Response Letter to Reviewers Comments on NHESS-2019-166#R2

Dear Prof. Merz

Many thanks for the constructive comments and suggestions from you and the reviewers. We carefully considered all issues mentioned in the reviewer's comments, and we outlined every change point by point, as highlighted in the reversion. We believe that the reviewer's comments and suggestions have helped us to improve the quality and readability of the paper. The point-by-point responses are provided below.

(The highlighted parts are added to the revised paper)

Responses to reviewer #1

1- Section 3. The presentation of the six steps need some improvements. Maybe it is better to have a purpose of each step, then followed by a description of how this purpose is achieved (methods, equations, etc.). For example, Step I, the purpose is to estimate the lag time. However, I do not understand how AMI method presented below can be used to estimate the lag time. Step II, how to estimate the influence of ENSO is not described, by regression or some other methods? Now there is too much information mixed in this part, which made the it hard to read and follow

Reply: It is corrected according to the reviewer comment

Step I: **(P5L3-8)** *As the effect of ENSO takes time to be experienced in far geographic locations, the lag time between the ENSO occurrence and the related influences in Kan River Basin was firstly calculated. This lag time can be revealed by comparison the variations of SOI and local precipitation time series. The monthly rainfall at the nearby synoptic stations of Mehrabad (1951-2017), Shemiran (1988-2017), Tehran-Geophysics (1992-2017) and Chitgar (1997-2017) (See Figure 1) and monthly SOI values are used. A statistical method, the average mutual information (AMI), is used to determine the time delay.*

Step II: **(P6L4-6)** *Secondly, the influence of El-Niño on the precipitation amount in Kan River Basin is quantified. The influence is estimated using a statistical* *method by calculating the expected value of the changes of precipitation amount in the El Nino episodes compared to those in the neutral periods.*

Step III: **(P6L23-25)** *Thirdly, several design storms are generated to be applied in a rainfall-runoff model. The rainfall storms are synthesized based upon the average precipitation change during El-Niño events. The designed storms are used for assessing the flood damages in a certain return period*.

Step IV: **(P7L14-16)** *Fourthly, the HEC-HMS hydrologic model is used to simulate the rainfall-runoff process. The hydrologic model is run for every scenario and every return period; then the peak discharges are used in the next step to estimate the flooding depths. In the hydrologic model, the SCS method is used to calculate the effective rainfall.*

Step V: **(P8L4-5)** *Fifthly, based on the obtained flood depth, the flooding areas are determined for designed storms in the El Nino and neutral periods.*

Step VI: **(P8L9-10)** *Finally, flood damage is assessed for all 9 runs of the model. These damages can be compared to each other in order to determine the role of El-Nino on the flood damages*.

2- Page 4, lines 11, error on the reference.

Reply: corrected

3- There are two Table 1 in the manuscript.

Reply: corrected

Responses to reviewer #2

1- **Fig. 4 in the paper clearly illustrates that the median % change of precipitation during El Nino years is equal to 0.**

Reply: Figure 3 of the paper shows that the occurrence of El-Nino increases the precipitation, and this increased value is significant (see Table 1). However, we confirm the median in Figure 4 is close to zero (4%) and the mode value (for which the probability density function is maximum) is 10.1% **(P9L20-21).**

