Responses to reviewer #1
Guyot et al. **under review at HESS**

https://doi.org/10.5194/hess-2019- 277, 2019

We would like to thank the three reviewers for their very constructive comments on our manuscript. We received genuine insights, which have significantly contributed to increasing the manuscript quality and potential impact.

In order to improve the clarity in our responses we have numbered the reviewers' comments for reviewer #2 and #3 (Reviewer #1's comments are already numbered): for example, the comment 1 from reviewer 2 is listed as R1C2 and will refer to these comments as such in the following.

We have addressed all comments in point-by-point responses.

REVIEWER #1

Review of "Effect of disdrometer type on rain drop size distribution characterisation: a new dataset for Southeastern Australia" by Guyot et al.
The article presents a detailed comparison of drop size distribution (DSD) measurements taken by four collocated instruments (by two different manufacturers) located in Australia. Such southern-hemisphere comparison studies are uncommon, especially for the mid-latitudes. The study is clearly organised, well written and presents a thorough analysis. The results are useful and future directions are outlined. Some minor changes are required before the article will be ready for publication: there are occasional grammar errors and spelling mistakes that should be fixed in the next revision.
At times more references should be provided (I have indicated below when this is the case). In a few cases, the statements made in the text were not supported by the figures, and these require clarification. It is significant that the DSD database collected by the authors is freely available for use.

Response: We would like to thank the reviewer for his/her insightful and detailed comments below. These helped greatly to improve the quality of the manuscript. We greatly appreciate that the reviewer has taken the time to provide such high quality comments. We provide a point-by-point response to the comments below:

Specific comments follow:

1. Lines 70–72: This section is rather light on references; please include some of the pioneering studies about microstructure and its effect on QPE. I would think scattering properties, being instantaneous, depend more on microstructure than microphysics as such.

   Response: We added to the three references already cited in our paper (as per below) by including two new ones (Uijlenhoet and Sempere Torres, 2006; Krajewski and Smith, 2002). We have changed "microphysics" to "microstructure".
   Uijlenhoet, R., J.A. Smith, and M. Steiner: The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra. Journal of Atmospheric Sciences, 60, 1220–1238, doi: 10.1175/1520-0469(2003)60<1220%3ATMSOEP>2.0.CO%3B2, 2003.

Uijlenhoet, R., M. Steiner, and J.A. Smith: Variability of raindrop size distributions in a squall line and implications for radar rainfall estimation. Journal of Hydrometeorology, 4, 43–61, doi:10.1175/1525-7541(2003)004<0043:VORSDI>2.0.CO;2, 2003.

Uijlenhoet, R.: Raindrop size distributions and radar reflectivity–rain rate relationships for radar hydrology, Hydrology and Earth System Sciences, 5(4), 615-628, https://doi.org/10.5194/hess-5-615-2001, 2001.

Uijlenhoet, R., Sempere Torres, D., Measurement and parameterization of rainfall microstructure, Journal of Hydrology, Volume 328, Issues 1–2, 2006, Pages 1-7, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2005.11.038.

W.F. Krajewski, J.A. Smith, Radar hydrology: rainfall estimation, Advances in Water Resources, Volume 25, Issues 8–12, 2002, Pages 1387-1394, ISSN 0309-1708, https://doi.org/10.1016/S0309-1708(02)00062-3.

2. Line 73: The DSD describes microstructure, not microphysics (unless changes in the DSD are studied over time).

Response: We have changed "microphysics" to "microstructure".

3. Line 76: References should be provided for stain and oil immersion techniques.

Response: We added the following references:

Fuchs, N., & Petrjanoff, I. (1937). Microscopic examination of fog-, cloud-and rain droplets. *Nature*, *139*(3507), 111.

Nawaby, A. S. (1970). A method of direct measurement of spray droplets in an oil bath. *Journal of agricultural engineering research*, *15*(2), 182-4.

Kathiravelu, G., Lucke, T., & Nichols, P. (2016). Rain drop measurement techniques: a review. *Water*, *8*(1), 29.

4. Line 87: The reference Thurai et al. 2017 seems to be missing from the references list.

Response: The reference has been added to the reference list.

5. Line 109: A reference should be provided for the 20 years of observations near Darwin.

Response: Two references have been added (Dolan et al., 2013; Thomason et al., 2018).

6. Line 140: Please also specify how far apart the two instrument types were and their relative orientation.

Response: We have now changed the sentence and it reads:

"A distance of 2 meters separated the Thies Clima LPM (T3) and the OTT Parsivel1 (OTT1) located on the edges of each of the rails (as seen in Figure 1). The laser beams of each sensor were oriented along the North-South axis with raw 1-min data collected."

7. Line 160: usually defined as the particle or drop concentration and given in m^{-3}. Is this different? It is also listed as unitless in Table 1.

Response: According to the OTT Parsivel manual, it is specified that Nt is unitless (or min^{-1} as this is a number per time step, with time-steps equal to minutes in our case) and calculated by the instrument internal software, based on the PSVD.

8. Line 189: Should "min" be "minute"?

Response: This has been corrected.

9. Table 1: Please double-check the units for PSVD (decibel seems an odd choice) and the symbol used for rainfall amount (amount is not a summation of hourly rain rate).

Response: This has been corrected changed to "unitless".

10. Line 201: The range around the expected velocity should be 60% to match the reference and Figure 6.

Response: Thanks: Indeed, this was a typo and has now been corrected.

11. Line 214: Please show how calculated; since depending on the Parsivel version used, the formula used to calculate (whether or not D or D/2 is used should depend on whether or not the Parsivel automatically removes drops detected in the edge region).

Response: The equation for removing edge droplets has been added as equation (2) and subsequent equations have been re-allocated an appropriate numbering.

