NC STATE UNIVERSITY

# Using a Multi-Resolution Approach to Improve the Accuracy and Efficiency of Flooding Predictions


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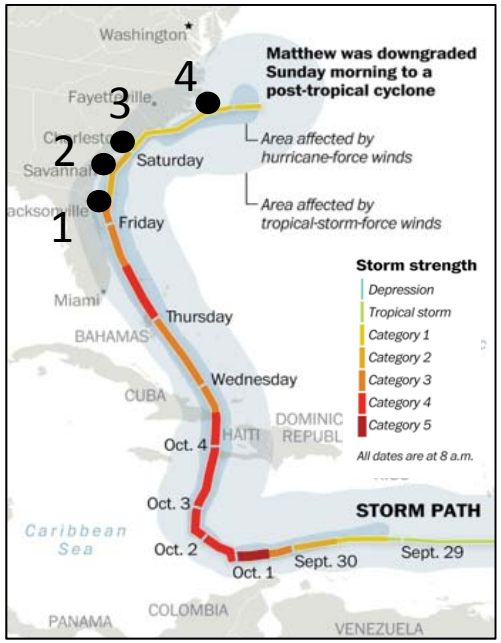
COASTAL RESILIENCE CENTER

*A U.S. Department of Homeland Security Center of Excellence*

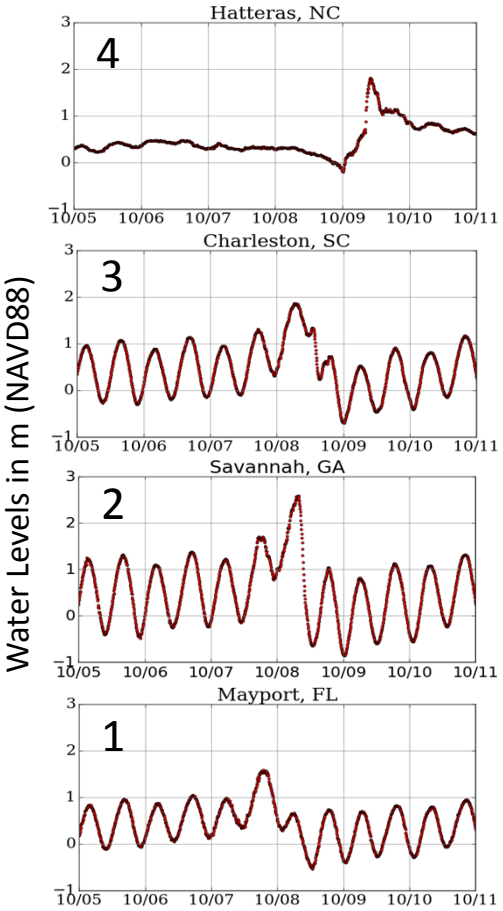
# Hurricane Matthew

## Introduction

- Category-5 storm
- Impacted the south-east coast of the U.S. during October 2016
- Shore-parallel storm
- Large variations in water levels lasting several days



