The German radar composite RX: Qualitative performance analysis for a precipitation climatology

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1 Introduction

Radar climatology creates a need and offers the chance to analyse quality aspects of radar measurements besides the research of precipitation patterns. Frequently recurring effects, especially systematical metrology effects are the main focus of such analyses. Small variations, which can often be neglected in individual radar images, may significantly influence true rain patterns on a longer temporal scale (Wagner et al., 2012). The metrology of radar systems inevitably leads to differences between radar measurements at close and at far ranges from the radar site. This is due to the fact that the range bin size and the beam elevation increase with distance from the radar site. These effects are enhanced by increasing attenuation with range and by shading effects behind obstacles. Moreover, the German Met. Service does not run a correction scheme for the Vertical Profile of Reflectivity (VPR). This again contributes to systematic differences between close and far ranges from the radar site. The aim of this investigation is to identify non-meteorological spatial patterns within long-term composite radar data. Based on this knowledge a statistical post-correction scheme for radar data on a time-scale of at least one year has been developed (not shown here) to enhance radar data quality for an improved analysis of precipitation patterns.

2 Data

The German radar composite RX combines measurements from up to 16 radar systems during the investigation period from 2005 to 2009. This product provides high resolution reflectivity measurements every 5 minutes with 256 levels (-31.5 dBZ to 95.5 dBZ at a resolution of 0.5 dB) on a 900x900 km Cartesian grid (1x1 km) over Germany and is based on DWD's terrain-following precipitation scan with a maximum range of 128 km and a resolution of 1x1 km. Compositing effects are analysed on this basis. Moreover, the local radar products with 6 reflectivity levels (PX, based on the same terrain-following precipitation scan) are analysed for each of the 16 radar sites over the timespan from 2000 through 2006. Data from the Munich, Hamburg and Emden radars are shown.

3 Method

In a first step, two different types of accumulation products have been created: Annual frequencies of occurrence of each reflectivity level were calculated at each pixel, and annual rain amounts were derived by the three-part Z/R relationship used in DWD's operational RADOLAN adjustment procedure (Bartels et al., 2004). The accumulation period is one year, with an additional subdivision into months for the single radar images. In Figure 1 the mean annual frequencies of occurrence of radar reflectivity level 1 (0-17.5 dBZ) and level 3 (28-36.5 dBZ) are shown. Some variations of rain patterns become apparent in both images, besides a couple of artefacts and metrology effects under discussion here.

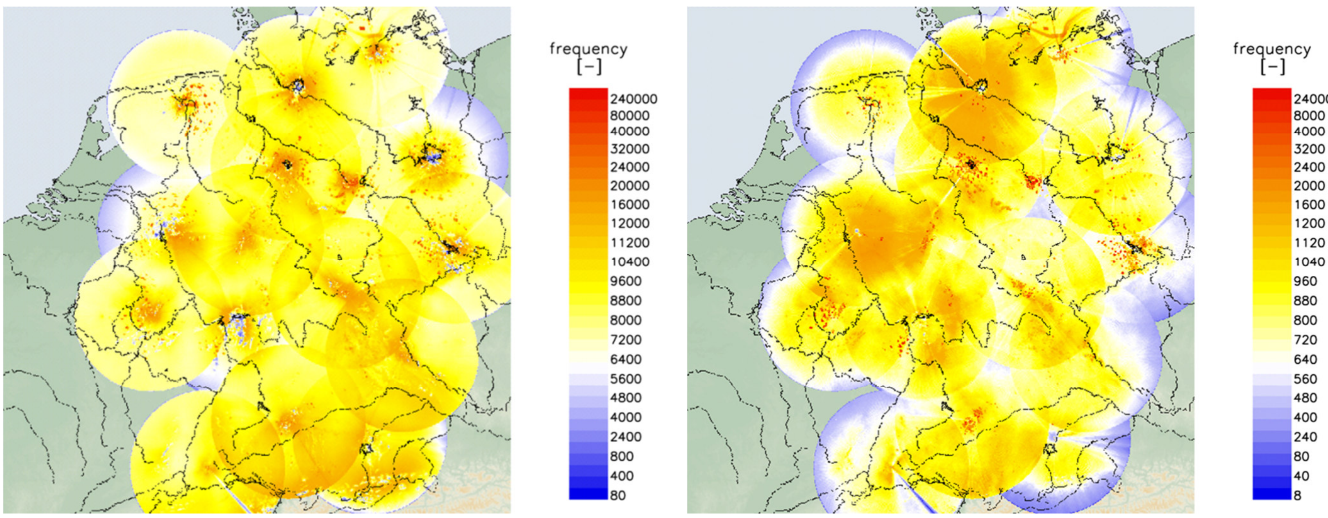

Figure 1: Uncorrected mean annual frequencies of occurrence of radar reflectivity level 1 (0-17.5 dBZ) (left) and level 3 (28-36.5 dBZ) (right) based on RX composite radar data averaged over 2005-2009.

