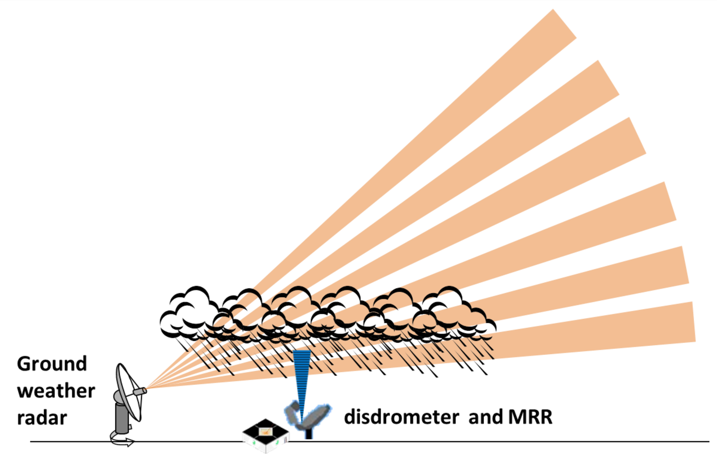
Vertical Variability of Rain Drop Size Distribution

Elisa Adirosi and Luca Baldini (*Institute of Atmospheric Sciences and Climate, CNR, Rome, Italy*)
Ali Tokay (*Joint Center for Earth Systems Technology, UMBC, Baltimore, Maryland / NASA-GSFC, Greenbelt, Maryland*)

1. Motivation and Objective

Disdrometers provide point measurements of the rainDrop Size Distribution (DSD) at the ground, while Micro Rain Radar (MRR) is a vertically pointing K-band ground radar that measures power spectra from which DSD can be retrieved at different heights. The **objectives** of the present study are:

1. to determine measurement uncertainties between scanning radar and in-situ data
2. to quantify the vertical variability of DSD and integral rain parameters.

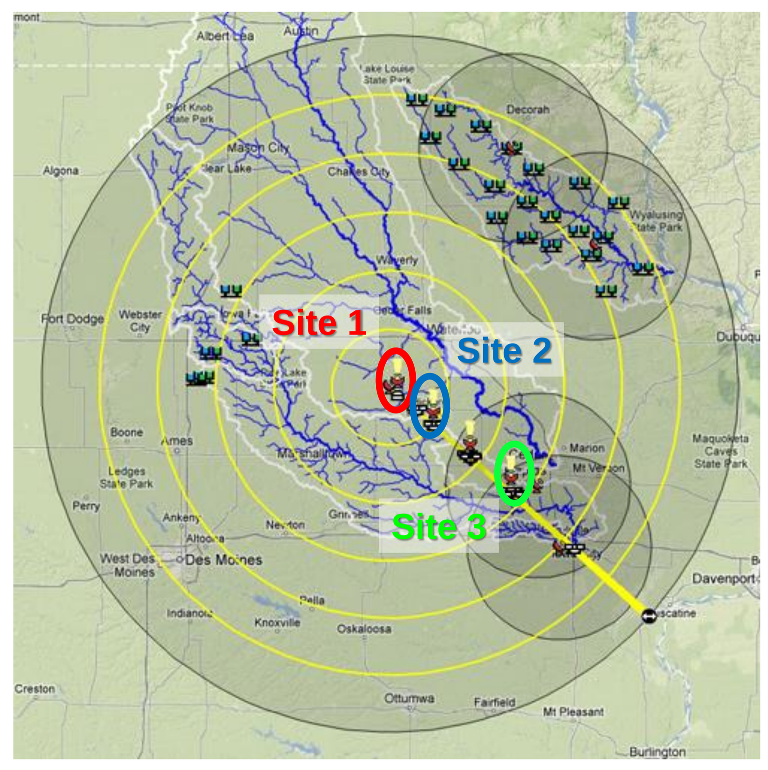


MRR is a unique toll which **fill the gap** between ground and the first available radar elevation. Furthermore, one of the main uncertainties of Global Precipitation Measurement (GPM) mission Dual frequency Precipitation Radar (DPR) is the non-uniform beam filling, which requires the knowledge on DSD variability in both horizontal an vertical directions.

