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INTEGRATED MODELING OF HYDRODYANMICS AND MARSH EVOLUTION UNDER SEA LEVEL RISE IN APALACHICOLA, FL

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INTRODUCTION

The northern Gulf of Mexico is home to a vast amount of coastal ecosystems that provide natural and economic resources. Rising sea levels may threaten these resources with increased flood magnitude and frequency, accelerated erosion, loss of wetlands, and saltwater intrusion. The Ecological Effects of Sea Level Rise in Northern Gulf Of Mexico (EESLR-NGOM), a five year interdisciplinary effort funded by the National Oceanic and Atmospheric Administration (NOAA), aims to assess these effects and provide local coastal managers with the knowledge and tools to prepare for the dynamic impacts of tides and storm surge magnified by sea level rise (SLR). The project builds on field observations centered at three National Estuarine Research Reserves (NERR) including Apalachicola, Grand Bay and Weeks Bay. The field observations aid in the development, parameterization and validation of integrated models (e.g. hydrodynamic and biologic) to predict the response of the coastal system under various SLR scenarios.

The accurate development and parameterization of these models is crucial for simulating future sea level rise scenarios; however, modeling the physical processes of estuaries can be challenging due to their complex nature. To accomplish this, hydrodynamic, sediment transport and biological models are integrated, as their respective processes depend on and interact with one another.

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STUDY DOMAIN

This paper focuses on the Apalachicola NERR (ANERR), including the lower Apalachicola River, situated in the Florida Panhandle (Figure 1). Apalachicola is home to an array of ecosystems including oyster beds and a vast expanse of marshes. Apalachicola oysters provide a wealth of economic resources, accounting for 90% of Florida's oyster production (Huang & Jones, 2001). Salt marshes are found throughout the estuary, between fresh and saline water bodies, covering over 170 square kilometers, and are accustomed to daily tidal flooding and occasional storm surges (Fagherazzi *et al*, 2012, Livingston, 1984). They are dominated by salt tolerant species such as *Spartina cynosuriodes* and *Juncus roemerianus* and provide feeding and reproductive habitats for many of the ecologically and commercially significant species (Livingston *et al.*, 1974). The marsh grasses slow water currents, allowing for the settlement and accretion of fine sediments required for marsh evolution. Preliminary results from Smar (2012) show that the majority of suspended sediments originate overland rather than tidal flooding [the Apalachicola River is an alluvial dominated system]. Extreme precipitation events loosen and suspend sediment overland, transferring them into the river system, and eventually depositing them onto the marsh platform (Smar, 2012). To overcome a rise in sea level, the elevation of the marsh table must maintain the rate of SLR by accreting sediments and decomposing organic material (Marion et al., 2009).

FIELD AND LABORATORY EXPERIMENTS

An integral aspect of the project is the field data collection (Figure 2) for parameterization and validation of the integrated hydrodynamic, sediment transport and marsh productivity models (Smar, 2012). Morris *et al.* (2002) characterized marsh productivity using a parabolic function dependent on water depth, herein referred to as a biomass curve. The biomass curve serves as the basis for the marsh equilibrium model (MEM), which determines spatially varying biomass in the marsh system. The range of the biomass curve is determined by the marsh type and location. Coefficients for the biomass curve are derived from field collected above and below ground biomass densities using marsh organs (developed by Professor Jim Morris). The marsh organs (Figures 2a and 2d) simulate different states of sea level, allowing for measurements of above and below ground biomass density. In addition, nineteen biomass samples (Figures 2b and 2f) were collected and analyzed for each marsh species and compared with satellite based passive and active optical remotely sensed data to determine the accuracy of the remotely sensed data and validate the MEM. Spatially accurate biomass densities are also necessary for describing surface roughness in the hydrodynamic model, as dense marsh grasses may slow currents, thereby reducing the inundation extent.

Thirty 50-centimeter sediment cores (Figure 2e) were collected in one of Apalachicola's salt marshes and analyzed for organic content to determine the percentage of organic matter in the marsh platform. This enables quantification of accretion rates within the marsh, which is another input to the MEM (Hagen *et al.*, 2012).

