UNIVERSITY of DELAWARE

Morphological Response of Barrier Beaches During Tsunami Inundation

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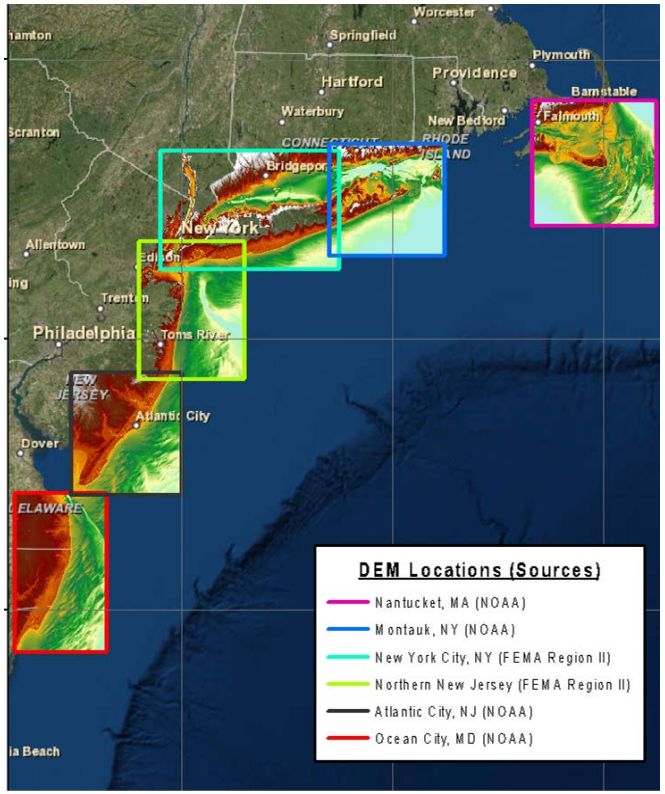
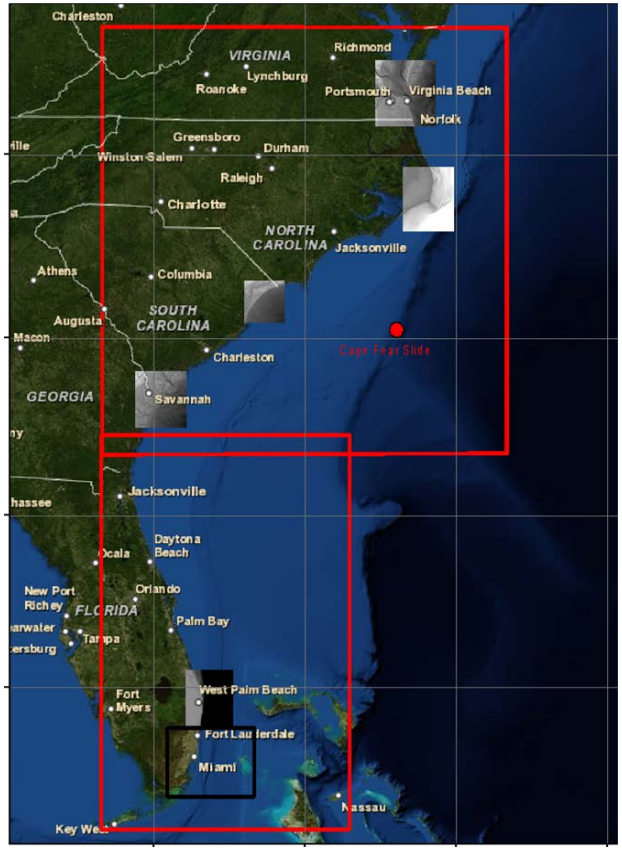
- **NTHMP inundation mapping work** has been conducted to date for the US East Coast *without considering sediment processes*.

- **Simulations** use 3 types of *Atlantic tsunami sources* (coseismic, volcanic, landslide)





Phase I (North Atlantic)

- Nantucket, MA
- Montauk, NY
- New York City, NY
- Northern New Jersey
- Atlantic City, NJ
- Ocean City, MD

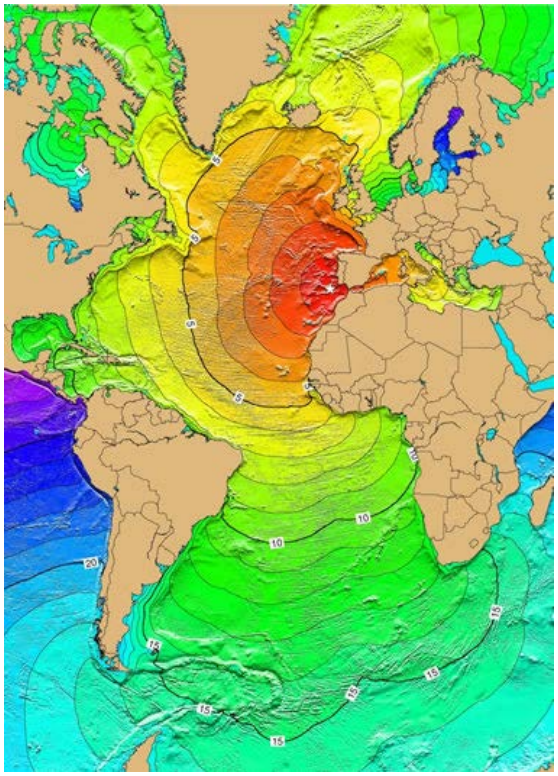
Phase II (Mid/South - Atlantic)

- Virginia Beach, VA
- Cape Hatteras, NC
- Myrtle Beach, SC
- Savannah Beach, GA
- Daytona Beach, FL
- Palm Beach, FL
- Miami, FL

Historical Tsunami events in Atlantic Ocean

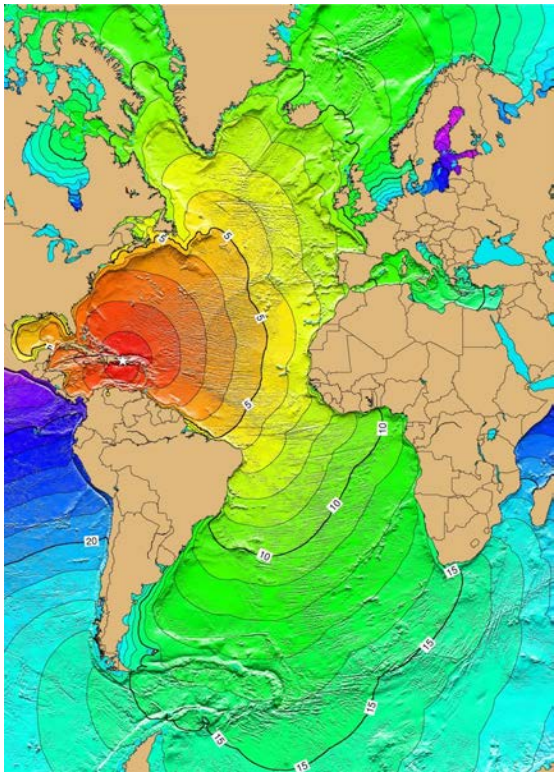
Lisbon, Portugal, 1755

A M8.9 (estimated) earthquake and tsunami killed between 60,000 and 100,000 people.



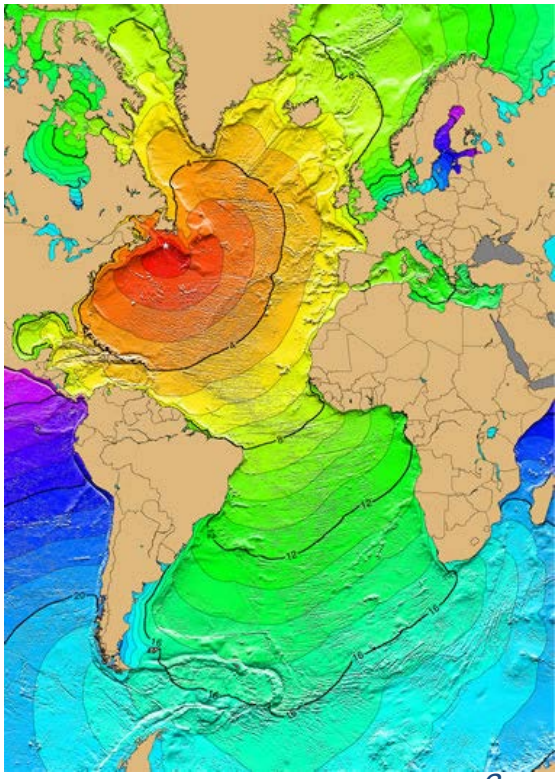
Puerto Rico, 1918

A M7.1 earthquake and tsunami killed 116 people, 100 were reported missing, and caused $29M in damage.



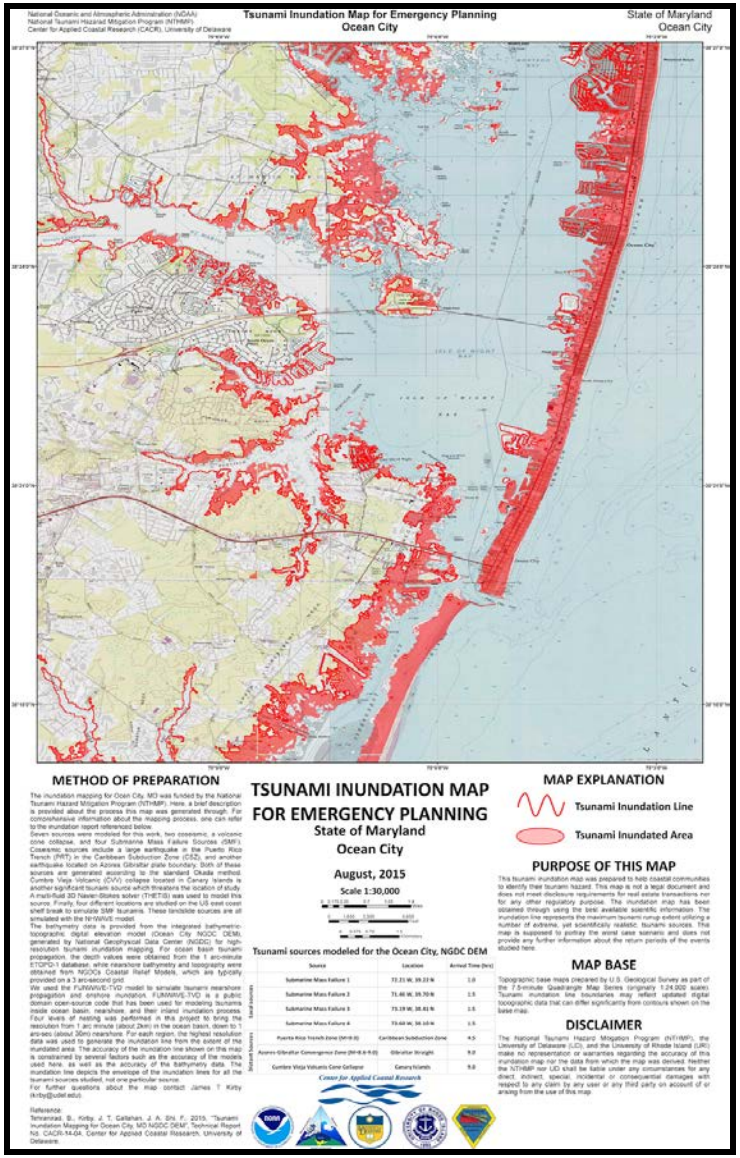
Grand Banks - 1929

A M7.2 earthquake triggered a large submarine slump which caused a tsunami, killing 20+ people.