12. Line 217 and Eq. 2: This version of Z is in mm^6 m^{-3}, not dBZ.

Response: This is now corrected.

13. Line 224: Is this canting angle the standard deviation of an angle distribution?

Response: Yes, it is probabilistic. We conducted some research (unpublished work) on the sensitivity of the canting angle on the T matrix retrievals following the same approach as Louf et al. (2019) by comparing ground based DSD and radar observed dual pol moments, using the self-consistency technique. These results are beyond the scope of the work presented here so have not been included.

14. Line 228: "attentuations" → "specific attenuations".

Response: This has been changed.

15. Line 238: Λ has unit of mm^{-1}. Which fitting method was used to find the ordinary gamma model parameters?

Response: Thanks, we added units to the text. The "Moments method" of Ulbrich and Atlas (1998) has been used to derive the parameters. A sentence has been added to the end of the paragraph and the reference of Ulbrich and Atlas (1998) to the reference list.

16. Line 266: By my reading the Parsivels showed more than 100 mm difference in cumulated amount.

Response: The exact reading based on Table 2 is 89 mm (derived from the absolute value of (1244 mm – 1155 mm)) but it exceeds 100 mm when comparing Parsivel to LPM. We have modified the text as per below:

"The two Thies LPM systems recorded very similar rainfall totals, while the two OTT Parsivel[1] systems showed a difference of 89 mm between them and above 100 mm when compared to the Thies LPM during the common observational period."

17. Line 268: This is first mention of a second tipping bucket 9 km away; it should be introduced alongside the first gauge in Section 2.5.

Response: Thanks. The sentence below was added to section 2.5:

"Another gauge located at Melbourne Airport (Bureau of Meteorology station #086282) and situated 9.0 km from the experimental site was also used for comparison."

18. Table 2: What does "Equivalent" mean in this instance? I assume the cumulated amounts are for all rainy minutes per instrument, not over the 40062 common time steps?

Response: No: these are for the 40,062 common time steps. We have added this to the column label in order to clarify.

19. Line 290: "can measure smaller diameter drops and include a 0.125 to 0.25 mm bin size than OTT" – sentence doesn't make sense.

Response: Indeed, that was rather obscure… we have corrected and now it reads:

"The Thies LPM instruments can measure smaller diameter drops as they include a 0.125 to 0.25 mm bin size which the OTT Parsivel[1] does not cover. Therefore, only Thies LPM observations are plotted for that diameter range."

20. Line 300: What explanation is there for the differences being greatest at the ends of the spectrum? I would guess sensitivity differences for the Thies differences for small drops, and sampling effects for the large drops.

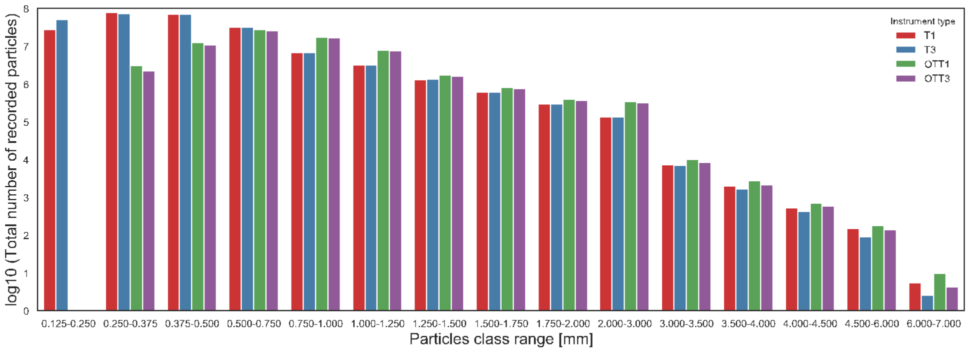
Response: Yes that is the most reasonable hypothesis. With the error (see comment below), this is even clearer for larger drops for the OTT instruments. We added a sentence such as:

"The observed differences for the lowest diameter bins are likely due to sensitivity differences between the Thies LPM instruments, while the differences for the largest diameter particle class range (6 to 7 mm) seen across all four instruments are likely due to sampling effects. The observed particles for the range 6 to 7 mm correspond to only 3 or 8 recorded minutes (out of 40,062) depending on the instrument."

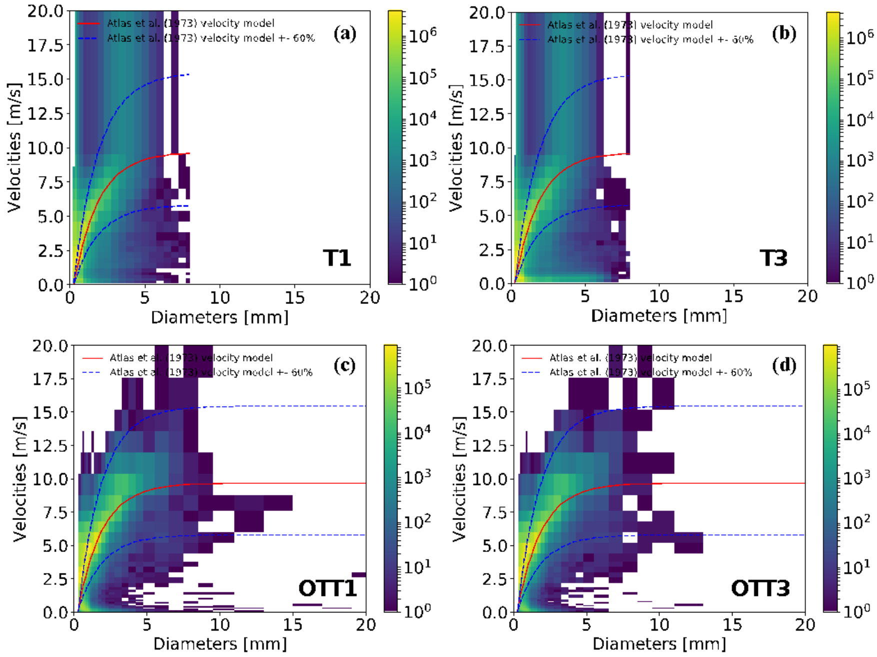
21. Figure 3: why do no Parsivels record any drops larger than 6 mm? (Were they removed, or were there simply no recorded drops by the OTTs?). This is also strange given that in the example event in the next section, OTTs record larger numbers of larger drops.

