Numerical Modeling and Uncertainty Analysis for Effects of Near-Term Sea-Level Rise on Barrier Islands

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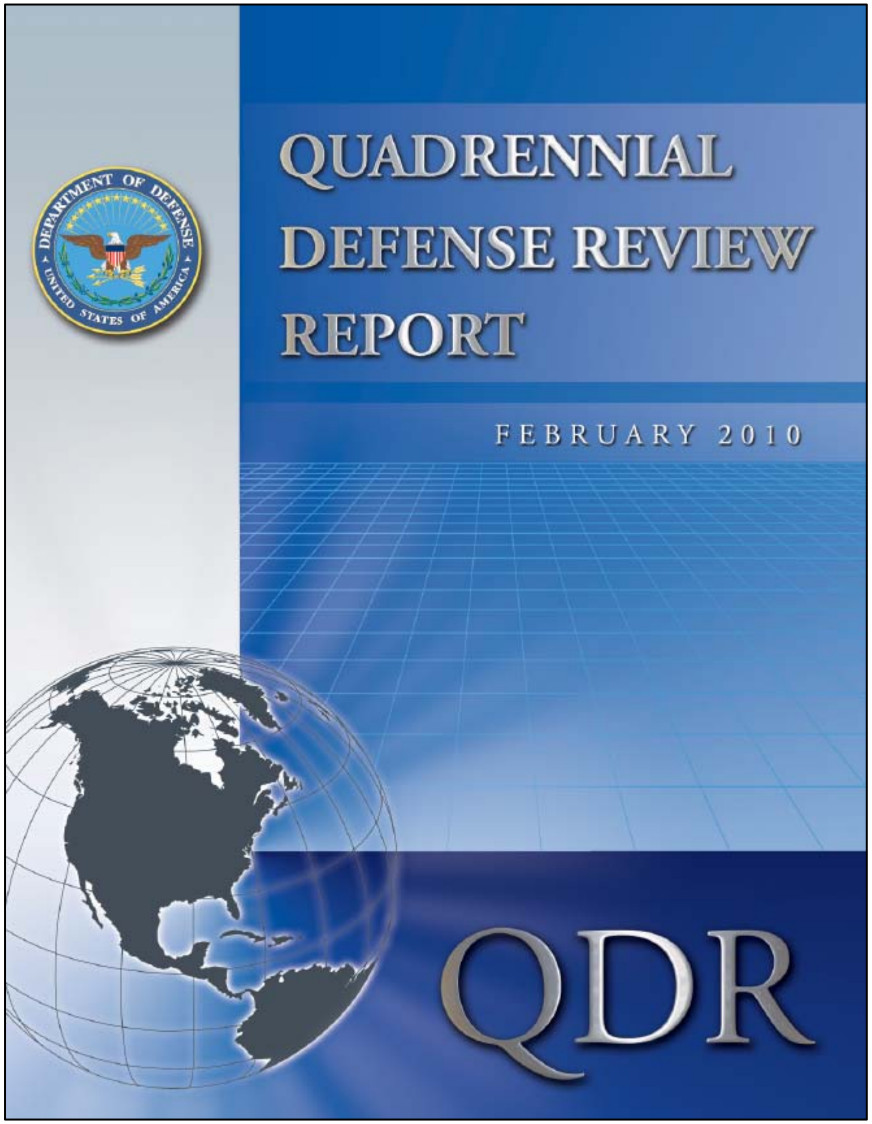
Project Overview

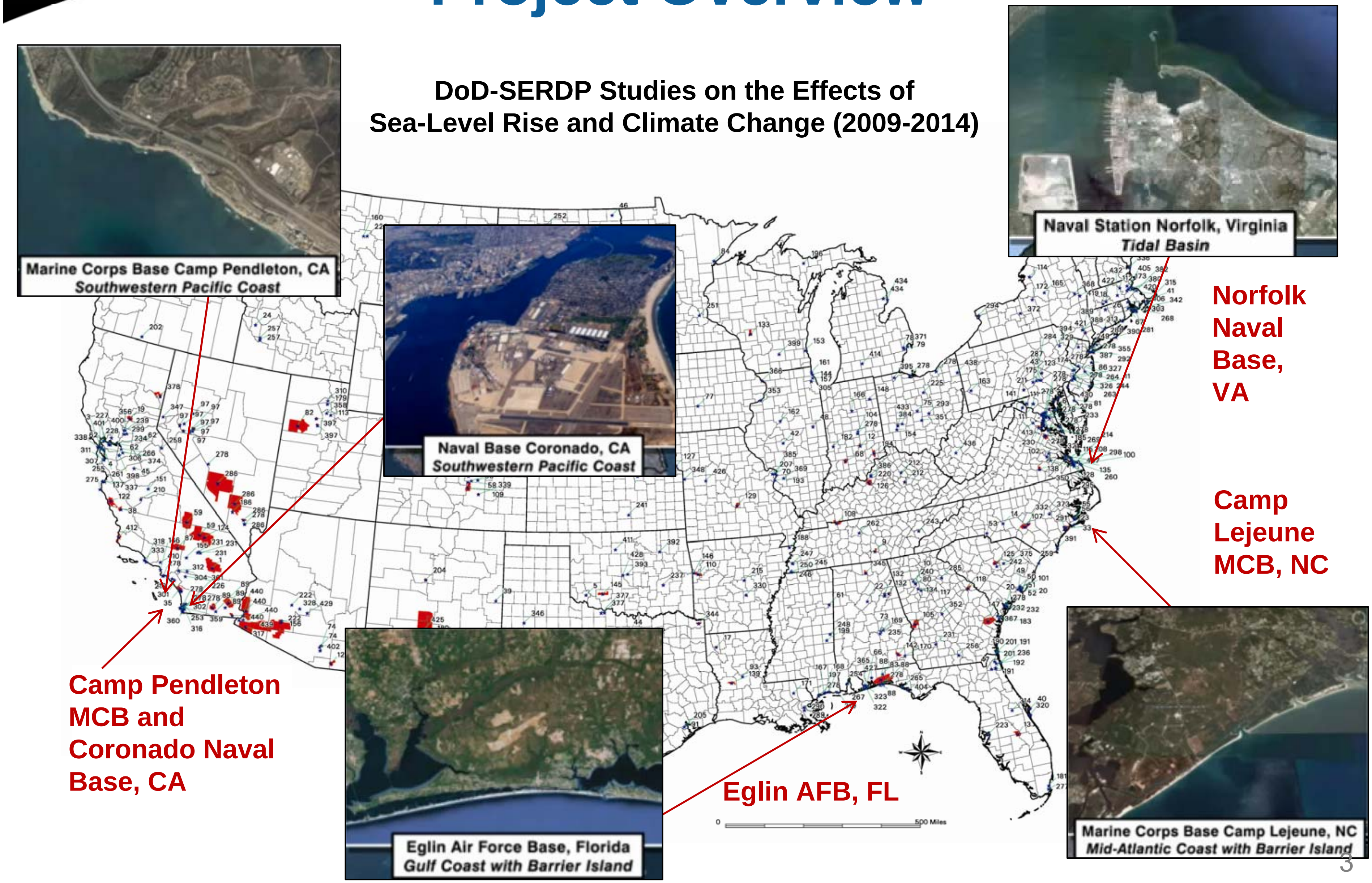


(http://www.defense.gov/qdr/images/QDR_as_of_12Feb10_1000.pdf)

"… the **National Intelligence Council judged that more than 30 U.S. military installations were already facing elevated levels of risk from rising sea levels.** DoD's operational readiness hinges on continued access to land, air, and sea training and test space. Consequently, the Department must complete a comprehensive assessment of all installations to **assess the potential impacts of climate change on its missions and adapt as required**. In this regard, DoD will work to foster efforts to assess, adapt to, and mitigate the impacts of climate change. Domestically, the Department will leverage the **Strategic Environmental Research and Development Program**, a joint effort among DoD, the Department of Energy, and the Environmental Protection Agency, to develop climate change assessment tools."

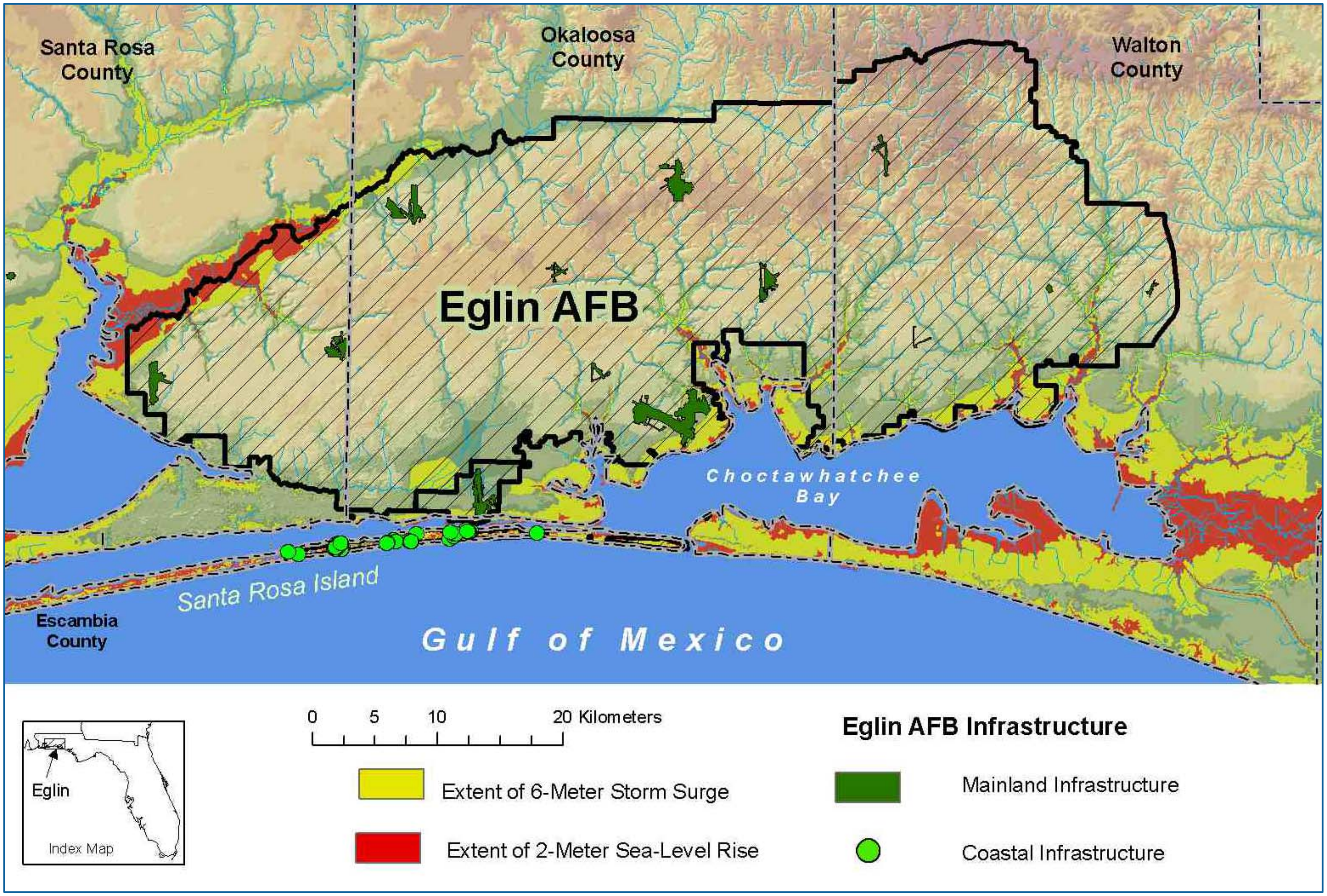
Project Overview

DoD-SERDP Studies on the Effects of Sea-Level Rise and Climate Change (2009-2014)



