Stability of the Intrinsic Shape of the DSD using Data from Different Rain Climatologies

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0. Introduction

1. Using the double-moment scaling-normalization framework of Lee et al. (2004), the DSD can be expressed in compact form as N(D)=N$_0$' h(x) where x is the scaled diameter (D/D$_m$') and N$_0$' is the normalization parameter. The N$_0$' and D$_m$' are defined by the two reference moments selected here as [M$_3$, M$_4$) to be consistent with the DPR and combined algorithm representation. The D'$_m$=[M$_4$/M3] and N$_0$'= M$_3$/[D$_m$']^4 which are, respectively, the same as D$_m$ (mass-weighted mean diameter) and N$_W$ = 4^4/6 N$_0$' used by the DPR and combined algorithms. The h(x) is termed as the "intrinsic" shape which has been found to be remarkably stable or "invariant" based on measured DSDs in various climatologies.

2. Whereas h(x) can be any function that has finite moments, the DPR and combined algorithms assume *apriori* that h(x) is the gamma distribution with one shape parameter μ assumed to be constant (μ= 2 or 3). Recently, the generalized gamma model with two shape parameters (μ_{GG}, c) has been used to describe h(x) since it gives more flexibility for characterizing simultaneously the shapes at the small drop end, the large drop end as well as the "shoulder" region in between.

3. The small drop end of the DSD (typically < 0.5 mm) cannot be measured with sufficient accuracy with the Joss, Parsivel or the 2D-video disdrometers (2DVD) as they do not have the required resolution (e.g., 50 microns or better). The resulting truncated DSD while giving a stable h(x) will be incorrect (for x<0.75 or so) and for the gamma model will give positive μ (typically 2 to 3) resulting in a convex down shape. However, when an optical array probe with high resolution is collocated with 2D-video, then the complete size spectrum is measurable from drizzle (0.1 mm) to the large drops. In essence the array probe data are used for D< 0.8 mm and for larger sizes the 2DVD data are used. The resulting h(x) was found to be close to the generalized gamma distribution with concave up shape at small x (i.e., the $\mu_{GG}\approx$-0.5).

4. The optical array probe and the 2DVC were collocated at three sites (Greeley CO; semi-arid), (Huntsville AL; sub-tropical) and (Wallops Island; coastal mid-latitude). We also use DSDs from the "fast" 2D-cloud probe (resolution of 25 microns) on the C-130 aircraft during the *Drizzle (0ceanic Shallow Warm Rain Stratocumulus Clouds SE Pacific west of Chile)* . For rainfall over the open ocean, the OceanRain database from shipborne ODM disdrometer measurements in 2018 were used (R/V Investigator which departed Perth and followed a SSE path towards the southern mid-latitudes). While the resolution of the ODM is unclear the smallest drop size recorded is 0.4 mm. The other database is from JAMSTEC (Japan) using the Thies LPM disdrometer on the R/V Mirai. Data from open ocean, inland (Laos), coastal land and coastal ocean (all sites close to the equator near Sumatra.). Hence, we have sampled different rain climatologies to determine the stability of h(x) by fitting to a generalized gamma model and determining the variations of the shape parameters (μ, c).

5. If the h(x) is in fact found to be stable, then most of the variability in the DSDs can be attributed to N$_W$ and D$_m$.

1. Instruments

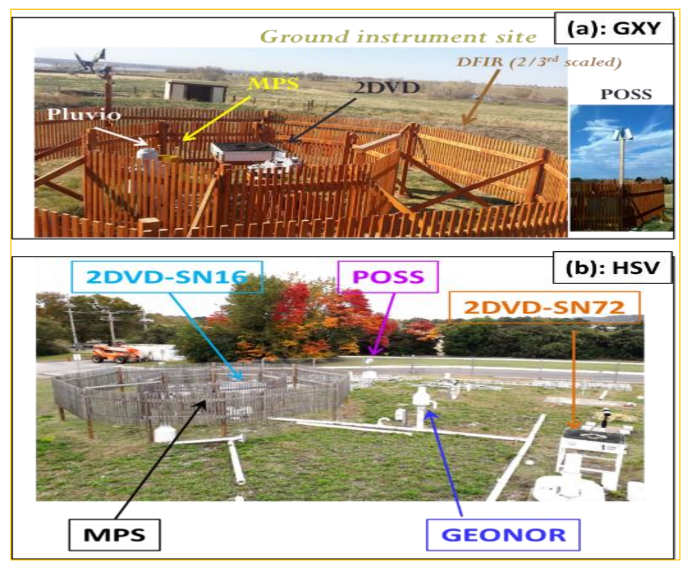


Fig. 1.1: The MPS, 2DVD and Pluvio gage inside DFIR at (a) Greeley, CO, (GXY) and (b) Huntsville, AL, (HSV)

