NC STATE UNIVERSITY

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

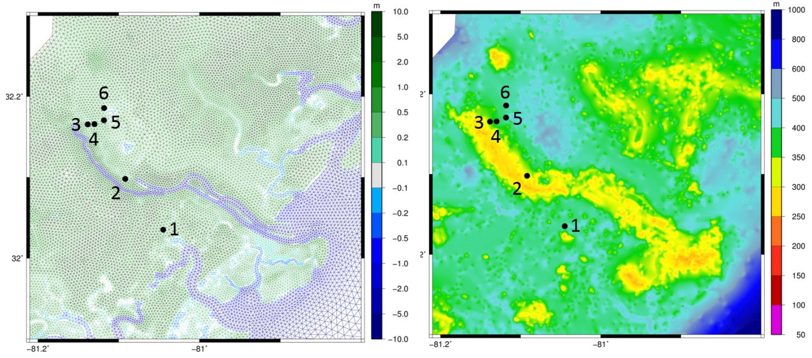
Ajimon Thomas[1], J.C. Dietrich[1],
C.N. Dawson[2], M. Loveland[2]

[1]Civil, Construction and Environmental Engineering, North Carolina State University
[2]Institute of Computational Engineering and Sciences, UT Austin

COASTAL RESILIENCE CENTER
A U.S. Department of Homeland Security Center of Excellence

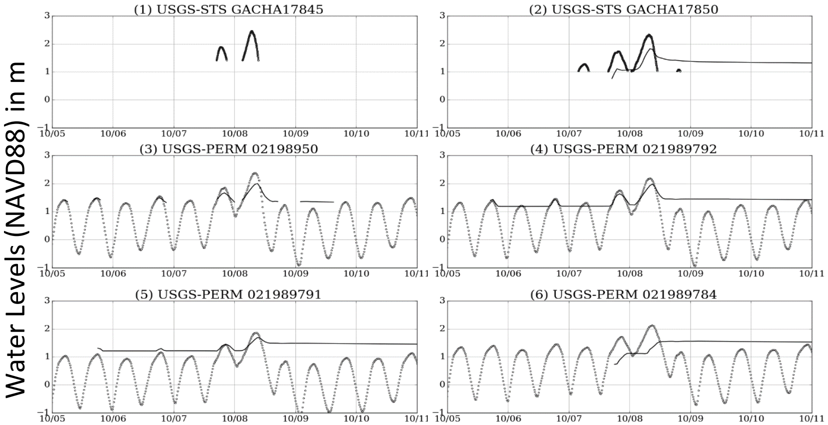
Motivation

- Need for Higher Resolution
  1. Experience from hindcasts of Hurricane Matthew (2016)
     - HSOFS mesh with an average coastal resolution of 500 m
     - 622 peaks analyzed. R^2 = 0.78, RMSE = 0.28m, Bias = -0.03, Best fit slope = 0.96



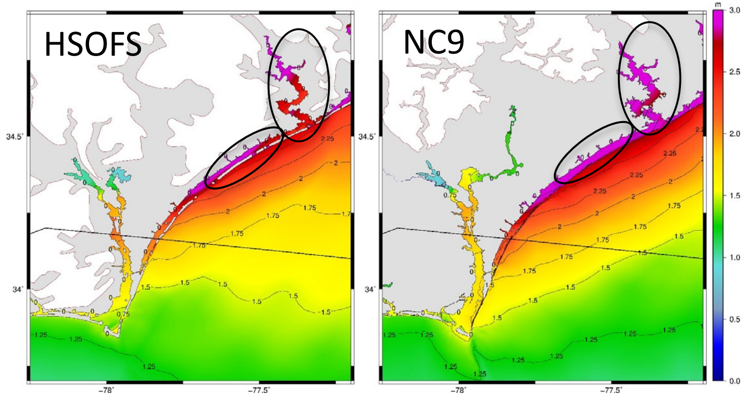
Topo-Bathy

Resolution



Motivation

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



Maximum water levels corresponding to Advisory 58

- Need for Faster Forecasts

  Ensemble Possibilities
    - For each advisory, there is uncertainty in the storm parameters
    - ASGS runs only a few variations (eg. veer-left, veer-right)
    - Faster simulations will allow for more scenario-testing

Goals and Objectives

Main Objectives

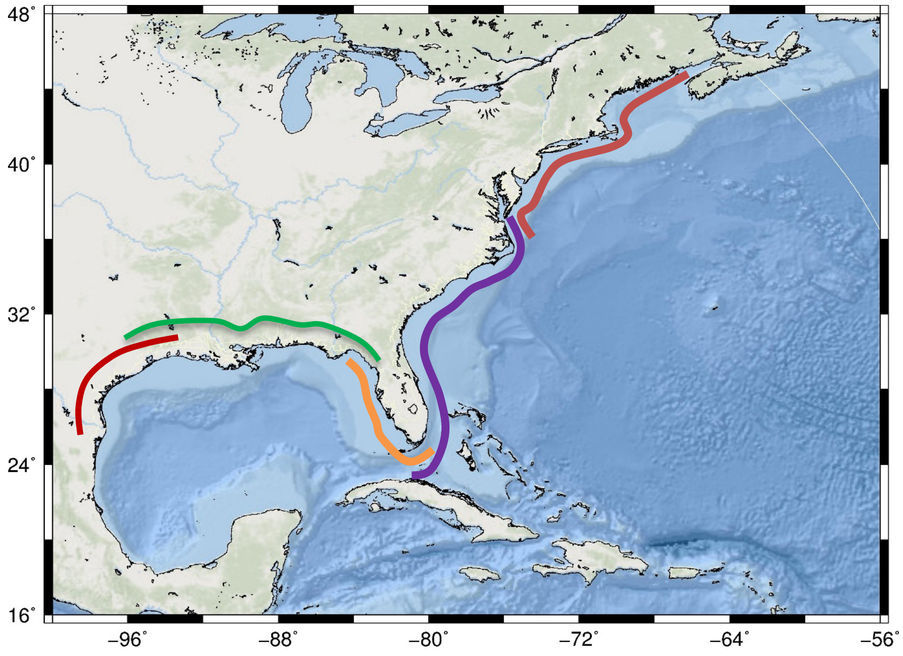
- Reduce the computational load by using a coarser resolution mesh when the storm track is uncertain
- Increase the accuracy of predictions by using a higher resolution mesh as the storm approaches landfall
- Increase the simulation possibilities including ensemble generation during operational forecasting

