Impact of Storm-Induced Morphological Changes on Extreme Wave Runup and Overtopping of Sandy Beaches and Dunes under Rising Sea Levels

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Content:

- **Motivation**
- **Research Goal and Objectives**
- **Methods**
- **Results**
- **Conclusions**

Motivation: Wave Hazard

- Hurricanes are considered a major threat to coastal regions.
- Severe coastal erosion of sandy beaches and dunes and overtopping of dunes.
- The NJ coastline (204 km) and coastal areas accommodate 80% of NJ population.

- NJ beach-dune system is an important defense system for the barrier islands.
- Hurricane Sandy: 37 deaths and $30 billion statewide.

Hurricane Sandy

CNBC News

Sept 10th, 2012

Nov 1st , 2012

Motivation:

- The need for an accurate modeling of storm-induced wave hazards.

- Storm-induced surge and waves will be influenced by climate change.

- Storm climatology change: Changes in storm intensity and frequency in a warmer climate.

- Sea Level Rise (SLR): Deeper nearshore zone will allow larger waves to reach the shoreline.

- The need for a modeling framework to account for future climate effects.

- The framework should accurately capture all processes during an extreme event, and couple them together.

Goal

Develop an integrated physics-based modeling framework to simulate storm-induced wave hazards

Research Objectives

- Develop a calibrated regional-scale phase-averaged **wave and hydrodynamic model** to simulate storm-induced **waves and water levels.**

- Develop a calibrated numerical **morphodynamic** model to simulate storm-induced **erosional changes** to sandy beaches and dunes.

- Develop a calibrated phase-resolving **wave model** to simulate storm-induced wave run-up and overtopping.

- Couple the three models in one framework.

Wave hazards

- **Run up:** maximum elevation the bore reaches after wave breaking.

- **Run down:** elevation under which the beach remains under water.

- **Erosion:** The beach and dune start to get eroded exposing the cities to coastal flooding

- **Swashing:** Run-up is confined to the foreshore area of the beach.

- **Collision:** Run-up reaches to the dune and erodes the toe and face of the dune.

- **Overwash:** Run-up elevation is higher than the dune and causes larger transport landward.

- **Inundation:** The beach-dune system is inundated and totally eroded.
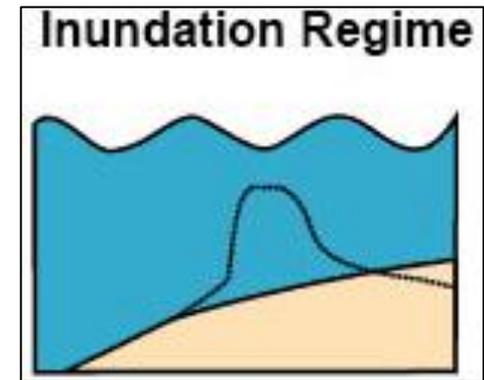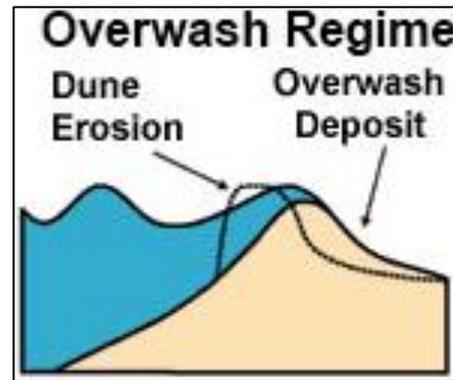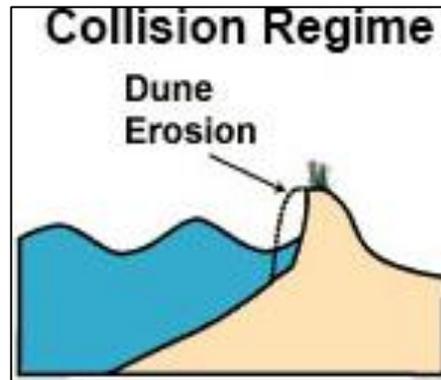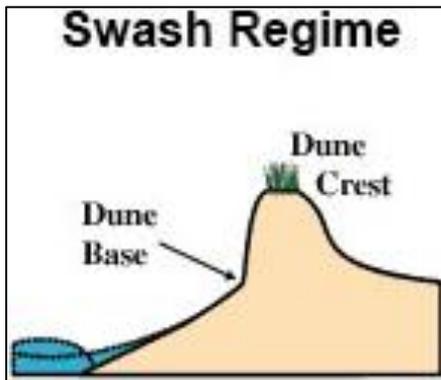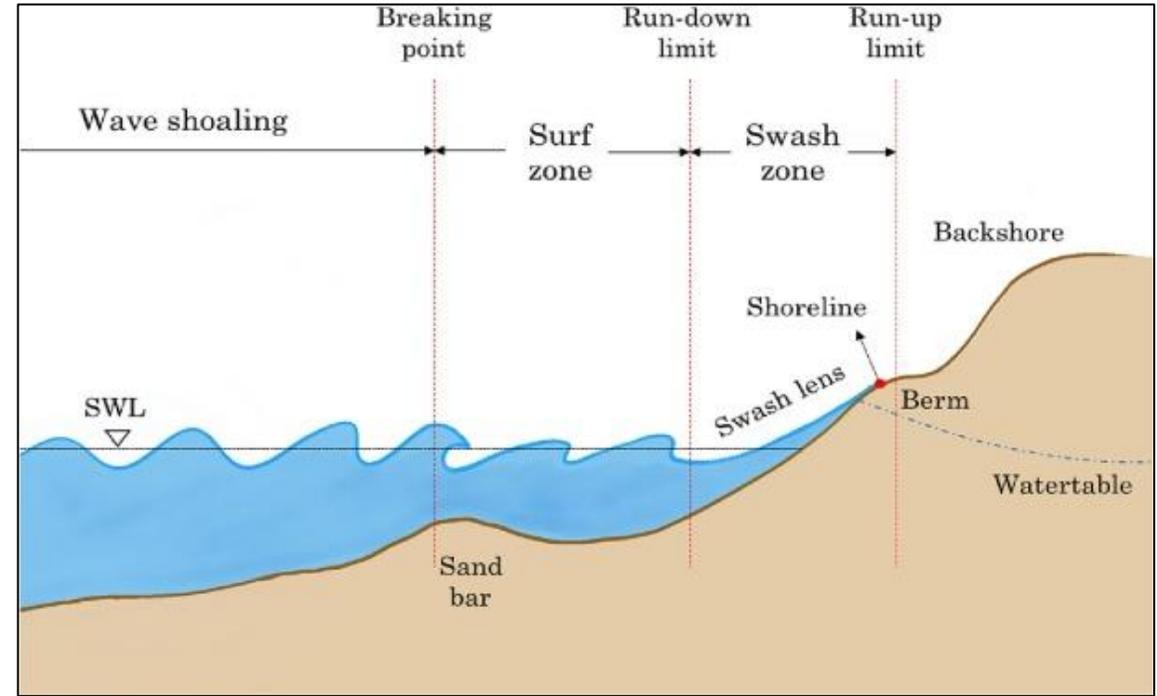
Methods: Proposed framework

