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

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Outline

Part I

- Validate winds, waves and water levels during Matthew on a mesh with floodplains coverage over a large extent

Part 2

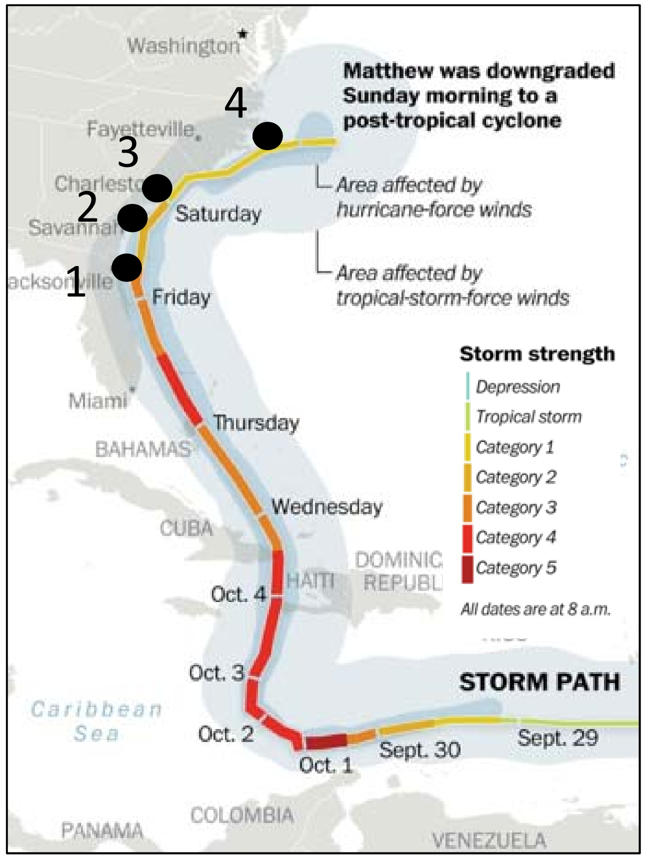
- Multi-resolution approach to improve the accuracy and efficiency of flooding predictions

Part I

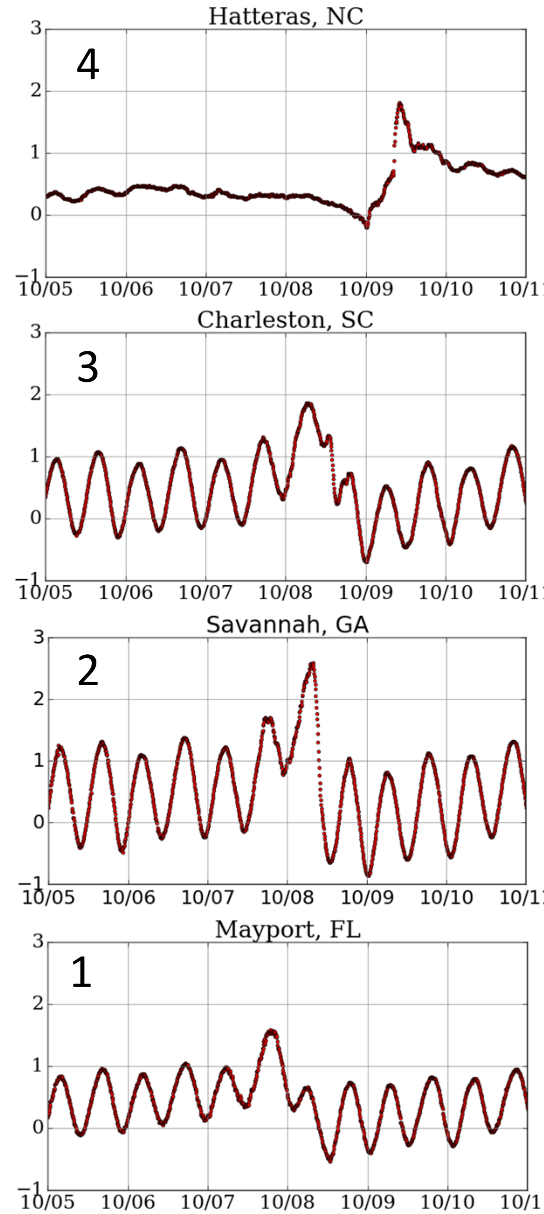
Introduction

Matthew

- 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



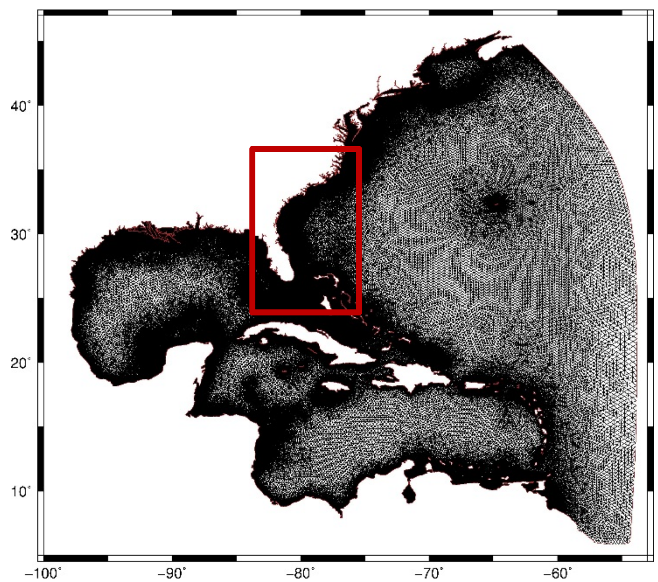
Water Levels in m (NAVD88)