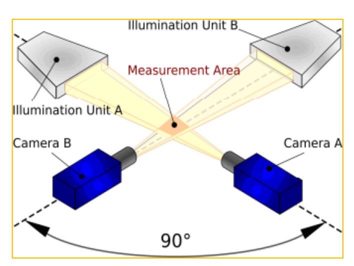


Fig. 1.2 (a): Schematic of the 2DVD. Drop images in two orthogonal planes are provided from which 3D-reconstruction of drops can be deduced.

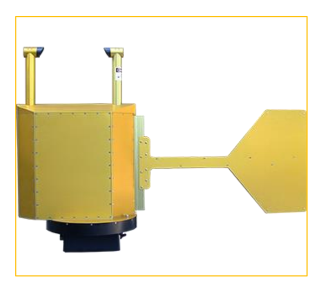


Fig. 1.2 (b): Photo of the optical array probe or MPS made by Droplet Meas. Tech. DMT. The rotating vane is not used as the unit was installed inside a DFIR.

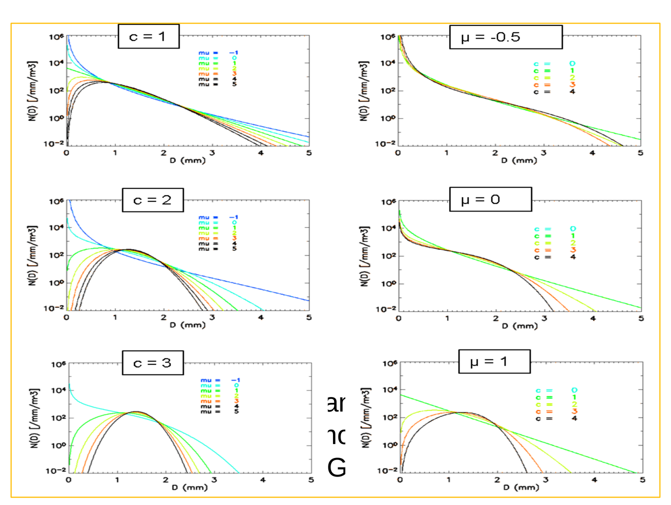


Fig. 1.3: The generalized gamma distribution with N$_W$=4266 mm^{-1} m^{-3} and D$_m$=1.5 mm. The exponential shape corresponds to μ_{GG}=1 and c=1. The standard gamma corresponds to c=1.

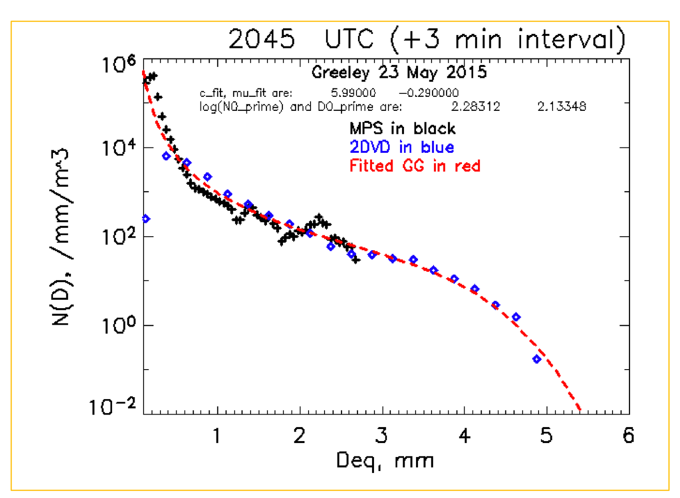


Fig. 1.4: Example of a 3-min DSD from MPS, 2DVD and "complete" spectrum fitted to the generalized gamma model. The μ_{GG}= -0.29 and c=6

