Comment on: Binning effects on in-situ raindrop size distribution measurement

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Abstract
This document contains the replies to the referees of the paper, *Binning effects on in-situ raindrop size distribution measurement*. The main concern about the manuscript on both authors is related with the presence of measurement errors, then additional information and results including this error source is included. Specific questions are analyzed concisely but a more supporting material is available for discussion, if required.

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Contents

1. Response to Referee 1

This section is organized as follows: first sub-section contains a brief general response to explain the orientation (and limitations) of this study as suggested by the referee. The second sub-section is related to the English corrections. The last section respond to specific comments of the Referee 1.

1.1 General overview of the paper and limitations of the study

This paper analyzes the effect of discretization (together with truncation) of raindrop size distribution measurements. The effects are present, and shown across the manuscript. The quantification for each instrument is challenging because it depends on properties of the drop-size distribution (DSD) itself. Given the large variability of the experimental DSDs any numerical value (to characterize a bias due to binning, for instance) is conditioned by the dataset used or constrained by DSD models assumptions. I agree with the referee that for a specific measurement, a sample, we could not differentiate binning effects from sampling. This is because each measurement resulting on an stochastic generated subset of drops could produce values of rainfall parameters (or DSD parameters of a distribution model) quite different from the underlying population of drop sizes. However, specific methods and instruments are more likely to produce a positive or negative bias, and it could be asserted by analyzing a large number of samples and therefore analyzing their *sampling distribution*. This sampling distribution is shown for different disdrometers, rain conditions, and DSD parameters.

In this situation, by comparing the bias produced only by sampling (including all the sampled drops and actual sizes) with a situation with additional errors, we could differentiate sampling bias from truncation and binning. This is easy for an a priori distribution because we know analytically the rainfall parameters (usually directly derived from the moments) and we know the DSD parameters values. This fact constrains and motivates the methodology exposed on the paper. In the first part of the paper the selection of the underlying distribution was a gamma distribution. While in the second part of the paper, with the limitations of the dataset available I performed a study with measured drop-sizes samples. Under the hypothesis that the 2DVD captured sample is representative of the actual DSD a study of sampling uncertainty was carried on, in order to achieve this hypothesis only samples with at least 100 drops were considered (with the underlying hypothesis that the size measured by different instrument is the same, which is necessary to assert only truncation and binning effects).

Concerning truncation, most of previous studies recognized the truncation effects, but in the knowledge of the author there is not a previous consistent study comparing them for a broad set of instruments. In order to differentiate binning effects from truncation effects two artificial instruments called R-Trunc and L-Trunc were introduced (also see section 3 of this document). Given that one of the goals of the paper is to present a comparison of the performance of actual devices it is not possible to neglect truncation properties of instruments. Technically, the title of the paper could be "Truncation and binning effects". But given that other authors analyzed before the truncation, this paper is focused on evaluating the binning to recognize other authors studies. I agree with the referee that truncation is more relevant than typical binning on the estimation of DSD parameters but discretization of large drop sizes has an effect on the large order moments. Additional studies concerning left and right truncation vs bins width has been done as a complement and supporting material for this paper, some results are shown on section 3 of this manuscript.

1.2 English language

I would like to thank to the referee for the list of English issues of the paper. For non-native English speaker, like in my case, this is an important challenge. I wrote all this paper and no other authors were involved in preparation of this manuscript, therefore that is my responsibility. Concerning the editing stage, I had previously submitted a draft to a editing service, while some mistakes where corrected also by Dr. Ali Tokay. But I would submit to a English grammar check service if necessary. Thanks for the tips.

1.3 Specific questions

1. Precipitation is a key element, or phenomena, of the energy cycle (and quite obviously of the water cycle). Technically satellite missions like TRMM or GPM are also interested on evaluate the latent heat involved in the processes of condensation of water vapor on drops as part of the energy balance of the atmospheric processes. Rainfall will be replaced by rainfall intensity and the paragraph restructured to avoid confusion about the meaning of 'element of energy and water cycles'. Thank you for the comment.

2. The diameter of drops is defined by the sphere with the same volume of the actual drop, which often is called *equivolumetric diameter*. I agree with the referee that the asymmetry of the drops is relevant (for medium to large drops). In the case of 2DVD measurements the asymmetry is measured and the equivolumetric diameter faithfully calculated. *I am not using other empirical disdrometer data than 2DVD measurements*. However for other disdrometers some pre-processing techniques may be applied (please see, the reference with the link to the Dr. Checa-Garcia PhD Thesis Dissertation [1] there are much more details about this question, information about the best methodologies of pre-processing was provided by Dr. Ali Tokay).

3. Thank you for the reference of *Jaffrain and Berne*, it would be included on the references and their work recognized. By the way, several studies of sampling rely on the comparison of collocated disdrometers, for example two Parsivel OTT disdrometers. In this case the differences are attributed to the sampling, under the hypothesis of identical instruments. On the other hand on the second part of this paper a novel and different approach is proposed, by using the measurements of a 2DVD disdrometer and a resampling technique. The collecting area of a 2DVD disdrometer is twice the collecting area of a Parsivel OTT therefore an study with a 2DVD disdrometer includes, in some sense, a study of two Parsivel OTT. Thus, in this paper another analysis of Parsivel OTT sampling (by assuming that the only role of sampling is the capture area) is performed.