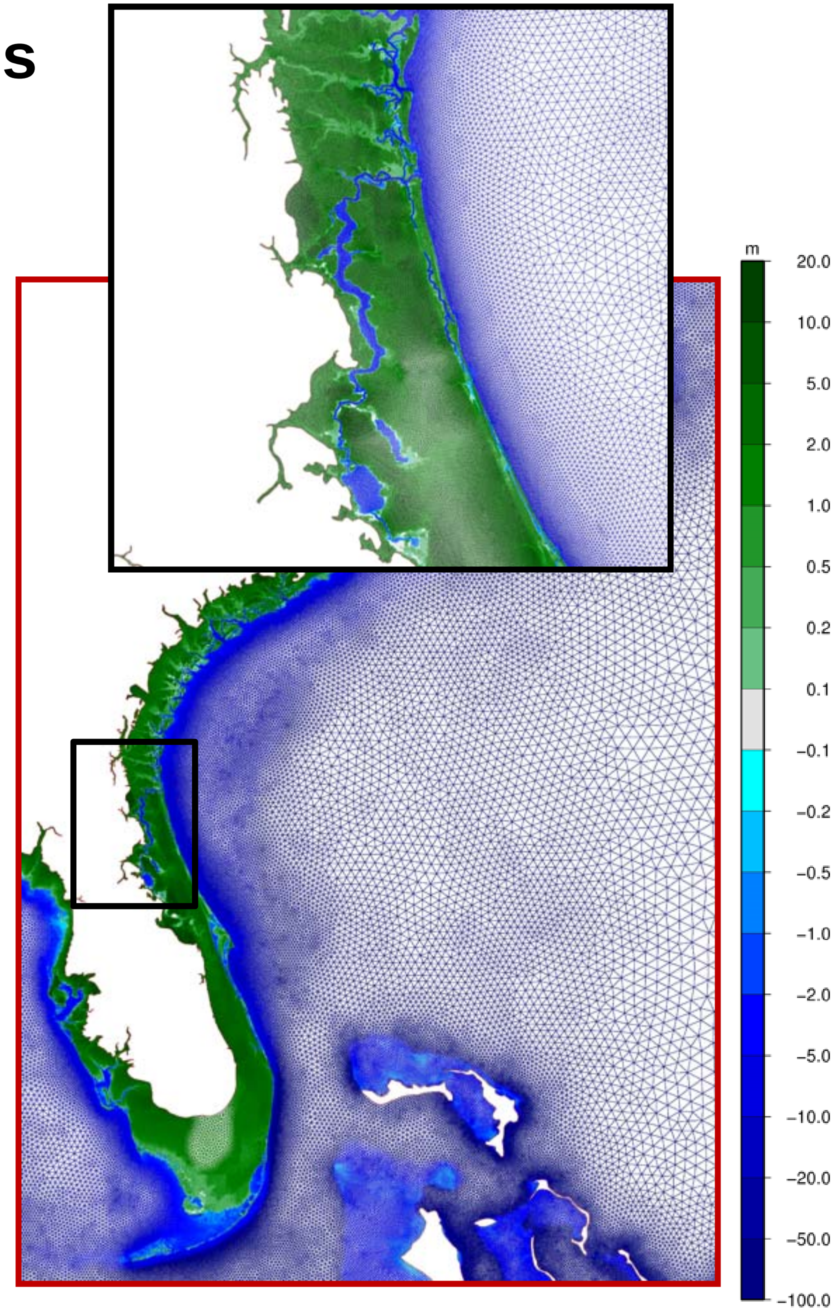
Methods

- Coupled ADCIRC + SWAN model
- ADCIRC
  - Solves the generalized wave continuity equation (GWCE) for water levels (ζ)
  - Solves the depth-averaged momentum equations for currents (U,V)
  - Geographic space is represented using Piecewise-linear, continuous, Galerkin finite elements
- SWAN
  - Solves the action balance equation

Methods

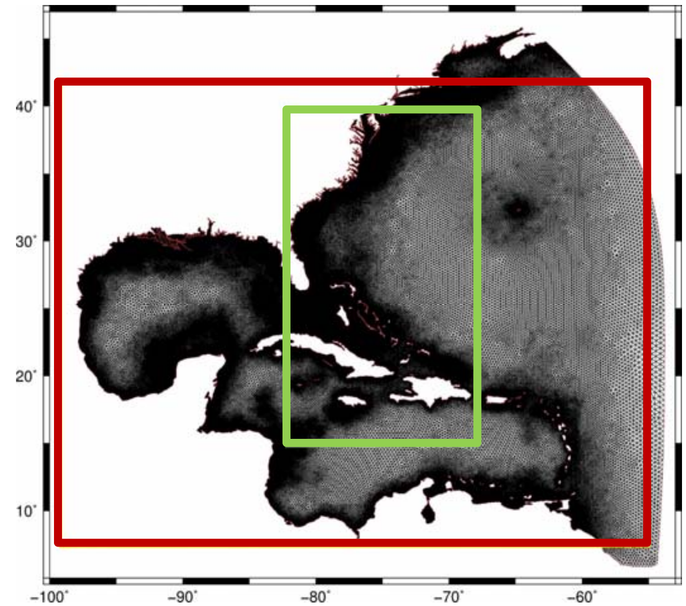
- The HSOFS unstructured mesh
  - Riverside, AECOM & NOAA - 2015
  - 500m average coastal resolution
  - 1.8 million vertices





Methods

- Winds from OWI
  - Data-assimilated fields
  - Basin grid at resolution of 1/4°
  - Region grid at resolution of 1/20°



Parameter	Error	GAHM	WF	OWI
Surface Pressure	Stations	282	283	283
	RMSE (hPa)	6.72	4.23	**2.14**
	Bias	-0.16	-0.02	**0.06**
Wind Speed	Stations	66	61	66
	RMSE (m/s)	5.60	2.98	**2.29**
	Bias	-0.29	0.16	**0.06**

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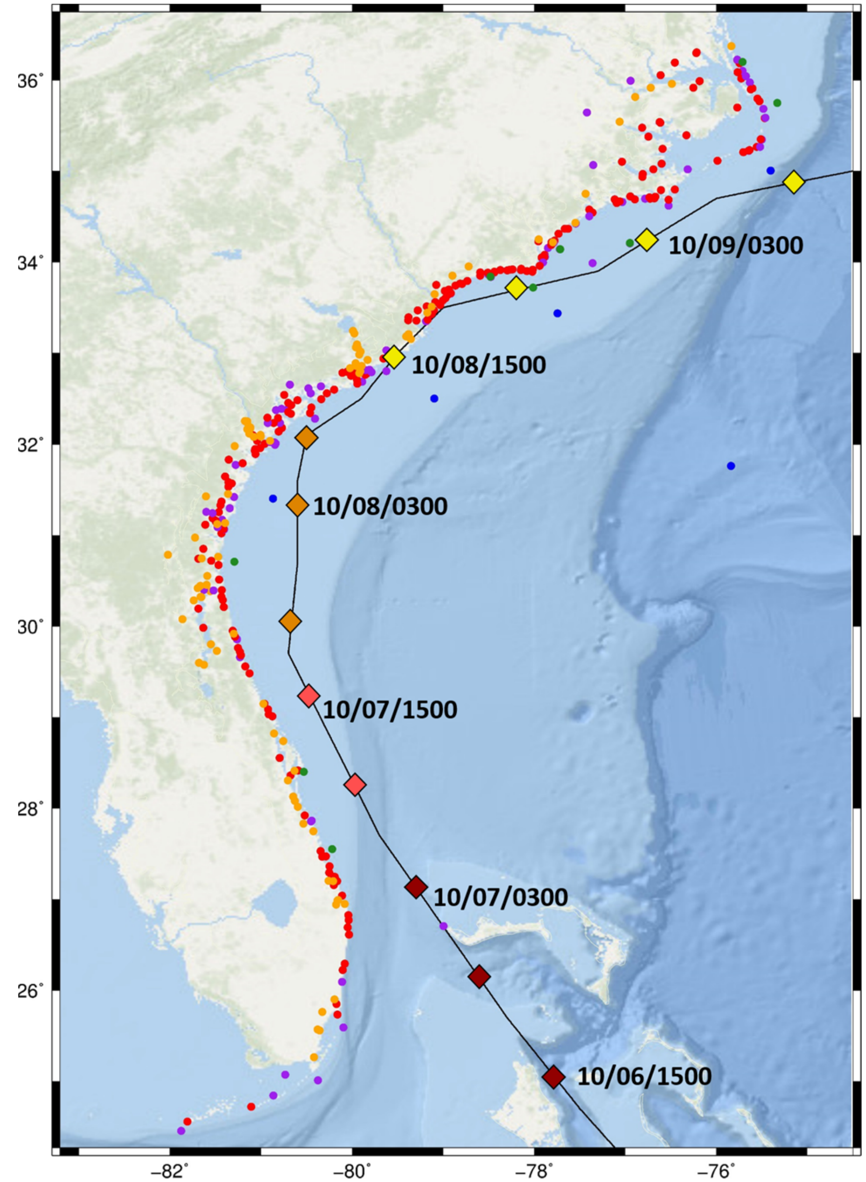
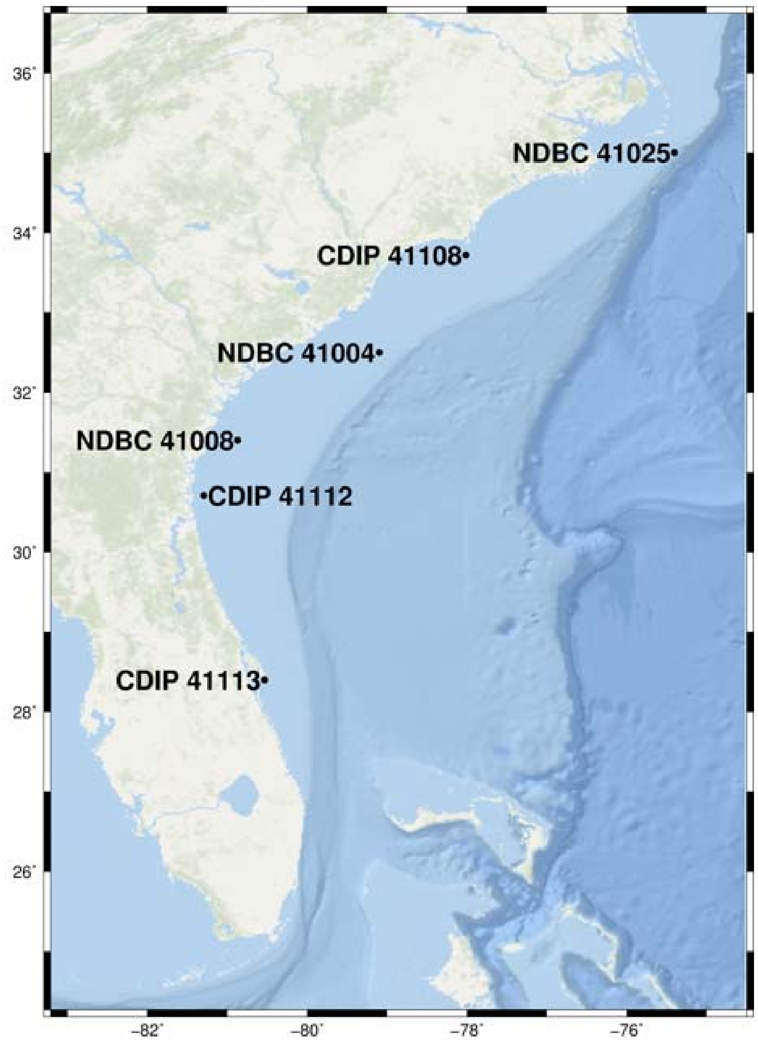
Model Validation – Observations