- **Step 1:** regional-scale phase-averaged wave and hydrodynamic model.
  - **Input:**
    1. Topobathy
    2. Atmospheric and tidal forcing conditions
  - **Output:** Wave and total water level time series.

- **Step 2:** Coupled hydrodynamic and morphodynamic model.
  - **Input:**
    1. Pre-storm bed elevation measurements.
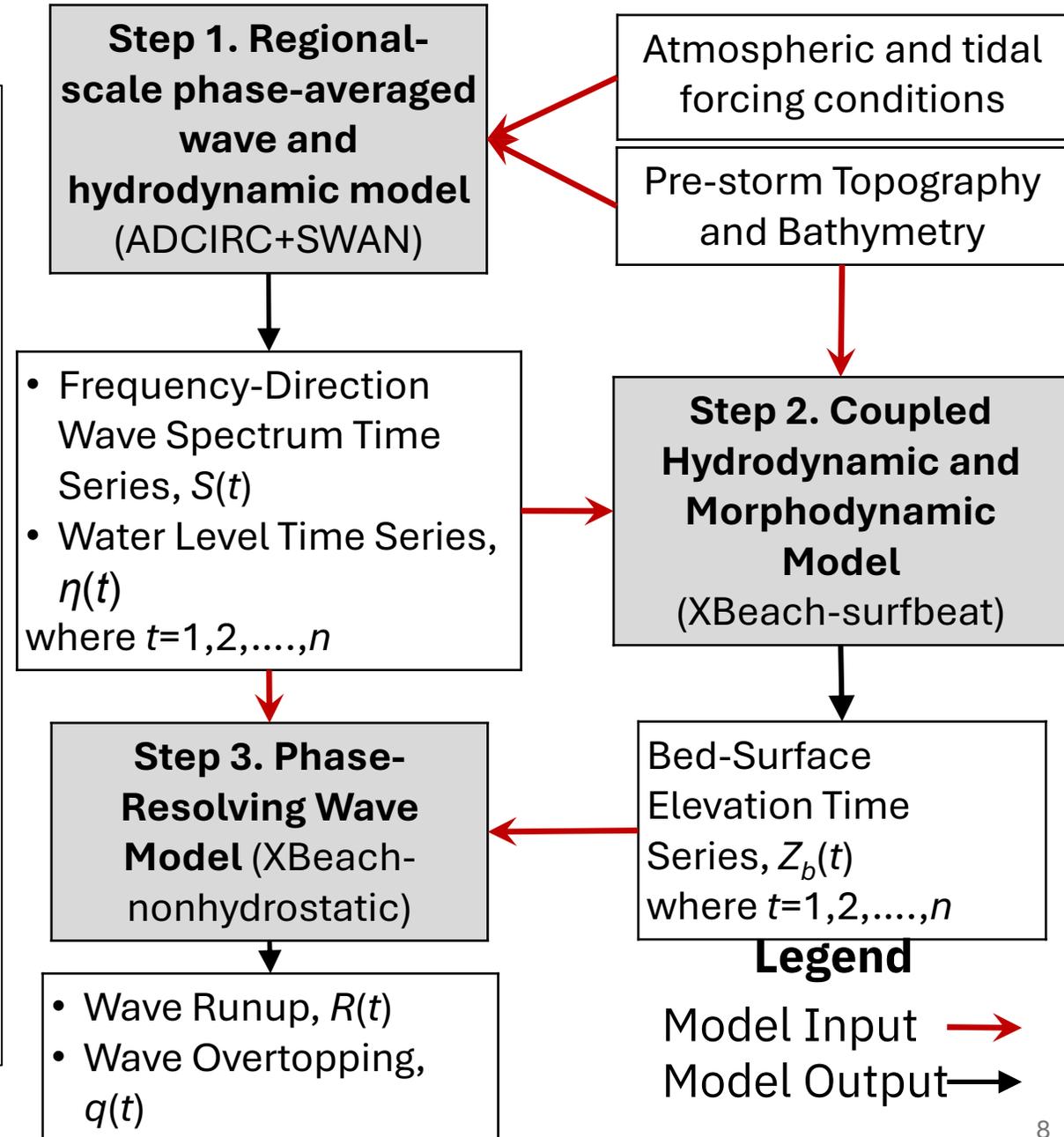   2. Boundary conditions from **Step 1**.
  - **Output:** Elevation changes time series.

- **Step 3:** phase-resolving wave model.
  - **Input:**
    1. Boundary conditions from **Step 1**
   2. Elevation changes from **Step 2**
  - **Output:** Surface water elevation, run-up and overtopping.

Step 1. Regional-scale phase-averaged wave and hydrodynamic model (ADCIRC+SWAN)

Atmospheric and tidal forcing conditions

Pre-storm Topography and Bathymetry

- Frequency-Direction Wave Spectrum Time Series, $S(t)$
- Water Level Time Series, $\eta(t)$

where $t=1,2,....,n$

Step 2. Coupled Hydrodynamic and Morphodynamic Model (XBeach-surfbeat)

Step 3. Phase-Resolving Wave Model (XBeach-nonhydrostatic)

