Answers to referee #2

We would like to thank the reviewer for the detailed comments about our manuscript, and the insightful propositions of improvement. We provide hereafter a detailed response on how we plan to revise our manuscript for each comment. The original comments are in italic, our response in normal font. For cross-referencing, we numbered the comments.

1) I was a priori very interested by this work and I found the introduction of the article well focussed and documented. I was a bit sceptic however about the first objective of characterizing "the effect of spatial location of rainfall fields on the timing and amplitude of the hydrological response", based on data analysis only (no modelling) and for such a small watershed. I began to be disillusioned:

We will make sure the revised manuscript version does not raise too high expectations in the abstract.

2) in page 6, with (i) the lack of analysis of the spatial variability of rainfall and, e.g. with the implementation of the Thiessen's method for 2-min rain resolution data;

It is true that using a basic interpolation approach for 2-min resolution data does not fully take advantage of the quality of the rain dataset. Therefore, we propose to replace the Thiessen interpolation method by a high-resolution interpolation procedure developed by Benoit et al. (2018). In a nutshell, it aims at generating an ensemble of stochastic space-time rain fields constrained by the actual observations at raingauge locations (over 20 realizations), and to use this ensemble to interpolate sparse rain observations.

As an illustration, the Fig 1 shows 2 examples of rainfall events interpolated from the Thiessen method and the method from Benoit et al. (2018). The plots for all the 48 events will be uploaded later in the discussion. The total rainfall amounts computed with both methods is summarized in the Table 1.

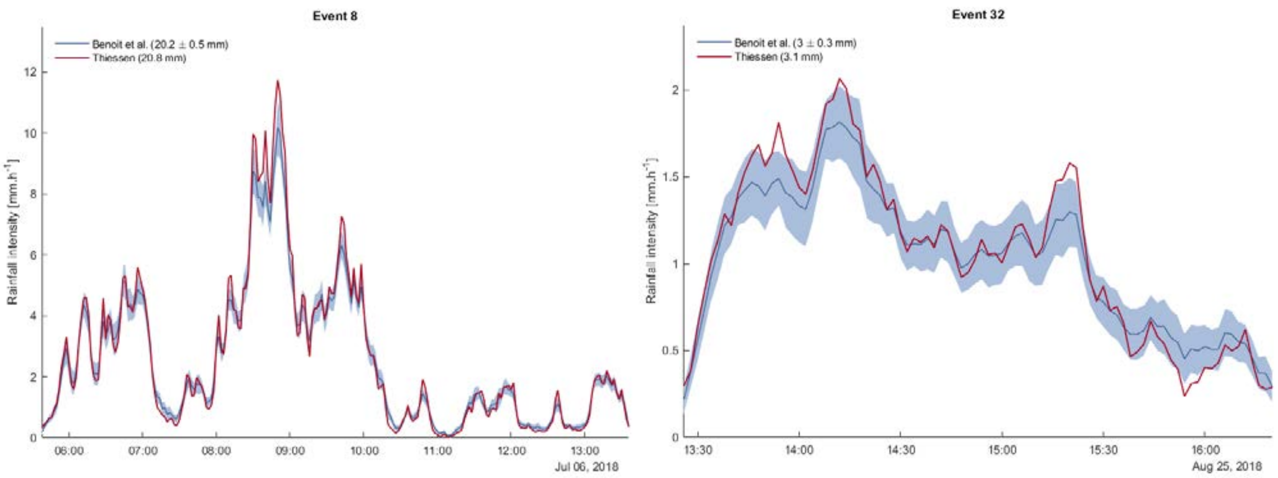

***Figure 1**. Example for 2 events of rainfall amounts interpolated over the catchment using the Thiessen method and the method developed by Benoit et al. (2018).*

Table 1. Summary of total rainfall amounts computed for each rainfall event, using the Thiessen interpolation method, and the stochastic approach developed by Benoit et al. (2018).