Response: In order to process the data to plot Figure 3, we had to find overlapping bin classes for the OTT and THIES instruments, as shown in Table A1 (in appendix). We realised that there was an overlapping class category missing in the Table A1 (e.g. 0.375 to 0.500 mm range). The corresponding pipeline python code therefore had the same error and that led to a shift in the corresponding bin class for the OTTs. Correcting this, the new Figure shows more particles counted for OTT1 and OTT3. Looking into the details, only 8 minutes for OTT1 and 3 minutes for OTT3 for the full dataset present particles falling into that bin class (6 to 7 mm). In Figure 6 the log scale magnifies the importance of that data.

Below is our new Figure 3:



Below is our new Figure 6:



22. Line 308: It would be useful to include the time (or at least month/season) of the event.

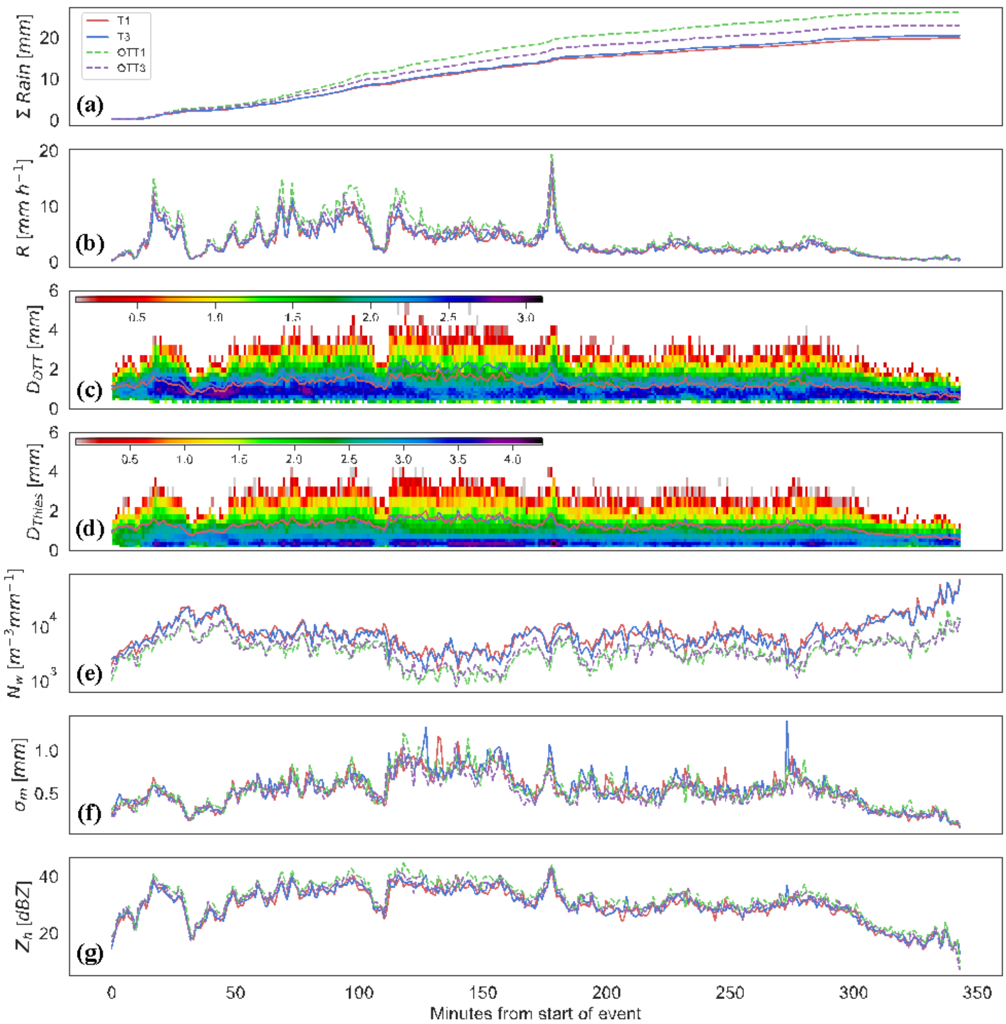
Response: The event happened on the 24th September 2014 starting in the morning at 9:09am local time (AEDT). We have now included that information in the Figure caption.

23. Line 329: Please include a reference for KDE. KDE is used to estimate probability distributions of observed variables, not to estimate the DSD parameters for each minute as written here.

Response: Thanks, a reference has been added and the text modified accordingly.

24. Figure 4: What are the lines in the density distribution plots? Please also label the plots a) to g) to match the caption.

