Performance of S-band Ground-Based Radar Precipitation Rate Retrieval Algorithms over a Dense Gauge Array

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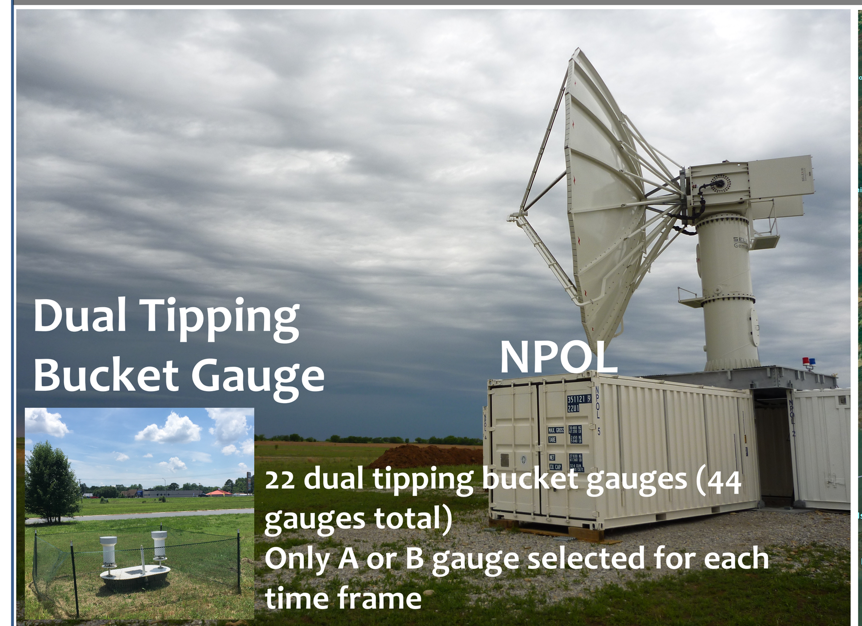
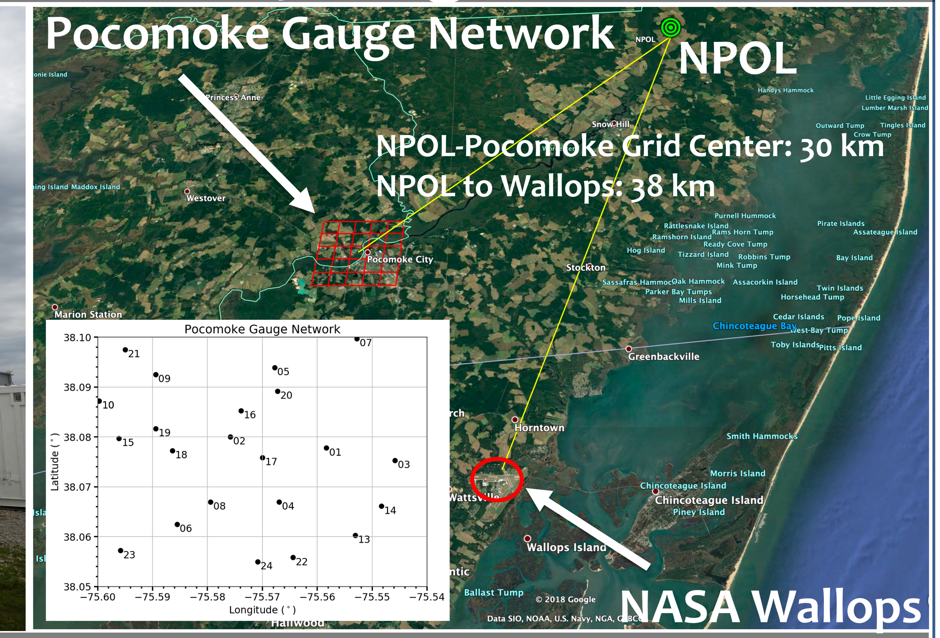
1. Motivation

- The Global Precipitation Measurement (GPM) mission Ground Validation (GV) supersite Precipitation Research Facility at NASA Wallops Flight Facility is equipped with the high-resolution S-band NASA Polarimetric (NPOL) radar and a 25 km² gauge network since 2013 for nearly continuous precipitation observations.
- A high-density gauge network was designed to match the GPM Dual-frequency Precipitation Radar (DPR) 25 km² nadir footprint.
- **In order to accurately validate GPM DPR rainfall with GV radars, we must quantify the performance of several surface rainfall algorithms.**
- This study **assesses the non-uniform beam filling (NUBF) problem** by comparing NPOL-derived rain rates against 5-, 10-, and 15-minute averaged gauge estimates at three beam filling (BF) thresholds.
- With the robust observational dataset, we also evaluated a drop-size distribution (DSD) based convective-stratiform rain classification technique.

