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Interactive comment on "Exploring the potential of utilizing high resolution X-band radar for urban rainfall estimation" *by* Wen-Yu Yang et al.

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Response to Reviewer 2

We deeply appreciate the reviewer for his/her very insightful and constructive comments.

We would note that we decided to change our topic to "Utilizing X-band radar monitoring fast-moving rainfall events" considering the nature of the revision. Such change is motivated by following reasons: 1) The urban hydrologic simulations are very sensitive to the spatiotemporal variability of rainfall (Schilling, 1991, Emmanuel,et al, 2012) and thus require rainfall inputs of high spatiotemporal resolution. Although X-band radars can provide rainfall products of high spatial resolution (Chen and Chandrasekar, 2015), they still lack the ability to provide products of high temporal resolution. 2) The radar-

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rainfall accumulations generated from periodic sampling often poorly represent the actual rain fields due to the coarse temporal resolution of the radar rainfall product. This error will be amplified for fast moving storms and fine spatial resolution data (Seo and Krajewski, 2015). In the revised manuscript, we monitor the fast-moving rainfall events with downscaled X-band radar product using the extrapolation technique. First, we quantitatively evaluate the "common error" correction approach to assess the quality of the coarse temporal resolution product. Then, we investigate the impacts of advection correction on the radar QPE. We also examine impacts of the physical factors on the correction accuracy.

The connection between the previous and revised manuscripts are: 1. Same observations from the Beijing X-band radar system, including an X-band radar and a disdrometer; 2. Same QPE algorithm to retrieve rainfall from radar measurement.

However, due to the unexpected amount of work in the revision, we are unable to finish the revision in time even though one extension had been kindly granted by the editor. As such, we first address the specific concerns of the reviewer as best as we can; meanwhile we are working on the revision with more thorough analysis.

Below we detail how we addressed the specific concerns of the reviewer: Major comments: 1. The use of disdrometer measurements for radar calibration in single polarization is an interesting approach since the DSDs measured are representative of the climatology of the region in which are collected. However, different points need to be clarified before applied this method: How the Mie calculation is performed? Which radar pixels are considered for the comparisons in Fig. 3? What is the error of the relationship shown in Fig.3? I suggest to investigate deeply the calibration results in particular, quantitative results, performances of the method and the extension at the entire dataset. These actions are indispensable before to decide if the calibration factor found is necessary or not to be applied. Response: We thank the reviewer for the suggestions. The details of Mie calculation can be found in www.ou.edu/radar/module01radarApps.pdf. The error may come from several sources:

1) The attenuation caused by the wet radome: since the disdrometer in our study is very close to the radar, most of the measurements analyzed are likely coming from situations with rain over the radar also; 2) Different sampling methods: radar performs the volumetric measurement while disdrometer conducts measurement at the point scale; 3) The vertical variability of reflectivity. A deeper analysis of the fast-moving events is conducted in the revised manuscript.

2. Certain issues (such as the instrumental error and the sampling error) have to be carefully considered when the disdrometer data have been used. Since in this work the disdrometer measurements are taken as reference, some considerations on instrumental limitations are needed. In relation to the attenuation correction: how is the performance of the relation between specific attenuation (k) and reflectivity shown in Fig.4? What indicate each point in the figure? Is the reflectivity at which time? How many radar volumes are plotted? Response: In the revise manuscript, a comparison between disdrometer and gauges will be added. And as state above, there will be a deep analysis for the fast-moving events in the revised manuscript. In the previous manuscript, each point in the figure indicates 5 min averaged Z and k calculated based on disdrometer data. The correlation coefficient of the regression is 0.99. Actually, this figure is based on one-year measurements of disdrometer from July 2014 to September 2015. There is no radar data used here.

3. The spectra of DSD collected by disdrometer have an error structure, being more or less sensitive to small drops or more precise for larger drops. Such errors impact applications, like the study of radar algorithms. Furthermore, some procedure of post processing for DSDs collected by disdrometer are necessary, for example to filter out spurious drops due to splashing or wind effect (Tokay et al, 2001). Furthermore, the R-Z relations obtained from the DSDs measurements need to be validate. In particular, the intrinsic validation (that can be obtained from the scatter plot between the Rain Rate (RR) derived from DSDs and the RR obtained from R-Z relation) and the comparison of rain with rain gauges. Response: Such comparison will be conducted in the revised

manuscript.

4. Besides the application of a fixed threshold (why 39 dBZ?) to divide stratiform/convective events a classification of rain regimes based on disdrometer measurements can be used (see Bringi et al 2003, Roberto et al 2016, Adirosi et al, 2015).

Response: We thank the reviewer for pointing out our incorrect citation of Steiner et al. (1995). In the previous manuscript, we used this simple threshold method due to its computational efficiency compared with the radar-based LWC method. In the revised manuscript, as we now focus on only four rainfall events, it is feasible to use the radar-based LWC method.

5. In section beam integration the partial beam blocking is not correct, rather the elevation with optimal visibility is select without compensate the part of signal blocked. There are different approach to compensate the partial beam blocking effect for instance, that proposed by Bech et al 2003.

Response: We thank the reviewer for the suggestion. As Reviewer 1 pointed out, what we did was a simple elevation selection depending on the visibility rather than beam integration. Therefore, partial beam blocking correction is not considered in this manuscript,

6. The largest improvements found in the results shown in Tab. 3, are found for the beam integration procedure. This result appears obvious, if the radar beam is blocked the rain estimated by radar, compared to that measured by rain gauge will be underestimated. The correction that should be assessed is the rain estimated at the optimal visibility elevation before and after applied the partial beam blocking correction..

