

***Interactive comment on “Joint statistical correction of clutters, spokes and beam height for a radar climatology in Southern Germany” by A. Wagner et al.***

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We wish to thank the reviewer for her/his detailed and constructive remarks. The comments being so to the point it does not make it easier for us as we share most of the reviewers' concerns. In the following, we answer the reviewers' individual comments; either correcting our text accordingly or making our point clear and -hopefully- the text more readable.

**GENERAL COMMENTS**

REFeree #1: ...Nevertheless I have some concerns about the applicability of the  
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proposed algorithm. First an important part of the correction is based on the so-called PX-product which includes only six reflectivity classes. Is such a poor data resolution sufficient to identify and correct for uncertainties related to the height of the radar measurements? A second major issue is that the errors are considered as systematic while most of radar uncertainties are strongly variable. For example, ground echoes strongly depend on the propagation conditions. It is questionable whether a static correction scheme is appropriate. At the end, the authors propose a long-term statistical correction which is applied to estimate annual rainfall amounts. It is not clear to me whether there is an added-value of these rainfall statistics with respect to those derived from a dense climatological network of rain gauges. In my view these major issues must be addressed by the authors before final publication. More details are given below.

ANSWER: We share the reviewer's major concerns but we want to elaborate in the following why our approach is justified:

1) We are aware of the handicap imposed by the use of classified products; higher resolution data would certainly be desirable for detailed investigation, but our data base would be very scarce if more than six classes were analyzed. We chose to fit fewer classes based on safe statistics, and feel justified by the result: With this data base, we were able to estimate the average bias due to beam elevation, clutter, and beam shading. The altitude correction factor proves to be stable for level 2 to level 5. The amount of these effects, to our knowledge has not been published before, nor used in a statistical correction scheme.

2) We are also aware of the high variabilities of clutter, beam propagation and beam blocking. Still the net effect may be climatologically described. We believe and try to prove that the correction for this mean effect will de-bias the statistics. This could not be achieved using the available networks of rain gauges because of network density and additional systematic errors.

3) It is not the aim of this work to correct the mean annual rain amount. The main

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aim is to estimate the mean biases and to establish a correction algorithm which can be used for all kinds of frequencies of occurrence derived from radar products. For example the areal distribution of convective cells derived from cell-tracking-products may be corrected by this correction algorithm. The quantitative comparison is only used to prove the beneficial average effect of the proposed algorithms.

We do admit that the values of our biases and corrections of course depend on the specific radar and may no longer be applicable if the radar is replaced/moved.

### SPECIFIC COMMENTS

REFEREE #1: Title - The word "precipitation" or "rainfall" is missing.

ANSWER: Initially, these words have been avoided because the correction algorithm is used for frequencies of occurrence of radar reflectivities. But to be more precise the climatology is used for reflectivities not for wind so the title may be modified:

“Joint statistical correction of clutters, spokes and beam height for a radar derived precipitation climatology in Southern Germany”

REFEREE #1: Abstract - It should better explain the objective of the study and, in particular, the time scale of interest.

ANSWER: We tried to clarify our objective.

REFEREE #1: L15: "measuring effect": the authors should already explain here which effects are considered

ANSWER: p 4705, L15: Modified: “. . . or measuring effects like beam broadening and increasing beam height with distance from the radar but to conserve . . . ”

REFEREE #1: p 4705, L 20: Bright band effect is an important source of error but is not the only one related to the height of the measurements.

ANSWER: We added: “Differences in reflectivities at different altitudes are often natu-

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rally induced. Besides the bright band influence and the transition from snow to rain, the low vertical extensions of clouds may result in partial beam-filling or overshooting, and the beam filling inhomogeneity increases with beam width.

REFEREE #1: p 4706, L10: In order to better understand the difference between the two approaches it would be useful to explain what is included in "usual correction algorithms for single radar images".

ANSWER: Only standard radar products are used including the following corrections within the signal processor: doppler filtering, speckle remover, thresholding for noise (log), signal quality (spectral width with SNR) and clutter correction.

