Long Term 2DVD Observations of Rainfall Characteristics in the Equatorial Indian and West Pacific Oceans

Elizabeth J. Thompson[1] (liz@atmos.colostate.edu), Steven A. Rutledge[1], Brenda Dolan[1], Merhala Thurai[2]

[1]Dept. of Atmospheric Science, [2]Dept. of Electrical and Computer Engineering, Colorado State Univ.

Overview

Raining Drop Size Distribution (DSD) data are analyzed from two equatorial, oceanic regions affected primarily by weather associated with the Madden-Julian Oscillation. Over 2 years of 2D Video Disdrometer (2DVD) data at Manus Island (West Pacific Warm Pool: TOGA-COARE) and 4 months worth at Gan Island (Indian Ocean: DYNAMO) show:

1. The two sites have nearly identical spectra of integral rainfall quantities
2. A robust separation between convective and stratiform DSDs exists in all rainfall parameters for both sites, confirmed with coincident S-Pol radar RHIs (8 km away from 2DVD)
3. Simulated radar variables from these 2DVD data helped form local rainfall and attenuation estimation relationships for single and dual-polarization radars during DYNAMO and TOGA-COARE
4. We elaborate upon implications of using a single or convective/stratiform $R(z)$ relationship(s) for case study and MJO rainfall studies.
5. The dual-polarization Blended Algorithm's performance in tropical, oceanic rainfall is evaluated with new rainfall relations.

Data / Methods

- 31,276 (Manus), 4,436 (Gan) 1 min raining DSD points after 100 total drop and 0.05 mm hr^{-1} thresholds.
- Original 2DVD data had numerical and time lag errors; required reprocessing
- EM scattering simulations of radar variables: Z_h, Z_{dr}, K_{dp}, A_h
- Normalized Gamma DSD parameter estimation: N_w, D_0, μ
- **New CONV/STRAT rain partitioning method:** The original N_w-D_0 method proposed by Bringi et al. 2009 (Darwin) has been adapted: a new separation line is formed to fit these tropical, maritime rainfall DSD w/o *any* influence of continental air masses:

$$\log_{10}(N_w^{sep}) = 3.7$$

CONV: $\log_{10}(N_w) > \log_{10} N_w^{sep}$
STRAT: $\log_{10}(N_w) \leq \log_{10} N_w^{sep}$

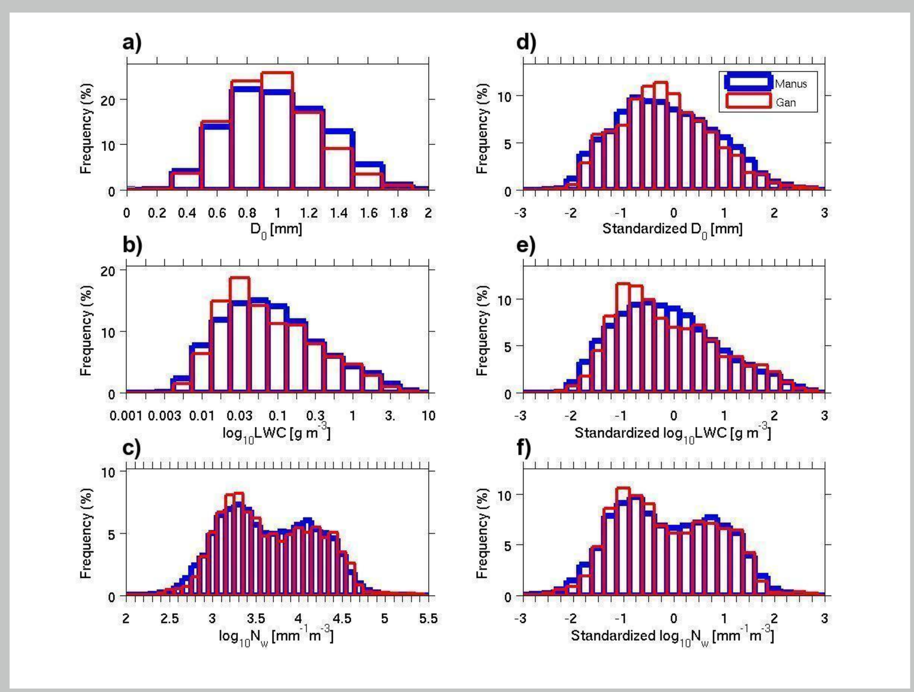

Figure 1: Normalized histograms of Manus and Gan 2DVD data.

