DSD Characterization and Computations of Expected Reflectivity using data from a Two-Dimensional Video Disdrometer deployed in a Tropical Environment

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***Abstract* — A two-dimensional video disdrometer (2DVD) has been deployed in Puerto Rico northern coastal zone since mid-August 2004. An initial drop-size distribution (DSD) characterization has been performed to compare with previous results of other studies made in the island of Puerto Rico. The event studied was Tropical Storm Jeanne, affecting the region on 15-16 September 2004. Preliminary results confirmed that DSDs are highly variable between coastal and mountainous regions, even in a small island (~9000 km^2), as suggested by Ulbrich in [1]. In addition, this work intends to improve the reliability of rain algorithms currently used in tropical regions, contributing to better estimation of rainfall rates (*R*). The expected radar reflectivity *Z* is calculated from 2DVD-measured DSDs and compared with measured *Z* from the National Weather Service WSR-88D radar (S-band Doppler radar a.k.a. NEXRAD). Different Z-R relationships – used to determine the rainfall amount from measured *Z* – for each of the two days of the storm are obtained from these calculations. Discrepancies between storm days are adduced to differences in stratiform and convective rain components.**

I. Introduction

Drop size distribution (DSD) is the most fundamental component in rainfall estimation techniques, since it governs all rainfall integral relations. Therefore, its accurate estimation for all rain-rates is necessary in order to develop and validate rainfall retrieval algorithms. The Two-Dimensional Video Disdrometer (2DVD) offers a new approach to measuring DSDs [2]. Under low-wind conditions it provides accurate and detailed information about drop size, terminal velocity, and drop shape. It allows for a detailed verification of rain measurements, in some cases more detailed than traditional rain gauges, using the DSD information.

Rainfall rates obtained from the 2DVD are required to be compared with the Rosenfeld Tropical Z-R relationship – defined for use in tropical convective systems – in order to confirm its validity for tropical areas or to calibrate accordingly. These results will contribute to solve discrepancies between different findings regarding radar and ground instruments rainfall estimation. In the past, only 4 out of 21 2DVDs deploy-locations have been in tropical environments.

DSD estimations derived from radar reflectivities have shown huge overestimations of rain-rate, especially because the overestimation of the number of big drops; in tropical climates, the number of drops tends to be more –in number– and smaller –in size– than in moderate climates. On the contrary, previous work on the island of Puerto Rico using a Joss-Waldvogel disdrometer claimed that there is not significant difference between the computed reflectivity from the measured DSD and the one observed by NEXRAD. Therefore the use of the 2DVD in a tropical location will increase the confidence of the information about drops distribution in tropical climates. Puerto Rico is the smaller of the Greater Antilles in the Caribbean, east of the Dominican Republic and west of St. Thomas, one of the U.S. Virgin Islands.

The Collaborative Adaptive Sensing of the Atmosphere (CASA) Engineering Research Center (ERC), who is partially funding this work, is aimed towards creating a new engineering paradigm in observing, detecting and predicting weather and other atmospheric phenomena [3]. One significant part of this new effort is Quantitative Precipitation Estimation (QPE), which pursues to improve the precipitation estimates and enhance the reliability of flood prediction. The results of this work will present important information for the QPE algorithms that will be used in the near future within the CASA ERC. This will yield enhanced rainfall estimations, much needed for the tropical zones communities.

Data analysis was performed for rainfall during Tropical Storm Jeanne accumulation affecting the island of Puerto Rico on the 15th-16th September 2004.

II. DSD Characterization

A. Procedure

DSD information is obtained using a program provided by Colorado State University, dubbed FIRM_DSD. This program reads 2DVD proprietary-formatted files and converts them to text files with the following information: time, diameter range, DSD values, and rain rate. For each minute a

DSD value is reported for each diameter range, varying from 0 to 0.25 mm to 10 to 10.25 mm. Additionally the computed rain rate for each minute is provided.

To characterize DSDs, two parameters were computed: the mass-weighted mean diameter, D_m, and the normalized intercept, N_w, using

$$D_m = \frac{\int D^4 N(D)dD}{\int D^3 N(D)dD} \tag{1}$$

$$Nw = \frac{(4)^4}{\pi\rho_w}\left(\frac{10^3 W}{D_m^4}\right) \tag{2}$$

Both parameters are used to normalize DSDs, reducing the scattering of data points. This is useful in comparing the shapes of distributions with widely different rain rates [4].

