

Dear anonymous referee #3,

Thank you very much for your comments and suggestions. They are all significant for our research work and paper writing. Based on all referee's suggestions we have much improved the presentation of the manuscript in the revised version. Now we reply to your comments as follows.

MAJOR POINTS

1) The clarity of the manuscript should be improved in factual precision and flow of reasoning as well as in English grammar. The authors should first thoroughly examine their entire text to refine its meaning where necessary before handing it to a native English speaker for correction.

An example is P7487 L18-22.

* Firstly "joint probability of rainfall and tidal level" is imprecise without mention of exceedance of return periods or some reference. There is presumably always a tidal level, hence taken literally, the "joint probability [that there is] rainfall and tidal level" is currently referring to the percentage of rainy days.

A: We would specify the variables with explicit definition in the revised manuscript. "Joint probability of rainfall and tidal level" would be replaced by "joint probability of rainfall and tidal level both over threshold values".

* My initial guess (without inspecting table 2) at what the authors meant to say was "the probability of rainfall exceeding a particular threshold when tidal level is also high is larger than the probability of rainfall exceeding that same threshold regardless of tidal level, even though the chance of observing simultaneous extremes in rainfall and tidal level is very slight." In other words $P(H>h \mid Z>z) > P(H>h)$, implying that there is some positive dependence between the variables.

This is what referee #1 appears to have understood and has attempted an explanation. If this is what the authors mean (although I now doubt it), it would be interesting to hear why they think this is the case. I am not an expert in river systems but would guess that heavy precipitation over several days will lead to higher water levels of the receiving body being measured at the same time as heavy precipitation, which raises another point: Has tidal level the same meaning as water level of the receiving body (as measured by a hydrological station) or has the influence of precipitation on water/tide level been removed or is it considered too small? However ...

A: $P(H>h \mid Z>z)$ will be calculated and the results will be added in Table 2. In addition, we would add the values of copula parameters in Table 1. These parameters and the values of $P(H>h \mid Z>z)$ would help us to estimate the correlation between the two variables. The results (added in the revised paper) indicate rainfall and tidal level have low correlation and positive dependence.

The tidal level measured by LB hydrological station is the level of the receiving body, which

is a part of a tidal river (Ming River). It is composed by the sea level and the level caused by flow from Ming River upstream. So it involves the influence of precipitation on tide level.

* ... In their reply to referee #2, the authors rephrase these lines to mean something very different to my guess above by replacing “joint probability” with “union probability”. Expanding the lines 18-20 using the description of union probability they provide lower down in their answer I get: “It is interesting to note that the union probability [that at least one variable exceeds a certain standard] of rainfall and tidal level is always larger than [the probability that one of them exceeds that standard] the exceedance probability of corresponding return period rainfall, even though the encounter probability is very slight”. This is not interesting however, as $P(H > h \cup Z > z) \geq P(H > h)$ must always hold. It seems the revised message is “the smaller the intersection probability, the greater the union probability and the greater the chance that the flood threshold is crossed”. The point now being made is simply that the design of flood defense currently ignores the extra set of days with low rainfall and high tidal level which can lead to flooding. This message however only relates to the chance of flooding and not the severity of the flood which is what in most cases is more important and will tend to be large when both $H > h$ and $Z > z$. The intersection probability is small but depending on the risk (losses associated with a specific flood severity), could be important. Whether or not severe flooding can be modelled well using precipitation input alone is of interest.

* Note that the reason for my initial misunderstanding of these lines comes from the impact the words “even though” have on the rest of the sentence. They indicate that something unusual happens despite a low encounter probability. However, given the fact that the encounter probability is slight, it is not surprising that the union probability is much larger than the probability that the condition is met for one variable alone e.g. $P(H > h)$.

A: There are two aspects we want to make analyze in Section 4.3.3.