P event No.	Thiessen method Total P [mm]	Benoit et al. (2018) Total P [mm]	Benoit et al. (2018) std(P) [mm]
1	3,2	2,9	0,25
2	8,0	7,7	1,02
3	1,3	1,2	0,13
4	13,4	12,1	2,06
5	1,2	1,2	0,02
6	1,7	1,6	0,13
7	8,1	8,2	0,29
8	1,5	1,5	0,05
9	20,8	20,2	0,49
10	19,2	18,7	0,95
11	11,5	10,7	0,68
12	3,2	3,0	0,30
13	18,5	18,8	0,28
14	1,3	1,1	0,04
15	1,7	1,6	0,11
16	10,6	8,0	1,33
17	4,0	4,3	0,56
18	6,9	6,8	0,24
19	5,1	5,0	0,39
20	1,3	1,2	0,10
21	1,2	0,9	0,26
22	42,4	43,5	2,58
23	2,4	1,9	0,57
24	2,4	2,3	0,16
25	1,5	1,5	0,03
26	3,7	3,7	0,07
27	2,9	2,9	0,34
28	2,7	2,9	0,13
29	11,2	11,1	0,67
30	1,6	1,5	0,09
31	11,5	11,9	1,02
32	2,3	2,3	0,32
33	3,2	3,2	0,25
34	23,6	22,1	0,59
35	8,5	8,1	0,13
36	1,2	1,2	0,06
37	3,1	3,0	0,26
38	2,6	2,6	0,24
39	1,0	0,8	0,13
40	8,4	7,8	0,43
41	5,8	4,8	0,25
42	3,4	3,4	0,21
43	10,7	11,4	0,32
44	4,4	4,2	0,13
45	12,3	10,9	0,40
46	1,8	1,8	0,04
47	2,5	2,4	0,21
48	8,2	8,0	0,20

3) (ii) the fact that Figs. 4 and 5 are hardly readable;

The figures 4 and 5 of the paper will be simplified in order to make them more readable. In particular, we will delete the top plot showing the location of the event within the whole period of observation, which is not essential. The 3 remaining plots per figure (hydrogram, hyetograms and the map) will be easier to read this way.

4) (iii) the too many references to the supplementary material, starting on line 181 (the general reader will not follow you there; the article has to be synthetic and "self-contained");

We agree and will considerably reduce the number of references to the supplementary material in the revised version.

5) in page 7, with the choice of the spatial rainfall asymmetry index. The shape of the watershed matters, so why not consider differences in distance and amplitude between the catchment and the rainfall "width functions", as proposed by several authors in the literature; the topography could be included as well in some way, a metrics to be invented, which would be relevant especially in such a high-mountain context;

The used distance metrics D_{HILLS} and D_{STREAM} are inspired by the catchment's width function: D_{HILLS} and D_{STREAM} also integrates the distance of precipitation, but differ from the width function as i) they are accounting separately for the travel along the river network and the travel distance to the network and ii) they correspond to an average value of the distances rather than to the entire distribution of distances as the width function.

We thank you for the suggestion to compare the catchment and the rainfall width functions directly. In the revised version, we plan to use one or several indicators that assess explicitly the differences between the width functions.

Some preliminary results are presented hereafter: Fig. 2 presents the river network in "wet" conditions and in "dry" conditions. These networks are used to calculate the width function of the Vallon de Nant in Fig. 3 using i) the distance to the outlet, ii) the distance to the river network in "wet" conditions and the iii) the distance to the river network in "dry" conditions. Fig. 4, 5 and 6 (at the end of the document) present the distribution of the precipitation amounts for the 48 events relatively to these 3 curves. We propose to use these metrics in addition to D_{HILLS} and D_{STREAM} in the revised version of the paper.

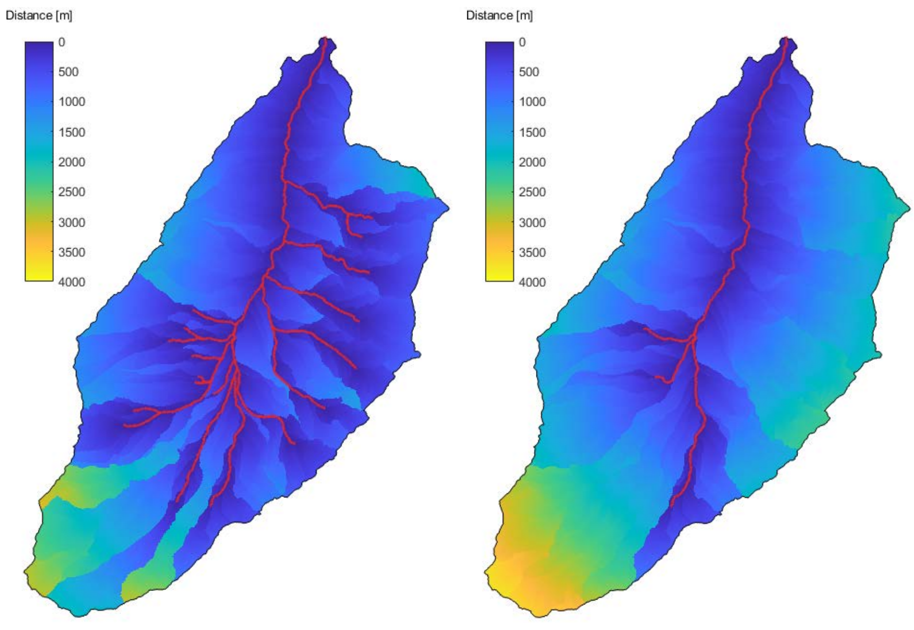

Figure 2*. Map of distances to the river network in 'wet' conditions (left) and 'dry' conditions (right)*

