Responses to Dr Mazzetti's comments on "Singularity-sensitive gauge-based radar rainfall adjustment methods for urban hydrological applications" by L.-P. Wang et al.

1. General comments:

   (1) The authors present a technique for merging weather radar and raingauge data that is suitable for application in small urban catchments. Validation of the proposed technique is performed through the comparison between estimated rainfall, raingauges and alternative merging techniques. Finally, results from urban flow simulations are compared. The paper is well written, concepts and application are clearly described, results are presented in a straightforward way.

   Answer: We would like to thank the reviewer for taking time to read the manuscript and for the instructive comments.

   (2) The subject of rainfall data merging is not original or unexplored, but the paper has the advantage of providing an example of coupling data merging and urban flow simulations.

   Answer: Indeed, as the reviewer indicated, rainfall data merging is not an unexplored subject; however, its applications to urban hydrological modelling are rather limited and mainly subject to the testing of the existing merging techniques (that have been widely used in large-scale hydrological applications). This paper therefore focused on developing a merging methodology that is especially suitable for urban-scale applications by integrating existing merging techniques (mostly resting upon Gaussian assumption) with the local singularity (or fractal) analysis (Cheng et al., 1994).
   It is worth mentioning that the proposed methodology is not limited to the use of Bayesian data merging (Mazzetti and Todini, 2004; Todini, 2001a, 2001b). In fact, the proposed methodology can also be integrated with other existing merging techniques, such as Kriging with External Drift. The reason we chose the Bayesian data merging is because it has shown to outperform many other merging techniques at urban scales (Ochoa-Rodríguez et al., 2013a, 2013b; Wang et al., 2013).

   (3) One of the weak points in the paper is the fact that, raingauge precipitation estimates are assumed to be a better representation of the "true" rainfall field and used as a reference to evaluate the performances of the different areal gridded rainfall estimates. In this way, rainfall data merging that gets the better results is the one that better represents raingauge estimates, which in fact is not the true rainfall field, because of the 1) raingauge point measurement errors and 2) the extrapolation technique used to extend the point measurement to the grid average. Although raingauge density is an important factor in assessing performances of rainfall estimates, it is not the only one and in general, the availability of a dense raingauge network is necessary, but not sufficient condition to provide a good approximation of the actual rainfall field, particularly during intense

events. Moreover, raingauge point measurements are affected by errors, particularly due to wind, which tend to introduce a negative bias. A small discussion on how to deal with this issue would be of interest, particularly for the high intensities of short duration rainstorms that affect urban environment.

Answer: We totally agree with the reviewer that it is not ideal to 'over-trust' rain gauge rainfall data because they are also affected by a number of error sources (e.g. the effect of wind, evaporation, splashing, discalibration, amongst others). In this work, rain gauge records were obtained from tipping bucket rain gauges. According to the literature (Luyckx and Berlamont, 2001; Molini et al., 2005), the most critical source of error from this type of rain gauges is that due to the loss of water during the tipping action, which is strongly dependent on rainfall rate. Errors due to this may amount up to 10 % for rainfall intensities of 100 mm/h and 20 % for intensities of 200 mm/h in non-mountainous areas. Because the storm events studied in the work were not extremely heavy and some basic treatments had been applied to ensure the quality of rain gauge measurements (e.g. manual comparison between neighbouring rain gauge data), we worked with the assumption that the errors due to the loss of water during tipping action and other sources were not significant. Therefore, the rain gauge data could be an acceptable reference for the comparison.
However, as suggested by the reviewer, rain gauge errors should be better treated, in particular for the high intensity and short duration storms. A brief discussion of this topic will be added in the revised manuscript.