First, according to flood severity isolines in Section 4.2, it is a conclusion that the combination of rainfall and tidal level has a significant impact on flood risk (flood occurrence and flood severity). So we have a quantitative analysis of the probability of rainfall and tidal level both over their threshold values simultaneously. The results indicate this joint probability is very small for Fuzhou city.

Second, for Fuzhou city the design of flood defense currently ignores the extra risk from tidal level. However, the probability for flood occurrence should be determined by the value of $P(H > h \cup Z > z)$. Also, according to the analysis in Section 4.2, a single source either heavy rainfall or high tidal level could cause flooding and influence flood severity. So it is necessary to analyze the probability that at least one variable exceeds its threshold value ($P(H > h \cup Z > z)$), even though the probability that high tidal level and heavy rainfall happen at the same time is very small. By the way, that is why we said “even though” in the paper.

As to your misunderstanding of these lines, we would majorly revise this section and would improve the presentation.

* It would help the reader if the points being made in this section could be illustrated schematically so that there is no doubt about what is meant, especially given the difficulties with English. The distinction between discussing the chances of a flood occurring and the severity of flooding when it occurs should be made more obvious.

A: Good advice. We would illustrate the points more schematically and distinctly. Also, a well organized discussion would be presented in this section.

2) Comments on the uncertainty and significance of the results are lacking. How reliable are the data in table 2? If results of this study are to be useful in flood defense design for the near and far future, how representative is the input data for the current/future climate?

A: The data in Table 2 are derived by means of two methodologies, extreme value theory and copula theory. These two theories have been widely employed and verified. The uncertainty of the data in Table 2 is mainly attributed to the sample size. The parameters of copulas are derived by the marginal distribution (cumulative distribution function of each variable) whose fitting accuracy depends on the size of sample.

The sample in this study ranges from 1952 to 2008. It is enough to derive the marginal distribution and it meets accuracy requirement. In addition, the Gumbel copula derived by the sample can well fit the empirical frequency for the combination of rainfall and tidal level (see Fig. 11). So we think the results based on the data and methods are reliable to be employed in flood defense design for the future.

MINOR POINTS

C: The word “level” is sometimes used without specifying the variable it is describing. I suggest either writing “tidal level” etc explicitly or defining “level” to mean “tidal level” somewhere early in the manuscript, if all levels referred to actually are “tidal levels”.

A: Agree. We would specify the variables with explicit definition in the revised manuscript.

C: Abstract: The first sentence could be clearer, especially if it is to serve the purpose of enticing the reader to read on. Avoid the use of the confusing phrase “multi-variable variables”. The given examples of multi-variable variables, “heavy rainfall, high sea level and large waves”, are not variables themselves but rather amplitudes of variables on the high end of their scales, etc. These kinds of oversights are not solely due to difficulties in writing in a second language but to a lack of care with precision in communication – something the authors should be capable of improving.

A: Good point. We have much improved the presentation of abstract in the revised manuscript, and the first sentence in abstract is replaced by “Coastal cities are particularly vulnerable to flood under the multi-variable conditions, such as heavy precipitation, high sea levels and large waves”.

Specify the range of return periods considered in the abstract.

A: Agree. We would specify the range of return periods in the revised paper.

P7477 L12-14: Check sentence meaning, and “interested” should probably be “interesting” or “useful”.

A: Introduction of this paper has been revised for better presentation, and “interested” in line 13 has been replaced by “useful”.

P7478 L5: “the encounter probability of two variables”: probably “event” or “condition” is meant rather than “variable”.

A: Agree. “The encounter probability of two variables” would be replaced by “the encounter probability of two conditions”.

P7478: Would be helpful to describe what the concept of a copula is, in addition to the reasons given for using it.

A: We have described the concept of a copula following the suggestion of former referee, and the concept has added in the revised paper.

A copula is a kind of distribution function, and can be employed to describe the dependencies among n random variables. Description of the spatial dependence structure independent of the marginal distribution is one of the most attractive features of copulas. For given marginal distributions, multivariate joint distribution can be derived using copulas.

