Investigations on Vertical Variability of Precipitation using Micro Rain Radar and Disdrometer Measurements Collected During Ifloods Campaign

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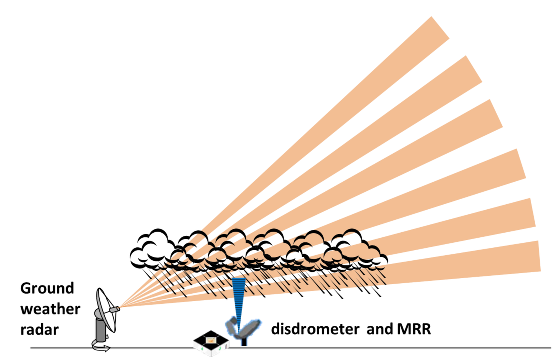
1. Motivation and Objective

Motivation

Spatial variability within GPM-DPR footprint in both horizontal and vertical direction causes Non-Uniform Beam Filling (NUBF) that is one of the key uncertainties in interpretation of DPR. Vertically pointing radars are useful to:

1) investigate the vertical variability of raindrop size distribution (DSD) and of bulk descriptors of rainfall.
2) fill the gap between the ground level and the first available elevation of scanning radar.



Research Objectives

1. Evaluate the agreement among DSD and integral rain parameters estimated by:
   - disdrometers (namely 2-D video disdrometer, 2DVD, and Autonomous OTT Parsivel2 Unit, APU)
   - vertically pointing radar (Micro rain radar, MRR)
   - S-Band Dual Polarimetric Doppler Radar scanning radar (NPOL)
2. Investigate the vertical variability of DSD and integral rainfall parameters within 1085 m above the ground in convective and stratiform rain by means of 35-m vertical resolution MRR vertical profiles.

GPM DPR algorithms assume the normalized gamma distribution defined as

$$N(D) = N_W\, f(\mu)\left(\frac{D}{D_{mass}}\right)^{\mu} \exp\left[-(4+\mu)\left(\frac{D}{D_{mass}}\right)\right]$$

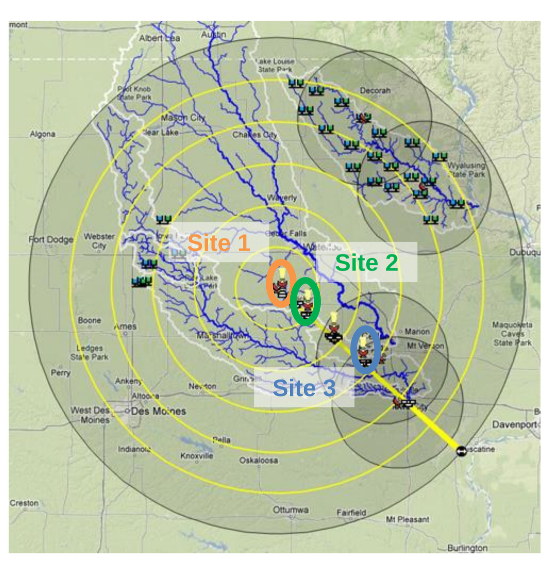
D_{mass} is the mass-weighted raindrop diameter; N_w is normalized intercept parameter; μ is the shape parameter (kept constant).

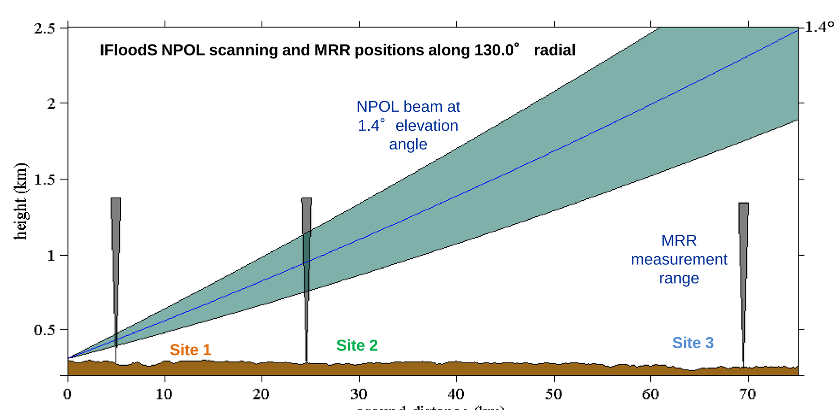
2. IFloodS DSD datasets

The Iowa Flood Studies (IFloodS) Field Experiment was conducted in Eastern Iowa from May 1 to June 15, 2013. DSDs were collected by:

i) 6 2DVDs
ii) 14 APUs
iii) 4 MRRs

MRRs were co-located with one 2DVD and one APU. Gate spacing was set to 35m to sample precipitation from 105m to ~1 km height. All sites were within NPOL coverage.



