

# Annual Briefing 2025

## CaMa-Flood progress report

By CaMa-Flood developer/user community  
(Edited by Dai Yamazaki, Xudong Zhou, Gang Zhao)

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### Preface

We summarize the achievements and progress of CaMa-Flood developments and applications in the years 2025 and around in this annual briefing report. This briefing covers:

1. CaMa-Flood development highlight 2025
2. Achievement reports (papers published mainly in 2025)
3. Reports on related events and info on upcoming meetings.

The primary purpose of this briefing is to highlight the research using CaMa-Flood published in 2025 and around, and to make it visible among the CaMa-Flood community and beyond.

The briefing meeting is held on 13th March 2026, online on Zoom.

- For joining on time, please register on Google Form from meeting webpage <https://global-hydrodynamics.github.io/cmf-annual-brief/>
- The meeting recording will be available later on Yamazaki lab YouTube. <https://www.youtube.com/channel/UCPz6TRypvD4G4HS4PCQ8HKQ>

## Program of annual briefing (online)

note: times are in Japanese time zone (GMT +9)

[20:00 - 20:40]

### 1. Status of CaMa-Flood core developments 2025 [40 min]

#### **[G1] Major Updates of CaMa-Flood in 2025**

Dai Yamazaki [10 min]

#### **[G2] Developing a Levee Module for Global Flood Modeling With a Reach-Level Parameterization Approach**

Gang Zhao [15 min]

#### **[G3] CaMa-Flood-GPU: A GPU-based Hydrodynamic Model Implementation for Scalable Global Simulations**

Shengyu Kang [15 min]

### 2. CaMa-Flood achievement reports

[20:40 - 21:30]

#### 2A. Highlight of CaMa-Flood application papers [10 min \* 5 talks]

#### **[A1] Climate change and ENSO significantly enhances seasonal flood occurrence in the Ganges-Brahmaputra-Meghna basin**

Uddin Shahab [10 min]

#### **[A2] A multi-scenario framework for quantifying flood hazard and exposure, accounting for runoff-driven uncertainty in global flood models**

Jayesh Parmar [10 min]

#### **[A3] Reduction of the uncertainty of flood hazard analyses under a future climate by focusing on similarities among multiple SSP-RCP scenarios**

Yuki Kimura [10 min]

**[A4] Impact of tropical cyclones and socioeconomic exposure on flood risk distribution in the Mekong Basin**

Aifang Chen [10 min]

**[A5] Climate change and effectiveness of dams in flood mitigation in India**

Urmin Vegad [10 min]

[21:30 - 22:20]

2B. Highlight of CaMa-Flood development papers [10 min \* 5 talks]

**[B1] Rapid Assessment of Mega-Dam Impacts Using a Satellite-Derived Reservoir Operation Scheme**

Youjiang Shen [10 min]

**[B2] Does Spatial Resolution Matter? Effects on Large-Scale Hydrodynamic Simulations**

Prakat Modi [10 min]

**[B3] Analysis and comparison of the flood simulations with the routing model CaMa-Flood at different spatial resolutions in the CONUS**

Ruijie Jiang [10 min]

**[B4] Assessment of JULES Land Surface Model Coupled With CaMa-Flood for an Operational Streamflow Forecasting Across Australia**

Fitsum Woldemeskel [10 min]

**[B5] Benchmark Framework for Global River Models**

Xudong Zhou [10 min]

[22:20 - 22:30]

3 Reports on related events and info on upcoming meetings.

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# 1. Status of CaMa-Flood core developments 2025

## [G1] Major Updates of CaMa-Flood in 2025

Dai Yamazaki

*Institute of Industrial Science, The University of Tokyo*

### <1> Publication of the CaMa-Flood review paper in **AOGS Geoscience Letters**

The CaMa-Flood review paper summarizing more than 15 years of model development and applications has been published in AOGS Geoscience Letters. The paper introduces the concept of the Catchment-based Macro-scale Floodplain (CMF) modeling approach and reviews the evolution of CaMa-Flood and related models, highlighting how physically consistent representations of water surface elevation and floodplain dynamics enable global-scale river simulations and diverse applications. The review also discusses recent advances and future directions of CMF-based global river modeling, including integration with satellite observations, flood risk assessment, and Earth system science applications.

**Yamazaki D. (2025)** Advancing global river hydrodynamics simulations by catchment-based macro-scale floodplain modeling approach

*Geoscience Letters*, 12, 72. <https://doi.org/10.1186/s40562-025-00452-z>

### <2> Release of CaMa-Flood v4.30

The next major version of CaMa-Flood (v4.30) is scheduled to be released in mid-March 2026. This version introduces several new developments to the model core, including the implementation of a levee scheme for representing flood protection structures, computational acceleration using SIMD and a quasi-sparse matrix formulation, and a simple tracer scheme for tracking transported quantities within the river network. These new features expand the model's capability for flood risk assessment, computational efficiency, and process-oriented studies.

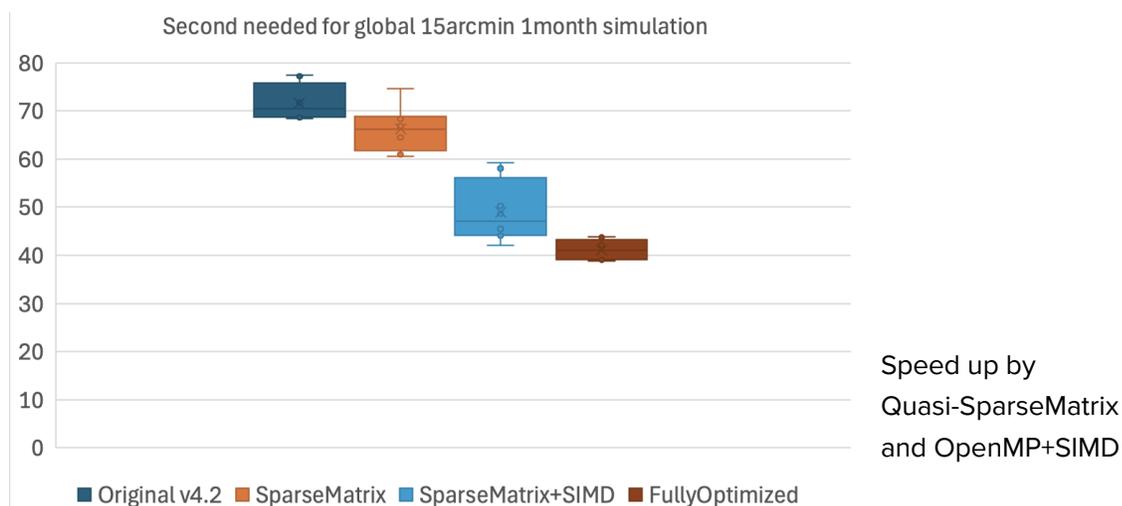
#### **2a: Efficient calculation by SIMD + SparseMatrix**

In CaMa-Flood v4.30, several low-level optimizations were introduced to improve computational efficiency and ensure bit-level reproducibility in parallel simulations. One key improvement is the reformulation of upstream flow accumulation using a quasi-sparse upstream matrix structure. In previous implementations, OpenMP atomic operations were required when multiple upstream cells updated a downstream cell, which caused non-deterministic rounding differences and limited parallel scalability. By pre-compiling the upstream connectivity into a sparse-like routing structure, each thread

can update independent targets without atomic operations, ensuring deterministic summation order and improving performance (about 30% speed-up in benchmark tests).

Additional acceleration was achieved through explicit SIMD (Single Instruction Multiple Data) vectorization within OpenMP loops. Loop structures were reorganized and SIMD directives were introduced to better utilize CPU vector units, particularly in single-precision simulations. This optimization provided a further reduction in wall-clock time (approximately 40% speed up on top of the sparse-matrix), resulting in a substantial cumulative speed-up and making CaMa-Flood more suitable for large-scale ensemble simulations and operational environments.

In addition, a more efficient GPU version is released. Please refer to the progress report [G3].



## 2b: Tracer Scheme

CaMa-Flood v4.30 also introduces a simple tracer transport scheme for tracking substances within the river network. The scheme accepts externally provided tracer runoff inputs and simulates their downstream transport following the river discharge simulated by CaMa-Flood.

Tracer concentrations are calculated assuming complete mixing within river–floodplain water storage in each unit catchment, and the transported tracer flux is computed consistently with the modeled river flow, including bifurcation channels and possible flow reversals.

At present, the scheme focuses on advective transport only and does not consider sedimentation or chemical transformations, providing a lightweight framework for process-oriented studies and future model extensions.

## 2c: Levee scheme

For the newly developed levee scheme, please refer to the report [G2].

# [G2] Developing a Levee Module for Global Flood Modeling With a Reach-Level Parameterization Approach

Gang Zhao (*Tokyo Institute of Science*), Dai Yamazaki, Yoshiaki Tanaka, Xudong Zhou, Shuping Li, Yang Hu, Yukiko Hirabayashi, Jeff Neal, Paul Bates

Journal: *Water Resources Research*, 61, (2025) <https://doi.org/10.1029/2024WR039790>

## 1. Introduction and Background

Global Flood Models (GFMs) frequently overestimate flood hazards in developed regions. A primary reason for this discrepancy is the widespread omission of flood protection infrastructures—specifically levees—in global simulations. Integrating levees into GFMs has historically been hindered by two major challenges: the severe scarcity of comprehensive global levee datasets and the inherent complexity of representing levee functionalities within large-scale river hydrodynamics. To address this critical gap, this study develops a simplified levee module within the CaMa-Flood global hydrodynamic model and proposes a novel reach-level parameterization approach to estimate levee parameters globally using open-access data.

## 2. The Levee Module and Parameterization

The proposed levee scheme extends the CaMa-Flood model by representing levee protection through only two essential parameters:

- **Levee Unprotected Fraction** : This parameter defines the proportion of a river reach's floodplain that is not protected by levees (e.g., the riparian zone between the river centerline and the levee).
- **Equivalent Levee Height**: This represents the effective protection height of the levee system. It acts as a critical threshold: floodwaters are confined within the main channel and the unprotected floodplain until the water level exceeds this threshold .

Figure 1 illustrates how open-access data are used to estimate two critical parameters and integrate them into the global model (more details are described in the paper).

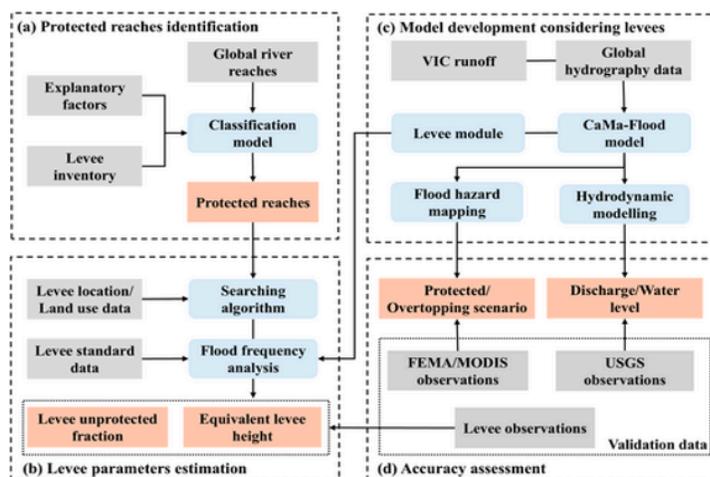


Figure 1: The framework of this research: (a) Protected reaches identification (in Section 2.2), (b) Levee parameters estimation (in Section 2.3), (c) Global flood model development considering levees (in Section 2.4), and (d) Validation and accuracy assessment (in Section 2.5).

### 3. Model Evaluation and Results

We evaluated the model's performance by comparing simulations with and without the levee module against observed gauge data and official high-resolution flood hazard maps from representative case studies.

#### 3.1. Improvements in River Hydrodynamics

Integrating levee protection fundamentally altered the simulated river hydrodynamics. The levees effectively confined floodwaters during moderate to high events, which limited floodplain storage, lowered overbank volumes, and altered flood wave propagation.

