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

Ph.D. Defense
June 15, 2020

Ajimon Thomas

Department of Civil, Construction and Environmental Engineering
North Carolina State University

Acknowledgements

Thesis Committee

Dr. Casey Dietrich[1], Dr. John Baugh[1], Dr. Elizabeth Sciaudone[1], Dr. Rick Luettich[2]

[1]Civil, Construction and Environmental Engineering, North Carolina State University, Raleigh, NC
[2]Institute of Marine Sciences, UNC Chapel Hill, Morehead City, NC

Other Collaborators

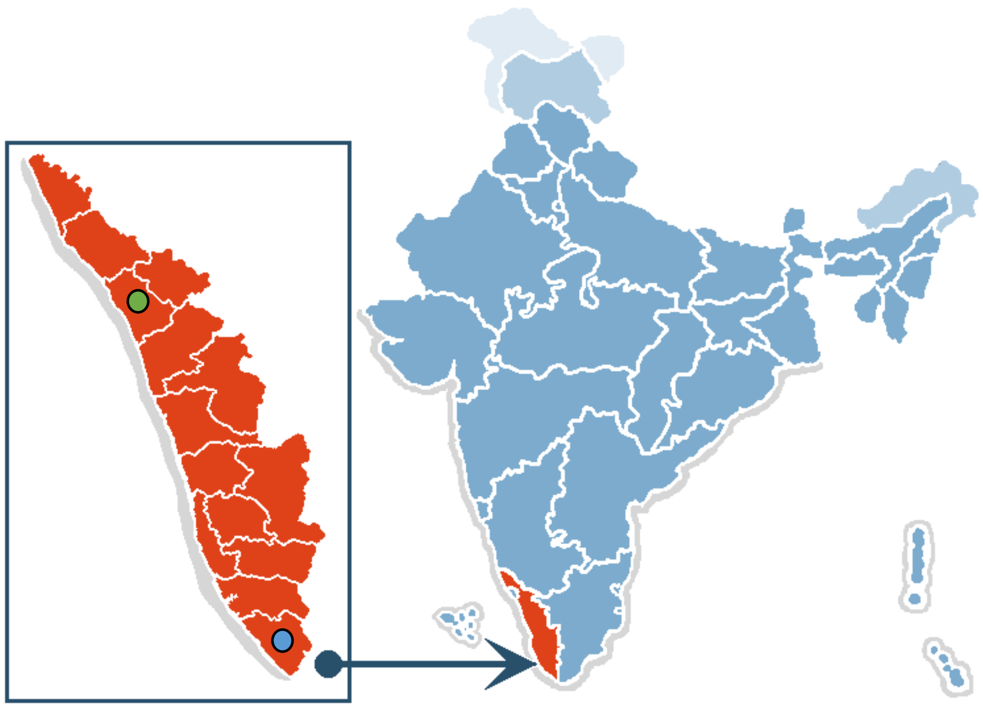
Taylor Asher[1], Dr. Clint Dawson[2],
Dr. Jason Fleming[3], Ashley Kauppila[4], Mark Loveland[2], Dr. Ali Samii[2], Chloe Stokes[5]

[1]Institute of Marine Sciences, UNC Chapel Hill, Morehead City, NC
[2]Institute of Computational Engineering and Sciences, The University of Texas at Austin, Austin, TX
[3]Seahorse Coastal Consulting, Morehead City, NC
[4]Taylor Engineering, Charlottesville, VA
[5]Civil, Construction and Environmental Engineering, North Carolina State University, Raleigh, NC

About Myself

Masters in Offshore Structures
2012, NIT Calicut

Bachelors in Civil Engineering
2009, CET



KERALA

About Myself

Graduate Studies at NC State

Casey Dietrich <jcdietrich@ncsu.edu> Thu, Jan 30, 2014, 11:23 AM
to me

Dear Ajimon:

My name is Casey Dietrich, and I am an assistant professor in the Department of Civil, Construction, and Environmental Engineering at NC State University. I viewed recently your application for graduate studies with a focus in coastal engineering.

My research is in predictive modeling of coastal hazards, especially with respect to hurricane waves and storm surge. I was involved in the response in Louisiana following Hurricane Katrina, and I helped to develop finite-element models of the coastal ocean that were used to evaluate and design surge barriers, and to develop flood risk maps. More recently, I have been running our models to forecast waves and surge in real-time. I have attached a PDF with a short description of my research interests, and you can find more information at my personal Web site (http://www.caseydietrich.com/).

I would enjoy the opportunity to learn more about your interests and answer any questions you may have. Please let me know if you would like to schedule a Skype call during the next few weeks.

Thanks for your interest in NC State.

Casey Dietrich
jcdietrich@ncsu.edu

NCSU Graduate Scholarship Award

Ranji Ranjithan <ranji@ncsu.edu> Mar 11, 2014, 2:47 PM
to me, Renee, Casey

Dear Ajimon,

Congratulations! Based on your strong record, we are very pleased to inform you that the Department of Civil, Construction, and Environmental Engineering (CCEE) has selected you to receive a CCEE Graduate Scholarship award for study toward a PHD in Civil Engineering. This decision was made after a careful review of applications. You were selected in recognition of your promising abilities to conduct research and potential to succeed in our graduate program. Please see the enclosed letter for details.

We hope that the educational opportunities we provide and the scholarship award will allow you to make an early decision to begin your PHD studies at NC State. The official deadline for your written response is April 15; however, if possible, we would truly appreciate your decision at an earlier date.

We look forward to you joining our program and letting us help foster your professional development and career in coastal engineering. If you have any questions in the meantime, please do not hesitate to contact us.

Sincerely yours,

Ranji Ranjithan

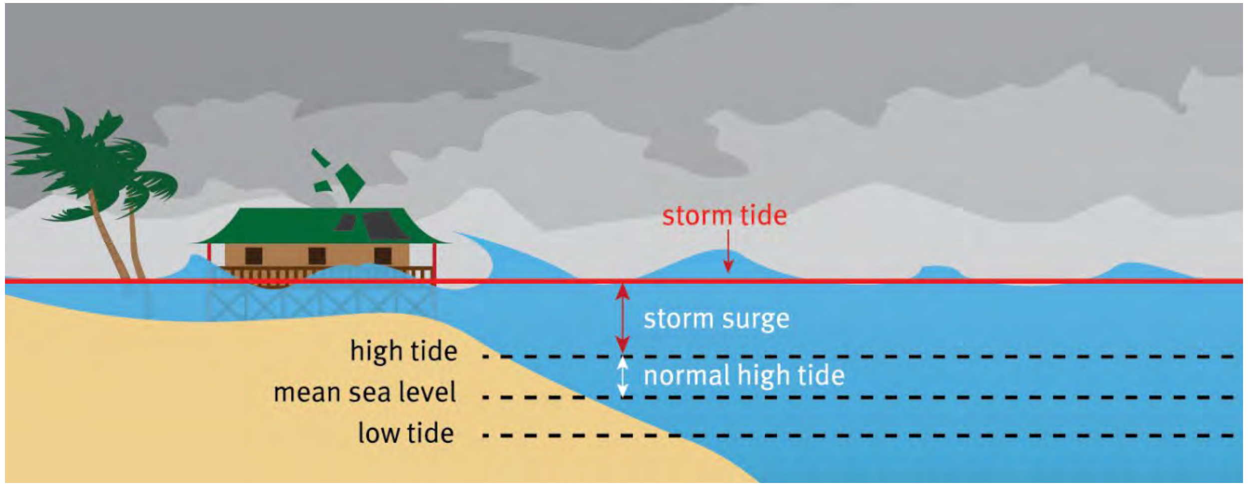
Ph.D. in Civil Engineering, NC State University
Arrived in Raleigh in Fall 2014

Outline

- Introduction
- Case Study
- Background and Motivation
- FEMA-SAB Mesh Development and Validation
- Multi-Resolution Approach
- Summary and Conclusion

Storm Surge

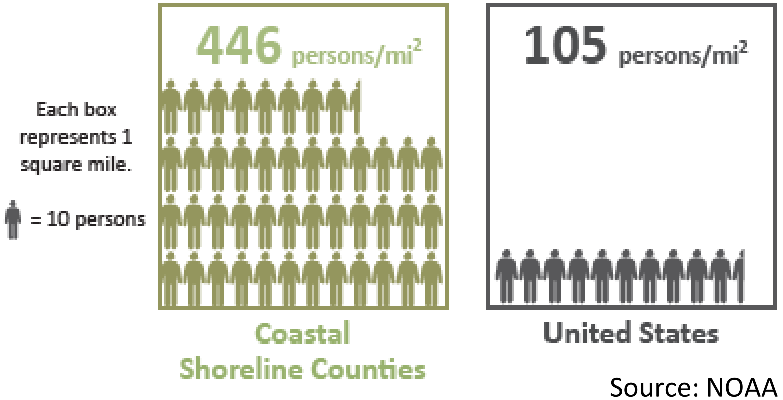
- Height of the water above the normal predicted astronomical tide
- Large-scale features
  - the intensity, size, speed, and path of the storm, the general configuration of the coastline, bottom topography near the coast, the stage of the astronomical tide
- Small-scale features
  - convergence or divergence in bays and estuaries, local wind-setup, seiching



Source: ivaluesafety.com

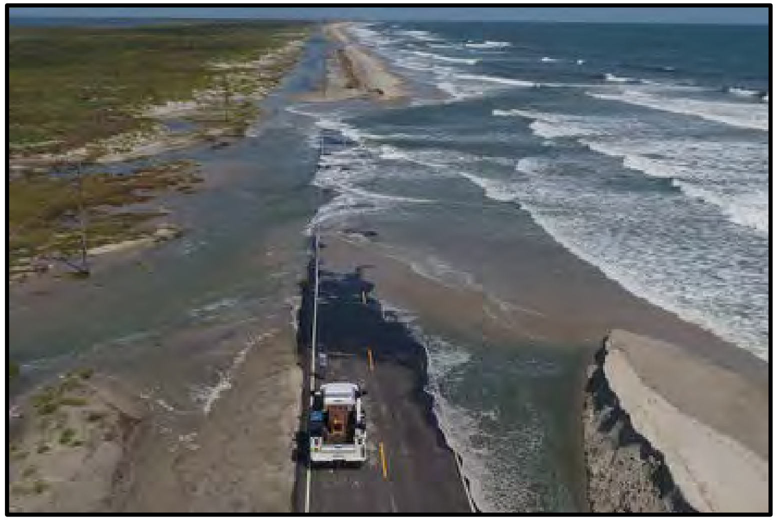
Importance of Storm Surge Modeling

- 44 % of the worlds population live within 150 km of the coast (UN Atlas of the oceans, 2018)
- In the U.S., > 39 % (123.3 million) of the population lived in coastal shoreline counties in 2010 (NOAA and U.S. Census Bureau, 2013)



Source: NOAA

Source: ABC News



Source: The Weather Channel

Numerical Modeling of Storm Surge

Central pressure to calculate max surge

Hoover, 1957

Conner et al. 1957

Improvements

Tancreto, 1958

Wave heights
stratifying cyclones acc. to wind dir.

