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Interactive comment on "5 year radar-based rainfall statistics: disturbances analysis and development of a post-correction scheme for the German radar composite" *by* A. Wagner et al.

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We wish to thank the reviewer for her/his comprehensive and inspiring review.
The referee addresses three main topics (general remarks); we want to discuss them in more detail, first. Then, we will clarify and discuss the specific remarks in the following.
The questions are inserted below (italic) followed by our responses:

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General remarks:

REFEREE#2: international perspective

Therefore, an appreciation of the presented work in in the light of international work would be useful. Else, the presented paper which consists of a large amount of work would be difficult to be put into an international perspective which is one main focus of an international journal.

ANSWER: We agree with Referee #2 and will elaborate in more detail the international perspective of our work.

For several years, large area analyses and the assimilation of weather radar data into numerical weather prediction models have increased the importance of composite radar products. The generation of composites covering large geographical areas such as several northern European countries (in NORDRAD and BALTRAD) or entire Europe (EUMETNET) creates the need for consistent data quality and comparable input data. Programs such as the COST programs (e.g. COST717, COST731, OPERA-4, etc.) help to create these standards. In parallel, weather services operate their own networks (e.g. Finland, Spain, France, United Kingdom, Germany, etc.) with their own philosophy, partly historical, regarding the scan strategy or correction schemes. In most countries the composite is created based on volume data where the range of each radar system is covered by more than one elevation. In this way it is possible to bypass obstacles. In Germany the compositing is realised based on a terrain-following scan called "Precip scan" which is a particular feature in Germany. Nevertheless, some main problems of radar measurements remain that apply to all countries: 1) remaining clutter effects and beam-blockage; 2) the increase of size and altitude of range-bins with distance from the radar site; 3) systematic, but weak variations which may be accumulated on a longer temporal scale; 4) the way of compositing, where measurements from two or more radar systems have to be combined without producing sharp gradients.

We will elaborate and discuss this in the revised version.
We think, independent from the national philosophy of radar measurement, correction strategy and composite generation, that such an analysis of these effects on a longer temporal scale is important to be conducted. In our study we demonstrate and analyse these effects based on the data and processing-chain peculiar to the German radar composite. If a comparable analysis with annual rain patterns and its derivates (intense precipitation or hail) is planned elsewhere, the correction scheme can be transferred accordingly.

REFEREE#2: holistic methodology

A drawback of the paper is the holistic methodology, i.e. where summary effects of impacts on radar measurements are attempted to be solved on a yearly basis although more detailed information is available.
ANSWER: We analysed the data basis and derived dependencies and correction factors where we observed stable conditions. In Wagner et al. (2012) we analysed the dependence of frequencies of occurrence of radar reflectivities on altitude on a shorter time-scale. Even the monthly variations were significant, as the relationship of these frequencies with height depend e.g. on rain type and temperature. We believe that such a statistical correction only make sense on a temporal basis of at least one year. An alternative would be to use a VPR correction scheme on single radar images which may not completely remove this altitude effect and additionally, which was not used nor available, here. This time scale is sufficient for our concern to correct precipitation patterns on a longer temporal scale.
We will elaborate and discuss this in the revised version.

REFEREE#2: Usage of the PX-product

Another methodological problem is the use of the PX product which is not representative for the RX data: (1) observed was a different time period - most radars were non Doppler until 2004, so the results cannot be transferred. It would be required to have identical time intervals for single and composite data for a consistent approach (2) different value resolution: PX is 6 classes, RX is 0.5 dBZ steps (3) PX already is a single radar cartesian product, RX becomes only cartesian when compositing and is based on the DX polar product => DX product would be the logical choice for an analysis of the compositing effects

ANSWER: We comprehend the referee #2 concerns about the usage of the PX-product. We are aware of the handicap imposed by the use of classified and projected products.

