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Does High-Resolution Downscaling Improve the Accuracy of Global Flood Model Inundation Estimates?

An Analysis Across Biomes

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Research Questions and Presentation Agenda

Primary Analysis – Q1

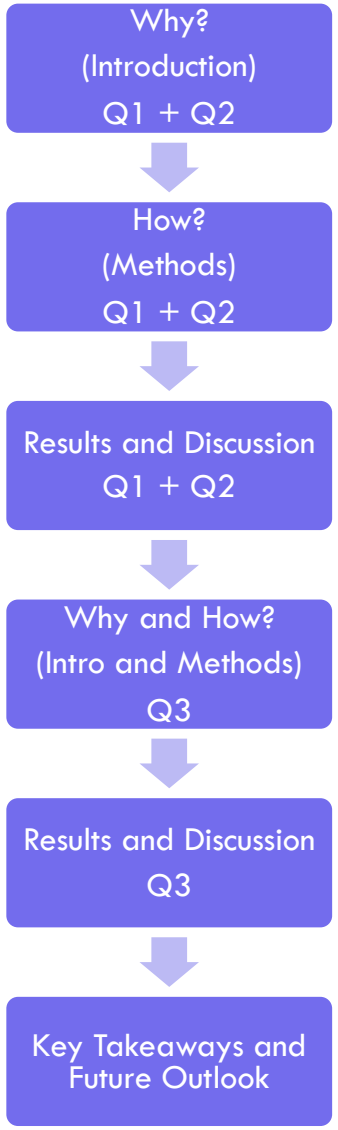
Evaluate if downscaling to 15 arcsec vs. 1 arcmin measurably improves performance.

Secondary Analysis – Q2

Compare downscaling vs. resampling to isolate resolution effects and validation impacts.

Tertiary Analysis – Q3

Assesses if downscaling performance differs across the ecological context biome.



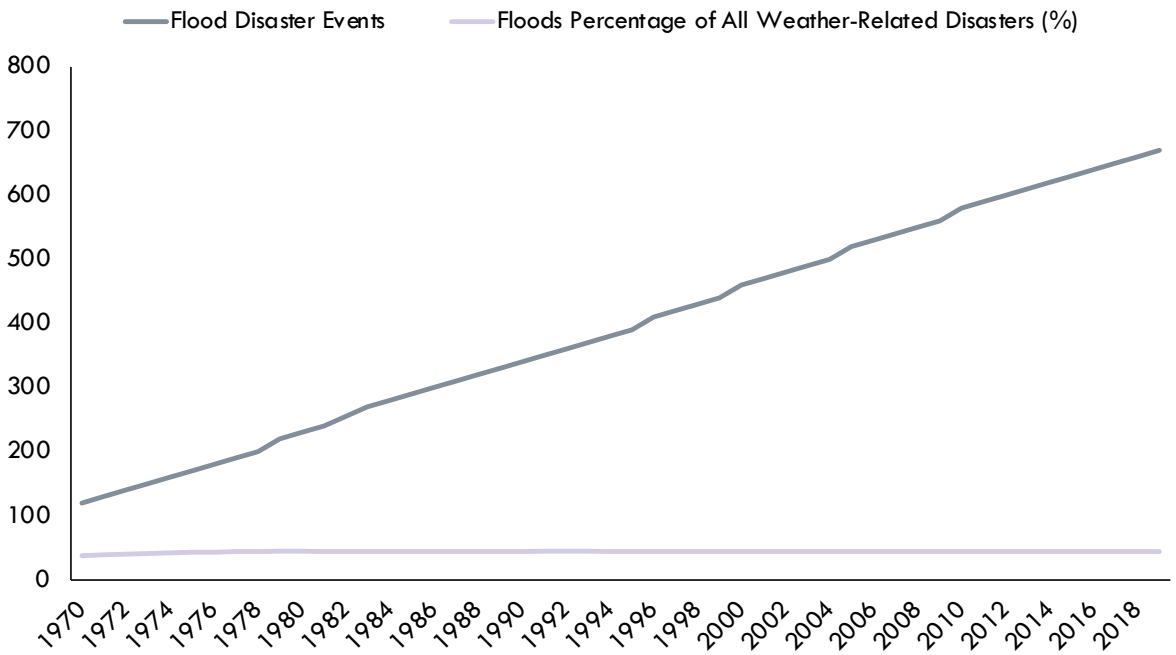
Introduction

Why Study Floods?

Flood Frequency and Risks

- Floods are most frequent weather-related natural hazard (44% from 1970-2019).
- Can cause billions in damages and widespread loss of life
- Flood hazards are increasing in frequency and magnitude
- Rising flood risks threaten sustainable development

Flood Frequency and Risks



Introduction

Global Flood Models: Potential and Limitations

Global Flood Models' Strengths

- Consistent, global flood mapping using standardized methods,
- Filling gaps in regions without local flood data or models

Limitations and Challenges

- Limited local detail—insufficient for floodplain plans
- Need higher spatial resolution for decisions

Research Gap

- Higher resolution increases model complexity
- Must be justified by clear gains in accuracy

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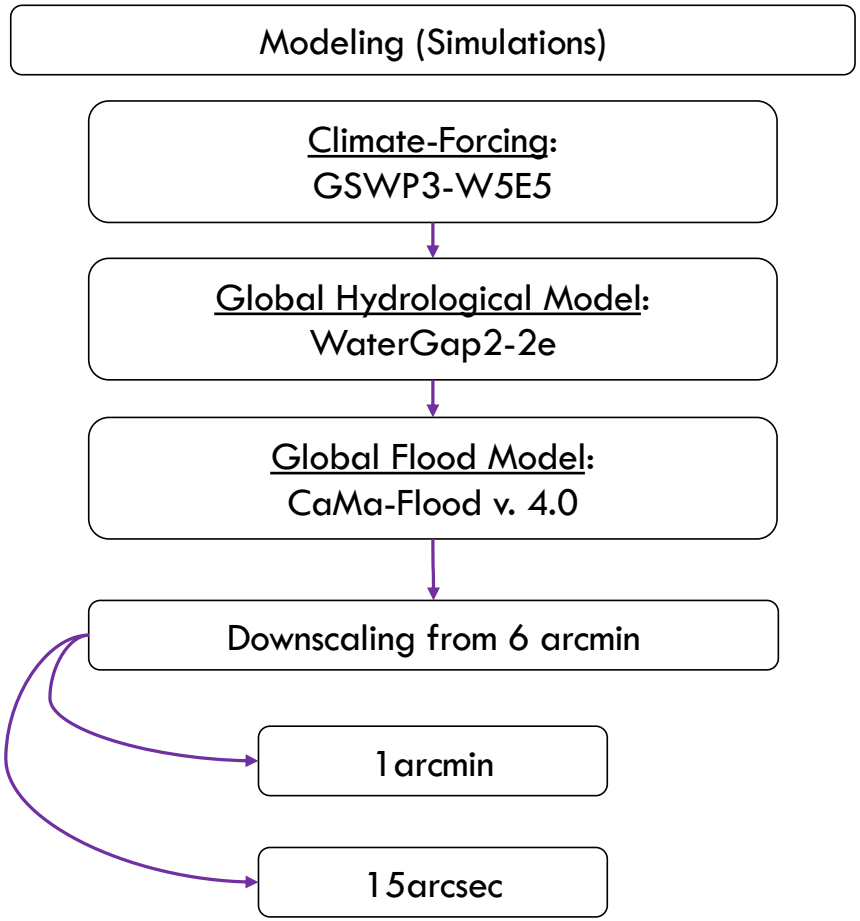
- Must be justified by clear gains in accuracy

Primary Research Aim:

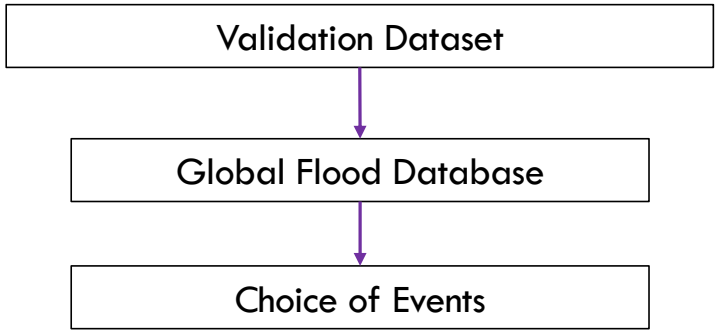
Systematically investigate whether enhancing the resolution of a Global Flood Model through downscaling yields significant accuracy gains.