4. All instruments are affected by uncertainties on the measurement of the diameter for each drop. This is conditioned for technical reasons (quality of the components) or physical reasons (limitations of each physical methodology to estimate the diameter). For example JWD is an impact disdrometer which measure/estimate the velocity of the drops and infer the diameter for a given v(D) relationship. Field measurements are therefore affected by sampling, measurement errors, binning effects and truncation effects. The binning effects are shown for gamma distributions but also for gamma distributions with an uncertainty on the shape parameter; in both cases I found an overestimation of 5% for heavy/very heavy rain (quite important, an overestimation of 5% in addition to the sampling bias). Including error in the shape parameter doesn't change the main pattern of the bias, and that is a reason to hypothesize that the binning effect is additive with respect to other error sources. In the additional material (section 3). I have included a simulated measurement error study (see the reference [1] because a study with measurement errors is there). By inspecting these figures also the binning effect seems additive with respect to measurement errors.

5. This question was already commented on the first subsection. Truncation and binning effects are present on other distribution models as well. For instance, a log-normal distribution with the same *mean* and *variance* than a gamma distribution would have more drops with sizes between 0.5 and 1 mm but less around 2 mm, but binning effects on largest drops are expected to be similar.

6. The artificial gamma drop-size distributions simulated accumulation times of 60 seconds. For the 2DVD measurement the histogram are the accumulated drops for 60 seconds. Given the extension of the paper, I could not cover also normalized DSD.

2. Response to Referee 2

2.1 General considerations

Some questions of Referee 2 were similar to referee 1, so I am only going to introduce here some comments. The main concern seems to be that "*...this manuscript is missing some explanations of the scientific assumptions behind this approach*" in particular that "*...disdrometers are considered to sample correctly all the drops that fall in their respective sampling area, which is unfortunately not true in more realistic conditions*."

A similar question has been commented by Referee 1. I have included more details on the scientific assumptions on this document, I thank you for point out its necessity. The study presented is not including measurement errors but this is not invalidating the conclusions nor the methodologies of this paper. The supplementary material may proves that the presented conclusions have been tested in a large set of different conditions, including measurement errors.

2.2 Specific comments

I agree with the referee that the interaction between the instrument and the drops may induce additional errors on the measurements. Usually this is addressed on the data-preprocessing by filtering drops with anomalous terminal velocities. From a general point of view, the effect of binning on the largest drops is not affected by this phenomenon, and the conclusions regarding reflectivity bias should be the same. In the case of smallest drops this phenomena may have a role on truncation and binning if the preprocessing methodologies would not correctly address this issue.

The referee also commented on the 2DVD dataset, indicating that two month of measurements were included. I agree that an ideal situation would be a dataset covering more rain events, this was the reason to focus on the methodologies and not on numerical values. An underlying hypothesis on the 2DVD sampling study is that the spatial structure of the drops is homogeneous, which is only an approximation to the actual structure. But this hypothesis is consistent with the first part of the study based on homogeneous Poisson processes. Include the three-dimensional structure of the precipitation is outside of the goals of this study, and it would need other methodologies, instruments and datasets.

2.3 References

Concerning references, this paper includes 51 references covering a large set of topics related with raindrop measurements from disdrometers. And I will include some of your suggestions as well, thank you for those. Here I include more specific information about this topic,

1. About the representativeness of disdrometer measurements the references included are the pioneer Miriovsky study[2] and the PhD Thesis of R. Checa-Garcia [1]. But the paper, *Tapiador et al, 2010* [3], has proven issues in the data preprocessing and in the geo-location of the instruments. All the issues were corrected on the reference [1].

2. Some papers the referee is requesting to be cited, I think that are already included on the references, Uijlenhoet, 2001 [4] ; Campos, E. and Zawadzki, I 2000[5]; Tokay et al 2005 [6]; Krajewski, 2006 [7]. But I will include some other suggested by the referee.

3. The references Mallet, C. and Barthes, L. [8] and Cao, Q. and Zhang, G.[9] explain in detail the simulation methodology based on the gamma distribution.

2.4 Specific tips/questions

- p.2345, Section 2.1, Eq (1). D represents equivolumetric diameter, while f(D) is a normalized distribution. In the reference [10] it is explained. With respect to other notations I will check the whole document for consistency.

- p.2347, Section 2.1.2, l.10-11 I will refer to the supplementary material for a broader comparison. The two artificial disdrometers are included to interpret visually the actual devices.

- p.2352, Section 2.3.2, l.10 Thanks for the comment. In this equation the index i represent the bin of the disdrometer and D0 represents the first value of the center bin. The notation will be changed to avoid any confusion with statistics of the distribution N(D).

- p.2356, Section 3.1: Thanks for the comment. The readers may also check the references included on the paper concerning 2DVD instrument. From a practical point of view the information provided to the user are those three parameters.

- Section 3.2: Thanks for the comment. Yes this was already considered and analyzed (see references and supplementary material).

- p.2357, Section 3.3: Thanks, yes this notation will be included.

- p.2357, Section 3.3, l.24-25. Thanks another notation will be included.

- In Section 3. Yes the time resolution is always 60 seconds.

- p.2359, Section 4, l.8-9: Thanks, yes "collocated instruments" is more explicit. Thank you.

- p.2370, Table 4 and -p.2377, Fig.7 the notation will be explained on the Table/Figure itself.