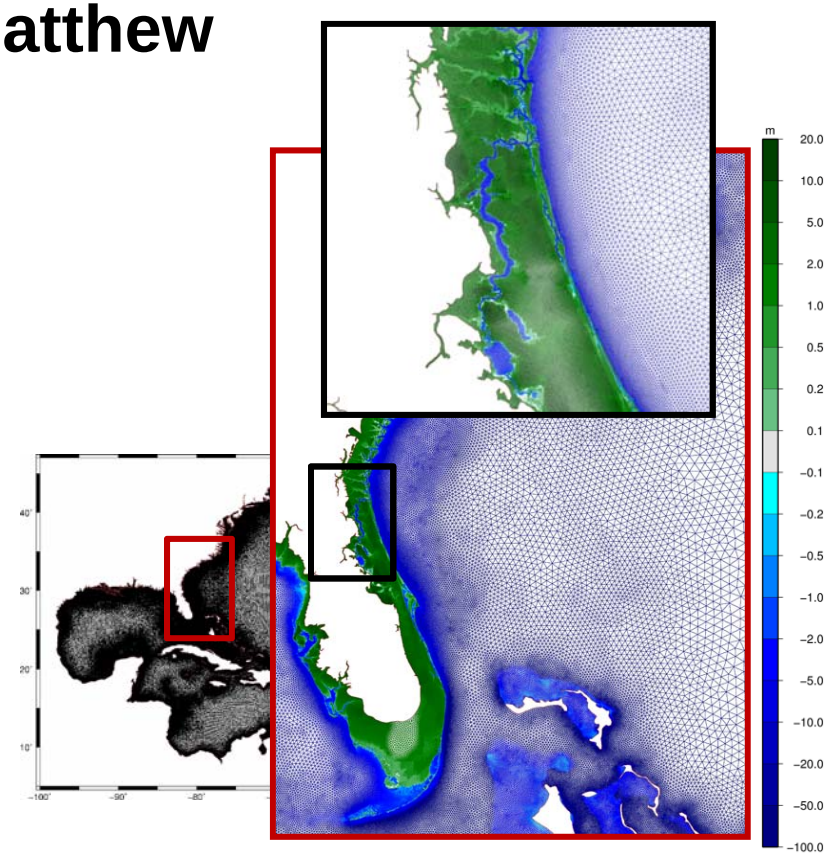

Source: NOAA



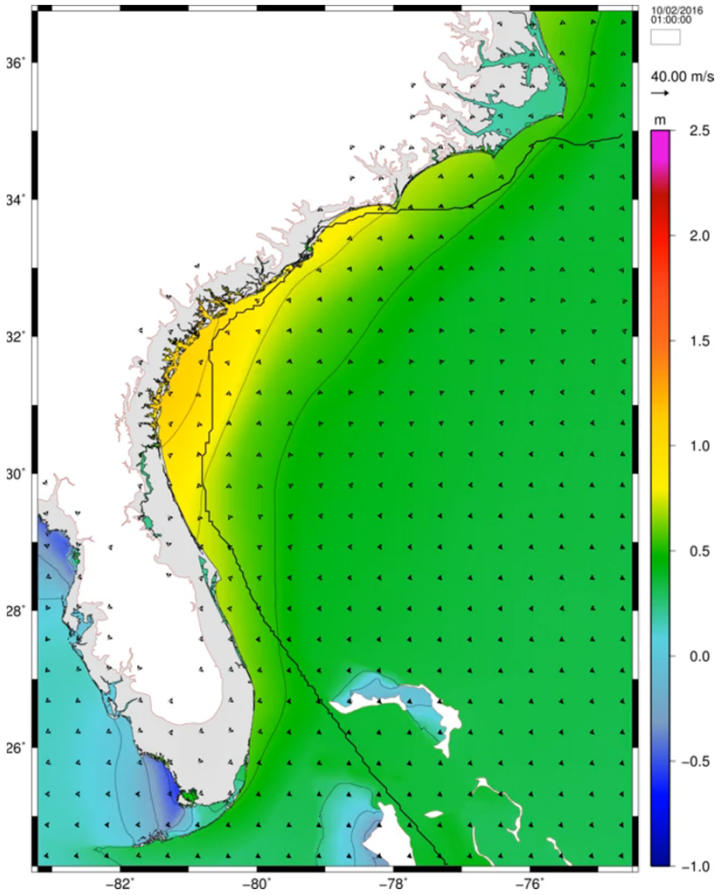
# Hurricane Matthew

## Methods

- ADCIRC + SWAN
- OWI Winds
  - Data-assimilated fields
- Offset surface
  - Spatially varying but temporarily constant
- HSOFS Mesh
  - 500m average coastal resolution