Methods

Flood Simulation and Downscaling

- CaMa-Flood is a cascade Global Flood Model
- Resolution Enhancement via diagnostic downscaling
  - Distributes daily flood volumes from coarse grid to finger grids based on elevation
  - Elevation derived from digital elevation model MERIT



- **Event selection criteria:**
  - Major disasters on **large river systems**
  - Excluded coastal & infrastructure-related floods
  - Limited to **events from 2019** (climate data availability)
  - Chose **4 distinct terrestrial biomes** for eco-hydrological diversity

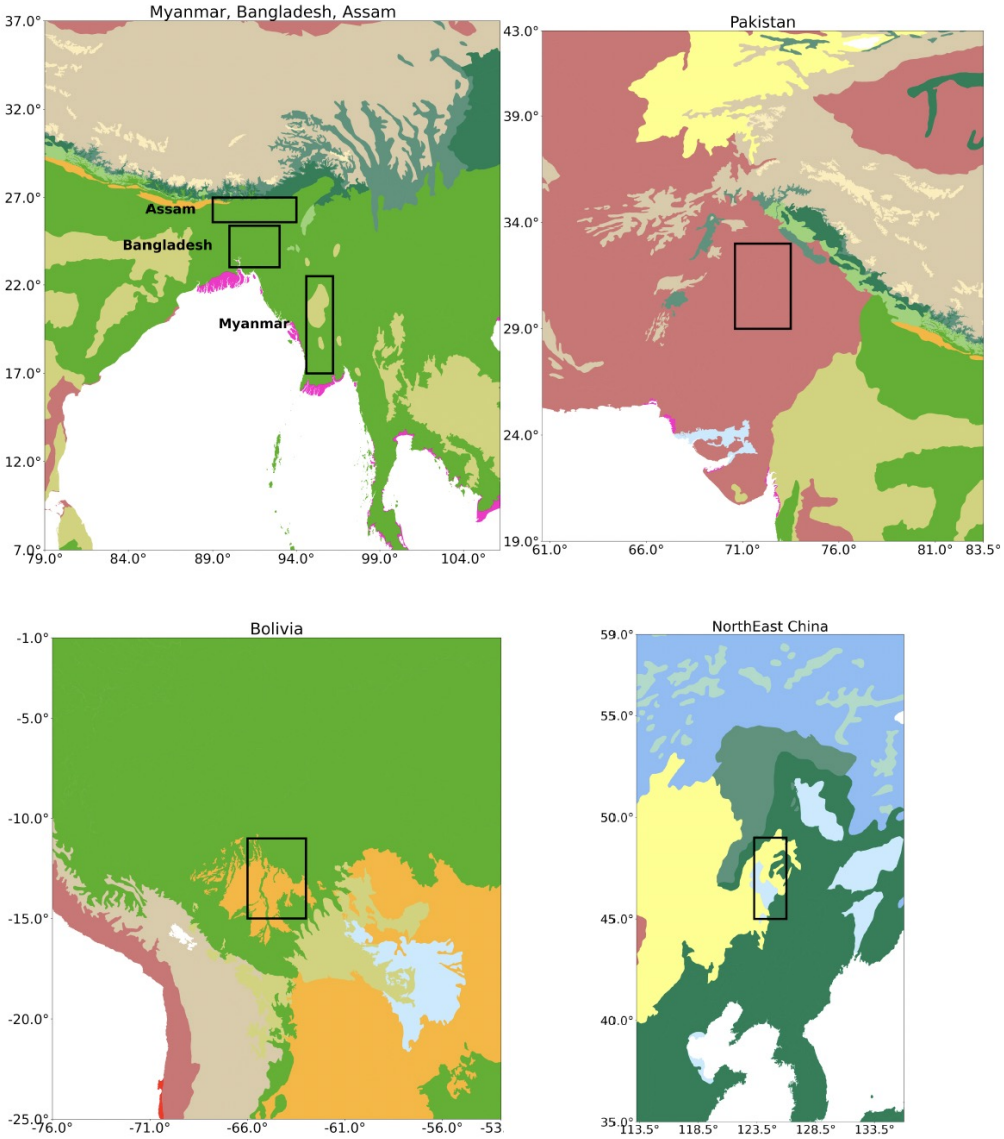
Validation with Observed Flood Data

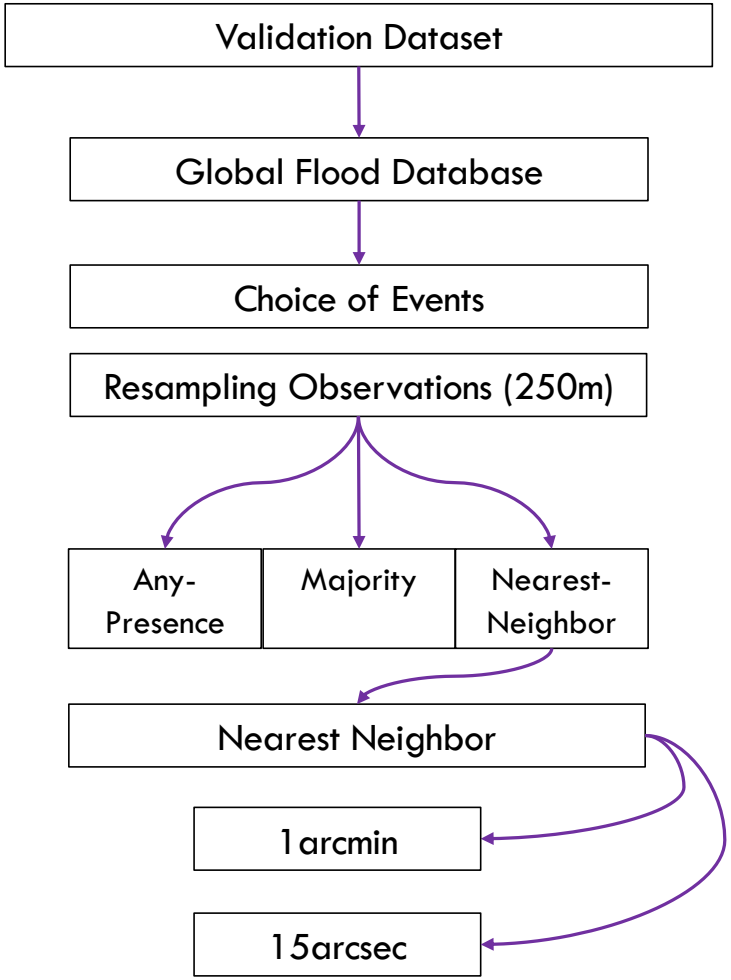
- Compared simulations at **1 arcmin & 15 arcsec** against an **independent reference map**
- **Reference data: satellite-derived flood maps**
- Used **Global Flood Database** (Tellman et al., 2021)
- Contains **250 m resolution maps** of **913 large flood events**