2. Instrument & Study Region





3. Rain Rate Algorithms

DROPS2.0, Chen et al. 2017 (hereafter RR)
- Dual-polarimetric quality-controlled data and K_{DP} estimation
- A region-based hydrometeor classification with sounding data as input
- Rate equations are derived from 14 APU disdrometer data during NASA's IFloodS experiment
- Non-linear regression applied to derive equations $R(Z_H)$, $R(K_{DP})$, $R(Z_H, Z_{DR})$, $R(Z_{DR}, K_{DP})$

Cifelli et al. 2003, 2001 (hereafter RC)
- A bin-by-bin fuzzy-logic based hydrometeor classification
- Dual-polarimetric information incorporated to improve drop size and shape
- Rainfall equations $R(Z_H)$, $R(K_{DP})$, $R(Z_H, Z_{DR})$, $R(Z_{DR}, K_{DP})$ based off simulated DSD

Bringi et al. 2004 (hereafter RP)
- Strictly uses Z-R relation $Z = aR^{1.5}$
- The multiplicative coefficient "a" changes continuously in space and time as DSD evolves
- DSD parameters estimated following Gorgucci et al. 2002 method

Wang et al. 2008 (hereafter RG)
- Gauge tips are converted to rain rate (bucket size is 0.254 mm, time resolution is 1 second)
- Rates are derived using a cubic spline (CS) method
- Cubic polynomials are constructed between 2 tips in a given rain event
- Multiple tips and no rain tips are accounted for

4. Analysis Framework

System for Integrating Multi-platform data to Build the Atmospheric column SIMBA (Wingo et al. 2018)

Define Column Grid
- Grid Center: Pocomoke Grid
- Horizontal and vertical extent: 5 x 5 x 1 km
- Grid spacing: 1 km horizontal, 0.25 km vertical

Ingest Data
- NPOL 250 meter native resolution
- multi-tilt PPI volume every 3 min
- 1 min gauge rates

Output netCDF File
- Column 3D gridded data

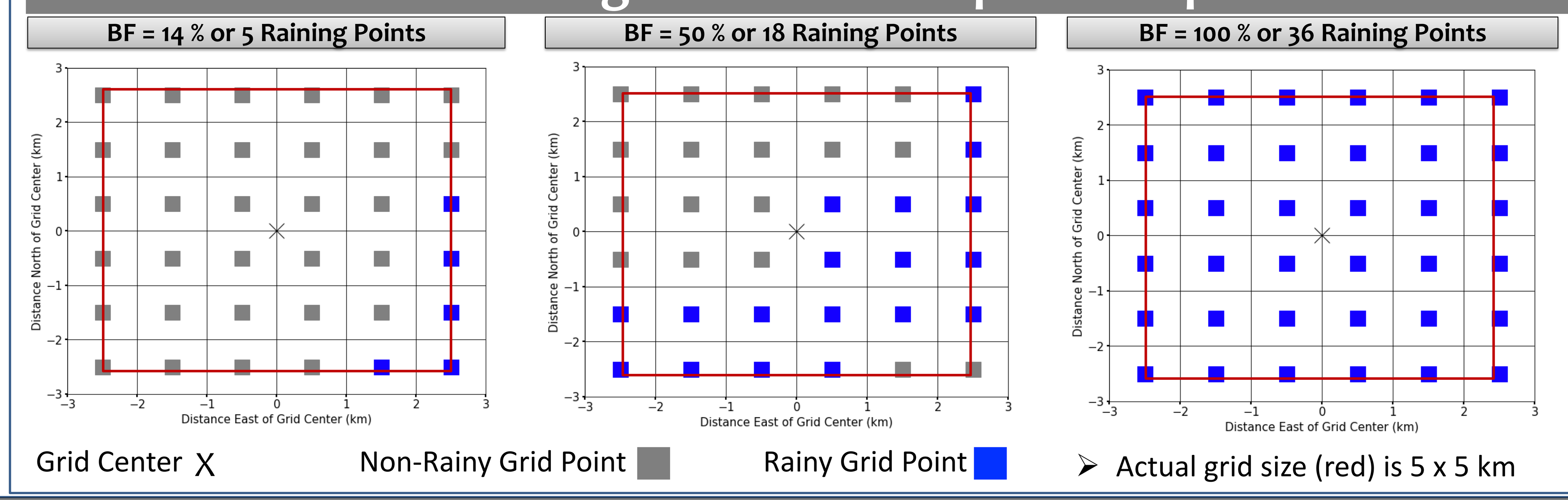
$$MAE = \frac{1}{n}\sum_{1}^{n}|Radar - Gauge|$$