2. Site and Instrumentation

GPM Ground Validation Iowa Flood Studies (IFloodS) Field Experiment was conducted in Eastern Iowa from May 1 to June 15, 2013. During IFloodS, DSD data were collected with six 2D video disdrometers (2DVD), fourteen Autonomous OTT Parsivel[2] Units (APU) and four MRR profilers. All MRR units were co-located with one 2DVD and one APU. All sites were within S-Band Dual Polarimetric Doppler Radar (NPOL) coverage area. One of the MRR unit failed to operated during the experiment. MRRs were set to 35 gate spacing mode which samples the precipitation from 105 m to approximately 1 km height.

	latitude (deg)	Longitude (deg)	distance (km)	First elevation height (m)
Site 1	42.239	-92.464	4.98	70
Site 2	42.126	-92.282	24.5	332
Site 3	41.861	-91.874	69.2	1100



3. Rainfall Parameters

Knowing the DSD (N(D)) each 1 minute, either from 2DVD, APU or MRR data, the following rainfall parameters can be obtained: Reflectivity factor (Z in dBz), Rain rate (R in mm h^{-1}), mean mass-weighted raindrop diameter (D_{mass}), normalized intercept parameter (N_w in $mm^{-1}\,m^{-3}$) and gamma shape parameter (μ).

$$Z = 10\log_{10}\left(\sum_{D_{min}}^{D_{max}} N(D)D^6 dD\right); \qquad R = 6\pi 10^{-4}\sum_{D_{min}}^{D_{max}} N(D)D^3 v(D)dD; \qquad D_{mass} = \frac{\sum_{D_{min}}^{D_{max}} N(D)D^4 dD}{\sum_{D_{min}}^{D_{max}} N(D)D^3 dD}$$

$$N_w = \frac{256}{\pi\rho_w}\frac{LWC}{D_{mass}^4}; \qquad LWC = \frac{\pi 10^{-3}}{6}\sum_{D_{min}}^{D_{max}} N(D)D^3 dD$$

where v(D) in the drop terminal fall velocity. The shape parameter can be computed minimizing the difference between the rain rate obtained from measured DSD and from the normalized gamma distribution given by

$$N(D) = N_w f_2(\mu)\left(\frac{D}{D_{mass}}\right)^{\mu}\exp\left[-(4+\mu)\frac{D}{D_{mass}}\right]; \qquad f_2(\mu) = \frac{6}{256}\frac{(4+\mu)^{\mu+4}}{\Gamma(\mu+4)}$$

