

XBeach Modeling of Erosion During Hurricane Isabel: Resolution Requirements For Coupling With ADCIRC

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Understanding Erosion of Beaches and Dunes

Objectives and Motivations

We want to:

- Understand beach behavior during storms
- Model morphological response of the beach
- Learn how XBeach works and how to use it

Why coupling with ADCIRC?

- Update ADCIRC topo/bathy during simulation
- Waves and storm surge see the morphology evolution

Objectives:

- Model beach morphology evolution with XBeach
- Validate results and avoid use of XBeach as a blackbox
- Understand the mesh resolution requirements

Understanding Erosion of Beaches and Dunes

eXtreme Beach (XBeach): xbeach.org

Wave action balance equation:

$$\frac{\partial A}{\partial t} + \frac{\partial c_{gx} A}{\partial x} + \frac{\partial c_{gy} A}{\partial y} + \frac{\partial c_{\theta} A}{\partial \theta} = -\frac{D_w + D_f + D_v}{\sigma}$$

$$A(x, y, t, \theta) = \frac{S_w(x, y, t, \theta)}{\sigma(x, y, t)}$$

Shallow water equations:

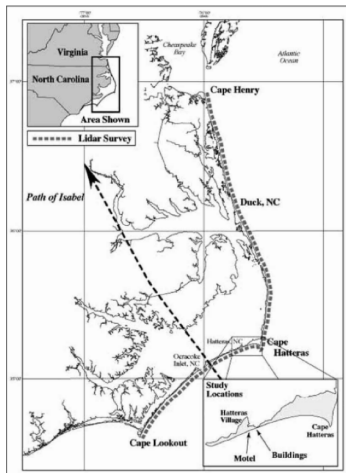
$$\frac{\partial u^L}{\partial t} + u^L \frac{\partial u^L}{\partial x} + v^L \frac{\partial u^L}{\partial y} - f v^L - v_h \left(\frac{\partial^2 u^L}{\partial x^2} + \frac{\partial^2 u^L}{\partial y^2} \right) = \frac{\tau_{sx}}{\rho h} - \frac{\tau_{bx}^E}{\rho h} - g \frac{\partial \eta}{\partial x} + \frac{F_x}{\rho h} - \frac{F_{v,x}}{\rho h}$$

$$\frac{\partial v^L}{\partial t} + u^L \frac{\partial v^L}{\partial x} + v^L \frac{\partial v^L}{\partial y} + f u^L - v_h \left(\frac{\partial^2 v^L}{\partial x^2} + \frac{\partial^2 v^L}{\partial y^2} \right) = \frac{\tau_{sy}}{\rho h} - \frac{\tau_{by}^E}{\rho h} - g \frac{\partial \eta}{\partial y} + \frac{F_y}{\rho h} - \frac{F_{v,y}}{\rho h}$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial h u^L}{\partial x} + \frac{\partial h v^L}{\partial y} = 0$$

Exploring Morphodynamics during Isabel (2003)

Extensive Erosion and Breaching



We examine storm impacts during Isabel

- Most powerful hurricane in 2003
- Made landfall on the Outer Banks on 18 Sep as Category 2 hurricane
- Caused overwash, dune breaching, and infrastructure destruction
- NC-12 closed at identified hotspots
- Major breaching occurred northeast of Hatteras Inlet

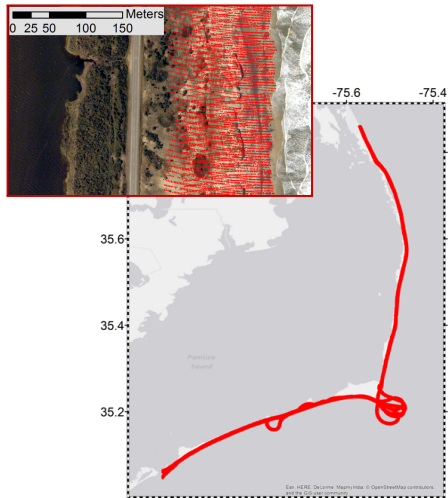


Exploring Morphodynamics during Isabel (2003)

Pre- and Post-Storm LiDAR Data

Available LiDAR data:

- Pre- and post-storm data sets available from the NASA / USGS Experimental Advanced Airborne Research LiDAR
 - 16 Sep 2003
 - 21 Sep 2003
- Coverage of Outer Banks from Ocracoke Inlet to Oregon Inlet
- Surveyed width of 250-300 m
- Resolution of 2 m
- Only the topographic data are used, due to water turbidity in bathymetric regions

