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Discussions

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 explores the use of cloud-to-ground lightening data for improving radar-based (and raingauge-adjusted radar-based) precipitation estimation, with a focus on high intensity, convective storms. The study includes an evaluation of resulting rainfall estimates at different temporal accumulations.

The topic of the paper is interesting and the results are potentially useful. However, the paper has a number of major flaws which should be addressed before it can be

published.

AUTHORS: The authors want to thank the reviewer for the professional and thorough revision of this paper. The new updated article version is attached as Supplement (see PDF-file).

General comments / major flaws:

- The structure of the article is rather unorganised and the description of data, methods and results are often unclear. The description of the way in which lightening and radar data are merged is very unclear (and bits and pieces of the methodology are spread throughout several sections of the paper), descriptions of the methods are included in the data and results sections, amongst other things (more details are provided below).

AUTHORS ANSWER: Also other reviewers have commented on this and therefore the article has now been reorganized in several ways: - Methodology is now better collected into Sect. 3 (moved text from Sect. 4, merged 3.2 with 3.3 etc). - Lightning and radar merging is now better explained. - Result section is now more asserted and concise. - Plus many other changes (see below comments). We believe this has improved the readablilty and objectives of the paper.

- The fact that only 7 independent rain gauges are used for evaluation renders the results statistically weak. This issue is so critical that in one of the cases (Table 2), there are simply no data available for evaluation from any of the independent gauges. Why out of 472 available rain gauges would you only select 7 for independent evaluation? I am aware that you also present the results of performance statistics at nonindependent rain gauge locations; however, I truly believe that more interesting results could be achieved if either more independent rain gauges were used or if a crossvalidation approach were implemented.

AUTHORS ANSWER: The results in this article were performed during operational LAPS runs, we could not set more stations aside, without risking the quality of the endusers products and applications. This is now mentioned in the introduction section: "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." Unfortunately the summer of 2015 had an unusually low frequency of lightning, which limited the statistics for this study.

- The results, as currently presented, are too vague and far from the objectives initially set in the abstract and introduction. As stated in the title of the paper, you aim at "improving precipitation accumulation analysis using radar, gauge and lightening measurements". Throughout the paper, the focus is mostly on the added value of lightening data, which does not really lead to significant improvements in radar-based QPEs, let alone gauge-based adjusted radar QPEs. One option would be to change the focus (and consequently the title) of the paper to "the added value of lightening measurements" for generation of QPEs. The added value could be more clearly assessed under different scenarios, including with and without radar data available, with / without rain gauge data. From the results you present, the real advantage of lightening data appears to be in cases when radar data are not available (which can occur either because there simply are no weather radars, due to malfunctioning of the radar or to issues such as beam blockage and/or attenuation); this is very valuable and should be made clearer (and, from my point of view, justifies changing the focus of the paper/ changing the way in which objectives and results are described).

AUTHORS ANSWER: We now stress the importance of using lightning data (especially in case of no radar data availability), in the abstract, result and discsussion sections. Also, the title is changed: "Improving the precipitation accumulation analysis using lightning measurements and different integration periods"

Detailed comments:

Introduction: Work by the co-authors of the paper is often cited and a proper review of relevant literature on the actual topic of the paper is lacking. The introduction should be extended to include: - A review on the use of lightening data for QPE generation

AUTHORS ANSWER: We have now included text in the introduction section, where work on this topic is elaborated (including references) as follows: "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 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. 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."

- A more in depth and critical discussion of adjustment of radar QPEs. The only comment so far is that “the use of monthly adjustment factors leads to less than optimal results”. Several studies have been carried out which have shown a clear advantage of adjusting radar QPEs based on rain gauge data and other sources of information, with corrections implemented at significantly shorter time scales (as compared to the monthly one that you mention). Also, since the focus of your study is mostly on convective storms, it may be worth discussing the performance of merging techniques for convective storms, which is still a problematic issue (see Jewell & Gaussiat, 2015; Wang et al., 2015) and which could be a case in which lightening information could be useful.

AUTHORS ANSWER: Together with previous answer (see above) we have also added the following text into the introduction part: “The research of combining radar and surface observations, to perform corrections to precipitation accumulation, is well explored. Many have made developments in this field and much literature is available, for example Sideris et al. (2014), Schiemann et al. (2011) and Goudenhoofdt and Delobbe (2009). Recently, Jewell and Gaussiat (2015) compared performances of different merging schemas, and noted a large difference between convective and stratiform situations. In their study, the non-parametric kriging with external drift (KEDn) outperformed other methods in accumulation period of 60 minutes. Wang et al (2015) developed a sophisticated method for urban hydrology, which preserves the non-normal charactersitics of the precipitation field. They also noticed that common methods have a tendency to smooth out the important but spatially limited extremes of precipitation.”