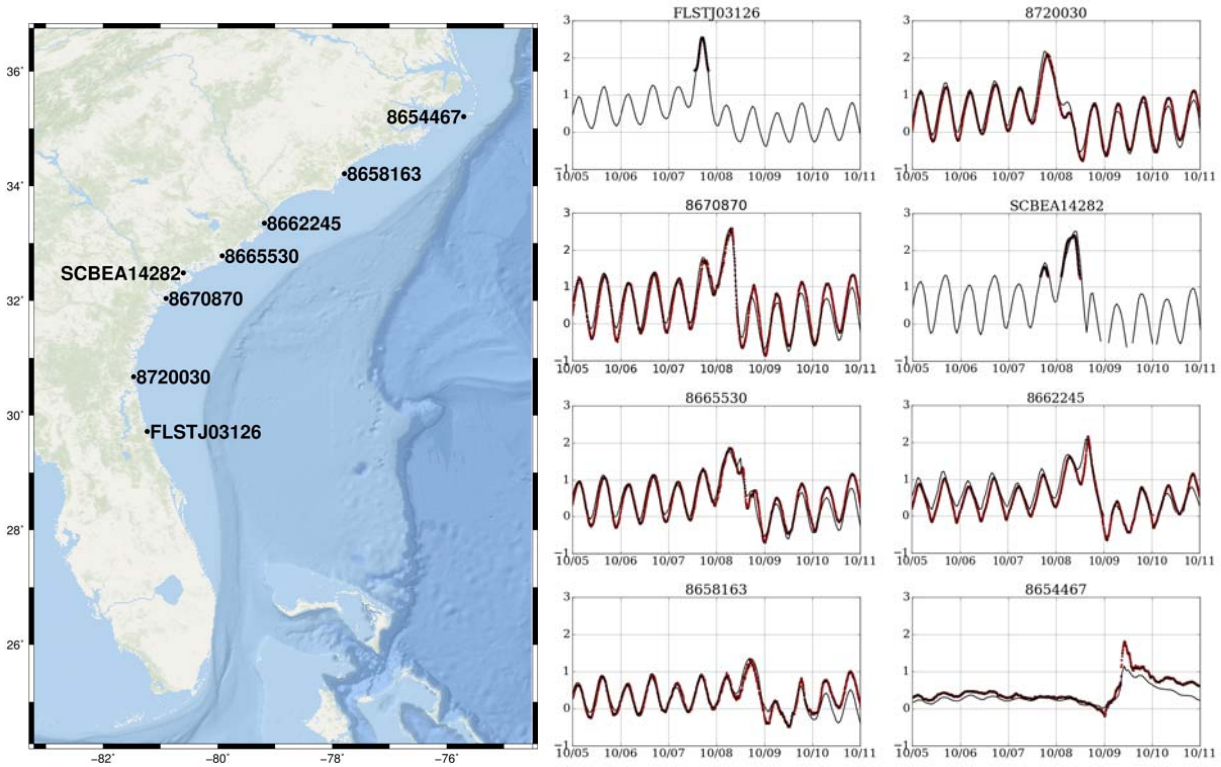
# Results




Water Levels

# Hurricane Matthew

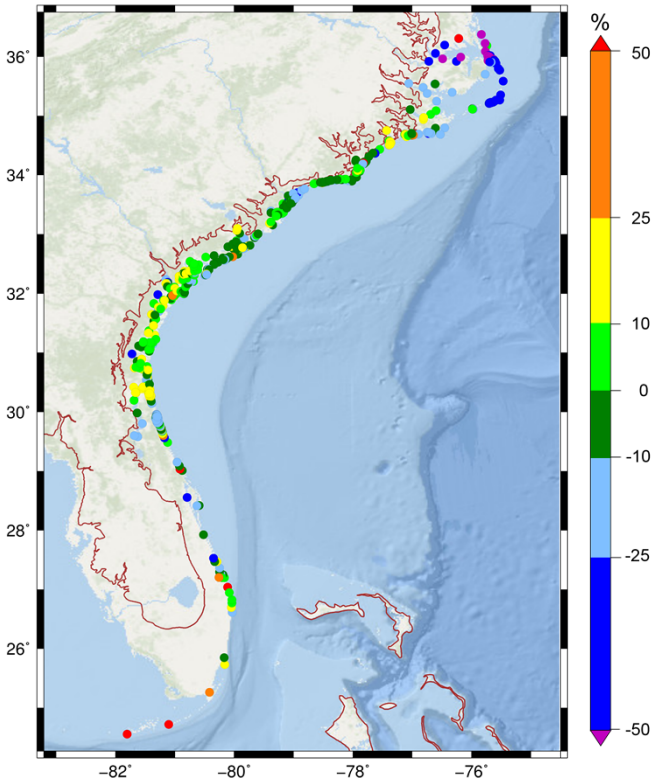
Results

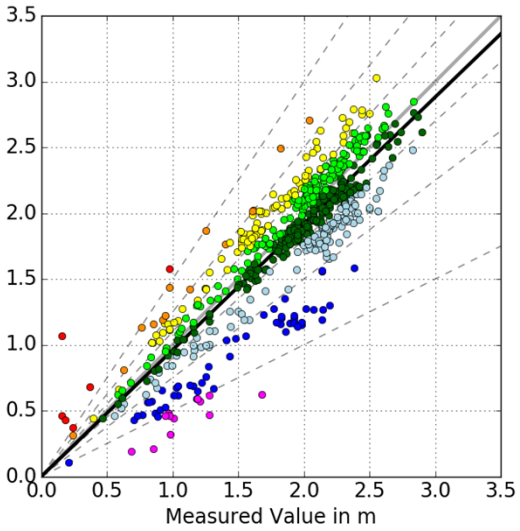



241 stations
RMSE = 0.28m
Bias = 0.04

# Hurricane Matthew

Results




622 peaks
$R^2$ = 0.78
RMSE = 0.28m
Bias = -0.03
Best fit slope = 0.96

# Hurricane Matthew

## Conclusion

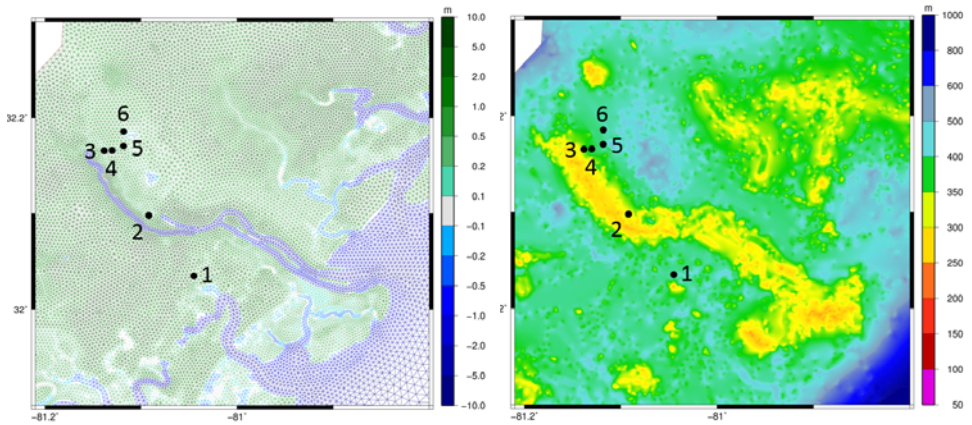
- Matthew's effects are well represented by the model even when applied on the relatively-coarse HSOFS mesh

A Thomas, *et al*. (2019). "Influence of Storm Timing and Forward Speed on Tide-Surge Interactions during Hurricane Matthew." *Ocean Modelling*, 137, 1-19, DOI:10.1016/j.ocemod.2019.03.004.

