colorado, and Huntsville, Alabama, and we report here on observations and analysis from two events from the two sites.

II. THE GREELEY CAMPAIGN

At the Greeley site, a six month measurement campaign began in April 2015, involving not only a 2DVD and an MPS but also a precipitation occurrence sensor system (POSS, [3]) and a Pluvio raingauge [4], all installed within a small double wind fence (Fig. 1) at a site which is approximately 13 km from the S-band and X-band CSU-CHILL polarimetric radar [5]. An earlier paper [6] had utilized disdrometer data to examine the propagation effects at X-band and to derive rainfall rates from the X-band radar data for an intense event that occurred over the disdrometer site, for which the CHILL radar observations were made both at S and X bands.

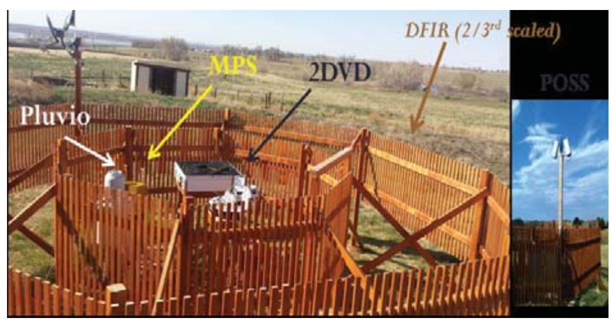

Fig. 1: The MPS, 2DVD and Pluvio inside the DFIR double wind fence, as well as POSS installed at the site near Greeley, Colorado. A similar set-up was installed in Huntsville, Alabama.

A. CHILL Radar Observations

Figure 2 shows an example of an RHI scan from the CHILL S and X band radars taken during a convective event on 10 August 2015 which lasted over the instrument site at Greeley for 35 minutes. The radar azimuth corresponds to the direction of the ground instrument site (with 13 km range annotated). There is good 'resemblance' between the S and the X band observations of reflectivity (Z_h in dBZ) and differential reflectivity (Z_{dr} in dB) but note at 15 km range Z_{dr} is much lower at X-band than at S-band due to differential attenuation caused by the rain cell over the disdrometer site.

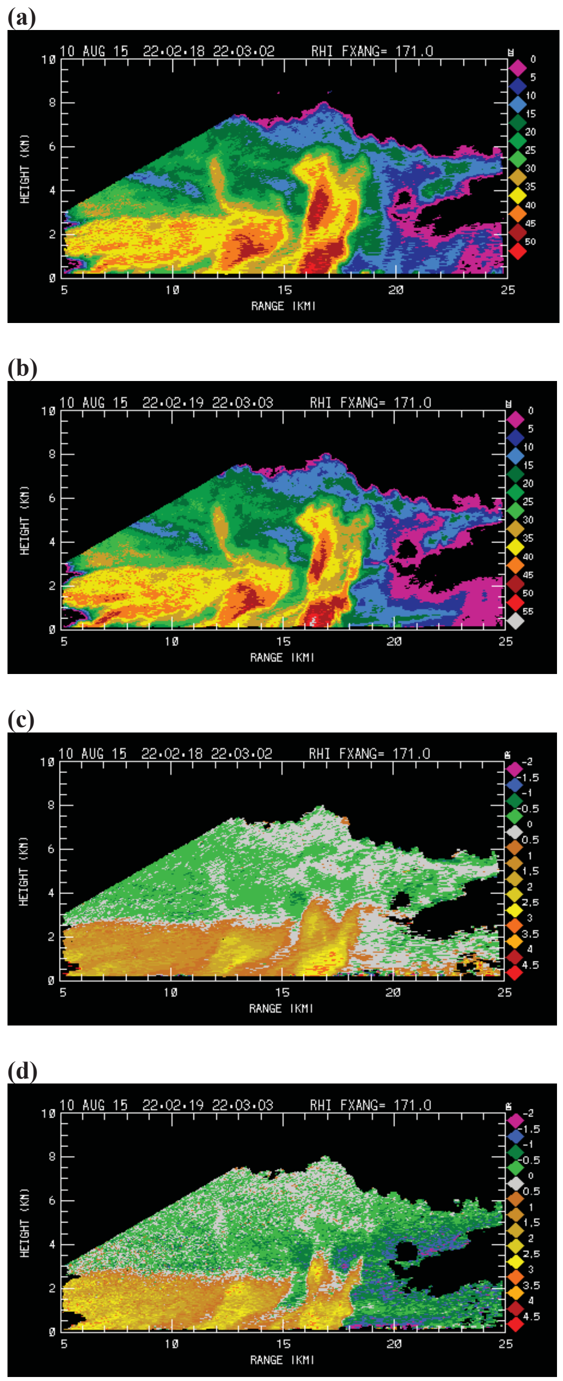

Fig. 2: CHILL radar RHI scans taken on 10 Aug 2015 at 20:03 UTC showing (a) S-band Z_h, (b) X-band Z_h, (c) S-band Z_{dr}, (d) X-band Z_{dr}, along the azimuth over the ground instrument site (13 km range).