- Methods

Regions

- Assam (3 events)
- Bangladesh (3 events)
- Myanmar (2 events)
- Pakistan (2 events)
- Bolivia (4 events)
- NorthEast China (4 events)





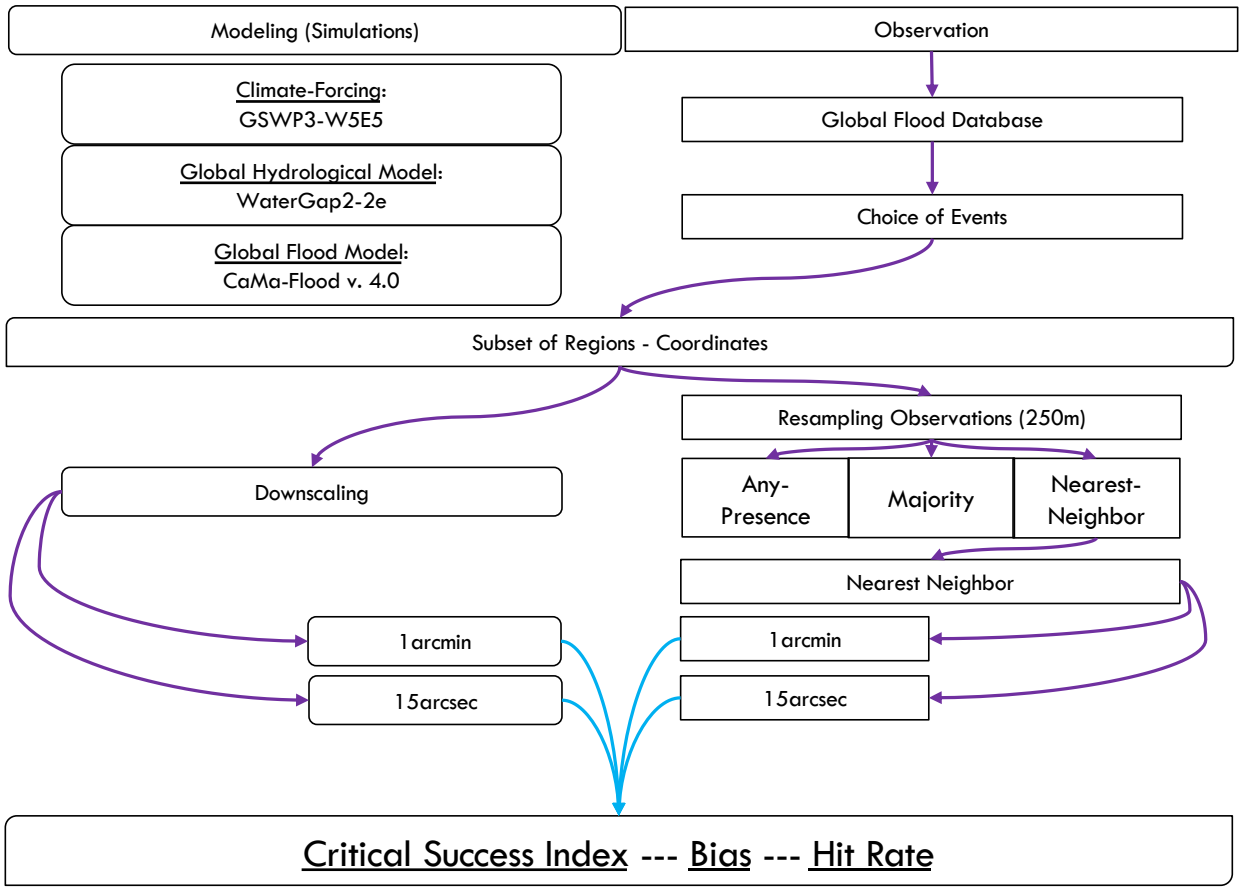
Methods

Validation with Observed Flood Data

- **Pre-processing of observation data**
- Resampled **GFD maps** to match model resolutions
  - **15 arcsec** and **1 arcmin**
- GFD maps are **binary (flooded / non-flooded)**
- Used **nearest-neighbour resampling,** appropriate for categorical data

- Methods

Analysis



Performance Metrics for Flood Model Evaluation

All scores have different ways of determining relation of true positive, false positive, true negative and false negative predictions.

Critical Success Index (CSI)

- Penalizes **overestimation**
- Ranges **0 to 1; 1 = perfect fit**

Bias Score

- Indicates **tendency to over- or under-estimate**
- **0 = unbiased,**
  positive = overestimation,
  negative = underestimation

Hit Rate

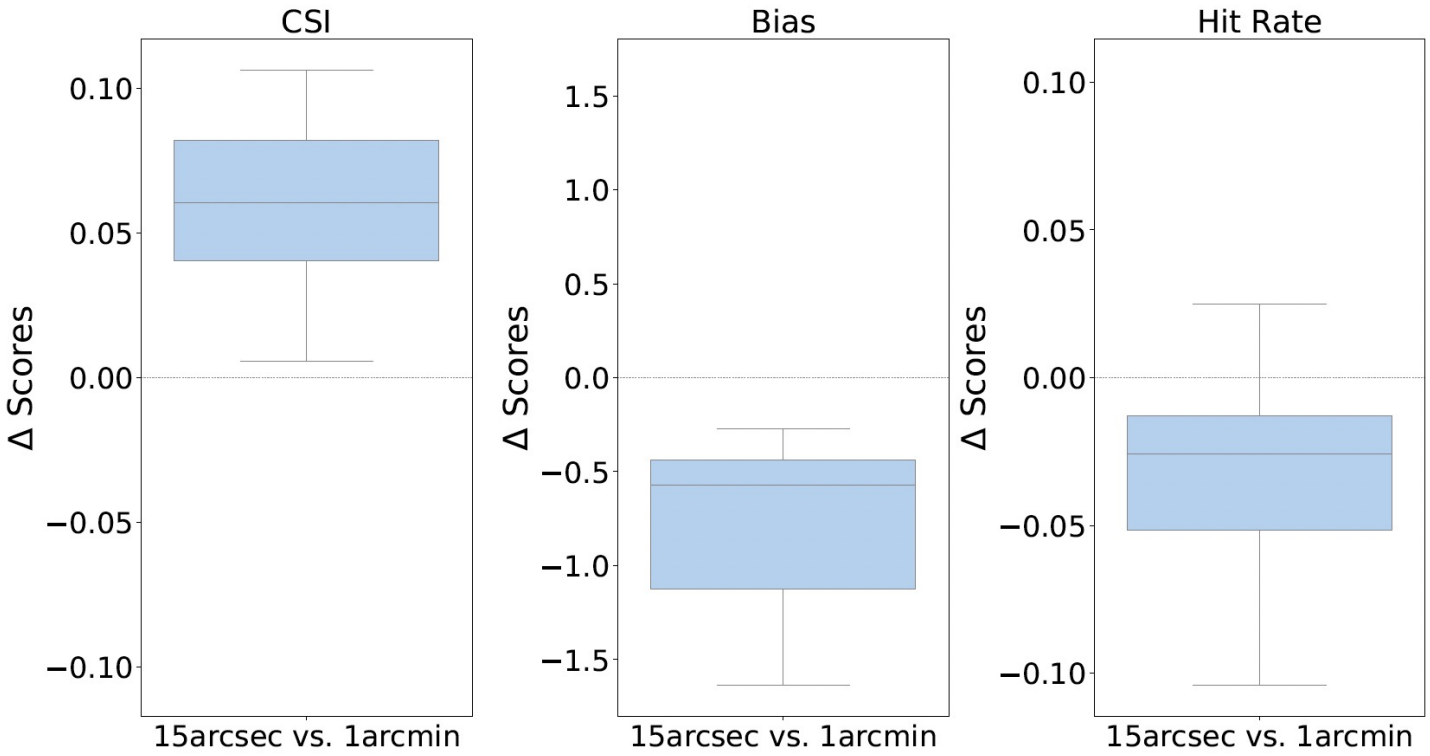
- Measures **how much of the observed flood was captured**
- Ignores overestimation, focuses on coverage
- Ranges from **0 (none captured) to 1 (fully captured)**