(4) Regarding the urban flow model, I think it is a valuable tool, but results must be evaluated carefully. In general it is not a good idea to evaluate the performances of the rain field estimates downstream an additional model, because it involves calibration and introduces additional uncertainty elements. The model was calibrated using raingauge data, therefore it has been "instructed" to provide the best results with that type of input information. No wonder that it provides the best results using outputs from the merging technique that was better reproducing raingauges, but still this is not a valid proof that the technique is also the most appropriate to conveniently represent the true rainfall field. As a paradox we might get worse results using the true rainfall field as input to the urban flow model, than the ones obtained using the raingauges based estimate utilized for calibrating the model. Moreover using an urban flow model to evaluate performances of rainfall merging introduces more modelling uncertainty (model approximation, parameter calibrated values, initial and boundary conditions, etc) into the process making it difficult to distinguish rainfall "errors" from model "errors". It can be acknowledged that is difficult to find a way out to the problem of "true" rainfall (unless via extensive simulation with synthetic data) and the authors clearly indicate the limits of their assumptions in the paper. For this reason I think the paper can be published.

Answer: It is indeed difficult to find the best way to evaluate rainfall results. As mentioned by the reviewer, the use of urban hydraulic modelling will inevitably introduce additional errors. However, it is a pragmatic and straightforward way to compare different rainfall estimates, in particular when other independent and reliable rainfall measurements are not reliable. Another important consideration is that this comparison serves the purpose of identifying the best rainfall estimates for urban drainage applications: some discrepancies in the rainfall may not turn out to be relevant to the generated flows, and we need to know if and when that is the case.

In addition, because the model was calibrated using rain gauge data, merged rainfall estimates (i.e. BAY and SIN, in this work) could be indeed expected to result in better hydraulic output than the original radar rainfall estimates (i.e. RD). However, if we only focus on the hydraulic performance of the BAY and SIN estimates (and assume that the model errors remain similar), we may still characterise the different features of these two rainfall inputs and have the useful insight of the benefit that we can gain from using the proposed methodology.

As the reviewer indicated, the limitations associated to the hydraulic verification have been clearly stated in the paper.

2. Detailed and editorial comments:

(1) Page 1868 lines 7: It could be interesting using radar estimates with higher spatial resolution, for example provided by an X-band RADAR.

Answer: Indeed, it is very interesting yet more challenging to work with higher-resolution datasets. In fact, some research works are on-going in this aspect in the Interreg IVB NWE RainGain project (http://www.raingain.eu/). The associated results and findings will be published soon.

(2) Page 1870, lines 17-22: Density and coverage of rain-gauges are not the only factor to be considered. Rain-gauges may have errors themselves.

Answer: As mentioned by the reviewer previously in the general comments, the rain gauge measurement errors are also very critical apart from the coverage and density of rain gauge network. This will be better discussed in the revised manuscript.

(3) Page 1873, lines 13-15: Radar should in principle be better than raingauge network in capturing rainfall dynamics. If not, I would investigate also if it might depend on space or time resolution, type of radar, type of corrections.

Answer: What we meant to say here is that radar rainfall estimates fail to well capture instantaneous (dynamic) rain fall rates. As explained between page 1857/line 21 and page 1858/line 8, this is due to the way in which radar reflectivity is generally converted to rainfall rate, using a single Z-R relationship. This is insufficient to deal with dynamic changes in storm type and associated changes in raindrop size distribution. It is true that the term 'dynamics' that we used may cause some confusion, so we have rephrased this sentence as follows:

The relative difference between RG and RD areal average peak intensities is approximately 20–30% for Storms 1 and 2, and it is as high as 60% for Storms 3 and 4. This indicates that the RD estimates could not satisfactorily capture instantaneous rainfall rates, particularly high rainfall rate values, and corroborates the need for dynamic adjustment of RD estimates using local RG measurements.

(4) **Fig. 7: I would suggest to find a better representation for hydrographs. Different signs and colors are not enough to distinguish different lines, even if you improve quality of the picture. Maybe you should consider to make a different figure for each hydrograph.**

Answer: This figure will be improved in the revised manuscript.

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