B215

Future Coastal Flooding Projections in Bali Considering Climate Change

○Calvin SANDI, Nobuhito MORI, Tomoya SHIMURA, Takuya MIYASHITA

Introduction

Coastal flooding is one of the most severe natural hazards worldwide, with climate change-driven sea level rise (SLR) significantly increasing risks in low-lying coastal regions. Projections further suggest that climate change will also induce changes in storm surge and wind waves in the future, potentially further amplifying coastal flooding hazards. The tropical regions, particularly Southeast Asia, are expected to experience more severe impacts from climate change due to their low water level variability, which reduces resilience to SLR and extreme events.

While many studies have primarily focused on SLR as the dominant driver of future flooding, relatively few have assessed its combined influence with storm surge and wind waves. To address this gap, this study estimates extreme sea levels by jointly accounting for SLR, storm surge, and wind wave contributions under future climate scenarios and applies the results to numerical coastal flooding simulations for adaptation planning. Singaraja City, located on the northern coast of Bali Island, is selected as a representative case study due to its high vulnerability to coastal flooding.

Data and Methods

Extreme sea levels are estimated using multiple datasets, including an ocean wave reanalysis model forced by JRA-3Q, a storm surge reanalysis model forced by JRA-55, tidal predictions from the TPXO model, and satellite altimetry-derived sea level anomaly (SLA) data. The still water level (SWL) is computed by combining all components, excluding the ocean wave.

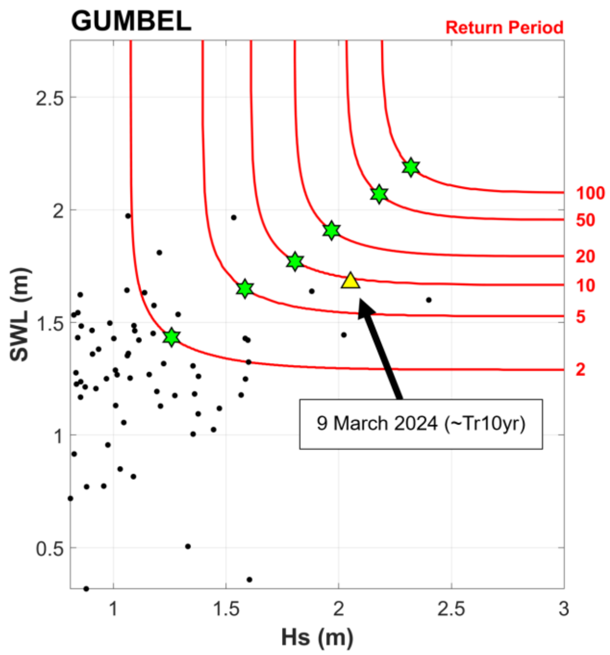

Figure 1 – Multivariate return periods isolines of Hs-SWL from the Gumbel copula.

Extreme wave conditions are identified using a peak over threshold (POT) analysis applied to significant wave height (Hs), with the threshold set at the 95th percentile and treated as independent storm when the time interval between consecutive peaks exceeds 48 hours. To reflect site exposure, only wave events approaching within ±45° of the shoreline angle were considered. The corresponding SWLs were extracted and used to construct a copula model to model their joint probability distribution. Prior to the copula, the marginal distributions were initially fitted to each variable, and the best-fitting marginals were subsequently used to construct the copula.

To estimate the future changes under climate scenarios, we utilize a dataset from a seamless projection study of global storm surges and waves

(Shimura et al., 2022) for the RCP8.5 scenario. The dataset was analyzed using generalized extreme value non-stationary extreme value analysis, in which we apply time-varying parameters to the location and scale parameters. Furthermore, the projected SLR dataset was sourced from the IPCC AR6 dataset, under the SSP5-8.5 medium confidence projection.