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Using a pattern recognition scheme, single pixels or groups of pixels that show unusual signatures compared to precipitation echoes, are identified in these accumulation products. Such signatures may be straight edges, high gradients or systematic over- or underestimations compared to adjacent areas, which cannot be explained in terms of precipitation. The separation of disturbed and undisturbed areas is realised using thresholds, histograms and non-parametric distributions. The results are visually checked afterwards. Clutter effects or negative spokes caused by shading effects behind obstacles were visually compared to undisturbed areas. For undisturbed areas, the systematical differences between pixels at close and at far ranges from the radar site are analysed, even monthly. Additional systematical differences or compositing effects are investigated based on the RX composite data. The differences in rain amounts between adjacent radar systems and the variations between single radar areas and areas where two or more radar systems provide measurements (overlapping areas) are analysed based on Box and Whisker Diagrams (see Fig. 5). The systematical differences between pixels at close and at far ranges as well as the mean allocation of pixels to one radar system in overlapping areas is investigated by plotting the mean annual rain amounts of every pixel against height or distance from the contributing radar system (see Fig. 3, 4 and 6).

4 Results

Figure 2 (left) gives an overview of uncorrected mean annual rain amounts derived by accumulating RX products from 2005 through 2009. Only measurements are considered where all 16 radar systems contribute to eliminate the effect of radar availability. Some obvious disturbances and systematic variations within this image become apparent: Clutter effects from ships in the northwestern and in the northeastern part of the image, clutter remnants that survived clutter filtering caused by obstacles near the radar site, negative spokes caused by these obstacles, obvious gradients at the borders between single radar areas and overlapping areas as well as differences in rain amounts based on measurements of adjacent radar systems. The right image of Figure 2 separates disturbed and undisturbed areas of the composite with clutter pixels (red), negative spokes which still include rain patterns (yellow) and the overlapping areas in blue colours. In the following, certain aspects of the entire analysis are presented including some remarks on the correction algorithm.

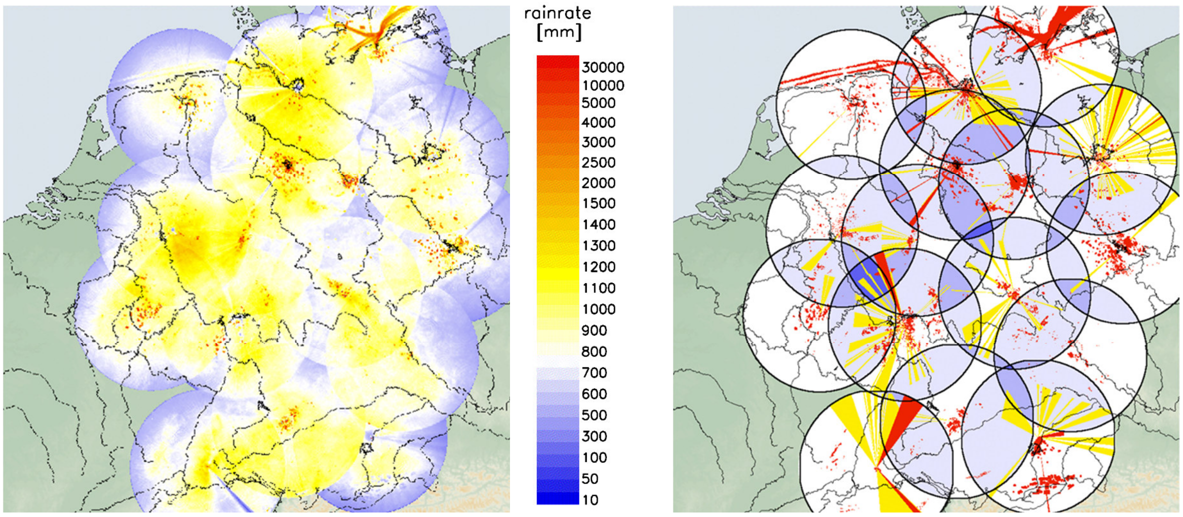

Figure 2: Left: Uncorrected mean annual rain amounts for Germany based on radar composite data RX averaged over 2005-2009 including only measurements where all 16 radar systems contribute. The scale is 900 x 900 km². Right: Overview of clutter and disturbances within the radar composite product RX including clutter pixels (red), spokes (yellow) and the overlapping areas of several radar systems in blue colours.