- A review and discussion on the topic of the impact of temporal aggregation on precipitation products. The impact of the temporal scale at which adjustments are performed is a key part of this study. This issue has been discussed in a number of papers which should be reviewed and in the light of which the results of the present study should be analysed (e.g. you should discuss how the optimal temporal resolution that you found (1h) compares to that found in previous studies for the case of convective storms). See

for example Berndt et al. 2014.

AUTHORS ANSWER: This is addressed by including following section in the introduction: “Comparing radars and gauges, an additional challenge arises from the different sampling sizes of the instruments. Radar measurement volume can be several kilometers wide and thick (one degree beam is approximately 5 kilometres wide at 250 kilometres), while the measurement area of a gauge is 400 cm2 (weighing gauges) or 100 cm3 (optical instruments). Part of the disparateness of radar and gauge measurements is due to variability of the raindrop size distribution within area of a single radar pixel. Jaffrain and Berne (2012) have observed variability up to 15% of the rainrate in a 1x1 km pixel, with timesteps of 1 minute. Gires et al (2014) have shown that the scale difference has an effect in verification measures (such as normalized bias, e.g. RMSE) but it decreases with growing accumulation time (e.g. from 5 to 60 minutes). In our study, the 60 minutes accumulation period is smoothing some of the differences.”

- I would suggest to remove irrelevant information, such as L26-27 (projected annual precipitation in Northern EU) and keep the introduction focused on the topic of the paper.

AUTHORS ANSWER: This sentence has now been removed.

Data Section: - L47-50 include description of methods and should be removed from the data section. I would suggest that you simply say that three data sources are employed in this study and then go on to explain them (without starting to describe the LAPS, which should be done in the methods section).

AUTHORS ANSWER: Text have been modified (text about rain gauges moved into Sect. 2.1) and now follows your suggestion (Sect. 2): “Here we describe the three data sources employed in this study: rain gauge observations, radar and lightning observations.”

- Section 2.1 – I would change title to “Ground rain gauges” or would at least include the word “rain gauge” in it.

AUTHORS ANSWER: Title has been changed to “Rain gauge observations”

- Section 2.1, L57-58 is a repetition of L52; try merging these sentences.

AUTHORS ANSWER: The sentences have been merged and the whole section reorganized.

- Section 2.3: A bit more details about lightening sensors would be desirable. It would help the reader understand how is it that lightening measurements can be translated into vertical ‘radar’ rainfall profiles and so on. I am aware that this information can be found in other papers, but I think it would be helpful and interesting for the reader to find a brief description of the sensors here. Just in the same way that you provide a brief overview of radar QPE generation.

AUTHORS ANSWER: We have now added more details about the lightning sensors: “Lightning location sensors detect the electromagnetic (EM) signals emitted by lightning return strokes, measure the signal azimuth and exact time (GPS). Sensors send these information to the central processing computer in real time which combines them, optimises the most probable strike point and outputs this information to the end user. More detailed informationÂăof LLS principles are described in Cummins et al. (1998).” Also, the section related to translating radar-lightning into profiles has been rewritten and made more clear.

- While all but one of the Finnish radars are dual-pol, it appears that dual-pol parameters are not being used for QPE generation. The authors mention that a single Z-R relationship is used, which implies simplification and assumptions about variable drop-size distribution and the like. Such simplification could clearly be avoided were dual-pol parameters used. It should be made clear (in Section 2.2) that dual-pol parameters are not being used at all and the implications of this should be discussed (I reckon that the use of dual-pol parameters would lead to much larger improvements in the quality of

radar QPEs than the use lightening information).

AUTHORS ANSWER: Thank you, we agree. Due to cold climate and relatively long distances between radars, a significant part of our radar measurements are made above melting layer, so the benefits of pure KDP-based QPE are not as obvious as in some other areas. We have tested the use of PhiDP-based attenuation correction methods, but some uncertainties remains. We have now made this clearer by adding following sentence into Sect. 2.2: “At the moment, the quantitative precipitation estimation based on dual-polarization is not used operationally in FMI, but the polarimetric properties contribute to the improved clutter cancellation (i.e. removal of non-meteorological echoes, especially sea clutter, birds and insects).”

Methods Section: this section is rather unorganised and a thorough re-structuring would be desirable.