- In five specific evaluation regions in the United States, the enhanced CaMa-Flood model incorporating the levee module dramatically improved the simulation of river water levels, raising the mean **Nash-Sutcliffe Efficiency (NSE)** from **0.68 to 0.84**. (left in Figure 2)

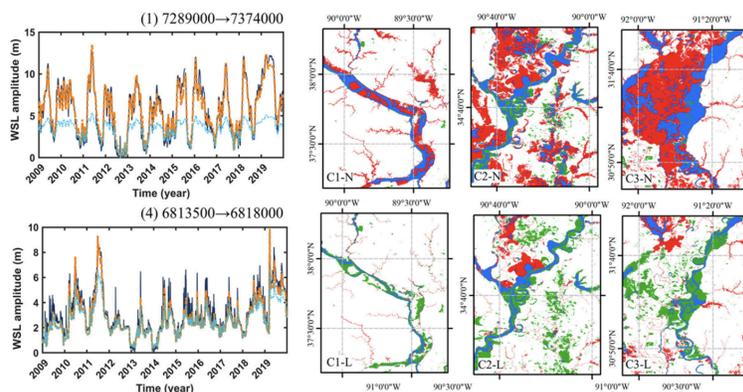


Figure 2. Improvements in water-level simulation (left) and flood hazard mapping (right).

#### 3.2. Enhancements in Flood Hazard Mapping

By physically constraining water within the unprotected side during high flood events, the levee-integrated downscaling approach captured the spatial variability in protection effectiveness.

- The accuracy of flood hazard mapping increased significantly, improving from **0.76 to 0.87** in the evaluated US regions. (right in Figure 2)
- Validation of flood mapping across eight other representative regions worldwide confirmed the model's robust performance, demonstrating a 10–15% improvement in flood hazard map accuracy.

### 4. Conclusions and Significance

The findings demonstrate that accounting for levees significantly reduces the overestimation of flood extents and improves the temporal dynamics of flood routing. Although levee data at the global scale remain relatively limited, this research proposes a method to estimate levee parameters for ungauged areas, enabling global coverage. By integrating hydraulic modeling, frequency analysis, and levee representation, this study establishes a comprehensive and robust framework for global flood depth mapping, offering strong potential to support resilience planning, climate change adaptation, and basin management worldwide.

# [G3] CaMa-Flood-GPU: A GPU-based Hydrodynamic Model Implementation for Scalable Global Simulations

Shengyu Kang (Wuhan University), Jiabo Yin, Dai Yamazaki

Journal: ESS Open Archive (in review), <https://doi.org/10.22541/essoar.176442648.85093032/v3>

## 1. Introduction and Background

The Catchment-based Macro-scale Floodplain model (CaMa-Flood) is a leading global river routing system, but its CPU-based implementation is computationally demanding at high resolutions. This study presents CaMa-Flood-GPU, a GPU implementation of CaMa-Flood's hydrodynamic core that preserves physical and numerical fidelity while dramatically reducing simulation time. Porting CaMa-Flood to GPUs must overcome three challenges: (1) irregular river network topology with non-uniform memory access, (2) conditional branching in floodplain water-level diagnosis, and (3) communication/I/O overhead across multiple GPUs. Implemented in Python with Triton kernels and PyTorch distributed, the model combines rapid development with kernel-level performance.

## 2. Implementation and GPU Parallelization

The implementation follows a modular architecture (Figure 1). To handle the irregular river topology, each catchment computes its outflow and atomically scatters it to the downstream neighbor's buffer, enabling fully parallel updates. For water depth diagnosis, topographic profiles are flattened into 1D arrays and processed by a fixed-loop kernel with conditional assignments, eliminating thread divergence for millions of catchments. Communication overhead is minimized through a single-reader broadcast for forcing data, background data loaders for latency hiding, and local accumulation with end-of-step reduction — limiting synchronization to two collective operations per time step. The system also provides flexible customization: a sparse weight matrix maps gridded runoff to irregular catchments supporting multiple formats, users can regionalize the domain to specific gauge locations, and output statistics are computed on-the-fly via fused GPU kernels.

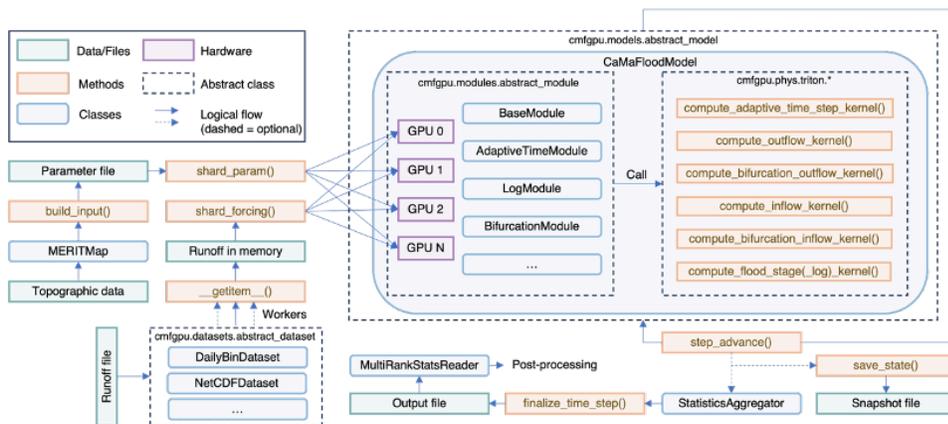


Figure 1. Schematic architecture of the CaMa-Flood-GPU system.

### 3.1. Performance Comparison

Benchmarks across four hardware environments (RTX 4070 Ti workstation, V100/A100 GPU servers, 192-core CPU servers) show order-of-magnitude speedups at fine resolutions.

- At 3-arcmin (~6.2M catchments): 192 CPU cores require 2 h 45 m vs. 7 m 21 s on 4×A100 (~22.5× speedup).
- At 1-arcmin (~55.8M catchments): 192 CPU cores require ~141 hours vs. 3 h 51 m on 4×A100 (up to 36.6× speedup).
- Multi-GPU scaling is near-linear at fine resolutions, with 3.5× speedup from 1 to 4 A100 GPUs at 1-arcmin.

### 3.2. Numerical Stability

GPU outputs are virtually identical to the CPU baseline (Figure 2): discharge differences average  $\sim 10^{-6}$  mm/day, water depth differences  $\sim 10^{-6}$  m, and daily hydrographs at major outlets (Amazon, Mississippi, Yangtze) nearly overlap, with differences never exceeding  $\sim 20$  m<sup>3</sup>/s against peak flows of  $\sim 10^6$  m<sup>3</sup>/s. Residual discrepancies arise only from floating-point summation order and single vs. double precision, without affecting scientific usability.

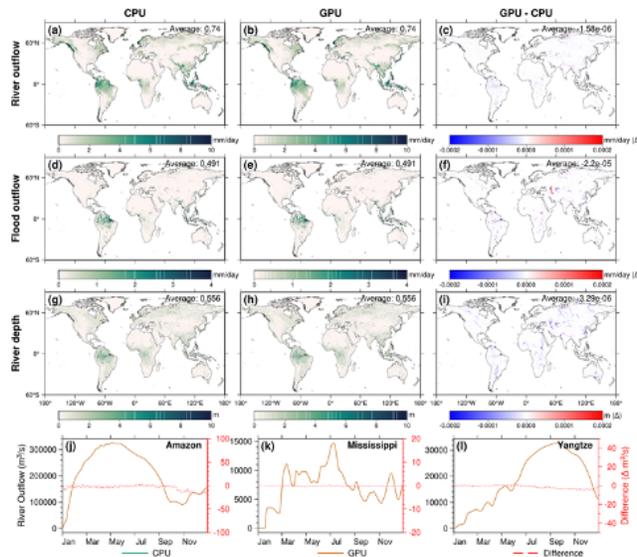


Figure 2. Comparison of CPU vs GPU simulation outputs without the bifurcation module.

(a-c) Mean river discharge for CPU, GPU, and their difference.

(d-f) Mean floodplain discharge for CPU, GPU, and their difference.

(g-i) Mean river water depth for CPU, GPU, and their difference.

(j-l) Daily river discharge time series at the outlets of three major river basins (Amazon, Mississippi, Yangtze).

## 4. Conclusions and Significance

CaMa-Flood-GPU achieves substantial speedups without compromising physical accuracy — all governing equations for mass and momentum conservation are preserved. High-resolution global simulations (1-arcmin) that previously required days on large CPU clusters can now be completed in hours on a few GPUs. The modular design supports flexible input/output, optional physics modules, and coupling with external models. Future directions include mixed-precision arithmetic, reservoir/sediment transport modules, and integration with deep learning frameworks for hybrid modeling. This work paves the way for real-time global flood forecasting and large ensemble simulations for climate risk assessment.

## 2A. Highlight of CaMa-Flood application papers

### [A1] Climate change and ENSO significantly enhances seasonal flood occurrence in the Ganges-Brahmaputra-Meghna basin

Shahab Uddin (Monash University), Dai Yamazaki, Anna Lintern, Menaka Revel and Prakat Modi

**Journal:** Journal of Hydrology, 2025. <https://doi.org/10.1016/j.jhydrol.2025.133207>

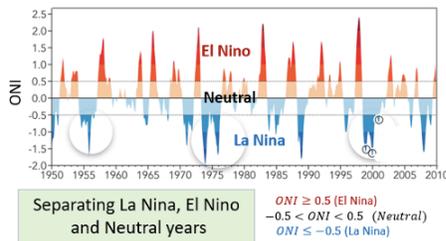
**Abstract:** Seasonal hydrological dynamics have profound socio-economic implications for communities in the Ganges-Brahmaputra-Meghna (GBM) River basin. Climate change and El Niño-Southern Oscillation (ENSO) phase are known to impact extreme flood magnitude in GBM River, however how they affect seasonal flooding pattern is not revealed. Utilizing large ensemble climate data (comprising 6000 years of non-warming and warming climate scenarios) and the global hydrodynamic model CaMa-Flood, we assess the influence of climate change and ENSO on seasonal hydrological patterns specially focusing on maximum river flow. The quantitative effects of La Niña and El Niño are calculated utilizing the Fractional Attribution Risk (FAR) method, separately for non-warming and historical climate scenarios. We assess climate change's impact on flooding by contrasting historical and non-warming climate conditions using the FAR method. Climate change has substantially increased the maximum river flow for all seasons. In the monsoon season, climate change amplifies the likelihood of flooding with a 10-year return period of 34 %, 46 %, and 31 % at the Hardinge Bridge, Bahadurabad, and Bhairab Bazar gauge stations of the Ganges, Brahmaputra, and Meghna Rivers, respectively. The influence of ENSO still remains significant even with the influence of climate change. ENSO influence presents a nuanced picture, exhibiting variations both between seasons and across different rivers within the GBM basin. The relationship between ENSO and seasonal flood occurrence in the GBM basin can be effectively elucidated by the upward movement of moisture through vertical wind velocity, which serves as a large-scale controlling factor for flood variation datasets is essential for precise attribution of the impacts of internal climate variability on flooding in Bangladesh.

**Background:** The GBM basin, encompassing a vast geographical expanse across South Asian countries (Bangladesh, Bhutan, China, India, and Nepal), represents a region of paramount importance due to its significant contributions to water resources ([Rasul, 2015](#)). 630 million people live in the GBM basin ([Sharma et al., 2021](#)). Past studies that focused on annual peak discharge used statistical analyses of this metric to study the ENSO influence on flood occurrence ([Del Rio Amador et al., 2023](#), [Lee et al., 2018](#), [Uddin et al., 2023](#), [Ward et al., 2010](#), [Ward et al., 2014](#), [Yamazaki et al., 2023](#)). These approaches fail to account for the nuanced seasonal variations in hydrological patterns and the diverse responses in streamflow to La Niña and El Niño events. Moreover, prior studies primarily employed statistical analyses to attribute the influence of ENSO on flood occurrence. However, to refine flood prediction

capabilities within the GBM basin during La Niña or El Niño occurrences, it is crucial to underpin the findings of statistical analyses with an understanding of fundamental physical mechanisms.

### Proposed Method:

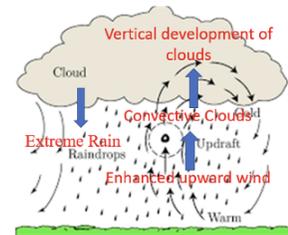
- 1) Large-ensemble River simulation using d4PDF and CaMa-Flood River model.
- 2) Count the number of flood event for each season which exceed 10yr return period in both Historical and Non-warming simulations.
- 3) Calculate occurrence probability separately for each ENSO phases.
- 4) Calculate additional risk in each ENSO phase, compared to long term mean.



