Response to Anonymous Referee #2's Comments

The authors presented a study that examines the spatiotemporal characteristics of Tropical Cyclones (Typhoons) in their study area and how they compare to existing IDF and spatial rainfall distribution methods used for design purposes. The study tackles an important issue that has a potential positive impact on the ability to identify areas at risk, for example, by improving the rainfall inputs used in applications like hydrodynamic modeling. The manuscript is well-written, and the portion of the results that is presented is well-presented.

That said, I highly recommend including additional details about the results and analysis at all the monitoring stations used and intermediary steps etc. in the supplementary materials since the amount of results presented within the manuscript itself is limited. Additionally, while there was enough explanation of the methods used to create the IDF analysis, much less detailes were presented about the spatial analysis side of the study. Below are some detailed comments:

Sincere thanks are extended to the Reviewer 2 for the positive and constructive assessment of this work. It is encouraging that the reviewer recognizes the importance of this study. The reviewer's two major concerns are greatly appreciated. In response to these two major concerns, the manuscript has been carefully revised accordingly. Supplementary materials have been added to provide comprehensive results from all monitoring stations and the intermediary analytical steps. Specifically, S1_Example for Fig2, S2_Obtaining spatial weights, S3_Different attempts for different distributions, S4_IDF table for different station during two periods, and S5_Fig4 for other stations. Details on the spatial analysis have been mentioned in supplementary material, as well as in the responses to the Comments #12, #13, #24 and #25.

Below are point-by-point responses to all the reviewer's comments.

Comment #1 Abstract: The abstract is well-written but quite long and can benefit from shortening.

Thank you for the suggestion. In response to this comment, the abstract has been shortened from 328 to 233 words to make it more concise. The revised version is as follows: "Conventional urban-scale precipitation characterization often overlooks the uniqueness of typhoon rainfall in terms of intensity–duration–frequency (IDF) relationships and rainfall patterns. Consequently, urban flood control and drainage systems are prone to failure when subjected to extreme typhoon rainfall events. To address this problem, this study used meteorological station observations and assimilated gridded data from Ningbo, China, to derive county-level IDF curves for annual maximum rainfall at specific durations and to extract typical typhoon rainfall spatiotemporal patterns via K-means clustering. The main findings are as follows: Typhoon impacts in Ningbo are dominated by long-duration extreme rainfall, most notably 24-h rainfall. Current published IDF curves underestimate the extremes for such prolonged typhoon-related events. Furthermore, a comparison of the results for the two periods (1980–2014 and 1980–2024) reveals a spatially inhomogeneous enhancement of typhoon impacts, with a notable increase in the northern region, which is associated with an increased frequency of extreme events. The extracted temporal rainfall patterns for typhoon events are dominated by the central-peaked pattern (with rainfall concentrated in the middle phase) and the late-peaked pattern, differing substantially from the Chicago hyetograph. The latter exhibits limitations in characterizing the structure of long-duration typhoon-related rainfall because it tends to overestimate peak rainfall intensity. Spatially, rainfall patterns were categorized into dispersed-dominated and concentrated types. Topography, intrinsic typhoon characteristics, and interactions with other weather systems all play important roles in shaping spatiotemporal rainfall patterns.".

Comment #2 L32: Helene was not a typhoon; it was an Atlantic hurricane. If the authors intend to refer collectively to Helene and Kalmaegi, a more appropriate umbrella term would be 'tropical cyclones.' But since the study is focused on Typhoons, I'd recommend eliminating Helene or separating it as a Hurricane.

Thank you for the suggestion. The expression "Typhoon Helene (2024)" has been modified into "Hurricane Helene (2024)".

Comment #3 L54: NOAA acronym mentioned for the first time and not explained, same with MLIT, NILIM and BURGER in Lines 57 through 58. Please check for others like that as well.

Thank you for pointing out this shortcoming. The sentences "In the United States, NOAA's Office of Hydrology developed a national... to the catchment level (Sivapalan and Blöschl, 1998; MLIT, 2015; MLIT and NILIM, 2023). In recent years, global high-resolution IDF datasets such as BURGER (Hoch et al., 2025) have been successively released." have been modified into "In the United States, the National Oceanic and Atmospheric Administration's (NOAA) Office of Hydrology developed a national... to the catchment level (Sivapalan and Blöschl, 1998; Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 2015; MLIT and National Institute for Land and Infrastructure Management (NILIM), 2023). In recent years, global high-resolution IDF datasets such as the Bottom Up Regionalized Global Extreme Rainfall (BURGER) dataset (Hoch et al., 2025) have been successively released.".

Comment #4 L94: I recommend checking the literature in this field, for example (Amorim, R., Villarini, G., Kim, H., Jane, R. A., & Wahl, T. (2025). A Practitioner's Approach to Process-Driven Modeling of Compound Rainfall and Storm Surge Extremes for Coastal Texas. Journal of Hydrologic Engineering, 30(5), 04025025.) and the literature cited in it by Thomas Wahl and his team. This approach allows the use of spatial rainfall observations of historical Tropical Cyclones.

Thank you for the suggestion. Following the suggestion, two modifications have been conducted:

1. The sentences "Spatial rainfall patterns mostly lack a universally applicable theoretical framework or standardized analytical methods. The scarcity and/or inaccessibility of high-resolution, long-term rainfall data have largely confined research on spatial rainfall patterns to hypothetical scenarios, resulting in incomplete understanding of their physical characteristics." have been changed into "Given that long-term observational data are difficult to obtain, some studies on spatial rainfall patterns rely on idealized scenarios constructed with mathematical functions for conducting stochastic experiments, lacking a physical basis (Lin et al., 2022). Meanwhile, some studies have utilized spatial rainfall observations from historical tropical cyclones to design spatially distributed events, offering a potential pathway (Amorim et al., 2025; Kim et al., 2023; Nasr et al., 2023)." have

been added into the "Introduction".