$$NBias = \frac{1}{n}\sum_{1}^{n}\frac{Radar - Gauge}{Gauge}100\%$$

$$NRMSE = \frac{\sqrt{\frac{1}{n}\sum(Radar - Gauge)^2}}{Gauge}100\%$$

Analysis
- 2014-2018 March to October liquid rain events considered
- 6,410 multi-tilt PPI volumes analyzed
- Radar rates are extracted from 1.0 km vertical grid level (to avoid beam blockage and remain near the surface)
- Instantaneous gauge rates are averaged to 5-, 10-, and 15-minute and compared with radar derived snapshots
- 5th and 95th percentile difference between radar and gauge pairs filtered due to noise

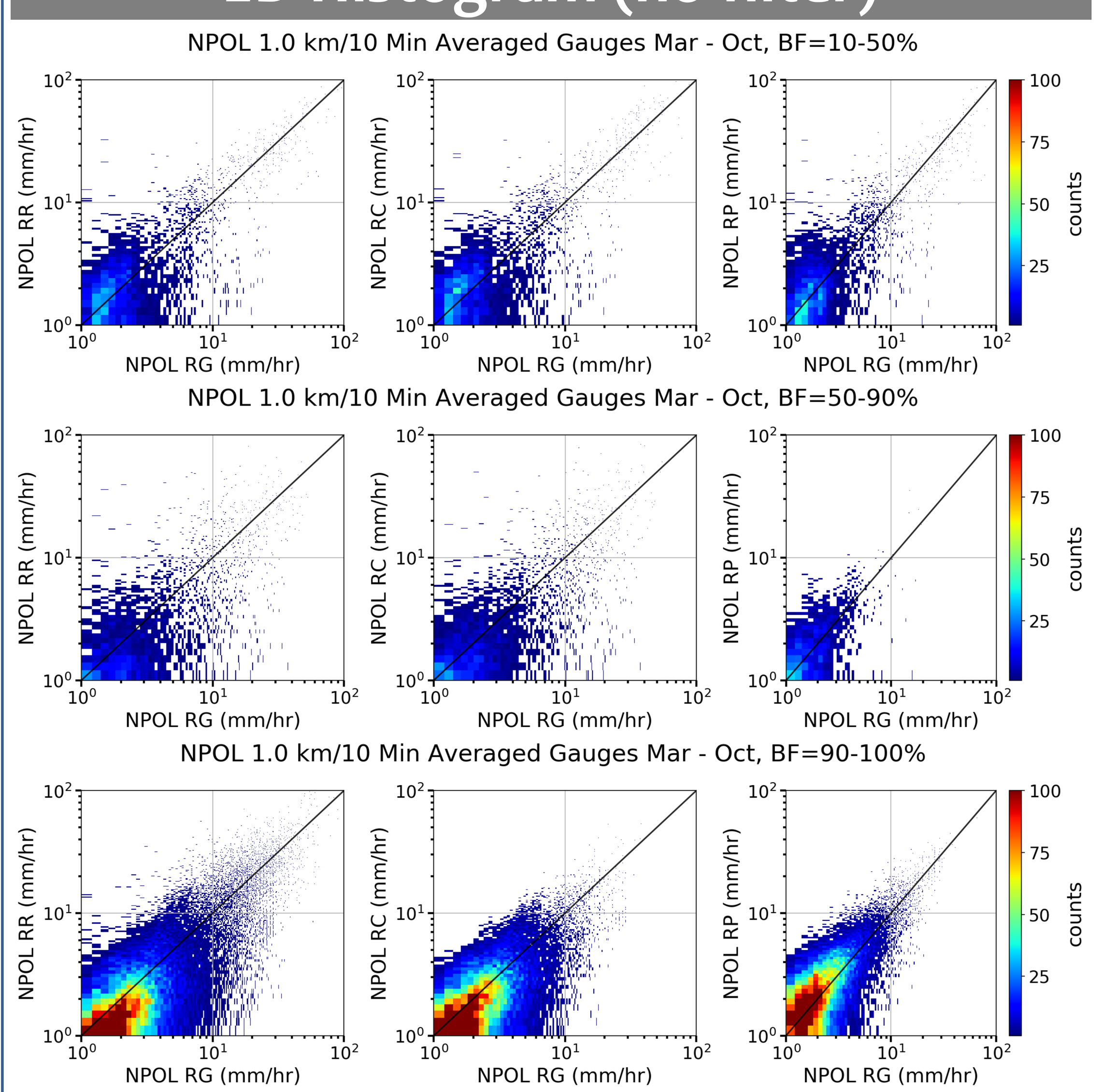
Beam Filing Threshold Simple Example



- Actual grid size (red) is 5 x 5 km

5. Results

2D Histogram (no filter)



- Rates are binned at 0.2 mm/hr
- 5 and 15 min gauge averaged comparisons showed similar trends

Statistics (no filter)

