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Hydrology and Earth System Sciences
Discussions

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

E. Gregow et al.

erik.gregow@fmi.fi

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Anonymous Referee #3

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This paper addresses the question of how to the use of lightning data can help improve rainfall accumulation estimation. The topic is relevant and paper on this issue are welcomed. However the manuscript exhibit severe flaws, and cannot be published in its current form. The modification needed require in-depth modification.

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

Printer-friendly version

Discussion paper

PDF-file).

General comments:

Overall the paper is quite difficult to read, many processing techniques are tested on various data sets, presented not at the same time. Maybe a scheme summarizing the techniques would help. I think the paper should also be organized better. A solution could be to present “data”, then methods with a subsection on the various products from the radar, gauge and lightning, and a subsection on how the comparison is performed.

AUTHORS ANSWER: The paper has undergone a significant reorganization, which has now improved the readability accordingly. The methods have now been bundled from different sections, the observations have a better structure and the result section is more concise.

There seems to be a contradiction between the abstract and the content. abstract l.8-9 : “the performed... usefullness of...” and l.201 “The overall result... neutral to positive impact...” and same comment on the dependent sub-set (l.211-212).

AUTHORS ANSWER: We have changed the second paragraph in abstract to be more consistent with the result section, which has been rewritten: “Lightning data does improve the analysis when no radar is available, and even with radar, lightnings have a neutral to positive impact on the results.”

The conclusion seems to be that basically when radar data is available lightning data is rather useless. This is already a result that should be stressed (it is already mentioned). That said I have the feeling that the paper could be more interesting by shifting its scope to how to estimate rainfall (locally) from lightning data when no radar data is available (this would correspond to developing more in depth what is done with figure 7). After this analysis, you could practically test the interest by artificially removing some radar data.

AUTHORS ANSWER: We now stress the importance of lightning data for situations of no radar information in the abstract, the result- and discussion sections. The results in this article was performed during operational LAPS runs, i.e. with all input data availabe at that time. Hence, rerunning longer periods would require resources not available, due to all the extensive data input needed (i.e. regenerate the data input and format conversions). For the 4-days period we manually saved the input data in order to rerun experiment, where we exclude/include lighting from the data ingest and, additionally, test different profile relationship generations. This is now 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."

Detailed comments:

The title "radar -,gauge-" formula is not very clear.

AUTHORS ANSWER: The title is changed to: "Improving the precipitation accumulation analysis using lightning measurements and different integration periods"

1) Introduction - It should be extended to include a state of art section on the actual topic of the paper, i.e. lightning measurement assimilation for rainfall or more generally in meteorology. (ex among many others: Papadopoulos et al. 2005; Morales et al 2003)

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."

2) Observations and instrumentation - p2 l.49 : "LAPS" is used but was not defined before in the manuscript

AUTHORS ANSWER: LAPS is now defined properly.

- p3 l.76: "as as proxy", one "as" should be removed

AUTHORS ANSWER: This is corrected.

- section 2.2 : how mosaicking is done ? Some more detail on the radar processing should be provided. How dual polarisation is used? The differences in terms of sampling area between rain gauges and radar are almost not mentioned (l.81). This

discussion should at least be expanded because it can have an influence on the standard scores used after. See for example reference such as Jaffrain and Berne 2012; Gires et al. 2014; on this issue

AUTHORS ANSWER: The text related to LAPS processes is reorganized (now in Sect. 3.1), including a reference to (Albers et al., 1996): "The Finnish radar volume scans are read into LAPS as NetCDF format files, thereafter the data is remapped to LAPS internal Cartesian grid and the mosaic process combines data of the different radar stations (Albers et al., 1996)."

A sentence related to the use of dual polarisation radar is included (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)."

The differences in sampling size (both spacial and temporal) has now been inlcuded in the introduction section, with text and references as follows: "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."

3) Methods

- l94 : randB method mentioned but not defined after

AUTHORS ANSWER: This has been corrected.

- section 3.1 : more details on LAPS are needed. Sentences such as “LAPS uses statistical methods to perform high-resolution analysis” are too general for a scientific paper. It is not clear what is the purpose of LAPS and what data is used out of it, and how it is related to the radar mosaic product of FMI.

AUTHORS ANSWER: We have now added more information and references to the LAPS processes: “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. The domain used in this article covers the whole Finland and some parts of the neighbouring countries (Fig. 1b). LAPS highly relies on the existence of high-resolution observational network, in both space and time, and especially on remote sensing data. 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. The Finnish radar volume scans are read into LAPS as NetCDF format files, thereafter the data is remapped to LAPS internal Cartesian grid and the mosaic process combines data of the different radar stations (Albers et al., 1996). The rain-rates are calculated from the lowest levels of the LAPS 3D radar mosaic data, via the standard Z-R formula (Marshall and Palmer, 1948), which is then used for precipitation accumulation calculations (see Sect. 3.2). Other information on observational usage, first-guess fields, the coordinate system etc. is described in Gregow et al. (2013).“

- Section 3.2: Some indication on the number of lightning strokes used to calibrate the relation should be given. Figure 3.b : the vertical scale should be changed to improve the visibility of the relation. Could you confirm that the temporal resolution is indeed of

5 min

AUTHORS ANSWER: We included (in Sect. 3.2): “A total of approximately 220’000 lightning strokes were used for this calibration.” We have changed y-axis scale in Fig. 3b, to make improve the readability. Yes, the radar and lightning data have 5 minutes resolution and the final accumulation product is hourly.