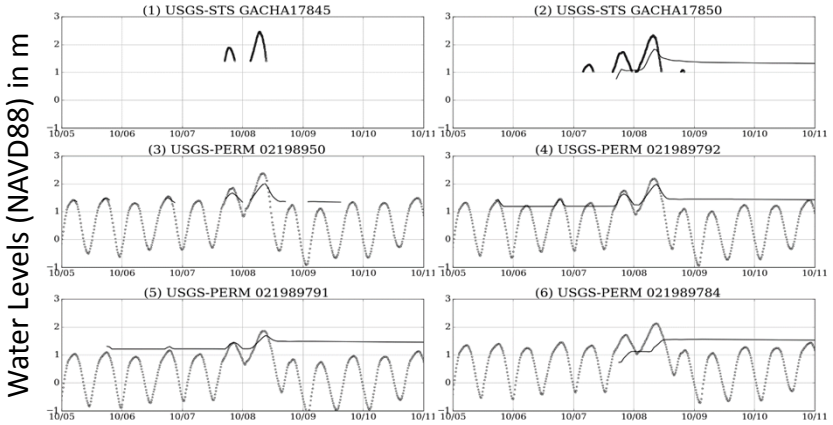
# The Multi-Resolution Approach

## Motivation

- Need for Higher Resolution
  1. Experience from hindcasts of Hurricane Matthew



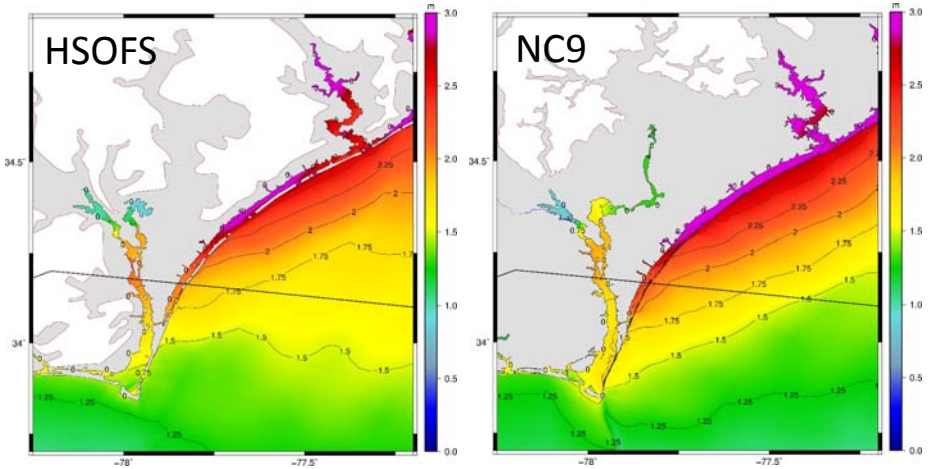

Topo-Bathy Resolution



# The Multi-Resolution Approach

## Motivation

- Need for Higher Resolution
  2. Forecasting during Hurricane Florence (2018)
     - HSOFS mesh was used when the storm was far away (up till Advisory 41)
     - As the storm approached NC coast, NC9 mesh was employed (starting from Advisory 42)




Maximum water levels corresponding to Advisory 58

# The Multi-Resolution Approach

## Motivation

- Need for Faster Forecasts
  1. Ensemble Possibilities
     - For each advisory, there is uncertainty in the storm parameters , which translates directly into uncertainty in the predicted surge
     - SLOSH computes Probabilistic Storm Surge (P-surge) in real-time
       - Includes uncertainty in track/landfall location, forward speed, intensity, and historical errors
       - Results are approximately 30 minutes after full advisory release time
     - ASGS runs only a few variations (eg. veer-left, veer-right)
     - Faster simulations will allow for more scenario-testing, which can help in reducing uncertainties in the forecast results (Leutbecher and Palmer, 2008)

# The Multi-Resolution Approach

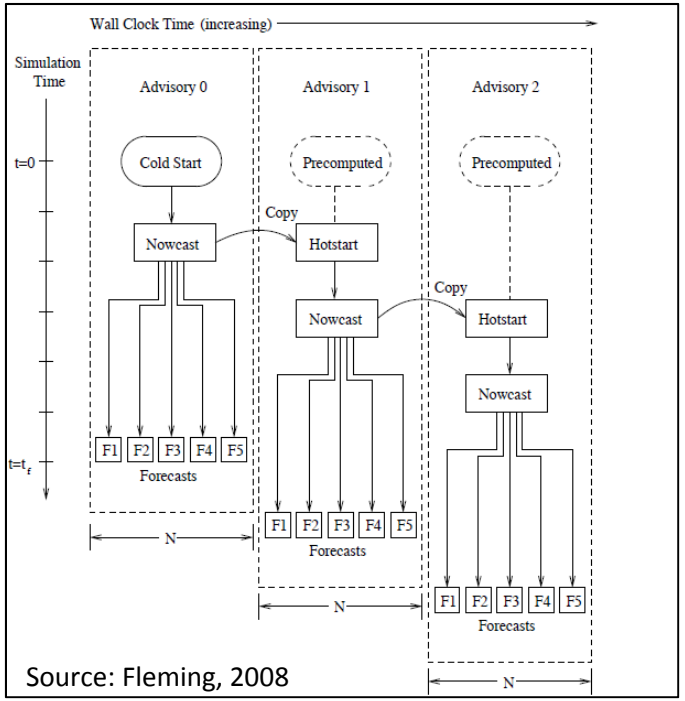
## Motivation

- Need for Faster Forecasts
  2. Hurricane Bill (2015)
     - Made landfall in southeast Texas
     - When the storm was in Gulf, high-res mesh (6.7 million elements) for Texas was used
     - Tidal spin-up on this mesh even on 1120 cores at TACC, took 18 hours
     - By this time, the storm had already moved inland

# The Multi-Resolution Approach

## Current Forecasting Technique

- Save the state of the simulation right at the nowcast point (end of the hindcast)
- Reload this saved state during the next advisory cycle
- The system thus always builds on previous results
- The hot-starts have to be always done on the same mesh
- This prevents use of high resolution meshes- without having to run tidal spin-up that take several hours of computational time




Source: Fleming, 2008

# The Multi-Resolution Approach

## Steps

- Use a relatively coarse resolution when the storm is far
- As the storm approaches the coastline, switch to a fine-resolution mesh **without doing a cold-start**
- Map results from coarse to the fine mesh and continue simulation on fine mesh

