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Reply on RC1

Guy Delrieu et al.

Author comment on "Sensitivity analysis of attenuation in convective rainfall at X-band frequency using the mountain reference technique" by Guy Delrieu et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-8-AC1, 2022

Reviewer 1: This is a useful, well written paper that describes estimates of the attenuation-corrected radar reflectivity factor from a ground-based X-band radar using radar returns from the surrounding mountains as a path-attenuation constraint. I recommend publication.

Comment/Reply: Thank you for the time spent reviewing this article and the positive feedback.

Reviewer 1: One advantage of having a fixed radar and fixed targets, as opposed to airborne/spaceborne radar geometry, is that measurements of the reference target can be made before and after the rain event so that an assessment can be made as to how the target reflectivity might have changed during the event. Although dry and wet mountain targets can have different radar reflectivities, I would expect that a good assessment of the accuracy of the PIA estimate can be made.

Comment/Reply: The accuracy of the MRT-derived PIAs was studied by Delrieu et al. (1999) by comparing MRT estimates with direct measurements obtained with a receiving antenna set up in the mountain range. We showed at that time that (i) selecting strong mountain returns (typically greater than 45-50 dBZ) allows to mitigate the impact of precipitation falling over the target (negative bias), (ii) that a refined estimation of the so-called dry-weather baseline is required to account for the possible modification of backscattering properties of the mountain surfaces before and after the event and (iii) that the time variability of the dry-weather returns defines the minimum detectable PIA. These findings were accounted for in the present study with the selection of strong mountain targets (dry-weather reflectivities > 45 dBZ), a refined characterization of the dry-weather baselines and consideration of a 1 dB lower limit for “reliable” MRT PIAs.

Reviewer 1: A disadvantage of this geometry is that the mountain targets do not exist along all rays so that, I would imagine, some assumptions must be made to transfer information from estimates along rays/range-profiles with reference data to those without. Perhaps this is where the cost function becomes necessary.

Comment/Reply: The cost function is indeed one element of the proposed sensitivity analysis which uses the MRT PIAs available in some specific directions to optimize the parameters of the attenuation model (coefficients of the A-Z and A-Kdp relationships, calibration error, on-site attenuation). In a further step, this may allow implementation of attenuation correction algorithms in all directions, e.g. with polarimetric algorithms for significant/strong attenuations and/or with the AZhb algorithm for moderate attenuations (< 10 dB) for which the PHIdp signal is often too noisy.

Reviewer 1: Another difficulty is that the reflectivities of the targets are not all the same so the dynamic range of rain rates that are observable will vary from target to target. Similar issues arise with air/spaceborne platforms since the strength of the radar return from the surface depends on incidence angle and surface type. The authors note that most of the targets have a Zref value of at least 45 dB. For very strong target returns, I would guess that it's possible to see the mountain return even when the nearby rain signal is lost. (I realize that the authors address some of these issues in lines 311-331 and in some of their previous papers.)

Comment/Reply: The higher the dry-weather reflectivity of the mountain target, the wider the measurable PIA dynamic range. Maximum PIA values of about 60 dB were estimated in our study. For such big PIAs, both the reflectivity and the polarimetric signals are likely to be lost at some range between the radar and the target. So yes, it may be possible to quantify the PIA but not necessarily to reconstruct the entire rain profile. Note also that, due to the additivity of powers, considering mountain targets with high dry-weather reflectivity (typically greater than the maximum expected precipitation reflectivity) is desirable to limit the effect of rain falling over the mountain. For example, a 50 dBZ rain falling over a 50 dBZ mountain target would result in a total signal of about 53 dBZ, introducing a 3 dB negative bias on the MRT PIA. While we would have preferred a 50 dBZ threshold in our study, consideration of a lower value (45 dBZ) was found necessary to get targets with rather homogeneous sizes. The dynamic range of the reflectivities of the selected mountain targets is [45 – 65 dBZ], therefore we expect a limited influence of rain falling over the targets, even for the convective cases considered in the article.

