Response to the reviewers' comments

Reviewer 2

The Authors proposed a new model to represent the μ-λ relationships. The parameters of the proposed μ-λ relationships are obtained considering 20 months of disdrometers data in the Netherlands. μ-λ relationships for stratiform and convective conditions are also obtained and compared with models in the literature. The manuscript is well written and easy to follow. I suggest the publication on Journal of Hydrology after addressing my comments.

Answer

We appreciate your time and effort in reviewing our paper, as well as your valuable suggestions. We have revised the initial draft basis your feedback, and you can find a point-by-point response to the comments below.

1) I suggest to slightly change the title in order to stress the fact that in the paper a new model is proposed to model the μ-λ relationships.

Answer

Thanks for your comment. We re-formulated the title to highlight the fact that a new power-law model is used for the μ-Λ relationship. The new title is:
"A new power-law model for μ-Λ relationships in convective and stratiform rainfall".

2) *In the Introduction (last sentence) it should be highlighted that a new model is proposed to model the μ-λ relationships and the advantages of this model with respect to the classical ones*

Answer

Following your advice, we re-formulated the last part of the Introduction and now the advantages of the new model are clearly highlighted.
"Within the double-moment normalization framework, a new μ-Λ power-law relationship is introduced and fitted to the remaining data, resulting in coefficients with meaningful physical interpretation.".

3) Section 3.1 To help the reader please add which moments the Authors use to fit the gamma DSD. Furthermore, recent works have criticized Method of Moments for producing biased parameters, whereas the maximum likelihood method proves to perform better (see e.g. Smith and Kliche, 2005 ; Smith et al., 2009 ; Kliche et al., 2008). Please provide some comments/consideration on this important aspect.

Answer

Done.

The revised text:
"Similarly to Bringi and Chandrasekar (2001); Gatidis et al. (2020); Thurai et al. (2014), the method of moments and more particularly the 3rd and 4th DSD moments were used to fit the gamma DSD and estimate the three unknown parameters μ, Λ and N_w from empirical DSD spectra, with μ values ranging between -3 and 15, as described by Thurai et al. (2014).

About the second comment: Yes, we are well aware of the limitations of Method of Moments (MoM). In fact, in a previous study of ours (Gatidis et al., 2020), we investigated this very important issue by comparing MoM and Maximum Likelihood Estimation (MLE). Our conclusion was that the performance of the different fitting procedures depends on the characteristic of the DSD spectra themselves and the accuracy of disdrometer measurements (e.g., the ability to correctly capture small and large drops). For example, MLE performs better than MoM if the goal is to fit low order moments such as NT. Also, MLE is superior to MoM for cases where the DSD really follows a gamma distribution. On the other hand, when the true distribution deviates from the gamma, or when the goal is to accurately reproduce specific, higher order moments such as LWC, or Z, MoM tends to be the superior choice.

Gatidis, C., Schleiss, M., Unal, C., and Russchenberg, H.: A Critical Evaluation of the Adequacy of the Gamma Model for Representing Raindrop Size Distributions, Journal of Atmospheric and Oceanic Technology.

In order to make this clear in the paper, we added the following sentence:
"The advantages and disadvantages of method of moments with respect to other methods such as maximum likelihood estimation were discussed in previous studies (Smith and Kliche, 2005; Smith et al., 2009; Kliche et al., 2008; Gatidis et al., 2020) and will not be repeated here."

4) *Equation 13: can the Authors write the equation of Mj and Mj-1 that lead to the right hand side?*

Answer

Thanks for your comment. We re-formulated the text in order to avoid any confusion to the reader. The new sentence in the manuscript is the following:

"Considering that the DSD is assumed to follow a gamma model, and given that $\int_0^{\infty} D^{\alpha} e^{-bD} dD = \Gamma(\alpha+1)/b^{(\alpha+1)}$ and $\Gamma(\alpha+1) = \alpha\Gamma(\alpha)$, where Γ(α) is gamma function, then D_c (the ratio of two successive reference moments with i=j-1) is given by:"

5) *Section 3.3: please add more information on the methodology used to classify stratiform and convective period. The classification is done for each minute or on a longer time period? How the lighting information are used for the classification?*

Answer

We added some additional information about this in the manuscript (Section 3.4):
"To determine the convective events, we start by identifying all 1-min DSD measurements for which the rain rate exceeds 10 mm/h. We then remove all periods for which there is a clear melting layer signature, since these correspond to stratiform rain. Regarding requirements 3 and 4, please note that no processing was performed on the associated data sets. CAPE and lightning activity are only used as additional diagnostic variables to help with the final classification decision. For the final selection of convective events, only the periods for which the CAPE values were larger than 1000 J/kg and for which lightning strikes were detected over the Cabauw area are kept. High CAPE level indicate favourable conditions for strong updrafts and storm development, potentially leading to convective rain, while lightning is a phenomenon that can accompany convective storms. However, it is important to state that they are not the exclusive drivers of convective processes (Schumacher et al., 2013). In this study, they are used as an additional indicator for potential convection which together with the high rain intensity and the absence of melting layer will ensure that no false convective events are identified. The reasoning behind this approach is that we think it is preferable to be too strict and exclude a few convective events rather than being too tolerant and include some stratiform or mixed-type events into the convective dataset."

6) *Section 4.1: please insert the data quality methodology in the previous section*

Answer

Thank you for your comment. We moved the overview of the quality control in Methodology (see Section 3.3, DSD filtering) and only left the results of the quality control in Section 4.1 (Results).

7) *Section 4.1: Is it possible to know if the discarder DSDs correspond mostly to convective of stratiform period? It would be interesting to know some characteristic of the discarded DSDs to understand when the two devices differ more*

Answer

A further investigation of the characteristics of the discarded DSDs would be an interesting follow-up study. However, we feel that this is beyond the scope of this study. Also, a systematic analysis of discarded DSDs would require a different procedure for rain type classification. As stated in Section 3.4, the current method for identifying convective events is based on a few simple quantitative criteria (e.g., rain rate above 10 mm/h), together with a more subjective and qualitative visual analysis by human experts (i.e., melting layer detection from MRR and cloud radar, CAPE and lightning activity). In the manuscript, we clearly state that these criteria are quite strict, which means that we may have missed some convective events. Therefore, if we wanted to analyze the properties of the discarded DSDs in more detail, we would need a more elaborate, reliable and automatic rain-type classification method.

We added the following sentence at the end of the revised manuscript as an interesting follow-up study:
"Finally, a future work could further investigate the characteristics of the discarded DSDs to determine when the two sensors exhibit the most significant differences and under which rainfall regime."

8) *Section 5, point 1): to check this conclusion two μ-λ relationships can be obtained (one for each disdrometer) and then compared.*

Answer

Thank you for your suggestion. The μ-Λ relationship for each disdrometer was obtained and then compared. There is relatively good agreement between the sensors. We added the following sentence in the revised manuscript:
"Furthermore, the $\mu - \Lambda$ relationship for each disdrometer was obtained and then compared, with a relatively good agreement between the two sensors, especially for smaller μ values ($\mu < 4$) where RMSD is 0.28 while for cases with μ greater than 4 RMSD is increased to 1.1. The slightly bigger differences between the two relations for higher μ values can be explained by the existing sampling uncertainty in the lower rainfall intensities. All the above imply that a single disdrometer may suffice to derive representative μ-Λ relationships without requiring co-location."