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Collided with COVID-19 Pandemic, the 2020 Yangtze Flood Is Exceptionally Severe

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ABSTRACT. During June to July, 2020, persistent heavy precipitation in the Yangtze River Basin (YRB) is resulting in extensive flooding, with over 158 fatalities and tremendous economic losses. This year's disastrous flooding extreme is exceptionally different from those of other years. It contains over 1000-year return period events (for 30-day cumulative precipitation) as observed in Anhui, Guizhou and Sichuan Provinces. The mean precipitation is 308 mm in July 2020, being 54 mm higher than that of July 1998, when serious floods affected the entire Basin causing tremendous socio-economic consequences. Compared with 1998, the short-term (e.g., 1 day) precipitation in YRB did not show significant increases, while the long-term (e.g., 30 days) cumulative precipitation increases significantly. The highest observed 30-day cumulative precipitation is 1221 mm (in Anhui Province) in 2020, while the highest one in 1998 was 1028 mm (in Jiangxi Province). We thus find that this persistent heavy precipitation is the main cause of flooding in 2020. At the same time, TGR may mitigate up 43% of upstream flood, although the main contributors to this year's YRB flood are in the middle and lower reaches. Affected by COVID-19, the number of people at risk in the threatened area are increased, and their capacities to mitigate the dual impacts of COVID-19 pandemic and flooding are hindered since (a) the flooding-caused mitigations may limit people's ability to prevent from virus spreading, and (b) the pandemic is retaining a large amount of migrant workers being within YRB and subject to flooding impacts. Overall, our main discovery is that, although the short-term precipitation in YRB did not increase significantly in 2020, the cumulative one increased significantly in 2020!

Keywords: 2020 Yangtze River flooding, COVID-19, Three Gorges Reservoir, persistent precipitation

1. Introduction

In summer 2020, Yangtze River Basin (YRB) is suffering from an exceptionally serious flood, which is showing to be even more serious than that of 1998. So far, four heavy floods have occurred on July 2, 17 and 26, and August 14. According to the Ministry of Emergency Management (released on 28 July), the floods have led to 158 deaths (or missing), 3.67 million displaced residents, 54.8 million affected people, and ￥144 billion ($20.5 billion) direct economic losses (Ministry of Emergency Management of the People's Republic of China, 2020). The basin-wide catastrophic floods in YRB have attracted attention world widely. Historically, such unusual catastrophic flooding and inundation (e.g., 1998 flooding (Lu, 2000; Sun et al., 2016)) were mainly caused by persistent heavy precipitation (Huang et al., 1998; Tao et al., 1998). However, for 2020, we may be curious of the role of Three Gorges Dam in intercepting the floodwater; moreover, in collision with the COVID-19 pandemic, it is desired to learn what additional hazards it will bring about. Therefore, the objective of this research is to address these queries through in-depth analyses of the characteristics of persistent heavy precipitation events and the roles of reservoirs. It is expected that the results will help provided scientific basis for assessing and managing the floods.

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2. Data and Methods

YRB is one of the most climate sensitive areas in East Asian, and experiences large year-to-year variability in its summer precipitation during June to July (Li and Lu 2017, Wang et al., 2021a, 2021b). To characterize the persistent heavy precipitation events, the observed daily precipitation of 166 stations (as shown in Figure 1(a)) during 1960 to 2020 are obtained from the National Meteorological Data Center (http:// data.cma.cn). The characteristics of persistent heavy precipita-tion events are iden-tified as 1-, 5-, 7-, 15-, and 30- day maximum; the 1- day max-imum denotes the annual maximum dai-ly precipitation, while the 5-, 7-, 15-, and 30- day maximums are obtained from the graphs of maximum precipitation events (as shown in Figure 1(b)).

The estimated return periods are obtained based on Generalized Extreme Value (GEV) distribution. According to (AghaKouchak et al., 2014), the concurrent extreme return periods can be obtained through the copulas for examining the dependences among multiple variables (Fan et al., 2017, 2020). In this study, the Copula-based concurrent return periods and the marginal distributions of cumulative precipitation are developed firstly. Subsequently, the joint probabilities of multi-scale cumulative precipitation events are investigated through Gaussian Copula. Finally, the return periods are obtained for single and joint cases based on the fitted GEV and Gaussian Copula (AghaKouchak et al., 2014).

