Hydrol. Earth Syst. Sci. Discuss., 9, C3061–C3075, 2012
www.hydrol-earth-syst-sci-discuss.net/9/C3061/2012/

Hydrology and Earth System Sciences Discussions

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

A. Wagner et al.

andreas.wagner@hydron-gmbh.de

Received and published: 16 July 2012

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.

REFEREE #2: p 4704, L8: change "was not achieved before" by "was often not achieved before".

Probably longer archives have been stored for the United States.

ANSWER: Modified accordingly

REFEREE #2: p 4705, L 5: RMSE of what? Please describe the variable exactly.

ANSWER: Modified to: "…the Root-Mean-Square-Error (RMSE) between mean annual rain amounts of rain gauges and corresponding radar pixels decreases."

REFEREE #2: p 4706, L 12-17: A statistical correction can also be combined with correcting single radar images. These two approaches do not automatically exclude each other. "The other way" is not to use statistical corrections. I would change this into, for instance: "Another way is to solely use statistical corrections".

ANSWER: Modified accordingly.

REFEREE #2: p 4708: Is the temporal resolution of the data set 5 min or 15 min? If 5 min, then mention clearly that only the near-surface precipitation scan is used for the analyses. If 15 min, mention which elevations (angle of radiation) are used, and how/when the elevations are used. If 15 min, also discuss that this will give some errors with respect to rain gauge measurements, since only one observation per 15 min is available.

ANSWER: L 4: "It is also based on the near-surface precipitation scan every 5 minutes."

REFEREE #2: p 4708, L 4: "It is continuously available since 2004". Thus this implies that there are no missing images? Mention the data availability for both the DX- and PX-product.

ANSWER: p 4707, L 25: Modified: "The availability of this product for the Munich weather radar is between 75 % and 95 % per year.

ANSWER: p 4708, L 4: "It has continuously been stored since 2004 for the Munich weather radar and its availability is about 85 % until 2006 and afterwards between 95 % and 98 %."

REFEREE #2: p 4708: 8-bit depth means 256 classes. Please mention the resolution, e.g., 0.5 dBZ, and mention the range of the observations, e.g., 0.1 - 100 mm per hour. No threshold was applied to exclude hail (e.g., 60 dBZ) or noise (e.g., 7 dBZ)?

ANSWER: “The second radar product used is the DX-product with 256 classes from -31.5 dBZ to 95.5 dBZ and a resolution of 0.5 dBZ. For this analysis the reflectivity range is limited. It ranges from 1 dBZ (noise) to 60 dBZ (hail)

REFEREE #2: p 4709, L 1-5: First the assumption is mentioned, and subsequently it is stated that differences due to geographical characteristics have to be taken into account. It is probably meant that geographical characteristics are not specifically taken into account.

ANSWER: a detailed explanation can now be found at REFEREE #1: p 4718, L25

“The main assumption of this statistical correction is that for light and moderate rain the mean frequency of occurrence of the associated radar reflectivities at each distance from the radar site should be almost equal on average. So for a reflectivity level the median of the frequencies of occurrence of one ring of range-bins with the same height should be almost equal to the median for all other heights. Systematic variations like the mean decrease of frequencies with height are regarded as a bias. Variations within such a ring are regarded as naturally induced. So certain geographical characteristics resulting in different meteorological situations with different rain amounts are not specifically taken into account but remain in the data base”

REFEREE #2: p 4709: The detection of corrupted pixels is not completely clear to me. It seems that first a visual selection is made, which would be quite laborious. Next, pixels which obviously differ from the distribution of uncorrupted pixels are manually separated by using histograms of frequencies of occurrence of radar reflectivities. This seems also to be quite laborious. Could it be explained how it is feasible to do these selections visually and manually? Finally, an additional separation is applied (automatically?). Please provide some more details regarding the method of detecting

uncorrupted and corrupted pixels. Also mention how the classification between "city clutter", "mountain clutter", and "spokes" is carried out.

ANSWER: The separation of corrected and uncorrected pixels is indeed laborious and it also includes manual work. But this work has only been done once based on the total data set. Of course, it has to be done very carefully because on one hand we do not want to rely on pixels which still are affected by clutter and on the other hand we want to avoid interpolating uncorrupted pixels.