Bed-Surface Elevation Time Series, $Z_b(t)$
where $t=1,2,....,n$

Legend

- Wave Runup, $R(t)$
- Wave Overtopping, $q(t)$

Model Input →
Model Output →

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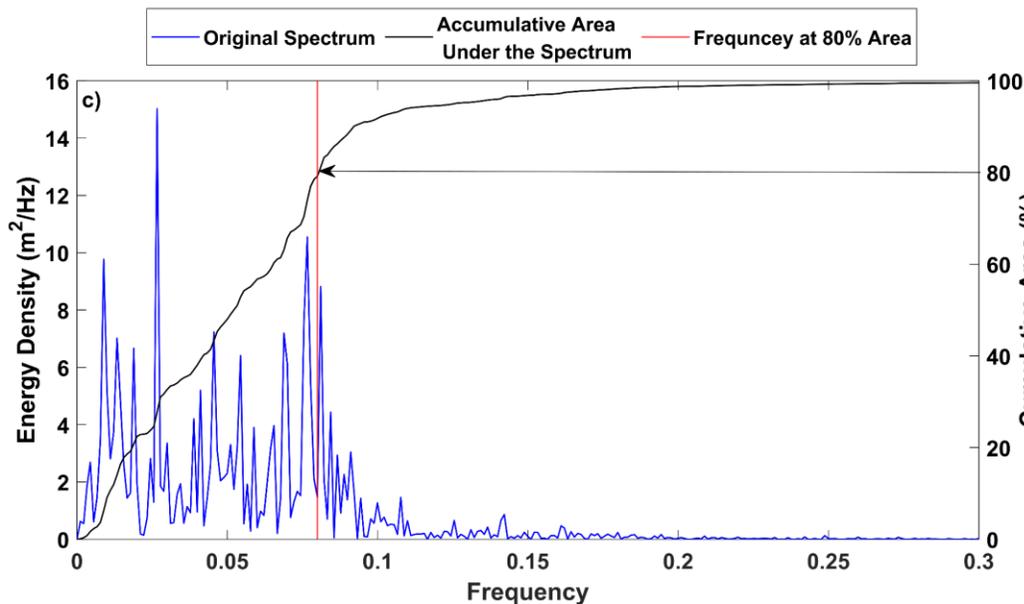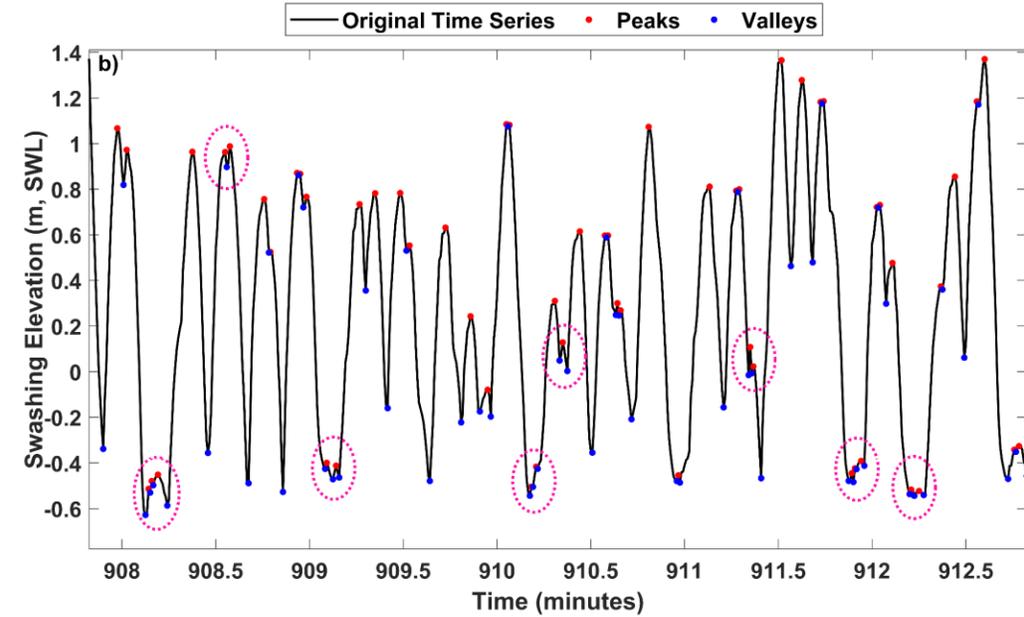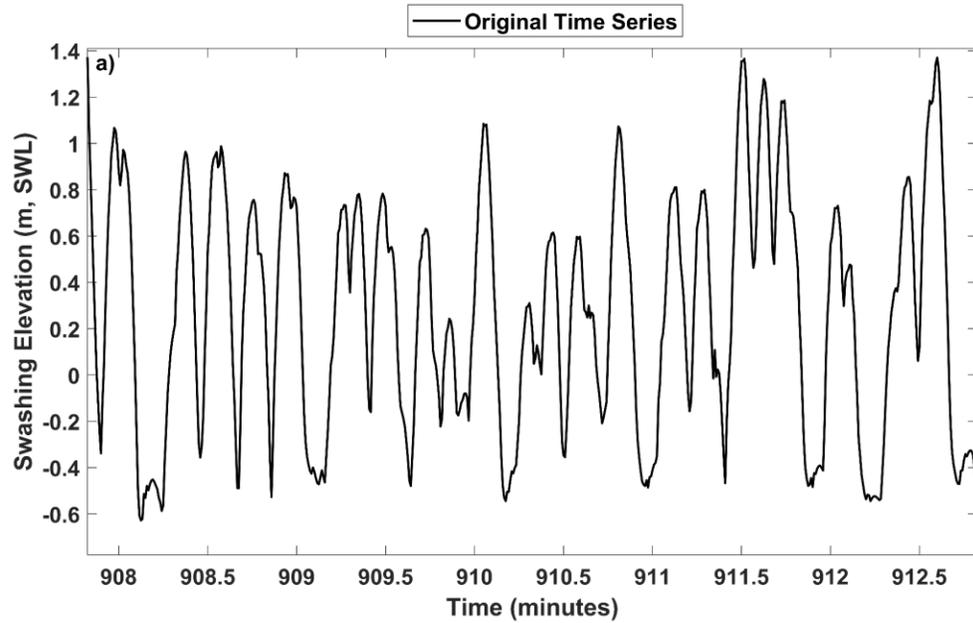# Methods: Study Area and Extreme Event

Study Area:

- ADCIRC-SWAN: New Jersey Barrier Islands.
- XBeach: 1D profiles.
- Hurricane Sandy
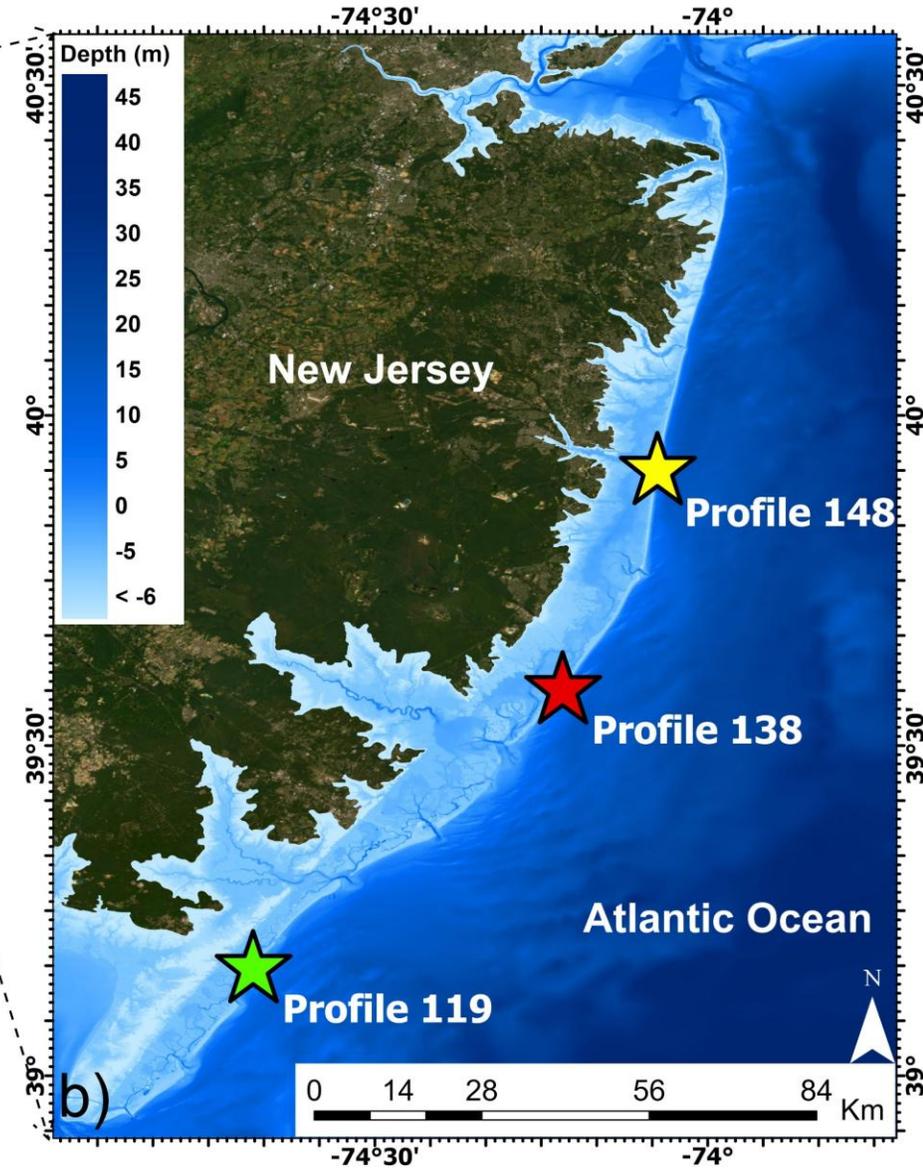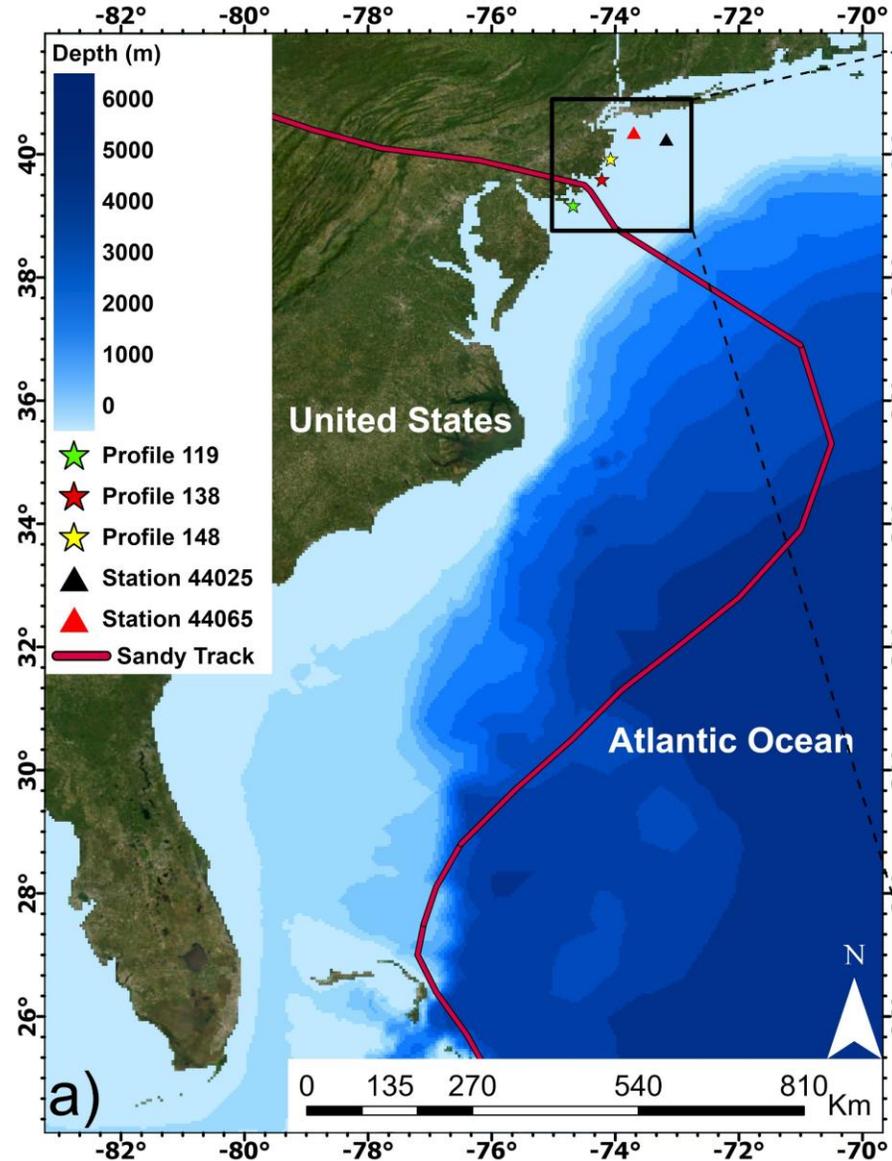
Methods: Run-up and run-down calculations

- **Swashing time series**

- Simply finding the peaks is not accurate.