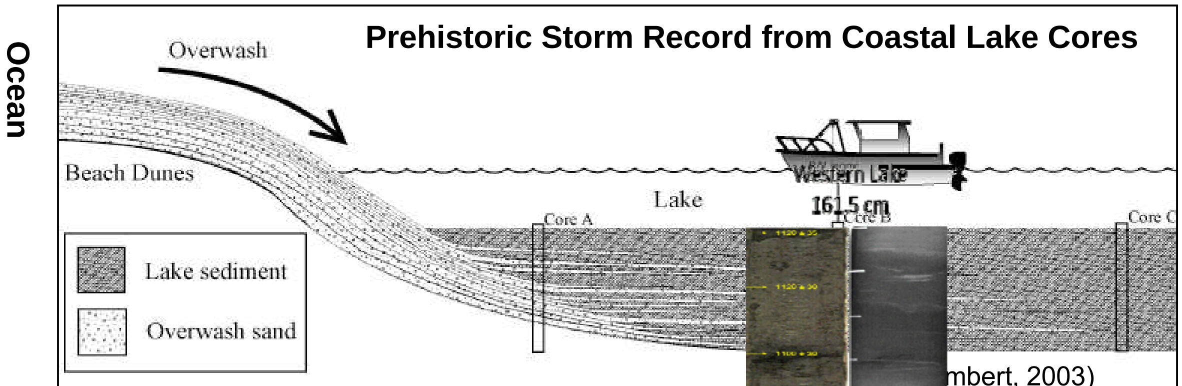
Project Overview

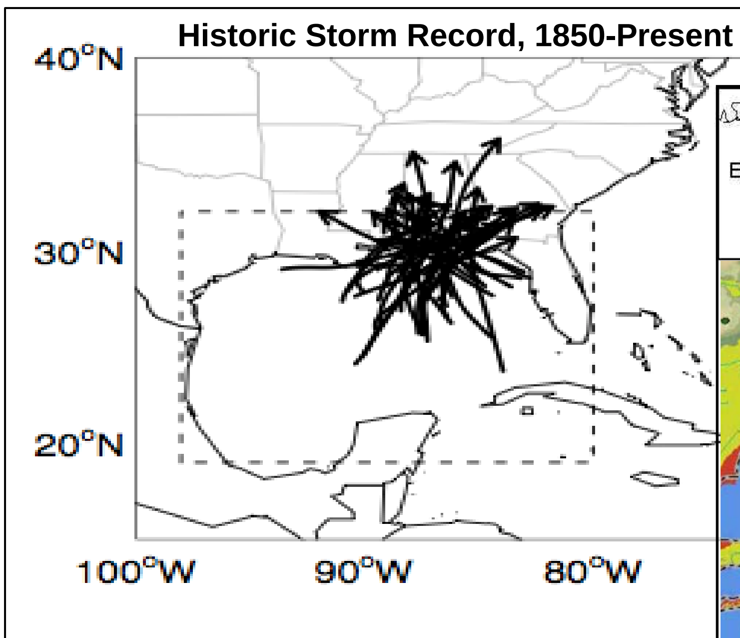
Study Area

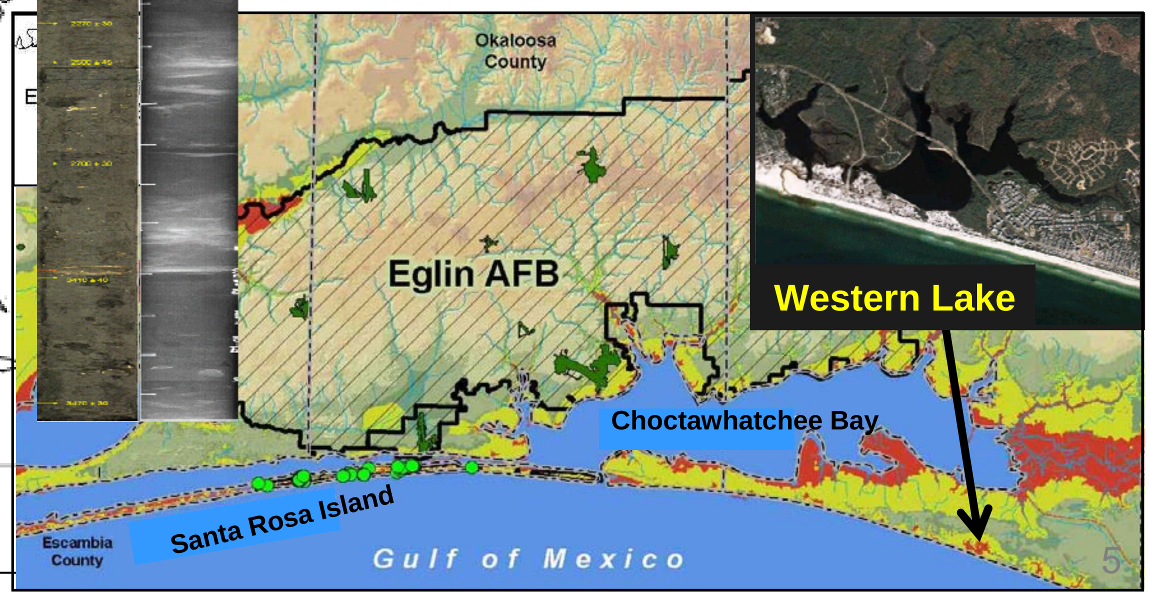


Coastal Storms

Analyzing Paleostorm Record in Coastal Sediments







Coastal Change

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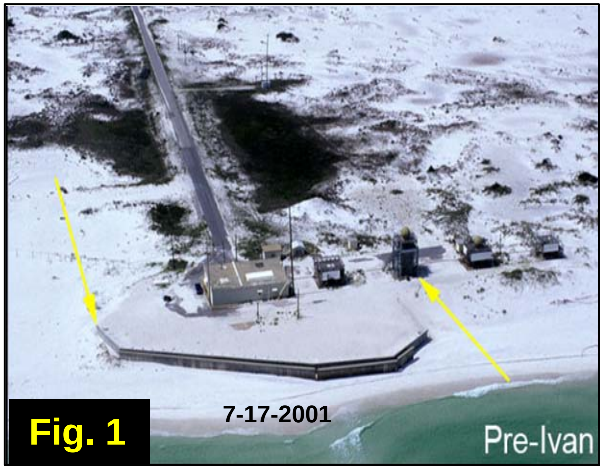
Shoreline Change on Santa Rosa Island, Site A-13



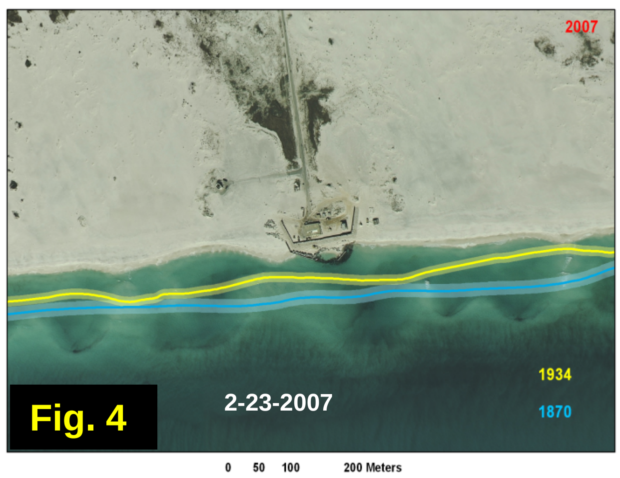


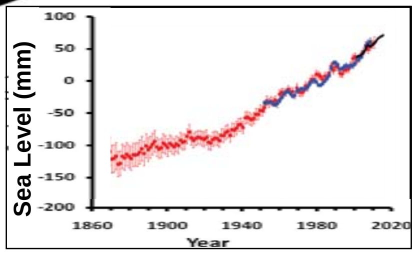
Figure 1. Aerial imagery of infrastructure located on Santa Island, Eglin Air Force Base, protected by a sea wall before Hurricane Ivan, 2004. Yellow arrows indicate location of features common to all photos.

Figure 2. Same location, after Hurricane Ivan (2004) and before Hurricane Dennis (2005).

Figure 3. Same location, after Hurricane Dennis (2005).

Figure 4. Historic shorelines of 1870 and 1934 are superimposed on a recent aerial image. Shoreline borders represent uncertainty in shoreline position measurement, +/- 15 m.

Project Overview



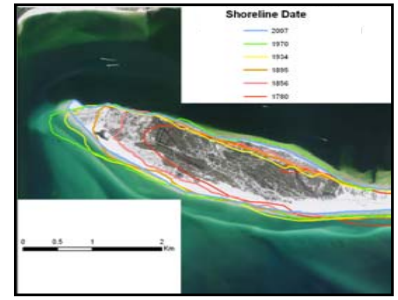
Research Objectives

- Identify and quantify the responses of coastal system components to sea-level rise and increased hurricane activity out to 2100 AD.
- Develop guidelines for using existing techniques and developing new methods for evaluating risk to coastal military installations.
- Develop probability methods for quantifying uncertainty in coastal risk analysis.
- Evaluate mitigation and adaptation strategies for near-future climate change.

Project Overview

Modeling Strategy

Lidar imagery



Shoreline change-
1780-2007

COASTAL DATA

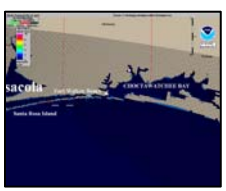
New → Inputs and forcing; New → Calibration/verification

Historic → Inputs and forcing; Historic → Calibration/verification

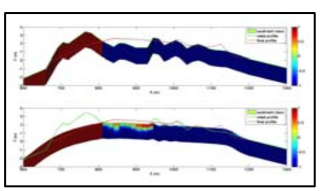
Inputs and forcing → MODELING ANALYSES

Calibration/verification → MODELING ANALYSES

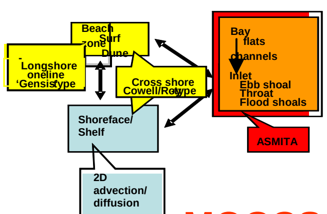
MODELING ANALYSES



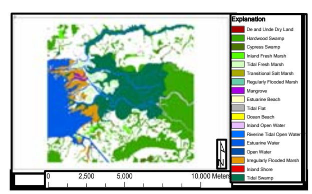
SLOSH



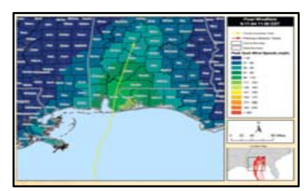
X-BEACH



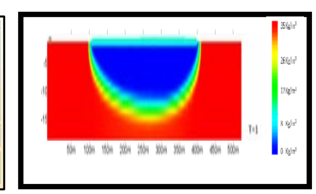
MOCCS



SLAMM



HAZUS



SEAWAT

Sea-Level Change

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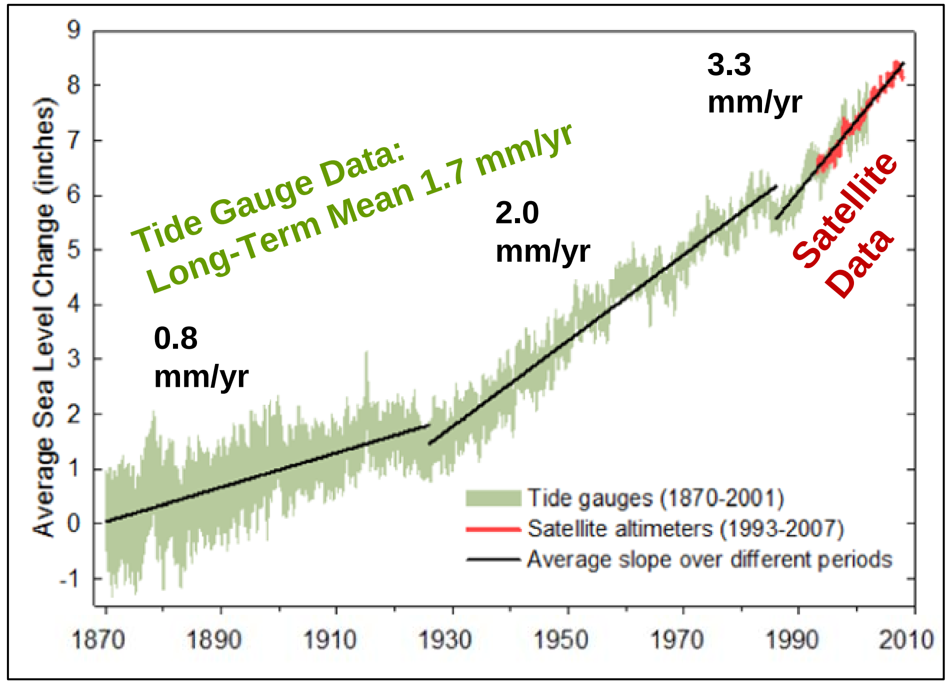
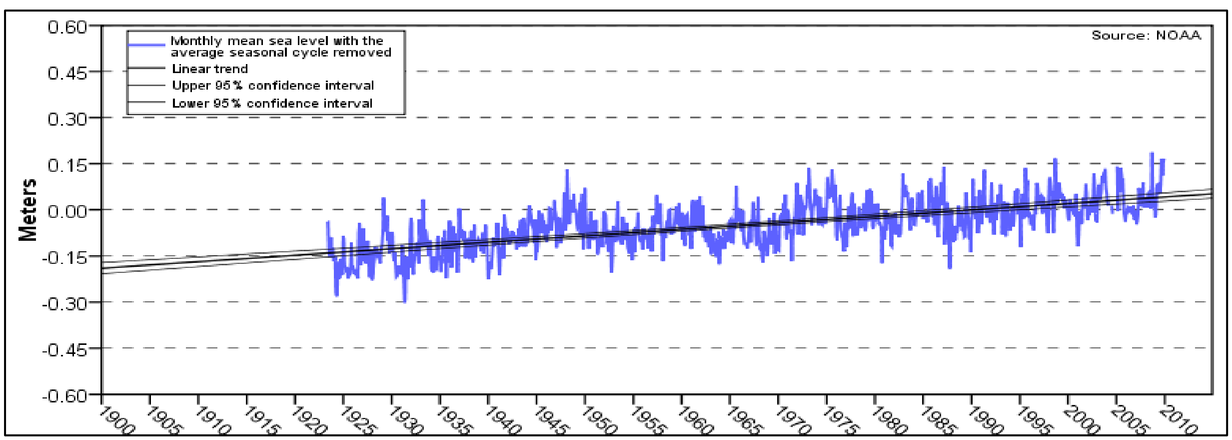
Global mean sea-level rise, from tide gage and satellite data





Pensacola, FL, tide gage data, 1923-2010. Mean sea-level rise: 2.1 mm/yr.