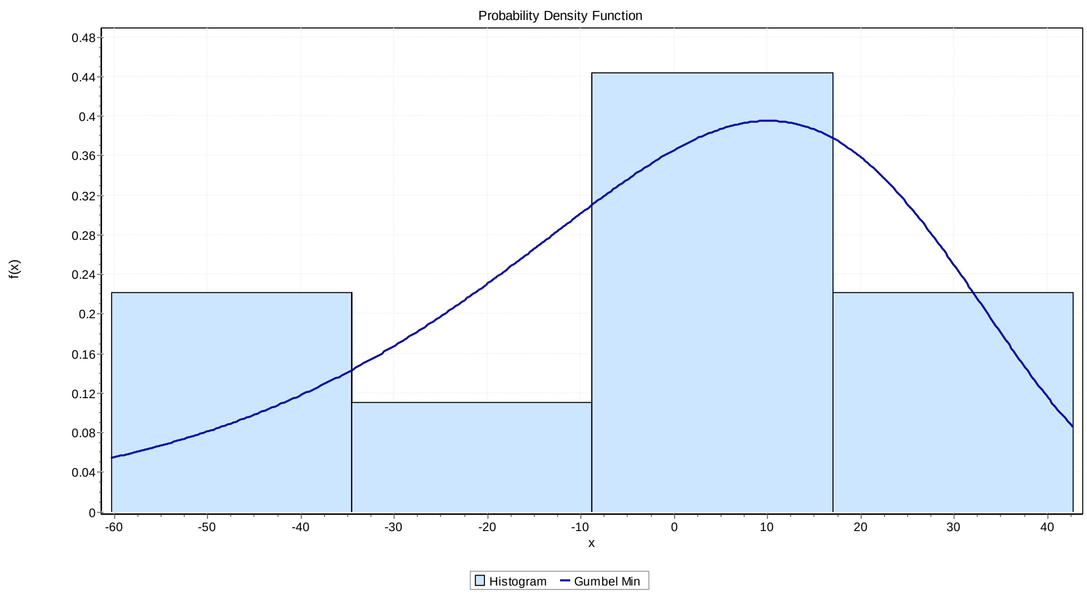

Figure 1. Probability density function (PDF) of %-increased rainfall values under the effect of El Nino (SOI<-0.8)

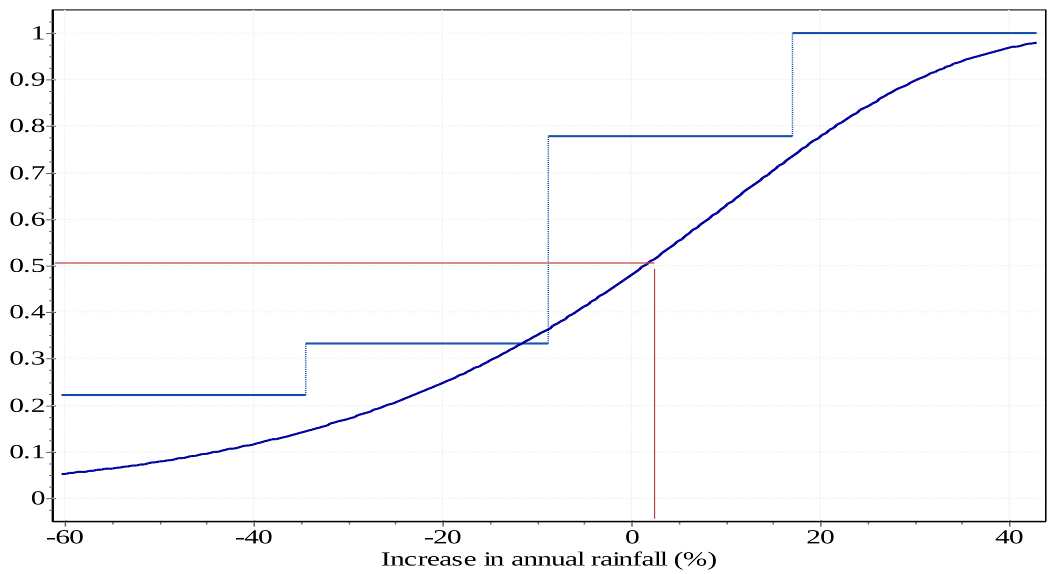

Figure 2. Cumulative distribution function (CDF) of %-increased rainfall values under the effect of El Nino (SOI<-0.8)

(P9L21-23) In fact, the reason for that the median is close to zero is due to the selection criterion of 9 events as the El Nino events out of total events; (SOI less than -0.8 according to Australia Bureau of Meteorology). If this criterion is set as SOI<-1.0 (according to the Western Regional Climate Center, USA), the number of El Nino events will decrease to 6. Using frequency analysis approach, the probability distribution of data is as Figure 3:

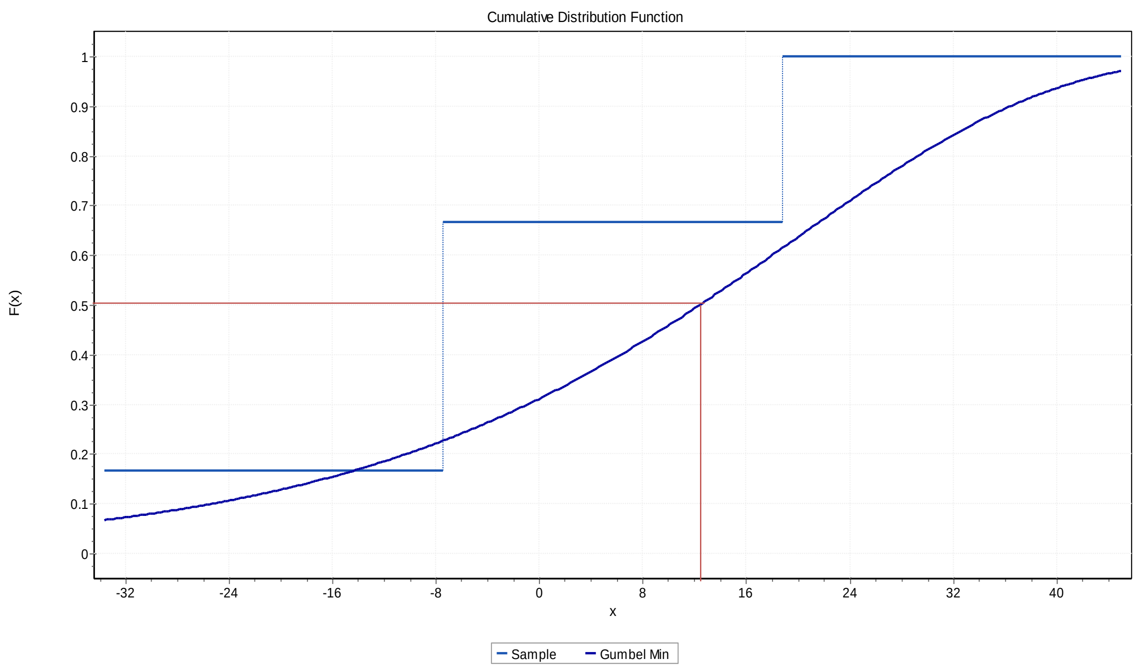

Figure 3. CDF of %-increased rainfall values under the effect of El Nino (SOI<-1.0)

(P9L23-26) As can be seen, in this condition the median increases to 12.2; because two El Nino events with negative %-increased precipitation which had a great impact on the results, were eliminated. Therefore, there will be just one El Nino event (in which SOI = -1.018) with negative %-increased precipitation (-33%) in the data. It is clear that if the criterion for determining the occurrence of El Nino be changed as SOI< -1.02, the only negative value would be omitted and in this case, there would be 5 El Nino events in the analysis. Therefore, the probabilistic distribution on the %-increased values changes as follow:

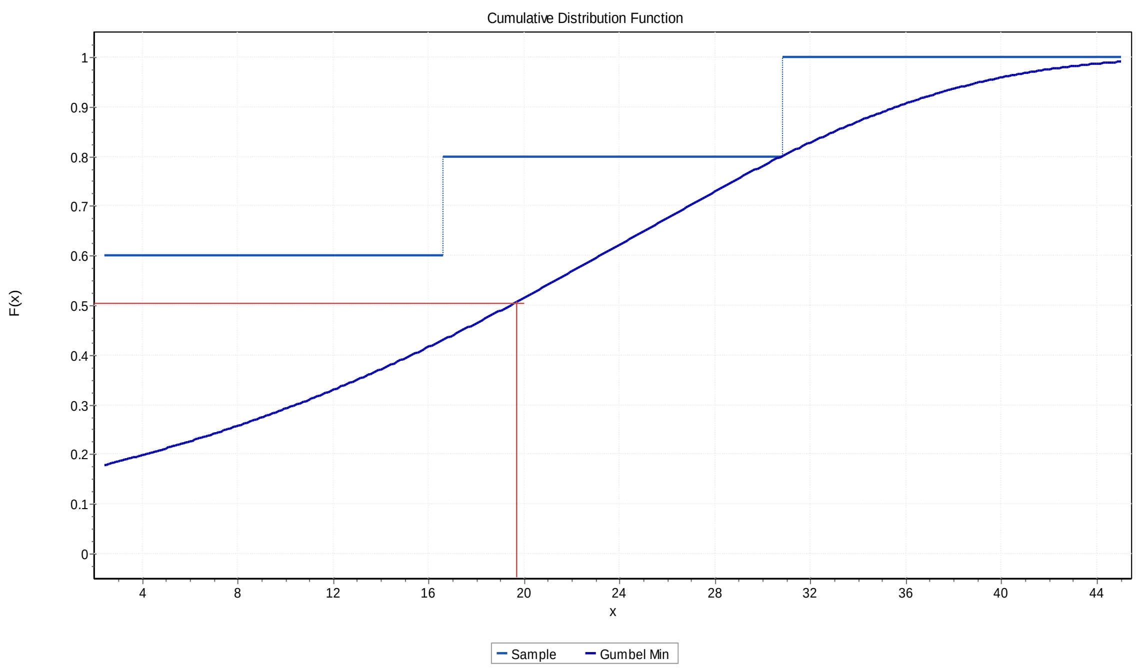

Figure 4. CDF of %-increased rainfall values under the effect of El Nino (SOI<-1.018)