2. Three references have been added:

Amorim, R., Villarini, G., Kim, H., Jane, R. A., and Wahl, T.: A Practitioner's Approach to Process-Driven Modeling of Compound Rainfall and Storm Surge Extremes for Coastal Texas, Journal of Hydrologic Engineering, 30(5), 04025025, https://doi.org/10.1061/(ASCE)HE.1943-5584.0002525, 2025.

Kim, H., Villarini, G., Jane, R., Wahl, T., Misra, S., and Michalek, A.: On the generation of high-resolution probabilistic design events capturing the joint occurrence of rainfall and storm surge in coastal basins, Int. J. Climatol., 43(2), 761–771, https://doi.org/10.1002/joc.7825, 2023.

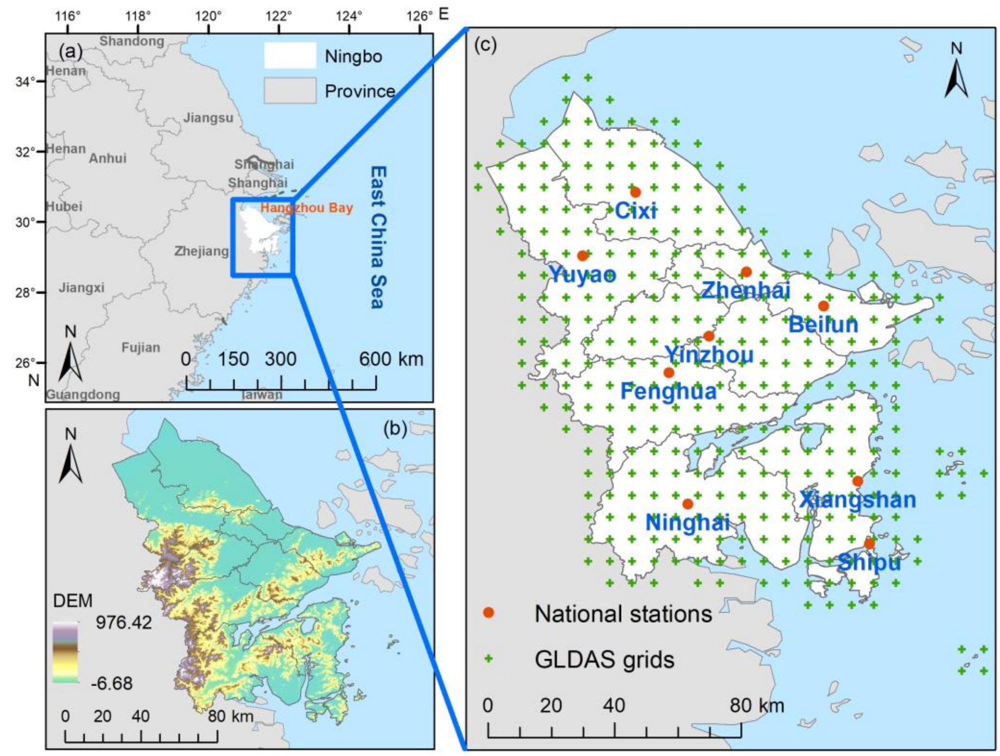
Nasr, A. A., Wahl, T., Rashid, M. M., Jane, R. A., Camus, P., and Haigh, I. D.: Temporal changes in dependence between compound coastal and inland flooding drivers around the contiguous United States coastline, Weather Clim. Extremes, 41, 100594, https://doi.org/10.1016/j.wace.2023.100594, 2023.

Comment #5 L121 This line mentions TC which I am assuming refers to Tropical Cyclones. It is not explained.

Thank you for the suggestion. The expression "TC" has been modified into "Tropical Cyclone". In addition, at the beginning of the Introduction, "Typhoons (i.e., tropical cyclones)" has been revised to "Typhoons (i.e., tropical cyclones, TC)" to introduce the abbreviation for later use.

Comment #6 L124 The figure is small and the station names are only visible at 200%+ Zoom level, also the text color makes it difficult to read.

Thank you for the suggestion. The size of Figure 1 has been modified (enlarged and color-modified) as recommended.



Comment #7 L130 Please explain how 0.0625 degrees translate to km or meters in your study area.

Thank you for the suggestion. The sentence "…have a spatial resolution of 0.0625°." has been modified into "…have a spatial resolution of 0.0625° in both longitude and latitude. The spatial resolution of 0.0625° can be converted to linear distance using the great-circle distance formula, where the east–west distance depends on latitude."

Comment #8 L135 Please check if 1.12 meters MAE is globally or for built areas.

Thank you for pointing out this issue. The sentence "It is currently one of the most accurate free digital elevation datasets worldwide, with a mean absolute vertical error of 1.12 and 2.88 m globally and in forested areas, respectively (Hawker et al., 2022)." has been modified into "It is currently one of the most accurate free digital elevation datasets worldwide, with a mean absolute vertical error of 3.41 m over global land points, 1.12 m over built-up areas, and 2.88 m over forested areas (Hawker et al., 2022)."

Comment #9 L 146 Please explain what is this curve fitting for, IDF curves? "For sample selection in curve fitting, each station was processed independently."

Thank you for the comment. The sentence "For sample selection in curve fitting, each station was processed independently." has been modified into "For sample selection in IDF curve fitting specifically for typhoon rainfall, each station was processed independently.".

Comment #10 L150- 162 I think an example or a diagram (in addition to figure 2) of this in the supplementary materials would greatly help visualize and understand the process.