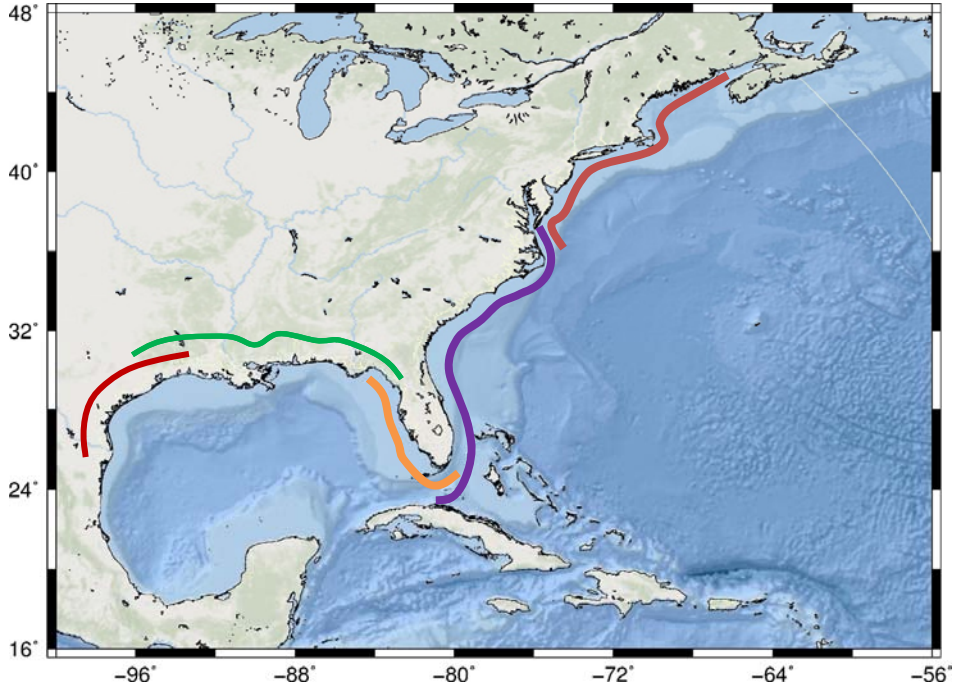
## Main Objectives

- Reduce the computational load by using a coarser resolution mesh when the storm track is uncertain
- Increase the accuracy of predictions by using a higher resolution mesh as the storm approaches landfall
- Increase the simulation possibilities including ensemble generation during operational forecasting

# The Multi-Resolution Approach

Long Term Goal

- Coarse Resolution Mesh
  - HSOFS (1.8 million vertices)
- Fine Resolution Meshes for the U.S. Gulf and Atlantic coasts
  - Each 3-4 million vertices
  1. Western Gulf
  2. Northern Gulf
  3. Eastern Gulf
  4. South and Central Atlantic
  5. Northern Atlantic



# The Multi-Resolution Approach

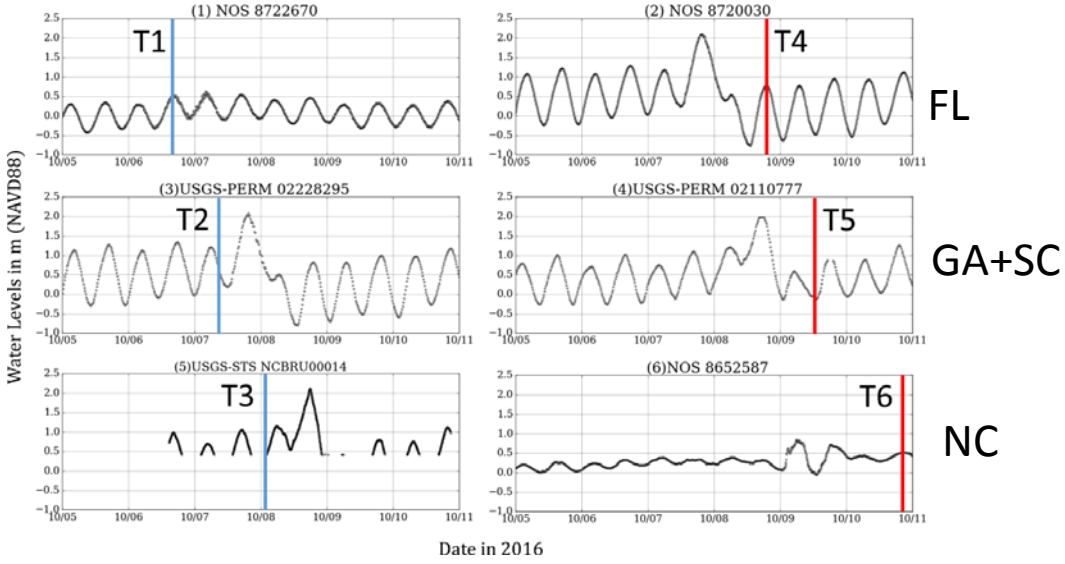
## Adcirpolate

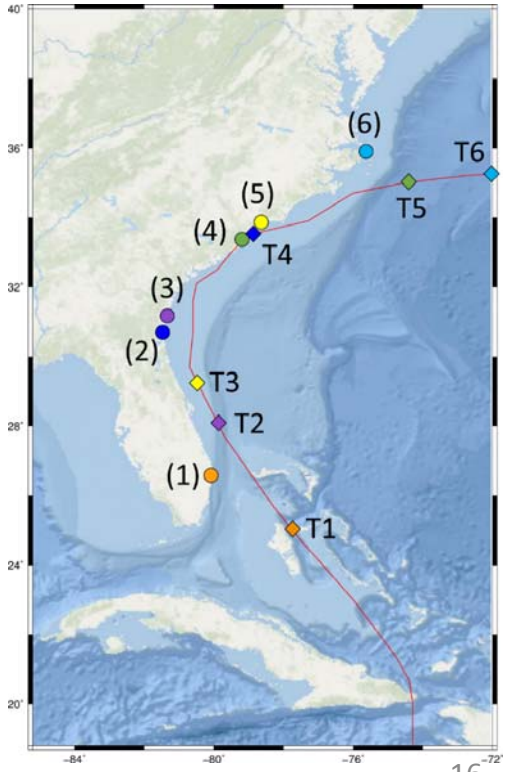
- A toolset for interpolating between meshes
- Developed by our collaborators at U.T. Austin
- Implemented via the Earth System Modeling Framework (ESMF)
  - Allows for parallel interpolation between unstructured meshes
- Interpolation is done bilinearly in region destination points
- Extrapolation is done for the remaining points with nearest source to destination
- Proper checks to take care of wetting/drying state of elements
- Convert the hot-start file from the coarse mesh simulation to a hot-start file for the fine mesh simulation

