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Discussions

Interactive comment on "Comparison of precipitation measurements by Ott Parsivel^2 and Thies LPM optical disdrometers" *by* Marta Angulo-Martínez et al.

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General comments

This article compares the performance of two models of optical disdrometers in terms of rainfall accumulation, number of drops, kinetic energy (flux?), and radar reflectivity. This is an important topic, as optical disdrometers allow the continuous measurement of rainfall properties that are otherwise difficult to observe, such as drop-size and ve- locity distributions, kinetic energy flux, radar reflectivity, etc. However, there are a multitude of poorly understood sources of uncertainty associated with such measure- ments. The authors collocate two

widely used models of disdrometers and compares their outputs for a large number of events, which is really a strong point of this article.

I'm puzzled that the experimental setup does not include tipping buckets. They are inexpensive, their uncertainties are well understood, and they would provide another independent measure of rainfall accumulation, useful to help us understand which of the models (or both models?) are likely to be overestimating rainfall volumes during the study period. As a shortcoming that should be improved before acceptance for publication, I would like to point out that some of the plots are underexplored. For example, Figure 2 shows a striking difference between the behaviors of KE and rainfall accumulation, however, there is little interpretation of the plot (more on this under specific comments). Figure 3 is not called in the text, although the discussion mentions the events. Finally, the acronyms for variables and the instruments should be unified throughout the text.

We thank the reviewer for the thorough review and useful comments. We have improved the interpretation and discussion of the plots, unified the acronyms for variables and instruments, and undertaken a careful revision of most sections. We believe that the article has been greatly improved thanks to these amendments.

We also provide the corrected manuscript as an attached pdf file.

Regarding the tipping buckets, the main objective of the experiment was to compare the two disdrometer types and their recording of the particle size and velocity distribution (PSVD) and related moments. Deploying a tippying bucket pluviometer would allow us compare one of these moments, the rainfall amount, with yet another instrument, but that's all. One simple tipping bucket does not provide a valid reference for rainfall amount, since they are also subject to many uncertainties. At this respect, we participate in an ongoing experiment in which different rainfall sensors are compared against a Double-Fence Automated Reference(DFAR) pluviometer, which provides a validated reference. This would be the objective of a different study, however.

Specific comments

Page 2 Lines 12-14: "Disdrometers are also widely used to validate the reflectivity values obtained by weather radars, for what the studies on small scale PSD spatio- temporal variation and its influence in modeling PSD and rainfall rate - reflectivity (Z(R)) relations are particularly important". This sentence is a bit confusing. Please consider rephrasing. Moreover, more important than the validation of reflectivity values measured by a radar, disdrometer observations of drop-size distribution are used to derive relationships between radar reflectivity and rainfall rates (Z-R relationships). The biggest difficulty when one compares disdrometer and Radar measurements is the mismatch between the sensing area of a disdrometer (few cm2) and a radar pixel (km2). It would be interesting to point this out here.

We have rephrased this sentence as suggested.

Page 5 Lines 5-15: The authors describe the principle of operation and list sources of biases in the instruments. One missing source of biases in laser disdrometers is the uneven power distribution across the laser beam as described by Frasson et al. [2011]. Please consider adding it.

We have included uneven power distribution (in space and also in time) as a potential bias source. We have added a citation to Frasson et al. 2011, whose reference was already in the reference list.

Page 9 Lines 2-4: "Missing values were found in all disdrometers and can be attributed to technical issues (power supply failures, data communication problems, or spurious measures), being Ott PARSIVEL2 disdrometers the ones with the highest number of missing values." I worked with Thies disdrometers quite a few years back. During my data acquisition campaign, I had several records

showing rainfall when in fact there was no rain. Did you experience such events? Could such "phantom" events be a cause for some of the "missing PARSIVEL data", in which case it wouldn't be rain missed by the PARSIVEL unit, but rather a problem in LPM?

Here we refer only to periods when one of the devices did not work due to technical problems due to power supply, communication issues, or directly to device hangouts. We have removed the reference to 'spurious measures', that was not correct. We have added more details on this on Table 3.