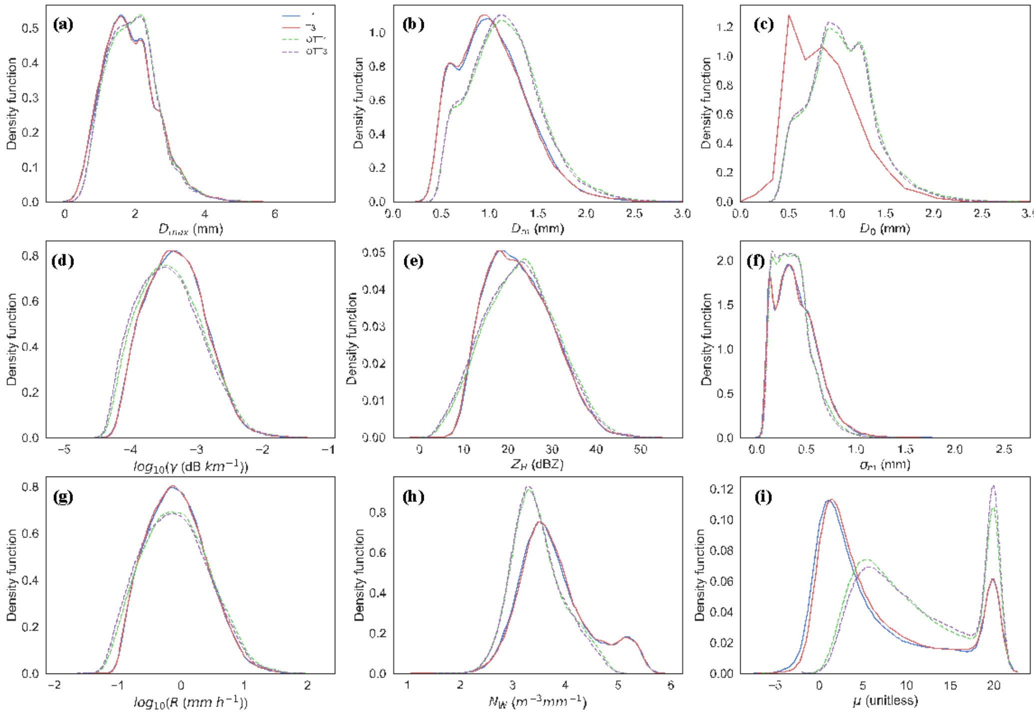
Response: The red and blue lines in the density plot represent respectively the mean diameter D_m for OTT1 and OTT3 (panel c) and T1 and T3 (panel d). The caption of the figure has been updated and labels (a) to (g) have been added to the plot. Here below is the new Figure 4:



25. Figure 5: Dmax should be defined in the text. The “spiky” density estimated for D max is presumably due to the discrete diameter classes used and would disappear if different KDE bandwidths were used. Incidentally, is Dmax here calculated on the shared classes? If not I would expect the densities to differ by instrument just because of the different class definitions.

Response: The definition of D_{max} has been added to the text next to the existing definition of D_m. We have tested different bandwidths for the KDE and modified the figures using the optimised bandwidth for each of the figures presenting KDEs (Figures 5, 7 and 8, and appendix A1, A2, A3, A4 (as shown at the end of this rebuttal)). Bandwidths used are 0.2 and 0.3 as opposed to 0.1 used previously. Given the resolution of the KDEs, class differences should have a minimal impact on the distributions, especially when the amount of data points is large enough. For the higher rain rates with fewer data points, yes, probably, the difference class definition would have an impact on the KDEs.

Here below is the new Figure 5:



26. μ and μ0 are used interchangeably here. It would be of interest to show the mean DSD per instrument (ie mean/median and bars for quantiles on N(D) by D class) to empirically show the differences in shape.

Response: μ should have been the only notation used here. These are typo that remains from a initial version of the manuscript where μ_0 was used instead.

The mean/median of N(D) by D will be very similar or identical to our current Figure 3, where we plot the total number of recorded droplet by D (common overlapping bins for the two instruments). In the manuscript, we already explore in depth the variability of the recorded droplets per bin size with the KDEs plots. Adding the quantiles for N(D) would rather be anecdotic additional information.

27. Lines 357–358: "one of the Thies LPM instruments (T3) measured a very large number of particles falling into these two categories" – I do not see this very large number of particles in Figure 6, which shows more particles outside the expected velocity ranges for OTT1 and OTT3.

Response: Figure 6 is now updated showing also the non-filtered particles (outside of the boundaries defined using Atlas et al. (1973) model of fall velocity). Our apologies for this mistake: the OTT figure was the correct version showing non-filtered and filtered while the Thies LPM were showing only the filtered particles. Figure 6 now supports this statement as you can see for T3 in particular.

28. Figure 7: Please clarify "mean diameter" as meaning DSDs with small drops removed, since "mean diameter" could be taken to discussion on lines 369–373 is confusing and requires rephrasing – is the point that the Thies instruments seem to have a lot of drops in the first class after 0.6 mm, where as the drops are more evenly distributed in the OTT cases?