B. DSD Measurements

According to the disdrometer data, the event at the instrument location began at 21:51 and ended at 22:26 UTC. Figure 3 compares the 35 minute DSDs derived from the MPS, the 2DVD and the POSS data. The upper panel shows the drop concentration comparisons in the 0.1 to 5 mm range (on a log-log scale), and the lower panel shows and enlarged/zoomed-in version at the small drop diameter end. The pertinent points to note are: (i) in the 0.7 - 1.3 mm drop diameter region, good agreement between all three; (ii) between 0.4 and 0.7 mm, MPS and POSS agree well; (iii) below 0.4 mm, down to 0.1 mm, MPS can be considered to be more accurate; (iv) at the other end of the size spectrum, the 2DVD can be considered more accurate (> 1.2 mm diameter)

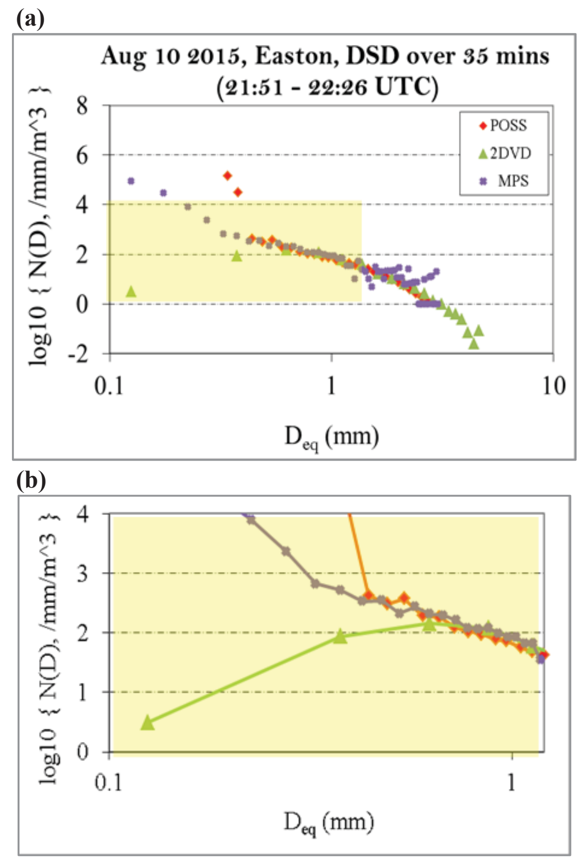

Fig. 3: 35-minute DSDs (from 21:51 to 22:26 UTC) from MPS, 2DVD and POSS measurements for the on 10 Aug 2015 event; (a) for 0.1 to 10 mm drop diameter; and (b) enlarged version from 0.1 to 2 mm (highlighted in yellow)

Utilizing the combined/composite DSDs, the S-band and X-band Z_h and Z_{dr} were calculated using a T-matrix based method. The differences between the two were found to be very small. Figure 4 compares the DSD-based calculations with the radar data extracted over and surrounding the disdrometer site. The agreement is reasonable given the convective nature of the event which would have significant horizontal and vertical non-uniformity associated with it. However, at around 22:25 UTC, discrepancies between the S-band data and the X-band data are also evident, which is due to path attenuation from the radar site to the disdrometer site.

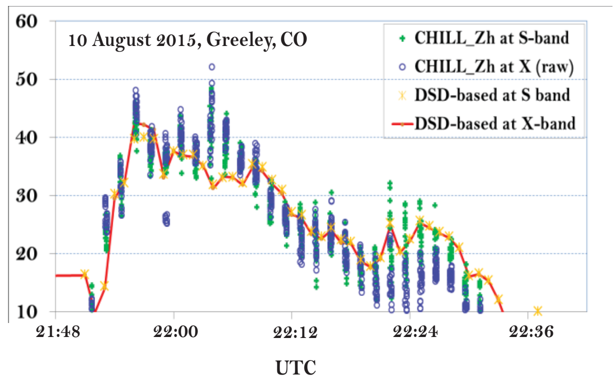

Fig. 4: Reflectivity comparisons between CHILL radar measurements over the disdrometer site and the DSD-based calculations at S and X bands.

III. HUNTSVILLE DATA

Here we consider a more stratiform rain event with some embedded convection, which lasted more than three hours at the disdrometer site. The MPS and the 2DVD data were processed in the same way as before, and Figure 5 shows the hourly DSD comparisons. Once again, there is good agreement in the drop concentration measurements between the two in the overlap region of 0.7 to 1.3 mm drop diameter, and once again the MPS can be assumed to be more accurate for the small drop end (< 0.7 mm) and the 2DVD can be assumed to be more accurate for the moderate and large size drops (>1.3 mm).

