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Hydrology and Earth System Sciences Discussions

Interactive comment on "Radar rainfall estimation for the post-event analysis of a Slovenian flash-flood case: application of the mountain reference technique at C-band frequency" *by* L. Bouilloud et al.

L. Bouilloud et al.

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Firstly, we would like to thank the reviewers for their valuable comments about this manuscript. Our replies are inserted between the comments.

Answers to reviewer 1 (H. Leijnse)

Comment: In Section 2 (page 671), Table 1 is introduced, in which the parameters of the Lisca radar are given. Given the importance of the calibration factor in this paper, could you add some information on whether or not the electronic calibration and the transmitter/ receiver stability are monitored, and if so, how this is done? This is also relevant in relation to Section 4.2 and Figure 2, where the signal stability is discussed.

Reply: We suppose that standard calibration procedures are applied for this operational radar. However, such procedures offer little guarantee about the quality of the absolute calibration for a given event. The proposed MRT technique does not require an absolute calibration, but simply the stability of the transmitter-receiver during the event of interest. The stability of the mountain reference target value prior to and after the rain event (see Fig. 2) is considered as a sufficient index of the radar calibration stability in the present case. Like for microwave link measurements, a baseline can also be defined to account for possible drifts of the reference signal during the course of the rain event. See: G. Delrieu, S. Serrar, E. Guardo and J.-D. Creutin, 1999: Rain assessment in hilly terrain with X-band weather radar systems – accuracy of path-integrated attenuation estimates derived from mountain returns, JAOT, 16, 405-416.

Comment: On page 671, lines 18-19, it is stated that a strong ground clutter area can be seen in Figure 1 at about 20 km from the radar in the North-west direction. Because of the importance of this clutter area for the rest of this paper, and because it is not very clear from the figure, could you add an inset to Figure 1, in which th clutter area is shown in greater detail? This would also allow you to delineate the clutter area, making it clear to the reader which radar pixels are actually used.

Reply: Figure 1 was improved according to the suggestions of the reviewer

Comment: On pages 675-676 it is stated that “Such a condition may not be fulfilled for a growing number of profiles as _c increases.” Shouldn’t this be “decreases” (because _c is in the denominator as _ is always positive)?

Reply: The authors agree with the comment! Thank you for detecting the mistake.

Comment: On page 676, lines 6-7, it is indicated that the capping of the calculated

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PIA values is accounted for in the optimization criterion. Could you explain how this is accounted for?

Reply: For the computation of the optimization criterion, the calculated PIA corresponding to divergent profiles are set to the maximum allowed value (i.e. 20 dB) and accounted for in the criterion evaluation. Other solutions could be imagined such as setting them to missing values or setting them to much higher values (e.g. 100 dB). The first option is clearly not appropriate. The second one was found to be very detrimental here (and in previous case studies) since divergences may occur for the optimal deltaC value. Penalizing too much the divergences lead to underestimate the calibration correction (overestimate the radar calibration factor).This is explained in the following paragraph: “. It may happen however that divergences occur for a number of comparison points while the considered value is optimal for the majority of points. To cope with this problem, we have limited the calculated PIA to the maximum measured value (20 dB) and we have accounted for such capped calculated PIA values in the optimization criterion calculation”

Comment: On page 679, lines 3-5, it is stated that “Due to the strong non-linearity of the attenuation correction, it was found important to perform the screening correction before the attenuation correction.” I do not think that the (strong) nonlinearity of the attenuation correction is the cause of this. I believe the main cause for this is the fact that the attenuation correction factor at a given range depends on what happens on the path between the radar and the given range cell. Even if the attenuation correction factor was independent of the given range cell (i.e. the correction itself is linear), but dependent on the path between it and the radar, it would still be important to correct for screening before correcting for attenuation.

Reply: The sentence was misleading. It was modified to read as: “The screening correction is naturally performed prior to the attenuation correction because of the dependence of the latter on the rainfall occurring between the radar and the range cell of interest.”