BF = [10-50)	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.95	**0.94**	0.91	-4.4	**0.53**	7.4	4.0	**4.2**	5.0	4924	3912	3206
RC	0.95	0.94	0.91	4.1	9.7	17.0	4.1	4.6	5.6	4924	3912	3206
RP	0.95	0.93	0.90	-2.4	2.3	9.1	3.9	4.3	5.2	4924	3912	3206

BF = [50-90)	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.77	0.75	0.71	-21.3	-17.8	-21.3	3.6	3.5	3.5	4539	3556	2971
RC	0.78	0.76	0.71	-7.8	-3.6	-7.8	3.8	3.7	3.7	4539	3556	2971
RP	0.78	**0.77**	0.74	-5.7	**-0.15**	-3.7	3.4	**3.2**	3.3	4539	3556	2971

BF >= 90	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.86	0.87	0.83	-14.6	-11.8	-10.0	3.3	3.1	3.4	33349	30619	28136
RC	0.85	0.84	0.81	0.44	4.2	6.4	3.6	3.6	4.0	33349	30619	28136
RP	0.88	**0.88**	0.84	1.6	**5.0**	7.2	2.9	**2.8**	3.1	33349	30619	28136

- RR performs best with BF < 50% while RP does better at high BF thresholds

Statistics (with filter)