4.1 Variation with height (single radar)

Based on the PX single radar data, the dependence of the frequency of occurrence of each radar reflectivity level on the altitude of each individual range bin is investigated. Due to the terrain-following scan the relationship between the distance from the radar site and the beam elevations are not isotropic for various azimuth. In general, the frequencies of occurrence of radar reflectivities decrease with increasing beam elevation. A mixture of meteorological and metrological reasons is responsible for this behavior: The rain amounts usually decrease from the cloud base to higher altitudes. With higher altitudes overshooting and partial beam-filling effects occur more often. The positive elevation angle for all radar sites combined with earth curvature effects result in increasing beam altitudes with distance from the radar site. Additionally, the range-bin sizes increase with height so that the patterns of small convective cells are blurred and the maxima are underestimated.

Figure 3 shows the mean frequencies of occurrence of radar reflectivity level 3 over height from 2000 to 2006 for the months of January, April, July and October at the Munich weather radar. The black crosses mark each single pixel and their spread indicates the natural variability of precipitation. The red crosses show the behavior of the median of the frequency of occurrence with altitude, separated into classes of height (100 m), which can be regarded as the mean behavior.

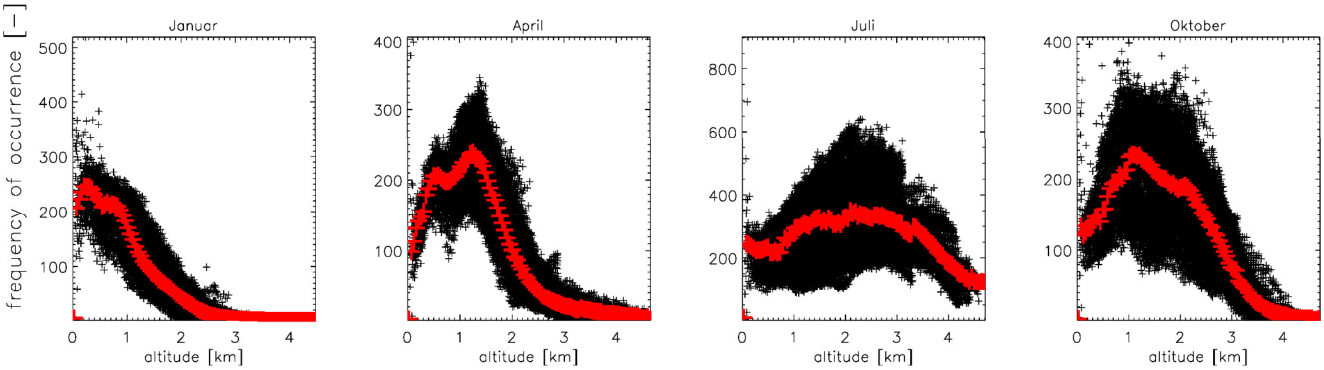

Figure 3: Characteristics of the median of the frequency of occurrence of uncorrupted pixels over height for equidistant classes of altitude for the reflectivity levels 3 for January (first), April (second), July (third) and October (fourth) of the Munich weather radar from 2000-2006 (PX data).

The lowest radar measurements (at left in the figures) must be neglected because only very few pixels remain and may additionally be affected by clutter originating from clutter in downtown Munich. Subsequently a plateau with a more or less pronounced maximum follows. The altitude of the maximum of frequencies of occurrence approximately agrees with the altitude of the freezing level calculated from mean monthly temperatures and may be enhanced by Bright Band effects. With still higher altitudes the frequencies of occurrence decrease, as the snow measurements result in lower reflectivities. So these monthly differences may be attributed to changing meteorology effects. Moreover, the precipitation regime changes from stratiform rain with low vertical extensions in winter to more frequent convective rain events with higher vertical extensions in summer, which contributes to seasonal variations.