AUTHORS ANSWER: We have made a thorough reorganization of the methods sections, following the suggestions by reviewer (see comments below). Note: Also the other reviewers comments have been implemented and the final structure has now become better.

Some specific comments/suggestions are the following: - Section 3.1, L97: “: : : where a dense observational input, from several sources, are fitted to a coarser background model first-guess field”. Please indicate which data sources are used.

AUTHORS ANSWER: This section has now been enlarged and we inlcude a sentence and reference related to this: “The FMI-LAPS is able to process several types of in-situ and remotely sensed observations (Koskinen et al., 2011), among which radar reflectivity, weighting gauges and road weather observations are used for calculating the precipitation accumulation.” We prefer not to mention all observational input, because most of them are not relevant for the accumulation process (in previous article, i.e. Gregow et al., 2013, this was pointed out by reviewers and we had to remove this information). But for your information, FMI-LAPS is using input from satellite, radar, lightning, synop, metar, local surface observational network, soundings, air-plane reports, lidars and background model.

- Section 3.1, L102: you indicate the spatial resolution of the FMI-LAPS output, but not the temporal resolution. From subsequent sections I gather that the temporal resolution is 5 min, but it should be clearly indicated in Section 3.1.

AUTHORS ANSWER: FMI-LAPS temporal resolution is 1 hour and this has been added (together with more information): "The FMI-LAPS use a pressure coordinate system including 44 vertical levels distributed with a higher resolution (e.g. 10 hPa) at lower altitudes and decreasing with height. The horizontal resolution is 3 kilometres and the temporal resolution is 1 hour." Note: FMI-LAPS produce hourly analysis, i.e. the accumulation product is for 1 hour and calculated using 5 minutes segments of radar and lightning data. Correction with rain gauges are done using the hourly data (since rain gauge data is availabe as 1 hour accumulation from our FMI real-time database).

- Sections 3.2 and 3.3: these two sections present overlapping information and a clear and integrated description of the integration of lightening data with radar data is missing. I suggest merging these two sections and producing a new and clearer description of the merging method.

AUTHORS ANSWER: The sections 3.2 and 3.3 have now been merged, according to suggestion, and the new section has become more clear and readable.

Results section: - Why using coefficient of determination AND Pearson's correlation coefficient? Their only difference is that the correlation coefficient has a sign, so it may be useful to include both in cases where you expect the correlation coefficient to take negative values. Since this is not the case here, the two performance measures provide very similar information. I would suggest to use only one of the two.

AUTHORS ANSWER: Yes, we agree. We have now removed the coefficient of deter-

mination (R2) from the verification.

- A description of the log STDEV is missing and a justification for using a log-STDEV instead of the non-log STDEV should be included.

AUTHORS ANSWER: An explenation to STDEV has now been included: "STDEV quantifies the amount of variation (i.e. spread) of a dataset. A low STDEV indicates that the data points tend to be close to the mean value of the dataset. Here we use the logarithm of the quotients, in order to get the datasets closer to be normally distributed."

- As mentioned above, this section (results) is unorganised and includes a great deal of description of methods, which should be transferred to Section 3. Also, results should be presented in a more concise and assertive manner (comments such as "neutral to positive impact" should be removed). As suggested above, a shift in the focus of the paper could make it easier to describe the results in a more assertive / critical manner.

AUTHORS ANSWER: The results are now presented in a more clear and assertive way. Text related to methods have been moved accordingly, part of text is moved to discsussion and unnecessary subjective comments have been removed.

- A scale bar should be included in Figure 1. AUTHORS ANSWER: We have now included a scale bar in Fig. 1. (Scale bar in Fig. 2 was also corrected)

- Why using log scales in figures 4, 5, 7 and 8? I think a normal (linear) scale would be better. A linear scale is normally used in papers on this topic, so readers are used to it. I do not see any added value in using a log scale and I do think that it hinders interpretation of results.

AUTHORS ANSWER: The intention is to increase the readability of high precipitation values but without disturbring the overal readability. Plotting the values on linear axes will decrease the overal readability, which has been seen after testing different plotting techniques. The log-log scales was the best way to produce the plots (according to us). Therefore we prefer to keep Fig. 5 and 7 with log-scales. As an example we here plot log-scale vs linear-scale (please see Fig. 1 attached below).

It is the same with Fig. 4 and 8, the visualization of the results is more clear and better with log-scales. Here we show Fig. 4a with log-scale vs linear-scale (please see Fig. 2 attached below).