It is clear that in the new situation, the median will increase significantly to about 20 **(P9L25).**

The purpose of the above explanation is to state that in the analysis used in this paper, the criterion for distinguishing the El Nino condition is the criterion for distinguishing the El-Niño condition is an effective assumption in this paper and it affects the results significantly. Therefore, the results of Figure 4 (in the paper) should not be evaluated as the insignificant effect of El Nino on the Kan River Basin precipitation **(P9L25-27)**. Certainly, to assess the impact of El Nino on the amount of annual rainfall, Figure 3 (in the paper) can be used in which the trend of annual rainfall against the SOI variation (without omitting any data) has been shown.

2- **Taking the 60 and 90% quantiles of this distribution and declaring these as representative for flood risk changes due to El Nino is simply not a valid approach, because it completely ignores the lower tail of the distribution where rainfall during El Nino years is actually decreased. I included some possible options for fixing this below, but the author's may have different ideas. In any case the risk analysis probably needs to be redone, so a major revision will be required.**

Reply: We agree with the opinion of the reviewer. To have a comprehensive study on the risk of flood due to El Nino, it is required to consider the whole range of probabilities: in both magnitude of hazard (flood) and magnitude of El Nino **(P12L16-18)**. But at first, as explained previously, Figure 4 is not enough to show the impact of El Nino on the precipitation and it is required to considered all the time series of SOI for such judgment. In the current condition, taking all range of %-increased precipitation probabilities consisting the lower tail of distribution where rainfall during El Nino years is actually decreased and then numerically integrate over the distribution will be close to the median of the distribution **(P12L21-24)** which is less than those calculated for 60 and 90 percentiles**.** Secondly, one of the purposes of this article was to show the importance of small floods (floods with a low return period) in flood management plans, and for this reason we have compared 5-yr and 10-yr floods with larger flood of 50-yr return periods (These values are selected in accordance with the paper's objective to show the importance of small floods (floods with a low return period) in flood management plans compared to the high return period floods) **(P6L28-29)**. Therefore, three floods with specific return periods (low to high return periods) are considered to cover the range of probability for flooding. This means that in terms of flood risk and probability of flood occurrence, the concern of the reviewer about the magnitude of hazard has been addressed. Therefore, by comparing the 5-yr and 10-yr flood with floods of larger return periods, the importance of El Nino on the floods with the low return period and the resultant damages has been shown and emphasized in the "abstract" and "results and discussion" sections.

However, about the full coverage of the probabilistic distribution of %-increased precipitations due to the El Nino (Figure 4), it should be noted that the probability levels of

60% and 90% are considered in accordance with the purpose of the paper. The objective of the paper as has been mentioned in the end of introduction **(P3L25-26)** is to show the amount of flood damage **that can be added (possible increase in the damages)** due to the El Nino. These percentiles are not representative for flood risk changes due to El Nino but are the selective high probability levels represent for the highest influence of El Nino with low probability levels of occurrence. This objective was mentioned in the paper as (**P7L9-13)**:

> "*The reason behind the choice of 60% and 90% probability levels is to estimate the average amount of damages and the maximum amount of damages that are expected per year due to moderate to strong El-Niño events. Therefore, a probability level representative of the maximum possible damage and a probability level representative of average damage caused by El Niño were selected.* "

Indeed, the fact that El Nino increases the precipitation amount has been proven in the previous section of the paper (Figure 3 and related explanations), and there is no doubt that there is a significant direct relationship between precipitation and the magnitude of El Nino (see Table 1). In this part of the paper, we seek to show the **possible increase** in flood damages due to El Nino, not the possible decrease value and not the expected value. This objective was highlighted in the abstract as (**P1L16-18**):

> *"To determine the flood damage costs, the annual precipitation enhancement during El-Niño condition was firstly estimated using a probabilistic approach and the inundation area was then determined under high probability levels of increased rainfall due to El Nino for 5-, 10- and 50-year return period floods."*

Also in the introduction section, it has been mentioned that **(P3L25-26):**

> "*The question addressed in this research is that, given the increasing impact of rainfall due to El-Niño, how much losses/damages are expected to be added in a specified study area."*

In this regard, we selected two percentiles in the upper tail of probabilistic distribution: 1) increase in the probability level of 60%, and 2) increase in the probability level of 90%; then we compared the results with those in the normal condition. Doing so, three return periods in three scenarios of El Nino event were defined and a total of 9 model runs were performed.