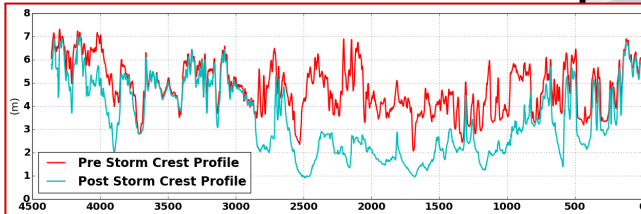
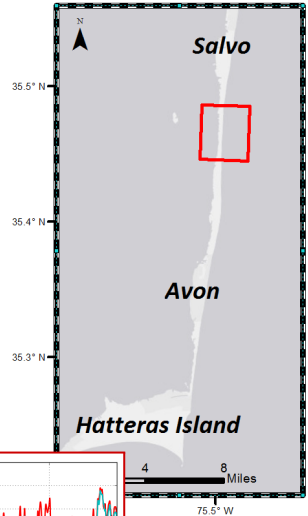


Exploring Morphodynamics during Isabel (2003)

Storm Impacts in Study Area

Alongshore crest elevation change:

- Study area between Avon and Salvo
 - Distance of about 4.5 km
- Elevation changes at pre-storm crest line
 - Average = 1.5 m
 - Maximum = 5.6 m
- Total of 8 major dune erosion events
 - All wider than 15 m



Initial Results with XBeach

Generating Mesh for XBeach Simulations

Combining data sets:

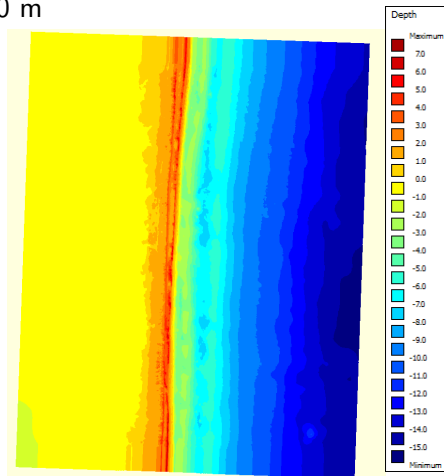
- Pre-storm LiDAR with 1 m resolution
- NC flood mapping DEM with 10 m resolution

Converting to computational mesh:

- Total of 990×440 cells
- Cell widths:
 - Alongshore = 5 m
 - Cross-shore
 - At offshore boundary = 30 m
 - At shoreline = 3 m

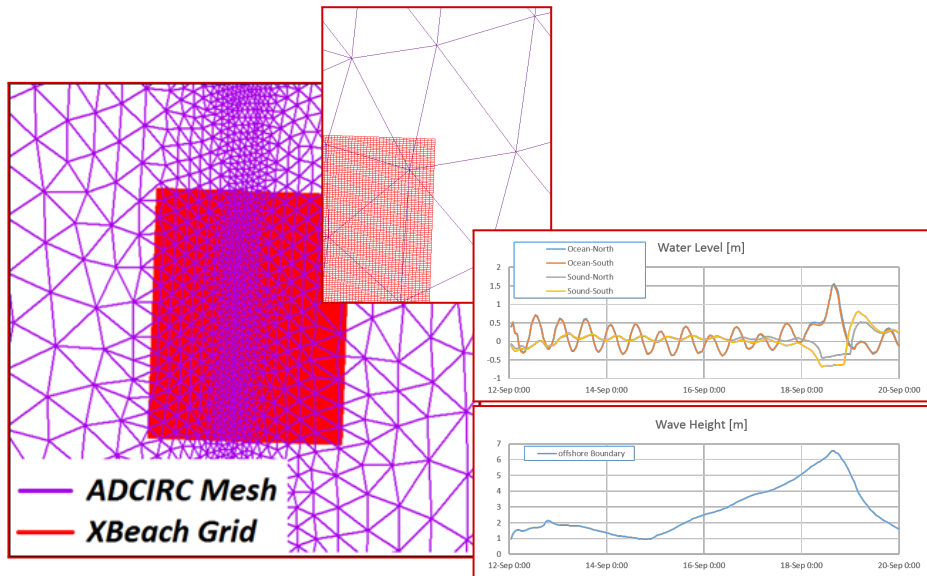
Need to assign values:

- Waves and water levels
- Sediment properties



Initial Results with XBeach

Wave and Surge Boundary Conditions from SWAN+ADCIRC



Initial Results with XBeach

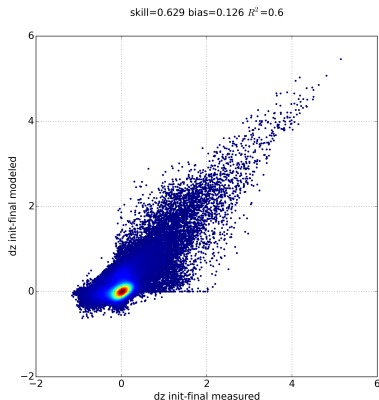
Model Accuracy

Skill Score:

- Compares measured to modeled elevation change
- Skill score greater than 0.5 is “Excellent”
- Modeled profiles match observations: scatter points close to 1:1

$$Skill = 1 - \frac{\sum_{i=1}^N \left(dz_{b_{LIDAR,i}} - dz_{b_{XBeach,i}} \right)^2}{\sum_{i=1}^N \left(dz_{b_{LIDAR,i}} \right)^2}$$

Skill Score = 0.629

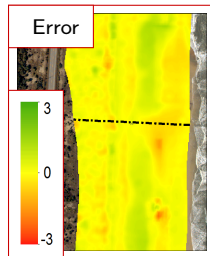
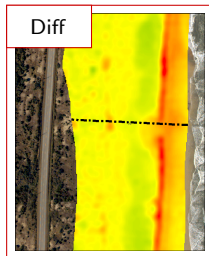
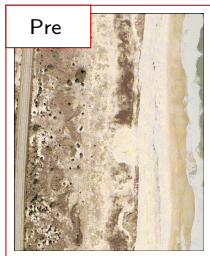
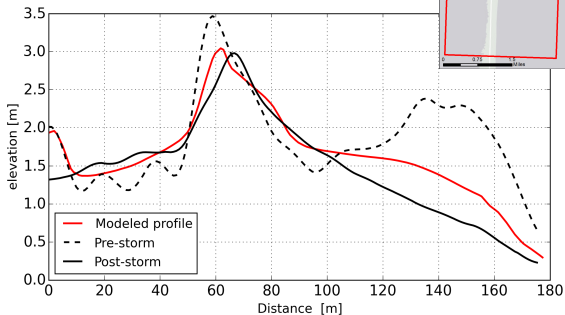


Initial Results with XBeach

XBeach Profiles at Major Dune Erosion Events

Dune Erosion Event #1:

- Erosion of the first dune
- Deposition behind the second dune

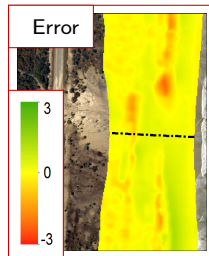
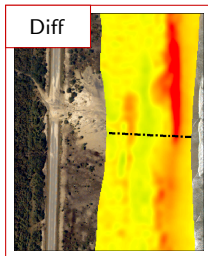
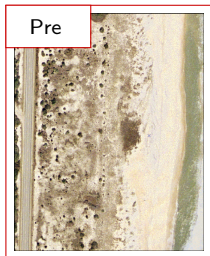
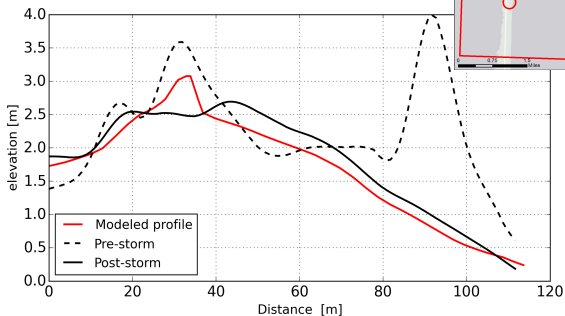


Initial Results with XBeach

XBeach Profiles at Major Dune Erosion Events

Dune Erosion Event #2:

- Removal of first and second dunes
- Erosion and overwash modeled almost correct

