

ASSESSING COMPOUND FLOOD PROCESSES THROUGH A MULTIDIMENSIONAL FRAMEWORK IN COASTAL WATERSHEDS

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INTRODUCTION

Water is vital for any civilization to prosper; thus, settlements have been established within the coastal or fluvial floodplain throughout history. These communities, especially low-gradient ones, are prone to flood hazards such as nuisance flooding, storm surges, extreme rainfall, and high river discharge. However, when two or more flood drivers (e.g., coastal, pluvial, and fluvial) coincide or are in close succession, it can be classified as a compound flood event (Bilskie and Hagen, 2018) (Figure 1). Consequently, the inundation impacts can be exacerbated (rather than being a linear superposition) due to the nonlinear interaction of the coastal and hydrologic processes (Santiago-Collazo et al., 2019). With the effects of climate change, coastal watersheds will be subjected to additional flood stressors, resulting in catastrophic effects if future planning tools do not consider the compounding behavior of these flood drivers. Numerical modeling tools may allow the design of risk-mitigation strategies but require simulations of several flooding scenarios to be considered simultaneously to account for compound floods. However, the current techniques cannot simulate multiple processes simultaneously and lose accuracy when modeling events with numerous flood drivers by coupling different modeling tools.

METHODS

This research presents a unified approach for compound flood assessments based on a reduced-physics numerical scheme. This unstructured finite element model simulates coastal, fluvial, and pluvial processes that employ the full or a reduced form of shallow water equations (i.e., diffusive and kinematic wave equations). As a first step, a one-dimensional (1-D) approach was employed in idealized coastal watersheds to understand better the physical processes and their interaction during a compound flood event. This reduced-physics modeling approach employs the kinematic wave equations (KWE) to simulate overland runoff in the watershed. In contrast, the diffusive wave equations (DWE) are applied to simulate riverine flow and account for backwater processes. The KWE is also used to simulate riverine flow in non-estuarine locations, while the full shallow water equations are applied in the coastal regions, similar to robust models like the ADvanced CIRCulation (ADCIRC) model. Therefore, the 1-D modeling framework encompasses three separate modules seamlessly coupled by a moving boundary condition.

The next step in this multidimensional framework was to apply the lessons from the 1-D approach to extend this technique to a two-dimensional (2-D) approach. A hydrologic model based on the reduced-physics

approach was developed. This model was formulated by adjusting subroutines from ADCIRC to be fit for overland flow calculations, such as finite element spatial discretization and a Crank-Nicolson scheme for time discretization, thus providing a suitable environment for coupling the hydrologic model with ADCIRC.

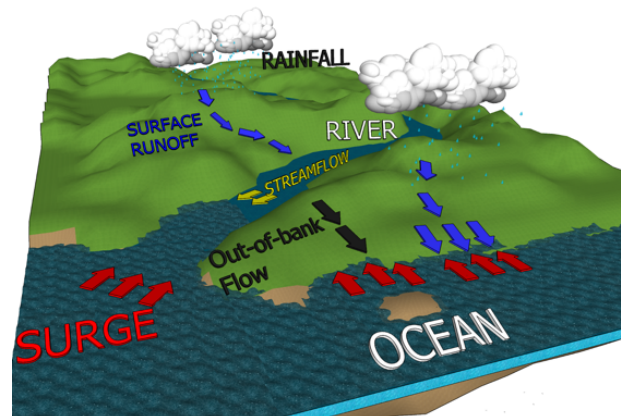


Figure 1 - Flooding mechanisms produced by a tropical cyclone event in an idealized coastal watershed (Santiago-Collazo et al., 2019).

CASE STUDY

Two different idealized coastal watersheds were developed as part of an initial testbed to understand more deeply the hydrodynamic processes between coastal and hydrologic drivers. For the 1-D approach, a transect was developed based on the observed conditions in the Gulf of Mexico (Figure 2A). For example, the middle segment has a mild slope, representing the typical wetland characteristics of the region (Santiago-Collazo et al., 2023). Similarly, a 2-D idealized coastal watershed was developed to verify the lessons learned from the 1-D approach (Figure 2B). For this 2-D basin, the river outlet has a downstream boundary condition governed by coastal processes, while the river inlet has an upstream boundary condition governed by runoff from upstream watersheds.

These case studies were tested using various flood scenarios and possible combinations. The considered process for the 1-D approach was storm surge, tides, and rainfall runoff, while for the 2-D approach was rainfall-runoff, riverine flow, and tides. The simulated flood scenarios considered were hydrologic processes only, coastal processes only, and coastal and hydrologic processes (i.e., compound flood). The flood driver magnitude and timing were varied uniformly to create a matrix of simulation within the 3,000 events. Therefore, a “sensitivity analysis” could be performed to verify which

flood driver (time and/or magnitude) contributes more during a compound flood event.