Harris, 1963

computer-aided empirical model
wind, pressure, Coriolis, waves, rainfall

Pore, 1964

multi-station surge models

Chan and Walker, 1979

approach paths

Computing power

SPLASH
(Jelesnianski, 1972)

Computed peak surge
via nomograms

TTSURGE
(Dresser et al. , 1985)

FEMA
Finite-difference model
Rectangular and nested grids

SLOSH
(Jelesnianski et al., 1992)

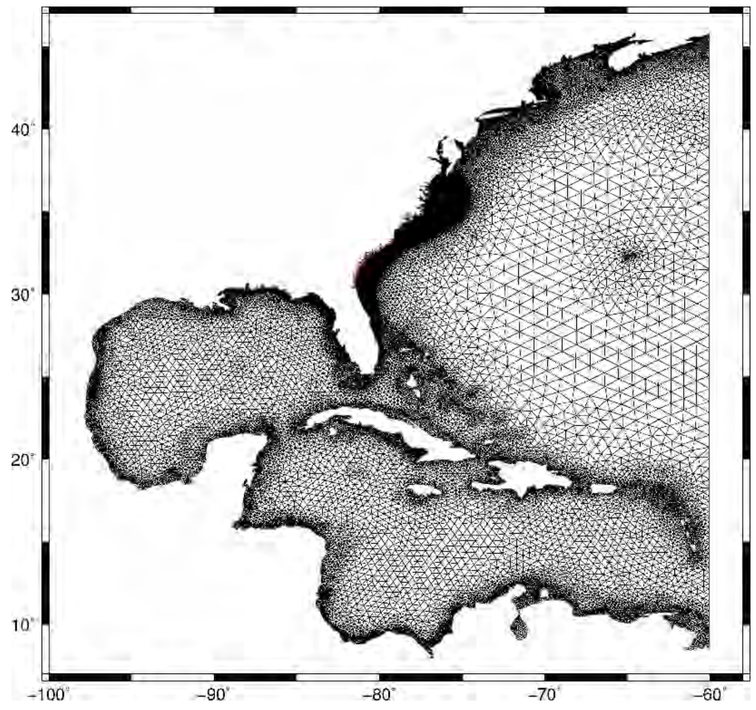
NWS
Computationally efficient, small coverage, structured mesh,
does not model wave impacts or tides

ADCIRC
(Luettich et al., 1992)

FEMA in the development of FIRMs,
USACE for navigation & storm protection projects
NOAA for tidal calibrations

Storm Surge Modeling using ADCIRC

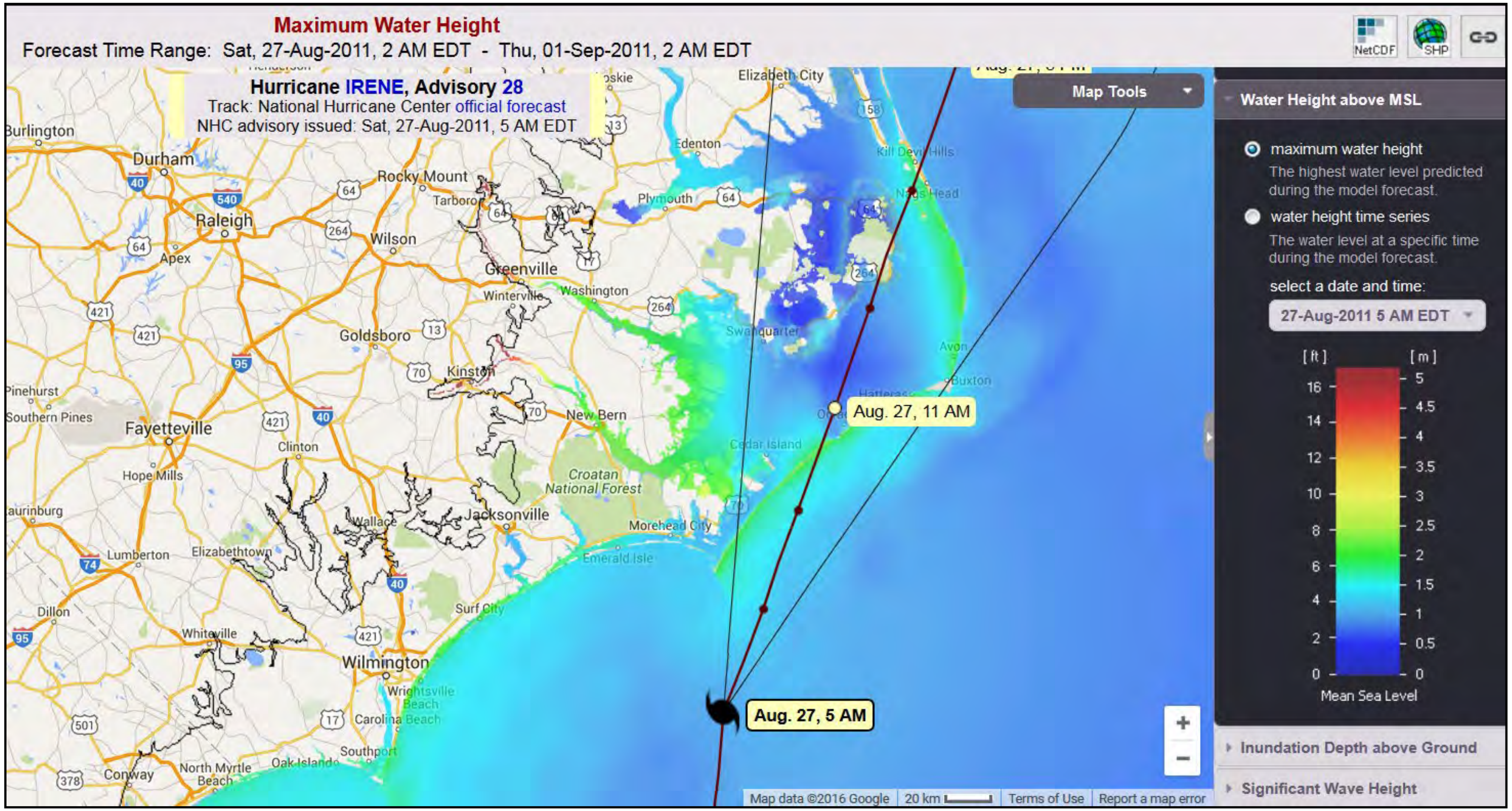
- ADvanced CIRCulation
- Finite-element model for oceanic, coastal and estuarine waters
- Unstructured meshes are used to represent relatively small features while maintaining coarser resolution elsewhere in a large domain
- Solves water levels using the Generalized Wave Continuity Equation (GWCE) and the velocities using vertically-integrated momentum equations
- Two-dimensional depth averaged version (2DDI) is commonly used in modeling of storm surge and flooding



Storm Surge Forecasting using ADCIRC

- ADCIRC Surge Guidance System (ASGS) provides forecast guidance for winds, waves and storm surge during a hurricane, especially for the coastlines of NC, LA, and TX
- Done by running ADCIRC on high performance super computers
  - Texas Advanced Computing Center (TACC) at University of Texas, LONI Network at Louisiana State University, Renaissance Computing Institute (RENCI) at University of North Carolina
- For NC Coast, ADCIRC is run twice daily during normal conditions, and four times daily during severe storms
- Different meshes are used depending on where the storm is at that point in time
- Coastal Emergency Risks Assessment (CERA) (https://cera.coastalrisk.live)
  - an interactive visualization tool that integrates modeled results with measured data
  - presentation of results to emergency managers, decision makers, and the scientific community

Storm Surge Forecasting using ADCIRC



Hurricane Irene, 28th Advisory

Outline

- Introduction
- **Case Study**
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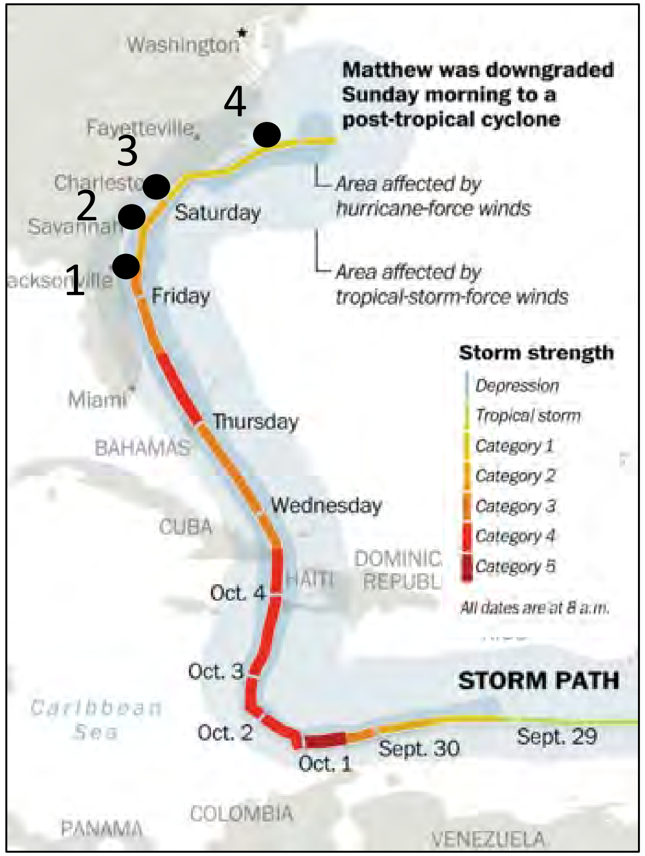
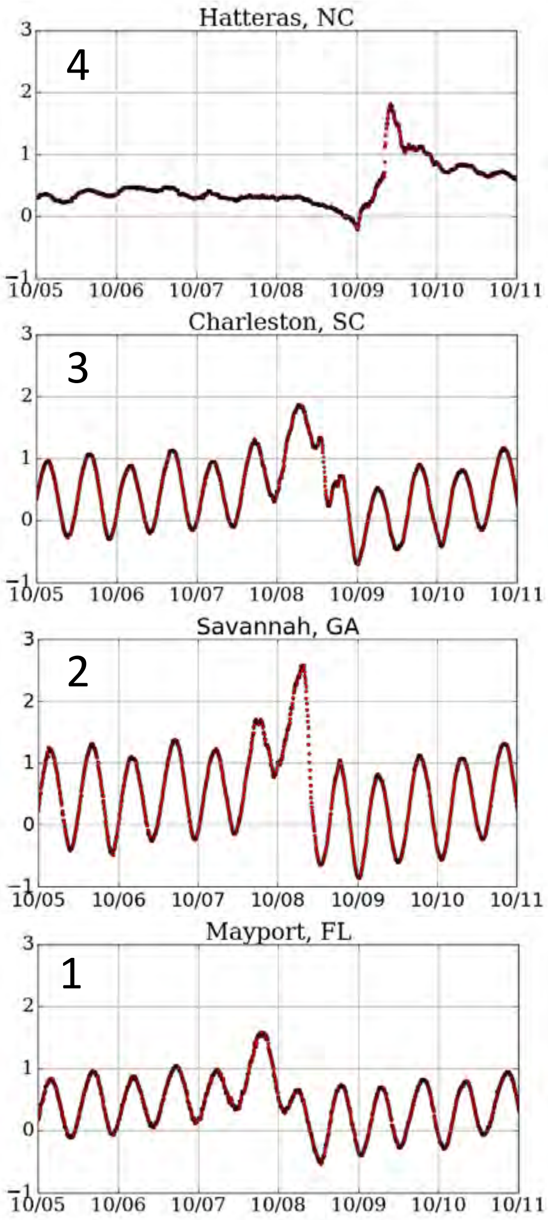
Hurricane Matthew

- Category-5 storm
- Impacted the south-east coast of the U.S. during October 2016
- Caused 34 direct deaths and forced evacuations by 3 million people
- Shore-parallel storm
- Large variations in water levels lasting several days