These results provide decision makers with essential information on flood risk and highlight the importance to take in to account the probable effect of El Nino in flood risk management **(P13L1-4).**

Also, in some other studies of flood risk analysis, depending on the purpose of the study some parts of the probability distribution may have been neglected. For example:

To evaluate the risk of flood using a fuzzy approach, Nandalal and Ratnayake (2011) just selected rainfalls of a 100-year return period. They did not consider the lower and higher tails of the probability distribution. Grabs (2015) evaluated the flood risk reduction measures in the Elbe River for 100-yr flood. He took two 100-yr return period floods in 2002 and 2013 and did not analyzed the other floods with lower return periods. Noted that, the flood event of 2002 in the entire Elbe River Basin has become a reference in Europe for extreme flood events so in this paper the extreme floods were analyzed. Van Dau et al. (2017) evaluated only 25-yr return period precipitation to quantify flood damage under potential climate change impacts in central Vietnam neglecting the other floods with lower or higher frequencies. To consider the effect of climate change on flood risks, Van Dau et al. (2017) considered the HadGEM3–RA Regional Climate Model (RCM) under two Representative Concentration Pathways (RCP) 4.5 and 8.5 climate change scenarios neglecting RCP 2.6 a representative for the lower tail of climate change scenarios.

Apart from this, as probability distribution of Figure 4 is not a full representative for El Nino effect on the precipitation, to make the point of view of the respected reviewer (regarding the study of the entire range of probability distribution), it is better to consider the whole range of ENSO without excluding some smaller events of El Nino (may be $-0.8<SOI<0$) and/or events of La Nina. In this case, it is necessary to use a different methodology in another independent study. The following figure shows the probabilistic distribution of SOI values. Figure 5 shows the PDF (here normal distribution) and Figure 6 shows the CDF. As shown, changes in the SOI index follow a normal distribution. The whole probability range can now be considered to examine the impact of ENSO on flood damage.