In order to compare to results from similar studies, stratiform rain was defined as that with R greater than 0.5 mm/hr and standard deviation from R less than 1.5 mm/hr. Conversely convective rain was defined as that with R greater than 5 mm/hr and standard deviation from R greater than 1.5 mm/hr.

For 15 September 712 minutes of data were recorded by the 2DVD, whereas for 16 September 970 minutes are available for analysis. To reduce computing times, data was averaged every 2 minutes, for DSD characterization analysis, thus 356 data points were used for the 15th and 485 for the 16th.

B. D_m and N_w values

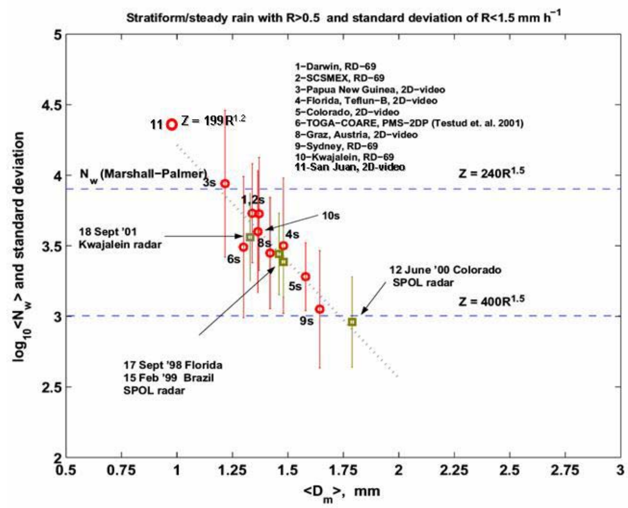
Table I summarizes values found for both $<D_m>$ and $\log_{10}<N_w>$; these were as expected.

Figure 1(a) shows results from previous studies on stratiform rain parameters as well as findings from this work (See #11 in the figure). Regarding stratiform rain, about 50% of data points were classified as this type on the 15th September, while about 33% were selected on the 16th of September.

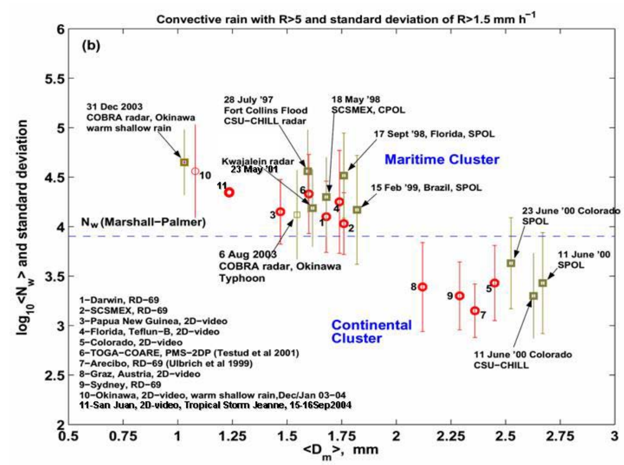
TABLE I PARAMETERS SUMMARY

DAY/RAIN TYPE	$<D_m>$ [mm]	$\log_{10}<N_w>$
15 Sep 2004 stratiform	1.14	4.19
15 Sep 2004 convective	1.38	3.96
16 Sep 2004 stratiform	0.98	4.61
16 Sep 2004 convective	1.04	4.80

On the other hand, as opposed as found by Ulbrich *et al* in 1999 in a mountainous region of the island, when continental properties were found in the DSDs, $\log_{10}<N_w>$ versus $<D_m>$ plot shows characteristics similar to the Maritime Cluster (see Figure 1(b)).



(a)



(b)

Figure 1. (a) The value of log10$<N_w>$ (with 1s std dev bars) versus $<D_m>$ from disdrometer data (numbered open circles) and dual-polarization radar retrievals (open squares as marked) for stratiform rain. Dotted line is the least squares fit. (b) As in (a) except data for convective rain. Note that N_w is the 'normalized' intercept parameter and D_m is the mass-weighted mean diameter of a 'normalized' gamma DSD.

Since less than 20% of data points were classified as convective rain in any of the two days, these results require further analysis to make it statistically significant.