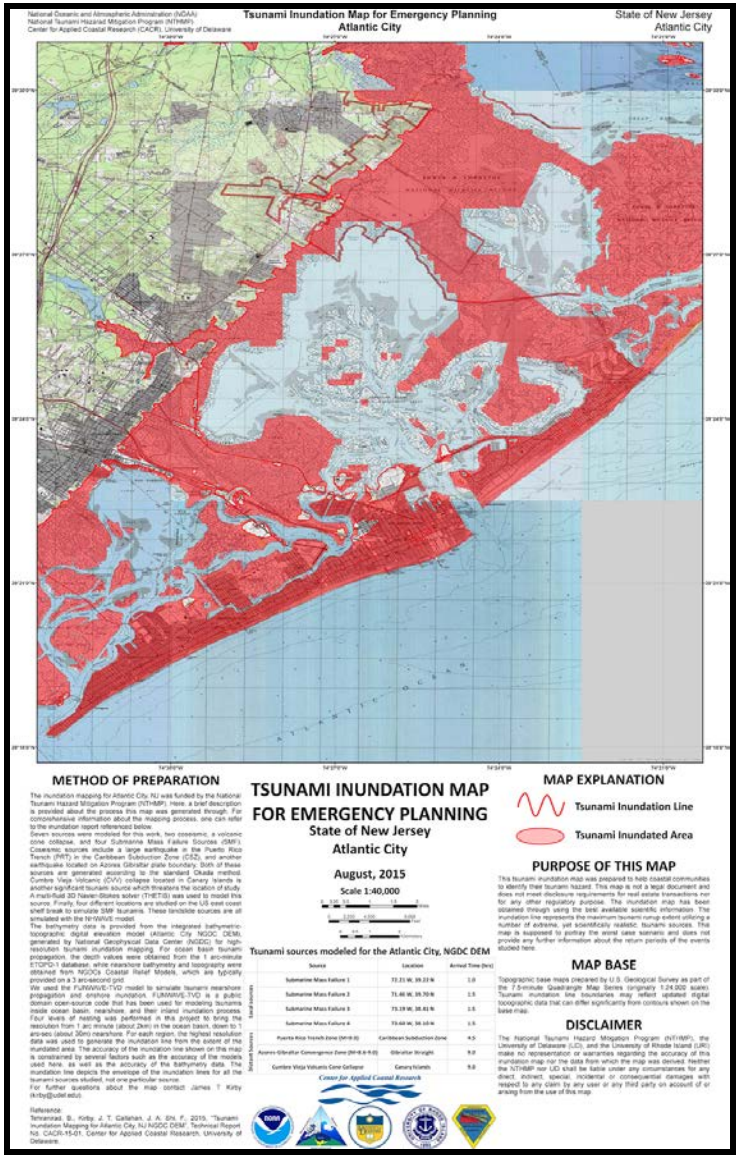


Typical envelope inundation maps

Ocean City, MD



Atlantic City, NJ



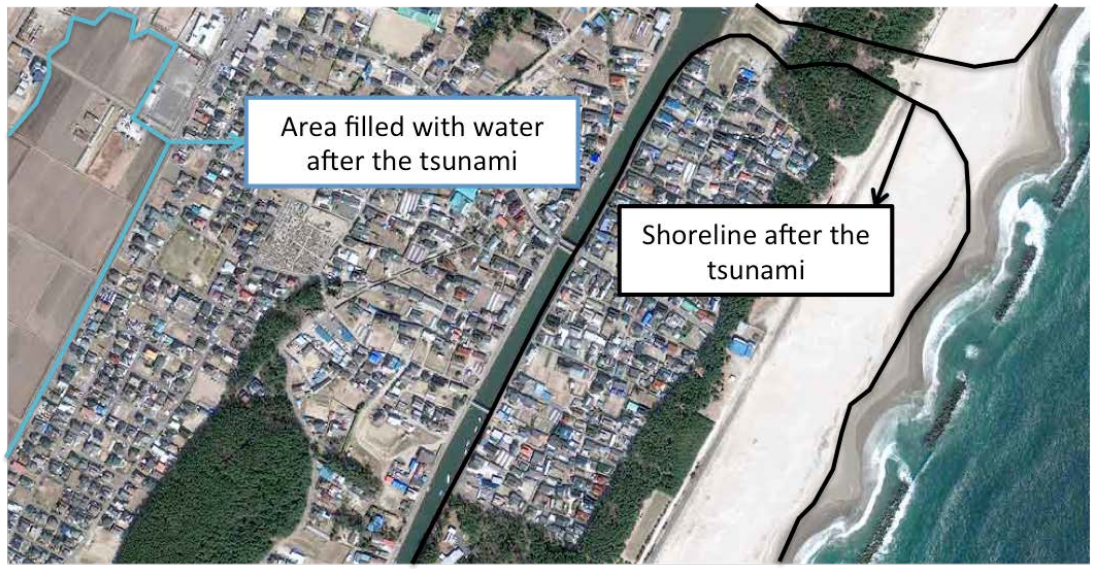
Other products: e.g., maximum velocity

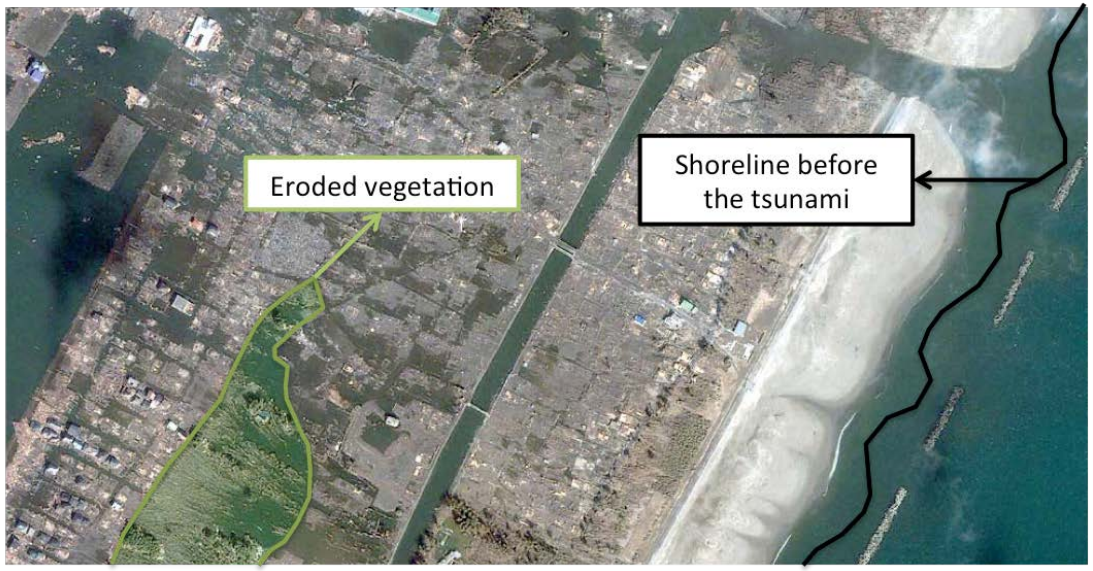
(a)

(b)

- **Tsunami impact** can significantly modify coastal morphology

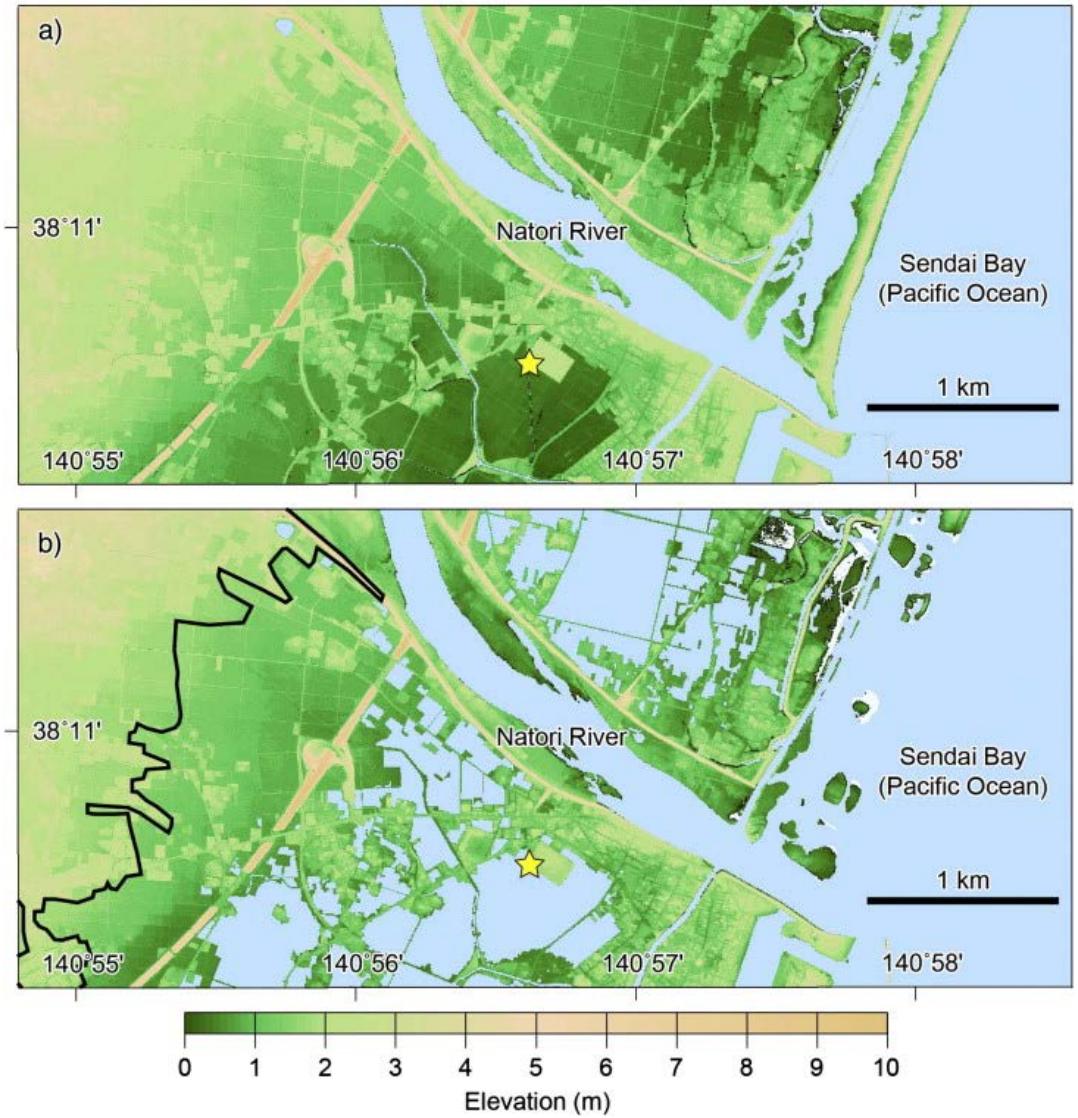
- **Post-tsunami measurements** suggest that, during tsunami inundation, large amounts of coastal sediment is eroded and deposited onshore and offshore