3. Supporting material

In this section additional material done is presented to support the results and methods included on the submitted paper. All this material was done by Dr. Checa-Garcia but not as part of reference [1]. Only few figures are included on this supplement.

3.1 Base vs additional experiments

The paper is based on a comparison of 8 different disdrometers (two of them artificial), this is called *base experiment* however to faithfully understand the role of binning and truncation additional experiments were done (see Table 1). Also for each set from Base to Set-6, four models of measurement errors are evaluated (while another case is already present of reference [1]). The comparison between Figures 1 and 3 shows the role of binning on largest DSD moments, for instance.

3.2 Measurement errors analysis

Two kinds of error measurements were evaluated: an error on the measured diameter based on Gaussian distribution with standard deviation equal to a fraction of the diameter value (see Table 2), and also another type of error designed to simulate problems on the detection of smallest drops. This last one discards a percentage of smallest drops (diameter lower than 0.8 mm)[1]. For the first type of errors 4 different models are analyzed (see table 2). Therefore the total number of analyzed cases for each experimental set is 8. Some results are shown in the following figures to assert that the binning effects are still present with measurement errors. The figures included on this manuscript show both types of errors simultaneously. The Figures 5 to 8 show that the binning effects are still present, while the Figures 9 and 10 show that the sampling distribution of DSD gamma parameters are also affected by truncation and binning effects in presence of measurement errors.

References

[1] Ramiro Checa-Garcia. *First measurement of the small-scale spatial variability of the raindrop size distribution: Results from a crucial experiment and maximum entropy modelling (http://arxiv.org/abs/1306.5649)*. PhD thesis, Univ. of Castilla-La Mancha, Spain, 2012.

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[3] F. J. Tapiador, R. Checa, and M. de Castro. An experiment to measure the spatial variability of rain drop size distribution using sixteen laser disdrometers. *Geophysical Research Letters*, 37:16803–+, August 2010.

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Acknowledgments

Dr. Checa-Garcia thanks to *Karlsruhe Institute of Technology* for the computational support that allowed these calculations.

Figure 1. Analysis for Set-1 without measurement errors.

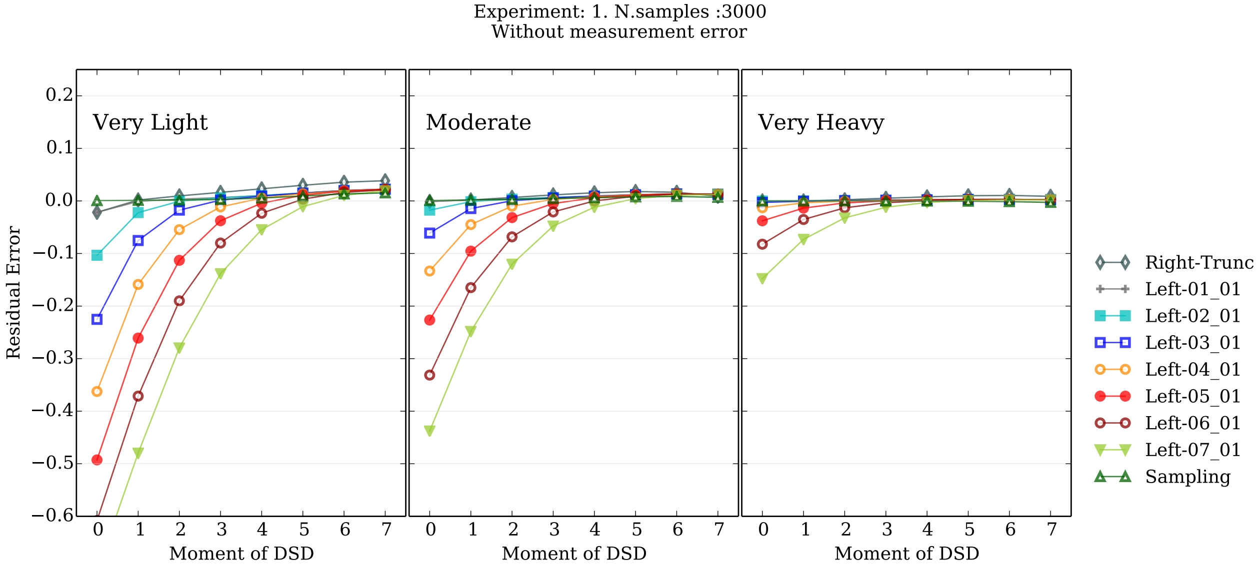


Figure 2. Analysis for Set-2 without measurement errors.

