Response to Reviewer 1

This manuscript addresses the impact of the changes in temporal pattern and volume of rainfall due to climate change on urban floods. In addition to the impact of total change in rainfall, the impact of the projected changes in temporal patterns alone is estimated. The background scientific question is important and the results are interesting. However, there are several issues that should be addressed before it is published.

We thank the reviewer for their time and positive assessment of the manuscript. We address the reviewer's concerns in turn with our responses in italics. Please note that the author comment (AC) and Proposed Changes in Manuscript (PCiM) based on the comments are indicated as such separately for each comment.

Major comments

MC1R1

My major concern is the applicability of the scaling methods (both for volume and temporal pattern) for estimating the "projected" changes in the rainfall. The scaling factors are based on the relationship between the rainfall and temperature in the present climate. However, the present manuscript uses the scaling factor to estimate the "projected" changes in the rainfall induced by the climate change. Both the temporal pattern and rainfall volume will be affected by the changes in various dynamic and thermodynamic factors, not only by the changes in temperature. The applicability of the scaling method, which is based on the present climate variability, to the estimation of changes in rainfall under climate change should be verified. At least, it should be discussed in the manuscript.

AC- In this work we assume that temperature is the primary climatic variable associated with changing rainfall extremes and have adopted a scaling of 4.7% per degree Celsius. This value appears to be consistent both with historical trends and climate change projections.

Figure 4c of Barbero et al (2017) looks at a non-stationary extreme value analysis and finds a sensitivity of approximately 7%/ºC for a non-stationary Theil-Sen estimator for North America. Globally, Westra et al., (2013) find historical trends have global sensitivity between 5.9%/ºC and 7.7%/ºC. However, Kharin et al (2013) report an approximately 4% sensitivity over land globally from the CMIP5 model results with a range of 2.5-5% for the U.S.A.

In regard to the evidence above we believe our projections are consistent with the available evidence regarding precipitation change. There is a possibility that it slightly underestimates historical trends, but is at the upper end of predictions from climate model predictions.

Finally, there are a number of published works which show that temperature is a recommended covariate for projecting rainfall e.g. Agilan and Umamahesh (2017) and Ali and Mishra (2017) may indeed implicitly account for dynamic factors (Wasko and Sharma (2017).

PCiM- The above discussion on sensitivity will be added at line 316 to help the reader evaluate the scaling used. We note that the value of 2.92 at Line 310 is a typo and indeed should be 4.7% (as shown correctly in Figure 4).

A discussion regarding the validity of using temperature as a covariate for projecting rainfall would be included in the modified manuscript at line 263 to expand on the justification of using temperature scaling beyond the reference to Lenderink and Attema (2015).

MC2R1

L231-232: The characteristics of the temporal pattern selected from NOAA ATLAS is important in this study. It should be explained more in the manuscript or figures about what the six temporal patterns are like.

AC- We agree with this comment. The quartiles indicate the timing of the greatest percentage of total rainfall that occurs during a storm. First quartile would indicate that the majority of the rainfall including the peak will occur in the 1st ¼ of the duration, which is between hours 1 through 6 in the case of a 24-hour storm (As indicated in chart a). The distributions were further analysed to determine the frequency of occurrence within each quartile to determine a percentile for each distribution.

PCiM-Figure R1 will be added to the manuscript which shows the different patterns that were used in this manuscript. Further, the following text will be added at line 243-'The quartiles indicate the timing of the greatest percentage of total rainfall that occurs during a storm. First quartile would indicate that the majority of the rainfall including the peak will occur in the 1st ¼ of the duration, which is between hours 1 through 6 in the case of a 24-hour storm. The temporal distributions were also separated in Atlas 14 to determine the frequency of occurrence within each quartile to determine a percentile for each distribution." Will also add reference to Figure 4 in Appendix A5 of NOAA Atlas 14.