Lastly, 734 water samples (Figure 2c) were collected tri-hourly, over a 14 day tidal cycle and analyzed for Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS). Concentrations are compared with meteorological data (i.e. tides, winds, precipitation, and streamflow) to determine which aspects should be incorporated as boundary and initial conditions within the hydrodynamic and sediment transport models to accurately simulate sediment transport in the estuary. Preliminary results show that base levels of TSS are controlled by the Jim Woodruff dam, located north of the ANERR boundary. Base concentrations may fluctuate with tides, which have more of an effect near the mouth of the Apalachicola River and

Bay. Higher TSS concentrations occur after precipitation events, in which overland runoff increases the sediment in the river. High wind events also re-suspend sediments in the water column, increasing TSS concentrations (Smar, 2012). Understanding the factors influencing suspended sediments is necessary for developing predictions on salt-marsh accretion and in turn marsh productivity.

INTEGRATED MODELS

Three physically-based numerical models are integrated to simulate tidal hydrodynamics, sediment transport, and marsh biomass production. A large-scale, high-resolution, hydrodynamic model (ADCIRC, with over 1 million computational points in the marsh system) simulates time-dependent tides (Luettich *et al.*, 1992), and from these result the spatially varying mean high water (MHW) and mean low water (MLW) throughout the bay, river, and tidal creeks (Figure 3). MHW is the mean high water level over a tidal record, and MLW is the mean low water level over a tidal record (U.S. Department of Commerce, 2000). MHW and MLW, along with a digital elevation model (DEM), are inputs to the MEM model to determine biomass density (Hagen *et al.*, 2012) (Figure 4). An overland model simulates the sediment load traveling within the river and ultimately depositing on the marsh table (accretion).

Within the hydrodynamic model, it is crucial that the marsh table and tidal creeks are well represented in order to obtain accurate elevations of MHW and MLW. For salt marshes, there is an optimum rate of relative sea level rise (RSLR), optimum mean sea level (MSL), and optimum depth at which the marsh community is most productive (i.e. an optimum hydroperiod and depth of inundation). As MSL is non-homogenous and constantly changing, the marsh is always adapting towards a new equilibrium (Morris, *et al.*, 2002).

Sediment accretion, another effective parameter in the productivity of marsh communities alters the marsh table and state of MSL. This factor is considered by modeling overland flow and sediment transport with the WASH123D numerical code (Yeh, *et al.*, 1998). The 1D (one-dimensional) portion of the code simulates flow in small stream networks and 2D (two-dimensional) simulates overland flow and transport across a watershed system using kinematic, diffusive, or dynamic wave models (the 3D component is not considered for this application). The overland flow model will ultimately predict marsh accretion rates under SLR scenarios. In addition, the sediment loadings to the bay systems will be incorporated with 3D circulation models and linked to oyster and submerged aquatic vegetation models.

SUMMARY AND FUTURE WORK

This paper presents an overview of the integrated modeling approach used to predict the state of the coastal system under various SLR scenarios. A field data collection campaign informs the integrated models of current conditions, enabling the prediction of future states, such as mean sea level, marsh table accretion, and biomass production under future scenarios. To reduce uncertainly in model parameters and results, a need for additional field samples is required to expand current data sets.

We have found that bare earth lidar over predicts the marsh table elevation (+/- 0.50 meters) due to the inability of the laser to penetrate the thick marsh grasses, leading to inaccurate results in MLW and MHW, and in turn biomass production. With a tide range of about 1 meter, an elevation error of +/- 50 centimeters in the intertidal zones can drastically alter simulated tidal flooding. An RTK (Real Time Kinematic) survey campaign is underway to produce a more accurate DEM [RTK is a correction method for GPS/GNSS surveying with accuracy on the order of centimeters in both the vertical and horizontal directions].

Further, obtaining additional biomass samples will create a more robust validation set to confirm the correlation between sampled density values and remotely sensed data, as well as the output of the MEM.

Sea level rise is only one of the consequences of the climate change; climate change also alters the hydrologic cycle. Global climate models not only show increase in potential storm intensities, but also the amount of precipitation (Emanuel, 1987). Climate change impact on extreme events will be considered through the use of intensity-duration-frequency (IDF) curves to predict future rainfall events. Assessment of the climate change impact on IDF curves were performed by the method of sequential monthly bias correction and maximum intensity percentile-based bias correction method. Rainfall data for present and future years (30 year periods) were acquired from the North American Regional Climate Change Assessment Program (NARCCAP), where the A2 emission scenario was used. The primary driving force for the event simulation is varied design storms derived from IDF curves (Wang, *et al.*, 2013). Results from the WASH2D numerical model using future IDF curves and ADCIRC generated downstream hydrographs will be examined to gain insight into the flow and watershed responses to these potential storms. In addition, the IDF curves will be used to simulate sediment transport and flow in small streams under SLR and extreme events resulting from climate change. These effects will be investigated in terms of future marsh productivity.