Results

Downscaling to 15 arcsec Significantly Improves Accuracy

Key-Results

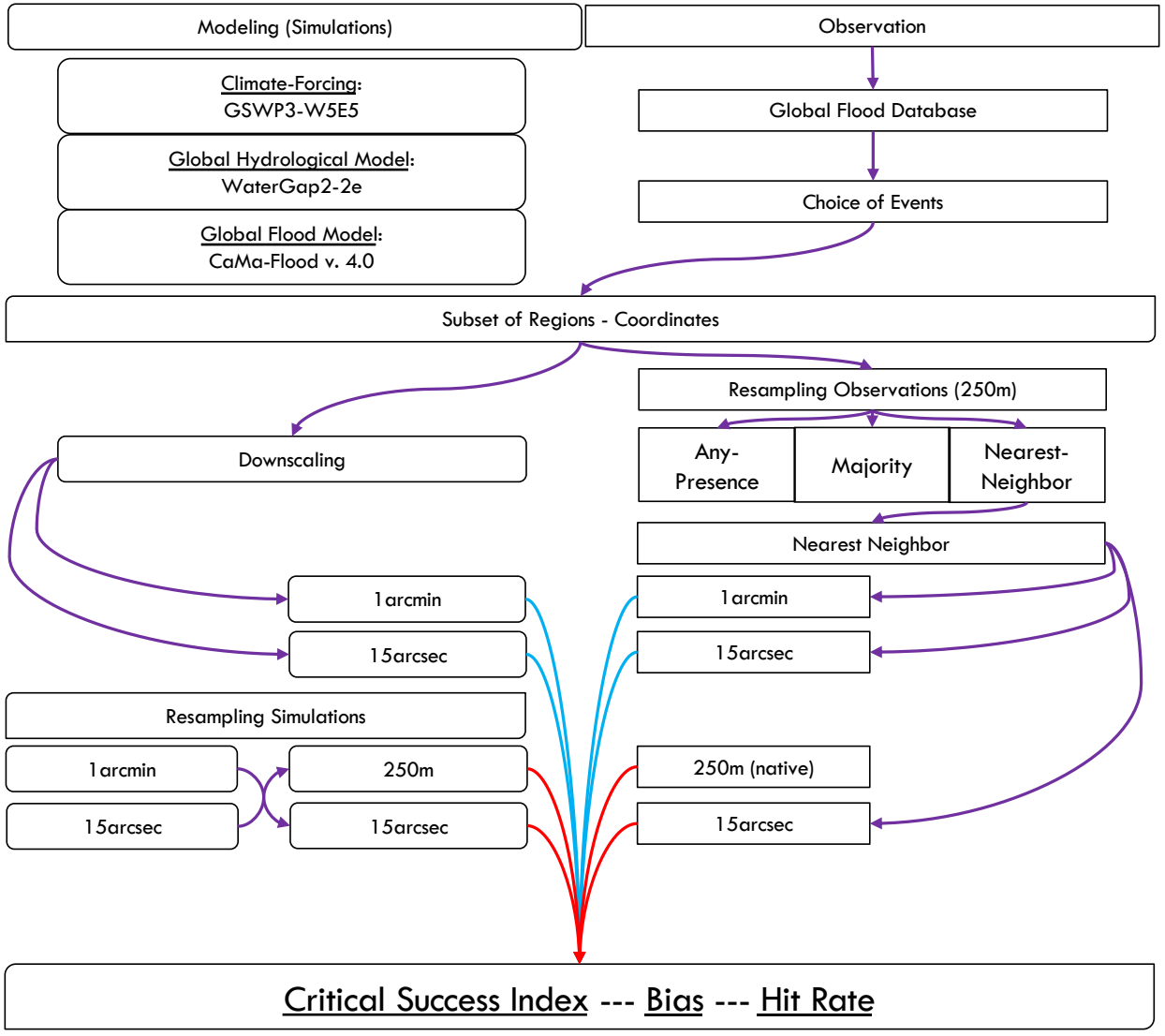
- Boxplots show difference (15 arcsec – 1 arcmin) across **18 flood events**
- **CSI increased for all events** → better overall fit
- **Bias reduced for all events** → less overestimation
- **Hit Rate mostly declined** → smaller portion of observed flood captured



