Assessment of Parametric and Scenario Uncertainty of Dune and Barrier Island Responses to Sea Level Rise

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1. INTRODUCTION

Significance: In response to potential increasing rates of sea level rise, planners and engineers are making accommodations in their management plans for protection of coastal infrastructure and natural resources. Dunes and barrier islands are important for coastal protection and restoration, because they absorb storm energy and play an essential role in sediment transportation.

Numerical model: Accurate estimation of response of dunes and barrier islands to future sea level rise is required, and this is always done using numerical modeling. .

Uncertainty Analysis: The modeling results are inherently uncertain due to epistemic and aleatory uncertainty. We developed a new method to quantify epistemic uncertainty in model parameters (e.g., storm variability) and aleatory uncertainty in scenarios (e.g., future sea level rise) under which the modeling is conducted. The storm uncertainty and its propagation to the modeling results are assessed using the Monte Carlo (MC) method. The scenario uncertainty is quantified using a recently developed scenario averaging method.

The uncertainty analysis is conducted for a semi-synthetic barrier island with physical features and hurricanes exposure similar to Santa Rosa Island, in northwest Florida. A total of 1000 realizations of 100-yr storm sequences are generated, each of which has distinct storm magnitudes, frequencies, and tracks that are consistent with the present hurricane climate. Five scenarios of sea level rise are considered in the modeling; one is continuation of the present rate and the other four projected rates by 2100 to 0.15 m, 0.5 m, 1.0 m, 1.5 m, and 2.0 m, respectively. One thousand MC simulations are conducted under each scenario. The final result shows that sea-level rise scenarios have significant impact on the forecasted bayshore position changes but relatively small effect on dune height. Probability density functions (PDF) of dune height and relative bayshore migration are different at different times and for different scenarios.

2. Uncertainty Sources

This study addresses two types of uncertainty:

- Parametric uncertainty (storm climate)
- Scenario uncertainty (sea-level rise scenarios)

2.1 Parametric uncertainty

Three storm parameters are treated as random variables due to their natural variability. They are storm magnitude, track and number within a given year in the vicinity of the island .

Storm Number

Based on the FEMA Okaloosa Co. flood study, the average annual storm rate within a 45 km 'capture length' centered on the island is 0.06 storms/yr. The Poisson distribution is used to assess the occurrence of hurricanes during each model year. (Figure 1).

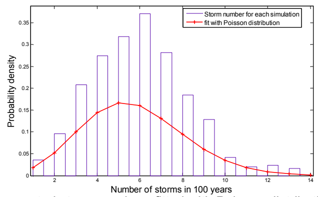

Figure 1. Generated storm numbers fitted with Poisson distribution

Storm Track

Uniform distribution is used to generate random storm track number.

Storm Magnitude

Four different storm magnitudes are used in this modeling. These were back-calculated for selected surge height values using the NOAA SLOSH model. The probability ranges of the four storms were derived from the surge height cumulative probability distribution given in the FEMA FIS report (Figure 2).

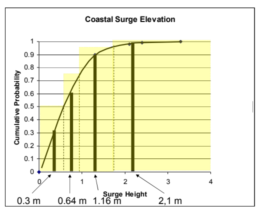

Figure 2. Surge height values and probabilities for different storm sizes

2.2 Scenario Uncertainty

Future sea-levels are treated as scenario uncertainty. Five different sea-level rise scenarios are used (Figure 3).

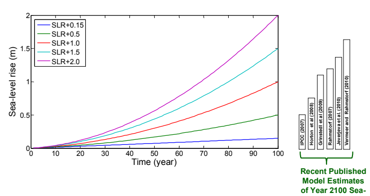

Figure 3. 5 different sea-level rise scenarios and some existed predictions

3. Monte Carlo Simulation

The Monte Carlo method is used to create multiple realizations of 100-yr hurricane sequences in order to quantify the parametric and scenario uncertainty.

Convergence of MC Method

Mean and variance of MC simulations are checked for convergence (Figure 4). One thousand simulations are shown to be sufficient.

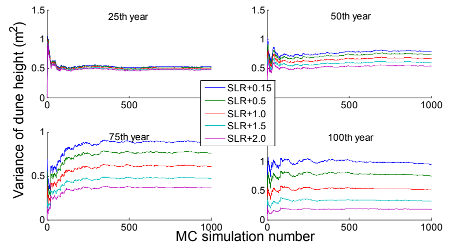

Figure 4. Convergence of variance of dune height using 5 different sea-level rise scenarios at 4 different years.

Monte Carlo Results

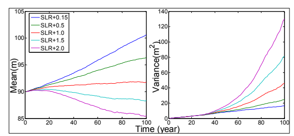

Figure 5. Mean and variance of bay shore change with time at cross-section 60

Figure 5 shows the trend of bay shore change with time. The uncertainty (variance) grows with time.

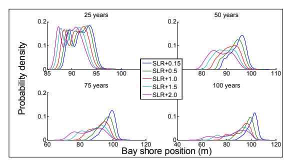

Figure 6. Probability density function (PDF) of bay shore on single years at cross-section 60

Figure 6 shows that the distributions of bay shore positions at cross-section 60 at index years have two modes, the smaller mode becomes less distinguished with time increases.

In addition, larger sea-level rise will cause a wider distribution.

Dune height results almost have the same pattern for mean and variance change. But PDFs of dune height for the index years have different characteristics. AS time increases the distributions are closer to a normal distribution (Figure 7).

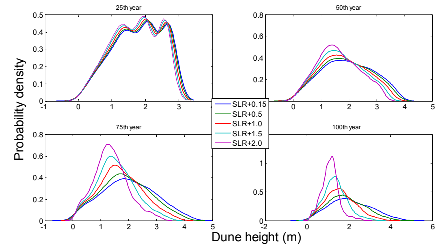

Figure 7. Probability density function (PDF) of dune height on single years at cross-section 60

4. Scenario Averaging

The exact probability of each sea-level rise scenario is impossible to be obtained. To average different scenarios' results, 126 arbitrary sets of probabilities are used in equation (1), (2), (3). These probability sets satisfy $10\% < P_i < 60\%$ and $\sum_{i=1}^{5} P_i = 1$. The range of scenario averaging results are smaller than individual scenario results (Figure 8). This method can provide better predictions.

$$P(\Delta) = \sum_{k=1}^{K} P(\Delta \mid S_k) P(S_k) \quad (1)$$

$$E[\Delta] = \sum_{k=1}^{K} E[\Delta \mid S_k] P(S_k) \quad (2)$$

$$Var[\Delta] = \sum_{k=1}^{K} Var[\Delta \mid S_k] P(S_k) + \sum_{k=1}^{K} (E[\Delta \mid S_k] - E[\Delta])^2 P(S_k) \quad (3)$$

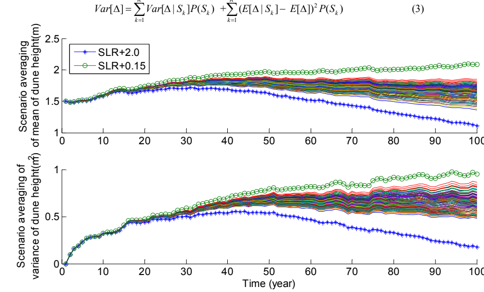

Figure 8. Scenario averaging of mean and variance of dune height at cross-section 60

Acknowledgement

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