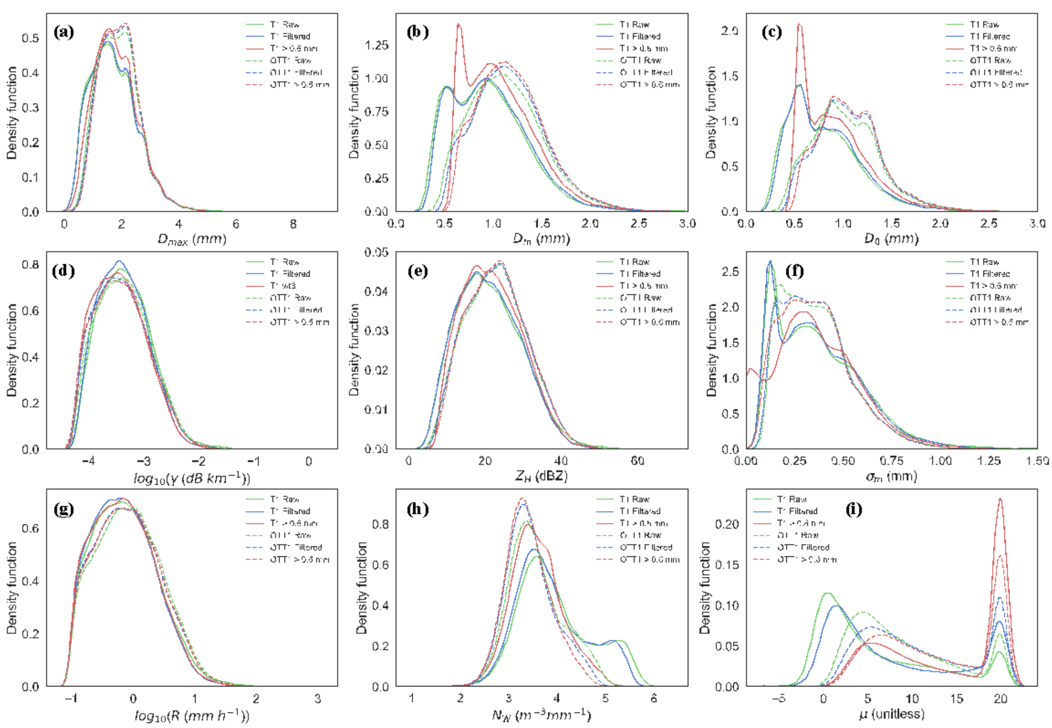
Response: it now reads “and for minute data **meeting D_m > 0.6 mm** (red).” Maybe the explanation given by the reviewer is a way to interpret the difference, but we think it would be speculative to interpret the differences in the distributions of drop per bin size… as there are many factors that can explain this: sensitivity of the instruments, differences in threshold sensitivities, manufacturer post-processing software…etc

29. Lines 374–375 and Figure 7: I interpret the plot for R in Figure 7 as showing that without the small drops there are more very low rain rates, since for example the left tail on the solid red line is left of the blue and green lines; this appears to clash with the statements made in the article text. In the OTT distributions and the T1 > 0.6 distribution there are rain rate values less than 0.1 which was stated to be the minimum allowed in these analyses. What explains these low values?

Response: Thanks very much for noticing this issue. We looked back in our code, and in the version of figure 7 we included in the manuscript the data was indeed also including rain rates < 0.1 mm/h. We have now corrected the figure such that it includes only the rain rates > 0.1 mm/h, as indicated in the manuscript method section. We revised the last sentence of the paragraph introducing Figure 7, especially in regards to the impact of the filtering on the instruments integrated variables. It now reads:

“Only the fitting parameters N_w and μ_0 as well as D_m were slightly affected for the Thies LPM. In contrast, the OTT Parsivel[1] data were less affected, as expected since the OTT Parsivel[1] recorded smaller amounts of droplets with diameter ranges < 0.6 mm.”

Here below is our new Figure 7:



30. Lines 391–392: The statement here (that differences between instruments are larger as R increases) is not supported by Figure 4, in which there is not a clear effect on the differences that correlates with the peaks in R.

Response: We have removed this sentence. The paragraph now starts directly with the subsequent sentence, which introduces the figures in the appendix and Figure 8, exploring the effect of rainfall rate on the integrated variables.

31. Lines 397–398: The statements here are not supported by the plots in Figure 8. OTT1 shows similar frequencies to OTT3 for for high reflectivity, attenuation, and R. The big difference is that in the OTT1 distributions there are more low values and less frequent mid-range values than in OTT3 distributions.

Response: We agree and have changed the sentence to:

"OTT1 showed similar frequencies to OTT3 for rain rates, reflectivity and attenuation values, but in OTT1 there were more low values and less frequent mid-range values than in OTT3 distributions. Both of the Thies LPM statistics were similar."

32. Line 398: Which variables are meant by "first order" moments here? Since high rain rates mean many drops of all sizes, the stated link between high rain rates and large-drop sampling uncertainty requires some more argument, e.g. by looking specifically at the variables influenced more by large drop occurrences Z). I think that sampling uncertainty due to sample numbers decreasing with increasing rain rates may play a much larger role than the large drops in the observed differences (e.g. there are only 129 points in Figure 8, but 29815 in Figure A1).

Response: Thanks: we have removed the terminology "first order" which was confusing. We explain in the text that the sampling effect is a factor, and we added the effect of the small sample size. It now reads:

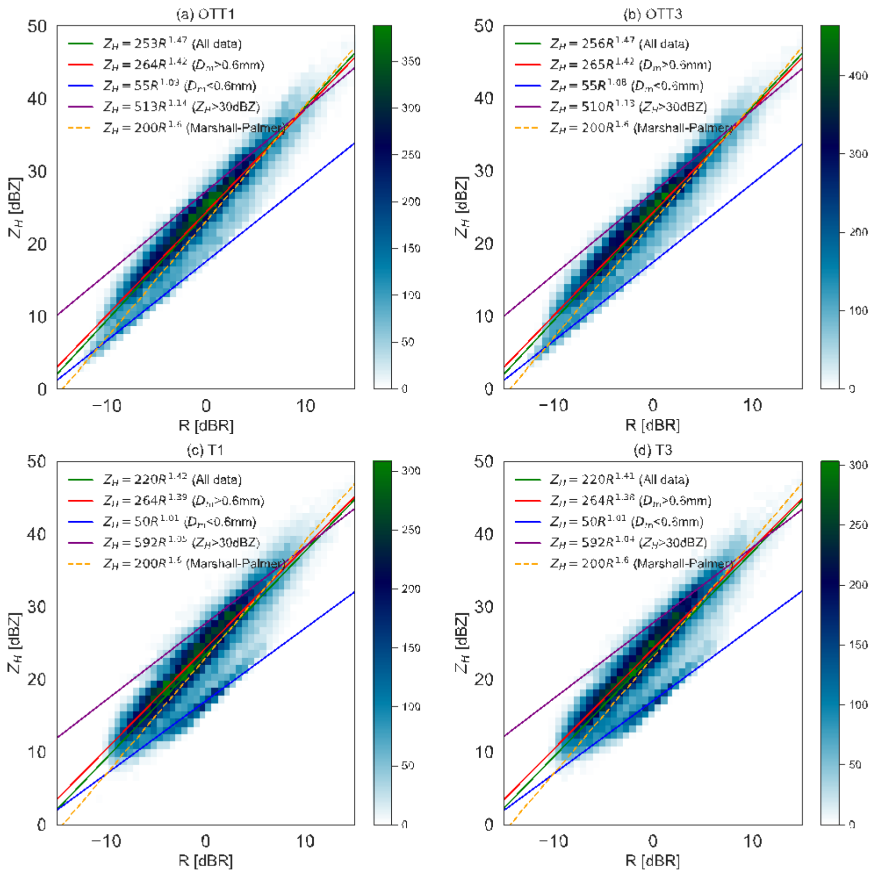
"All DSD parameters (Figure 8) started to show discrepancies between all instruments for rain rates > 10 mm h^{-1}, due to the sampling effect related to the occurrence of larger drops falling erratically in space and time, therefore being captured by some instruments while not by co-located neighbours, this being enhanced by the small data sample (128 minutes of data in Figure 8). "