Thank you for the suggestion. The supplementary material "S1_Example for Fig2" has been provided, consisting three sections corresponding to the three key steps shown in Fig.2.

S1.1_Individual Rainfall Event & Sliding Window Results_Orginial scheme

S1.2_Individual Rainfall Event & Sliding Window Results_Typhoon-Influence Process

S1.3_Annual maximum series

Add citations to the three sentences:

The sentence "…for window lengths of 1, 3, 6, 9, 12, 15, 18, 24, 36, and 48 h." in Line 148-149 has been modified into "…for window lengths of 1, 3, 6, 9, 12, 15, 18, 24, 36, and 48 h (S1.1 and S1.2).".

The sentence "Unlike the rainfall-event definition, which required specific rainfall intensity thresholds to initiate or terminate an event, this broader definition captured the entire duration of the direct influence of the typhoon." in Lines 159-160 has been modified into "Unlike the rainfall-event definition, which required specific rainfall intensity thresholds to initiate or terminate an event, this broader definition captured the entire duration of the direct influence of the typhoon (S1.2)."

The sentence "Then, the cumulative rainfall over this extended series was used to replace the original annual maximum rainfall for the longer duration." in Line 168-169 has been modified into "Then, the cumulative rainfall over this extended series was used to replace the original annual maximum rainfall for the longer duration (S1.3).".

Comment #11 L215: A reference to K-means and explanation of the method is

needed.

Thank you for the suggestion. In response, the following two revisions have been made to the manuscript.

1. A reference and an explanation of the K-means method have been added to "2.3.2 Extraction of typical spatiotemporal characteristics of typhoon rainfall": "K-means remains a commonly used, intuitive, and effective method for clustering rainfall patterns (Jin et al., 2024; Zhang et al., 2026). This method partitions the dataset into *K* distinct clusters by minimizing the within-cluster sum of squared Euclidean distances between each sample and its corresponding cluster centroid. The algorithm iterates between two steps: (1) assigning each sample to the nearest centroid, and (2) updating each centroid as the mean of the samples assigned to that cluster, until convergence. Prior to clustering, the data were standardized. The optimal number of clusters was determined through repeated experimentation, combined with practical considerations, and by examining the behavior of clustering quality metrics.".

2. Two references are cited.

Jin, C., Yuan, W.-X., Zhou, H., et al.: Application of Partitioning Clustering in Short-duration Storm Pattern Design, China Water & Wastewater, 40(3), 113–119, https://doi.org/10.19853/j.zgjsps.1000-4602.2024.03.017, 2024. (in Chinese)

Zhang, H. and Fan, K.: K-means clustering analysis of autumn rainfall patterns over West China and their underlying mechanisms, Atmospheric Research, 334, 108745, https://doi.org/10.1016/j.atmosres.2026.108745, 2026.

Comment #12 L226: Please explain "For spatial patterns, the classification indices were defined as follows. First, the location of the main rainfall area was considered."

Thank you for the suggestion. The responses to both Comment #12 and Comment #13 have been addressed together in the revised manuscript. Please refer to the response to the Comment #13 for the detailed explanation and the revised text.

Comment #13 L227-234: Can you please explain why you chose these constrains/conditions.

Thank you for the comment. In conjunction with the response to Comment #12. Considering that the current set of spatial classification indices was excessive and complex, and drawing on recommendations from previous researches (Chen et al., 2022; Lin et al., 2022; both cited in the original manuscript), two features ("the distance between the centroids of the top 30% and top 5% of grids ranked by process-total rainfall" and "the distance between the centroids of the bottom 30% and top 5% of grids ranked by process-total rainfall") were removed to simplify the classification framework and improve interpretability, followed by a reclassification to achieve a new clustering outcome. The sentences "For spatial patterns, the classification indices were defined as follows. First, the location of the main rainfall area was considered…Next, the spatial distribution of the rainfall was examined, with focus on the dispersion of regions of high rainfall and the spatial gradient of precipitation. Four indices were calculated… and the corresponding ratio for the bottom 30% of grids." have been supplemented and improved as follows:

"Previous studies have focused on the location of heavy rainfall centers and the spatial gradient of rainfall to characterize the spatial distribution patterns (Chen et al., 2022; Lin et al., 2022). Based on these considerations, the classification indices for the spatial patterns in this study were defined as follows. First, the location of the rainfall concentrated or high-impact area was considered. The average position of the grids whose process-total rainfall was within the top 30% of all grids within a given duration was computed, and its distance (haversine formula) from the regional centre was taken as the first index. The location of the target point relative to the regional centre was represented by two indices: its east–west and north–south orientations. Next, the spatial gradient characteristics of rainfall were examined, with a focus on the dispersion of the high-impact rainfall area and the overall spatial gradient of precipitation. Two indices were calculated. The first index measures the regional contribution of the top 30% of grids to the total process rainfall, reflecting rainfall concentration. The second index represents the contribution of the bottom 30% of grids, indicating the proportion of rainfall in lightly affected areas. The chosen percentiles were determined to be optimal through repeated experimentation.”.

Comment #14 L237-244: Can you please mention if the existing IDF curves produced in 2015 took tropical vs. non-tropical events into consideration and how that might affect the comparison with your work.