Comment: On pages 680-681, it is first stated that “the application of the _c brings a significant, though insufficient, improvement”, after which the attenuation correction is said to be “effective in improving the radar QPE”. This, together with the remarks “attenuation correction using the Hitschfeld Bordan algorithm allowed obtaining good radar QPEs/satisfactory radar rain estimates” in both the conclusions and the abstract (pages 682-683 and 668, respectively), could lead the reader to conclude that the attenuation correction is far more important than the adjustment of the calibration factor. However, because the attenuation correction is highly dependent on the calibration factor, this is not generally the case. To clarify this, consider the following example: If the total path-integrated attenuation (PIA) to a certain radar pixel is 10 dB (which is quite high), S(r0, r) can be computed using Eq. (3), with A(r0) = 1, _c = 0.56, and _ = 1.09. The resulting value of S is 0.516. Given measured reflectivities, this value is independent of _c. This value can therefore be used to assess the relative impact of the calibration correction and the attenuation correction. If both the calibration and attenuation would be corrected for in the radar pixel under consideration, the correction factor that would have to be applied is (A_c)−1 = (0.1 • 0.56)−1 = 17.9. If only the calibration would be corrected, this would become _−1c = (0.56)−1 = 1.8. If only attenuation correction would be applied, the correction factor A should be computed using Eq. (3), with _c = 1 (because no calibration correction is used). This yields A = 0.45. This in turn leads to a correction factor to be applied to the given radar pixel of A−1 = (0.45)−1 = 2.2.These correction factors show that the calibration correction has great influence on the attenuation correction, and that the two should not be viewed separately. I therefore strongly suggest that this be more strongly stated in Section 5, as well as in the conclusions and the abstract.

Reply: We fully agree with this comment and we have tried to improve the text accordingly: In the abstract: “The proposed technique allows estimation of an effective radar calibration correction factor to be accounted for in the parameterization of the attenuation correction, assuming the reflectivity-attenuation relationship to be known.

…Implementation of the radar data processing indicates that: (1) the combined correction for radar calibration and attenuation effects allows for obtaining satisfactory radar rain estimates In section 5: “Application of the correction alone brings a significant, though insufficient, improvement as can be seen in the second line of Table 3 and Figs 6b-7b. The combined correction for calibration and attenuation effects proves to be both effective in improving the radar QPE…” In the conclusion: “(1) the combined correction for radar calibration and attenuation over the entire detection domain using the Hitschfeld Bordan algorithm allowed obtaining good radar QPEs”

Comment: On page 681, lines 8-9, it is stated that scatter in Figure 6 is enhanced by radar-gauge pairs affected by screening and by pairs at ranges greater than 120 km. I think it would be instructive to use different symbold for those points in Figure 6. For instance, you could use circles for the radar-gauge pairs that are affected by screening and squares for the pairs at ranges greater than 120 km.

Reply: Figure 6 was modified according to this comment. Radar/raingauges pairs were sorted in 3 classes: - range from the radar greater than 120km - range from the radar lower than 120 km and radar not affected by screening effects - range from the radar lower than 120 km and radar affected by screening effects

Technical corrections The typographic and grammar mistakes were corrected.

Answers to reviewer 2

Comment: Is it really possible to separate the "global" vertical radar profile (subsection 4.3 and Figure 5) into the "convective" and the "stratiform" parts with an appropriate reliability? The authors themselves express some doubt in this respect by saying: "Due to the convection predominance in the region of the affected watershed, the similarity of the convective and global mean VPRs and the non availability of rain-typed (Z, k, R) relationships, we have used the global VPR to represent the vertical variation of the reflectivity in the following section." So: it is worth to consider omitting the complete

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subsection 4.3 and Figure 5?

Reply: We can hardly follow the recommendation of the reviewer to “omitting the complete subsection 4.3 and Fig. 5” for the following reasons: • The automatic separation of convective and stratiform regions with volume radar data has been the subject of a recent work in our institute (Delrieu et al. JAMC 2009, in press): we do not pretend such algorithms to be perfect, but they do provide valuable information about the heterogeneity of the rain fields. • The combined effects of the heterogeneities associated with the VPR and the attenuation are likely to make their correction particularly difficult especially in case of marked bright band effects. The comparison of the apparent VPR obtained before and after attenuation correction allows for a preliminary quantification of such effects. • The decision of finally considering simply the global VPR is reasonable owing to the reasons mentioned in the text, especially the fact that convection was the dominant process in the region of the affected watershed during the rain event.