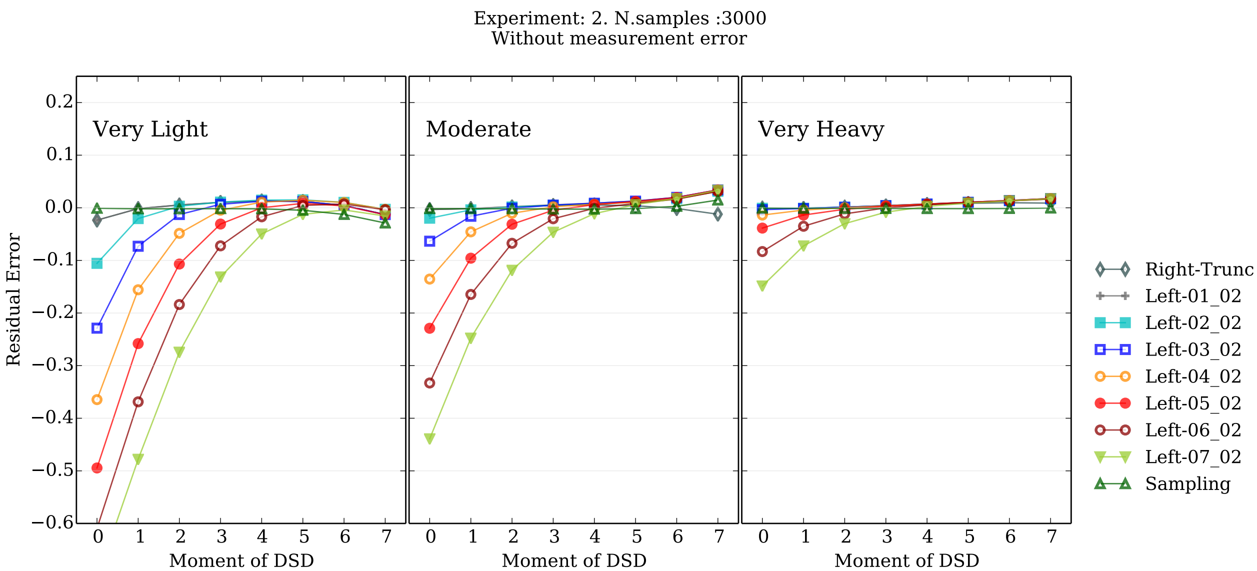


Figure 3. Analysis for Set-3 without measurement errors.

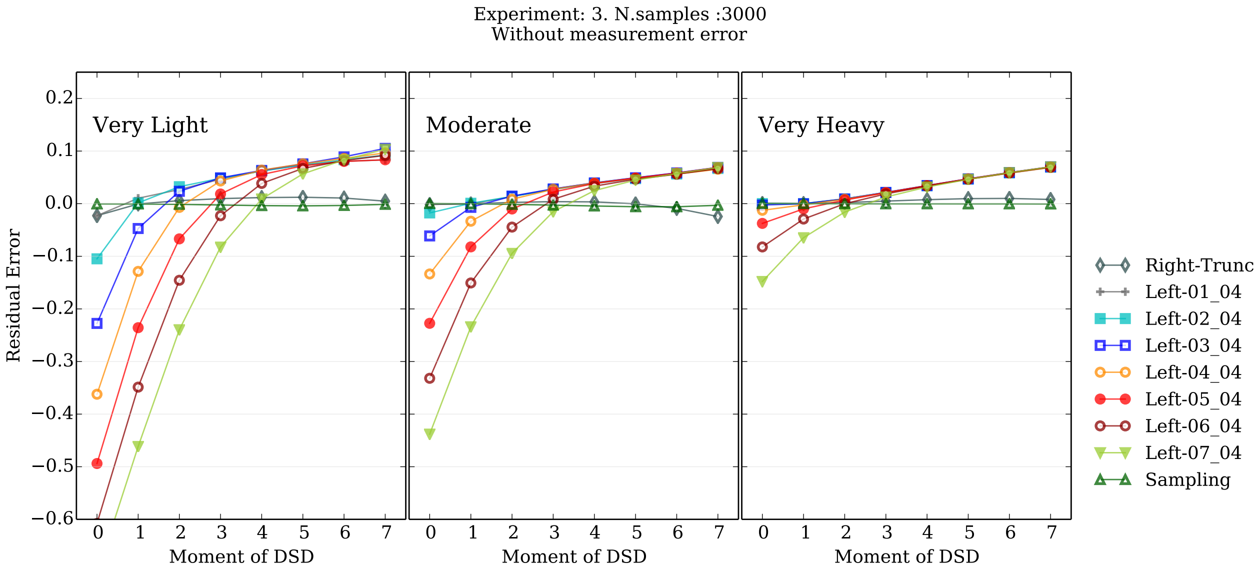


Figure 4. Analysis for Set-4 without measurement errors.

