NC STATE UNIVERSITY

Coupling of Inlet-Scale Erosion and Region-Scale Flooding Predictions

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USCRP FY18 Academic Award in Progress Review
Web Meeting, 16 Oct 2019

Inlet-Scale Erosion

Hatteras Island during Florence (2018)

Region-Scale Flooding

Isabel Inlet (2003)

Goals:

1. Better understand the storm-induced erosion of barrier islands
2. Develop ways to represent that erosion in predictive models on large domains

Objectives:

1. Develop a high-resolution hindcast of inlet creation in a barrier island system
2. Explore the sensitivity of erosion predictions to the quality of input data
3. Implement a two-way coupling of small-scale erosion to larger-scale flooding

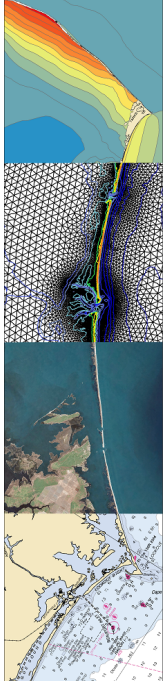
1. *An Outward Connection: How can your results be translated and shared with the community, other agencies, or other academics? What is the planned timing for sharing in-progress and final results?*
   - Coupling of erosion and flooding predictions has wide applicability and interest
     - Allows for scenario-based analysis and design
     - Support from NCEM, NWS, FEMA, USACE
   - This research has a significant development component
     - Dissemination in academic settings (journals, conferences)
     - Will continue to share with partners as research matures
2. *Thinking Beyond Your Research: How does your work fit into addressing a broader societal need?*
   - Coastal residents and decision-makers rely on predictions of storm-driven flooding
   - Better predictions will have direct benefits to safety and prosperity along our coasts

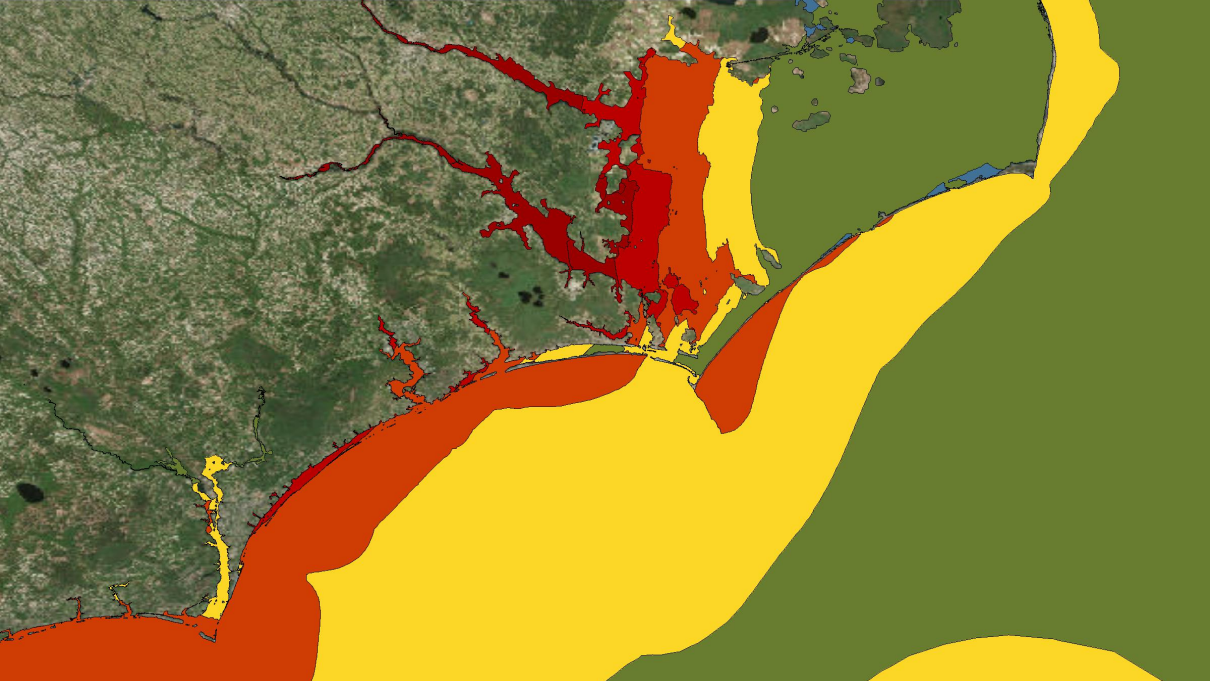
3. *Leveraging: Are you leveraging your research with outcomes from other research, either funded by USCRP or externally?*
   - Directly connected to other funded projects to couple erosion and flooding
     - NC Sea Grant (2016-2018)
     - USCRP (2019-2021)
   - Indirectly related to other projects about multi-scale coastal processes
     - DHS CRCoE (2016-2020)
     - NSF PREEVENTS (2017-2021)
4. *Problems: Is there anything holding you back from making progress?*
   - This is a tough problem!
5. *Solutions: How can the USCRP help you?*
   - Need to better plug into expertise at USCRP member agencies
   - Need feedback, both today and at ASBPA conference

Prior Work – Beach and Dune Erosion
- ADCIRC+XBeach
- Example for Isabel (2003)

Progress Review – Island Breaching
- Inlet Creation
- Idealized Domain
- Isabel Inlet