Regarding the 'phantom events', sometimes we found one of the devices recording particles during one single minute when the others did not record anything. These were automatically removed, since we only considered those minutes when the four devices recorded particles. This procedure has been made clearer in the manuscript, and numerical details are also provided.

Page 9 Lines 15-20: It is interesting to see that for KE only, T1, T2, and P1 showed remarkable agreement until October 2014, when suddenly T2 steeply increased its KE and caught up to P2. The pattern is different for cumulative rainfall, which shows more similarity in instruments of the same type and showed that the difference between Thies and Parsivel measurements increased gradually. Were there any anomalies in T2's measurements of velocity in November or December 2014? This figure deserves a bit more discussion. This event is likely a good candidate to be shown on its own, alongside the other events in figure 3. I find it quite interesting that before this event, there was a bias in volume measurements, but not in KE among three of the four disdrometers. Especially because for this type of instrument, errors in drop diameter are strongly correlated with velocity errors. As a minor comment, the text discusses instruments in terms of T1 and T2, P1, P2, but the figure labels them as Par1, Par2, Th1, Th2. It might be best to make the names more consistent.

Revising the figure, we have found an error that affected the filtering of the minutes specifically on this figure. Thus, some minutes were included where not all the four disdrometers had record. We have therefore re-done the plots. At the request of another reviewer, the figure now include the values calculated internally by the disdrometers ('measured') and also the values computed from the PSVD data. We have extended the discussion of the figure in the text.

I am not sure that the same effect can be seen now. The event E365, depicted on Figures 3 and 5, corresponds to the end of November 2014, and yes, in this case T2 recorded faster velocities than T1. The median particle size was also higher, and as a result both the radar reflectivity and kinetic energy were higher. In a previous event on the same month (E338, on 03/11/2014) this effect was not found.

Regarding the symbols used to refer to the four devices, we have generalised T1, T2, P1 and P2 throughout the article.

ÂăPage 10 Line 7: "These particles, as well as relatively large ones with low falling velocities, seem to be filtered out from the PARSIVEL2 output" Did the authors attempted to reach out to OTT and ask if there is any filtering of drops based on departures from expected the velocity-diameter curves? This would be particularly helpful to users who deploy the instrument in situations when drops are expected to deviate from theoretical drop size-velocity curves.

Yes, we have attempted to get more information from OTT regarding the (likely) filtering of the raw data, but we have not been given any more details. We have, however, stressed out the details that can be inferred from the literature (mostly from Löflfer-Mang and Joss, 2000, and from Tokay et al., 2013).

Figure 10 Line 14: Thies disdrometers recorded a much higher number of particles NP (a mean difference of 422 vs. 219). What does the mean number of particles represent? The mean number of particles across all events? Considering the magnitudes of the NPs in figure 3, it is difficult to believe that the average

number of drops per event is a couple hundreds. Please consider defining how the average NP was computed and what it represents (averaging a drizzle and an intense thunderstorm doesn't seem to be useful).

NP refers to the number of particles detected ***per minute***. We have made this clearer in the text. However, we have in general opted to use the more representative particle density number (ND), which represents the number of particles per cubic meter of air and mm of rain.

Section 3.4 – data filtering. Was the data presented in Figure 2 before or after filtering? Page 11 lines 26-27: "In brief, PARSIVEL2 tended to underestimate the number of particles recorded, and tended to record a larger number of bigger particles than Thies. At the same time, Thies recorded a very large number of small particles that may mask the amount of bigger particles recorded." Did you compute rainfall rate from the classified drop counts (from the matrix that shows drop counts per diameter-velocity class) or did you use the rainfall rates from the telegrams.ÂăIt appears that the Thies disdrometer is overestimating the number of small drops in the first diameter class. Could the authors examine what happened when the rainfall moments (NP, Rainfall rate, kinetic energy flux, reflectivity, etc) are computed without considering the first class of drops? Knowing that the Parsivel disregards the first two classes due to noise induced by the power supply (as pointed out in the discussion), it would be fair to compute rainfall moments for the Thies also without considering the first two classes. Furthermore, if the authors compute the moments themselves, they might be counting classes that the Thies manufacturer already disregards. By no means I suggest replacing all plots, however, it would be interesting to add to the cumulative rainfall and KE in the beginning of the Results section computed with and without filtering the first two classes of the Thies disdrometer. The authors mention in the discussion the following sentence (Page 13, lines 13-14): "When PSVD data were filtered, considering only particles with diameters greater than 0.3 mm, these