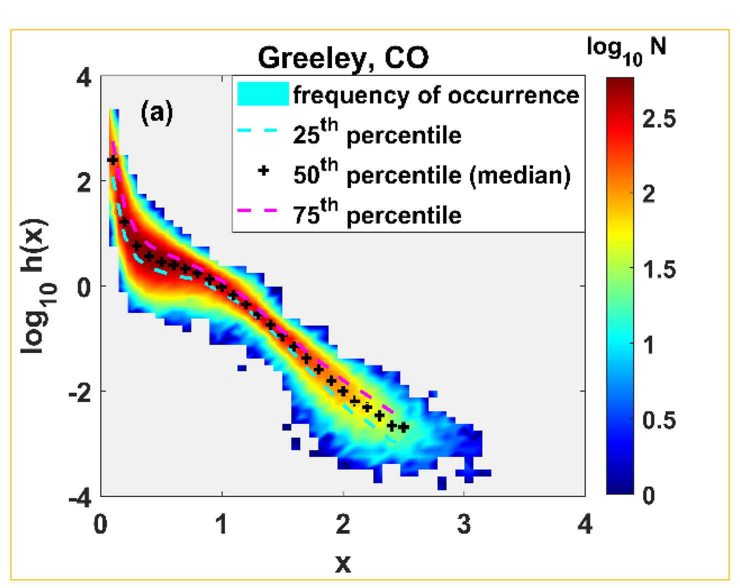


Fig. 1.5: The frequency of occurrence (or, density) plot of h(x) for 3-min averaged DSDs along with the IQR. From GXY

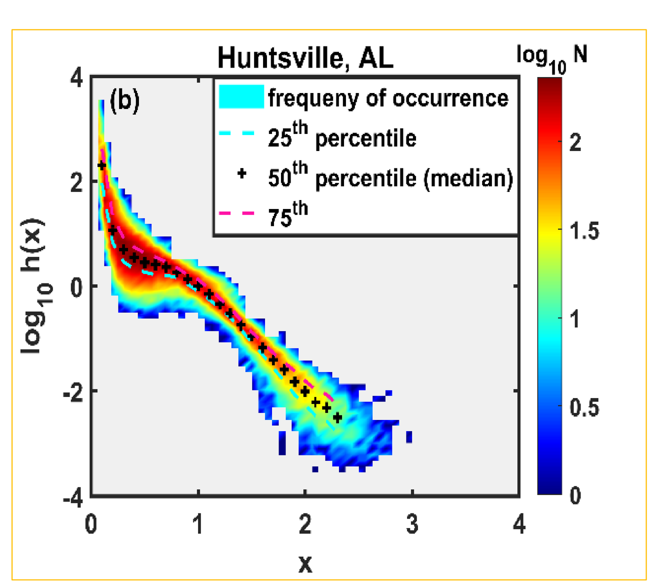


Fig. 1.6: Same as Fig. 1.5, except h(x) is from 3-min DSDs from HSV

The median h(x) in Fig. 1.5 and 1.6 are very similar in spite of the semi-arid and sub-tropical rain climatologies. The median h(x) can be fitted to the generalized gamma model . A "bulge" in h(x) is evident in both cases, centered around x≈0.4 region. It is unlikely that the bulge is caused by instrumentation problems, rather it is possible that the bulge reflects specific drop break-up mechanism such as filament break-up (McFarquhar 2004) from collisions of sub-mm sized (~0.5 mm) drops with mm-sizes (~ 2-3 mm). Such a bulge has also been noted for DSDs from Korea and Oklahoma. The histograms of μ and c for Greeley DSDs are given below in Fig. 1.7

