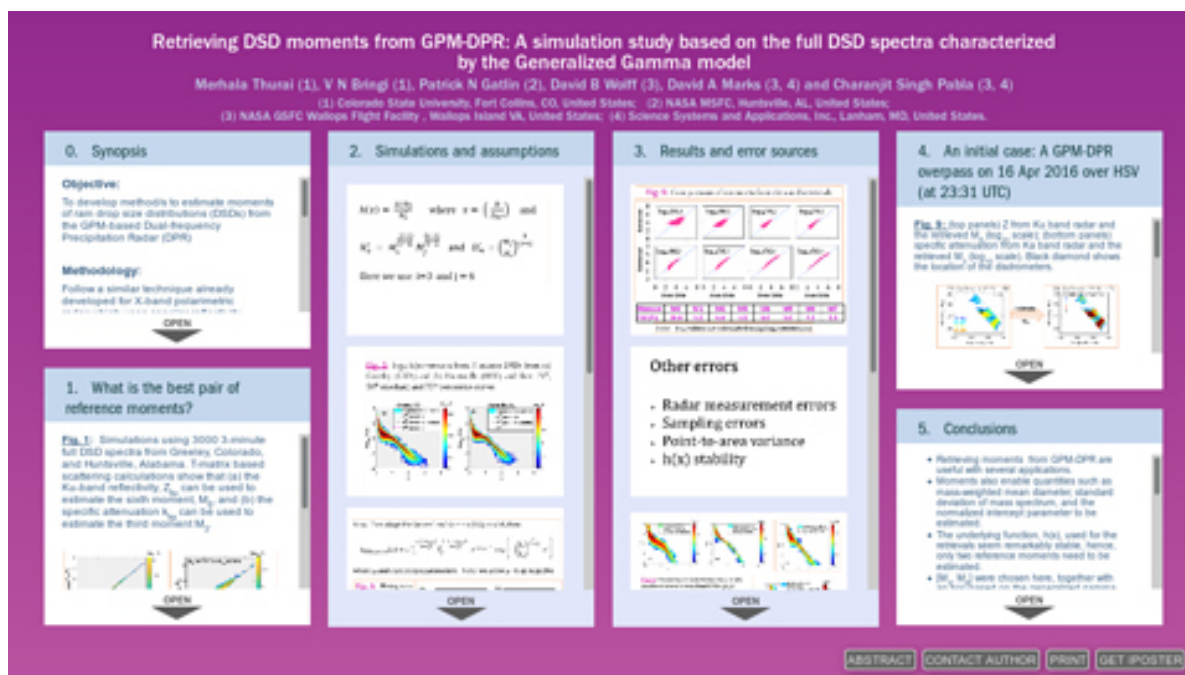


Retrieving DSD moments from GPM-DPR: A simulation study based on the full DSD spectra characterized by the Generalized Gamma model



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PRESENTED AT:



0. SYNOPSIS

Objective:

To develop method/s to estimate moments of rain drop size distributions (DSDs) from the GPM-based Dual-frequency Precipitation Radar (DPR)

Methodology:

Follow a similar technique already developed for X-band polarimetric radar which uses copolar reflectivity, differential reflectivity and specific attenuation. (Reference: Bringi et al., Atmos. Meas. Tech., 13, 4727–4750, 2020.

<https://amt.copernicus.org/articles/13/4727/2020/> (<https://amt.copernicus.org/articles/13/4727/2020/>)

Approach:

1. Estimate two reference moments (M_i , M_j) from DPR-based products
2. Take full DSD spectra from ground-based measurements (database)
3. Fit to the generalized-gamma model, after double-moment normalization
4. Derive the intrinsic shape, $h(x)$, from (2) above
5. Using M_i , M_j , and the $h(x)$, reconstruct the DSD for each radar pixel.
6. Calculate other DSD moments

Questions:

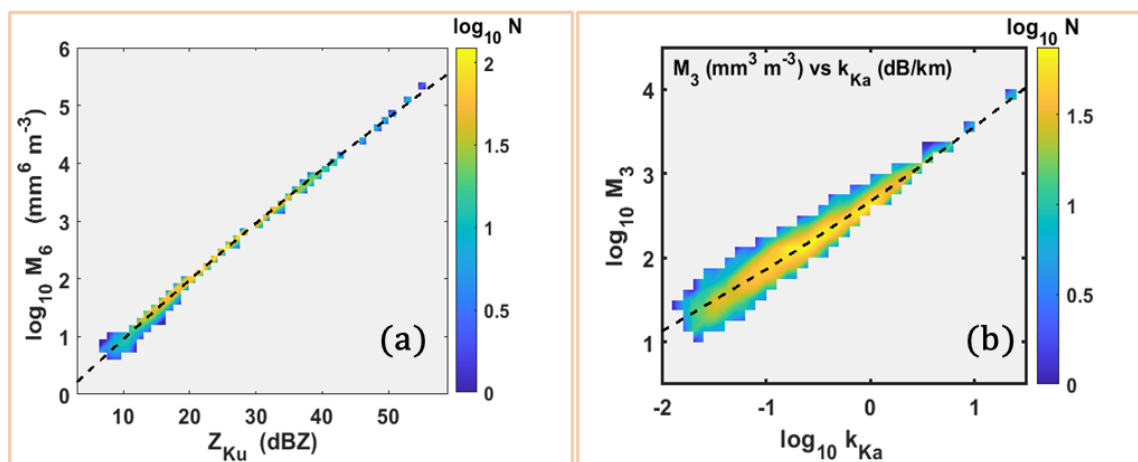
1. What are the best reference moments?
2. Which DPR products to use to estimate the two reference moments?
3. What are the error estimates for the ‘best-we-can-do’ scenario?
4. How stable is $h(x)$, and is it dependent on rain-type?
5. Other error sources, e.g. radar measurement errors, point-to-area variance?