P7479 L4: Units of temperature missing.

A: Agree. The units of temperature that is degrees centigrade would be added in the revised paper.

P7479 L6: What is meant by “directly throughout”? Providing a definition of a typhoon and nearness criterion as suggested by referee #2 is important for the interpretation of the frequency of typhoon occurrence.

A: Typhoon is a specific form of tropical cyclone. In China, once the maximum winds of a tropical cyclone reach a wind speed of 32.7 m/s within a 2-minute averaging period, it will be designated as a typhoon. Typhoon landing Fuzhou refers to the center of the typhoon gets to some place of Fuzhou. The distance between the center of a typhoon and the center of Fuzhou depends on the landfall of the center of a typhoon and on the boundary of Fuzhou.

According to history records (1949-2011), the center of typhoon gets to Fuzhou (including Fuzhou city and its county) 39 times and tropical cyclones which are main sources of heavy rains land Fuzhou 56 times.

P7480 L2: Where do the precipitation and tidal levels data come from (P7481 L24 is a bit late) and from what period in time? In what format (spatial scale, temporal interval) is the original data and how is it processed for input to the model?

A: The specific data in this study are spread following the methods in different sections. The

precipitation and tidal level records (1952-2008) are measured by LB hydrologic station (introduced in P7481). The precipitation data include maximum rainfalls with different periods of time (10-min, 30-min, 1-h, 3-h, 6-h, 12-h and 24-h) and a typical rainfall process. The tidal level records include annual maximum tidal levels, the highest tidal levels within one day of annual maximum 24-h rainfalls (corresponding tidal levels), and a typical tidal level process.

The process that original data are translated into the flow hydrographs for input to the model encompasses three five steps: (1) selection of a typical rainfall process and a typical level hydrograph;(2) deriving design standard rainfalls and tidal levels based on annual maximum 24-h precipitation series and annual maximum tidal level series; (3) deriving design rainfall processes based on design standard rainfalls and the typical rainfall process, and deriving design tidal level hydrographs according to design standard tidal levels and the typical level hydrograph; (4) deriving the flow hydrographs according to design rainfall processes; and (5) taking the flow hydrographs and the tidal level processes hydrographs as the boundary conditions input to the model.

P7480 L3: What should be understood by “hydraulic parameters” and by “sewers information”?

A: hydraulic parameters in this study mainly mean roughness coefficients of rivers, and sewers information includes distribution of pipelines and maximum outflow capacity of pipelines. We would specify them in the revised paper.

P7481 L3: SWAT and ARCGIS?

A: SWAT and ARCGIS used in this study refer to the soft of ARCSWAT.

P7481 L11: The process of “data collection” for precipitation and its translation into the flow hydrograph is not described.

A: The precipitation records (1952-2008) include maximum rainfalls with different periods of time (1-h, 6-h, 12-h and 24-h) and a typical rainfall process. The process that original data are translated into flow hydrographs for input to the model encompasses four steps: (1) deriving design standard rainfalls according to annual maximum 24-h precipitation series; (2) deriving design rainfall processes based on design standard rainfalls and the typical rainfall process; (3) deriving the flow hydrographs according to design rainfall processes; and (4) taking the flow hydrographs as the boundary conditions input to the model.

P7481 L15: Reasoning Formula Method?

A: Reasoning Formula Method will be replaced by Rational Method in section 3.1.1, page 7481.

P7482 L7: Describe the design standard rainfall. The range of precipitation and tidal levels covered could also be mentioned. Is it a time series with realistic variability or something else?

A: The design standard rainfalls in this study involved rainfalls with different return periods (5 years, 10 years, 20 years, 50 years and 100 years). The tidal levels covered in the paper range from 4.4 m to 9.5 m. They are realistic variables.

P7482 L8-9: What is the reasoning here? Sounds like the exceedance of the critical condition is decided by eye.

A: The exceedance of the critical condition is decided by the value comparison between the river level and the elevation of banks. This sentence would be deleted in the revised paper.

