Author replies to comments of reviewer 2

First of all we would like to thank the reviewer for his/her positive review of the MS and the constructive comments. All of them were taken into account in the revised MS. In the following details of how the comments were considered are given.

Comment 1: Thanks for the suggestion. How the fluvial and pluvial floods are combined is indeed a relevant information for the abstract. We added two sentences: "The combined fluvial-pluvial flood scenarios were derived by adding rain storms to the fluvial flood events during the highest fluvial water levels. The probabilities of occurrence of the combined events were determined assuming independence of the two flood types and taking the seasonality and probability of coincidence into account."

Comment 2: corrected.

Comment 3: We added a statement as suggested and referred to section 3.2.2 where the temporal disaggregation of the synthetic rain storms is described in detail.

Comment 4: corrected.

Comment 5: As suggested we discuss the issue of possible biases caused by the randomization of the rain storm locations and the limited extend in section 4.5.

Comment 6: Thanks for pointing this out. We clarified the difference between dependence at coincidence at the beginning of section 3.3. It reads now "The essential question for a combined fluvial and pluvial hazard analysis is the question of dependency. At this point a clear distinction between dependence and coincidence is made: Dependence infers a causal or functional relationship, i.e. in the given context one flood type would cause or influence the other, either in its probability of occurrence or its magnitude. Coincidence does not include any relationship as in dependence. It is rather defined as the chances that the two flood types occur at the same time. Following these definitions, for this particular study it can be assumed that fluvial and pluvial flood events are completely independent from each other. ....". We hope that with this definition the following sections will be more clear.

Comments 7 and 8: Following the definition of dependence and coincidence above we added some more explanations to section 3.3. We believe that the derivation of the probabilities of occurrence of the combined flood events is now more clear. The relevant paragraphs read now:

"Thus fluvial and pluvial floods can be considered as independent, which has a direct consequence on the calculation of the probabilities of coinciding flood events: in a first step the joint probability of occurrence within a flood season can be quantified by the product of the individual probabilities of occurrences. For example, a joint occurrence of a fluvial flood event with an annual exceedance probability 0.5 and a pluvial flood event of probability 0.5 within the same flood season is 0.25. However, this joint probability of occurrence within the same flood season has to be corrected by the probability that the flood events actually occur at the same time and cause a combined flood event. This probability is termed “probability of coincidence” in the given context. Thus the probability of occurrence of joint fluvial-pluvial flood events is generally calculated as:

$$P(fl * pl) = P(fl) \cdot P(pl) \cdot P(co)$$

with *P(co)* as the probability of coincidence of fluvial and pluvial flood events.

In this study *P(co)* is estimated by the typical length of the flood season in relation to the duration of the fluvial flood events. The period of the flood season in which fluvial floods in Can Tho typically appear is mid-September to end of November, i.e. lasting about 76 days (cf. **Fehler! Verweisquelle konnte nicht gefunden werden.**). Flood peaks of the Mekong with high water levels last typically about 6 days (cf. **Fehler! Verweisquelle konnte nicht gefunden werden.**). Within these 6 days 12 distinct flood peaks, i.e. periods of high water levels, occur due to the semi-diurnal tidal regime. The high water levels differ only slightly, as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. Furthermore, sensitivity runs with the hydraulic model have shown that the maximum inundation depths of a combined flood event do not differ significantly, if the rain storm event occurs exact at the time of highest water level, or if it occurs within +/- 3 hours around high water levels. This means that the sensitive time window for coincidence of a fluvial and pluvial event is 12 flood peaks * 6 hours duration of high water levels = 3 days within a flood period of 76 days. Considering the average number of rainfall events in the critical fluvial flood period, which amounts to 5, *P(co)* evaluates to 5 * 3/76 = 0.1974. In order to account for the unavoidable uncertainty in the assumption taken for this calculation, a value of *P(co)* = 0.2 was used for calculating the joint fluvial-pluvial flood probabilities.

For the combined fluvial-pluvial hazard analysis a set of joint flood events was simulated by combining fluvial and pluvial flood events with the same individual probability of occurrence. I.e. fluvial flood events of a probability of occurrence of 0.5 were combined with pluvial flood events of a probability of occurrence of 0.5, fluvial events of 0.8 occurrence probability with pluvial events of 0.8 occurrence probability, and so forth. A complete permutation of different probability levels for fluvial and pluvial flood events was not performed in order to obtain the same number of probability levels, but also to keep the required simulation time in manageable limits.”