Regarding the annual behavior of frequencies of occurrence of radar reflectivities with height, an almost linear decrease can be observed (see Fig. 4). This decrease varies for different radar sites and different reflectivity levels. For all radar sites the reflectivity level 1 with a high portion of snow shows the lowest decreases with height in frequency of occurrence. There is a tendency for this decrease to appear steeper at higher rain rates (level 3 and level 5, 46 – 55 dBZ), but this is not true for the Munich weather radar (see Fig. 4) and some other radar not shown here.

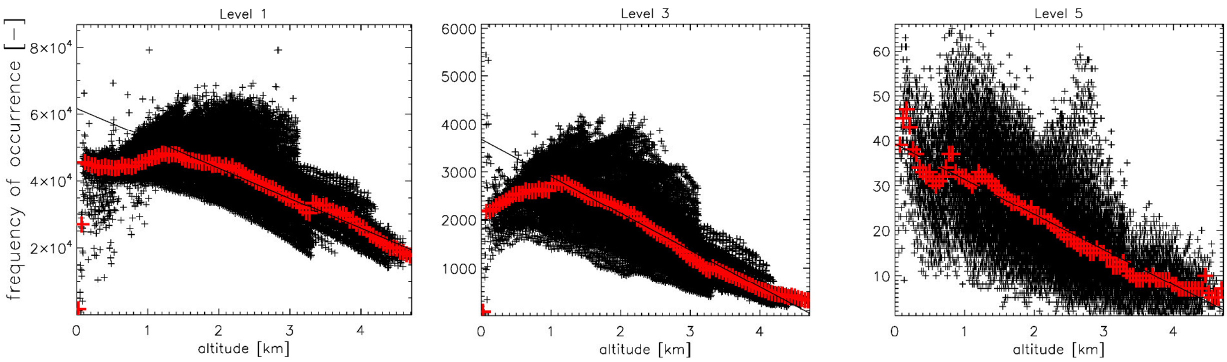

Figure 4: Same as Fig. 3, but based on the annual amounts for reflectivity levels 1 (left), 3 (middle) and 5 (right).

4.2 Non-meteorological variations of annual rain amounts

Based on the mean annual rain amounts of Figure 2, box and whisker diagrams are shown to highlight differences between adjacent radar sites as well as differences between single radar areas and overlapping areas. Figure 5 shows the distributions of rain amounts for the Hamburg radar and for the Emden radar in the northwestern part of Germany. The single radar area of the Hamburg radar shows rain amounts which exceed the Emden ones by more than 200 mm. Meteorological reasons, beam elevation or the altitude of the radar site are not able to explain these differences. Different radar calibrations seem to be responsible for these variations.

The mean annual rain amounts within the overlapping areas of all pairs of radar sites are higher than in the adjacent single radar area, although the rain amounts usually decrease with distance from the radar site (see Fig. 5). This behavior can be attributed to the maximum criterion applied for compositing radar data: In overlapping areas, the highest value is always chosen. The sharp gradients at the borders of overlapping areas in Fig. 2 are further effects of this maximum criterion. Remember that in Fig. 2 and 5 only those measurements are included where all radar sites contribute. If all measurements had been used, the differences between single radar areas and overlapping areas would have been still more pronounced.

