Responses to comments from Anonymus Referee #1

On „Use of dual-polarization weather radar quantitative precipitation estimation for climatology“ by Tanel Voormansik et al.(HESS-2019-624)

Referee's comment

GENERAL COMMENTS

This study presents an evaluation of quantitative precipitation estimates based on dualpolarization radar measurements for 1h, 24h, and one-month durations. It is based on relatively long radar datasets collected from two radars located in two different places with different climate conditions. The results show the added value of dual-pol rainfall estimates compared with the traditional method based on the horizontal reflectivity only.

The focus on the paper is clearly on the evaluation of the performance of the method and as mentioned in the abstract the main application is hydrological forecast and early warning system. The use for climatology is not addressed and the datasets are actually not long enough to derive climatological information. I would recommend to change the title of the paper to reflect the actual scope of the study.

The paper is well organized and the study is relevant for the scientific community. However, there are some weaknesses and, in my view, the paper requires a major revision before publication. I recommend the following improvements:

- The description of the state of the art should be extended. Very little reference is made to previous studies on the evaluation of QPE based on dual-polarization measurements

- The description of the radar processing must be improved. Very little is said on the choice of various settings and parameters. Some tuning has been applied but without explained how it has been performed.

- The impact of some settings in the selection of the dataset and in the method for comparing and evaluating the various QPE methods should be tested.

- I would recommend to test the use of horizontal reflectivity without re-calibration based on dual-polarization data. This would allow to point out the benefit of such re-calibration.

- The impact of the 5-min to 15-min temporal sampling is addressed but the present study does not allow to isolate this effect from many other factors influencing the quality of the QPE. In the specific comments hereafter I propose a simple method that would allow to evaluate this impact. I recommend to test it.

- The main results of the study should be better presented in the abstract and the conclusion. What are the most original results of the study ?

Authors' response

Authors would like to sincerely thank the referee for the time and effort spent in reading the initial manuscript and for making many clear and constructive suggestions for improvement. This helped a lot to improve the manuscript.

SPECIFIC COMMENTS

Abstract

Referee's comment

The length of the datasets should be mentioned in the abstract.

Authors' response

Agreed. Sentence about the length of the datasets added to the abstract.

Referee's comment

The use for climatology is not mentioned in the abstract and it is indeed not the main focus of the study.

The abstract should shortly present the main results of the study.

Authors' response

We agree with the comments. The short conclusion of main results was added to the abstract:

"Overall the radar products showed similar results in Estonia and Italy when compared to each other. The product where radar reflectivity and specific differential phase were combined based on a threshold exhibited the best agreement with gauge values on all accumulation periods. In both countries reflectivity based rainfall quantitative precipitation estimation underestimated and specific differential phase based product overestimated gauge measurements in general."

Referee's comment

1. Introduction

Satellite-based rainfall estimates are not only limited by the resolution but also by the accuracy of the estimates.

Authors' response

Agreed. Added short description with reference about the accuracy of the estimates to the manuscript:

"What is more, satellite-based precipitation estimates are limited by the accuracy of the estimates. The accuracy of the estimates has regional dependency and therefore can vary due to physiography of the study areas (e.g. precipitation climate, land use and geomorphology) (Petropoulos and Islam, 2017)."

Referee's comment

The dataset starts in 2011. This record is probably long enough to perform an evaluation of the quality but still too short to derive robust climatological information. Climatology is certainly one of the future applications of radar-based QPEs (e.g., Saltikoff et al., BAMS, 2019) and it should be mentioned here as one of the applications of QPEs next to nowcasting, hydrological forecasts or agriculture. Thera are very few references to similar studies evaluating the quality of dual-pol based QPE.

Authors' response

We agree that the dataset we had for the study is too short to derive robust rainfall climatology. Additional references to studies evaluating the quality of dual-pol based QPE were added:

"Previous studies where the benefits of dual polarimetric radar QPE have been shown are mostly based on selected short time periods or only single events (Wang and Chandrasekar, 2010; Chang et al., 2016; Cao et al., 2018)"

Referee's comment

2. Data and methods

2.1 Rain gauge measurements

Can you shortly describe how the measurements are quality-controlled?

Authors' response

Short description of the quality control process added to the manuscript.

Referee's comment

L74 : why and how is this subset selected ?

Authors' response

The rain gauge subset consists of gauges that are located within the range limit that is applied to the radar data which is explained in Section 2.3 where comparison framework is described.

Referee's comment

2.2 Weather radar precipitation estimates

One of the benefits of dual-pol measurements is the reduction of ground clutter. Is there any clutter filtering based on these measurements in the processing ?

Authors' response

Agreed. Short description of polarimetric filtering used on data added to the manuscript.

Referee's comment

L85 : why are KDP measurements unreliable at short range ?