Summary and Future Work



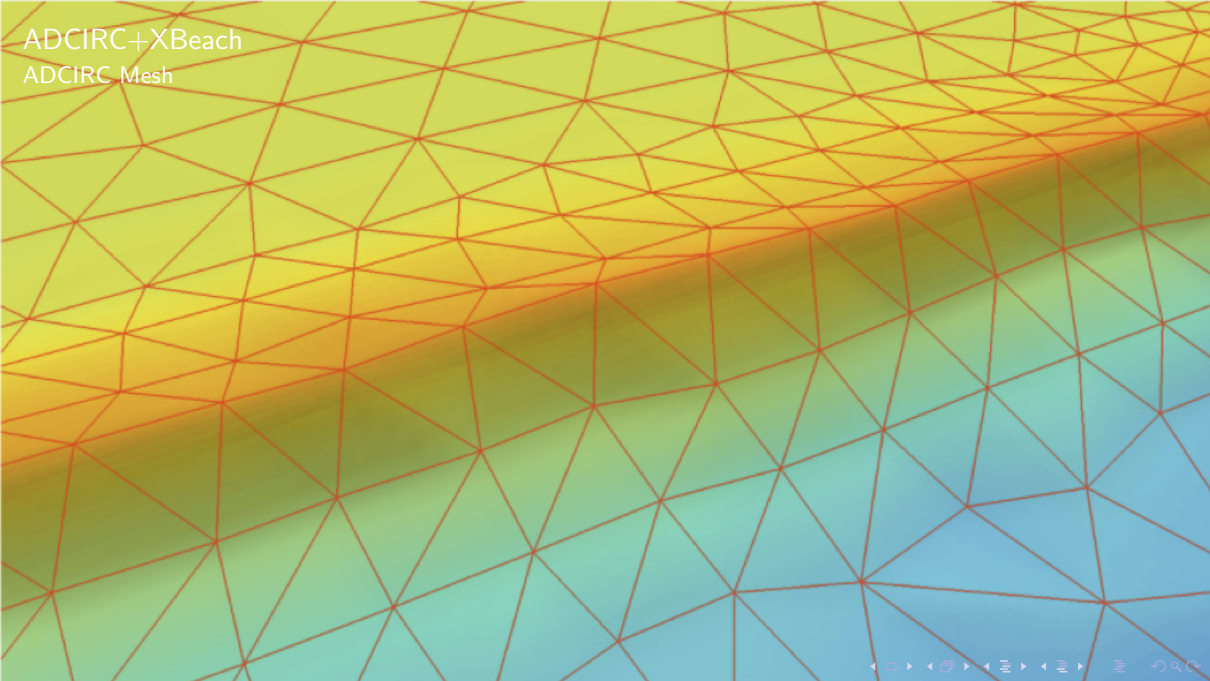


ADCIRC+XBeach

Aerial Photo of Hatteras Island

ADCIRC+XBeach

ADCIRC Mesh



Our forecast system is limited:

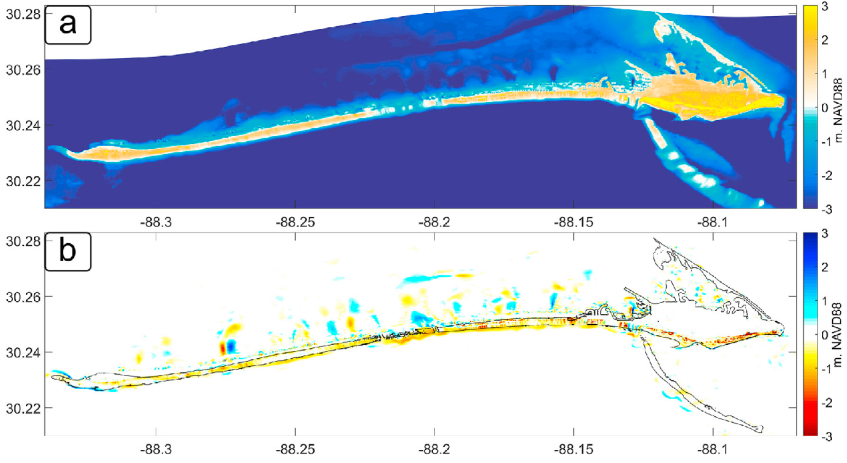
- Bathymetry and topography are fixed / constant
- No consideration of beach erosion, dune breaching, etc.
- Flooding impacts are limited behind the dunes

We are coupling with XBeach (eXtreme Beach):

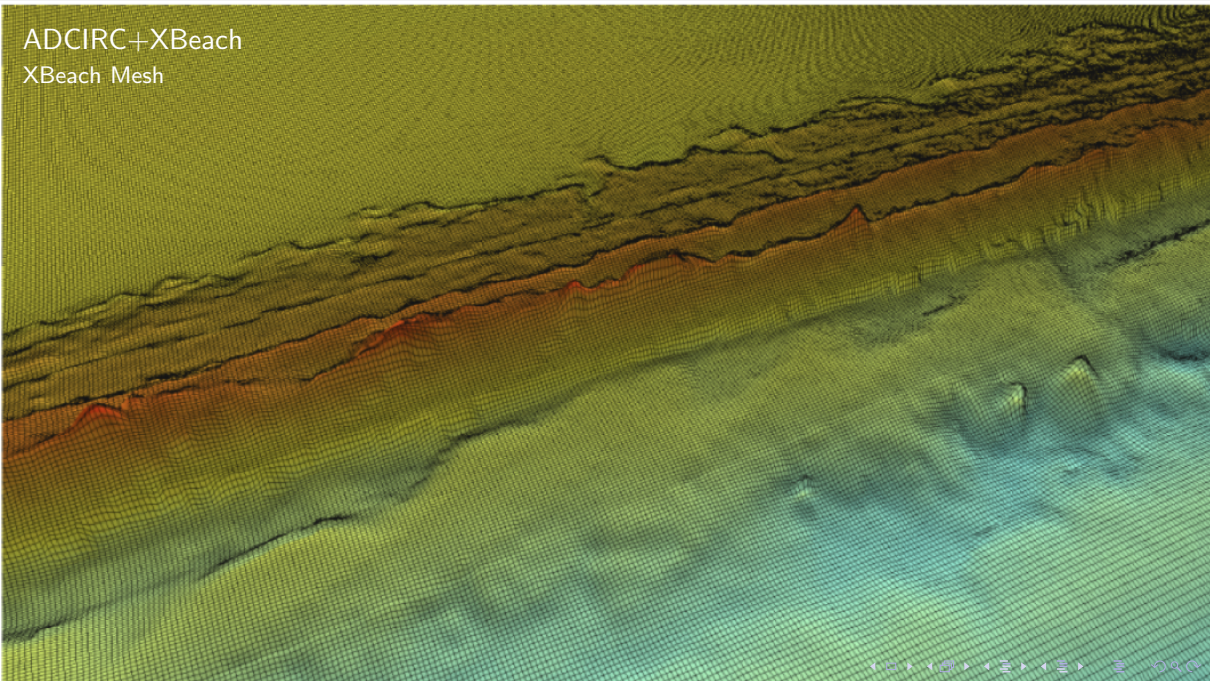
- Open-source model developed in the Netherlands
- Capable of simulating hydrodynamic and morphodynamic processes
- Applied typically at beach scales (a few kilometers)

ADCIRC+XBeach

eXtreme Beach (XBeach)



Passeri et al. (2018)


ADCIRC+XBeach
XBeach Mesh

Mechanics of Coupling:

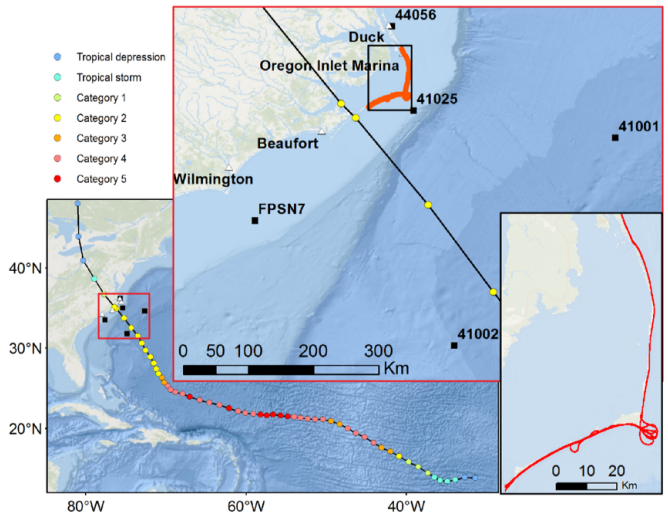
- Predict storm-driven erosion over large domains
- Develop techniques for coarsening predictions and coupling back to flooding models

Goals:

1. Validate XBeach erosion predictions on larger domains
   - Quantify model performance on 30-km of Hatteras Island during Isabel
2. Loose coupling of XBeach and ADCIRC
   - What are implications as a hydraulic control to stop or allow flooding?
   - How will ADCIRC predictions change with updated topography?

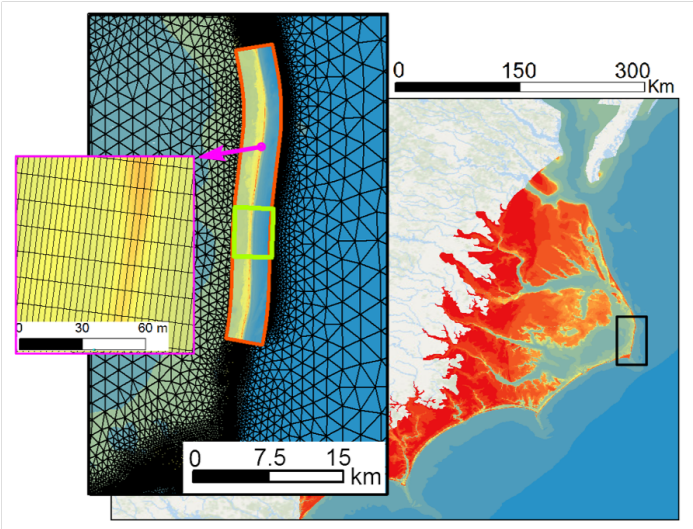
Example for Isabel (2003)

Inlet- and Region-Scales



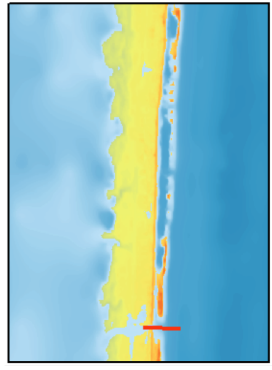
Example for Isabel (2003)

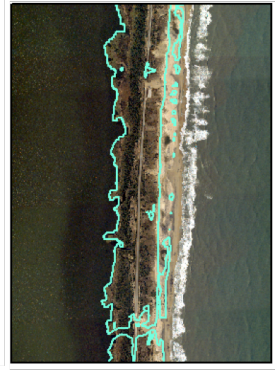
Structured and Unstructured Meshes

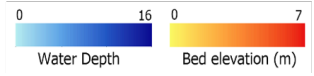


Example for Isabel (2003)

Comparison of XBeach Overwash Extents

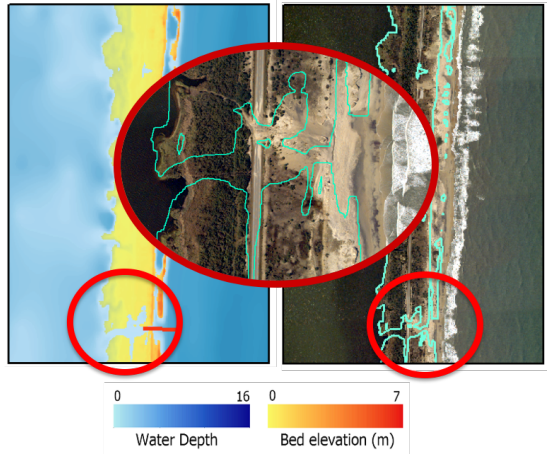






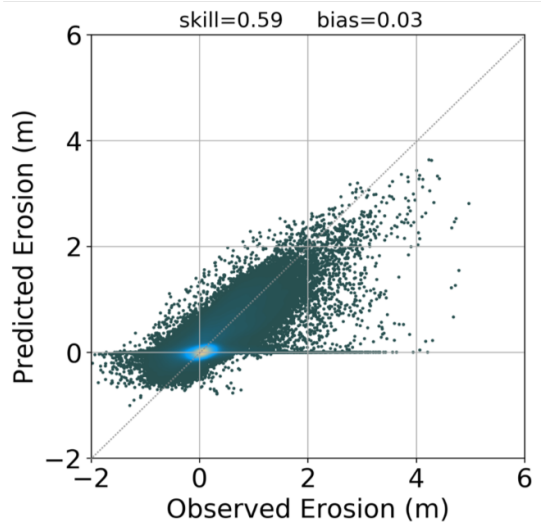
Example for Isabel (2003)