- This simplifies to: $LWC^{sep} = 0.0937 D_0^4$; C/S populations also evident in R vs. D_0, R vs. LWC, z vs. LWC
- Stratiform rain < 40 dBZ; < 10 mm hr^{-1}; Convective rain could have *any* Z_h or R
- All results sensitive to line placement between $\log_{10} N_w{}^{sep} = 3.6$-$3.9$ in "transition rain" (Williams et al. 1995), which results in $\pm$3.5% C/S rain occurrence and accum.; $\log_{10} N_w{}^{sep} = 3.7$ chosen for convergence of R statistics

New CONV/STRAT 2DVD Partitioning Method

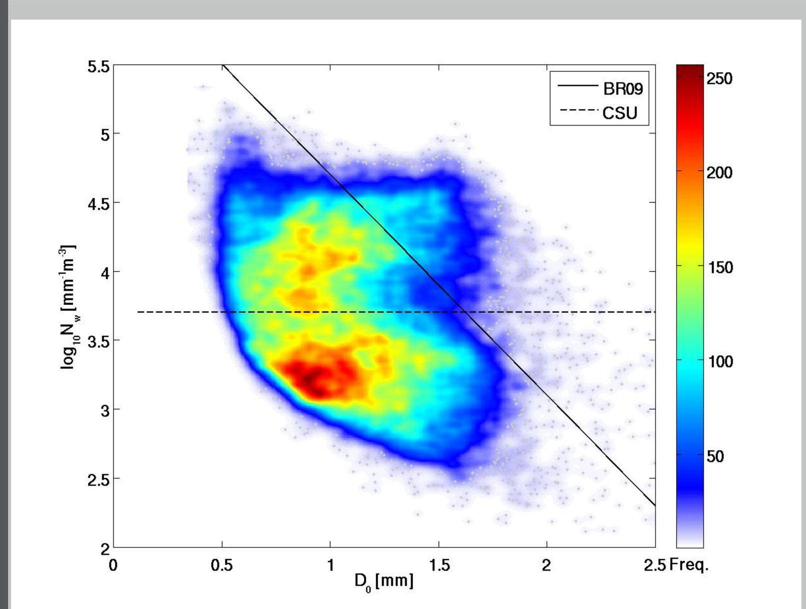

Figure 2: Manus $\log_{10} N_w$ vs. D_0 2D histogram (Identical at Gan).

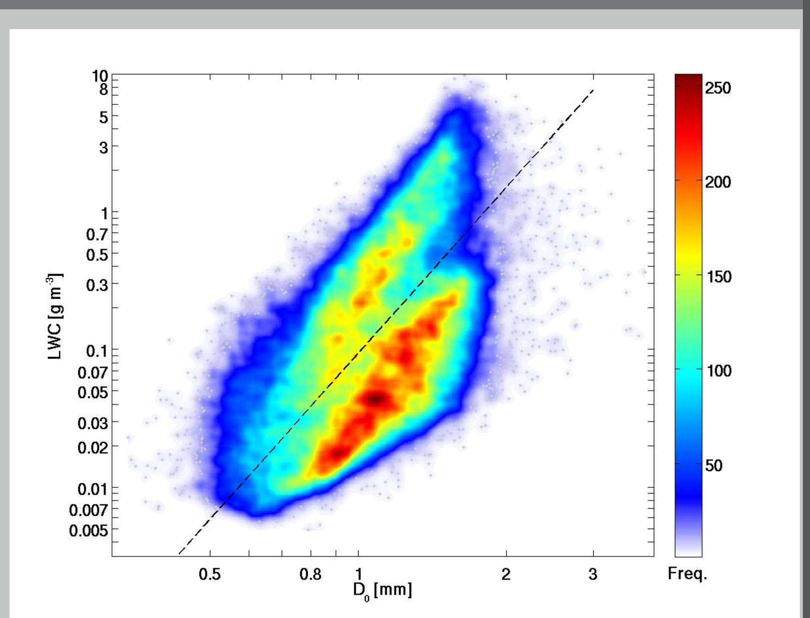

Figure 3: Manus $\log_{10} LWC$ vs. D_0 2D histogram (Identical at Gan).