REFEREE #1: L15: The errors listed here cannot be considered as systematic. Ground echoes depend on atmospheric propagation conditions. Errors related to the height of the measurements and the beam width depends on the precipitation type and are highly variable in space and time. It is questionable whether a static correction is appropriate.

ANSWER: We agree that 1) individual errors are highly variable and 2) a parameterized correction would be highly preferable to a static one. We tried the latter (e.g., seasonal and regional differentiation; we did not try to include actual propagation conditions) but did not find the results to be stable enough for publication. So all we dare present here is the mean quantitative behavior and a zeroth order (=static) correction.

REFEREE #1: p 4707, L11: The expression "oscillating scan" is somewhat misleading.

ANSWER: We changed this to "terrain-following"

REFEREE #1: p 4708: which kind of rain gauges are used? Is there any quality control?

ANSWER: We included: Tipping-buckets as well as rain collectors from the German Met. Service are used both quality controlled according to official quality insurance standards. The temporal resolution was daily. The original data base was 140 rain

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gauges. Only 91 rain gauges cover the total time range from 2004 to 2009, showed only few missing-values for longer times and accomplished the following additional quality controls. The rain gauges were manually quality controlled for any bias including limit exceedance of daily, monthly, and annually mean values as well as intercompared to time series of adjacent rain gauges.

REFEREE #1: p 4708, L21: How do you define light, moderate and heavy rain? It is stated that correction of light rain is of minor interest and that the frequency of occurrence of heavy rain is too small to be statistically significant. Does it mean that you concentrate only on moderate rain?

ANSWER: There is no universal definition of rain intensities based on reflectivities. In this study, we identify levels 1, 3, and 5 to light, moderate and heavy rain (see Tab. 1). The aim of this study is to develop a correction algorithm especially for moderate and heavy precipitation with a profound data base. For moderate rain the data base is large enough to rely on these results. For heavy precipitation the data base is too scarce to only rely on these results. So also light rain and especially moderate rain is analyzed. If a certain behavior (e.g. concerning clutter) increases from light to moderate rain or remains constant for these rain intensities and the results for heavy rain exactly show this expected behavior it is some kind of justification of the reliability of the results of heavy precipitation. So the aim is to possibly transfer from the findings of light and moderate rain to heavy precipitation or to support the results of heavy precipitation. We will modify the text accordingly.

REFEREE #1: p4709, L4: How to distinguish between radar artefacts and real climatological variations is a crucial issue. It is briefly addressed here but it should be more extensively discussed.

ANSWER: We added: How to distinguish between radar artefacts and real climatological variations is a crucial issue. One often has to make assumptions to distinguish between artefacts and meteorological echoes. For the altitude correction e.g. the as-

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sumption is made that the decrease of frequencies of occurrence is a measuring effect and that the true mean frequency of occurrence is almost equal at each height above ground at least for light and moderate rain. The statistical analysis has the advantage to rely on a more extensive data base, so small systematic differences are accumulated. As the radar artefacts are usually (except for propagation effects etc.) situated at the same place, sharp gradients in radar climatologies are hints for non-meteorological disturbances.

REFEREE #1: p4709, L8 and further: The clutter correction method does not allow removal of anaprop ground echoes. Can you comment on this?

ANSWER: The clutter correction is also based on frequencies. If anaprop ground echoes are “statistically significant”, they are treated like common clutter pixel.

REFEREE #1: p4709, L14-18: This part of the correction method is not very clearly explained.

ANSWER: Also referee #2 mentioned this. A detailed explanation can now be found at REFEREE #2: p 4709

REFEREE #1: p 4710, L25: How do you deal with possible changes in electronic calibration?