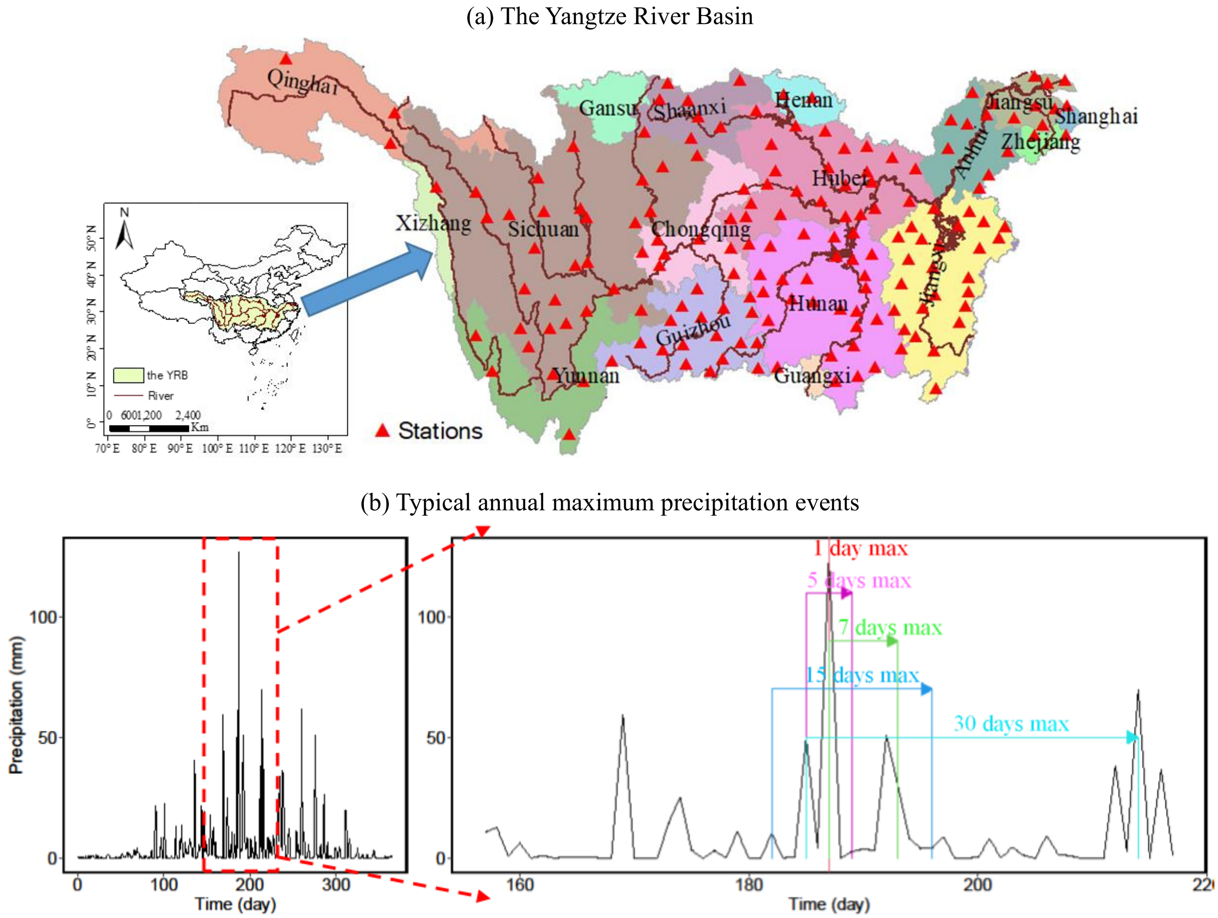

Figure 1. (a) The Yangtze River Basin (YRB), and (b) typical annual maximum precipitation events (showing cumulative characteristics).

According to (AghaKouchak et al., 2014), the concurrent extreme return period can be obtained through the copulas widely used in modeling the dependence between multiple variables (Fan et al., 2017, 2020). Assuming two variables X (e.g., 1 day cumulative precipitation) and Y (e.g., 30 days cumulative precipitation) with cumulative distribution functions $F_x(x) = \Pr(X \le x)$ and $F_y(y) = \Pr(Y \le y)$, the copula (C) can be used to obtain their joint distribution function:

$$F(x,y) = \Pr(X \le x, Y \le y) = C\left(F_X(x), F_Y(y)\right) \quad (1)$$

where $F(x, y)$ is the joint distribution function of X and Y.

From the joint distribution function F, the so-called joint survival distribution $\bar{F}$ and be obtained:

$$F(x,y) = \Pr(X \le x, Y \le y)$$
$$\bar{F}(x,y) = \Pr(X > x, Y > y) = \hat{C}\left(1-F_X(x), 1-F_Y(y)\right) \quad (2)$$

where $\hat{C}$ is the survival copula. Similar to the univariate return period analysis, the survival return period of X and Y is defined as follows:

$$\bar{k}_{x,y} = \frac{\mu}{1-\bar{K}(t)} \quad (3)$$

where $\bar{k}_{x,y}$ is the survival Kendall's return period; $\mu > 0$ is the average interarrival time of X and Y ($\mu = 1$ in this study); and $\bar{K}$ is the Kendall's survival function associated with $\bar{F}$ defined as:

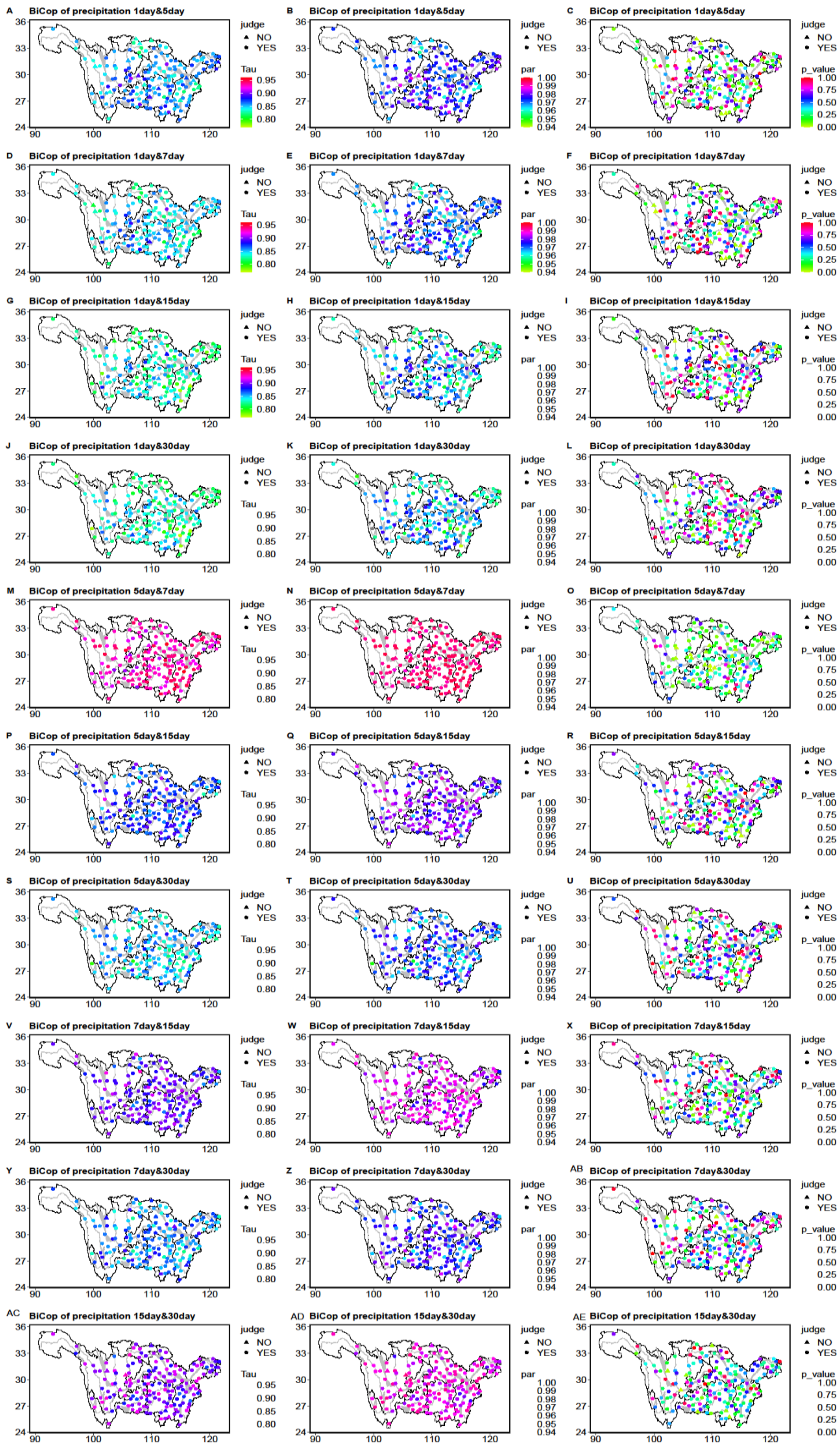

Figure 2. The *tau*, *par* and *p* value of fitted Bi-Copula for different cumulative precipitation during 1960 ~ 2019.

$$\bar{K}(t) = \Pr\left(\bar{F}(X,Y) \ge t\right) = \Pr\left(C\left(\bar{F}_X(x), \bar{F}_Y(y)\right) \ge t\right) \quad (4)$$

In this study, Gaussian Copula model the dependence between two-dimensional variables, the *tau*, *par* and *p* value of fitted Gaussian Copula for different cumulative precipitation are presented in Figure 2. The inverse distance weighted interpolation method is used for presenting the spatial distributions.