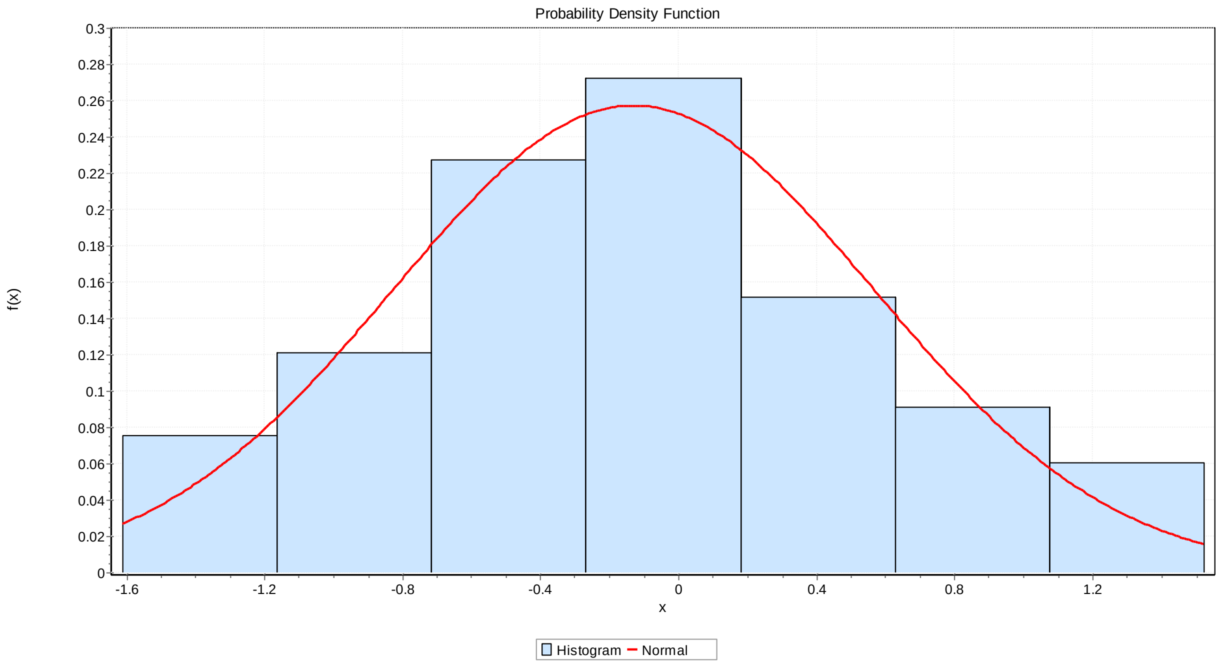

Figure 5. PDF of entire ranges of SOI values

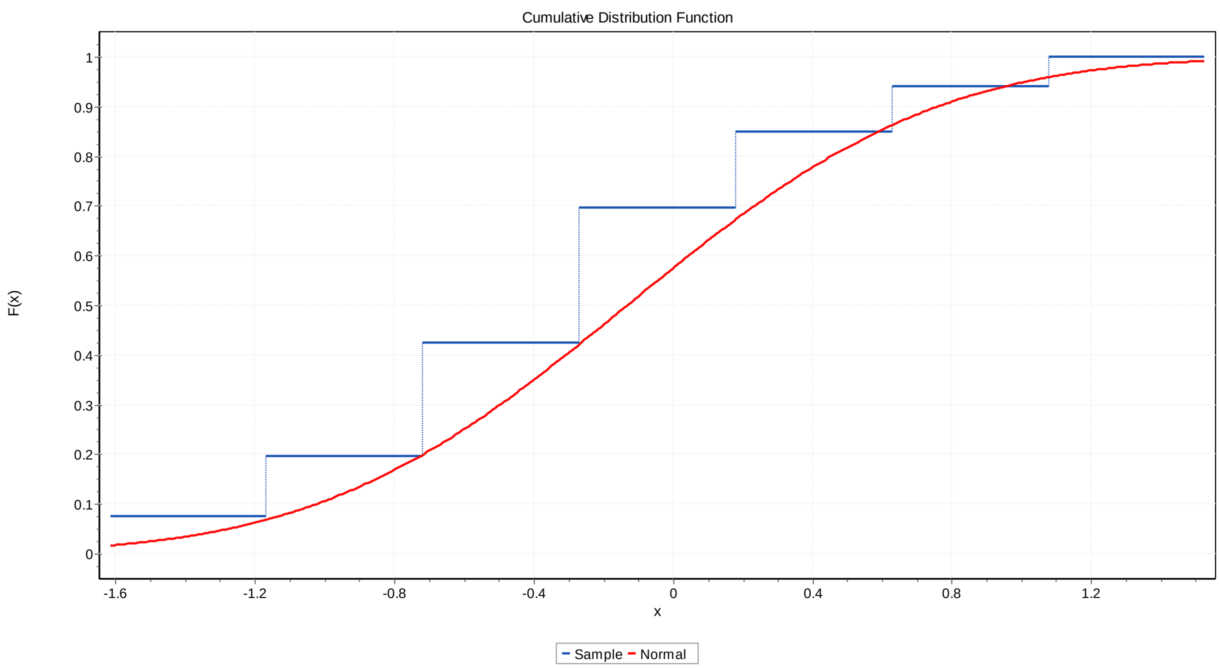

Figure 6. CDF of entire ranges of SOI values

3- The above assumes that it is a valid approach to apply annual precipitation change factors directly to extreme rainfall on short time scales. This is another major

limitation of the paper which needs to be stated clearly in the discussion and conclusions. The author's quite nicely illustrate this in their reply to reviewer 1 (comment 1) in that average change of monthly precipitation in El Nino years is +36% in January, but -28% in April. The former is likely to be linked to snowfall, while the latter actually suggests a decrease of rainfall during the flooding season.

Reply: this limitation is explained in the paper as **(P6L15-20):**

> *PC values then will be used to construct synthesized rainfall storms for simulation of the El-Niño influence. It is a major limitation of this research that the annual change factor is applied in the extreme rainfalls of short time scales. Certainly, it was better to consider the monthly or seasonal change factor or calculation of change factor on the basis of recorded storms the applying it in a continues hydrologic model to have a more accurate prediction of El-Niño effect on the flood damages then calculation of the annual damages over years, but because of data limitation the analyses performed for the annual data.*

Major comments:

4- **Quantification of rainfall changes - I could imagine 2 ways of doing this:**

- **Compute flood risk for 10 or so quantiles of the distribution in Figure 4 (considering positive AND negative changes) and then numerically integrate over the distribution.**
- **Compute flood risk for each of the 9 El Nino years and compare average against non El-Nino years.**

Reply: please see the reply to comment Number 2.

5- **Merge Fig. 5 and/or 6 from the author's response into Fig. 3 in the paper. These are much more illustrative, while the data in Fig.3 currently may or may not support the assumption of a trend.**

Reply: Fig 3 was modified and Fig6 (in the previous author responses) was added.

