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Hydrology and Earth System Sciences
Discussions

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Interactive comment

Interactive comment on "Improving the precipitation accumulation analysis using radar-, gauge- and lightning measurements" *by* E. Gregow et al.

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This paper describes an assessment of the quality of quantitative rainfall estimates using a combination radar, cloud-to-ground lightning, and rain gauge data. The effect of adding GC lightning data to radar data on rainfall accumulations is investigated, both before and after gauge adjustment. In these analyses, several methods of estimating relations between lightning activity and rain intensity are utilized. Furthermore, the effect of the length of the accumulation interval used for gauge adjustment is also

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studied. The paper is interesting, and its topic relevant. It is not entirely clear to me what the main goal of this paper is. I think that the paper could benefit from a clearer description of what its main goals are, how the analyses that are presented contribute to these goals, and coming back to these goals in the Discussions and Conclusions section. When reading the paper for the first time I was sometimes confused because new analyses are proposed in the Results section and some of the methods described in the Methods section were not entirely clear to me. Hence, the paper could benefit from some restructuring, where all methods that are used are presented clearly in the Methods section. I think that the paper needs major revisions in order for it to be suitable for publication. More specific remarks are given below.

AUTHORS: The authors want to thank the reviewer for the professional and thorough revision of this paper. The paper has undergone a significant reorganization and has now a better structure. Please see the new updated article version, attached as Supplement.

Specific comments

1. Section 1, Given the fact that there are not very many lightning strikes in Finland, how much would you expect that adding this information would influence the final rainfall estimates? I think that this should be thoroughly discussed in the introduction of the paper.

AUTHORS ANSWER: Yes, it is correct that due to low lighting frequency in Finland the quantitative effect during a year is small. But the goal is to improve the quality of the few (but important) existing intense precipitation cases (i.e. causing flash floods etc). Here the LDA method have an impact, since the largest uncertainties took place during heavy rainfall (i.e. convective weather situations and lightning; Gregow et al., 2013). We have added text related to this in the Introduction section: “Radar reflectivity can in some cases suffer from poor quality, resulting from electronic mis-calibration, beam blocking, clutter, attenuation and overhanging precipitation (Saltikoff et al., 2010). In some cases the radar can even be missing, due to upgrading or technical problems. Thunderstorms add probability of many of these problems in form of interruptions in electicity and telecommunications, and attenuation due to intervening heavy precipitation. In general, combining radar and rain gauge data is very difficult in the vicinity of heavy, local rain cells (Einfalt et al., 2005)." Also, the intention is to enlarge the analysis area to whole Scandinavia. For this reason the LDA will have a larger contribution to the precipitaion accumulation analysis, since there are gaps in radar coverage for this area and the retrieval of data is not always stable (i.e. radars can be missing more frequently from neighbouring countries). This is mentioned in the Introduction with following text: "Our situation is different from the above mentioned experiments because lightning activity is usually low in Finland, compared to warmer climates (Mäkelä et al., 2011). Also, our analysis area already has a good radar coverage and relatively evenly distributed network of 1 hour gauge measurements. However, if we want to enlarge the analysis area, we will soon go to either sea areas or neighbouring countries where availability of radar data and frequent gauge measurements is low. Our principal goal is to have as good analysis as possible, which is different from having a best analysis to start a model."

2. Section 3.3, It's not entirely clear how radar and lightning data are merged to come up with a final rainfall estimate. Did I understand correctly that the number of recorded GC lightning strikes within a LAPS pixel (3x3 km) and in a 5-minute interval are counted. These counts are then related to a vertical reflectivity profile, and subsequently the maximum of the radar reflectivity and the 'lightning reflectivity' are taken at a given height. The rainfall estimate is then based on the lowest data point. In practice, this means that the rainfall estimate is based on the maximum of the lowest-level radar reflectivity and the lowest-level 'lightning reflectivity'. If this is indeed the case, the description of the method to estimate rain rates could be simplified and clarified. If not, I recommend clarifying this section.

AUTHORS ANSWER: Sections 3.2 and 3.3 are now merged. The text is reorganized and we have clarified the process better.