3. Results

3.1. More Precipitation in 2020

YRB is hit by persistent heavy precipitation events during June to July 2020, with a mean precipitation is 579 mm (61 mm higher than that of 1998). Particularly, the mean was 308 mm in July 2020, which is 54 mm higher than that of 998. The probability density functions (PDFs) of monthly precipitations for 166 stations in 1998 and 2020 present in Figure 3(a). There are significant increases in monthly precipitation levels (250 mm higher in June and July 2020 compared with 1998). Figures 3 (b, c, and d) shows the spatial distributions of the differences in monthly precipitation between 2020 and 1998. In June to July 2020, most of YRB were subject to more precipitation than those 1998. The increased precipitation in June is mainly concentrated in Anhui, Hubei, Shaanxi, and Chongqing Provinces. As for July, the precipitation is focused on the middle and lower reaches, with parts of Anhui, Jiangxi, Jiangsu, Zhejiang, Shanghai, and Hubei having 200 to 400 mm more precipitation (than those in 1998).

Figure 4(a) shows the PDFs of cumulative precipitation for 166 stations in 1998 and 2020. Five cumulative periods (1, 5, 7, 15, and 30 days) are analyzed. It can be found that there is no significant difference between 1998 and 2020 in the PDFs of 1-day precipitation (i.e., maximum daily precipitation for the year) of the 166 stations. As the cumulative number of days increases, the differences in PDFs becomes increasingly obvious. For instance, the PDFs of 30-day cumulative precipitation in 2020 is higher than that in 1998. The spatial distribution of the precipitation differences presents in Figures 4(b, c, d, e, and f). At the end of July, compared with 1998, only the lower reaches of YRB were subject to more severe short-term precipitation in 2020. At the same time, the middle and lower reaches (Hubei, Anhui and Jiangsu) had more long-term cumulative precipitation (especially 30-day precipitation) in 2020. Overall, our main discovery is that, although the short-term precipitation in YRB did not increase significantly in 2020, the cumulative one increased significantly in 2020!

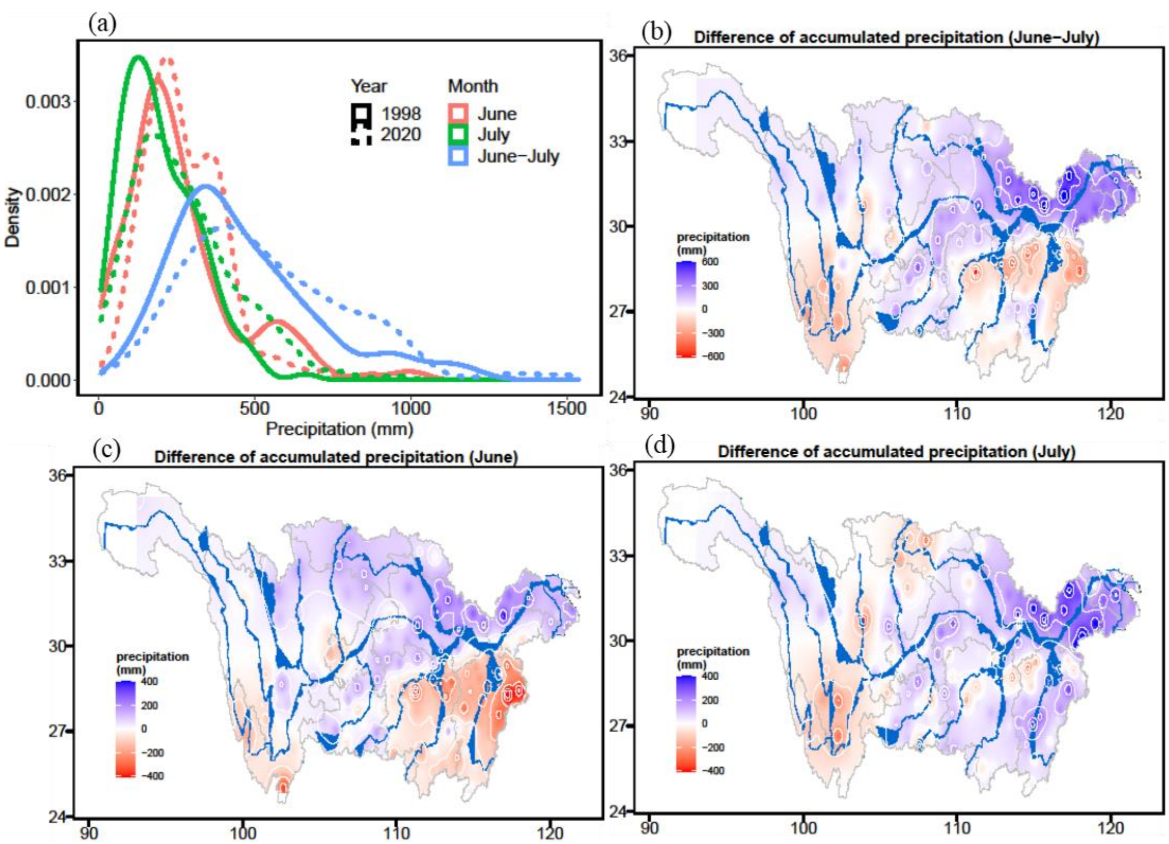

Figure 3. The probability density functions of monthly precipitation and the spatial distributions of monthly precipitation differences between 2020 and 1998.