Goals and Objectives

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

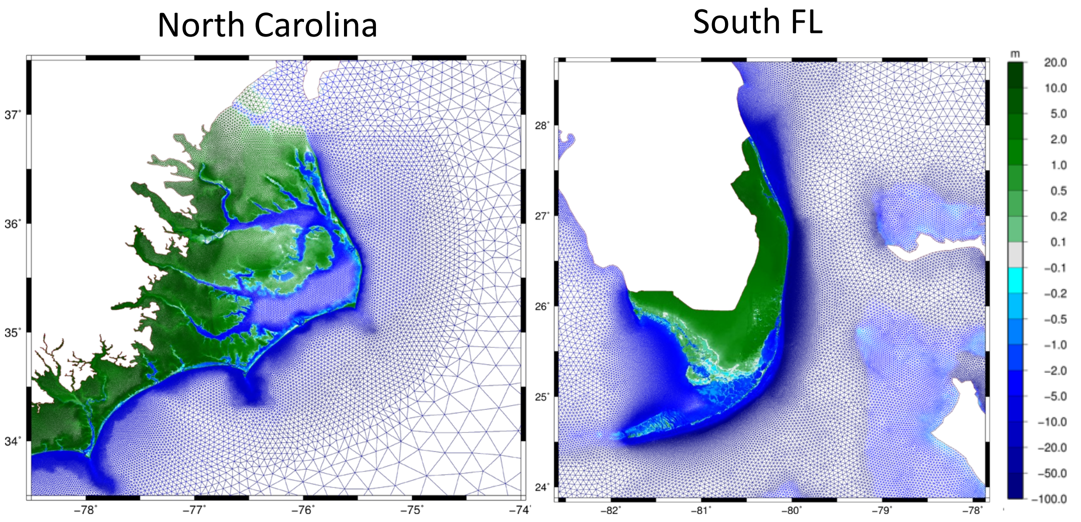
1. Western Gulf
2. Northern Gulf
3. Eastern Gulf
4. South and Central Atlantic
5. Northern Atlantic



High Resolution Mesh for FL to NC

Mesh Development

- 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

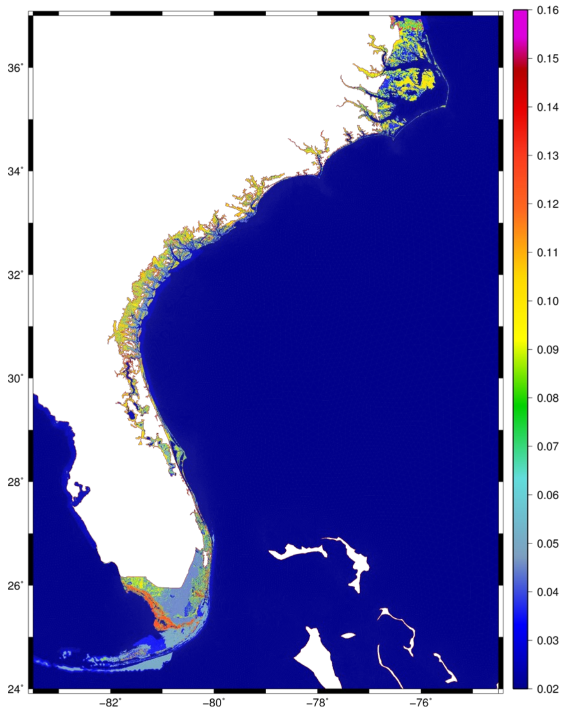


Topo-bathy

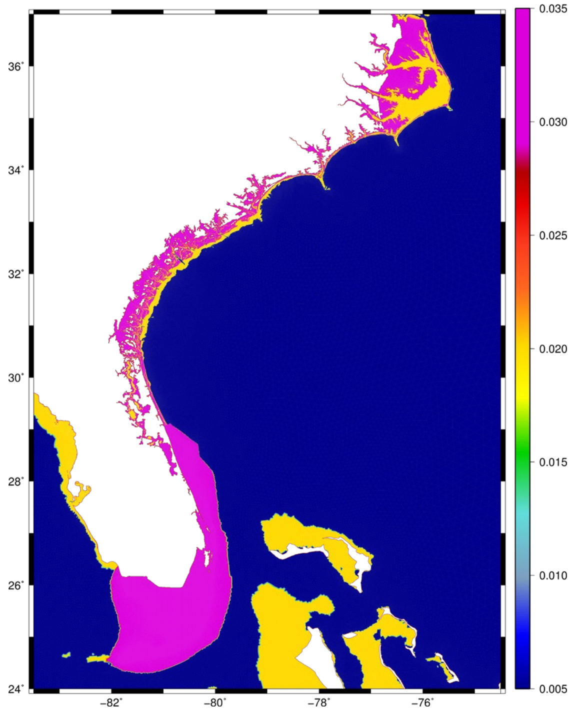
High Resolution Mesh for FL to NC

Mesh Development

- Nodal Attributes
  1. Eddy viscosity
  2. Tau0
  3. ManningsN
  4. z0Land
  5. VCanopy
  6. elemental_slope_limiter
  7. advection_state



