Dear anonymous referee #2,

Thank you very much for your comments and suggestions. They are all significant for our research work and paper writing. We would improve the presentation of the manuscript, and revise the paper according to the following comments.

C: The paper purports to focus on "flood risk", which is normally understood to be a function of both probability of occurrence and consequence of occurrence. There are frequent references to "severity", "flood risk", "combined risk" etc. The probability of occurrence is addressed in the paper, but consequence is poorly represented, with, I think, no attempt to combine the two into a single risk function. Consequence is expressed only in terms of a poorly defined percentage, with no context as to what percentage is significant, although the consequence of Typhoon Longwang is described.

A: The previous research on flood risk focuses on the assessment of consequences based on flood simulation results and information regarding population density and spatial distribution of economic assets. In this paper the joint impact on flood risk is analyzed from two aspects, combined flood severity and joint flood probability. We aim to show an integrated approach to study flood risk. With the hydrological modeling, flood risk under the combination of rainfall and tidal level is investigated with the length ratio of the flooded reaches to the total rivers as the evaluation index of flood severity. The results show that both rainfall and tidal level are key influence factors to flood risk. Therefore, the threshold condition that flood happens with some extent is proposed with a joint probability distribution of rainfall and tidal level. It is useful information to support managers to make applicable measures to reduce flood risk.

In flood consequence aspect, we just focus on the flood severity as a function of different rainfalls and of tidal levels in this paper. There are some reasons as follows.

Firstly, influence of rainfall and tidal level to flood of Fuzhou city and the threshold conditions of flood with some extent are focused in this paper. It is a feasible method for managers to take steps to reduce flood risk or to do a better design of flood defences. Therefore, only consequence of flood occurrence during Typhoon Longwang is described to show necessity of our study.

Secondly, for a city with high urbanization in China, when urban flooding happens, there probably are some costs from it. With the increase of flood severity, the costs will be rising. So we think the flood severity could represent the consequence of flood to some extent.

Thirdly, for specific assessment of the consequence for flood, massive information and data should be investigated, including population density, spatial distribution of economic assets and so on.

As to the attempt to combine the consequence and the probability into a single risk function, we believe it is an interesting topic. Considering the information we have is not adequate for a specific assessment of the consequence of flood, we propose a simplified method to address this problem. According to flooded length of rivers and consequence of flood during Typhoon Longwang, the losses in the combined condition of a certain rainfall and tidal level could be estimated with the ratio of flooded length of rivers times the losses during Typhoon Longwang. The risk function is $R(h,z)=P(h,z)F(h,z)$, where, $R(h,z)$ is the risk under a certain rainfall h and tidal level z, $P(h,z)$ is the joint probability that a certain rainfall h and tidal level z happened at the same time, $F(h,z)$ is the consequence of flood under a certain rainfall h and tidal level z.

C: The wording of the top six lines of Page 7477 implies that previous researchers have failed to "tackle the problem properly", although I doubt if that is the authors' intended meaning. The authors suggest that the focus should be on "the threshold conditions for flood", although this would not be true for most flood risk studies, for example where threshold flooding may have no consequence. The low-lying parts of the grounds in which my office stands flood about one winter in three, sometimes to a metre or so of water depth, but there is no significant consequence and hence no significant flood risk.

A: In the wording of the top six lines of page 7477, we point out the traditional methods "cannot effectively reflect the threshold conditions of flood and the probability of flood", and we should "develop an integrated approach in managing the risk of flood". So in this paper two aspects are considered in the assessment of joint impact on flood risk, namely combined flood severity and the joint flood probability. In flood severity aspect, we focus on "the threshold conditions for flood". There are some explanations as follows.

Firstly, for a city with high urbanization in China, when urban flooding happens, there probably are some costs from it. The "start" condition that flood just occurs means the consequence just coming up. And when someplace stands flood to a metre water depth, there must be some severe problems about food, shelter and transportation, and may be some casualties. Taking the storm in Beijing on July 21, 2012 as an example, someplace stood flood to more than a metre water depth, many cars were submerged in the water and 5 people died in the cars. This disaster with mean rainfall of 170 mm, caused 77 people killed, more than 56000 evacuated, almost 2 million affected and economic losses more than $1.5 billion.