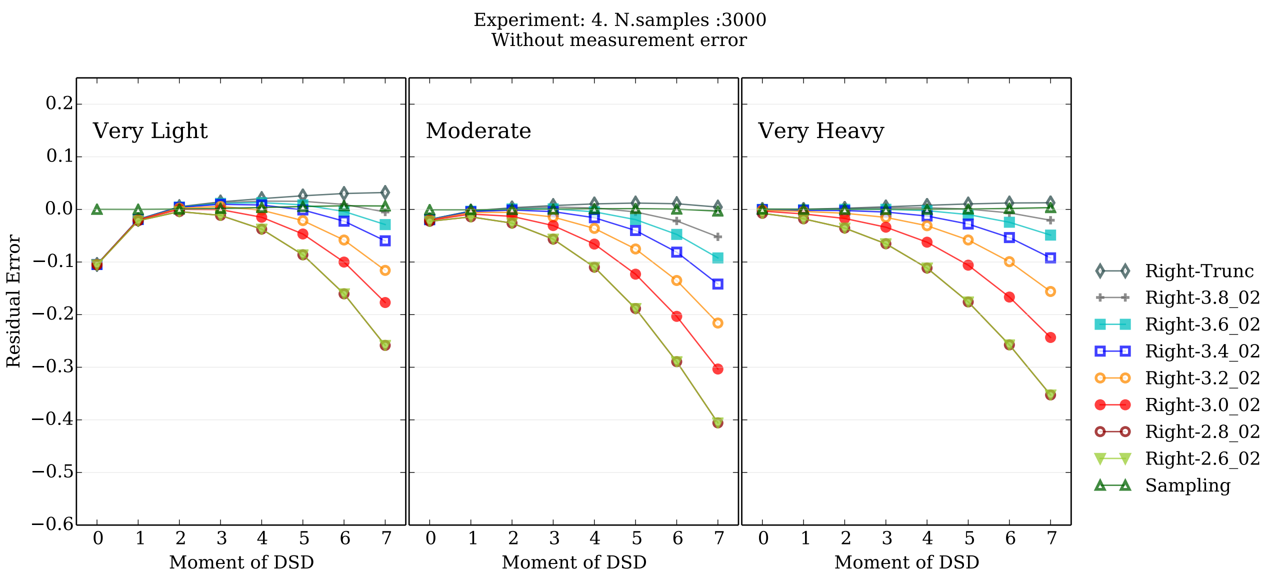


Figure 5. Analysis for Set-0 with measurement errors **type A**

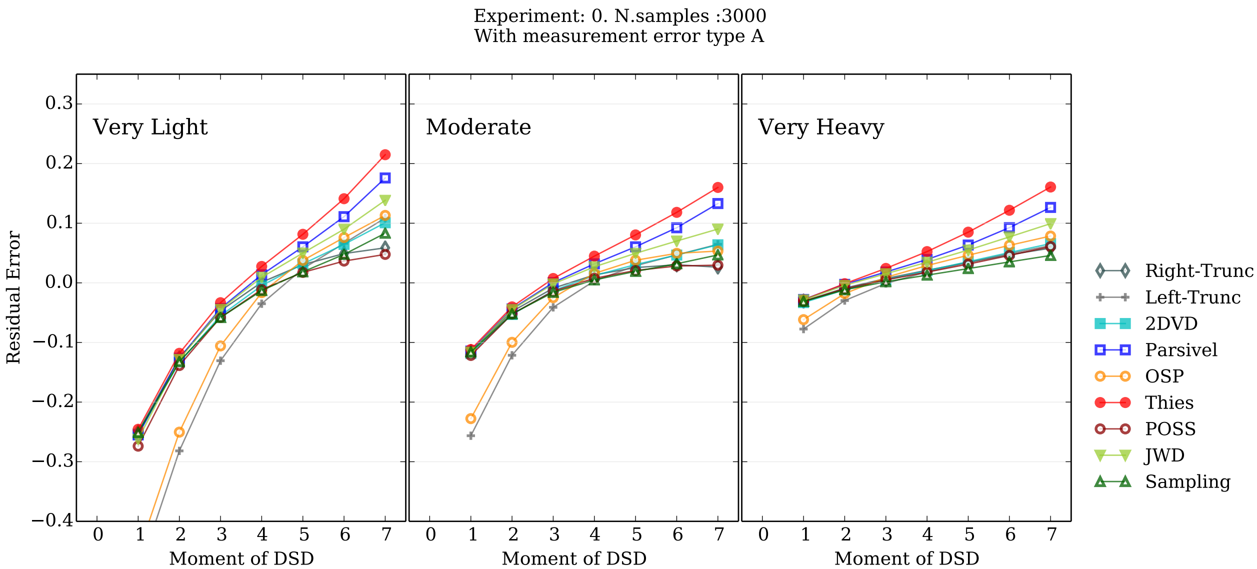


Figure 6. Analysis for Set-0 with measurement errors **type B**

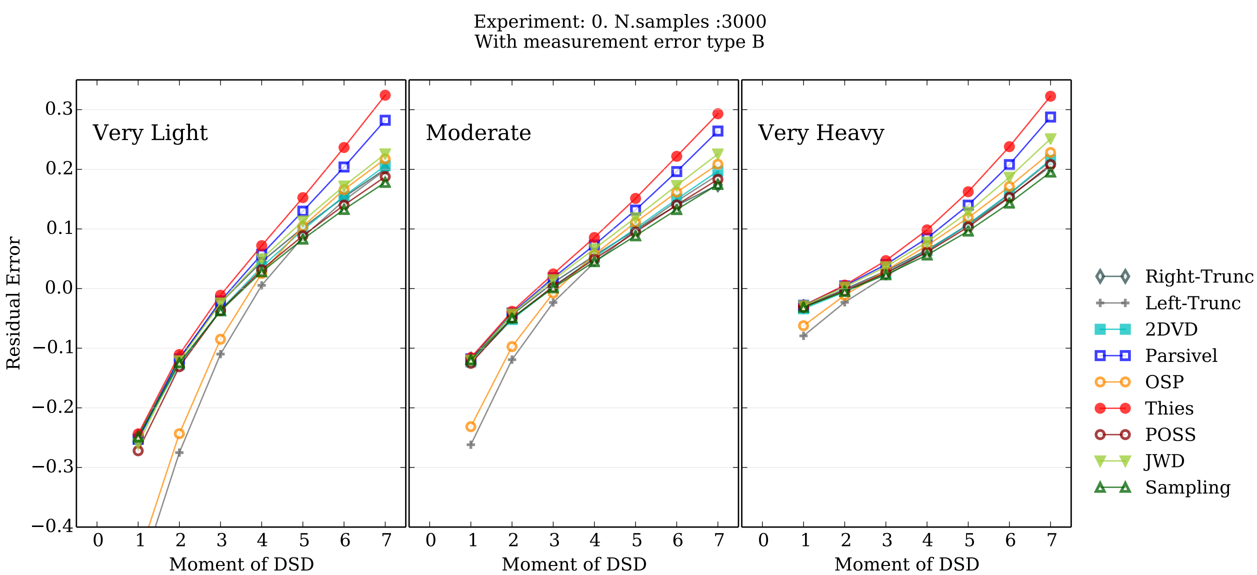


