Reply to Referee #2

General Comments:

The manuscript presents downstream flood frequency analysis framework using the annual maximum daily flows (AMDF). Joint cumulative probability of multiple rainfall variables (maximum, intensity, volume and timing) are considered as multiday rainfall input (MRI) and employed in C-vine copula model. Flood frequency model is defined by nonstationary generalized extreme value (NGEV) distribution model including uncertainty deliberation with Bayesian approach. Rainfall reservoir composite index (RRCI) is proposed and used to quantify the reservoir effects as covariate for expression of distribution parameters. According to the different metrics, the results of the proposed method outperforms typical reservoir index (RI) based flood frequency model which only accounts reservoir capacity and mean annual runoff. I believe the study is quite interesting for the readership of the journal and contributing to better modeling of downstream flood peak mechanism. The model results give reasonable outcomes and can be useful for regions where large reservoirs are located. The manuscript deserves publication after a major revision considering my below comments.

Response:

Thank you very much for the good summary and the positive evaluation of the paper. All your valuable comments have been carefully addressed in the revision. Please see our point to point replay below.

- Language needs some refinements before publication. Also, there are some typos and repeated sentences, which make hard to follow and disturb the readability. It would be nice to revise the manuscript totally by dividing long sentences and eliminating the repeated ones. Same tense should be used (is or was) thought the text.

Response:

Thanks for your kind suggestion. We have carefully revised the text to correct all issues about typos, unclear long sentences, repeated sentences and different tenses.

- Studies dealing with downstream hydrograph alterations caused by dams are not discussed enough in the literature.

Response:

In the first paragraph of the modified version, we have added literature review on studies dealing with downstream hydrograph alterations caused by dams as follows:

Under intensified human activities, significant hydrological alterations caused by reserviors are demonstrated in the many areas of the world. Graf (1999) shown that the dams probably have a greater effect on the streamflow than the global climate change in America. And the large dams have a strong downstream hydrologic effect (Graf, 2006). Batalla et al. (2004) demonstrated an evident reservoir-induced hydrologic alteration in the North-Eastern Spain. Yang et al. (2008) indicated the spatial variability of the hydrological regimes alteration caused by the reservoirs in the middle and lower Yellow River, China. Mei et al. (2015) suggested that the Three Gorges Dam, as the largest dam in the world, has significantly changed the downstream hydrological regimes. In recent years, the cause-effect mechanisms of the downstream flood peak reduction were investigated in some literature (Ayalew et al., 2013; 2015; Volpi et al., 2018). For example, Volpi et al. (2018) demonstrated that for a single reservoir, the downstream flood peak reduction is mainly dependent on its position along the river, its spillway and its storage capacity based on a parsimonious instantaneous unit hydrograph-based model.

Newly added literature

Ayalew, T.B., Krajewski W.F., Mantilla R., 2015. Insights into Expected Changes in Regulated Flood Frequencies due to the Spatial Configuration of Flood Retention Ponds. Journal of Hydrologic Engineering, 20(10): 04015010.

Graf, W.L., 1999. Dam nation: A geographic census of American dams and their large - scale hydrologic impacts. Water resources research, 35(4): 1305-1311.

Graf, W.L., 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology, 79(3-4): 336-360.

Mei, X., Dai, Z., Van Gelder, P.H.A.J.M., and Gao, J., 2015. Linking Three Gorges Dam and downstream hydrological regimes along the Yangtze River, China. Earth and Space Science, 2(4): 94-106.

Volpi, E., Di Lazzaro M., Bertola M., Viglione A., and Fiori A., 2018. Reservoir Effects on Flood Peak Discharge at the Catchment Scale. Water Resources Research, 54(11): 9623-9636.

Yang, T., Zhang Q., Chen Y.D., Tao X., Xu C.Y., and Chen X., 2008. A spatial assessment of hydrologic alteration caused by dam construction in the middle and lower Yellow River, China. Hydrological Processes: An International Journal, 22(18): 3829-3843.