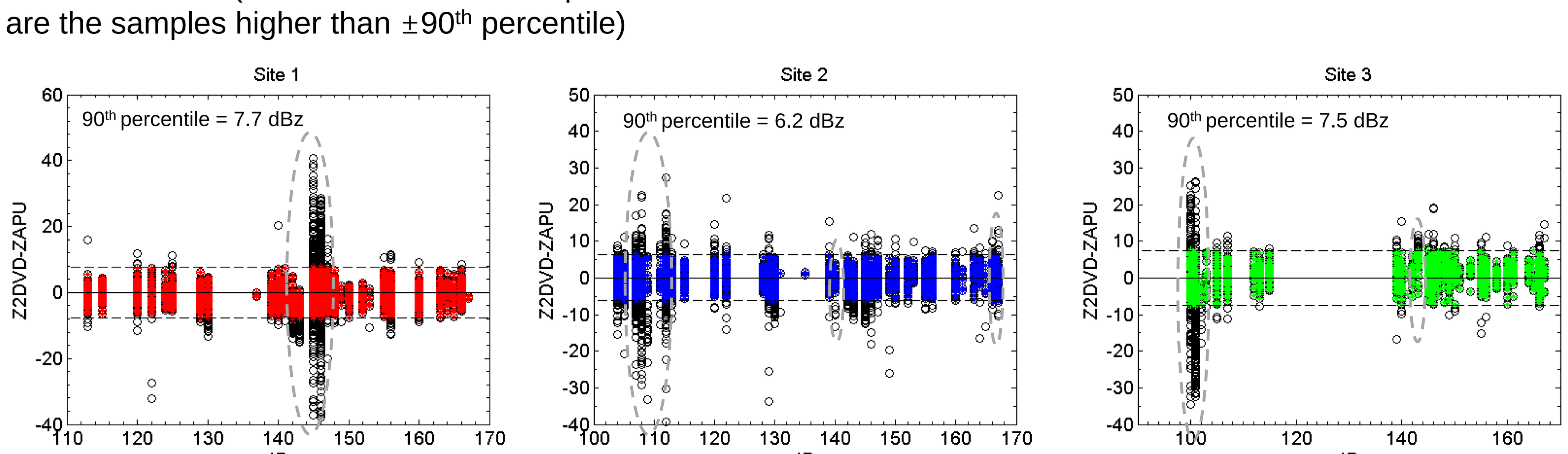
In order to evaluate the performance of disdrometers and MRR the following statistics have been used:

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

where X_i is a given rainfall od DSD parameter of the reference device and Y_i is the corresponding parameter of the other device.

4. APU vs 2DVD

Before comparing MRR based rainfall and DSD parameters with the ones of 2DVD a quality check of the 2DVD data has been done comparing each 2DVD with the co-located APU. The following plots shown for each site and for each days of the field campaign