- Spectrum of swashing time series.

- Choose frequency that corresponds to 80% of the area.

- Low pass filter, find the run-up and run-down
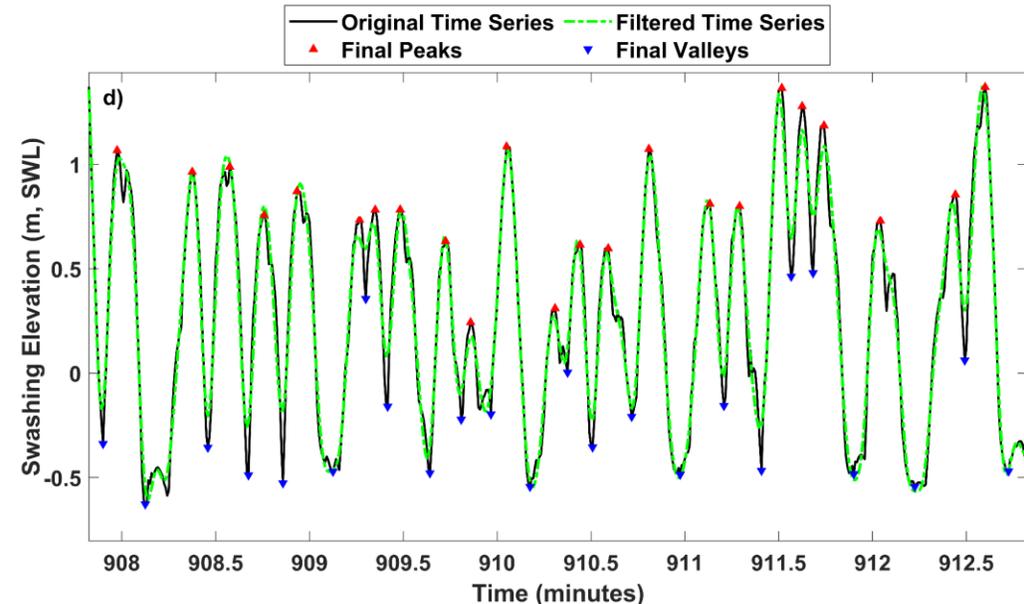
Methods: Hazard metrics (Sallenger 2000)

- R_{low}: elevation below which the beach is continuously subaqueous.
  - R_{low} = mean of run-down time series.

- R_{high}: high elevation of landward margin of the swash.
  - R_{high} = 2% exceedance of run-up time series = $R_{2\%}$.

- D_{high}: elevation of the highest part of the first line of defense.

- D_{low}: elevation of the base of the dune (front toe).
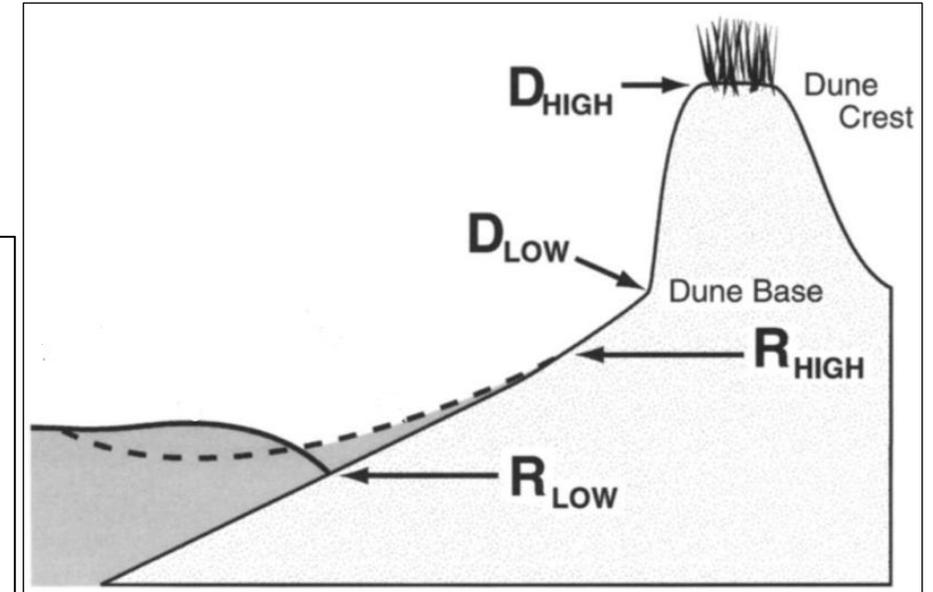
| Range on R_{high}/D_{high} and R_{low}/D_{high}	Impact regime
$0 < R_{high}/D_{high} < D_{low}/D_{high}$	Swash
$D_{low}/D_{high} \leq R_{high}/D_{high} \leq 1$	Collision
$R_{high}/D_{high} > 1$ & $R_{low}/D_{high} < 1$	Overwash
$R_{high}/D_{high} > 1$ & $R_{low}/D_{high} > 1$	Inundation
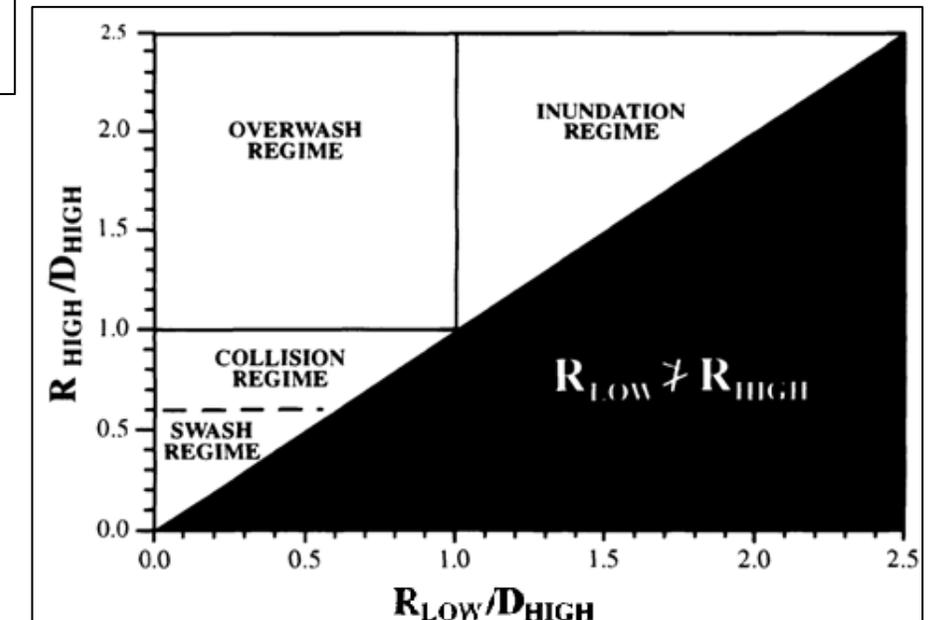
Sallenger Jr, A. H. (2000). Storm impact scale for barrier islands. *Journal of coastal research*, 890-895.