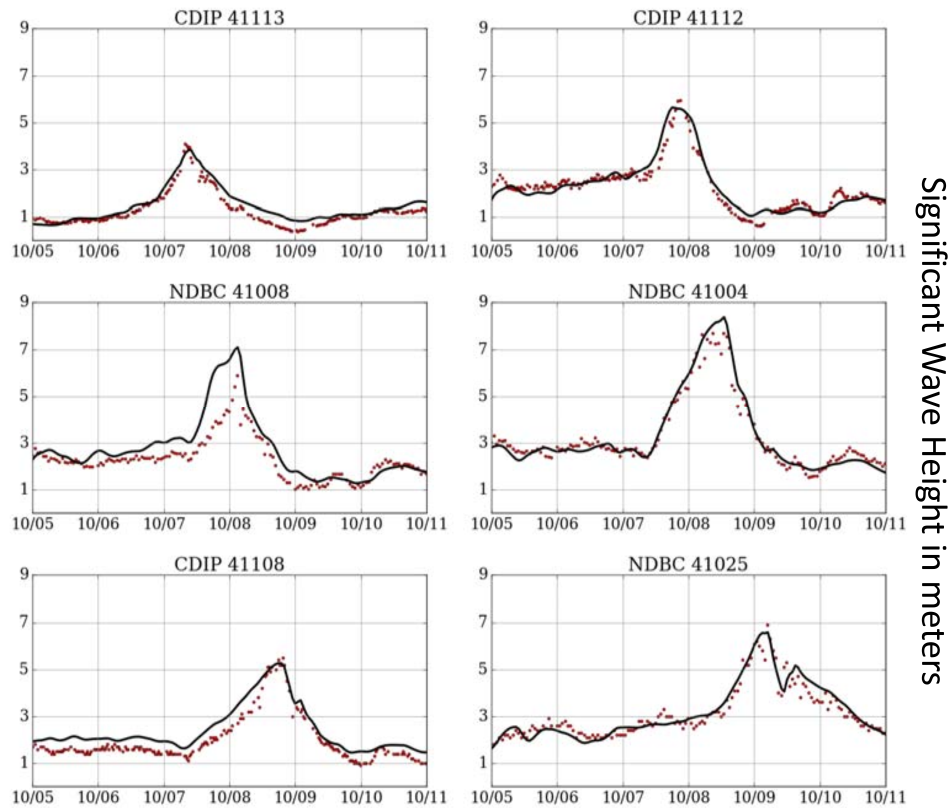
Symbol	Saffir-Simpson Category	Wind Speed (ms^{-1})
◆ (dark red)	4	59-69
◆ (red)	3	50-58
◆ (orange)	2	43-49
◆ (yellow)	1	33-42



Symbol	Data Available
● (orange)	WL
● (red)	WL + MET
● (purple)	MET
● (blue)	MET + WH
● (green)	WH