Modified: “The first step of the analysis is to identify pixel groups within the radar image that are obviously affected by the same type of clutter. Three different types of clutter were classified: The “city clutter” of Munich caused by obstacles within a distance of 40 km to the South of the radar site, “mountain clutter” of the Alps in the South with distances of over 70 km from the radar site and “spokes” originating from obstacles near the radar. The city clutter and the mountain clutter can easily be separated because of the underlying landscape. For these two clutter types, a certain area including corrupted pixels of the same source is visually defined, where uncorrupted pixels form the majority of pixels. For the mountain clutter e.g. the whole area between 100˚ (azimuth) and 220˚ (azimuth) at ranges higher than 70 km is taken into account. Pixels in this area should have comparable beam heights and distances from the radar. Corrupted and uncorrupted pixels within these areas have to be separated. This separation has only been made once and includes manual work. For each area of correction, thresholds of frequencies of occurrence are used to separate those pixels which are obviously corrupted from the rest. Additionally, a buffer of 2 km is established around the corrupted pixels to mark those pixels which are likely to be influenced by clutter. For the residual pixels a histogram of frequencies of occurrence is established. The uncorrupted pixels show comparable frequencies of occurrence and therefore, form a distinctive peak in the histogram. Pixels which differ from this distribution can be separated manually if the pre-selection of uncorrupted pixels was difficult. As a last step, the final separation is realized by the analysis of an empirical distribution of frequencies of occurrence, where its 95 % interval marks the range of uncorrupted pixels.

For the spokes, the separation of corrupted and uncorrupted pixels is similar but each angle of radiation (1˚ azimuth) is treated as a whole. So first, for each angle of radiation the median of all pixels except those affected by city clutter or mountain clutter, is calculated. Using thresholds, the obvious spokes can be separated from uncorrupted pixels. The transition from uncorrupted pixels to a spoke forms a distinctive gradient, so the extension of one spoke can be determined by comparing the median of adjacent angles of radiation. If the median differs more than 10 % this usually is an indication for the transition from uncorrupted to corrupted angles of radiation, but this can easily be checked visually."

REFEREE #2: p 4709, L 21: Please clarify "the median of the frequency of occurrence of each radar reflectivity level for each altitude class". It is probably meant that all 5-min radar images are used to calculate the frequency of occurrence of level x for every radar pixel in a certain altitude class. For instance, the median is taken from the frequency of occurrence (calculated over all radar images) as found for each pixel in the altitude class. Or did you calculate it differently? Try to describe precisely how the median was calculated.

ANSWER: Modified: "All 5-min radar images are used to calculate the frequency of occurrence of each reflectivity level for every radar pixel in a certain altitude class. Then, the median of each altitude class and level is calculated and plotted against height."

REFEREE #2: p 4710, L 8-12: Why calculate a mean bias correction factor on an annual basis? If such a factor would, e.g., be calculated on a daily basis, this would greatly improve the usefulness of this data set. I.e., the quality of daily rainfall depths would be increased, and these could be used for applications.

ANSWER: We fully agree. If one calculates a usual adjustment factor a higher temporal resolution of the correction factor would improve the usefulness of this correction.

However, we have some concerns how to transfer e.g. a daily correction factor from one year to the next, but this is not the point here. The main aim of the adjustment is also to correct the side-effect of the altitude correction. Regarding Fig 9 it is obvious that using a linear regression equalizes the frequencies of occurrence at different ranges but at the same time it overestimates the measured frequencies of occurrence and also rain rates, accordingly. This adjustment is only useful on an annual basis at least for light and moderate rain. So the adjustment factor and the altitude correction are closely related. If one does not use the altitude correction an adjustment factor of 0.94 (instead of 1.26) would result. We will eloborate this in more detail in the modified paper.

REFEREE #2: p 4710, L 15: Representativeness errors could be mentioned. A radar measures at a different height and samples a larger volume compared to a rain gauge.

ANSWER: Modified: "A radar measures at a different height and samples a larger volume compared to a rain gauge. Regarding convective rain events the representativeness of a point measurement is often only a few meters. So representativeness errors result. "

REFEREE #2: p 4710, L 19: I do not understand this sentence. Probably "proportion of the" should be added.

ANSWER: Modified: "It is more important that the proportion of the rain amount of a rain gauge and the corresponding radar pixel close to the radar is equal to the proportion of the rain amount of a rain gauge and the corresponding radar pixel at greater distances from the radar, than their absolute magnitude is."

REFEREE #2: p 4711: A map with the locations of the uncorrupted and corrupted pixels would be interesting.

ANSWER: This map will be added as a new figure.