We will clarify what is meant by “transfer” of the single radar results to the composite: We did not identify spokes and clutter pixels on single radar data and transfer them “uncontrolled” to the composite data. Then, indeed, it would not make sense to use different (only partly overlapping) time periods for the analysis of single radar data and composite data. The results from the single radar analysis were used as a first coarse selection of corrupted pixels. Based on accumulated images of the RX composite, this coarse selection is checked and verified. Therefore, identical tools may be applied to identify corrupted pixels in single and composite radar data. The aim is to correct as many pixels as necessary and as little pixels as possible. The verification of clutter pixels, massively corrupted spokes and spokes that still include precipitation patterns, but with higher degrees of shading effects, is easy and could even be performed visually. Only spokes with a minimal deviation from the surrounded pixels are more difficult to identify.

The three products RX, DX and PX are based on the same scan and the same corrections (speckle remover, thresholding for noise, signal quality and Doppler filtering) within the signal processor (p. 1772, ll. 3-5). There are further similarities among these three products: The DX-product and the RX-product have the same resolution (0.5 dBZ); the PX-product and the RX-product are converted to a Cartesian grid with similar spatial resolution.

We would not recommend the PX-product for any kind of quantitative usage nor correction of single radar images. We would prefer the DX-product, but here we cannot benefit from its advantages. The identification of spokes would be easier relying on polar coordinates, but this is not a problem here, either. The necessarily transfer of corrupted pixels from the DX-product in polar coordinates to the RX-product in Cartesian coordinates would be more difficult, especially near the radar site where the range-bins of the DX-product are significantly smaller than the Cartesian grid. One would have to take care how the Cartesian product RX is created and whether a remaining clutter pixel within the DX-product would really enter the composite data. The RX and PX are both sampled from DX-like data in polar coordinates using identical procedures (nearest neighbor). The bias might be introduced if these polar range-bins were averaged and not sampled. In other words we need to use the same procedure to sample the DX-product which leaves us with the PX-product. If the identification of clutter on a Cartesian grid avoid this problem, why not use it?

Radar data which originate before 2004 show a higher density of clutter pixels. The redundant clutter is not transferred to the RX composite as mentioned above. An uncontrolled transfer would probably lead to a useless overcorrection.

The reason why we use time series of radar data starting in 2000 is that for the altitude correction we need safe statistics especially for the rare intense precipitation events. The longer the time-series the better the results are. For the same reason, the reflectivities have to be separated into classes to further increase the amounts for higher reflectivity levels. The six levels of the PX are sufficient whereas the DX-data would have to be divided into classes.

We choose a time-period for the analysis of PX-data between 2000 and 2006 as a compromise between long-time series (safe statistics), temporal independency from the validation period (2007 and 2008) and temporal dependency on the calibration period (2005, 2006 and 2009).

The proposed switch to the DX-product (instead of the PX-product) would result in a shorter time period (we have a continuous data base only since 2004) and probably some difficulties when transferring corrupted pixels to the RX composite. The unquestionable general advantages of the DX-product cannot be exploited, here. In Wagner et al. (2012) a comparable correction scheme is developed based on the PX-product and successfully applied to the DX-product at the Munich weather radar. Furthermore, it is unlikely that the results of the correction algorithm would change, due to our "controlled" transfer of the results from single radar analysis to the composite. Probably, the altitude correction (with the largest impact) would even become less stable with the shorter time period.

So in spite of the general limitations of classified products we prefer to use the PX-product. The similar question from both referees showed us, that we have to explain why we want to use the PX-product in more detail in the manuscript.

Specific remarks:

REFEREE#2: *p 1771 line 9: which range: 128, 150 or 250 km?*

ANSWER: The RX-product is based on the terrain following-scan with 128 km maximum range (p. 1771, ll. 3-5). We will add the range in brackets in line 9.

REFEREE#2: *p 1772 Derivation of rain amounts from PX is somewhat coarse*

ANSWER: We only use the frequencies of occurrence of radar reflectivities for our analysis of the PX-product (p. 1772, ll. 22-24). We will clarify that in the text.

