Responses to comments posted by Referee #1

We thank the referee for reviewing our manuscript and providing constructive feedback. It helped us to clarify unambiguous phrasings and the presentation of the analysis. We answer all comments in the following text. Our answers are in blue.

6: it is not very clear whether the d and z coefficients have been estimated from a different set of events or from the same events used for the analysis.

True, we complemented the text.

The changes in the original text (lines 213 ff) are in red:

… Reference rain rates were calculated as a mean of rain rates along a CML path weighted by a CML path length intersecting radar product grid cells. The parameters for all links are optimized to minimum root mean squared error (RMSE) between CML and radar rain rates at hourly timesteps. The optimization uses complete hourly observations from the same rainfall events as used in the analysis.

Lines 276-277: please specify what you mean with link sensitivity and how it is estimated.

We suggest a more detailed explanation of the meaning of CML sensitivity in the second section *CML rainfall retrieval and its uncertainty* (line 130 ff in original manuscript), where sensitivity is mentioned for the first time.

The changes in the original text (line 130 ff) are in red:

The magnitude of total rainfall estimation error and the ratio between its components is strongly related to CML sensitivity to raindrop path attenuation, which is given by CML path length, frequency, and polarization. Sensitivity is defined as a measure of change in raindrop path attenuation per change in rainfall intensity.

Figure 6 – Caption: I guess the number of collocated pairs should be 8 and not 5.

Thank you for spotting this typo. We corrected this in a revised version of the manuscript.

Figures 7 and 9: the two figures look a little confusing. I suggest to color or tag them with respect to the different pairs. In this way they could also be better referred in the main text. Moreover, I think that it could be useful two split each figure into two, providing double-mass curves of cumulative rain for stratiform and convective events separately. The starting and ending of each event could also be marked on the curves.

We introduced color-coding for individual sites. We also separated the event types in side-by plots while keeping the overall double-mass curves with distinguished CML pairs. However, indication of the starts of individual events in double mass curves did not work well. Having relatively good fit for all pairs along the diagonal and having different accumulated rainfall amounts at each site, the plots appeared to be too crowded by the event start indicators. This would work well for simple time-accumulated rainfall, but this is not the case.

The changes in the original text (line 282 ff) are in red:

To explore the systematic component of the measurement deviations, double-mass curves of cumulative rain of the CML pairs are displayed ~~(~~in Figure~~.~~ 7 (left). The lines show the main direction of the curves parallel to the diagonal, which indicates synchronized systematic errors of the independent sensors. Distinguishing the convective and stratiform events does not highlight any change in overall good fit (Fig. 7 right). However, changes in the trend of systematic errors can be observed in the course of time. For example, by the pair with highest cumulative rainfall (site 10a), link 2 observes systematically lower rain rates than link 1 up to rainfall depths around 200 mm, however, this trend then changes resulting in very low relative error between overall cumulative rainfalls at the end of the observation period. Overall, the pairs have a relative error between 0.01 and 0.18.

The new plots are below with changes in the original caption text in red:

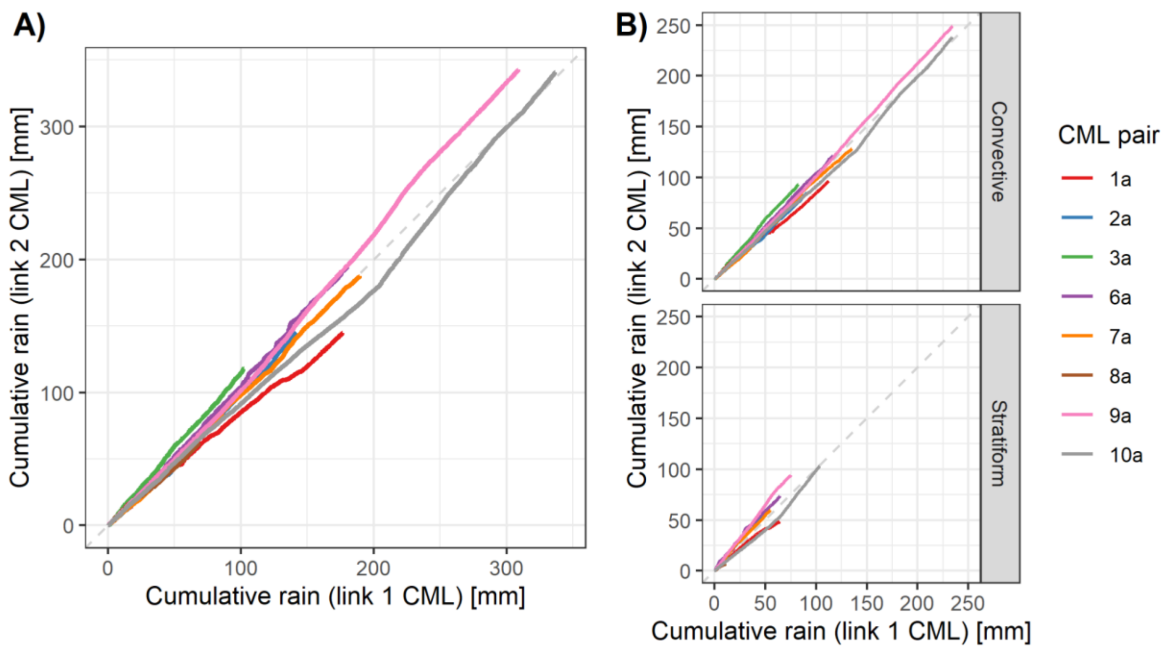

Figure 7: (left) Double-mass curve for collocated sensors operating at identical frequency bands. (right) The same, but the convective and stratiform rainfall types are separated.

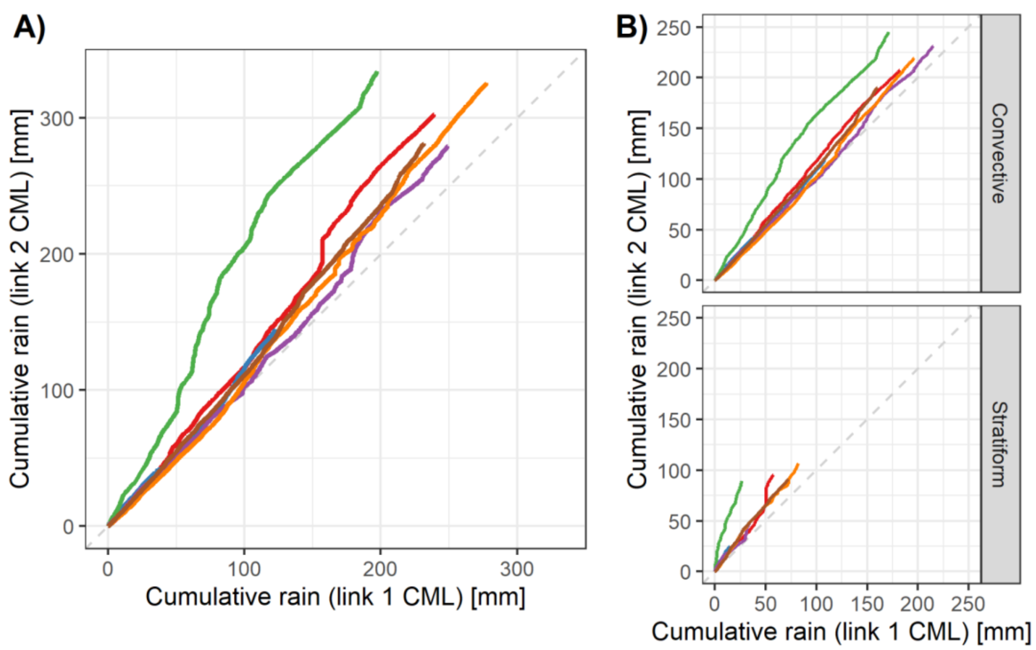

Figure 9: (left) Double-mass curve for collocated sensors operating at different frequency bands. ~~The curve, which differs the most from the line $y = x$, belongs to site 4b.~~ (right) The same, but the convective and stratiform rainfall types are separated.

Did you try to calibrate WAA parameter for every single link? In this way you would have the best WAA calibration for each link and maybe it could be possible to better identify the discrepancies in Fig. 9.

