# Interactive comment on “Rainfall estimation using moving cars as rain gauges – laboratory experiments” referring to the comments of both referees

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## GENERAL REMARKS (BOTH REFEREES):

We are very thankful to both referees for their comments and remarks on our manuscript. We believe that considering them will improve the understanding of the manuscript significantly.

In the following we will respond all the comments from the referees, separately. All the numbers corresponding to figures and tables in this document refer to the numbers used in the original manuscript provided for HESSD.

## SPECIFIC COMMENTS OF REFEREE #1:

C: P 4208, L 19:

A: More information regarding different settings implemented in this study is added to the abstract of the Manuscript.

C: P 4208, L 25 - 26:

A: The need for higher resolution data with 1 min time resolution and 1 $km^2$ spatial resolution, especially in urban hydrology, has been discussed in several studies. For example, Schilling (1991) has discussed about the need for higher resolution data in urban hydrology and Chandrasekar et al. (2012) showed the urban flash flood application of high-resolution rainfall data using X-band radar network. More information is added to the introduction.

C: P 4209, L 4:

A: Yes, as it is not always the case, the strength of the sentence is weakened by adding the adverb “often” to the sentence.

C: P 4209:

A: We agree with the reviewer about the improvement of areal rainfall when merging radar data and rain gauge data. We added more information regarding different methods applied in combining radar data and rain gauge data to the introduction part. We also believe that combining rainfall data from moving cars with other sources of data like radar or rain gauges could be a good possibility for future applications. The introduction is extended accordingly.

C: P 4209, L5:

A: Yes, this phrase is changed to “*an important source for rainfall estimation*”.

C: P 4209, L6:

A: The statement is weakened and changed to “has often a large space-time variable in rainfall estimation”

C: P 4209, L8:

A: Yes, we have added some additional information and references to the introduction part.

C: P 4209, L14:

A: The text is changed accordingly.

C: P 4209, L 21:

A: The text is changed accordingly.

C: P 4209, L 26:

A: It is added to the text.

C: P 4210, L 20:

A: All are corrected accordingly.

C: P 4210:

A: Some information had already been given in section 3.1. This part is extended a bit by some more information and references regarding tipping bucket.

C: P 4213:

A: It is changed accordingly.

C: P 4213, L 13:

A: Sensitivity settings can change from one car to another. This depends on the specific protocols implemented by the manufacturers. Different sensitivities are mainly defined for drivers’ comfort in different precipitation conditions. This information is added to the text.

C: P 4213, L 17:

A: Beside the effect of car dimensional characteristics, as mentioned earlier different cars have different wiper systems which lead to different classes of wiper frequency. A detailed discussion about aerodynamics and corresponding influence is provided in the answer to the second referee (see the answer to “On the car speed simulator”. This part is extended accordingly.

C: P 4213, L 18-20:

A: According to the functionality of the optical sensors measuring the rainfall, i.e. change in beam intensity, any foreign object passing the optical sensor might have influence on the signals coming from the device. More detailed explanation is added to the text.

C: P 4214, L 7-8:

A: This phenomenon can be explained by the principles of light refraction. The new figure added to manuscript explains how this device works. As can bee seen, a raindrop on the surface results in escaping some beams and, accordingly, changing in beam intensity. The explanation and the figure are added to the text.

C: P 4219, L 8:

A: Confidence intervals can be provided for the prediction of the mean $\bar{Y}$ at location $X_0$ or for the prediction of an individual $Y_0$ at location $X_0$. The latter interval adds uncertainty and is wider than the former (e.g. see Haan, 1977, p. 191). This had been called here “prediction interval”. The equation can be obtained from textbooks and has been omitted here for better readability. The text has been modified to make this clearer.

C: P 4219, L 9:

A: Because of technical constraints and restriction in using all the nozzles when placing the car, depending on its dimension, it was not possible to apply all the cases. As a result, the number of points in Figure 6 differs from the number of possible runs provided in Table 3. The same is valid for the automatic wiper adjustment scenario with the difference of not continuing after reaching the threshold. The design has been adjusted for future experiments. The text is modified.

C: P 4219, L 12:

A: The definition is added to the text.

C: P 4219, L 22:

A: The text is changed accordingly.

C: P 4219, L 26-28:

A: It is expected that advancements in the development of automatic wiper systems will provide better W-R relationships in the future. With the current sensors, the driver has to adjust the sensitivity manually for different conditions to have optimal front visibility. This should not be the case if the automatic wiper control works optimally. Text has been added for better understanding.

C: P 4220:

A: “w” is generally considered as the sensor readings which involve wiper speed, as well as signals from optical sensors (see P 409, L 25-27). Thus, Figure 6 shows the derived W-R relationship for optical sensors.

C: P 4220, L21:

A: Since we had similar W-R relationship for both of them, it might be concluded that they follow similar principles. The text has been modified for better understanding.

C: P 4222, L 5:

A: Yes, the meaning is added to the text.

C: P 4222, L22:

A: For simplification, as a first step in the investigation, it is assumed that the W-R relationships are linear. No physical evidence was sought, only empirical evidence from the first experiments was used. However, after finishing the experiments closer inspection of the results has shown that the relationships may be nonlinear especially for small intensities (see last paragraph in 4.2.1).