(Global data adpted from Burke et al. (2008); original data from Church and White (2006), and Cazenave and Nerem (2004))

Sea-Level Change

Projecting Future Sea-Level Rise

U.S. Army Corps of Engineers (2009) Sea-Level Rise Scenarios for Civil Works Project Planning

EC 1165-2-211
1 Jul 09

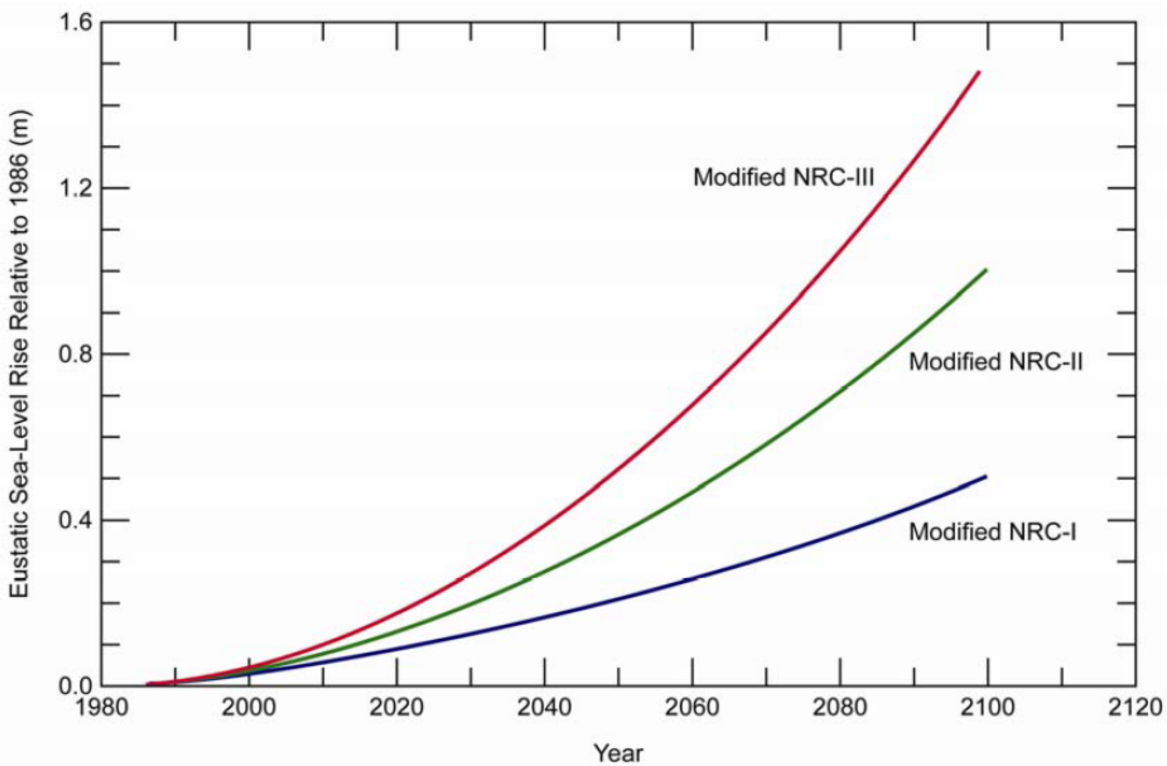
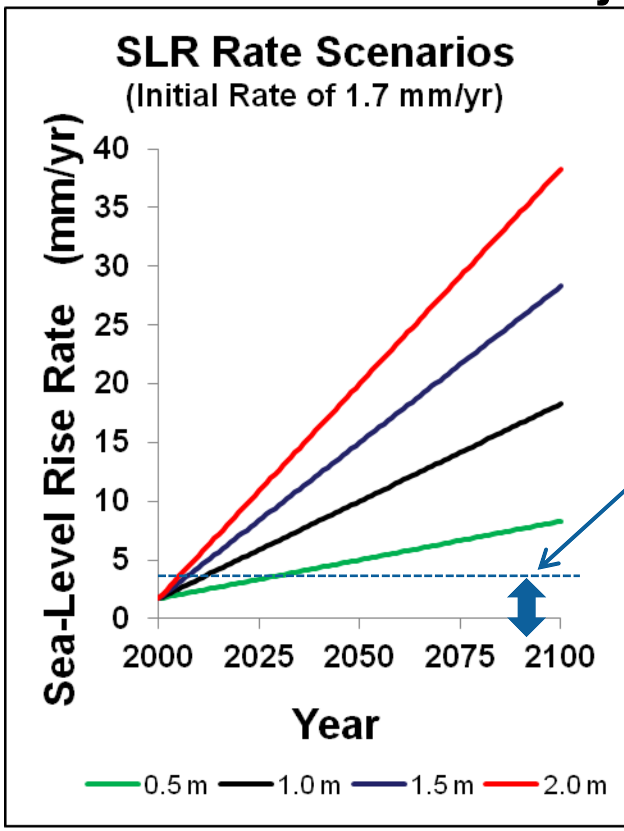


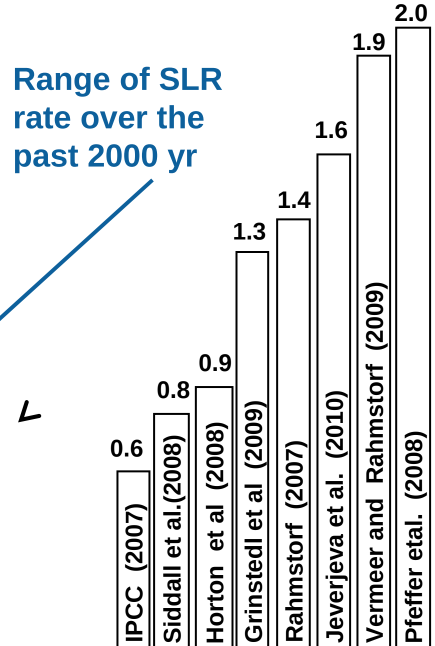
Figure B-9. Scenarios for Eustatic Sea-level Rise (based on updates to NRC 1987 equation).

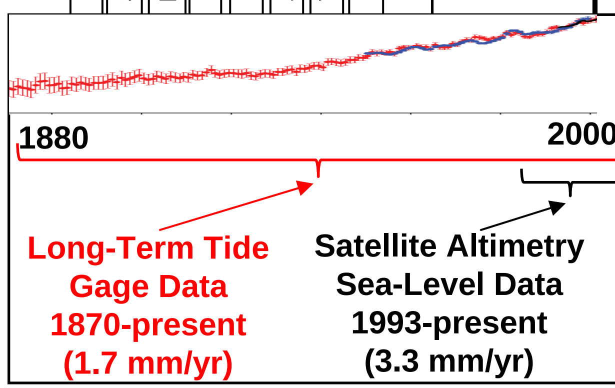
(U.S. Army Corps of Engineers, 2009, Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations into Civil Works Programs: USACOE Circular No. 1165-2-211)

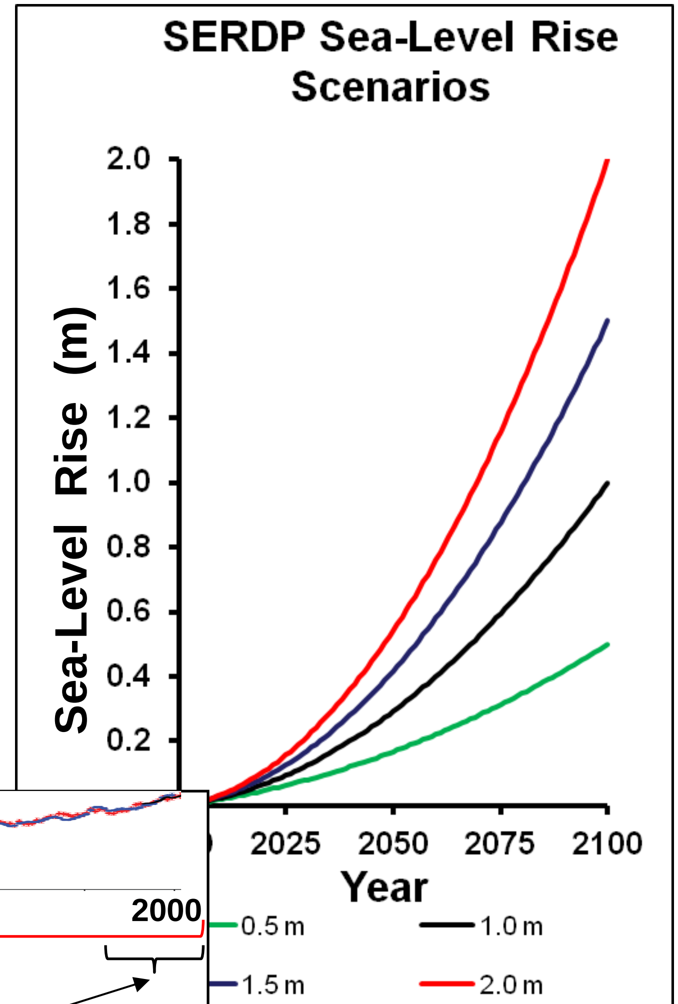
Sea-Level Change

Projecting Future Sea-Level Rise









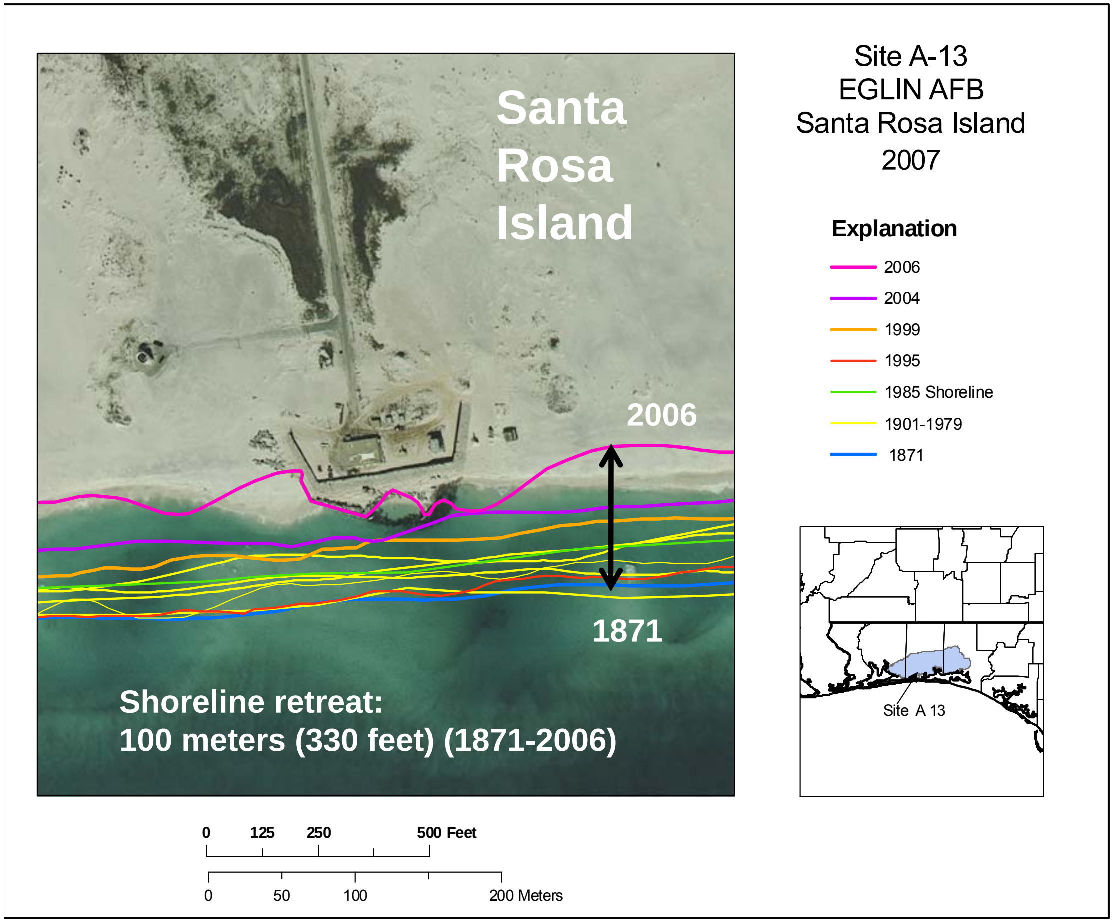
Sea-level rise equation: $S-S_0 = a\,(Y-Y_0) + b\,(Y-Y_0)^2$

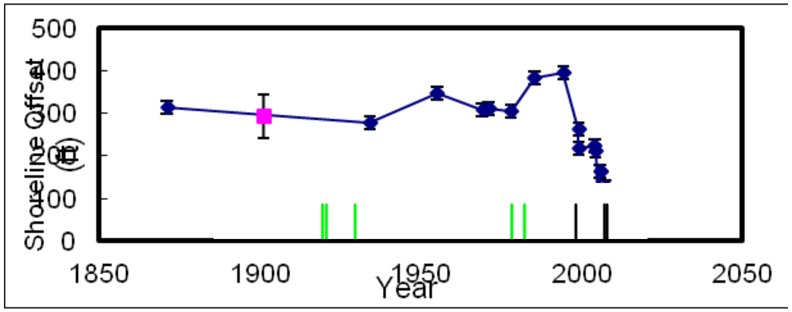
Where:

- **S** = Sea level at year Y (taken to be 2100)
- **S_0** = Sea level at year Y_0 (taken to be 2000)
- **a** = Initial rate of SLR
- **b** = Rate of increase in rate of rise

Coastal Storms

Effect of Storms on Coastal Retreat

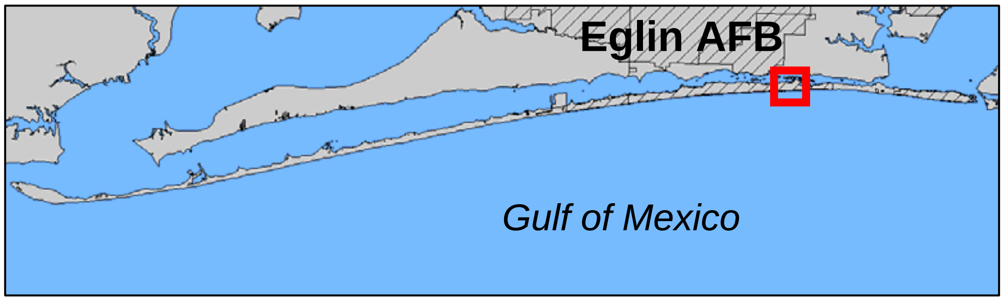


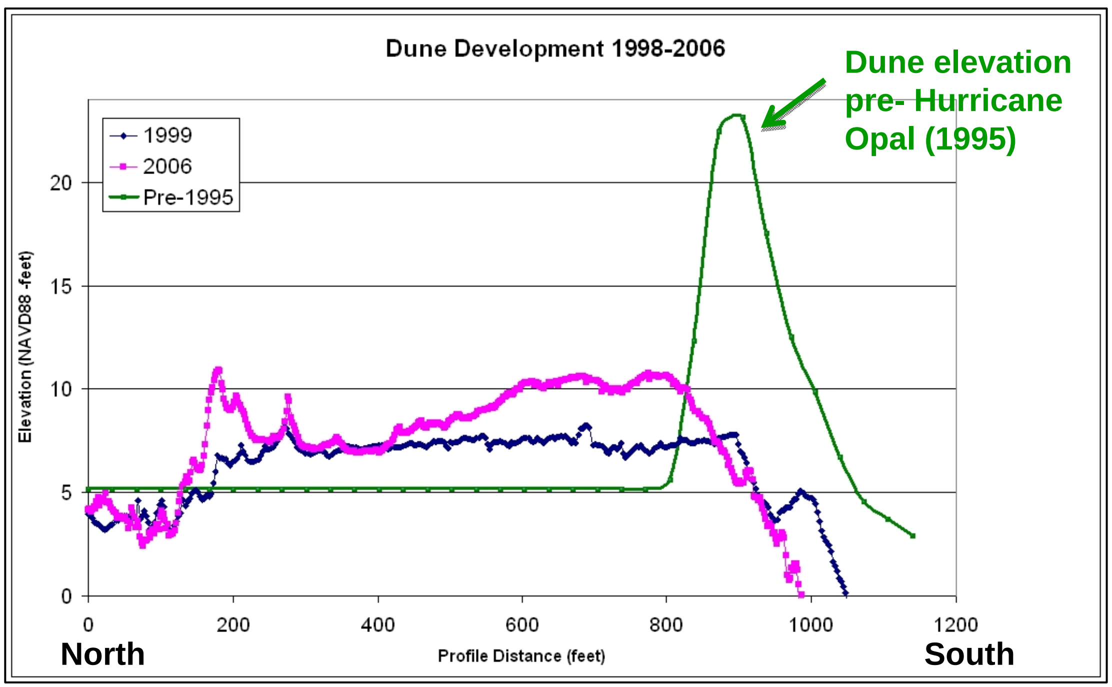


Shoreline retreat, eastern portion of Eglin AFB facilities on Santa Rosa Island, 1871-2006