Comment: On which basis it is concluded that "a generalized stratification of the rain system occurred in the latest stages (after 17:00 UTC)" of the event? Several descriptions of the case (e.g. on the Slovenian ARSO web page www.arso.gov.si/ search for the case of 18. September 2007 and there is a description of the case - in Slovenian, so it is difficult for the authors to understand the complete description of the case without some help from a person knowing the language) characterize the case to be fully convective. Also the Figure 7 (Slika 7) on the above mentioned web page clearly shows the squall line, that developed at 19h CET, at the time of the cold front passage. So even at that evening time the event was still very convective.

Reply: Our comment is based on the visualization of the radar animations which present clear signature of stratification in the late stages of the rain event. The authors accounted for the comment of the reviewer by stating: “while the stratification of the rain system was observed behind the squall line which occurred during the cold front passage between 1900 and 2100 UTC.”

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Comment: One rather "general" comment: the improvement of the radar derived precipitation data after the corrections is very successful in adjustment to the rain gauge measurements. But it is worth to have in mind the well known fact that also the rain gauge data are in principle biased: the raingauges almost never measure "too much", they more or less systematically measure "less". For rainfall these biases are relatively small, but not negligible: 2% to 10% (WWB 1974; Sevruk 1982; Legates 1987). So eventually, the ”correct“ values should perhaps be even slightly higher.

Reply: Obviouly, raingauges cannot be considered as error-free measurement devices. Random errors are known to be highly dependent on rainrate and accumulation time step (e.g. Ciach, 2002: Local random errors in tipping-bucket rain gauge measurements, JAOT, 20, 752-759) and to filter out for long accumulations time steps such as those considered in this study. Systematic errors, such as wind-induced undercatch, depend on the instantaneous rainrates and on the wind conditions during the rain event.

The text was modified to mention the critical analysis applied to the raingauge dataset and the possible existence of systematic errors: “The radar QPE performance was assessed with respect to the rain total amounts observed with the ARSO raingauge network. Note that the raingauge data were critically analyzed with a geostatistical method aimed at detecting the most obvious inconsistencies between neighbouring stations. Considering large integration time steps such as the event time step is certainly efficient in reducing random errors, however systematic errors, associated for instance with wind-induced undercatch, may be substantial for this rain event.”

Comment: It is perhaps worth to stress that all corrections, and perhaps especially the screening correction (subsection 4.2) based on "a simple interpolation scheme" or based on screening factors could work well only on the accumulated precipitation, but most probably do not perform well on the individual radar echoes (in 10-mim intervals). In the strongly convective case with great spatial and temporal variability the interpolation might individually cause very big individual errors - but these may cancel out, when

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applied on many echoes giving the precipitation accumulation.

Reply: Well, we agree on the fact that the quality of radar QPE decreases with decreasing accumulation time step, but this is true also for the raingauge QPE. Therefore the assessment problem becomes also more acute for short time steps. We can hardly think however that corrections may generate bigger errors (compared to no correction) at certain time steps and result in reduced bias and scatter at larger time steps…

Comment: In equation (2) it would be worth to replace (and explain) the numerical factor -0.46; if it is only written as "a number -0.46" a non specialist in radar meteorology has no idea where it comes from. So consider replacing -0.46 with -2ln(10)/10 = 0.46 and perhaps explaining it a bit. (Like: 2 from the two-way attenuation to the target and back, and ln(10)/10 from the fact that attenuation is expressed in decibels per kilometer?)

Reply: This was done

Comment: Zelezniki is not a city - it is an old small ironworks and market town (approx 3200 inhabitants).

Reply: We use the word “town” in the revision.

Answer to short comment 1 (M. Brilly)

Comment: Paper well present application several correction algorithms to improve radar derived rainfall measurement. Results are presented on fig 6 and describe on page 680 and 681. Rainfall data range from almost zero too more than 300 mm. I suggest that data with less than 100-mm rainfall or even less than 150 mm, will be remove from sample. The best solution will be just take data from Sora watershed. If all rainfall data are mixed together high diverse low values of rainfall or values far away of the main event deform diagrams.

Reply: Thanks for this comment. We prefer however consider all the available raingauges in the assessment procedure to increase its robustness. Of course we have a

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special interest for the raingauge located in the Sora watershed (and we note that the radar and raingauge estimates are very consistent there). In new Figure 6, we have also considered three classes of radar-raingauge pairs as a function of the radar range and the presence of screening effects that may help in refining the analysis.

