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Interactive comment

Interactive comment on "Gauge-Adjusted Rainfall Estimates from Commercial Microwave Links" *by* Martin Fencl et al.

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General comments

<u>Reviewer:</u> *The manuscript provides methods for adjusting rainfall estimates from commercial microwave links (CMLs) to rain gauges (RGs). It compares different temporal scales for adjustment and different layouts of gauge/CML systems. The work is novel and addresses very relevant issues in high resolution rainfall estimation in urban areas. It is well written and understandable and would fit well into the scope of HESS. Although not an expert in CMLs (but in radar rainfall estimation), I have some comments and suggestions which in my opinion could improve the manuscript.*

<u>Authors:</u> First, we would like to thank reviewer for all the remarks and recommendations

how to complete the manuscript and improve its clarity. Clearly, an expert on weather radars experienced in adjusting to rain gauges can give substantial advice.

Specific comments

1. It is unclear whether the paper aims for on-line (real-time) adjustment of CML's and thus real-time rainfall estimation or to estimate historical rainfall. Real-time adjustment would be associated with larger uncertainties.

In our analysis we assess the method in the setting for historical rainfalls. However, the method does not "look into future" when continuously adjusting model (2), but uses rainfall intensity from the time point for which the adjustment is done and then from several time points in the past (P7L14-24). Thus, method can be used with additional tuning in near real-time setting.

To have a better evidence base, we performed additional analyses where CML rainfall retrieval model is continuously adjusted based only on past data. The results of these analyses confirmed that use of the method in real-time setting leads to only slightly worse CML performance in comparison to the original analysis. We therefore suggest to explicitly state in the section 2.6 that we assess the method in the setting for historical rainfalls and discuss the use of the method for real-time setting in the Discussion section.

2. P4L31-P5L3: This is almost a conclusion of the paper. It does not belong in an introduction – but could be applied in the abstract.

Thank you for this comment. In our view, this paragraph improves the understandability and clarity of a manuscript to i) have a very specific message and ii) convey the message to the reader. This can include explicitly stating the novelty of the work, but also concrete results. Then, a reader is not left in the dark what to expect and will not have major surprises - which are always confusing - during reading. As the abstract is too short, this info can go into the introduction. In our view, the redundancy of information-pieces (twice mentioned in the abstract and the intro) is a small price to pay for the increased clarity.

3. In section 2, it should be argued why two different experimental sites are used. Could the same results not have been derived using only one site – or is there an objective to compare the two sites in terms of data, layout, etc.

Thank you for this comment. The reasons behind using data from two sites are distributed over the two sections 2.1.1 and 2.1.2 (differences in operational mode P5L16-17, P5L22-24, P6L1-2, or P6L12-13) and they include different reference rainfall data and power-control settings of CMLs on each of the sites. We agree that this is sub-optimal. We suggest to briefly mention our main reasons in the introductory paragraph of the section 2.1: "We deliberately analyze datasets from two different experimental sites. This enables us to test the feasibility of the proposed approach on CMLs operated with and without automatic power control. Moreover, the dataset from Dübenbdorf contains detailed reference rainfall measurements along a CML path, which provide very good basis for investigating specifics of a rainfall from a single CML. In contrast, the areal rainfall observations from Prague are more appropriate to analyze rainfall retrieval from multiple CMLs, which is also more relevant to evaluate the proposed adjusting method for common urban hydrological applications."

4. During the paper it is also a bit confusing where averages of CMLs are used (in Prague) and when single CMLs are used. Please be clearer on this.

Thanks, we now see that this information is indeed missing in the method section (2.6 performance assessment), but we present it in the Result section (P93-4 and P9L31-P10L3) instead. We will therefore improve section 2.6., P9, line 19.

5. P6 bottom. It is unclear how you define an event. This is not necessarily an easy task operating with more than one rain sensor. Please clarify.

The events at both experimental sites are first defined from each of the sensors and then the event periods are merged by simply increasing the duration to include the very first and the very last observation of a sensor. In the case of Dübendorf the events were defined based on disdrometer classification. In the case of Prague, events were defined from reference RG measurements. The beginning of an event is assumed to be 15 minutes before the first tip of RG and end of event 15 minutes after the last tip. In addition, the beginnings and ends of the events in Prague area were rounded (down resp. up) to full hours to ease the analysis with aggregated rainfall intensities. At both sites two rainy periods separated by shorter interval than 30 minutes are assumed to be the same event.