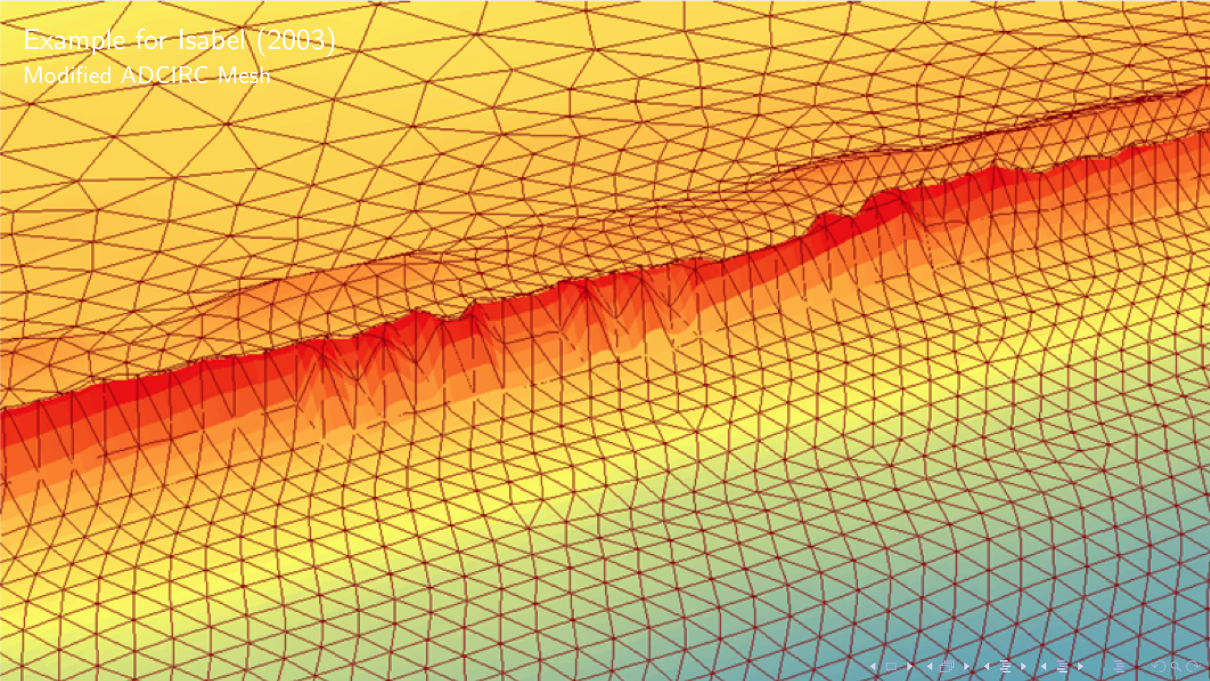
Comparison of XBeach Overwash Extents



Example for Isabel (2003)

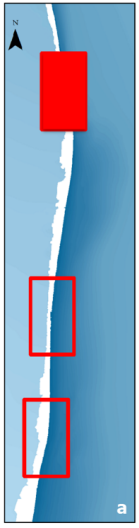
'Excellent' Skill Score




Example for Isabel (2003)
Modified ADCIRC Mesh

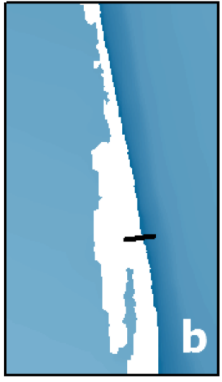
Example for Isabel (2003)

Static Updates to ADCIRC Topography

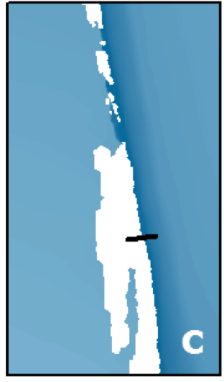


ADCIRC Simulations with Static Topography from ...

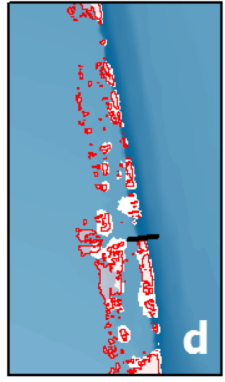
Observed Pre-Storm



Observed Post-Storm



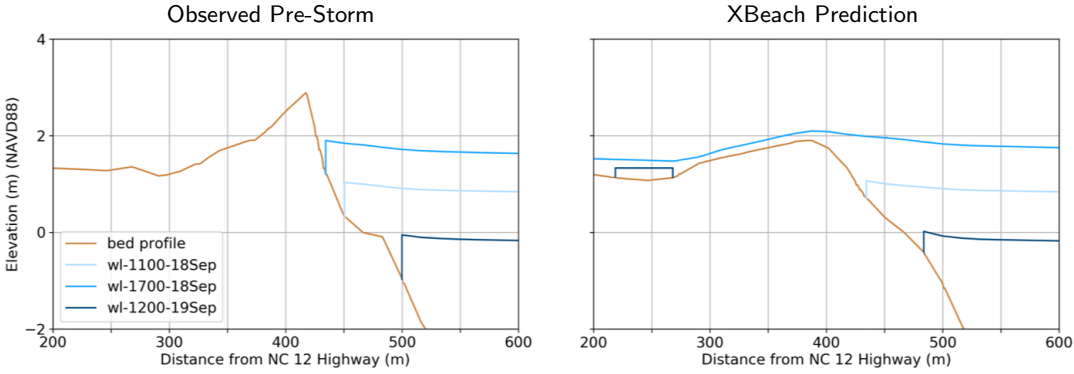
XBeach Prediction



Example for Isabel (2003)

Comparison of ADCIRC Flooding

ADCIRC Simulations with Static Topography from ...



Example from Isabel (2003)

Summary

1. XBeach performance:
   - Model performance on 30 km domain is very encouraging
   - Beach profile, Erosion events, flooding extents match post-storm observation
2. XBeach mesh resolution:
   - Skill score is not sensitive to alongshore mesh spacing
   - Skill score gets worse as the cross-shore mesh resolution increases
3. ADCIRC-updated topo/bathy:
   - Beach and dune erosion contribute to flooding predictions
   - Results match the prediction in XBeach and post-storm observation

Prior Work – Beach and Dune Erosion
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Progress Review – Island Breaching
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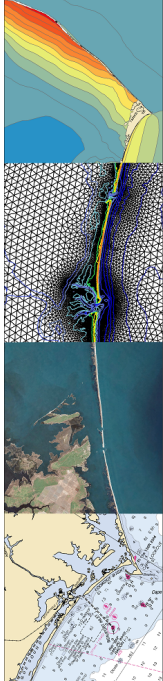
- Idealized Domain
- Isabel Inlet

Summary and Future Work



Inlet Creation

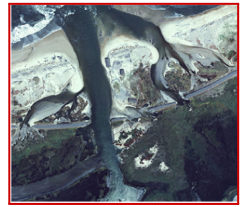
Isabel Inlet (2003)

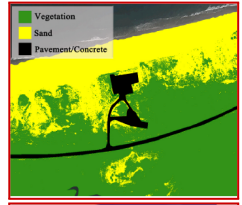
Previous studies on breach modeling:

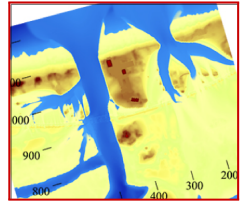
(1) Kraus (2003), De-Vet (2014), Elsayed et al. (2017)
   - Breaching, erosion, channel formation
   - Physics-based model improvement
   - Small domain models

(2) Kurum and Overton (2013)
   - Land cover effects on breaching
   - Multiple sediment layers
   - Different sediment properties (median size and erodability)

Summary:
- Many studies on behavior of inlets *after* their formation
- Limited studies about creation of inlets





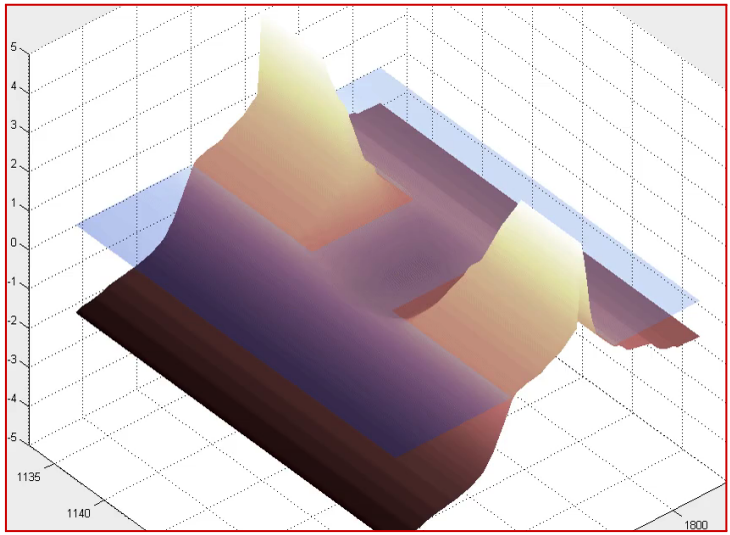


We used a combination of XBeach and ADCIRC modeling:

- **Idealized Domain** – Uniform geometry, smooth hydrodynamic forcing
  - XBeach:
    - Can we initiate the inlet formation?
    - Can we control the location of the inlet?
- **Isabel Inlet** – Real geometry, real hydrodynamic and atmospheric forcing
  - XBeach:
    - How much of a 'seed' is necessary?
    - Instead of calibration factors, can we use bed friction?
  - ADCIRC:
    - Can we use the erosion timing from XBeach to inform the variation of the bathymetry in ADCIRC?

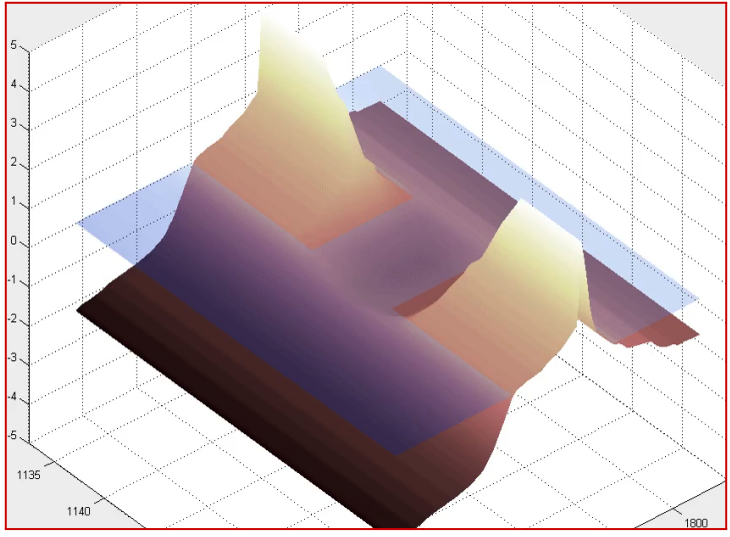
Idealized Domain

Barrier Island with Notch In Dune



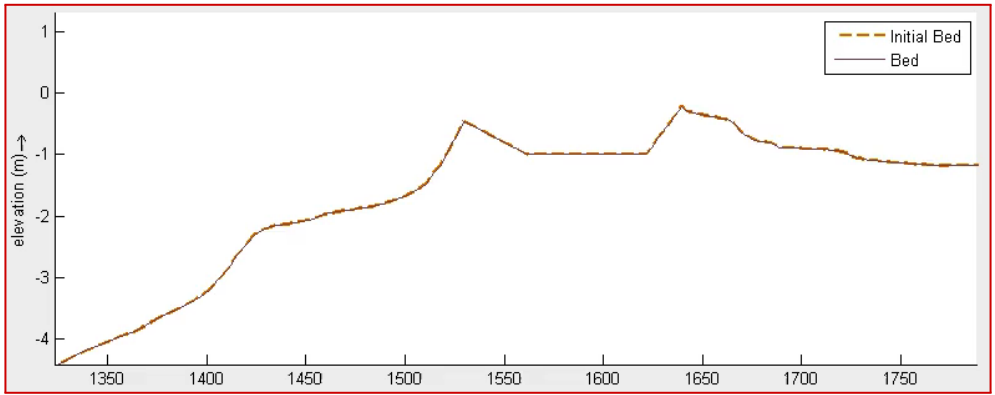
Idealized Domain

Barrier Island with Notch In Dune



We are unable to erode a full channel:

- Even with the initial cut to -1 m (below sea level), the channel doesn't get any deeper
- Animation of ground surface at centerline of channel:



Idealized Domain

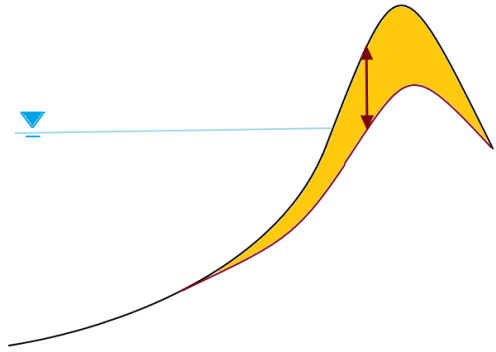
Use of Non-Erodible Layer

So we added a non-erodible layer:

- Specified as a second ground surface as input to XBeach
- Erosion is computed until the ground surface is lowered to the non-erodible layer
- Then erosion is stopped