Mean differences: **CSI +0.06** **Bias -0.74** **HR -0.03**

- Methods

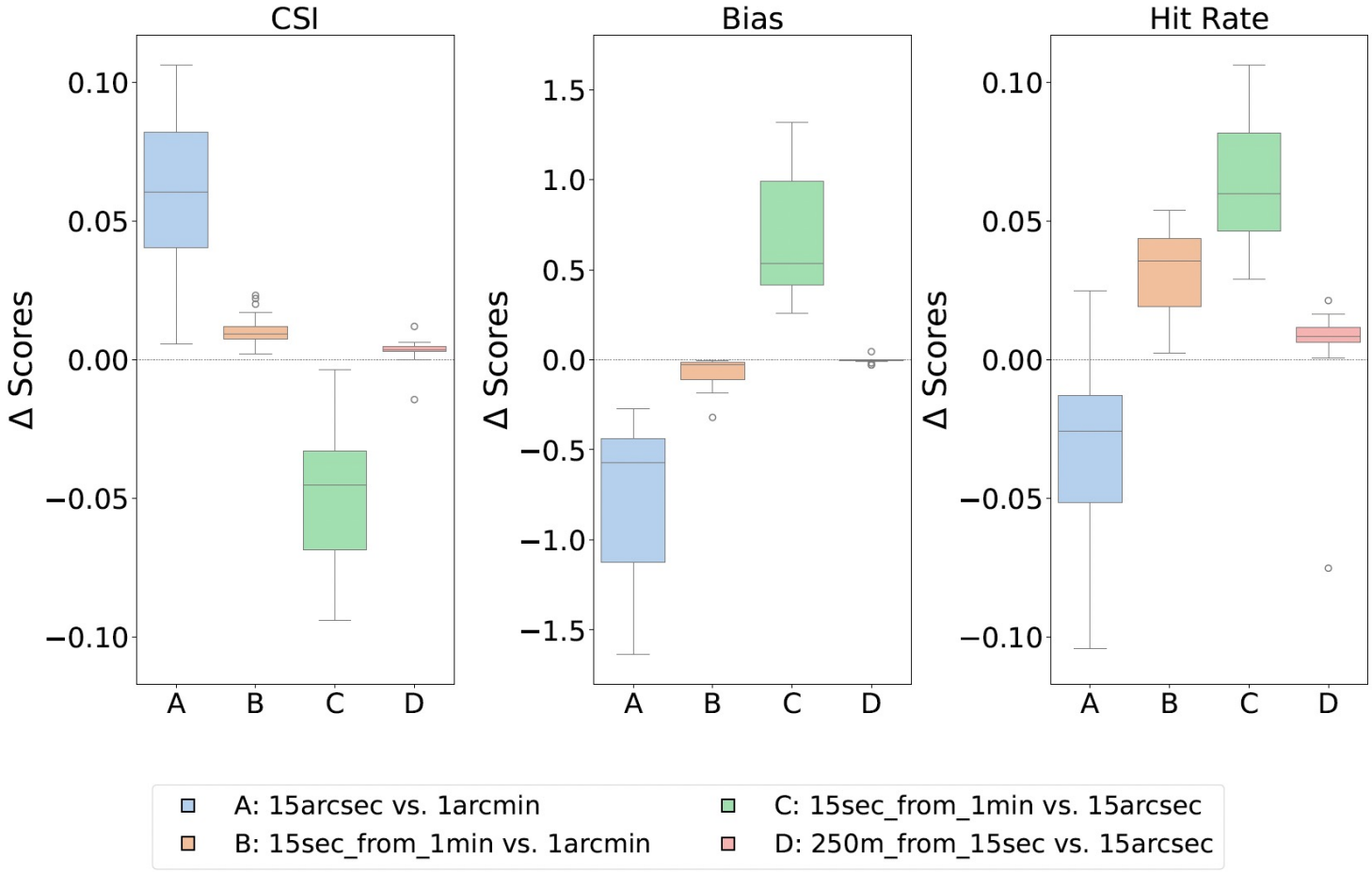
Analysis



Downscaling Significantly Outperforms Resampling

Key-Results

- Plot basics same as before: boxplots show differences between two setups across **18 flood events**
- Even **simple resampling improves performance metrics slightly**
- **Higher CSI, lower Bias, and even higher Hit Rate** vs. 1arcmin
- But **gains much smaller than with diagnostic downscaling**



Diagnostic Downscaling: Mechanistic Benefits and Trade-offs

Beyond higher resolution

15 arcsec improvements reflect mechanistic advantages of elevation-based flood volume redistribution.

Why this matters

Enhances large-scale analyses and could inform local flood management.

Critical trade-off

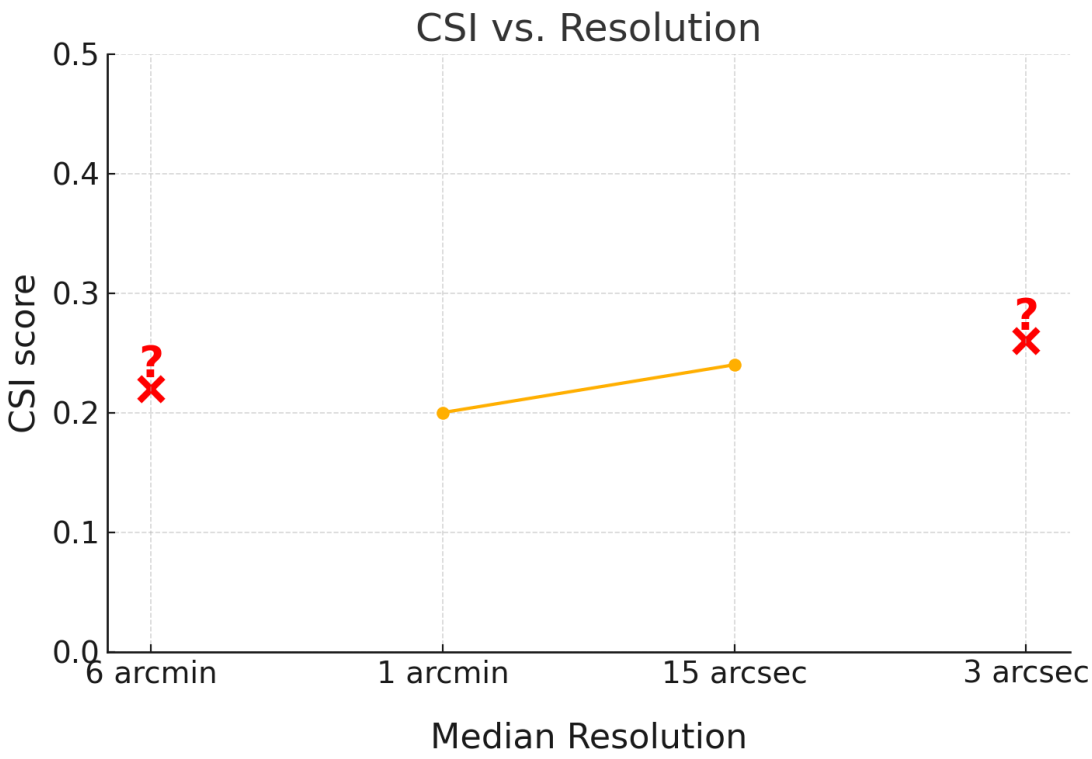
Fewer false positives (overestimation) → good.
More false negatives (missed floods) → risky in practice

Bottom line

For large-scale studies, downscaling's benefits far outweigh coverage losses.

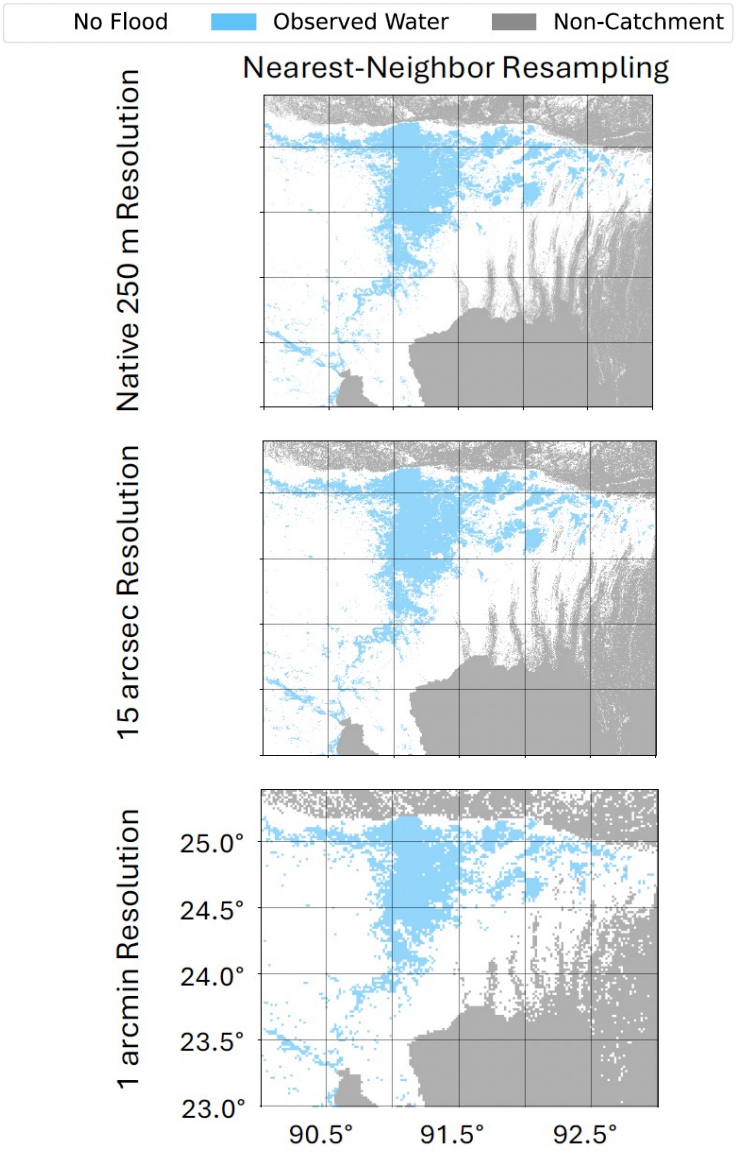
Future Research: Resolution Gains & Validation Challenges

- Is improvement in downscaling linear?
- Compare gains across steps
- Determine added value of finer scaling