Simulations

An initial test case

1. WHAT IS THE BEST PAIR OF REFERENCE MOMENTS?

Fig. 1: Simulations using 3000 3-minute full DSD spectra from Greeley, Colorado, and Huntsville, Alabama. T-matrix based scattering calculations show that (a) the Ku-band reflectivity, Z_{ku} can be used to estimate the sixth moment, M_6 , and (b) the specific attenuation k_{ka} can be used to estimate the third moment M_3 .



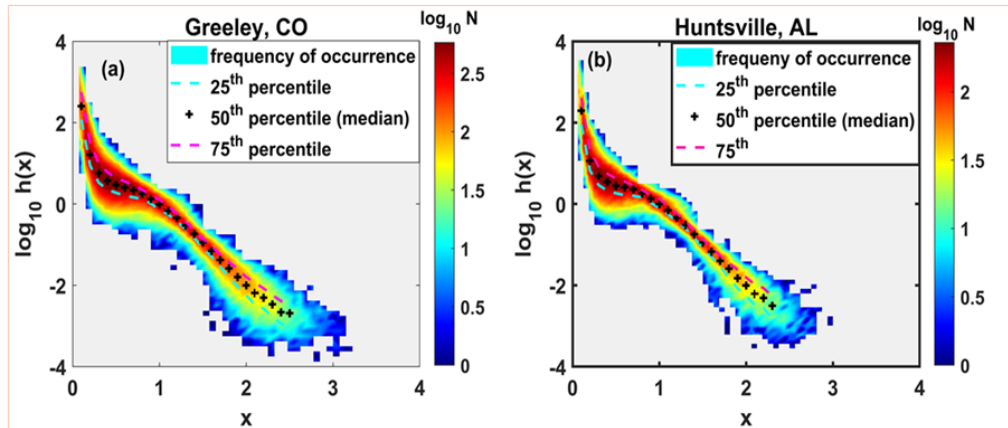
2. SIMULATIONS AND ASSUMPTIONS

$$h(x) = \frac{N(D)}{N'_0} \quad \text{where } x = \left(\frac{D}{D_{m'}} \right) \quad \text{and}$$

$$N'_0 = M_i^{\frac{(j+1)}{(j-i)}} M_j^{\frac{(i+1)}{(i-j)}} \quad \text{and} \quad D'_m = \left(\frac{M_j}{M_i} \right)^{\frac{1}{(j-i)}}$$

Here we use $i=3$ and $j=6$

Fig. 2: $\log_{10} h(x)$ versus x from 3-minute DSDs from (a) Greeley (GXY) and (b) Huntsville (HSV) and their 25th, 50th (median) and 75th percentile curves



Now, if we adopt the Generalized Gamma (GG) model, then

$$h_{GG(i,j,\mu,c)}(x) = c \Gamma_i^{\frac{(j+c\mu_{GG})}{(i-j)}} \Gamma_j^{\frac{(-i-c\mu_{GG})}{(i-j)}} x^{c\mu_{GG}-1} \exp \left[- \left(\frac{\Gamma_i}{\Gamma_j} \right)^{\frac{c}{(i-j)}} x^c \right]$$

where μ and c are shape parameters. Note: we allow μ to go negative

Fig. 3: Histograms of GG fitted (a) μ and (b) c for GXY and HSV datasets

Use the median values for μ and c from (a) and (b)