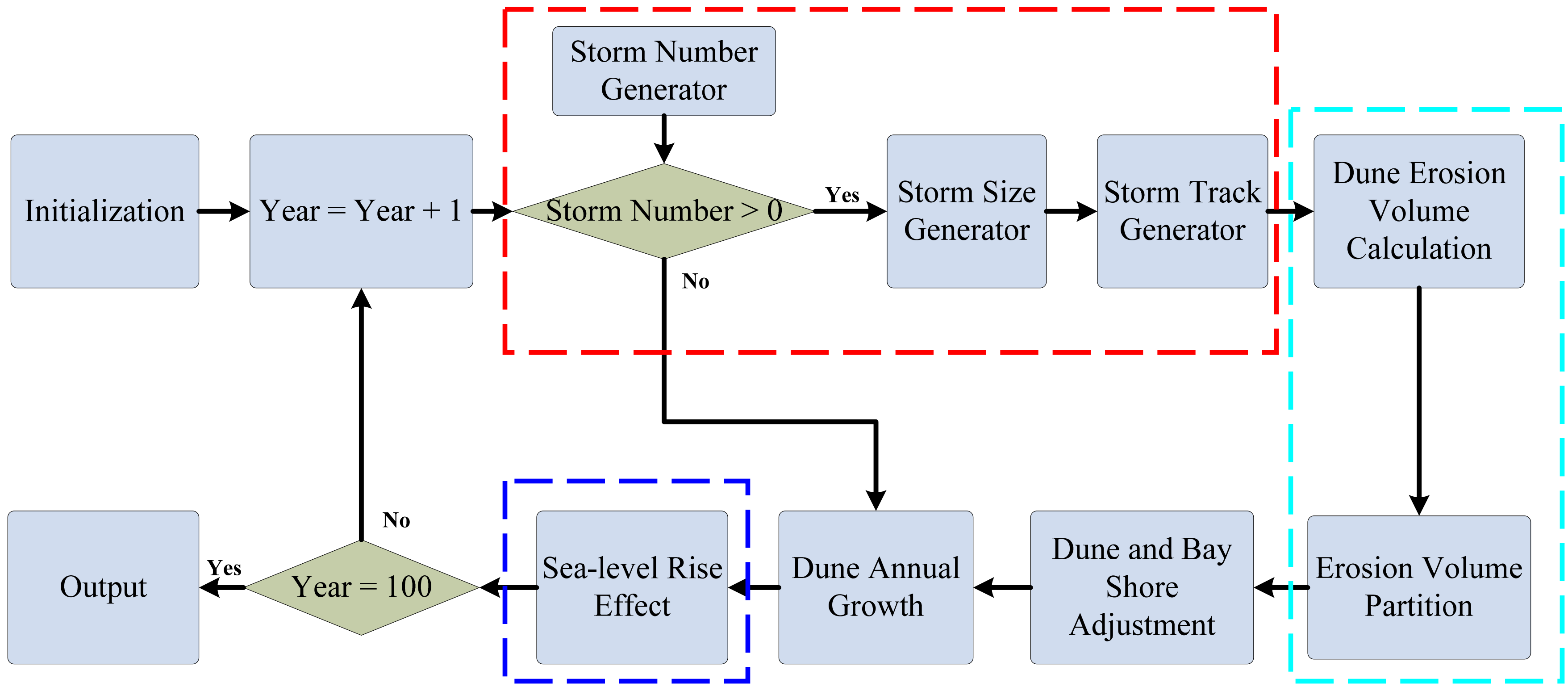
Coastal Storms

Effect of Storms on Coastal Morphology



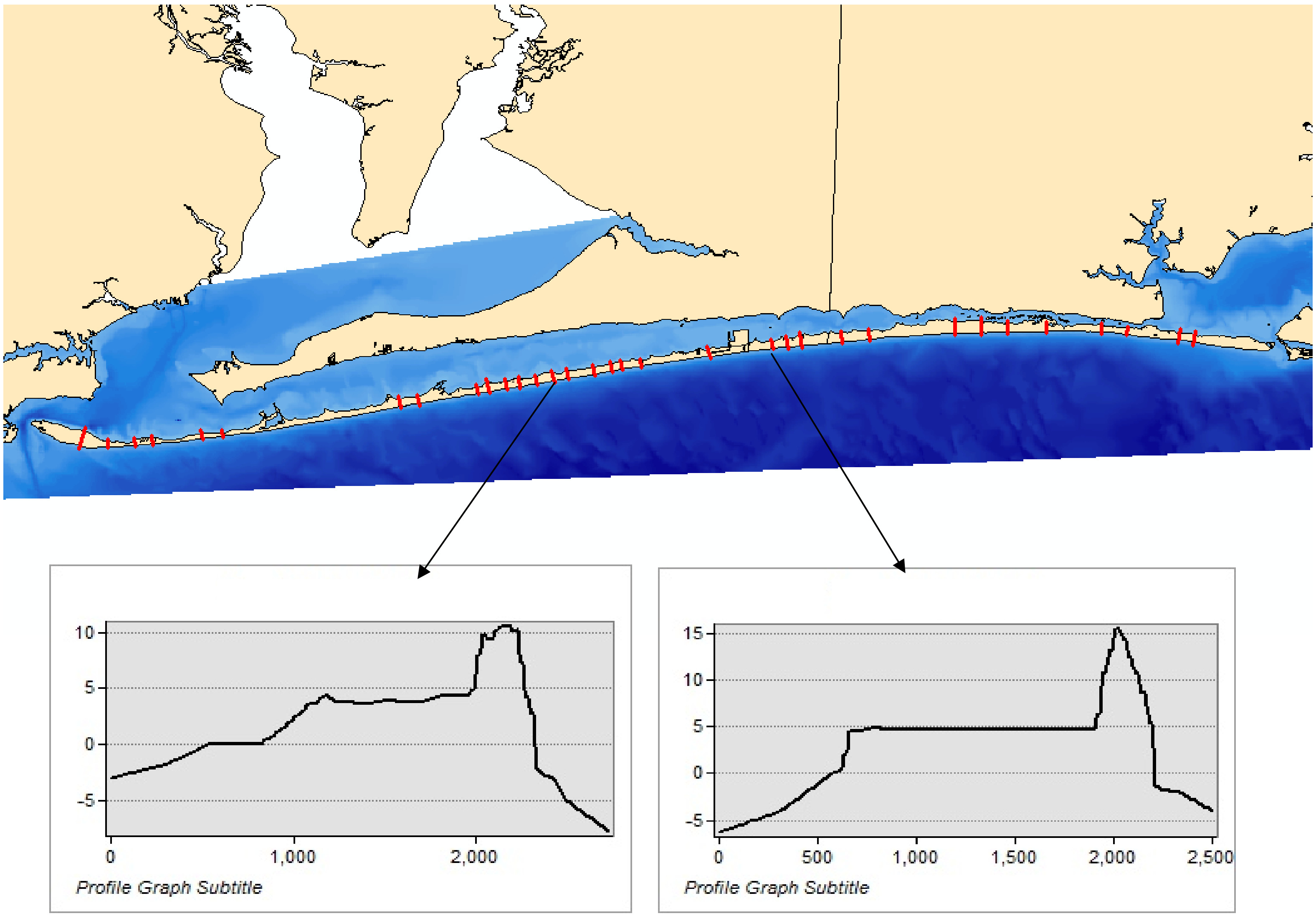


Flow Chart of Dune Modeling (ACUTE)

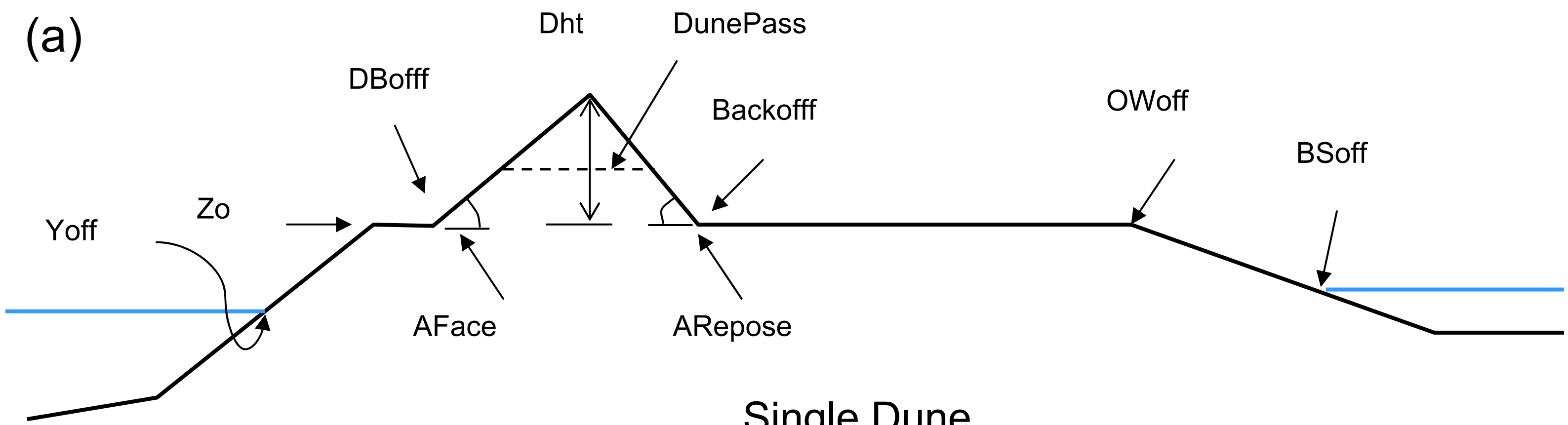


- Total simulation time is 100 years.
- Consider storm, sediment transport, dune growth, and sea-level rise.
- Model simulation under random storm events and different sea-level rise scenarios.