Authors' response

To get reliable KDP estimations averaging among range bins is required. However, close to the antenna, stable and reliable observations are not available, due to both the antenna itself and TR-limiters response time (or the dual polar switch in case of alternate transmission). The explanation was added to the manuscript as well.

Referee's comment

L100: what happens after 2016 ?

Authors' response

Reworded the sentence so it would be unambiguously understood: “Bric della Croce observations used in the study range from 2012 to 2016 whereas observations from 2012 to 2013 are with ten-minutes interval and from 2013 to 2016 with five minutes interval time resolution.”

Referee’s comment

The processing of the raw PHIDP data to derive K_{DP} is only very briefly described. Some parameters have been tuned but we don’t know which and how. What is the impact of this tuning on the final results? Is there any impact of the PHIDP processing on the resolution in range? Is the final resolution appropriate for estimating heavy rainfall from convective cells with relatively small spatial extent? More must be said on how the optimal settings have been determined. Is the dataset used for verification independent of the dataset used for tuning?

Authors’ response

Following the referee comment several sentences to describe the derivation of KDP were added to the manuscript:

“With default parameter values the rays where differential propagation phase folding occurred did not unfold correctly and thus the function did not produce correct specific differential phase values. In order to fix the folding issue function parameters self_const (self-consistency factor) and low_z (low limit for reflectivity – reflectivity below this value is set to this limit) had to be tuned. The default values were 60000.0 and 10.0 respectively and after testing with various combinations of various values the values 12000.0 and 0.0 were found to produce optimal results and therefore were chosen for final calculations.”

Referee’s comment

The re-calibration of the horizontal reflectivity using the self-consistency theory should be a bit more explained even if a detailed description is available elsewhere. For example, is there also some fine tuning in this re-calibration ? The re-calibration is another benefit of dual-pol measurements and it would be interesting to show what is the impact on the quality of the derived QPEs. Comparisons of QPE derived from horizontal reflectivity with and without re-calibration would be very interesting. I recommend to include these comparisons.

Authors’ response

We agree that the paper would benefit from providing more details about the re-calibration method. As the comparisons of QPE with and without re-calibrated horizontal reflectivity would be out of the scope and focus of this paper we would not include it. Following the referee comment short explanation of the theory along with the used filtering thresholds was added to the manuscript:

“The method essentially compares the observed differential propagation phase (Φ_{DP}^{obs}) to a calculated theoretical differential propagation phase (Φ_{DP}^{th}). The data used for calibration had to be filtered using a number of restrictions: only data from June to September was allowed; data from 0.5° elevation and 10-70 km range only used; only bins where horizontal and vertical polarization channel correlation coefficient was over 0.92 were used; any bins where Φ_{DP} was greater than 12° were removed; whole ray where reflectivity was greater than 50 dBZ was removed; whole ray where Z_{DR} was greater than 3.5 dB was rejected; only rays where $\Delta\Phi_{DP}^{obs}$ was greater than 8° and where the consecutive rain path was at least 10 km was used; any scans in which precipitation occurred on top of the radome were removed.”

Referee's comment

L 127 : how is the 25 dBZ threshold selected?

Authors' response

The threshold was selected after testing on a few months dataset with various reflectivity levels and this provided the best correlation with gauges. Following the referee comment a short description was also added to the manuscript.

Referee's comment

2.3 Comparison framework

L 137 : 30 km seems very small. Why such a limited study area?

Authors' response

The applied range limit is aimed mainly at eliminating uncertainties due to complex orography, like shielding by the mountains. Up to 30 km from Bric della Croce terrain is relatively flat while beyond that mountains block most of the radar signal for lowest elevations. It is explained in manuscript Section 2.3.

Referee's comment

L 139 : hail is not considered as as possible precipitation type. Is this valid for Estonia? In the description of the comparison framework, nothing is said about the minimum rainfall amounts used for the selection of the valid pairs and the production of the statistics. A threshold of 0.1 mm is mentioned in the legend of the figures. Is this threshold used all through the study? It seems very small which means that some statistics might be strongly influenced by very small rainfall amounts. How do you apply this threshold? Should gauge and QPE values both exceed 0.1 mm to make the pair valid?

Authors' response

We agree that hail as solid precipitation type was overlooked. It is now added to the manuscript. A threshold of 0.1 mm is set and applied such that both gauge and radar QPE values must exceed this value to make the pair valid. It is used all through the study. This clarification is added to the manuscript.

Referee's comment

3. Results and discussion

3.1 Case comparisons

L157- 159 : unclear formulation

Authors' response

The formulation was changed so it would be more clearly understood.

Referee's comment

Figure 2 : the agreement between gauge and R(Z_H,K_{DP}) is almost perfect for this particular month. Does it give a realistic view on the results obtained in Estonia? Perhaps showing a few additional cases (perhaps, as a supplement) would allow to get a better picture of the overall agreement between gauge and QPE values?