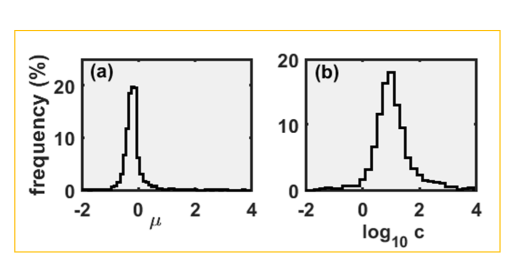


Fig. 1.7: Histograms of μ and log$_{10}$c from fitting each 3-min DSDs from GXY

2. h(x) for Outer Rainbands from Irma, Nate, Dorian

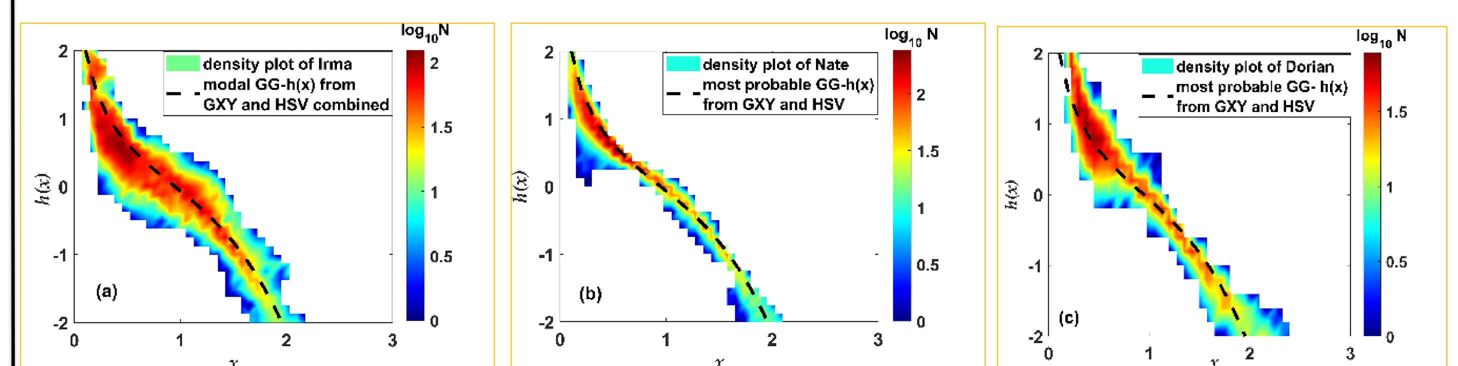


Fig. 2.1: Density plot of h(x) from (a) Irma and (b) Nate as the rainbands traversed the site in Huntsville. Panel (c) shows h(x) for Dorian rainbands over the site at Wallops Is. The black dashed line is the most probable h(x) fitted to the generalized Gamma model using DSDs from Greeley and Huntsville. This curve passes close to the median h(x) from the 3-min DSDs measured in the rainbands of Irma, Nate and Dorian. The stability of h(x) is quite remarkable considering the differences between the rainbands and the rainfall occurring in Greeley and Huntsville.

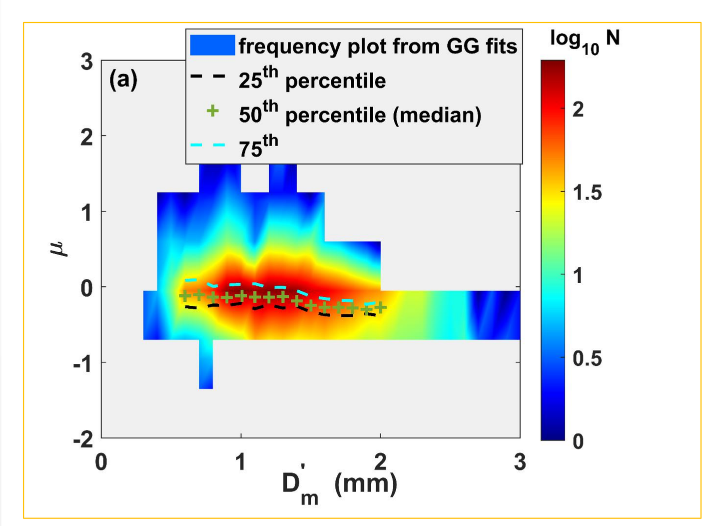


Fig. 2.2: Density plot of μ from GG fits to 3-min DSDs from the Greeley site. The IQR is shown for bins of D$_m$'. There is no correlation between μ and D$_m$' in this dataset. More generally, empirical relations between μ and D$_m$' are inconsistent with these data.

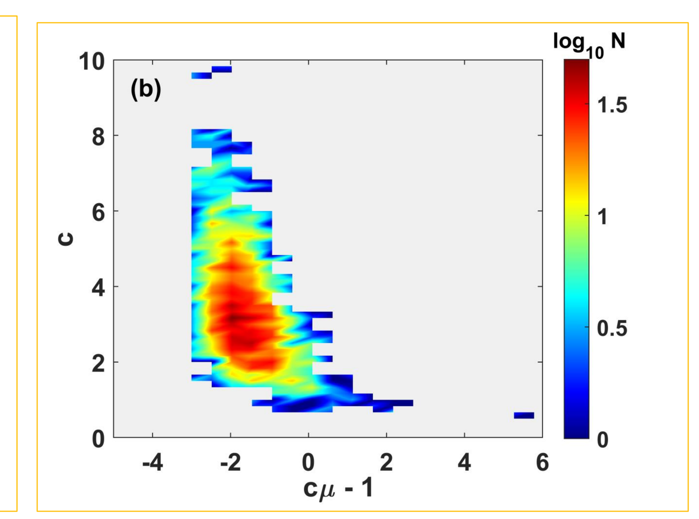


Fig. 2.3: Density plot of c from same DSDs as in left panel. Note that c=1 rarely occurs (standard gamma). The range of c values is seen to vary from 2-6 in this dataset.