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FIGURES

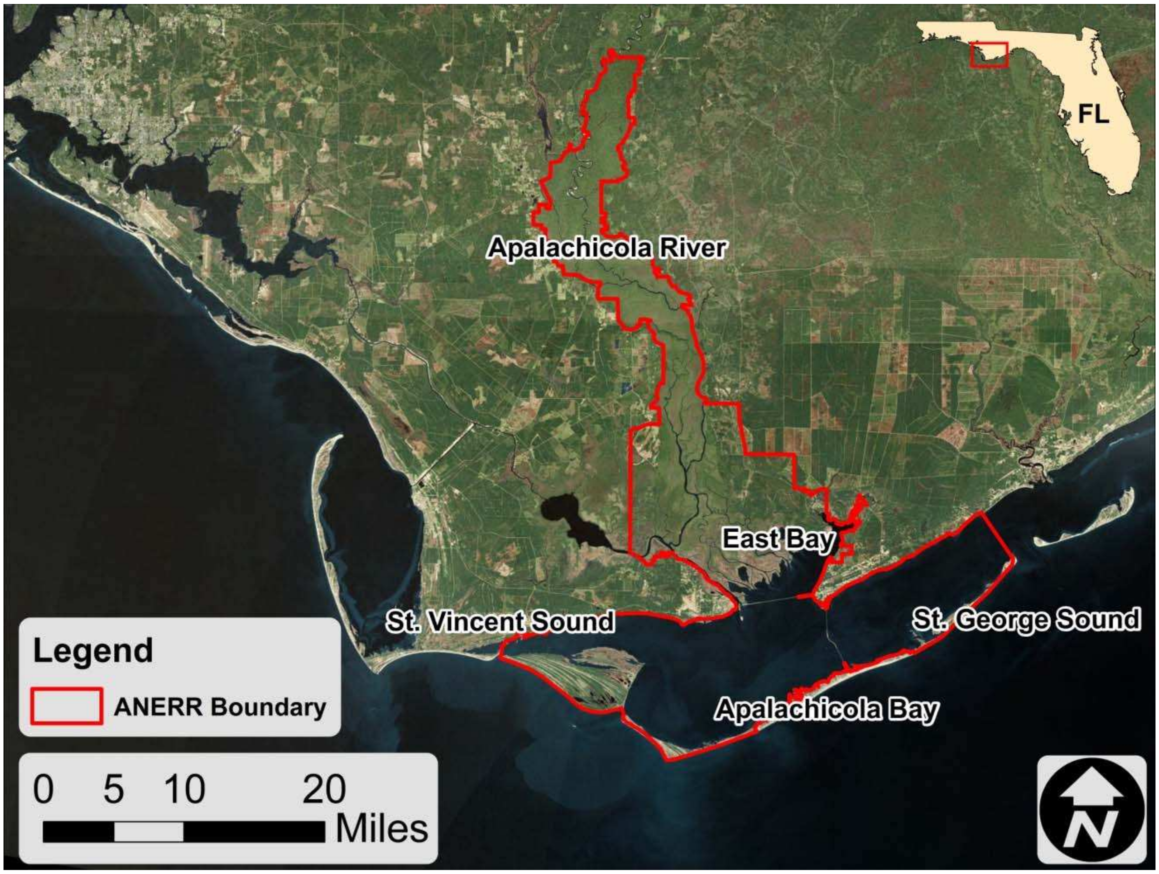

Figure 1 – Apalachicola National Estuarine Research Reserve (ANERR) Location Map

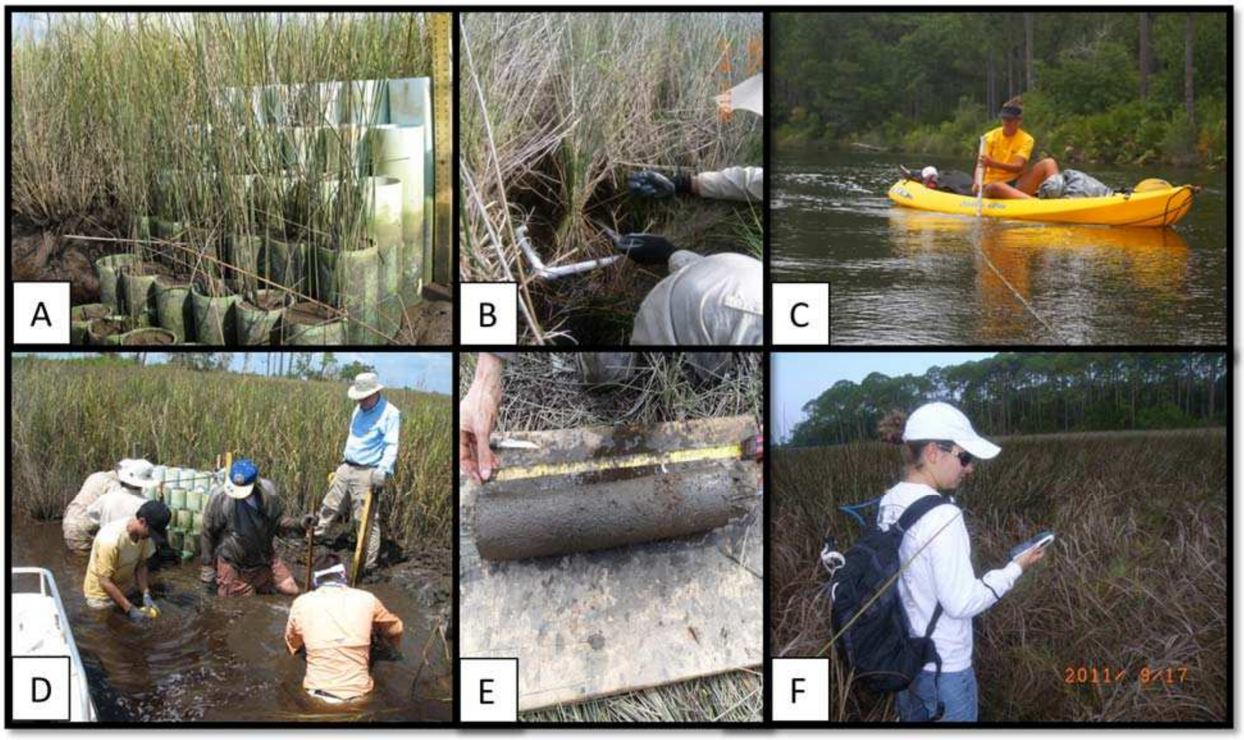

Figure 2 – Field collection campaign in Apalachicola, FL (A) marsh organ; (B) gathering a biomass sample; (C) collecting water sample to determine TSS and VSS; (D) harvesting a marsh organ (E) measuring a sediment core; and (F) using GPS to determine biomass sampling locations

