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Hydrology and Earth System Sciences Discussions

Interactive comment on "Uncertainties in rainfall retrievals from ground-based weather radar: overview, case study, and simulation experiment" *by* R. Uijlenhoet et al.

R. Uijlenhoet et al.

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General remarks

Anonymous referee 1 qualifies the Monte Carlo simulation study presented in Section 5 of the original manuscript as 'interesting'. Regarding the same section, referee 2 mentions the 'proposed and nicely described stochastic simulation model' and remarks that the 'proposed correction procedure for attenuation effects is nicely described and of relevance for the hydrological community'. Finally, referee 4 finds that 'the simulation experiment section is well structured and enables the reader to easily follow the experiment and its results'. The referees were in general less satisfied with the overview part of the manuscript (Sections 2 and 3) and with the presented case study (Section 4).

Following the referees' suggestions, we re-organized the paper completely, significantly reducing the 'overview' part (which has now been combined with the introduction), entirely skipping the 'case study' part (which lead to omitting the second author, who was instrumental in that part of the paper), and emphasizing the 'simulation study' part. As a consequence of these changes, Figs. 1-10 of the original manuscript have also disappeared. The new title of the paper ('Stochastic simulation experiment to assess radar rainfall retrieval uncertainties associated with attenuation and its correction') reflects the new focus of the revised manuscript and we thank the three anonymous referees for convincing us in thoroughly revising and thereby improving our paper (see 'acknowledgments').

In comparison with the original manuscript, we enlarged the 'simulation study' part of the paper by not only treating the rainfall retrieval uncertainties associated with rain-induced attenuation (correction) as a function of the mean rain rate over the path considered, but as a function of the distance from the radar as well. This has lead to a subdivision of the section concerned (Section 5: 'Resulting uncertainties in radar rainfall retrievals') into two subsections, namely Section 5.1 ('Influence of the path-average rain rate') and Section 5.2 ('Influence of the distance from the radar'). We feel this new addition has significantly increased the hydrological relevance of the presented simulation experiment. Finally, we have included an appendix in the revised version of the manuscript, where we present a complete derivation of both attenuation correction schemes considered in the Monte Carlo simulation study. Such a derivation will help the hydrological audience of HESS to better appreciate the assumptions on which these algorithms have been based.

Anonymous referee 1

The main criticism of this referee is that the connection between the three parts of which the paper consists, namely the overview, the case study, and the simulation experiment, is 'somewhat artificial'. Moreover, the referee finds the overview 'overly general' and not clearly targeted at a particular (hydrological) audience, qualifies the range effect case study as 'interesting' but 'hardly representing a new finding', and finally feels that the 'simulation study of the attenuation correction methods is interesting' although it could be 'much more relevant if it included polarimetric variables'.

We largely agree with these comments, although we find the referee's statement that 'the authors seem to be unaware of the literature' rather bold. We have been actively involved in numerous conferences on radar hydrology over the past 15 years and have contributed a number of papers on this topic (a few of which have been included in the reference list). Nevertheless, to better appreciate why we submitted the manuscript in the form we did, it should be noted that we were asked to contribute to a special issue of Hydrology and Earth System Sciences on 'Uncertainties in hydrological observations', with Jim Freer, Jens Refsgaard, Jan Seibert, and Emiel van Loon as guest editors. In particular, the guest editors asked us to contribute a manuscript dealing with uncertainties in radar rainfall measurements.

Hence, the target audience of our paper were fellow hydrologists, largely non-experts in the field of radar hydrology, but interested in hydrological measurement techniques. Although we were aware of the fact that the most interesting part of our paper was undoubtedly the simulation study, we felt that an overview of the literature and issues involved in radar rainfall estimation and a case study to illustrate some of these issues could be relevant and interesting introductory material in such a paper, given the target audience. However, a fresh look at our own work about one year after we received the referees' comments (a significant delay for which we apologize) convinced us that the original paper indeed lacked focus, in particular if it is read as a stand-alone HESS paper, not necessarily part of a targeted special issue. That is why we re-organized the paper completely, significantly reducing the 'overview' part, entirely skipping the 'case study' part, and emphasizing the 'simulation study' part, as explained above (see 'General remarks').

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Finally, the focus of the simulation experiment has remained on non-coherent, single-frequency, single-polarization, operational weather radars. While we agree with the referee that polarimetric radars are currently becoming more widely available, we maintain that a large part of the operational radars currently in use (in Europe and elsewhere) do not yet employ polarimetric rainfall estimators. In other words, the dependence of the radar rainfall estimation uncertainties on the mean rain rate and on the distance from the radar as presented in our paper are still quite relevant for hydrologists employing weather radars to estimate catchment-scale rainfall input for hydrological (rainfall-runoff) modeling purposes. Certainly, the application of our stochastic rainfall model to polarimetric radar is currently receiving our attention (e.g. Vulpiani et al., 2005, 2006a,b), but this is an entirely new subject which is clearly beyond the scope of the current paper. Nevertheless, we have added a few lines and some relevant references to recent books on this topic in the introductory section of our paper (right before the listing of sources of error and uncertainty).