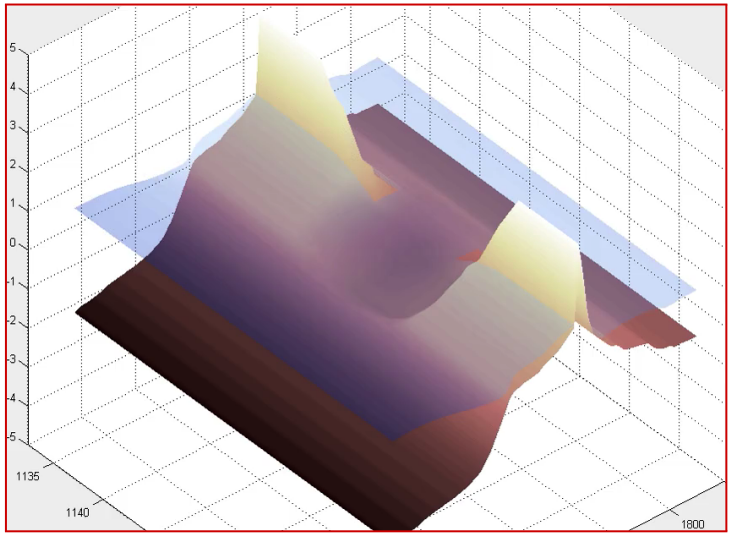
Used first on the idealized domain:

- Allowed erosion in the channel
- Prevent erosion in the beaches and dunes



Idealized Domain

Inlet is Created ... with an Initial Cut



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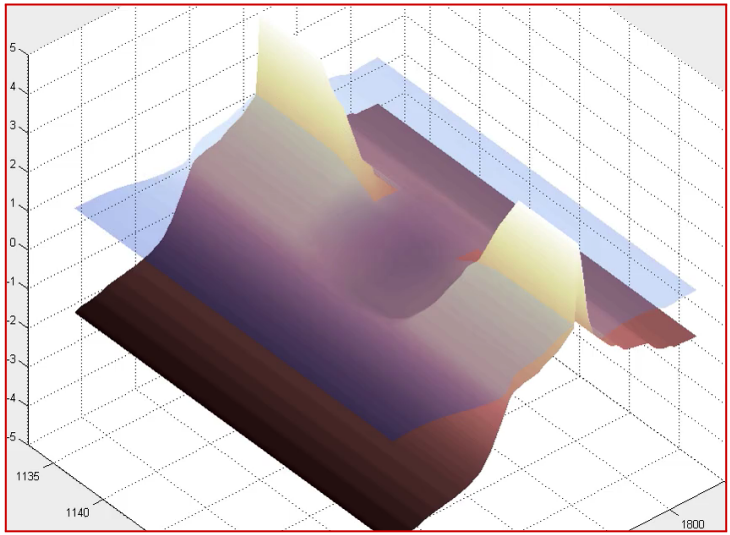
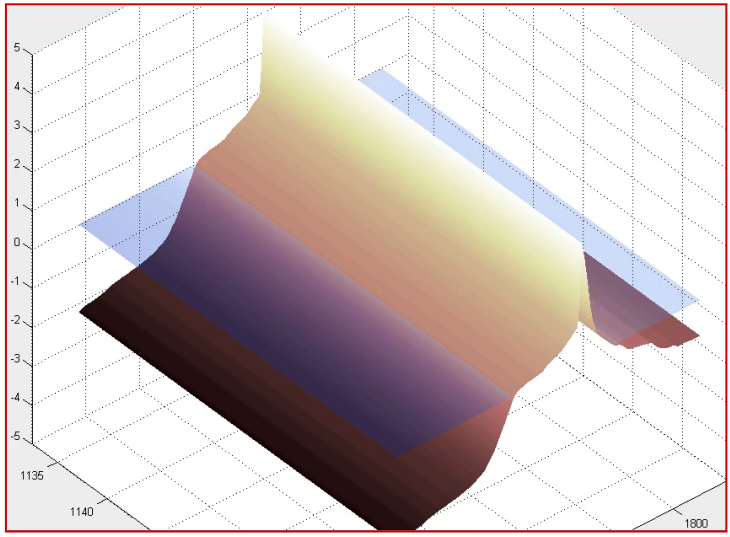


Idealized Domain

Inlet is Created ... without an Initial Cut



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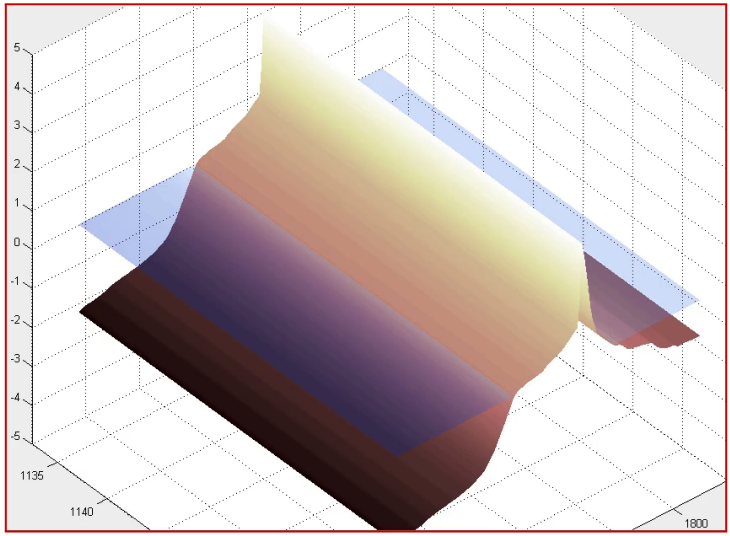
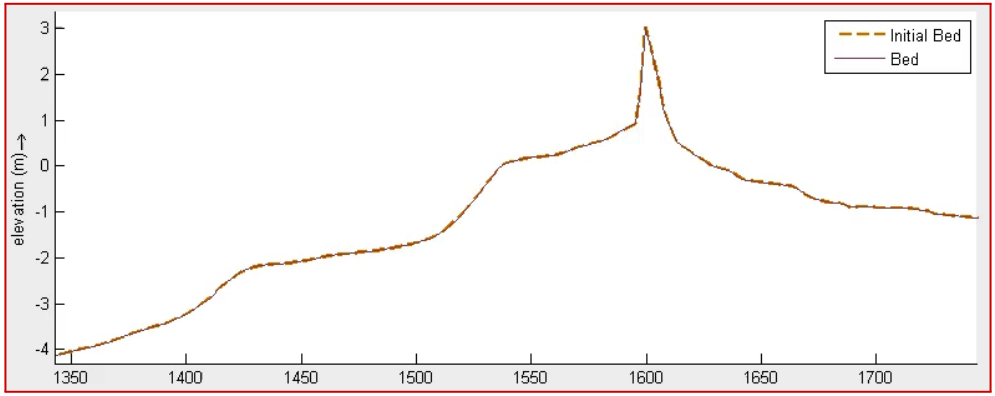
Inlet is Created ... without an Initial Cut



Now we can erode a full channel:

- Without any initial seed, the full beach and dune are removed
- Animation of ground surface at centerline of channel:



Challenges in controlling location and magnitude of breach:

- With default settings, XBeach prefers to remove entire beach/dune system
- Even with an initial cut and channel through the dune

We can work around this with a non-erodible layer:

- Controls exactly where erosion is allowed
- User can specify location and magnitude
- XBeach determines the timing of the inlet creation

This raises questions about how to forecast?