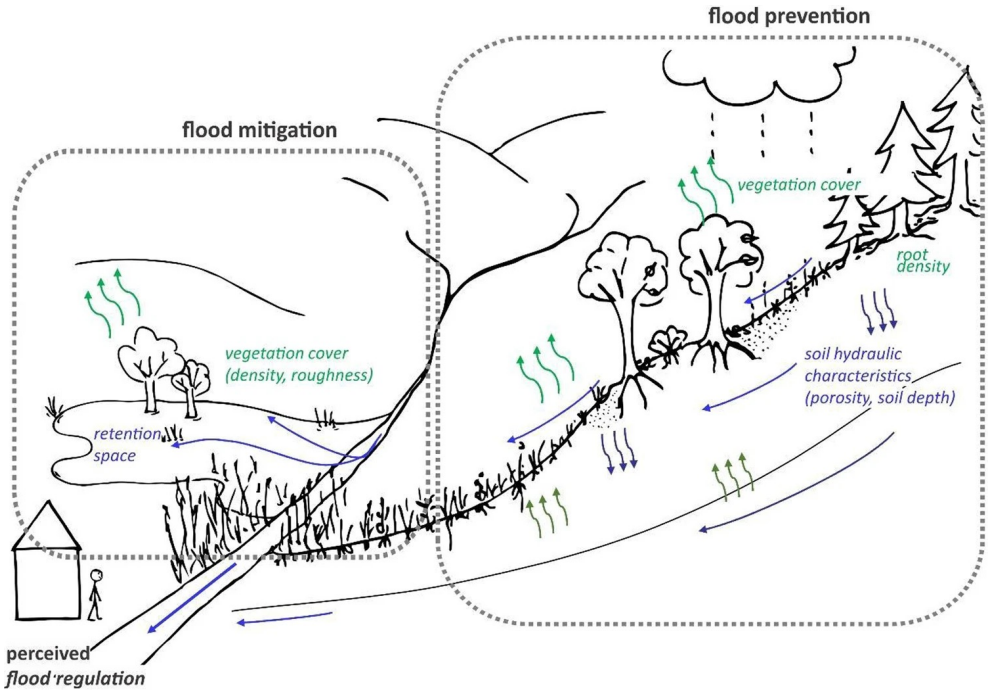


Future Research: Resolution Gains & Validation Challenges

- **Idea:** Compare gains across steps
- **Problem:** Coarser maps become biased toward the majority class, underestimating overall flood area.
  - Every resampling algorithm has its own distinct shortcomings
- **Conclusion:** Comparing simulations with one reference dataset at separate resolutions is not straightforward.



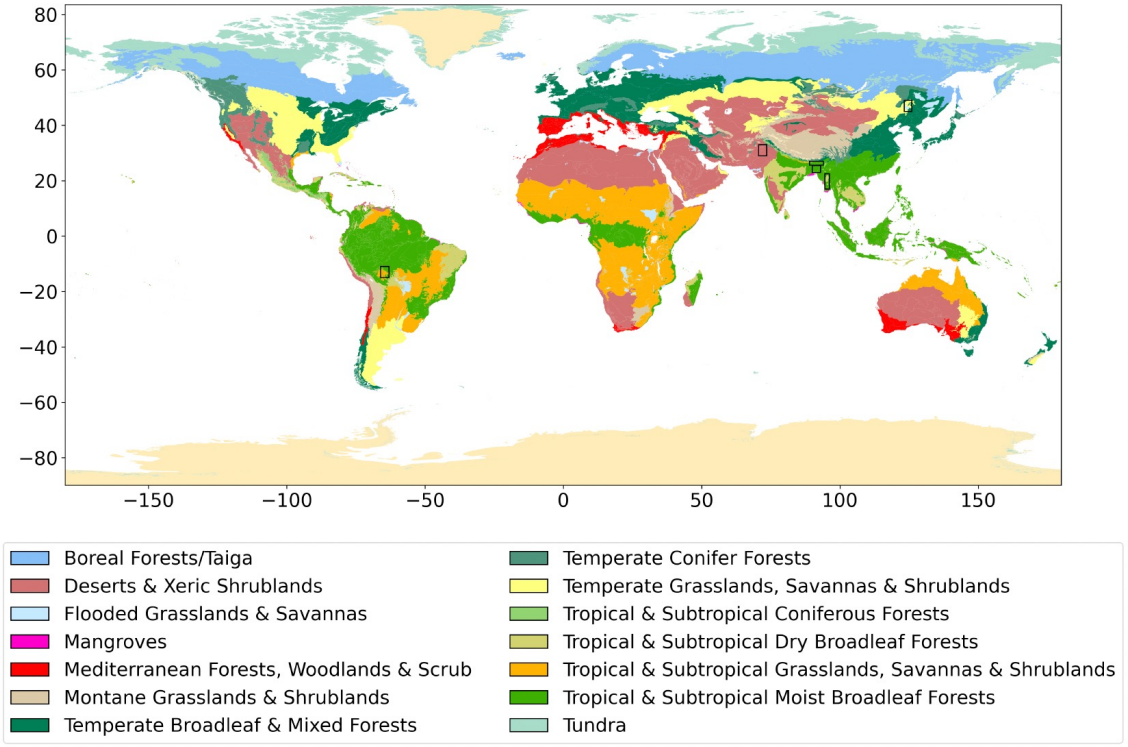
Why ecosystems matter for floods



- Ecosystems **reduce the magnitude of developing flood waves:**
  - Vegetation intercepts rainfall
  - Roots enhance soil infiltration
- Ecosystems **lower peak flood intensity:**
  - Provide storage capacity
  - Increase surface roughness

(Vari et al., 2022)

Why use Biomes?



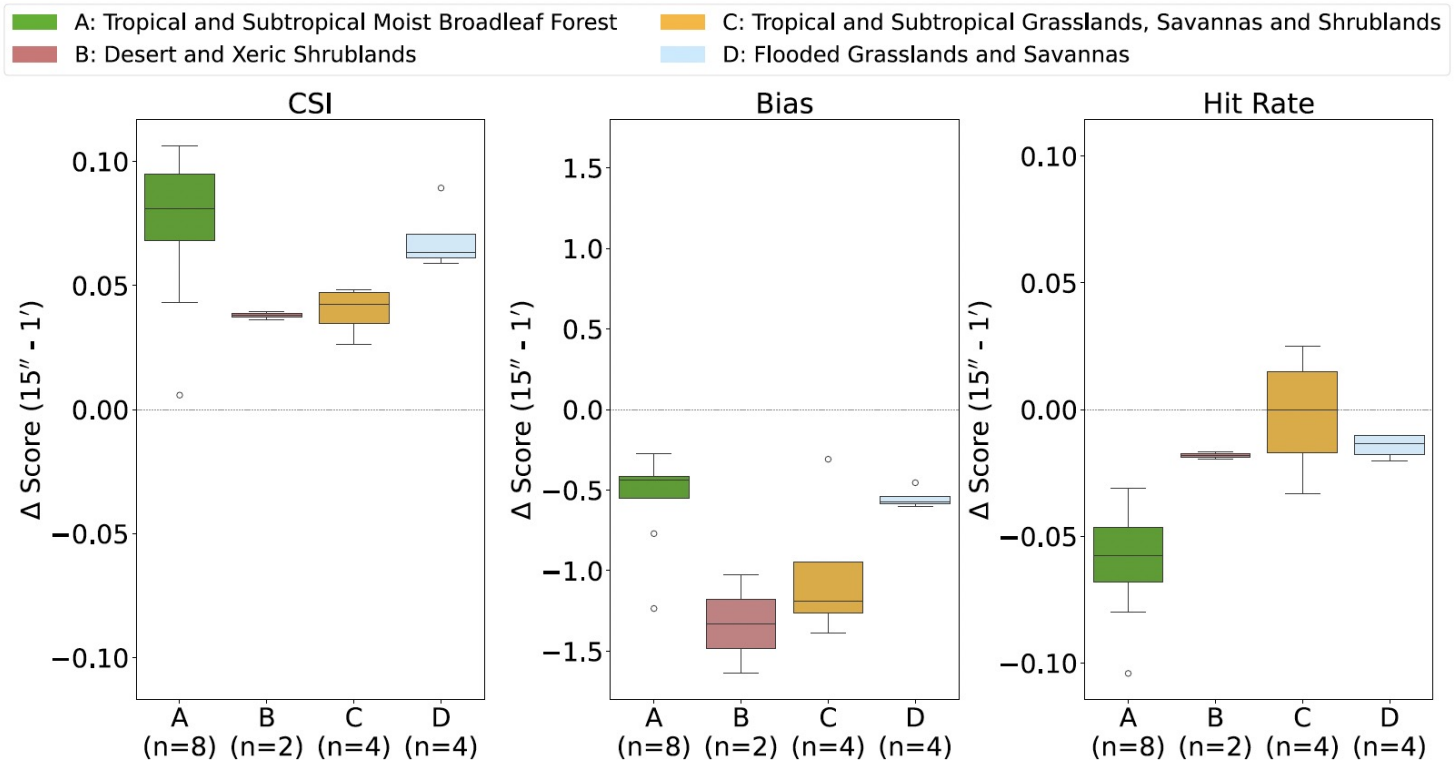
- Biomes **widely used** in ecological & biogeographical studies
- Flood events in this study:
  - Occur at **large geographic scales**
  - Span **multiple ecosystems**—just like biomes
- Biome characteristics also influence floods:
  - **Soil & water availability**
  - **Physiognomy** (structure & appearance of dominant vegetation)