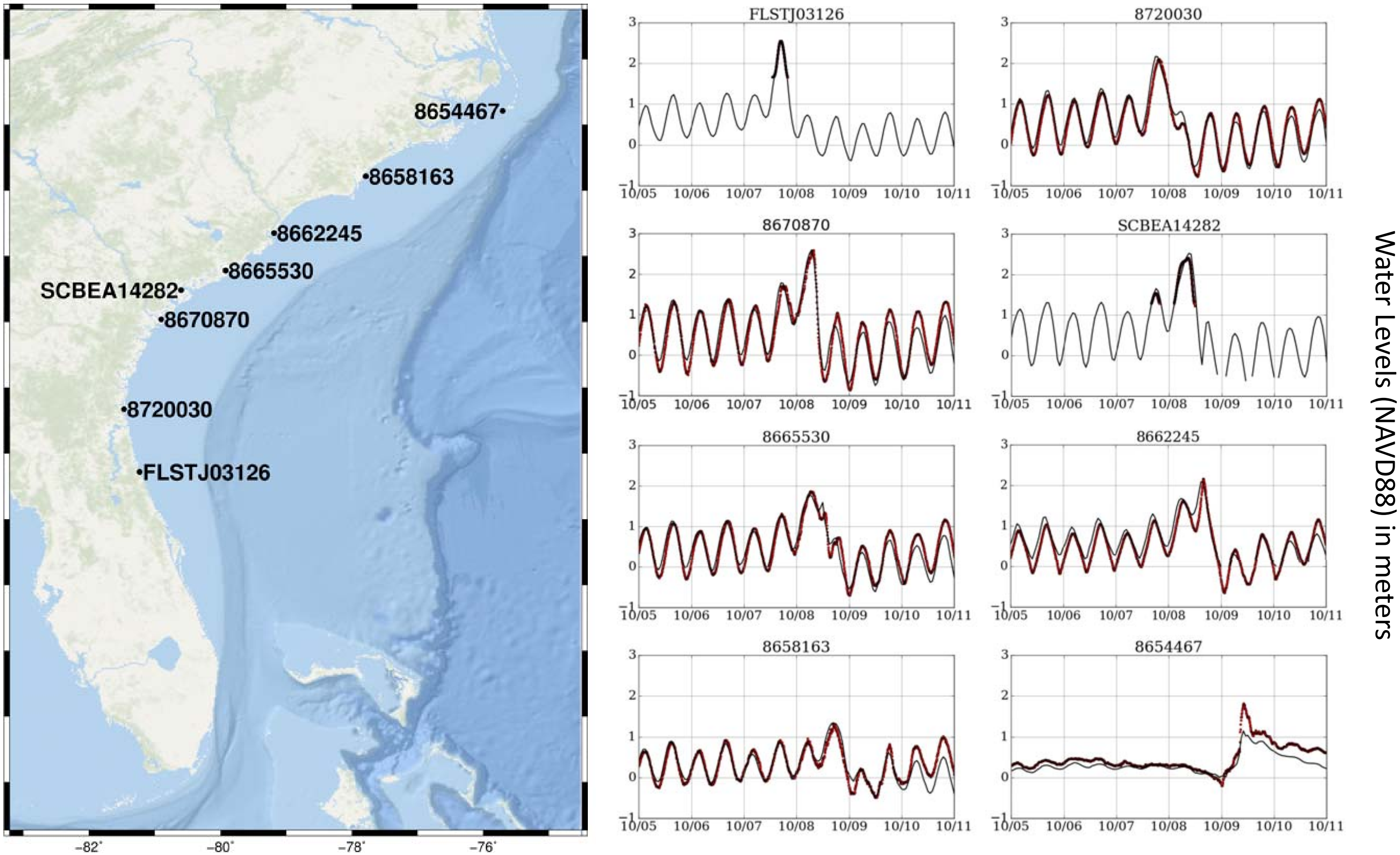
Model Validation – Waves





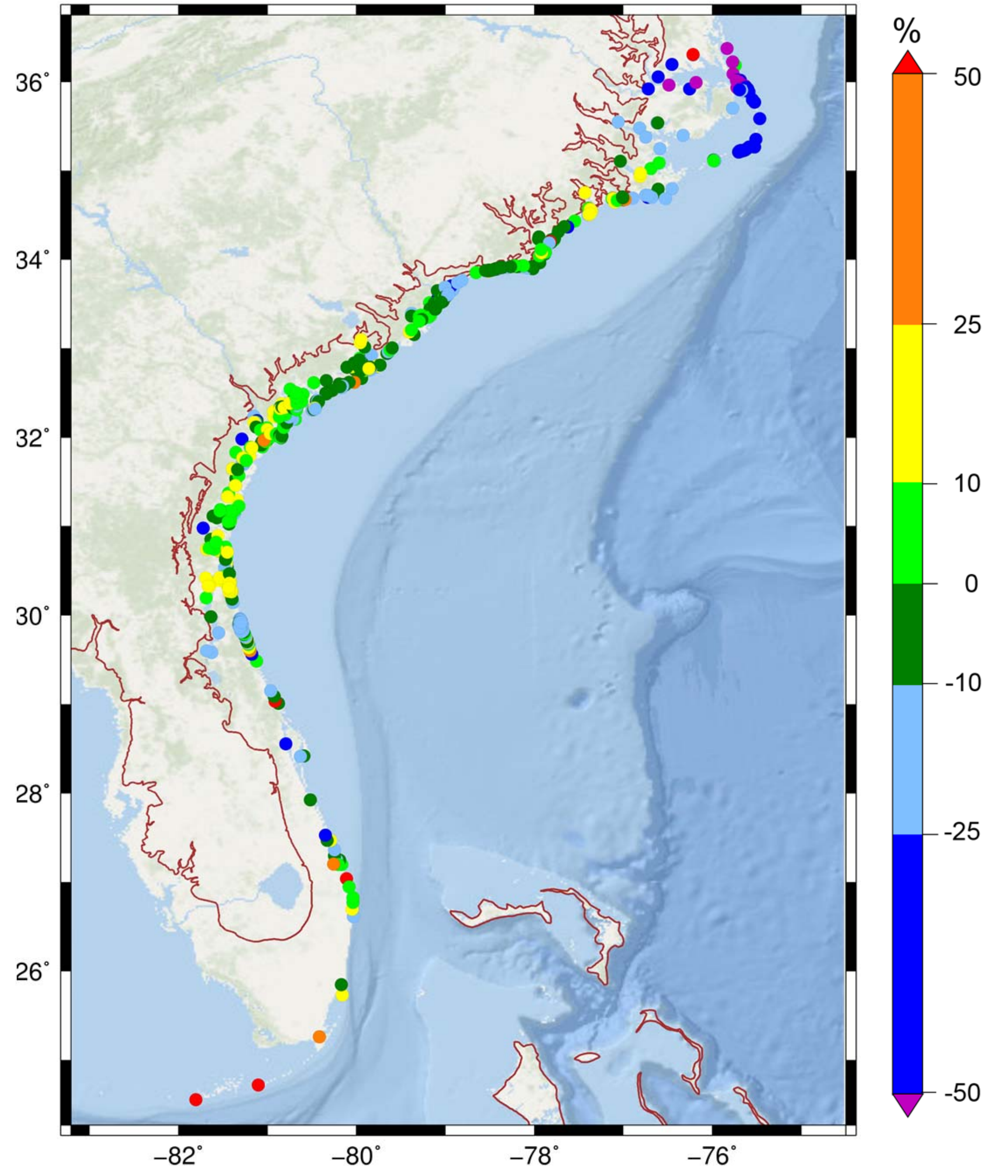
16 stations, RMSE of 0.46m, Bias of 0.11

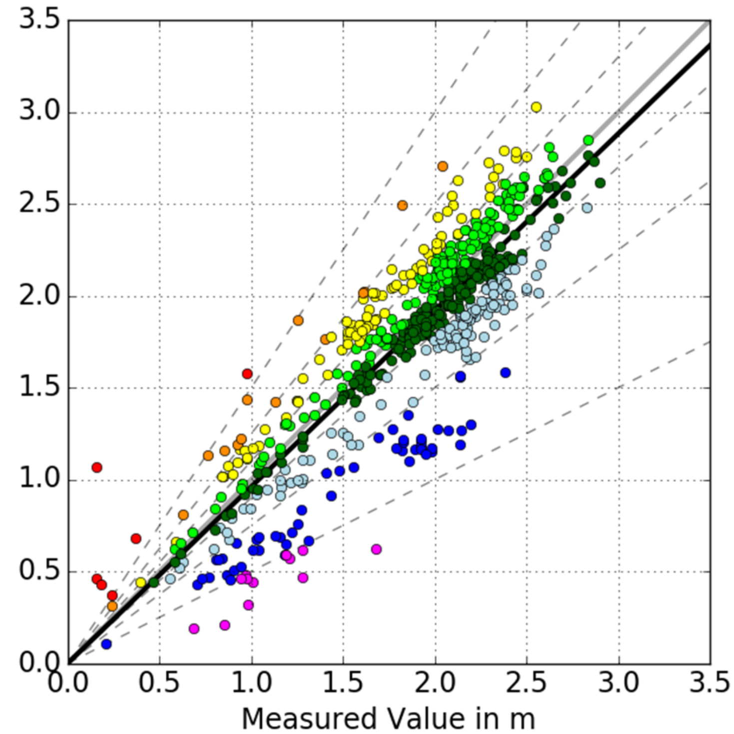
Model Validation – Water Levels



241 stations, RMSE of 0.28m, Bias of 0.04

Model Validation – High Water Marks





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

Part I - Conclusions

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

A Thomas, JC Dietrich, TG Asher, M Bell, BO Blanton, JH Copeland, AT Cox, CN Dawson, JG Fleming, RA Luettich (2018). "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.

