Response to Reviewer Comments

Reviewer #4:

Dear Reviewer:

Thank you for your thoughtful and detailed review of our manuscript. We greatly appreciate the time and effort you dedicated to providing feedback. We have carefully considered all your comments and suggestions and revised our manuscript accordingly, and changes to our manuscript are highlighted within the document by using red colored text. Point-to-point response to your comments is listed below:

1. The manuscript adopts a CC3D algorithm for FCP event identification, but it fails to clearly elaborate on the core innovations of this algorithm in the context of the study, for example, the rationale for optimizing the 95th percentile threshold for extreme precipitation or the criteria for judging event independence. Notably, the study solely uses the 95th percentile threshold without comparing it with the fixed threshold (e.g., 16 mm/h, as defined by the China Meteorological Administration) for validation. This omission makes it impossible to verify whether the selected threshold is universally applicable to FCP event identification across different regions (e.g., the arid northwest and humid southern China), potentially leading to under-detection or misdetection of events in specific areas.

Response: We sincerely appreciate this valuable and constructive comment. In the revised manuscript, we have added a detailed comparison of different precipitation thresholds. As shown in Fig. 1 and Fig. 2, we used two schemes to extract the three-dimensional (3D) properties of FCP events: (1) fixed intensity thresholds ranging from 1 to 16 mm h^{-1} (used in Fig. 1); (2) percentile-derived thresholds, defined as the 10th–90th percentiles of grid-scale 95th-percentile extreme precipitation thresholds across rainfall-affected areas (used in Fig. 2). We found that FCP events identified by the fixed 16 mm/h threshold fail to fully cover disaster-affected regions (Fig. 1). In contrast, FCP events extracted using the 10th–90th percentile thresholds derived from the 95th-percentile extreme precipitation can well capture the disaster-affected areas (Fig. 2). This confirms that the percentile-based threshold exhibits higher effectiveness and regional applicability for detecting the three-dimensional characteristics of FCP events across mainland China. We have established the threshold criteria for extracting the 3D properties of FCP events as suggested in the revised manuscript in Lines 195-196.

