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Hydrology and Earth System Sciences
Discussions

Interactive comment on "More frequent flooding? Changes in flood frequency in Pearl River basin, China since 1951 and over the past 1000 years" *by* Qiang Zhang et al.

Qiang Zhang et al.

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Anonymous Referee #1 Received and published: 4 January 2018 The manuscript presents a descriptive study of the extreme flows of a set of basin stations in the Pearl River basin, China. The database of the various stations is very interesting either at the flow rates or for the precipitation stations. As we all know, inconsistent results about how changes in flooding under global warming have been reported due to the limited sample of flood series. The highlight of this study obtaining flood data from historical documents can effectively break through this limitation. Thus, I recommend this paper is accepted after a minor revision. The following is my specific comments. Reply:

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Discussion paper

Thank you so much for your kindness and for your generous encouragement by your kindly allowing us such an opportunity to improve our manuscript.

(1) L93-97, this paper incorporates the floods records of 1000 years from Guangdong and Guangxi provinces. Whether the same historical dataset has been used in previous studies and what were their results? A review on the historical dataset should be added. Thank you for your kind comment. The historical flood records were collected from two books compiled by Wen and Song (2006) and Wen and Yang (2007). These two books included abundant records relevant to various meteorological disasters, such as tropical cyclones, droughts, floods, frosts, and so on. The historical flood records should be screened out from those abundant records and it is a kind of time-consuming job. Therefore, to our knowledge, few reports were found concerning flooding changes over long period such as 1000 years in this study based on historical records. To introduce the historical dataset more detail, we have added the information of the group that compiled the dataset in section Data. Additionally, the selected flood events used in this study will be posted as Supplementary Information.

Wen, K. and Song, L., 2006. Collections of meteorological hazards in China-Guangdong version. Beijing: Meteorological Press. Wen, K. and Yang, N., 2007. Collections of meteorological hazards in China-Guangxi version. Beijing: Meteorological Press.

(2) L113-114, why 10-year flood was selected? Thank you for your kind comment. Thank you for your comment. 10-year flood is defined as the flood peak is expected to occur, on average, once every 10 years. Usually, 10-year flood event may cause severe life and property loss which was also paid much attention by previous studies, such as Villarini et al. (2014).

Villarini G., Goska R., Smith J.A., Vecchi G.A., 2014. North atlantic tropical cyclones and U.S. floodings. Bulletin of the American Meteorological Society, 95(9), 1381-1388.

(3) L152, Is "The largest 1 day streamflow" the monthly or annual maximum? Thank

you for your kind comment. "The largest 1 day streamflow" indicates annual maximum.

(4) L156, some of stations seem not covering the period of 1951-2014. A detail information such a table about the data should be provided. Thank you for your kind comment. The detail information of hydrological stations in this study has been added in the Table 1. Table 1 The detail information of hydrological stations in this study. No. Station name Longitude (°E) Latitude (°N) Basin area (km2) Region Starting year Ending year Record length 1 Qilinzui2 113.85 23.35 2866 III 1954 2014 61 2 Pingshi2 113.05 25.28 3567 II 1964 2014 51 3 Wenjiang 113.93 24.30 2000 II 1955 2014 60 4 Chixi4 113.13 25.38 396 II 1967 2014 48 5 Lishi2 113.53 24.85 6976 II 1955 2014 60 6 Xiaogulu 114.20 25.07 1881 II 1958 2014 57 7 Renhua3 113.75 25.10 1476 II 1964 2014 51 8 Jielongwan 114.18 24.90 281 II 1958 2014 57 9 Sanshui2 112.83 23.17 46646 II 1951 2014 64 10 Makou 112.80 23.12 353100 II 1951 2014 64 11 Shuangqiao 112.57 22.97 938 I 1958 2014 57 12 Dulin 109.90 20.83 47 IV 1975 2014 40 13 Hedishuiku 110.30 21.72 1495 IV 1965 2014 50 14 Gangwajiao3 110.07 21.50 3086 IV 1970 2014 45 15 Ruipo 110.03 21.77 208 IV 1967 2014 48 16 Gaozhou4 110.83 21.92 2905 IV 1975 2014 40 17 Xinhe 111.12 21.72 649 IV 1958 2014 57 18 Shigushuiku1 111.04 22.07 509 IV 1965 2014 50 19 Dabai 111.15 22.05 394 IV 1967 2014 48 20 Huazhoucheng 110.65 21.65 6151 IV 1956 2014 59 21 Liangdeshuiku 110.98 22.15 494 IV 1965 2014 50 22 Gaoyao 112.47 23.05 351535 I 1951 2014 64 23 Gulan 111.68 23.57 8273 I 1954 2007 54 24 Xiaoluo 111.67 23.25 76.2 I 1977 2014 38 25 Lingxia 114.57 23.25 20557 III 1953 2014 62 26 Boluo2 114.30 23.17 25325 III 1953 2014 62 27 Jianshan 115.63 23.67 1578 III 1958 2014 57 28 Shuikou2 115.90 23.98 6480 III 1953 2014 62 29 Tangjin 116.22 23.98 267 III 1959 2014 56 30 Hengshan2 116.35 24.47 12954 III 1954 2014 61 31 Xikou 116.65 24.53 9228 III 1959 2014 56 32 Baokeng 116.42 24.68 437 III 1958 2014 57 33 Lantang2 114.93 23.43 1080 III 1958 2014 57 34 Shuntian 114.77 24.12 1357 III 1966 2014 49 35 Heyuan 114.70 23.73 15750 III 1951 2014 64 36 Longchuan 115.25 24.12 7699 III 1952 2014 63 37 Lianping2 114.47 24.37 388 III 1971 2014 44 38 Xingfeng2 115.04 24.40 290 III 1972 2014 43 39 Jinshan 111.53 22.03 950 IV 1959 2014 56 40 Shigushuiku2 111.02 22.05 509 IV 1965 2013 49 41