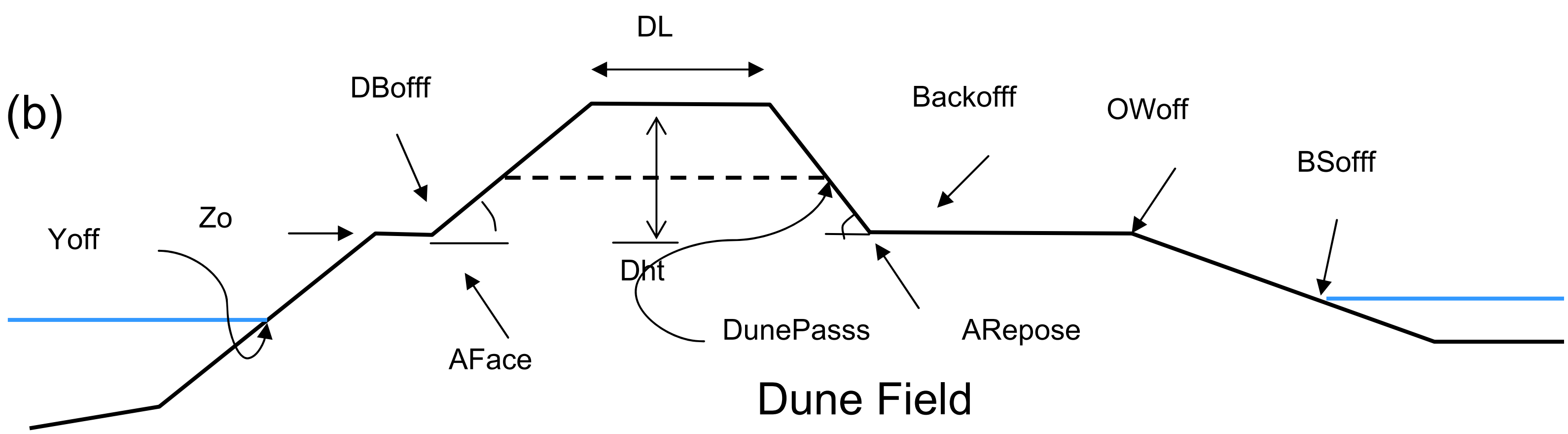
Characterization of Dune Geomorphology



Characterization of Dune Geomorphology

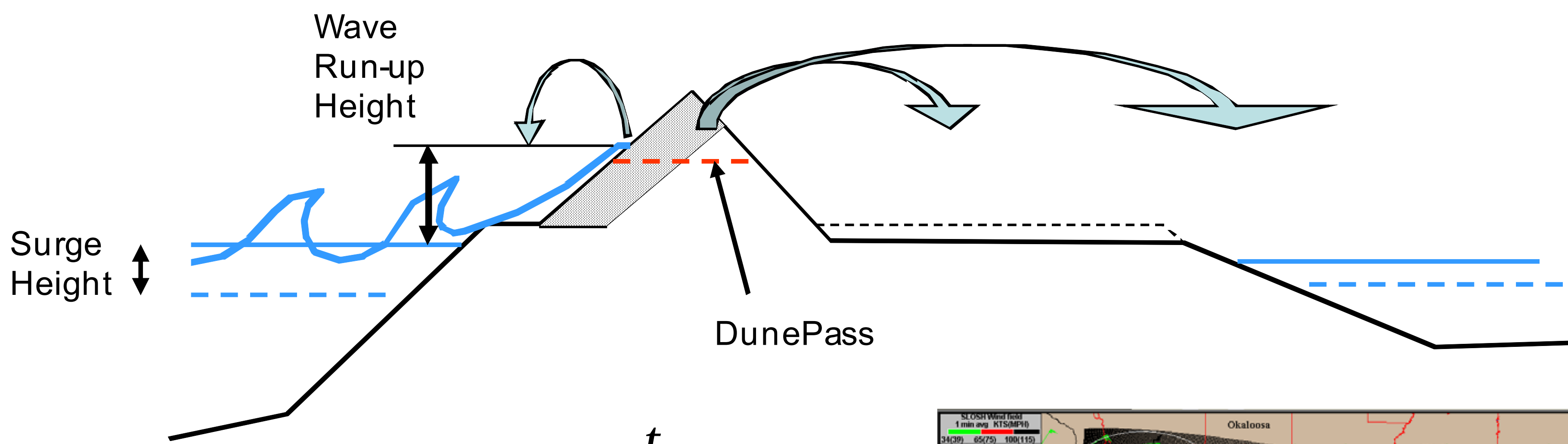


Single Dune



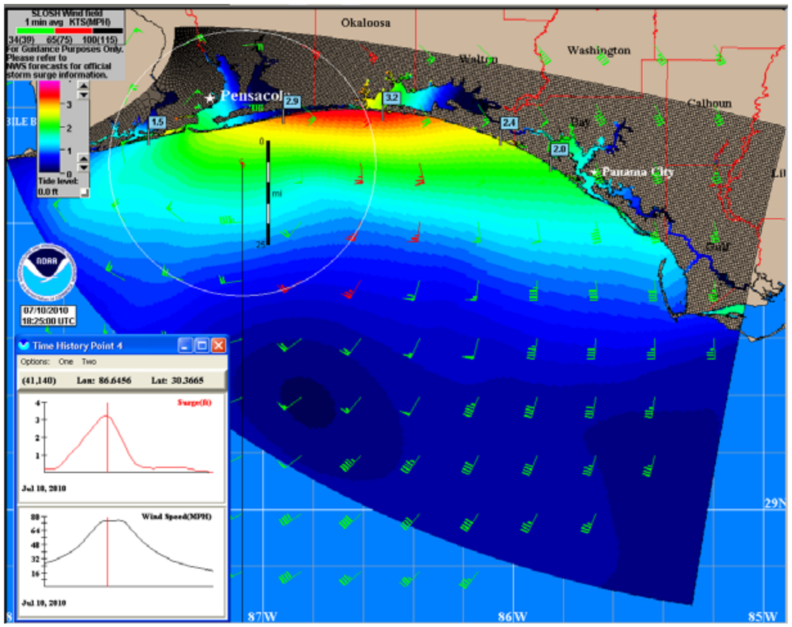
Dune Field

Dune Erosion and Eroded Volume Partition



$$\Delta V_E = 4C_s(R + Sht - Zo)^2 \frac{t}{T}$$

Calculation of the volume of storm erosion requires running SLOSH (Sea, Lake, and Overland Surges from Hurricanes).

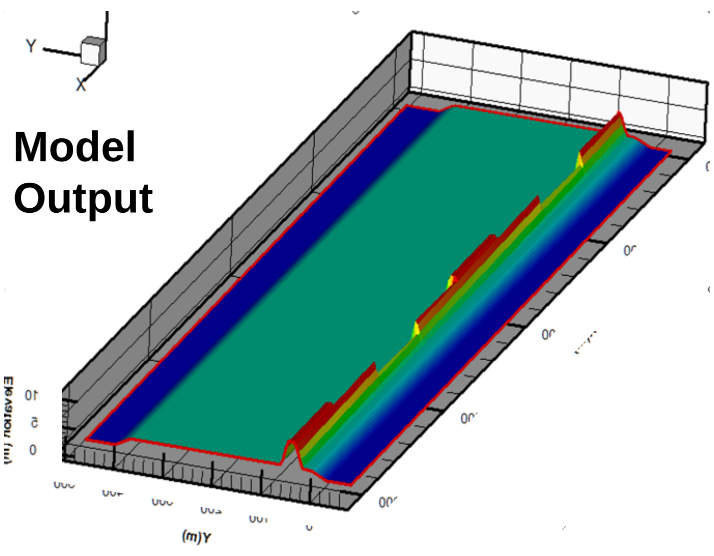


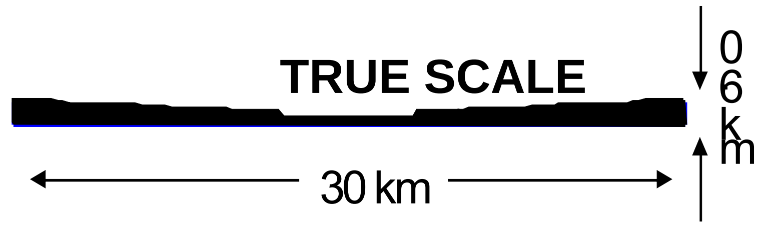
Model Simulation with a Test Island

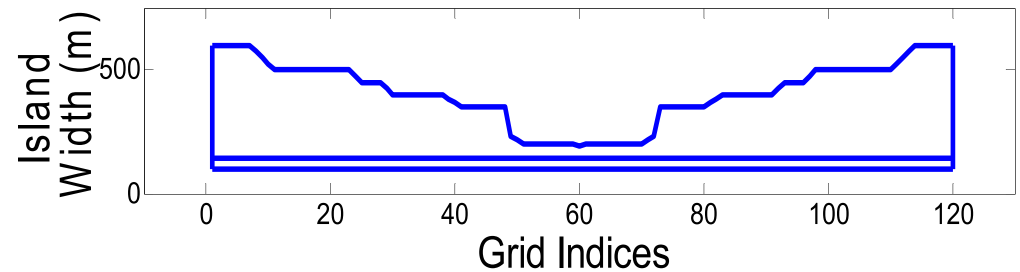
ACUTE Component Description

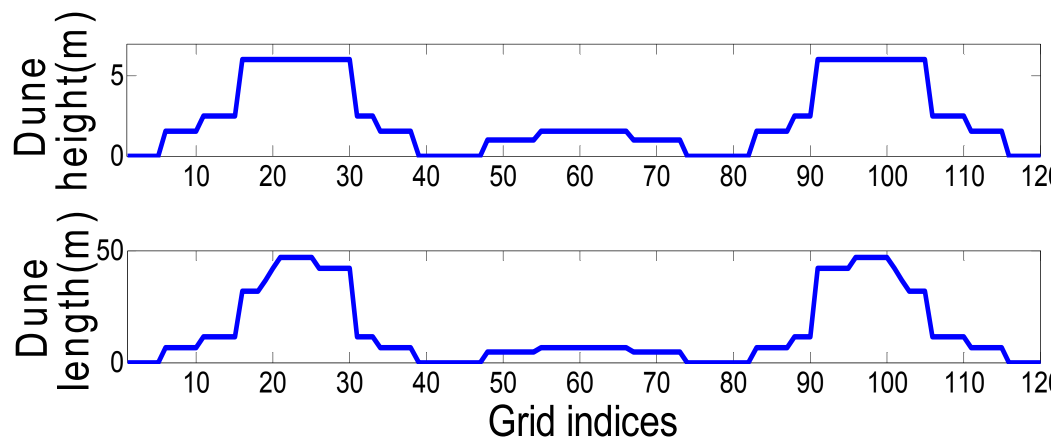
Lidar DEM

Model Output









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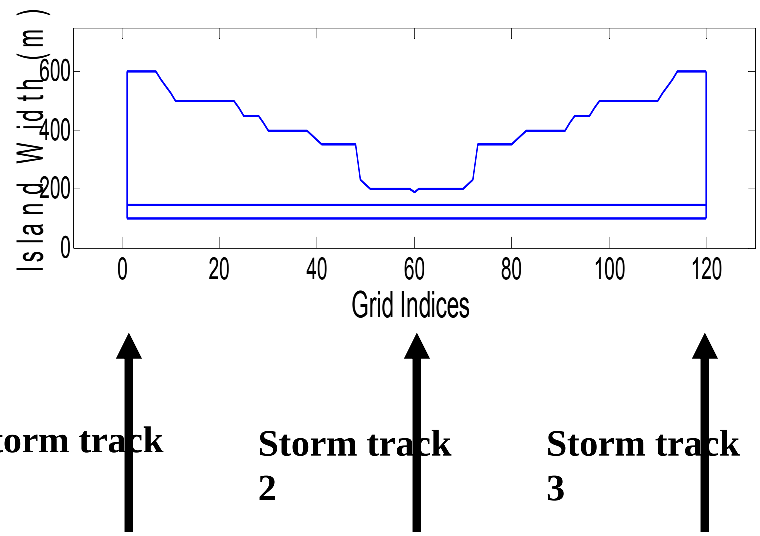
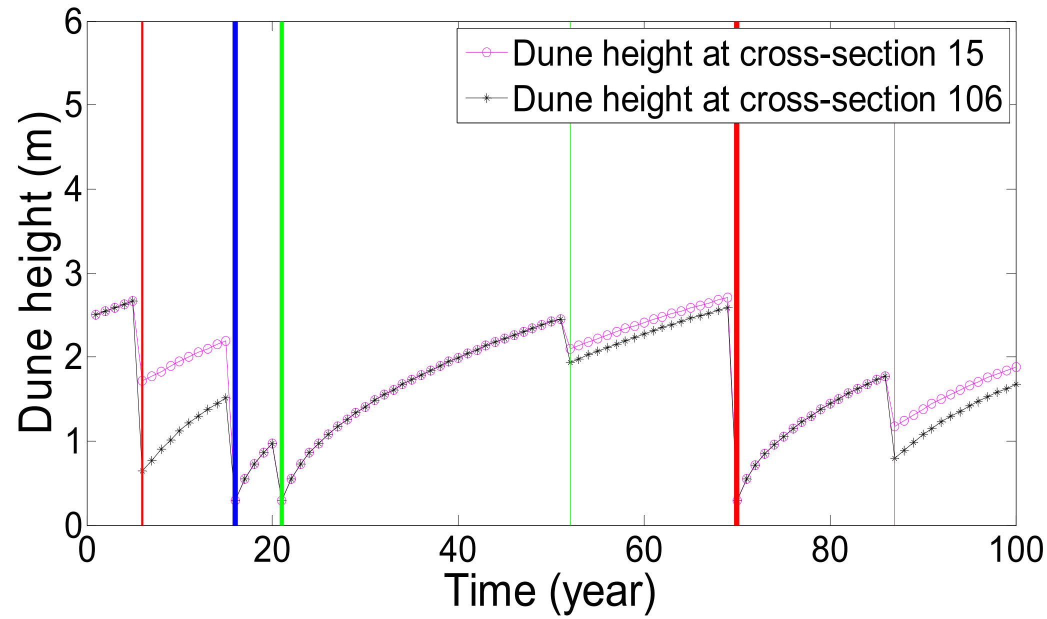
Storm Sequence

Year	6	16	21	52	70	70	87
Storm number	1	1	1	1	2	2	1
Storm track	2	1	3	3	2	2	2
Storm size	2	4	3	1	3	2	1