Authors' response

We agree that Figure 2 might leave unrealistic view of the results obtained in Estonia. Another case was added to the manuscript Section 3.1 where the agreement between radar QPE and gauge was not so perfect.

Referee's comment

L188 – 196 : Can you further elaborate on random versus systematic errors . As statement like "Systematic errors cannot be excluded" seems somewhat obvious when it concerns radar-based rainfall estimates. In the paper, the word "randomness" seems to be used for expressing "scatter".

Authors' response

Systematic errors can originate for example from radar hardware calibration or unsuitable Z-R relationship (the actual drop size distribution is different than assumed in the Z-R relationship). Random errors can originate for example from incomplete beam filling, high intensity small scale rainfall events not completely resolved by the radar (spatial and/or temporal) resolution. Following the referee comment the word "scatter" was used in the paper instead of "randomness".

Referee's comment

L220. Many factors influence the scatter. The temporal sampling is one of them and the results shown here do not allow to isolate this effect. A proper way to test the impact of the temporal sampling on the scatter is possible with the Italian radar which produces a 5-min sampling dataset. A degraded dataset with 15-min temporal sampling can be produced by removing 2 out of 3 date files. The results obtained using the original 5-min and the degraded 15-min dataset would allow evaluating the impact of the temporal sampling.

Authors' response

We agree with the explanation and description of the methodology provided by the referee but decided to not include it in the study because it would be out of the scope and main focus of this study. Long accumulation datasets comprised of many years even out the errors, even on shorter accumulation periods but especially on longer periods.

Referee's comment

Figure 7 : two regimes seem to appear. Can you comment on this ?

Authors' response

The reviewer is right. The Bric della Croce weather radar is located on a top of hill at 770 m asl and during the winter season a vertical profile reflectivity correction (VPR) is applied (Koistinen, 1991). This correction is manually switched on at the beginning of the cold season and it is switched off at the end. In case of convective precipitation, this correction may lead to rainfall overestimation. On

the other hand, stratiform cold precipitation is heavily underestimated when VPR correction is switched off. So, the VPR correction leads to these regimes. The separation between the two regimes could be obtained by reducing the study area even more, limiting the study to June, July and August. Unfortunately only the corrected reflectivity (including VPR) is available for studied years; later both corrected and uncorrected become available. The explanation was added to the manuscript as well.

Referee's comment

Figure 8 :why is a contour plot used here and not in the other figures ?

Authors' response

The same plotting function was used for all scatterplots (Python seaborn data visualization library function *kdeplot* with scatter), but only on Figure 8 the number of data points was low and distribution coarse enough to make contours clearly visible. We agree that the plots do not look uniform enough and we are going to remake them.

Referee's comment

Conclusion

L 306 : A fourth radar rainfall estimate would be useful : $R(Z_H)$ without re-calibration based on dual-pol data.

Authors' response

While we agree that it would allow direct comparison of the reflectivity based rainfall estimates we would still not include it in this study because it would not add enough value to the comparison of other radar QPE products. Also the comparison results and conclusions would depend very much on radar calibration quality and it was not the focus of this paper to evaluate this.

Referee's comment

L 327-329 : the formulation is not very clear. What do you mean with "filtering the radar accumulations" ? It seems also that the conclusion is known before performing the study.

Authors' response

Agreed. Reworded the sentences.

Referee's comment

The conclusion does not make clear what are the original results of the present study.

Authors' response

Agreed. The conclusion was improved to make main original results of the study stand out more clearly.

Referee's comment

TYPOS AND FORMULATIONS

Discussion paper

Strange formulations and spelling errors are present throughout the text. Some are listed below. I would recommend having the text proofread by a native English speaker.

L 12 and further : precipitation without s all through the text

Authors' response

Agreed and corrected in manuscript.

Referee's comment

L16 : legacy ?

Authors' response

Agreed. Replaced the word "legacy" with a more suitable "'conventional".

Referee's comment

L 30 : to a good effect ?

Authors' response

The phrase was replaced with a word "successfully".

Referee's comment

L97 : central respect Piemonte : strange formulation

Authors' response

Agreed. Reworded the sentence to be more clear.

Cited references:

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Chang, W.Y., Vivekanandan, J., Ikeda, K. and Lin, P.L.: Quantitative precipitation estimation of the epic 2013 Colorado flood event: Polarization radar-based variational scheme, J. Appl. Meteorol. Climatol., 55, 1477-1495, https://doi.org/10.1175/JAMC-D-15-0222.1, 2016

Koistinen, J.: Operational correction of radar rainfall errors due to the vertical reflectivity profile, in: Proceedings of the 25th Radar Meteorology Conference, American Meteorological Society, Paris, France, 91–96, 1991.

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