Reviewer 1: What about rain that occurs beyond or above the ranges at which targets are present. Do the methods work well in these areas? Visual comparisons of the PPIs in Figs. 1 and 2 seem to indicate the existence of radar returns from rain beyond the mountain returns. These plots also seem to show some rays that contain multiple targets that are widely separated in range. Can these methods be generalized to rays having multiple reference targets?

Comment/Reply: In the presented case study, we intentionally used the lowest elevation angle (0°) of the volume-scanning protocol of the Moucherotte radar to get the strongest mountain returns in order to obtain the most accurate PIA estimates. Applicability of the AZC, AZα and AZ0 algorithms is limited to profiles with a MRT PIA estimate at a given range rm (beginning of the mountain target). Hence for ranges above and beyond the mountain target, one must rely on measurements made at upper elevation angles and on AZhb and polarimetric algorithms, eventually constrained by the proposed parameter optimization method.

Reviewer 1: The modified α (eq. 2.21) or C methods (eq. 2.17) depend on the unknown attenuation factor to range r0 whereas the final-value method (eq. 2.26) does not. This would appear to be an advantage of the final-value. However, it doesn't seem to be possible to apply the final-value method to rays that do not contain a reference target.

Comment/Reply: Indeed the three formulations require a PIA estimate at range rm. Each of them "filters out" one of the three important sources of error associated respectively with the (rather subjective) choice of the α value, the determination of the radar calibration error and possible on-site attenuation. I find difficult to say whether one of the three formulations has an advantage over the others. The "philosophy" of our method is more to use these three formulations all together for estimating the ɑ, dC and PIA0 values that lead to a convergence of their solutions (the cost function being a "simple" measure of this convergence).

Reviewer 1: I had some difficulty understanding the motivation for the cost function given by eq. (3.1)

Comment/reply. This is a crucial point, explained in detail in section 3.1. Let's try to rephrase it in another way: we propose in fact a parameter optimization procedure based (initially) on four different mathematical formulations of the attenuation-reflectivity equations (4 AZ algorithms: AZhb, AZC, AZɑ and AZ0) accounting (or not for AZhb) for a MRT PIA estimate available at a given range rm:

- Using the "Latin Hypercubes Sampling" technique, we draw randomly sets of parameter values (ɑ, dC and PIA0; but also an error term on the MRT PIA value) sampling uniformly the "parameter space".
- For each of these parameter sets, we compute the corrected reflectivity profiles given by the 4 formulations.
- We are happy when a given parameter set allows a satisfactory convergence of the solutions of the 4 algorithms. Measuring this convergence is the role of the cost function.
- Considering the resulting "optimal parameter sets" obtained for all the targets and all the time steps of an event and a series of events, we infer some values and trends on the calibration error, the coefficients of the AZ relationship and the radome attenuation, that can be used in a further step in the implementation of given algorithms.

But, as noted early (e.g. Haddad et al. 1995), the system of attenuation-reflectivity equations is prone to mathematical ambiguity, i.e. several combination of parameters (including non-physical values) may lead to the convergence of the solutions of the different algorithms. This is a fundamental limitation of our attempts to optimize the attenuation equation parameters (this is quite a frequent situation in environmental sciences…). We have found however that this mathematical ambiguity was significantly reduced when we took into account more information (more constraints) with a fifth algorithm based on polarimetric data (the Phidp profiles). This led to a complexification of the cost function (eq 3.1) but also to added results about the coefficients of the A-Kdp relationship.

Also, due to its "explosivity", we found necessary to limit consideration of the AZhb algorithm in the cost function to moderate PIAs (less than 10 dB).

Reviewer 1: so let me ask the following question. Assume that modified ɑ's from, say N, mountain targets are obtained, at a given time step, and the mean is taken. This modified mean ɑ could then be used to obtain attenuation-corrected Z profiles over the full volume scan of the radar, including rays with no reference target. Would these profiles be significantly different from the profiles obtained by minimizing the cost function? The same procedure could be done for the C-adjustment approach but it would be difficult to interpret this physically since C should be independent of the viewing angle - unless this adjustable C could somehow account for radome loses that change with look-angle.