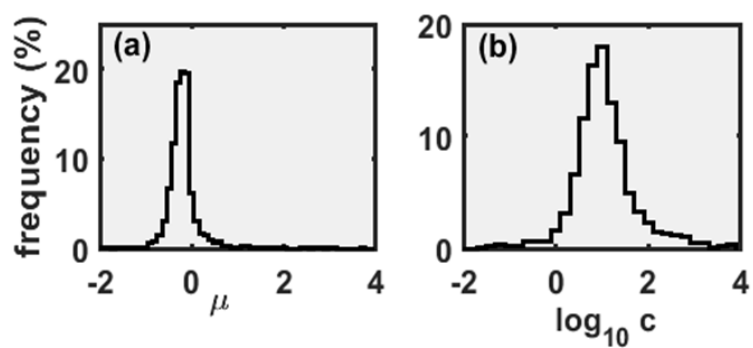
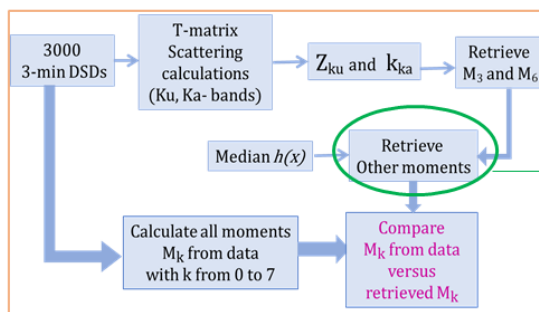
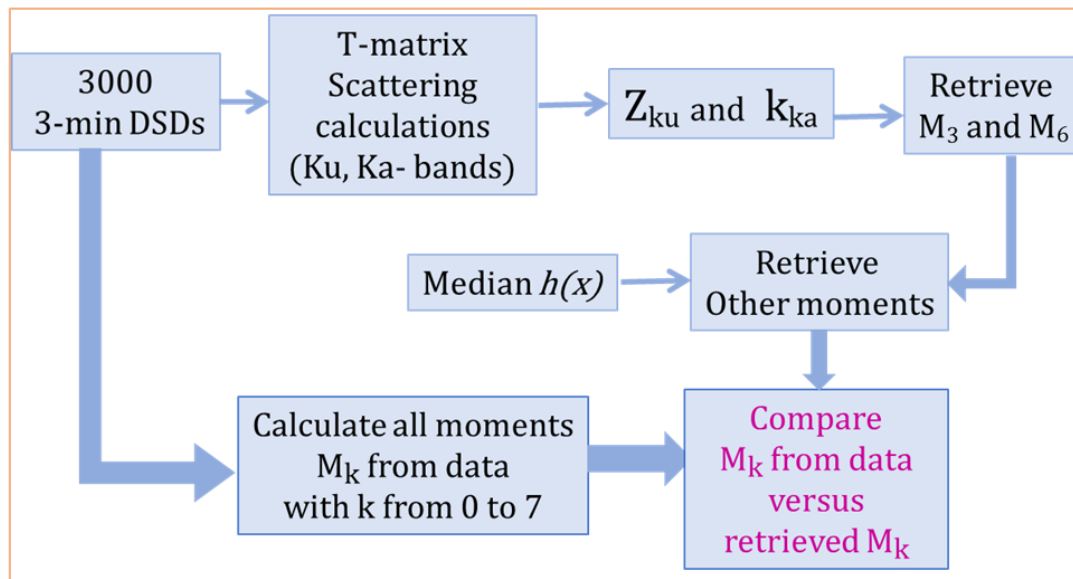


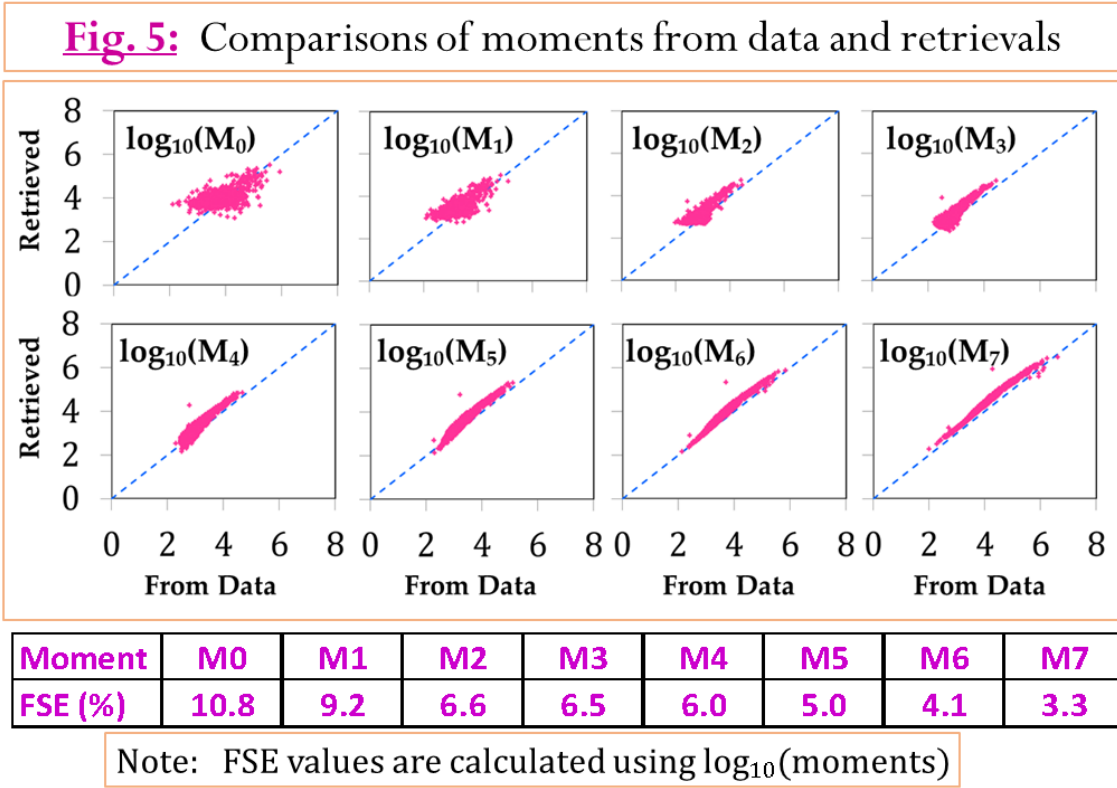
Fig. 4: Block diagram outlining the simulation procedure