3. l.137-149, Given the fact that lightning only occurs in convective situations, it would make sense to me if a Z-R relation specifically derived for convective rain is used wherever lightning is observed. This would be a simple addition to the LDA that could improve results even further.

AUTHORS ANSWER: Thank you, this is a very good suggestion. This article presents the first results in an on-going process of developing the LAPS-LDA system at FMI. We have thought of different ways to improve the system, learned much during this study and the plan is to implement new routines, in future versions of LAPS-LDA system. The suggestion by reviewer is clearly one that should be considered then.

4. l.174-177, the rationale behind the regression part of the RandB method is that radar rainfall estimates often suffer from large-scale multiplicative biases, and that using regression on radar and gauge data can correct for this error. When adding lightning data to radar data, the errors are likely to be very different, and this could have a large effect on the final rainfall estimates. Something similar can be said for the Barnes-part of the RandB method, where the influence of a gauge correction is in general relatively large compared to the area affected by lightning. I therefore strongly suggest to add a discussion of this in the paper.

AUTHORS ANSWER: We agree that this is a simplification of mixing different scale-processes. In the Introduction we included following text: “Lightning is associated with convective precipitation, but in areas where a large portion of precipitation is stratiform, lightning data alone is not adequate for precipitation estimation. However, lightning has been used to complement and improve other datasets. Morales and Agnastou (2003) combined lightning with satellite-based measurements to distinguish between convective and stratiform precipitation area and achieved a remarkable 31% bias reduction, compared to satellite-only techniques. Lightning has also been assimilated to numerical weather prediction models to improve the initialization process of the model. This

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can be done by blending them with other remote sensing data to create heating profiles (e.g. estimating the latent heat release when precipitation is condensed). Papadopulos et al. (2005) used lightning data to identify convective areas and then modified the model humidity profiles, allowing the model to produce convection and release latent heat using its own convective parameterization scheme. They combined lightning with 6-hourly gauge data, within a mesoscale model in the Mediterraiean area, and showed improvement in forecasts up to 12 hours lead time." And we added text about this in the discussions section: "In the RandB-method the Regression is used to correct for large-scale multiplicative biases between radar and gauge data. In this article we introduce lightning into the RandB-method, as an additional data source. However, lightning errors are likely to be different from those of radar and gauges and this could have an effect on the methodology used here. In future developments, after collecting longer time series to quantify the nature of uncertainty of lightning-based precipitation estimates, we intend to improve the analysis in this direction."

5. l.176-177, What does it mean that Rad_LDA_Accum is the reference?

AUTHORS ANSWER: This sentence (now in Sect. 4.2) is changed to: "Note that Rad_LDA_Accum (e.g. a method not using RandB, as an reference) is included when comparing the results of different integration periods."

6. Section 4, Why are the graphs where rainfall intensities are compared plotted on log-log scales? If the aim is to study the performance of quantitative precipitation estimation algorithms for high intensities (as is stated in the paper), it would make most sense to me if these graphs were plotted using linear axes.

AUTHORS ANSWER: Yes, the intention is to increase the readability of high precipitation values but without disturbing the overal readability. Plotting the values on linear axes will decrease the readability of the low-middle values. The log-log scales was the best way we could produce these plots (according to us), after testing different plotting techniques (see below). Therefore we suggest to keep Figs. 5 and 7 with log-scales.

As an example we plot Fig. 5 in log-scale vs linear-scale (please see the attached Fig. 1). And it is the same with Fig. 4 and 8, the visualization of data is more clear with log-scales. Here we show Fig. 4a with log-scale vs linear-scale (please see the attached Fig. 2).

7. l.187-188, what exactly is meant by “the averaged (i.e. 50%-percentile) Rad-Lig reflectivity profiles from the LDA-method.”? How were these profiles determined, and based on what data? I think this should be discussed in the Methods section.