Thank you for the comment. The existing IDF curves are derived from complete mixed rainfall data and are primarily focused on short-duration events (sliding windows of 6 hours or less). Previous studies have shown that most extreme hourly rainfall events are often caused by non-typhoon systems. Consequently, the short-duration extreme rainfall intensities obtained from mixed rainfall data are significantly higher than those derived from typhoon-only rainfall data. For long durations (above 6 hours), the results from mixed rainfall data are often distorted. In response to the comment, the following two revisions have been conducted:

1. The sentences “In this study, two sets of IDF curve fitting were conducted. The first was performed for the period 1980–2014, … The second fitting utilized more comprehensive rainfall data from 1980–2024, with the specific objective of deriving IDF curves for typhoons that met current conditions and requirements.” have been rephrased:

“In this study, two sets of IDF curve fitting were conducted. The first was performed for the period 1980–2014, consistent with the data period coverage of the existing published IDF curves, which were published in 2015 and remain in current use. This period was selected as both the quantity and quality of rainfall data have increased substantially since 1980, and the data naturally ended in 2014 based on the local practical conditions and demands of that time. The existing published IDF curves were derived using the complete mixed rainfall data, without distinguishing between typhoon and non-typhoon rainfall, and were primarily focused on short-duration events, with sliding windows mainly of 6 hours or less during sampling. Research indicates that the majority of extreme hourly rainfall events are often caused by non-typhoon systems, including surface fronts, vortex/shear lines, and the weak-synoptic forcing type (Luo et al., 2016). Consequently, short-duration (e.g., hourly scale) extreme rainfall intensity/frequency information derived from complete mixed rainfall data will be higher than that derived from typhoon-only rainfall data. This can lead to fitted IDF curves with higher rainfall intensities for short durations. For long durations (above 6 hours), the results from mixed rainfall data may be distorted. The second fitting utilized typhoon rainfall data extended from 1980 to 2024 (i.e., updated to include recent years) to capture how the features of IDF curves have changed over time (compared to the 1980–2014 period).”.

2. One reference has been cited:

Luo, Y., Wu, M., Ren, F., Li, J., and Wong, W.-K.: Synoptic Situations of Extreme Hourly

Precipitation over China, J. Climate, 29, 8703–8719, https://doi.org/10.1175/JCLI-D-16-0057.1, 2016.

Comment #15 L 245-250: I think you should present the different attempts for different distributions etc. and how they performed either within the body of the manuscript or in the supplementary materials so the readers can compare the performance.

Thank you for the suggestion. The relevant results for different stations have been added to the supplementary material "S3_Different attempts for different distributions". Following the suggestion, the sentence "Curve fitting performed best when using the Exponential distribution combined with the minimum sum of squared deviations criterion (Fig. 3)." has been modified into "By comparing the results obtained under different distributions and fitting criteria (S3), the Exponential distribution combined with the minimum sum of squared deviations criterion (Fig. 3) was found to be generally applicable across all stations for the final fitting results.".

Comment #16 L250: It was previously mentioned that the RMSE threshold is 0.05 mm/min (L 199).

Thank you for the comment. According to the comment, the following two clarifications are provided.

1. The relevant results for different stations have been added to the supplementary material "S4_IDF table for different station during two periods".

2. To better clarify the differences between the two thresholds, the original description "Given the varied characteristics among different typhoons and the notable interannual differences in frequency, validation based on absolute error was found more suitable for assessing the results of this study. The RMSE of all curve fitting results was <0.06 mm/min, meeting standard accuracy requirements." has been revised to "It should be noted that the error threshold criterion mentioned in the methods section was originally established only for short-duration events and did not distinguish between typhoon and non-typhoon rainfall. In this study, this criterion is used as a reference rather than being strictly enforced. Given the varied characteristics among different typhoons and the notable interannual differences in typhoon frequency, the threshold has been reasonably relaxed. Furthermore, validation based on absolute error was found to be more suitable for assessing the results of this study. In practice, except for a very few cases where the absolute error was 0.06 mm/min, all other results satisfied the condition of being less than 0.05 mm/min (S4)."

Comment #17 L255: So far only one station is shown, I believe the other stations should be presented too in the supplementary materials.

1. In response to Comment #15 and Comment #16, the fitting results for different stations have been provided in supplementary materials S3–S4.

2. Additionally, the results for other stations related to Figure 4 have also been provided; see "S5_ Fig4 for other stations" for details.

3. A statement is added after the analysis of Figure 4: "The above conclusions are generally applicable across all stations (S5), although minor differences exist.".

Comment #18 L256-257: Please explain why you chose different definitions for how events start and end for tropical versus non-tropical and why you chose 24 hours of no rain as an indication for both non-typhoon and 'complete rainfall data' (which I assume includes typhoons). Would that impact short duration storms and exclude some of them?

Thank you for the suggestion. In accordance with the suggestion, the following explanation is provided:

1. Further clarification has been added to the original manuscript at this location. "In this study, typhoon events can be clearly defined in terms of onset and termination based on their definition. For non-typhoon rainfall data and complete rainfall data, however, because no further differentiation of other weather systems is made, individual rainfall events lack clear physical boundaries. Therefore, a unified time-interval threshold is required to delineate independent rainfall processes and ensure consistency in the delineation criteria. Based on the characteristics of typhoon rainfall processes, a 24-hour interval is typically adequate to separate two impact processes of different typhoons. In this study, 24 h was selected as the unified threshold: when delineating rainfall processes from the complete rainfall data, it can ensure, to the greatest extent possible, that impact events of different typhoons are correctly separated. While this threshold may merge some short-duration storms separated by less than 24 hours into a multi-peak, long-duration process, it does not exclude the storms themselves. Under the Annual Maximum (AM) sampling framework adopted in this study, processes are first delineated, and then a moving window is applied. The peak rainfall intensity within any merged process is still retained and has the opportunity to be selected as the annual maximum value."

2. The sentences "The 24-hour threshold adopted in this study is a simplified approach with certain limitations. Future work will conduct more refined event delineation analyses, such as sensitivity comparisons using alternative thresholds." have been added to the outlook section.