- Still ... we push forward to the Isabel Inlet


Isabel Inlet
Pre-Storm Ground Surface
6 m
0 m

Isabel Inlet

Post-Storm Ground Surface

Isabel Inlet

XBeach Grid

Domain Size:

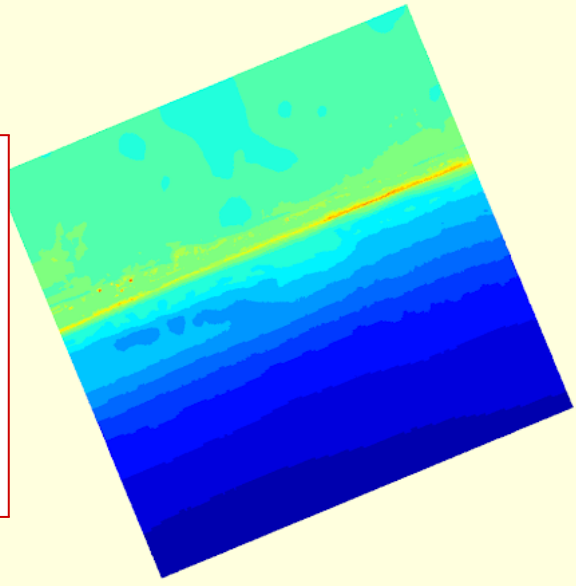
- 2.2 km $\times$ 2.2 km

Resolution:

- Alongshore: 2 to 5 m
- Cross-shore: 2 to 15 m

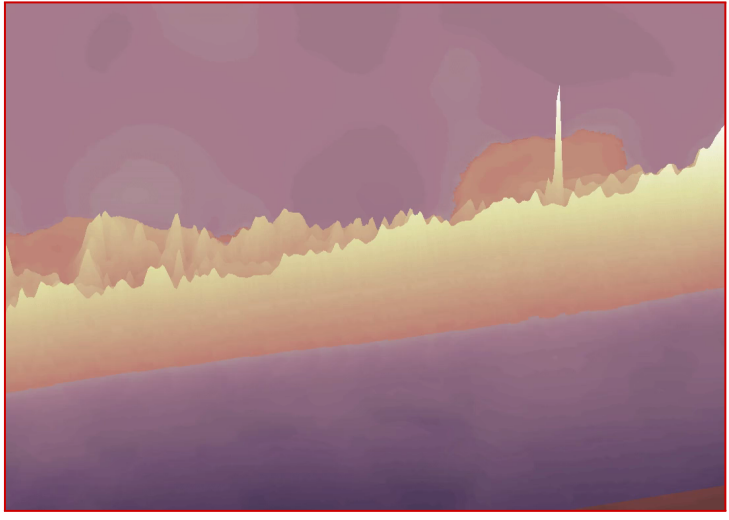
Layers:

- Pre-storm: bathy/topo
- Post-storm: non-erodible



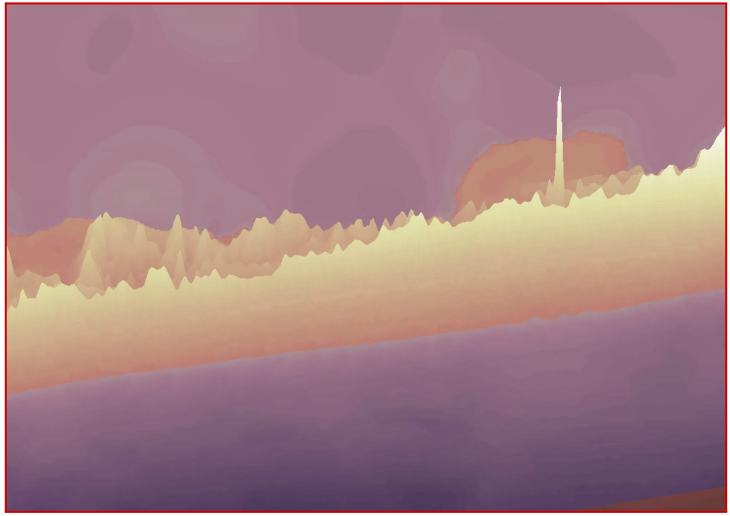
Isabel Inlet

XBeach Hindcast of Inlet Creation



Isabel Inlet

XBeach Hindcast of Inlet Creation

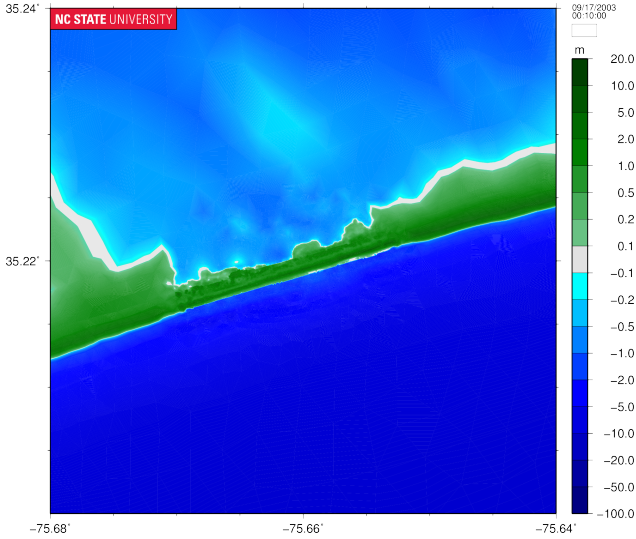


Remaining questions:

- Is it possible for XBeach to predict this inlet creation, without the erodible layer?
  - Exploring ways to slow the erosion by adjusting the maximum Shields parameter
  - Exploring ways to control location via variable bed friction
- How to connect to ADCIRC?
  - Can we use the erosion predictions to inform the flooding predictions?