Supplementary Table S4: Fraction of Attribution Risk (FAR) equations for climate change and ENSO

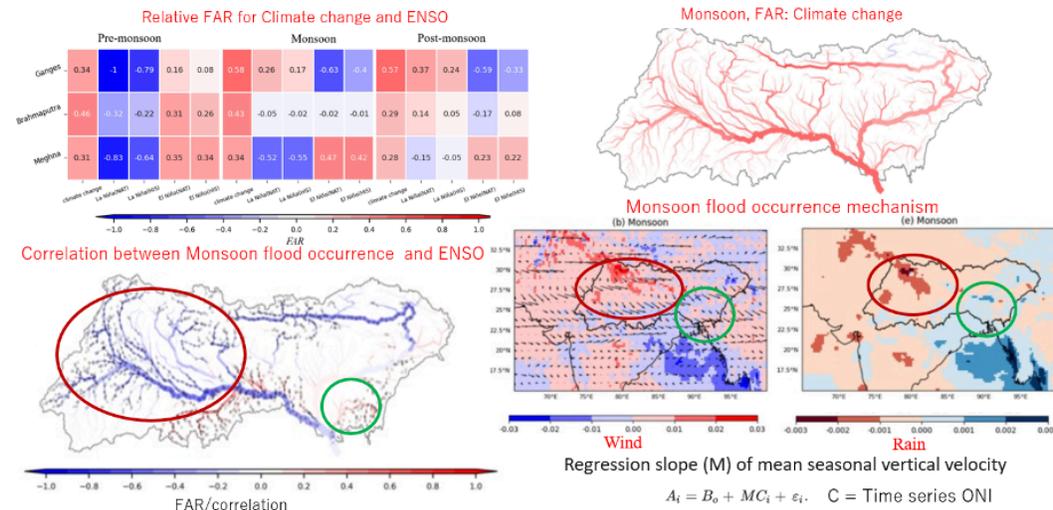
Driver		FAR equation
Climate change		$\frac{P_{HIS(all)} - P_{NAT(all)}}{P_{HIS(all)}}$
		$\frac{P_{NAT(La Niña)} - P_{NAT(all)}}{P_{NAT(La Niña)}}$
ENSO (When climate change impact is absent)	La Niña	$\frac{P_{NAT(La Niña)} - P_{NAT(all)}}{P_{NAT(La Niña)}}$
	El Niño	$\frac{P_{NAT(El Niño)} - P_{NAT(all)}}{P_{NAT(El Niño)}}$
ENSO (When climate change impact is present)	La Niña	$\frac{P_{HIS(La Niña)} - P_{HIS(all)}}{P_{HIS(La Niña)}}$
	El Niño	$\frac{P_{HIS(El Niño)} - P_{HIS(all)}}{P_{HIS(El Niño)}}$

$FAR_{ENiño} > 0$  if more flood occurs in El Niño phase



5) Vertical pressure velocity of 500 hPa and horizontal wind velocity of 850 hPa, were employed to investigate the mechanisms underlying seasonal flood occurrences in relation to the climate internal variability

### Results:



### Summary:

- We assessed climate change and ENSO impacts on seasonal floods in Bangladesh.
- Climate change increases flood frequency by 40% across seasons and rivers.
- La Niña and El Niño impacts vary by both seasons and locations.
- El Niño raises pre-monsoon flood frequency by 31% in the Brahmaputra.
- La Niña raises post-monsoon floods by 37% in the Ganges.
- The potential relationship between the ENSO and seasonal flood occurrence in these areas can be effectively interpreted by vertical wind velocity, which serves as a large-scale controlling factor for flood variation.

# [A2] A multi-scenario framework for quantifying flood hazard and exposure, accounting for runoff-driven uncertainty in global flood models

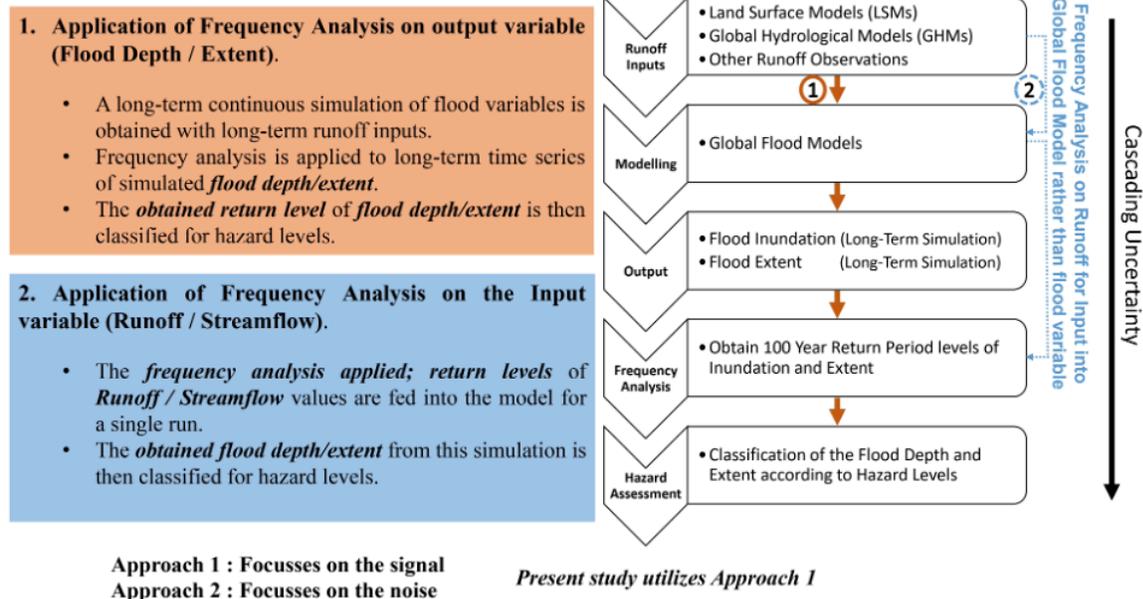
Jayesh Parmar and Subhankar Karmakar (Indian Institute of Technology Bombay)

Journal: Science of The Total Environment, 2025, <https://doi.org/10.1016/j.scitotenv.2025.180381>

**Abstract:** With growing populations and an increasing frequency of flood events, large-scale flood hazard assessment (LSFHA) and exposure analyses have become critically important. Global Flood Models (GFM) significantly contribute to these efforts by simulating flood dynamics based on runoff inputs from Land Surface Models (LSMs), Global Hydrological Models (GHMs), or Reanalysis datasets. However, GFM outputs remain highly sensitive to runoff input choice, leading to substantial uncertainty in LSFHA. To address this challenge, we develop a multi-scenario framework integrating diverse runoff forcings into the CaMa-Flood GFM to capture a plausible range of hazard and exposure outcome scenarios, ranging from optimistic to conservative. The framework defines optimistic and conservative scenarios as the minimum and maximum simulated flood depth among all simulations, while the best-case is derived from the most efficient and validated simulation. ERA5-Reanalysis runoff forced streamflow simulation emerges as the most efficient, achieving Nash–Sutcliffe efficiency greater than 0.5 at approximately 50 % of analysed gauge stations, thus representing the best-case scenario. For a precise estimation of the return period flood depth, multiple parametric and non-parametric distributions are employed in frequency analysis. Hazard analysis for a 1-in-100-year flood event reveals around 48 % (range: 20 % - 60 %) of India's land area falls in the disastrous hazard class, approximating 1.6 (range: 0.65–1.95) million km<sup>2</sup>. Exposure analysis, aligning closely with government estimates and previous studies, indicates approximately 690 million people (range: 335–786 million) are exposed to significant flood risk. Validated using India as a case study, this scalable framework offers an open-source tool enabling national-scale risk-informed decision-making, addressing runoff-driven uncertainty critical for both immediate and long-term flood risk management.

## Background

## Large-Scale Flood Hazard Assessment

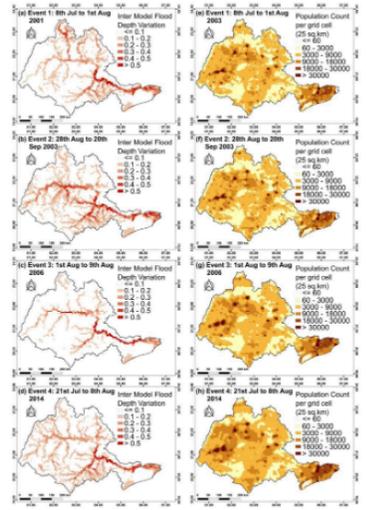


## Motivation

- Global Flood Models (GFM) are essential for large-scale flood hazard assessment (LSFHA).
- Runoff choice alone can contribute up to ~80% in simulated outputs, often not disseminated to policy/decision makers.
- Single-model or ensemble-mean runoff can mask extremes in flood hazard.
- The various runoff forced simulation based inter-model flood depth variation shows pronounced depth variation in highly populated regions.

This study addresses these gaps

1. Explicitly accounting for runoff uncertainty using a scenario-based framework derived from multiple GFM simulations



Left Panel: Normalised inter-model flood depth variation  
Right Panel: Gridded population for various flood events

Parmar, J., Mohanty, M. P., & Karmakar, S. (2025). Need for judicious selection of runoff inputs in a global flood model. Environmental Research Letters, 20(2), 024032. DOI 10.1088/1748-9326/adaa89

## Methodology

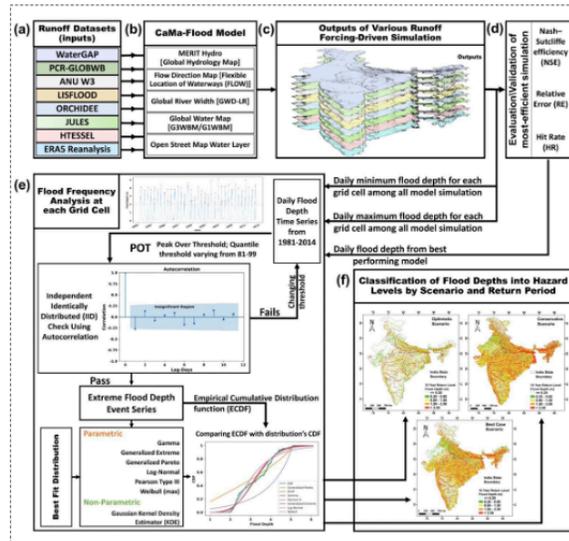
1. We drive CaMa-Flood with multiple runoff datasets and obtain flood depth (a, b, c, d)

$$f_{d,i}^{con,m} = \max_n(f_{d,i}^{n,m})$$

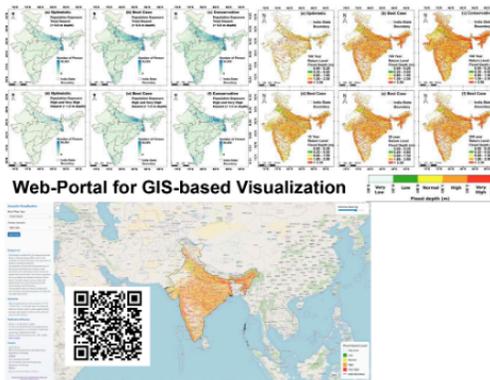
$$f_{d,i}^{opt,m} = \min_n(f_{d,i}^{n,m})$$

$f_{d,i}^{n,m}$  is flood depth for cell  $m$  on  $i^{th}$  day, using the  $n^{th}$  runoff forced simulation for  $s$  scenario

2. The scenarios quantify variability due to runoff selection in the flood simulations (a, b, c, d)
3. Apply extreme value analysis at each grid cell to assess the flood depth return levels (e)
4. Classify obtained return levels of obtained flood depth based on physical impacts



## Result and Summary



- Accounting for runoff driven uncertainty is essential for credible national flood risk assessments.
- Developed a multi-scenario flood hazard & exposure framework using CaMa-Flood driven by multiple runoff forcings.
- ERA5-Reanalysis Runoff forcing performs best for India, forming the best-case scenario
- Improve spatial resolution to support district- and sub-district-level hazard and exposure assessment.