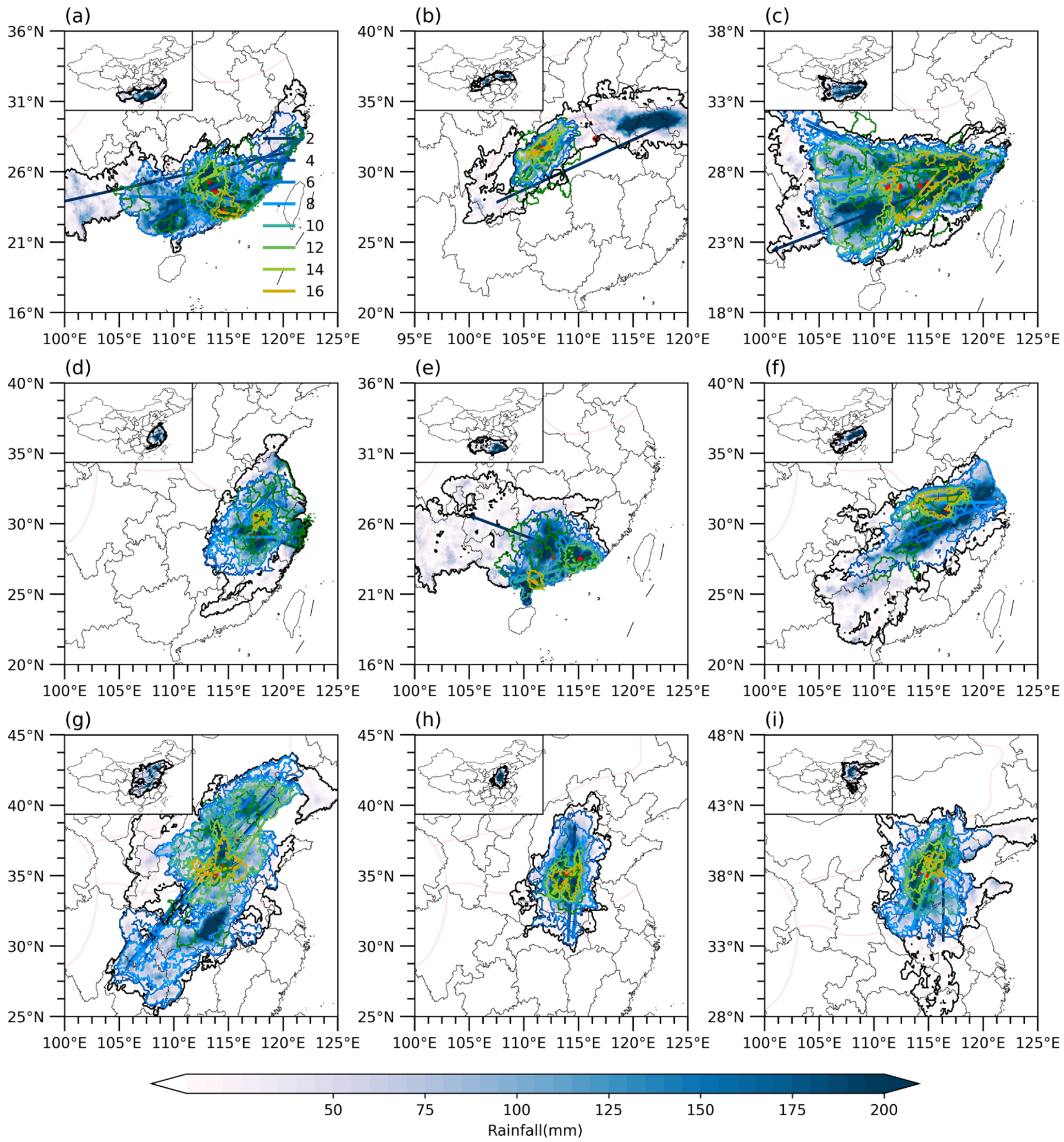

Fig. 1 The evaluation features of ten FCP events. The shading indicates the FCP accumulated area. The color polygons represent the precipitation extraction thresholds, ranging from 2 to 16 mm. The color arrows represent the movement of FCP event; the moving direction is from the tail to the head of the arrow; the length of arrow indicates moving distance.