- Eq 3 : so the dual pol capacities are not used ? AUTHORS ANSWER: At the moment, the quantitative precipitation estimation based on dual-polarization is not used, but the polarimetric properties contribute to the improved clutter cancellation (see also answer above).

- l.151-152 : when merging radar and lighting data, why choosing the maximum ? When radar data is available, is not radar more reliable than one choice among the 6 different profiles for lightning ? Please justify this choice.

AUTHORS ANSWER: In most cases the radar data are more reliable, compared to lightning-profiles. Though, in cases where there occur attenuation or the grid-point is at the far end of radar coverage, the lightning-profiles could be of better quality and hence, in these situtaions would have higher reflectivity values (therefore we choose the dataset with higher value). We included text explaining this: “The logic behind this is that the radars are more likely to underestimate, than overestimate the precipitation (due to attenuation, beam blocking or the nearest radar missing from network; e.g. Battan, 1973 and Germann, 1999), especially in thunderstorm situations.”

- Section 3.4 : why only one sub section? You have to say at least few words on Rand B method and Barnes analysis. It is very difficult to understand this section with so little explanations.

AUTHORS ANSWER: We admit we were perhaps too careful not to repeat too much from the earlier paper in Sect. 3.4. We now added new text describing the RandB-method: “The FMI-LAPS RandB-method corrects the precipitation accumulation esti-

mates using radar and gauges datasets. The first step in this method is to make the radar-gauge correction using the Regression method. Data of hourly accumulation values are derived from the gauge-radar pairs within the LAPS grid (i.e. from same location and time), and from this a linear regression function can be established. The corrections from Regression method is applied to the whole radar accumulation field and thereafter used as input for the second step, the Barnes analysis. Within LAPS routines the Barnes interpolation converge the radar field towards gauge accumulation measurements at smaller areas (i.e. for gauge station surroundings). Several iterative correction steps are performed within the Barnes analysis, adjusting the final accumuation. The FMI-LAPS RandB-method is described in more details in Gregow et al. (2013).“

4) Results and verification

- p. 7 is methodology and should be moved in the corresponding section. Please confirm that in eq. 4-7, values are taken at the hourly resolution ? It might be interesting to test other time steps.

AUTHORS ANSWER: The result section has been rewritten and parts related to methods have been moved accordingly. Yes, we confirm that these values are hourly. We agree, it would be interesting and important to use lower time-resolution. However, the surface gauge measurements, coming from FMI real-time database, are given as hourly values. Therefore we are restricted to make the corrections using the time resolution of 1 hour.

- l.187-188 : “the avg Radlig reflectivity profile. Please clarify ?

AUTHORS ANSWER: This text is moved and rewritten in methods section (Sect. 3.2, now merged with Sect. 3.3).

- Figure 4 : please clarify what is plotted and how it was obtained. It is also almost not commented in the text.

AUTHORS ANSWER: The figure caption has been updated with more information: “Figure 4. The FMI-LAPS precipitation accumulation (described in plots with density iso-lines of hourly accumulation values, in mm and log-scale) calculated using 4 different methods: a) Rad_Accum, b) Rad_LDA_Accum, c) Rad_RandB and in d) Rad_LDA_RandB. Results are from the dependent gauge dataset during summer 2015. Shown is also the best fit line (1:1).”

- Figure 5 : again mention time steps used (1h ?). l.220-224 : the figure should be more commented. - l.228-230 : the quantiles mentioned are not clear.

AUTHORS ANSWER: We added information about hourly accumulation into the caption of Fig. 5. The result section has been rewritten to become more readable and asserted.

- Figure 7 and comments : the change in quantile seems to improve rainfall estimates. Why was not it used in the first place ?

AUTHORS ANSWER: Note: Figs. 6-8 have now changed order. Why not use the Quartile method in first place? This is because we had a test-dataset, a 4-days case from year 2014 (with all the extensive input data), which was used to perform autonomous experiments/reruns. But, the idea of calculating/testing different Quartile profiles were not thought of until we saw the results from summer 2015. Then, we made reruns using data from 2014 to establish these findings (i.e. Variable Quartile approach give the best profiles).

- Figure 8 : please comment more the figure...

AUTHORS ANSWER: We have added text to the figure caption.

References (reviewer):

Extending the Capabilities of High-Frequency Rainfall Estimation from Geostationary-Based Satellite Infrared via a Network of Long-Range Lightning Observations Carlos A. Morales and Emmanouil N. Anagnostou Journal of Hydrometeorology 2003 4:2,

141-159

Improving Convective Precipitation Forecasting through Assimilation of Regional Lightning Measurements in a Mesoscale Model Anastasios Papadopoulos, Themis G. Chronis, and Emmanouil N. Anagnostou Monthly Weather Review 2005 133:7, 1961-1977

Gires, A. et al., 2014. Influence of small scale rainfall variability on standard comparison tools between radar and rain gauge data. Atmospheric Research, 138(0): 125-138.

Jaffrain, J. and Berne, A., 2012. Influence of the Subgrid Variability of the Raindrop Size Distribution on Radar Rainfall Estimators. Journal of Applied Meteorology and Climatology, 51(4), 780-785.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-113/hess-2016-113-AC3-supplement.pdf

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