- I suggest using mm to indicate rainfall accumulations (accompanied by the temporal aggregation scale), instead of using mm/h (which is the unit normally used for intensities).

AUTHORS ANSWER: We have now changed the units to “mm” and explain that this is hourly accumulation values in the figure captions (Fig. 4, 5, 7 and 8).

Other comments: - Why not work with sub-hourly temporal accumulations? The lifetime of convective cells is often < 1 h. Since the focus of the study is on convective storms and lightening and radar data are available at high temporal resolution (5 min), it would make sense to evaluate sub-hourly scales.

AUTHORS ANSWER: The limiting factor for this is the gauge information, which is available as 1 hour accumulation from FMI real-time database. Therefore, the time resolution for analysis is bound to be as hourly accumulation data.

- Misuse of semicolons throughout the paper. The semicolon should be either removed or replaced by a colon. E.g.: L16: “such as;” (remove semicolon) L133: “resulting from;” (either remove or change to colon) L218: “analysis time;” (change to colon) Many others! Please check.

AUTHORS ANSWER: We have now made corrections to the above comments (plus several other places in the text).

REFERENCES (by reviewer):

Berndt, C., Rabiei, E. & Haberlandt, U. (2014). Geostatistical merging of rain gauge and radar data for high temporal resolutions and various station density scenarios.

Journal of Hydrology, 508, 88-101.

Jewell, S. A. & Gaussiat, N. (2015). An assessment of kriging-based rain-gauge-radar merging techniques. Quarterly Journal of the Royal Meteorological Society.

Wang, L.-P., Ochoa-Rodríguez, S., Onof, C. & Willems, P. (2015). Singularity-sensitive gauge-based radar rainfall adjustment methods for urban hydrological applications. Hydrology and Earth System Sciences, 19 (9), 4001-4021.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-113/hess-2016-113-AC4-supplement.pdf

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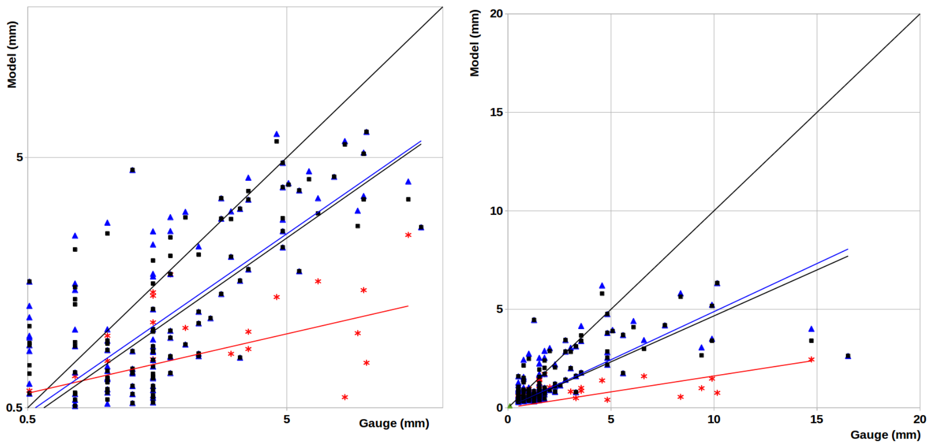

Fig. 1. Refers to comment above.

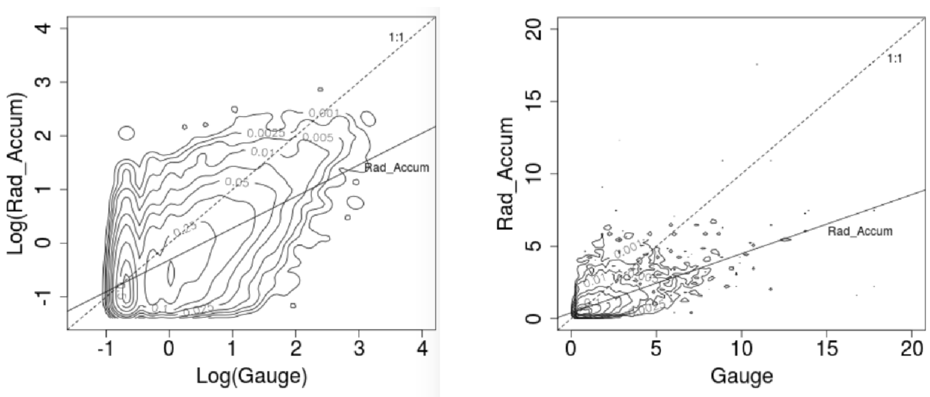

Fig. 2. Refers to comment above.