AUTHORS ANSWER: It is now moved into Methods, Sect. 3.2 (merged and changed with other sections). The related text now reads: “For this study over Finland, climatological Rad-Lig reflectivity relationship profiles were estimated using NORDLIS-LLS lightning information and operational radar volume data from Finland area, during summer 2014. A total of approximately 220’000 lightning strokes were used for this calibration. The FMI-LAPS LDA is using 5 minutes interval of lightning- and radar data, within a LAPS grid-box of resolution 3*3 km. The collected strokes are divided into binned categories using an exponential division (i.e. 2n...2n+1), following the same method used in Pessi (2013). This result in 6 different lightning categories (e.g. with 1, 2-3, 4-7, 8-15, 16-31 and 32-63 strokes) for the NORDLIS-LLS dataset. For each of these 6 categories, the average radar reflectivity profile is calculated and gives the Average Rad-Lig profiles (Fig. 3a), which is the baseline method. We extend this method to also calculate the 3’rd Quartile (i.e. 75%-percentile) and a Variable Quartile Rad-Lig profiles. The Variable Quartile method uses a range between 50%-percentile (for the lower dBZ values) up to the 95%-percentile (for the highest dBZ values).”

In this answer (to reviewer) we also provide a plot which visualize the process. For each category we collect the relevant radar reflectivity profiles. From these selections of profiles, the average is calculted and further used as the LDA-lightning profile (please see the attached Fig. 3).

8. l.192-200, I suggest to remove the R2 statistic, because it is simply the correlation

coefficient squared (see Eqs (6) and (7)) and it hence doesn't add any information relative to CORR.

AUTHORS ANSWER: We have now removed the R2 statistics from the text and tables.

9. l.202-207, The panels of Fig. 4 with LDA added (i.e. panels b and d) do not really add any information, as they are extremely similar to panels a and c, respectively. I therefore suggest making a remark in the text about this, and removing either panels a and c, or panels b and d.

AUTHORS ANSWER: We have added this into Discussion: "The accumulation products generated from RandB-method are corrected using gauge information. This process is influencing the final accumulation results much more than the contribution from the LDA-method (seen in Fig. 4 results from dependent dataset, where a, c and b, d panels, respectively, are almost identical). The same result was seen for the independent dataset." We suggest to keep Fig. 4 as it is. Removing either a,c- or b,d-panels, only mentioning this in the text, would most probably result in contradicting comments by other reviewers (i.e. that this should be shown with figures).

10. l.208-212, I would strongly suggest using different gauges for the independent measurements to test whether using LDA improves rain estimates, because this is what I understand the main objective of this paper to be.

AUTHORS ANSWER: The verification in this article was performed during operational LAPS runs (i.e. products are used within end-users applications). Seven independent stations were pre-selected (from different parts of Finland). Because of this we could not set more stations aside, without risking the quality of the end product. Re-running longer periods with different independent stations, manually set for each event and re-generate the extensive input datasets (retrieval/extraction of data, format conversions etc), would require resources not available. By running the operational system for whole summer, we intended to retrieve a large statistical sample for verification. Unfortunately, summer 2015 was a period with very small amount of lightning cases.

This restriction is now mentioned and explained in the Introduction: “The work reported here has been performed using the operational Local Analysis and Prediction System (LAPS), which is used in the wether service of Finnish Meteorological Institute (FMI). Testing new approaches in an operational system has its limitations in e.g. excluding independent reference stations. Also the possibilities to rerun cases with different settings have been limited. The benefit of the approach is that we can be sure that we only use data which is operationally available.”

11. l.209-210, The use of a 25-day subset is introduced here. I suggest introducing this earlier in the paper (the Methods section). And if this subset is used, what is the added value of using the 4-day subset? I think the clarity of the paper would improve if either the 4-day or the 25-day subset is used.