# The Multi-Resolution Approach

Application during Hurricane Matthew

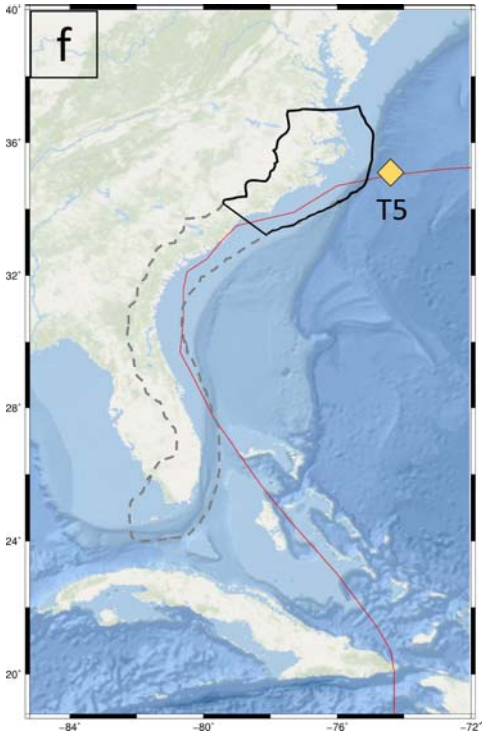
- Shore-parallel storm moved from south-to-north
- But it did not impact this entire region at the same time
- Dividing the coastline into 3 extents



# The Multi-Resolution Approach

Application during Hurricane Matthew



# The Multi-Resolution Approach

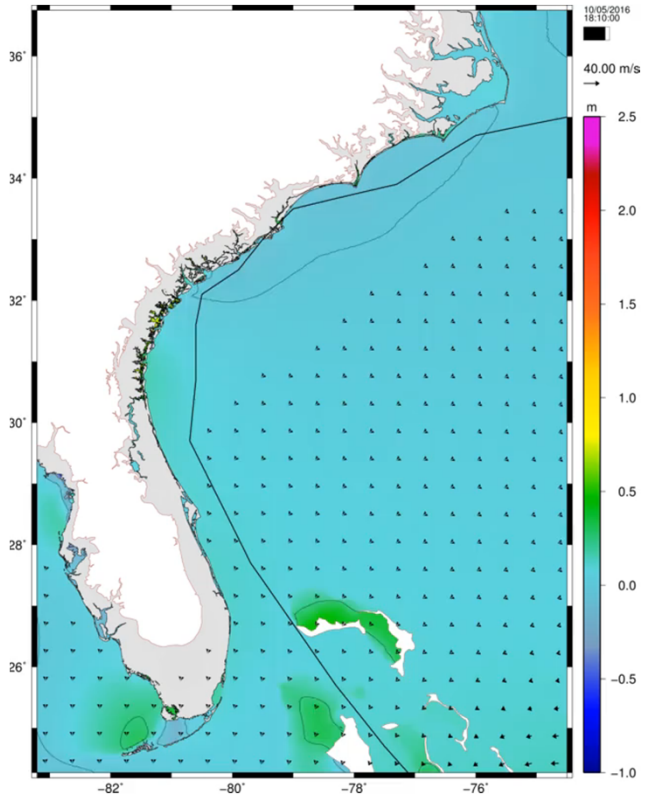
Application during Hurricane Matthew

| Mesh | No. of Nodes | Days of Simulation |
|---|---|---|
| HSOFS | 1,813,443 | 4.5 |
| HSOFS_FL | 804,964 | 0.75 |
| HSOFS_FL+GA+SC | 942,427 | 0.75 |
| HSOFS_FL+GA+SC+NC | 1,057,880 | 0.75 |
| HSOFS_GA+SC+NC | 886,565 | 0.75 |
| HSOFS_NC | 784,911 | 1.5 |

