Dear Reviewer #1:

The manuscript describes a rainfall design method using multivariate distribution of critical rainfall duration. Moreover a small basin case study application, where 49 years of hourly rainfall records are available, is presented. The method proposes to identify different source of potential floods using concentration time for estimating critical rainfall durations. Moreover, it proposes to use copula function to generate triplets of critical rainfall in order to estimate design storms. While I found the paper interesting, I have several doubts listed as in the following:

Thank you very much for your set of critical review and comments for technical improvement of this manuscript. The summary of our specific response is as follows:

1) I did not well understand the rational of the proposed methodology, maybe the section 2.3 should be much more clear. Apparently, but maybe I am wrong, using a Chicago hyetograph the author could identify the desired possible flood sources related to different critical duration.

Thank you for your comments. I would like to add an example to illustrate the problems which may be not very clear in the paper. As shown in Fig. 1, in an area there are two rivers, we want to estimate the flood risk at the blue color area which influenced by two rivers. Because the whole area is not very large. We may use area representative rainfall followed by a rainfall-runoff-inundation simulation to solve this problem.

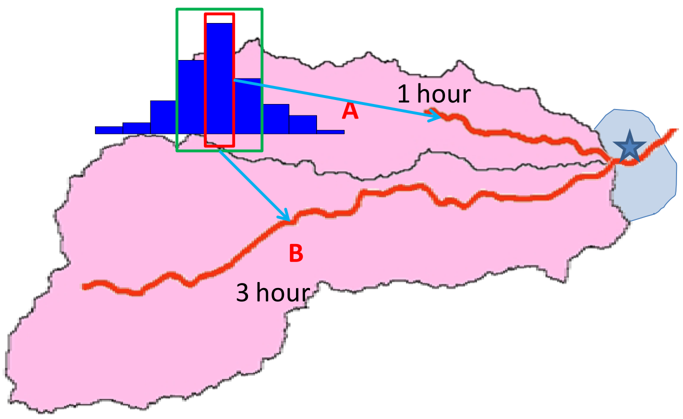

Fig. 1 Flood risk from two rivers

The first question is how to properly design area representative rainfalls. It is the focus of this paper. The response characteristic of a basin to rainfall could be represented by concentration time of flood. For example, in Fig.1, for the small basin A, the concentration time of flood is 1 hour which means flood can reach to the blue area in 1 hour from basin A. As for basin A, the maximum 1 hour rainfall could be the most dangerous part to cause a flood to the risk assessment area (shown in the red box of design rainfall). For the big basin B, the concentration time of flood is 3 hour which means flood can reach to the blue area in 3 hour from basin B. As for basin B, the maximum 3 hour rainfall could be the most dangerous part to cause a flood to the risk assessment area (shown in the green box of design rainfall).

Since the blue area is influenced by both rivers, a design rainfall for this area should carefully consider such correlations between maximum 1h rainfall and maximum 3h rainfall. The probability distribution of maximum 1h rainfall reflects the probability distribution of flood from river A. The probability distribution of maximum 3h rainfall reflects the probability distribution of flood from river B. To evaluate the flood risk from both river A and river B, the joint distribution of maximum 1h and 3h should be evaluated and such correlation should be reflected in rainfall design.

In this study, we want to develop a rainfall design method include consideration of flood risk from multiple rivers and local inundation. Concentration time is considered as important index that indicates critical duration of rainfall for different flood sources; Maximum rainfall amount in different critical durations are considered as critical rainfalls which may cause flood from different flood sources. To evaluate the flood risk from multiple sources, it is necessary to estimate the correlations and joint distributions of maximum rainfall amounts in different durations and reflect them into rainfall design.

The correlation of maximum rainfall amounts in different durations (critical rainfalls) are our concerns. We do not use Chicago method because firstly, Chicago method (or some other empirical methods), from another perspective, empirically assumed such correlations. Using Chicago method, it is possible to calculate a “deterministic” synthetic hyetograph given the return period. It facilitate the use in engineering designing, however, it probably not appropriate for flood risk assessment. Flood risk assessment should deal with variety of rainfall scenarios and consider probability of occurrence of rainfall especially the critical rainfall. This is one reason of using copula method in our research to catch the correlation of critical rainfall such as maximum 1h, 2h ,3h rainfall etc from rainfall events. And therefore generate such correlated critical rainfall according to joint-distribution.