### [A3] Reduction of the uncertainty of flood hazard analyses under a future climate by focusing on similarities among multiple SSP-RCP scenarios

Yuki Kimura (MS&AD InterRisk Inc), Yukiko Hirabayashi Dai Yamazaki

**Journal:** Scientific Reports, 2025. <https://doi.org/10.1038/s41598-025-16327-4>

**Abstract:** This study investigated whether the uncertainty in future flood prediction due to small number of ensemble members could be reasonably reduced by merging multiple SSP-RCPs and extracting the periods with the same warming level under each SSP-RCP. The uncertainty due to small number of ensemble members is a one of the major sources of uncertainty in climate predictions. Projection uncertainty due to the above could be mitigated by increasing the effective number of ensemble members. However, only a limited number of large-ensemble experiments are available for each of the CMIP6 GCMs. Therefore, while increasing the ensemble size may be difficult, evaluating future projections of X°C warming by integrating multiple SSP-RCP with data at the time of that warming may increase the sample size. This study investigated whether the uncertainty in future flood prediction due to small number of ensemble members could be reasonably reduced by merging multiple SSP-RCPs and extracting those periods with the same warming level under each SSP-RCP.

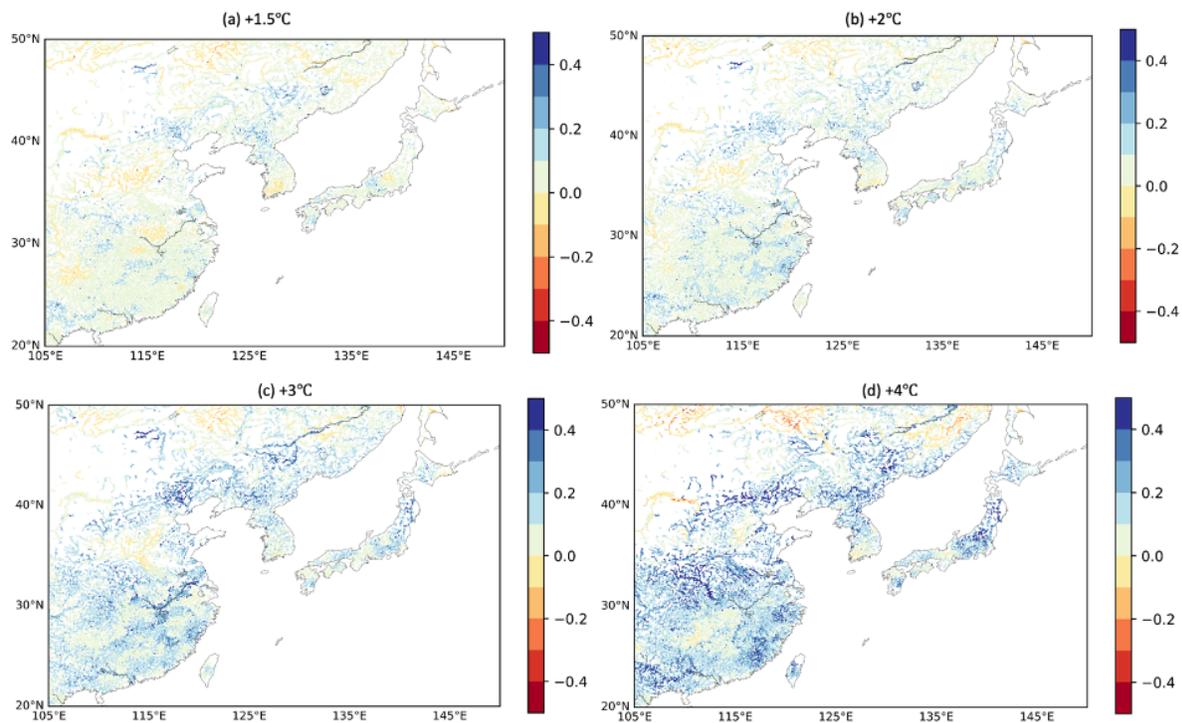
A preliminary investigation of the similarity in flood projection at the same level of warming among SSP-RCP scenarios showed that at 2 °C warming the change ratio in the flood magnitude showed similar distributions for all SSP-RCPs. Moreover, the uncertainty due to the different SSP-RCPs (5–10%) was smaller than the difference in flood projection between 2 and 3 °C or between 3 and 4 °C (20–50%), which suggests that differences among SSP-RCPs as to future flood discharge change are relatively small. Accordingly, integrating multiple SSP-RCPs is an appropriate method for reducing the uncertainty due to small number of ensemble members in impact assessments at X°C warming.

The ability of our method to reduce the variability among GCMs regarding future flood changes was compared to the use of SSP5-RCP8.5 alone. The unbiased variance among GCMs in our method was reduced in about 70% of the grid points compared to when SSP5-RCP8.5 alone was applied. In regions characterized by an initially significant unbiased variance among GCMs, the reduction increased to about 80% of the grid points, with significant decreases in the Mississippi River (USA) and extending from China to Southeast Asia.

Finally, the proposed method was tested by creating future hazard maps based on the change in flood frequency in each GCM using the lookup method with only nine GCMs under the SSP5-RCP8.5 scenario vs. using the proposed method. Then the size of the affected population at X°C warming was calculated according to these two approaches. The results showed a reduction in the variation among GCMs of the affected population of 5–10%.

Based on the above results, our proposed method is very helpful for assessing climate change impacts because it could not only meet the growing need to evaluate impacts of specific

warming levels but also reduce the uncertainty as to future flood impact assessment. Furthermore, the warming-level-based approach adopted in this study aligns more directly with international climate policy targets such as those set by the Paris Agreement (e.g., 1.5 and 2.0 °C warming goals). Unlike time- or scenario-based projections, which depend heavily on assumptions about socioeconomic development and emissions pathways, warming-level approaches enable more consistent comparison of physical climate responses across scenarios. This approach is particularly relevant for risk assessments and adaptation planning because it focuses on the impacts associated with specific levels of global warming, irrespective of the pathway taken to reach them. Therefore, it facilitates actionable insights for policymakers by linking projected hazards—such as floods—to clearly defined policy-relevant temperature thresholds. Thus, the proposed method is expected to be commonly used as a method to reduce the uncertainty of small number of ensemble members regarding future projections in CMIP6 and to provide a more accurate and helpful estimates of the impacts of climate change.



We calculated the projected change ratio(\*) of the 100-year return period flood discharge based on our proposed method. By integrating multiple climate projection scenarios, we more precisely estimated the change ratio in discharge under warming levels of 1.5°C, 2°C, 3°C, and 4°C.

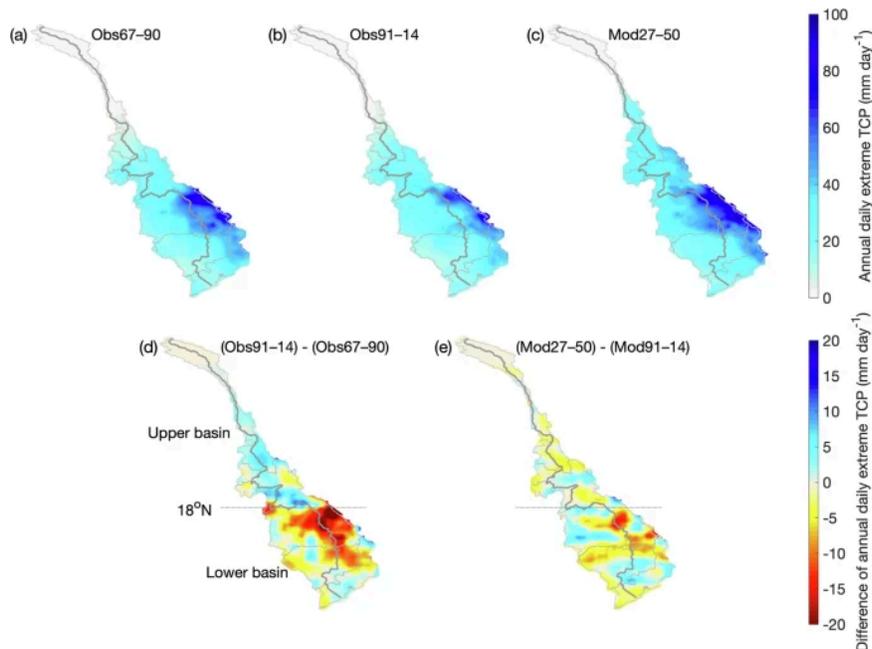
\*Change ratio of the 100-year return period flood discharge: the ratio indicating how much the river discharge associated with 1% annual exceedance probability (i.e., a 100-year return period event) is projected to increase in the future climate relative to the baseline.

## [A4] Impact of tropical cyclones and socioeconomic exposure on flood risk distribution in the Mekong Basin

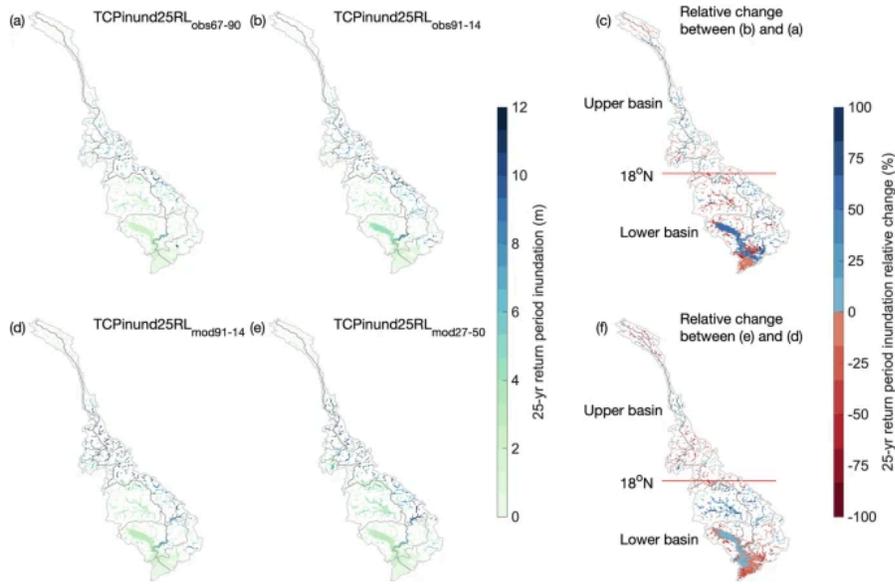
Aifang Chen (Dongguan University of Technology), Yadu Pokhrel, Deliang Chen, Hao Huang, Zhijun Dai, Bin He, Jie Wang, Jiaye Li, Hong Wang, Junguo Liu

**Journal:** Communications Earth & Environment, 2024, <https://doi.org/10.1038/s43247-024-01868-9>

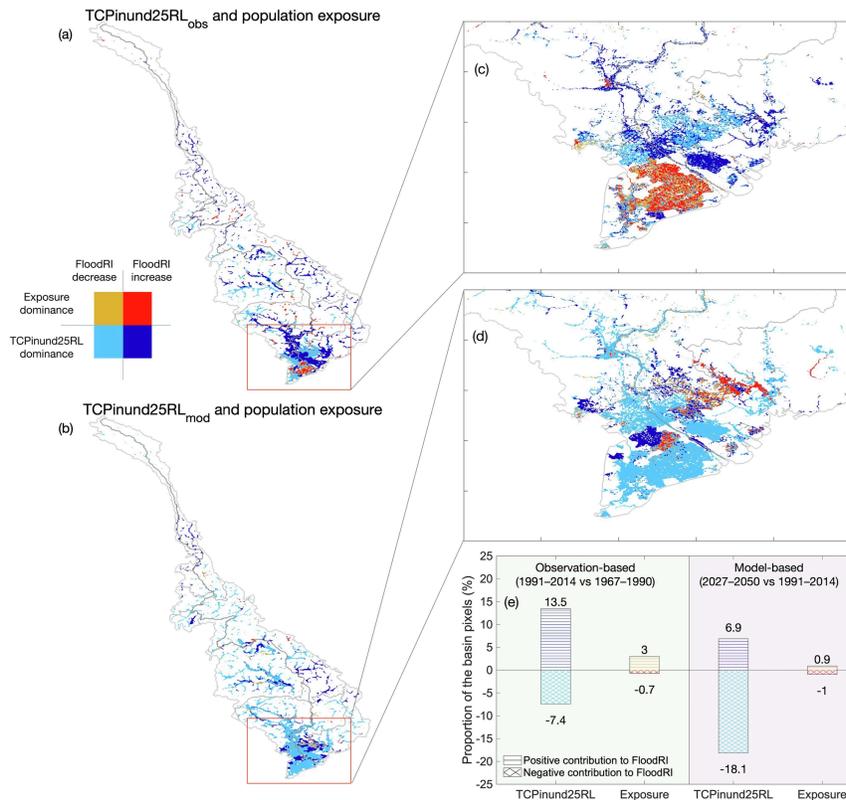
**Abstract:** Tropical cyclones have a big impact on flood risk, and understanding how their activity interacts with population exposure under climate change is critical. Here, we investigate spatiotemporal changes in flood risk using numerical models together with historical observations and future projections of tropical cyclone tracks. We find that tropical cyclone-related flood risk shifts from the Mekong Delta to the eastern lower Mekong Basin, driven by the interaction between tropical cyclones and population exposure. Historically, extreme precipitation from tropical cyclones increased flood risk in about 14% and decreased in 7% of the basin. Future tropical cyclones may increase flood risk in about 7% and reduce in nearly 18% of the basin. Moreover, population exposure growth has historically increased flood risk in 3% of the basin and is projected to result in a 1% increase. These findings highlight the complex interactions between tropical cyclone hazards and socioeconomic factors that influence flood risk.