We will add an information about event definition at the end of the paragraph in section 2.3. Note, however, that adjusting is performed over whole experimental period and thus it is independent of event definition. The event definition therefore influences the performance evaluation, i.e. by the (non-)selection of events.

6. Section 2.6. You state that you adjust on different aggregation levels ranging from 5 min to 1 day, but compare on 1 minute values. Couldn't there be reason also to compare on larger aggregation levels than 1 min. It is well known that for small rain intensities rain gauges are not very accurate. E.g. one tip of 0.1 mm per minute in a tipping bucket rain gauge corresponds to 6 mm/h. An error of +/- 6 mm/h on gauge estimates over one minute for intensities larger than 6 mm/h, it therefore not unrealistic. For smaller intensities where the intensities are estimated using the time between two tips, the intensity at minute scale might be somewhat uncertain. In a paper (Thorndahl et al. 2014) we made radar-rain gauge adjustment over different temporal scales, but also compared the results over different scales. Maybe you could find some inspiration here.

Thank you for this suggestion. We used one minute reference data because this is the temporal resolution required for rainfall-runoff modeling at the scale of small urban catchments and our long-term intention is to provide rainfall data which could be used for this purpose. In the case of Dubendorf site, disdrometers are very well suited for providing rainfall data at 1 min resolution. The sampling error of tipping bucket RGs in Prague is partly reduced by calculating areal rainfall from six RGs relatively close to each other. Nevertheless, we agree that this sampling error may influence R^2 values. We have therefore compared rainfall estimates from CML data also at other temporal scales (Fig 1, this response).

We find only small changes in R^2 values when comparing CML rainfall to reference rainfall at larger temporal scales. This indicates that the analysis even at 1 min scale is not substantially influenced by random errors. Interestingly, we see a slight increase in R^2 values for larger temporal scales of reference rainfall, although aggregation should reduce RG sampling errors. In our view, giving a larger weight to the RG data in the adjusting procedure increases the R^2, because the temporal scale of reference rainfall gets closer to the aggregation interval used for CML adjusting (for details see comment no. 11 of the reviewer 1). The results presented here do not, however, change our conclusions drawn in the original manuscript where we only presented the performance for 1 minute data.

7. With regards to estimating area rainfall (section 2.2 and 3.2) I guess results are still compared on the minute scale and adjustment is performed on larges temporal scales. I guess this will be associated with many random errors if there is rain in one gauge and not in another? Again I suggest to also comparing e.g. hourly estimates of Rainfall.

Yes, the discrepancy between rainfall measured by those RG layouts which were used for adjusting and those used for validation purposes (reference rainfall), indeed influences the performance of the adjusting procedure. Here, we reduce these errors by aggregating the RG data used for adjusting to longer intervals (up to 1 h). The performance of the procedure is then evaluated by comparing adjusted CMLs to the reference rainfall (i.e. RGs in the catchment). Thus, all rainfall observation errors which stem from RG layouts (including instrumental errors, sampling errors and limited spatial representativeness of point RG measurements) are implicitly included in the evaluation. The comparison at larger time scales would indeed reduce the sampling error in reference rainfall. However, as discussed in the reply above, their influence on the performance is small. Moreover, our adjusting procedure is only relevant where the temporal scale of reference rainfall (resp. adjusted rainfall) is finer than the aggregation interval used for CML adjusting. As we identified in our analysis that optimal aggregation intervals for the evaluated RG layouts are relatively short (15 min for layouts A1 resp. B1 and 1 h for layout B2), the comparison to e.g. hourly estimates is not useful.

8. Related to my comment no 4. I think it would be interesting to see a scatter plot of a single CML vs a single RG and how R^2 would depend on the range between CML and RG?

Thank you for this suggestion. Unfortunately, although this might be an interesting analysis our experimental layout is not suitable for that. Each CML included in the analysis (see Fig. 1 in the manuscript) has different features (lengths, frequencies, polarizations) which considerably influences its performance in terms of rainfall estimation. The differences between single CMLs and a corresponding RG would be dominated by these differences. In our experience, the discrepancy between path integrated and point measured rainfall usually dominates the discrepancy due to different locations of the CML and the RG.