Pomian_qudao 112.00 22.40 768 IV 1958 2014 57 42 Pomian3 111.83 22.38 768 IV 1954 2014 61 43 Shuangjie 111.80 21.95 4345 IV 1952 2014 63 44 Huangjingtang 112.42 24.58 595 II 1958 2014 57 45 Gaodao 113.17 24.17 7007 II 1954 2014 61 46 Shijiao 112.95 23.57 38363 II 1954 2014 61 47 Mawu2 113.16 23.85 34.7 II 1972 2014 43 48 Damiaoxia 113.50 23.83 472 II 1960 2014 55 49 Gaolang2 113.30 23.86 216 II 1972 2014 43 50 Chaoan 116.65 23.67 29077 III 1951 2014 64 51 Chikan 116.25 23.68 641 III 1967 2014 48 52 Fukou 115.77 23.40 355 III 1959 2014 56 53 Cijiao 116.02 23.05 820 III 1955 2014 60 54 Dongqiaoyuan 116.13 23.48 2016 III 1953 2014 62 55 Guanliang 111.67 22.83 3164 I 1958 2014 57 56 Yaogu 112.28 22.87 1776 I 1958 2014 57 57 Hejiang2 110.57 21.90 3000 IV 1958 2014 57 58 Daxiang2 112.15 23.97 671 II 1959 2005 47 59 Denghuangshan 112.38 24.83 1084 II 1959 2005 47 60 Machi 113.20 23.90 300 II 1959 2005 47 61 Zhuzhou 112.35 23.73 553 II 1959 2005 47 62 Qianjiang 108.97 23.63 128938 I 1951 2010 60 63 Dahuangjiangkou 110.20 23.57 288544 I 1951 2010 60 64 Wuzhou 111.30 23.48 327006 I 1951 2010 60 65 Jiangbian 103.62 24.00 25116 I 1951 2010 60 66 Panjiangqiao 105.38 25.88 14492 I 1951 2010 60 67 Zhexiang 106.20 24.92 82480 I 1951 2009 59 68 Yongwei 109.28 25.70 13045 I 1951 2010 60 69 Sancha 108.95 24.47 16280 I 1951 2010 60 70 Liuzhou 109.40 24.32 45413 I 1951 2010 60 71 Pingle 110.67 24.60 12159 I 1951 2010 60 72 Baise 106.63 23.90 21720 I 1951 2010 60 73 Xinhe 107.20 22.45 5791 I 1951 2010 60 74 Nanning 108.23 22.83 72656 I 1951 2010 60 75 Guigang 109.62 23.08 86333 I 1951 2010 60 76 Jinji 110.83 23.22 9103 I 1951 2010 60 77 Changba 113.68 24.87 6794 II 1951 2010 60 78 Changle 109.42 21.83 6645 I 1951 2010 60

(5) The missing data of precipitation and streamflow should be introduced and told to us how to deal it. Thank you for your kind comment. There is less than 1% missing values in daily precipitation data (Zhang et al., 2018). The missing values of precipitation for 1–2 days were filled by the average precipitation of the neighboring days. Consecutive days with missing data were interpolated by the long-term average of the same days of other years. For the objectives of this study, the gap-fill method did not significantly affect the final results. A similar method had been used by Zhang et al. (2011) to

fill daily missing precipitation values. The annual largest 1 day streamflow data from 78 hydrological stations are directly collected from the Water Conservancy Bureau of the Pearl River Water Conservancy Commission. Because the annual largest 1 day streamflow data have been compiled before released, only several values in several stations are missed. The missing values of annual largest 1 day streamflow data were filled by the average value of the neighboring years.