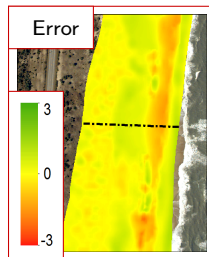
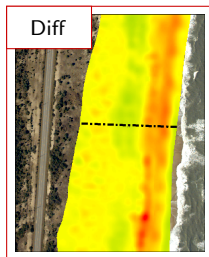
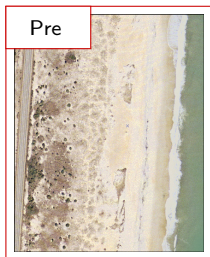
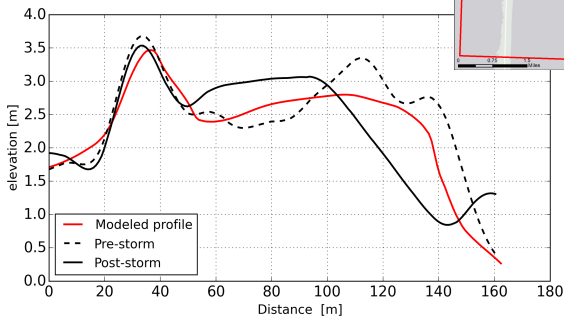


Initial Results with XBeach

XBeach Profiles at Major Dune Erosion Events

Dune Erosion Event #3:

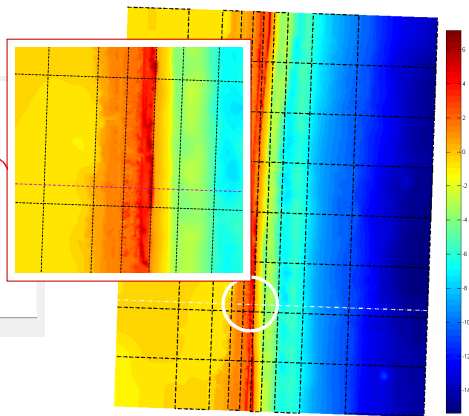
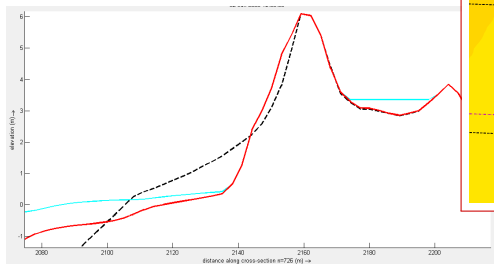
- Inaccurate result
- First dune removal modeled poorly
- No changes to profile behind first dune



XBeach MPI issue

Incorrect data passing between cores

- Problem in data passing between sub-domains
- Cells located in the subdomain overlaps do not reflect erosion correctly

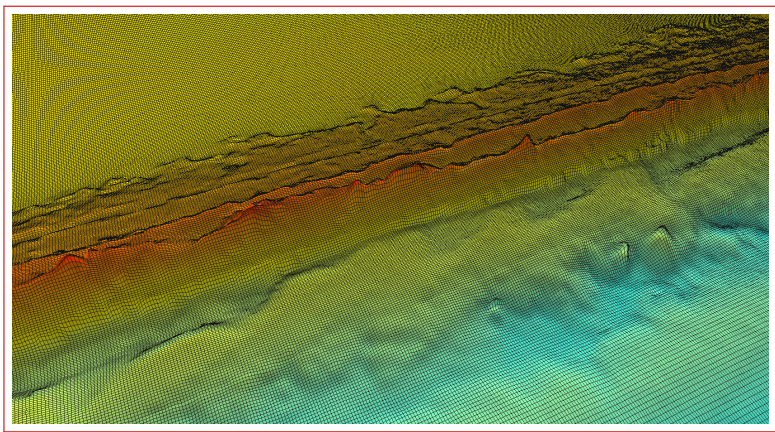


Mesh Resolution

Resolution comparison between XBeach and ADCIRC

XBeach mesh:

- 5m x 3m grid near shoreline
- Both dunes and the topographic features

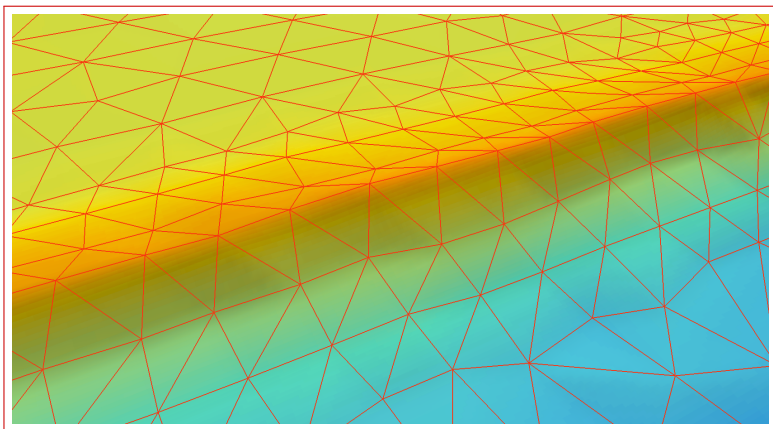


Mesh Resolution

Resolution comparison between XBeach and ADCIRC

ADCIRC mesh:

- NC9 mesh with about 100m resolution on Hatteras Island
- Nodes located on dunes but details are not resolved



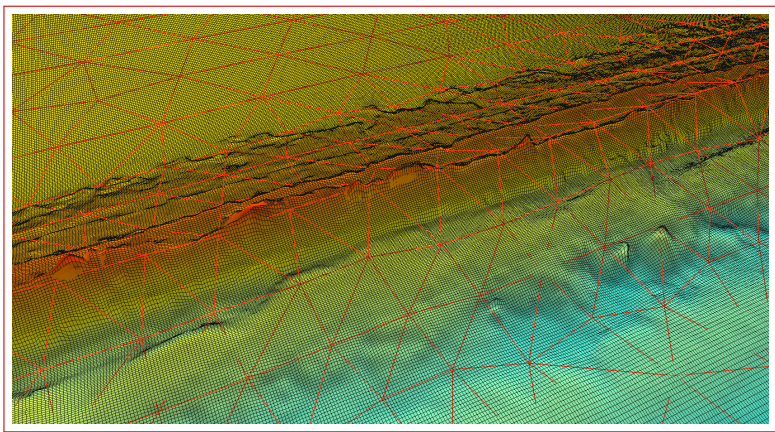
Mesh Resolution

Resolution comparison between XBeach and ADCIRC

Limitation:

- We cannot use 5m spacing in ADCIRC/XBeach for Hatteras Island

How to bridge the gap between XBeach and ADCIRC?



XBeach mesh resolution sensitivity

XBeach mesh

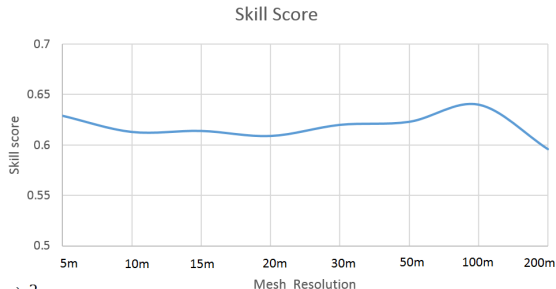
- Coarsening XBeach mesh gradually from 5m to 200m alongshore
- Same cross-shore resolution, with minimum spacing of 3m at shoreline
- Bathy/topo re-interpolated onto each grid

XBeach mesh resolution sensitivity

Skill Score

- Skill Score computed for each grid model result
- The skill score stays the same
- Need to use different criteria??

Mesh	Skill	Bias	R ²
5m	0.629	0.126	0.6
10m	0.613	0.123	0.582
15m	0.614	0.122	0.583
20m	0.609	0.123	0.577
30m	0.62	0.124	0.589
50m	0.623	0.12	0.59
100m	0.64	0.118	0.61
200m	0.596	0.113	0.59

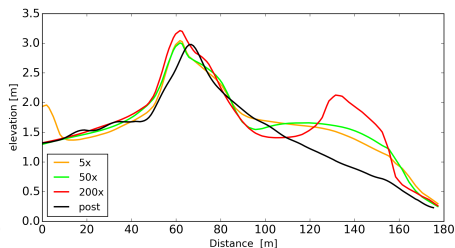
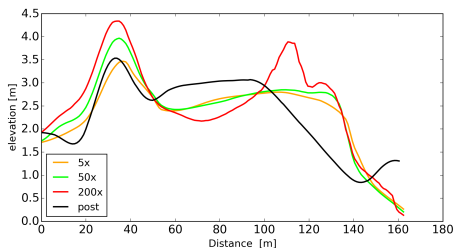


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XBeach mesh resolution sensitivity

Cross-sections Comparison

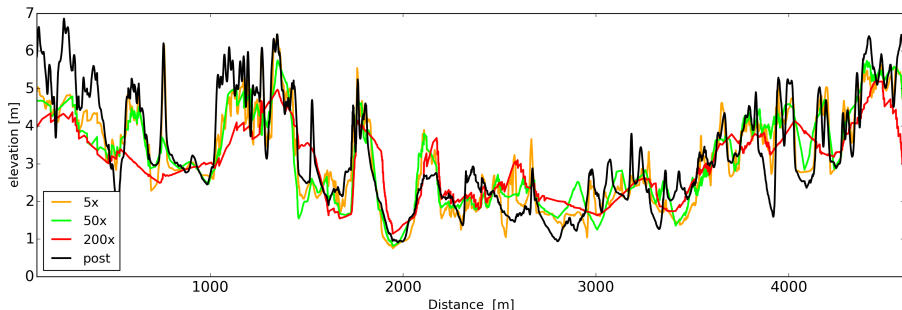
- Meshes with resolution lower than 50m produce very similar results
- But larger spacing (100m and 200m) causes huge differences
- Part of the error is because of different initial profile