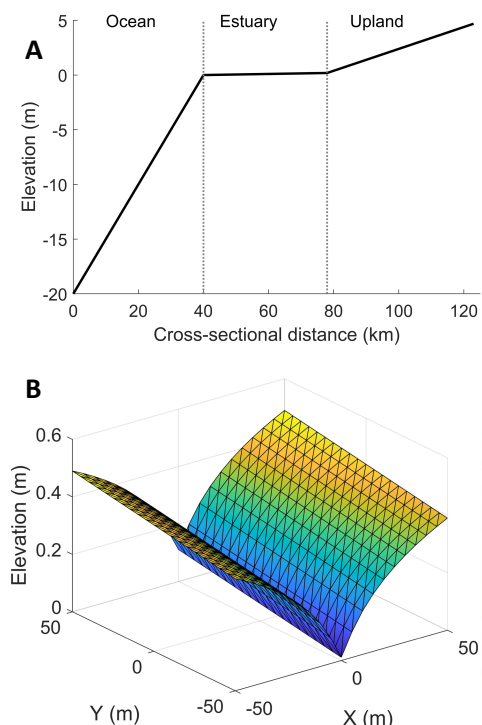


Figure 2 - Idealized coastal watersheds tested with the multidimensional modeling framework: A) 1-D transect and B) 2-D watershed.

PRELIMINARY FINDINGS

Initial results highlight the nonlinearity of the flood processes within a compound flood event (Figure 3). For example, the linear superposition of the individual flood driver scenarios (R+S in Figure 3) can overestimate the water levels compared to the compound scenario (RS in Figure 3). However, this relationship between R+S and RS is spatially varying within the transect, and closer to the upper segment, R+S underestimates the compound threat.

This nonlinearity may be attributed mainly to the peak levels occurring at different times for each flood driver. However, when assessing the time-to-peak water levels component, it was noted that in some simulations, all the flood scenarios arrive within an hour at the same location. For this situation, water level hydrographs illustrated that the linear superposition overestimates the total inundation (Figure 4). Therefore, the non-linearity depends not only on the time-to-peak water levels but also on the momentum exchange.

CONCLUSIONS

Findings highlight the importance of adequately accounting for momentum exchange, the timing and magnitude of each flood mechanism, and their nonlinear relationship. Decision-makers, stakeholders, and authorities need a holistic compound inundation model that can serve as a critical planning tool by providing aid

in disaster and evacuation planning to save human lives and decrease property damage potentially.

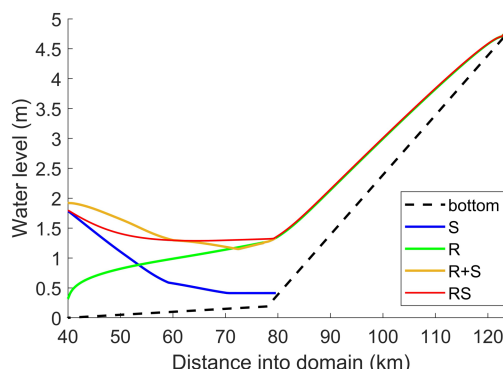


Figure 3 - Maximum water level results from simulation #525 over the 1-D coastal watershed transect. The different colored lines represent the different flooding scenarios. For example, S = tides + surge, R = rain + tides, RS= tides + surge + rain, and R+S = linear superposition of R and S.

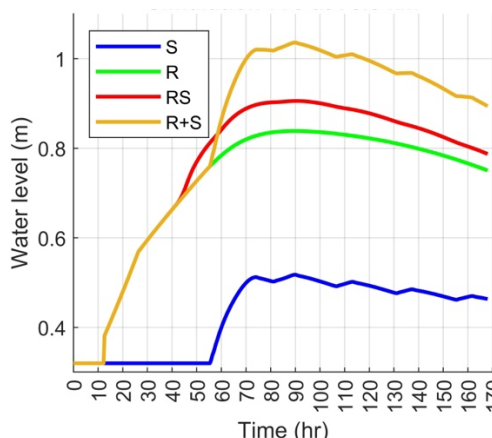


Figure 4 - Water level hydrographs for Simulation 773 at 78.8km from the open ocean boundary. Color legend represents the same as the previous figure.

REFERENCES

Bilskie, Hagen (2018): Defining Flood Zone Transitions in Low-Gradient Coastal Regions, *Geophysical Research Letter*, AGU, 45, 2761-2770.

Santiago-Collazo, Bilskie, Hagen (2019): A comprehensive review of compound inundation models in low-gradient coastal watersheds, *Environmental Modelling & Software*, ELSEVIER, vol. 119, 166-181

Santiago-Collazo, Bilskie, Bacopoulos, Hagen (2023): Compound Inundation Modeling of a 1-D Idealized Coastal Watershed Using a Reduce-Physics Approach, *Water Resources Research*, AGU, in press.