ManningsN

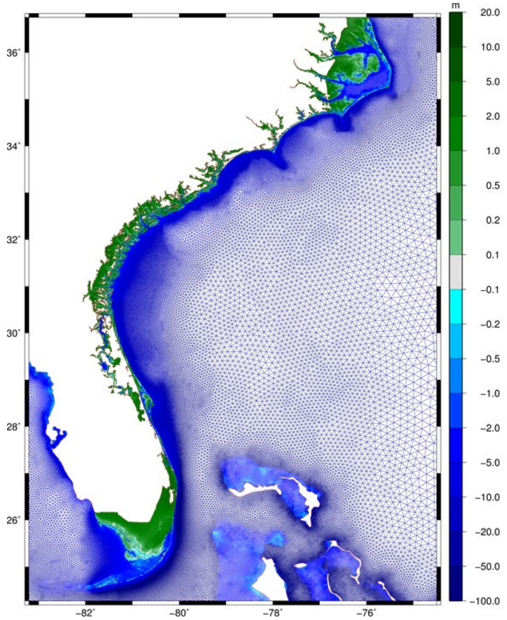


Tau0

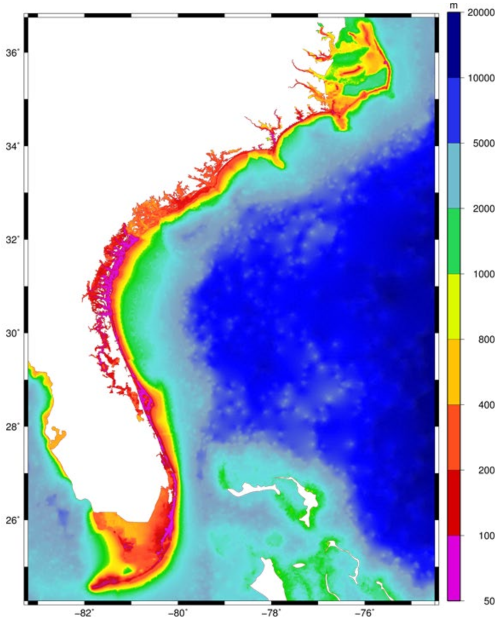
High Resolution Mesh for FL to NC

Mesh Development

- 5,641,135 nodes



Bathy-topo

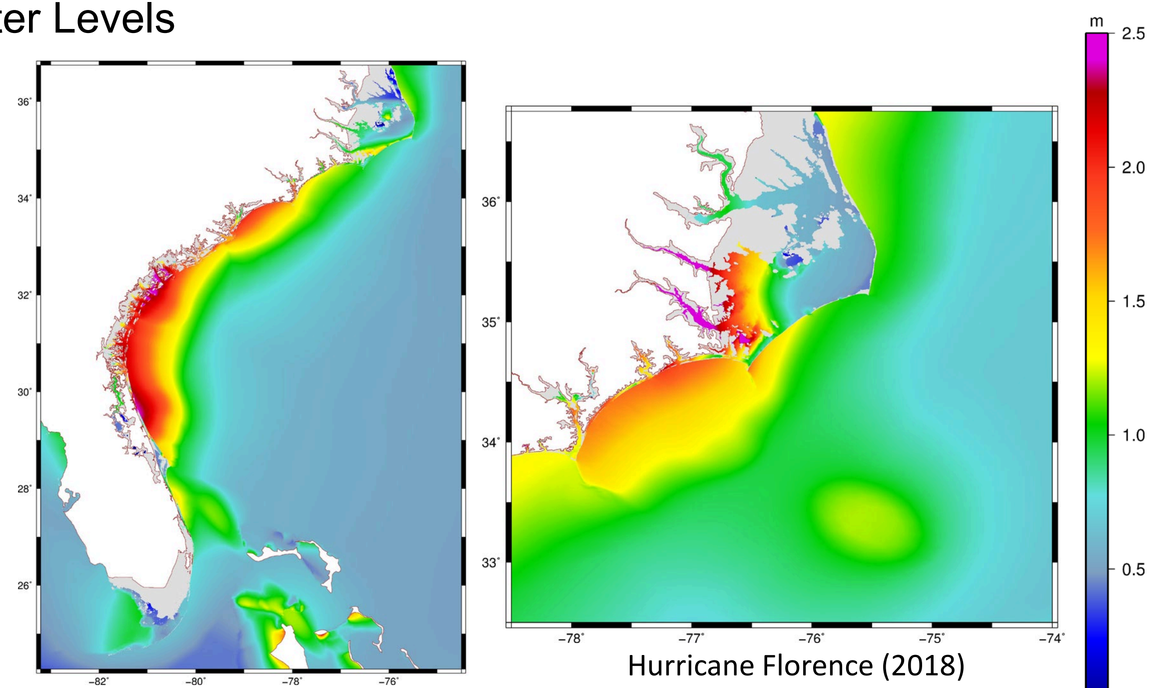


Element Spacing

High Resolution Mesh for FL to NC

Results

- Maximum Water Levels



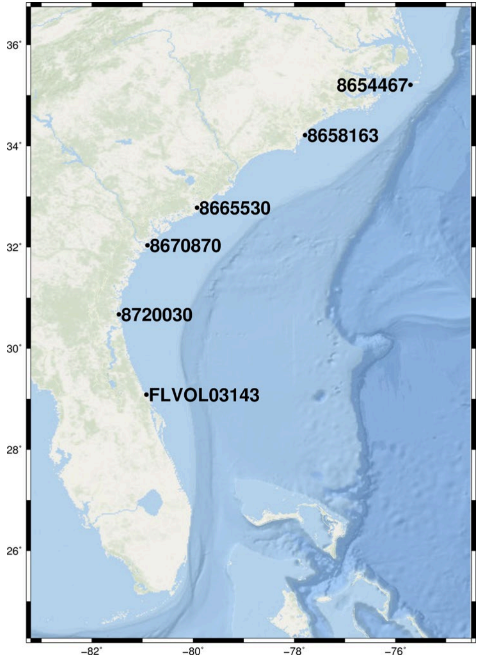
Hurricane Matthew (2016)