ANSWER: There are some parameters, such as transmitter- and receiver characteristics, or wet radome effects, that affect the absolute returned power. As monthly calibration parameters changed very little over the time investigated, there will at least be no calibration induced trend in the frequencies of our threshold exceedances. Additionally, you have to know which effects result from these changes. For the altitude correction no changes are expected as the correction is used for all pixels only depending on the altitude of the range-bins. The “static clutter map” has to be updated if new disturbances arise or old ones disappear, especially for the spokes. So, we think at least one year of radar data with the new electronic calibration has to be analyzed to know

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which changes in the correction has to be implemented. But there will probably be no changes in the methodology of the proposed algorithms. As already mentioned, we would be cautious to extrapolate our results to new radar systems.

REFeree #1: p 4711: The analysis of the variations in height is based on the analysis of the frequency of occurrence in the different reflectivity classes (6 in total). The general mean systematic variations with altitude or distance from the radar is obtained using a linear regression model. We know that height-related errors strongly vary in time and space, which makes this approach questionable. Furthermore, I'm not convinced that vertical profiles of frequency of occurrence can be used to correct for vertical variations of rainfall. This point should be clarified.

ANSWER: As already mentioned with the clutter analysis, the altitude correction is suitable at least on an annual basis. This includes, so to say, a climatological mean vertical profile. It is noted that DWD does not run an operational VPR correction. Using the proposed correction factors for single radar images may often result in impairment. This is obvious, even if one looks at a monthly scale (see Fig. 4). There is no correction for vertical variations of rainfall. Only the frequencies of occurrence of radar reflectivities are corrected and the calculation of rain rates, if any, will always follow after the corrections. The whole algorithm is based on and used for frequencies of occurrence. Only the step of adjustment can be used for precipitation as well as for the correction of frequencies of occurrence for each level, so no changes in the distribution of frequencies of occurrence are expected.

REFeree #1: p 4712: The analysis of the seasonal variation of the variation in height is very interesting but the seasonal dependence is apparently not used in the correction scheme.

ANSWER: The analysis of the seasonal variation is indeed interesting. The large differences from month to month show the high variability of the VPR, as noted by the reviewer. This analysis is valuable to show the dynamic, but for corrections of data on

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an annual basis there is, to our opinion no real added value. If one intends to correct the VPR on a shorter time-scale one may prefer a VPR correction algorithm on single radar images, because the VPR is likely to be more dependent on air temperature and other meteorological conditions than on the pure date. See also previous answer and answer to REFEREE #1: L15.

REFEREE #1: p 4714, L4: This sentence is somewhat confusing. It concerns the clutter correction performed on single images, we guess. Please describe it here and not further in the text.

ANSWER: All corrections are performed on the annual frequencies of occurrence of radar reflectivities. No statistical corrections are performed on single radar images.

Modified: “This is likely due to clutter correction where too much of the signal is reduced.”

REFEREE #1: 4.2.3. Spokes: As far as I know, spokes (beam blockage effect) is generally not considered as a clutter effect. It is true that it is caused by obstacles, mountains, .. which also produce ground clutter.

ANSWER: We agree and changed the text accordingly. In radar climatology, in most cases spokes are the average result of beam blockage as you clearly mentioned; in individual radar images, there may be more reasons for spokes, even positive spokes (jamming transmitters, sun).

REFEREE #1: p 4715, L2-3: I don't see what you mean

ANSWER: Modified: “Only spoke #10 (east-north-east) differs completely from the others in displaying increased frequencies of occurrence of radar reflectivities instead of decreased frequencies.”

REFEREE #1: p 4716: The altitude correction is apparently performed before the clutter correction. Can you explain this choice? Is it not reasonable to start with ground clutter removal and to apply the altitude correction on clutter free data?



ANSWER: This was also a question of REFEREE #2. A detailed explanation can be found at REFEREE #2: p 4720

REFEREE #1: p 4718, L25: "The result of the altitude correction is a radar image with comparable frequencies of occurrence of radar reflectivities independent of the distance from the radar". Does this assume that the real frequency of occurrence is uniform over the geographical area of interest? Is it valid to make this assumption if the final objective is to produce a radar-derived climatology in which spatial variations of precipitation are allowed. This is a crucial point which requires clarification.

