11B.4 A STATISTICAL ANALYSIS OF 2D-VIDEO-DISDROMETER DATA: IMPACT ON POLARIMETRIC RAINFALL ESTIMATION

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1. INTRODUCTION

Naturally occurring variations in drop size distributions (DSDs) can substantially limit the accuracy of radar-derived rainfall estimates. Though less susceptible than conventional radar methods, even polarimetric methods of rainfall estimation have been shown to depend on DSD variability. Unfortunately, however, the DSDs that typically account for much of this variability (DSDs that have a large number of very small and/or very big drops) are not well sampled by traditional, impact disdrometers.

Over the past three years, the National Severe Storms Laboratory in Norman, Oklahoma has collected an extensive, multi-seasonal data set of 2D-video-disdrometer (2DVD) measurements that document the precipitation characteristics of 80 rain events. Unlike impact disdrometers, the 2DVD provides highly accurate measurements of both small (D < 1.5 mm) and big (D > 5.0 mm) drop sizes. In this study, we examine this large data set to gain a better understanding of naturally occurring DSD variability, gauge its impact on radar-based rainfall estimation algorithms, and investigate the sensitivity of polarimetric rainfall relations to drop oblateness assumptions. Based on our measurements, we also present new polarimetric rainfall relations for the southern U.S. Great Plains and offer suggestions on how to use the $R(K_{DP},Z_{DR})$ and $R(Z,Z_{DR})$ relations in light, moderate, and heavy rainfall regimes.

2. RAINFALL CHARACTERISTICS

The 2DVD data presented in this study were collected over a three-year period from 1998-2000. While the data are not contiguous, the combined data from all three years provides a data set in which all four seasons are well represented. In total, the data comprise over 210 hours of precipitation and 930 mm of accumulated rainfall. Rain rates range from 0.1 to 175.0 mm h^{-1}. The median rain rate is 1.46 mm h^{-1}, but rain rates below the median account for only 6.5% of the total rainfall. On the other hand, half of the total rainfall is accounted for by the upper 6.7% of all DSDs (those with rain rates > 12.94 mm h^{-1}). This suggests that rainfall in the southern U.S. Great Plains may be dominated by brief, but heavy rainfall events.

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The frequency of occurrence of DSDs that are dominated by big drops is also investigated. Assuming a median volume diameter of D_0 > 2.5 mm to be representative of "big drop DSDs", we find that big drop DSDs, while accounting for only 2.7% of the DSDs, are responsible for nearly 10.0% of the total rainfall. This clearly shows that DSDs with an anomalously large number of big drops contribute a significant portion of the total rainfall in the southern U.S. Great Plains. Just as interestingly, the big drop DSDs were found to be associated with rain rates as small as 1.0 mm h^{-1} (though they were much more common for rain rates of approximately 25 to 75 mm h^{-1}). The heaviest rain rates in our data set tended to be dominated by large numbers of relatively small drops.

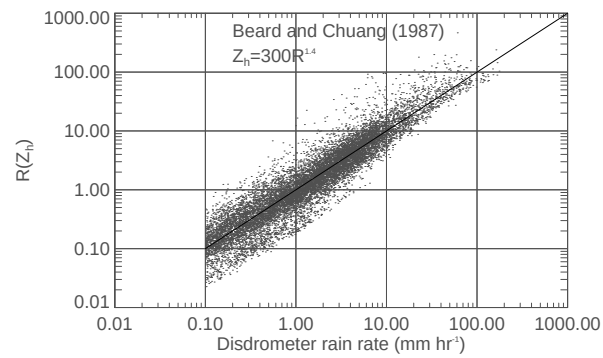

Figure 1. Scatterplot of disdrometer-measured rain rate versus rain rate from the WSR-88D R(Z) relation of Z_h=300$R^{1.4}$.