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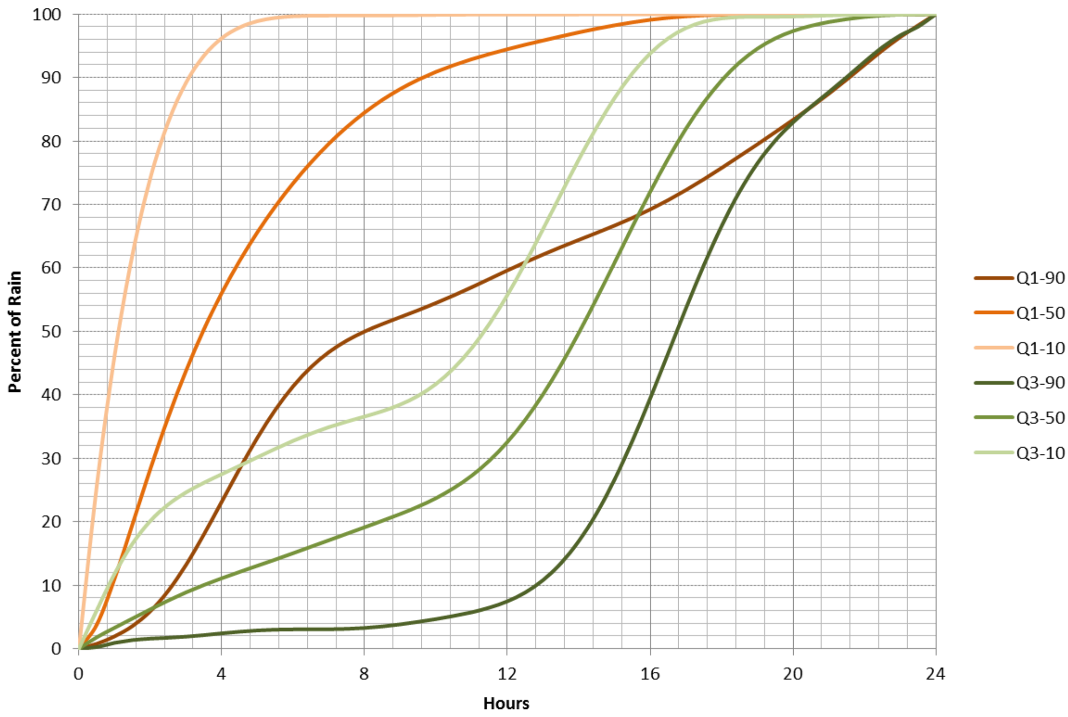

Figure R1. NOAA Atlas 14 temporal patterns used in the modelling

Reviewer 1 Minor Comments

C1R1

L224-226: How was the spatial distribution of rainfall in the catchment considered? Is it uniform over the catchment? Please describe it in the manuscript.

AC- Yes, the rainfall is assumed to be uniform over the catchment.

PCiM- A statement on the spatial distribution of rainfall will be added in the manuscript at Line 240.

C2R1

Table 2 (Design Rainfall): Why don't you use the same unit (e.g., mm/24hour) for all three rainfalls?

AC- We agree and thank you for catching that oversight. We will correct the table to ensure all rainfalls appear in mm.

PCiM- the table will be updated to;

Table 2. Description of notation used in reference to the modelled storm depths and temporal distributions (NOAA Atlas 14 volume 8 appendix 5)

Design Rainfall	Description
160 mm 24 hour	2 % exceedance 24-hour duration (50-year return period) rainfall depth
125 mm 24 hour	Lower margin of the 90% confidence interval of the 2 % exceedance 24-hour duration (50-year return period) rainfall depth-Approximately Equivalent to the 20-year 24 hour ARI
210 mm 24 hour	Upper margin of the 90% confidence interval of the 2 % exceedance 24-hour duration (50-year return period) rainfall depth-Approximately Equivalent to the 200-year 24 hour ARI

C3R1

Table 2 (descriptions of temporal patterns): I don't understand what the "1st quantile 10th percentile" is. Explaining more about the temporal pattern will help reader's better understanding. To show the shape of the pattern in the figure may be helpful.

AC-As explained in the response above, the quartiles indicate the timing of the greatest percentage of total rainfall that occurs during a storm. First quartile would indicate that the majority of the rainfall including the peak will occur in the 1st ¼ of the duration, which is between hours 1 through 6 in the case of a 24-hour storm. The percentile indicates the frequency of occurrence of each pattern within each quartile. In general, the percentile indicates the level of intensity within each quartile with a lower percentile referring to a higher intensity and a lower probability of occurrence. The reviewer is right that this was not adequately explained in the original manuscript and this discussion will be added to the paper.

PCiM- Please refer to response in comment MC2R1

C4R1

L264-270: Using some equations for the explanation on the volume scaling may be helpful for readers.