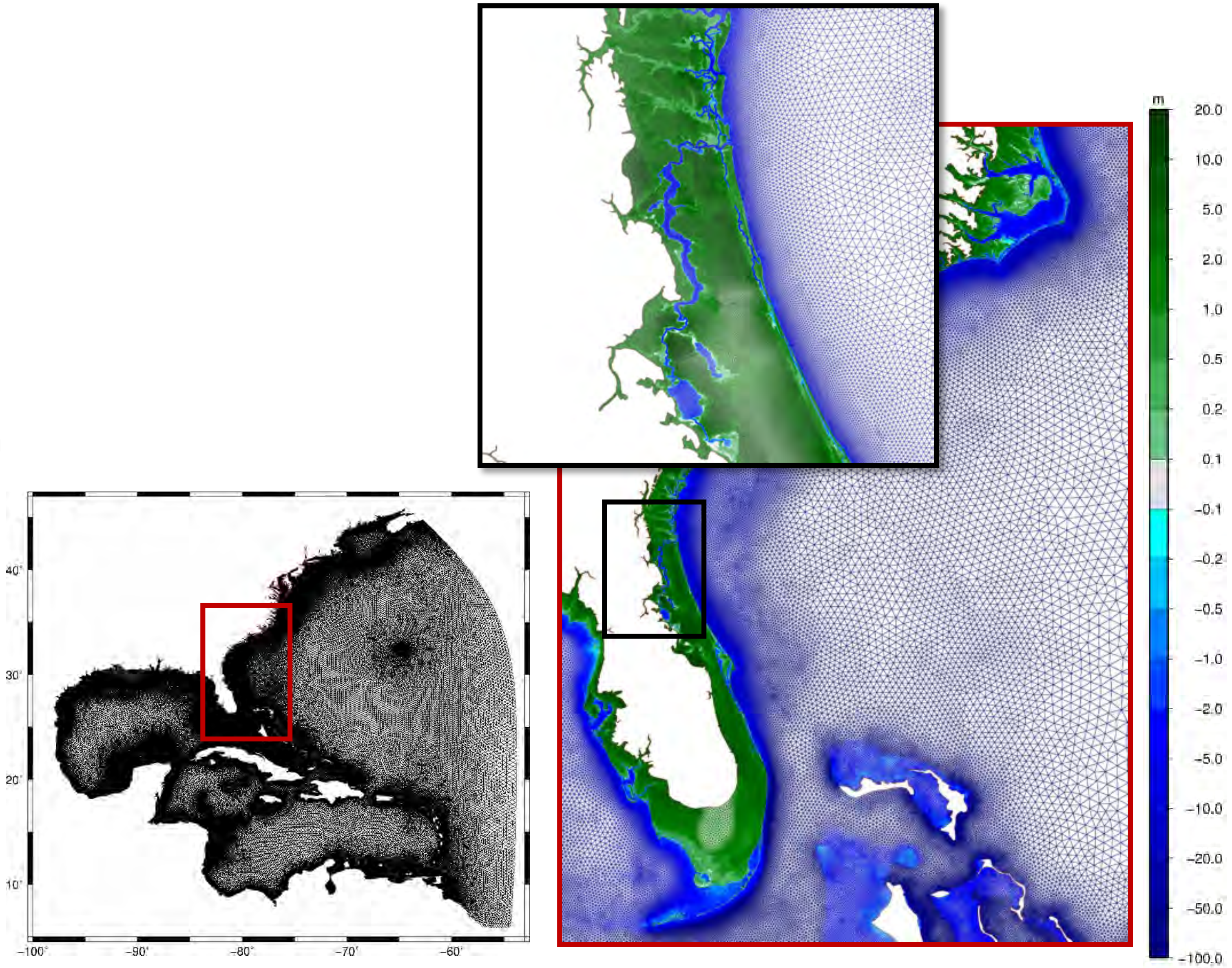




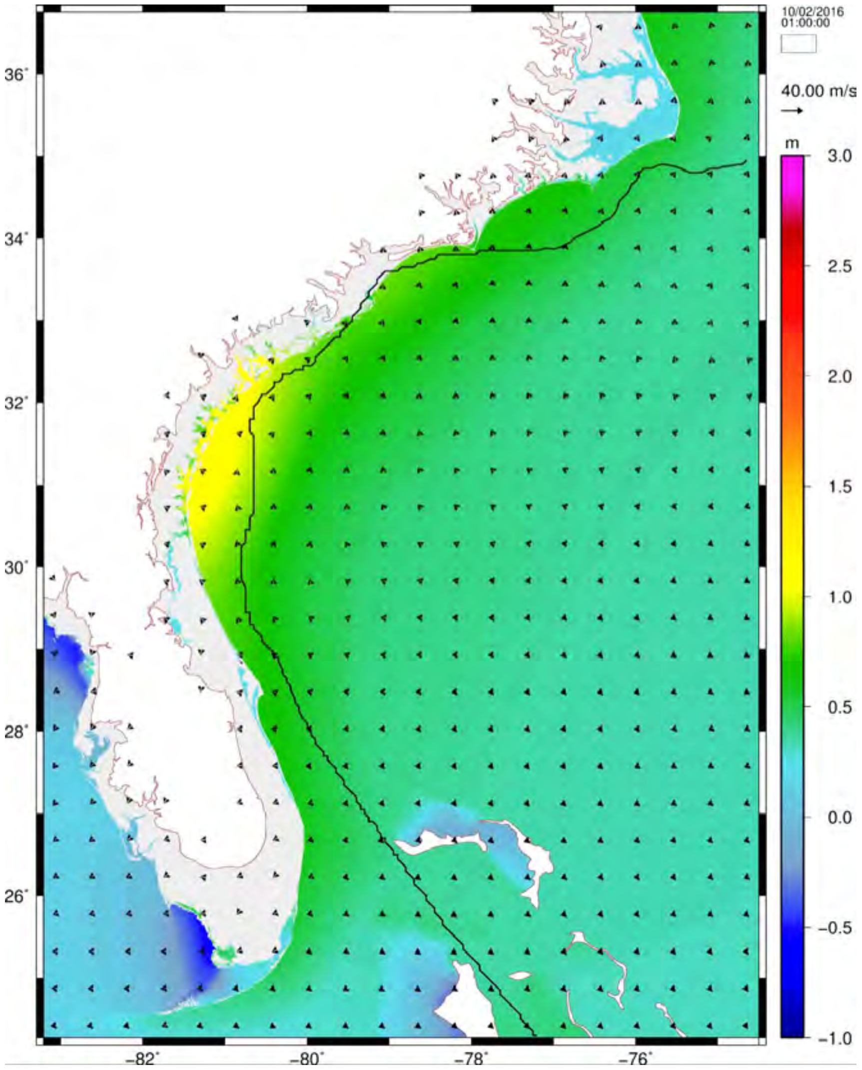
Water Levels in m (NAVD88)

Methods

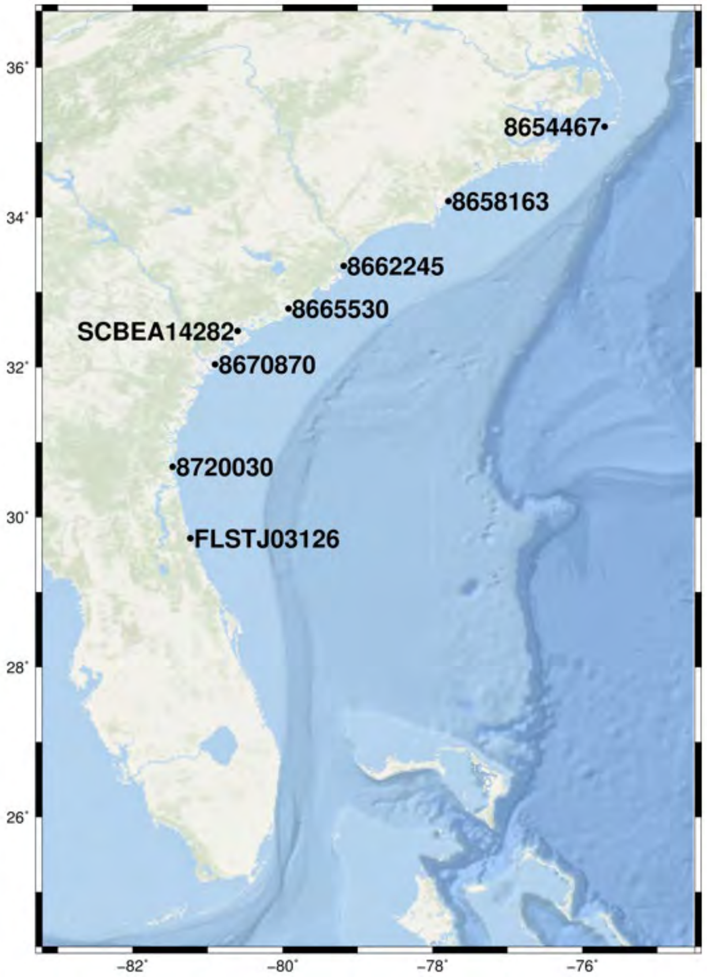
- ADCIRC + SWAN
- OWI Winds
- Offset Surface
- HSOFS Mesh
    - 500 m average coastal resolution
    - 1.8 million vertices