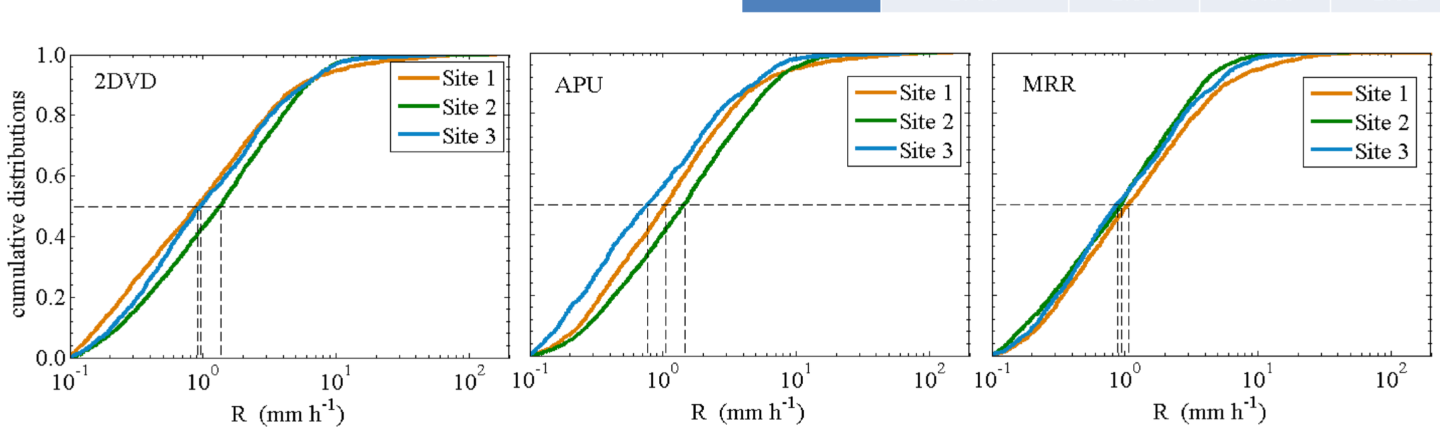


	latitude (deg)	Longitude (deg)	Distance from NPOL (km)	NPOL 1.4° beam height (m)
Site 1	42.239	-92.464	4.98	132
Site 2	42.126	-92.282	24.5	640
Site 3	41.861	-91.874	69.2	1971

***Volume sampling issues**: NPOL sample volumes at the three surface sites are 10^3 -10^5 times larger than the sampling volumes of MRR (from 372 m^3 @105m to ~ 40,000 m^3 at its higher gate) and 2DVD (~4 m^3). NPOL 1.4° elevation was chosen because free from clutter/blocking effect at all the three sites.*

MRR post-processing:
The method by Adirosi et al. (2016) was applied to MRR raw spectra to reduce uncertainty of MRR profiles and increase the reliability of MRR data in convection.

	# of rainy minutes	R (mm h^{-1}) 2DVD		R (mm h^{-1}) APU		R (mm h^{-1}) MRR@105m	
		mean	max	mean	max	mean	max
Site 1	2759	2.95	160.81	3.07	148.74	2.82	251.07
Site 2	4709	2.62	139.11	2.89	112.86	1.70	48.33
Site 3	1733	2.38	65.98	2.02	69.71	1.94	38.78



Cumulative distribution functions of rain rates obtained from 2DVD, APU and MRR data in the three different sites

3. Instrument performance

A quality check of disdrometer data was performed by comparing measurements using the following statistics