Figure 7. Analysis for Set-0 with measurement errors **type C**

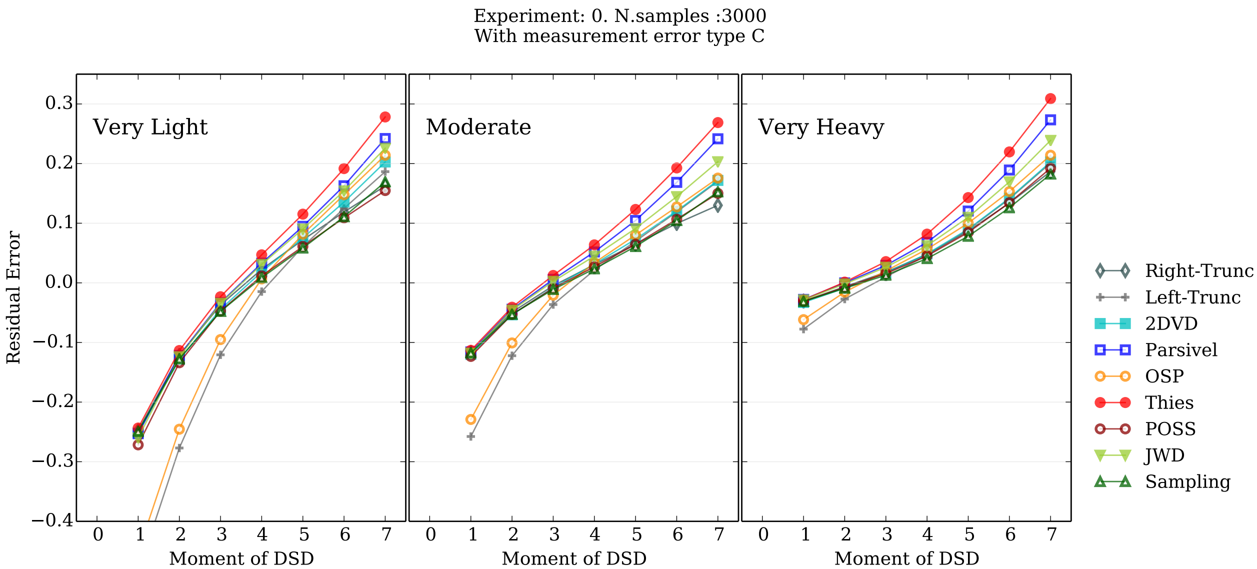


Figure 8. Analysis for Set-0 with measurement errors **type D**

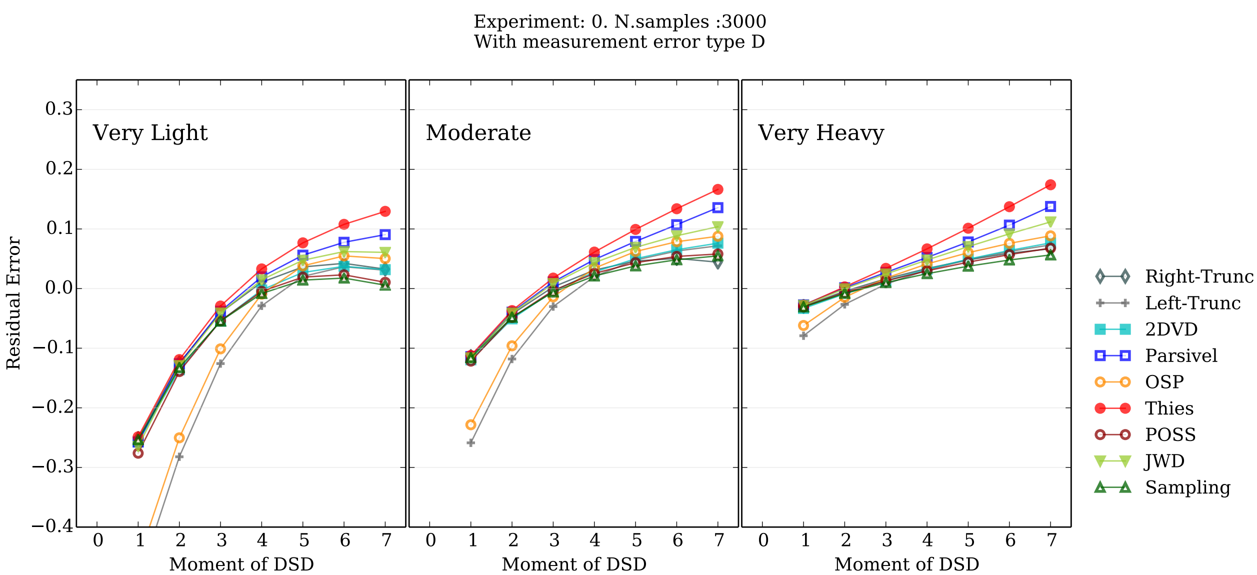
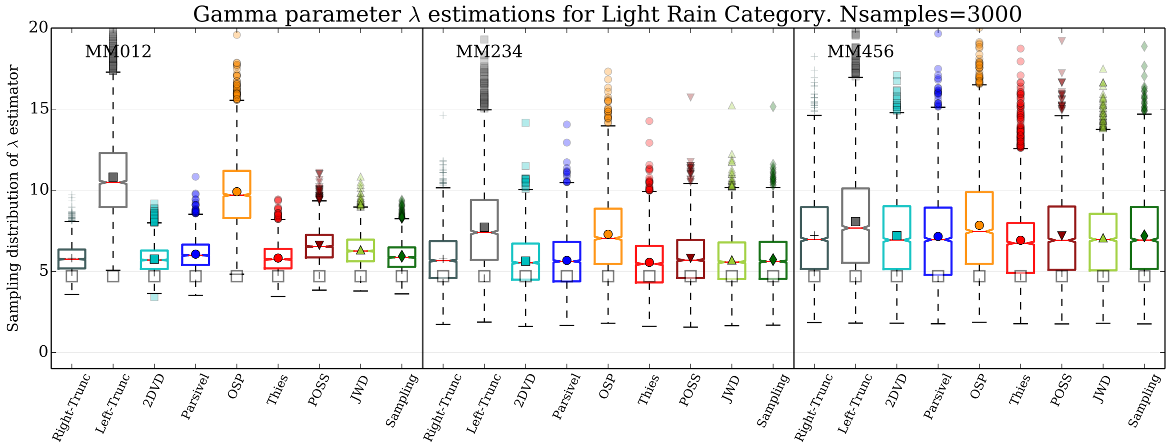