Effect of Storm on Dune Height Evolution

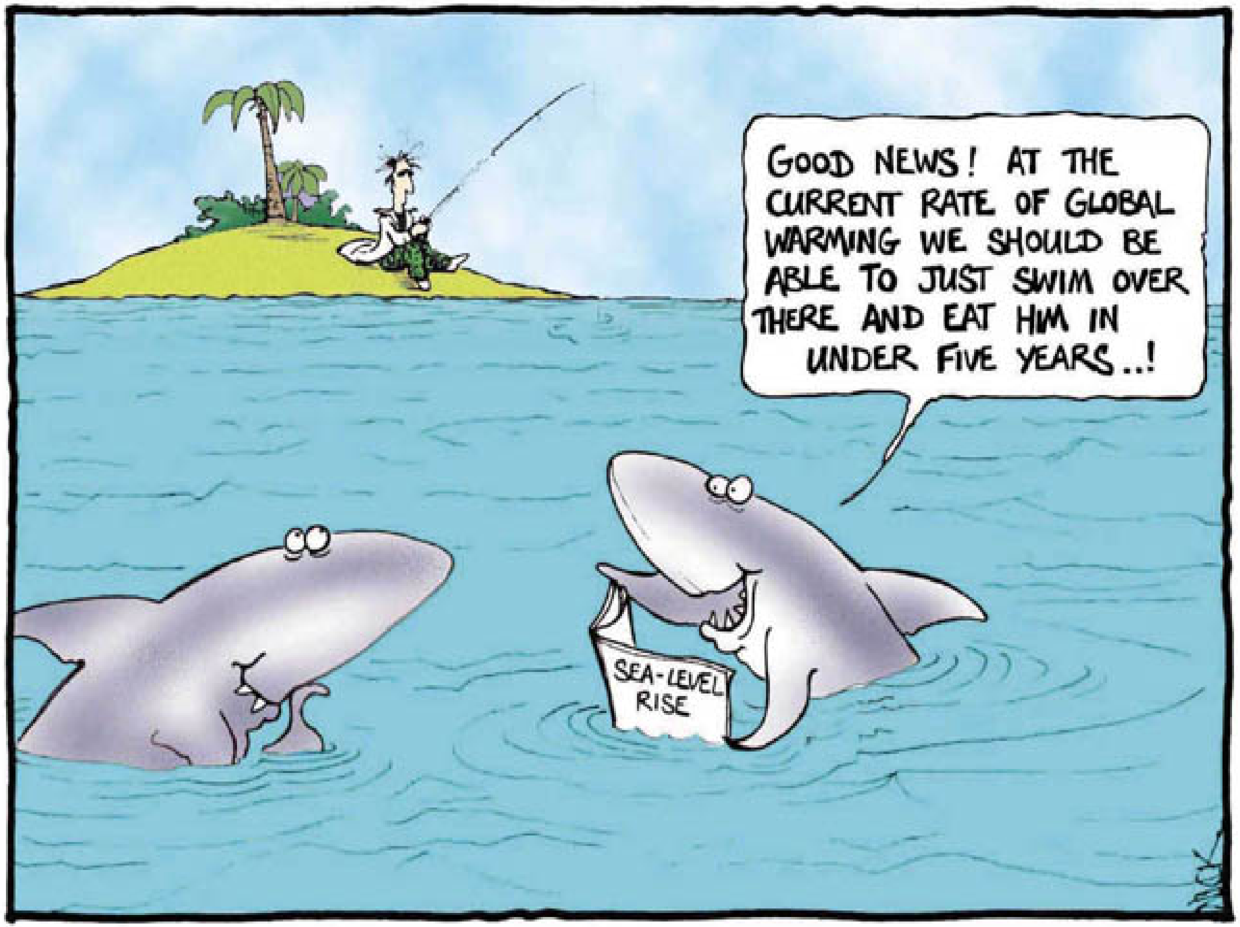




Analyzing Uncertainty

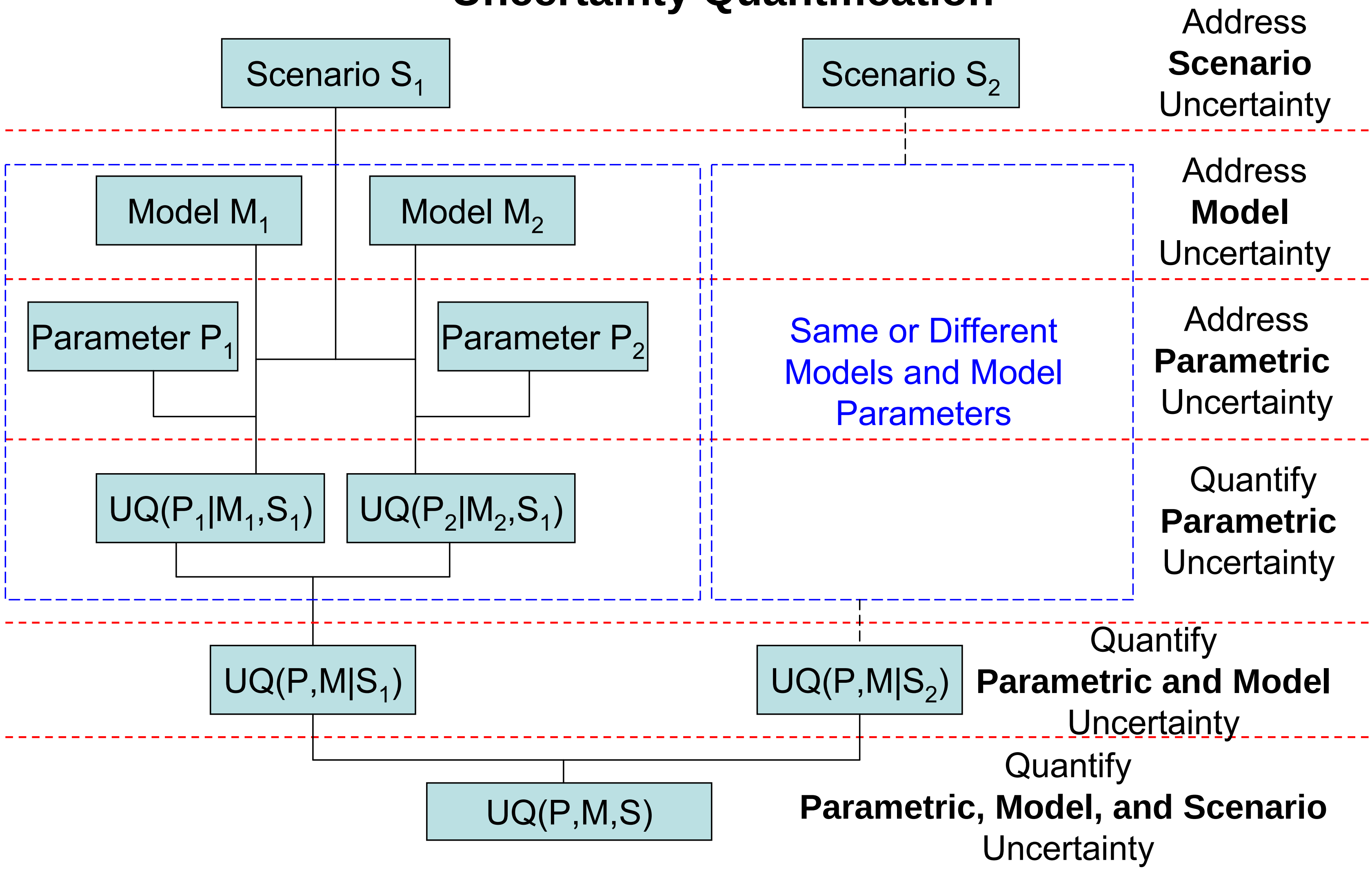
Predictive Uncertainty

Quantification of predictive uncertainty is needed for coastal management and decision-making.



Analyzing Uncertainty

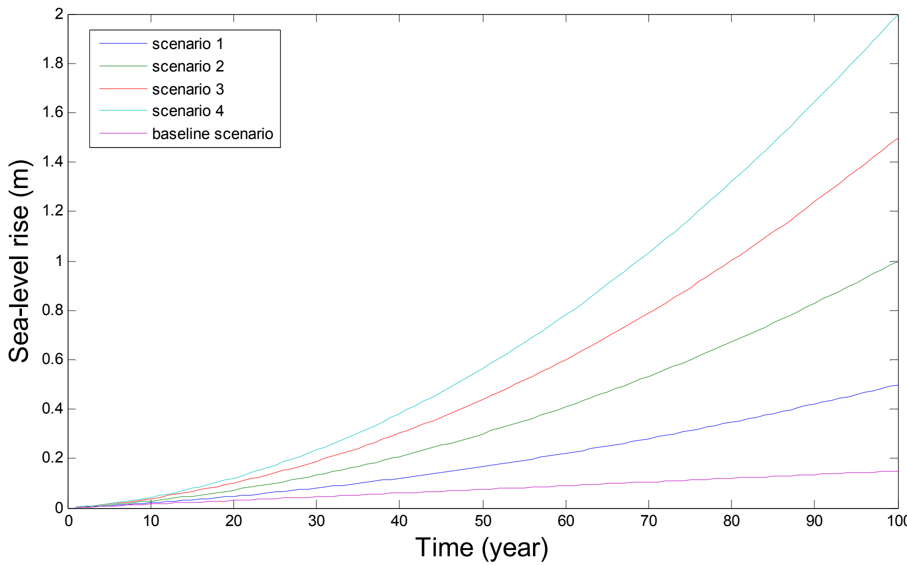
Uncertainty Sources Classification and Uncertainty Quantification



Analyzing Uncertainty

Uncertainty Quantification in Modeling of Barrier Island Evolution: Uncertainty Sources

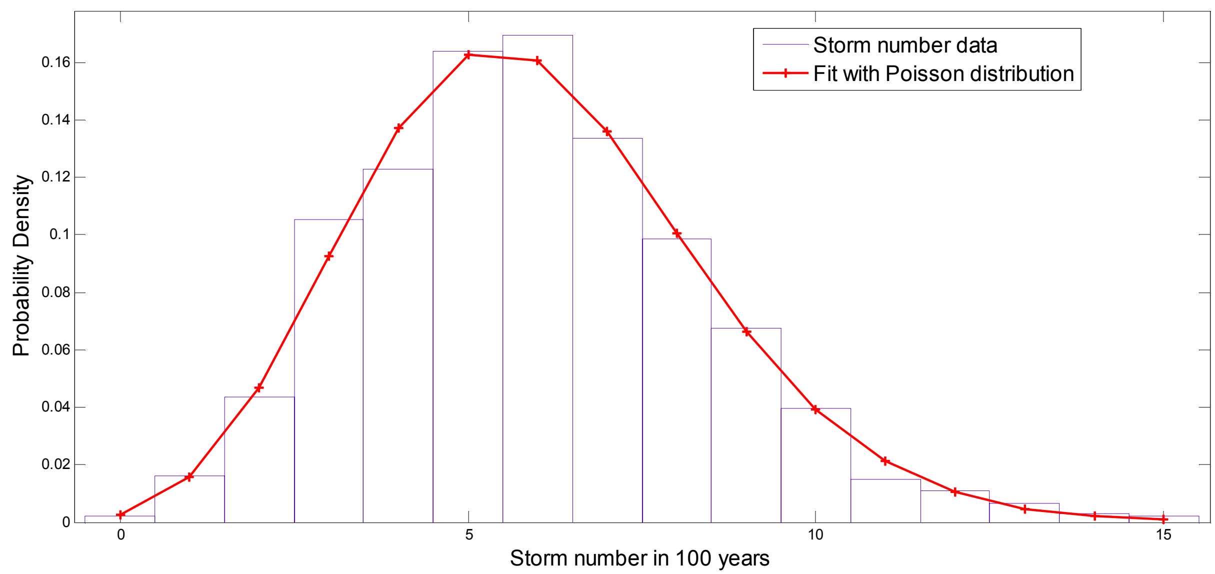
- Scenario Uncertainty: consider five scenarios
  - Four SERDP SLR scenarios
  - Baseline scenario with the current rate of sea-level rise
- Parametric Uncertainty: parameters of storms
  - Storm numbers
  - Storm tracks
  - Storm size



Analyzing Uncertainty

Uncertainty Characterization: Storm Number

Storm number follows the Poisson distribution



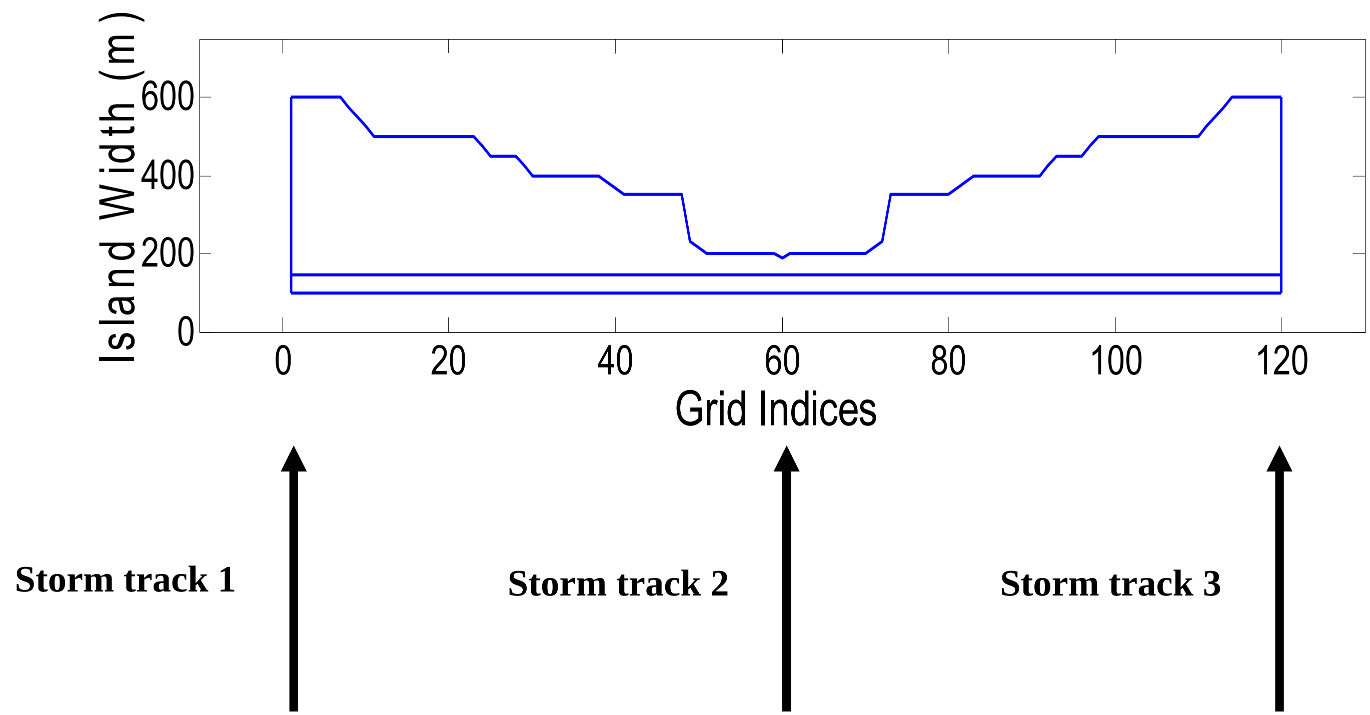
$$P(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

λ = 6: on average six storms occur in 100 years.
k: random number of storms over 100 years

Analyzing Uncertainty

Uncertainty Characterization: Storm Track

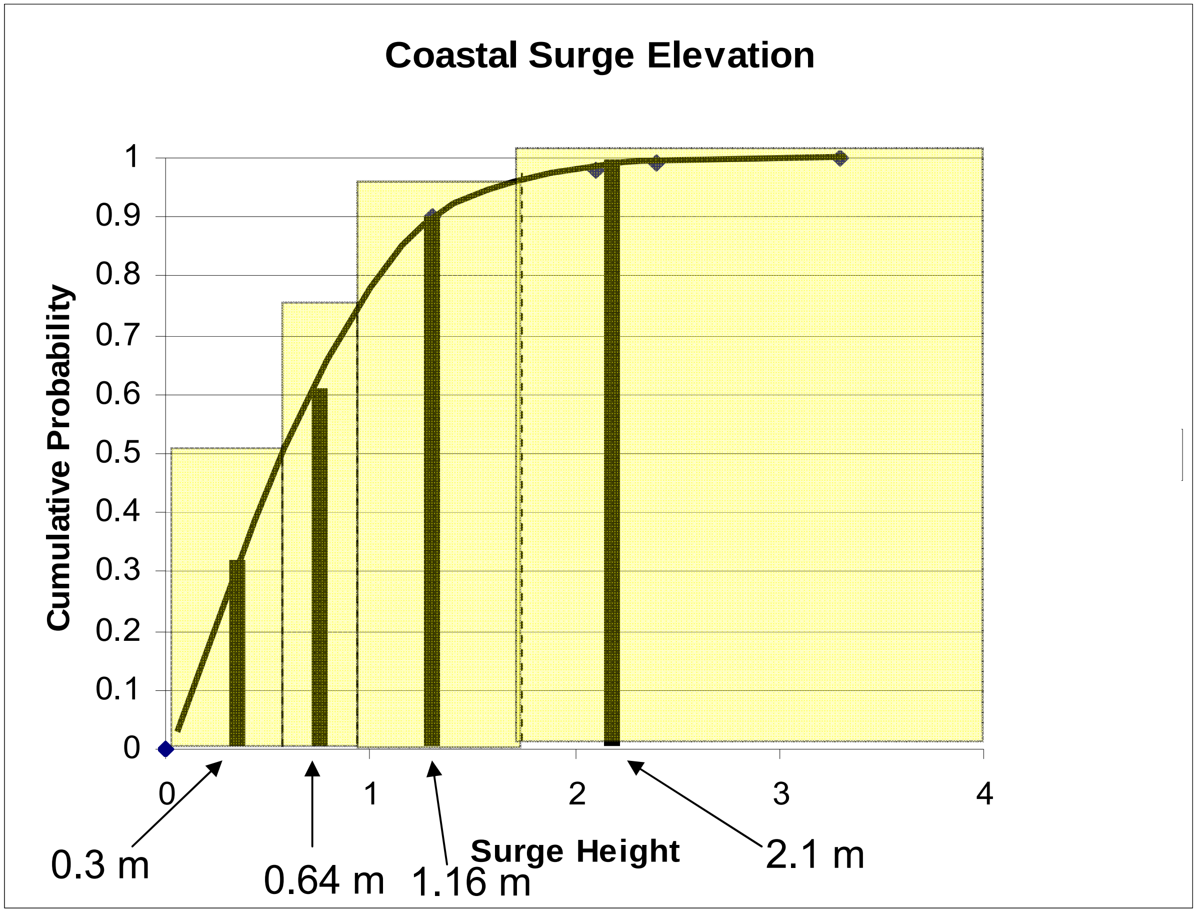
- Storm track follows the uniform distribution
- A storm hits the island along one of the three tracks with equal probability (1/3)