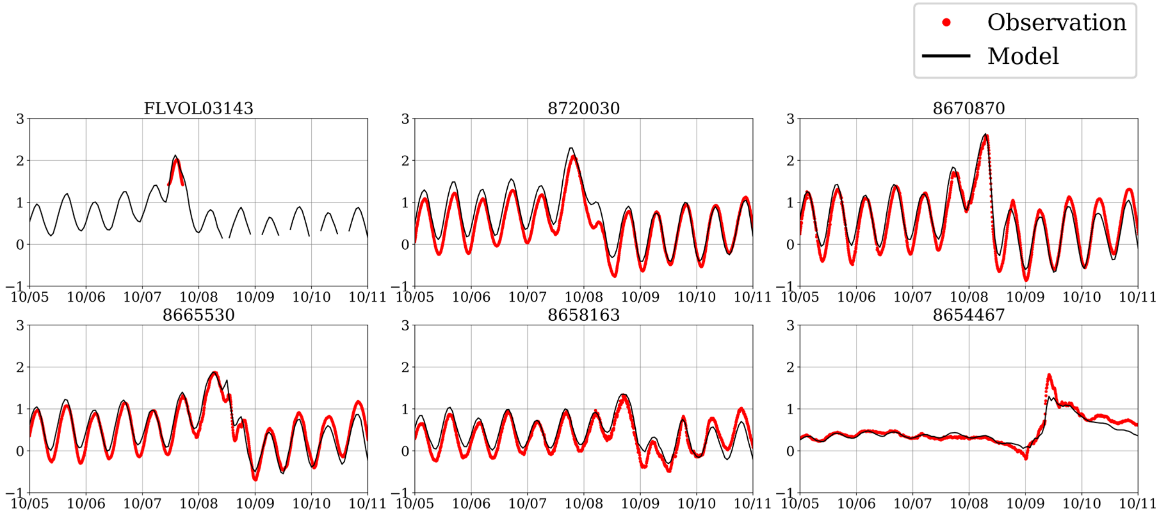
Hurricane Florence (2018)