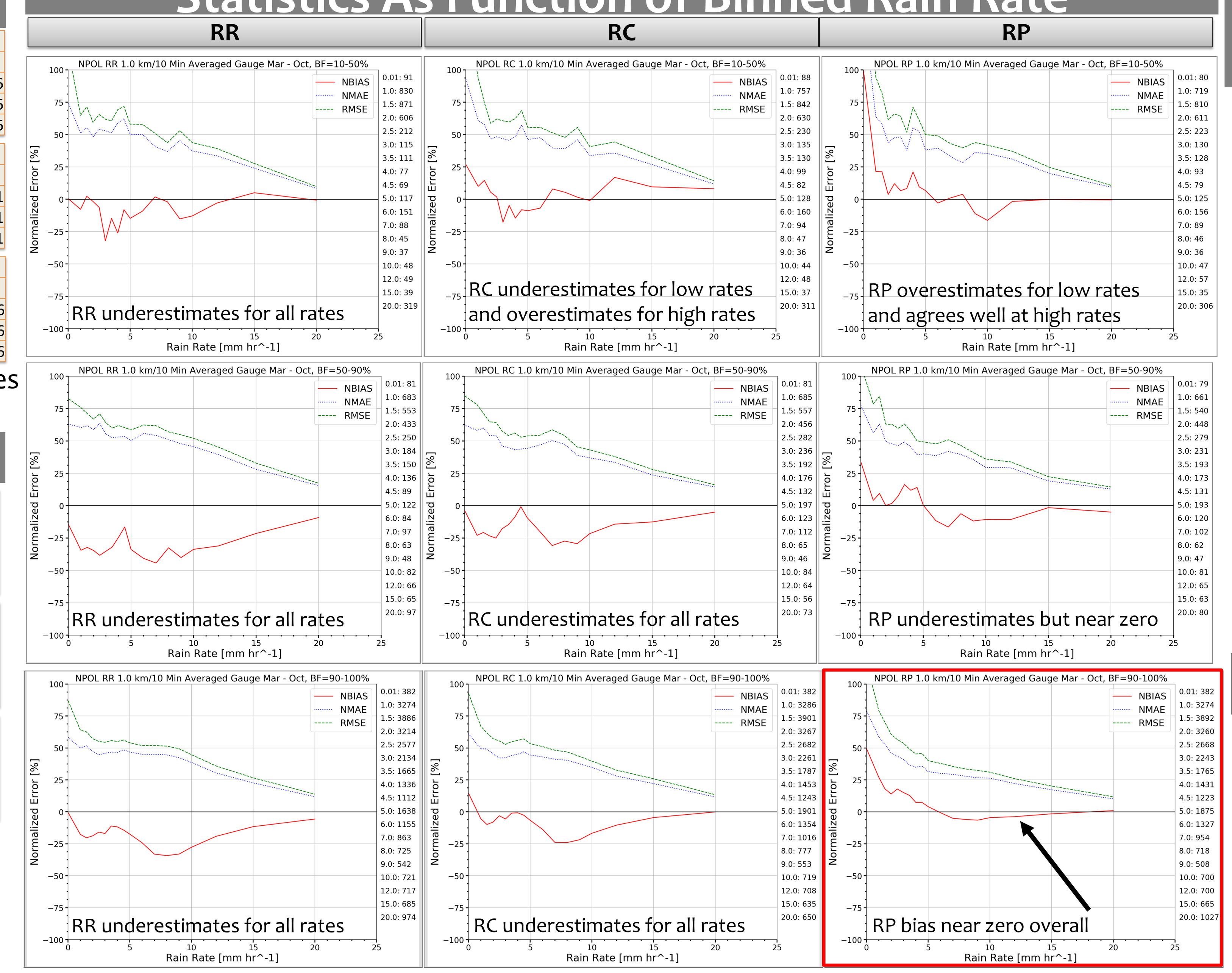
BF = [10-50)	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.99	0.99	0.98	-11.7	-3.0	5.7	1.9	1.7	1.9	4907	3875	3182
RC	0.99	0.99	0.98	-3.3	6.0	14.7	1.9	1.9	2.1	4961	3898	3170
RP	0.99	**0.99**	0.98	-5.8	**2.6**	12.1	1.8	**1.7**	1.8	4733	3770	3083

BF = [50-90)	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.92	0.92	0.90	-30.6	-27.7	-30.0	2.1	1.9	2.0	4201	3283	2734
RC	0.92	0.91	0.90	-19.7	-16.4	-16.9	1.9	1.7	1.7	4545	3617	3058
RP	0.92	**0.92**	0.90	-6.6	**-0.84**	-1.1	1.8	**1.6**	1.7	4441	3548	3013

