MORPHOLOGICAL MODELING OF LOW-DUNE BARRIER HEADLAND SYSTEM CHANGES DUE TO HURRICANE FORCING

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INTRODUCTION

Coastal barrier landforms serve as the first line of defense against oceanic and meteorological forces. Landward infrastructure and ecosystems, without these barriers, would be significantly more at risk to the flooding and wave forcing caused by extreme storms. Widespread recognition of this function has prompted coastal managers to adopt systematic restoration programs. As an exemplar, the Caminada Headlands (CH) Beach and Dune Restoration Project, located adjacent Port Fourchon, Louisiana (LA), USA cost an estimated $220 million USD and restored ~22.5 kilometers of coastline with a 6.4 million m^3 sediment placement. Insight into the performance of the CH restoration during future hurricane impacts requires an understanding of the system's response to historical storms. In general, the CH experiences high background shoreline erosion rates. Recent historical averages are on the order of 15 m yr^{-1} [Byres et al., 2017]. This rate may double during active tropical storm seasons, e.g. the year of hurricane Katrina (2005) [Byres et al., 2017] and, at the event time-scale, localized erosion rates spike dramatically as shorelines may translate 100s of meters landward due to dune overwashing and breaching. Calibration of realistic process based morphological models that can accurately simulate these effects require extensive, high-fidelity input data. To achieve this end, this study makes use of several monitoring projects in the LA region while employing a coupled XBeach and Delft3D modeling system to simulate the impact of hurricane Gustav (2008) on the CH.

COUPLED MODELING SYSTEM

XBeach, an open-source processed-based extreme storm driven morphodynamic model [Roelvink et al., 2009], is coupled with Delft3D, a widely used hydrodynamic modeling suite. XBeach, when executed in "surf-beat" mode, solves a parameterized, time-dependent wave action balance equation to drive nearshore currents as a source term in the non-linear shallow water equations. The hydrodynamics are coupled with advection-diffusion and sediment transport models that are used for bed-level evolution. In order to simulate dune scarping and collapse, a dune avalanching algorithm is used to redistribute sediment when the topography's slope stability criteria are invalidated by ongoing localized erosion. Biogeophysical properties are allowed to vary spatially in order to capture the large sedimentary and ecological gradients present in coastal systems. Within the Delft3D component of our modeling system, a nested two-tier curvilinear mesh was designed to simulate water levels and surface wave propagation driven by hurricane Gustav. A continental basin scale mesh covered the Gulf of Mexico, Caribbean Sea, and northwestern Atlantic Ocean. Nested within the basin scale domain, a regional mesh covered the northern Gulf of Mexico coast extending from Galveston, TX to Mobile Bay, LA. Validated water levels and surface waves [Liu et al., 2018] from the Delft3D model were imposed as temporally and spatially variable boundary conditions within a local XBeach model of the CH. A high-resolution curvilinear mesh was implemented that covered the majority of the CH's coastline and extended ~2.5 km into its complex and fragmented back-barrier marsh (see Figure 1).

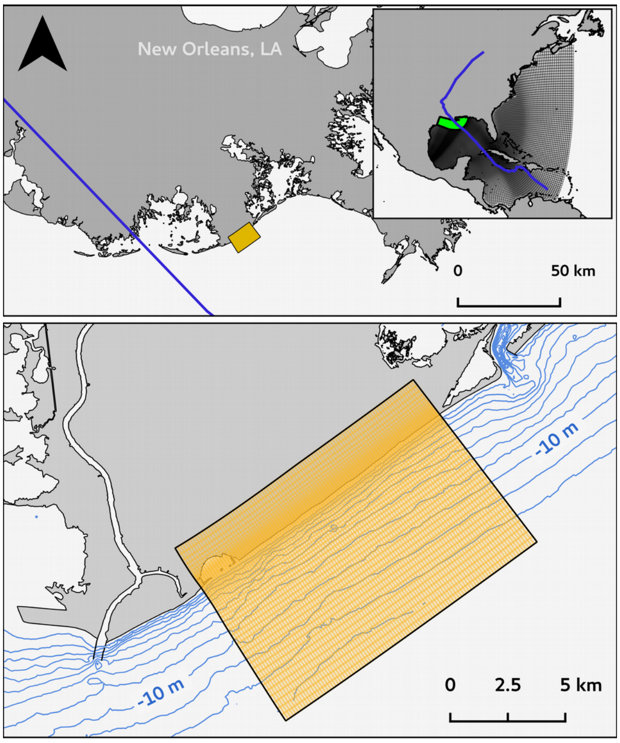

Figure 1 – Bottom panel shows the Caminada Headlands, Louisiana, USA with the XBeach domain drawn in orange. The upper panel contains the basin scale mesh and the nested regional mesh coverage in green. Hurricane Gustav's path is displayed in blue. The bathymetric contours are referenced to NAVD88 (GEOID12B).