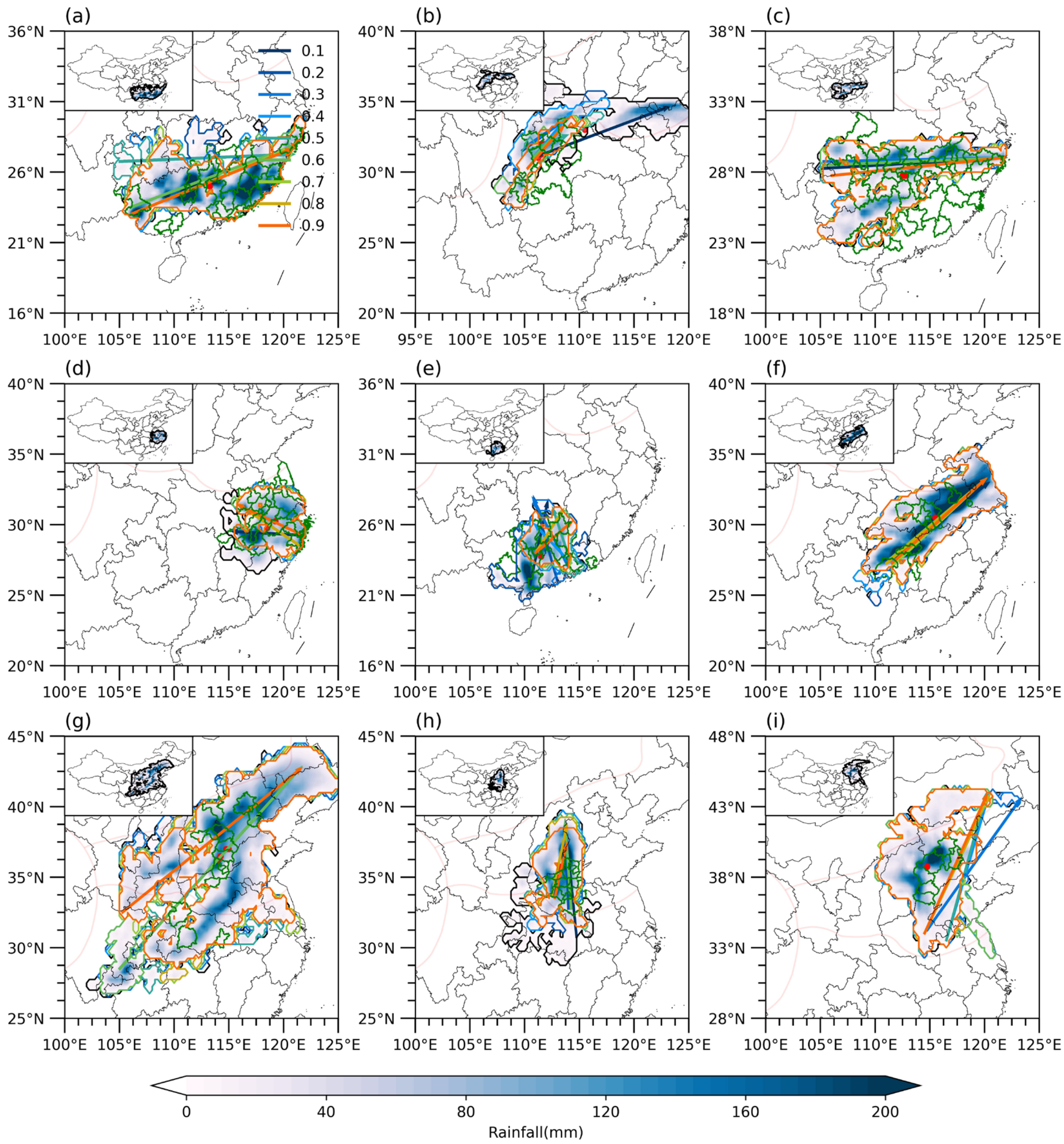

Fig. 2 The evaluation features of ten FCP events. The shading indicates the FCP accumulated area. The color polygons represent the precipitation extraction thresholds, which are derived from the 10th and 90th percentiles of the 95th percentile extreme precipitation thresholds over the precipitation affected areas. The color arrows represent the movement of FCP event; the moving direction is from the tail to the head of the arrow; the length of arrow indicates moving distance.

2. Population and GDP data use only two time points (2005 and 2020) to represent annual data for 2000–2010 and 2010–2020, respectively. This simplification ignores spatiotemporal heterogeneity in population migration and economic growth (e.g., rapid urbanization in the Yangtze River Delta), which could significantly distort the assessment of human activities' impact on flood disasters.

Response: We sincerely appreciate this constructive comment. We fully agree that using only two time points (2005 and 2020) to represent population and GDP data for 2000–2010 and 2010–2020 may oversimplify spatiotemporal variations and introduce uncertainties in assessing human impacts on floods. To address this issue, we have updated the population and GDP datasets for 2000–2020 at 5-year intervals from the website http://www.resdc.cn. The detailed data information is presented in Table 1 of the revised manuscript.

3. The manuscript acknowledges that hydraulic engineering (e.g., dams, reservoirs) is an important flood mitigation factor but excludes it from the driving factor analysis due to data limitations. However, large-scale hydraulic projects in China (e.g., the Three Gorges Dam) have significantly altered flood regimes, especially in SC and NC. Omitting these factors may limit the comprehensiveness of the driving factor analysis, and the manuscript should discuss how this omission impacts the interpretation of results.

Response: We sincerely appreciate this insightful comment. We fully recognize that large-scale hydraulic engineering (e.g., dams and reservoirs, particularly the Three Gorges Dam) exerts considerable influences on regional flood regimes in South China (SC) and North China (NC). Due to data availability constraints, we were unable to include hydraulic engineering variables in our quantitative driving-factor analysis in the current study. To improve the comprehensiveness of our results, we have supplemented a detailed discussion on the limitations caused by the exclusion of hydraulic engineering in the revised manuscript. We have added the following in Discussion (Lines 554-559) of the revised manuscript:

"This discrepancy might be caused by larger-scale hydraulic projects, such as dams and reservoirs. By the end of 2018, there are 98,822 reservoirs exist in China, with a total storage capacity of $8.95 \times 10^{12}\ m^3$ (Data are derived from China Water Statistical Yearbook 2018), which may significantly modulate the flood risks. Tang et al. (2023) studied the impact of dams on the flood in the Yangtze River, and found that dams and reservoirs mitigated the extreme flood by contributing to 94 % of the water level changes."

