Costal Zone Responses to Sea-Level Rise: Numerical Modeling and Uncertainty Analysis

Heng Dai[1], Ming Ye[2], Alan Niedoroda[3], Dejun Feng[4], Steven Kish[5], Bikash Saha[6], Joseph Donoghue[7]

[1]hd09@fsu.edu, [2]mye@fsu.edu, [4]dfeng@fsu.edu, Department of Scientific Computing, Florida State University, Tallahassee, FL 32306

[3]Alan_Niedoroda@URSCorp.com, [6]Bikash_Saha@URSCorp.com, URS corporation, Tallahassee, FL 32317

[5]kish@gly.fsu.edu, [7]donohue@gly.fsu.edu, Department of Earth, Ocean and Atmospheric Science , Florida State University, Tallahassee, FL 32306

1. Introduction

- We have developed a numerical Model of Complex Coastal Systems (MoCCS), derived from earlier morphdynamic models, to represent the large-scale time-averaged physical processes that shape several important coastal components (e.g., beach, surf zone, dune, inlet, bay shore) and govern their interactions. These control the ongoing evolution of the barrier islands, beach and dune erosion, shoal formation and sand withdrawal at tidal inlets, depth changes in the bay, and changes in storm flooding.
- The model has been used to study the evolution of Santa Rosa Island coastal area on the Florida Panhandle coast and a synthetic case with physical characteristics and storm climatology similar to Santa Rosa Island. Five SLR scenarios have been used, covering the range of recently published projections for the next century. Each scenario has been input with a constant and then a time-varying storm climate.

2. Model Description

Model of Complex Coastal Systems (MoCCS) consists of two model components: Coastal System Tract (CST) module and ACUTE module.

2.1 Coastal System Tract (CST) Module

CST module is developed to simulate coastline and ocean bathymetric change under sea-level rise.

Module Flowchart

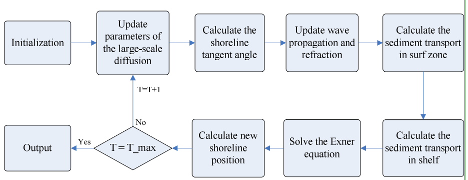

Figure 1. module flowchart of Coastal System Tract module

Governing Equation

Exner equation is used to describe the relationship between sediment volume flux and ocean bathmetry:

$$\frac{\partial h}{\partial t} = -\frac{1}{1-e}\nabla \cdot \overline{Q} = -\frac{1}{1-e}\left(\frac{\partial \overline{Q}_x}{\partial x} + \frac{\partial \overline{Q}_y}{\partial y}\right)$$

where Q is time-generalized total sediment transport volume flux; e is ocean bed porosity; h is shelf profile height.

2.2 ACUTE Module

ACUTE module is a barrier island model. It is capable of simulating barrier island morphological change due to storms and sea-level rise.

Module Flowchart

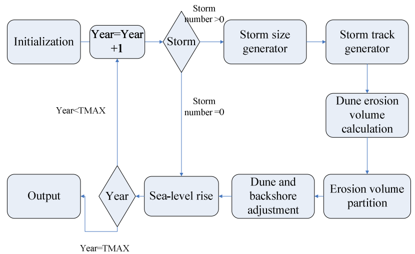

Figure 2. Model flowchart of ACUTE module

2.3 MoCCS

Model of Complex Coastal System is built by combining CST and ACUTE modules. ACUTE is used as the main program. The flowchart of MoCCS is shown in figure 3.

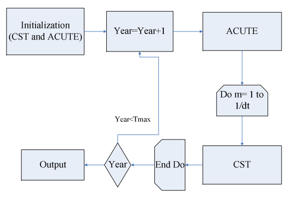

Figure 3. Flowchart of MoCCS

2.4 Sea-level Rise Scenarios

Sea-level rise in future state is treated as scenario uncertainty. 5 different sea-level rise scenarios are used (Figure 3).

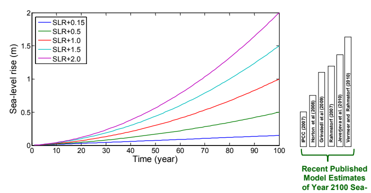

Figure 4. Five different sea-level rise scenarios

3. Model Results

3.1 CST Results

Santa Rosa Island Implementation

The CST model was implemented into the Santa Rosa island area. The morphological data of the domain was abstracted from LIDAR database. The whole modeling area was 81 kilometers long, 30 kilometers wide and it was divided into 324*120 uniform square grids with 250 meters length. Two different years' shoreline data were used as initial input and comparison of modeling result.