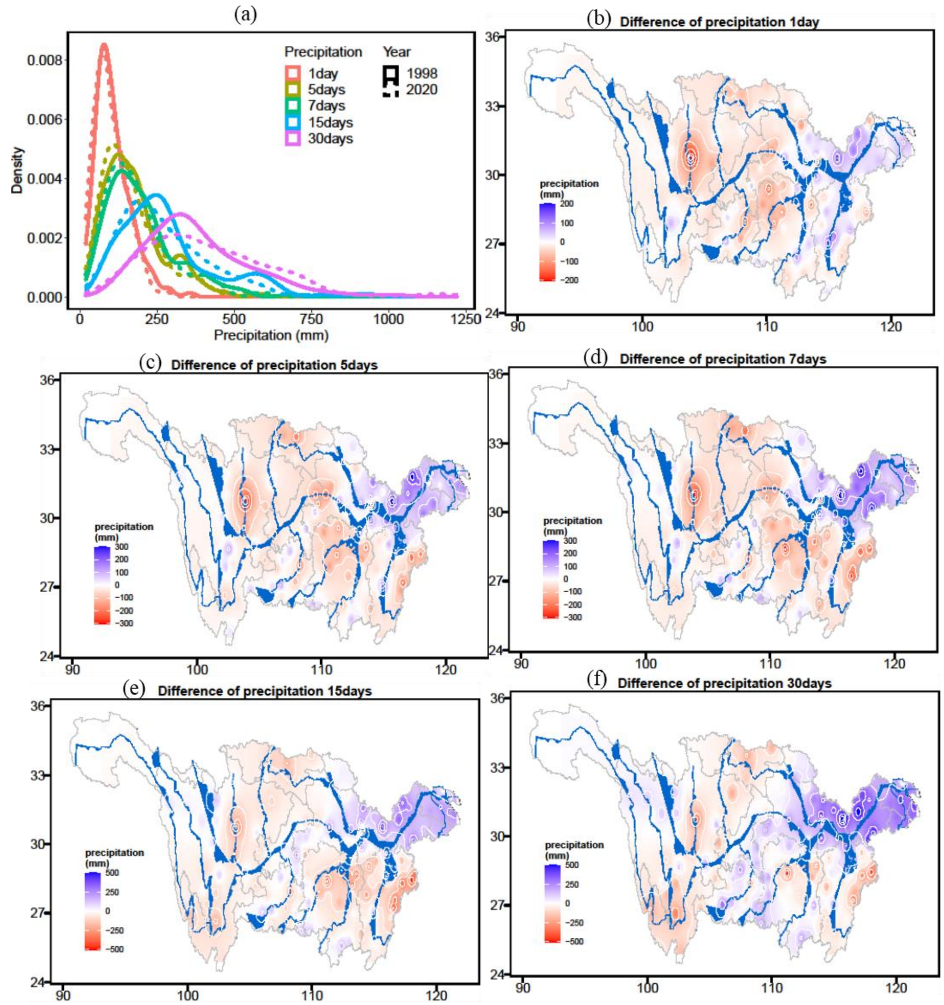

Figure 4. The probability density functions of cumulative precipitation and the spatial distributions of cumulative precipitation differences between 1998 and 2020.

3.2. Long-Term Cumulative Extremes Observed in 2020

A GEV fit of the observed cumulative precipitation demonstrates more long-term precipitation extremes in 2020. Figures 5 and 6 present the spatial distribution of the return period differences for short-term (i.e., 1 day), and long-term (i.e., 30 days) cumulative precipitation between 2020 and 1998. Compared to 1998, the short-term cumulative precipitation levels of most stations are at their lower levels, except the stations of Yingshan (station id: 58402, return period = 195 year), Xichang (station id: 56571, return period = 97 year), and Jian (station id: 57799, return period = 121 year) (Figure 4). However, more long-term cumulative precipitation extremes are observed in 2020. For instance, over 200-year return period events (for 30-day cumulative precipitation) were observed at eight stations in 2020, while none in 1998 (Figure 5); moreover, over 1000-year return period events (for 30-day cumulative precipitation) were recorded at three stations (located in Anhui, Guizhou, and Sichuan provinces) in 2020, while none in 1998.

Figure 7 presents the combined effect of short- and long-term cumulative precipitation. Longer combined return-periods (for short- and long-term cumulative precipitation) are observed in 2020 (compared to 1998), which are mainly located in the lower reach of YRB. It is found that the over 200-year combined return period events (for 1- and 5- day cumulative precipitation) are based on relevant individual events with return period being less than 200 years. Four stations are with combined return periods over 200 years (for 1- and 5- day cumulative precipitation) in 2020, while six in 1998. The longest combined return period in 2020 occurred at Hefei station (station id: 58321, 1-day precipitation = 178 mm, 5-day precipitation = 394 mm, combined return period > 1000 year). For long-term cumulative (15- and 30- day precipitation), there are nine stations with a combined return period of 400 years in 2020, while none in 1998. The highest combined return period (of 15- and 30-day precipitation) occurred at Zhengan station (station id: 57625, 15-day precipitation = 357 mm, 30-day precipitation = 624 mm, combined return period > 10000 year).