4. The manuscript reports that FCP 3D features (e.g., accumulated magnitude, lifespan) have increased, while most flood disaster metrics (except direct economic loss) have decreased. The explanation attributes this discrepancy to hydraulic engineering, but no quantitative evidence is provided to support this claim. For example, could the reduction in disaster impacts be quantified by the number or storage capacity of reservoirs built during the study period? Additionally, the increase in direct economic loss is linked to economic development, but a regression analysis or correlation between GDP growth and economic losses would strengthen this argument.

Response: Thank you for your comment. We fully agree that quantitative evidence is critical to validate the roles of hydraulic engineering and economic development. However, due to the lack of high-resolution and long-term spatial datasets on reservoir storage capacity at the national scale, we are unable to conduct reservoir-based quantitative attribution analysis in the current study. Accordingly, we have supplemented relevant published evidence and discussed the qualitative regulatory effects of hydraulic engineering on flood disasters in Lines 554-559 of the revised manuscript. For the relationship between GDP growth and direct economic losses, we have conducted corresponding correlation analysis. The results show that no significant correlation exists between them, with an R^2 value of only 0.228 (Fig. 3). Therefore, performing further regression or correlation analysis between GDP growth and economic losses would be of limited significance.

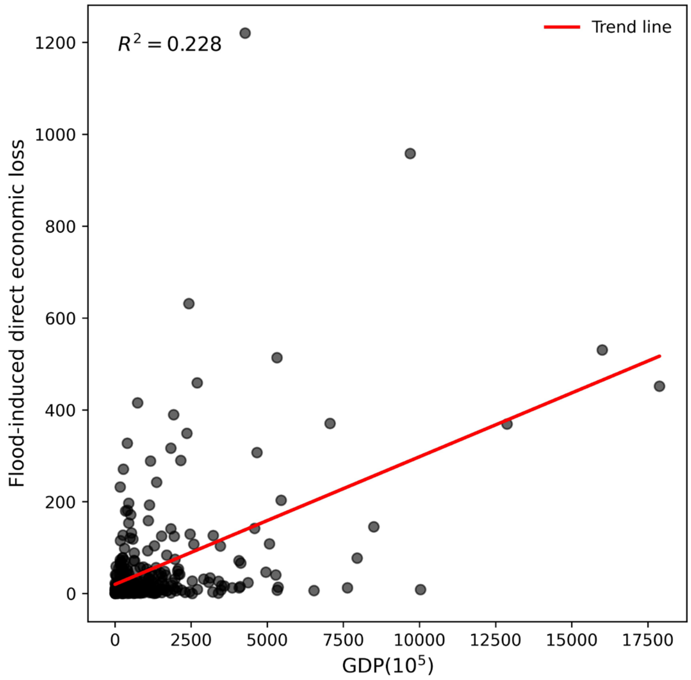

Fig. 3 Correlation analysis between flood-induced direct economic loss and GDP.

5. The finding of high death rates in the southeastern fringe of TP and SWC is attributed to the lack of flood mitigation infrastructure and flash floods triggered by landslides/debris flows. However, the manuscript does not provide data on infrastructure coverage (e.g., levee density, early warning systems) or the frequency of secondary disasters (landslides) in these regions. Incorporating such data or citing relevant studies would enhance the explanation of spatial loss patterns.

Response: Thank you for your comment. Given the difficulty in obtaining long-term, spatially explicit data on levee density and early-warning system coverage at the national scale, we are unable to carry out quantitative spatial analysis in this study. Accordingly, we have supplemented relevant published studies in the revised manuscript. These references confirm that the mountainous regions feature insufficient flood-mitigation infrastructure, inadequate early-warning capacity, and frequent flash floods triggered by landslides and debris flows, which collectively lead to higher flood-related mortality. Following your suggestion, we have added the above discussion in Lines 561–565 of the revised manuscript.

"The robustness of the findings is supported by existing studies, suggesting that numerous engineering measures around the world have improved flood control standards and mitigated the rising risks of flash floods. Lim et al. (2018) analysed the global benefits of existing flood-control projects and identified an 8 % reduction in the exposed population and 7 % GDP property exposure losses per year in flood-inundated areas from 1986 to 2005. Zhao et al. (2022) indicated that reservoirs can decrease housing losses caused by flash floods by 9.7-45.7 %."