Secondly, the threshold conditions would help us efficiently reduce flood risk. For a city, the current flood drainage facilities could cope with some rain events. When the combined effect of rainfall and tidal level gets to a certain condition, which is the threshold condition, the extent and loss of flood will increase, due to the flow capacity and the characters of river network, and the effect of pumps and drainage gates. Therefore, understanding the threshold condition would help address the problem feasibly and efficiently. For example, if the joint condition of heavy rainfall and low tidal level is beyond the threshold condition, the measures restricting flood from northern mountains coming in should be taken. And if the joint condition of low precipitation and high tidal level is beyond the threshold condition, the pumps should be working to lower the river level in advance.

C: The first paragraph of Section 2 states that "typhoons land directly throughout the city twice a year on average". This high frequency would be highly improbable if typhoons were defined the same way as hurricanes or tropical cyclones are defined in some other countries. If this statement is retained, it should be accompanied by the definition of a typhoon, including the nearness criterion applied to the distance between the centre of a typhoon and the centre of Fuzhou.

A: We are so sorry for our mistake in the statistical data of typhoon landing Fuzhou. Thank you very much for pointing out it. In fact, tropical cyclones landed the whole Fujian province 128 times from 1949 to 2011. They landed Fuzhou city 56 times in the 63 years, and typhoons landed 39 times from 1949 to 2011. These data reference the website http://www.typhoon.gov.cn.

We would correct it in section 2, page 7479.

C: Context for "Luo Zero Vertical Datum of China" in Section 3 would be helpful, for example that it represents mean sea level; plus some reference levels for the range of levels that can occur in the river.

A: Luo Zero Vertical Datum of China equals National Vertical Datum 1985 plus 2.179 m. National Vertical Datum 1985 takes the mean sea level of Yellow Sea as 0.0 m.

In this paper the warning river level for LB hydrologic station is 6 m and the highest river level recorded at this station is 9.53 m on July 7, 1992 measured by Luo Zero Vertical Datum of China.

We would add relevant contexts for "Luo Zero Vertical Datum of China" in section 3, page 7480.

C: Reference the first paragraphs of Sections 3.3 and 4.3.3. It is unclear whether the tidal levels used in the analysis are taken coincident in time with the annual maximum rainfall, or whether they are themselves high and extreme values. For example, the first line of Section 4.3.3 refers to "annual maximum flood tidal level" but this may refer to something different to the "annual maximum daily rainfall AND ITS CORRESPONDING TIDAL LEVEL" in Section 3.3. If the values of the two variables are taken coincident in time, then presumably the majority of river level values would be just normal average river levels, and not suitable values from which to estimate extreme river levels. If they are, for example, the highest river levels within one day or one month of the annual maximum rainfall, or just in the same year, then these value-pairs may provide a poor representation of "joint" extremes. The imprecise wording suggests different definitions in different places so I can’t tell whether the definition used is appropriate. It is possible that high and extreme values of both variables occur only during typhoon conditions, and if so this point should be made somewhere in the paper, perhaps with a note that the method is unsuitable for use in non-typhoon conditions.

A: We would present better in the revised paper. As section 3.3 mentioned, the tidal levels used in the analysis are taken coincident in time with the annual maximum rainfall, and they are different to the annual maximum flood tidal levels.

Three types of data are collected for the analysis of joint probability of rainfall and tidal level, namely annual maximum 24-h rainfall series in 1952 to 2008, corresponding tidal levels, and annual maximum river level series in 1952 to 2008. The “corresponding tidal level” refers to the highest river level within one day of the annual maximum 24-h rainfall. For the 3 types of data, there are 3 distribution curves to fit each of them. We assess the joint distribution of the annual maximum 24-h rainfalls and the corresponding tidal levels by copula in this paper. By the joint distribution function we can calculate the joint probability of any combination of rainfall and tidal level. For each tidal level, there is a probability in the distribution curve of corresponding tidal level, also there is another probability in the distribution curve of annual maximum tidal level. So we can calculate the joint probability of rainfall return periods and tidal level return periods by the joint distribution function of annual maximum 24-h rainfall and corresponding tidal level. The results are shown in Table 2.

In terms of the data we collected, the method in this paper to analyze the joint probability rainfall and tidal level return period is suitable for use in both non-typhoon conditions and typhoon conditions.

C: Section 4.3.3, Lines 18-20. As written, this statement is illogical, implying that the imposition of an additional condition increases the probability of occurrence; analogous to saying, incorrectly, that the probability of drawing specifically an ace and a king in two cards is higher than the probability of drawing specifically an ace in one card. The authors' intended point is unclear.