Figure 9. Analysis for Set-0 with measurement errors **type B**. Estimation of parameters μ and λ



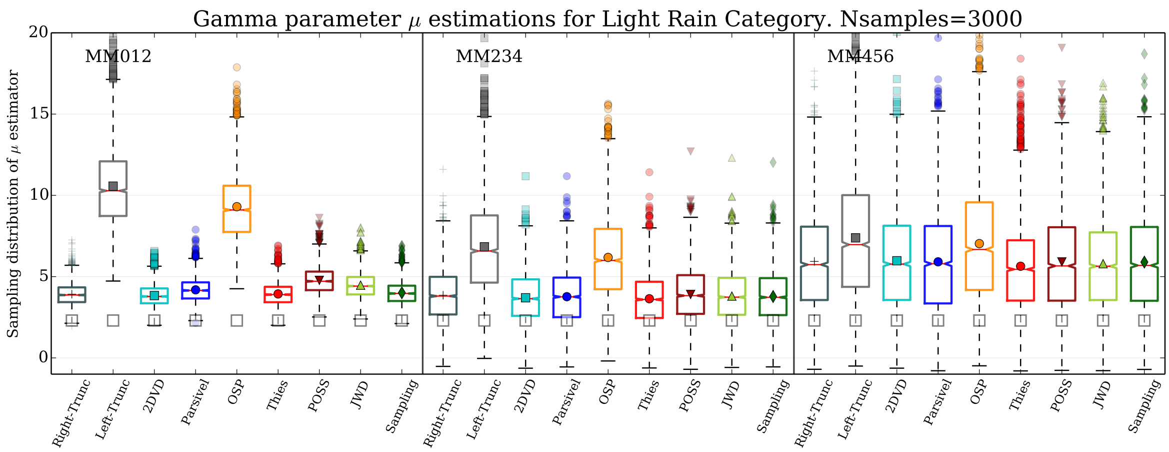


Figure 10. Analysis for Set-0 with measurement errors **type D**. Estimation of parameters μ and λ