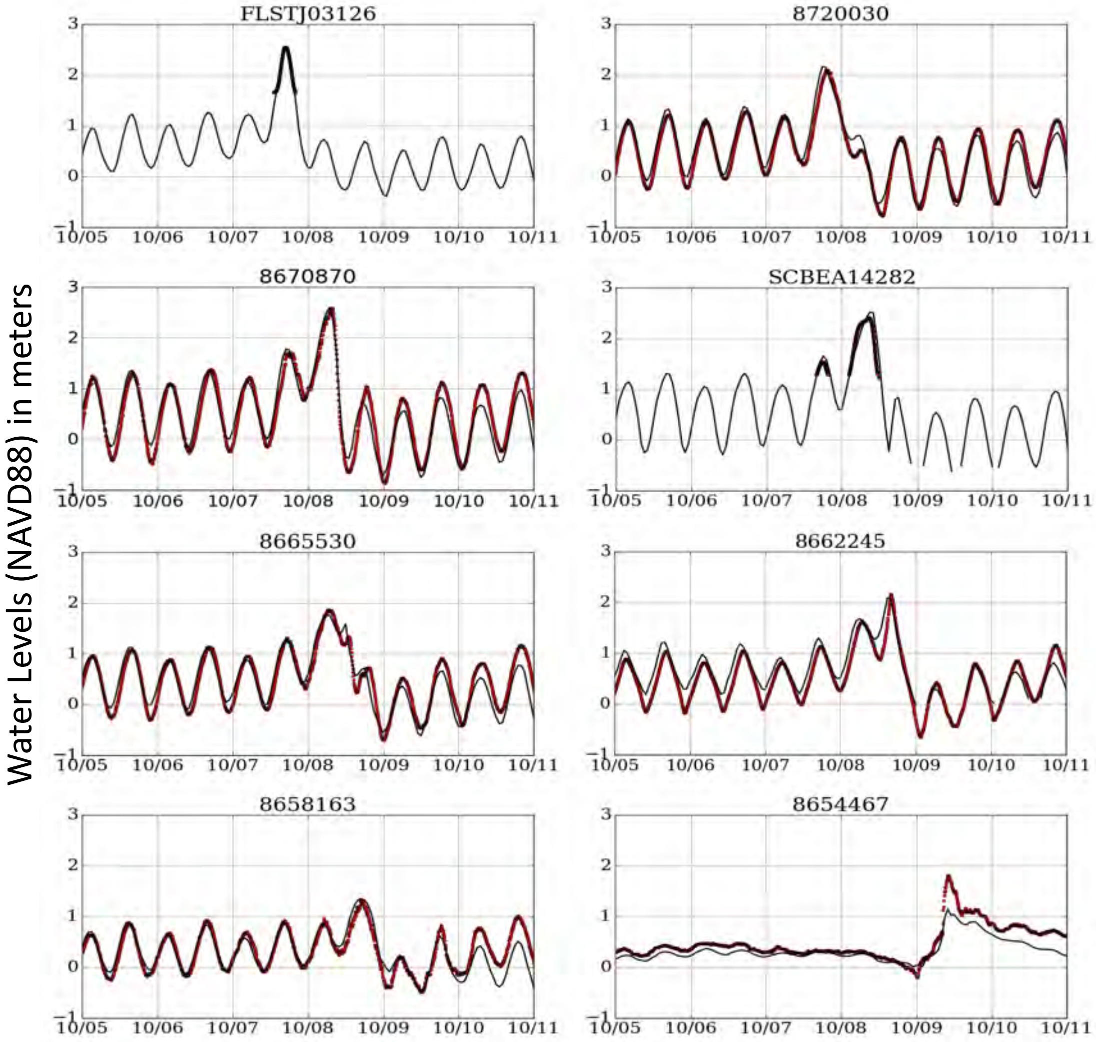


Results – Water Levels



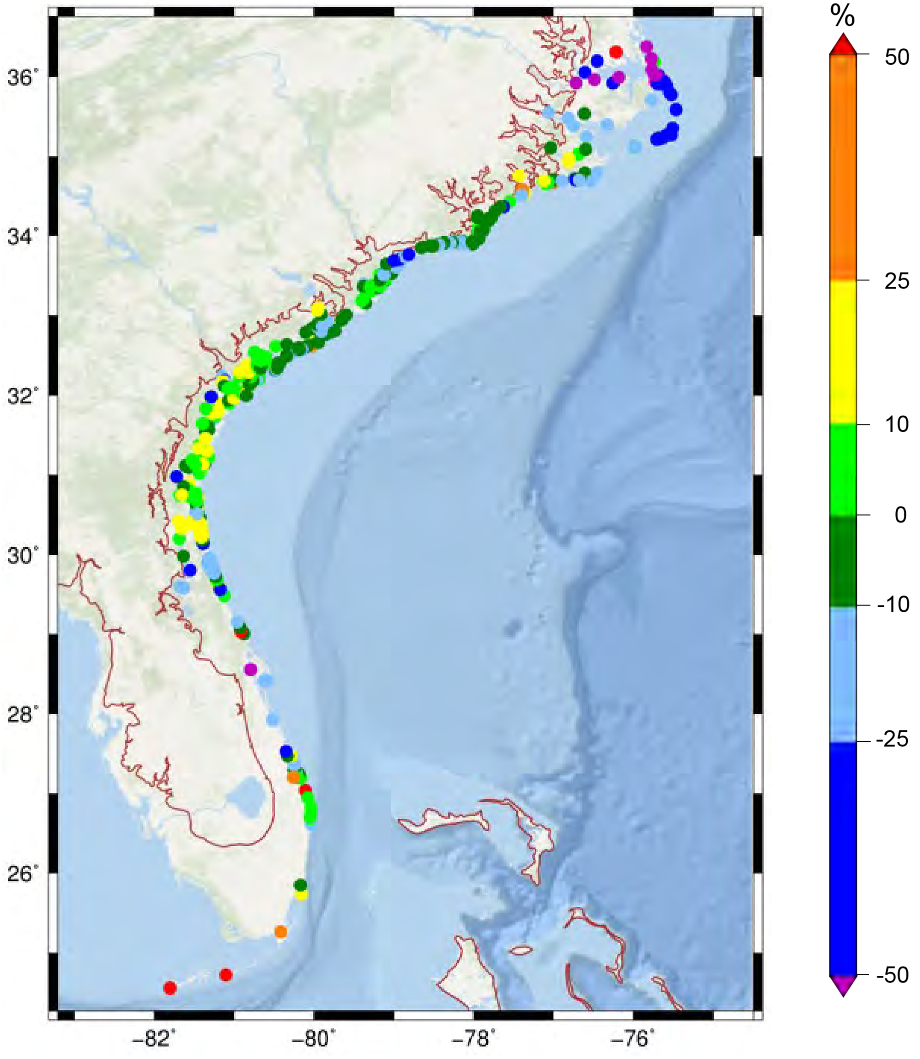
Model Validation – Water Levels

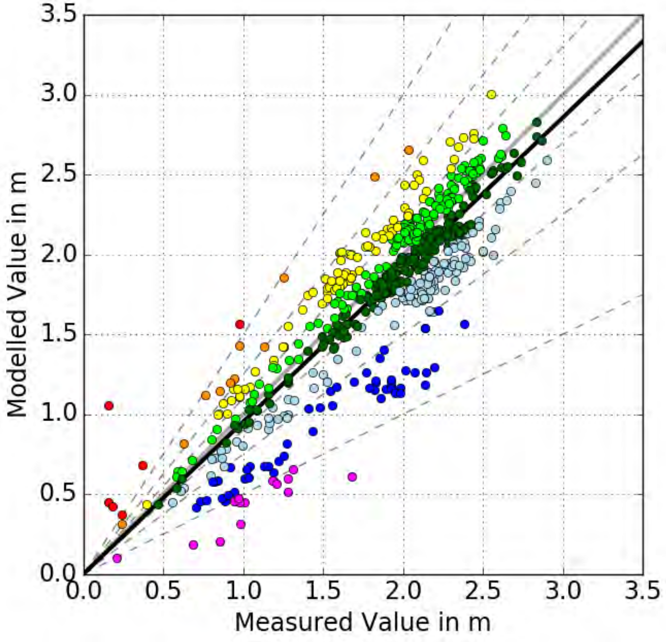




241 stations, RMSE of 0.28m, Bias of 0.04

Model Validation – High Water Marks





622 peaks
R^2 = 0.78
RMSE = 0.28m
Bias = -0.04
Best fit slope = 0.95

Summary

- Even on the relatively coarse HSOFS mesh, the ADCIRC+SWAN model does a remarkable job of capturing the Matthew's impact all along the U.S. southeast coast
- The effects of storm timing and forward speed on flooding

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.

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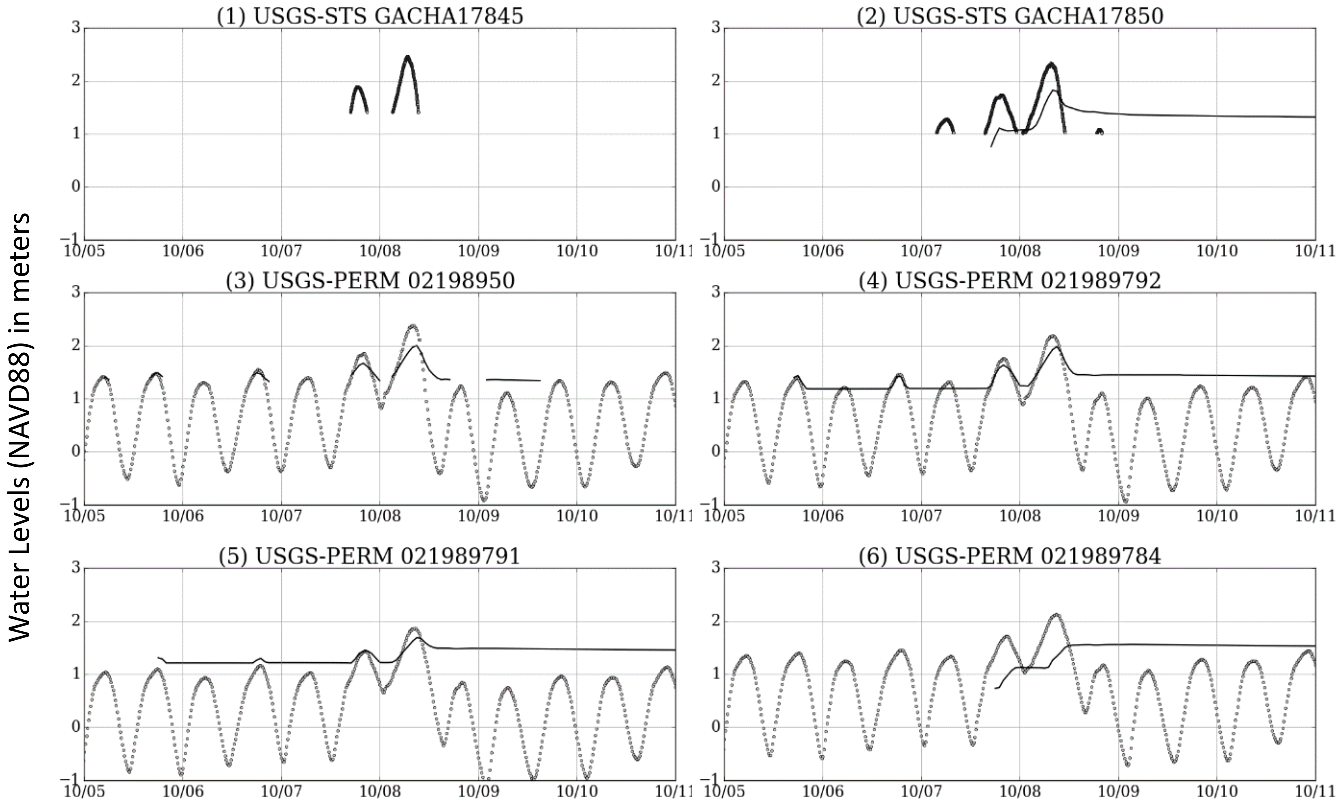
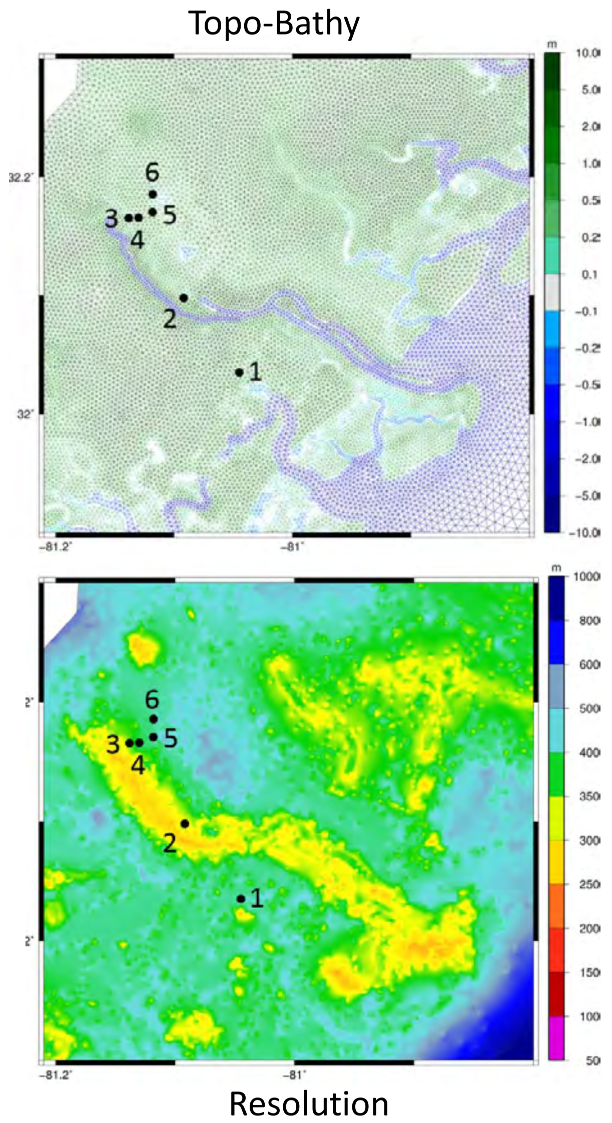
Motivation - Need for Higher Resolution

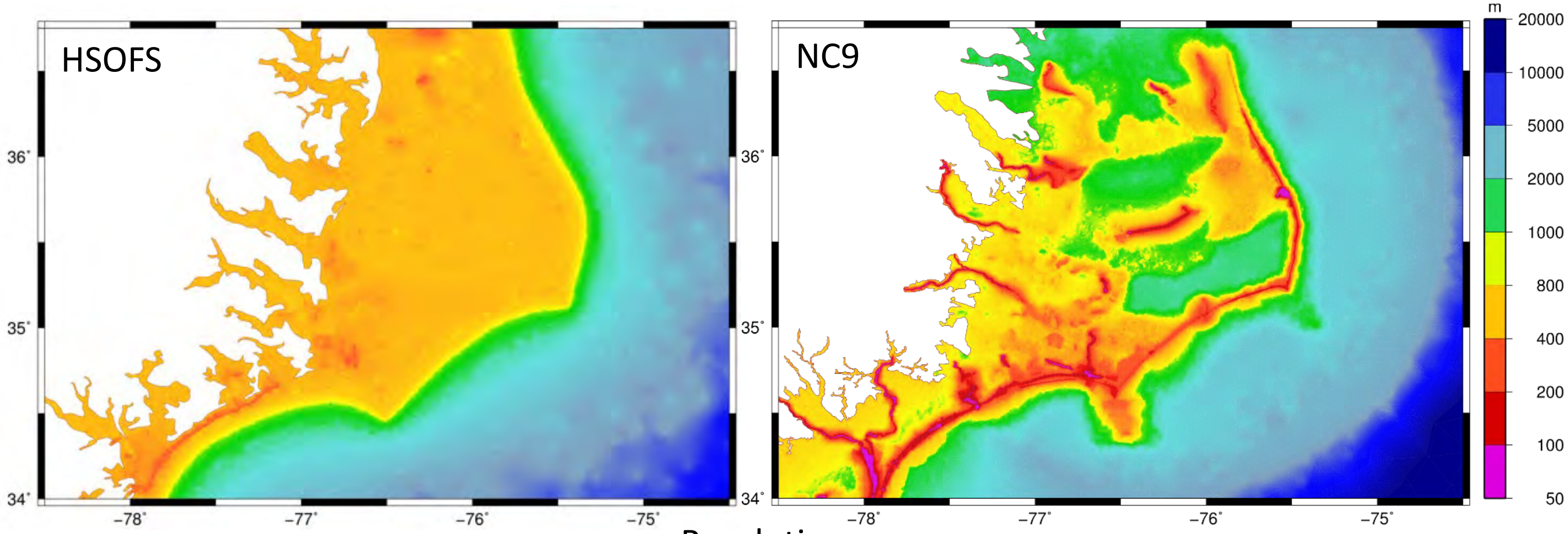
1) Experience from hindcasts of Hurricane Matthew