Results: Step 1: Effects of sea level rise on waves

- Sea level rise will increase existing shallow waters during Hurricane Sandy.
- Larger waves will reach the shoreline.

- The significant wave height (H_s) increase is more than 14% in shallow waters under the SLR = 1.12 m scenario and 4-8% under the SLR = 0.43 m

- Under both Scenarios shallow waters experience higher increases than deeper ones.
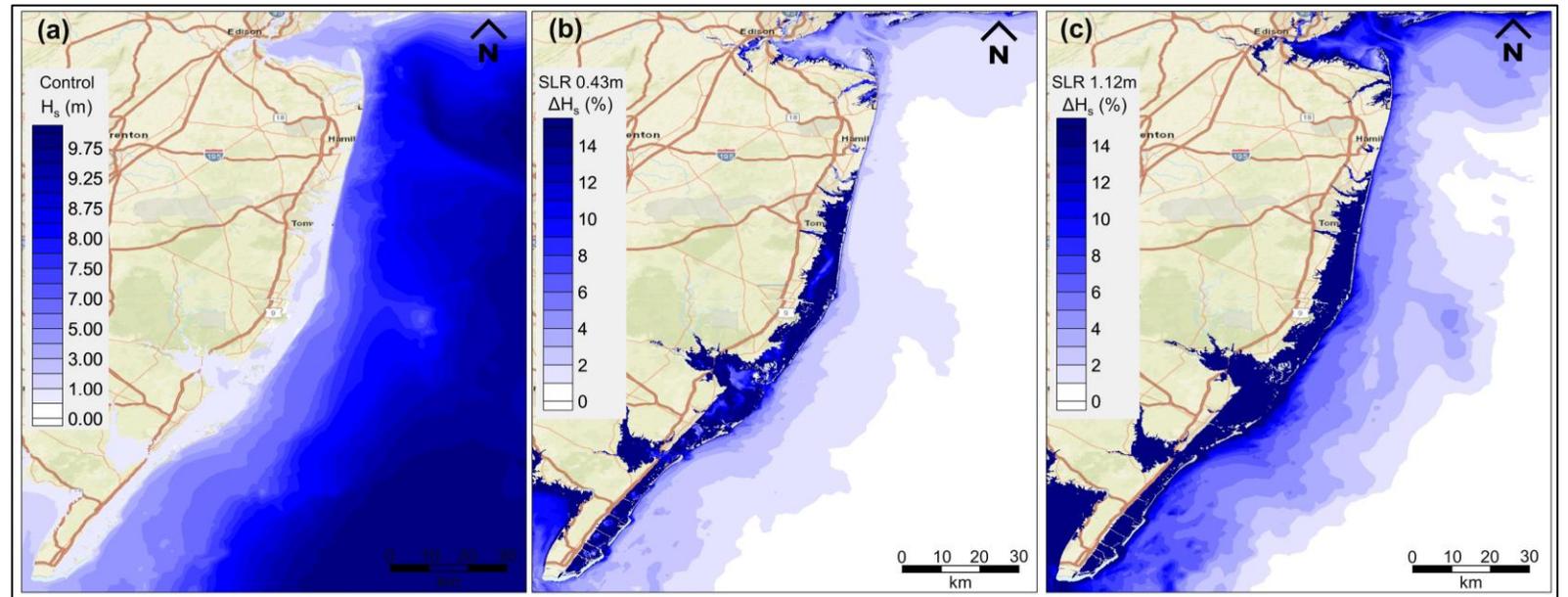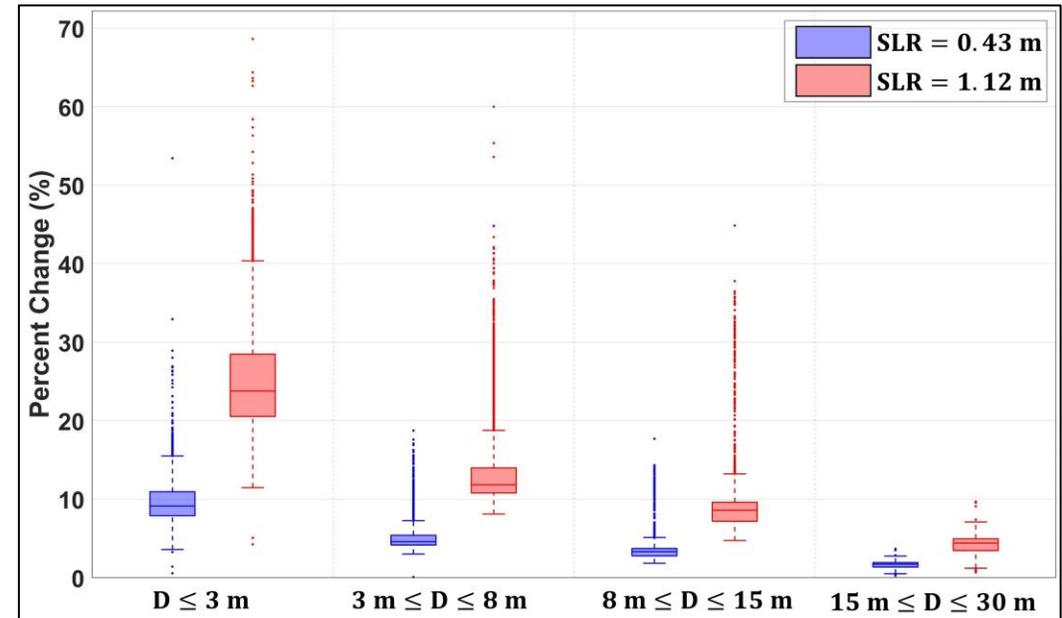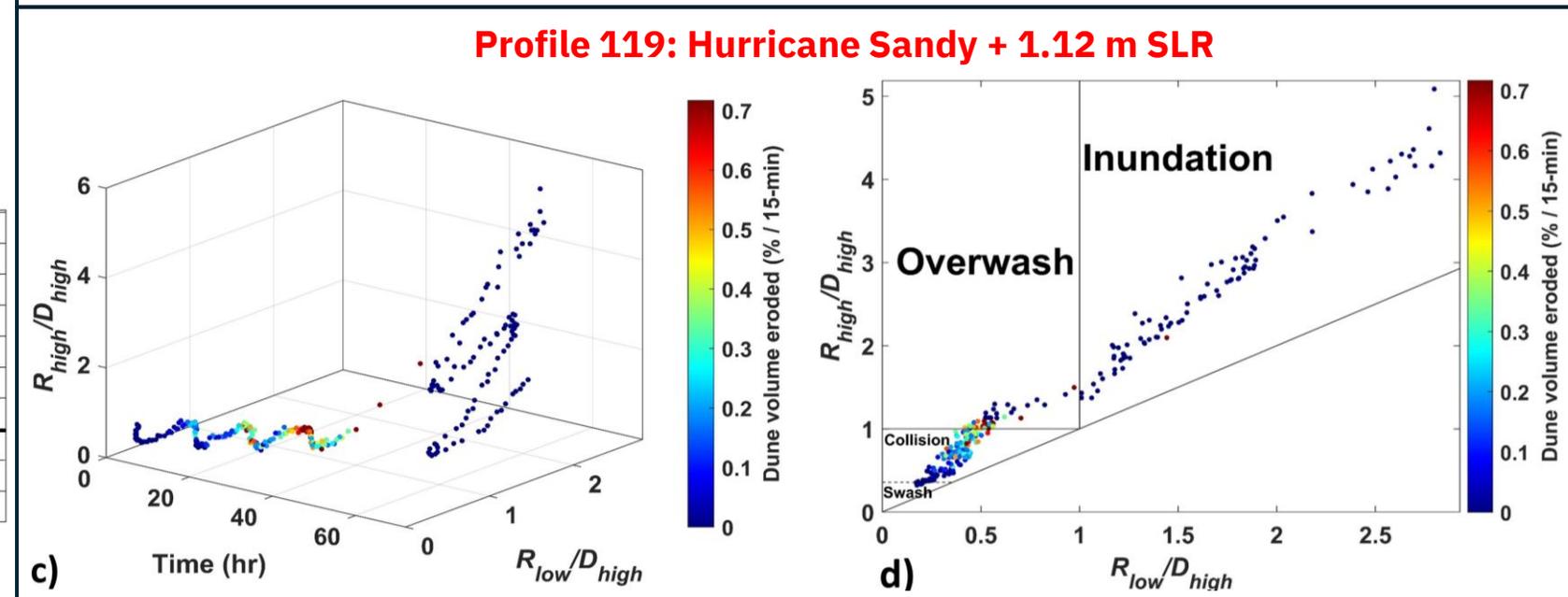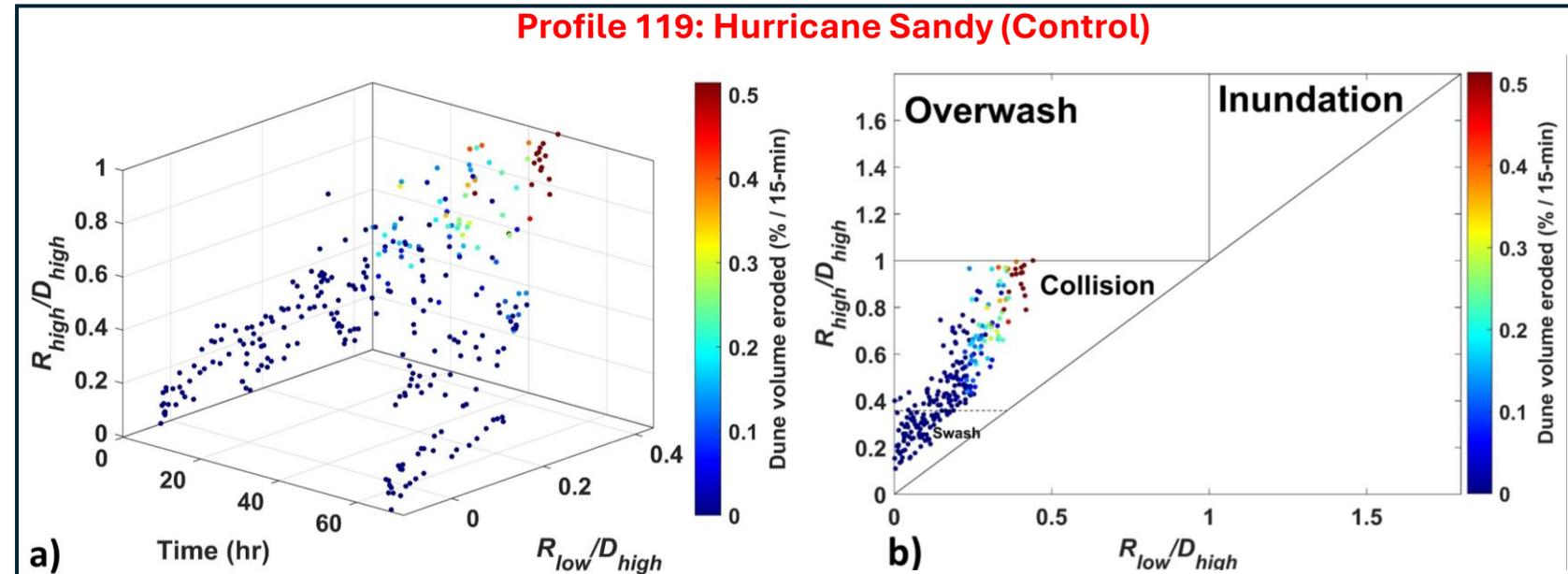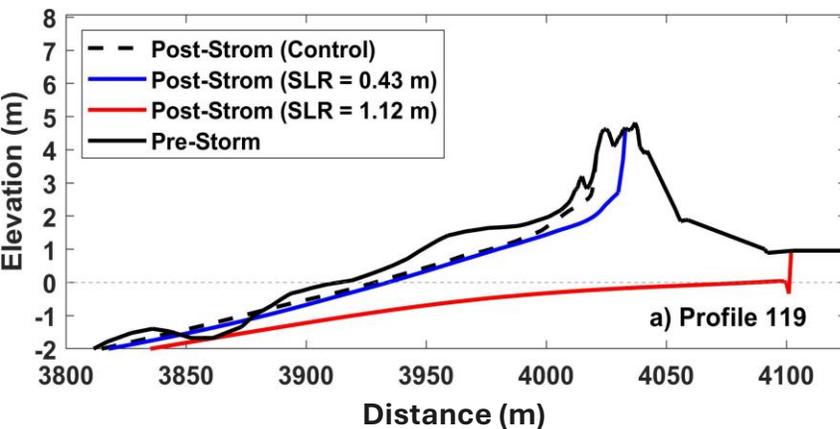
Results: Step 2: Effects of sea level rise on erosion