ANSWER: This is really a critical point. We may not assume uniform rainfall, as this would indeed exclude any reasonable climatology. Instead, we assume a homogeneous distribution of frequencies of occurrence including rain patterns with areas of higher and lower frequencies of occurrence. But we claim that the mean frequencies of occurrence should not be dependent on the position of the radar. Hence a (pure) range dependence is not considered natural but taken as a bias.

REFEREE #1: p 4719: It is not clear to me how the 3 correction modules are combined. Can you explain a bit more?

ANSWER: The three modules are stand-alone corrections. For the explanation of the order of the three modules please refer to REFEREE #2: p 4720

REFEREE #1: p 4720, L14: Can you easily identify bright band effects with only 6 reflectivity classes?

ANSWER: The bright band is sometimes visible even in individual image, as the increase in reflectivity due to the bright band may exceed 10 dB. The range of one reflectivity class is 9 dBZ. In any case, a certain amount of measurements are shifted to the next reflectivity level. The frequency of occurrence in a lower class is much higher than in a higher class. So if only a small percentage of reflectivities are increased, an effect in the higher class will result. Thus it becomes possible to observe a bright band

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Discussion Paper



effect even with only 6 reflectivity classes. But we think it is hardly possible to make any statement about the strength of the bright band with 6 reflectivity classes.

REFEREE #1: L25: It is assumed that the mean adjustment factor can be used to correct the frequency of occurrence of radar reflectivities. The rationale is not obvious. Can you further explain?

ANSWER: The adjustment factor is calculated on an annual rain amount. The assumption here is as follows: an integral rain amount (e.g. annual rain amount) is the result of the calculation of certain frequencies of occurrence for each radar reflectivity. For the calculation of rain rate a three-part Z-R-relation is used which is only based on reflectivities. So for a specific reflectivity a specific rainfall amount results. If the adjustment factor is 2 the rain rate based on radar reflectivities must be halved. Accordingly, this can also be achieved by halving the absolute frequencies of occurrence for each radar reflectivity class. The relative distribution of frequencies of occurrence of radar reflectivities for all reflectivity levels regarded as a whole will not change. Consequently, the adjustment factor may be applied to frequencies in order to integrate the rain amount of the respective class, as long as the calculation of rain rate is performed by a static Z-R-relationship.

REFEREE #1: General question on correction methods: how do you deal with contamination by hail and orographic enhancement?

ANSWER: So far, individual DWD radar products (our data base) are not corrected for hail not orographic enhancement. (There are dual-pol hail projects.) In our statistical approach, we would not correct for these effects even if we could, because we consider them part of the real climatology. In fact, regions of orographic enhancement or preferred hail corridors were at the beginning of our radar climatological considerations.

REFEREE #1: 6. Evaluation of the method - All along section 6 and the figures there is a confusion between rainrates and rainfall amounts. It is not clear which radar and rain gauge quantities are compared. Mean yearly rainfall amounts? The terminology

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must be more precise.

ANSWER: Only mean yearly rainfall amounts are used. We have clarified the text.

REFEREE #1: 7. Summary - The discussion on the validity of the long-term correction approach is fundamental but not very extensive. I think that this discussion could be deepened.

ANSWER: The whole presented correction algorithm is only suitable for climatological or statistical analysis with a temporal resolution coarser than one year. Admittedly, this limits the application of the proposed algorithm. We do not claim the mean annual rain amount based on radar measurements after our statistical corrections to be superior to an interpolation of a dense network of rain gauges. Possibly, for a very sparse network of rain gauges there would be an added value. We do prove to have corrected the radar integral towards the gauge value. But the main application should be for statistical analyses. It is used for frequencies of occurrence which can be transferred to rain rates afterwards. It is important that there are no corrections on individual radar images of the original radar product (e.g. PX-product or DX-product). In this way, radar products like DWD's cell-tracking-product CONRAD which is based on the PX-product can be exploited for warnings of heavy precipitation, hail or cell tracks and corrected by this statistical correction afterwards. The possibility to correct even those radar products is very valuable for establishing reliable hazard maps. We will modify accordingly.

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