Part II

Motivation

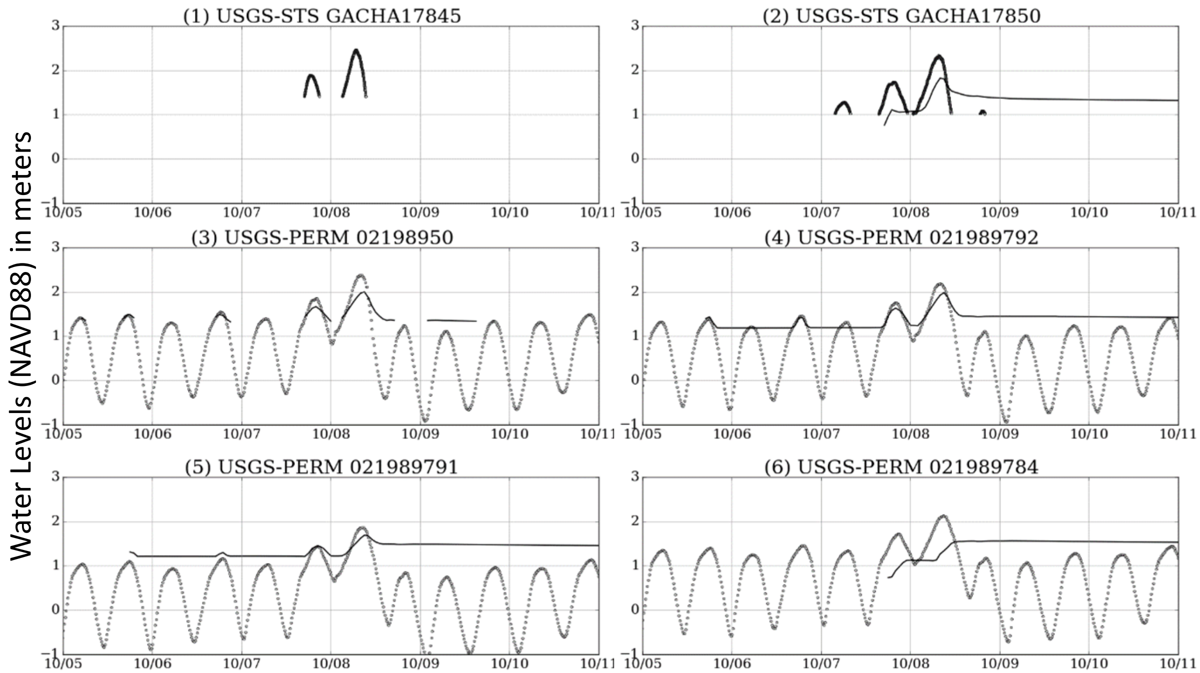
#1 Need for Higher Resolution

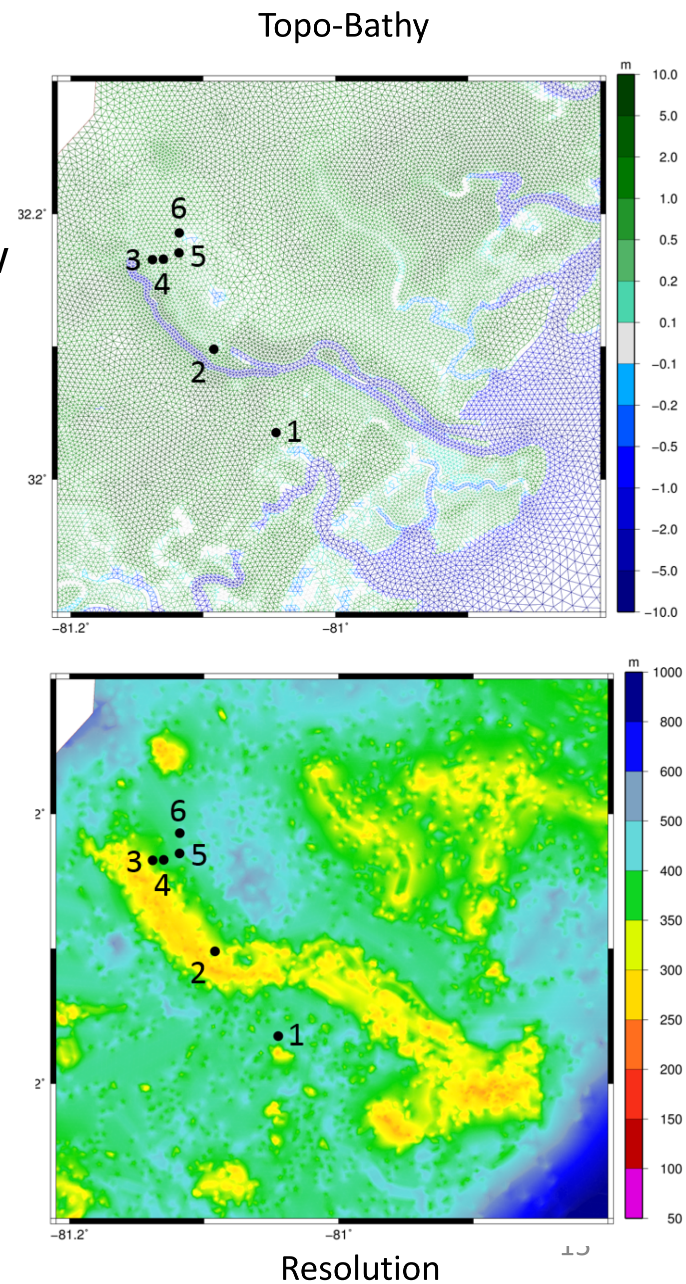
#2 Need for Faster Forecasts

Motivation

Need for higher resolution

1. Experience from hindcasts of Hurricane Matthew

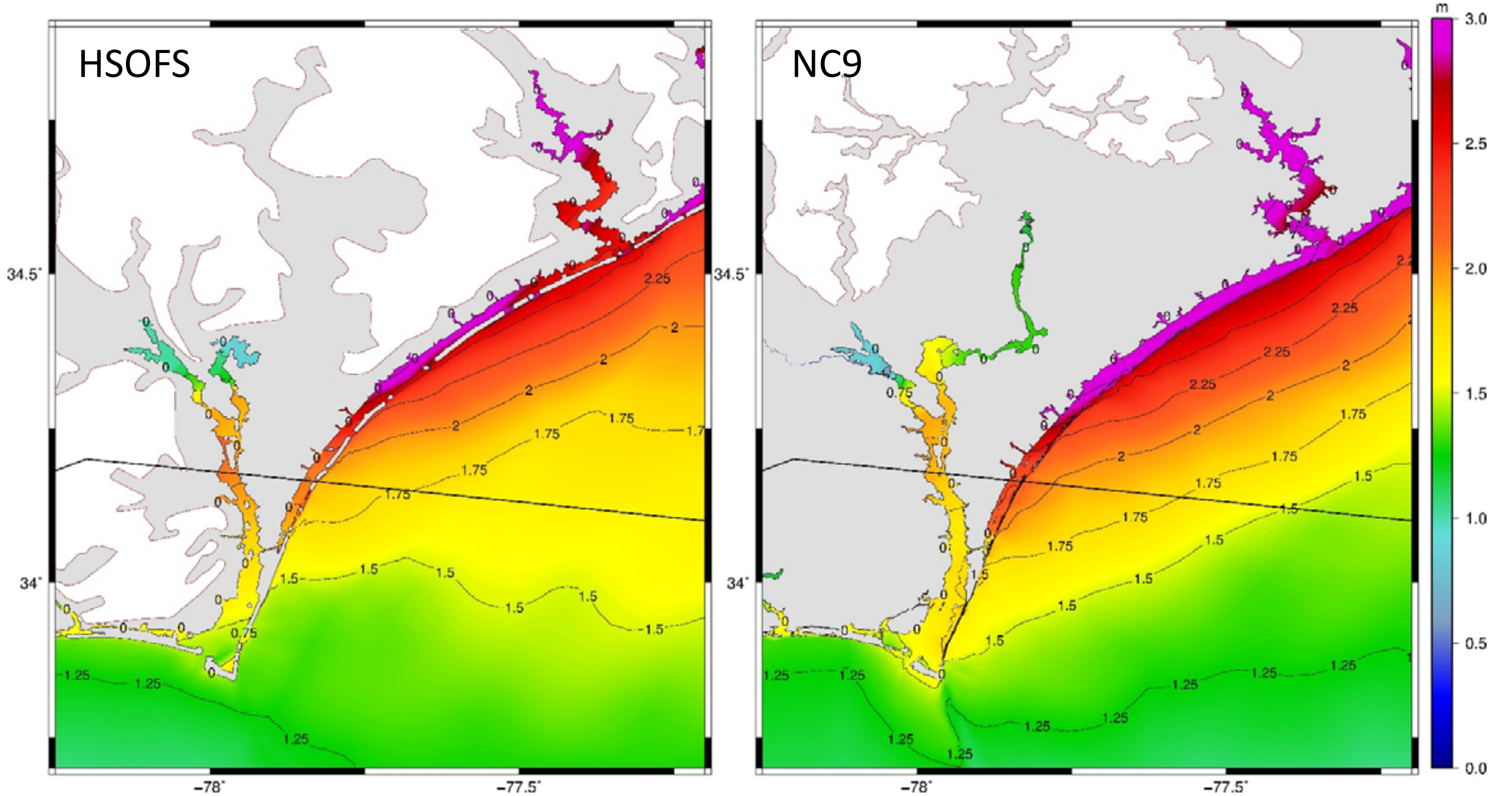




Motivation

Need for higher resolution

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



Maximum water levels corresponding to Advisory 58

Motivation

#1 Need for Higher Resolution

#2 Need for Faster Forecasts

Motivation

Need for Faster Forecasts

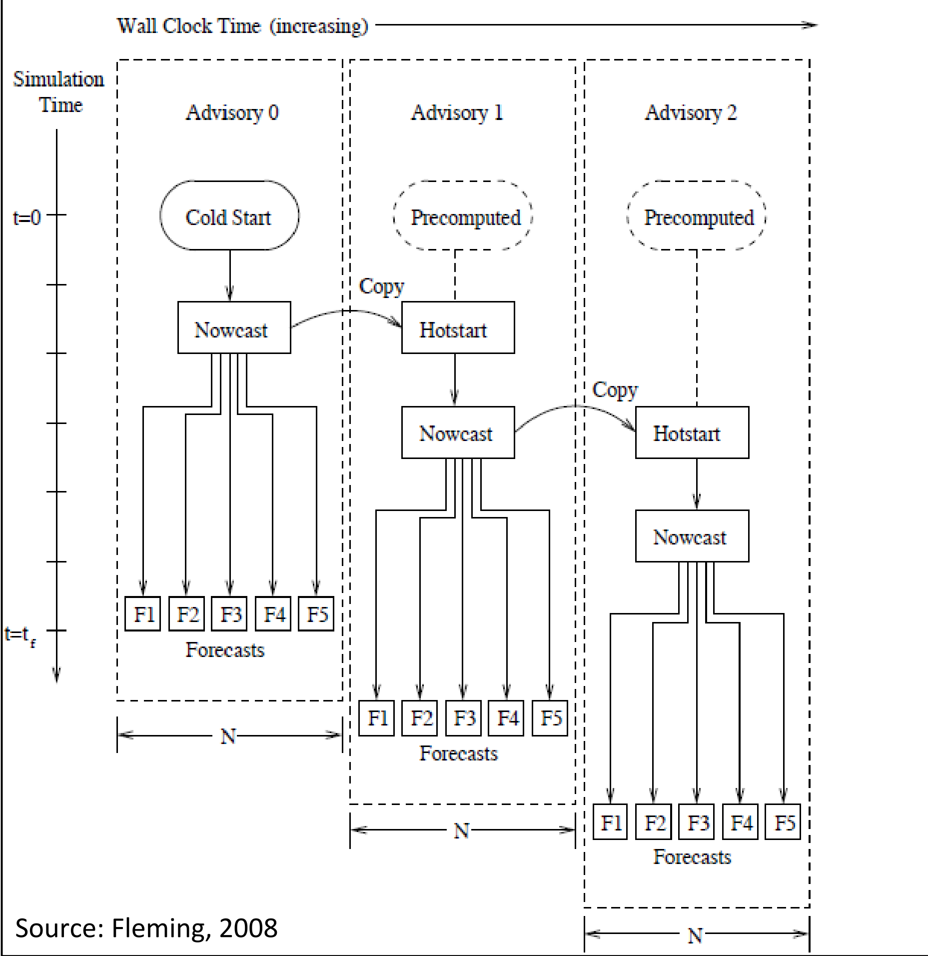
1. Ensemble Possibilities
   - For each advisory, there is uncertainty in the storm parameters , which translates directly into uncertainty in the predicted surge
   - SLOSH computes Probabilistic Storm Surge (P-surge) in real-time
     - Includes uncertainty in track/landfall location, forward speed, 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)

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 to avoid having to start the simulation from the beginning
- 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 the coarse to the fine mesh and continue the simulation on the 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