Note: if μ was positive, we could have used the analytic expression given in eq. (42) of Lee et al. (JAM, 2004) to retrieve other moments

$$M_n = C_{GG,2,n} M_i^{(n-j)/(l-j)} M_j^{(l-n)/(l-j)}, \text{ with} \\ C_{GG,2,n} = [\Gamma(\mu + i/c)]^{(j-n)/(l-j)} [\Gamma(\mu + j/c)]^{(n-l)/(l-j)} \\ \times \Gamma(\mu + n/c). \quad (42)$$

But because our median of the fitted μ is (slightly) negative, we need to construct the full DSDs from M_i , M_j and the $h(x)$ $\Rightarrow$ then determine the other moments

3. RESULTS AND ERROR SOURCES



Other errors

- ❖ Radar measurement errors
- ❖ Sampling errors
- ❖ Point-to-area variance
- ❖ $h(x)$ stability

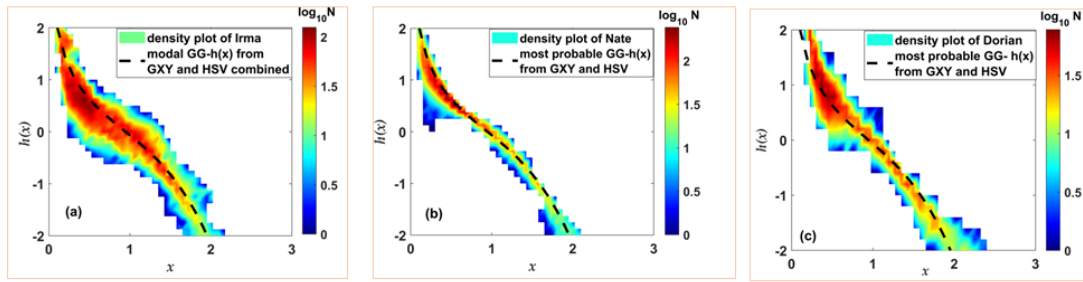


Fig. 6: Frequency of occurrence plots of the double moment normalized DSDs ($h(x)$ versus x) for 3-minute DSDs from rain-bands of (a) Irma storm, Huntsville, (b) tropical depression Nate, Huntsville, (c) Hurricane Dorian at Wallops, Virginia, and (d) remnants of storm Sally at Wallops. The dashed black lines in all three panels represent the most probable $h(x)$ curve derive from the Greeley and Huntsville combined data sets. $h(x)$ appears to be relatively stable.

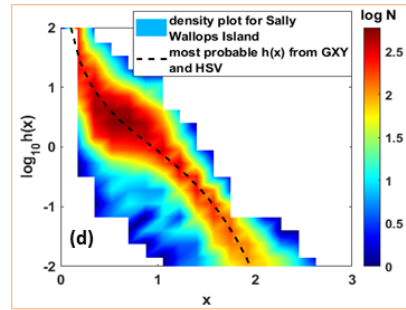
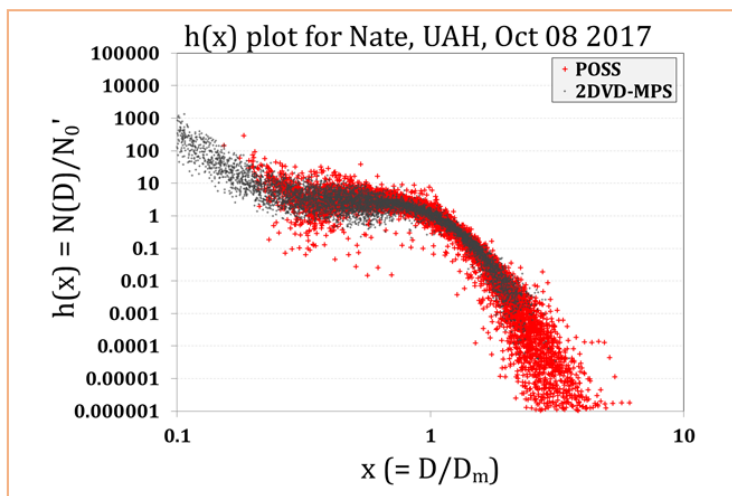
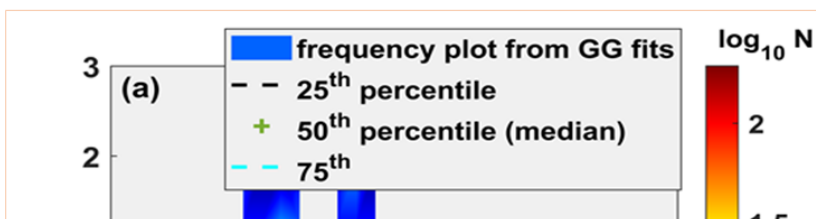