High Resolution Mesh for FL to NC

Results

- Time Series of Water Levels



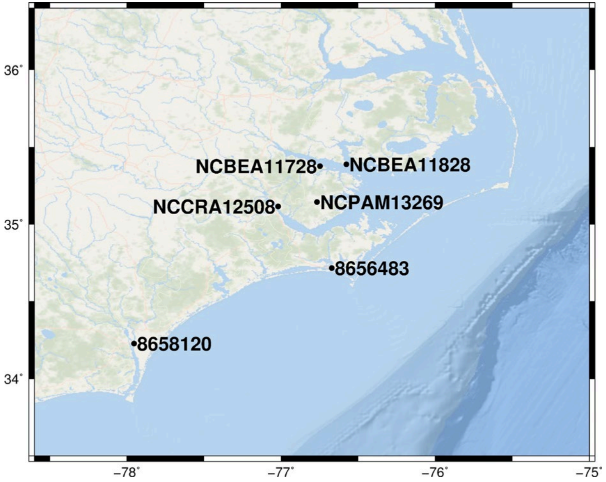


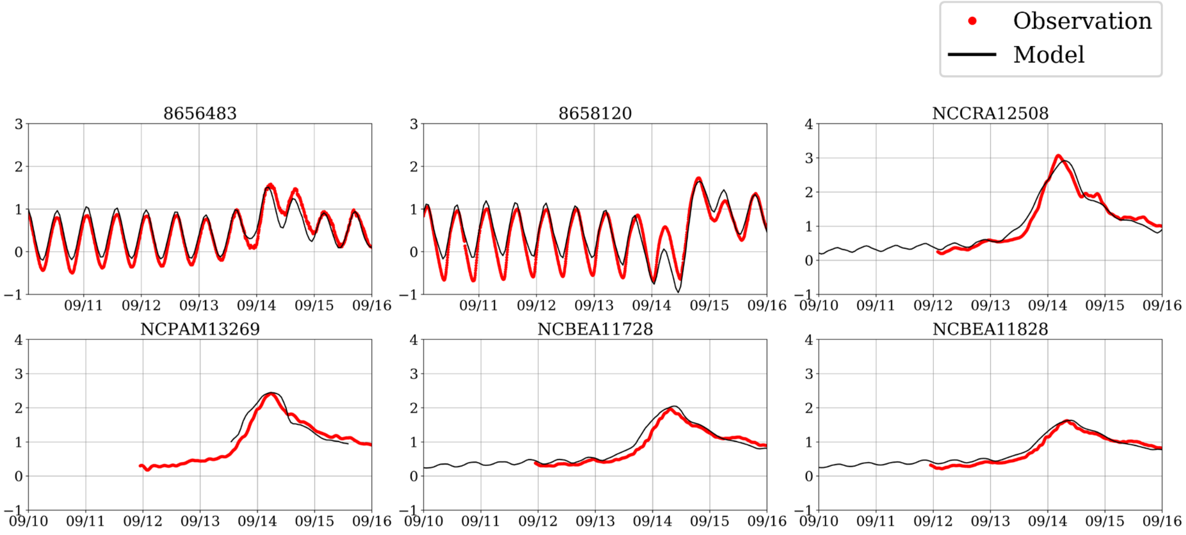
Hurricane Matthew

High Resolution Mesh for FL to NC

Results

- Time Series of Water Levels

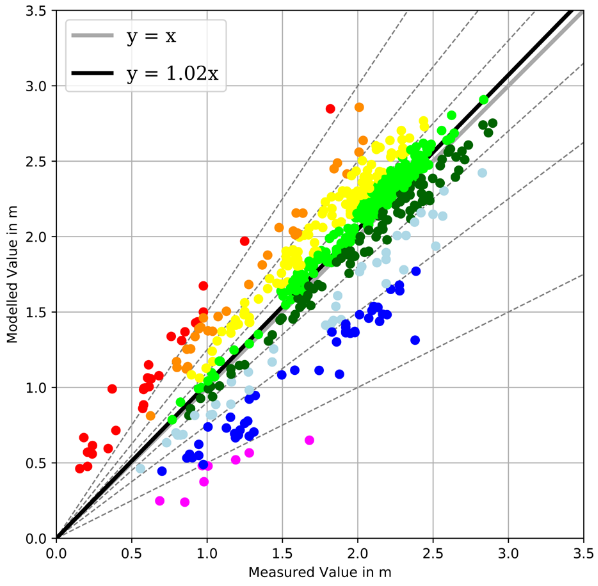




Hurricane Florence

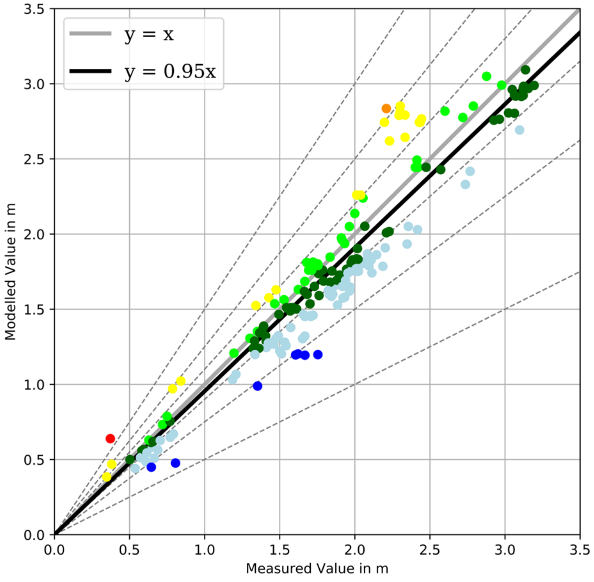
High Resolution Mesh for FL to NC

Validation



Bias 0.03
$R^2 = 0.76$
RMSE = 0.29
No of values = 600

Hurricane Matthew



Bias -0.05
$R^2 = 0.91$
RMSE = 0.22
No of values = 190

Hurricane Florence

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

The Multi-Resolution Approach

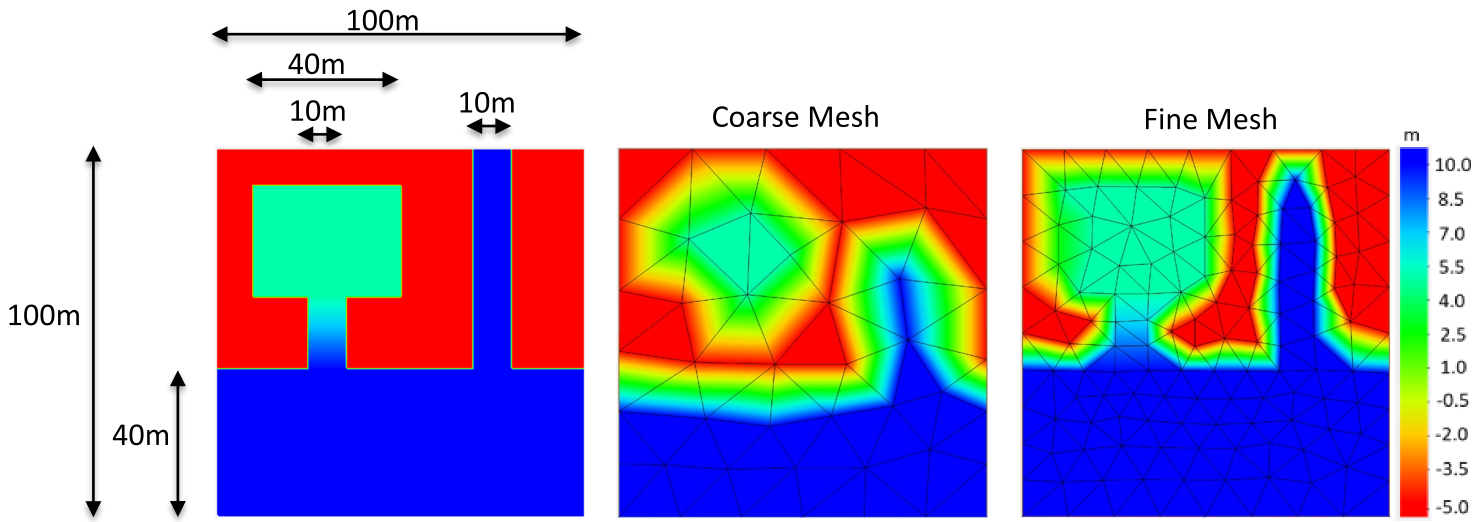
Adcirpolate

- 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

Test Case

- Scatter at 0.5m resolution
- Average spacing is 20m for coarse and 10m for fine mesh