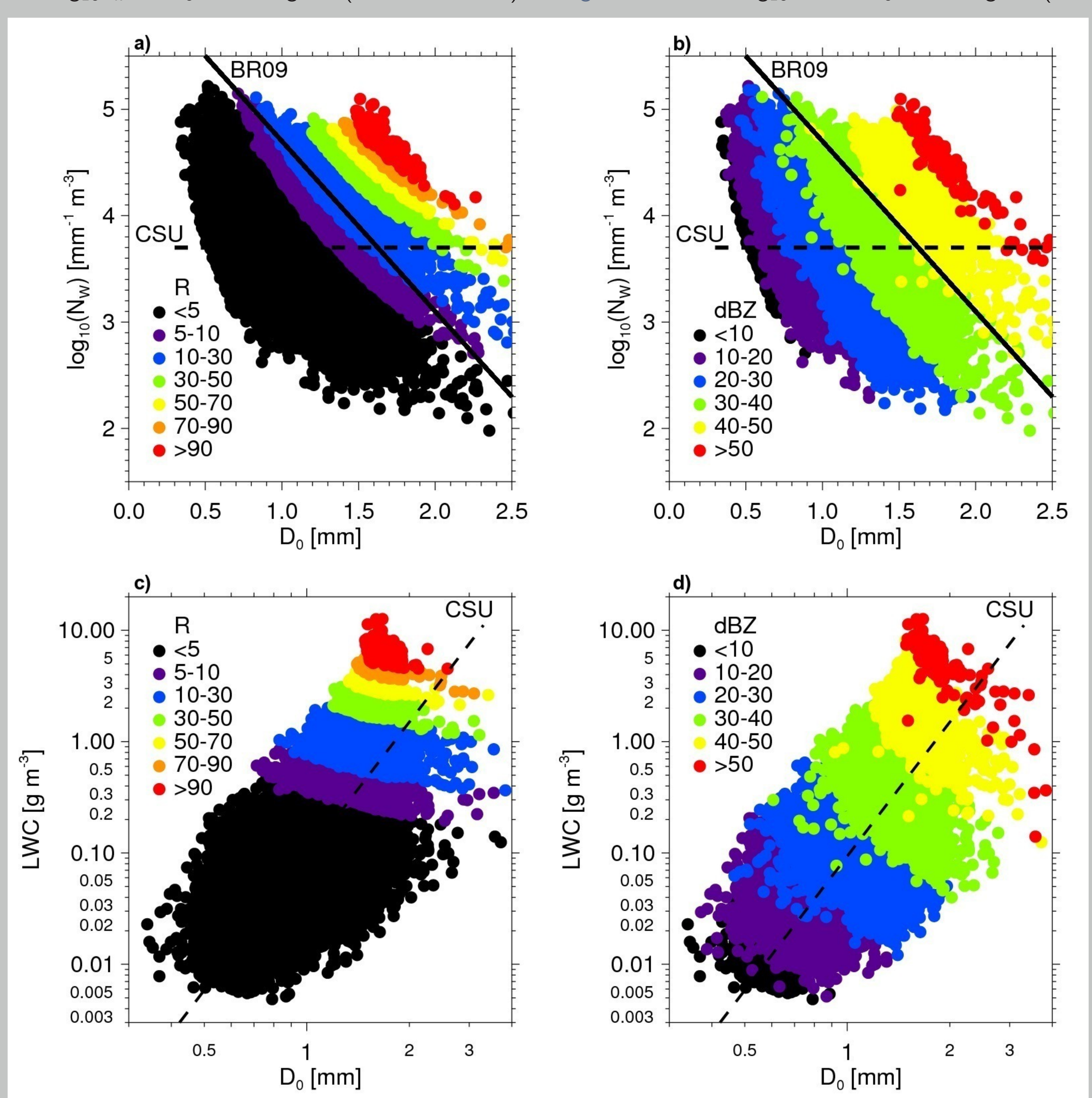

Figure 4: Manus Island scatterplots colored by 2DVD rain rate (left panels) and simulated Z_h (right panels). N_w-D_0 conv/strat separation lines developed herein (CSU) and from Bringi et al. 2009 (BR09) are compared. Equivalent LWC-D_0 C/S separation line plotted.

