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A precipitation event extraction method for processing 5-km d4PDF and developing high-resolution national discharge quantile maps

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Introduction

Climate change has become an acknowledged reality, ushering in shifts in flood risk. High-resolution national flood quantile maps, which enhance public awareness of changes in flood frequency, are deemed essential from the perspectives of decision-making, transparent dissemination of disaster risk information, and collaborative scientific research.

Downscaled climate ensembles offer detailed precipitation data for understanding future floods. However, dealing with hourly data spanning centuries and large-scale, high-resolution simulations challenges the limits of existing hydrodynamic models. Continuous simulations are no longer a feasible solution.

Given that flood studies primarily focus on extreme scenarios below a certain frequency, theoretically, it is possible to simulate only the corresponding events. However, due to the spatiotemporal variability of precipitation and the complexity of interactions with basins, there is currently no method to extract extreme precipitation events corresponding to all river sections comprehensively. To address this, this study proposes a method to identify and extract extreme discharge-associated precipitation events for all river sections. This facilitates the direct simulation of the events of interest using hydrodynamic models and the establishment of frequency curves.

Method

The Aggregating Grid Events (AGE) method primarily involves the following four steps in processing precipitation data. As illustrated in Figure 1, Step 1 entails extracting precipitation data for singular grid. Potential extreme precipitation is detected using a threshold of 10 mm/h. An interval with physical significance of approximated basin concentration time (T) was used to ensure the independence of events. Step 2 involves calculating the T-hour Maximum Precipitation (TMP) for each event. According to the concept of unit hydrograph, precipitation within T hours contributes entirely to the peak discharge. Events are then arranged in descending order of TMP, and events with annual exceedance probability less than 0.1 are extracted. Steps 1 and 2 are applied to all grids at all resolutions to obtain a preliminary event set. The preliminary event set is arranged according to their starting time in Step 3, where overlapping events are aggregated, independent events are retained. As Step 1 sets a threshold, aggregated events need to undergo Step 4 to search for the actual start and end times of events. The corresponding precipitation data can then be extracted based on the full event period.

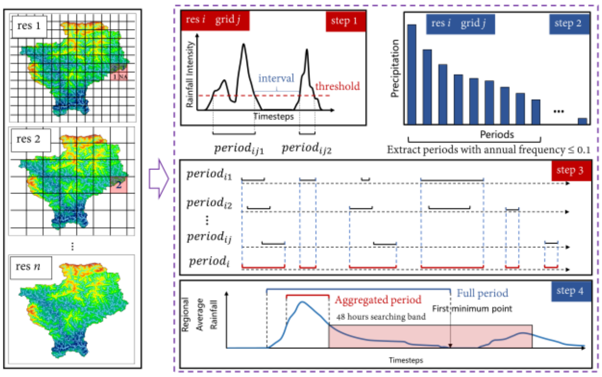

Figure 1 Aggregating Grid Events (AGE) method

To assess whether the events extracted by the AGE method have the capability to provide extreme discharge data for constructing flood frequency curves for all river sections, this study conducted detailed simulations in the Shikoku Island using the 150m Rainfall-Runoff-Inundation (RRI) model. Precipitation data were derived from the historical simulation results of the 5 km climate ensemble d4PDF, encompassing 12×60 years of hourly data. Any precipitation event with intensity exceeding 10 mm/h at any grid at any timestep is considered a valid event. The discharge simulation results of all valid events serve as the evaluation benchmark. Assessment is conducted for both discharge peaks and quantiles.

The results were assessed by correlation coefficients (R), relative bias (BIAS), and root mean square errors (RMSE).

$$R = \frac{\sum(y_e - \overline{y_e})(y_r - \overline{y_r})}{\sqrt{\sum(y_e - \overline{y_e})^2 \sum(y_r - \overline{y_r})^2}} \qquad \textbf{Eq. 1}$$

$$BIAS = \frac{\sum y_e - \sum y_r}{\sum y_r} \times 100\% \qquad \textbf{Eq. 2}$$

$$RMSE = \sqrt{\frac{1}{n}\sum(y_e - y_r)^2} \qquad \textbf{Eq. 3}$$

y_e is the predictions from the model to be evaluated.

y_r is the predictions from the reference model.