C: P 4222:

A: Yes, one limitation is producing rainfall intensities smaller than 9 mm/h. The rainfall range in laboratory starts from a quite high rain intensity, compared with natural rain events, but it is quite wide for analyzing the sensor readings from optical sensors. Field experiments considering lower intensities are currently carried out to obtain W-R- relationships in natural conditions. Results will be reported elsewhere.

Yes, the result of the W-R relationship considering manual adjustment of the wiper activity could be subjective to the driver. In this experiment, only one person adjusted the wiper activity. In future work more people will be involved for wiper adjustment and different cars will be used.

C: P 4223, L 19:

A: It is changed.

C: P 4224:

A: Analysing the effect of the droplet size distribution on the W-R relationships can be achieved using a disdrometer which was already placed in the laboratory. The same devices (cars sensors and disdrometers) will be used for analysing natural rain events. A comparison of the results will allow an assessment of the additional error contributed to using artificial rain instead of natural rain. After completing these additional experiments the results will be reported elsewhere with reference to this paper (see also our response to referee #2 "On the rainfall simulator"). In addition, currently a field study is carried out involving several cars and different sensors with the main aim to obtain W-R relationships in natural conditions. This also involves some investigations regarding the feasibility for operational applications. However, it is too early at this stage to draw conclusions about these experiments.

C: Figure 6:

A: We are afraid that giving additional statistics beside the coefficient of determination like averages over arbitrary classes of experiments might distract the reader from the main message of the figure and better prefer not to plot them here. Basic statistics might be calculated from the information given in Table 3.

C: Figure 7:

A: Yes, this does not involve using a car but the car speed simulator. The black lines and the gray range in Figure 7a and 7b represent the same data; the only difference between the two figures is the dimension of the y-axis. The text has been modified for better understanding.

## SPECIFIC COMMENTS OF REFEREE #2:

C: On the rainfall simulator.

A: We agree with the reviewer that the rain in the laboratory is not natural considering its generation and the droplet size distribution (DSD). Actually, we used a laser disdrometer to measure the DSD in the lab, which has shown clear differences to natural rain. We did not report about those results since we could not answer the question which influence would this have on the quantification of the W-R relationships. This influence can only be judged objectively when the lab experiments are repeated at least partly in the field using the same instruments (car sensors + rain gauge + disdrometer). We have started to do this, but those natural observations require much more time and results cannot be reported yet. For the current study we assumed that the car sensors (wipers and optical devices) are mainly influenced by the amount of rain and less by the drop size distribution. This hypothesis is supported by the functionality of the optical sensors (see section 3.2.2).

As argued here, the terminal velocity of the raindrops has a great influence on the derived ratio between the dynamic and static optical sensors. The theoretical influence of terminal velocity on the final ratio has been discussed in Figure 7. This figure also provides a possible solution of correcting $\eta$ when the terminal velocity is known.

Initially, the results from disdrometer measurements (not reported here) have shown that raindrops in the laboratory have lower velocities (mostly from 0.25 to 1.3 m/s). Knowing this, the black line in Figure 7 should have a steeper slope compared with red and blue lines representing natural rain with higher velocities. This behaviour may be explained by aerodynamic effects resulting in less drops hitting the small plane compared to reality (see also our comment for car speed simulator). A brief discussion of this has been added to section 5.

C: On the homogeneity of the rainfall simulator.

A: The spatial inhomogeneity of the rainfall produced in the laboratory varies slightly for different settings. As discussed in the text, the influence of spatial inhomogeneity is not significant on the final conclusion and could have been corrected using the RDev values. Since all the influential parameters, e.g. pressure, nozzle setting and etc, are constant within 15 min, the spatial distribution does not change within one run. This could be seen from the rainfall amount recorded by the tipping bucket which measured constant rainfall intensity within the run. The Figure R-1 compares the W-R relationships for the two optical sensors including and excluding the correction with RDevs From this figure it can be seen, that the effect on the W-R relationship is very small, so the correction factors RDev have not been applied.