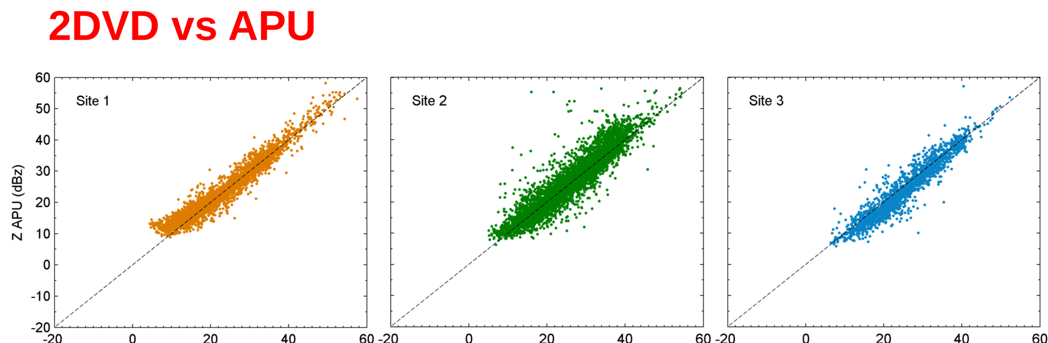
$$perc\_bias = \frac{\sum X_i - Y_i}{\sum X_i}; \quad perc\_abs\_bias = \frac{\sum |X_i - Y_i|}{\sum X_i}; \quad bias = \frac{\sum X_i - Y_i}{N}; \quad abs\_bias = \frac{\sum |X_i - Y_i|}{N};$$

where X_i is a measurement of the reference device and Y_i is the corresponding one of the other device.

2DVD vs APU

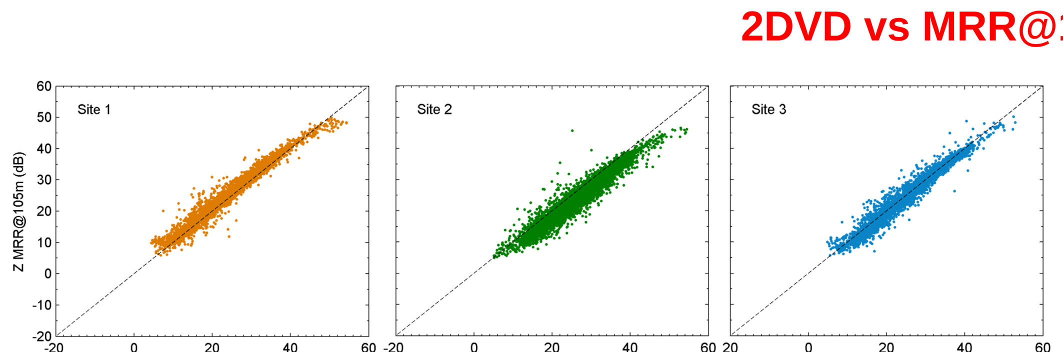
2DVD is the reference for the co-located APU.

- The bias for Z is less than 1 dB for sites 1 and 2 and negative, indicating that the APU slightly overestimates the reflectivity factor with respect to the 2DVD. The opposite is valid for site 3.
- The APU overestimation for Site 3 is confirmed also for the other considered measurements.
- A very good agreement is obtained for D_{mass}. Error is smaller than 0.2 mm that is roughly the size resolution of the 2DVD.



<	Z (dBz)		R		D_{mass} (mm)		$log_{10}(N_w)$	
	Bias<	abs. bias	%bias	abs. %bias	bias	abs. bias	bias	abs. bias
Site 1	-0.57	1.67	-3.0%	17.6%	-0.003	0.09	-0.04	0.13
Site 2	-0.57	2.24	-8.9%	28.8%	-0.024	0.16	-0.05	0.18
Site 3	1.17	2.25	15.8%	27.3%	0.017	0.09	0.04	0.16