REFEREE#2: *p 1773 spokes are much easier to detect and verify on polar data. the same is true -although to a lesser degree - for distance related characteristics*

ANSWER: As mentioned above, we agree on the obvious theoretical advantage of polar-coordinates regarding spokes. However, the identification of spokes in accumulated radar images in Cartesian coordinates is not a problem. So these advantages may not compensate the disadvantages of transferring the results based on polar-coordinates to Cartesian coordi-nates (including distance related characteristics) and the shorter time-period of available DX-data.

REFEREE#2: *p 1775 last line. the statement is trivial - what about the relative amount of values?*

ANSWER: The relative proportions of clutter pixels among reflectivity levels depend on the cause of clutter. At the end of the response one will find a table with relative proportions of clutter pixels for each reflectivity level and each radar system of DWD in Germany based on PX data from 2000 to 2006. The basis is the amount of clutter pixels of reflectivity level 1.

High amounts of clutter affected pixels become apparent near or in bigger cities or urban areas such as Hamburg, Frankfurt and Munich. In most of these cities the “City clutter” domi-nates the total amount of clutter pixels that is reduced significantly for higher reflectivities. The amount of clutter pixels decreases by 20 % for the Hamburg radar and by up to 50 % for the Frankfurt radar for reflectivity level 2 compared to reflectivity level 1. The lower relative decrease in Hamburg is influenced by additional clutter pixels due to ships. This “ship clutter” is mainly responsible for the large amount of clutter pixels in Rostock and Emden. The large amount of clutter pixels for the Feldberg radar can be explained by shaded areas in the north-eastern and in the south-eastern part of the Feldberg radar obvious in Fig. 5. The variations of the relative proportions at the Tuerkheim radar may appear astonishing, but the total amount of clutter pixels is very low.

We may add this table to the manuscript.

REFEREE#2: *p 1776 another effect of DWD clutter removal is empty pixels - this is severely disturbing further data use but not mentioned here*

ANSWER: On p. 1775, ll. 11-15 we described the effects of clutter. (“The second one is thresholded data resulting in lower amounts and counts”; ll. 14-15). So the clutter effects we describe in the following consists of both “types” of clutter. We will clarify that in the revised text.

REFEREE#2: *p 1778 Fig 5: what are the red spokes?*
ANSWER: The red spokes are spokes which are massively corrupted so that no precipitation patterns are visually any more compared to surrounded pixels. They are also “treated” like clutter within the correction scheme. We will clarify that further.
REFEREE#2: *p 1782 the altitude effect is different in winter and in summer - in winter also due to overshooting of shallow precipitation. A uniform correction of sums neglects the use of better information and better correction possibilities*
ANSWER: We agree with the Referee #2 as we already stated in ““holistic” methodology”. We investigated the seasonal effects but did not find stable dependencies which can be used as a correction.
REFEREE#2: *p 1782 did you degrade the RX pixel information to the PX levels for this?*
ANSWER: We do not degrade the RX pixel information to the PX-levels. As we described on p1782, ll. 15-16 we calculated the variation of the correction factor (based on the six PX-classes) by a linear relationship. In this way we derive correction factors with a resolution of 0.5 dB. A constant correction factor is only obtained for reflectivities with PX-level 1.
REFEREE#2: *p 1783 the spoke correction is applied to which unit? dBZ, mm/h or frequecy? Did you also consider an additive correction instead of multiplicative?*
ANSWER: The spoke correction is applied to rain amounts [mm/h], i.e. as a percentage or a factor. This would re-translate to a different factor on a Z-basis depending on Z-R relation, and to a corresponding additive correction on a dBZ-basis. Frequencies are intrinsically based on a percentage or a correction factor as well.
REFEREE#2: *p 1783 did you post-control gauge data before adjustment?*
ANSWER: We used quality controlled gauge data and post-controlled it with respect to limit exceedance of monthly and annual mean values and intercompared adjacent rain gauges (p. 1772, ll. 10-13).
REFEREE#2: *p 1784 can you elaborate on the density effect - what density gave how much reliability?*