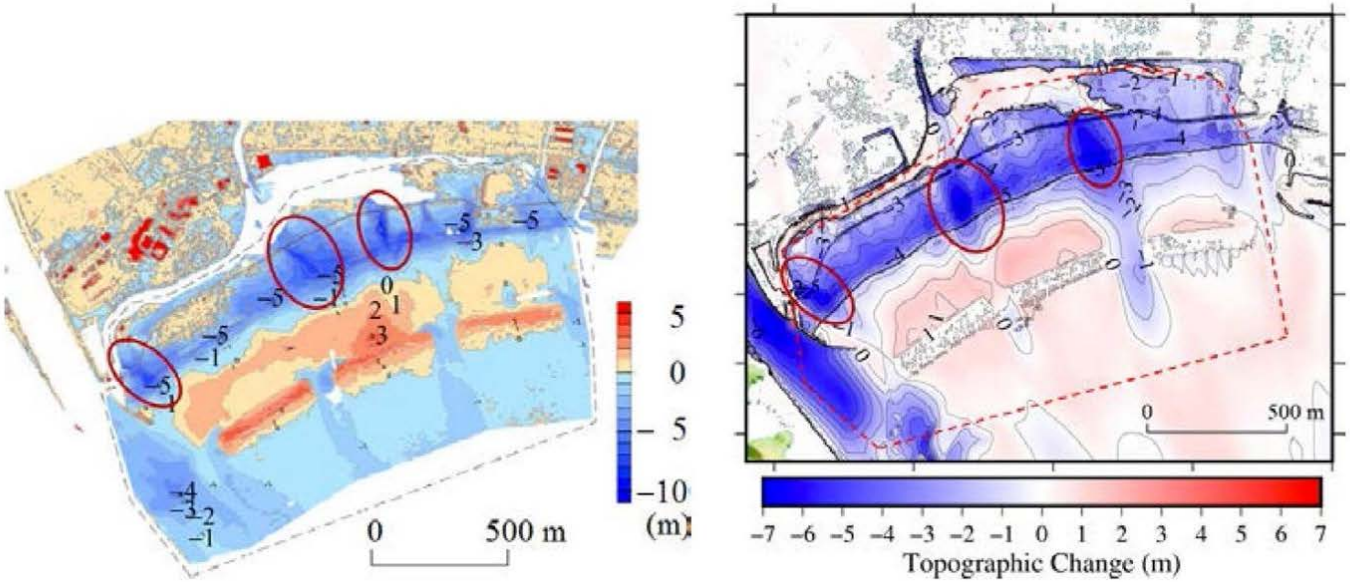
- **During recent tsunamis**, significant sediment processes were observed in coastal regions with barrier islands.

- For instance, **after the 2011 Tohoku-Oki Tsunami**, Udo et al. (2012) reported scours larger than 10 meters on the northern barrier at the mouths of the Natori River.



Sugawara et al. (2014)

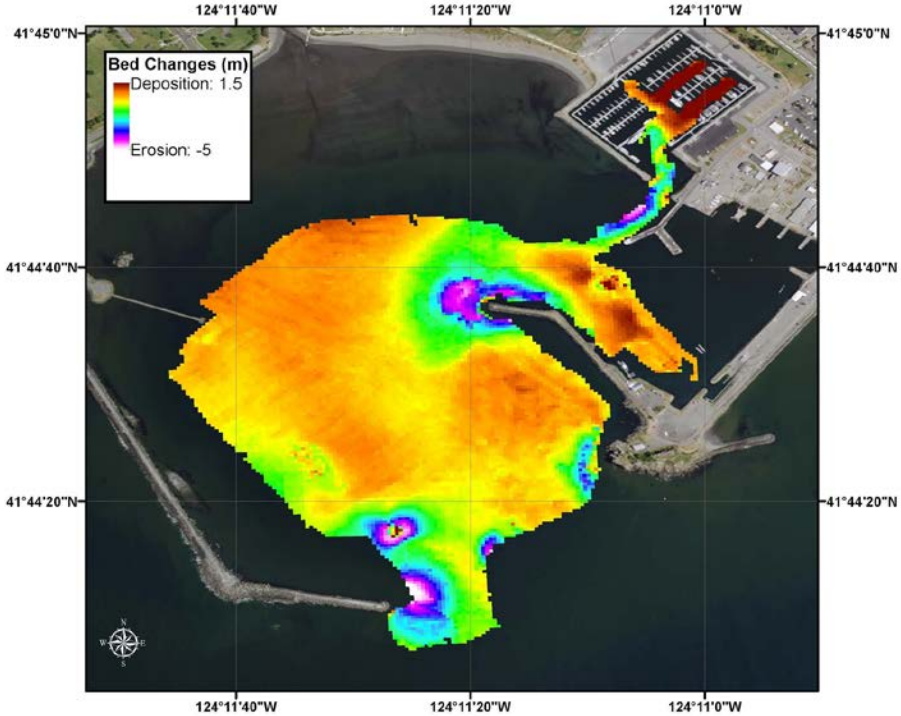
- ***Inundation mapping*** *so far uses fixed bathymetry/topography as basis for modeling*
- ***Significant morphological changes*** *can occur to bathymetry and topography during the course of an event.*
- ***Sediment transport models*** *based on fairly standard versions of shallow flows have skill in predicting patterns and magnitudes of topo/bathy change =>* ***Embedded sediment model in FUNWAVE***



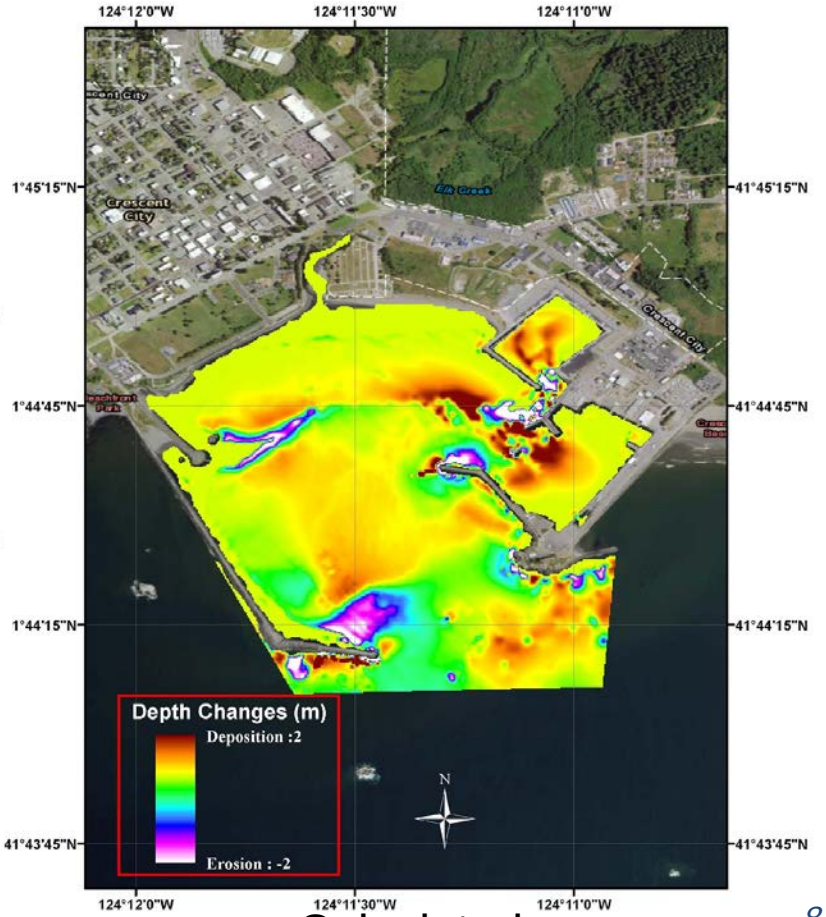
Yamashita et al. (2016)

Field validation test

2011 Tohoku tsunami impact was simulated on *Crescent City harbor*, using Grilli et al. (2012), Kirby et al. (2013) source. **Morphodynamic validation** is based on pre- and post-tsunami measurements of Wilson et al. (2012).