Comment/Reply: We had this kind of discussion in our section 2.4 about the analysis of the *a priori* values to be given to the parameters of the physical model at hand. In short:

- we assumed the radar calibration error to be constant for a given event;
- the PIA0 values were allowed to vary from one time step to the next and from one direction (target) to the next; we took into account (or not) the Z0 value at the radar

site as a proxy for significant radome attenuation;
- the MRT PIAm values were supposed to vary in a [-1, 1 dB] range around the measured value;
- acknowledging the dependency of the coefficients of the A-Z and A-Kdp relationships on the underlying drop size distribution, we choose to consider several fixed values for the exponents and to let the prefactors vary in a given range around central values. The a priori values of the exponents and central values of the prefactors were estimated from concomitant DSD measurements
- the optimal (a posteriori) parameter values were determined by considering the total number of optimal parameter sets for each simulation.

Reviewer 1: Again, this kind of approach probably wouldn't work for the final-value (Marzoug-Amayenc) method as the equation doesn't have an adjustable parameter.

Comment/Reply: not sure to understand. Both dC and alpha are parameters for the AZ0 algorithm…

Reviewer 1: In Fig. 3, results from 6 methods are shown but it's sometimes difficult to track the behavior of the individual methods. For example, the HB estimate seems to diverge for ranges beyond about 6 km. In fact, the blue line (HB) in panel a is only visible around 5 km; for closer ranges, it probably exists but is hidden by the other curves.

Comment/Reply: Yes, we acknowledge that the behaviour of the different algorithms is difficult to track since we are essentially looking for them to converge! This is effectively the case for the AZhb solution hidden by the others at range less than 5 km in Fig. 3. It is important to remind that for this profile with a 25 dB PIA, the AZhb algorithm was not accounted for in the cost function because of its inherent inability to deal with such great PIAs. The right panels of Fig. 9 present a case with full convergence of the 4 AZ algorithms for a profile with a PIA of about 10 dB, while the AZhb is also not considered in the calculations of the left panel (profile with a PIA of about 40 dB).

Reviewer 1: Z0 is defined at bottom of p. 10 as the measured reflectivity in the vicinity of the radar site, which is the range which is greater than the blind range and any clutter. If Z is the attenuation-corrected reflectivity at this range, then is the following equation correct: Z=Z0+PIA0? (where Z0, Z are in dBZ units).

Comment/Reply: Yes, in our calculations, Z0 value is just corrected for the supposed calibration error (dC) but not for the on-site attenuation. This is in part why this value is a poor predictor for PIA0. This could be improved by implementing some iterations in the (already heavy) calculations.

Reviewer 1: It seems that the phi-DP measurement has greater information content than the MRT in the sense that it provides an estimate of path attenuation to any range whereas the mountain return yields only a single path-attenuation estimate between the radar and the target. Is it correct to say that the phi-DP used in this paper is the value near the reference target? Couldn't it be used as a continuous variable to help validate the MRT estimates or is it too noisy? (Not sure if I'm making myself clear: if, at an arbitrary range, r, the phi-DP is used to estimate the two-way attenuation to that range, A(r), then Z(r)=Zm(r)+A(r), where Z, Zm are in dBZ units.)

Comment/Reply: Yes, the polarimetric measurements are much more convenient in the sense they allow PIA estimation for any ray at different ranges. However these estimates are undirect: for their interpretation we need to specify the A-Kdp relationship which depend on the precipitation type. In addition, the Phidp profiles are known to be noisy for low precipitation rates. Yes the Phidp used for the PIA estimates are the values near the mountain target (with a possible slight underestimation of the resulting polarimetric PIA compared to the MRT PIA which is determined over the entire range extent of the target). In our approach, we trust the MRT PIAs and, among other points, we use them for the interpretation of the Phidp measurements and the optimization of the A-Kdp coefficients.