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ANSWER: Each interpolation technique is based on supporting points. The higher the density of these supporting points the higher the quality of the interpolation result usually is. Then, the quality depends on the interpolation algorithm itself and which quality the spatial patterns between the supporting points (rain gauges) can achieve. We used external drift kriging that is based on the altitude as drift variable. In this way the dependence of rainrate on altitude (for longer periods) can additionally be exploited to determine the spatial patterns of rain amounts. There are other dependencies of rainrate that are not used here such as the dependence of rainrate on wind direction (windward and leeward). So, the density effects cannot be quantified in general terms. If the density of rain gauges is very high one may even succeed in recovering these windward and leeward effects in areas characterized by a dynamic relief. In flat land areas you may receive good results for mean annual rain amounts based on a much lower density of rain gauges. In general, the quality of the interpolation strongly depends on how well the interpolation technique (and here the drift variable) may capture the main effects which are responsible for spatial rain patterns. So, the density of rain gauges must be higher in areas where the interpolation technique poorly represents significant effects which influence rain patterns and can be lower where the rain amounts show only small variations in space or are well captured by the interpolation algorithm. Additionally, the quality of the interpolation results may vary with temporal resolution. The higher the temporal resolution the higher the density of rain gauges usually has to be. We regret that we cannot give any numbers of the density.

REFEREE#2: *p 1785 the internal module is not clear: do you give weights for each source pixel according to their distance to their radar (e.g. 30% radar1, 50% radar2, 20% radar3)and add them on each target pixel?*

ANSWER: We give weights to each source pixel and add them on each target pixel, as the referee #2 stated. The weights depend on the distances to the single radar areas of the rele-vant radar-site and the distance to the respective transition area. If an overlapping area of three radar systems is regarded, individual weights e.g. 30 %

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for radar1, 50 % for radar2 and 20 % for radar3 will result. We will clarify this in the text.

REFEREE#2:*p 1787 why did you choose 3 non-connected years for setting up the system? what are the results for single years - is there a temporal development visible?*

ANSWER: We cannot see any temporal development. The annual variations of rain amounts will cover/mask it. Only the rings caused by the "push"-technique are patterns which only become obvious in the years 2005 and 2006. We chose three non-connected years as a cal-ibration period to have two comparable time periods. The better comparability of data from the calibration period and from the validation period was the only motivation for us to use these years.

REFEREE#2: *p 1790 didn't DWD already postprocess the RX data 2001 - 2013 for their RADOLAN climatology?*

ANSWER: Within the RADOLAN processing chain some products were reanalysed. Even though outside RADOLAN the RX product is widely used, it will NOT be reanalysed to our knowledge.

Table. Relative proportions of clutter pixels for each reflectivity level and each radar system of DWD in Germany based on PX data from 2000 to 2006. The basis is the amount of clutter pixels of reflectivity level 1.

name	amount [-]	lev1 [%]	lev2 [%]	lev3 [%]	lev4 [%]	lev5 [%]	lev6 [%]
Hamburg	4684	100	79	77	80	79	79
Rostock	5892	100	97	96	94	103	103
Emden	2368	100	77	68	69	68	68
Hannover	2318	100	94	74	78	78	78
Ummendorf	1250	100	100	100	100	100	100
Berlin	2324	100	62	56	59	55	55
Essen	2678	100	42	33	31	30	30
Flechtdorf	1352	100	25	22	21	16	16
Dresden	2660	100	75	67	67	67	67
Neuhaus	1963	100	39	34	34	34	34
Neuheilenbach	1290	100	29	31	27	27	27
Frankfurt	5660	100	49	51	53	51	51
Eisberg	566	100	53	45	74	74	74
Tuerkheim	234	100	117	144	129	129	129
Muenchen	5078	100	63	43	43	43	43
Feldberg	3587	100	100	100	100	100	100