differences were reduced although the tendency remains and increases for high intensity rains." However, I could not find the recomputed totals or to know for sure if figures such as figure 2 showed rainfall totals after excluding the Thies' first diameter class.

This is a central issue in our comparison, and we present alternative results using the raw data and filtered (removing the small drops from the Thies PSVD matrix). We now see that it was not very clear which results belong to which dataset, and we have worked to make it clearer in the revised manuscript.

We have also added a few new figures in which we used the filtered dataset. For instance, the cumulative variables represented in Figure 2 now include the values calculated by the disdrometer software and the values calculated from PSVD, after filtering.

Regarding the filtering scheme, a major change has been done as per recommendation of another reviewer. Thus, in addition to fixing the drop size to a common range (which was, in fact, 0.250 to 8 mm), it was suggested that we removed the particles with unlikely combinations of size and velocity. We have implemented this filter, which implied repeating all the analyses. For assessing the influence of this filtering, and of the required adjustment of the sensing area, we have also included results without filtering, which are shown in the Appendix (Figures A.1, A.2, A.3 and Table A.1).

As mentioned by the authors in the discussion, two further causes for differences in the drop counts may be related to turbulence and splashing. Due to the Thies bulky electronics enclosure, this instrument might be especially susceptible to splashing and to turbulence induced errors (please see [Constantinescu et al., 2007] for an evaluation of turbulence effects on tipping buckets). Particularly at high intensity events, splashing from the Thies electronics case could be producing droplets that end up falling inside its sensing area. The Parsivel heads are less bulky and have a protection to decrease splashing (although I'm sure it still happens). I'm eager to see a future study employing high speed video

to examine the occurrence of splashing and possible effects on the data.

This is indeed a very relevant issue in our opinion, and we have further stressed it in the discussion section.

Technical corrections

Page 2 Line 10: you could also add interactions of rainfall with crop and forest canopies [Frasson and Krajewski, 2011; Nanko et al., 2004; Nanko et al., 2013].

We were not aware of these references, which are relevant examples of another field where disdrometers provide useful data. We have therefore included them.

Page 2 Line 17: "helping developing better sensors" please consider changing to "helping the development of better sensors".

We have rephrased this sentence as suggested.

Page 2 Line 21: "radar reflectivity or rainfall kinetic energy" I suggest replacing the "or" with a comma.

Done.

Page 2 Lines 21-22: "rain rate, liquid water content, radar reflectivity or rainfall kinetic energy, among others, can also be calculated from PSD moments" Aren't the rain rate, radar reflectivity, kinetic energy flux et al DSD moments themselves instead of quantities "calculated from DSD moments"?

You are right, these are referred to normally as DSD moments. We have changed it.

Page 2 Lines 29-30: "Pressure disdrometers, however, can only measure the PSD": Impact based and pressure disdrometers cannot directly measure particle size distribution. As the authors mentioned in the beginning of the sentence, such disdrometers measure impact (a discussion on whether they see kinetic energy or drop momentum can be found in Licznar et al. [2008]). In order to esti-

mate the PSD, the velocity of the hydrometeors is taken from theoretical terminal velocity curves. I believe that this is what the authors referred to here. Please rephrase.

This is right, and we have rephrased the sentence to better express the idea that impact / pressure disdrometers rely on theoretical terminal velocity models.