REFEREE #2: p 4711, L 21-22: This is not generally true. "In summer, convective rainfall occurs more frequently, which has a larger vertical extent and strong reflectivity cores aloft causing positive VPR gradients. For the United Kingdom, Hand (1996) shows idealized vertical reflectivity profiles for the cell stages of cumulonimbus clouds. For most stages reflectivities between the cloud base and the midcloud level are considerably larger than those below the cloud base." (Overeem, 2009).

ANSWER: These are two very interesting papers. We agree with you when one looks at reflectivity. A typical VPR with a distinctive bright band influence usually shows a maximum of reflectivity which is independent from the cloud base. We will skip this sentence as we were talking of (falling) rain here, which perhaps is confusing as the frequencies of occurrence are based on reflectivity classes.

The text will be modified: "The main reasons for possible differences at certain ranges are the measurements at different altitudes. Rainfall is a highly variable meteorological variable in space and time. Rain with a low vertical extent may lead to only partly beam filling or "overshooting" at greater distances from the radar. Additionally, reflectivity is highly dependent on drop sizes. So the height of the reflectivity maximum is variable. In summer, convective rainfall occurs more frequently, which has a larger vertical extent and strong reflectivity cores aloft causing positive VPR gradients. For the United Kingdom, Hand (1996) shows idealized vertical reflectivity profiles for the cell stages of cumulonimbus clouds. For most stages reflectivities between the cloud base and the midcloud level are considerably larger than those below the cloud base (Overeem, 2009). So a variety of sources exists why variations at different ranges from the radar can be deduced from measurement."

REFEREE #2: p 4713, L 2-5: I don't understand this part. Could this be clarified?

ANSWER: Modified: "Therefore, range-bins with altitudes higher than 2.5 km were neglected and the resulting range-bins below 2.5 km were stretched to fill the whole radar image. . . . "

The aim of this figure is to show a ring of maximum frequencies of occurrence which

should depend on the temperature and therefore on the altitude and not on the distance from the radar.

REFEREE #2: p 4713: For other months the bright band is not that clear. Underestimation in January at long distance from the radar is apparent and probably mainly related to overshooting. The bright band classifies between the rainy and snowy region, but I believe that too much attention is paid to the bright band (also in the Summary). Please try to explain Figure 5 also by using other (sources of) error.

ANSWER: There are some further hints why the bright band is at least partly responsible for the peak of frequencies of occurrence at a certain altitude like the agreement of the mean 0˚C-level per month and the altitude of the maximum frequency of occurrence. We think the explanation of the decrease of the frequencies of occurrence with height is much easier than of the increase for the lower altitudes. The figures could also be explained by a monthly variable height of maximum precipitation. In winter, the vertical extension of clouds is very low, so at higher altitudes there is a lot of overshooting whereas in summer the maximum rain seems to be at much higher altitudes reflecting the higher vertical extension of clouds in the warmer season.

REFEREE #2: p 4713, L 15: Probably "from rain to snow" is meant.

ANSWER: Probably you mean "from snow to rain"? We changed the text that way.

REFEREE #2: p 4713, L 23-25: The comparison with the median of uncorrupted pixels of the closer environment is a bit vague. What is the definition of the closer environment?

ANSWER: "The closer environment" are the uncorrupted pixels which represent the comparison group for the respective clutter type. A detailed explanation can now be found at REFEREE #2: p 4709.

Modified: ". . . and the median of the corresponding uncorrupted pixels (comparison group) for the reflectivity levels 1, 3 and 5 . . . "

REFEREE #2: p 4714, "City clutter": This paragraph could be clarified. If clutter is present you would expect positive values for "variation" in Figure 6. If the clutter has already been (partially) removed, this will result in negative values for "variation". It is mentioned that "This is likely due to clutter correction with less correct measurements". It is probably meant that the algorithm to remove clutter removes too much of the signal. In addition, I have a remark about the results for radar reflectivities of higher levels. Clutter will be less apparent because surrounding pixels also have larger values due to rainfall. This does not automatically imply that the clutter is not a problem anymore.

ANSWER: We fully agree. At the moment, clutter affected pixels include measurements of pixels with clutter as well as pixels with clutter correction. This will be clarified. Your remark concerning the remaining clutter influence is absolutely right and we will include it.

REFEREE #2: p 4714, L 8-9: This only holds for the left figure.

ANSWER: Modified: "According to Fig. 7 the mountain clutter for light rain seems to have the same characteristics as the city clutter."

