A Physics-Based Classification of Coastal Land-Margins based on Surface Flow

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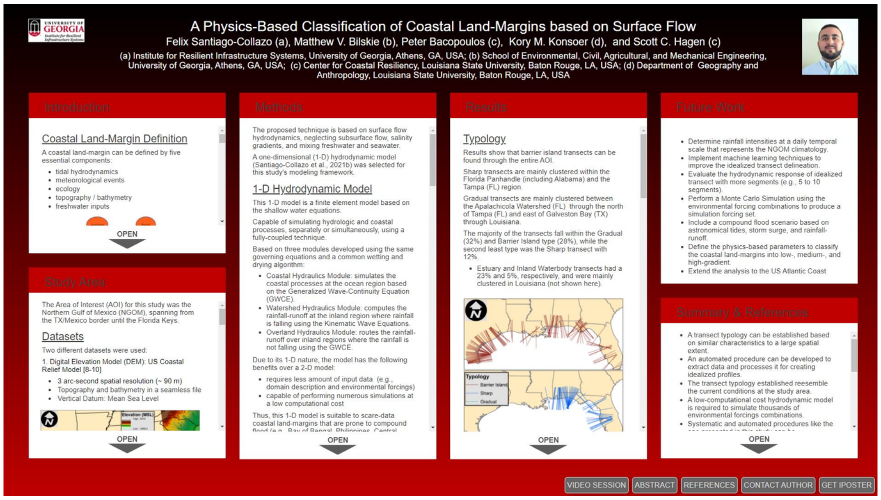
Abstract

Worldwide coastal land-margins are prone to many flood hazards such as astronomical tides, tropical cyclones, sea-level rise, and extreme precipitation events. Compound flood events, in which two or more flooding mechanisms occur simultaneously or in close succession (Santiago-Collazo et al., 2019, https://doi.org/10.1016/j.envsoft. 2019.06.002), can exacerbate the inundation impacts due to the highly non-linear interaction of coastal and hydrologic processes. Furthermore, sea-level rise will increase the hazard at low-gradient coastal land-margins when assessing future projections due to its non-linear nuance on the compound flood (Santiago-Collazo et al., 2021, https://doi.org/10.3389/fclim.2021.684035). Therefore, there is an urgent need to develop new technologies capable of comprehensively studying compound flood events and identifying hotspots prone to these inundations. This research aims to develop a technique capable of defining and classifying coastal land- margins based on physically-based criteria due to surface flow hydrodynamics. A one-dimensional (1-D) hydrodynamic model was used to quantify the hydrodynamic response of thousands of different combinations of input parameters (e.g., astronomical tides, storm surge, precipitation, and landscape) that define a coastal land-margin. This 1-D fully-coupled model, based on the shallow water equations, was applied at a national spatial scale, considering several coastal watersheds within the Gulf of Mexico and the US East coast. One of the main goals of this tool is to identify coastal land-margins vulnerable to compound flood hazards over broad spatial scales (e.g., national or global scale). Findings suggest that low-gradient (e.g., slopes less than 0.01 m km^{-1}) coastal land-margins are more susceptible to compound flood impacts than ones with a steeper gradient under most flooding scenarios. Future research will focus on applying this tool on a worldwide basis to test its capabilities at low-resolution, scarce data regions. A worldwide classification of coastal land-margins may help authorities, policy-makers, and professionals converge on better coastal resilience measures, such as comprehensive compound flood analysis to delineate accurate compound flood hazard maps.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Introduction
Coastal Land-Margin Definition
A coastal land-margin can be defined by five essential components:
tidal hydrodynamics
meteorological events
ecology
topography / bathymetry
freshwater inputs
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Study Area
The Area of Interest (AOI) for this study was the Northern Gulf of Mexico (NGOM), spanning from the TX/Mexico border until the Florida Keys.
Datasets
Two different datasets were used:
1. Digital Elevation Model (DEM): US Coastal Relief Model [8-10]
3 arc-second spatial resolution (~ 90 m)
Topography and bathymetry in a seamless file
Vertical Datum: Mean Sea Level
Elevation (MSL)
OPEN
Methods
The proposed technique is based on surface flow hydrodynamics, neglecting subsurface flow, salinity gradients, and mixing freshwater and seawater.
A one-dimensional (1-D) hydrodynamic model (Santiago-Collazo et al., 2021b) was selected for this study's modeling framework.
1-D Hydrodynamic Model
This 1-D model is a finite element model based on the shallow water equations.
Capable of simulating hydrologic and coastal processes, separately or simultaneously, using a fully-coupled technique.
Based on three modules developed using the same governing equations and a common wetting and drying algorithm:
Coastal Hydraulics Module: simulates the coastal processes at the ocean region based on the Generalized Wave-Continuity Equation (GWCE).
Watershed Hydraulics Module: computes the rainfall-runoff at the inland region where rainfall is falling using the Kinematic Wave Equations.
Overland Hydraulics Module: routes the rainfall-runoff over inland regions where the rainfall is not falling using the GWCE.
Due to its 1-D nature, the model has the following benefits over a 2-D model:
requires less amount of input data (e.g., domain description and environmental forcings)
capable of performing numerous simulations at a low computational cost
Thus, this 1-D model is suitable to scare-data coastal land-margins that are prone to compound
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Results
Typology
Results show that barrier island transects can be found through the entire AOI.
Sharp transects are mainly clustered within the Florida Panhandle (including Alabama) and the Tampa (FL) region.
Gradual transects are mainly clustered between the Apalachicola Watershed (FL) through the north of Tampa (FL) and east of Galveston Bay (TX) through Louisiana.
The majority of the transects fall within the Gradual (32%) and Barrier Island type (28%), while the second least type was the Sharp transect with 12%.
Estuary and Inland Waterbody transects had a 23% and 5%, respectively, and were mainly clustered in Louisiana (not shown here).
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Typology
Barrier Island
Sharp
Gradual
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Future Work
Determine rainfall intensities at a daily temporal scale that represents the NGOM climatology.
Implement machine learning techniques to improve the idealized transect delineation.
Evaluate the hydrodynamic response of idealized transect with more segments (e.g., 5 to 10 segments).
Perform a Monte Carlo Simulation using the environmental forcing combinations to produce a simulation forcing set.
Include a compound flood scenario based on astronomical tides, storm surge, and rainfall-runoff.
Define the physics-based parameters to classify the coastal land-margins into low-, medium-, and high-gradient.
Extend the analysis to the US Atlantic Coast
Summary & References
A transect typology can be established based on similar characteristics to a large spatial extent.
An automated procedure can be developed to extract data and processes it for creating idealized profiles.
The transect typology established reesemble the current conditions at the study area.
A low-computational cost hydrodynamic model is required to simulate thousands of environmental forcings combinations.
Systematic and automated procedures like the
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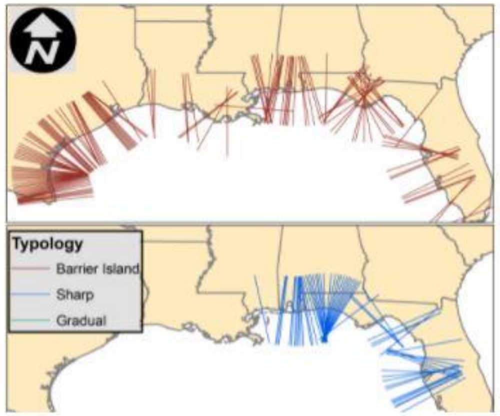

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