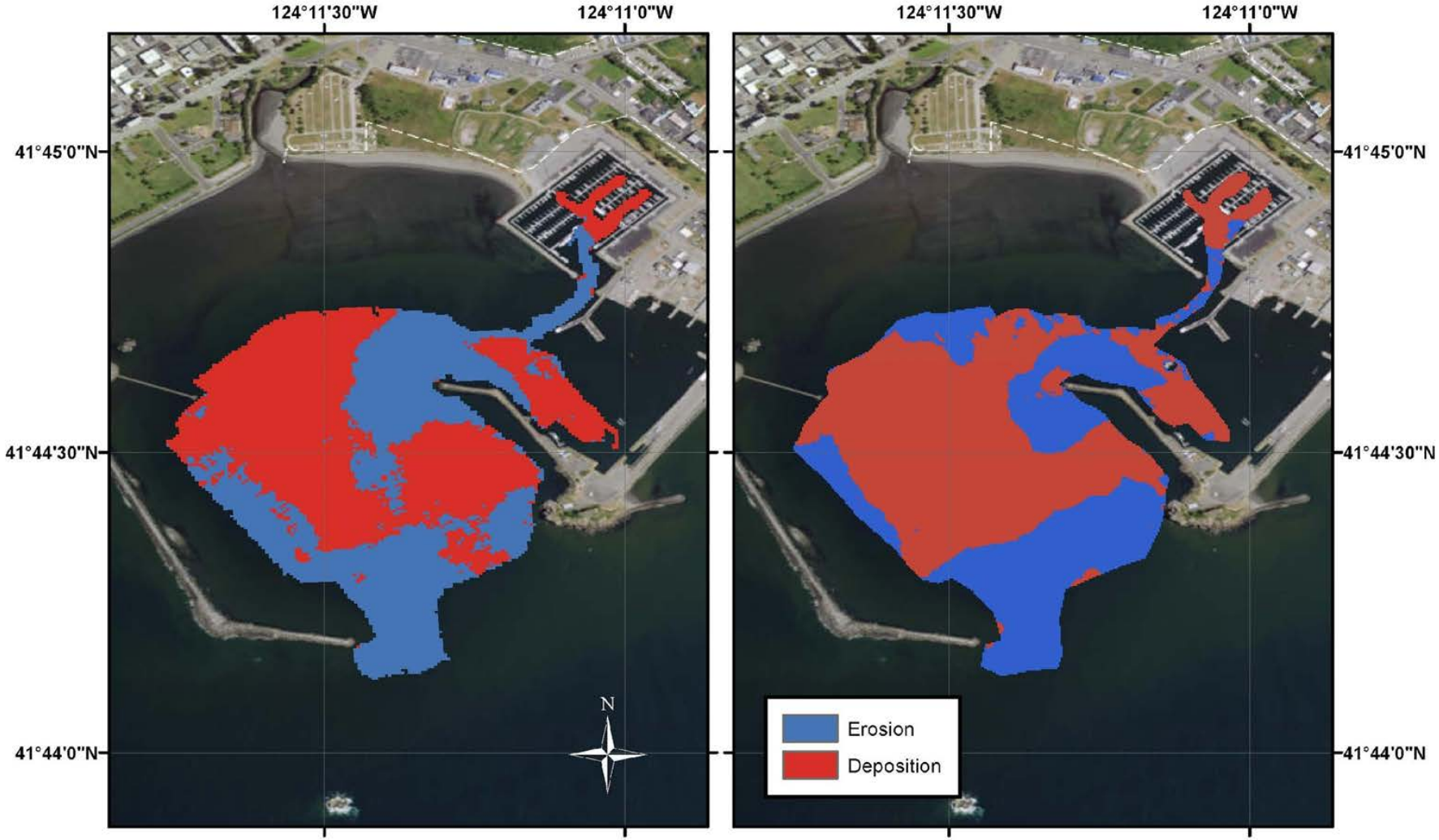


Measured (Wilson et al., 2012)



Calculated

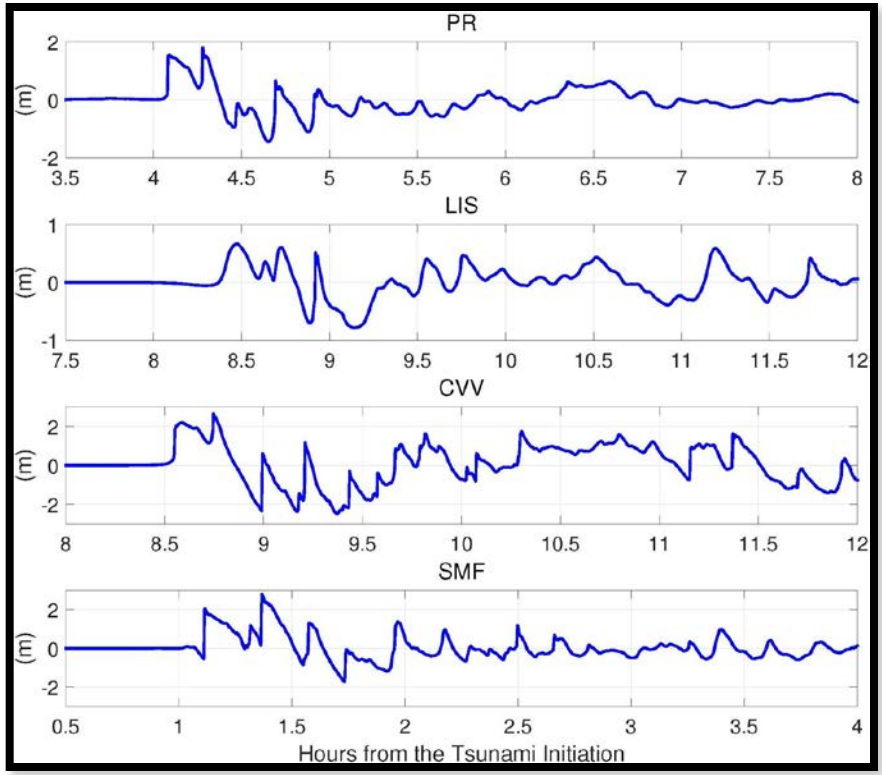
Changes Inside Crescent City Harbor During 2011 Tsunami

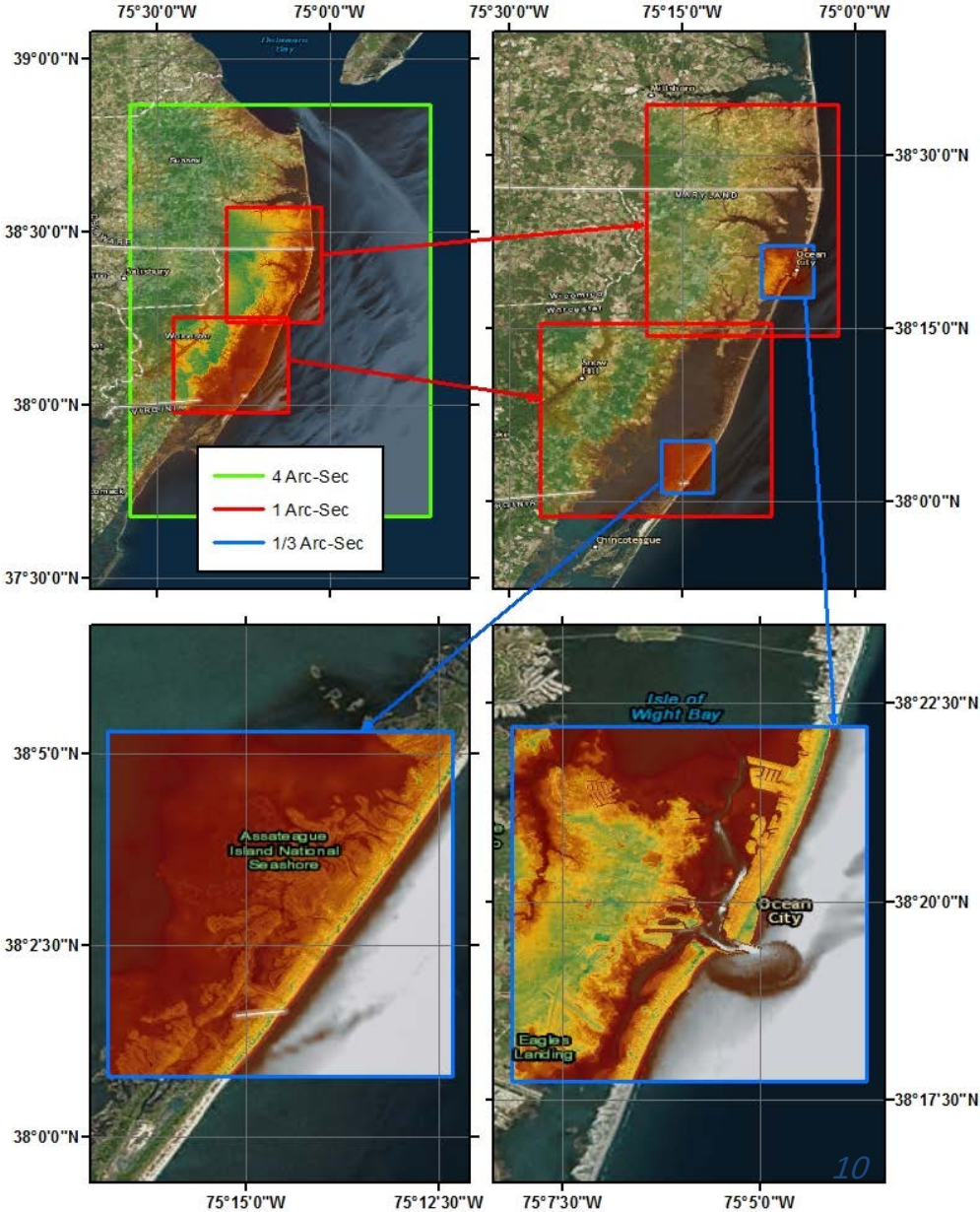


Measured (Wilson et al., 2012)

