High-resolution compound flood modeling with publicly available datasets: A case-study over Madagascar land-ocean continuum

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Abstract

Compound flooding occurs when multiple flood drivers co-occurs. This phenomenon is particularly relevant in the regions exposed to tropical cyclone (TC), where oceanic (e.g., storm surges, tides, waves), and continental drivers (e.g., rainfall, and river discharge) combine non-linearly, often amplifying flood severity beyond their individual contributions. Realistic compound flood modeling requires cross-scale hydrology-hydrodynamics integration, yet it faces significant technical and data constraints. Particularly in data-scarce regions like Madagascar, obtaining the necessary datasets for such modeling presents a major challenge. Yet, Madagascar stands out as the most exposed and vulnerable region to TC in the southern hemisphere, where the ability to assess compound flooding is a critical societal need.

Using predominantly remote sensing-derived datasets—including bathymetry, topography, land-use/land-cover, and soil characteristics—we developed a coupled ocean-inland flood model for Madagascar. This framework integrates a high-resolution (500 m) coupled coastal ocean-wave model (SCHISM-WWM) with a fine-scale (30 m) inland flood model (SFINCS), forced by globally available meteorological datasets that we corrected for bias. Model validation against remote sensing-derived water extent demonstrates strong agreement (skill score: 0.83) across both long-term flood frequency estimates and short-term cyclone-driven flooding (TC Batsirai 2022).

During TC Batsirai (Cat-4 storm, >300 mm/day rainfall), our model captured large-scale flooding, revealing significant compounding effects in estuaries and strong non-linear interactions between oceanic and inland drivers. The modeled flood extent closely aligns with reported agricultural impacts and local observations.

This study demonstrates the feasibility of a scalable approach to high-resolution compound flood modeling using publicly available datasets. Such fine-scale knowledge on flooding hazards should lead to improved vulnerability assessment, informed coastal development and engineering interventions not only in Madagascar but also other similarly data-limited yet compound flood-prone regions facing increasing risks due to climate change and sea level rise.