Acknowledgments

This research was primarily funded by the NSF Graduate Research Fellowship Award # DGE-1321845 as well as NSF Award # AGS-1063928 and DOE/ASR grant DE#SC0007016 . We appreciate the long-term Manus and Gan Island 2DVD data collected and disseminated by ARM/DOE. Thanks to Paul Hein for data management, Gwo-Jong Huang for DSD data processing, and Weixin Xu for radar data processing (all CSU). We greatly appreciate useful research conversations with Nick Guy (NSSL), Bob Houze and Scott Powell (UW), Courtney Schumacher (TAMU), Scott Collis (Argonne National Laboratory), as well as V. N. Bringi, Elizabeth A. Barnes, and John M. Peters (CSU). Thanks to Michael Dixon, Bob Rilling, Scott Ellis (NCAR) and many people at Univ. of Washington for research discussions in addition to helping collect, quality control, and provide DYNAMO S-Pol radar data.

Tropical, Oceanic Radar Rainfall Relationships

Table 1: Manus Island orthogonal linear regression best-fit lines for rain rate (R mm hr^{-1}) as a function of linear reflectivity $R(z)$ and $z(R)$, specific differential phase $R(K_{dp})$, specific differential phase and linear differential reflectivity $R(K_{dp}, \zeta_{dr})$, or linear reflectivity and linear differential reflectivity $R(z, \zeta_{dr})$. Equations are expressed as $y = aax^{bb}$ or $y = aax_1^{bb}x_2^{cc}$. Distinct $R(z)$ and $R(K_{dp})$ relationships were formed for either convective and stratiform populations denoted with C or S subscripts. Gan $\sim$ Manus.

coefficient	X-band	C-band	S-band
$R(z, \zeta_{dr})aa$	0.0157	0.0157	0.0139
$R(z, \zeta_{dr})bb$	0.8579	0.8491	0.8812
$R(z, \zeta_{dr})cc$	-4.6670	-4.8706	-6.0314
$R(K_{dp}, \zeta_{dr})aa$	31.8840	59.3227	133.5483
$R(K_{dp}, \zeta_{dr})bb$	0.8445	0.8670	0.9054
$R(K_{dp}, \zeta_{dr})cc$	-2.7440	-3.4047	-4.0391
$R(K_{dp})aa$	18.6599	30.6181	56.0339
$R(K_{dp})bb$	0.7650	0.7779	0.7960
$R(K_{dp})aa_C$	21.5170	34.0579	58.8955
$R(K_{dp})bb_C$	0.7299	0.7411	0.7521
$R(K_{dp})aa_S$	12.1064	19.3335	34.2556
$R(K_{dp})bb_S$	0.7076	0.7186	0.7349
$R(z)aa$	0.0225	0.0212	0.0207
$R(z)bb$	0.7167	0.7222	0.7211
$R(z)aa_C$	0.0344	0.0333	0.0339
$R(z)bb_C$	0.6927	0.6946	0.6892
$R(z)aa_S$	0.0261	0.0251	0.0254
$R(z)bb_S$	0.6435	0.6461	0.6396
$z(R)aa_C$	129.6064	134.0526	136.0188
$z(R)bb_C$	1.4436	1.4397	1.4510
$z(R)aa_S$	288.3073	300.2840	311.1649
$z(R)bb_S$	1.5540	1.5478	1.5635
$z(R)aa$	198.5782	207.8236	216.0665
$z(R)bb$	1.3953	1.3847	1.3867