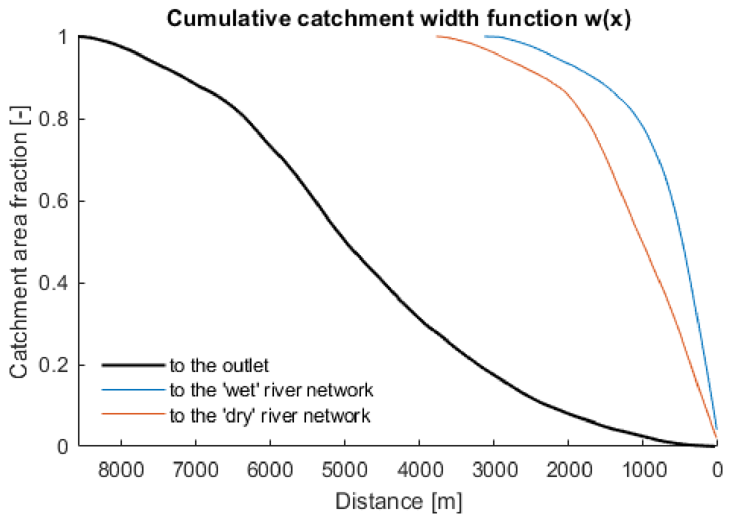

Figure 3. *Catchment width function using the distance to the outlet or to the river network in 'wet' and 'dry' conditions.*

6) in page 8, with consideration of the initial wetness conditions as "hydrological response metrics" (while this variable is more on the forcing side), the absence of standard indices on lag times between the hyetogram and the hydrogram (e.g. response time, time of concentration, etc)

These standard indices were calculated but not shown in the first version of the paper. They will be added and used in the revised version of the paper, with the aim of having one robust metric for the flow reaction in terms of quantity and one in terms of timing.

7) […] the way you have determined the runoff volume.

The determination of runoff volume indeed relies on our expertise and implicates a possible estimation error. In response also to reviewer 1, the calculation will be explained in more details. We will also try to associate an uncertainty estimate to the runoff volume estimation: an uncertainty will be introduced for each start and end of a discharge event, giving each a low and high runoff volume. This uncertainty will propagate then into the rest of the analysis by using these 2 values.

8) Among other points, it is indeed difficult to get an idea of the response time of the watershed, which could drive a basic discussion about time and spatial sampling issues, (e.g. Berne et al., J. Hydrol., 2004, 299, 166-179);

The response time lag of the catchments (i.e. difference of start of rainfall events and start of streamflow reaction) varies between 12 and 90 minutes. We will explicitly include these estimates in the revised version and discuss the rainfall observation scheme (spatial and temporal resolution) with respect to this. The challenge hereby is to find relevant literature for rural, alpine catchments where surface runoff is not dominating (the key body of relevant literature is developed for surface runoff (Berne et al., 2004;Kim and Kim, 2018) or for hydrological models, as discussed in the introduction of the original manuscript (e.g.Huang et al., 2019).

9) in page 8 with the description of the statistical analysis (pure quadratic regression) while Fig. 6 is based on simple linear regression and the regression attempts presented in Table 2 could have been done with standard multiple regression.

We agree that the Fig. 6 is confusing as it mixes in the same figure the correlation among explanatory variables, and between explanatory variables and the response variable. The plots will therefore be separated into 2 figures in the revised version. In addition, we will extend the regression analysis for the revised version. Final results to be presented will depend on the effect of the additional rainfall indicators.

10) Note that, rather than p-values and AIC criteria listed in Table 2, the number of points considered in each regression would be sufficient for the reader to assess the robustness of the inferences. (But more importantly, I doubt that any statistical technique of forcing and hydrological response variables will be able to replace a hydrological model…)

We agree that AIC and the p-value could be removed. In contrast, the AICc will be kept to allow for model selection in case of different numbers of model parameters. We further comment on the need of using a hydrological model in our response to comment 11 below.