Spatial patterns of mean annual daily extreme tropical cyclone precipitation (TCP) and their difference between 1967–1990, 1991–2014, and 2027–2050.



Spatial patterns of the 25-year return period of TCPinund (TCPinund25RL) and their difference between the historical and projected study periods.



Spatial patterns of the relative contributions of the 25-year return period of TCPinund (TCPinund25RL) and population exposure to changes in the flood inundation risk index (FloodRI) in the LMRB during the periods 1967–1990, 1991–2014, and 2027–2050.

## [A5] Climate change and effectiveness of dams in flood mitigation in India

Urmin Vegad & Vimal Mishra (Indian Institute of Technology (IIT) Gandhinagar)

npj Natural Hazards (2025). <https://doi.org/10.1038/s44304-025-00117-z>

### Abstract

India, the third-largest dam-building nation, highly relies on dams for irrigation, hydropower, and flood control. Observations show that dams both mitigated and triggered floods across Indian river basins. However, their effectiveness in mitigating floods under current and future climates remains unknown. Using in-situ and satellite observations and model simulations for 178 major dams, we show that flood mitigation depends more on antecedent reservoir storage than upstream rainfall. Downstream floods are more likely when reservoirs exceed 90% of their full capacity. The duration with reservoir storage exceeding 90% is projected to increase threefold at 3°C warming compared to 1°C. A substantial rise in compound events of high inflow and high antecedent reservoir storage is also projected from  $0.55 \pm 0.22$  events/year at 1°C warming to  $1.1 \pm 0.4$  events/year at 3°C warming. Our findings highlight the need for advanced approaches for dam operations (maintaining buffer storage) integrated with early warnings of extreme inflow in India.

### Research Questions:

- How do dams influence high-flow downstream of reservoirs during the summer monsoon season in India?
- To what extent precipitation in upstream catchments of dams and antecedent reservoir storage affect high-flow variability downstream of the dams? and
- How will the effectiveness of dams in reducing flood risk change under projected future climate scenarios?

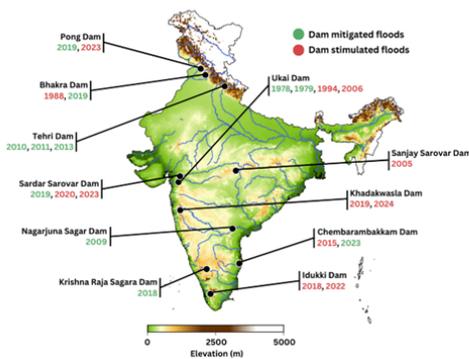


Figure: Reported cases highlighting the dual role of dams in flood events. Map illustrating the reported cases where dams played a major role in either mitigating or stimulating floods.

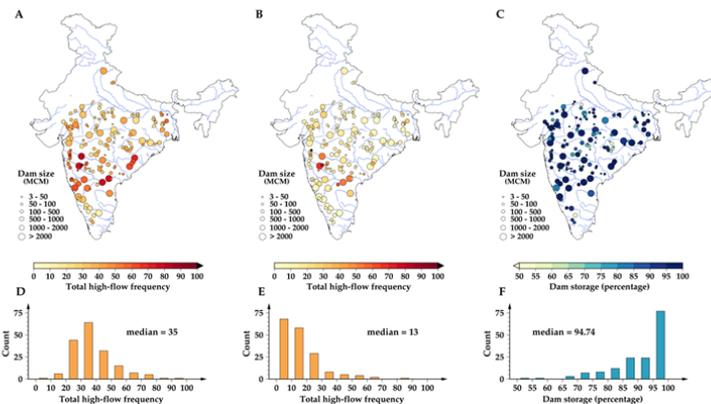
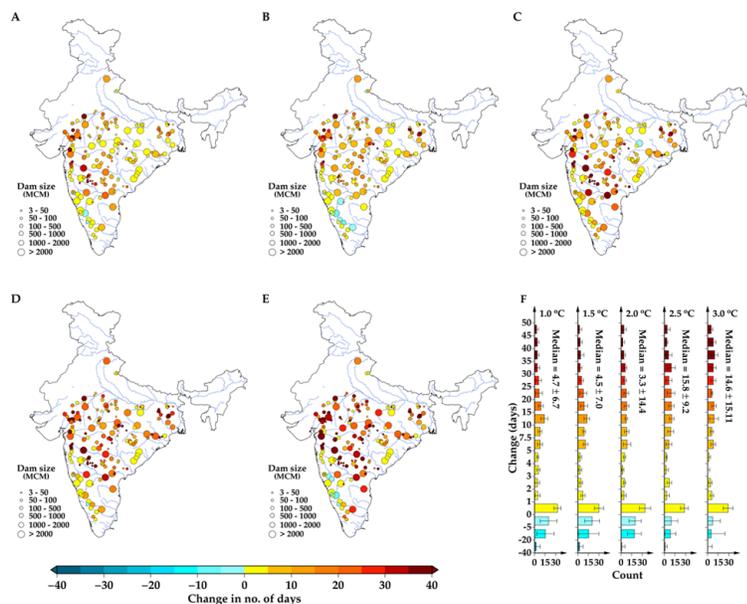


Figure: Changes in high-flow frequency and antecedent dam storage. (A) Total frequency of high-flows in the downstream of the dams under the NAI scenario for the 30-year period (1991–2020). (B) Total frequency of high-flows in the downstream of the dams under the DAM scenario for the 30-year period (1991–2020). (C) Corresponding antecedent dam storage one day before high-flow events in the DAM scenario. (D, E, F) Show distribution of values plotted in A, B, and C respectively.

## Influence of Dams in Reducing Future Flood Risk:



Climate change will prolong high-storage conditions in dams, with the number of days above 90% capacity increasing from  $4.7 \pm 6.7$  days at  $1^\circ\text{C}$  to  $14.6 \pm 15.1$  days at  $3^\circ\text{C}$  warming.

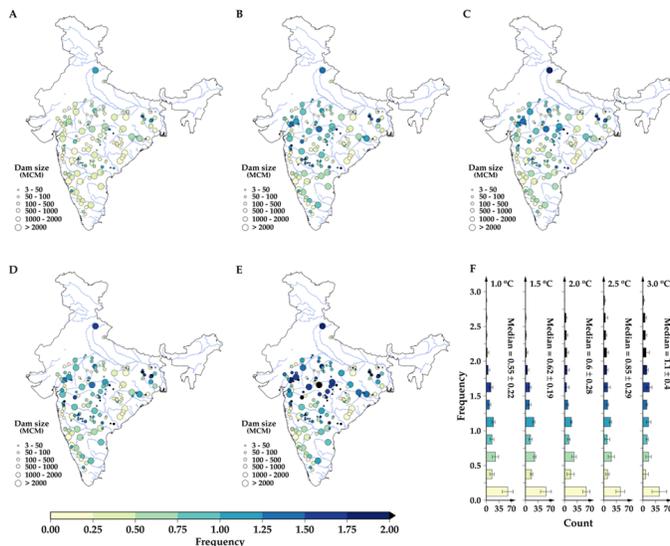
Prolonged periods of near-full storage reduce flood mitigation capacity, heightening downstream flood risk under higher warming levels.

**Figure:** Change in days with high dam storage levels under a warming climate. *Change in the number of days when dam storage remains full more than 90% of their live storage capacity for the selected global warming levels (A 1.0 °C, B 1.5 °C, C 2.0 °C, D 2.5°C, E 3.0°C). The change is computed against the historical reference period (1995–2014). (F) Distribution of change in the number of days when dam storage remains full more than 90% of their live storage capacity for the global warming levels shown through (A–E).*

The frequency of compound extremes (high inflow + >90% storage) is projected to double, increasing from  $0.55 \pm 0.22$  events/year at  $1^\circ\text{C}$  warming to  $1.1 \pm 0.4$  events/year at  $3^\circ\text{C}$ .

Rising compound events under higher warming levels highlight the urgent need for adaptive dam management to reduce downstream flood risks.

**Figure:** Frequency of the compound events of high inflow and nearly full dam storage under a warming climate. *Frequency of high inflow events when dam storage is more than 90% of total live storage for the selected global warming levels (A 1.0 °C, B 1.5°C, C 2.0°C, D 2.5°C, E 3.0°C). F Distribution of frequency of the compound event for the global warming levels shown through (A–E). The median  $\pm$  standard deviation is calculated across all GCMs.*



## Summary:

- Dams play a critical role in mitigating downstream flooding in India, but their effectiveness strongly depends on antecedent storage levels and adaptive management during the monsoon season.
- The duration of high storage conditions is projected to increase threefold at three degrees of warming compared to one degree. Compound events of high inflow and high antecedent storage are also projected to increase twofold.

## 2B. Highlight of CaMa-Flood development papers

### [B1] Rapid Assessment of Mega-Dam Impacts Using a Satellite-Derived Reservoir Operation Scheme

Youjiang Shen (University of Tokyo), Dai Yamazaki

Water Resources Research, 2025, <https://doi.org/10.1029/2024WR037620>

Journal of Hydrology: Regional Studies, 2025, <https://doi.org/10.1016/j.ejrh.2025.103017>

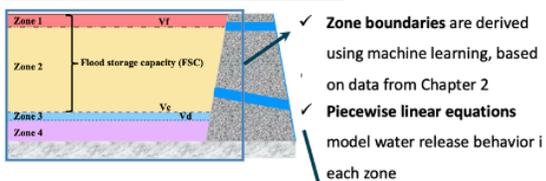
**Abstract:** As hundreds of mega-dams are planned globally, understanding their collective impact on river basins is essential for effective water management. We present a new Satellite-Based Target Storage (SBTS) scheme integrated with river modeling to provide these insights. SBTS is a generic, globally applicable method that uses satellite data and reservoir zoning to approximate operations for flood-control reservoirs, including newly built ones lacking local data. Applying this scheme within the CaMa-Flood model, we evaluate the impact of two recent mega-dams in the Yangtze River. Results show that these reservoirs are reshaping Yangtze hydrology to a degree comparable to the Three Gorges Dam. Our findings demonstrate that the SBTS framework allows for rapid, global-scale impact assessments of new reservoirs without requiring site-specific operational records, offering a powerful tool for large-scale hydrological monitoring.