Motivation - Need for Higher Resolution

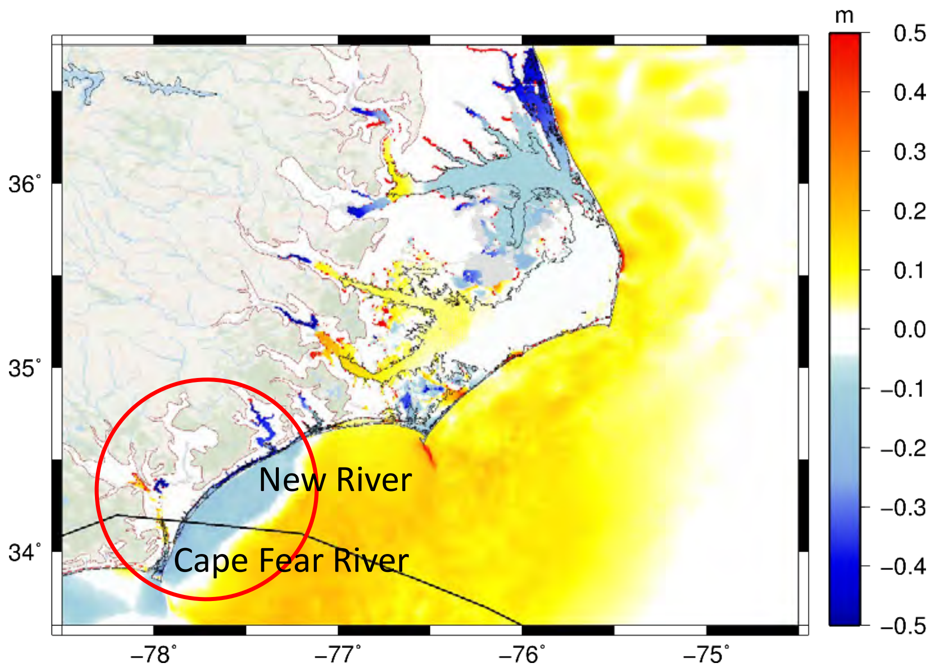
2) Forecasting during Hurricane Florence (2018)
   - HSOFS mesh was used when the storm was far away (up till Advisory 41)
   - As the storm approached the NC coast, NC9 mesh was employed (starting from Advisory 42)



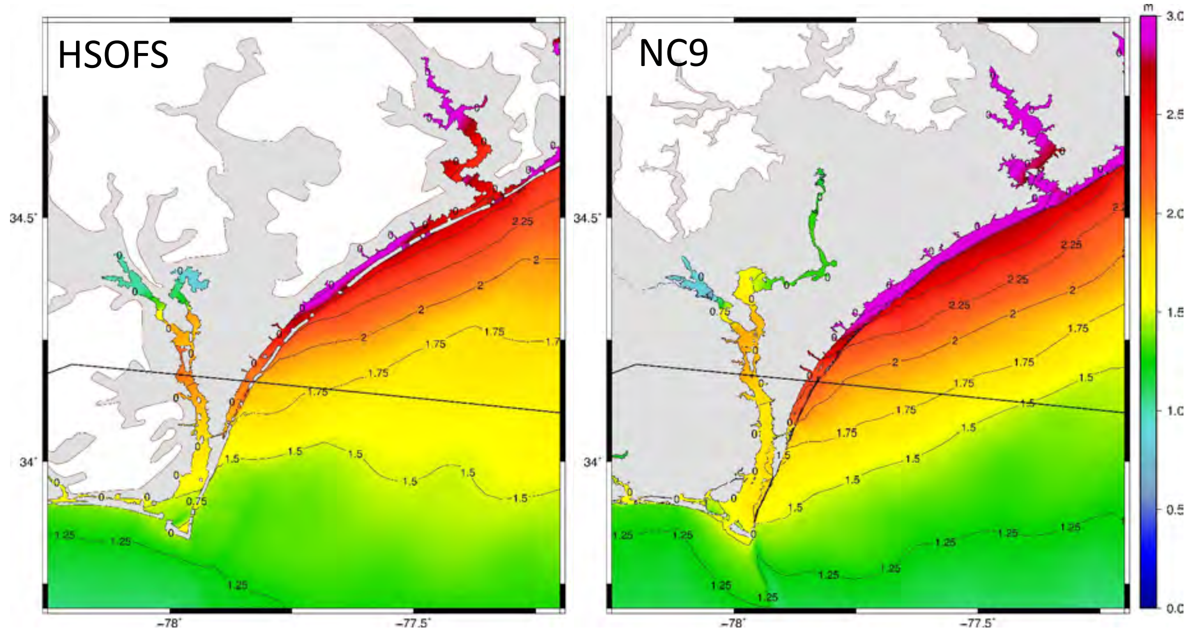
Resolution

Motivation - Need for Higher Resolution

2) Forecasting during Hurricane Florence (2018)



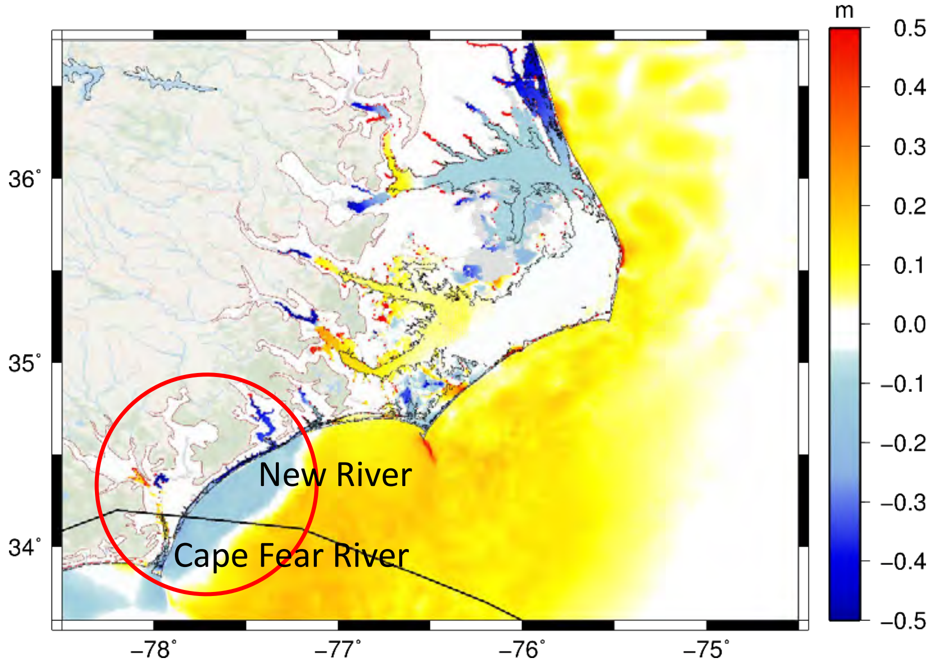
Difference in the HSOFS and NC9 maximum water levels corresponding to Advisory 58



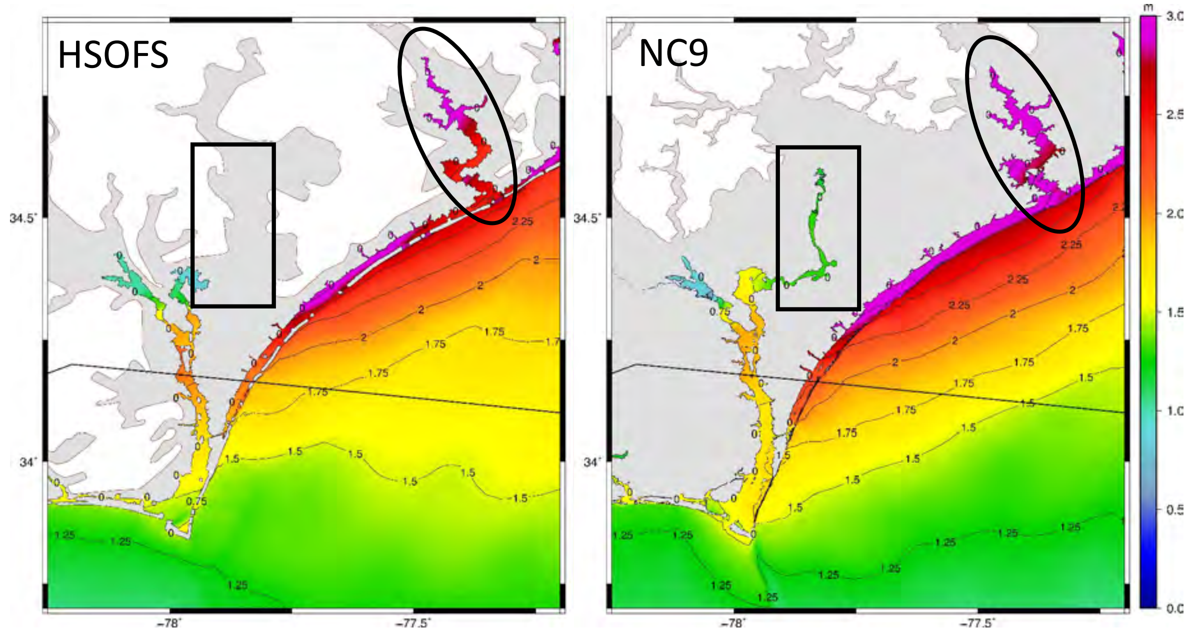
Maximum water levels corresponding to Advisory 58

Motivation - Need for Higher Resolution

2) Forecasting during Hurricane Florence (2018)



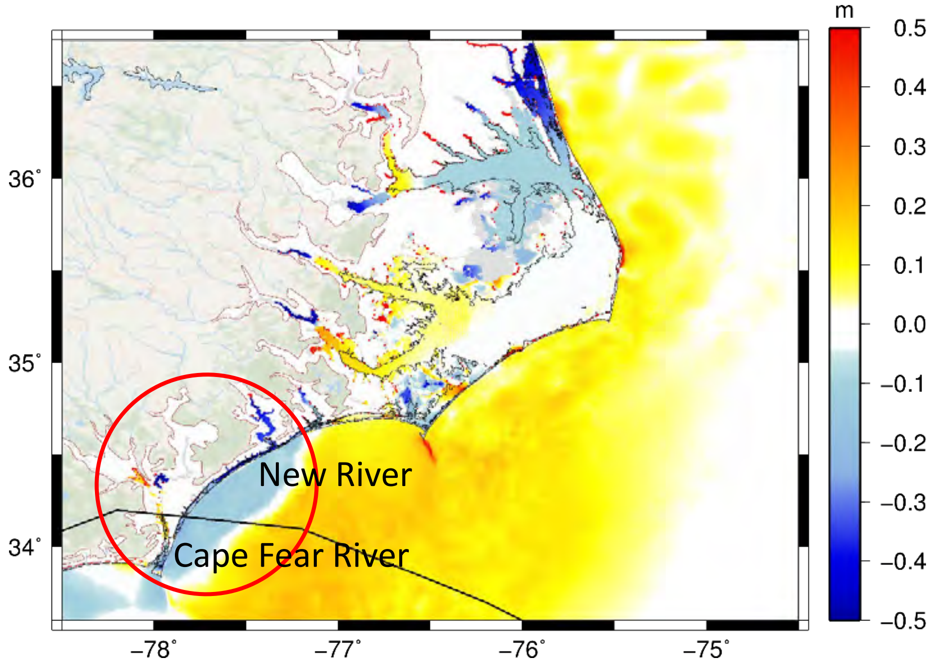
Difference in the HSOFS and NC9 maximum water levels corresponding to Advisory 58