AUTHORS ANSWER: The lightning information is local in terms of time (e.g. also in space). Therefore, the potential effects of the use of LDA is not detected when long periods (seasonal) are used for the assessment, as they are masked out. We are trying to show this by using different verification periods (summer-, 25- and down to the 4-days periods). The 4-days subset (for which we have saved all the extensive input data) also fills another purpose, namely being able to rerun and test different developments (such as the verification of average-, 3'rd- and Variable Quartile Rad-Lig profiles). The paper has undergone many changes and is reorganized. We now introduce the 25-day subset in Methods, Sect. 3.4, together with the other periods, as follows: “The verification periods consists of one long period ranging from 1 April to 1 September, 2015 (i.e. to avoid the winter season and snow precipitation). This dataset includes many precipitating cases without lightning and therefore, the effective impact by lightning is diluted (e.g. no influence by the LDA-method). Therefore, a subset of 25 days with frequent lightning (e.g. > 100 CG strokes/day) were selected from summer 2015. Additionally, in order to perform several autonomous experiments with the FMI-LAPS LDA system, a dataset consisting of four days with heavy rain and strong convection were used: 03, 23, 24 and 30 of July 2014 (hereafter 4-days period). These were the 4 days with highest lightning intensity (e.g. > 100 strokes/day) in Finland, during year 2014."

12. l.225-238, It's unclear to me how the new profiles are exactly generated. I strongly suggest to include a good description of this in the Methods section (preferably in Section 3.2).

AUTHORS ANSWER: Please, also see reply to comment 7 here above. We have now moved and merged sections. The description of Rad-Lig relationship profiles is now better explained in Sect. 3.2.

13. l.240-245, Why not test sub-hourly scales?

AUTHORS ANSWER: The gauge information is available as 1 hour accumulation, from our FMI real-time database, and this is used in our operational runs. Therefore, the time resolution for analyzed accumulation is bound to be on hourly data.

Minor remarks

1. l.16, replace "such as;" by "such as" (remove semicolon)

AUTHORS ANSWER: This is done.

2. l.17, replace "eceonomically" by "economically"

AUTHORS ANSWER: This is done.

3. l.39, replace "leass" by "less"

AUTHORS ANSWER: This is done.

4. l.41, what is meant by "a timely accurate manner"?

AUTHORS ANSWER: This is changed to "...timely manner (i.e. near real-time).".

5. l.133, replace "resulting from;" by "resulting from" (remove semicolon)

AUTHORS ANSWER: This is done.

6. l.133-134, consider including clutter as an important source of error

AUTHORS ANSWER: Clutter has been added to the sentence.

7. l.144-145, do you mean to say here that convective rain is important for flooding events? I so, I suggest changing “such situations” to “convective events”. The first time I read this sentence I interpreted “such situations” to be the drizzle that is mentioned in the previous sentence.

AUTHORS ANSWER: Yes, this is what we meant and it is now changed to “convective events”.

8. l.187, the 50th percentile is not the average, but the median, and it is either the 50th percentile or the 50% quantile. So I suggest replacing “averaged (i.e. 50%- percentile)” by “median (i.e. 50% quantile).”

AUTHORS ANSWER: Correct, well spotted. We have remove the “(i.e. 50%-percentile)” here and in other places in the text, where this occur.

9. l.192, I suggest calling STDEV “relative standard deviation” or “logarithmic standard deviation” to make clear that it is different from a regular standard deviation.

AUTHORS ANSWER: We have now changed this to read “the logarithmic standard deviation”.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-113/hess-2016-113-AC2-supplement.pdf

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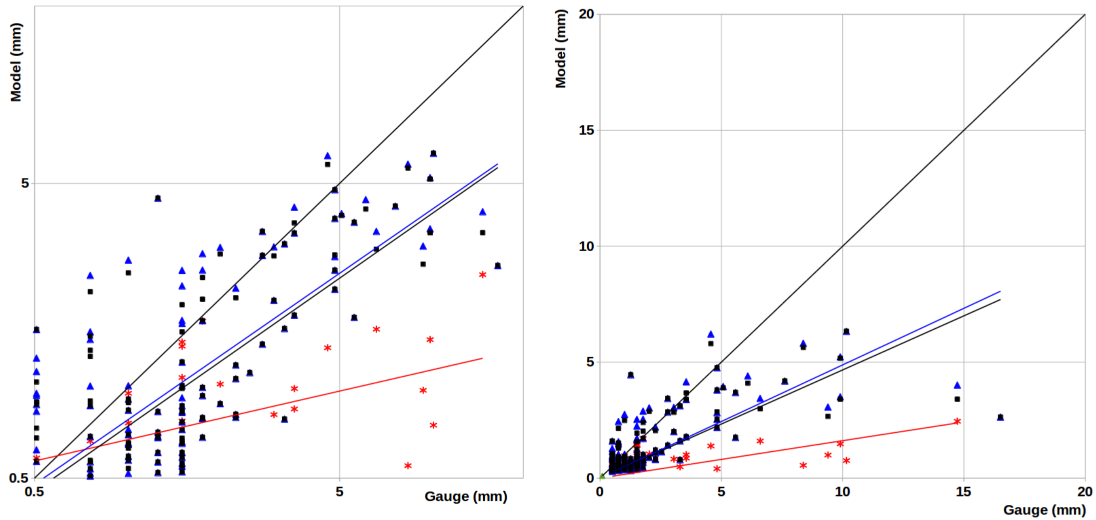