- Larger waves reaching shallower waters will increase the beach-dune erosion.
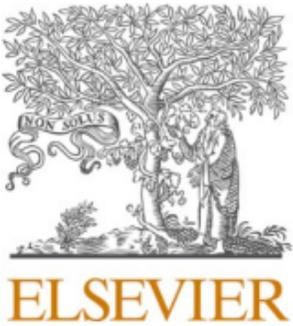- Leading to higher risks of overtopping and inundation.
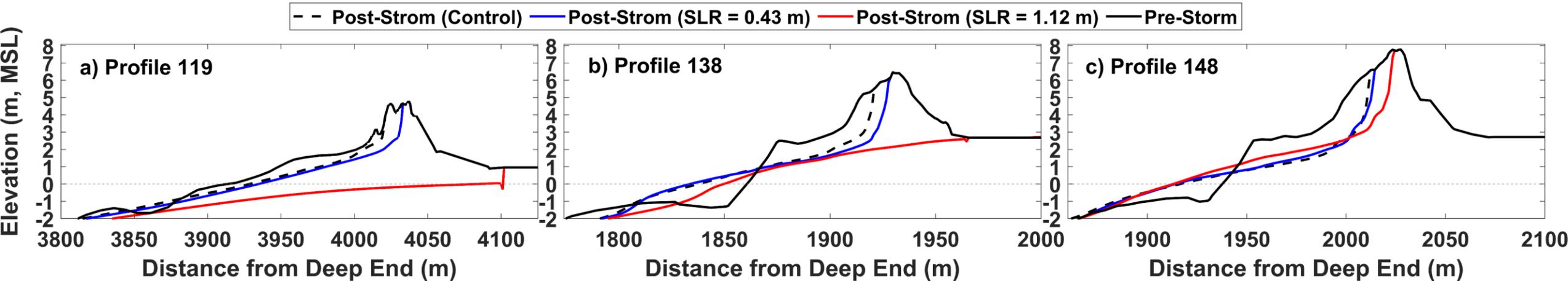
Results: Step 3: Effects of sea level rise on run-up and overtopping

- Every 15 minutes of Sandy
- Sandy under normal conditions.
- With SLR larger waves and more dune erosion (colored bar).
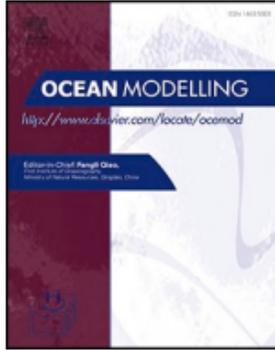- Leading to higher risks of overtopping and inundation.

Profile 119: Hurricane Sandy (Control)

Profile 119: Hurricane Sandy + 1.12 m SLR

Results: Effects of including or excluding morphological changes

- Turing Geomophology ON and OFF.

- Not including the morphological changes overestimates the run-up and overtopping.

- Dunes and beaches sacrifice themselves for lower risk of overtopping

Legend: Beach Volume · Dune Volume · Overwash volume (with morphology change) · Overwash volume (no morphology change)

a) Profile 119

b) Profile 138

c) Profile 148

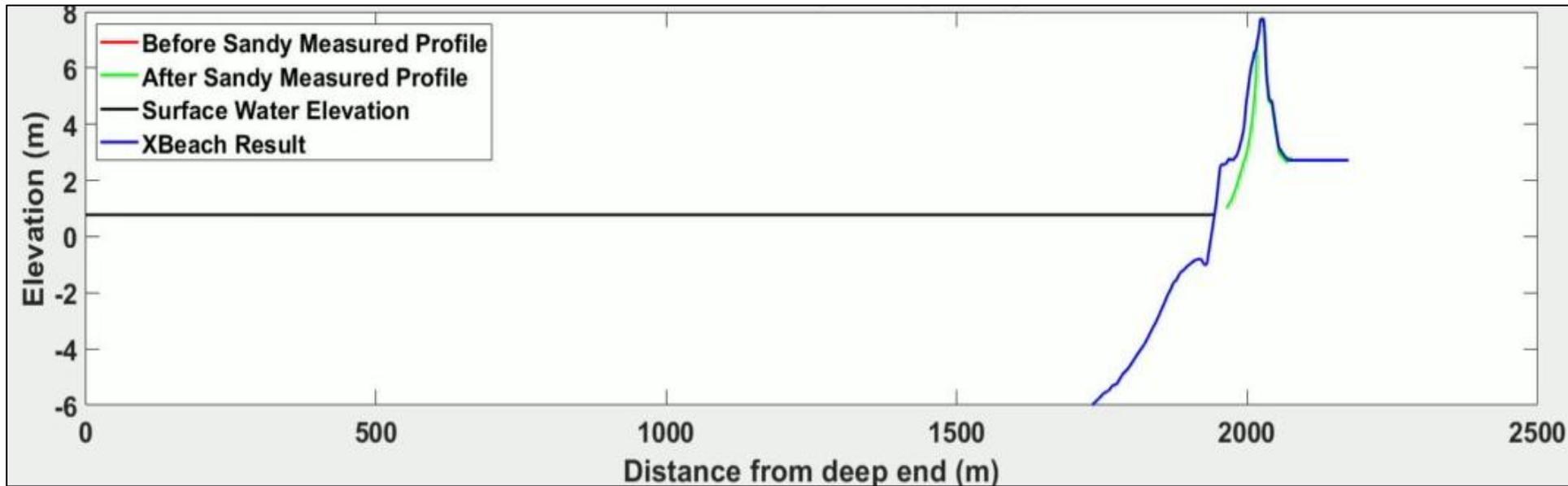Distance from Deep End (m)

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Conclusions

Impact of storm-induced morphological changes on extreme wave runup and overtopping of sandy beaches and dunes

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Thank You