Comment 9: Thanks for pointing this out. We indeed analyzed if the spatial distribution of maximum rainfall resulting from the assumptions and the random locations of the storm centers is biased. We did not include this in the MS because it is already quite long. We will now include this analysis in the method part, section 3.2.2. In summary, the spatial distribution of the maximum rainfall is practically not biased, except for the frequent rainfall events. Here a small underestimation can occur due to the assumed limited extend of the storms. This finding will be taken up and discussed in the limitation section. A possible solution would be an increased number of Monte Carlo runs. However, as the bias is rather small, the overall small gain in precision might not be justified by the increasing computational cost. The revised section 3.2.2 now reads:

“In order to simulate inundation caused by heavy rainfalls the statistically derived rainfall intensities recorded at the rain gauge are translated into a spatial rainfall fields, based on the following assumptions:

1. The rainfall events do not cover the whole study area with uniform intensity.
2. The extent of the convective rainfall cell is assumed to be circular.
3. The intensity of the rainfall of the convective cell is highest at its centre and decreasing to the border.
4. The intensity within the circular extent is distributed according to a Gaussian bell.
5. The intensity along the border of the convective cell is 1/10 of the maximum intensity.
6. The diameter of the storm cell increases with intensity.
7. The location of the storm cell is stationary during the event duration of 1 hour.

Assumption 1 is based on local observations and has been confirmed by regional meteorologists in personal communication. Assumption 2 is also confirmed by meteorologists dealing with radar rainfall observations in the region. A similar assumption was also taken by Nuswantoro et al. (2014) for a storm generator for Jakarta in Indonesia, which has similar rainfall characteristics as the South of Vietnam. Assumptions 3 to 6 are also based on observations in the area and have also been used by Nuswantoro et al. (2014) for Jakarta. Assumption 4 is reasonable for tropical rain storm cells. This approach of describing the rainfall intensity has been adopted from the weather generator of Willems (2001). For assumption 6 the extent of the large storm events was estimated at approx. 8 km, based on detailed meteorological simulations of two large storm events in Can Tho (both around 80 mm/h) by Huong and Pathirana (2013). **Fehler! Verweisquelle konnte nicht gefunden werden.** lists the assumed relation of probability of non-exceedance p, rainfall intensity R(p), and extent of the storm cells (Full Width at Tenth of Maximum FWTM). The functional relation between FWTM and R(p) was empirically derived as *FWTM = R(p) * 90,* based on the simulated storm events in Huong and Pathirana (2013). **Fehler! Verweisquelle konnte nicht gefunden werden.** shows two synthetic storm events resulting from this procedure for probabilities of non-exceedance of 0.5 and 0.99.

In order to compensate for the negligence of the movement of convective storm cells (assumption 7), the pluvial hazard analysis was embedded in a Monte Carlo analysis randomizing the location of the storm centres. Through this procedure the random nature of the location of the maximum rainfall is captured, but also the effect of moving rainfall cells can be mimicked. Analogously to the fluvial hazard analysis 140 Monte Carlo runs with random selection of storm centres over the simulation domain for each probability level were conducted. In order to test the stability of the Monte Carlo procedure in terms of spatial distribution of maximum rainfall intensity, the maximum rainfall of the synthetic rain storms with random storm centres was evaluated at 25 evenly spaced grid cells over the simulation domain. For each grid cell the maximum rainfall intensity was extracted from the 140 synthetic storms for all probability levels. The reasoning behind this analysis is, that a stable MC simulation would yield at least one time the rainfall intensity quantified by the extreme value statistics (cf. 3.2.1) for the given probability level. As the box plots in Figure 6 show, not all of the 25 grid cells received 100% of the potential maximum rainfall, i.e. some underestimation occurs at some grid cells. However, for all but the probability of non-exceedance of 0.5 this negative bias is very small (< 1%) and thus negligible, particularly considering the uncertainties of the analysis. But even for p = 0.5 the median of the maximum rainfall of the grid cells is 98.4% of the rainfall given by the GP distribution, i.e. the bias is -1.6% only, which can also be considered acceptable.