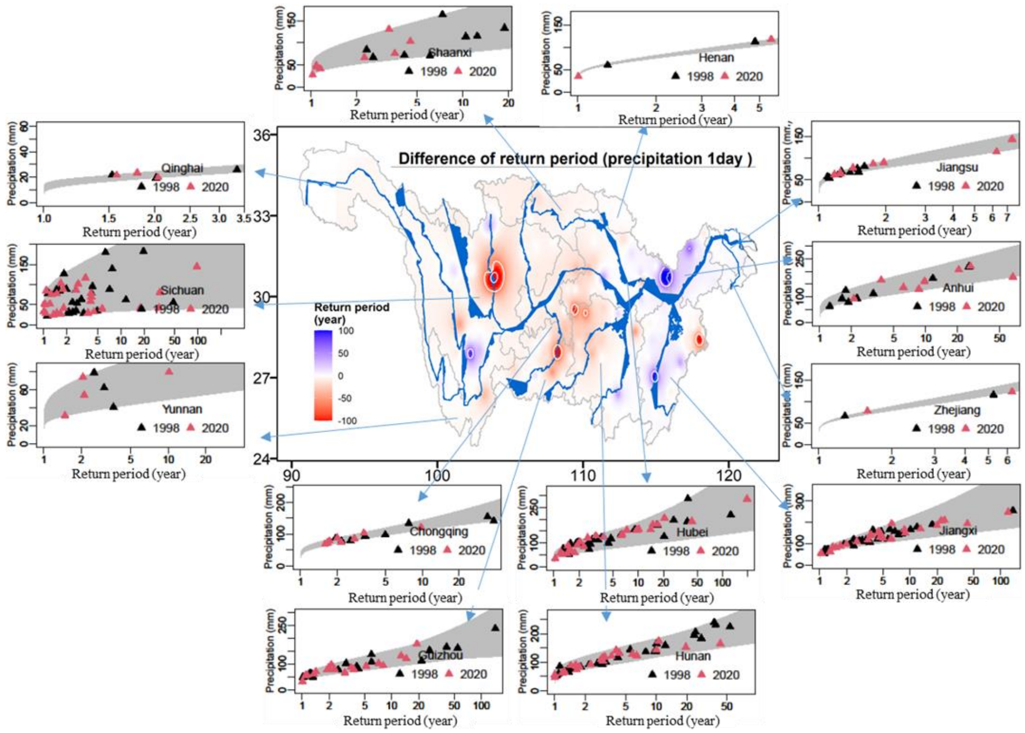

Figure 5. The spatial distributions of the return period differences for short- (i.e., 1 day) cumulative precipitation levels between 2020 and 1998. The blue and red colors respectively represent higher and lower return periods in 2020 (compared with those of 1998). In the sub-graphs divided by province, the gray band indicates the uncertainty of return period in each province.