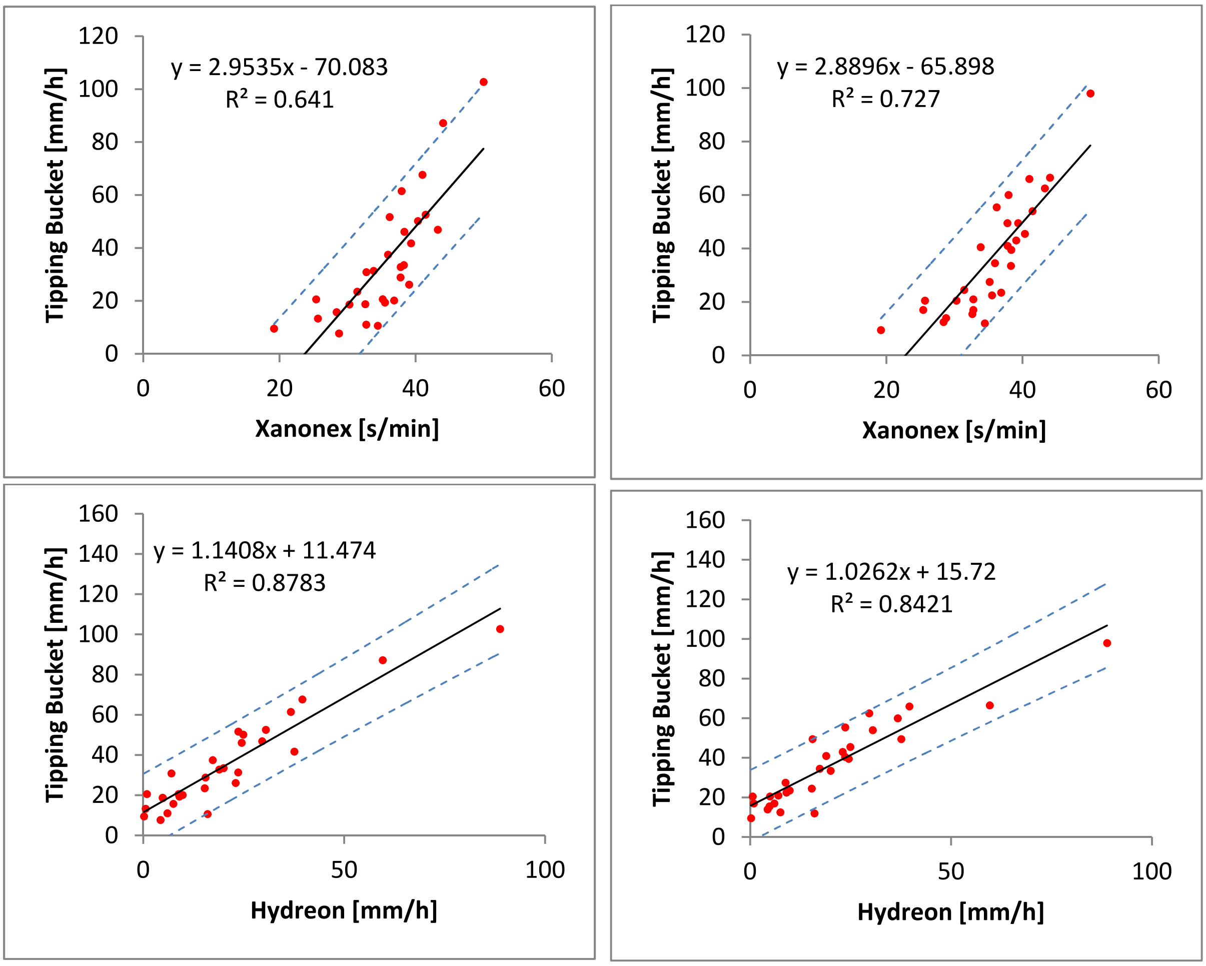


Fig. R-1. Comparing of uncorrected (right) and corrected (left) W-R relationships according to spatial inhomogeneity of rainfall

C: On the car speed simulator.

A: We thank the reviewer for raising this very important point. Although all the influential parameters, e.g. speed, windshield angle and etc, stay constant for different runs, the effect can be different for different cars. According to the principles of fluid mechanics, the streamlines surrounding a moving object depend strongly upon its shape. Therefore, since the characteristics of the plane we used in the laboratory experiments are not similar to the characteristics of a common windshield, the amount of drops hitting the optical sensor's surface could differ from that of the optical sensors on the cars. This difference may be the reason that the empirical curve in figure 7 is too low considering the low droplet velocities. Due to aerodynamic effects, the small plane may not receive all drops in the air volume in front, but several drops may be blown away. This issue needs to be addressed in future laboratory and field experiments. This explanation has been added to the text.

C: On the manual wiper speed adjustment experiment.

A: The manual adjustment of the wiper activity is applied by a person sitting on the driver's seat and the front visibility is considered by judging the clear view of lamps placed on the front wall which is a similar condition to seeing the car rear lights on streets. More details of the experiment are added to the text.

C: On the conclusion.

A: Yes, we agree with the reviewer. We have tried to weaken the statements in the conclusions and added some limitations.

C: On language.

A: We carefully double checked the revised version regarding spelling and grammar.

C: On future work and other publications

A: Yes, we think that is a very good suggestion to have the option to add some additional results of experiments as an update or erratum. Usually, those results do not justify a full paper and might never be published. We would welcome a comment from the editor about this possibility. The future work will mainly be carried out by the same group and, as mentioned in the text, it includes implementing more drivers in the laboratory experiments, investigating other options for installing the optical sensors, e.g. horizontally for less influence of the speed, etc. After deriving the W-R relationships from the laboratory and field experiments, they will be used in computer simulations for objective statements about the estimation errors for assessing areal rainfall.

## Reference

Chandrasekar, V., Chen, H., and Maki, M.: Urban flash flood applications of high-resolution rainfall estimation by X-band dual-polarization radar network, 85230K-85230K, 10.1117/12.977602, 2012.

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