the difference between reflectivity computed from 1-min DSD collected by 2DVD and APU (dashed lines are ±90th percentile of the absolute differences between the two Z and black circles are the samples higher than ±90th percentile)



All dataset

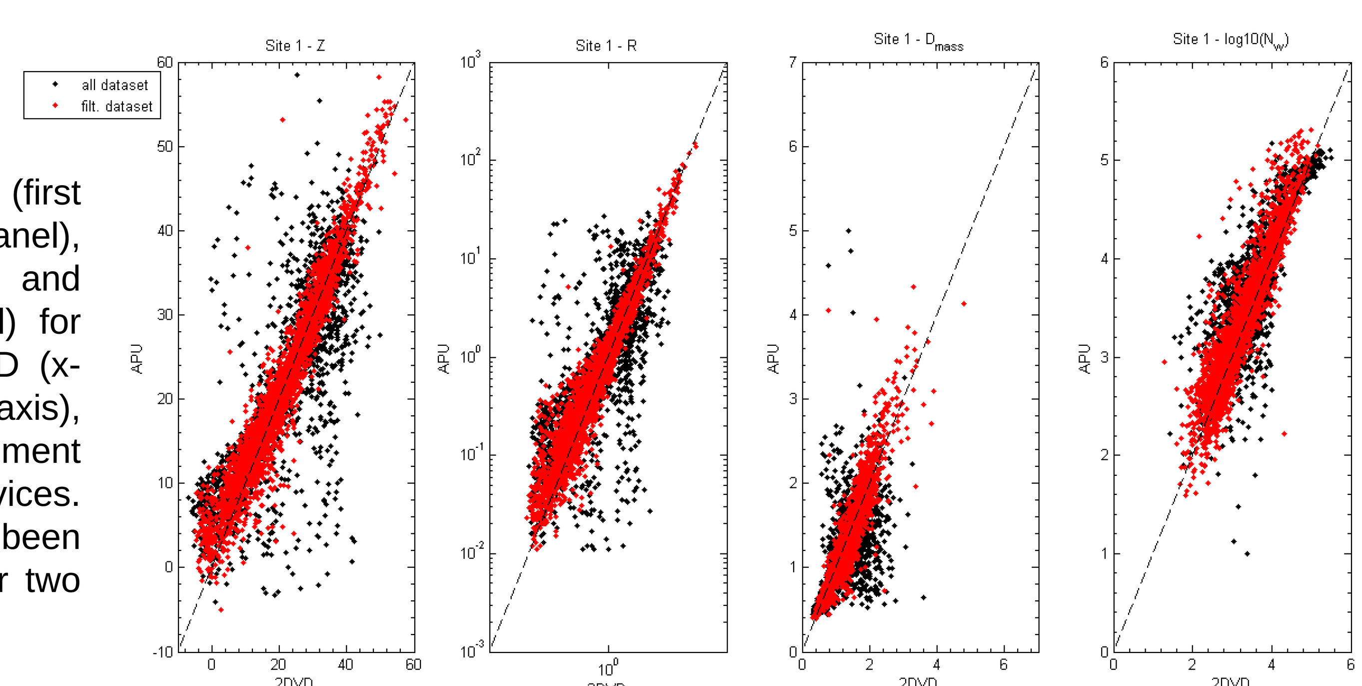
	Z (dBz)		R (mm h^{-1})		D_{mass} (mm)		$\log_{10}(N_w)$ ($mm^{-1}\,m^{-3}$)	
	bias	abs. bias	perc. bias	abs. perc. bias	bias	abs. bias	bias	abs. bias
Site 1	-0.89	3.40	-2.77%	35.6%	0.027	0.17	-0.11	0.22
Site 2	-0.79	2.79	-8.90%	29.7%	-0.012	10.7	-0.10	0.23
Site 3	1.26	3.63	16.12%	36.1%	-0.009	10.3	0.08	0.25