Comment #19 Fig 4 and Figure 5: Please show the confidence intervals of the fitted curves.

Thank you for the comment. It should be noted that the results obtained in this study are deterministic, and thus, the concept of confidence intervals is not applicable here. A supplementary explanation has been added to the description of the results from Figure 4 and Figure 5 in the original manuscript: "The optimal fitted curves are obtained through deterministic stepwise optimization. Starting from initial guesses, the method uses gradient information to determine the direction and step size for parameter updates within allowable ranges, systematically approaching the best fit. The process stops when the maximum iteration limit is reached or the convergence condition is met, yielding a uniquely determined optimal solution. The fitting accuracy is evaluated through three approaches…".

Comment #20 Fig 5: similar to what I mentioned in L237-244 I think the fitted curve is TC only and it is compared to 'complete record' IDF. I think this should be mentioned in the figure caption similar to Figure 4. Also, station name should be mentioned in the caption.

Thank you for the suggestion. Figure 5 has been revised accordingly. Corresponding information has also been added in the figure caption.

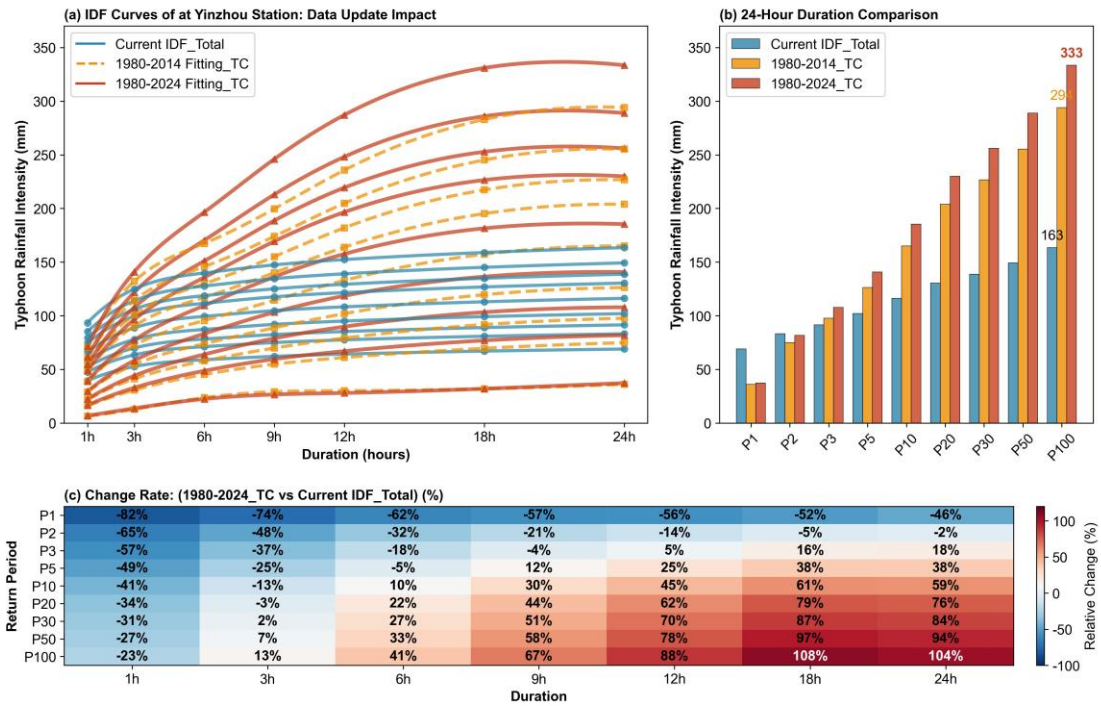


Figure 5: Comparison of fitted IDF curves from typhoon rainfall data (this study) and currently published IDF curves (derived from complete rainfall data without rainfall type distinction) for Yinzhou station. (a) Impact of data update on IDF curves: solid blue line represents the currently published IDF curves, dashed orange line represents the fitting curve for 1980–2014, and solid red line represents the fitting curve for 1980–2024. (b) Comparison of 24-h duration: blue bars represent the currently published IDF curves, orange bars represent the fitting curve for 1980–2014, and red bars represent the fitting curve for 1980–2024. (c) Change rate from the latest IDF curves to the currently published curves.

Comment #21 Figure 6: The text is very hard to read. Also, I think using lines is easier to interpret (or something else). It is currently difficult to extract patterns or information directly from the figure.

Thank you for the suggestion. The Figure 6 has been modified.