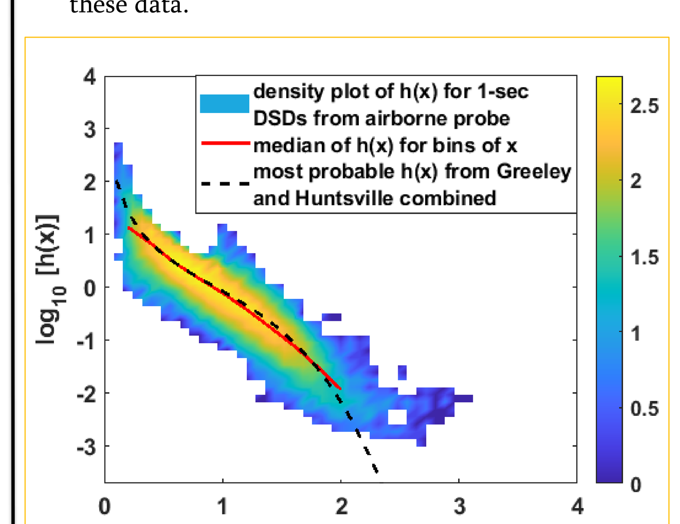
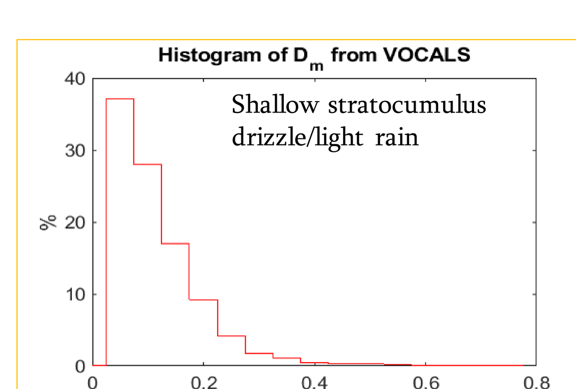
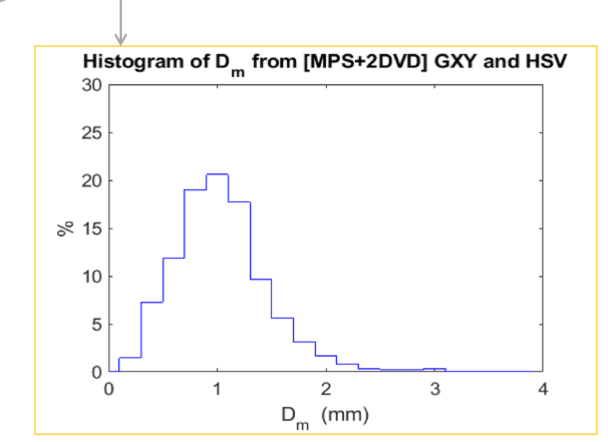


Fig. 2.4: Aircraft 1-sec DSDs from NSF/NCAR C-130 with fast 2D-C probe with 25 micron resolution from 50-1600 microns Data collected in drizzle in marine stratocumulus during VOCALS project at 1.4 km MSL in SE Pacific, West of Chile (12-31 deg S; 69-86 deg W; Mean altitude of 1.4 km; warm rain processes) Wood et al. Atmos Chem Phys (2011). (Quality controlled DSDs provided by Dr. Jorgen Jensen NCAR).

Solid red line is the median h(x) for bins of x. Overlay of black dashed line is most probable h(x) from Greeley and Huntsville combined DSDs. The overlap of h(x) from shallow stratocumulus drizzle with the h(x) from Greeley-Huntsville is indicative of stability across very different rainfall regimes.

See histograms of D$_m$ below.