We feel that the main contribution of our paper is not just on the quantification of the radar rainfall retrieval uncertainties per se, but on the idea of using a stochastic model of rainfall microstructure to accomplish this task as well. To the best of our knowledge, this is the first time a stochastic rainfall model explicitly treating the spatial variability of raindrop size distributions is presented in the hydrological literature. Such a model has an interest from a hydrological perspective in its own right and could be relevant for several other hydrological applications, e.g. in models of rainfall interception by vegetation canopies or soil erosion by raindrop impact, and the study of sampling uncertainties in in situ rainfall observations using rain gauges or disdrometers. We have added a final paragraph to the conclusions section of our paper to explain this issue.

Anonymous referee 2

According to this referee ’the present paper tries to contribute to bridge this gap [between radar meteorologists and hydrologists, RU] by proposing a correction algorithm for attenuation effects which seems to be well applicable also to operational ”conventional" one-parameter radars. Hence it addresses relevant scientific questions for the scope of HESS and as such should be seen as a valuable contribution for the HESS-readership. The proposed correction procedure for attenuation effects is nicely described and of relevance for the hydrological community'. We appreciate this encouraging comment.

Nevertheless, this referee finds that 'the historical overview section should be restructured'. This is something we have taken care of in the revised version of the paper by reducing the length of the overview section significantly and combining it with the introductory section (see our 'General remarks' and our response to the comments of referee 1). The referee also notes that 'more credit to multi-parameter radars should be given'. As explained in our response to the comments of referee 1, we have added a few lines with appropriate references dealing with this topic in the introductory section of the revised version of our paper, plus an additional paragraph at the end of the conclusions section of the paper.

Specific remarks:

1. Although it is true that individual rain gauges with one-minute temporal resolution exist, we do not know of operational rain gauge networks that provide areal rainfall estimates at the one-minute time step. To better explain what we mean we changed the formulation from 'their spatial and temporal resolution...' to 'their combined spatial and temporal resolution...'.

2. While it is certainly true that weather radars, particularly further away from the radar, receive backscattered signals from clouds, the use of weather radar for quantitative rainfall estimation is based on the backscattered signal from raindrops on their way from the cloud base to the ground. Moreover, due to the D^6-dependence of the backscattered signal (where D is the drop diameter) in the Rayleigh regime, weather radar is much more sensitive to raindrops than to cloud droplets. Of course, the quantitative estimation of frozen precipitation is another story, but we have clearly stated

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in the first sentences of the introductory section that the focus of this paper is on rain rather than on precipitation in general. Nevertheless, in order to avoid any possible confusion, we have changed 'electromagnetic properties of rain' into 'backscattered signal from rain'.

3. This sentence is no longer part of the condensed overview section of the revised version of our paper (which is now combined with the introductory section).

4. This is something we have taken care of in the revised version of the paper by reducing the length of the overview section significantly and combining it with the introductory section (see our response to the comments of referee 1).

5. Regarding multi-parameter radar, we have added a few lines and some relevant references to recent books on this topic in the introductory section of our paper (right before the listing of sources of error and uncertainty). We have also added a paragraph to the conclusions section.

6. The 'artificial' subdivision of sources of uncertainty in "instrumental effects" and "environmental effects" has been removed as part of the restructuring and reduction applied to the overview part of the paper. We now provide a concise listing of the main sources of error and uncertainty involved in radar rainfall estimation, including some relevant literature references.

7. Since the revised version of the paper is no longer pretending to be an 'overview paper', we feel that an exhaustive treatment of all sources of error and uncertainty involved in radar rainfall estimation is beyond the scope of the paper. The most important sources have been mentioned (together with some appropriate references) in the listing discussed under the previous point.

8. See our response to the previous point. As the revised version of the paper no longer pretends to be an 'overview paper', it seems to us that it is not necessary to 'discuss possible solutions to overcome these errors'. Possible solutions to the discussed errors

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and uncertainties are presented in the literature references we provide.

9. This remark is no longer relevant, as we entirely removed the case study from the revised version of the paper.

10. We thank this reviewer for the encouraging remark concerning our 'proposed and nicely described stochastic simulation model'. Although the reviewer correctly remarks that Fig. 11 (of the original manuscript) only pertains to X-band radar, the simulation results presented in Figs. 12-15 (of the original manuscript) cover both X-, C- and S-band radar. Hence the comparison of 'the applicability of this Monte Carlo framework also for longer wave lengths where attenuation is not so enhanced' was already included in the original version of our manuscript.