Filterd dataset

	Z (dBz)		R (mm h^{-1})		D_{mass} (mm)		$\log_{10}(N_w)$ ($mm^{-1}\,m^{-3}$)	
	Bias	abs. bias	perc. bias	abs. perc. bias	bias	abs. bias	bias	abs. bias
Site 1	-0.67	2.14	-2.83%	18.0%	0.0075	0.11	-0.093	0.18
Site 2	-0.61	2.44	-5.81%	26.1%	0.0040	0.15	-0.102	0.21
Site 3	1.11	2.38	15.65%	28.0%	0.0317	0.13	0.003	0.17

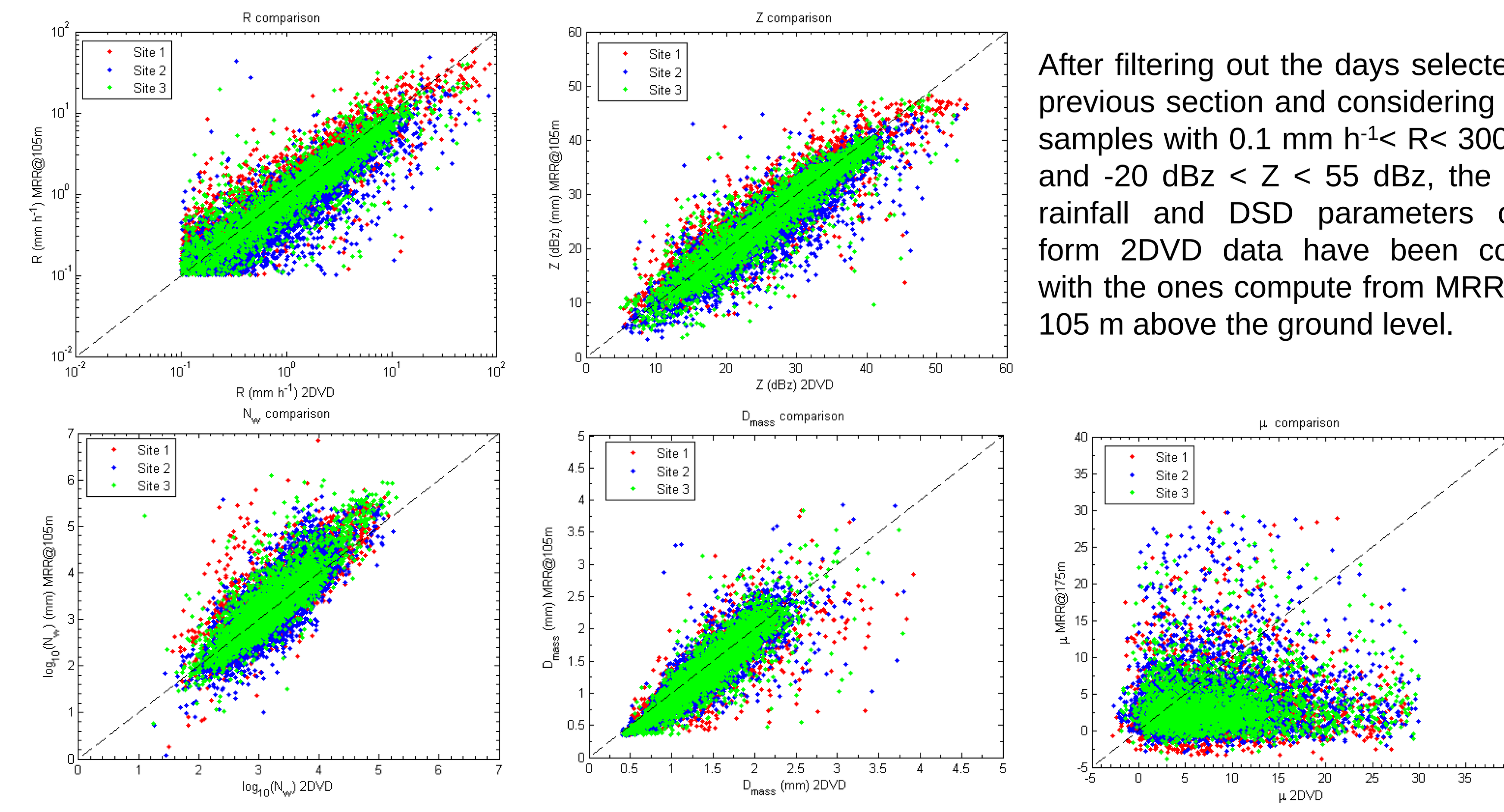
Filter criterion: we filtered out the days that have more than 20% of the samples above the ±90th percentile.

Following this criterion the 9.5% (441 1-min DSD), 4.4% (285 1-min DSD) and 9.1% (239 1-min DSD) has been discarded for Site 1, Site 2 and Site 3, respectively.



Scatterplots of Z (first panel), R (second panel), D_{mass} (third panel) and $\log_{10}(N_w)$ (forth panel) for Site 1 between 2DVD (x-axis) and APU (y-axis), shown a good agreement between the two devices. Similar results has been obtained for the other two sites (not shown).