Also the following text was added to the paper (**P9L4-10**):

> *"In Figure 3, the annual rainfall of stations is plotted against the SOI index. It is obvious that with decreasing SOI index, annual rainfall increases in the study area and vice versa. In the period of 1951 to 2017, a total of 9 El-Niño*

(SOI<-0.8) and 7 La-Niña (SOI>+0.8) events have been occurred. Out of them, 6 years have experienced increase in the precipitation and 3 years with decrease in the precipitation. The largest event for El-Niño dates back to 1983 and 1987 with respectively 334 mm and 252 mm recorded rainfall in Mehrabad station. Furthermore, based on the trendlines, in average one unit decrease in the SOI, will enhance 22.5 mm annual rainfall in Mehrabad station. For further analyses, Mehrabad station was chosen because it has more data than the other stations."

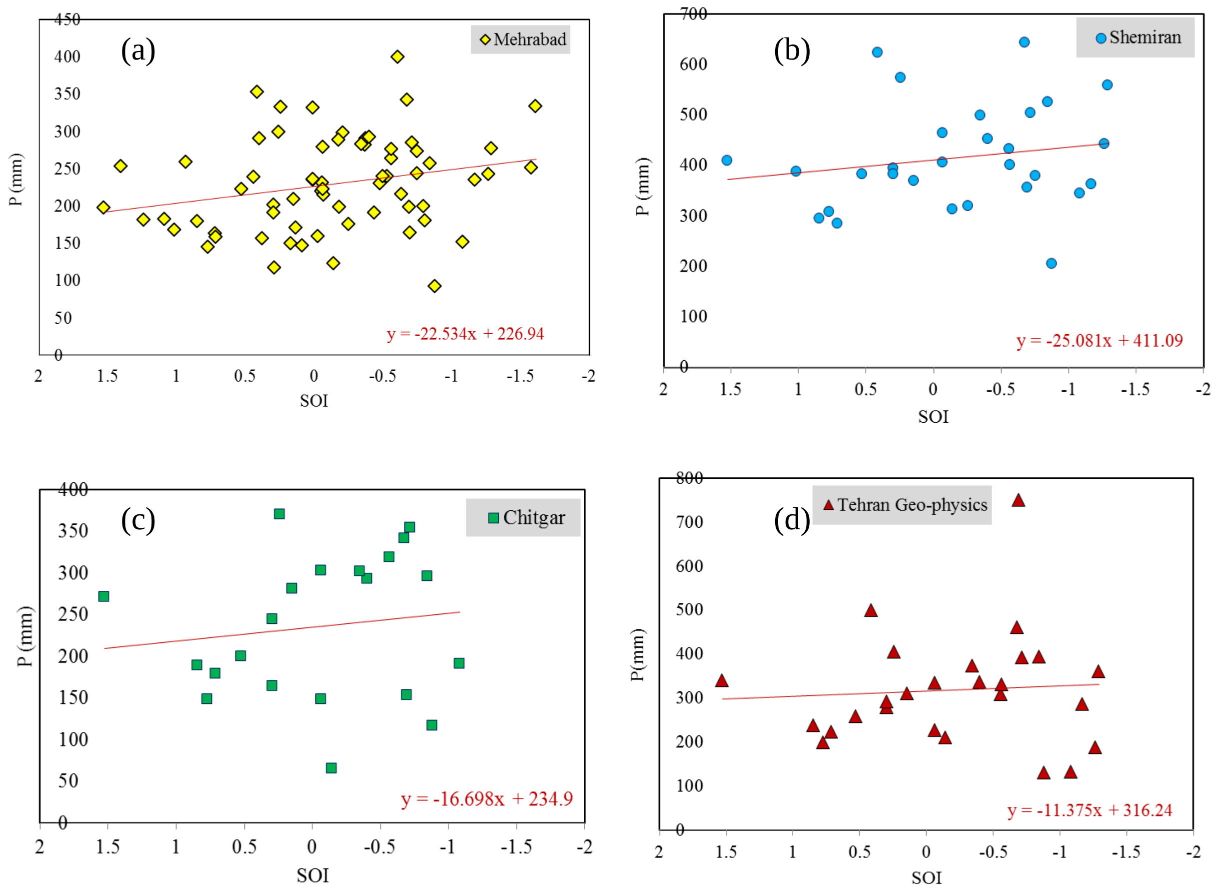

Figure 3- Annual rainfall against SOI index in the station of a) Mehrabad, b) Shemiran, c) Chitgar and 4) Tehran Geophysics

Minor comments:

6- **p.4 l.13: all your result figures suggest annual rain depths around 250-300mm, so I'm surprised to see 640mm here?**

Reply: Kan River Basin is part of a larger basin. The larger basin includes Mehrabad, Shemiran, Chitgar and Tehran Geo-physics rain stations in lower levels than the Kan River Basin. The basin is a small mountainous basin located at upstream. Therefore, the average annual precipitation of Kan River Basin is more than those presented in Fig.3.