33. Lines 415–419: It is not clear why it is important to separate 0.6 mm, or which previous bimodal distributions the authors are referencing. A reference to the scheme used to separate convective from stratiform regimes should be included here.

Response: Thanks, we added more information on the bimodal distributions and on the scheme used to separate convective and stratiform rainfall. It now reads:

"Figure 9 shows the scatter plots together with fitted Z_H-R relations, with the fitting for DSD done corresponding to D_m < 0.6 mm and to D_m > 0.6 mm. Indeed, in the frequency distributions seen in the previous sections, integrated parameters of the DSD showed the occurrence of bimodal distributions (for N_W, D_0 and D_m in particular). This implies that if considering the full dataset, there should be at least two corresponding power-law relations for each distribution of the data. We have now re-defined the categories as: convective rainfall (*Zh* > 30 dBZ), stratiform rainfall (*Zh* < 30 dBZ and D_m > 0.6 mm) and drizzle (D_m < 0.6 mm). These are shown in Table 3."

Here below is our new Figure 9:



34. Lines 428–430: The statement that b decreases with raindrop size diameter increases is not true when comparing the fits on the two stratiform data sets, and because all data contains the convective data it is hard to compare the results for "all" to the convective results.

Response: We realised that our definition of stratiform – and having two stratiform labelled data categories was confusing, and the likely cause of your comment. We have now re-defined the categories as: convective rainfall (*Zh* > 30 dBZ), stratiform rainfall (*Zh* < 30 dBZ and D_m > 0.6 mm) and drizzle (D_m < 0.6 mm). When comparing stratiform rainfall to convective rainfall, the statement "b decreases with raindrop size diameter increases" is correct as demonstrated in the literature to date. We then discuss the case of drizzle separately in the next paragraph.

Line 444: While true that this paper showed Thies can capture small drops related to drizzle, no estimate of the measurements' accuracy can be made without another instrument that also captures those drop sizes.

Response: Indeed: we added an additional sentence to clarify that aspect. The new sentence reads:

"The findings of this paper showed that the Thies LPM has the capacity to capture this part of the DSD spectrum, although some additional research using co-located disdrometers also capturing this lower part of the DSD spectrum will be needed to evaluate the accuracy of these Thies LPM measurements."

35. Table 4: log → were these differences calculated; i.e. for each value in the left-most column, what was the class size in dBZ? Which instrument was taken as the reference, i.e. the percentage is of which value of R?

Response: T1 was taken as the reference. We have now added this information in the table caption.

36. Figure 9: The logarithms should be the axis labels. Some brief discussion in the main text about the differences between the fitted relationships and the normal Marshall-Palmer Z-R relation should be included. Also, the b exponent in the Marshall-Palmer version is 1.6 not 1.5 as stated in the plot key; please include a reference to Marshall 1955 in the caption for this plot and clarify which relationship is shown in the plot.

Response: Reference to Marshall et al. (1955) has been added as well as the corresponding relationship in the caption of the figure. We corrected the figure box legend, with b exponent of the MP relation equal to 1.6 as well as the plotted relation on the figure (which was mistakenly plotted initially with b = 1.5). The Figure now doesn't mention the logarithms in the axis legend but specify the units of the legends as dBZ and dBR for the y- and x- axis.

We added two sentences to compare to Marshall Palmer:

(1) At the end of the first paragraph of section 3.7: "Relationships considering all data were the closest to the Marshall-Palmer relations, and differed significantly for stratiform rainfall for both instrument types."
(2) In the 4th paragraph of the same section, last sentence now reads: "Disdrometer-derived Z_H-R relations as compared to the Marshall-Palmer relation $Z_H = 200R^{1.6}$ led to a bias in rainfall rates for reflectivities of 50 dBZ of up to 21.6 mm h^{-1}."

37. Figure 11 caption: "augmented by numbers of authors since" – which authors? Please provide references.

Response: We added Marzuki et al. (2013) to the reference list, in which the authors summarise in a plot the additional observations to Bringi et al. (2003).

38. Line 544: Another possible future direction could be comparisons of Thies LPM to other instruments that, unlike Parsivel, are able to accurately measure concentrations of small drops.

Response: Thanks! We added this additional sentence to the manuscript after the first proposed research direction.