Analyzing Uncertainty

Uncertainty Characterization: Storm Size

Determined empirically based on the Okaloosa County flood study (FEMA, 2002)



Analyzing Uncertainty

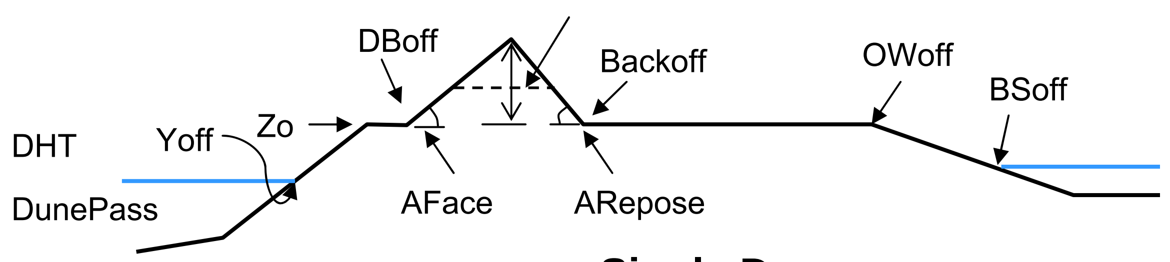
Example: Realization and Quantities of Interest

- Generate 1,000 parameter realizations
- Run the Acute model for the 1,000 realizations

Year	6	16	21	52	70	70	87
Storm number	1	1	1	1	2	2	1
Storm track	2	1	3	3	2	2	2
Storm size	2	4	3	1	3	2	1

Quantities of interest:

- Dune height
- Backshore position
- Backflat elevation

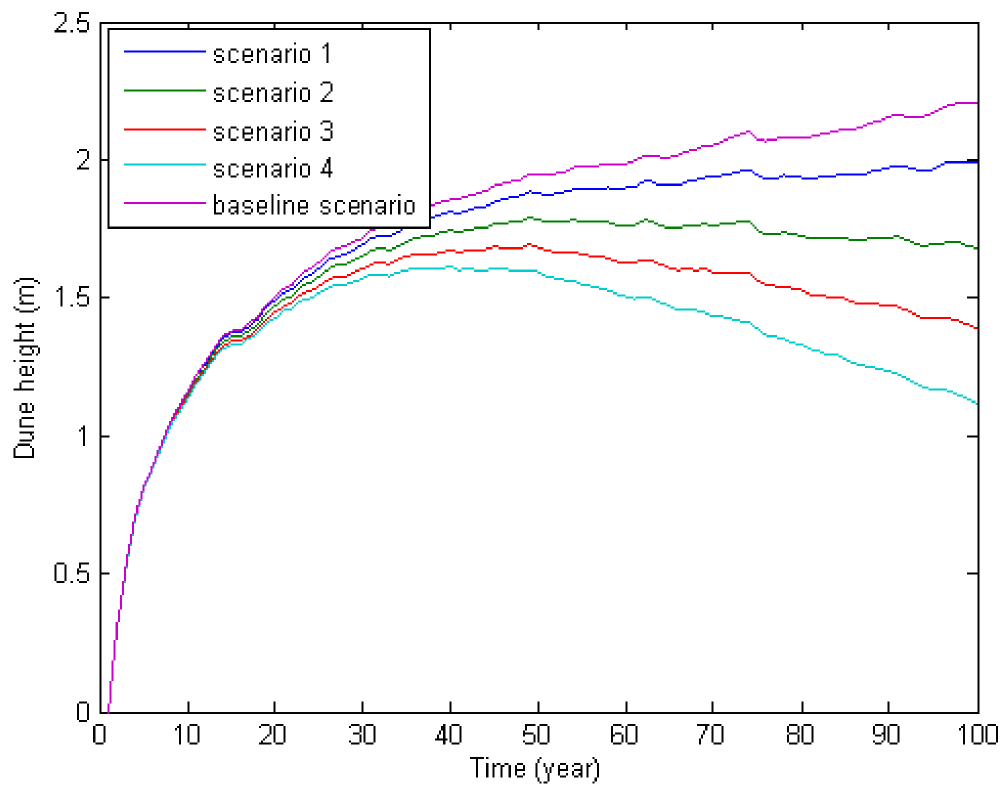


Single Dune

Analyzing Uncertainty

Predictive Uncertainty of Dune Height

- Temporal variation of mean prediction of dune height at the center of the island under the five sea-level rise scenarios.
- Dune height increases under the baseline scenario and SERDP scenario 1 (m), but decreases under the other three scenarios.

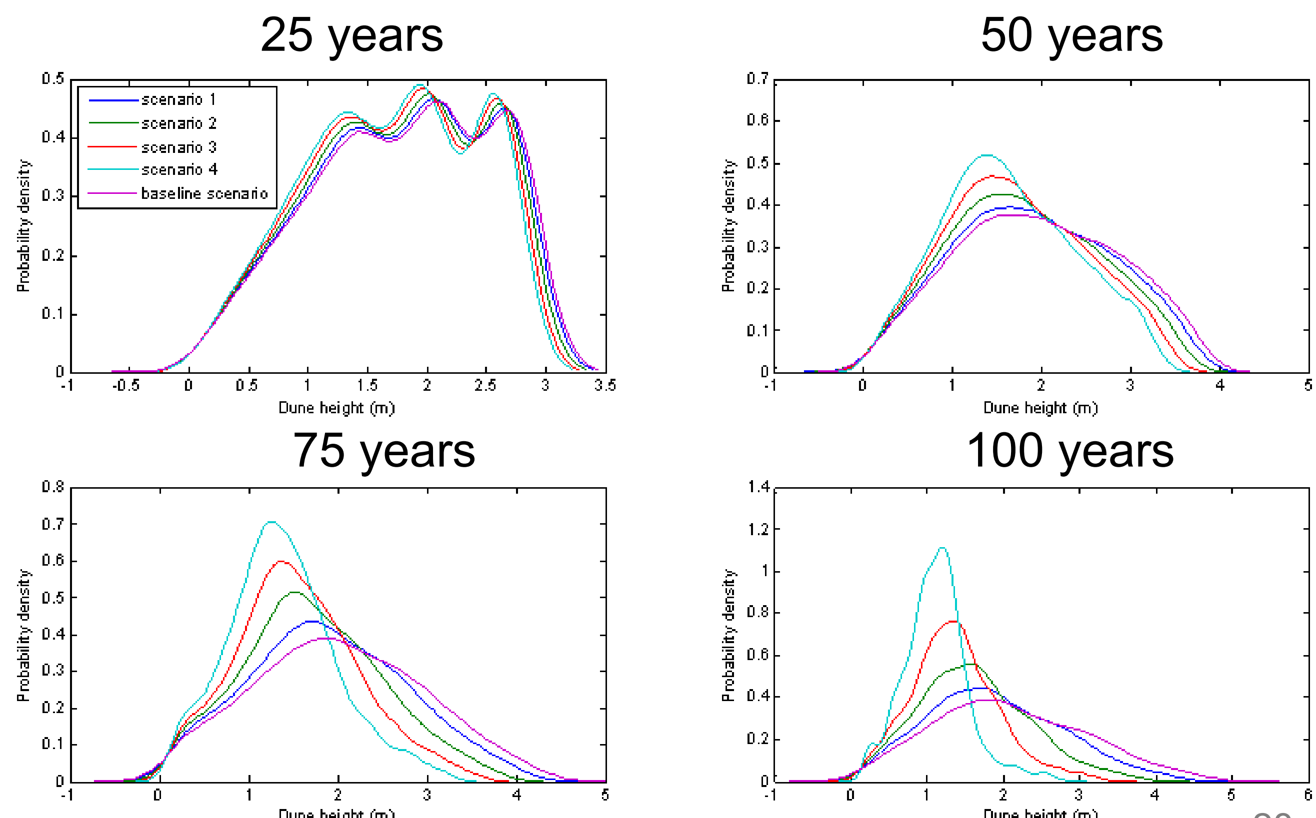


Analyzing Uncertainty

Predictive Uncertainty of Dune Height

Probability density function (PDF) of dune height at the island center

- For all the scenarios, predictive uncertainty increases with time.
- At early time, predictive uncertainty is similar under different scenarios.
- At later time, predictive uncertainty is smaller for larger sea-level rise.



Analyzing Uncertainty

Scenario Averaging

$$p\left(\Delta \middle| \mathbf{D}\right) = \sum_{i=1}^{I} p\left(\Delta \middle| \mathbf{D}, S_i\right) p\left(S_i\right)$$

- Consider *I* scenarios (five sea-level rise scenarios)
- $p(\Delta|D,S_i)$: probability density of Δ under scenario S_i
- $p(S_i)$: probability of occurrence of scenario S_i
- $p(\Delta|D)$: averaged over all scenarios
- How to determine the scenario probability?
  - Expert elimination
  - Quantitative assessment

(Kopp et al. (2009, Nature): Probabilistic assessment of sea level during the last interglacial stage)

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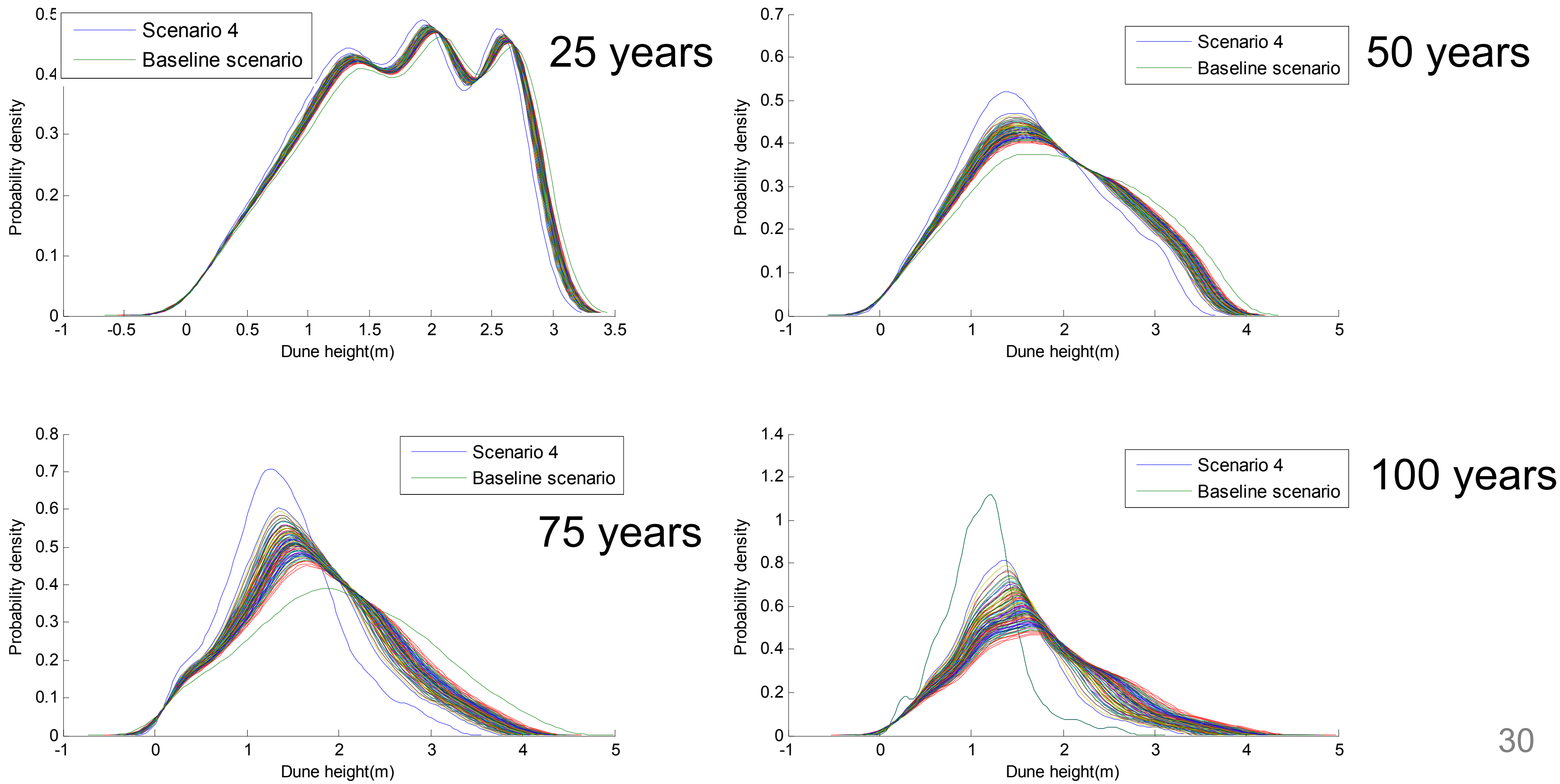
Analyzing Uncertainty

Scenario Uncertainty

- Results of scenario averaging for dune height at the island center using 126 sets of scenario probability
- Predictive uncertainty is between the uncertainties of the two scenarios of the smallest and larger sea-level rise.