Calculated

Tsunami impact on Assateague Island and Ocean City Barrier Islands

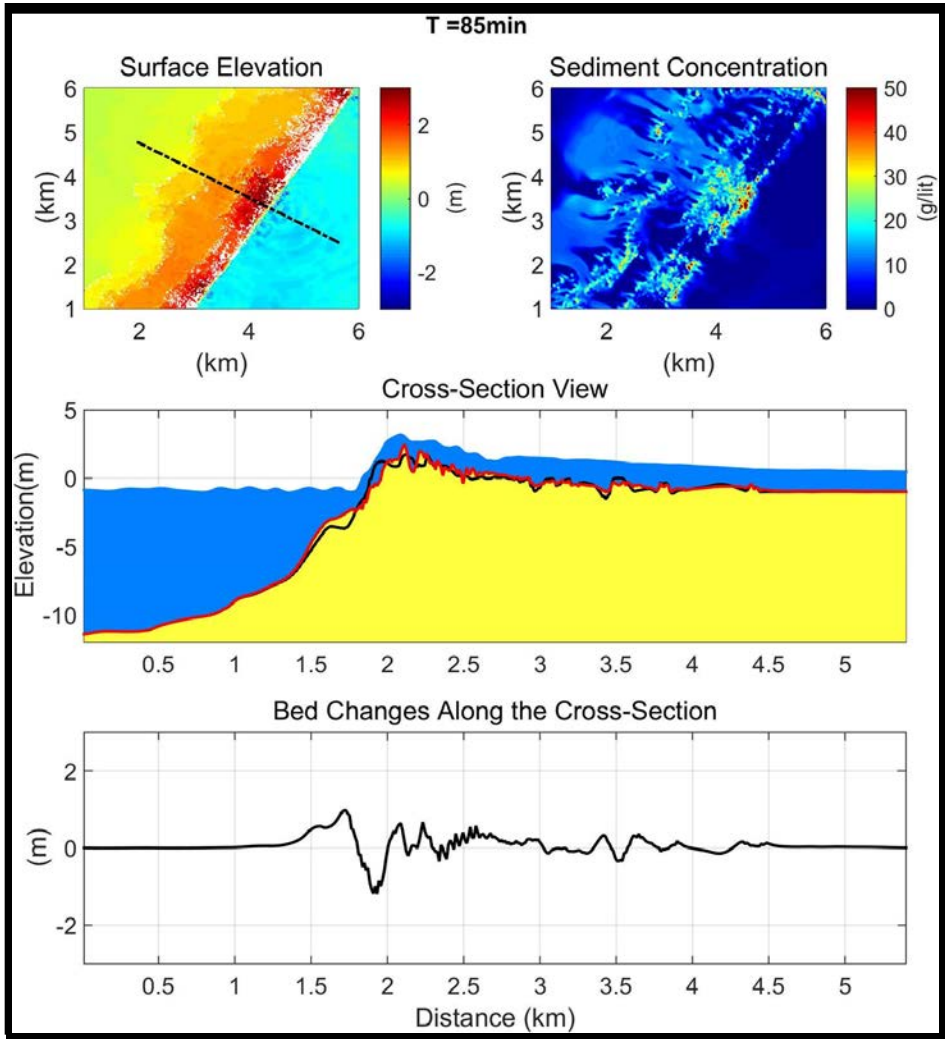




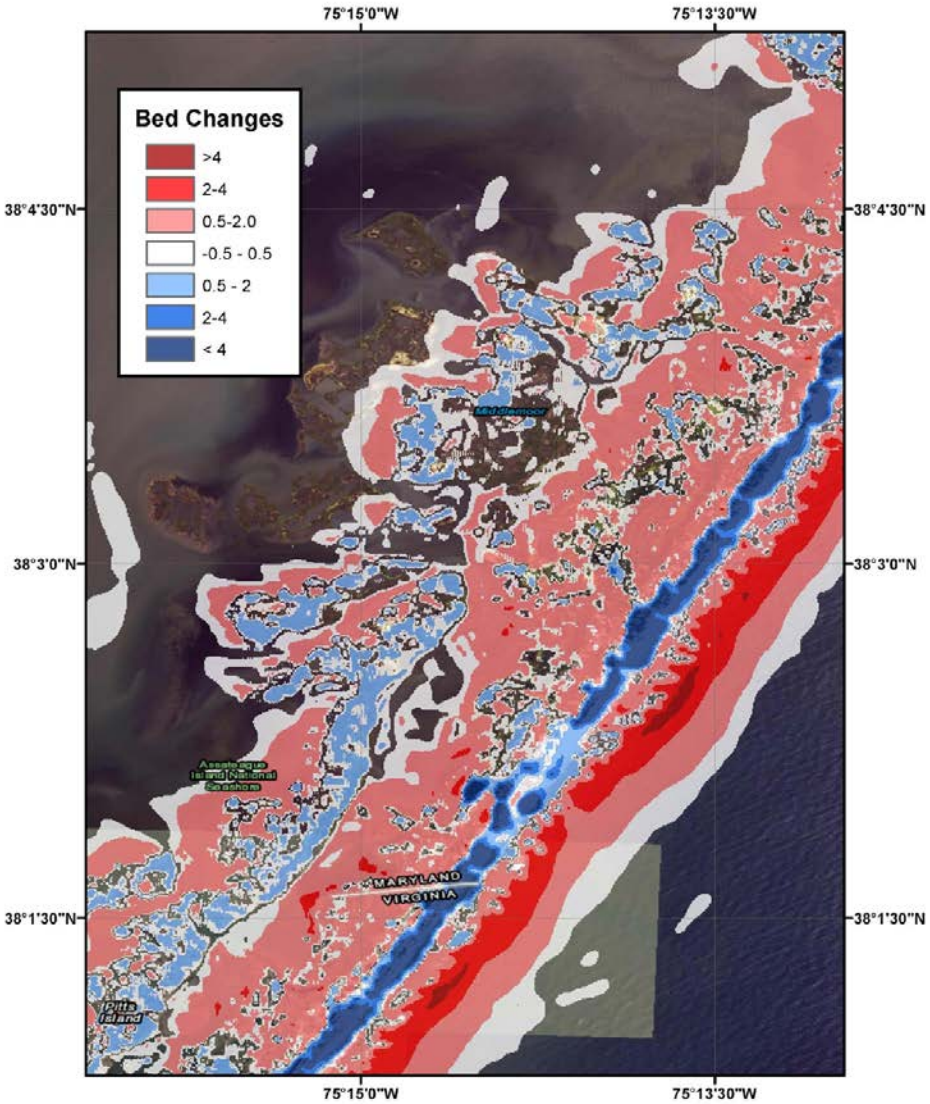
Tsunami impact on Assateague Island and Ocean City Barrier Islands

Barrier Islands Response Under Tsunami Inundation

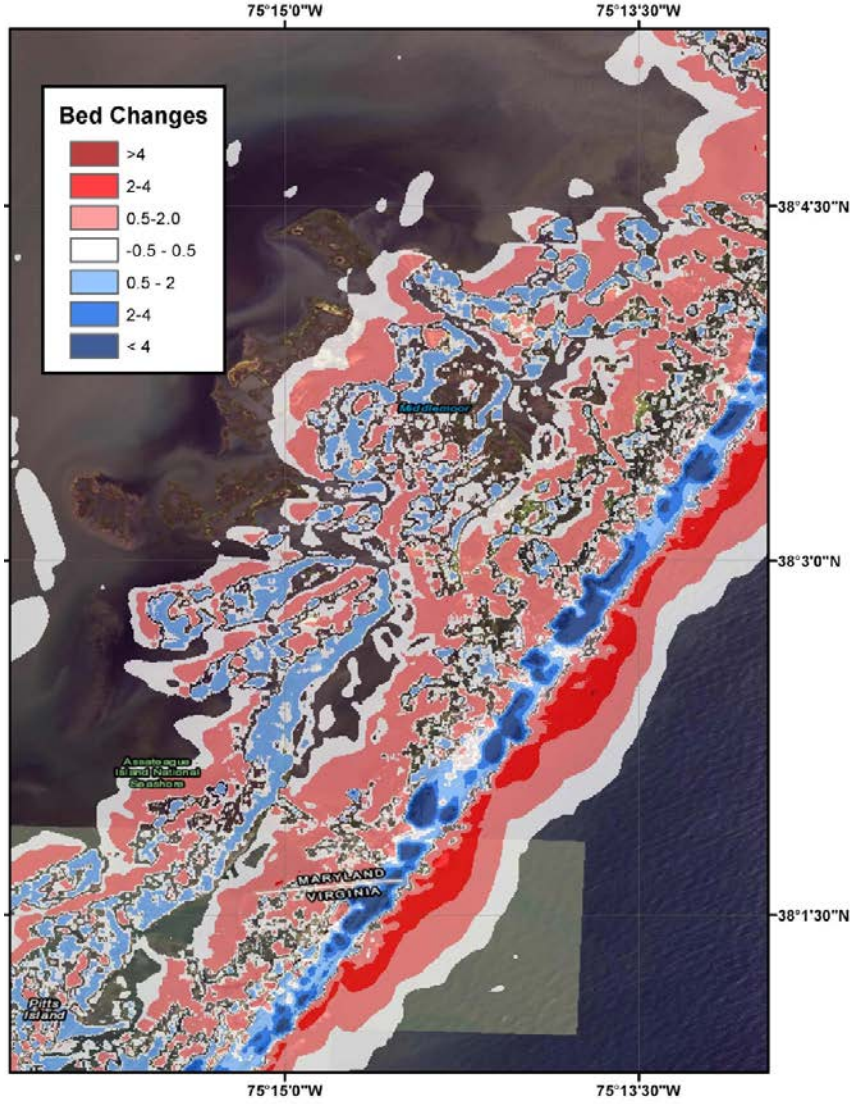
- **Phase I**
  - Tsunami Waves **overtop** barrier and cause erosion on top of the barrier and deposition in the back bay.
  - During rundown significant **shoreface erosion** occurs, with sediment deposited offshore.
- **Phase II**
  - Higher water elevation in back bay than in ocean, causing offshore directed flow => **significant shoreface scouring** and large deposition offshore.