# The Multi-Resolution Approach

Application during Hurricane Matthew

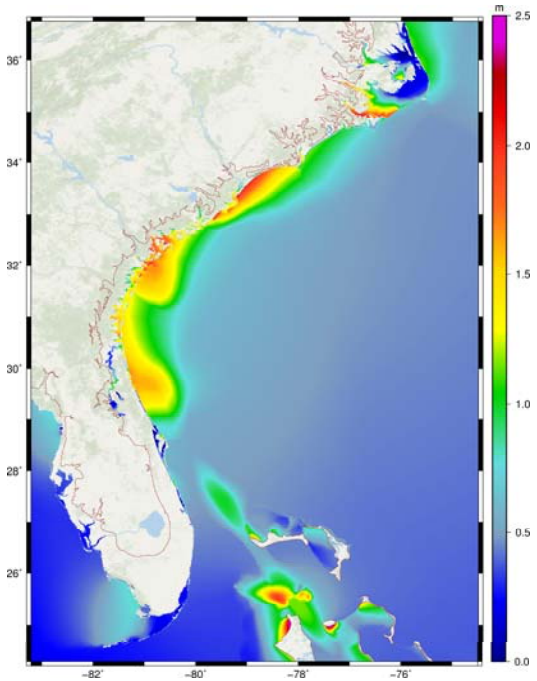
- Video



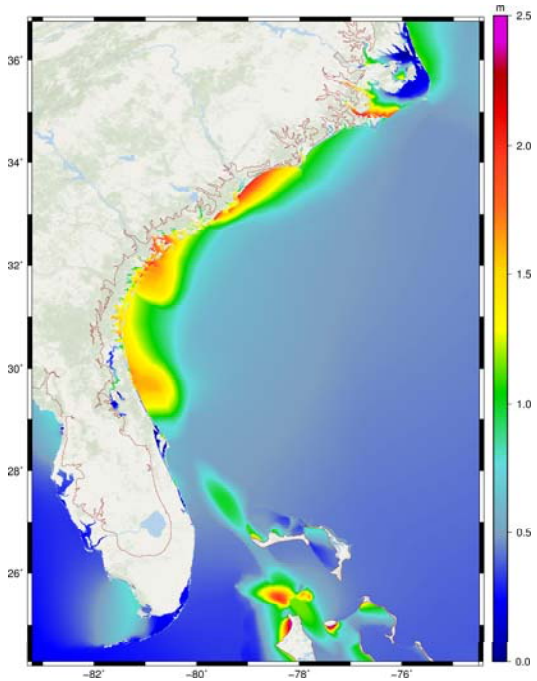
# The Multi-Resolution Approach

Application during Hurricane Matthew

- Maxele




Using the approach

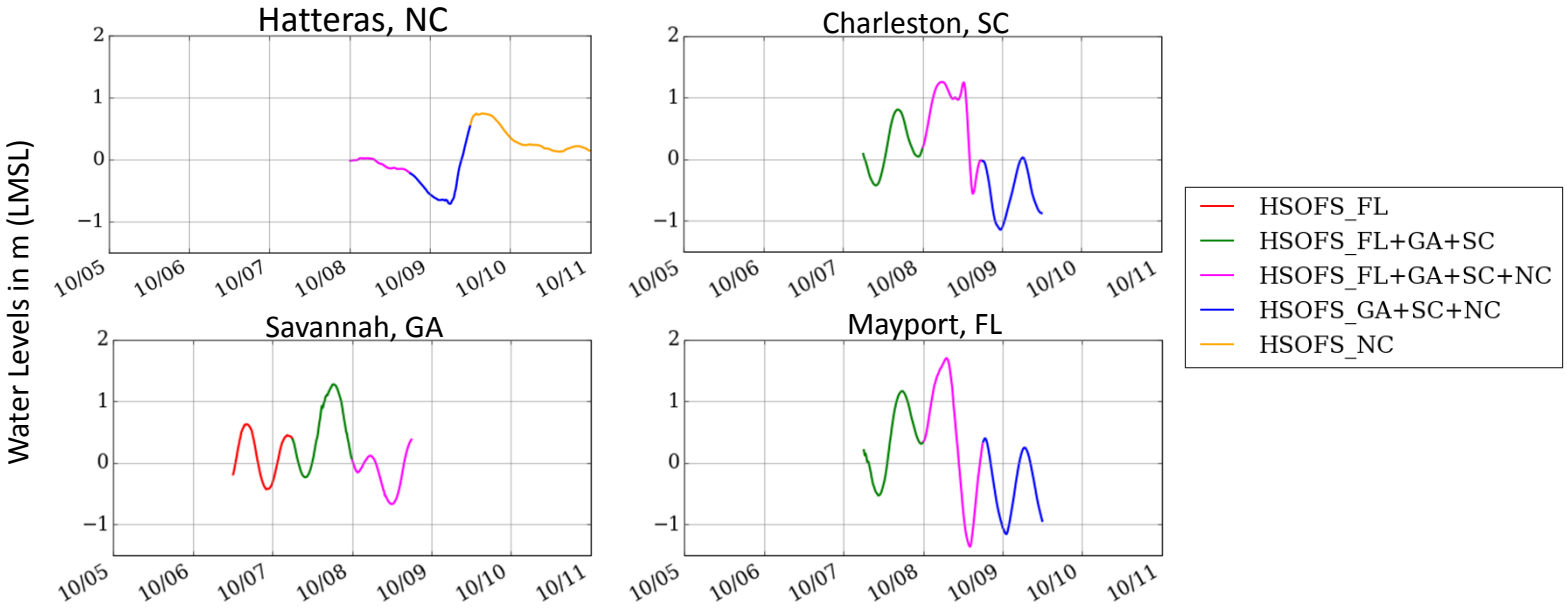



HSOFS for full 9 days

# The Multi-Resolution Approach

## Application during Hurricane Matthew

- Time Series of Water Levels



# The Multi-Resolution Approach

## Application during Hurricane Matthew

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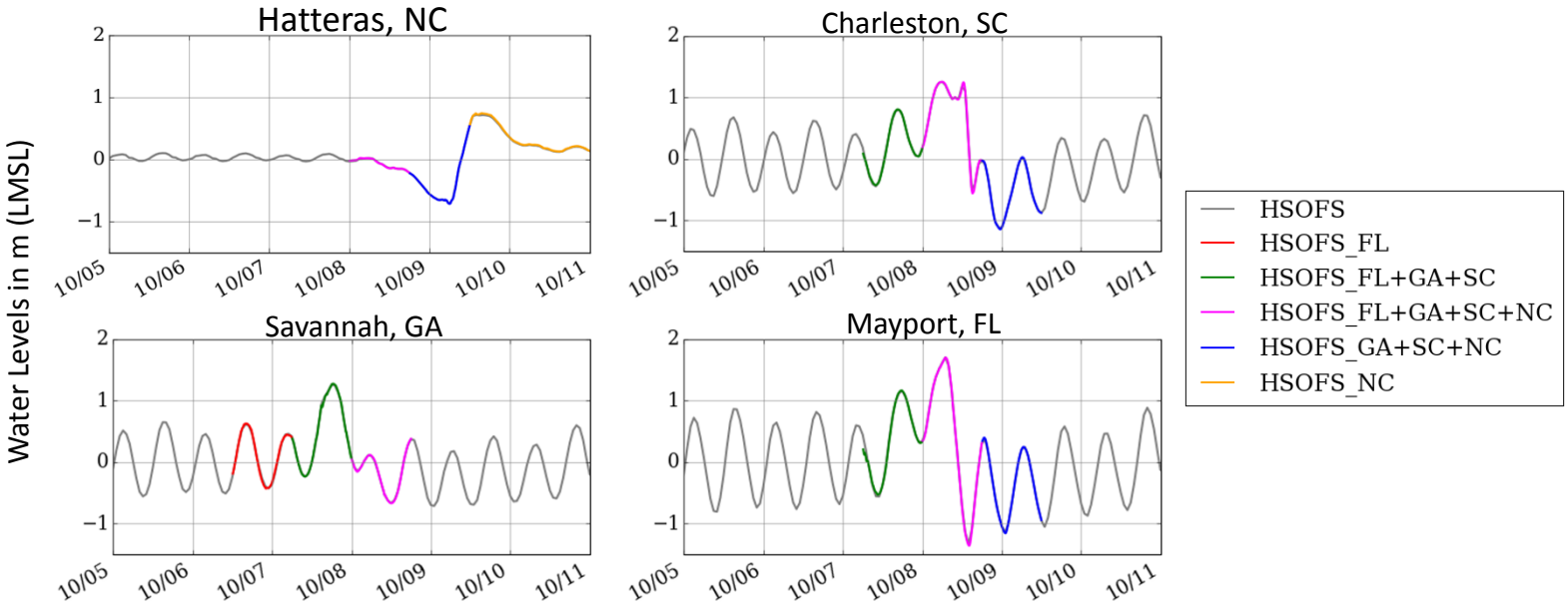