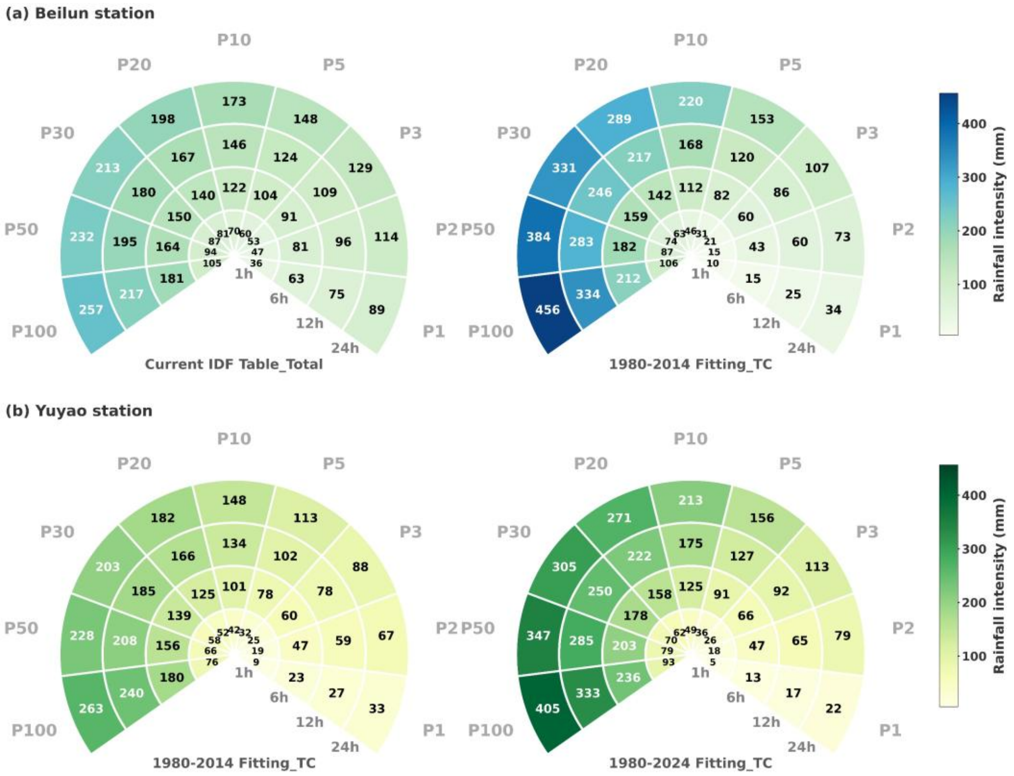


Figure 6: Rainfall intensities for various durations and return periods. (a) Beilun station: published sources (upper left) and fitting results (upper right) for 1980–2014 and (b) Yuyao station: fitting results for 1980–2014 (lower left) and 1980– 2024 (lower right). The currently published IDF table in panel (a) is based on complete rainfall data without rainfall type distinction, whereas the fitted IDF tables in panels (a) and (b) are derived from typhoon rainfall data from this study.

Comment #22 L347: Please explain what is the marked rainfall phase "while the mean proportions of rainfall during the marked rainfall phase were 60.69%, 56.09%, and 62.69%." maybe use something like 'The peak rainfall (rainfall accumulations) were 0.79 (60.69%), 0.24 (56.09%), 0.51 (62.69%) respectively. That's if I understood the sentence correctly and if proportion means accumulated rainfall.

Thank you for pointing out this ambiguity. The original sentence "The proportions of the rainfall processes in the three categories were 33.77%, 22.73%, and 43.51%; the corresponding mean peak rainfall coefficients were 0.79, 0.24, and 0.51, while the mean proportions of rainfall during the marked rainfall phase were 60.69%, 56.09%, and 62.69%." was not sufficiently clear, and it has been rephrased: "The proportions of the rainfall processes in the three categories were 33.77%, 22.73%, and 43.51%; the corresponding mean peak rainfall coefficients were 0.79, 0.24, and 0.51. Additionally, as described in the methods of this study, each 24-hour process was equally divided into three consecutive 8-hour sub-phases. The proportion of event-total rainfall occurring in the sub-phase with the largest rainfall accumulation, averaged by category, was 60.69%, 56.09%, and 62.69%, respectively.".

Comment #23 L376- 377 Please explain how you reached this conclusion by explaining what is observed in the figure "All three metrics consistently showed that the gridded data reliably captured the spatial rainfall distributions reflected by the station observations."

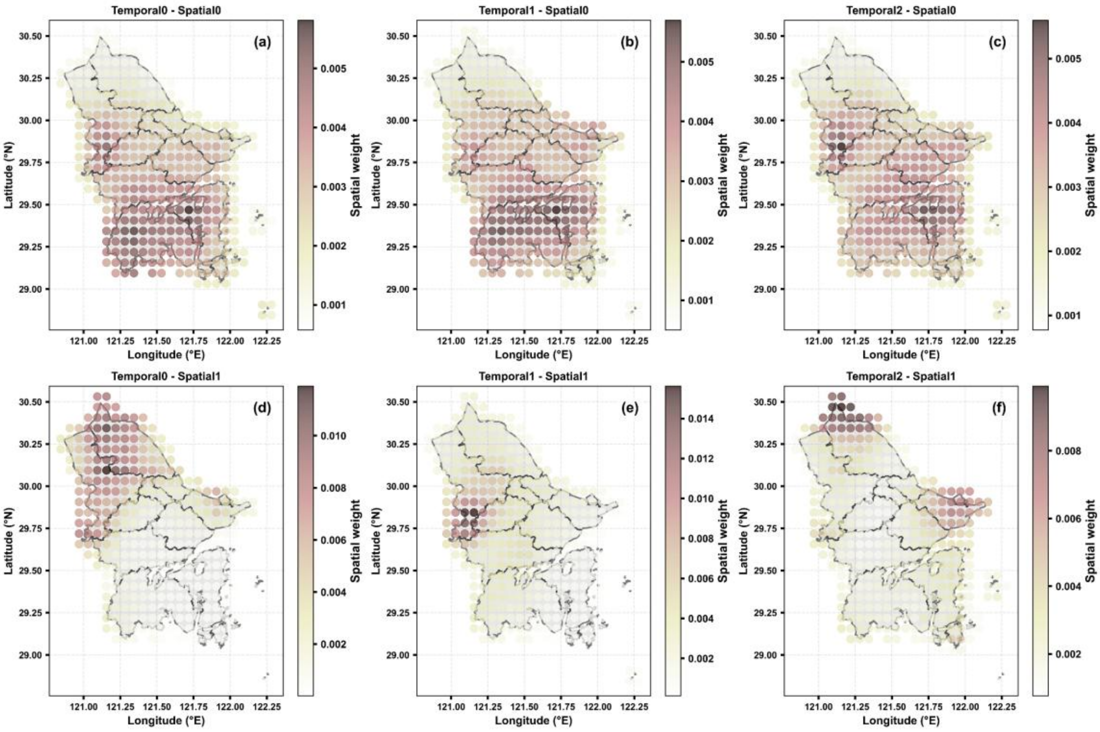
Thank you for the comment. The observations from the figure have been described to support the conclusion: "The median Spearman's rank correlation coefficient is 0.638 (Fig. 8a), reflecting acceptable agreement between the gridded data and station observations in terms of spatial precipitation ranking. The median adjacent percentile match rate reaches 0.803 (Fig. 8b), meaning that for the great majority of processes, the precipitation category differs by no more than one level between the two datasets. With a median value of 0.031 (Fig. 8c), the spatial pattern shift index reveals that the precipitation centroids are almost perfectly aligned between the two datasets. All three metrics consistently show that the gridded data reliably capture the spatial rainfall distributions reflected by the station observations.".