On the other hand, the bathymetric data were obtained from field measurements, while the topography data was derived from a combination of drone photogrammetry and ground-based LiDAR. Coastal flooding was simulated using the 2DH non-hydrostatic version of XBeach, a short-wave resolving model capable of simulating individual short-wave propagation, including runup and overwash. A reduced two-layer system was applied. The numerical model covered a domain area of 595 x 775 m, with a grid resolution of 0.75 x 0.75 m.

Results

Several marginal distributions were fitted to Hs and SWL, and the models were ranked according to the Bayesian Information Criterion (BIC). Hs and SWL were best described by the generalized Pareto and logistic distributions, respectively. These distributions were subsequently used for Gumbel copula fitting, with the results given in Figure 1. A sensitivity analysis was also conducted by comparing with three commonly used copulas in coastal hazard studies: Gaussian, Clayton, and Frank. The comparison showed good agreement among the copulas, with only negligible differences in the estimated joint probabilities. Based on these results, the Gumbel copula was adopted for the subsequent analysis.

The model was first validated against a storm event that occurred on 9 March 2024, during which peak Hs and SWL reached 2.05 m and 1.68 m, respectively, resulting in observed inundation depths of approximately 20-30 cm on the western side of the study area. The simulation successfully reproduced this event, yielding inundation depths of 25-30 cm, although a slight overestimation was observed.

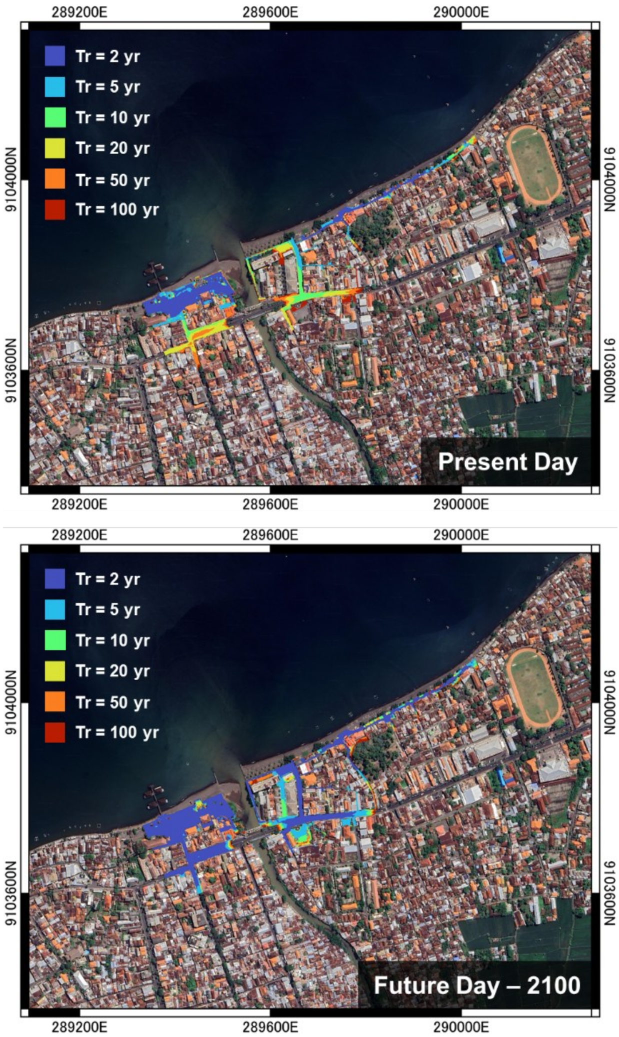

Figure 2 – Flood inundation extends under present (top) and future day-2100 (bottom) conditions.

The validated model was subsequently applied to simulate coastal flooding under present and future extreme events across multiple return periods (Figure 2). By 2100, the inundated area increases by an average of 9,549 m^2, with the maximum flood elevation rising by an average of 61 cm across all considered return periods. For the 2-year event, the flooded area expands by 11,765 m^2, approaching the present-day inundation extent associated with the 50-year event. These results indicate a substantial shift in flood hazard frequency and severity, highlighting the urgent need for targeted coastal adaptation measures.