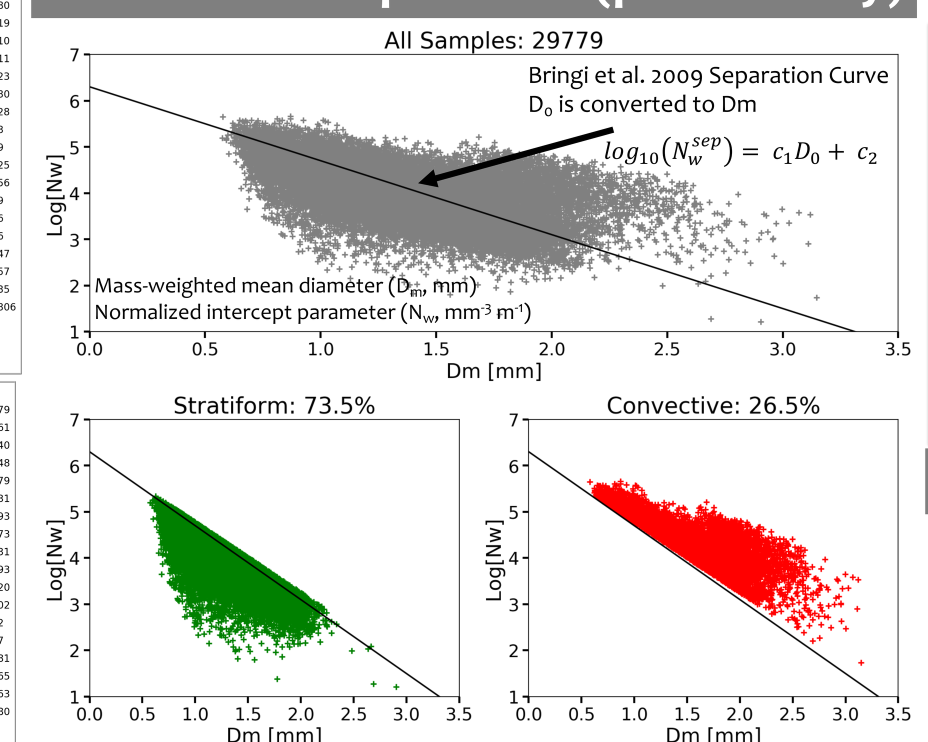
BF >= 90	Correlation 5 m	Correlation 10 m	Correlation 15 m	Bias [%] 5 m	Bias [%] 10 m	Bias [%] 15 m	MAE [mm/hr] 5 m	MAE [mm/hr] 10 m	MAE [mm/hr] 15 m	Samples 5 m	Samples 10 m	Samples 15 m
RR	0.94	0.94	0.92	-18.5	-16.8	-17.3	1.9	1.9	2.0	30039	27600	25302
RC	0.94	0.93	0.91	-9.2	-8.2	-9.3	1.8	1.8	1.9	31061	28575	26278
RP	0.95	**0.96**	0.93	2.7	**4.3**	4.7	1.6	**1.5**	1.6	31067	28612	26351

- Correlation increases with filtered results
- RP performs best regardless of BF threshold after removing 5th and 95th percentile difference between radar and gauge

Statistics As Function of Binned Rain Rate



NPOL DSD Stratiform and Convection Separation (preliminary)



Convective-Stratiform Classified NPOL Rates Vs 10 min averaged gauges		Correlation	Bias [%]	MAE[mm/hr]
All	RR	**0.90**	**-2.3**	3.4
All	RC	0.88	13.3	4.1
All	RP	0.90	5.6	3.2
Convective	RR	**0.86**	**4.0**	8.2
Convective	RC	0.83	24.0	10.8
Convective	RP	0.86	11.0	8.0
Stratiform	RR	0.56	-16.1	1.7
Stratiform	RC	0.55	-10.38	1.7
Stratiform	RP	**0.62**	**-6.5**	**1.5**

- NPOL DSDs computed using reflectivity and differential reflectivity measurements using Tokay et al. 2019 method
- Stats show high correlation and low positive bias for convective rain vs low correlation and high negative bias for stratiform
- The separation technique is questionable for several reasons:
  1. Default coefficients not adequate for all rain events
  2. Need to analyze single events rather than combined events

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6. Conclusions

- Overall stats show RP algorithm performs best against gauges in both bias and MAE with RC and RR second and third, respectively
- **Normalized bias error improves with better rain coverage over grid or as BF threshold increases**
- **Rain algorithms agree best with 10 min averaged gauges**
- **RR and RC algorithms underestimate** rainfall rate with **bias ranging from -5 to -25% low relative to gauges** for all rates regardless of BF threshold
- **RP performs best (bias < 5% at BF ~ 100%) against gauges for all rainfall rates**
- **RP outperforms RR and RC potentially due to coefficient used in algorithm evolves in space and time as DSD changes**
- RR agrees best with 10 min averaged gauges in convection while RP performs best in stratiform