REFEREE #2: p 4714, L 11-13: The mode is clearly larger than 0. Is this conclusion justified?

ANSWER: We have to apologize, in the discussion paper an old version of this figure was accidentally shown. Fig. 7 will be replaced.

REFEREE #2: p 4714, L 24-25: Usually, only part of the radar beam will be blocked. Therefore, most measurements in the spoke will still fall in class 1.

ANSWER: We will include this valuable remark. For the PX-product a threshold for noise is used: in winter the threshold is 1 dBZ and in summer it is 7 dBZ. So the class width is a little bit larger for level 1 (1 dBZ resp. 7 dBZ to 19 dBZ) than for the other levels. So many measurements in the spoke will still fall in class 1.

REFEREE #2: p 4720: I would find it more logical to first remove clutter, than apply

an altitude correction and, finally, apply a gauge adjustment. If I understand it correctly a different order is followed in this paper. First try to get the radar data as good as possible, without using additional data. I believe this is the usual approach.

ANSWER: Yes, the logical order would certainly be first to correct clutter, then to apply an altitude correction and finally to adjust to gauges. There are two reasons for the order presented here. Firstly, for the interpolation of clutter pixels as well as for the adjustment of spokes one has to use the adjacent uncorrupted radar pixels. Both corrections are more stable if based on a more homogeneous data base without mixtures of pixels from different heights or rays with different angles of radiation. Secondly, the gauge adjustment is in the second order because only in conjunction with the altitude correction an improvement can be shown. The aim is to show an improvement with each step of correction. Especially the altitude correction is responsible for the hugest improvement and this can only be shown in the diagrams and the RMSE with this order. For the correction itself it does not really matter if the gauge adjustment is in second or fourth order. We will clarify the used order in the paper.

REFEREE #2: p 4719, L 14-18: Are both ways subsequently used?

ANSWER: Yes, both ways are used. For the mountain clutter and the city clutter the interpolation technique is used (L 19-23) and for the spokes the adjustment is used (L 24 et sequentes).

REFEREE #2: p 4721, L 22-24: annual rainfall amounts?

ANSWER: Yes, annual rainfall amounts. The text will be checked whether further ambiguities of rain rate or rain amounts exist.

REFEREE #2: p 4722, L 11: "a certain variability in class 1". This box-plot is based on only 2 measurements. It would therefore be more appropriate to combine range class 0-20 km with range class 20-40 km.

ANSWER: Admittedly, two measurements are a very small basis for a comparison.

However, there are two reasons why we analyzed them separately. Firstly, the measurements within a few kilometers around the radar site are not very reliable. Secondly, regarding Fig. 3, the measurements between 20 and 40 km from the radar site are at the beginning of the descending branch of the frequencies of occurrence, whereas measurements below 20 km are in the ascending branch (at least for level 1 to level 4), where the regression line of the altitude correction does not really represent this behavior.

We would prefer to stay with the first class but to discuss its limitations.

REFEREE #2: p 4722, L 15-16: I find this quite remarkable, since the radar data have not been corrected. Is this an indication that the radar is well calibrated? Are there other explanations?

ANSWER: Yes, it is remarkable, even if annual values are used. The three-part Z-R-relationship used to calculate rain rate from reflectivity measurements is also based on long-term measurements. As we know from radar hydrology, for shorter time-spans much higher differences between radar measurements and gauge measurements occur. On the other hand, the Munich weather radar was one of the first weather radar of the German Met. Service, so a long time of experience may result in a good calibration.

REFEREE #2: p 4722, L 20-21: This is certainly the case in winter, but in summer this decreasing rain rate by radar measurements with distance from the radar will probably often not be found.

ANSWER: This is true, when one looks at single radar images. But here, the mean behavior of annual rain amounts is described. As this effect only appears, because the radar measurements are not at the same height, it is classified as a measuring effect. Azimuthal variations in rain amount at a fixed height of one radar image are attributed to meteorology.

We will clarify, that the “mean” behavior is described.

REFEREE #2: p 4723, L 19-20: And also by representativeness errors (different sampling volume and measurement height).

ANSWER: Modified accordingly:

REFEREE #2: p 4725, L 1-2: "additional pairs of value". The RMSE is larger for the calibration data set using the same gauges. Therefore, differences in RMSE cannot be explained by additional pairs of value.

ANSWER: Modified: “So the impairment of the RMSE of 91 pairs of values of the validation period compared to the RMSE of the 76 pairs of values of the calibration period (see Tab. 3) is mainly induced by the additional pairs of value.”