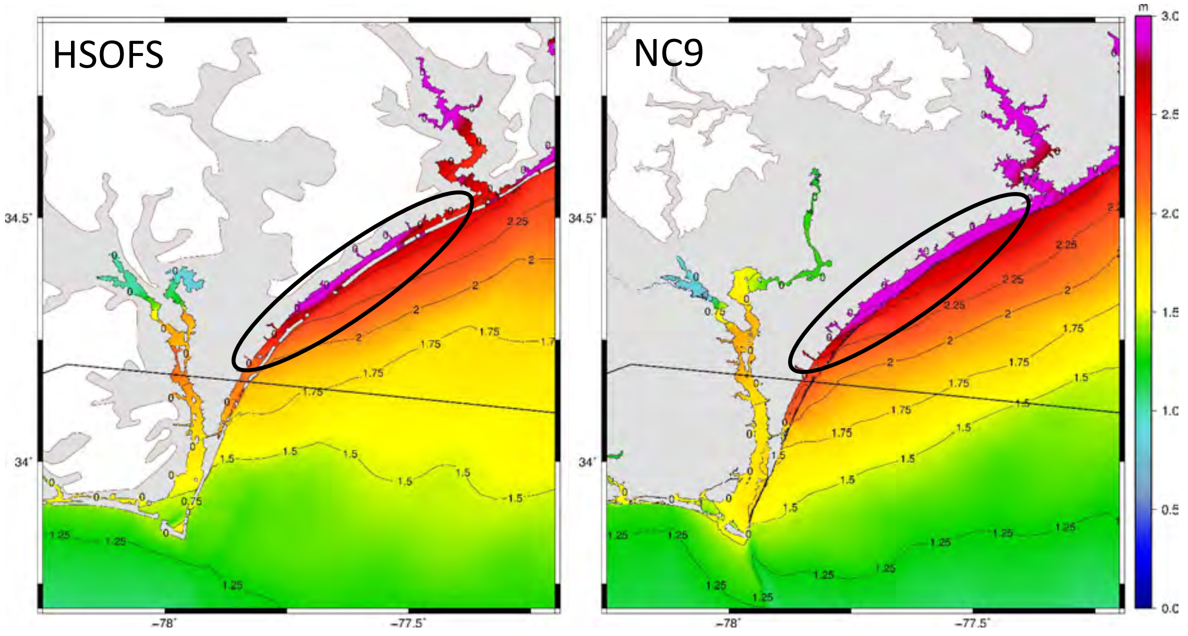
Maximum water levels corresponding to Advisory 58

Motivation - Need for Higher Resolution

2) Forecasting during Hurricane Florence (2018)



Difference in the HSOFS and NC9 maximum water levels corresponding to Advisory 58



Maximum water levels corresponding to Advisory 58

Motivation - Need for Faster Forecasts

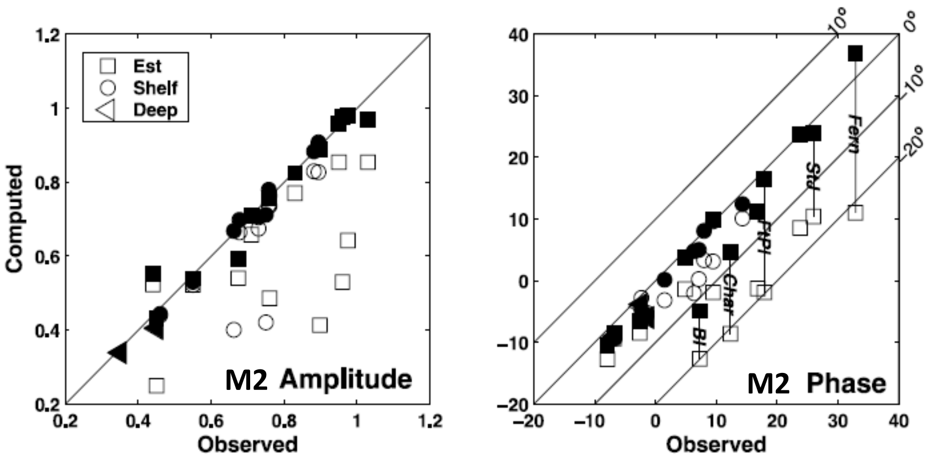
1) Ensemble Possibilities
   - For each advisory, there is uncertainty in the storm parameters, which translates directly into uncertainty in the predicted surge
   - SLOSH computes Probabilistic Storm Surge in real-time
     - Includes uncertainty in track/landfall location, forward speed, intensity,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

Motivation - Need for Faster Forecasts

2) Tropical Storm Bill (2015)
   - Made landfall in southeast Texas
   - As the storm developed in the Gulf, the CERA team prepared the high-res mesh (6.7 million elements) for the entire Texas coast
   - Tidal spin-up on this mesh even on 1120 cores at TACC, took 18 hours
   - By this time, the storm had already moved inland

Literature Review – Benefits of Resolution

- Required to represent
  - steep gradients in bathymetry like the continental shelf break (Westerink et al., 1992; Luettich and Westerink, 1995; Blain et al., 1998; Hagen et al., 2000)
  - wave propagation in shallow water regions (Hagen et al., 2001)
  - complex topography in overland regions (Westerink et al., 2008)
  - inter-tidal zones that can modify tidal propagation (Blanton et al., 2004; Bacopoulos and Hagen, 2017)
- Example – Blanton et al. (2004), studied the influence of the estuary/tidal inlet complex (ETIC) on barotropic tides in the South Atlantic Bight



Open symbols – No ETIC Solution
Solid symbols – ETIC solution

Literature Review – Ways to Provide Resolution

Ways to increase resolution

Adaptive Mesh Refinement (AMR)

use algorithms that dynamically refine the grids spatially, temporally or both, to obtain fine scale solutions in the areas of interest

Sub-domain Modelling

assess local changes without requiring separate full-scale simulations (Baugh et al. 2015; Altuntas and Baugh, 2017)

Multiple overlapping grids (**Nested approach**)

Moving grids - high-resolution grids to move with storms within larger domains with lower resolution (Harrison, 1973; Kurihara et al. 1979; Tolman and Alves, 2005, etc.)

Split elements of the mesh into finer elements on the same mesh

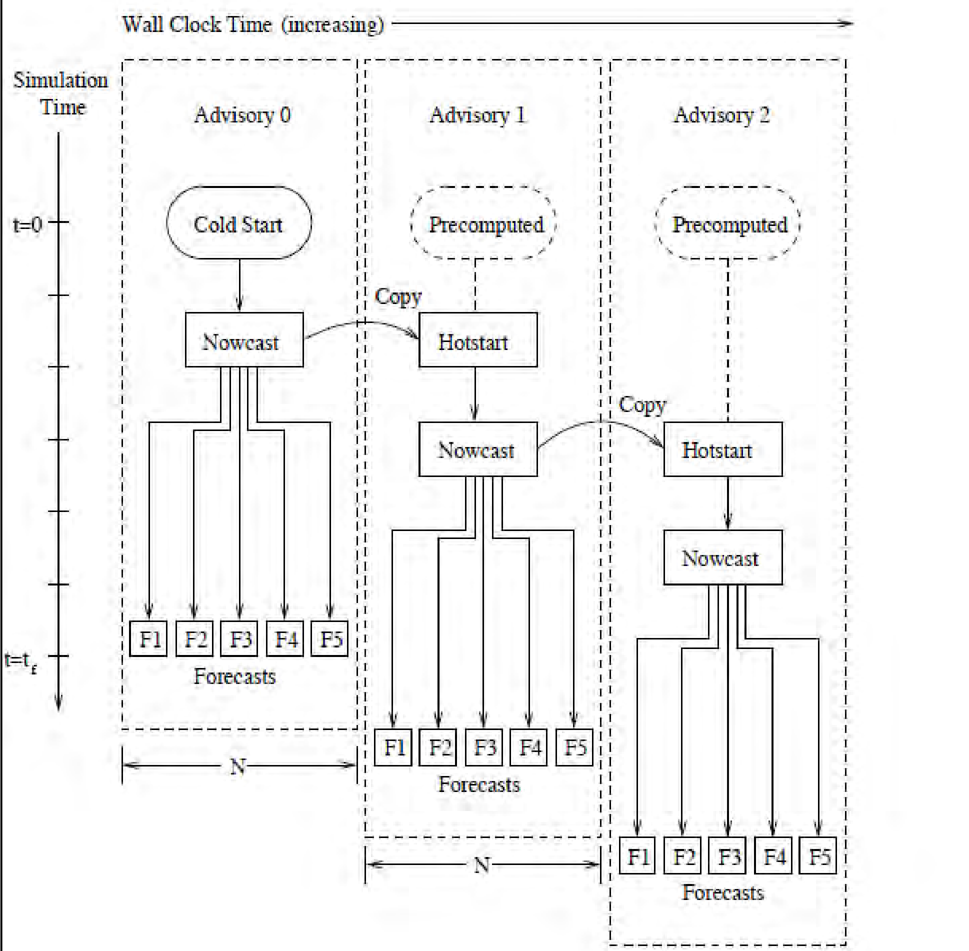
h (grid size) and/or p (polynomial order) refinement (Kubatko et al. 2006), Dynamic h- and/or p-adaptive techniques (Kubatko et al. 2009)

Storm surge modelling (Mandli and Dawson, 2014)

Implemented in the GEOCLAW framework (Berger et. al, 2011) for simulating Ike,
by splitting the elements during the simulation
Much faster, while capturing fine-scale features similar to ADCIRC

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

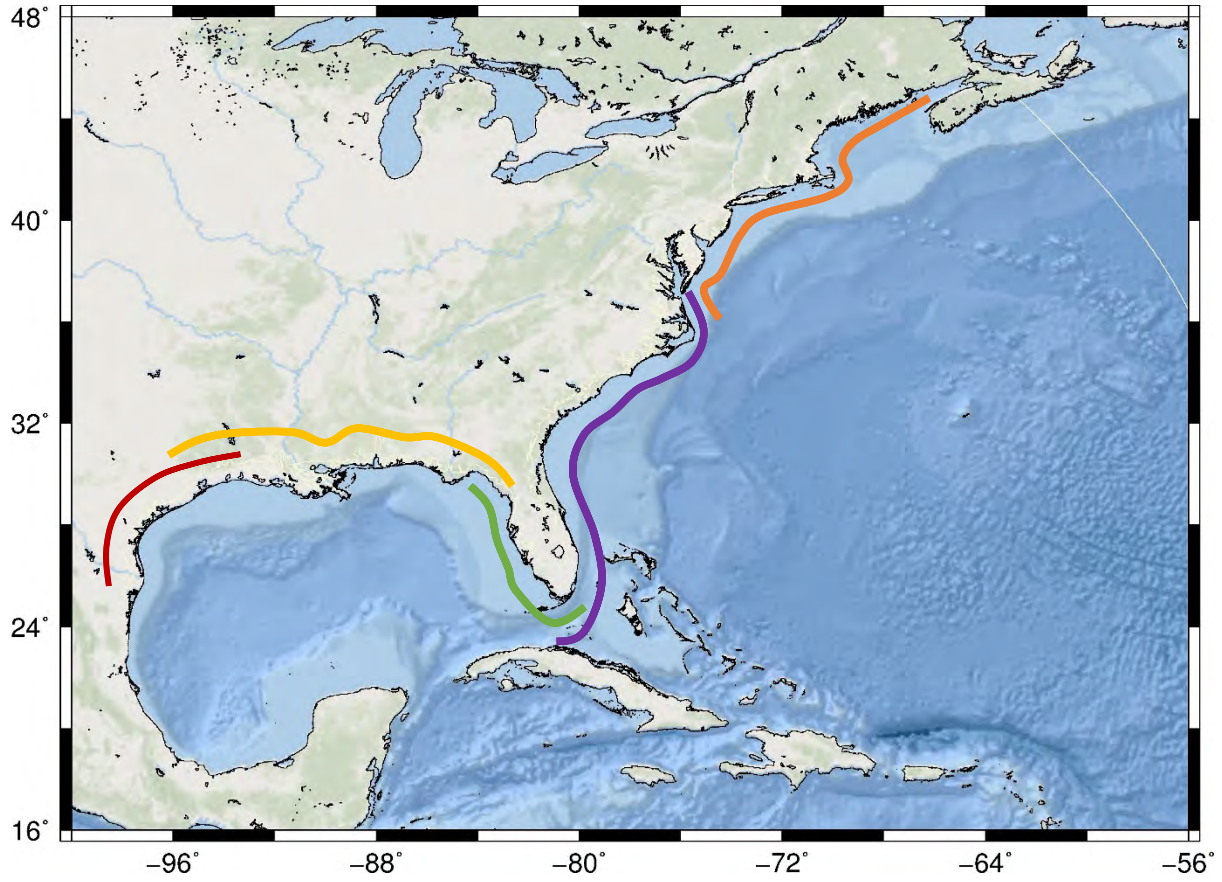
Objectives

- 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

Goal

- Coarse Resolution Mesh
  - HSOFS (1.8 million vertices)
- Fine Resolution Meshes for the U.S. Gulf and Atlantic coasts
  - Each 3-6 million vertices