11) In addition, Fig. 6a could have closed rapidly the debate on the spatial variability of rainfall at the scale of this watershed. Heterogeneous events, with significant rainfall, occur once in a while and may impact the flood dynamics; but you do not give any evidence (and in my view there is no way to get it without a model) of this impact in the article.

Thank you for this comment. We agree that there is no other way to answer this question than using a hydrological model. We therefore propose to use a semi-lumped box model to assess the sensitivity of catchment to different rainfall patterns. This will be a semi-virtual experiment in the sense that we will calibrate the model parameters on the observed rainfall-streamflow dynamics once (to ensure a plausible parameterisation) but we will then keep the parameters constant to test the effect of different rainfall patterns on the rainfall response. This will be completed as follows i) rescaling the interpolated spatial rainfall fields to different total precipitation amounts and ii) assessing the variability of the discharge reactions in response to the various rescaled rainfall events.

We are aware that more advanced models, parametrizations and rain generation methods could be proposed to this problem, but we also aim to not turn this paper into a heavy modelling paper, which was not our first objective.

12) The cases with runoff coefficients greater than 1 are interesting, especially the July 24th case. Indeed, the rainfall sampling in the steepest part of the watershed is probably deficient and it will be hard to obtain it with raingauges. Is there any hope to integrate some information from the Swiss radar network to compensate for this lack of data in this area, and eventually over the entire watershed?

MeteoSwiss produces 1 x 1 km radar data with a 5 min time step, which is pretty coarse in comparison with the dimensions of the catchment (6 km x 5 km). In addition, Fig. 8 (hereafter) shows that the correlation between the Pluvimate and RADAR is rather low, due to both radar measurement errors and differences of support between point rain gauge data and spatially averaged radar images. Moreover, radar data over the Vallon de Nant catchment is especially affected by mountains around, which generates artefacts due to beam blocking. We will include this comparison (Fig. 8) in the supplementary material.

13) With respect to the state of the art presented in the introduction, I may recommend the authors to read (and eventually to refer to) two articles by I. Emmanuel et al. in J. Hydrol. 2015 (531, 337-348) and 2017 (555, 314-322) (which I did not co-authored, I swear!).

Thank you, we will add these references in the revised version of the paper.

REFERENCES:

Benoit, L., Allard, D., and Mariethoz, G.: Stochastic Rainfall Modeling at Sub-kilometer Scale, Water Resour Res, 54, 4108-475 4130, 10.1029/2018WR022817, 2018.

Berne, A., Delrieu, G., Creutin, J.-D., and Obled, C.: Temporal and spatial resolution of rainfall measurements required for urban hydrology, Journal of Hydrology, 299, 166-179, https://doi.org/10.1016/j.jhydrol.2004.08.002, 2004.

Foehn, A., García Hernández, J., Schaefli, B., De Cesare, G., Spatial interpolation of precipitation from multiple rain gauge networks and weather radar data for operational applications in Alpine catchments, Journal of Hydrology, Volume 563, 2018, Pages 1092-1110, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2018.05.027.

Huang, Y. C., Bardossy, A., and Zhang, K.: Sensitivity of hydrological models to temporal and spatial resolutions of rainfall data, Hydrology and Earth System Sciences, 23, 2647-2663, 10.5194/hess-23-2647-2019, 2019.

Kim, C., and Kim, D. H.: Effect of rainfall spatial distribution and duration on minimum spatial resolution of rainfall data for accurate surface runoff prediction, J. Hydro-environ. Res., 20, 1-8, 10.1016/j.jher.2018.04.001, 2018.