For simulating the inundation caused by the synthetic storm events, the events have to be disaggregated, i.e. the temporal resolution of one hour needs to be reduced to time steps appropriate for the hydraulic model. Instead of a simple uniform disaggregation we opted for a disaggregation with a distinct precipitation peak, which is more realistic for heavy convective rains. Thus the hourly intensity of the synthetic storm events was disaggregated into 60 one-minute time steps by a normal distribution with μ = 30 min and σ = 5 min. This resulted in maximum rainfall intensities at 30 minutes after precipitation start and a concentration of the bulk of the precipitation in the 30 minutes surrounding the peak. This temporal disaggregation was applied to every pixel of the synthetic storm events. For the inundation simulation the rainfall amount of the disaggregated storm events was directly added to every pixel covered by the synthetic storms as surface water. The surface water was then routed by the 2D hydraulic model with an overall simulation time of three hours to allow for redistribution of the water after the end of the storm event. The resulting 140 maps of maximum inundation depths per probability level were then evaluated to create probabilistic flood hazard maps. This procedure is identical to the fluvial hazard analysis (cf. 3.1.2)."

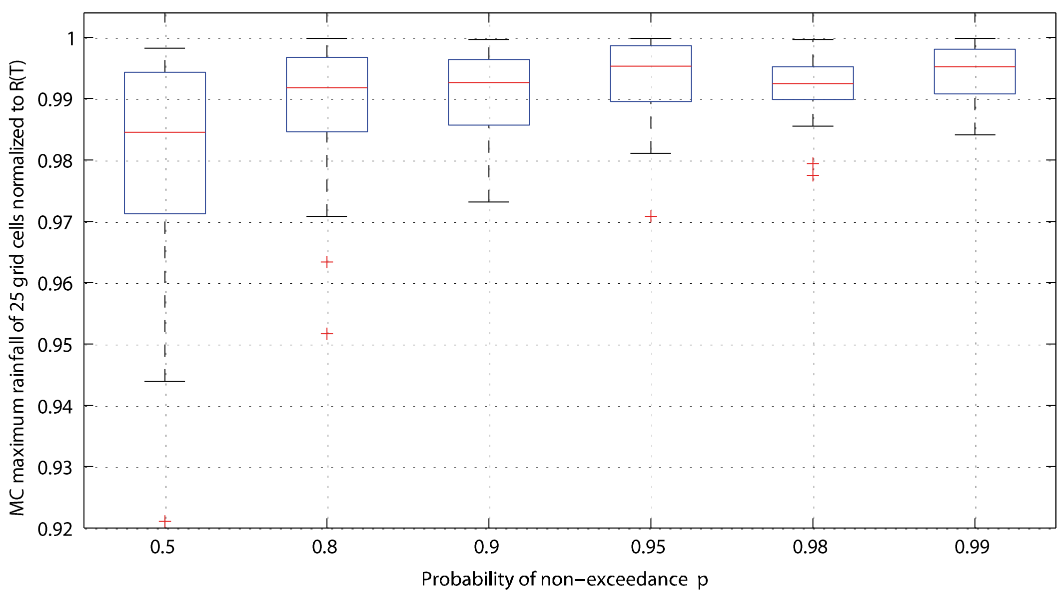

Figure 6: Estimation of the bias introduced by the assumptions taken for the synthetic rain storm events and the random location of the storm centres in the Monte Carlo analysis. For each probability level the maximum of the 140 synthetic storm events was extracted for 25 grid cells evenly spaced over the simulation domain. The maximum rainfall was normalized to the value given by the Generalized Pareto distribution fitted to the PoT rainfall series. A value of 1 thus indicates zero bias. The box plots show the distribution of the maximum rainfall among the 25 grid cells.

Comment 10: We changed the caption of Table 1 to "Probability of non-exceedance p, associated rainfall intensity R(p) as estimated with the fitted Generalized Pareto distribution, and the assumed extent (FWTM, Full Width at Tenth of Maximum) of the synthetic rain storm associated to the intensity."

Comment 11: Yes, that's correct. We changed the notation of the probabilities to "annual probability of non-exceedance" throughout the text. The caption of figure 10 (now 11) has been changed to:

"Examples of synthetic hourly rainfall events for annual probability of non-exceedance p = 0.5 (left) and annual probability of non-exceedance p = 0.99 (right). Note that the storms have different randomly drawn storm centre locations."

Comment 12: We changed the figure captions of Figures 11-13 (now 12-14) to differentiate clearly between the probability levels and the quantile maps. E.g. the caption of figure 11 now reads:

"Probabilistic fluvial flood hazard maps for Can Tho showing maximum inundation depths: for the selected p-levels (annual probabilities of non-exceedance) the median (50%-quantile) maps and associated 5% and 95% quantile maps are shown illustrating the uncertainty of the hazard estimation. Maximum inundation depths < 0.02 m are indicated as no inundation."