- As stated in Lines 45-49, there are several factors for the generation of the floods. Authors focused on meteorological conditions, but also indicating the importance of hydrological conditions such as snow cover. The elevation range of the study area is quite wide (13 – 3493 m) and most upstream reservoirs (especially Ankang gauge) should be dominated by snowmelt. The response of the basin will be complex compared to lower altitude basins. There is not much information about the assessment of the snowmelt contribution of the catchments and their effects on operational decisions. It is also interesting to see that linear correlations between the timing variable of multivariate MRI and AMDF give lowest (almost zero) Pearson r for AK gauge in Figure 5. Would snowmelt be a reason for this? If this is the case, maybe RRCI is not enough to explain downstream peak floods for the regions where reservoirs fed by snowmelt? Temperature data can also be effective to estimate flood peaks in such cases. I believe this situation should be clarified.

Response:

Thank you for this comment. Although the elevation range of the study area is quite wide (13–3493 m), the study area is a rainfall-dominated area and the snowmelt contribution is quite limited. This area has a warm temperate semi-humid continental monsoon climate. The temperature in the basin is not much different from upstream to downstream. The timing of flood is the main rainfall period between June and September (Figure S3a, c and d). And the winter is warm as shown in Figure S3b. It is indicated that the rainfall is the main contribution for floods. The above information will be added in the revised manuscript.

<Figure S3> (newly-added)

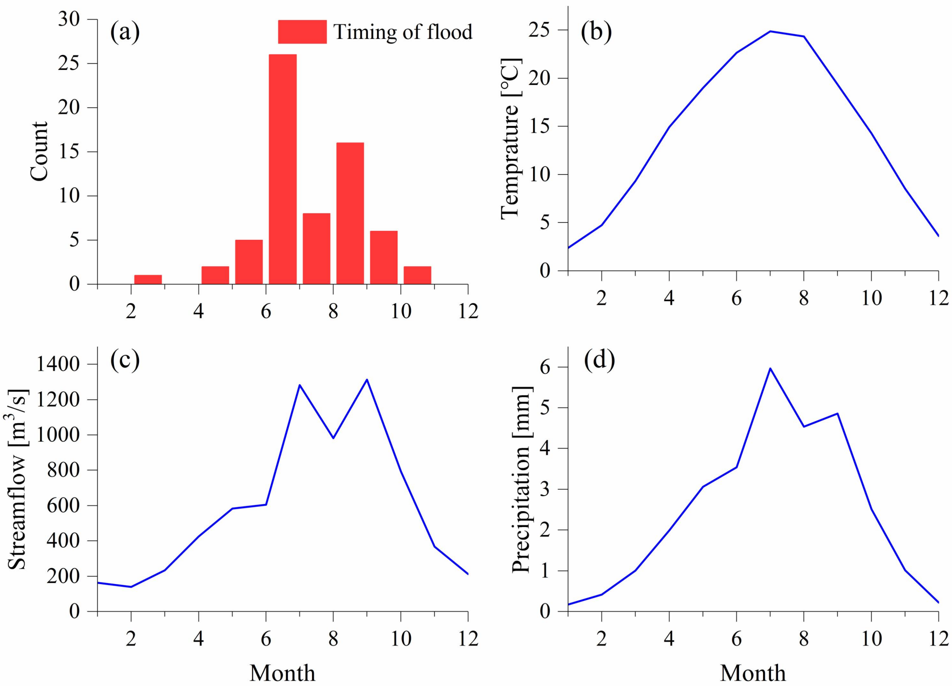

Figure S3 Preliminary analysis of the snowmelt contribution of the catchment upstream the AK station. (a) is the timing of flood; (b) is the monthly average temperature; (c) is the monthly average streamflow; and (d) is the monthly average precipitation.

The reason why AK gauge has a weak linear correlation between the timing variable of multivariate MRI and the annual maximum flood in Figure 5 is probably that there is a non-significant effect of the staged operation of the reservoirs on the floods. The reservoirs upstream of AK station have a smaller capacity than HJG and HZ stations. There may be a random variation of the remaining storage capacity in each staged period of the flood season for AK station. Thus, in the long term, the reduction of the peaks of AK station tends to be not different in each staged period of the flood season.

In the revision, the above situation has been clarified. And Figure S3 has been added in Supplementary Information (Please see Appendix A).

- In Data Section, the explanation of reservoir data is based on only their capacities. There is not much information how they are operated. For example, for what purposes they are operated, or how their reservoir pools are divided (flood control, conservation, dead storage etc.)?