P7483 L14-19: h , H , f , F , z , Z appear in these lines but not all are defined. $F_h(h)$ and $F_z(z)$ are not defined whereas $f_h(h)$ and $f_z(z)$ are mentioned twice.

A: We are sorry for some writing errors in the paper. “The marginal distribution functions are $f_h(h)$ and $f_z(z)$ ” would be replaced by “The marginal distribution functions are $F_h(h)$ and $F_z(z)$ ”.

P7484 L9: Too little information on the input. What is meant specifically by rainstorm data and operation of flood control?

A: As section 3 mentioned, the input for the model includes inflow boundary conditions and outlet boundary conditions. The inflow boundary conditions can be derived by the rainfall process during Typhoon Longwang. The tidal level hydrograph and the operation of pumps and tide-locks are taken as the outlet boundary input to the model.

P7484 L22: The calibration of the coefficients was not described.

A: The roughness coefficients ranging from 0.025 to 0.045 are calibrated by Department of River Management of Fuzhou city.

P7486 L8-9: These parameters are mentioned too suddenly. Some have been introduced but not all. U and V were dummy variables on page 7483 but now they are mixed with the assigned variable names and subscripts. Best to clearly state what they are at the point they are used or refer to the formula that contains them.

A: For a P-III distribution, there are three key parameters, mean value u_x , coefficient of variation C_v and coefficient of skew C_s .

P7486 L22: This equation needs a much better introduction. Writing the steps between eq 3 and eq 6 would help.

A: There are two key steps between Eq. 3 and Eq. 6: (1) estimation of Maximum Likelihood Function of Gumbel copula based on Eq. 3; and (2) parameter estimation of Gumbel copula for the joint distribution by means of Maximum Likelihood Function.

P7488 L11: The meaning of this sentence, in particular “changed combination” is unclear.

A: The meaning of this sentence was supposed to state that different combinations of rainfalls and tidal levels could make different flood severities.

This sentence would be deleted, and a major revision for the conclusions would be presented in the revised paper.

P7488 L12-14: Could be misread as “better to understand flood risk theory than try to do something about it”.

A: We would improve the presentation of this sentence in the revised paper.

P7494 Table 2: Explain the meaning of the symbols in the table caption.

A: Explanation of the symbols would be added in the revised paper.

The column named “Maximum annual 24 h rainfall” contains 3 columns, “ $H(\text{mm})$ ”, “ $P(\%)$ ”, and “ $T(\text{a})$ ”. H is the annual maximum 24-h rainfall. P is the exceedance probability of the rainfall. T is the return period of the rainfall. The column named “Corresponding tidal level” contains 4 columns, “ $Z(\text{m})$ ”, “ $P(\%)$ ”, “ $P_M(\%)$ ”, and “ $T_M(\text{a})$ ”. Z is the highest tidal level within one day of annual maximum 24-h rainfall (corresponding tidal level). P is the exceedance probability in the cumulative distribution function for corresponding tidal levels. P_M is the probability of the corresponding tidal level in the cumulative distribution function of annual maximum tidal level series. The return period of the corresponding tidal level is T_M , which is the reciprocal of P_M .

FIGURES

Some points to address in the figures and captions (taking into account the reply to referee #1):

1) The text in these panels is far too small, especially in the top panel. Enlarge text that is important to see and remove the rest. The same holds for the distance scale on the third panel.

A: We would improve the presentation of Figure 1 following your advice in the revised paper.

2) What do the small red dots and arrows signify?

A: The red dots represent the cross sections of rivers and the arrows indicate the direction of flow. We would specify their meanings in the revised paper.

3) State what is shown in colour and the units of the values shown on the colorbar. What is the significance of the letters n, p, g, j, b etc?

A: We would add the units of the values on the colorbar and revise the caption as follows.