#### Incorporating Satellite Observations to Develop a Model SBTS

**Core idea:** Can we use satellite observations to model reservoir operations more realistically worldwide?

**Rationale 1** – “Reservoirs typically have distinct storage zones, each serving a different purpose”

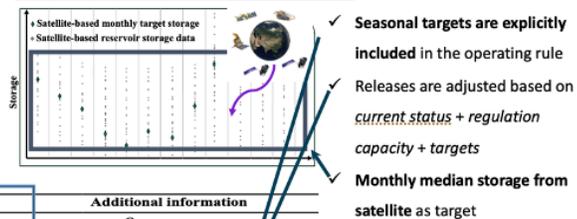
❖ I use Generic Reservoir Operating Zones



Storage zone	Equation
1. Overtopping prevention $V_t > V_f$	$Q_t = \max(Q_s, \frac{V_t - V_f}{\Delta t})$
2. Flood control $V_c < V_t \leq V_f$	$Q_t = r * Q_n + (Q_s - r * Q_n) * (\frac{V_t - V_c}{V_f - V_c})^k$
3. Water use and supply $V_d < V_t \leq V_c$	$Q_t = \max(Q_{min}, r * Q_n)$
4. Water use limitation $V_t \leq V_d$	$Q_t = \min(Q_{min}, \frac{V_t}{\Delta t})$

**Rationale 2** – “Reservoirs typically operate with seasonal targets, which are implicitly captured in historical storage time series”

❖ I use Dynamic Monthly Target Storage

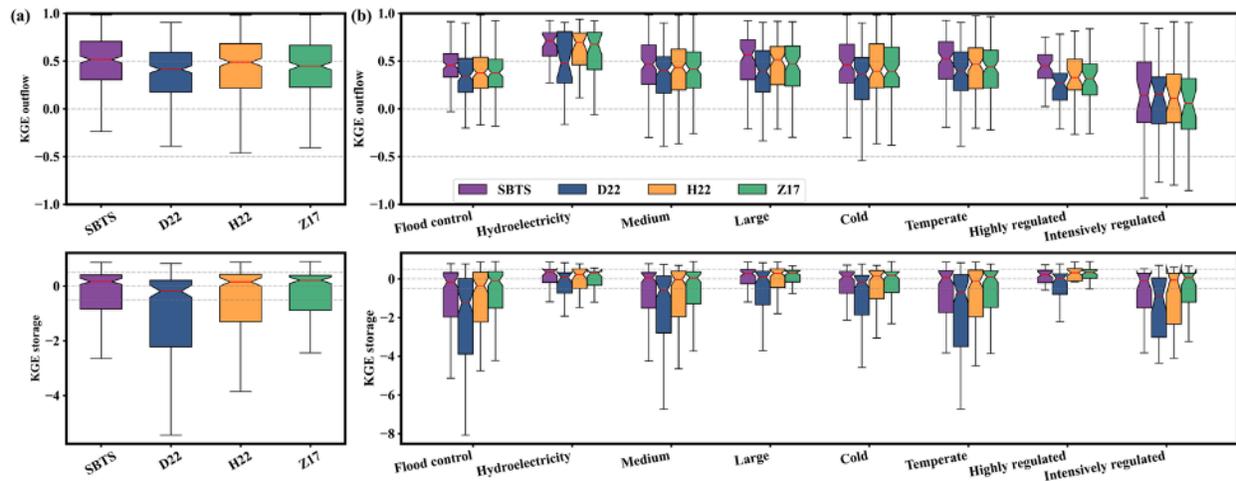


Additional information
$k = \frac{Q_s}{I_t}$
$r = (1 + \frac{V_t - V_{tar,m}}{V_c - V_d})^c$
$c = \min(1, \frac{Q_n}{3 * (V_c - V_d)})$

- Goal – make SBTS smarter to learn from the past
- First attempt to use satellite to develop a model.

**Overall Performance across Reservoirs** (Testing operational models at 289 reservoirs with observed inflows to assess outflow and storage simulations)

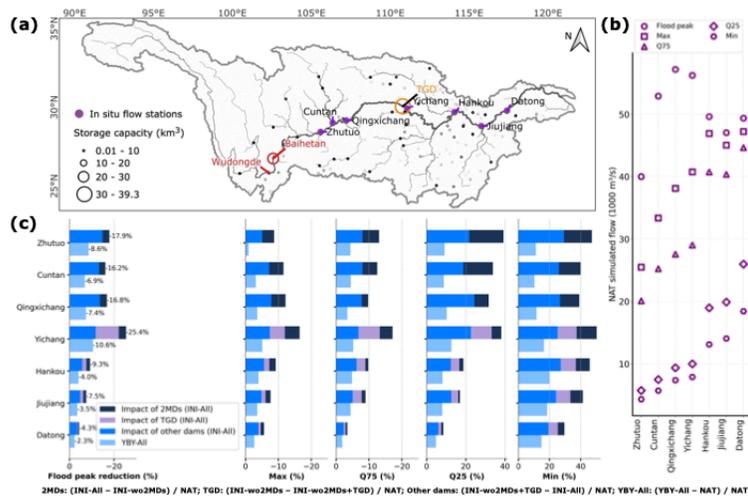
- Statistical Performance: SBTS achieves median KGE values of 0.52 for outflow and 0.17 for storage, outperforming D22 (0.41 and -0.19) and exceeding Z17 (0.45) and H22 (0.49) in outflow.
- Best Performance by Type: for reservoirs with regular inflow patterns (e.g., larger reservoirs, intensively managed basins, cold regions)



### Rapid Dam Impact Assessment Using SBTS

- Driven by increasing energy demands and climate mitigation goals, more than 3,400 hydroelectric plants over 1 MW are in planning or construction phases.
- New dams could further alter hydrological regimes and ecosystems.
- Timely assessment is crucial but hindered by lack of operational data.

**Case study & Results:** Recently, two mega-dams (hereafter, 2MDs) have been constructed upstream of the TGD: Wudongde (commissioned in 2021) and Baihetan (commissioned in 2022). Notably, Baihetan is the world's second-largest hydropower dam with a 20.6 km<sup>3</sup> storage capacity. Their storage capacity is 28.2 km<sup>3</sup>, which is equivalent to 70% of the TGD capacity. Given their immense size and capacity, they are likely to have substantial impacts comparable to those of the TGD. The potential flood peak reduction and flow alterations by 2MDs is remarkably comparable to that of the TGD.



### Summary:

1. We developed a generic, globally applicable reservoir operation model SBTS, using satellite observations, explicitly accounting for complex local operations.
2. It enables rapid impact assessments of new mega reservoirs.

## [B2] Does Spatial Resolution Matter? Effects on Large-Scale Hydrodynamic Simulations

Prakat Modi (Shibaura Institute of Technology),

Dai Yamazaki, Yukiko Hirabayashi, Menaka Revel, Xudong Zhou

*Journal of Advances in Modelling Earth Systems*, 2025, <https://doi.org/10.1029/2025MS004961>

**Abstract:** Large-scale hydrodynamic models are essential for assessing global flood risks and understanding the water cycle, yet they often face uncertainties related to spatial resolution. An analysis has been performed using the Catchment-based Macro-scale Floodplain (CaMa-Flood) model to evaluate how varying spatial resolutions (1, 3, 6, and 15 arcmin) impact simulated discharge, water depth, and flood extent in the Amazon River basin. The study found that sub-grid parameterization allows low-resolution simulations to achieve high consistency with high-resolution simulations as a benchmark. The inter-resolution model comparison showed coefficients of determination ( $R^2$ ) exceeding 0.88 in over 80% of locations, and normalized Nash-Sutcliffe efficiencies (NNSE) for discharge and water depth were greater than 0.83 and 0.68, respectively, for more than 75% locations. However, localized discrepancies ( $\sim 2.5\text{-}3\%$  of sites) persist due to limitations in representing bifurcation flow, floodplain conveyance, backwater effects, and channel bottlenecks. Ultimately, a 6-arcmin resolution offers an optimal balance between computational efficiency and simulation accuracy.

**Introduction:** Hydrodynamic modelling at continental and global scales is constrained by uncertainties in model structures, input data (like DEMs), and spatial resolution. While higher resolution is traditionally thought to provide more realistic terrain and flow representation, its impact on large-scale performance remains debated, with some studies showing minimal gains. Most previous research has focused solely on discharge at gauged sites, neglecting other variables like water depth and flood extent spatial patterns. This study addresses these gaps by using the Amazon River basin, the world's largest drainage system, as a testbed to identify where and why resolution matters in large-scale simulations.

**Methodology:** The research utilized the CaMa-Flood model, which treats river and floodplain hydrodynamics as sub-grid physics, with key parameters such as channel width, depth, and floodplain topography derived from high-resolution (3 arcsec) MERIT Hydro and MERIT DEM data, ensuring scale-independent physics. The model routes runoff through a unit-catchment-based network using the local inertial equation, which accounts for backwater effects and flood attenuation. Simulations were conducted at 1, 3, 6, and 15 arcmin resolutions, with higher resolution considered as reference for comparison among any two resolutions (Figure 1). To ensure consistent comparison across

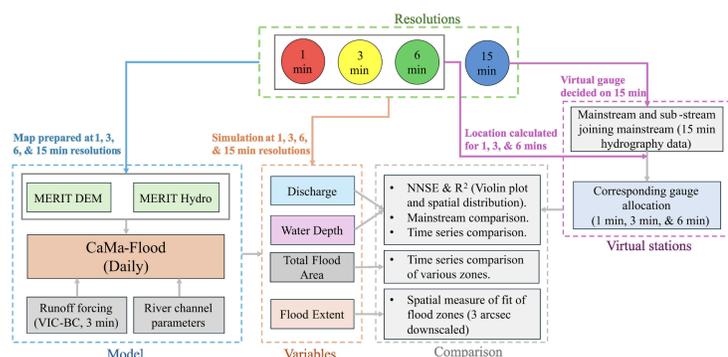


Figure 1: Experimental design framework for comparing the CaMa-Flood model across multiple spatial resolutions

scales, 1,198 virtual gauging stations were established at the 15-arcmin resolution and mapped to the higher-resolution grids. Performance was measured using Normalized Nash-Sutcliffe Efficiency (NNSE) and coefficient of determination ( $R^2$ ), for discharge and water depth. Flood extent was evaluated using the Critical Success Index (CSI) after downscaling to a 3-arcsec resolution.

**Results and Discussion:** The study demonstrated that CaMa-Flood's sub-grid parameterization effectively maintains consistency across scales. For discharge, 80% of stations showed an NNSE between 0.86 and 0.95 across 1, 3, and 6 arcmin resolutions. The high agreement in discharge and water depth suggests that the model's physics are largely scale-independent when sub-grid parameters are accurately upscaled from high-resolution data. The 6-arcmin resolution emerged as a highly practical choice, requiring approximately 450 times less runtime than the 1-arcmin simulation while maintaining comparable performance at most locations. Despite general agreement, significant discrepancies were found in a small percentage of locations, primarily driven by four physical mechanisms:

**1. Bifurcation Flow:** Differences in the net flow around river deltas and junctions occurred because low-resolution grids sometimes struggled to consistently represent complex branching networks (Figure 2, location 2).

**2. Floodplain Conveyance:** Low-resolution simulations often overestimated floodplain discharge by assuming a uniform cross-sectional area, which treats tributary floodplains as part of the main stream's conveyance (Figure 2, location 12).

**3. Backwater Effects:** These were sensitive to the relative positions of tributary and mainstream outlets, which can shift between resolutions (Figure 2, location 6).

**4. Channel Bottlenecks:** Sudden narrowing in river width, which causes upstream water level rises, was better captured at 1-arcmin resolution than at 15-arcmin (Figure 2, locations 7 & 8). The model effectively reproduced flood patterns for large streams (CSI values of 0.83-0.96). However, small sub-streams showed significant discrepancies (CSI values as low as 0.38). This is attributed to the fact that lower-resolution unit catchments cannot resolve small tributaries, leading to "missed" flooding in these areas despite downscaling efforts.

**Conclusions:** Model simulations are unaffected by the spatial resolution at most of the locations. For most global and continental applications, a moderate resolution of 6-arcmin is sufficient and efficient. Future model improvements should focus on updating the bifurcation channel representation in baseline hydrography data, improving floodplain parameterization to prevent over-conveyance in flat terrain, and river width parameters to improve the water depth simulation. Enhancements in downscaling methods can help to capture inundation from small tributaries. These advancements will allow large-scale models to better represent small-scale phenomena without necessitating the extreme computational costs of high-resolution simulations.