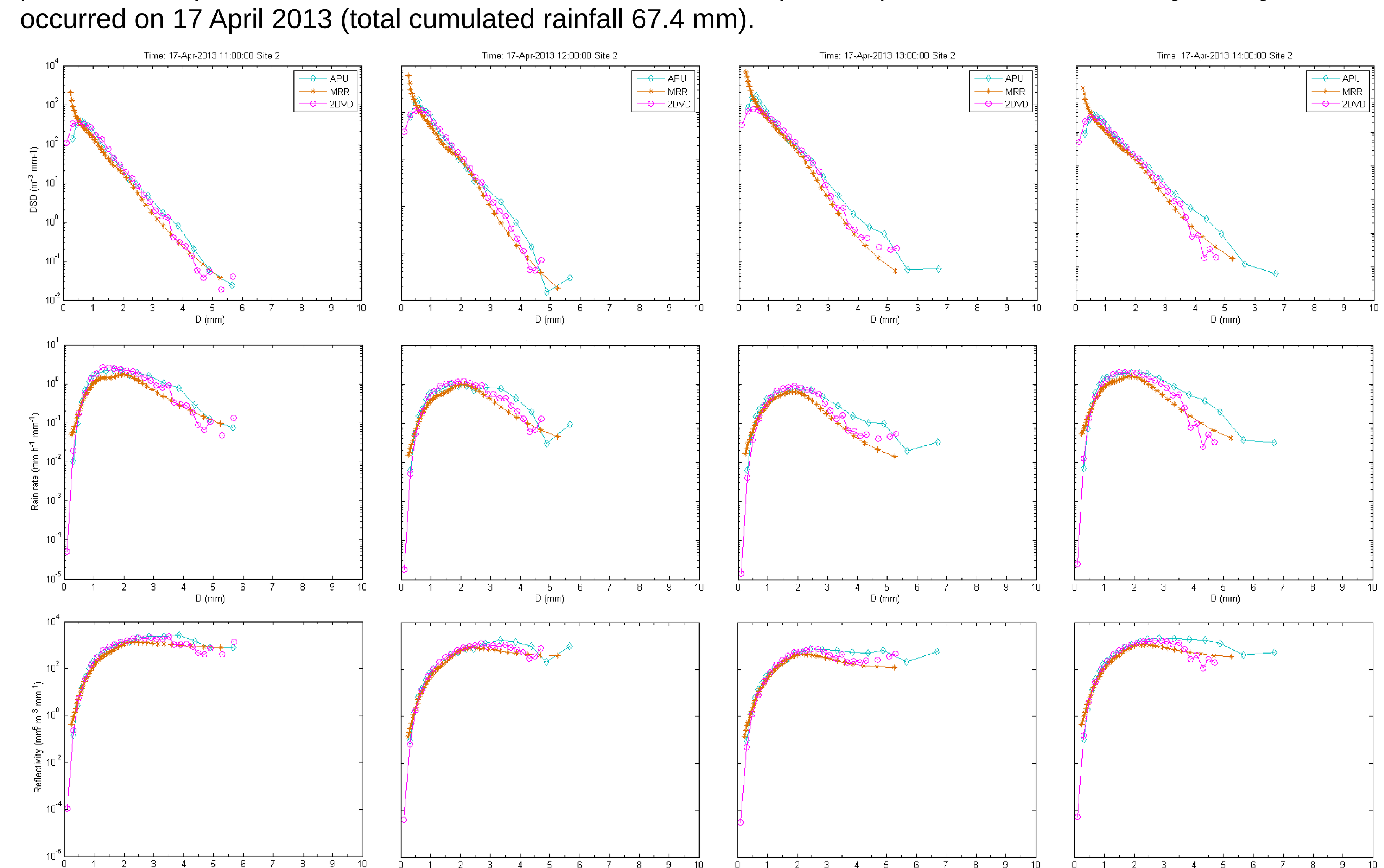
5. MRR @105m vs 2DVD



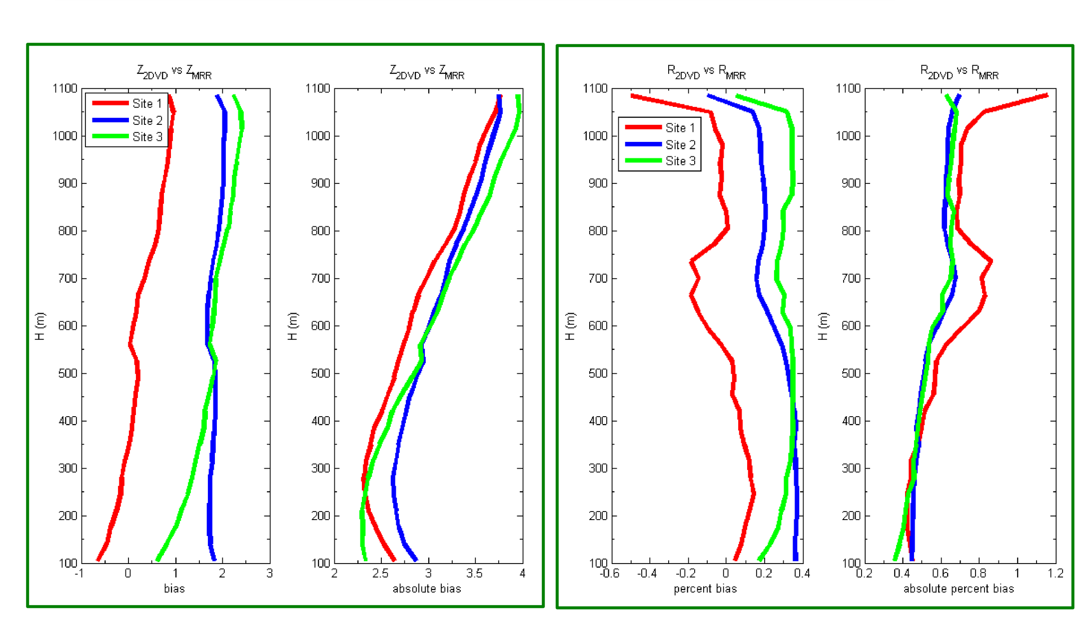
After filtering out the days selected in the previous section and considering only the samples with 0.1 mm h^{-1}< R< 300 mm h^{-1} and -20 dBz < Z < 55 dBz, the different rainfall and DSD parameters obtained form 2DVD data have been compared with the ones compute from MRR DSD at 105 m above the ground level.

	Z (dBz)		R (mm h^{-1})		D_{mass} (mm)		$\log_{10}(N_w)$ ($mm^{-1}\,m^{-3}$)		μ		
	Bias	abs. bias	perc. bias	abs. perc. bias	bias	abs. bias	bias	abs. bias	perc. bias	abs. perc. bias	% out range
Site 1	-0.65	2.64	5%	45%	0.06	0.19	-0.20	0.33	58.1%	78.3%	28.0%
Site 2	1.84	2.87	36%	45%	0.07	0.19	0.002	0.32	49.3%	75.4%	10.2%
Site 3	0.61	2.34	17%	36%	0.07	0.18	-0.12	0.29	55.9%	74.4%	16.9