# The Multi-Resolution Approach

## Application during Hurricane Matthew

- Timing Comparison

| Mesh | No. of Nodes | Days | Run Time on 532 Cores (min) |
|---|---|---|---|
| HSOFS | 1,813,443 | 4.5 | 34 |
| HSOFS_FL | 804,964 | 0.75 | 3 [2] |
| HSOFS_FL+GA+SC | 942,427 | 0.75 | 3 [2] |
| HSOFS_FL+GA+SC+NC | 1,057,880 | 0.75 | 4 [3] |
| HSOFS_GA+SC+NC | 886,565 | 0.75 | 3 [2] |
| HSOFS_NC | 784,911 | 1.5 | 6 [2] |

Total = 64 mins

HSOFS for the entire storm = 67 mins

# The Multi-Resolution Approach

## Application during Hurricane Matthew

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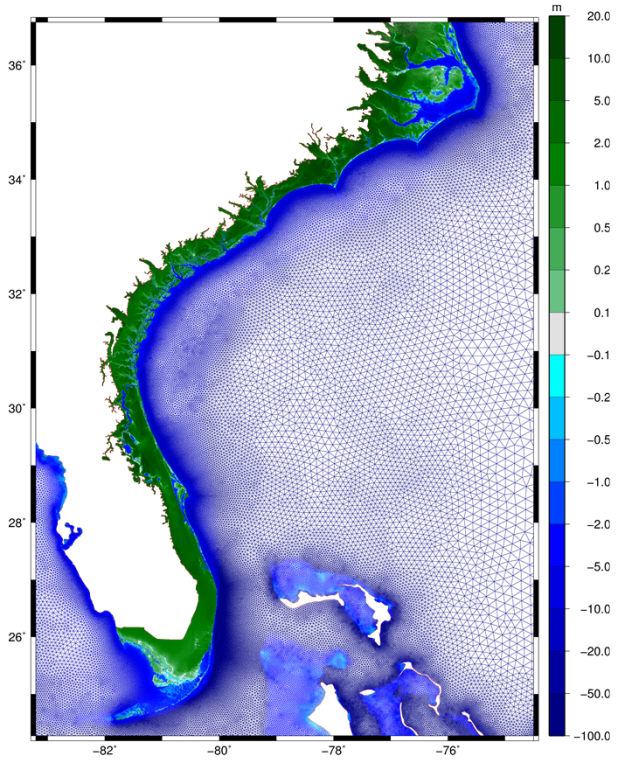
# The Multi-Resolution Approach

Creating a High Resolution Mesh (FL to NC)

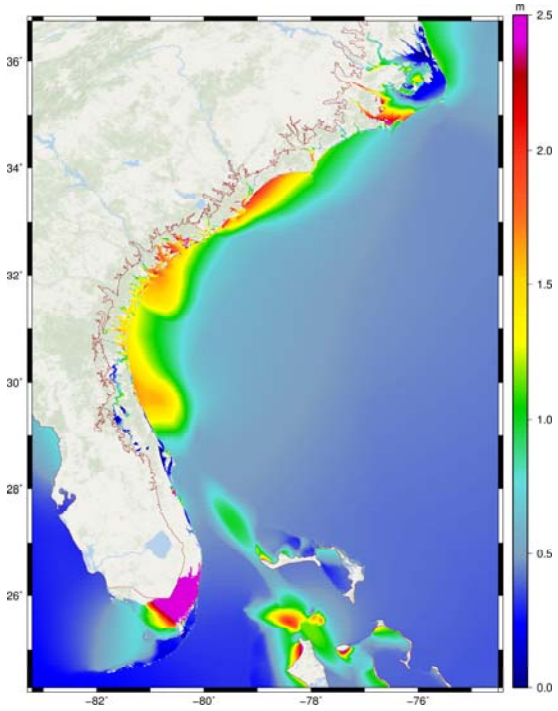
- By combining FEMA meshes
  - South FL
    - 2,249,093 nodes
  - North-east FL and GA
    - 2,968,735 nodes
  - East-central FL
    - 1,406,543 nodes
  - South Carolina
    - 542,809 nodes
  - North Carolina
    - 624,782 nodes
- HSOFS used in open-water regions




Total 5,641,135 nodes

# The Multi-Resolution Approach

Creating a High Resolution Mesh (FL to NC)




Maxele

# Thank You