A: The presentation of lines 18 to 20 is unclear. We would improve the presentation of this section. And in lines 18 to 20, "the joint probability of rainfall and tidal level" would be replaced by "the union probability of rainfall and tidal level". The union probability refers to the chance that at least one condition (heavy rainfall or a high tidal level) occurs.

In the page 7487, line 10, we point out the probability that high tidal level and heavy rainfall occur at the same time is very low. It can be seen in column 9 of Table 2. The column $P\bigcap(h,z)$ shows that the joint probability of 5-yr rainfall and 2-yr tidal level is 0.5017%, and with the increase of the return period of rainfall or tidal level, the joint probability is getting smaller. This means when heavy rainfall happens, high tidal level barely comes up in Fuzhou, which is different from some other coastal cities.

For Fuzhou city, the design standard of flood defense is derived only by the rainfall, ignoring the extra risk posed by tidal level. However, even though the probability that the heavy rainfall and the high tidal level occur at the same time is very low, the union probability that at least one variable exceeds a certain standard (denoted as $P\bigcup(h,z)$) is larger than the probability that one of them exceeds. So the return period of flood for a coastal city should be determined as the reciprocal of the union probability of rainfall and tidal level. That is based on the quantitative combined risk analysis. That is what we emphasize.

C: If a flood risk conclusion is added, it may be interesting also to demonstrate how it would be altered under a future climate change scenario.

A: With the climate changing, the amount of precipitation and the daily precipitation intensity are both have an increasing trend in southeastern China (Huang, 2012), and future sea level changes will maintain an upward trend with fluctuations in East China Sea (Wang, 2011). So, under these changes the encounter probability of heavy rainfall and high tidal level will increase. Considering the preparedness measures which are adequate 10 or 20 years will not seem so adequate in the future, the frequency of flood and the cost from flood will be rising. Therefore it is recommended building and maintaining sound infrastructures and integrated risk management as key steps to reduce the risks from future natural disasters.

C: Table 2. Maybe these variables are defined somewhere in the paper, but it would be helpful to summarise their meanings on the same page as the table. And again, the Z value, I think representing river level, is meaningless without a datum and some typical river levels for context.

A: Actually, the variables have been defined in section 3.3. We would summarize their meanings on the same page as Table 2 following the referee's advice.

We would also add the representing river levels in section 3, page 7480. The warning river level for LB hydrologic station is 6 metres. And the highest river level recorded at this station is 9.53 metres on July 7, 1992.

C: Would it be helpful, for context, to include Typhoon Longwang in some or all of Figures 8-10?

A: As Fig. 8 shown, the main factors influencing flood occurrence and flood severity are tidal level, precipitation and characteristics of river network. The characteristics of river network contain conveyance capacity, division and convergence of flow, regulation and storage capacity. For a coastal city, when precipitation gets to a certain standard, no matter what the tidal level is, the flood will happen due to the restriction of river conveyance capacity. When the tidal level reaches a certain standard, the outlet sluice will not work and the discharge of pumping will decrease. Then the flood would happen if the water volume to be drained of a rain exceeds the regulation and storage capacity of river network. Therefore, the combination of heavy rain and low tidal level and the combination of low rainfall and high tidal level could both cause flood.

For Fuzhou, in condition of no pumps working, flood severity has a deep tie with tidal level and rainfall within a certain standard of precipitation (50-yr return period). While the rainfall exceeds this standard, tidal level will be the main factor for flood severity. In pumping condition, pumps will efficiently reduce flood risk within 20-yr return period precipitation. When the rainfall exceeds 100-yr return period, pumps may not help because of the restriction of river conveyance capacity.

During Typhoon Longwang the maximum 24-h rainfall is 278 mm, which is close to the largest value in the Fig. 8. So we think it can be represented by the point of 266 mm.

References:

Huang, W., Yu, R., and Li, J.: Analysis of Changes in Precipitation Intensity in Later-Summer over Southeast Coast of China in 1967-2006, Adv. Clim. Change Res., 8, 164–170, 2012.

Wang, G. D., Kang, J. C., Han, G. Q., Liu, C., and Yan, G. D.: Analysis and Prediction of Sea-Level-Change Multi-Scale Cycle for East China Sea, Adv. Earth Sci., 26, 678-684, 2011.