Comment #24 Figure 9: While the methods section explains the overall process of how this was produced. Additional explanation of how the analysis was executed (similar to the temporal portion) including equations and R-packages (if applicable) which were used so the readers can replicate the analysis if needed.

Thank you for the suggestion. In conjunction with the response to your Comment #13, the definition of indices along with the rationale has been clarified. Additionally, the computation of the spatial weighted values has also been provided in the supplementary material (S2_Obtaining spatial weights). The specific modifications are as follows:

1. The sentence "For the processes with the same spatial type…These weighted values were then normalized to obtain spatial allocation weights." in "2.3.2 Extraction of typical spatiotemporal characteristics of typhoon rainfall" has been modified into "For each grid, the weighted total of cumulative rainfall across processes with the same spatial type was computed, where the weight for each process was assigned according to its actual cumulative rainfall at that grid. These weighted values were then normalized to obtain spatial allocation weights (S2).".

2. Considering the changes in the classification indices toward extracting spatial rainfall patterns (referring to the response to Comment #13), Figure 9 has been revised as follows:



3. A description of the results like that of the temporal portion has been added. In combination with our response to your Comment #25, the descriptions related to Figure 9 have been partially adjusted and simplified as follows:

"Overall, the spatial rainfall patterns can be summarized into the following two types. The first type can be described as the dispersed type, which predominates among the observed cases (Figs. 9a, b and c). This type is characterized by widespread rainfall coverage, with relatively scattered areas of heavy precipitation. The sample proportions for the three specific spatial patterns were 26.62% (Fig. 9a), 12.99% (Fig. 9b), and 37.66% (Fig. 9c), respectively. The median proportions of rainfall contributed by the top 30% of grids ranked by rainfall amount were 43.81%, 43.52%, and 42.70% across the three rainfall patterns, while the corresponding values for the bottom 30% were 16.55%, 17.89%, and 18.76%, respectively. This type exhibits a relatively uniform overall distribution, with centres of heavy rainfall scattered in high-elevation mountainous areas and a relatively gentle rainfall gradient. The second type is characterized by concentrated rainfall, with localized centres of heavy rainfall that account for a substantial proportion of the total regional rainfall (Fig. 9d, e and f). It also displays a markedly pronounced northward offset. Among the three specific spatial patterns, the sample proportions were 7.14% (Fig. 9c), 9.74% (Fig. 9a), and 5.84% (Fig. 9e), with the latter accounting for the lowest share. Across the three rainfall patterns, the median proportions of rainfall contributed by the top 30% of grids (ranked by rainfall amount) were 67.67%, 58.69%, and 63.77%, respectively, while those for the bottom 30% were 4.18%, 8.16%, and 6.53%, respectively. The formation of this type may be more complex, potentially influenced by inherent characteristics (Yu et al., 2017; Li et al., 2019; Lai et al., 2024), or interactions between typhoons and other weather systems, such as westerly troughs (He et al., 2020). This can be attributed to exceptionally abundant or sustained moisture transport, or to convergence, resulting in stronger localized impacts.

Analysis of the spatial and temporal patterns of typhoon rainfall reveals that both intrinsic typhoon characteristics and underlying surface properties play important roles. The counterclockwise circulation of a typhoon shapes its asymmetric moisture transport, which is typically strongest on its northern sides (Li et al., 2019; Wu et al., 2024). The warm and moist vapor transport from the eastern sea, driven by typhoons, creates favorable moisture conditions that facilitate the formation of heavy rainfall areas along the coast (Fig. 9d and f). As this warm, moist airflow, driven by the Coriolis force and pressure gradients, moves towards land, it interacts dynamically with complex underlying terrain (Feng et al., 2024; Wu et al., 2024; Wang et al., 2026). In areas with trumpet-shaped topography, pronounced windward slopes, or curved coasts, the airflow is forced to converge and ascend, greatly enhancing local updrafts and precipitation efficiency（Cheng et al., 2025）, thereby shaping the final distribution of the centres of heavy rainfall (Figs. 9a, b and c). Rainfall in mountainous areas can sometimes intensify abruptly. Under typhoon conditions, the dynamic forcing of terrain on airflow can rapidly trigger or enhance convection within a short period. Additionally, the complex thermal properties of the underlying surface in mountainous regions tend to accumulate unstable energy locally, which can be released abruptly. These conditions might cause rainfall intensity to increase sharply over time (Figs. 7d and e) and exhibit localized intensification spatially (Figs. 9d and e). Unlike mountainous regions, over the northern plains and other gently sloping areas where terrain forcing is weak, the occurrence of widespread heavy rainfall induced by typhoons often requires effective dynamic and thermal coordination with other large-scale weather systems, such as westerly troughs and shear lines (Fig. 9d and f).”.