Results

Differences in downscaling effect across biomes

Key-Results

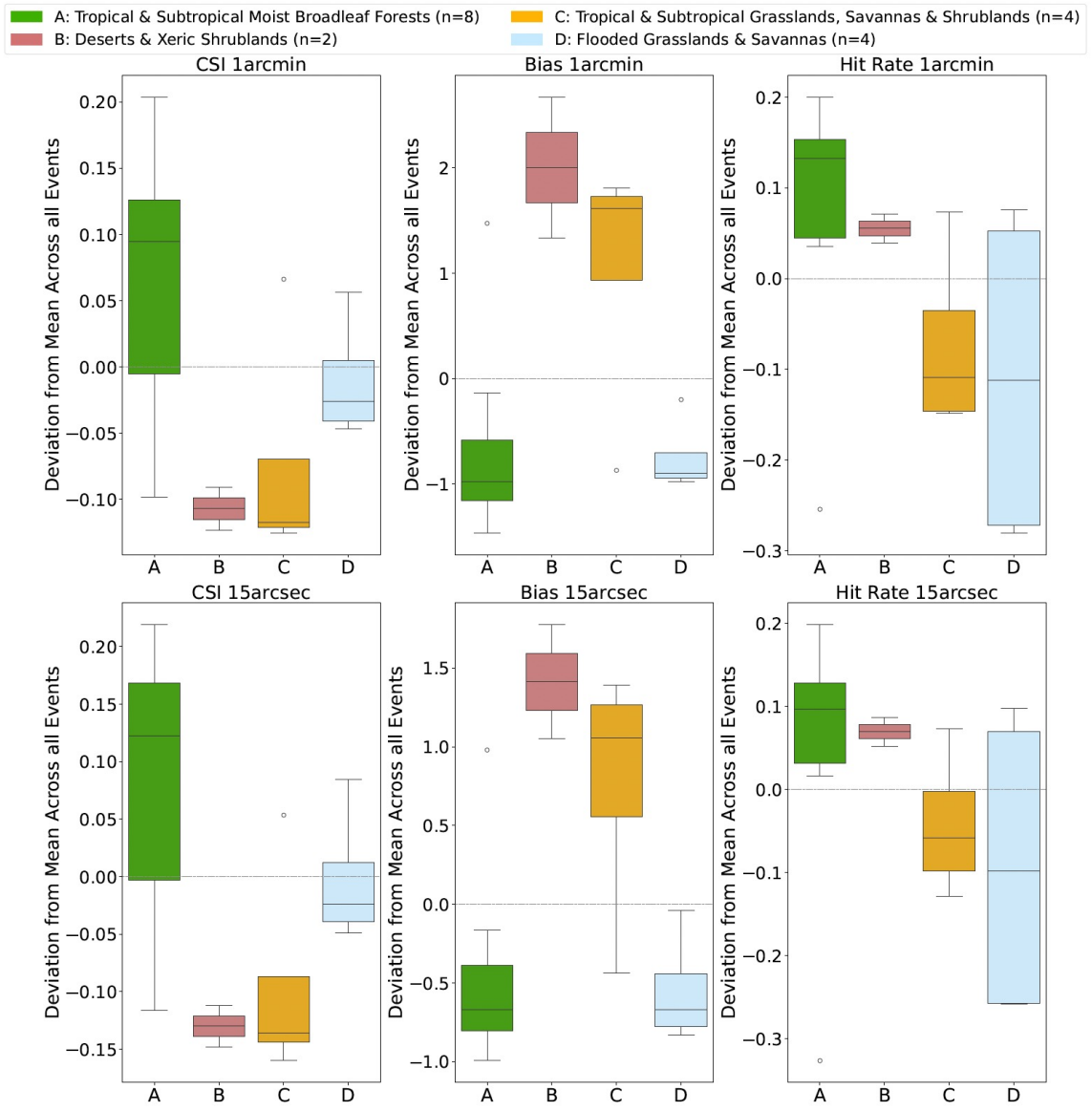
- Boxplots show difference (**15 arcsec – 1 arcmin**) across 18 flood events **grouped by biome**
- Found differences by biome — but **no clear conclusions.**
- **Tropical rainforests see largest gains in CSI, but smallest reduction in Bias** and **largest drop in Hit Rate.**
- **Counterintuitive:** biggest CSI gains where Bias & Hit Rate improved least.



Why this pattern?

Key-Results

- Boxplots show distance from mean for each event, grouped by biome
- Tropical rainforests **started with best scores** (highest CSI, lowest Bias)
- Higher baseline means **same reduction in Bias yields bigger CSI gain.**
- **Data don't give a clear answer on biome differences:**
  - Different signals from CSI vs. Bias.
  - **Small sample sizes**



Summary

Key Takeaways

Plus tip:

Use distinct colored icons for each key takeaway to enhance visual differentiation and audience retention.

Enhanced Accuracy with 15 Arcsec

Downscaling flood simulation data to 15 arcsec resolution consistently improves model accuracy and reduces overestimation across all studied flood events.

Resampling Reduces Quality

Lowering the resolution of flood maps through resampling, as done for GFD flood maps, causes notable deterioration in map quality that must be accounted for in validation.