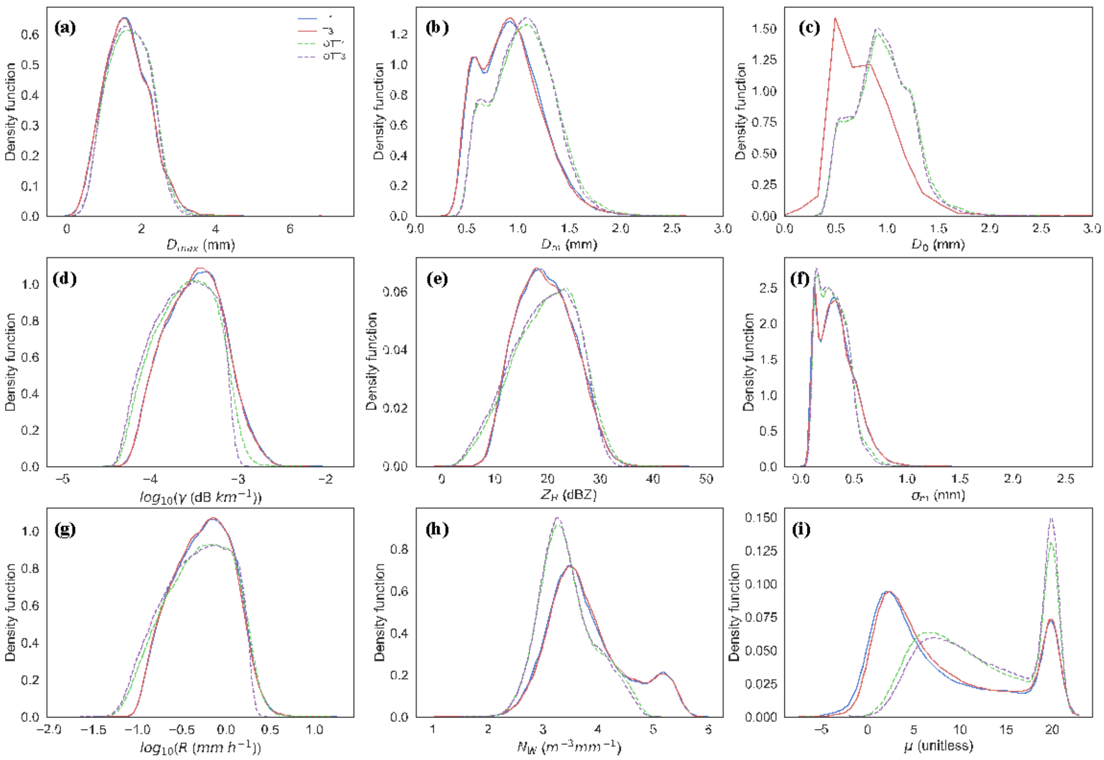
39. Line 545: The reference to Raupach et al. 2019 has year 2019 in the references list but 2018 in the text.

Response: It has now been corrected to Raupach et al. (2019) in the text.

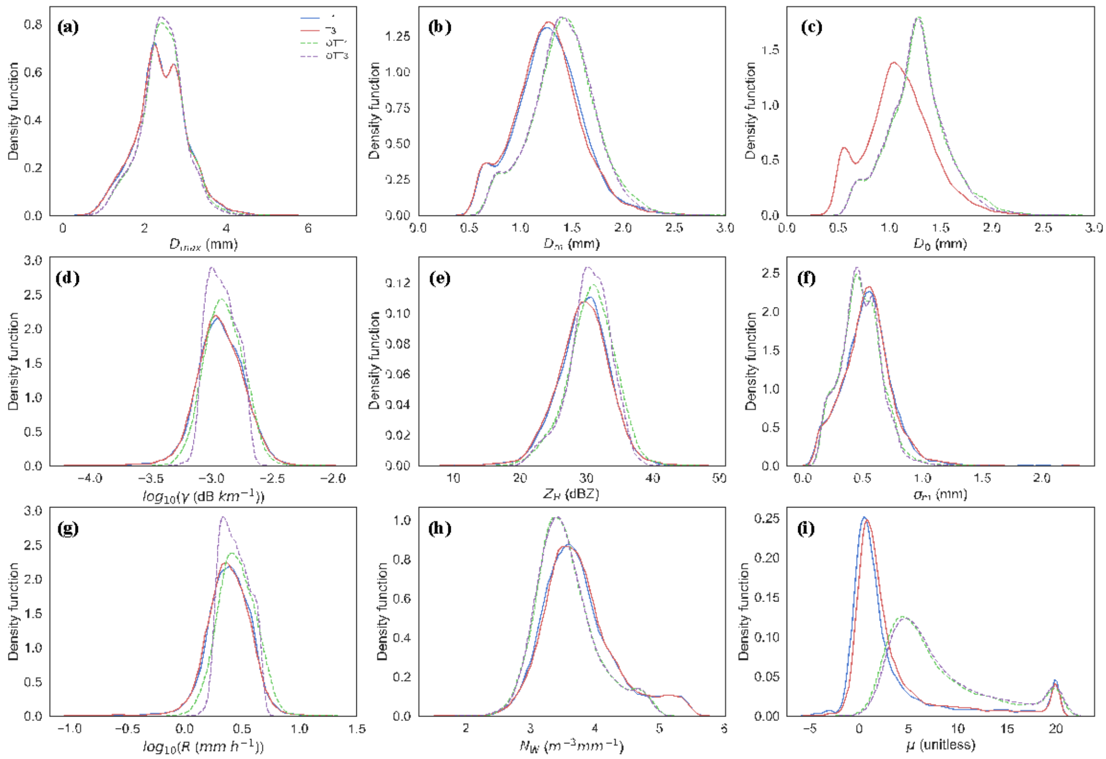
40. Lines 525–535: The appearance and discussion of Figure 11 do not fit well into this paragraph, which is ostensibly about a lack of DSD observations in Australia. Are the authors aiming to highlight the mismatch between their observations and the climate regimes shown in Figure 11? This discussion feels incomplete.

Response: We have split that original paragraph into two distinct ones: the first one starts with the original: "For the first time…" and discuss the novel observations in that climatological context.