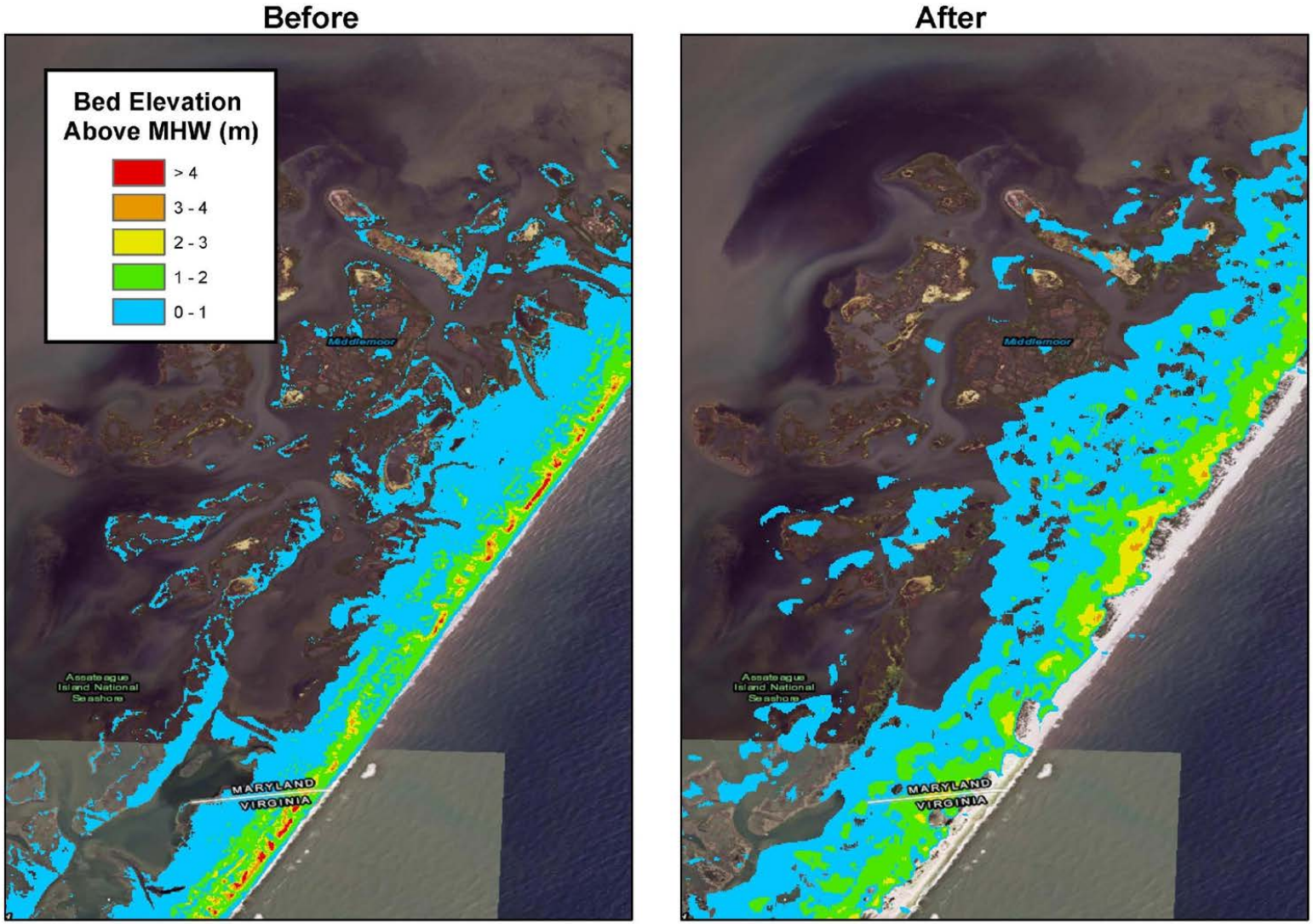
CVV 80 km³ Collapse



M9 Puerto Rico Trench



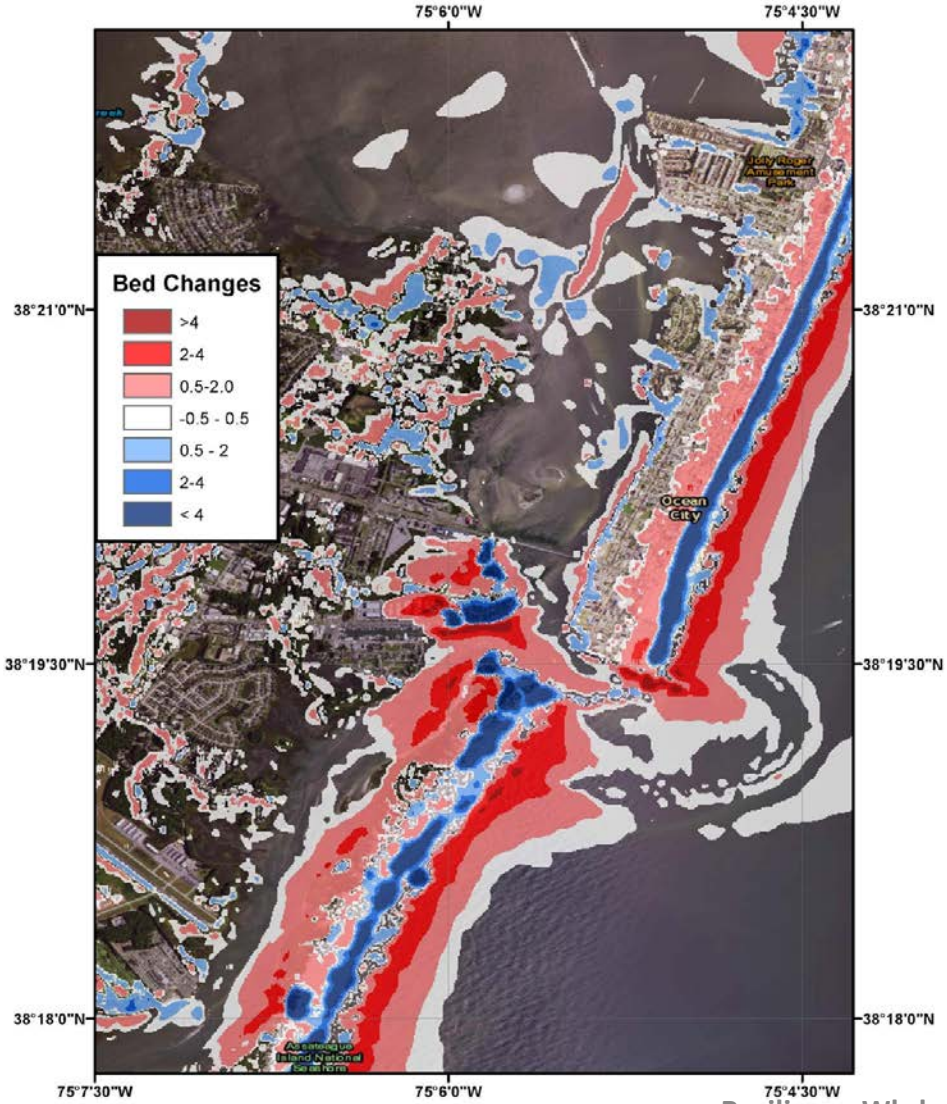
What happens to the Barrier after the Tsunami?