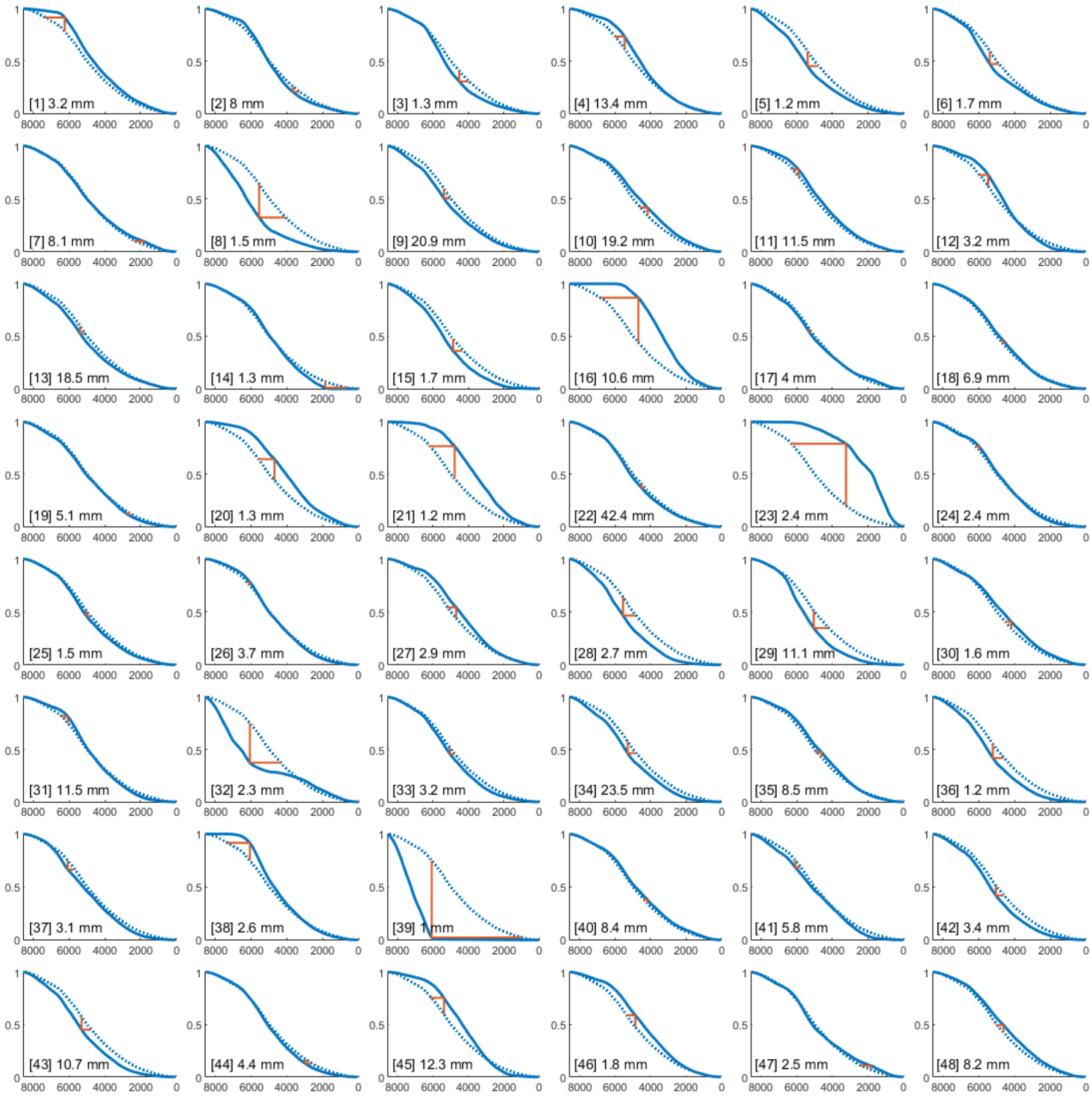

Figure 4. *Catchment width function w(x) and proportion of rainfall $W_P(x)$ falling at a distance x [m] to the outlet for each event. The event ID is between brackets, followed by the total amount of rainfall during the event.*