Conclusions

- Sea-level rise and storms have significant effects on barrier island evolution and on military infrastructure on the island.
- We have developed an ACUTE model for simulating barrier island evolution under sea-level rise; a large-scale model for the coastal system, MoCCS, is under development.
- We have developed a method of quantifying predictive uncertainty due to parametric and scenario uncertainty.
- Numerical modeling and uncertainty analysis were performed for a test island developed based on Santa Rosa Island, NW Florida.
- Predictive uncertainty is different at different simulation times and under different scenarios of sea-level rise.
- Parametric uncertainty dominates at early time, but scenario uncertainty becomes more important at a later time.
- Predictive uncertainty of scenario averaging is between that of the worst and best scenarios.

END

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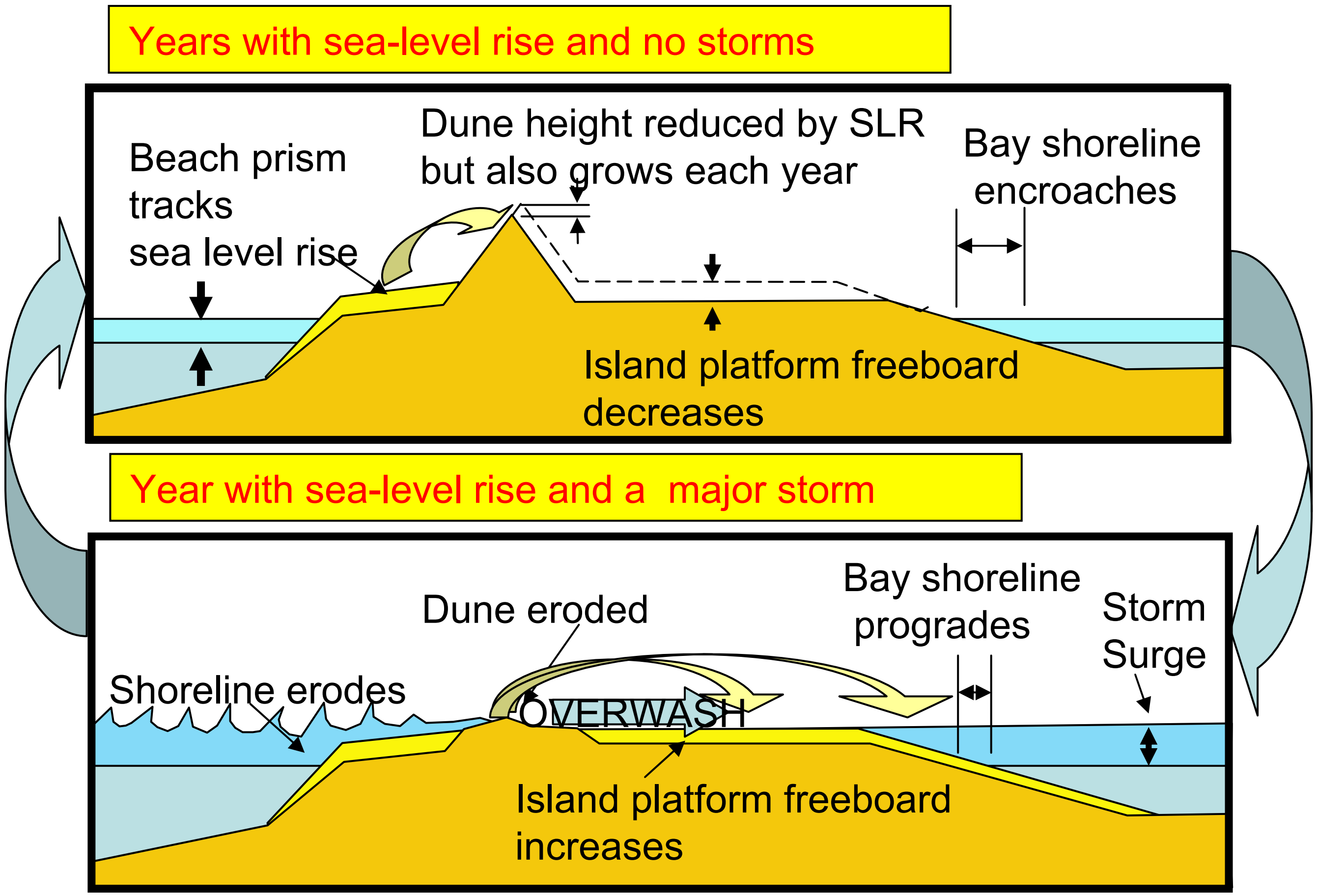
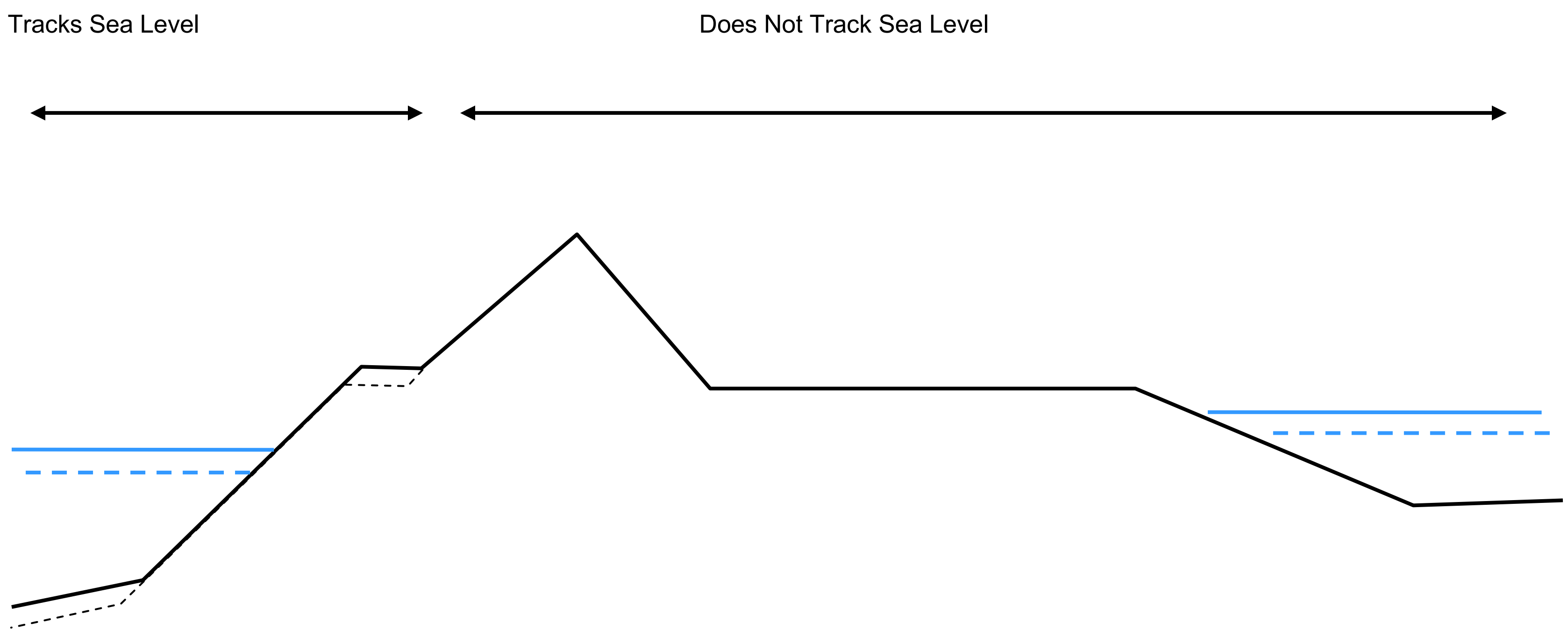
Coastal Change

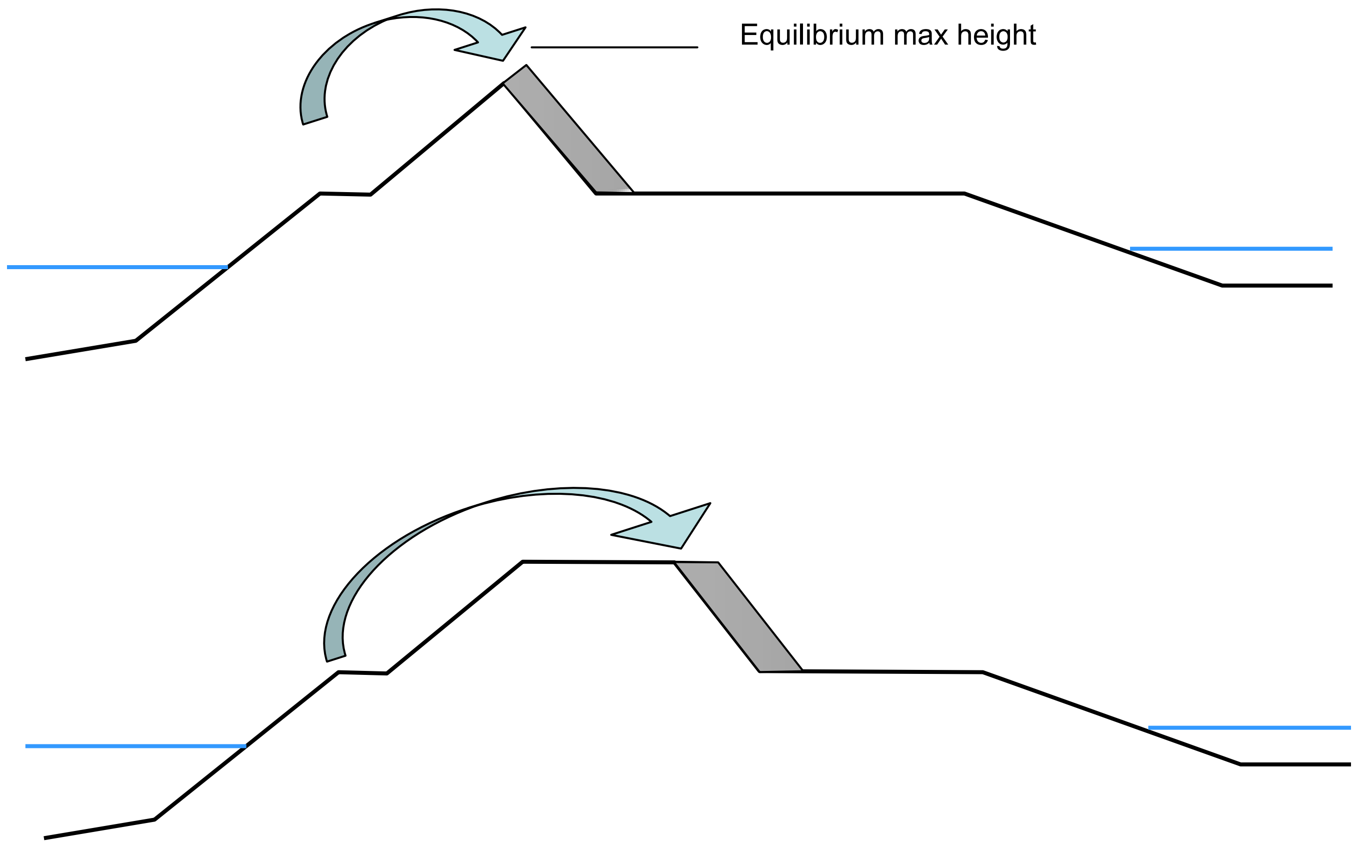
Model Component for Morphologic Change on a Barrier Island



Barrier Island Response to Sea-Level Rise



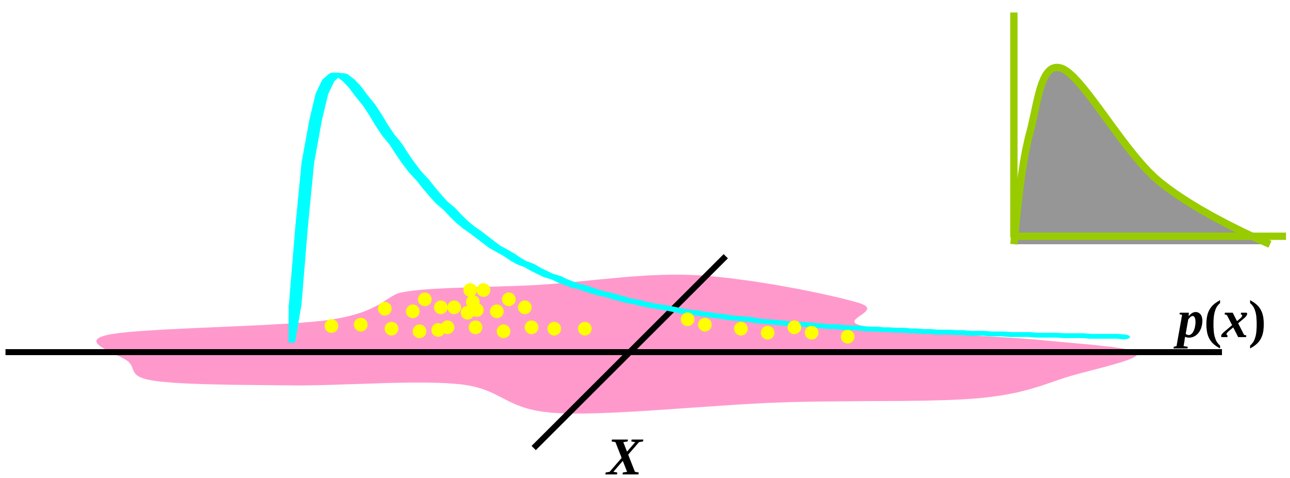
Dune Annual Growth



Analyzing Uncertainty

Monte Carlo Simulation

- Identify random parameters X and their distributions *p*(x) (uncertainty characterization)
- Draw samples from the distributions
- Run the model for each sample
- Obtain probability density function of desired predictions



Analyzing Uncertainty

Predictive Uncertainty of Backshore Position

Probability density function (PDF) of dune height at the island center

- At early time, predictive uncertainty is similar under different scenarios.
- At later time, predictive uncertainty is larger for larger sea-level rise.