Answer to short comment 2 (M. Zagar)

Comment: Please show the operationally processed radar image and describe what corrections had already been applied, and present your results in terms of the relative improvement obtained using the terrain occultation approach. For example, delta_c, the calibration error compensation is probably included in the abovementioned operational processing. In what is your delta_c different from the default one? The knowledge of the operational radar centre at the NWS who produced the data in the first place is completely ignored in this study.

Reply: As far as we know, the operational radar data processing in terms of quantitative precipitation estimation remains rather basic for this radar (no radar calibration or attenuation corrections) and the data are more used in a qualitative way for nowcasting purposes. Our point is not to “compete” with the operational service but rather to show that a signal parasite (ground clutter) can be useful for a global correction of calibration and attenuation effects.

Comment: It seems that by choosing an appropriate PIA the desired rain intensity can be achieved. Is there a deterministic way of defining the value of PIA? This would help, since the method aims to be perhaps operationally applied in the future.

Reply: The PIA is derived (deterministically) from the decrease of the reference mountain return when rain occurs between the radar and the mountain (see Fig. 2). Such PIA measurements could be used as such to correct the reflectivity profiles between the radar and the reference target using backward attenuation correction schemes that are known to be stable and insensitive to calibration errors (Marzoug, M., and P. Amayenc, 1994: A class of single and dual-frequency algorithms for rain rate profil-

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ing from a spaceborne radar: Part 1- Principle and tests from numerical simulations. J. Atmos. Oceanic Technol., 11, 1480-1506.). If we want to correct for attenuation for the whole radar image, we have to use forward attenuation correction schemes (e.g. the Hitschfeld-Bordan algorithm) that are known to be unstable and very sensitive to their parameterization (and notably to radar calibration errors). The technique proposed here is aimed at estimating from the PIA time series a calibration error correction that allows an efficient correction of the attenuation with such forward algorithm. Howver, due to the inherent instability of the correction scheme, it is necessary to limit the PIA to be corrected in a given direction to about 10 dB.

Comment: Does the method account for the fact that when it rains a water film is present on trees and other objects which can affect the surface radar return?

Reply: A detailed assessment of this point is proposed in the following article:

G. Delrieu, S. Serrar, E. Guardo and J.-D. Creutin, 1999: Rain assessment in hilly terrain with X-band weather radar systems – accuracy of path-integrated attenuation estimates derived from mountain returns, JAOT, 16, 405-416.

Basically, such effects can be accounted for by defining a baseline for the mountain return outside the rainy periods. In the present case (see Fig. 2, the value of the mountain returns before and after rainfall) there seems to be no difference while at X-band, an increase of about 2 dBZ of the mountain return value was generally observed after rainfall.

Comment: There is a peak in the rainfall field, reaching 300 mm, which appears some 15 km WNW from the radar site with PIA of 20 dB but is absent with the PIA of 10 dB. Also at other places the rainfall between PIA of 10 and 20 dB does not seem to increase equally. Why?

Reply: This is related to the instability of the forward attenuation correction algorithm. The PIA values of 10 and 20 dB are threshold values considered in the algorithm

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implementation to limit such instabilities: when a PIA of 10 (or 20 dB) is achieved at a given range, the attenuation correction for the following range bins is limited to 10 dB (or 20 dB). The 20 dB threshold is not strict enough to limit the instabilities and the 10 dB threshold is recommended although higher PIAs are measured between the radar and the reference mountain target.

Comment: It would be interesting to see a comparison of the radar QP estimate with one or more NWP model results, in absolute as well as in relative terms, i.e. west/east distribution, etc. Also one figure showing the best radar estimate and the actual observed values could be very informative.

Reply: This is beyond the scope of the present article dedicated to radar data processing for hydrological application. We do not have access to a NWP model which would allow for such comparison.

Comment: Figure 2: is rain rate measured with a gauge?

Reply: Yes, rainrate time series are derived from raingauges. In the case of the path-averaged rainrate time series, a simple interpolation technique (Thiessen method) is used to weight the various gauges measurements available in the vicinity of the radar-target path

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