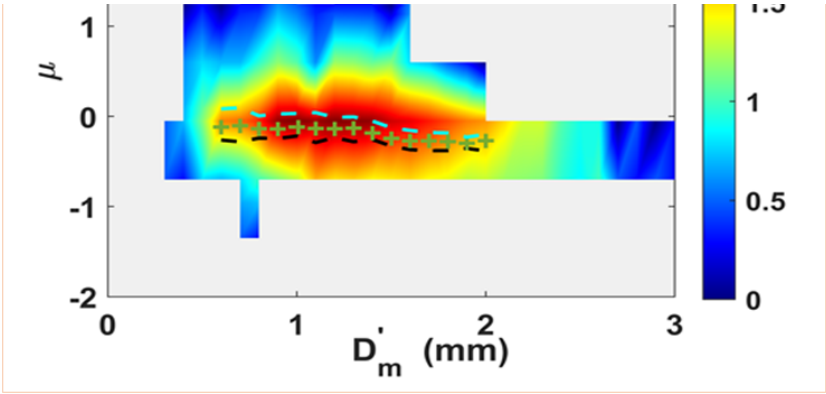
Fig. 7: We are also comparing $h(x)$ with collocated POSS (Precipitation Occurrence Sensor System). Below is the comparison for tropical depression Nate (at HSV).



Good overlap but POSS seems to sample the larger drop end of the DSD spectra better whereas MPS_2DVD data seem better for the small-sized drop end.

Fig. 8: Frequency of occurrence plot of the fitted μ versus D_m' from the GXY and HSV datasets, with their 25th, 50th and 75th percentile values.





μ shows a slight variation with D'_m

4. AN INITIAL CASE: A GPM-DPR OVERPASS ON 16 APR 2016 OVER HSV (AT 23:31 UTC)

Fig. 9: (top panels) Z from Ku band radar and the retrieved M_6 ($\log_{10}$ scale); (bottom panels) specific attenuation from Ka band radar and the retrieved M_3 ($\log_{10}$ scale). Black diamond shows the location of the disdrometers.

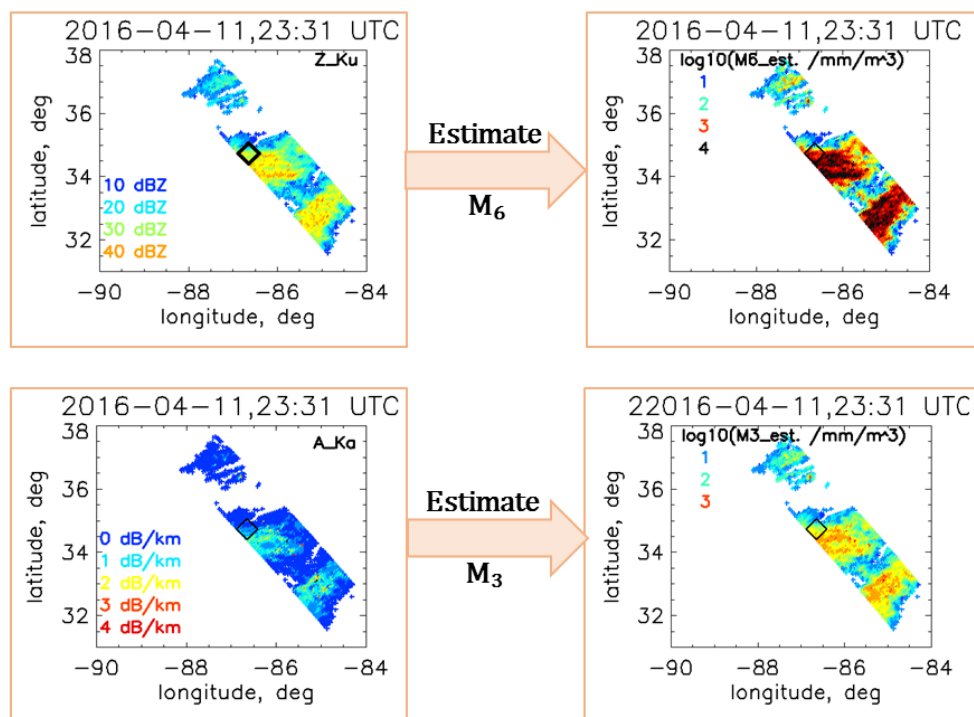


Fig. 10: Other estimated moments: M_1 , M_2 , M_4 , and M_5 are shown as examples.