2DVD vs MRR@105m



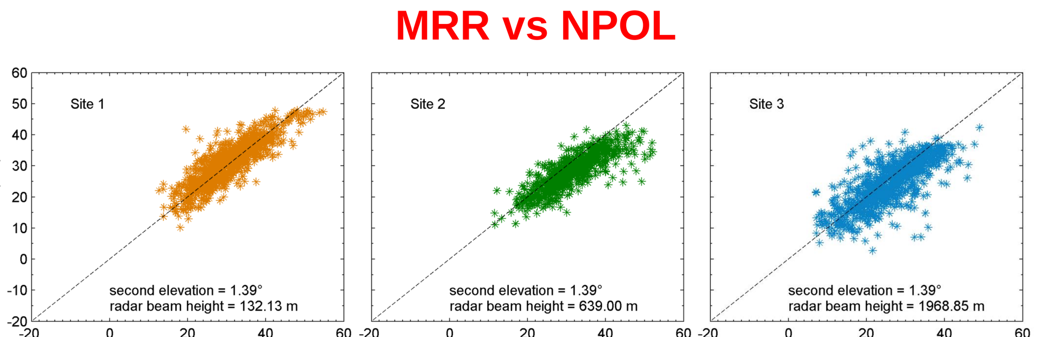
	Z (dBz)		R		D_{mass} (mm)		$log_{10}(N_w)$	
	bias	abs. bias	%bias	abs. %bias	bias	abs. bias	bias	abs. bias
Site 1	-1.07	1.59	-32.5%	46.8%	0.19	0.20	-0.55	0.56
Site 2	2.49	2.76	35.9%	42.0%	0.19	0.20	-0.17	0.33
Site 3	0.38	1.44	-6.5%	30.2%	0.18	0.19	-0.36	0.39

2DVD is the reference for the MRR measurements at 105m AGL.

- The comparison between the 6[th] moment of the DSD (i.e. the reflectivity factor under Rayleigh-Gans scattering assumption) obtained is good for Site 1 and 3.
- The MRR at Site 2 underestimates reflectivity factor with respect to the 2DVD.
- Underestimation at Site 2 MRR is evident also for the rain rate.
- In general, comparing 2DVD and MRR data Site 3 seems to perform the best.

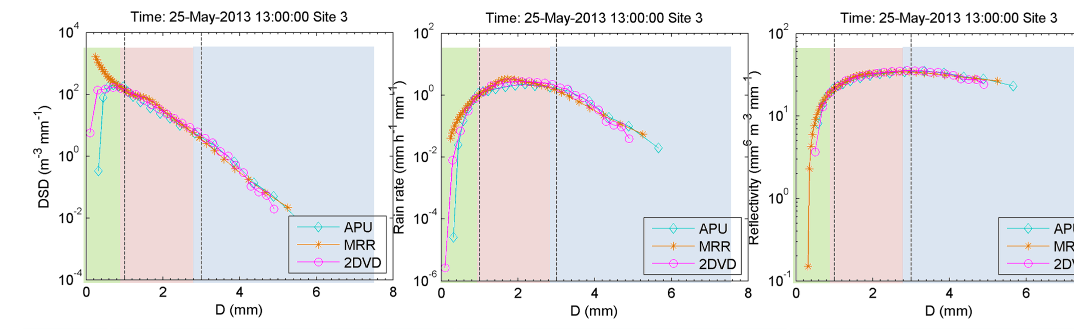
MRR vs NPOL

MRR reflectivity was resampled onto the NPOL sample volumes using a Gaussian shape beam weighting function.



	Z (dBz)	
	bias	abs. bias
Site 1	-1.07	1.59
Site 2	2.49	2.76
Site 3	0.38	1.44

4. Raindrop Size Distributions



	N_c (# m^{-3})				R (mm h^{-1})				Z (dBz)			
	small D	medium D	large D	all D	small D	medium D	large D	all D	small D	medium D	large D	all D
2DVD	123.53	85.24	2.00	210.8	0.24	4.70	1.27	6.20	13.26	35.67	35.40	38.56
APU	104.89	66.43	1.58	172.9	0.31	3.81	1.17	5.29	14.85	35.01	35.76	38.43
MRR	325.84	88.79	1.28	415.9	0.33	4.78	0.87	5.98	14.49	35.47	34.14	37.89

Small D → D < 1mm | Medium D → 1mm < D < 3 mm | Large D → D > 3 mm

- The agreement among 2DVD, APU, and MRR is very good for the 1-hour DSDs for medium and large diameters.
- For small drops the trends of MRR DSDs are different with respect to the other two instruments showing an upwards concavity in contrast with the downwards concavity of the 2DVD and APU DSDs.
- The effect of the MRR overestimation of small drops is evaluated in term of rain rate (second panel) and reflectivity factor (third panel)