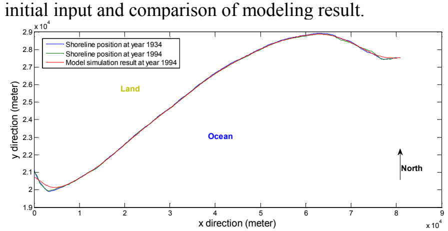

Figure 5. Santa Rosa island area modeling using CST model and comparing with real field data.

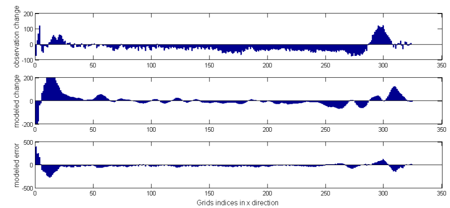

Figure 6. The bar figure of observed change using field data, simulated change and the modeling error comparing with field data (all in meter).

A relatively large error occurs near left boundary. This is because of an inlet locates at the area outside the left boundary and model can not consider its effect to the area.

3.2 ACUTE Results

A simple synthetic island which consists of conceptualized cross-section profiles is used in the model (figure 7 and 8). Dune height and bay shore positions at island profile 60 change under storms and five different sea-level rise scenarios is shown in figure 9. Using Monte Carlo simulations, we can get probability density functions of model output results (figure 10). Uncertainty analysis can be done using these results.

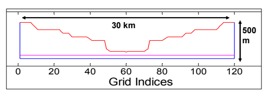

Figure 7. A simple synthetic island

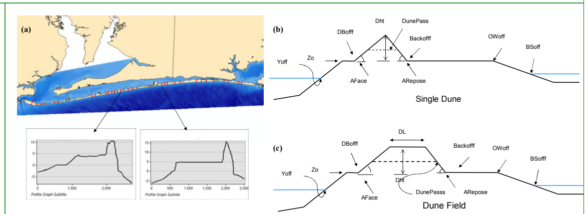

Figure 8. (a) Two cross-section profiles chosen from Santa Rosa Island and corresponding conceptualized island cross-section profiles with (b) dune and (c) dune field in ACUTE model.

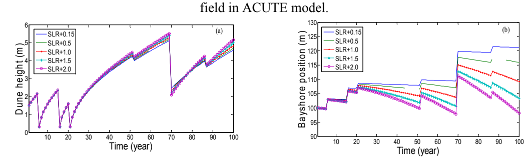

Figure 9. (a) Dune height and (b) bay shore positions change under five different sea-level rise scenarios

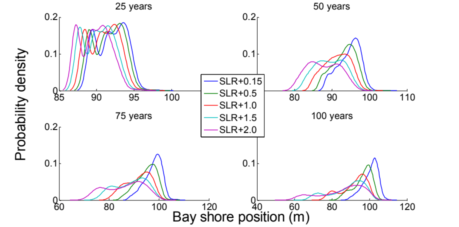

Figure 10. Probability density functions (pdf) of bay shore positions at profile 60 on four different times under five different sea-level rise scenarios using 1000 Monte Carlo simulations

4. Conclusions

- The implementation of model using Santa Rosa island data shows that it is capable of simulating right pattern of coastal line evolution but lack of certain information will cause inaccuracy.
- The barrier island undergoes cycles of dune destruction and regrowth, leading to sand deposition. This is progressively less effective in offsetting bayside inundation and marsh habitat loss at accelerated sea level rise rates. A hierarchical method of uncertainty analysis has been developed to address uncertainty in sea-level scenarios and storm parameters.
- The model predicts morphologic change to the barrier island and quantifies uncertainty in the simulated beach dune heights and bay shore positions under multiple sea-level rise scenarios. The outcomes of this study will be used to evaluate how to make reliable predictions of the effects of future climate change on coastal infrastructure and natural coastal systems. The expected result will be to enable cost-effective mitigation and adaptation strategies to prepare for future climate change.

Acknowledgement

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