The approach of calibrating all CMLs at once comes from the cited publication of Pastorek et al. (2022), which demonstrated similar results for calibration separately for each CML and for all CMLs at once. Nevertheless, we have also tested individual CML calibration and the impact was negligible (there were both improvements and deteriorations mostly in order of 0.1 mm h^{-1}), thus the manuscript follows the data processing using calibration for all CMLs all at once.

Pastorek, J., Fencl, M., Rieckermann, J., and Bareš, V.: Precipitation estimates from commercial microwave links: Practical approaches to wet-Antenna correction, IEEE Transactions on Geoscience and Remote Sensing, vol.60, pp.1-9, https://doi.org/10.1109/TGRS.2021.3110004, 2022.

Authors could provide a table summarizing the uncertainties associated to the different sources of error (taken from literature) in order to compare them with the inherent error of rain-induced attenuation.

Investigation of the individual components of rain-induced attenuation and their uncertainties is out of scope of the manuscript. However, based on this comment we decided to shortly discuss it in the Discussion section. The rain-induced attenuation is estimated as the difference between total loss and baseline. The total loss consists of several components (Eq.

1 in the manuscript) and for their quantification and quantification of their individual uncertainties is required thorough understanding of atmospheric conditions along the path of each CML and knowledge of each sensor hardware sensitivity to such atmospheric conditions. The rain-induced attenuation error was found to be at similar magnitude as the signal quantization. Thus, the rain-induced attenuation error is minor compared to the other errors. We decided to put a brief discussion on this and its consequences in the section 5 *Discussion*.

The changes in the original text (line 345 ff) are in red:

5 Discussion

~~This section discusses the effects of different antenna hardware and evaluates the size of the dataset and data availability.~~ In general, the collocated CMLs are in excellent agreement. The rain-induced attenuation error of CML pairs operating at identical frequency bands is 0.4 dB, which is close to the signal quantization level. The random error in rain-induced attenuation is minor compared to the systematic errors. The excellent agreement between collocated CMLs of the same frequency shows that CML hardware under the same atmospheric conditions provides homogeneous measurements of rain induced attenuation.

The errors of collocated CMLs operating at different frequencies are larger. Relative errors in estimated rain rate depths are 0.12 - 0.24 compared to 0.01 - 0.18 by CMLs of identical frequency. The increase of the relative error can be partly explained by different sensitivity of k-R relation accuracy on variable DSD along a CML path. Berne and Uijlenhoet (2007) simulated this effect and reported that systematic errors in rainfall depths (compared to the true rainfall) are relatively insensitive to CML path length and, for frequency range used in this study, are decreasing with increasing frequency by approx. -0.7 mm h-1 per 1 GHz. For the collocated CMLs operating at different frequency bands, the frequency separation reaches 3 to 7 GHz, and one can thus expect DSD related bias in the range of 2 mm h-1 to 5 mm h-1. The rest of the relative error is probably attributed to the hardware and differences in WAA. As this "residual relative error" is in the similar range as by the collocated CMLs of the same frequency, we suppose that CML frequency has relatively low impact on the WAA magnitude and pattern. In general, all the collocated CMLs are affected by almost the same WAA.

The errors reported in this study are attributed to hardware inhomogeneity and have similar magnitude as the errors reported by the studies evaluating CML performance against independent reference in dedicated experiments having optimal WAA model. For example, a dedicated experiment with accurate reference along the CML path reported errors 1.4 mm h-1 to 0.7 mm h-1 (for constant WAA model to the optimal dynamic model) by 38 GHz CML mainly attributed to WAA (Schleiss et al., 2013). The errors reported in larger case studies are, however, higher. The measurement accuracy errors might be partly explained by larger hardware inhomogeneity (de Vos et al., 2019) However, substantial part of these errors is probably also attributed to the uncertainties in the reference measurements, which are difficult to quantify in large-scale evaluations and thus none of these studies explicitly accounts for them.

Other aspects affecting the performance of collocated CMLs, such as different hardware, size of the dataset and different complexity of the data processing, are discussed in the following subsections.

5.1 Effect of different hardware

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