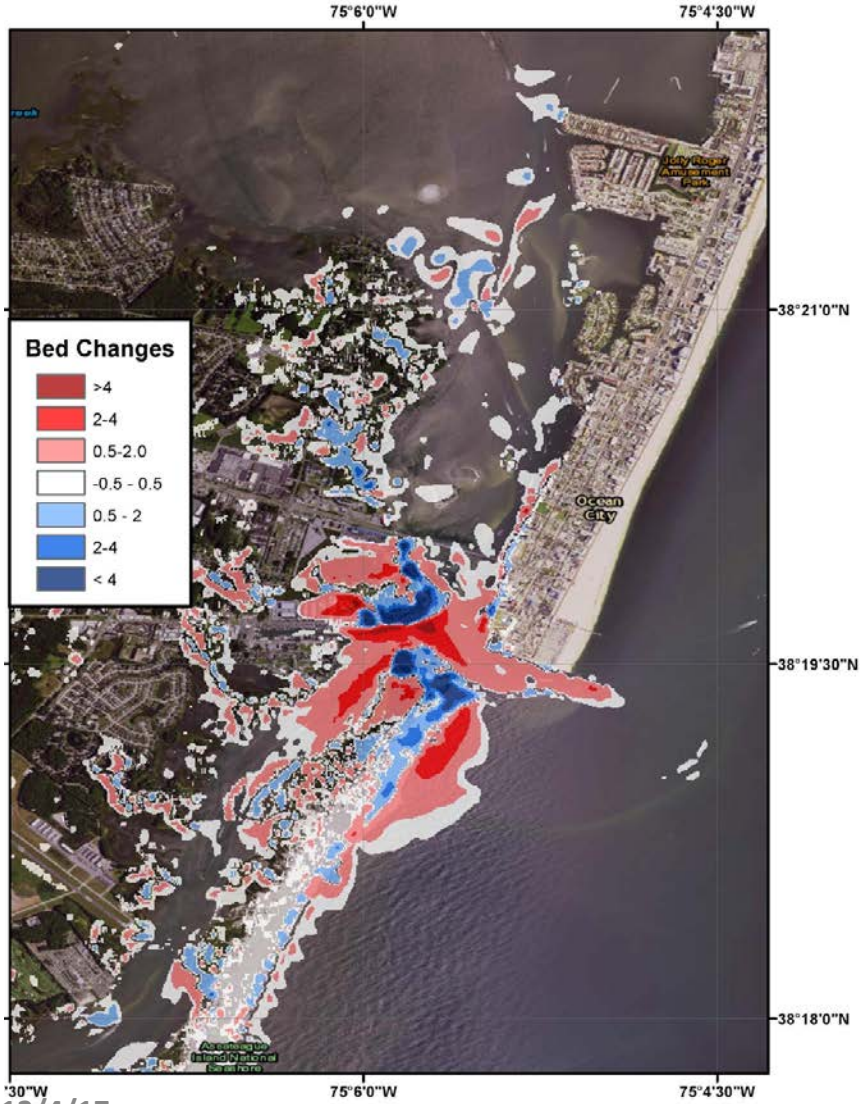
CVV 80 km³ Collapse Tsunami

Ocean City Inlet Morphological Response During Tsunami Inundation

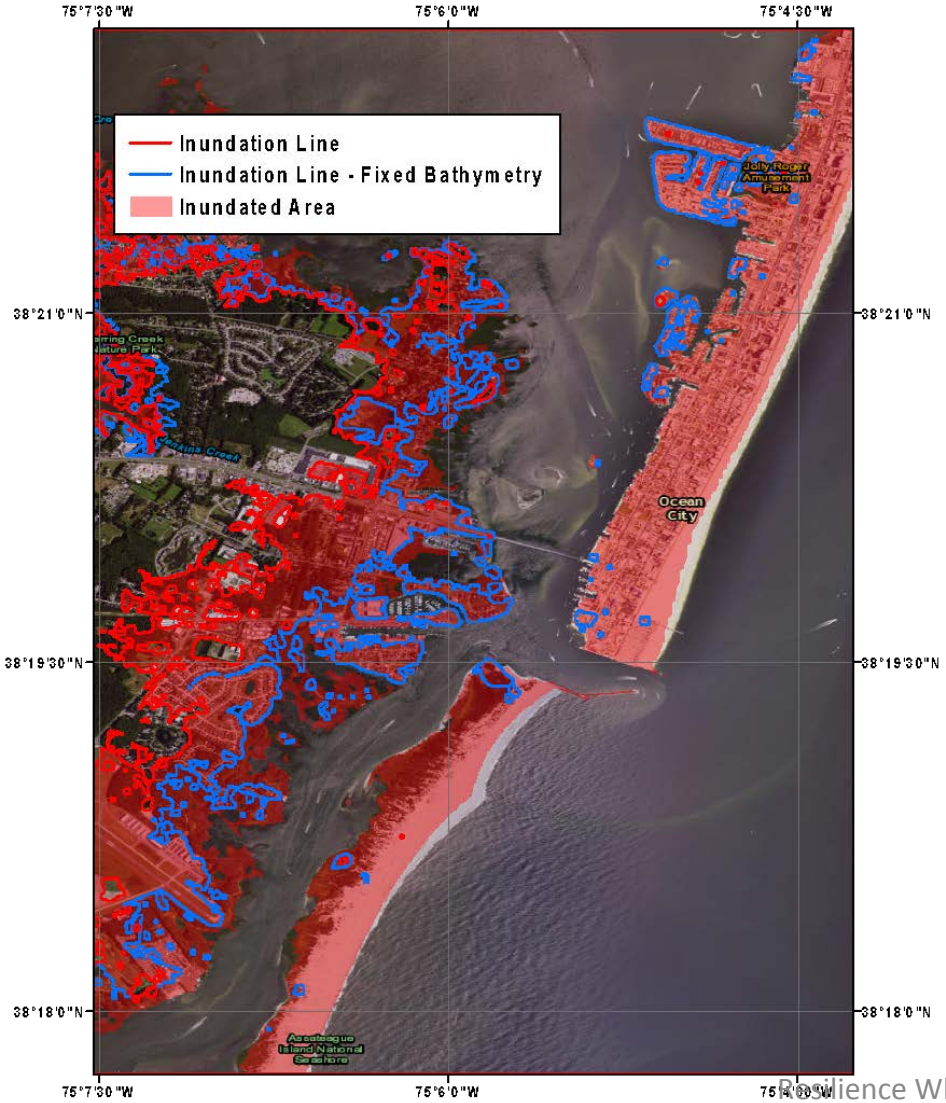
M9 Puerto Rico



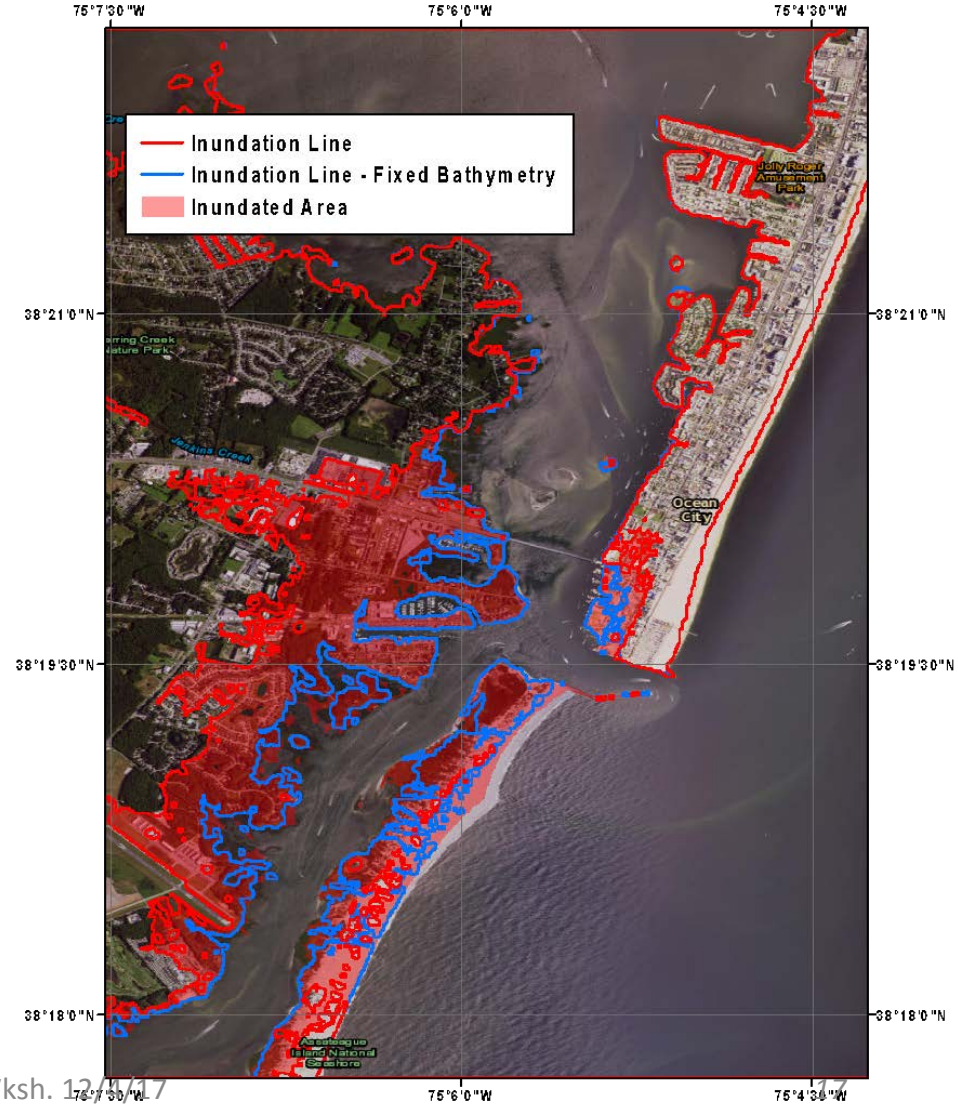
M9 Lisbon (1755 proxy)



Local SMF



M9 Lisbon (1755 proxy)

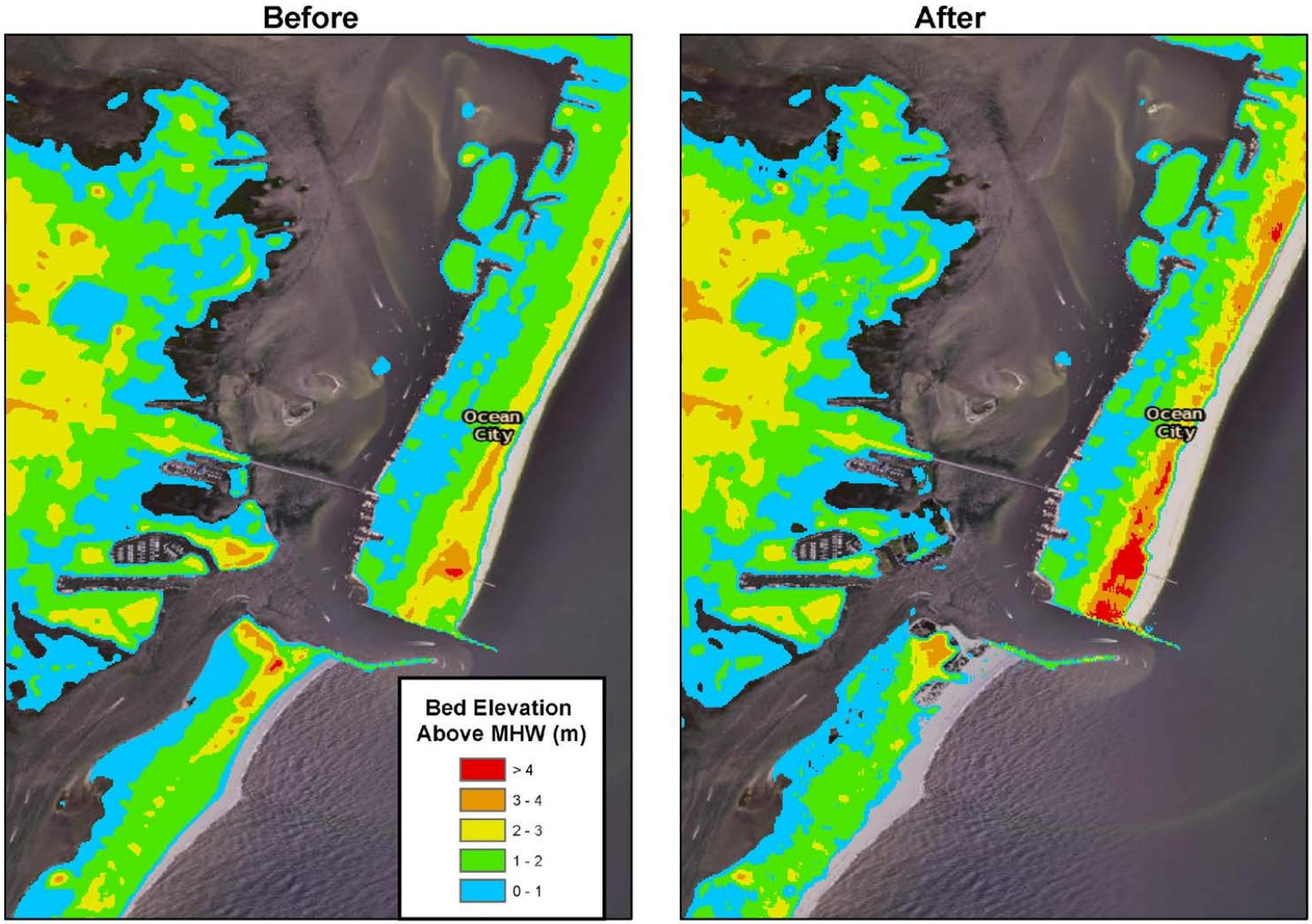


Resulting changes in inundated areas

Tsunami	Inundated Area (Static)	Inundated Area (Dynamic)	Inundation Area Increase (%)
Puerto Rico	7.03 km^2	10.61 km^2	51
Landslide	9.46 km^2	13.43 km^2	42
Volcanic cone collapse	10.94 km^2	19.25 km^2	76
Lisbon	1.28 km^2	7.02 km^2	547

- **Bed morphology** changes during extreme events leading to large increase in inundation extent
- Erosion for the **smallest event** (LSB) causes the largest relative increase (barrier island breaches)
- Similar effects are expected for large storms (and waves) associated with large storm surges => **other work** (A. Grilli et al.)

What happens to the Barrier after the Tsunami?