Fig. 1 depicts disdrometer measured rain rates plotted against rain rates computed using the current WSR-88D R(Z) relation of Z_h=300$R^{1.4}$ (throughout this paper, we use the aspect ratio of Beard and Chuang, 1987 for our radar-based rain rate calculations). Though significant spread exists, we find good overall agreement between the measured rainfall and that calculated using the WSR-88D relation. However, it is interesting to note the many DSDs that resulted in a rather extreme underestimation by the WSR-88D algorithm (those that fall well below the diagonal line in Fig.1, some with rain rates up to about 7 mm h^{-1}). An examination of R(Z) plots of the individual case studies that went into Fig. 1 reveals that the outlier small drop DSDs were associated with many different events. Many of the DSDs that resulted in the most extreme underestimation, however, were associated with a precipitation event that occurred in early May of 2000. Using our large data set, we obtained a R(Z) relation of

$$Z_h=270.4R^{1.467} \quad (1)$$

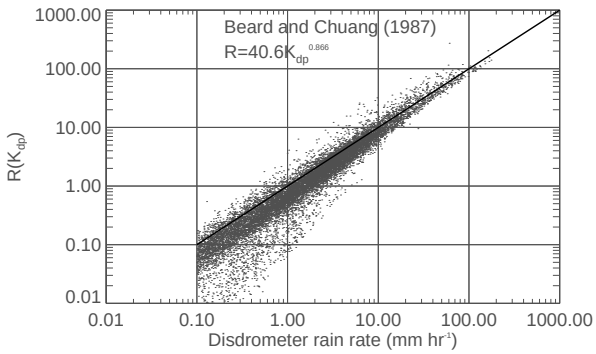

Figure 2. Scatterplot of disdrometer-measured rain rate versus rain rate from the relation $R=40.6K_{DP}^{0.866}$.

For comparison, Fig. 2 depicts the disdrometer measured rain rates versus rain rates computed using the $R(K_{DP})$ relation of $R=40.6K_{DP}^{0.866}$ (where K_{DP} is in units of ° km^{-1}). This comparison shows underestimation bias at low rain rates but a relatively smaller spread at more significant rain rates. As with the R(Z) relation in Fig. 1, there are also several instances of DSDs that result in a rather extreme radar underestimation, particularly for low rain rates (those that fall well below the diagonal line in Fig.2, some with rain rates up to about 7 mm h^{-1}). To minimize the bias, it is clear that an improved $R(K_{DP})$ relation needs to be determined for our large data set. We find a much better $R(K_{DP})$ relation of

$$R=42.78K_{DP}^{0.802} \quad (2)$$

A similar plot of $R(K_{DP})$ using the relation in eqn. 2 (not shown) showed much better agreement with the DSDs in our data set.

3. $R(Z,Z_{DR})$ AND $R(K_{DP},Z_{DR})$ RELATIONS

Outlier DSDs that contain anomalously large numbers of either small or big drops present significant challenges for radar-based rainfall estimation algorithms. In an attempt to address this problem, several investigators have examined the utility of combining R(Z) and $R(K_{DP})$ with measurements of Z_{DR}, with the goal of removing the bias associated with small drop (associated with small Z_{DR}s) and big drop (associated with large Z_{DR}s) DSDs. Using our large data set, we obtain the following relations for $R(Z,Z_{DR})$ of

$$R=6.42\text{x}10^{-3}Z_h^{0.824}Z_{DR}^{-0.654} \quad (3)$$

(where Z_h is in units of mm^6 m^{-3} and Z_{DR} is in units of dB), and $R(K_{DP},Z_{DR})$ of

$$R=53.72K_{DP}^{0.910}Z_{DR}^{-0.421} \quad (4)$$

(where K_{DP} is in units of ° km^{-1} and Z_{DR} is in units of dB).

In Fig. 3, the fractional rain estimation error derived from the relations (applied to all DSD in our data set) are presented with respect to rain rate. A fractional rain estimation error of +1 implies 100% radar overestimation relative to the gauges (i.e., a doubling of gauge rainfall) while a fractional rain estimation error of –1 implies a radar underestimation of 100% (i.e., radar rainfall is one-half of the gauge).