MORPHOLOGY DATA

The XBeach model's topobathymetric input was generated by merging pre-storm topographic lidar, real-time kinematic (RTK) dune, marsh, and shoreface surveys and nearshore single-beam sonar data sets for the sub-aerial and sub-aqueous areas, respectfully. The lidar data was collected approximately 6 months prior to hurricane Gustav's landfall by the U.S. Geological Survey's (USGS) Experimental Advanced Airborne Research Lidar [Doran et al., 2009]. The RTK and sonar data were collected by multiple agencies. As part of the Barrier Island Comprehensive Monitoring (BICM) Project, the USGS collected single-beam bathymetry of the entire LA coast in late 2006 [Kindinger et al., 2013]. LA's Coastal Protection and Restoration Agency (CPRA) surveyed the CH multiple times during the design and construction of the CH beach and dune restoration and the upcoming CH back-barrier marsh creation projects (personal data request). The numerical results are compared with a storm-impact assessment lidar survey conducted by the USGS less than a week after Gustav's landfall [Doran et al., 2009]. These data sets facilitate a high-quality XBeach model of hurricane Gustav's impact and in-depth post-storm geomorphic analyses.

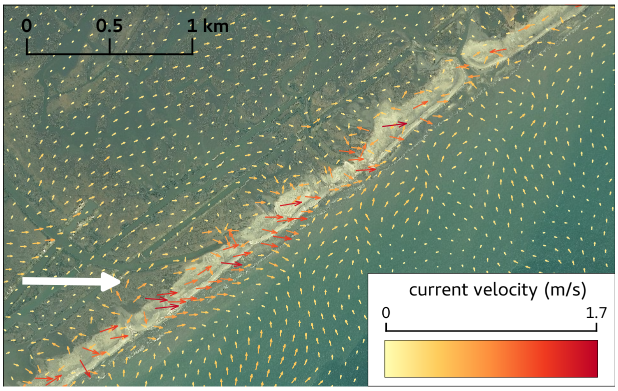

Figure 2 – Seaward-directed current velocities at peak surge. Note the consistent pattern of larger magnitude currents near the intersection of the channel and dune line. Post-Gustav imagery.

HYPOTHESIS TESTS

The direction and magnitude of net sediment transport depends on the elevation of the storm surge relative to that of the dune crest and, also, the evolution of the cross-shore water level gradient. It has been shown that low-elevation dune systems may undergo net seaward-directed sediment transport given an inundating storm surge and seaward-directed water level gradient forcing [Sherwood et al, 2014]. Multiple breaches, overwashing, and dune lowering were observed at the CH in association with hurricane Gustav. In addition, the large-scale Delft3D hydrodynamic model indicates that an seaward-directed water level gradient forcing was present contemporaneously with hurricane Gustav's peak surge. The hypothesis of net seaward-directed sediment transport for the CH from the dunes to the nearshore is evaluated for hurricane Gustav with the nested XBeach model. In addition, the CH back-barrier marsh is critically fragmented and incised with navigational channels. It is observed that chronic dune breaching is spatially correlated with proximity to the channels. Therefore, the role of these channels in sediment transport and the dune breaching process is further investigated with the XBeach model (see Figure 2).

SUMMARY

The hurricane-driven morphodynamics of the Caminada Headlands' (CH) dune and back-barrier marsh system is investigated with XBeach, a coupled hydrodynamic, sediment transport and morphological numerical model. Hindcast forcing for hurricane Gustav (2008) is applied to an extensive coastal morphological data set comprised of topographic lidar, RTK surveys, and single-beam sonar. The impact of hurricane Gustav, which made a first quadrant landfall directly on the CH as a category 2 storm, is assessed in the context of the CH's historical trends in erosion, spatial patterns of dune breaching and overwash, and the channelization of its back-barrier marsh. The implications of hurricane-driven sediment transport and morphological change for the major CH beach/dune restoration and march creations projects is discussed. Future work is proposed that employs the validated model to vary hurricane characteristics, e.g. storm intensity and track, through numerical experimentation in order to determine under which conditions net seaward or landward-directed sediment transport may be expected given the CH's current or future geophysical configuration.

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