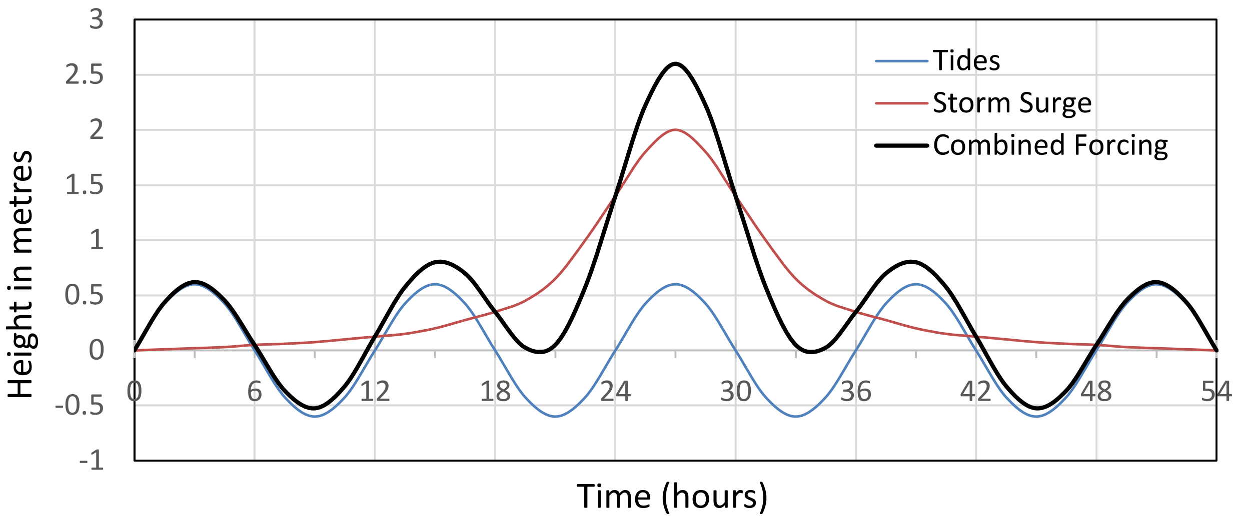


Bathy-topo

The Multi-Resolution Approach

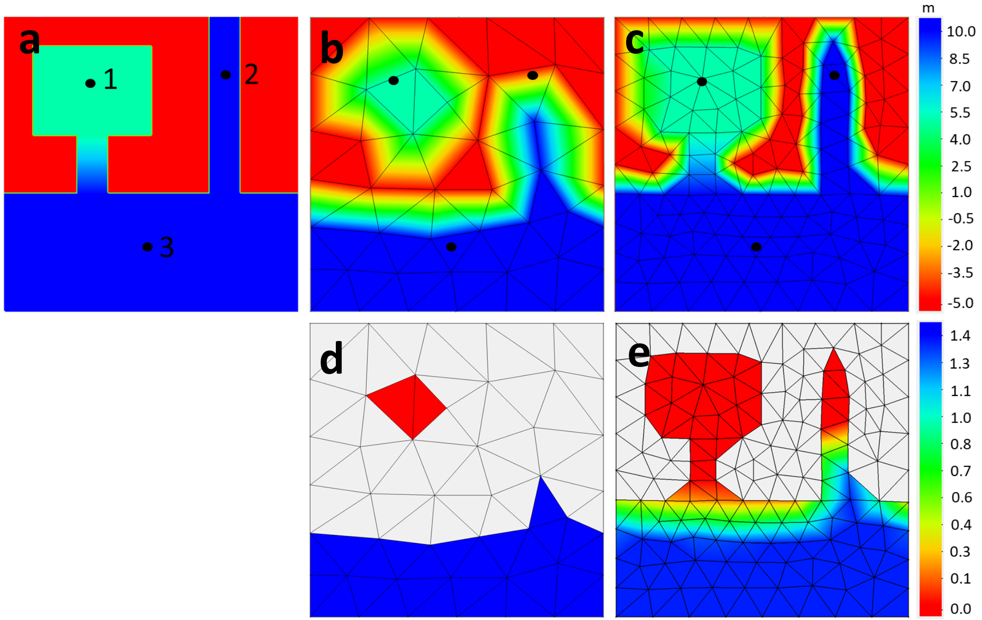
Test Case

- Switching after 1 day when water levels at boundary is 1.4 m
- Total run period is 2.25 days



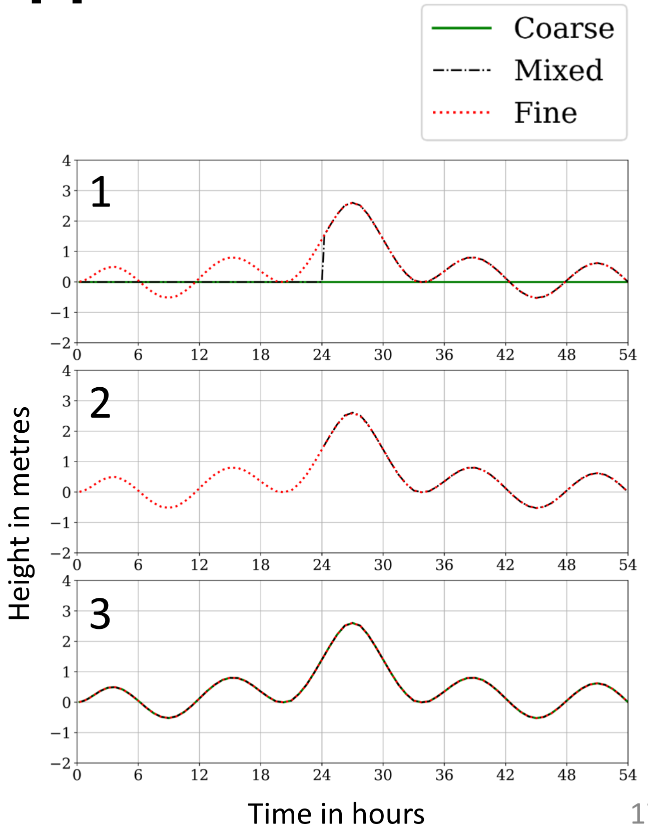
The Multi-Resolution Approach

Test Case



WL at end of coarse run

WL at start of fine run



The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- HSOFS when storm is far away
- High-res mesh when storm approaches the coastline
- Switching time understood by looking at water levels