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



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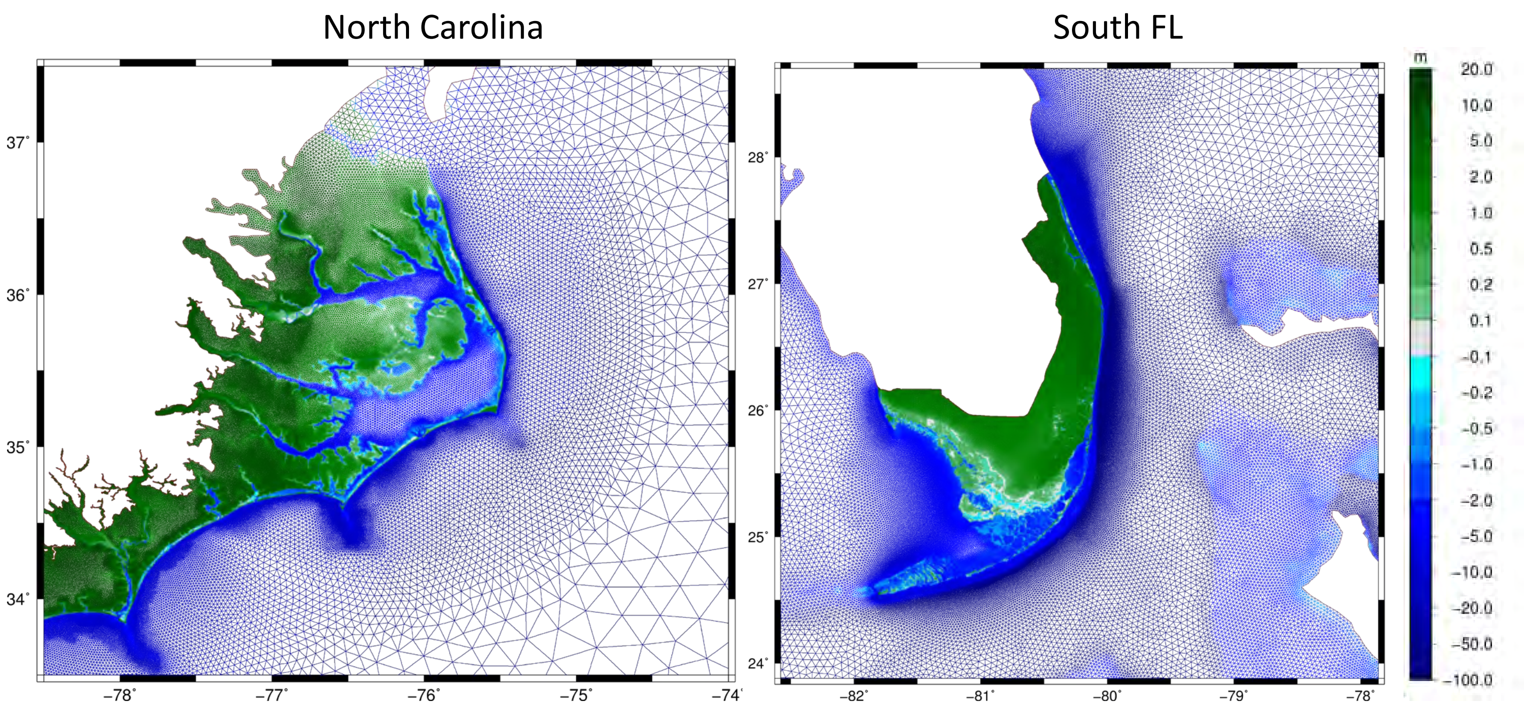
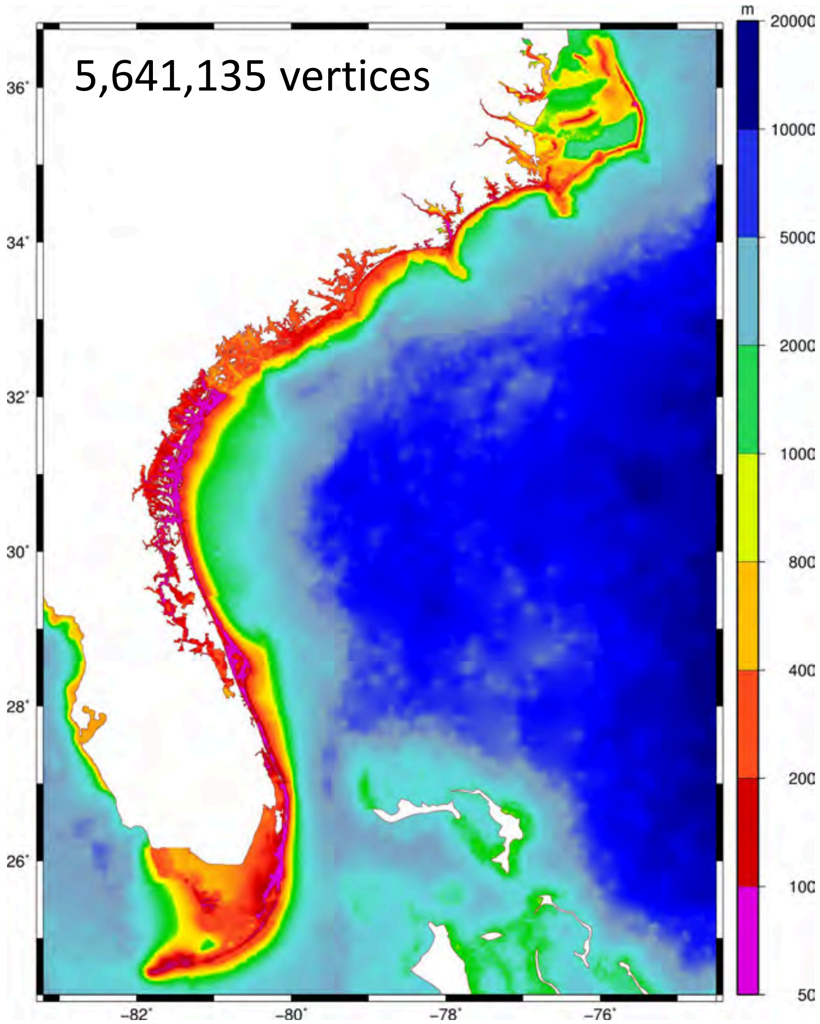
Mesh Development