Result

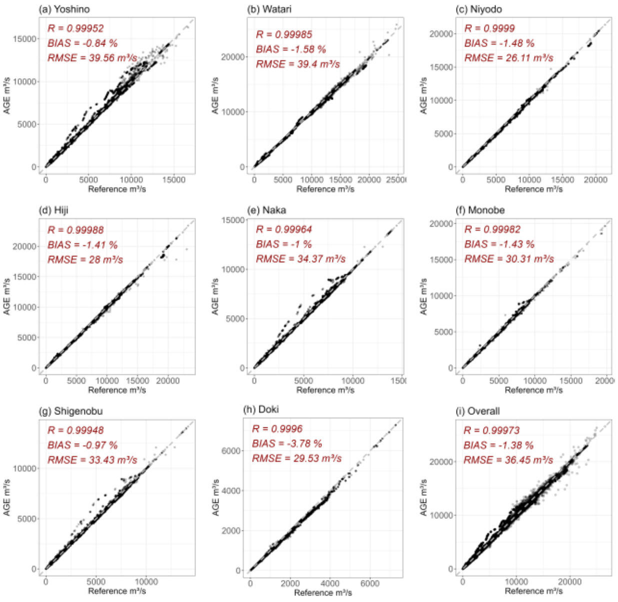

Figure 2 Comparison of discharge peaks from all river sections

Figure 1 shows the comparison of peak discharges from the AGE method and all valid events. These peaks are derived for all river sections, with the largest 72 values extracted for each section. The results indicate that the discharges based on the AGE method exhibit high accuracy, with BIAS ranging from -1% to -2% across various basins. Using these peaks, we estimated quantiles for each river section using the Peaks Over Threshold method, as the evaluation results shown in Figure 2. The BIAS is primarily distributed between 0% and -10%. The results in Figure 3 indicate that larger BIAS values predominantly occur in river sections with basin areas less than 25 km², while BIAS in the middle and lower reaches narrows to the range of 0% to -5%.

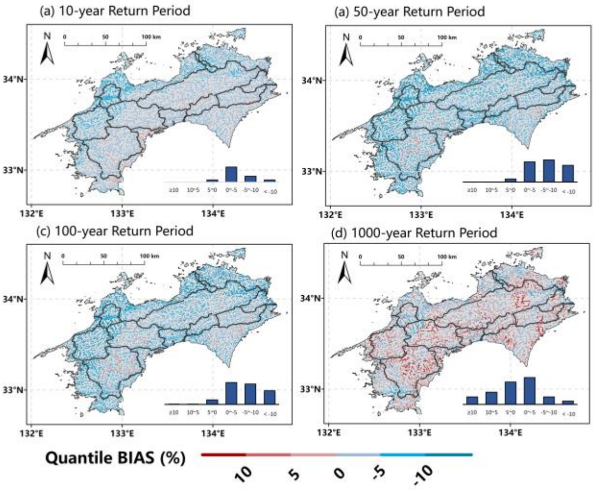

Figure 3 Spatial distribution of discharge quantile BIAS at different return periods

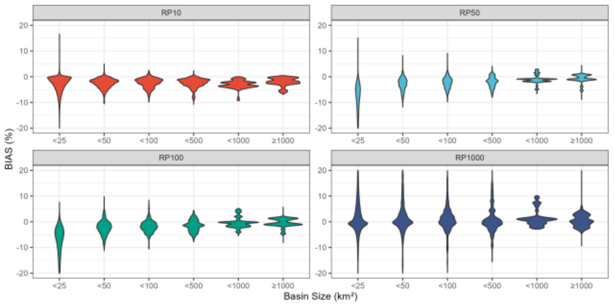

Figure 4 Changes of BIAS of discharge quantile with basin area

Conclusion

The AGE method significantly reduces the computational burden required for constructing discharge quantile maps, enabling hydrodynamic simulations over large areas, at high resolutions, and utilizing multiple climate ensembles.