Response:

Agree. In the revision, more information on the reservoir operation has been added as follows:

…The Danjiangkou Reservoir in central China's Hubei province is the largest one in this basin, which is completed by 1967. As a multi-purpose reservoir, it mainly aims to supply water and control floods, and is also used for electricity generation and irrigation. The reservoir has the total storage capacity of 21.0 billion m^3, the dead storage capacity of 7.23 billion m^3, the effective storage capacity of 10.2 billion m^3, and the flood control capacity of 7.72 billion m^3. After the Danjiangkou Dam Extension Project in 2010, the Danjiangkou Reservoir gained an additional total storage capacity of 13.0 billion m^3 and an extra flood control storage capacity of 3.3 billion m^3…

- It is not clear why inverse distance weighting (IDW) is selected for areal distribution of the rainfall records. The catchments are large and elevation ranges in between 13-3493 m, so that this method may not be representative especially for mountainous regions.

Response:

The reason why IDW is selected is that IDW is a handy method. Due to both the data limitation (16 sites) and the unstable relationship between rainfall and elevation, it is hard for us to demonstrate whether the other methods (e.g., the Kriging methods) will be better. In this study, the rainfall records from all national meteorological stations in the study area are used. The precision of areal rainfall with the IDW method should be able to meet the requirement in the study. In the revision, the error of estimation of areal rainfall will be discussed to remind readers.

- Maybe it would be better to call “downstream flood frequency analysis” rather than “flood frequency analysis” throughout the manuscript?

Response:

Agree. We have made a revision for this throughout the manuscript.

- Variation of RI and RRCI are quite different for AK gauge station in Figure 6. Please state the reason

Response:

Thanks. The reason has been stated in the revised manuscript as follows:

For AK gauge, there is a difference in the variation of RI and RRCI. This is because RRCI is dependent on both RI and the OR-joint exceedance probability (Figure 2). In spite of a low value of RI, the MRI with a high OR-joint exceedance probability will get a high RRCI. In fact, the reservoir effect on the downstream flood is great rather than small because of the fewer constraints from MRI. Thus, it is expected that RRCI can reflect a real reservoir effect more than RI.

- Uncertainty of flood estimates are greater in AK stations (Figure 8) compared to the others. The reason should be explained.

Response:
Thanks for this suggestion. The sample size of the regulated floods by the main reserviors upstream of AK station is smaller than HZ and HJG stations, and the dependent relationship between the floods and RRCI or RI in AK station is weaker. The greater uncertainty of the model parameters is produced. This explanation has been added in the revised manuscript.

- Discussion section is comparatively short to conclusion part. In general the paper describes a usable approach but the main weakness is insufficient discussion of the available results. I mean, it is stated that the downstream flood regime should be altered by upstream reservoirs and the magnitude of flood peaks are reduced due to the storage capacity of them. This is expected in such a reservoir system by analyzing long period AMDF values (see Figure 7, observed AMDF). Rather, the author should elaborately clarify GEV model results in Discussion part. Main results should be given under discussion, and conclusion should briefly summarize them. Considering these, I guess these two sections should be totally revised.

Response:
Agree. Discussion and Conclusion will be totally revised. And we will carefully modify these two sections according to your valuable suggestion.

- Figure and tables are appropriate. However, I have some doubts about the usefulness of Figure 9 to illustrate the reservoir effects on flood risk. It is not combining the results of the frequency model. It is not clear for what reason this figure stands for especially at the end of the result section. (I suggest removing this figure, as it is a bit confusing in terms of central theme of the paper). If authors would like to include it, I suggest them to re-organize its location through the manuscript and revise the descriptions to make it more clear (in Lines 387-395).

Response:
Agree. In order to highlight the central theme of the paper, Figure 9 has been deleted in the revised manuscript.

Specific comments:

-There are too much abbreviation in the manuscript. Maybe a glossary would be useful for the readers.

Response:
Thanks for this suggestion. We have added a glossary in Appendix B for these abbreviations.

- Line 49, what is "nature extreme flow"?

Response:
We have changed this sentence in the revised manuscript as follows:

In the absence of reservoirs, downstream flood extremes for most rain-dominated basins are mainly related to the corresponding extreme rainfall over the drainage area.…

- Lines 50-52, what about the operational targets and other constraints?

Response:
Thanks. Our statement exists imprecise. We have rephrased it as follows

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However, after the construction of large or medium-sized reservoirs, the downstream extreme flow is probably dependent on the result of the reservoir scheduling which is based on a series constrainsts (e.g., the reservior capacity, the inflow or rainfall input, the operational targets and the spillways).