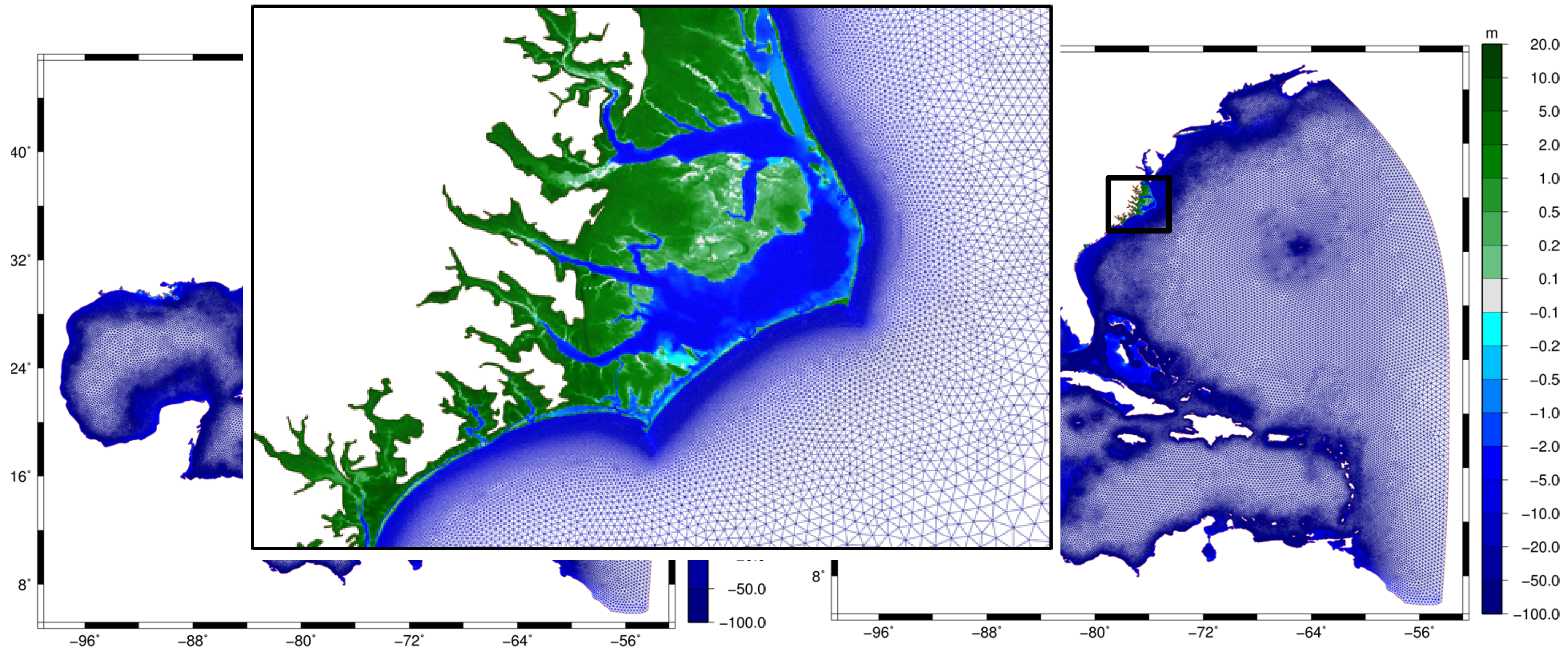
Adcirpolate

- 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

Initial Results

- When Matthew is away from NC (first 6 days), use the coarse/source mesh
- As the storm approaches NC, use adcirpolate to map the coarse/source data onto the fine/destination mesh
- Continue simulation on fine mesh for 3 days



Source Mesh: 616,113 nodes

Destination Mesh: 784,911 nodes

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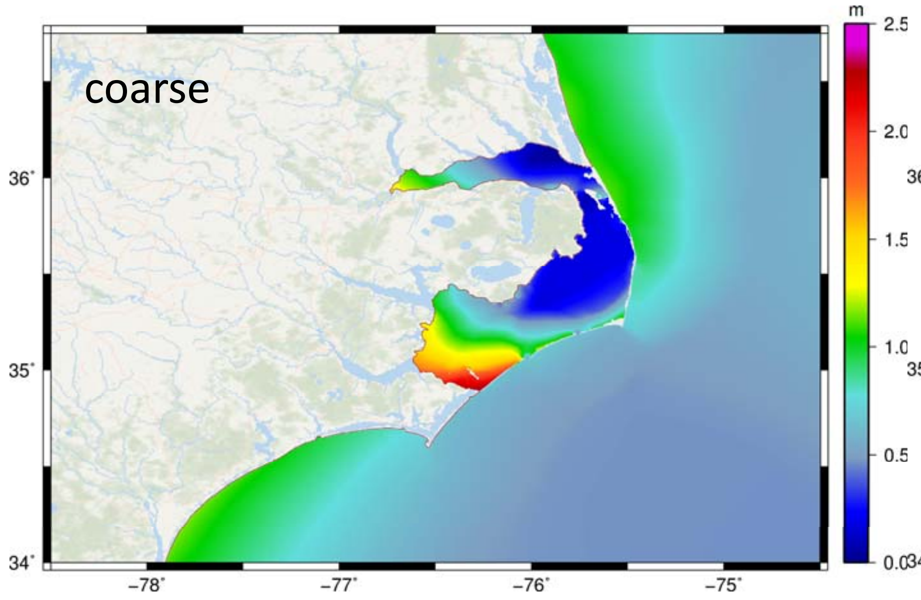
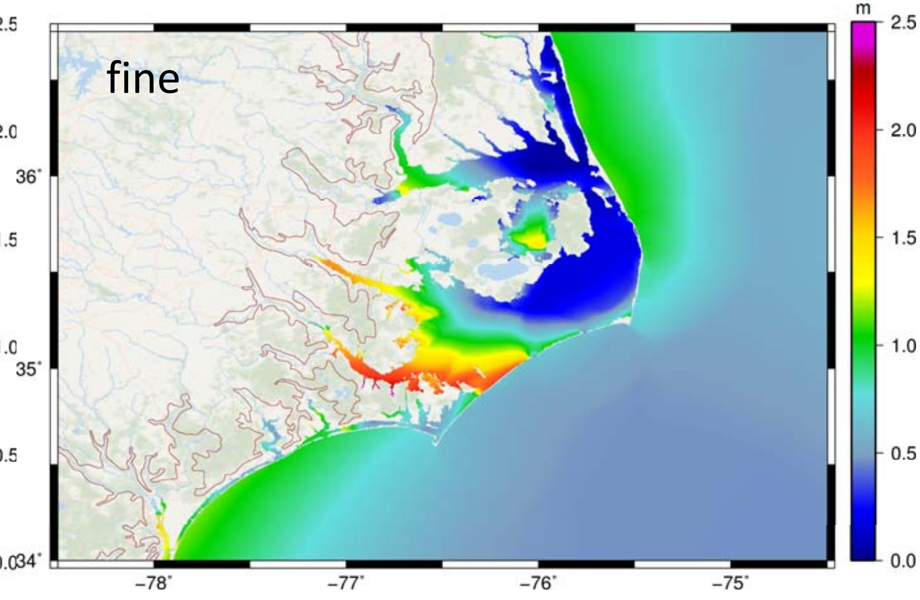
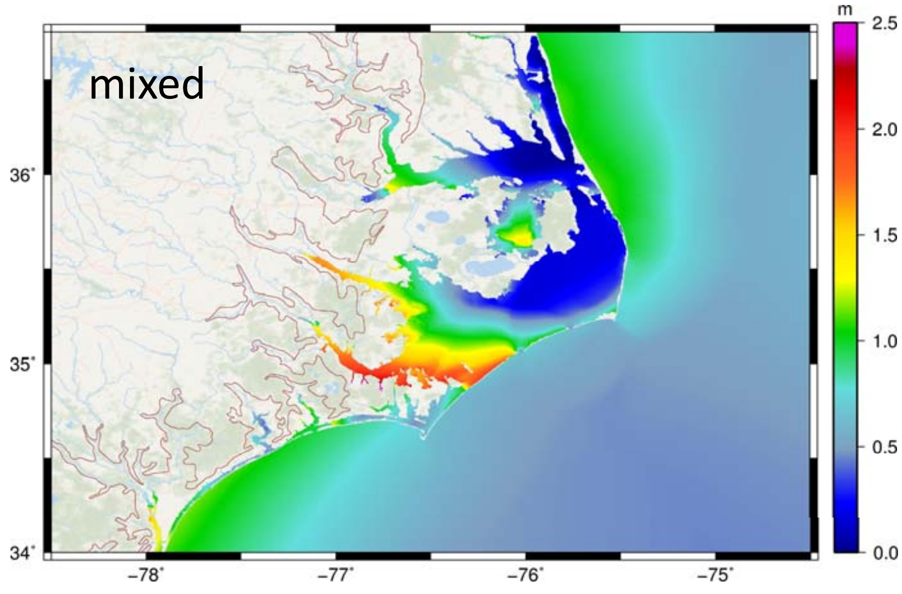
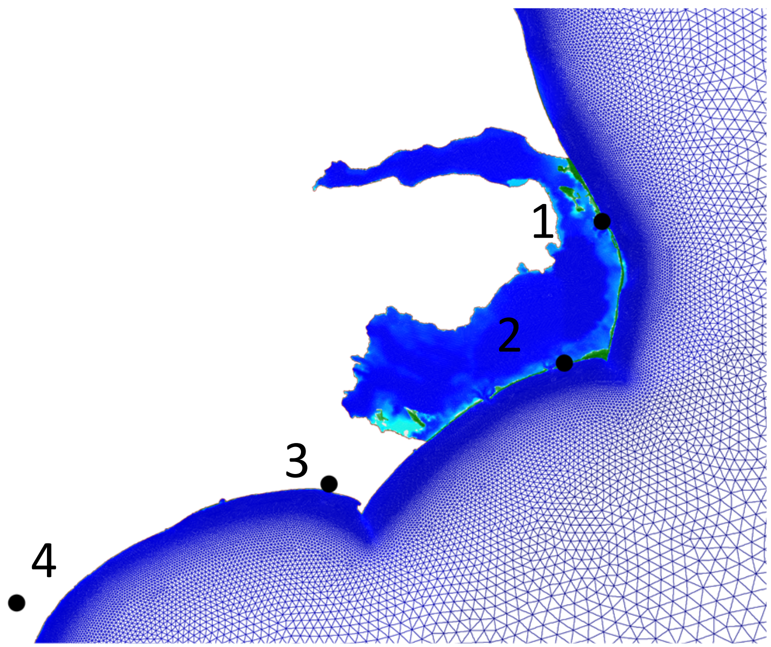
Initial Results