Secondly, the conventional IDF curves, based on which Chicago method and many other rainfall design methods are developed, are usually defined by a univariate statistical analysis and show the relationship between mean critical intensity and duration for an assigned value of return period. However, it may lose some important information such as peaks, total rainfall amounts. With the development of multivariate probability theory, especially copula theory, some research begin to focus on multivariate statistical analysis. A good example is ref [3] which use copula method to study the critical depth-total depth-peak-frequency relationship. In our research, for the purpose that estimate flood risk from multiple sources, rather than roughly consider the critical depth-total depth-peak-frequency relationship of enter rainfall, we pay special attention to the “critical rainfalls”, namely, the maximum rainfall amounts in different critical durations in a rainfall event. We think critical rainfall is the core part in rainfall design which may affect peak flood volume, and rainfall amount in different critical durations can cause peak flood volume from different sources.

2) The concentration time is particularly difficult to estimate so its application includes a high level of uncertainty difficult to evaluate [1].

Yes, we agree with you that the concentration time is particularly difficult to estimate. We also read the reference [1], it is very interesting. We will add it as a reference in this paper too.
It is just because the precise estimation of concentration time is very difficult that we finally use empirical formulas.

3) The case study data set is not appropriate for a trivariate copula analysis (49 data).

I am sorry for not explaining data clearly in the paper.

The trivariate copula is applied to analyze the correlation of rainfall amounts in different durations. In the case study, the concentration time of flood from different sources are 1h, 2h and 3h respectively. Therefore, in the case study, we are going to analyze the correlation of maximum 1h, 2h and 3h rainfall amounts in extreme rainfall events. 49 years rainfall records are adopted.

To analyze the correlation of maximum 1h, 2h and 3h rainfall amounts in extreme rainfall events, firstly we divide rainfall time series into rainfall events. Then, we select extreme rainfall events by criteria of annual maximum 1h rainfall amount, annual maximum 2h rainfall amount, annual maximum 3h rainfall amount.

For each year, taking annual maximum 1h rainfall amount as criteria, an extreme event could be selected. Then one triplet of (1h, 2h, 3h) rainfall amount could be obtained. Taking annual maximum 2h rainfall amount as criteria, another triplet of (1h, 2h, 3h) rainfall amount also could be obtained. And so do taking annual maximum 3h rainfall amount as criteria. We have 49 years records, therefore, we may have 49*3=147 triplets. However, many of them are overlapped because annual maximum 1h, 2h, 3h rainfall amounts are in the same rainfall event or two of them are in the same rainfall event. Remove the repetitive ones, we got 68 triplets data (1h, 2h, 3h rainfall amount). They are adopted to trivariate copula analysis.

4) It is not clear how the triplets are simulated starting from the multivariate distribution fixing the return periods 20-50-100 years.

We will explain this part more clear in the reversion.

The algorithms for sampling values from vine copulas were proposed by Aas et al (2009) [4]. Taking advantage of the algorithms, we can simulate large number of random triplets from the multivariate distribution. Then, we make a small program to select the triplets according to joint-probability (0.05, 0.02, 0.01).

5) In general, if the aim is the flood risk mapping, the design hyetographs based on critical duration are inclined to underestimation hydrograph volume. [2]

Thanks for this information. It is very interesting to read ref [2]. The conclusion in ref [2] that "In more detail, the realistic rainfall time pattern, given by the continuous simulation method influences the initial losses and allows preservation of the rainfall peaks. On the other hand, the shape of the synthetic hyetographs causes infiltration patterns that lead to an underestimation in the event-based approaches." is definitely convincing.

We have also tried to use a continuous simulation method to estimate the flood risk, however, we found that the low reliability of continuous rainfall generators is a problem. Although the statistical methods of continuous rainfall simulation are improving, it is hard to say a continuous simulation of 500 years even 100 years rainfall will be sufficiently reliable. Therefore, we decide to use design rainfall for flood risk assessment. The infiltration problem is usually empirically processed when using a design rainfall, for example, add a period of pre-design rainfall or assume soil moisture etc. This is also a topic widely discussed.

In addition, recently, some physical-statistical rainfall simulations considered climate change (e.g. General Circulation Model based rainfall generations) are proposed. They probably increase the reliability of continuous rainfall simulation and promote a widely use of continuous rainfall simulation.

[1] Grimaldi, S., Petroselli, A., Tauro, F., Porfiri, M. Time of concentration: a paradox in modern hydrology [Temps de concentration: un paradoxe dans l'hydrologie moderne] (2012) Hydrological Sciences Journal, 57 (2), pp. 217-228.

[2] Grimaldi, S., Petroselli, A., Serinaldi, F. Design hydrograph estimation in small and ungauged watersheds: Continuous simulation method versus event-based approach (2012) Hydrological Processes, 26 (20), pp. 3124-3134.

[3]Grimaldi, S. and Serinaldi, F.: Design hyetograph analysis with 3-copula function. Hydrol Sci J, 51(2), 223–238, 2006.

[4] Aas, K., Czado, C., Frigessi, A.: Pair-copula constructions of multiple dependence. Insur Math Econ, 44(2): 182–198, 2009.