Fig.3 Sub-catchments division and numbering with digital elevation nephogram for flood hydrographs. Different letters represent different areas (n representing northern mountain

areas, p representing Pingdong River areas, b representing Baima River areas, j representing Jinan River areas, g representing GMG River areas, m representing Moyang River areas, f representing Fengban River areas, and x representing Xindian areas).

4) What is meant by a drainage unit of the urban area? Is it a specific district used as an example? If so, which one? Or is it an average unit? The symbols should be defined in the caption or the reader should be referred to the definitions in the text.

A: “A drainage unit” will be replaced by “a sub-catchment”. It is an average sub-catchment, and the symbols have been defined in section 3.1.1. The caption of Fig. 4 would be revised as follows.

Fig.4 Surface runoff process and pipeline outflow process of a sub-catchment in an urban area shown in Fig 3.

5) Suggest writing in the caption something like “Submerged sections (thick overlay) of the rivers of Fuzhou city during Typhoon Longwang on day-month-year, according to observations”.

A: Good advice. The caption would be revised as “Submerged sections (thick overlay) of the rivers of Fuzhou city during Typhoon Longwang on October 2, 2012, according to observations”.

6) This is so similar to Fig. 5 that it takes time to spot the differences. It would be far better to show the differences. Perhaps eliminate Fig 6 and make 2 panels in Fig 5 as follows: Keep Fig 5 the same but add a second panel showing the differences between the model and observations, i.e. highlight the sections that are submerged by the model yet not in the observations and also the submerged sections that the model misses (in a different line colour/style). Clearly state what has been plotted in the caption.

A: Good advice. We would follow your advice to eliminate Fig. 6 and make 2 panels showing the differences in Fig. 5.

7) Where is this hydrograph made? You might want to mark the point location of these hydrographs on one of the spatial plots.

A: The hydrograph made in the midstream of Jinan River, we will mark the point location on Fig. 2.

8) Keep aspects of original caption as it is in the manuscript as it focusses the reader. “Isolines of flood severity as a function of 24-h rainfall and tidal level, shown under two conditions: (a) without pumps working; (b) with pumps working.” But add “Severity is measured as the percentage of the total river length that is flooded. The isoline “Start” indicates the conditions at the instant that the flooding threshold is crossed.”

A: Good advice. The caption of Fig. 8 would be revised as follows.

Fig. 8 Isolines of flood severity as a function of 24-h rainfall and tidal level, shown under two conditions: (a) without pumps working; (b) with pumps working. Severity is measured as the percentage of the total river length that is flooded. The isoline “Start” indicates the conditions at the instant that the flooding threshold is crossed.

9) Much better would be: “Same as Fig. 8 but plotting flood severity as a function of the return periods of 24-h rainfall and tidal level instead of absolute values.” This tells the reader immediately what the difference between the two plots is. What is the “(a)” unit on each axis? Better to state (years), as (a) can be confused with the panel labelling.

A: Good advice. We would revise the caption as “Same as Fig. 8 but plotting flood severity as a function of the return periods of 24-h rainfall and tidal level instead of absolute values”, and we would use “years” as the unit on each axis.

10) “(a)” -> “(years)”. “Comparison of the start isoline (conditions at the instant that the flooding threshold is crossed) from Fig 9, with and without pumping.” Alternatively, eliminate Fig 10 and combine Fig 9a and 9b into the same panel using different line colours or thicknesses for the pumping conditions. The same should then also be done for Fig 8. It would make comparison easier.

A: Good advice. We would keep Fig. 10 and revise the caption as “Comparison of the start isoline (conditions at the instant that the flooding threshold is crossed) from Fig. 9, with and without pumping”.

11) Need to explain what distribution is being modelled.

A: The caption of Fig. 11 would be revised as follows.

Fig. 11. Correlation between empirical joint distribution and theoretical joint distribution of Gumbel copula for the observed combinations of 24-h rainfalls and tidal levels. “ R^2 ” represents the square of the linear correlation coefficient between empirical frequency and theoretical frequency.