- MISMO $R(z) \sim$ CSU $R(z)$ equation
- Rainfall relationship R^2 are highest (0.98), 2% more 2DVD rain rate (R) variance explained, when C/S populations are separated.
- The new conv/strat partitioning method estimates that convective rainfall < 40 dBZ and < 10 mm hr^{-1} contributes 20% of total rain and accounts for 38% of all rain occurrences. The BR09 line results in vast overestimation of stratiform rain at the expense of underestimating weak, shallow convection. This was originally disconcerting because of the established agreement between the BR09 and radar-based C/S partitioning methods (Thurai et al. 2010).
- Applying a single $R(z)$ or conv/strat $R(z)$ to simulated Z_h yield different rainfall statistics. Taking 2DVD rain rate as ground truth, **statistics of rain accumulation [mm] and % of total rain by conv/strat elements can be reproduced if and only if data are partitioned by true conv/strat types and then treated with different $R(z)_C$ and $R(z)_S$.** Otherwise, stratiform(convective) rainfall is over(under)estimated by $\pm$9% and total rainfall is reduced by up to 7%.
- Because tropical, oceanic rain accomplishes very high LWC with numerous small drops, which are therefore not very oblate, K_{dp} and Z_{dr} are lower for a given Z_h and R compared to continental regimes.
- Dual-polarization relationships were used in the Blended Algorithm (Cifelli et al. 2011) on S-Pol radar data during DYNAMO. The 38 dBZ (and even 30 dBZ) threshold for use of $K_{dp} > 0.3$ ° km^{-1} and/or $Z_{dr} > 0.5$ dB are likely too conservative; the Blended Algorithm hardly ever ($<$ 25% of the time) *chooses* dual-polarization relationships. The current set up seems to underestimate convective rain at the expense of stratiform rain, yielding lower total rain amounts compared to 2DVD statistics (not direct ground validation).
- Despite the fact that shallow, weak convection are often missed completely or misclassified as stratiform by traditional radar texture-based C/S algorithms, **2DVD rainfall indicated %C/S rainfall statistics can be recreated with radar data if and only if different $R(z)_C$ and $R(z)_S$ are utilized.**
- Using a single $R(z)$ on radar Z_h results in under(over)estimation of stratiform(convective) rain ($\pm$7%)

DYNAMO 2DVD / Radar Rainfall Statistics

Table 2: 2DVD Manus Island convective and stratiform rainfall accumulation [mm] and % of total rain derived from 2DVD rain rate variable compared to simulated rainfall from simulated reflectivity values using different convective/stratiform partitioning methods and different rainfall estimation equations. The convective and stratiform rain amounts are divided by the total rain amount using the same methodology. Rainfall simulated for partial DSD populations in last two rows were divided by total 2DVD rainfall amount, so the percentage contribution to total rainfall is just an estimate. Results are identical for Gan and Manus Island.

Method	Total Rain	Conv Rain	Strat Rain	% Conv Rain	% Strat Rain
CSU partitioning with 2DVD rain rate	43.8	37.3	6.5	85	15
CSU partitioning with CSU conv/strat $R(z)$	43.6	37.2	6.3	85	15
BR09 partitioning with CSU conv/strat $R(z)$	40.8	31.0	9.8	76	24
All data with CSU all-data $R(z)$	40.9	31.1	9.8	76	24
Method		Rain w/ $R(z)_C$	Rain w/ $R(z)_S$	% Rain w/ $R(z)_C$	% Rain w/ $R(z)_S$
CSU conv / BR09 strat		8.8	4.6	20	11
CSU strat / BR09 conv		2.6	1.1	6	3

Table 3: S-Pol DYNAMO rainfall statistics for Nov 2011 at 1 km AGL, 1 km grid spacing, applying Steiner et al. (1995) C/S Z_h texture-based partitioning. Methods to estimate convective and stratiform rain occurrence and contribution to total rain are compared. DYNAMO Gan Island 2DVD data are considered ground truth and compared to radar-based convective stratiform partitioning methods using various radar-based rainfall relationships: new conv/strat $R(z)$, new dual-polarization Blended Algorithm, new single $R(z)$, MISMO single $R(z)$, Tokay and Short (1996) TOGA-COARE conv/strat $R(z)$ (TS96) $\sim$ CSU; their full experiment average also shown.