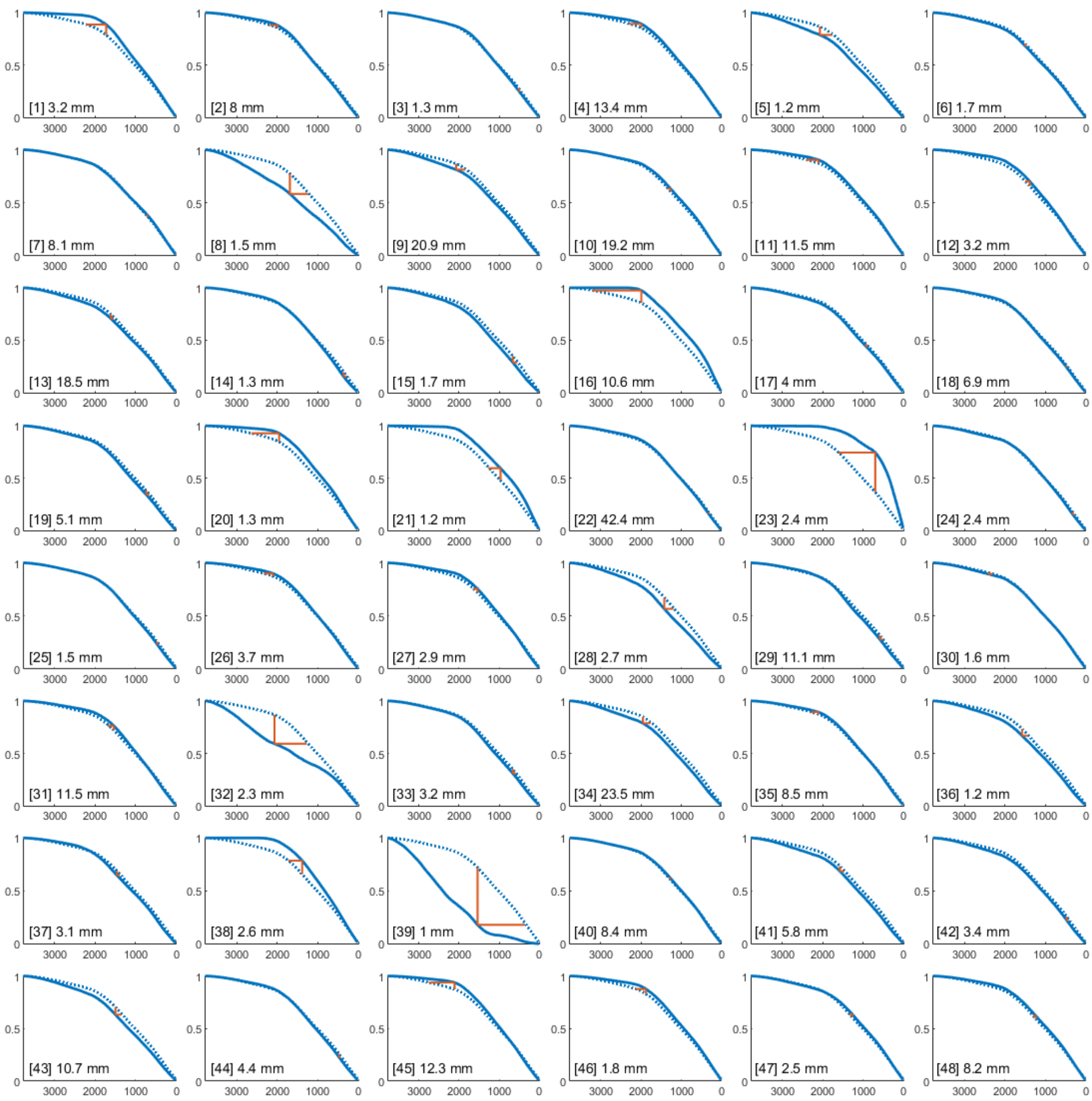

Figure 5. *Catchment width function w(x) and proportion of rainfall $W_P(x)$ falling at a distance x [m] to the river network in 'wet' conditions for each event. The event ID is between brackets, followed by the total amount of rainfall during the event.*