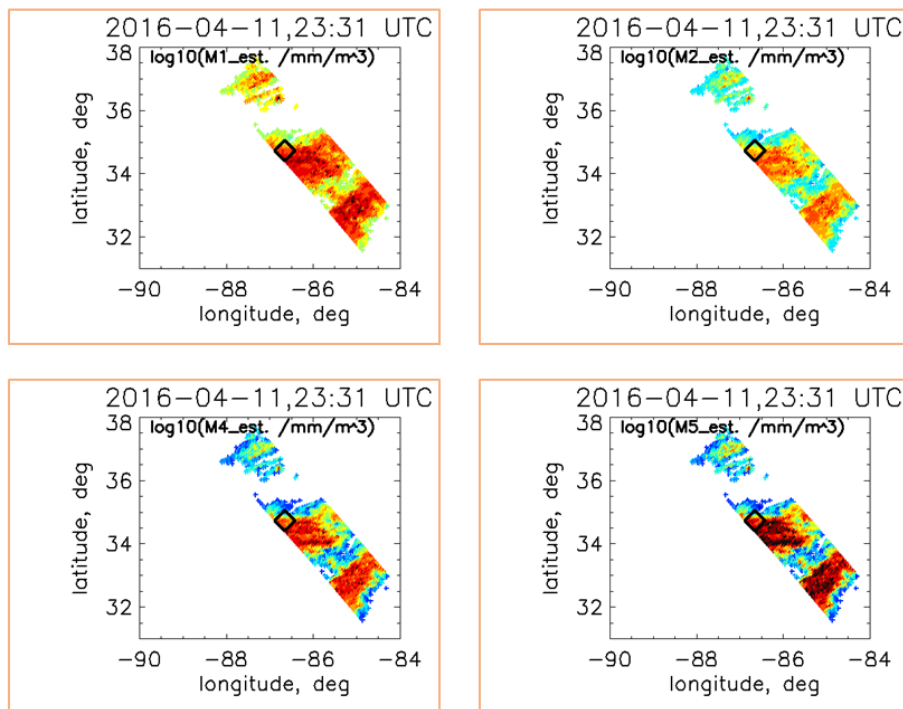


Fig. 11: Histograms of the retrieved moments corresponding to Fig. 9 and Fig. 10, over the location of the disdrometers (plus surrounding regions)