RAIN OCCURRENCE	% C	% S
Gan 2DVD DYNAMO	**48**	**52**
S-Pol DYNAMO	17	83
TOGA-COARE (area)	29	71
RAINFALL ACCUMULATION	% C	% S
Gan 2DVD DYNAMO	**84**	**16**
CSU conv/strat $R(z)$	84	16
CSU Blended dual-pol	79	21
CSU $R(z)$	77	23
MISMO $R(z)$	75	25
TOGA-COARE conv/strat $R(z)$	86	14
" " TS96 1996	74	26

DYNAMO S-Pol radar and Gan Island 2DVD Case Studies

- 2DVD (^ marker on RHI) N_w-D_0 (upper left) and LWC-D_0 (lower left) data compared to CSU/BR09 conv/strat partitioning lines during $\pm$15 min of corresponding RHI (141°)

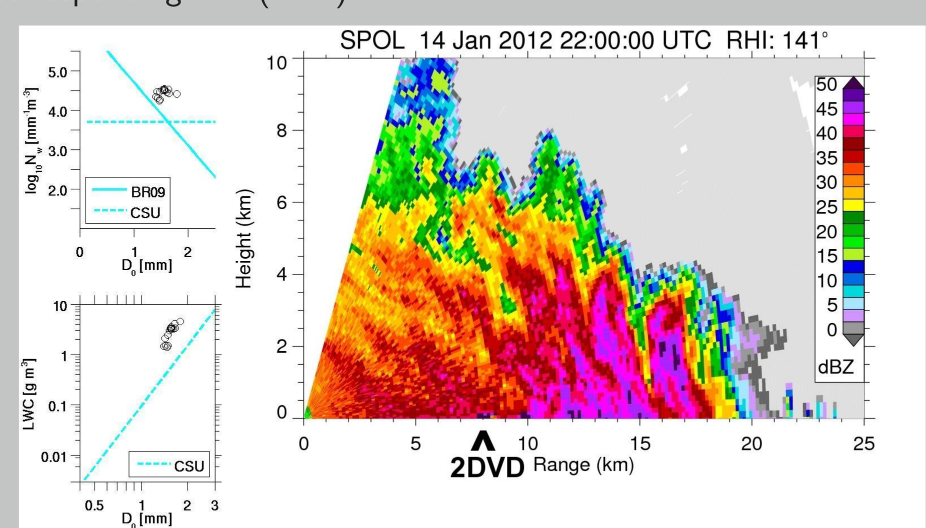

Figure 5: Strong convective rain

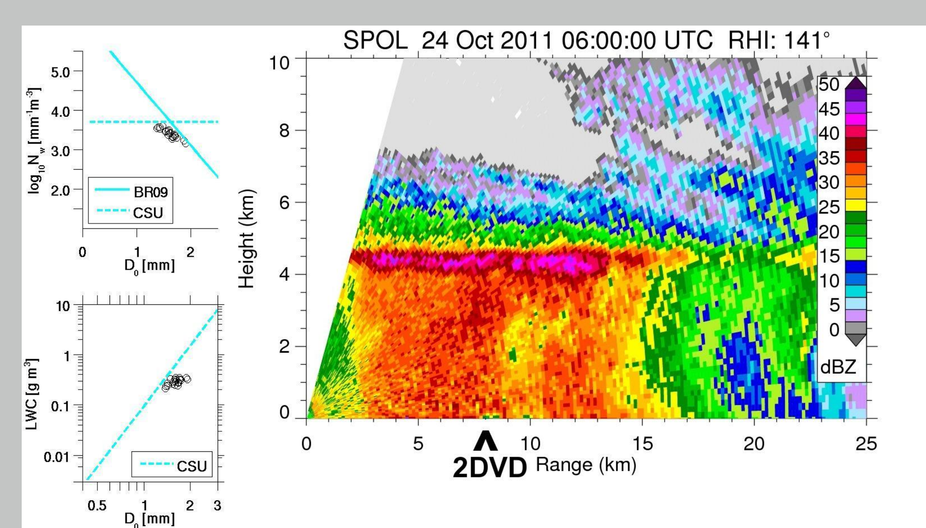

Figure 7: Strong stratiform rain

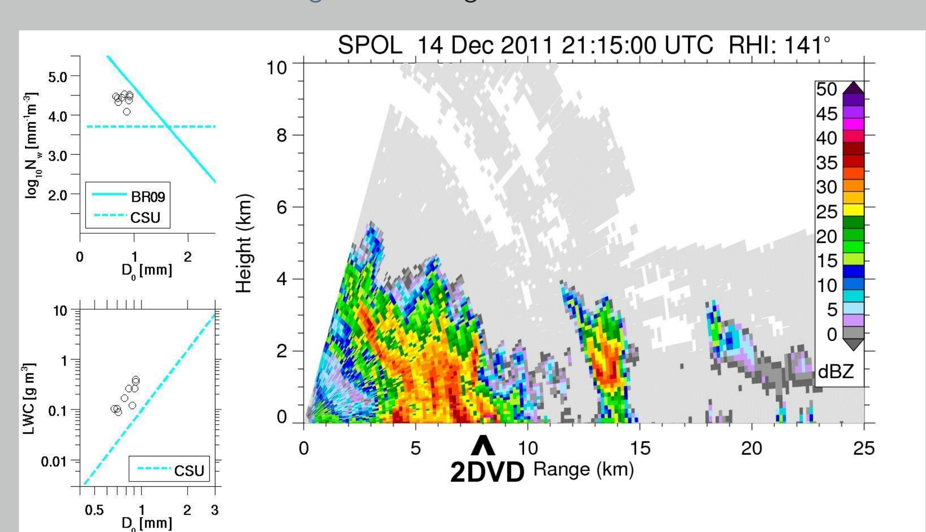

Figure 6: Weak convective rain

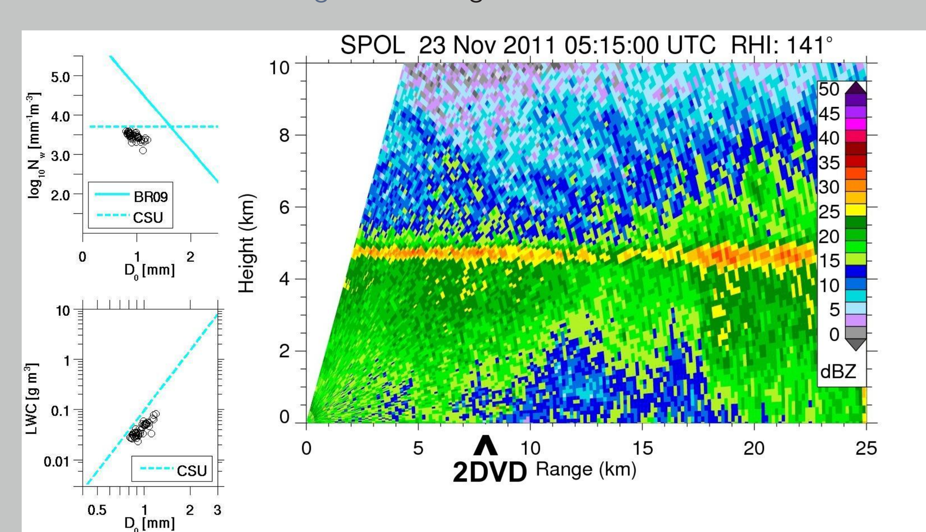

Figure 8: Weak stratiform rain.

Conclusions

- The dual-polarization Blended Algorithm needs tuning/testing in this unique tropical, oceanic environment before implementation of new relationships; also sensitive to K_{dp} filtering and gridding/interpolation techniques for all variables.
- **The best radar-based rainfall estimation methods for both single and dual-polarization radars at this time are to partition echoes into stratiform and convective areas and apply two different $R(z)_C$ and $R(z)_S$. Use of a single $R(z)$ over(under) estimates stratiform(convective) rainfall by $\pm$5-10%.**
- The sensitivity of rainfall statistics to choice of rainfall relationships is significant even on monthly and MJO time scales; up to 25% differences in %C/S rainfall occur for individual storm case study rainfall analyses.
- Weak, shallow convection is ubiquitous over the warm, tropical oceans and care should be taken to ensure that radar-based convective/stratiform partitioning algorithms can handle this important precipitation regime.
- Further exploration of convective/stratiform/transition precipitation populations should involve Gan 2DVD, wind profilers, cloud, and precipitation radar, etc. This will help characterize the role of *non-precipitating* cumulus and validate techniques developed herein.