REFEREE #2: p 4725: Two times a reference is made to Figure 1, but this can not be right.

ANSWER: The correct reference is to Figure 2 and will be mentioned only once.

REFEREE #2: p 4725, L 19: I don’t understand this sentence. Is it meant that the radar data have been adjusted using rain gauge data (point measurements)?

ANSWER: No, the explanation will be given as follows:

Modified: “The right panel of Figure 14 shows the result after the whole correction algorithm, where the correction is based on frequencies of occurrence of DX-data and calculated to rain amounts afterwards. The image now shows a map of mean annual rain amounts which is very similar to maps of annually rain amounts based on point measurements (not shown here).”

REFEREE #2: p 4726, L 19: "homogeneity" instead of "homogeneity".

ANSWER: We think "homogeneity" is spelled correctly.

REFEREE #2: p 4726, last paragraph: Why clutter or spoke corrections cannot be combined with a bright band or vertical profile of reflectivity correction? Moreover, a more sophisticated gauge adjustment, in which the adjustment factor field varies locally, could also be used to indirectly remove all kinds of (sources of) errors such as bright band and VPR-related errors. Of course this requires a sufficient number of rain gauges.

ANSWER: Of course, all kinds of combinations of statistical corrections and corrections on single radar images are feasible. The better the single radar pixels are corrected in advance the fewer statistical corrections are necessary afterwards. A detailed explanation can now be found at REFEREE #1: Summary. A more sophisticated real-time adjustment scheme is operational in DWD which would be used to obtain the best rain amount possible. But this is not required for this correction scheme as the main aim is to correct the side effects of the altitude correction. (see REFEREE #2: p 4710, L 8-12).

REFEREE #2: Table 1: It would be interesting to mention the corresponding rain intensities. In the text often level 1 data are analyzed. This is called "light rain", but according to Table 1 also contains dry periods. If this is the case it should be mentioned in the text that "light rain" also contains "no rain".

ANSWER: As already mentioned on p 4708 there is a threshold for noise for the PX-product: 7 dBZ (1 dBZ). This will be corrected in Table 1. Mean rain intensities can be added.

REFEREE #2: Table 3 refers to Figures 10 and 11, which contain, respectively, frequency of occurrence and annual precipitation. The RMSE will probably only refer to the annual precipitation. So, RMSE of what? Add this to the caption.

ANSWER: Right, the RMSE only refers to the annual precipitation. The caption of Table 3 will be corrected.

REFEREE #2: Table 4: RMSE of what? Figure 12 gives a percential difference, is the reference to this figure correct?

ANSWER: No, the reference is to the data base of Figure 13. This will be clarified.

REFEREE #2: Figures: It would be clarifying to add "PX" or "DX" to the caption of the figures.

ANSWER: Modified accordingly.

REFEREE #2: Figure 2: Could a distance scale be added to the figure?

ANSWER: „The scale is 200 x 200 km^2" will be added to the caption.

REFEREE #2: Figure 6: I believe that "difference" is a more appropriate term than "variation" in the label of the horizontal axis. The name of the label of the vertical axis could also be replaced. "quantity" is a generic term.

ANSWER: We will change the axis names.

REFEREE #2: Figures 10 - 11: You use "corrected" and "adjusted", but is not clear to which corrections or adjustments you refer to. "Corrected" can be used to specifically correct for radar errors. "Adjustment" refers to adjustment using other data sources, e.g., rain gauge data.

ANSWER: Yes, this is the case. "Adjusted" always refers to the adjustment using the rain gauges and "corrected" is used to specifically correct for radar errors.

REFEREE #2: Figure 11: Print quality of figure should be improved. Is this a calibration?

ANSWER: Print quality will be improved. It is the time-span of calibration ("Adjustment").

REFEREE #2: Figure 13: Mention "calibration" and "validation".

ANSWER: Modified accordingly.

REFEREE #2: Figure 14: A map based on interpolated rain gauge data would be interesting.

ANSWER: We did not add this map in order not to misguide the reader about the intention of our paper.

Literature will be added:

Hand, W. H., 1996: An object-oriented technique for nowcasting heavy showers and thunderstorms. Meteorological Applications, 3, 31–41.

Overeem, Aart, Iwan Holleman, Adri Buishand, 2009: Derivation of a 10-Year Radar-Based Climatology of Rainfall. J. Appl. Meteor. Climatol., 48, 1448–1463.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 4703, 2012.