6. What's 3D characteristic in Abstract?

Response: Thank you for your comment. We have added a detailed description of 3D characteristics at its first appearance in line 15, namely "**accumulated magnitude, accumulated affected area, centroid, lifespan, moving direction, and moving distance**".

7. Figure 3 (FCP identification algorithm flowchart) is poorly labeled: terms like '26 connectivity tracking' are not explained.

Response: Thank you for your comment. The detailed description of the FCP identification algorithm is provided in Section 3.2, which elaborates on the workflow shown in Fig. 3. We have supplemented a clear explanation of "26-connectivity tracking" in Section 3.2. We have added the following sentence in Lines 204–206 of the revised manuscript.

"The CC3D algorithm can move to a 3D 26-connected neighborhood, and searches for all 26-connected components in a 3D array along the dimensions of latitude, longitude, and time."

8. Table 1 (summarizing variables and data sources) is mentioned in the text (Section 2.3) but not included in the manuscript.

Response: Thanks for pointing this out. We have supplemented a table listing the data sources and cited it in Line 155 of the revised manuscript.

9. The term 'flood-causing precipitation (FCP)' is used throughout the manuscript but is not formally defined. It should be explicitly defined at the start of the Methods section to avoid confusion with 'extreme precipitation' or 'heavy rainfall'.

Response: Thank you for your comment. In our study, flood-causing precipitation (FCP) is defined as extreme precipitation events that trigger flood disasters at the regional scale. To avoid confusion with general extreme precipitation or heavy rainfall, we have provided an explicit formal definition of flood-causing precipitation (FCP) at the beginning of the Methods section (Lines 181-182) of the revised manuscript. We have added the following sentence in Lines 179-180 of the revised manuscript.

"It is an extreme precipitation event that trigger flood disasters at the regional scale"

10. The calculation method for 'accumulated affected area' (a 3D FCP indicator) is vague, whether it refers to horizontal projection area or curved surface area (critical for mountainous regions) is not specified.

Response: Thanks for pointing this out. The accumulated affected area in this study refers to the horizontal projected area of FCP events. We have clarified the definition of the accumulated affected area in Line 225 of the revised manuscript.

11. Page 7, Line 175: 'the 26-connectivity searching allows that a contiguous precipitation event occurring at a grid on the current hour can move to the adjacent grids in the following hour' is grammatically incorrect. It should be revised to 'the 26-connectivity search enables a contiguous precipitation event at a grid in the current hour to move to adjacent grids in the following hour.'

Response: Thanks for pointing this out. We amended as mentioned above.

12. Page 12, Line 295: 'the annually mean values and trend of TC FCP events' uses an incorrect adverb; it should be 'the annual mean values and trend of TC FCP events.'

Response: Thanks for pointing this out. We amended as mentioned above.

13. Page 15, Line 355: 'results in economic losses of USD 57.46 billion' lacks a clear time reference

(which flood event?)

Response: Thank you for your comment. This economic loss corresponds to the flood event that occurred in July 2016, and the relevant information has been supplemented in Lines 426–427 of the revised manuscript.

14. Figure 1's caption mentions a study period of 2000–2023, but the subplot label (a) 2024 is confusing.

Response: Thanks for pointing this out. We amended as mentioned above.

15. The abstract mentions "632 flood-causing precipitation (FCP) events" but does not specify how these events were derived from the 1,041 flood disaster records. A brief note on the event merging/classification process would improve clarity.

Response: Thank you for your comment. In Section 3.2 *Identification of flood-causing precipitation events*, we provide detailed description of the identification procedure for flood-causing precipitation events. We also explained how the 1,041 flood disaster records were processed by removing repeated events and ultimately classified into 632 FCP events.

16. The manuscript states that code is available upon request from the corresponding author, but making the code publicly available (e.g., on GitHub) would enhance reproducibility, which is increasingly important in environmental science research.

Response: Thank you very much for your valuable suggestion. The source code for identification of flood-causing precipitation events is available upon request from the corresponding author, as described in Line 636 of the revised manuscript. We will consider publicly sharing the code on GitHub in future research to improve the reproducibility of our work.