9. For the Dübendorf site it is unclear what you use the disdrometers for. Don't you use the RGs for adjustment/validation? Related to the problem above, disdrometers might be more accurate for small rain intensities?!

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Thank you, we will modify the sentence at P5L24-26 to: "In addition to the five disdrometers used in our analyses to retrieve reference rainfall, three tipping bucket RGs measure rainfall intensities, which makes it possible to validate the disdrometer data."

10. P9L18-19. A likely reason for the smaller scatter on the 1 day aggregation levels might be found in the fact that all of your events (except one) have duration shorter than 1 day. Thus, for some events same results for 12 and 24 h should be expected!

In our study we adjusted each CML over the whole experimental period, although it is evaluated only on events listed in the table 1. Thus for longer aggregation intervals also other events (with heights lower than 5 mm) influence the adjusting. This is also one of the reasons why CML adjusted with 12 h aggregation interval have different scatter than adjusted to 1 d aggregation interval. We will write more clearly that CMLs are adjusted over the whole experimental periods in the section 2.6, performance assessment.

11. Figure 1. Please use lat/long or UTM rather than a local coordinate system.

Thank you for the suggestion. We will change it as shown in the Fig. 2 in this response.

References:

Thorndahl, S., Nielsen, J.E., Rasmussen, M.R., 2014. Bias adjustment and advection interpolation of long-term high resolution radar rainfall series. Journal of Hydrology 508, 214–226. doi:10.1016/j.jhydrol.2013.10.056

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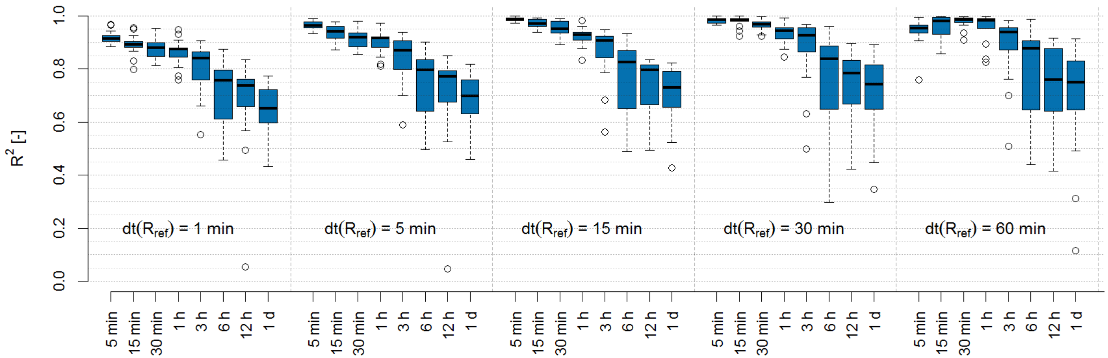

Fig. 1. Comparison of R^2 for different temporal aggregations of reference rainfall. Mean of four CMLs (see figure 2 of the original manuscript) adjusted to rainfall having different aggregation intervals

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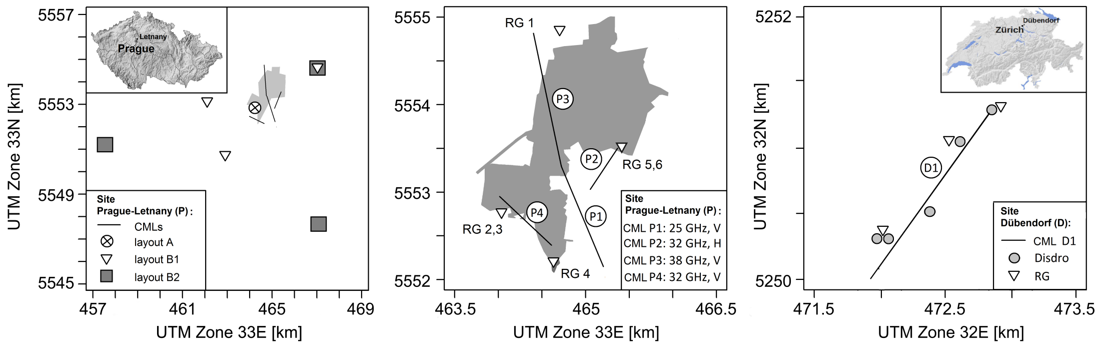

Fig. 2. Experimental layouts projected into UTM coordinate system.