- Lines 52-54, requires more up-to-date references.

Response:
In the revision, we have added literature review on studies dealing with downstream hydrograph alterations caused by dams. Please see the response to the third comment.

- Lines 76-78, even a small reservoir could be very complex to derive operational strategies and a lot of detailed information might be required. I am not sure about this classification. Please consider revising this part.

Response:
Agree. A modification of this statement has been made as follows:

The continuous simulation method can explicitly account for the reservior effects on flood in the hypothetical case. However, it is difficult to apply this approach to the most real cases (Volpi et al., 2018). The simplifying assumptions are just satisfied in a few of basins with single small reservoir. Even if some basins meet the simplifying assumptions, the detailed information required in this approach are probably unavailable.

- Line 96, what type of uncertainty?

Response:

The uncertainty of flood estimates is associated with the uncertainty of the parameters estimates. For clarity, we have revised this sentence as follows:

For the model parameters, the ML can only get one estimate through maximization of the likelihood function, while the Bayesian inference can get multiple estimates, forming a posterior distribution of model parameters. Thus, the ML is inconvenient to describe the uncertainty of flood estimates associated with the model parameter uncertainty.

- Line 84, which "previous studies"?

Response:

Thanks. The correction has been made as follows:

Thus, previous studies (Adlouni et al., 2007; Caroni and Panagoulia, 2016; Ouarda and El‐Adlouni, 2011; Panagoulia et al., 2014) have used the nonstationary generalized extreme value distribution (NGEV) to describe nonstationary maxima series.

Newly added literature

Caroni, C., Panagoulia, D., 2016. Non-stationary modelling of extreme temperatures in a mountainous area of Greece. REVSTAT, 14: 217-228.

Panagoulia, D., Economou, P., Caroni, C., 2014. Stationary and nonstationary generalized extreme value modelling of extreme precipitation over a mountainous area under climate change. Environmetrics, 25(1): 29-43.

- Line 108, it is a bit vague what do you mean by "more accurate effects of reservoirs?"

Response:

Thanks. For clarity, a modification of this sentence has been made as follows:

The precision and accuracy in the quantitative analysis of the reservoir effects on the downstream floods need to be improved further.

- Lines 115-117, please refer to Bayesian method in the objectives.

Response:

Agree. In the revision, Bayesian method has been referred in the objectives.

- Line 143, what do you mean by "more precise effects of reservoirs"?

Response:

Thanks. A modification of this sentence has been made as follows:

We develop a new index to improve the precision and accuracy in the quantitative analysis of the reservoir effects on the downstream flood reduction.

- Line 146, please briefly explain "multiday rainfall input".

Response:

In the revision, the brief explanation has been added as follows:

In addition to reservoir capacity, multiday rainfall input (i.e., a multivariate event with the continuous multi-day rainfall into the reservior system, MRI) is a key initial condition for the scheduling results of the reservoir system.

- Lines 147-150, It is a bit confusing whether scheduling related multivariate (SRMR) and MRI are same or not? Could you give more detail for their explanations.

Response:
Thanks. SRMR and MRI are different. All variables of SRMR are selected from the variables of MRI, and can be constraints for the reservoir operation. In the revised manuscript, these phrase will be accurately described and distinguished.

- Line 155, why OR-joint exceedance probability is selected as measure function?

Response:
We need a variable to measure the effect of a SRMR on the reservoir operation. The OR-joint exceedance probability is the likelihood that any variable in the given SRMR will be exceeded. The lower this likelihood, the greater degree of the constraint due to SRMR the reservoir operation has, so that the effect of the flood reduction is probably lower. The above explanation has been added in the revised manuscript.

- Line 158, what do you mean by "reservoir scheduling is more inflexible"?

Response:
We realize that the word "inflexible" may be inappropriate. Here, what we want to express is that the reservoir scheduling will have more constraints from the MRI. For example, when a large volume MRI occurs and its timing is near the end of flood season, the reservoir will probably face a large peak of inflow and a insufficient residual capacity due to reservoir impounding. The above explaination will been added in the revised manuscript.

- Lines 170-172, selected four variables require more explanation.

Response:
Agree. The more detailed explanation has been added.