III. REFLECTIVITY COMPUTATION

Determination of proper DSDs – or *N(D)* – is crucial to calculate reflectivity *Z*. The integral form

$$Z = \int D^6 N(D)dD \tag{3}$$

is used for this purpose, and defines Z as the sixth power of the hydrometeor diameter summed over all hydrometeors in a unit volume [6]. Radars, such as National Weather Service (NWS) WSR-88D, measure Z and use rainfall retrieval algorithms to determine the amount of precipitation expected, hence the importance of an accurate determination of DSDs.

Even if smaller drops are more numerous, calculating the sixth power of D causes that the fewer larger diameter drops contributes more to Z. In many cases DSD models overestimates the number of big drops for tropical climates (see Figure 2), then is clearly understood the reason for rain overestimation in some cases. This makes more important to obtain detailed information about DSDs, especially for smaller diameter drops, as less weight is given to them in this calculation. An accurate number of drops will account for their appropriate contribution to Z.

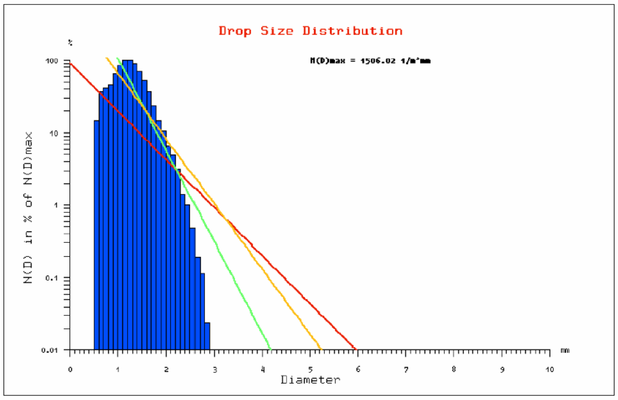


Figure 2. DSD out of tropical rain, recorded on 30 August 1995, 22:10-22:30, in Lae, Papua New Guinea. MP-DSD (yellow), JT-DSD (red), and JD-DSD (green) indicated. Mean R = 25.24 mm/hr. As shown in the figure all three methods overestimate the amount of large raindrops.

Rainfall rate R and Z have been related through

$$Z = aR^b \tag{4}$$

an equation known as Z-R relationship. The WSR-88D precipitation processing system (PPS) converts Z to R using a Z-R relationship [5]. A list of NWS Radar Operational Center (ROC) accepted Z-R relationships is presented in Table II. Other relationship are being suggested by former studies made in Puerto Rico, such as [5], but variations in rainfall characteristics made them suitable for some but not all cases.

In Puerto Rico, the Rosenfeld Tropical relationship, $Z=250R^{1.2}$, is widely used, though lately it has been changed for certain events, following local NWS findings from their research

TABLE II
NWS RADAR OPERATIONAL CENTER (ROC) ACCEPTED Z-R RELATIONSHIPS

RELATIONSHIP	RECOMMENDED USE	2ND RECOMMENDATION
Marshall-Palmer $Z = 200R^{1.6}$	General stratiform precipitation	
East-Cool Stratiform $Z = 130R^{2.0}$	Winter stratiform precipitation east of continental divide	Orographic rain-East
West-Cool Stratiform $Z = 75R^{2.0}$	Winter stratiform precipitation west of continental divide	Orographic rain-West
WSR-88D Convective $Z = 300R^{1.4}$	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical $Z = 250R^{1.2}$	Tropical convective systems	

With the intention of comparing and determining Z-R relationships, new Rs are calculated from 2DVD DSD information. To calculate R the following equation was used [4].

$$R = 0.6\pi \times 10^{-3} \int D^3 v(D) N(D) dD \tag{5}$$

This equation yields R in mmhr^{-1} when D is in mm, $v(D)$ is in ms^{-1}, and $N(D)dD$ is in drops m^{-3}. Drop terminal velocity $v(D)$ was found from [4].

$$v(D) = 9.65 - 10.3e^{(-0.6D)} \tag{6}$$

After calculating Z and R using (3) and (5), respectively, it is necessary to determine Z-R relationships between them, fitting data to find coefficients a and b that optimally fulfills equation (4). Base 10 logarithms were found on each side of (4) to make lineal instead of power or exponential fitting. Table III presents the summary of results from the coefficients found on each day for different Z-R relationships. It also shows the differences caused by differences in R between using FIRM_DSD data and calculating R using (5). As FIRM_DSD uses measured fall velocities instead of (6), results account for that difference.