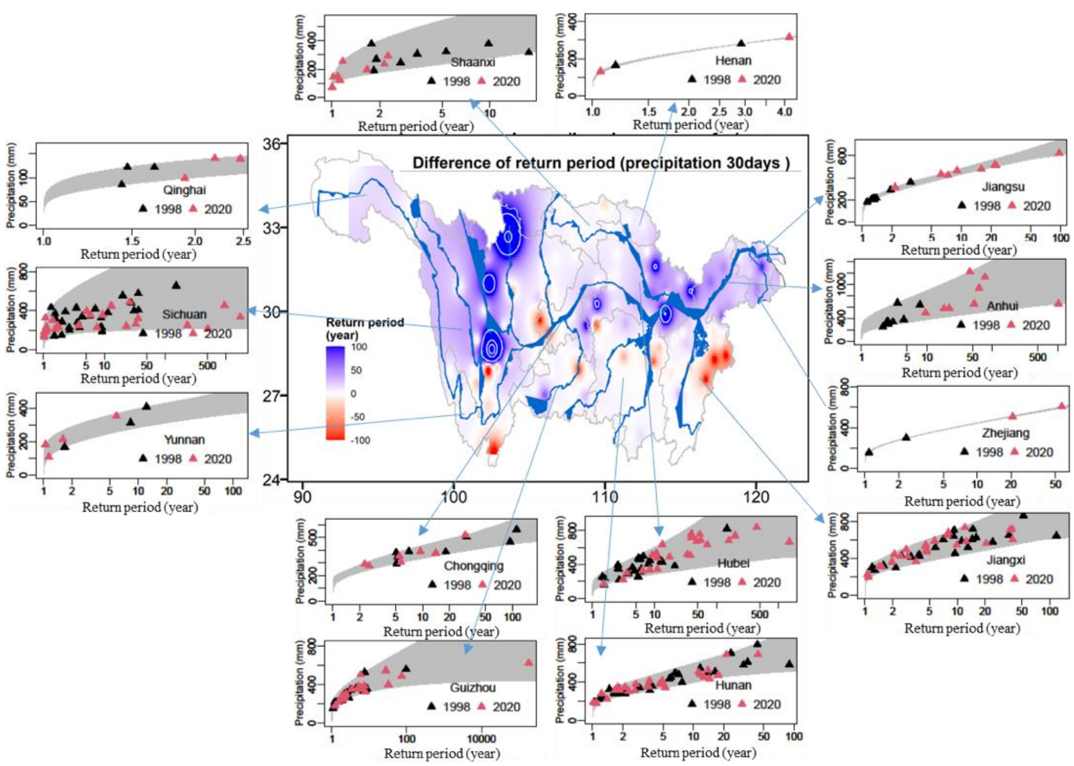

Figure 6. The spatial distributions of the return period differences for long-term (i.e., 30 days) cumulative precipitation levels between 2020 and 1998. The blue and red colors respectively represent higher and lower return periods in 2020 (compared with those of 1998). In the sub-graphs divided by province, the gray band indicates the uncertainty of return period in each province.

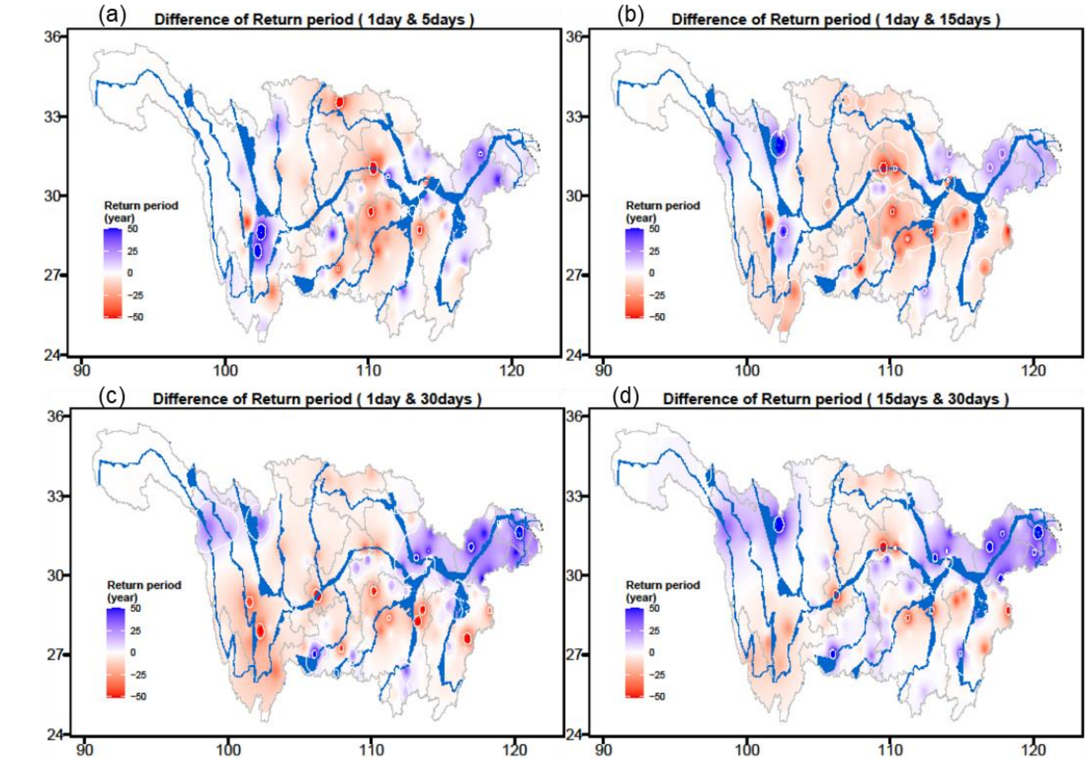

Figure 7. The spatial distribution of combined return-period differences for short- and long-term cumulative precipitation between 2020 and 1998. Blue and red colors respectively represent higher and lower joint return periods in 2020 (compared with those of 1998).