3. h(x) from Shipborne Disdrometers

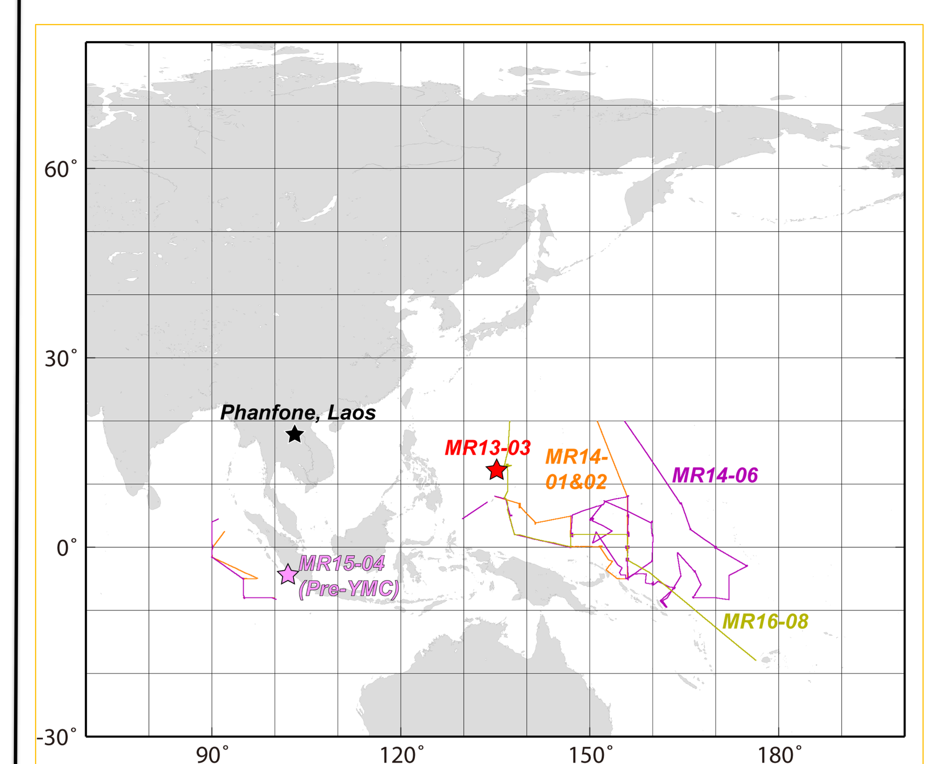


Fig. 3.1: Oceanic DSD observation onboard R/V "Mirai"
From: Katsumata et al., 2019, Japan Met. Soc. Meeting
日本気象学会2019年秋季大会（福岡）@2019/10/30

研究船「みらい」で観測された
海洋上の雨滴粒径分布の
モデル化の試みと、その降雨特性による差異

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V. N. Bringi（コロラド州立大）

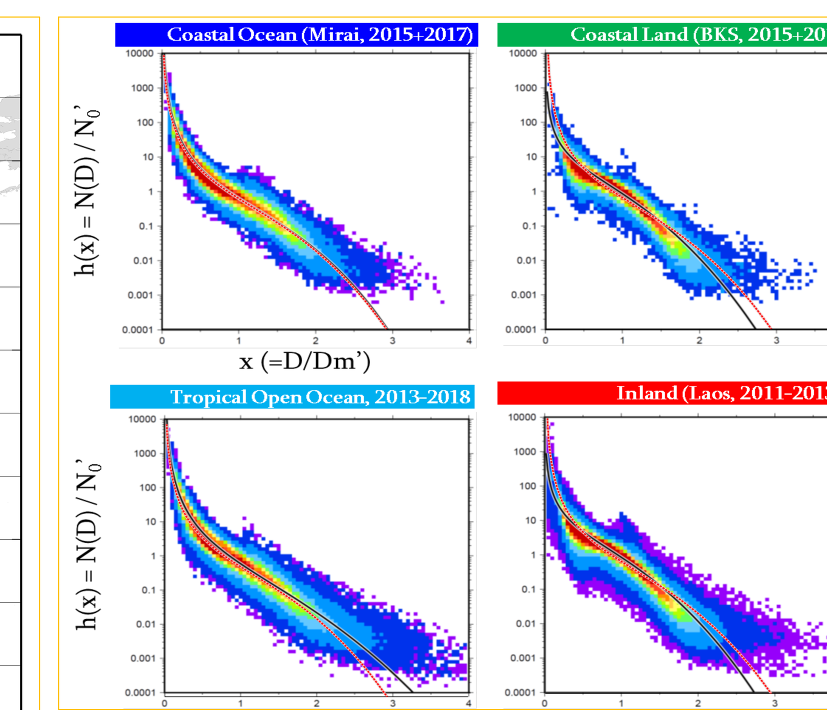

Fig. 3.2: Density plot of h(x) from the data collected in the four different regions. Black line: h(x), with c and μ determined by median of 1-min h(x). Red line: h(x) with c=3, μ=-0.5 (just for reference)