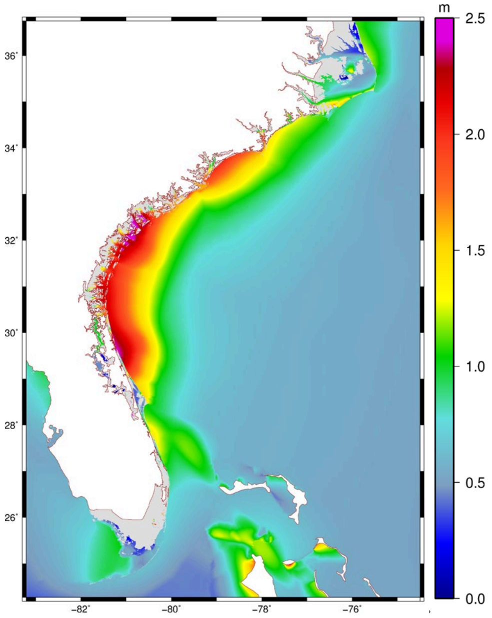
Storm	No. of Days of Simulation			Run Date
	HSOFS	High-Res	Total	
Matthew	4.5	4.5	9	Oct 2 – Oct 11, 2016
Florence	3	6	9	Sept 7 – Sept 16, 2018

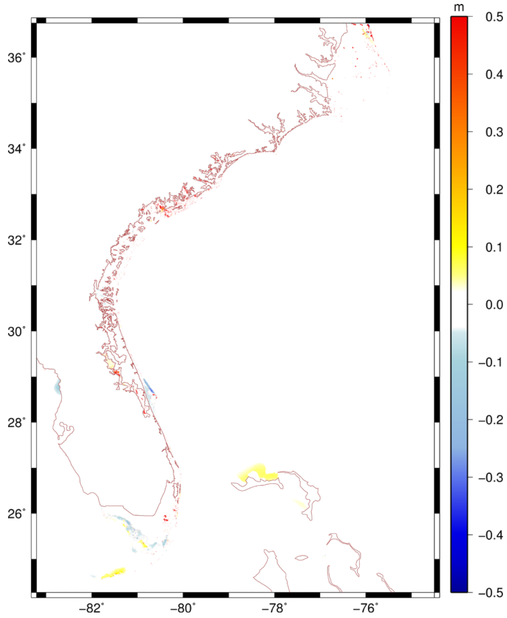
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Matthew – Max. Water Levels

Maximum water levels using the approach





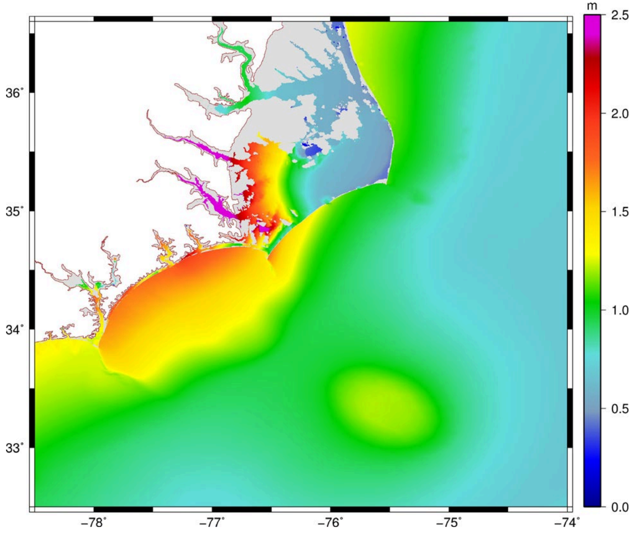
Difference in maximum water levels between the approach and a full run on the fine mesh

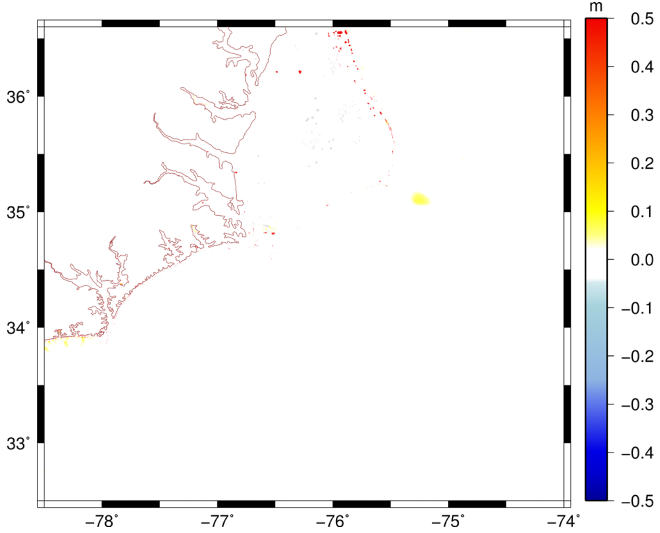
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Florence – Max. Water Levels

Maximum water levels using the approach





Difference in maximum water levels between the approach and a full run on the fine mesh

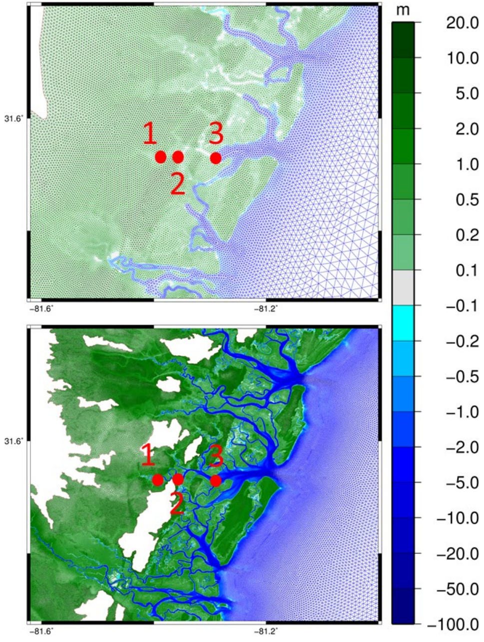
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

