INTEGRATING CLIMATE CHANGE PROJECTIONS AND HYDRODYNAMIC- WAVE MODELING FOR PRESENT AND FUTURE COMPOUND FLOOD RISK

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INTRODUCTION

As climate change progresses, the likelihood and complexity of compound flooding events—where storm surge, riverine, and precipitation-driven waters converge—are expected to increase (Garzon et.al., 2016). These events pose significant risks to coastal regions worldwide. Traditional flood risk assessments often fall short in capturing the multifaceted nature of such events, leading to potential underestimation of risks. Recognizing this gap, our study aims to present a generalized approach for simulating future climate scenarios that incorporate the intricacies of compound flooding, alongside other critical variables.

METHODOLOGY

This paper discusses the numerical modeling application of a future coastal compound flood risk study conducted in Chesapeake Bay, VA USA. In this study, we apply a generalized framework for simulating compound flood events under 4 global climate model results (i.e., CNRM, NORESM, HADGEM, MPI), for two future climate scenarios (i.e., SSP126, SSP585) and for two time horizons (i.e., Mid and Late 21st century). Using our methodology, we created approximately 15,000 synthetic Tropical Cyclones (TCs) and 6,000 Extra Tropical Cyclones (ETCs) representing both existing and future storms influenced by climate change. The developed TCs represents a 7,000-year period for each experiment whereas for ETCs the focus was on quantifying any systematic changes to track and intensity given the last 44 years (1979-2022) of historical ETCs due to increased temperatures and wetter climate states.

We generated, wind, pressure and rainfall forcing from the cyclones above and employed TELEMAC2D-Suite (Hervouet, 2007) to simulate compound hydrodynamic and wave phenomena. The HD model within the TELEMAC2D framework simulates a range of coastal processes including astronomical tides, with temporally varying streamflow discharges, pluvial processes with spatially and temporally varying rain on mesh to capture potential rainfall-runoff impacts where infiltration is considered using a Curve Number (CN) method based on soil characteristics. Sea level rise is accounted for with a historical rise rate, and both interannual and seasonal variations are dynamically added to the model. In addition, two sets of Sea Level Rise values were employed for Mid-Century and Late-Century synthetic TC and ETC runs. The HD and Wave models were de-coupled. First SW model running on a 26k elements wave domain generated the radiation stress gradients that were later transferred to the 230k elements HD domain. HD model covered elevations up to 10m to allow for rainfall-runoff build up and to accommodate future sea level rise scenarios. The resolution of the HD model varied from 15-6000 meters.

The model's validation involved a series of historical storm events, including Hurricanes Isabel, Irene, Arthur, Dorian, and the Oktober Flut event, utilizing wave and water level data for accuracy. The validation process demonstrated the model's robustness, with RMSE values averaging 0.45m for wave height and 0.15m for water levels, and a high correlation to observed data (Table 1), indicating the model's capability to simulate coastal processes with a high degree of reliability. The validation involved the use of all available NDBC and NOAA stations within the modeling domain.

Event Name	# Wave Sta. RMSE(m)/ Corr.	# WL Sta. RMSE(m)/ Corr.
Isabel	13 / 1.12 / 0.84	17 / 0.19 / 0.95
Irene	37 / 0.50 / 0.92	19 / 0.14 / 0.89
Arthur	44 / 0.20 / 0.80	18 / 0.12 / 0.86
Dorian	41 / 0.20 / 0.87	21 / 0.15 / 0.72
Oktober Flut	45 / 0.24 / 0.82	21 / 0.18 / 0.86

Table 1: Summary of model validation results
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RESULTS

This integrated approach allows us to simulate physical process that may have non-linear and compounding interactions in a single multi-scale (ocean to river) environment. The model outputs are multifaceted, providing detailed spatial distributions of water levels and wave heights, as well as depth-averaged velocities yielding a rich dataset, capturing the nuanced interplay of hydrodynamic and wave processes under varied climatic conditions, which is critical for future coastal resilience planning. Computational performance was a key outcome, with the models demonstrating robust scalability and efficiency costing less than 20 cpu-hours / storm simulation (e.g., using 48-cores. Wave + HD run is complete in 25 minutes).

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