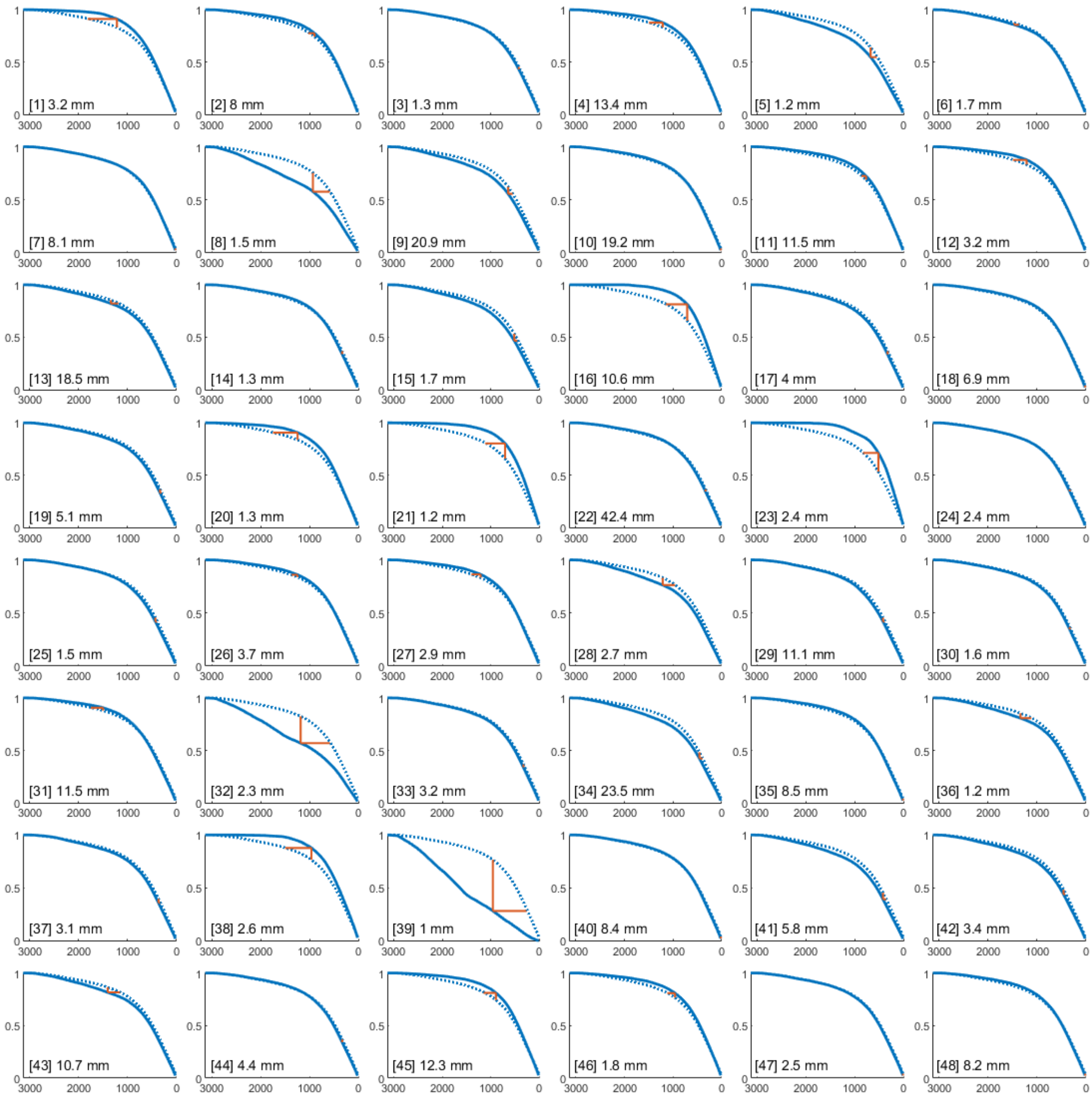

Figure 6. *Catchment width function w(x) and proportion of rainfall $W_P(x)$ falling at a distance x [m] to the river network in 'dry' conditions for each event. The event ID is between brackets, followed by the total amount of rainfall during the event.*