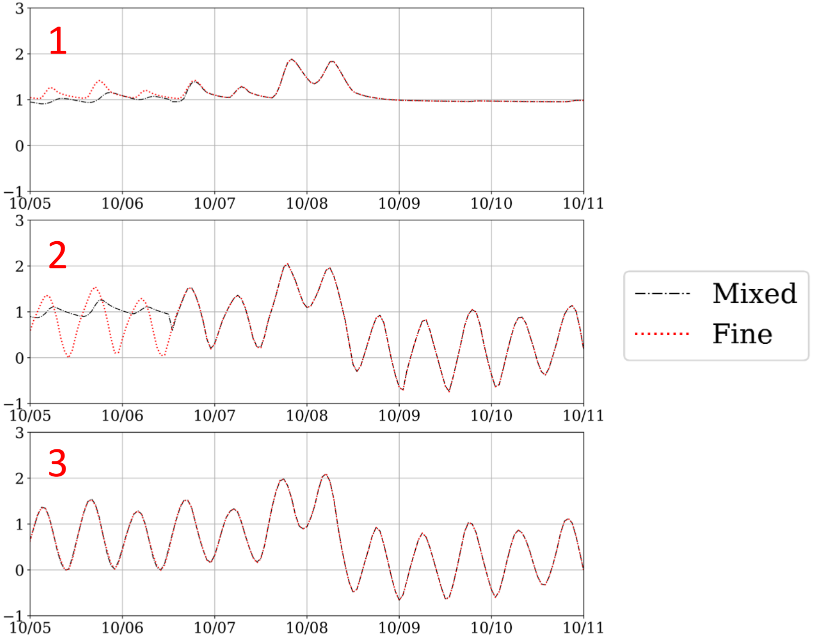
- Matthew – Time Series at Inland Locations

Coarse Mesh

Fine Mesh



Bathy-topo



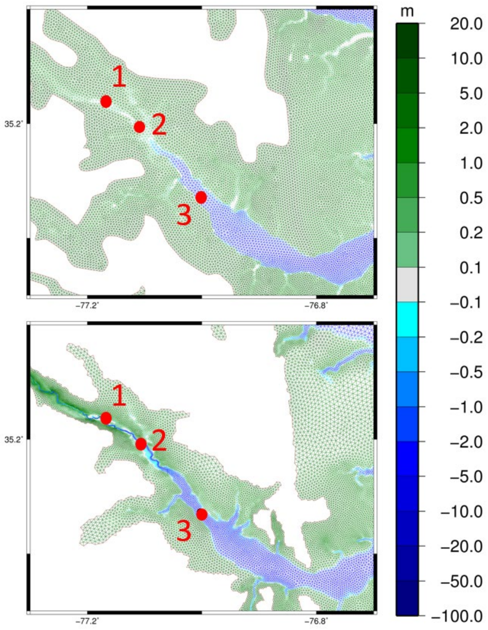
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

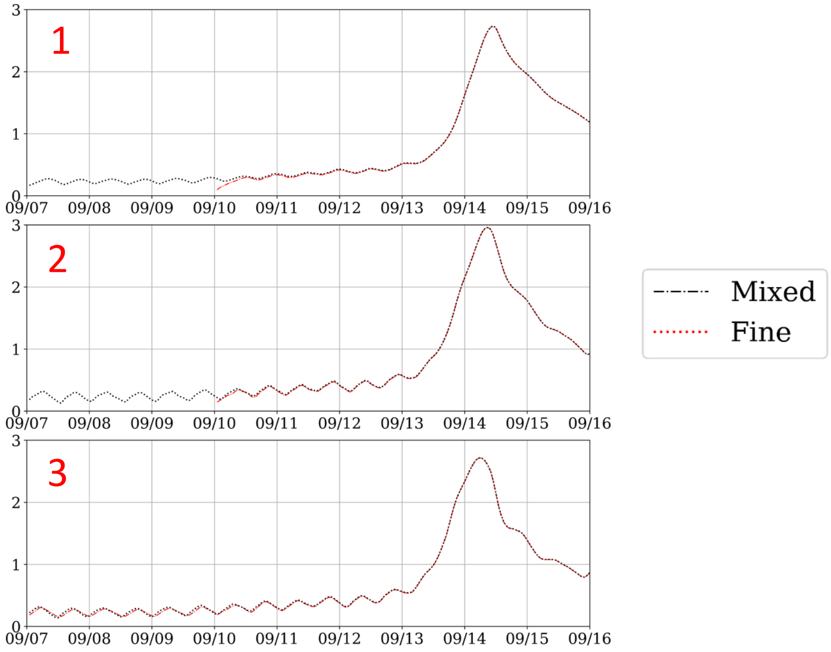
- Florence – Time Series at Inland Locations

Coarse Mesh

Fine Mesh



Bathy-topo



The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis
  - Accuracy Comparison
    - Observations as truth
    - No loss in accuracy

Error	Matthew		Florence	
	Mixed	Fine	Mixed	Fine
Stations	580	580	190	190
Best Fit Slope	0.93	0.93	0.95	0.95
R^2	0.77	0.78	0.88	0.91
ERMS (m)	0.29	0.29	0.26	0.22
B_{MN}	-0.06	-0.07	-0.06	-0.05

The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis
  - Accuracy Comparison
    - Fine Mesh Results as truth
    - Comparison at nodes that are inland (z<10m) and wetted in both meshes
    - Mixed approach wets more nodes with gain in accuracy

Error	Matthew		Florence	
	Coarse	Mixed	Coarse	Mixed
Stations	1,981,764	2,664,921	182,289	267,766
Best Fit Slope	0.99	1.0	0.95	1.0
R^2	0.91	0.96	0.86	0.96
ERMS (m)	0.22	0.13	0.22	0.11
B_{MN}	-0.014	-0.002	-0.051	0.004

The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis
  - Run Time Comparison
    - 24 to 33 % save in time without compromising on accuracy (comparison to observations)

Storm	Run Time in minutes				
	Mixed				Fine
	Coarse	Adcirpolate	Fine	Total	
Matthew	29	12	222	263	393
Florence	19	12	259	290	380

Future Work

- Utilize Watershed boundaries to create sub-meshes from the high-resh mesh
  - Use different sub-meshes (instead of 1 big high-res mesh) depending on where the storm is at that point in time
  - Should save more time
- Explore other factors to use as triggers for switching

Thank You