- Line 208, it is not clear "obeys nonstationary distribution". Please revise.

Response:
The statement has been revised as follows:

Suppose that flood variable Y_t obeys a distribution $f_{Y_t}(y_t|\boldsymbol{\eta}_t)$ with the covariate-dependent distribution parameters $\boldsymbol{\eta}_t$.

- Line 280-286. The sentence is too long and difficult to understand. Please separate and revise.

Response:
Thanks. The sentence has been separated and revised.

- Line 301, please revise "Actually, although: : :"

Response:
Thanks. In the revision, this sentence has been deleted.

- Line 303-304, it is not clear what do you mean by "(e.g., special extreme MRI may limit or reduce the effects of the reservoir)."

Response:
In the revision, this sentence has been deleted.

- Line 314-315, please describe and relate calculated Spearman correlations in the text, otherwise remove them.

Response:
The description and relation for the calculated Spearman correlations has been added in the revised text.

-Lines 338-339, please clarify "special rainfall events"

Response:
In the revision, we have clarified this phrase as follows:

On the other hand, for few special years, because of no considering the special rainfall events (i.e., the rainfall events with a very low OR-joint exceedance probability), RI probably overestimates the effect of reservoirs on AMDF.

- Lines 412-413, please mention future studies in Conclusion part, not under Discussion.

Response:
In the revision, we have followed your suggestion.

- Line 429, it is not clear what do you mean by "some rare multivariate MRI still would produce lower values of RRCI than that of RI". Please revise it.

Response:
Thanks. This sentence has been revised in the revised manuscript as follows:

The RRCI is lower than RI in some years, because of the rainfall events with a very low OR-joint exceedance probability in these years.

Technical corrections:

- Figure 1. The caption should be "The flowchart of nonstationary covariate-based flood frequency analysis with a rainfall-reservoir composite index (RRCI)

Response:
Thank you for this comment. We have revised the caption according to your suggestion.

- Figure 7. In the caption, "thick blue" should be "thick blue line".

Response:
Corrected.

- Table 2. It would be better to not to duplicate "Dangjiangkou reservoir" and remove first row. The details should be given in the text only.

Response:
Corrected.

- Line 26, please revise "of the previous study"

Response:
This is corrected as "López and Francés (2013)" in the revised manuscript.

- Line 35, please revise "What's more"

Response:
Revised.

- Lines 62-63, please revise the sentence.

Response:
In the revision, this sentence has been revised as follows:

In fact, the flood frequency downstream of dams is closely related to both the climate condition of the basin and the upstream reservoir operation.

– In Line 73, it is stated three model components but not clear which of them are ordered since only two are given?

Response:
Thanks. This is a mistake. We have corrected this sentence as follows:

…three model components, i.e., the stochastic rainfall generator model, the rainfall-runoff model and the reservoir flood operation module…

- Line 76-78, too long sentence and hard to follow. Please revise it.

Response:

Thanks. We have revised this sentence as follows:

The continuous simulation method can explicitly account for the reservior effects on flood in a hypothetical basin. However, it is difficult to apply this approach to the most real cases (Volpi et al., 2018). The simplifying assumptions are just satisfied in a few of basins with single small reservoir. Even if some basins satisfy the simplifying assumptions, the detailed information required in this approach probably are probably unavailable.

- Line 119, please explain AMDF.

Response:

The explanation has been added in the revision as follows:

…the annual maximum daily flow series (AMDF) at the downstream stations

- Line 114 and Line 120, "RRIC" should be "RRCI"

Response:

Corrected.

- Line 115, "to calculate" should be replaced with "to develop"

Response:

Corrected.

- Line 139, "the Eq. (1)" should be replaced with "Eq. (1)"

Response:

Corrected.

Appendix B: Glossary

AMDF —Annual maximum daily flow

CDF —Cumulative distribution functions

GEV —Generalized extreme value distribution

GML —Generalized maximum likelihood estimation method

IDW —Inverse distance weighting method

IRI —Impounded runoff index, a ratio of reservoir capacity to mean annual flow

JCP —Joint cumulative probability

ML —Maximum likelihood method

MRI —Multiday rainfall input

NGEV —Nonstationary generalized extreme value distribution

RRCI —Rainfall-reservoir composite index

RI —Reservoir index

SRMR —Scheduling-related multivariate rainfall