(6) L161-188. I suggest the authors put historical flood information as supplementary information. Thank you for your kind comment. The historical flood information and flood-induced losses in terms of people, room, and agriculture area have been put into the Supplementary information.

(7) Session 3., make it clear that the change point and trend detection are only applied for the observations of 1955-2014, instead of the past 1000 years. And, make it clear that the kernel density estimation is only applied for the historical floods. Thank you for your kind comment. In Method, we have added the following sentences: the change point and trend detection methods are only applied for the observations of 1951-2014, and the kernel density estimation method is only applied for the historical floods.

(8) L272-284, this part superficially discusses that climate change and human activities have kind of impacts on flood peak, which are very straightforward, but does not explain how these factors contribute to the changes. Furthermore, it does not mention that how the peak changes after the change points. Does the peak increase of decrease after the change point? Thank you for your kind comment. Our analyses changes in precipitation extremes are consistent with that in flood peaks. In addition, the abrupt change time in precipitation extremes is also in line with that in flood peaks. Therefore, changes in precipitation extremes may play a dominant role in change point of flood peaks. Only a few stations showed a change point in the flood peaks. Additionally, the trends in flood peaks before and after the change points have been detected in our previous studies (Zhang et al., 2014), indicating that no significant trends have been found. Change points of flood peaks in the mainstream of the West River oc-

curred approximately in 1990 in spite of a few difference. The flood peaks of the West River basin are heavily influenced by the confluences of tributaries on the upstream of the West River and the factors causing abrupt changes in mean are complicated and blurry. The influence of hydraulic facilities is considerable. However, after the 1990s a few hydraulic facilities have been constructed and their influence can be ignored. Analysis of precipitation extremes in the Pearl River basin indicated that the amount of rainfall had changed little but its variability had increased over the time interval divided by change points. Besides, increased precipitation variability and high-intensity rainfall were observed, although rainy days and low-intensity rainfall had decreased (Zhang et al., 2009b). Abrupt changes of precipitation maxima were shifting in different seasons. However, change points of precipitation maxima in summer occurred in 1990, 1988 and 1991, which are in line with changes points of flood peaks of the West River basin. It should be noted that floods occur mainly during the summer season. Therefore, it can be tentatively stated that abrupt changes of flood peaks of the West River basin are mainly the result of abrupt behavior of precipitation maxima. However, due to spatiotemporal patterns of precipitation maxima in the Pearl River basin and the production and confluence of flood streamflows, the abrupt behavior of flood peaks usually does not match that of precipitation maxima. Moreover, human interferences also introduce considerable uncertainty and cause obscure relations between abrupt changes of flood peaks and precipitation maxima. This analysis implies abrupt changes of flood peaks due to various influencing factors. The above sentences have been added in Discussion. The trends in flood peaks before and after change point have been added in Fig. 4. Most of stations show decreases in flood peaks both before and after change point, especially in Region I and IV (Fig. 4b and c). However, the flood peaks in Region III turned decreasing trend before change point to increasing trend after change point, suggesting the physical mechanism of flood generation may be shifted.

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Fig. 4 Trends in (a) flood peaks with the whole series, (b) flood peaks before change point, (c) flood peaks after change point, and (d) precipitation extremes. The gray dots in (b) and (c) indicate the stations without change point.

Zhang Q., Gu X., Singh V.P., Xiao M., Xu C.-Y., 2014. Stationarity of annual flood peaks during 1951–2010 in the Pearl River basin, China. Journal of Hydrology, 519, 3263-3274.