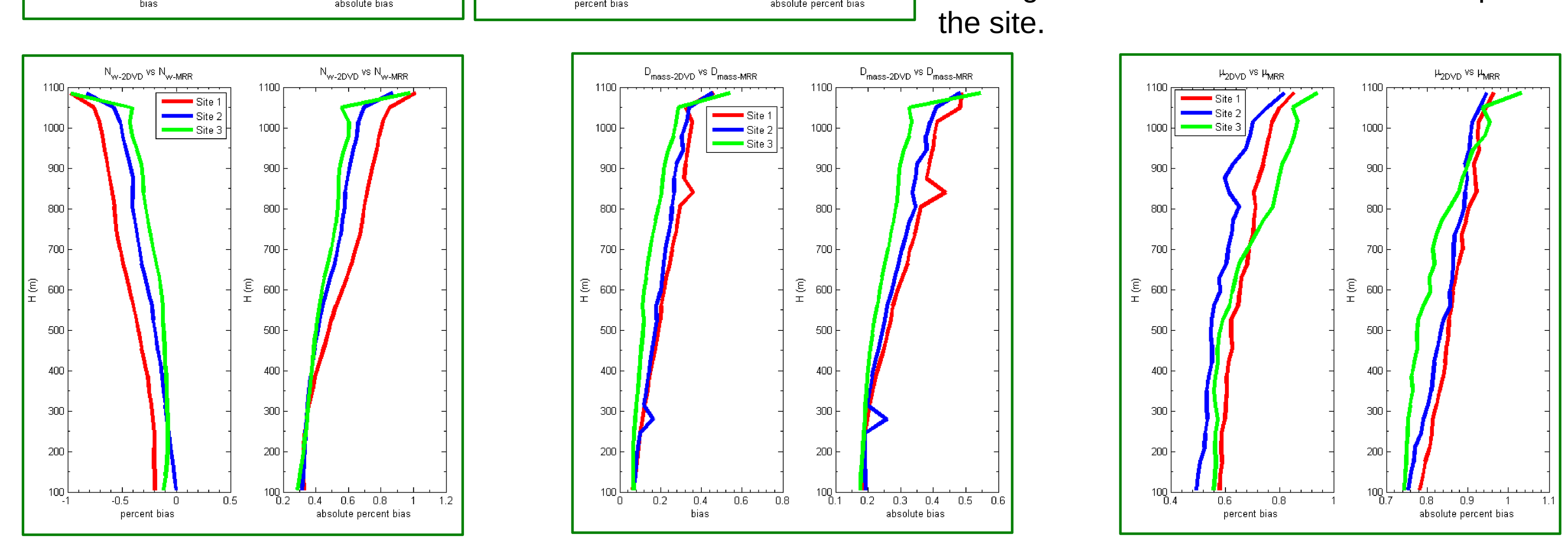
Although some dispersion, the scatterplot of Z, R, D_{mass} and $\log_{10}(N_w)$ show a fairly good agreement between the MRR and 2DVD parameters, the absolute bias for the reflectivity factor is between 2.3 dBz and 2.9 dBz considering all the sites. While the error on the rainfall rate is between 36% and 45%. A very good agreement is obtained for the D_{mass} with and error less than 0.2 mm that is roughly the minimum detectable drop diameter for both the devices. Site 3 seems to perform the best, the latter can be due to instrumental aspects but can be also related to the type of precipitation (such as convective or stratiform) that occurred on the site.
However, the scatterplot of the retrieved shape parameter of the gamma distribution shows an high underestimation of the μ parameter retrieved from the MRR data. Furthermore, there is a percentage of spectra (last column of the table) that do not yield a solution. The disagreement in the retrieved values of μ can be due to the fact that the MRR detects an higher number of small drops with respect to the 2DVD as shown in following plots that compare the 1-hour DSD of MRR, 2DVD and APU (first row) for four hours of a long lasting rain event occurred on 17 April 2013 (total cumulated rainfall 67.4 mm).



6. Vertical Variability



The plots shown the vertical variability of the statistics of the five considered rainfall and DSD parameters. Bias, absolute bias, percent bias and absolute percent bias have been computed between the 2DVD and the MRR measurements at different heights.
As expected, the overall trend indicates that the error increases with the height. The absolute bias of the reflectivity increases of 1.1 dBz, 0.9 dBz and 1.8 dBz in about 1 km for Site 1, Site 2 and Site 3, respectively, while for the rain rate the increase of the absolute percent bias between 105 m and 1050 m ranges between 21% and 37% depending on the site.



7. Future research

- ❑ Evaluate the role of small, medium and large drops on the computation of integral parameters from MRR DSD and 2DVD DSD
- ❑ Investigate the vertical variability of rainfall and DSD parameters within the MRR bins in order to provide some insight on the variability of the rainfall microphysical characteristics within 1 km above the ground
- ❑ Compare MRR based rainfall parameters with the one obtained from NPOL data at the two lower elevations

Acknowledgments: Elisa Adirosi thanks Prof. Ali Tokay and Dr. Luca Baldini of Institute of Atmospheric Sciences and Climate, National Research Council (Rome, Italy) for allowing my 1-months research visit at NASA Goddard Space Flight Center, and for their scientific contributions to this research.