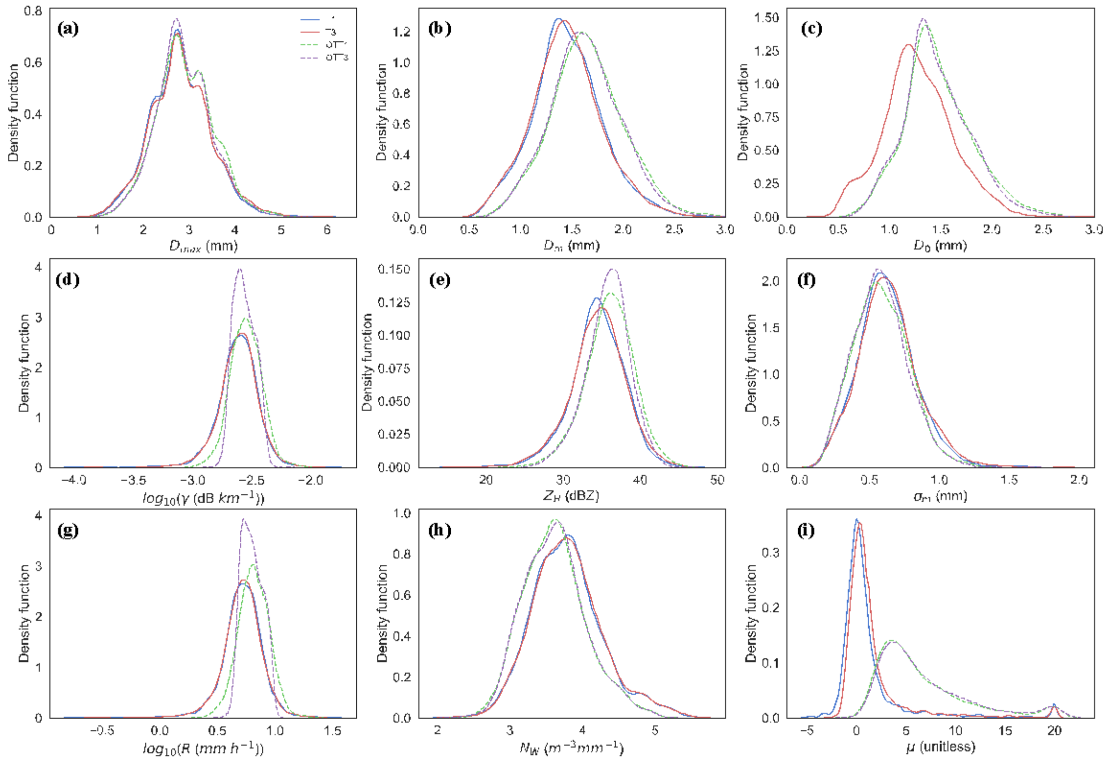
New appendix Figures as per below:



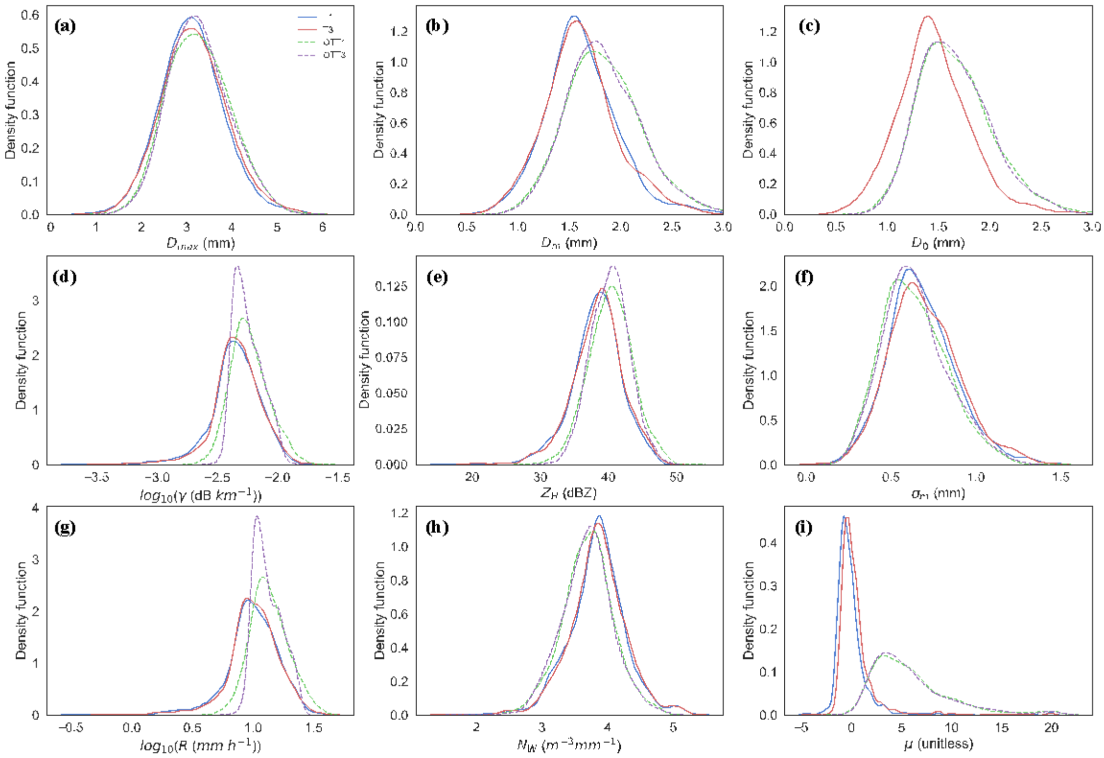
Revised Figure A1 above



Revised Figure A2 above



Revised Figure A3 above



Revised Figure A4 above