4. Eight references have been added to the revised manuscript:

(1) In conjunction with the response to the Comment #25. Concerning the mechanisms underlying rainfall pattern formation:

Yu, Z., Wang, Y., Xu, H., Davidson, N., Chen, Y., Chen, Y., and Yu, H.: On the Relationship between Intensity and Rainfall Distribution in Tropical Cyclones Making Landfall over China, J. Appl. Meteorol. Climatol., 56(10), 2883–2901, https://doi.org/10.1175/JAMC-D-16-0334.1, 2017.

Li, Y. and Zhao, D. J.: Climatology of Tropical Cyclone Extreme Rainfall over China from 1960 to 2019, Adv. Atmos. Sci., 39(2), 320–332, https://doi.org/10.1007/s00376-021-1080-4, 2022.

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Comment #25 L409-424 References are needed to explain and back up the processes that the authors suggest explaining the results. Moreover, showing the TC tracks with the clusters will help (maybe additional figures with the TC tracks mapped on top of the clusters in the supplementary materials can help).

Thank you for the suggestion. According to the suggestion, the revisions are as follows:

1.References related to the processes involved in explaining the results have been incorporated into the revised manuscript. Details are provided in the response to Comment #24.

2. Through a review of previous research and statistical analysis, the original statement is found to be simplistic and places excessive emphasis on the influence of typhoon tracks, although it may be one of the important factors. Accordingly, the relevant expressions in the manuscript have been revised, and a comprehensive statistical analysis of the inherent characteristic factors of typhoons has been conducted. In conjunction with the response to Reviewer 1's Comment #4, the specific modifications are as follows:

(1) Figure 10 and its analysis have been added: "

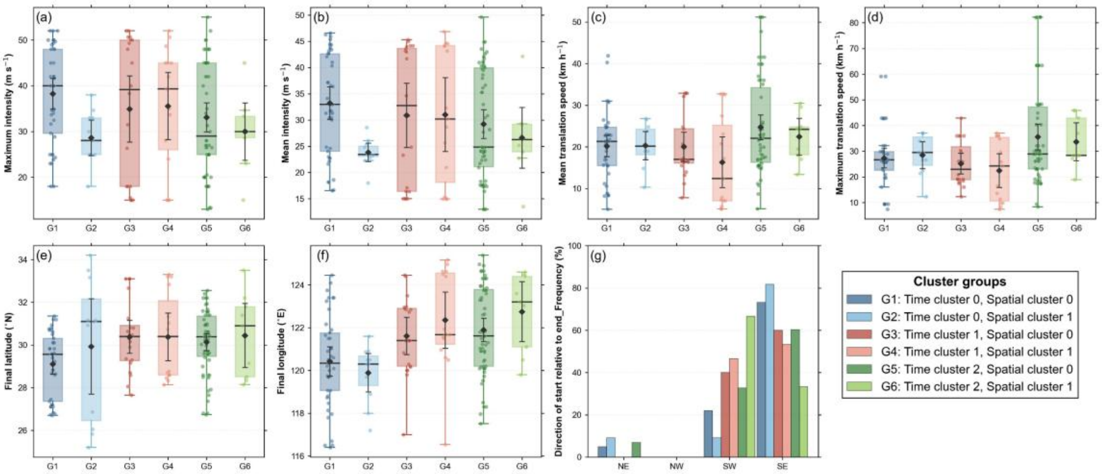

Figure 10 Typhoon characteristics corresponding to typical 24-hour rainfall processes under each spatiotemporal rainfall pattern (G1–G6): (a) maximum intensity; (b) mean intensity; (c) mean translation speed; (d) maximum translation speed; (e) latitude and (f) longitude of the track endpoint; and (g) direction of the track start position relative to the endpoint during the 24-hour rainfall process.

Further statistics were conducted on the characteristics of typhoon intensity, translation speed, and track during the 24-hour rainfall process of typical typhoons. Based on the median and mean values, stronger typhoons are associated with a larger and more dispersed spatial distribution of rainfall (Figs. 10a and b), while a slower average translation speed is associated with a longer duration within a certain region scale, resulting in stronger and more localized rainfall (Figs. 10c and d). For the central peak and spatially concentrated pattern, the regional concentration of rainfall may be related to other factors. In terms of track characteristics, cases with stronger local influence correspond to typhoon track endpoints that are more northward (Fig. 10e). As the track endpoint moves further northwest, the typhoon rainfall impact area tends to extend further toward the northwest inland (Figs. 10f and g). The overall tracks of typhoons are predominantly northeastward and northwestward, with northwestward tracks being more frequent (Fig. 10g). This implies that, for the processes examined in this study, typhoons affecting the Ningbo region are mainly of the northwestward track type. Combined with the rotational characteristics of typhoons, such tracks can bring a continuous supply of water vapor from the eastern sea.”.

(2) The corresponding description has been added to Section 4 (Summary and outlook) of the manuscript.

(i) The sentence “The statistical results show that stronger typhoons correspond to a larger rainfall-affected area and a more dispersed rainfall distribution. A slower average typhoon translation speed is associated with a stronger local concentration of rainfall. Additionally, the typhoon track is linked to the location of the rainfall-impacted region.” has been added in the summary.

(ii) The sentences “Current discussions on the factors influencing spatial rainfall patterns rely primarily on qualitative analyses based on regional characteristics. Future studies should further incorporate relevant influencing factors to conduct quantitative analyses and deepen the understanding of this issue.” have been changed into “Future work would combine high-resolution numerical simulations to conduct more targeted and quantitative research, deepening the understanding of the dynamic-thermodynamic mechanisms underlying rainfall pattern formation under multi-factor coupling effects.”.