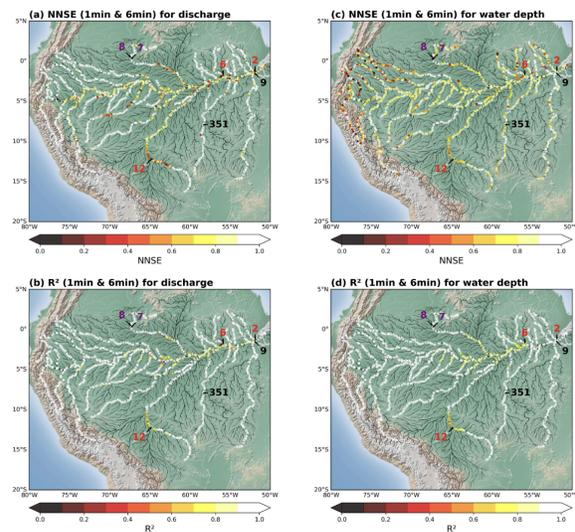


Figure 2: Spatial distribution of NNSE and  $R^2$  for all virtual locations considering 1 and 6 arcmin simulations<sup>4</sup>

## [B3] Analysis and comparison of the flood simulations with the routing model CaMa-Flood at different spatial resolutions in the CONUS

Ruijie Jiang (Tsinghua University), Hui Lu, Kun Yang, Hiroshi Cho, Dai Yamazaki

Environmental Modelling & Software, 2025, <https://doi.org/10.1016/j.envsoft.2024.106305>

**Abstract:** Accurate flood modelling is crucial for disaster prevention. Fine-resolution global routing models can offer more detailed flood information, but balancing model efficiency with accuracy remains challenging. This study examines the conditions under which a fine-resolution model outperforms a coarser one, using the CaMa-Flood model at 0.05°, 0.083°, 0.1°, and 0.25° resolutions across the contiguous United States. The results indicate finer resolution does not improve the simulation of flood timing, but better simulates the daily river discharge and flood peak flow due to better representation of the river network in small rivers. Notably, the improvement in daily discharge simulation is greater than that in peak flow. Nevertheless, uncertainties in channel parameters mean that a more detailed river network does not necessarily yield better flood simulations. For rivers with upstream drainage areas greater than 500 km<sup>2</sup>, a 0.25° model is sufficient if high-precision channel parameters are unavailable.

**Introduction:** The resolution of routing models is also a crucial factor that affect the accuracy of the flood simulation. With recent improvements in computational resources, the availability of high-precision topographic data, and the development of high-resolution runoff data, fine-resolution flood simulation has become possible. However, utilizing fine-resolution routing models also means consuming more computing resources. Balancing model efficiency and accuracy remains a significant challenge. There remains a knowledge gap regarding the optimal level of model resolution at which the real-world river network can be accurately represented.

### Results

(1) The CaMa-Flood model, with a resolution of 0.05°, 0.083°, 0.1° and 0.25°, is capable of accurately representing the upstream drainage areas for reaches with an upstream drainage area larger than 100, 300, 500 and 2,500 km<sup>2</sup>, respectively (Fig. 1). The areas of one 0.05°, 0.083°, 0.1° and 0.25° grid are nearly 25, 70, 100 and 625 km<sup>2</sup>. Therefore, for the accurate representation of river network, a resolution can be selected if the target watershed can be represented by more than four grids of that resolution.

(2) For the river reaches with upstream drainage areas larger than 100 km<sup>2</sup>, the flood peak flow simulated by 0.05°, 0.083°, and 0.1° CaMa-Flood are comparable (Fig. 3). For the river reaches with upstream drainage areas larger than 500 km<sup>2</sup>, the flood peak flow simulated at different resolutions by CaMa-Flood are comparable, indicating that increasing the resolution of the routing model didn't improve the simulation of flood peak flow for large reaches.

(3) When the resolution of the CaMa-Flood model shifts from coarse to fine, the proportion of stations exhibiting improvements in annual maximum discharge is generally smaller than the proportion of stations showing enhanced upstream drainage area. This can be partially attributed to the uncertainty of channel parameters.

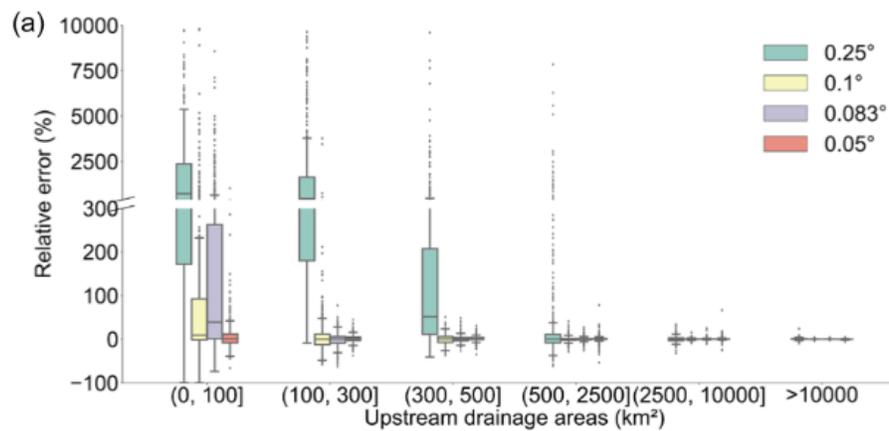


Figure 1. Relative error of upstream drainage area compared to observations at different resolutions for different sized rivers.

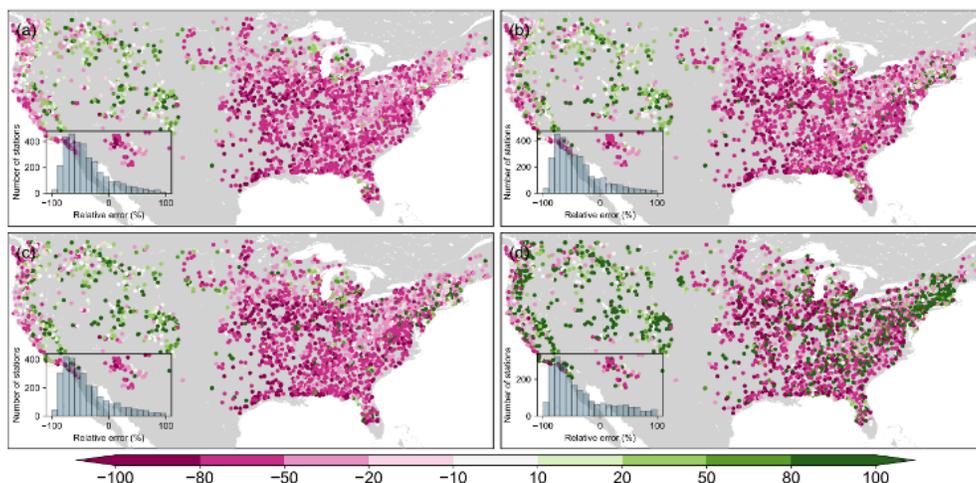


Figure 2. The relative error (%) of the multi-year average annual maximum discharge simulated by CaMa-Flood at different resolutions: (a) 0.05°, (b) 0.083°, (c) 0.1° and (d) 0.25°.

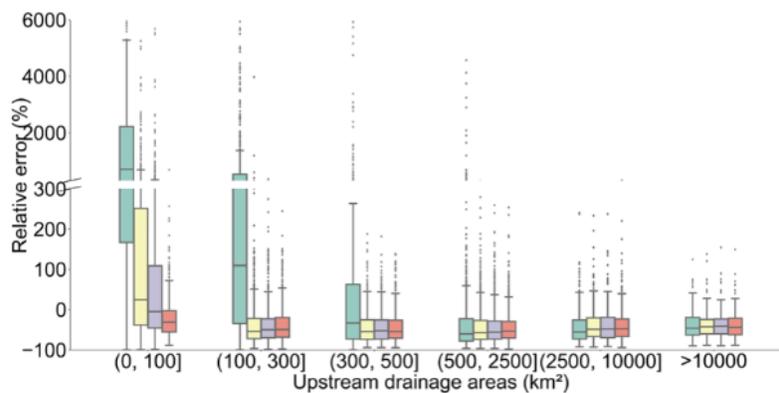


Figure 3. Relative error of multi-year average annual maximum discharge simulated by CaMa-Flood at different resolutions for different sized rivers.

## [B4] Assessment of JULES land surface model coupled with CaMa-Flood for an operational streamflow forecasting across Australia

Fitsum Woldemeskel (Bureau of Meteorology, Australia), Christoph Rüdiger, Dai Yamazaki, Siyuan Tian, Huqiang Zhang, Toby Marthews, Jiawei Hou, Wendy Sharples, Chun-Hsu Su, Martin Best, Elisabetta Carrara  
Hydrological Processes, 2025, <https://doi.org/10.1002/hyp.70345>

Hydrological forecasts are essential for managing water resources and providing early warnings during extreme events. This study 1-way coupled the gridded river routing scheme CaMa-Flood with the JULES land surface model (and others for comparison) to simulate the streamflow dynamics across Australia. The performance of the streamflow simulations was evaluated across 452 gauge locations in various hydroclimate regions (Figure 1). To contextualise the results, the streamflow simulations from JULES were compared with the Bureau's operational water balance model, AWRA-L, as well as two reanalysis products, ERA5-Land and BARRA-R2.

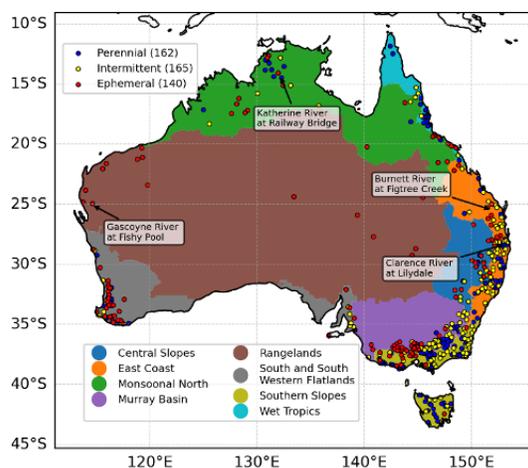


Figure 1: Locations of the Hydrologic Reference Stations (HRS) catchments used in this study.

Different models show varying runoff patterns across Australia due to different physical processes within the models, land cover parameterisations, and the impact of data assimilation on the water balance within the reanalyses. Based on the estimated runoff coefficients, it was found that offline JULES and AWRA-L generally produce better runoff outputs. However, offline JULES tends to overestimate runoff in central north Australia, while AWRA-L overestimates runoff in southeast Australia and eastern Tasmania. BARRA-R2 overestimate runoff in central north Australia but underestimates it in southeast Australia, while ERA5-Land underestimates runoff in southeast and southwest Australia. All models tend to underestimate runoff when the runoff coefficients are relatively high ( $>0.5$ ), particularly in far north Australia and western Tasmania. These differences in spatial runoff are mainly related with the respective rainfall forcing as well as the runoff generation

mechanisms within the models. Similar conclusion can be drawn from streamflow simulations when coupled with CaMa-Flood (Figure 2). Offline JULES and AWRA-L demonstrate high model performance with less bias and higher correlation coefficients than BARRA-R2 and ERA5-Land for both daily and monthly timescales. In terms of flow regimes, models generally perform well for perennial catchments, followed by intermittent ones, but show relatively low performance in ephemeral catchments. Whilst runoff generation processes in the models can be attributed to these differences, the rainfall forcing within BARRA-R2 and ERA5-Land can be erroneous and introduce large uncertainty.

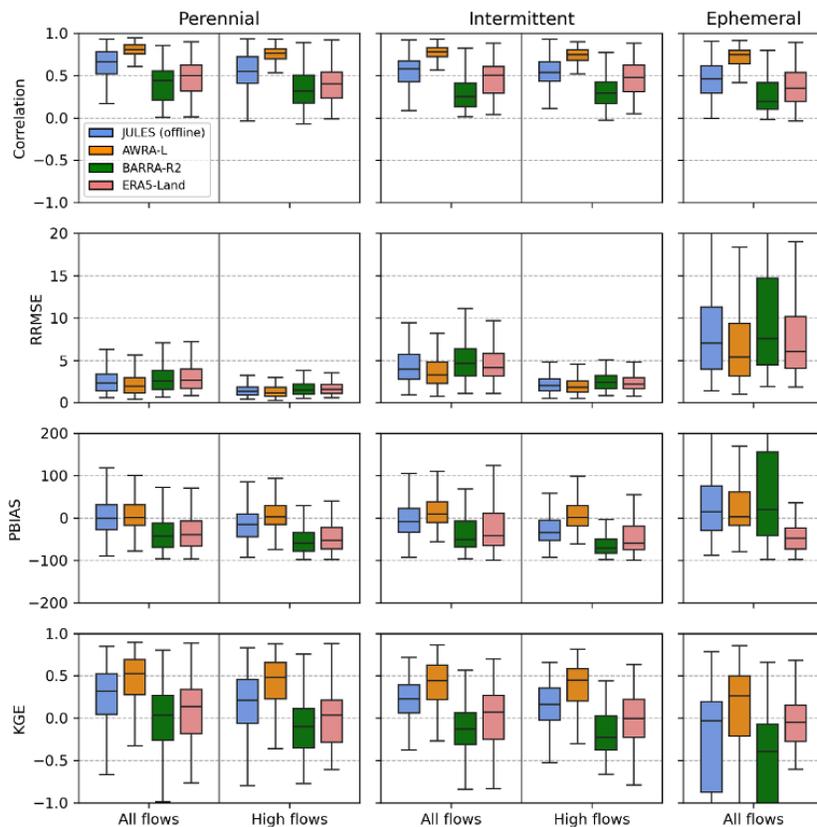


Figure 2: Performance of simulated streamflow in terms of Correlation, RRMSE, PBIAS and KGE metrics across the 452 Hydrologic Reference Stations (HRS) catchments at a daily timescale.