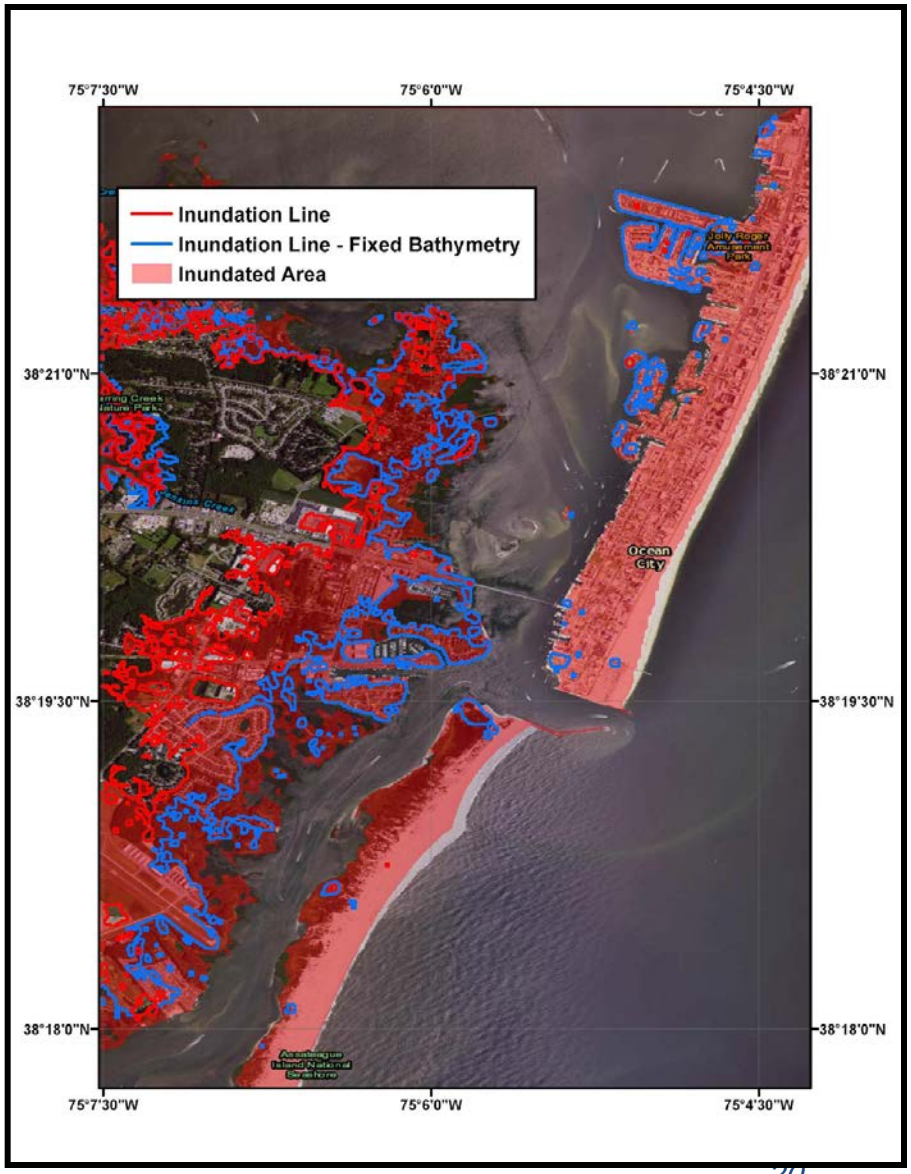
CVV 80 km³ Collapse Tsunami

Summary

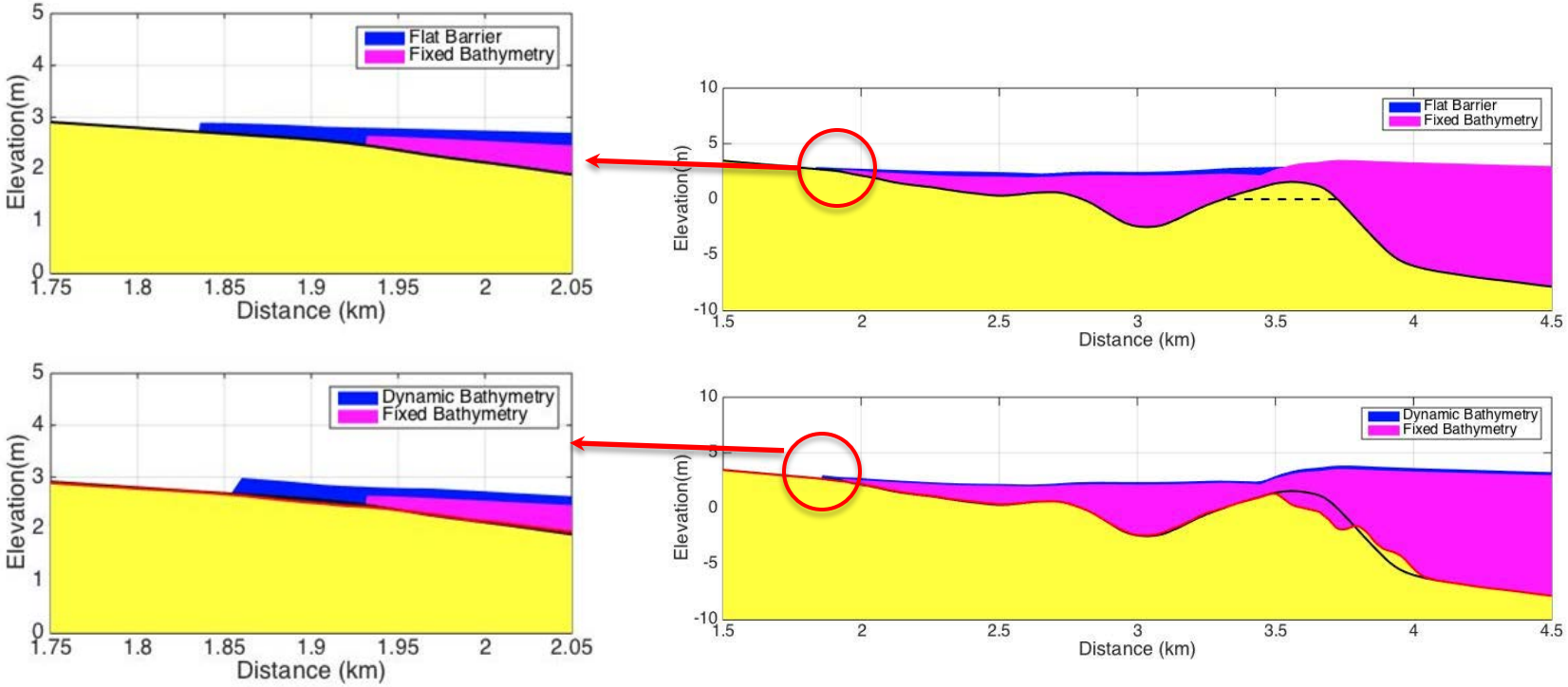
- **Morphological response** of barrier islands to tsunamis *can be simulated* by coupling tsunami model (e.g., FUNWAVE-TVD) with a sediment erosion/deposi-tion/transport model and a morphology scheme.

- **Most significant phase** in tsunami-sediment interactions is wave rundown which causes significant erosion/scouring of the shoreface leading to *permanent changes*.

- **Beach profile changes** during tsunami inundation can *increase tsunami runup* onshore, thus *increasing hazard level* in the mainland behind the barrier island.



Morphological change does increase tsunami Hazard



- **Runup** in the mainland behind the barrier is increased due *to barrier crest erosion*, making it *easier for later waves* in the tsunami to reach highland behind the barrier.
- **East Coast 5-year plan** includes recomputing inundation in high-hazard including shoreline/barrier erosion => *First year approved in FY19*

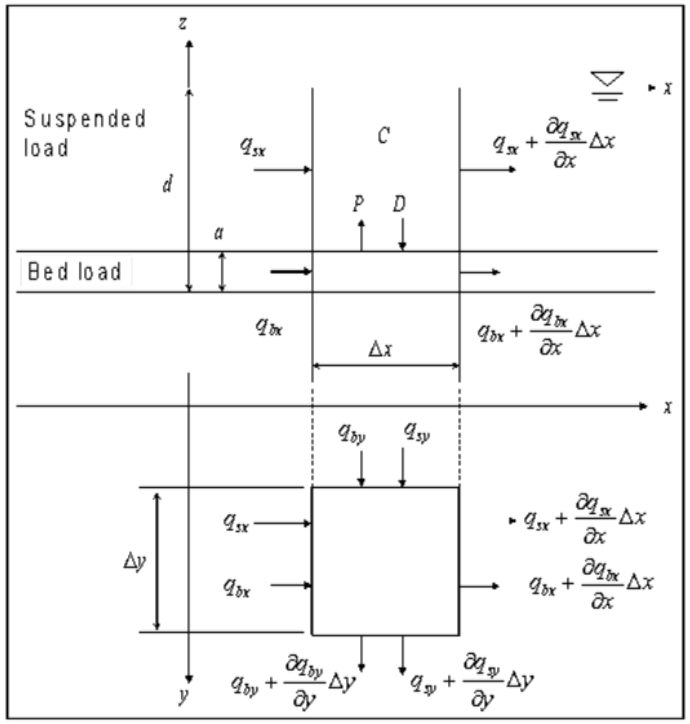
Thank you

Questions?

1 - Sediment Transport Model ($dt_{sed} = dt_{hyd}$)

FUNWAVE-TVD (η,u,v) at each time step are used to force a sediment transport equation (solved with finite different scheme).

$$\frac{\partial(dC)}{\partial t} + \frac{\partial(dC u_s)}{\partial x} + \frac{\partial(dC v_s)}{\partial y} = \frac{\partial}{\partial x}\left(K_x d \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y d \frac{\partial C}{\partial y}\right) + P - D$$



C depth-averaged sediment concentration

d total depth ($h+\eta$)

h still water depth

u_s flow per unit width parallel to the x axis (m^2/s)

v_s flow per unit width parallel to the y axis (m^2/s)

K_x sediment diffusion coefficient for the x direction

K_y sediment diffusion coefficient for the y direction

P sediment pick up rate (upward sediment flux)

D sediment deposition rate (downward sediment flux)

2 - Morphology Model ($dt_{morph} = N \times dt_{hyd}$)

$$\frac{dh}{dt} = \frac{1}{1-p}\left(\bar{P} - \bar{D}\right)$$

3 – Avalanche Model (dt_{morph})

- When the beach slope exceeds the repose angle of the sediment, the avalanching occurs, and form a new slope with the repose angle.

- Here we used the algorithm developed by Larson and Kraus (1989) for SBEACH.

Model Validation

Kobayashi and Lawrence (2004)

Laboratory experiments were performed to examine the cross-shore sediment transport processes under breaking solitary waves on a fine sand beach.