Response: We thank the reviewer for the suggestion. As stated in Response 5, we have realized what we did was a simple elevation selection. However, what we compared is not rainfall estimated based on the blocked radar beam. Instead, what we compared is rainfall estimated based on the single lowest elevation without beam blockage (i.e., 4.0 ° in this study). Both the rainfall estimated by beam selection and the single lowest elevation are not impacted by beam blockage. Also, as the theme of the revised manuscript is changed, this part will be removed.

7. In order to assess the improvements of Z-R relations from DSD measurements at least these validations are necessary: i) validate the performances of the Z-R relations in terms of intrinsic validation (as explained in previous comments) and ii) the performance of the Z-R relations applied to radar measurements comparing to the standard Z-R relations. In this work the intrinsic validation is not implemented, while if the validation using radar measurements is applied or not is not clear (see lines 392-396 pag 20). I think that in this work is necessary a session dedicated to DSDs measured by Parsivel, that describes the Parsivel data processing and the validation of the relations derived (calibration, attenuation correction and R-Z relations)..

Response: We thank the reviewer for the suggestion. We fully agree that an intrinsic validation is necessary and will be added in the revised manuscript.

Minor comments: 1. Line 110 pag 7 Among the advanced methods that mitigate the error for rain estimation using X-band radar measurements, an approach that reduces the attenuation effect and calibration error is the combined algorithm between Kdp-R and Z-R (Vulpiani et Al. 2015). Response: Corrected as suggested.

2. Line 290 pag 15 What is "BW"? Response: BW is the angular width of the radar beam between the half-power points (for Beijing radar the value is 0.9°). This information has been added in the revised manuscript in line 294.

3. Line 295 pag 15 Which is the origin of the threshold of 6.5 Kg m-2 to categorize stratiform and convective pixels? Response: The threshold 6.5 kg m-2 comes from Qi et al. (2013).

4. Lines 298 pag 16 Please insert the reference for the standard Z-R relationships Response: The references (Marshall and Palmer 1948, Fulton et al., 1998) have been

added in the revised manuscript.

5. Lines 326 pag 17 Since in this work the fall velocity is available from disdrometer measurements, did you check if the fixed falling speed of 5 m/s is representative of your case study? I suggest to use the fall velocity measured by disdrometer, at least for the pixels around the Parsivel in order to obtain the error on the hypothesis of fixed speed velocity. Response: In fact we intended to investigate the temporal sampling bias caused by advection rather than the wind drift effects (Thorndahl et al. 2017). For the advection correction, the assumption of fall velocity is not needed in the revised manuscript.

6. Lines 237 pag 17. Do you mean Eq.(9) instead of Eq.(12)? Response: Yes, we meant eq. (9) rather than eq. (12). And we thank the reviewer for pointing out our incorrect reference.

7. Lines 328-332 pag 17 Is not clear if the tracking algorithm is applied in this work? Please rewrite this part. Response: In the previous manuscript, the tracking algorithm is used to calculate the advection velocity. In the revised manuscript, this part is modified as follows: "The nowcasting algorithm in this study will be used to compute advection velocity vector and the rainfall trend; then, based on the linear interpolation of the computed velocity vector and the rainfall trend, rain rate maps with 1 min resolution will be generated; finally, rainfall accumulation using an increased number of rain rate maps will be computed and compared against the gauge data.

8. Lines 358-362 pag 19 Which are the radar pixels considered to calculate the rd and ra? Instead of select the event based on ra and rd ratio, you should associate a confidence level to each rain gauge based on the radar visibility and on the distance. Response: We thank the reviewer for the suggestion and will conduct such analysis in the revised manuscript. However, we did NOT use the ra and rd ratios to select the rainfall events for analysis; instead, we use these ratios to assess the performance of the X-band radar QPE system.

9. Line 366 pag 19 What about RMSE? Response: The RMSE is 2.1 mm h-1. It has been added in line 369 of the revised manuscript.

References: References: Chen, H., Chandrasekar, V.: The quantitative precipitation estimation system for Dallas–Fort Worth (DFW) urban remote sensing network, J. Hydrol., 531, 259-271, 2015. Emmanuel, I., Andrieu, H., Leblois, E., Flahaut, B.: Temporal and spatial variability of rainfall at the urban hydrological scale, J. Hydrol., 430, 162– 172, 2012. Fabry, F., Bellon, A., Duncan, M.R., Austin, G.L: High resolution rainfall measurements by radar for very small basins: the sampling problem reexamined, J. Hydrol., 161, 415–428, 1994. Qi, Y., Zhang, J., Zhang, P.: A real-time automated convective and stratiform precipitation segregation algorithm in native radar coordinates, Q. J. R. Meteorolog. Soc., 139, 2233-2240, 2013. Schilling, W.: Rainfall data for urban hydrology: what do we need, Atmos. Res., 27, 5–21, 1991. Seo, B., Krajewski, W.F.: Correcting temporal sampling error in radar-rainfall: Effect of advection parameters and rain storm characteristics on the correction accuracy. J. Hydrol., 531, 272–283, 2015. Thorndahl, S., Einfalt, T., Willems, P. et al.: Weather radar rainfall data in urban hydrology, Hydrol. Earth Syst. Sci., 21, 1359–1380, 2017

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2016-388/amt-2016-388-AC2-supplement.pdf

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