In conclusion, it is encouraging that the JULES land surface model coupled with CaMa-Flood has demonstrated streamflow simulation capabilities comparable to AWRA-L to simulate the unique hydrodynamics of Australia. Ongoing enhancements to the JULES model are expected to further improve the results, paving the way for using JULES coupled with CaMa-Flood as a foundation for continental-scale hydrological modelling. This approach, integrated with Numerical Environmental and Weather Prediction (NEWP) modelling capabilities, moves us closer to achieving a fully coupled land-atmosphere-ocean modelling system.

## [B5] Benchmark Framework for Global River Models

Xudong Zhou (Ningbo University), Dai Yamazaki, Menaka Revel, Gang Zhao, Prakat Modi

**Journal of Advances in Modeling Earth System**, 2025, <https://doi.org/10.1029/2024MS004379>

**Abstract:** Global River Models (GRMs), which simulate river flow and flood processes, have rapidly developed in recent decades. However, these advancements necessitate meaningful and standardized quality assessments and comparisons against a suitable set of observational variables using appropriate metrics, a requirement currently lacking within GRM communities. This study proposes implementing a benchmark system designed to facilitate the assessment of river models and enable comparisons against established benchmarks. The benchmark system incorporates satellite remote sensing data complementing in-situ data, including water surface elevation and inundation extent information, with necessary preprocessing. Consequently, this evaluation system encompasses a larger geographical area than traditional methods relying solely on in-situ river discharge measurements for GRMs. A set of evaluation and comparison metrics has been developed, including a quantile-based comparison metric that allows for a comprehensive analysis of multiple simulation outputs. The test application of this benchmark system to a global river model (CaMa-Flood), utilizing diverse runoff inputs, illustrates that incorporating bias-corrected runoff data leads to improved model performance across various observational variables and performance metrics. The current iteration of the benchmark system is suitable for global-scale assessments and can effectively evaluate the impact of model development and facilitate intercomparisons among different models. The source codes are accessible from <https://doi.org/10.5281/zenodo.10903210>.

The study introduces the first standardized benchmark system specifically designed for Global River Models (GRMs). It enables comprehensive, rapid, and reproducible model evaluation using three key variables including remote sensing data

- River discharge (Q) from in-situ data (e.g., GRDC)
- Water surface elevation (WSE) from satellite altimetry (e.g., HydroWeb)
- Inundation extent (WSA) from remote sensing (e.g., GIEMS-2)

Novel allocation strategies ensure accurate matching between model grid cells and observational data, with a two-step method using upstream area and river network topology (MERIT Hydro) to resolve mismatches near confluences or tributaries for river discharge. The AltiMap procedure corrects for elevation offsets and misallocations in virtual stations for WSE. The downscaling and aggregation techniques align model outputs with coarse-resolution satellite grids for WSA.

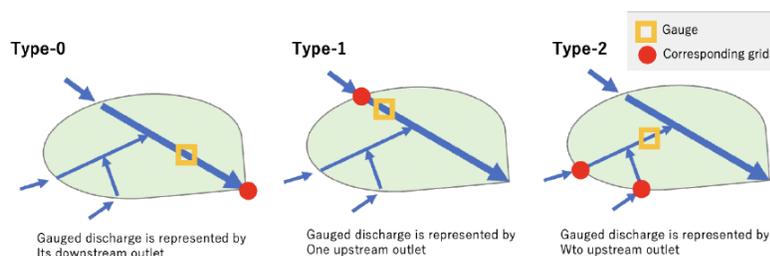


Figure 1. Allocation of River Discharge Gauge

A percentile-based comparison index that evaluates model improvements relative to the distribution of baseline performance is introduced. This method is unitless, scale-invariant, and robust across different variables and regions, enabling fair intercomparison and aggregation of multi-metric results.

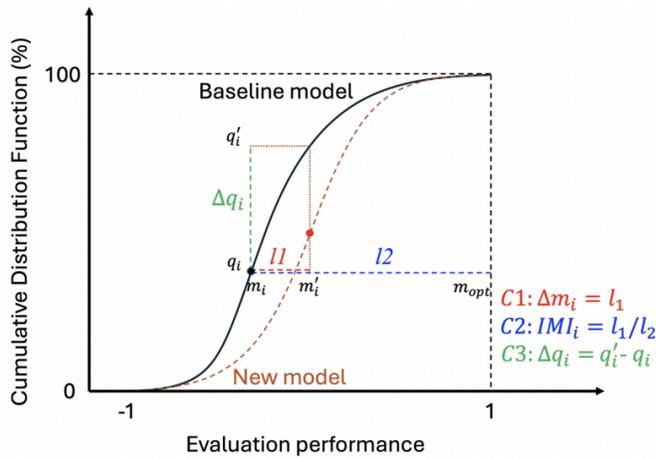


Figure 2. Illustration of different comparison metrics.

The framework is open-source, modular, and supports replacement or addition of observational datasets (e.g., SWOT, ICESat-2), integration of new evaluation metrics, comparison of different model versions or entirely different models.

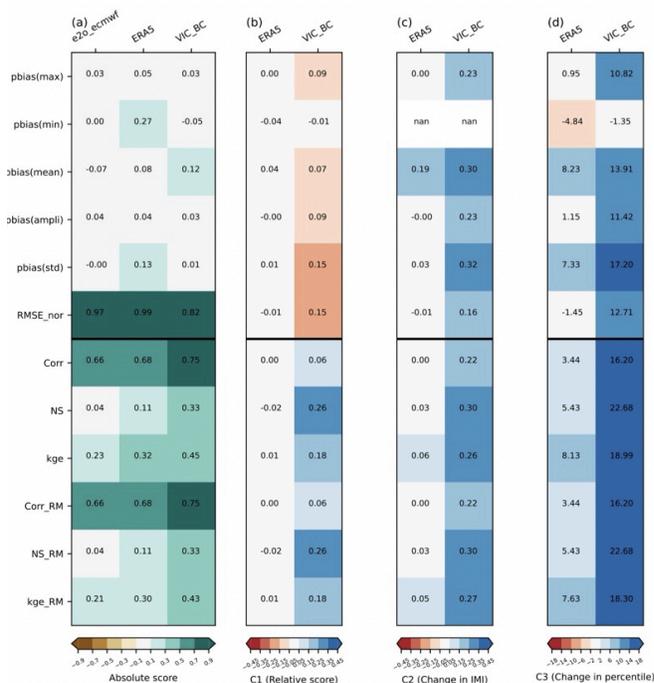


Figure 3. Overall performance comparisons among different model settings.

### 3. Reports on related events & info on upcoming meetings.

#### [X1] CaMa-Flood user/developer meeting 2026

We are planning to have the 2nd CaMa-Flood user/developer meeting, through 10-11 September 2026 (Thu-Fri) in ECMWF, Reading, United Kingdom.

The details of the meeting and registration will be announced soon after the annual progress briefing 2025.

The meeting info is available here.

<https://global-hydrodynamics.github.io/cmfm-meet/>



(Photo from CaMa-Flood user/developer meeting 2024).

#### [X2] AOGS Large-scale River Modelling session

We organized “Advances in Large-scale River Modeling: Developments and Applications” session in AOGS 2025 in Singapore. We hosted 12 Oral presentations + 10 Poster.

**Invited Speaker:**

**Dr. Qihong Tang (Institute of Geographic Sciences and Natural Resources Research, CAS)**

The same session “Advances in Large-scale River Modeling: Developments and Applications” will be held in AOGS 2026 in Fukuoka Japan. Please come to Japan and join the session!.



**Submit Now (Session ID: HS12, Due: Jan 23, 2026)**  
<https://www.asiaoceania.org/AOGS2026/Home>

**Abstract Call: H12. Recent Advances in Large-scale River Modeling**

Large-scale river modeling has continuously evolved in recent years. This evolution is due to many factors such as better conceptualization of river flow physics, new schemes to represent river infrastructures, advancement of baseline geography data like elevation and river networks, and increasing computational resources. These advancements enabled more advanced applications of large-scale river models, such as global-scale flood risk assessment, real-time flood forecast on the continental scale, coupling with Earth system models, and integration of satellite river observations into models through data assimilation. In this session, we welcome any research topics related to the development and/or applications of large-scale river models. New scientific discoveries obtained from large-scale river modeling and/or local decision-support applications are also welcome to submit. We will review the frontier research on large-scale river modeling and discuss next challenges and future directions.

Invited Speakers	 Paul Bates (Uni. Bristol)	 Tamlin Pavelsky (Uni. North Carolina)	 Yoshito Sugawara (Kyoto Uni.)	 Grey Nearing (Google)
Conveners	 Dr Dai Yamazaki (Tokyo Uni., Japan)	 Dr Peirong Lin (Peking Uni., China)	 Dr Fitsum Woldemeskel (BOM, Australia)	 Dr Xudong Zhou (Ningbo Uni., China)

**Paul Bates:** Development of a catastrophe risk model for global flood losses  
**Tamlin Pavelsky:** Improved global representation of river form and processes from SWOT  
**Yoshito Sugawara:** Compound Flooding Using High-Resolution Hydrological and Coastal Model with Large Ensemble Climate Simulations  
**Grey Nearing:** Google's Operational Flood Forecasting with Machine Learning

**Contacts:**  
 Dai Yamazaki: [yamadai@ijs.u-tokyo.ac.jp](mailto:yamadai@ijs.u-tokyo.ac.jp)  
 Xudong Zhou: [zhouxudong@nbu.edu.cn](mailto:zhouxudong@nbu.edu.cn)

## HS12: Recent Advances in Large-scale River Modeling 2026

Large-scale river modeling has continuously evolved in recent years. This evolution is due to many factors such as better conceptualization of river flow physics, new schemes to represent river infrastructures, advancement of baseline geography data like elevation and river networks, and increasing computational resources. These advancements enabled more advanced applications of large-scale river models, such as global-scale flood risk assessment, real-time flood forecast on the continental scale, coupling with Earth system models, and integration of satellite river observations into models through data assimilation. In this session, we welcome any research topics related to the development and/or applications of large-scale river models. New scientific discoveries obtained from large-scale river modeling and/or local decision-support applications are also welcome to submit. We will review the frontier research on large-scale river modeling and discuss next challenges and future directions.

### <Invited Speakers>

**Paul Bates** (University of Bristol) Development of a catastrophe risk model for global flood losses  
**Tamlin Pavelsky** (University of North Carolina) Improved global representation of river form & processes from SWOT  
**Kaito Sugawara** (Kyoto University) Compound Flooding Using High-Resolution Hydrological and Coastal Model with Large Ensemble Climate Simulations  
**Grey Nearing** (Google) Google's Operational Flood Forecasting with Machine Learning

### <Conveners>

**Dai Yamazaki, Xudong Zhou, Peirong Lin, Fitsum Woldemeskel**

## CaMa-Flood annual briefing: Logistics

### Organizing Committee

- Dai Yamazaki (Chair, UTokyo)
- Zhou Xudong (Ningbo Univ)
- Gang Zhao (Science Tokyo)

Please email to Dai Yamazaki ( yamadai [at] iis.u-tokyo.ac.jp ) for question about the meeting.

## CaMa-Flood resources

### [1] Product Webpage

<https://global-hydrodynamics.github.io/CaMa-Flood/>

### GitHub repository

[https://github.com/global-hydrodynamics/CaMa-Flood\\_v4](https://github.com/global-hydrodynamics/CaMa-Flood_v4)

### [2] Meeting Webpage

#### Annual Progress Briefing

<https://global-hydrodynamics.github.io/cm-f-annual-brief/>

#### User/developer meeting

<https://global-hydrodynamics.github.io/cm-f-meet/>

### [3] User mailing list

Join directly via the Google Groups page:

<https://groups.google.com/g/cama-flood-user>

Register via the Google Form:

<https://forms.gle/ziBMvBsPREcTkrDX7>