Fitted Values	μ	c
Open Ocean	-0.685	2.414
Coastal Ocean	-0.509	3.184
Coastal Land	-0.233	2.299
Inland (Laos)	-0.249	2.337

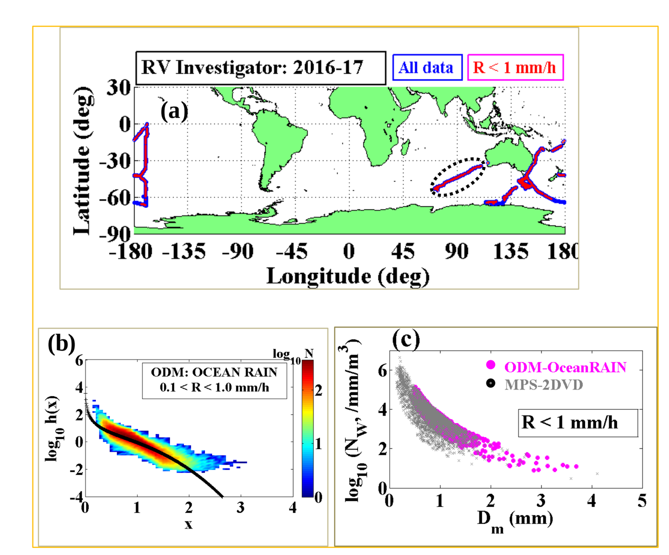

Fig. 3.3: RV Investigator ship tracks during 2016-17 campaign. The ODM470 measurements with R< 1 mm/h are shown in red while the dashed ellipse shows that part of the track from which the 1-min DSDs were analyzed to produce data in panels (b) and (c); (b) density plots of h(x) for the ODM data from the track inside the dashed ellipse; the black solid line is the optimized G-G fit to h(x) from GXY DSDs as in Fig. 1.5; (c) N$_W$ versus D$_m$ comparisons from the ODM data with the [MPS+2DVD] datasets from GXY, both for R < 1 mm/h.

4. Conclusions

- The double-moment scaling-normalization framework of Lee et al. (2004) is a powerful tool for DSD studies since it gives the intrinsic shape of the DSD [or, h(x)]. The density plot of h(x) is typically highly compressed (i.e., small IQR) and the generalized gamma fit to the median values is stable and not dependent on the rain type classification. This result was previously stated by Protat et al. (2020) using the OceanRain data set and the ODM disdrometer without a collocated high resolution optical array probe.
- The determination of an invariant h(x; μ, c) for the particular climatology depends on accurate measurements of the complete size spectrum, the choice of the reference moment orders, the method of fitting, the cost function used and the temporal resolution of the DSDs.
- The statistics of Nw and Dm and their co-variability are more important to characterize in different rain types as opposed to the much smaller variability in h(x).
- One caveat is that the complete DSD must be measured to give correct h(x) but most disdrometers cannot measure the small drops with good resolution, i.e., they give truncated distributions for which h(x) can be stable but incorrect.

References

i. Lee, G. Zawadzki, I., Szyrmer, W.; Sempere-Torres, D.; Uijlenhoet, R. A General Approach to Double-Moment Normalization of Drop Size Distributions. J. Appl. Meteor., 2004, 43, 264–281.
ii. Protat, A., C. Klepp, V. Louf, W. A. Petersen, S. P. Alexander, A. Barros, J. Leinonen, and G. G. Mace, 2019: The latitudinal variability of oceanic rainfall properties and its implication for satellite retrievals: 1. Drop size distribution properties. J. Geophys. Res. Atmos., 124, 13 291–13 311
iii. Wood et al., 2011: The VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-Rex): goals, platforms and field operations, Atmos. Chem. Phys., 11, 627-654
iv. Katsumata, M., B. Geng, S. Mori, and V. N. Bringi, 2019: An attempt to model the oceanic DSD observed on board R/V Mirai. Fall meeting of the Meteorological Society of Japan, C357.

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