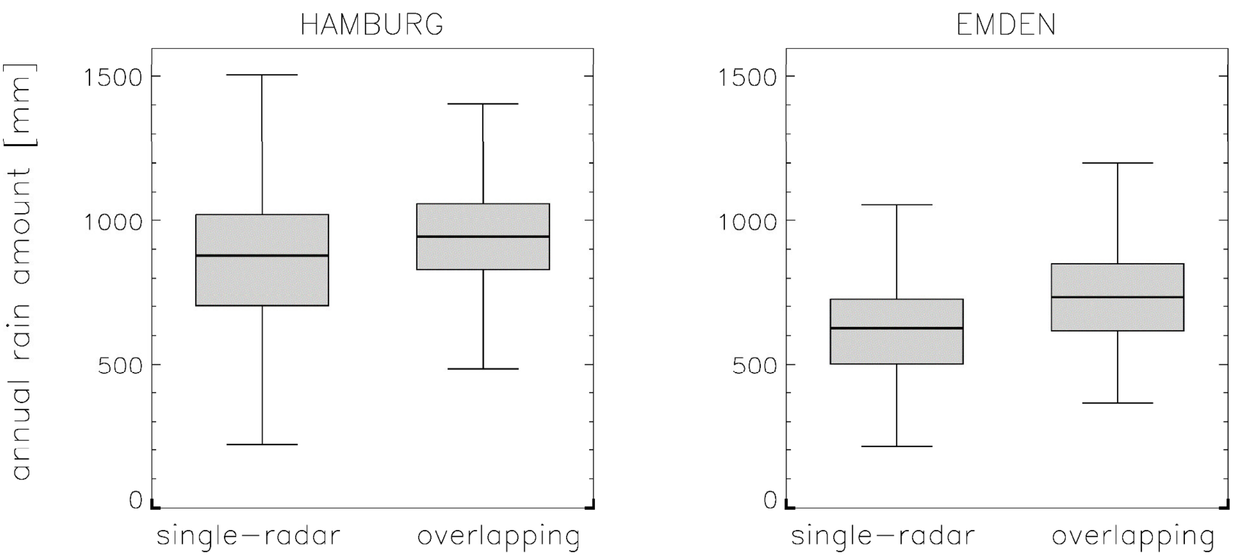

Figure 5: Box and Whisker Diagrams of all pixels of the Hamburg and the Emden weather radars separated into single radar area and overlapping area. The thick bar indicates the median of all rain amounts. The boxes show the deviation of 50 % of radar rainfall amounts. The whiskers mark 1.5 times the corresponding interquartile range or, if not reached, the maximum deviation.

4.3 Distribution of rain echoes in overlapping areas

The contribution of an individual radar system to rain echoes within overlapping areas is not invariable but depends on the respective reflectivity values according to the maximum criterion. Nevertheless, one can assume that for most pixels a "preferred" allocation to one of the radars exists because of differences in beam elevation, calibration or range bin size of the contributing radar systems. The dependence of the frequencies of occurrence of radar reflectivities on distance from each contributing radar site is analysed here. Figure 6 shows the result for an arbitrary overlapping area of two radar sites for reflectivity level 3. The red crosses, which represent the median of each distance class (10 km wide), reveal a typical regime: the decrease of the frequencies of occurrence indicates the decreasing prevalence of the considered radar site with increasing range. Then an area of transition follows where both radar systems provide similar numbers of measurements. The following increase can be interpreted in terms of increasing contributions of the second radar system. These gradients of decreases and increases are variable and depend on the availability of the radar systems and on the reflectivity level; only the area of transition is stable. Similar figures result for more than two contributing radar systems.

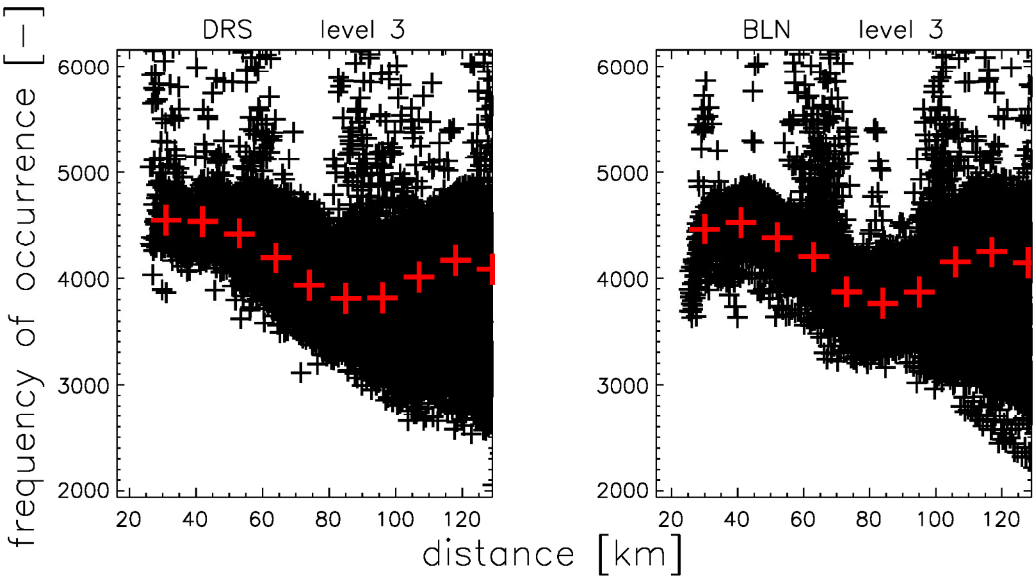

Figure 6: Characteristics of the frequency of occurrence of uncorrupted pixels with distance from the radar site for the reflectivity level 3 in the overlapping area of the Dresden and Berlin radars for the time span 2005 to 2009, overplotted by the corresponding median of equidistant classes of distance (red).