IV. DISCUSSION AND FURTHER ANALYSES

Both the Greeley data and the Huntsville data reveal a combination of (i) a drizzle mode for D<~0.7 mm and (ii) a precipitation mode for larger diameters. This is in agreement with such modes identified with aircraft imaging probes (2D-Cloud probe and 2D-Precipitation probe) in warm rain oceanic clouds [7]. While the two events reported here were from different regions (Northern Colorado and Northern Alabama), the two modes could be easily identified in the combined spectra. There seems negligible evidence of evaporation causing a depletion of tiny drops at either location as inferred from the presence of the drizzle mode throughout the duration of the precipitation events. Moreover, previous simulation studies, for example [8], suggest that collision-induced breakups were responsible for shaping the observed shoulder region, which was more prominent in the Huntsville warm rain event.

Further analyses of data will entail scattering calculations using our more accurate, composite, DSDs to derive (i) attenuation correction algorithms for S, C, and X band polarimetric radars, and (ii) specific attenuation versus rainfall relationships for 11 GHz, 20 GHz and 30 GHz for propagation applications.

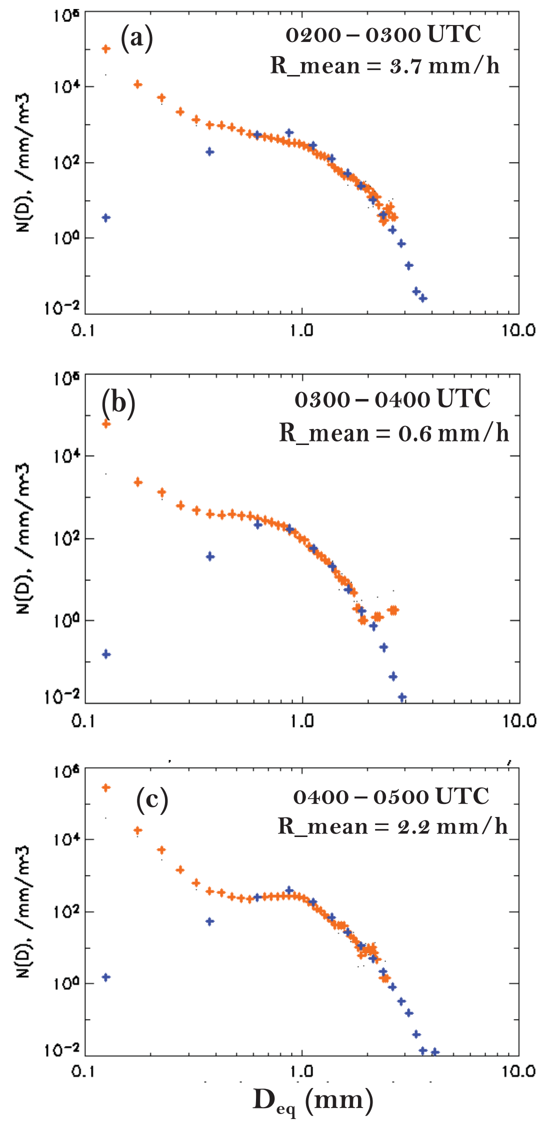

Fig. 5: Hourly DSD comparisons from the 2DVD (blue) and the MPS (red) for the 14 April 2016 event in Huntsville, Alabama. The start hour is specified foreach plot, together with the mean rain rate.

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References

[1] R. G. Knollenberg, "The optical array: An alternative to scattering and extinction for airborne particle size determination", J. Appl. Met., vol. 9, pp. 86-103, 1970.

[2] M. Shönhuber, G. Lammar and W. L. Randeu, "The 2D-video-vistrometer", Chapter 1 in "Precipitation: Advances in Measurement, Estimation and Prediction", Michaelides, Silas. (Ed.), Springer, ISBN: 978-3-540-77654-3, 2008.

[3] B. E. Sheppard, and P. Joe, "Performance of the precipitation occurrence sensor system as a precipitation gauge", Journal of Atmospheric and Oceanic Technology, Vol. 25, pp. 196-212, 2008.

[4] OTT Messtechnik GmbH, "Operating instructions Precipitation Gauge OTT Pluvio", 2010

[5] V. N. Bringi, R. Hoferer, D. A. Brunkow, R. Schwerdtfeger, V. Chandrasekar, S. A. Rutledge, and J. George, P. C., "Design and Performance Characteristics of the New 8.5-m Dual-Offset Gregorian Antenna for the CSU–CHILL Radar", Journal of Atmospheric and Oceanic Technology, Vol. 28, pp. 907-920, 2011.

[6] M. Thurai, P. Kennedy, V. Bringi, B. Notaroš, and S. Rutledge, "Propagation effects at X-band from the 2015 rain measurement campaign in Greeley, Colorado," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, pp. 1-5., 2016. doi: 10.1109/EuCAP.2016.7481927

[7] S. J. Abel, and I. A. Boutle, "An improved representation of the rain size spectra for single-moment microphysics schemes", Quart. J. Royal Meteorol. Soc., 138 (669), 2151–2162, doi: 10.1002/qj.1949. 2012.

[8] W. K., Straub, D. Beheng, A. Seifert, J. Schlottke, and B. Weigand, "Numerical investigation of collision-induced breakup of raindrops. Part II: Parameterizations of coalescence efficiencies and fragment size distributions". J. Atmos. Sci., 67, 576–588, 2010.