Pages 2-3 Lines 30-33: "More recent disdrometers are based in optical principles (Löffler-Mang and Joss, 2000), either from the occlusion of a laser light beam between an emisor and a receptor device produced by the particle passing through; or based on light scattering measurements from particles passing through the light beam." I suggest rephrasing the first part of the sentence to something along the lines of: "the occlusion of a light or laser beam between an emitter and a receiver or between an array of emitters and receivers, caused by the passing of a particle through the disdrometer's sensing volume". This would include the working principle used by the two dimensional video disdrometer.

We are not sure about this rephrasing. From one hand, it would omit the light scattering mechanisms, that we mention in our text. And on the other hand, the 2DVD is explained later in the same section. Considering this, we have preferred maintaining the current phrasing.

Page 3 Line 24-25: "more accurate disdrometers such as the 2DVD, the JWD, or by taking a pluviometer as a reference". I suggest replacing "more accurate disdrometers" with "other disdrometers". Although there is literature supporting the claim of higher accuracy of the 2DVD, I'm unsure if it is fair to claim that JWD is more accurate than the LPM and Parsivel, especially when measuring DSD.

We totally agree with this comment, and we have substituted 'more accurate' with just 'other'.

Page 3 Lines 28-29: "with the results obtained linked to the purchased PARSIVEL

version of the time, with its drawbacks" I did not understand it. Please rephrase.

Yes, the original phrasing did not make sense. We have rephrased it to 'PARSIVEL disdrometers have been evaluated since its first version became commercially available from PM Tech Inc (Sheppard and Joe, 1994), with slightly different results depending on the version of the device analysed'.

Page 4 Line 11: "if conclusions drawn from measurements made with these two disdrometers want to be compared". Please consider replacing want by another verb. Maybe are?

We have rephrased it to 'if measurements made with these two disdrometers are to be compared '.

Page 4 Line 12: "This study aims at comparing the" Aims to compare?

I just learnt that 'aim at' is not good style. We rephrased it to ' The objective of this study is to compare...'.

Page 5 Line 11: "Correct measurements are also limited to one input point" I didn't understand this. Please rephrase.

We have rephrased it to ' Other source of biased measurements is due to the co-ocurrence of simultaneous drops...'.

Page 6 Lines 21-22: "PARSIVEL2 disdrometers detect raindrops from 0.25 mm of diameter". This is redundant with the previous line. I suggest deleting it.

Quite right, and we have deleted it.

Page 7 Line 29: "plOtting" Please fix the typo, where O appears capitalized.

We have corrected this typo.

Page 9 Line 8: "a highest sensitivity of Thies disdrometers" I believe this should read "higher sensitivity" as opposed to the superlative highest.

Right again. Corrected.

Page 11 Line 20: "The differences between disdrometer types were similar at different rainfall intensitites" This is a bit confusing. Please consider rephrasing. Were the differences between disdrometer types homogenous with respect to rainfall intensities?

We have rephrased the whole paragraph, and we hope that now reads clearer.

Page 11 lines 22-23: "During minutes with rainfall intensity higher than 10 mm $h-1$, for instance, NP was almost nine times higher for Thies than for PARSIVEL". This sentence makes me believe that the difference between instruments was not homogeneous among different rainfall rates. I'm a bit confused here.

We agree that our phrasing was confusing. We have avoided using the word 'similar', and we clearly state that the magnitude of the effects varied with the rainfall intensity. We believe that the sense of the paragraph is much more clear now.

Page 13 line 15: "Frasson et al. (2011) and ? also noted the same result". I believe the question mark was a typo or a problem with the citation program. Please fix.

The missing reference was Lanzinger et al. We have corrected it.

Page 13 lines 23-22: "previously noted by citetupton2008 and shown by our results". Typo here. Please fix.

We have fixed the citation.

Page 13 line 25: "PARSIVEL manufacture recognized...' I believe this should read PARSIVEL manufacturer recognized.

Yes, it should read 'manufacturer'. We have corrected it.

Please also note the supplement to this comment:

https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-652/hess-2017-652-AC2-supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-652, 2017.