TABLE III RESULTS SUMMARY FOR TROPICAL STORM JEANNE ANALYSIS

T.S. Jeanne Date:	15 Sep 2004	16 Sep 2004
Using calculated R from 2DVD-measured DSDs	$Z = 239.8\ R^{1.25}$	$Z = 443.07\ R^{1.29}$
Using R from FIRM_DSD	$Z = 414.4\ R^{1.38}$	$Z = 523.26\ R^{1.32}$
Rainfall characterization	Most stratiform, some convective 349 stratiform 137 convective Total: 608 continuous data points (10.13 hrs).	Mostly stratiform 156 stratiform, 1 convective Total: 239 continuous data points (3.98 hrs).
Known Z-R relationships	Rosentfeld tropical $Z = 250\ R^{1.2}$ Convective $Z = 300\ R^{1.4}$	Tropical Maritime $Z = 335\ R^{1.37*}$ Thunderstorms $Z = 450\ R^{1.46**}$
		*Tokay et al., 1995 **Fujiware, 1965

IV. CONCLUSIONS

Fundamentally, at least two different types of DSD are involved in PR's rainfall systems. This validates findings in [1] that DSDs are highly variable between coastal and mountainous zones, even for a small region as the island of Puerto Rico, which posses a very complex orography. The importance of considering variations of Z-R relationships between ocean and land surfaces, as proposed by Ulbrich *et al* (1999), is therefore preliminary confirmed. This work contributes with supplementary data analysis for tropical environments that has been understood as necessary.

More events will be required to validate rainfall types differences found in this work. It was expected to find a bigger convective component in a tropical storm event, so further analysis of events with considerable amount of precipitation are suggested.

Differences in measured and computed fall velocities caused differences in Z-R relationships when using FIRM_DSD rain rate output and calculated R from measured DSDs. Therefore, is necessary to compare both results with rain gauge or other validated data as well as with NEXRAD data, to decide what would be the best path to follow when computing expected Z. It is known that measured velocity will have a strong horizontal component that will affect the measurements, especially in strong tropical storm winds as is this case. For that reason 2DVD literature specifies that it provides accurate data under low-wind conditions.

V. FUTURE WORK

Additional significant rainfall data from other events is available; these will be used to compare and validate these results. Data from other tropical regions will be considered and used for comparison purposes.

In terms of Z, some low-resolution data (3-minutes, 5 dBZ intervals) has been obtained from NWS local weather forecast office, and even when it will not serve for exact comparisons, it will impart confidence in our results.

Finally, existing techniques to filter errors that can be introduced by drops coming from different regions of the clouds are being analyzed. As bigger drops have different fall velocities than smaller drops, DSD estimation on the ground could not be in accordance with what radars are measuring above, causing errors in DSDs and therefore in Z computations. These errors are considered as observational noise. One of these techniques is the Sequential Intensity Filtering Technique (SIFT) which concentrates on the stability of the R-Z relationship during a physically uniform situation [7]. SIFT, aimed to filter out observational noise, will be investigated applying it to data sets considered here and to future sets as they become available from this ongoing measurement experiment.

ACKNOWLEDMENTS

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REFERENCES

[1] Ulbrich, C. W., M. Petitdidier, E.F. Campos, "Radar Properties of Tropical Rain found from Disdrometer Data at Arecibo, P.R.", *29th International Conference on Radar Meteorology*, Montreal, Canada, July 1999.

[2] Kruger, A., W.F. Krajewski, "Two-Dimensional Video Disdrometer: A description", Journal of Atmospheric and Oceanic Technology, Vol. 19, pp. 602-617, 2001

[3] Collaborative Adaptive Sensing of the Atmosphere (CASA) Engineering Research Center, "Overview" [Online]. Available from http://www.casa.umass.edu.

[4] Bringi, V.N. and V. Chandrasekar, *Polarimetric Doppler Weather Radar: Principles and Applications*, 1st ed., United Kingdom: Cambridge University Press, 2001.

[5] Vázquez, M. and A. Roche, "An evaluation of WSR-88D rainfall estimates across Puerto Rico during Hurricane Debbie", NEXRAD Weather Forecast Office San Juan, Carolina, Puerto Rico.

[6] Doviak, R.J. and D.S. Zrnić, Doppler Radar and Weather Observations, 2nd. edition, Academic Press, 1993.

[7] Lee, G. and I. Zawadzki, Sequential intensity filtering technique (SIFT): filtering out noise to highlight the physical variability of drop size distribution. 31st International Conference on Radar Meteorology, Aug 2003.