4.4 Results of the correction scheme

The findings of the above analyses may naturally be interpreted in terms of a “climatological” correction. This correction scheme, which will be presented in a separate paper, only relies on mean adjustments or linear relationships to correct for the effects described above while maintaining the true rain patterns as far as possible. E.g. the linear relationship of frequencies of occurrence of radar reflectivities and altitude can be used as a simple correction if one assumes that this linear decrease is not a natural pattern regarding areal precipitation. The consequence of the results derived from the box and whisker diagrams is that the single radar areas of each radar site have to be adjusted separately to rain gauge data. The single radar areas and the overlapping areas also have to be handled separately. If the transition areas for all overlapping areas are known, it is possible to implement the correction of the variation of rain echoes with height, even in the overlapping areas and adjust these areas to adjacent single radar areas.

One result of this correction scheme is presented in Fig. 7 for the mean annual rain amounts in Germany over the years 2005 to 2009, based on the RX composite data. The left image shows the uncorrected mean annual rain amounts of all radar measurements. The third image reveals the corrected rain amounts while the image in the middle is based on interpolated rain gauge data only. The overall distribution of rain patterns in the latter two images is very similar but regional precipitation patterns sometimes differ or are differently pronounced. Note the increase in precipitation over the Alps and in Eastern Bavaria and the smoother precipitation fields around the Hamburg, Hannover, Neuheilenbach and Frankfurt radars in the corrected as compared to the uncorrected radar data.

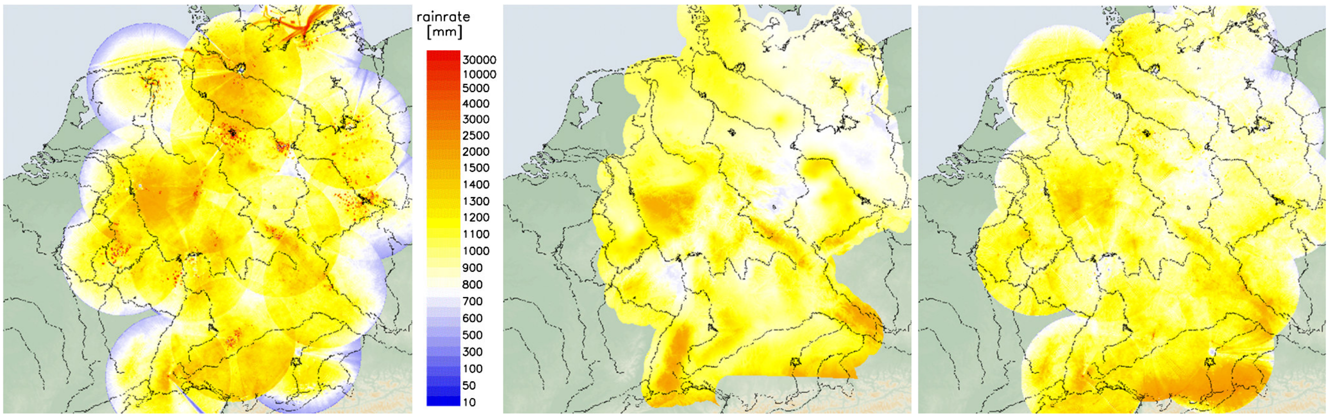

Figure 6: Annual rain amounts for Germany based on radar composite data RX for the years 2005 to 2009 for uncorrected radar data (left), based on gauge data only (middle) and corrected radar data (right).

5 Conclusion

The analysis of accumulated radar products reveals some of the shortcomings which still exist in individual radar products after operational quality control such as clutter filtering and calibration monitoring. Especially the “climatologic enhancement” of small systematic differences, which may become major sources of error, is shown. According to the findings here a correction of the Vertical Profile of Reflectivity would probably improve these products. As a substitute, a radar climatology based on these data may also use statistical correction schemes to avoid misinterpretations of patterns in precipitation radar products.

References

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