5. Vertical Variability from MRR data

A **three-parameter exponential function** is adopted :

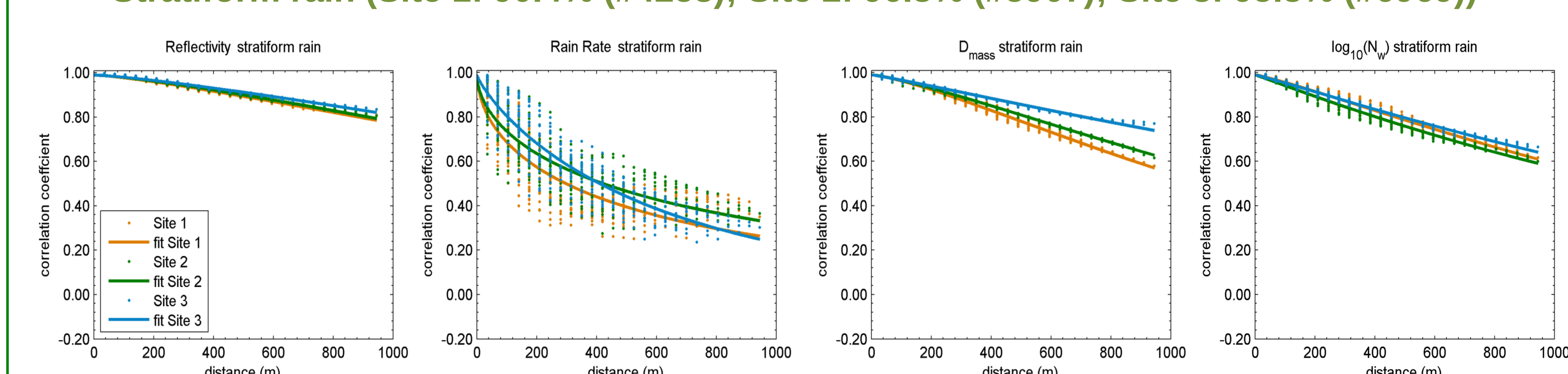
$$r(d) = r_0 \, exp\left[-\left(\frac{d}{d_0}\right)^{s_0}\right]$$

r_0 is the nugget parameter (set to 0.99), s_0 is the shape parameter, d_0 is the correlation distance, and d is the distance between paired of MRR observations .

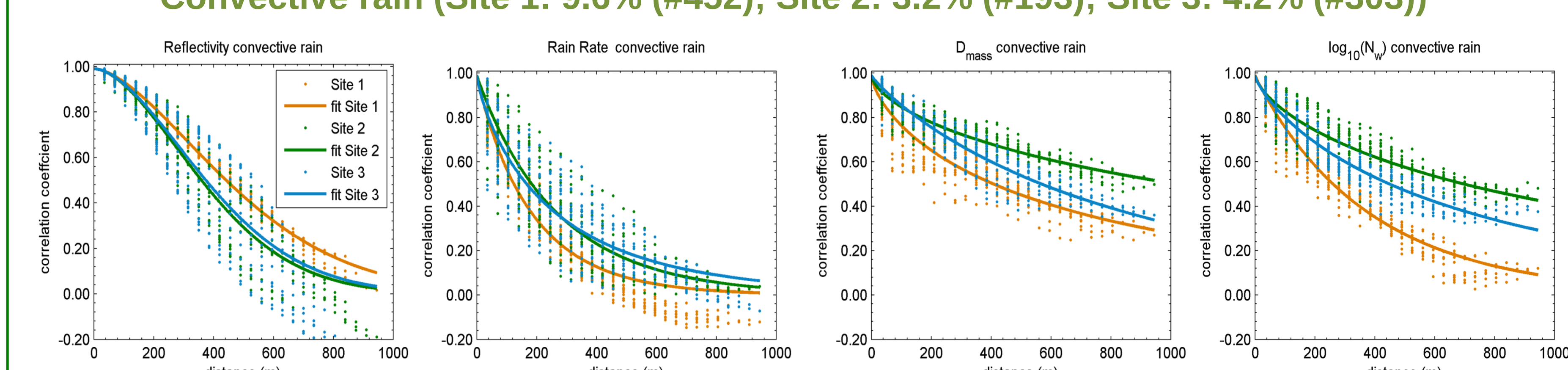
- The Pearson **correlation coefficient *r*** is calculated between the **paired MRR observations at distance *d*** (i.e. the measurement obtained by MRR at a certain height is compared with the measurement at each MRR bin above the given one). Minimum distance is 35 m, maximum is 945 m.
- Considering all the possible combinations, in total for each site we obtain 378 pairs of MRR observations.
- d_0 and s_0 are calculated by a **fitting** procedure minimizing the root-mean square error between the observation and equation based correlations
- two **different conditions** are considered: **Convective** and **Stratiform** rain. The C/S algorithm of Thurai et al. (2010) has been applied to MRR@105m to classify the rainy minutes.