XBeach mesh resolution sensitivity

Comparisons along dune crest

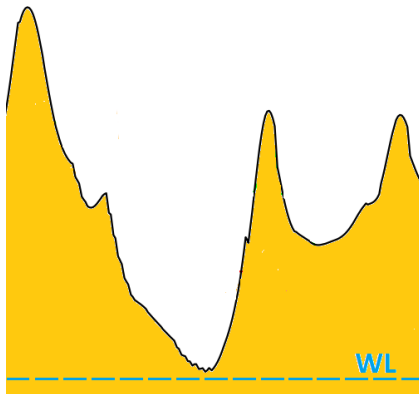
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XBeach mesh resolution sensitivity

Water Overpass Area

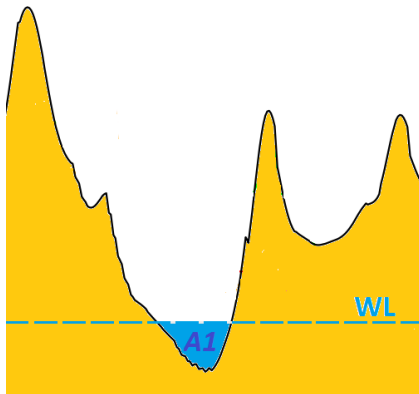
- WOA represents the amount of water that crosses the dune crest
- Area between dune crest and water level



XBeach mesh resolution sensitivity

Water Overpass Area

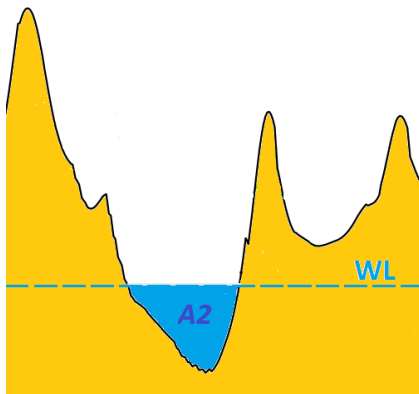
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XBeach mesh resolution sensitivity

Water Overpass Area

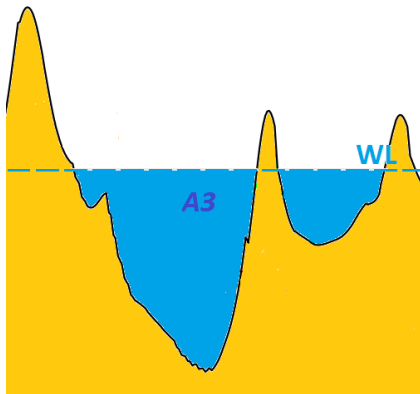
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XBeach mesh resolution sensitivity

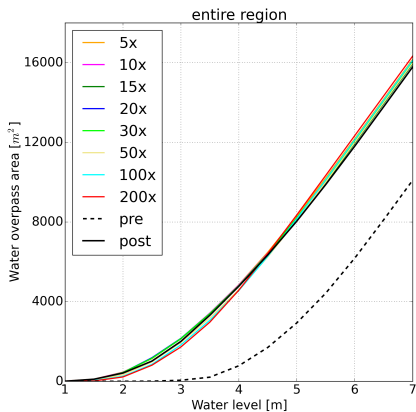
Water Overpass Area

- WOA represents the amount of water that crosses the dune crest
- Area between dune crest and water level



XBeach mesh resolution sensitivity

- Amount of water that crosses the dune crest
- To be used in coupling optimization
- How does it converge as resolution is increased?
- What are implications for ADCIRC?



Summary and Future Work

Predictive Models for Waves, Flooding, and Beach Morphodynamics

Working with XBeach to simulate beach and dune erosion:

- Preliminary results are encouraging
 - Developing model for Hatteras Island
 - Improving accuracy for complex erosion patterns
- Select proper mesh resolution
 - At this scale the results are not sensitive to alongshore mesh resolution
 - Using Skill score
 - Using WOA parameter
 - Other methods?
- Need to couple with wave and surge models
 - Revised topography to improve flood predictions