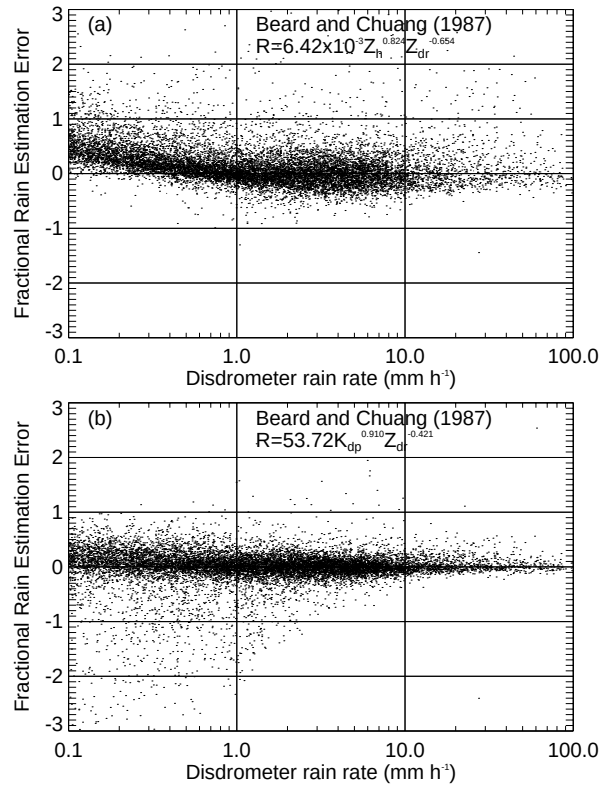

Figure 3. Fractional rain estimation error versus disdrometer measured rain rate for the relation (a) $R=6.42\text{x}10^{-3}Z_h^{0.824}Z_{DR}^{-0.654}$, and (b) $R=53.72K_{DP}^{0.910}Z_{DR}^{-0.421}$. Both relations were computed using aspect ratios of Beard and Chuang (1987).

Overall, both the mean and spread in the fractional rain estimation error appear to be better for the $R(K_{DP},Z_{DR})$ relation. A similar result for both local and areal estimates was found by Ryzhkov et al. (2001). In this study, the average fractional rain estimation error for light (0.1 < R <1.0), moderate (1.0 < R < 10.0), and heavy (10.0 < R <100.0) rain rates are 0.290, 0.056, and 0.137, respectively, for the $R(Z,Z_{DR})$ relation, and –0.069, -0.011, and 0.044, respectively, for the $R(K_{DP},Z_{DR})$ relation. It should be noted that the relations presented here were all computed using a logarithmic scale for Z_{DR}. In this study (though not shown), we also computed $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$ relations using a linear scale for Z_{DR}. For both types of relations, however, the logarithmic scale for Z_{DR} provided a fit that resulted in better rainfall estimates. Nevertheless, due to the large negative exponent for Z_{DR} in both the $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$ relations, it may be best to use relations derived using a linear

scale for DSDs with very small Z_{DR}s (particularly for light rain rates where K_{DP} is also noisy).

4. SENSITIVITY TO OBLATENESS

Another measure of a relation is to examine its sensitivity to aspect ratio. In this section we compare $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$ calculations derived using the aspect ratio of Beard and Chuang (1987, used throughout this paper) to those derived using the aspect ratio of Andsager et al. (1999, which suggests slightly more spherical drops in the range 0.5 mm < D < 4.5 mm). A comparison of the Beard and Chuang (1987) and Andsager et al. (1999) aspect ratios for drops between 0.5 and 4.5 mm is presented in Fig. 4a, while Figs. 4b and 4c illustrate the ratio of Beard and Chuang to Andsager et al. $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$, respectively, for all DSDs in our data set.