Fig. 1. Refers to comment 6)

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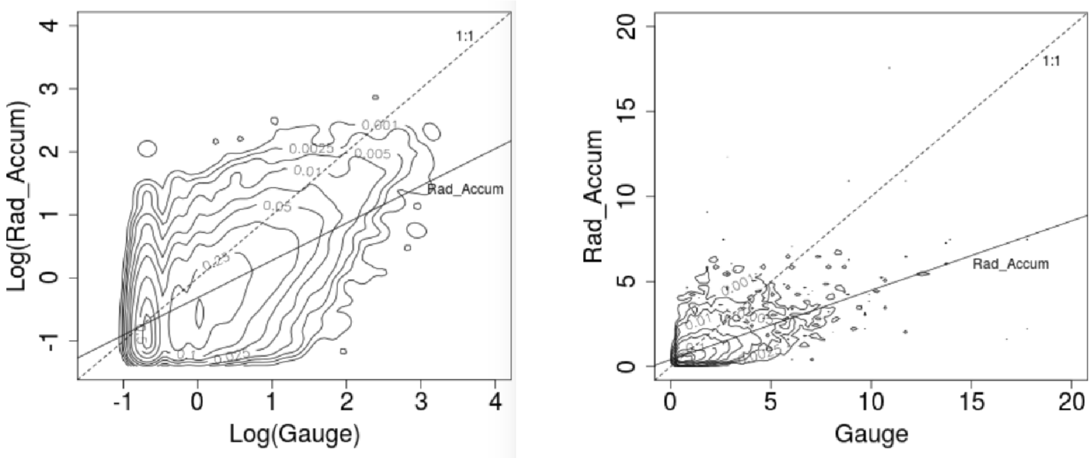

Fig. 2. Refers to comment 6)

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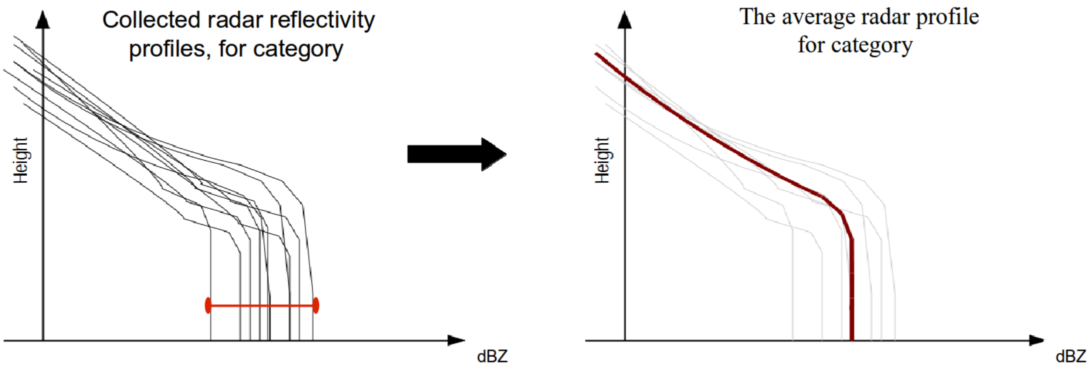

Fig. 3. Refers to comment 7)

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