(9) Section 4.3. The authors argued that the increased numbers of reports have limited impacts on the significant increased trends of the documented floods. They claimed that "in recent 200 years, the no reported extreme floods did not have so much differences that number of floods is still significant increasing". I wonder if this increase has an association with global warming? Thank you for your kind comment. Heavy precipitation is a major source of flood generation in Pearl River Basin. Under global warming, the magnitude and frequency tend to increase in Pearl River Basin (Gu et al., 2017), one the consequences of increasing heavy precipitation is that flooding may be more frequent. However, there are different meteorological, hydrological and climatological mechanisms that bring moisture that can produce flooding (i.e., tropical cyclone, convection, thunderstorm, frontal passages, sea surface temperature (SST) anomalies, and jet streams) (Hirschboeck, 1988). Therefore, it is difficult to attribute the increasing number of floods in recent 200 years to global warming certainly. For example, in our previous studies, more than 50% of flood events are induced by tropical cyclone in Guangdong province directly (Zhang et al., 2017). On the other hand, human influences may be more important to the increasing number of floods. Taking the Pearl River Delta (PRD) as an example, during recent 60 years, more than 20000 levees were combined with 400 levees and the length of river channel was reduced from 10000 km to 5000 km. Besides, the construction of large-scale reservoirs greatly reduced the occurrence rates and magnitude of floods (Figs. 11a, 11b and 11c). However, fast and massive urbanization, such as the urbanization rate of the Guangdong province reaching 67.67% caused fast production of floods and hence enhanced flood risk. The basin conditions including underlying surface, rivers, watercourse, runoff

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regulation, changed by human activities have irreversible impacts on flood generation mechanism. Compared with global warming, the increasing number of floods may have stronger association with human activities.

Hirschboeck, K.K., 1988. Flood hydroclimatology. In: Baker, V.R., Kochel, R.C., Patton, P.C. (Eds.), Flood Geomorphology. John Wiley & Sons, Hoboken, NJ, pp. 27–49. Xihui Gu, Qiang Zhang, Vijay P. Singh, Yongjie Zheng. Changes in magnitude and frequency of heavy precipitation across China and its potential links to summer temperature. Journal of Hydrology, 2017, 547, 718-731. Qiang Zhang, Xihui Gu, Peijun Shi, Vijay P. Singh, Ming Luo. Timing of floods in southeastern China: Seasonal properties and potential causes. Journal of Hydrology, 2017, 552, 732-744.

(10) How does floods in Pearl River Basin changes in future? Model simulations should be provided. Thank you for your kind comment. Future changes in floods in Pearl River basin have been analyzed by previous studies (e.g. Xiao et al., 2013; Li et al., 2016). The usual approach that models the future changes in floods is using projected meteorological data (such as phase 5 of the Coupled Model Intercomparison Project (CMIP5)) to force hydrological model and simulate the future flood process. There are four representative concentration pathways (RCPs), i.e. RCP26 (low-emission scenario that achieves), RCP45 and RCP60 (moderate-emission scenario that achieves), and RCP85 (high-emission scenario that achieves). Xiao et al. (2013) evaluated the changes of floods in future 30 years under RCP45 and pointed out that increasing trends in Xijiang basin (Region I) and Region IV can be expected. Li et al. (2016) used eight hydrological models to model future changes in floods under RCP26 and RCP85 and indicated that the floods will increase especially in Region III under both RCP26 and RCP85 and the increase extent will be more obvious under RCP85. In this study, future changes in floods in Pearl River basin are not focused and added because of the following reasons: (1) the previous studies have analyzed the changes in future floods in Pearl River basin detailedly; (2) analysis and project in future floods have large uncertainties (Li et al., 2016); (3) the purpose of study is to investigate the changes in

historical floods that is expected to provide more reference to understand how floods will change.

Xiao, H., Lu, G., Wu, Z., Liu, Z.: Flood response to climate change in the Pearl River basin for the next three decades, Shuilixuebao, 44, 1409-1419, 2013. Li, J., Chen, Y. D., Zhang, L., Zhang, Q., Chiew, F. H.: Future changes in floods and water availability across China: lingkage with changing climate and uncertainties.

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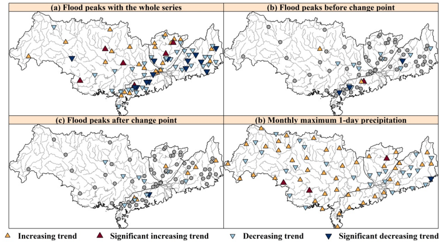

Fig. 4 Trends in (a) flood peaks with the whole series, (b) flood peaks before change point, (c) flood peaks after change point, and (d) precipitation extremes. The gray dots in (b) and (c) indicate the stations without change point.

Fig. 1. Trends in (a) flood peaks with the whole series, (b) flood peaks before change point, (c) flood peaks after change point, and (d) precipitation extremes. The gray dots in (b) and (c) indicate the stat