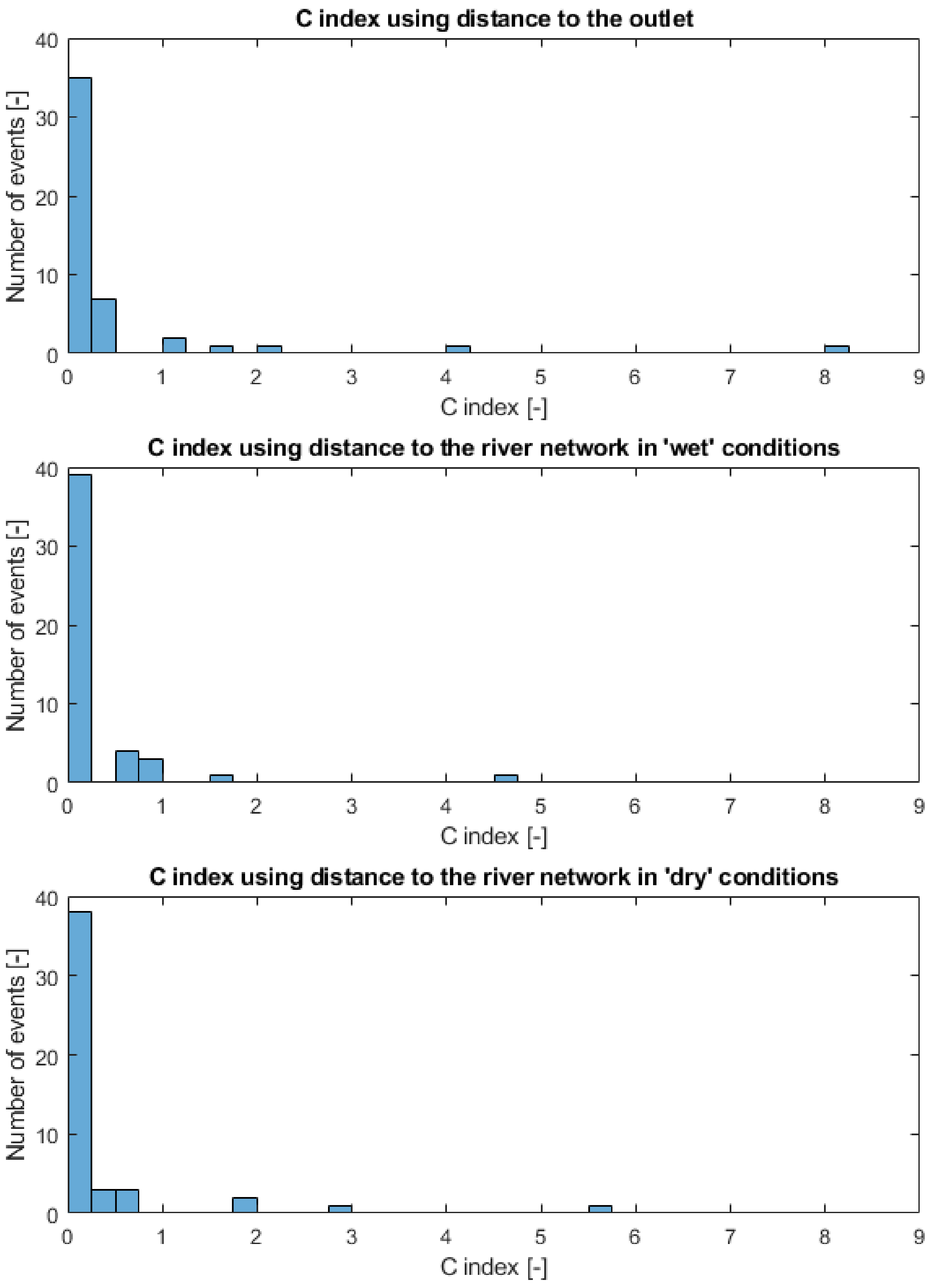

Figure 7. *Distribution of C index calculated for 48 events using the width function up to the outlet and up to the river network in 'wet' and 'dry' conditions.*

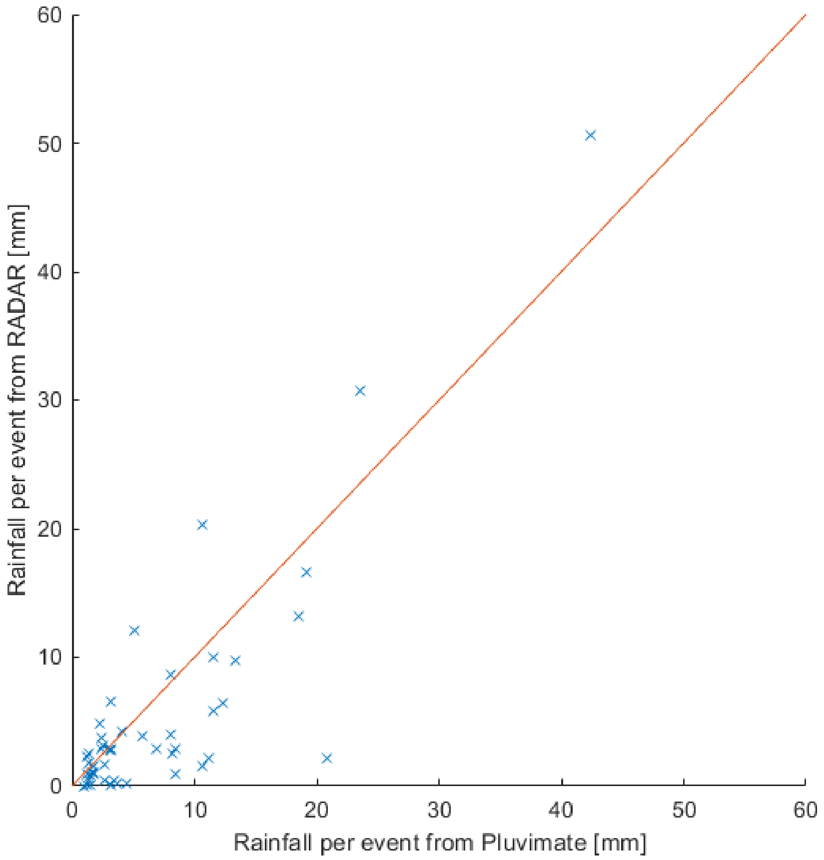

Figure 8. Total amount of rainfall per event measured by the RADAR vs. the amount measured by the Pluvimate network (interpolated using the Thiessen method).