1. Computation of the correlation coefficients

Stratiform rain (Site 1: 90.4% (#4253); Site 2: 96.8% (#5907); Site 3: 95.8% (#6969))



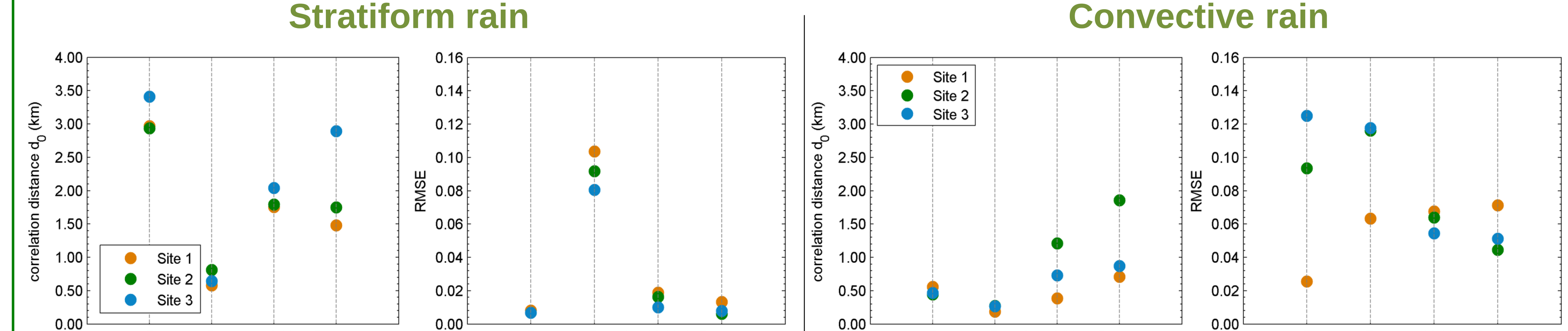
Convective rain (Site 1: 9.6% (#452); Site 2: 3.2% (#193); Site 3: 4.2% (#303))



- The correlations of all the considered parameters during stratiform rain are higher than during convective rain.
- The range of variability of the correlations for a given distance is wider for convective rain that for stratiform rain.
- In most of the cases, the exponential fit of the correlations in the three sites are in very good agreement.
- The correlation values during convectton decrease dramatically with d, reaching negative values in some cases.

2. Fitting results

Stratiform rain | **Convective rain**



- RMSE (Root Mean Square Error) represents the goodness of the fitting, smaller is the values and higher is the performance of the fitting.
- d_0 is the correlation distance that represents the maximum distance within the given variable can be considered statistically uniform.
- As expected, for a given variable the correlation distance during convective rain is smaller that during stratiform rain, indicating an higher spatial variability of the considered parameters along the vertical during convection. The decrease is particularly evident for the reflectivity factor.
- The highest correlation distances have been obtained for Z (in dB) during stratiform rain (values around 3 km) while the lowest one have been obtained for R during both convective (values around 0.3 km) and stratiform rain (values around 0.5 km).
- As far as the authors have been able to ascertain, the three-parameter exponential function has been applied for the first time in this study to investigate the vertical variability of a number of DSD and rain parameters obtained from MRR DSDs each 1 minute at different heights. Therefore, there is no direct comparison available for these parameters of exponential function with any other previous studies.

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