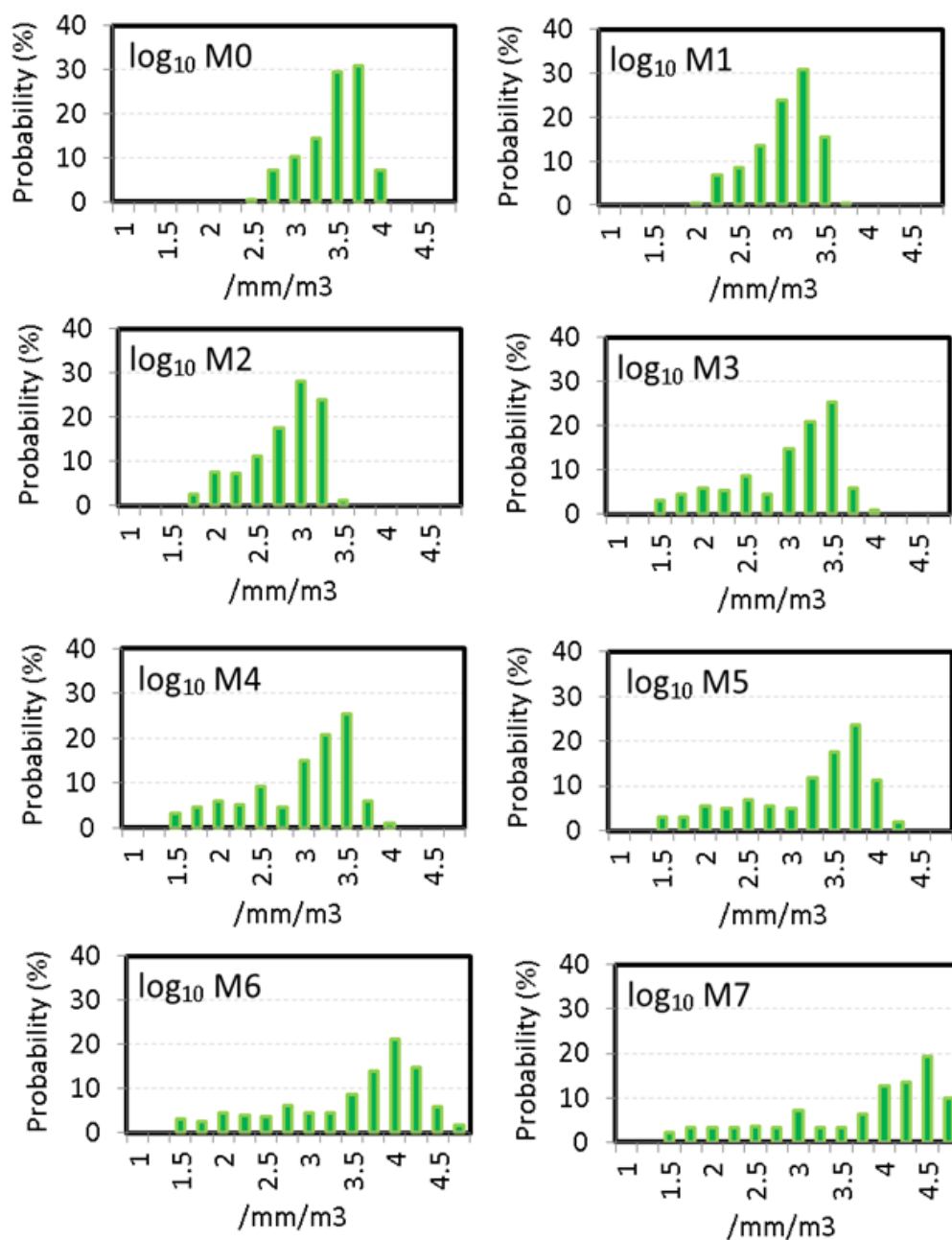


Fig. 12: Moments from the disdrometer-based DSDs (3-minute) during 1-hour time period, 23:00 to 24:00 UTC. (a) the two chosen reference moments; (b) four other moments; (c) all moments, M_0 to M_7 .

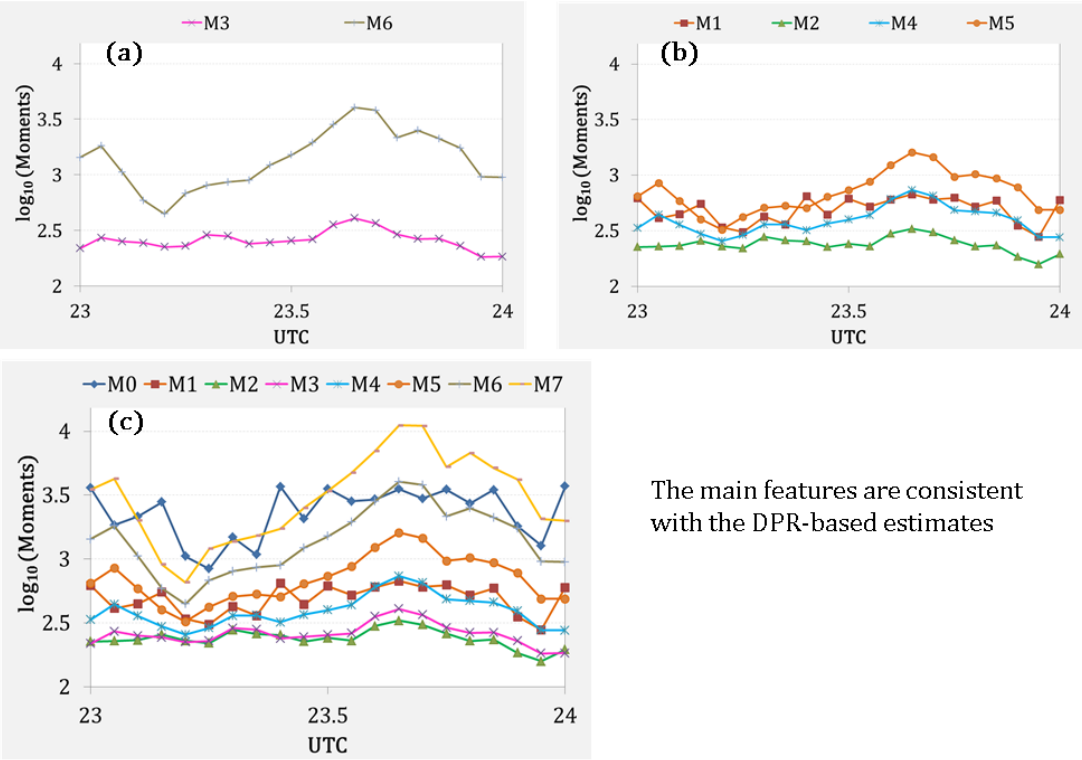
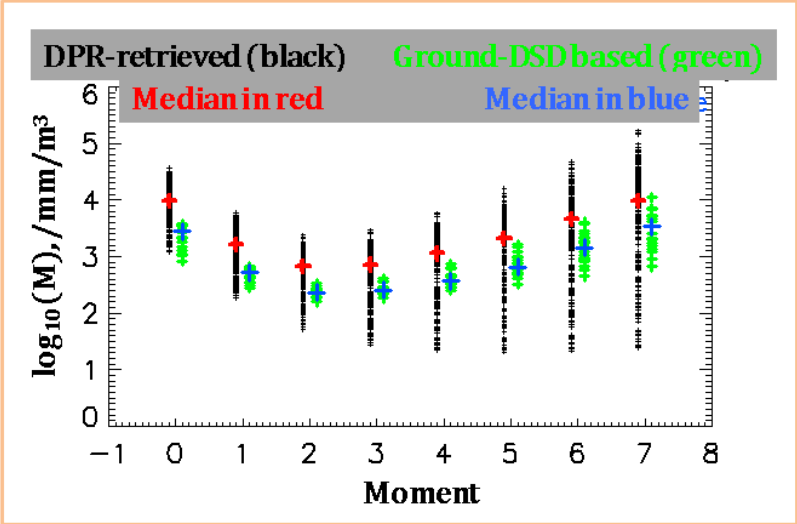