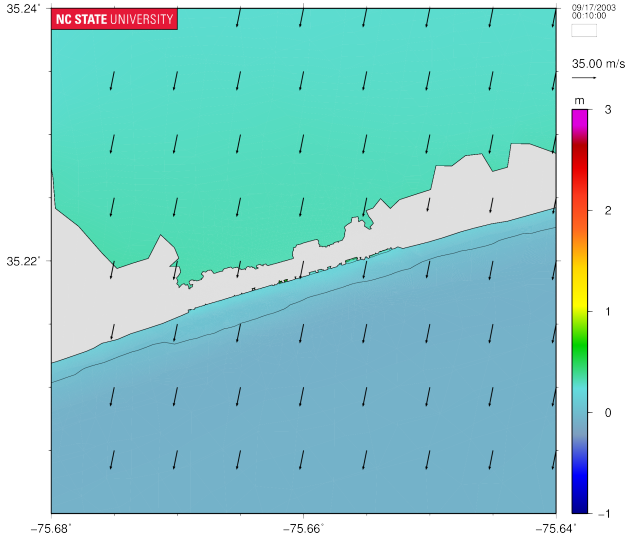
Isabel Inlet

Existing Capability with Static Ground Surface



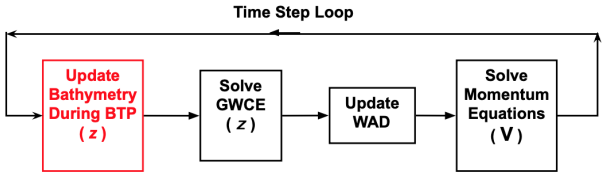
Isabel Inlet

Existing Capability with Static Ground Surface

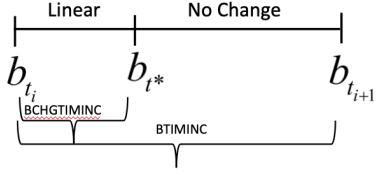


Dr. Chris Massey added capability for time-varying bathymetry:

- Occurs at start of time step:



- Control over timing during simulation:



We created ADCIRC input files with the erosion

- Changes in ground surface, specified at only the vertices near the breach

Location and magnitude of erosion is coming from the post-storm survey

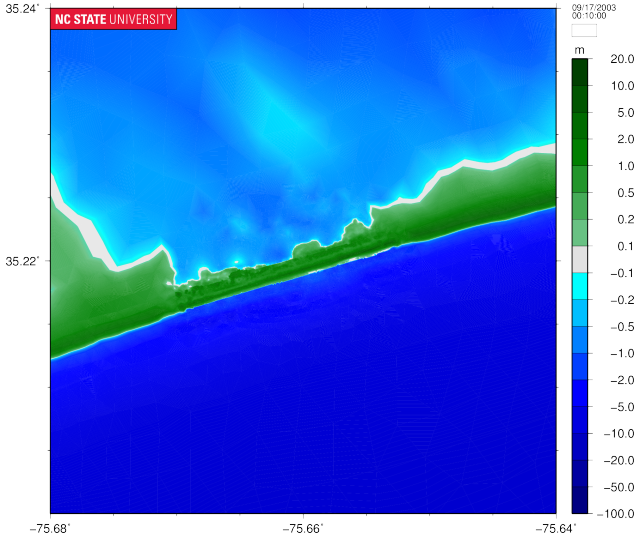
- Similar to the non-erodible layer in XBeach
- Need more work with XBeach to gain predictions of inlet creation

Timing of erosion is coming from XBeach

- Controlling the erosion over 1 day, during the landfall of the storm
- Incremental variations:
  - Changes over 1 hour
  - Static over 2 hours
- Repeat over 1 day

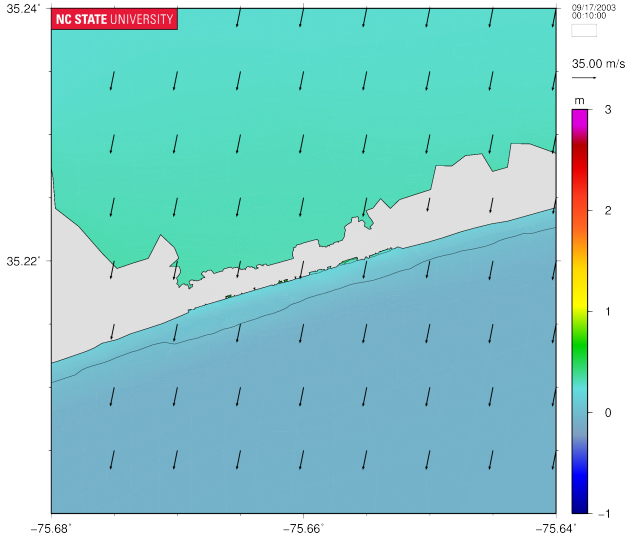
Isabel Inlet

Erosion over 1 Day



Isabel Inlet

Erosion over 1 Day



Summary

Implemented work-arounds by using the post-storm surveys:

- Non-erodible layer in XBeach
- Time-varying bathymetry in ADCIRC

Loose coupling between XBeach and ADCIRC

- Predicted timing of erosion is connected to varying ground surface in ADCIRC
- Significant flow over and through Hatteras Island

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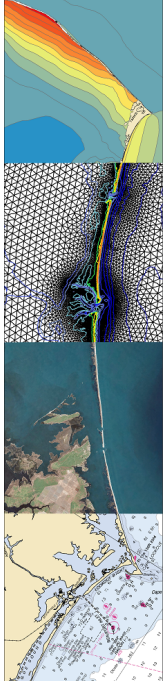

Summary and Future Work

Coupling of Inlet-Scale Erosion and Region-Scale Flooding Predictions

Objectives:

1. High-resolution hindcast of inlet creation in a barrier island system
   - XBeach, using non-erodible layer
   - ADCIRC, using time-varying bathymetry
2. Explore the sensitivity of erosion predictions to the quality of input data
   - Erosion is sensitive to grid resolution, presence of 'seed' cut in dune, sediment settings (Shields parameter, bed friction)
   - Still unable to initiate a deep channel in a desired location
   - Need a non-erodible layer
3. Two-way coupling of small-scale erosion to larger-scale flooding
   - Waves and water levels to XBeach, erosion timing to ADCIRC
   - Significant flows over and through the Isabel Inlet