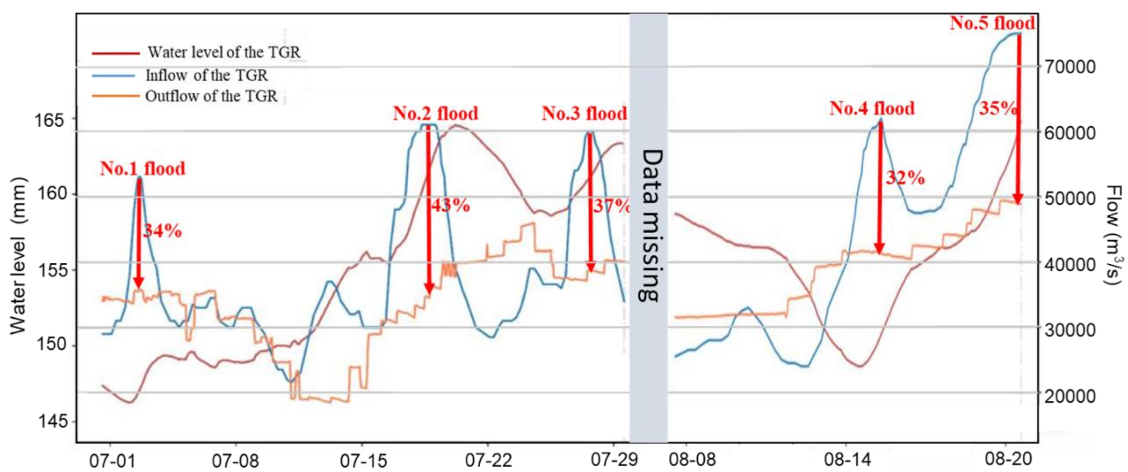

Figure 8. Dynamic variations of flow and water level in the Three Gorges Reservoir (TGR). (Data source: http://www.cjh.com.cn/article_2313_239291.html).

4. Discussions

4.1. The Role of Three Gorges Reservoir

Along the middle and lower reaches of Yangtze are some of China's most densely populated areas. For centuries, people have built levees to protect their communities and farmlands, such as the Three Gorges Reservoir (TGR) as designed to help tame the Yangtze River. Figure 8 presents the flow and water level of TGR which shows the “crucial role” in intercepting upstream floods (up to 43% mitigation) (Yangtze River Hydrology Network, 2020). As shown by multiple gauging stations, the role of TGR has been questioned by some reports (Gan 2020; MercoPress, 2020). When evaluating its flood interception effect, it is important to consider the location of the flood occurrence. The heavy precipitation in 2020 mainly occurs in the middle and lower reaches of YRB (Figures 2 and 3), such that TGR is not significantly helpful.

4.2. Extreme Flood Hazards Have Collided with COVID-19 Pandemic

COVID-19 coincided with the start of Chinese New Year when massive human migration took place. According to statistics, the total number of migrant workers reached 29.77 million. In the central region (including 6 provinces of Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan), 96.19 million migrant workers were exported, accounting for 33.1% of the country's total (National Bureau of Statistics, 2020). Affected by the global spread of COVID-19, the industrial chain has not continued smoothly, with the demand for labor decreasing in cities. Therefore, more than 8 million migrant workers are stranded in their hometowns (People's Daily, 2020). Thus, the number of people at risk in the threatened area are more than the expected. To avert negative impacts of flood, preparedness measures such as evacuation is increasingly necessary. As of July 28, the flood disaster affected 54.811 million people, and 3.76 million ones were relocated and resettled (Ministry of Emergency Management of the People's Republic of China, 2020; Wang et al., 2022). At the same time, the evacuation of residents affects their capacities to maintain social distancing, lockdown, or other necessary measures to curtail the spread of virus. The conditions of relocation sites for evacuees would also affect their abilities to maintain quarantine behaviors (The Heritage Foundation). It remains to be seen how the 2020 flood and COVID-19 will affect various socio-economic activities in China.

5. Conclusion

In this study, we analyze the unusual flood extreme of Yangtze River Basin (YRB) in 2020 and their disastrous impacts. The Basin's extreme cumulative precipitation events in 2020 are exceptional with over 1000-year return period events (for 30-day cumulative precipitation) being observed in Anhui, Guizhou, and Sichuan Provinces. The mean precipitation is 308 mm in July 2020, which is 54 mm higher than that of 1998. Compared with 1998, the short-term (e.g., 1 day) precipitation in YRB did not show significant increases, while the long-term (e.g., 30 days) cumulative precipitation increases significantly. The highest observed 30-day cumulative precipitation is 1221 mm (in Anhui Province) in 2020, while the highest one in 1998 was 1028 mm (in Jiangxi Province). We thus find that this persistent heavy precipitation is the main cause of flooding in 2020. At the same time, TGR may mitigate up 43% of upstream flood, although the main contributors to this year's YRB flood are in the middle and lower reaches. Affected by COVID-19, the number of people at risk in the threatened area are increased, and their capacities to mitigate the dual impacts of COVID-19 pandemic and flooding are hindered since (a) the flooding-caused mitigations may limit people's ability to prevent from virus spreading, and (b) the pandemic is retaining a large amount of migrant workers being within YRB and subject to flooding impacts.

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