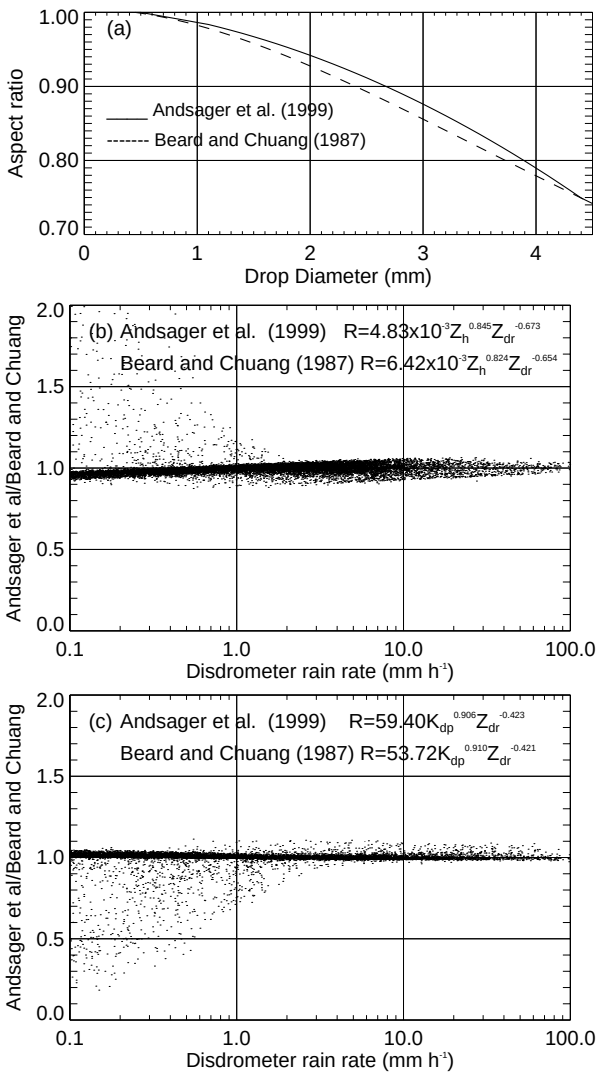

Figure 4. Comparison of (a) the aspect ratios for the 0.5 mm < D < 4.5 mm range for the data of Andsager et al., 1999 (solid line) and Beard and Chuang, 1987 (dashed line), (b) ratio of rain rate calculations of Andsager et al. to Beard and Chuang for the $R(Z,Z_{DR})$ relations, and (c) ratio of rain rate calculations of Andsager et al. to Beard and Chuang for the $R(K_{DP},Z_{DR})$ relations.

A comparison of Figs. 4b and 4c shows significantly less spread in the $R(K_{DP},Z_{DR})$ ratio than in the $R(Z,Z_{DR})$ ratio, suggesting that the $R(K_{DP},Z_{DR})$ relation, at least for this comparison, is much less sensitive to aspect ratio.

5. CONCLUSIONS

In this study, we examined a large, climatological DSD data set to gain a better understanding of naturally occurring DSD variability, gauge its impact on radar-based rainfall algorithms, and investigate the sensitivity of polarimetric rainfall relations to drop oblateness assumptions. The upper 6.7% of the rain rates in our DSD data set are found to account for 50% of the total rainfall, suggesting that brief, but heavy rainfall events are important contributors to the total rainfall in the southern U.S. Great Plains. Significant DSD variability is also found. Most interestingly, DSDs with a median volume diameter D_0 > 2.5 mm (chosen to be representative of DSDs that contain an anomalously large number of big drops), though representing only 2.7% of the data, are found to be responsible for as much as 10% of the total rainfall.

In a comparison of polarimetric power law relations, the $R(K_{DP},Z_{DR})$ relation is found to have slightly less bias and spread than the $R(Z,Z_{DR})$ relation (particularly for high rain rates). Furthermore, for both relations, using a logarithmic scale for Z_{DR} is found to provide better estimates than using a linear scale for Z_{DR}. Due to the large negative exponent for Z_{DR} in both relations, however, it may be better to use the one with a linear scale for light rain rates, where Z_{DR} is very small and K_{DP} is noisy.

Finally, we examined the sensitivity of $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$ relations to drop aspect ratios. By comparing the ratio of $R(Z,Z_{DR})$ and $R(K_{DP},Z_{DR})$ rain rate estimates computed using the aspect ratios of Andsager et al. (1999) and Beard and Chuang (1987), respectively, we find that the $R(K_{DP},Z_{DR})$ relation is less sensitive to aspect ratio.

6. ACKNOWLEDGEMENTS

We thank Sherman Fredrickson of NSSL for his assistance in maintaining the 2DVD.

7. REFERENCES

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