AC-Reviewer 2 also commented on the relatively short explanation of the methodology. The text at lines 264-270 will be expanded as per below:

PCiM- Lines 264-270 will be expanded to include;
"Using established methods (Hardwick Jones et al., 2010a; Utsumi et al., 2011; Wasko and Sharma, 2014), the volume scaling for the 24 hour storm duration was calculated using an exponential regression. The results are presented in Figure 4. First, daily rainfall was paired

with daily average temperature. The rainfall-temperature pairs were binned on 2°C temperature bins, overlapping with steps of one degree. For each 2°C bin a Generalized Pareto Distribution fitted to the rainfall data in the bin that was above the 99th percentile to find extreme rainfall percentiles (Lenderink et al., 2011; Lenderink and van Meijgaard, 2008). Extreme percentiles below the 99th percentile (inclusive) were calculated empirically. A linear regression was subsequently fitted to the fitted log-transformed extreme percentiles and used as the rainfall volume scaling (Figure 4). Hence the volume (V) is related to a change in temperature (T) by

$$V_2 = V_1(1+\alpha)^{\Delta T}$$

Where α is the scaling of the precipitation per degree change in temperature."

C5R1

L399 ".. as shown in Figure 5(a)": Should be Figure 6(a)?

AC- The Figure reference in the manuscript is correct as is. The intent is to show that the results at Location A are similar.

PCiM- Will change sentence to replace 'as shown' with "similar to results shown in".

C6R1

L443-445 "...the mean of the flood depth for projected events does exceed the upper limit of the variability in flood depths for the base scenario": I don't know which part of the figure shows the upper limit of the variability for the base scenario.

AC-We agree that this statement was a bit vague.
PCiM- This sentence will be re-written to read: "the mean of the flood depth for projected events (shown in red Figure 7) exceeds the upper limit of the variability, or spread, of flood depths for the base scenario (shown in blue in Figure 7)."

C7R1

L477-478 "The increase .. due to changes to temporal patterns alone range from 1% to 35%": Does these percentage numbers come from Figure 7? Since the unit of the Figure 7 is meter, it is difficult to figure out the percentage change from Figure 7.

AC-The percentages are based on the results that were used to generate Figures 6 and 7. Tables showing percentage calculations will be added to the supplemental information to make these results more clear.

PCiM- The following tables will be added in Supplementary Information

Impact on flood depth from projected temporal pattern

	A	B	C	E	D	F	G
Q1-10	1%	1%	1%	0%	2%	3%	0%
Q1-50	3%	3%	20%	8%	8%	1%	7%
Q1-90	0%	0%	12%	10%	13%	1%	-1%
Q3-10	4%	5%	19%	10%	16%	2%	9%
Q3-50	5%	8%	18%	10%	35%	2%	9%
Q3-90	4%	5%	16%	7%	12%	15%	1%

Impact on flood depth from projected volume and temporal pattern

	A	B	C	D	E	F	G
Q1-10	13%	40%	53%	95%	21%	108%	12%
Q1-50	31%	51%	74%	69%	37%	57%	25%
Q1-90	17%	34%	49%	37%	27%	9%	35%
Q3-10	27%	46%	61%	147%	59%	76%	22%
Q3-50	26%	52%	68%	173%	57%	119%	17%
Q3-90	23%	48%	78%	140%	49%	170%	8%

References:

Ali, H., and V. Mishra (2017), Contrasting response of rainfall extremes to increase in surface air and dewpoint temperatures at urban locations in India, Sci. Rep., 7(1), 1228, doi:10.1038/s41598-017-01306-1.

Agilan, V., and N. V Umamahesh (2017), What are the best covariates for developing non-stationary rainfall Intensity-Duration-Frequency relationship?, Adv. Water Resour., 101, 11–22, doi:10.1016/j.advwatres.2016.12.016.

Barbero, R., H. J. Fowler, G. Lenderink, and S. Blenkinsop (2017), Is the intensification of precipitation extremes with global warming better detected at hourly than daily resolutions?, Geophys. Res. Lett., 1–10, doi:10.1002/2016GL071917.

Kharin, V. V., F. W. Zwiers, X. Zhang, and M. Wehner (2013), Changes in temperature and precipitation extremes in the CMIP5 ensemble, Clim. Change, 119(2), 345–357, doi:10.1007/s10584-013-0705-8.

Westra, S., L. Alexander, and F. Zwiers (2013), Global increasing trends in annual maximum daily precipitation, J. Clim., 26, 3904–3918, doi:http://dx.doi.org/10.1175/JCLI-D-12-00502.1.