Fig. 13: Retrieved moments from DPR corresponding to Fig. 9 and Fig. 10, over the location of the disdrometers (plus surrounding regions) and those from the ground-based DSD measurements (for the whole event)



5. CONCLUSIONS

- Retrieving moments from GPM-DPR are useful with several applications.
- Moments also enable quantities such as mass-weighted mean diameter, standard deviation of mass spectrum, and the normalized intercept parameter to be estimated.
- The underlying function, $h(x)$, used for the retrievals seem remarkably stable, hence, only two reference moments need to be estimated.
- $[M_3, M_6]$ were chosen here, together with an $h(x)$ based on the generalized gamma model.
- Algorithm errors for the retrieval appear to be low but for lower-order moments, especially M_0 , they can be somewhat significant.
- Perhaps $h(x)$ may need improvement and/or a different pair of reference moments can be selected for the Ku and Ka band retrievals.
- Other error sources also need to be considered.
- However, initial test case shows encouraging results

Acknowledgements:

Support for this work (MT and VNB) was provided by NASA's Precipitation Measurement Mission via grant award number 80NSSC19K0676.

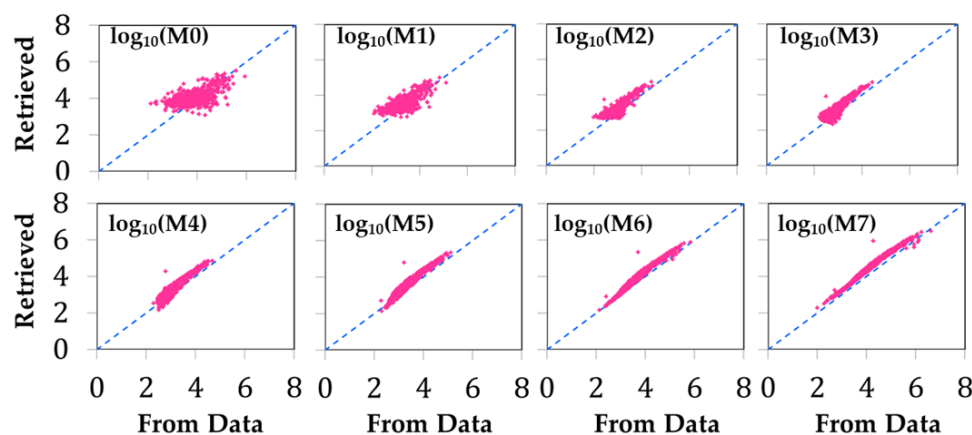
We also wish to thank Matt Wingo for providing access to HSV datasets used in this study, and to Dr. B. Sheppard for help with POSS data processing shown in Fig. 7.

ABSTRACT

Recently, a method to retrieve rain drop size distribution (DSD) moments from X-band dual polarization radar measurements has been developed using copolar reflectivity, differential reflectivity and specific attenuation. Two reference moments are retrieved first, followed by reconstructing the DSDs and calculating other moments using a generalized gamma model to represent the underlying shape, $h(x)$, corresponding to the pair of chosen reference moments. Here we explore a similar approach but the retrieval method in this study uses dual-frequency radar measurements. In the case of GPM-DPR, the two frequencies are 13.8 and 35 GHz, and their products include attenuation corrected reflectivities at both frequencies (Z_{Ku} and Z_{Ka}) and the specific attenuation (k_{Ku} , k_{Ka} , if available). Our approach is to use these products to determine two reference moments, namely M3 and M6 representing the third and the sixth moments respectively. Then, as with the polarimetric radar retrievals, we use the most probable $h(x)$ to reconstruct the full DSD spectra, from which other moments are calculated. The best two DPR products for estimating M3 and M6 appear to be A_{Ka} and Z_{Ku} . Figure 1 shows the retrievals versus the 'true' moments. 2930 three-minute DSDs were used for the (T-matrix) scattering calculations at Ku and Ka bands but only cases with $A_{Ka} > 0.5$ dB/km were chosen. For the retrieved moments, the integration was performed only up to 6 mm drop diameter.

The [1:1] line is included in Fig. 1. Even with just two DPR products as input the results seem promising, although the lower order moments show somewhat more scatter, especially the zeroth moment, M0. We will quantify the retrieval errors, and additionally examine the stability of $h(x)$. For the latter, data from (i) Greeley, Colorado, (ii) Huntsville, Alabama, and (iii) Wallops, Virginia, will be used. Finally, a GPM overpass case over Huntsville, during a widespread rain event on 11 April 2016, will be considered as an initial test case.

Fig. 1: Retrieved moments versus the 'true' moments (i.e. those from data)



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