7- **Eq.2: it is still unclear how you compute the probabilities. Please specify, possibly in an appendix**

Reply: The Average Mutual Information (AMI) measures how much one random variable tells us about another. In the context of time series analysis, AMI helps to quantify the amount of knowledge gained about the value of $x(t+\lambda)$ when observing $x(t)$. Since mutual information can be computed for a times series and a time-shifted version of the same time series, this is called the auto mutual information. However, it can be calculated for two different time series as average mutual information.

To measure the AMI of a time series, a histogram of the data using bins is created. Let Pi the probability that the signal has a value inside the i*th* bin, and let $Pij(\lambda)$ be the probability that $x(t)$ is in bin i and $x(t+\lambda)$ is in bin j. Note that only the joint probability $Pij(\lambda)$ depends on λ, and that the AMI function also depends on how the histograms are constructed, i.e., the width and position of the bins. Then, AMI for time delay λ is defined as

$$AMI(\lambda) = sum(Pij \log(Pij / (Pi*Pj)))$$

Depending on the base of the logarithm used to define AMI, the AMI is measured in bits (base 2, also called shannons), nats (base e) or bans (base 10, also called hartleys). In this paper shannons type was used and probabilities P_A and P_B were calculated using empirical frequency analysis in which the relative frequency histograms for both time series, SOI and precipitation were determined. The values of AMI for different arbitrary lag-times (1 to 12 months) between SOI and precipitation were calculated. The higher AMI value, the more dependency between two time series. Therefore, that lag-time corresponding to the highest AMI value was selected as the lag-time between the time series **(P5L19-23)**.

8- **p.8 l.25: This paragraph describes methodology which should be merged into the description of assessment steps (probably step 3)**

Reply: the paragraph was revised and those parts related to the methodology section were moved to the methodology section step II.

"Methodology" **(P6L30-P7L2)**

> *To determine the rainfall intensity in every scenario, PC values are employed and using an appropriate analytic probability distribution, the rainfall increase in different confident levels are determined. Here two probability levels, 60% and 90%, are considered for every rainfall return period. Accordingly, 9 different model runs were evaluated in the following scenarios:*

"Results and discussion" **(P9L17-20)**

> *Then, using Eq. (4), PC and ΔP can be calculated. According to the results, for 9 years with El-Niño condition, PC ranges from -60.34% to 42.8% while the latter is related to the year 1983 in which 334 mm rainfall was recorded. On the basis of Kolmogorov-Smirnov goodness of fit test with 99% certainty, Gumbel distribution well fits on these percentiles (Figure 4).*

9- the motiviation of the paper is still not quite clear. I would say we are trying to identify the potential variability due to El Nino to be able to separate from other (e.g., climate) effects?

Reply: the objective of the paper has been mentioned in Abstract and in the end of the introduction as:

Abstract **(P1L14-18)**

> *This study aims at determining the effect of the most emblematic teleconnection, El-Niño, on the expected damages of floods with low return periods in Kan River basin, Iran. To determine the flood damage costs, the annual precipitation enhancement during El-Niño condition was firstly estimated using a probabilistic approach and the inundation area was then determined under high probability levels of increased rainfall due to El Nino for 5-, 10- and 50-year return period floods.*

Introduction **(P3L22-23)**

> *The question addressed in this research is that, given the increasing impact of rainfall due to El-Niño, how much losses/damages are expected to be added in a specified study area.*

10- the paper does require language revisions if accepted

Reply: Done.

References

Grabs, W. (2015). Benchmarking flood risk reduction in the Elbe River. Journal of Flood Risk Management, 9(4), 335–342. doi:10.1111/jfr3.12217.

Nandalal, H. K., & Ratnayake, U. R. (2011). Flood risk analysis using fuzzy models. Journal of Flood Risk Management, 4(2), 128–139. doi:10.1111/j.1753-318x.2011.01097.x

Van Dau, Q., Kuntiyawichai, K., & Plermkamon, V. (2017). Quantification of Flood Damage under Potential Climate Change Impacts in Central Vietnam. Irrigation and Drainage, 66(5), 842–853. doi:10.1002/ird.2160

Western Regional Climate Center, USA; https://wrcc.dri.edu/