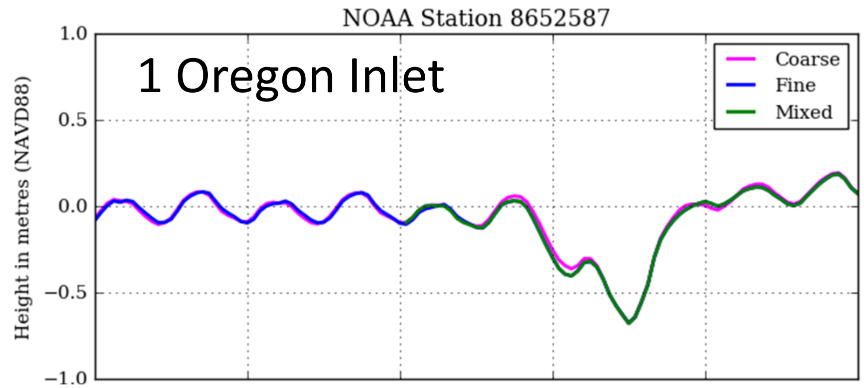


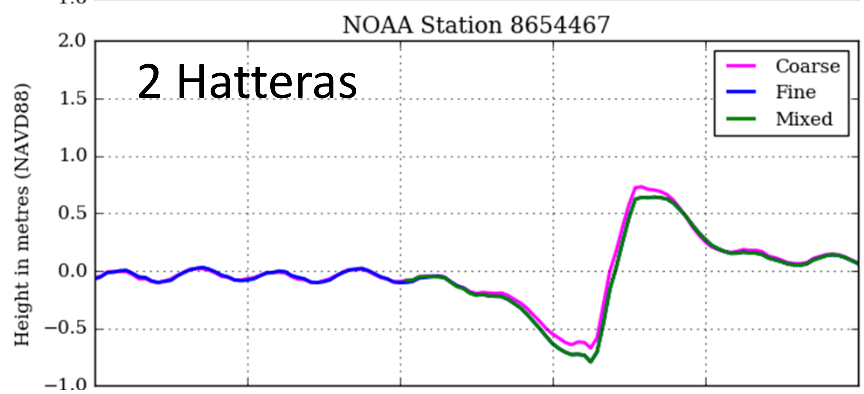


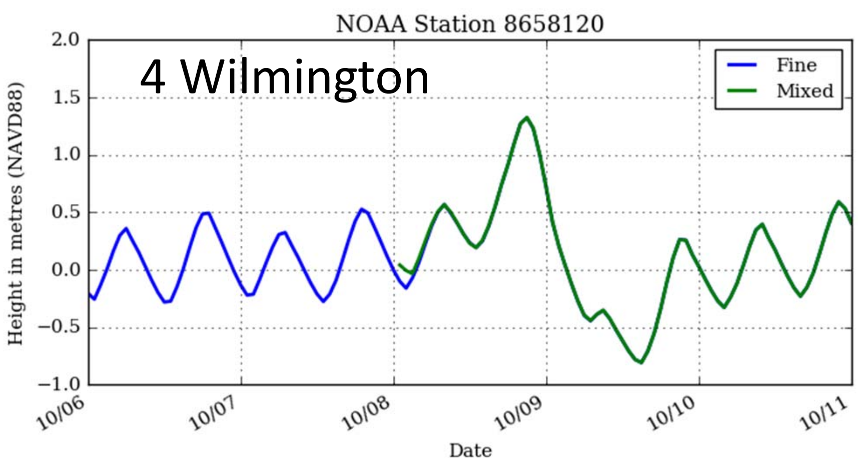


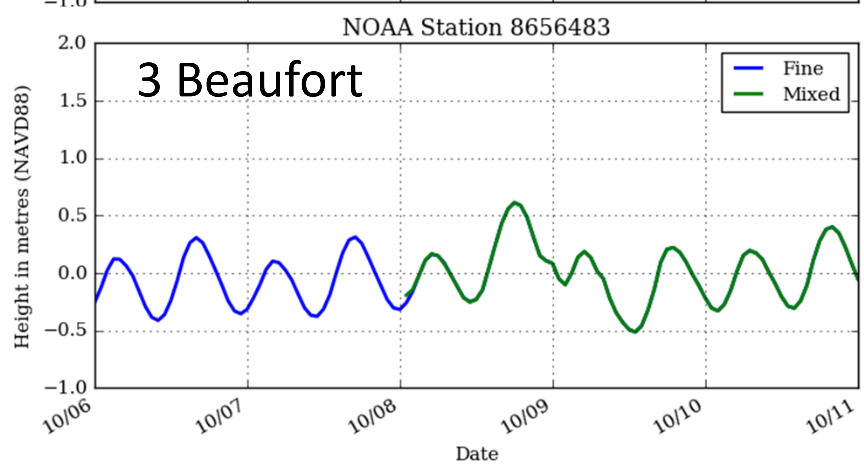
Initial Results











Initial Results

- On 532 cores,
  - Coarse Mesh
    - 9 days of winds 24 mins
  - Mixed Approach
    - 6 days of winds on coarse mesh 17 mins
    - Switching 1 min
    - 3 days of winds on fine mesh 10 mins
    - So total = 28 mins
  - Fine Mesh
    - 9 days on winds 30 mins
- Results from the mixed run are close to the ‘true’ solution of all 3 days on the fine mesh

Thank You!