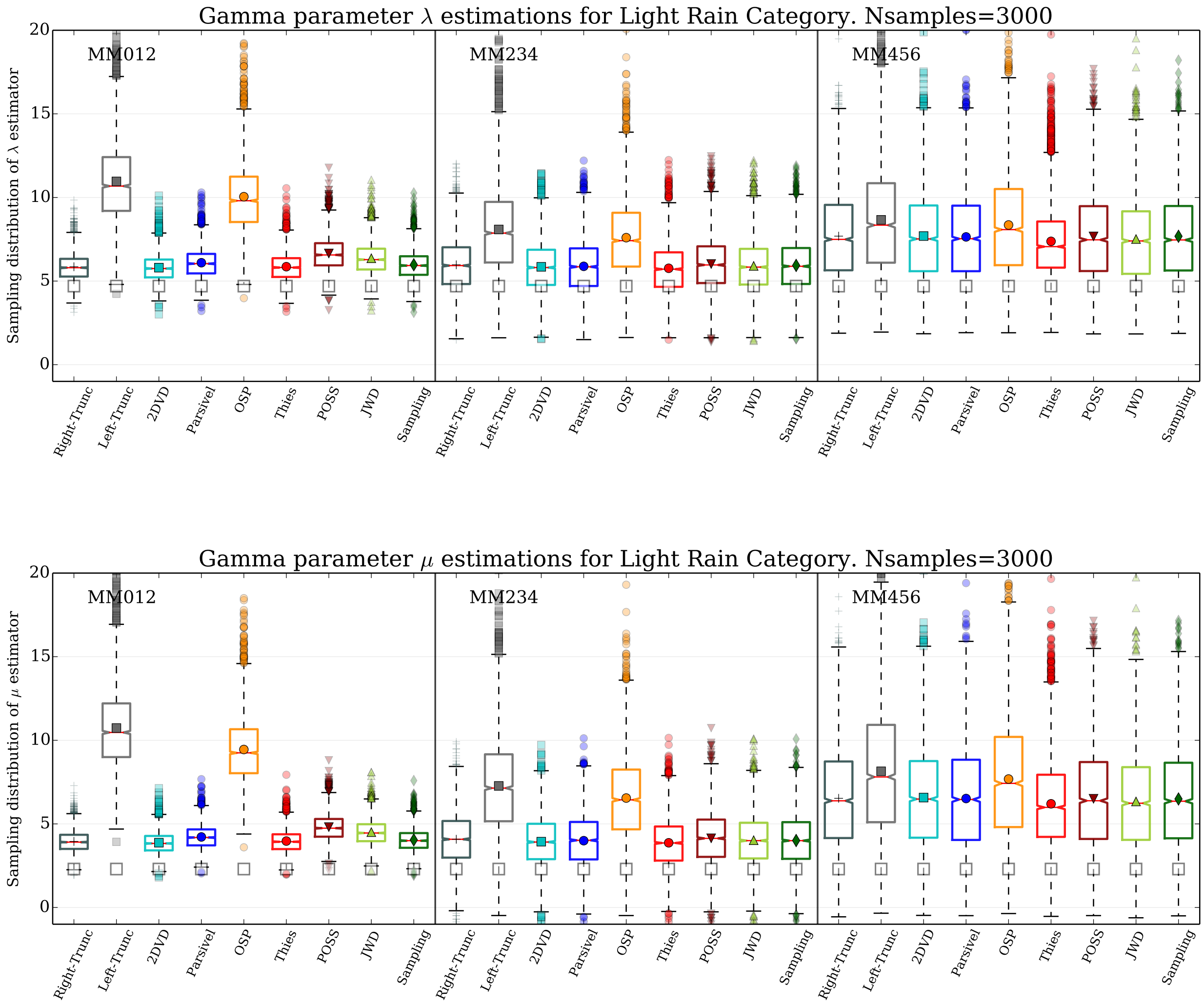


Table 2. New Noise models

Diameter	$D[mm] \leqslant 1.5$	$1.5 < D[mm] < 3$
Noise A	0.05%	0.05%
Noise B	0.10%	0.10%
Noise C	0.05%	0.10%
Noise D	0.10%	0.05%

Table 1. Table of Simulated Experiments. Each experiment contains 8 different disdrometer bins called *(Dis-n)*. *L-tr* means left-truncated, while *R-tr* means right-truncated. The numbers are the truncation value of the diameter of the drops and the width of the bins considered. Therefore the sets 1 to 6 allow to compare binning and truncation effects, and support the interpretations of the submitted paper. The code means the different software that were used on the calculations, in particular the random number generator functions used on UCLM and KIT are different in order to check that the results are not an artifact of a specific computational library. It also allowed to check the general calculations along the manuscript, so the previous cases calculated at UCLM were evaluated, checked and verified again. On the other hand, all mathematical expressions and their programming as computer algorithms (presented on the manuscript and done by Dr. Checa-Garcia) are also consistent with the last software.

Experiment	Dis-1	Dis-2	Dis-3	Dis-4	Dis-5	Dis-6	Dis-7	Dis-8	Code
Base (= Set-0)	R-Tr	L-Trun	2DVD	Parsivel	OSP	Thies	POSS	JWD	(UCLM)
Base + noise	R-Tr	L-Trun	2DVD	Parsivel	OSP	Thies	POSS	JWD	(UCLM)
Set-1	R-Tr	L-Tr-0.1-0.1	L-Tr-0.2-0.1	L-Tr-0.3-0.1	L-Tr-0.4-0.1	L-Tr-0.6-0.1	L-Tr-0.6-0.1	L-Tr-0.7-0.1	(KIT)
Set-2	R-Tr	L-Tr-0.1-0.2	L-Tr-0.2-0.2	L-Tr-0.3-0.2	L-Tr-0.4-0.2	L-Tr-0.6-0.2	L-Tr-0.6-0.2	L-Tr-0.7-0.2	(KIT)
Set-3	R-Tr	L-Tr-0.1-0.4	L-Tr-0.2-0.4	L-Tr-0.3-0.4	L-Tr-0.4-0.4	L-Tr-0.6-0.4	L-Tr-0.6-0.4	L-Tr-0.7-0.4	(KIT)
Set-4	R-Tr	R-Tr-3.8-0.2	R-Tr-3.6-0.2	R-Tr-3.4-0.2	R-Tr-3.2-0.2	R-Tr-3.0-0.2	R-Tr-2.8-0.2	R-Tr-2.6-0.2	(KIT)
Set-5	R-Tr	R-Tr-3.8-0.4	R-Tr-3.6-0.4	R-Tr-3.4-0.4	R-Tr-3.2-0.4	R-Tr-3.0-0.4	R-Tr-2.8-0.4	R-Tr-2.6-0.2	(KIT)
Set-6	R-Tr	L-Tr-0.5-0.5	L-Tr-0.5-0.4	L-Tr-0.5-0.3	L-Tr-0.5-0.2	L-Tr-0.7-0.4	L-Tr-0.7-0.3	L-Tr-2.6-0.2	(KIT)