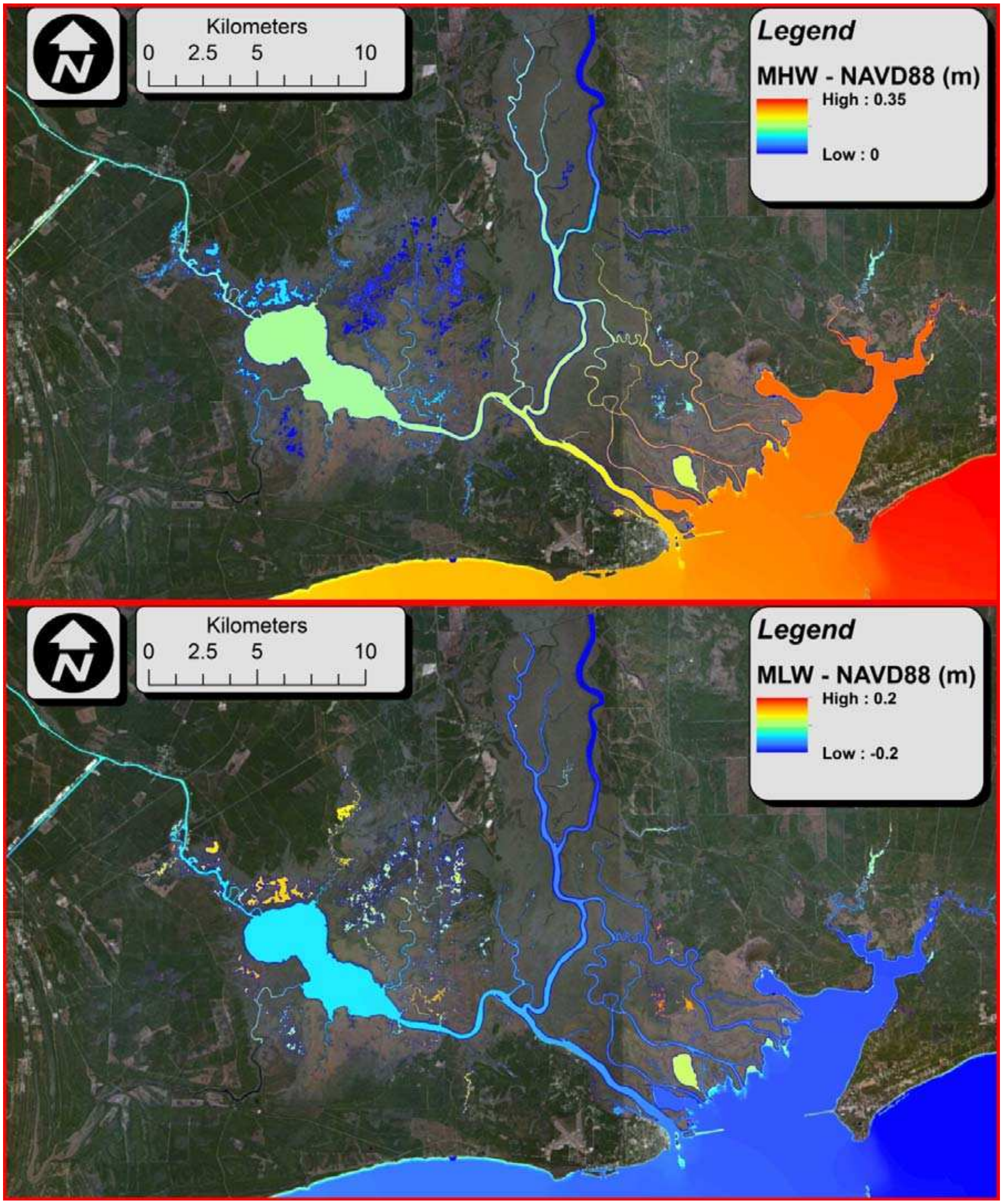

Figure 3 – Simulated mean high water (top) and mean low water (bottom)

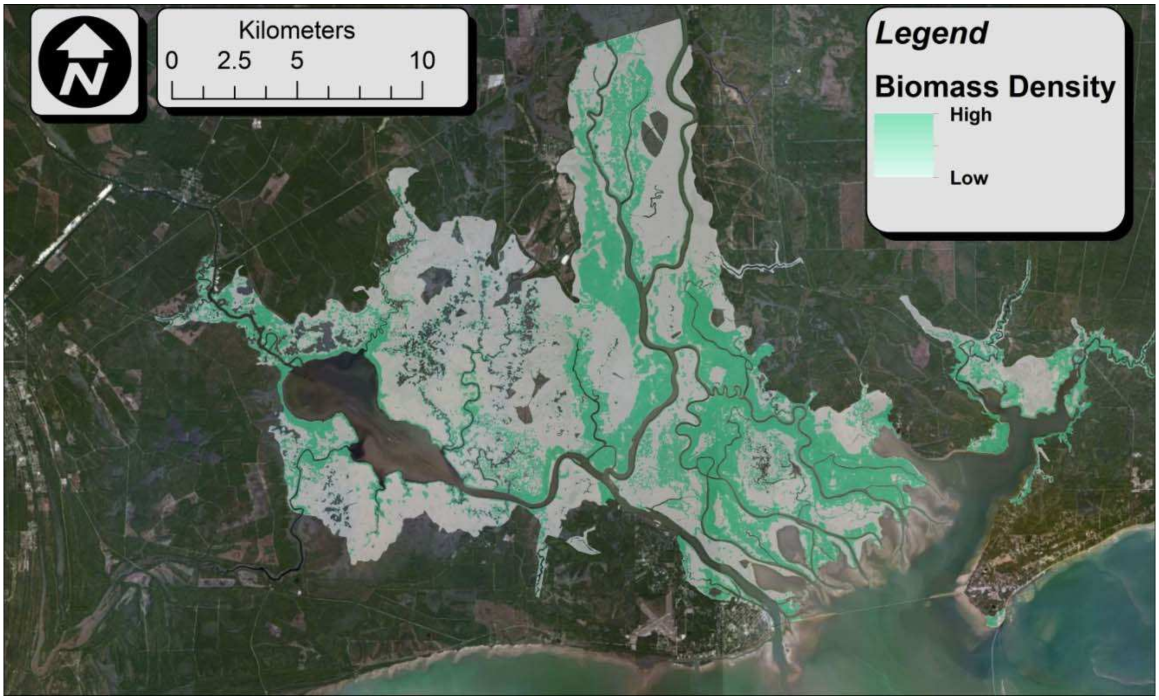

Figure 4 – Simulated marsh biomass density