Regarding the 'technical corrections' suggested by referee 2, the requested combination of Figs. 1 and 9 is no longer relevant as Figs. 1-10 of the original manuscript have been removed from the revised version of our paper (associated with the reduction of the overview part of the paper and the removal of the case study). Hence, the same holds for the referee's remark concerning Figs. 7 and 8. Regarding the requested combination of Figs. 12 and 13 and that of Figs. 14 and 15: these will probably be plotted on the same page of the final publication, which effectively means that they will be combined.

Anonymous referee 4

For our original motivation to include an 'overview' and a 'case study' section in our manuscript, we refer to our response to the comments of referee 1. As explained in our 'General remarks' and in our responses to referees 1 and 2, we have condensed the 'overview' section of the paper significantly (it is now combined with the introductory section) and we have removed the 'case study' entirely. This has also lead to the removal of Figs. 1-10 (of the original manuscript) from the revised version of our paper. We presume that the performed 'overhaul of this manuscript' has provided the 'focus' and 'consolidation' requested by this referee. In the process of revising the manuscript, we have also provided a more appropriate title, as suggested by this reviewer.

Specific remarks:

1. The abstract has been adapted following the reduction of the overview section and the removal of the case study. As a consequence, the phrase "a detailed analysis of the associated observation uncertainties" is no longer part of the abstract.

2. The era concept has been removed.

3. The referee suggests that Sections 2-4 'can and should easily be removed and replaced with no more than a couple of paragraphs (max one page) giving the background to the radar topic which is to be covered in this article'. This is exactly what we did in the revised version of our paper.

4. As a consequence of the reduction of the overview section and the removal of the case study, Figs. 1-10 (of the original manuscript) have been removed from the revised version of our paper.

The referee's remarks regarding Sections 2-4 of the original manuscript are no longer relevant, as Sections 2 and 3 have been condensed and combined with Section 1 (Introduction), whereas Section 4 has been entirely removed.

5. The referee finds that 'the simulation experiment section is well structured and enables the reader to easily follow the experiment and its results'. We thank the referee of the encouraging words. In fact, because all three referees appreciated this section, we have focused the revised version of our paper entirely on the simulation experiment.

6. We have kept the reference to the CASA website as in the original manuscript. We leave it to the HESS editorial office to decide on the format of references to websites.

7. We do not agree with the referee's remark that 'In case of 50 km scale there is no spatial variability of (moderate) rainfall at all'. There may be little or no correlation between rain rates at locations 50 km apart, but there is certainly variability at this

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scale.

8. Whether one defines the decorrelation distance as the distance where the correlation has decreased to e^{-1} (about 0.37) or to e^{-2} (about 0.14) is completely arbitrary. In this case, e^{-2} is consistent with our definition of the scale of fluctuation (following Vanmarcke, 1983). One could even argue that the e^{-2}-definition is better, since with 37% of correlation remaining, one can hardly call a signal 'decorrelated'.

9. We do not agree with the referee that $|K|^2$ represents the dielectric constant. Because by definition $|K|^2 = |(m^2 - 1)/(m^2 + 2)|^2$, where m^2 is the (complex) dielectric constant (e.g., Battan, 1973), we find that our definition of $|K|^2$ being 'a coefficient related to the dielectric constant' is correct.

10. We have corrected the spelling of 'observer's problem'.

11. The referee finds the statement 'the limit where the radar range resolution tends to zero' not clear. In the revised version of our paper, we have included an Appendix (A) which presents a derivation of the HB and MA algorithms, from which it should be clear to the reader that they are solutions to a differential equation with the appropriate boundary conditions, which implies that they pertain strictly only to cases where the range resolution, i.e. ds in Eqs. (11) and (12), tends to zero. To make this point more clear to the reader in the revised version of our manuscript, we have replaced the phrase 'in the limit where the radar range resolution tends to zero' with the phrase 'under the assumption that the apparent radar reflectivity profile $Z_A(r)$ is a continuous function of the range r (see Appendix A)'.

12. The referee finds that 'the beginning of this section repeats part of the introduction [...], which is unnecessary'. While we agree that strictly speaking it may be unnecessary to include these two or three sentences, we have kept them nevertheless, as we feel that they help the reader to recall what was the objective of the simulation exercise.

13. We have removed the closing parenthesis after Z_A.

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14. With 'over 50 km profiles' we mean 'averaged over profiles of 50 km length'. We have changed the text between the parentheses accordingly.

15. The order of the figures has been verified.

16. Because the case study has been removed from the revised manuscript, the sentence starting with 'As an example, we present' does no longer appear in the conclusions section.

17. Because the overview section has been significantly reduced, Fig. 7 of the original manuscript does no longer appear in the revised version of the paper.

References

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