Trade-Offs in Model Performance

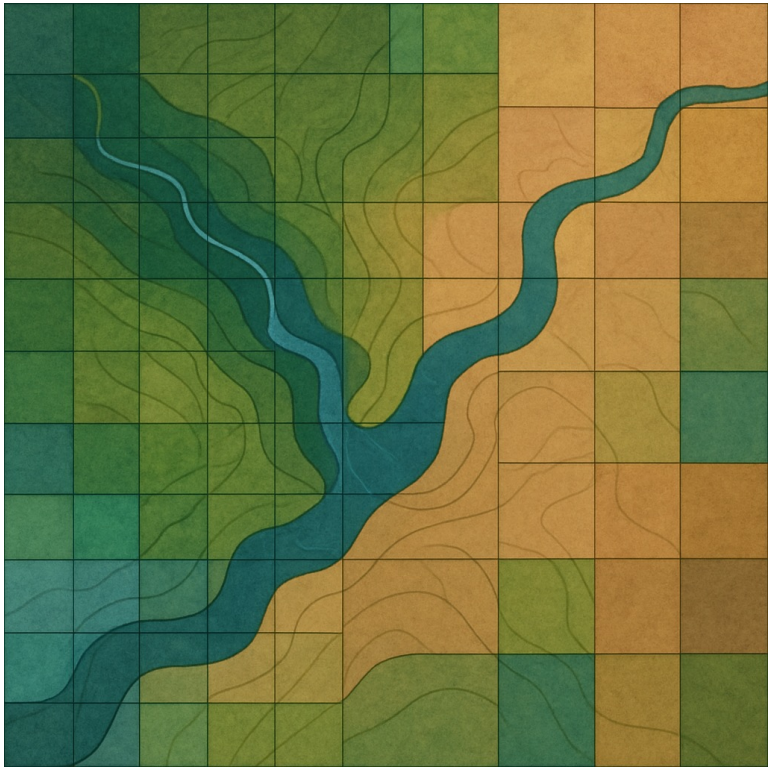
While 15 arcsec downscaling reduces overestimation, it slightly decreases detection of true positive flood events, requiring a balance between these factors.

Unclear Biome Effects

Differences in downscaling effects across ecological biomes are inconclusive; more detailed local data is needed to clarify biome-specific impacts.

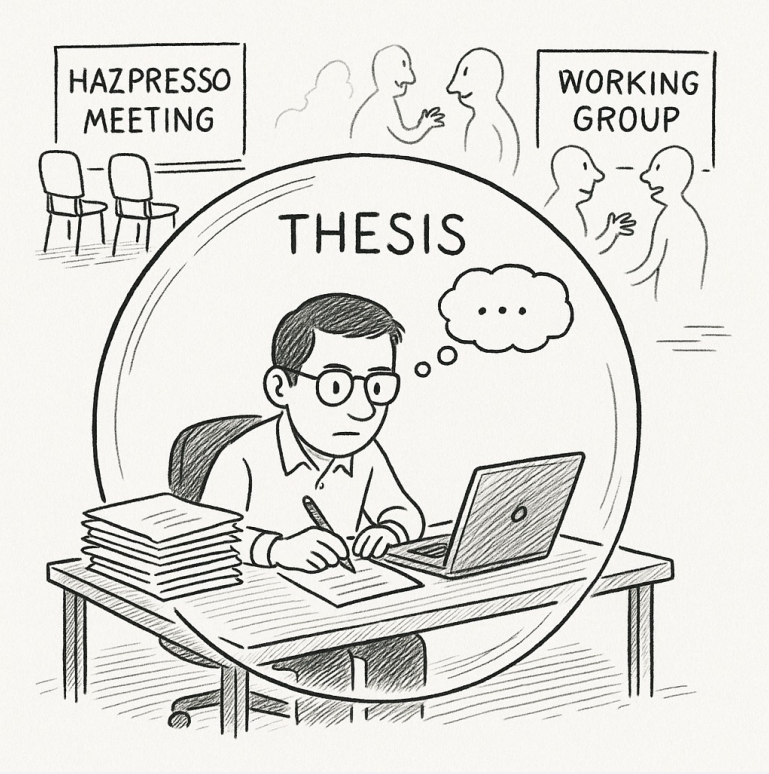
Outlook

Limitations and Future Outlook



- Test multiple GHM and climate forcing combinations for robustness
- Integrate explicit flood protection schemes in models
- Use high-resolution continuous flood-depth datasets for validation
- Focus on diverse topographies paired with ecological variables
- Explore additional grid resolutions to clarify scale effects

Reflection on the Proces



Closing

Thank you for your attention!

BACKUP SLIDES

Performance Metrics for Flood Model Evaluation

$$\text{CSI} = \frac{F_m \cap F_o}{F_m \cup F_o}$$

Critical Success Index (CSI)

- Penalizes **overestimation**
- Ranges **0 to 1; 1 = perfect fit**

$$\text{Bias} = \frac{(F_m \cap F_o) + F_m}{(F_m \cap F_o) + F_o} - 1$$

Bias Score

- Indicates **tendency to over- or under-estimate**
- **0 = unbiased,**
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$$\text{HR} = \frac{F_m \cap F_o}{F_o}$$

Hit Rate

- Measures **how much of the observed flood was captured**
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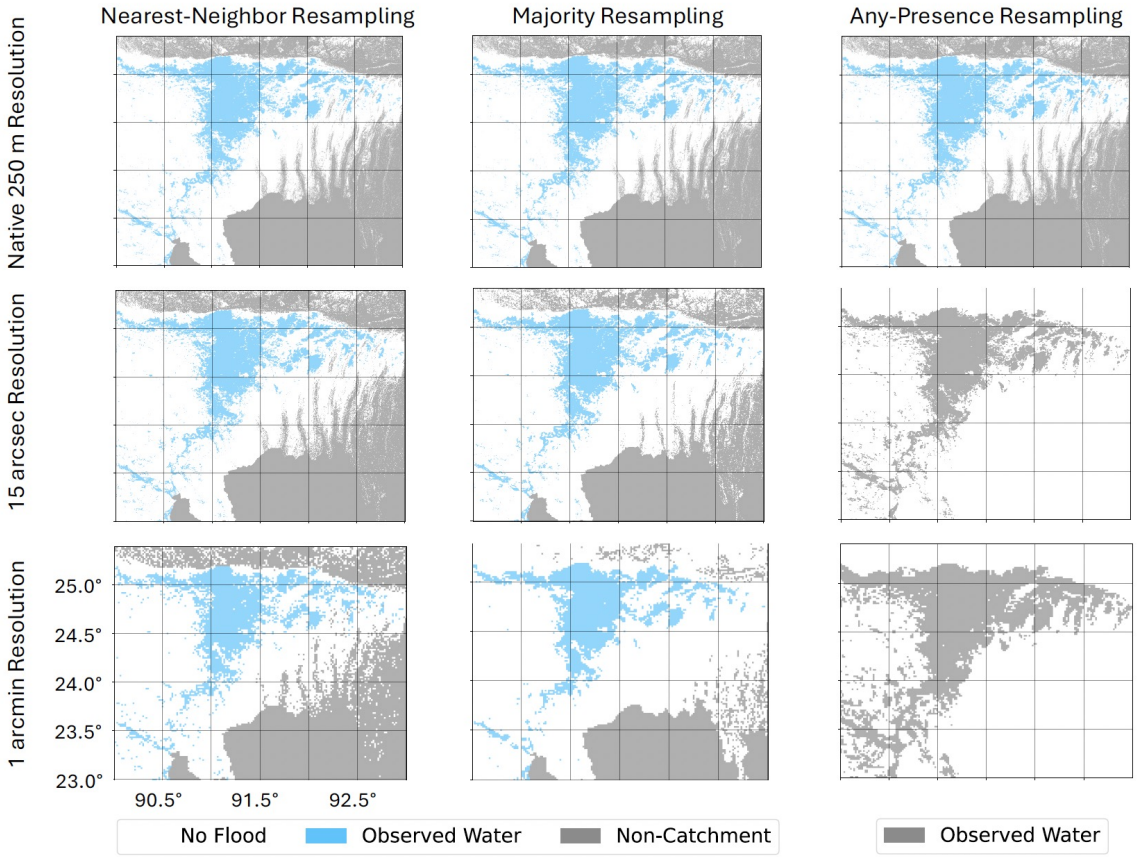
Validation Technicalities



Error Type: Underestimation of minority class—small flooded patches often aren't sampled, so they vanish entirely.

Error Type: Thresholding bias—patches smaller than half the block size disappear; conversely, patches just over half the block may exaggerate their shape.

Error Type: Overestimation of flood extent—even a single noisy or tiny flood pixel marks the entire block flooded.