- 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

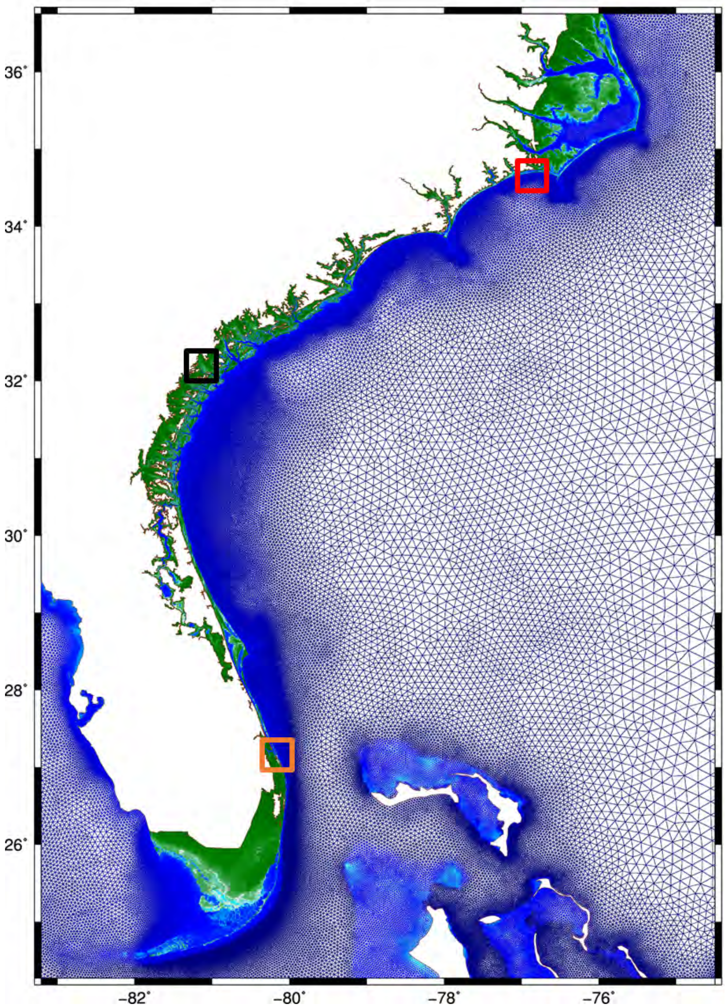


Topo-bathy

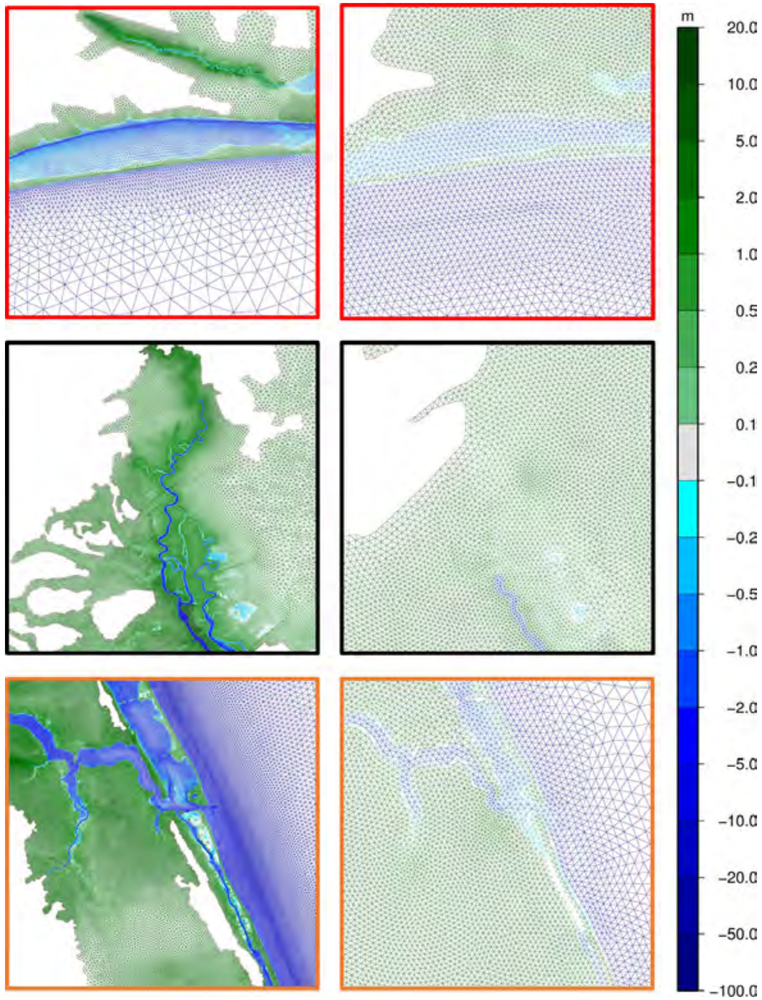
Mesh Development



Element Spacing

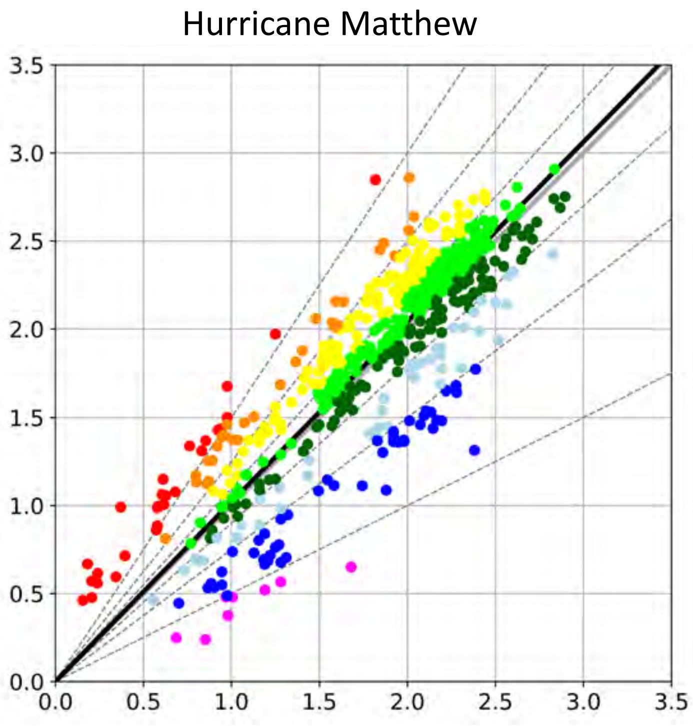


Bathy-topo

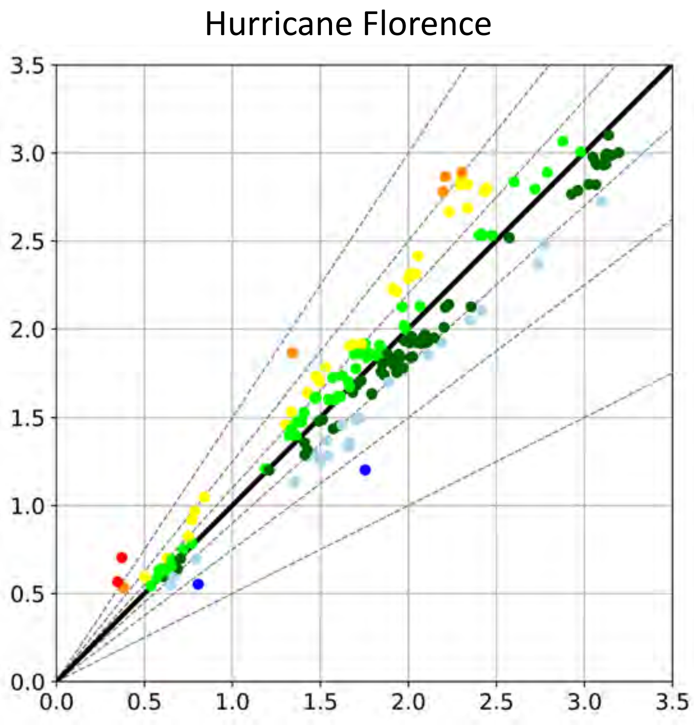


FEMA-SAB HSOFS

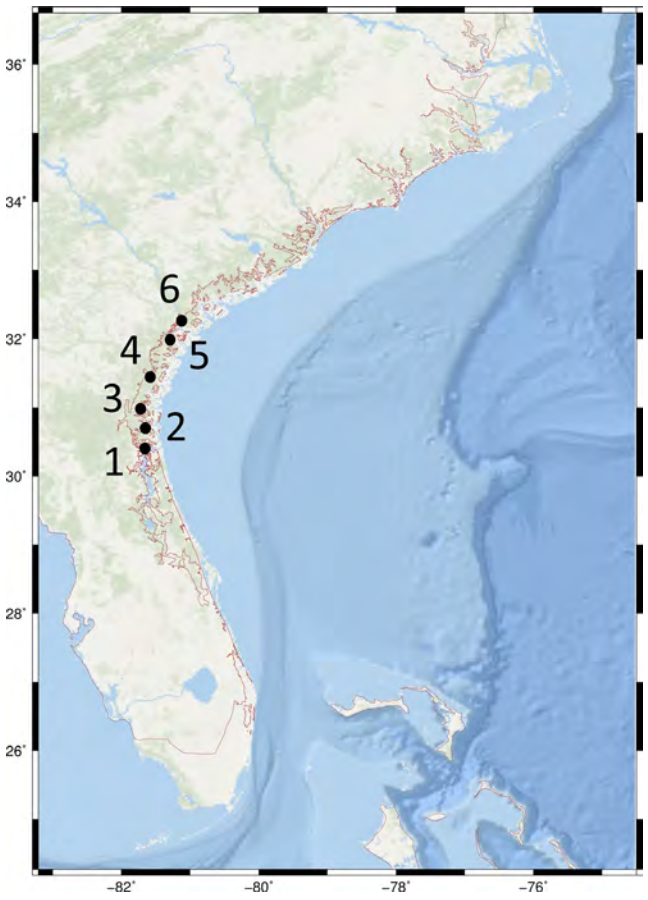
Validation



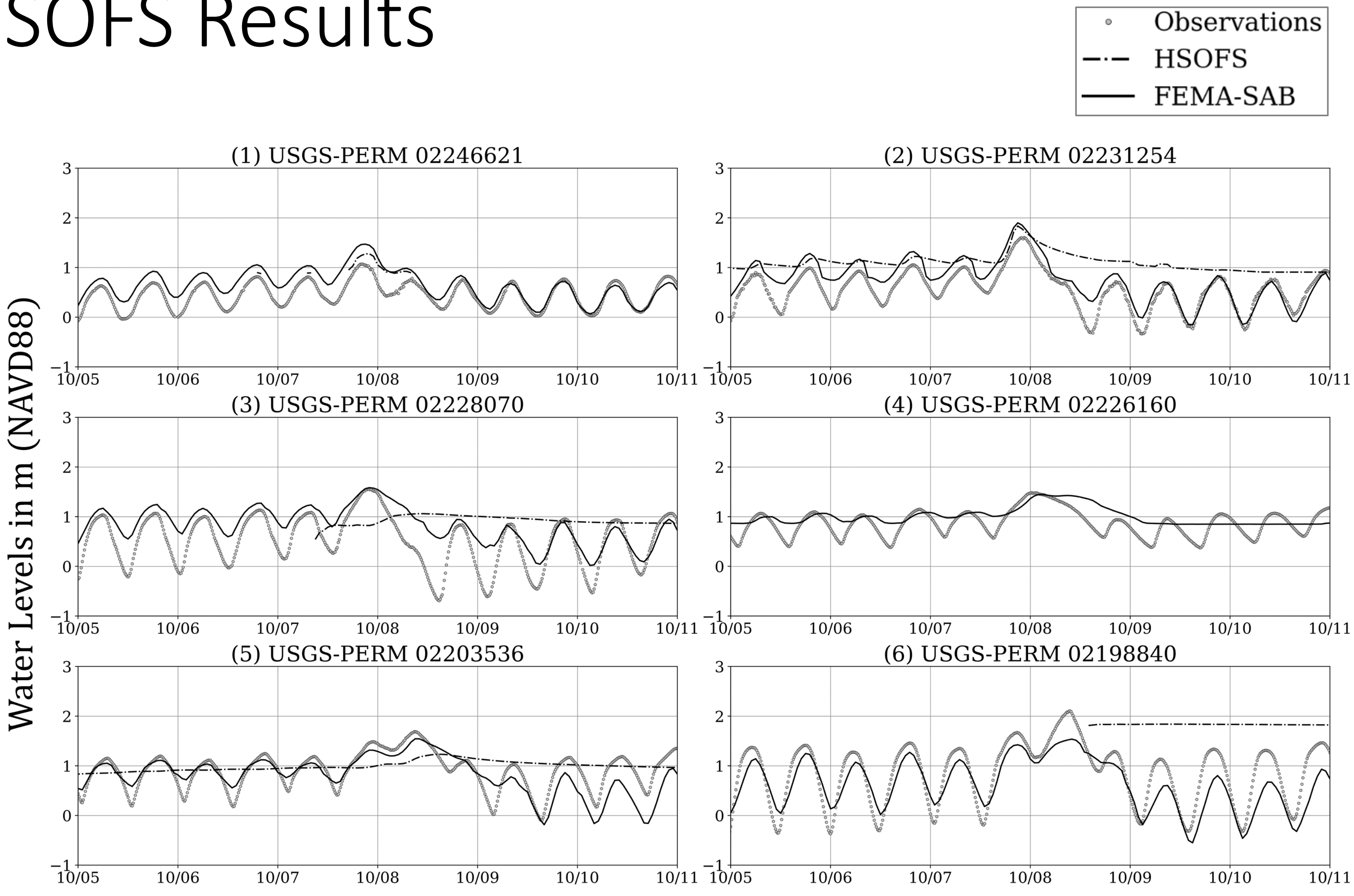
Error	FEMA-SAB	
	Matthew	Florence
Stations	626	190
Best Fit Slope	1.02	1.00
R^2	0.76	0.91
ERMS (m)	0.28	0.20
B_{MN}	0.03	0.01



Comparison to HSOFS Results



Comparison locations for Matthew



Date in 2016

Summary

- FEMA-SAB mesh was validated for Matthew and Florence
- Predictions are better than that using HSOFS, especially inland
  - Better capture tidal signals and/or better match to peak water levels
  - Floods a greater number of observation-locations

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Multi-Resolution Approach

- **Part I – Application of the approach to Hurricanes Matthew and Florence**
- Part II – Optimizing the approach for accuracy and efficiency during Matthew

Steps and Hypothesis

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

Hypothesis

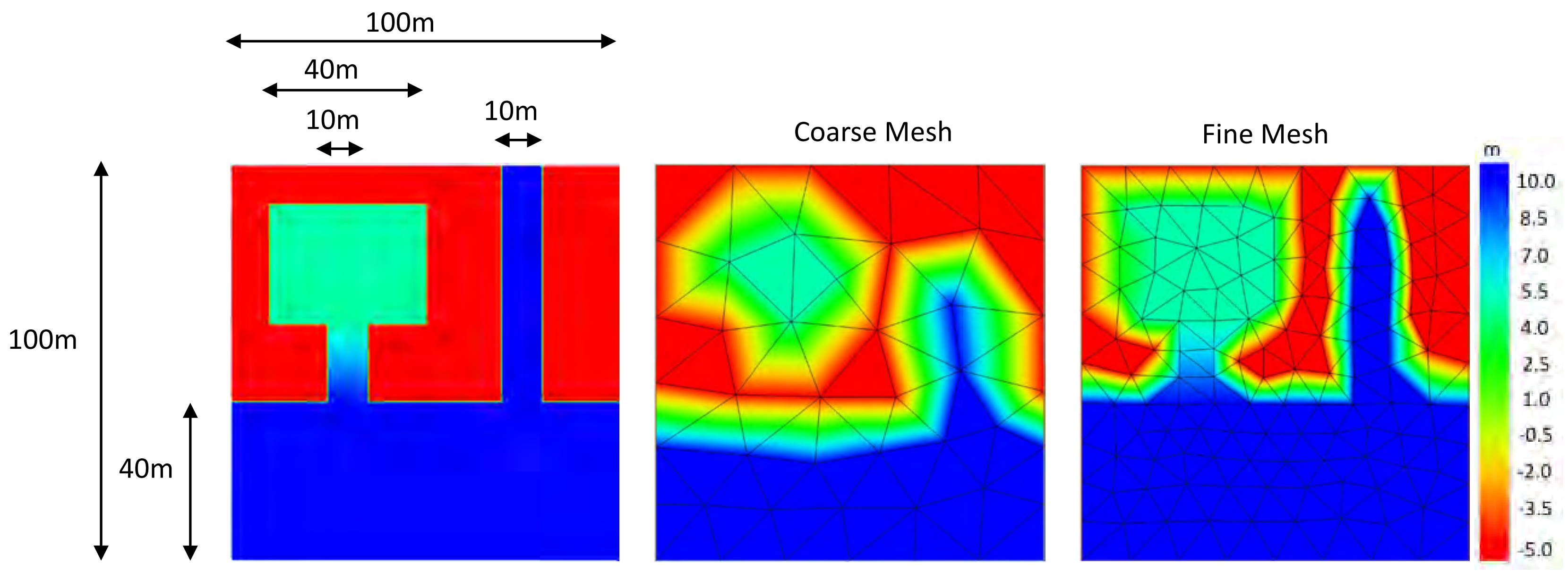
- It is hypothesized that, by `switching' from coarse- to fine-resolution meshes, with the resolution in the fine mesh concentrated only at specific coastal regions influenced by the storm at that point in time, both accuracy and computational gains can be achieved

Adcirpolate

- A toolset for interpolating between meshes
- Developed by our collaborators (Dr. Clint Dawson, Dr. Ali Samii, Mark Loveland) 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

Test Case

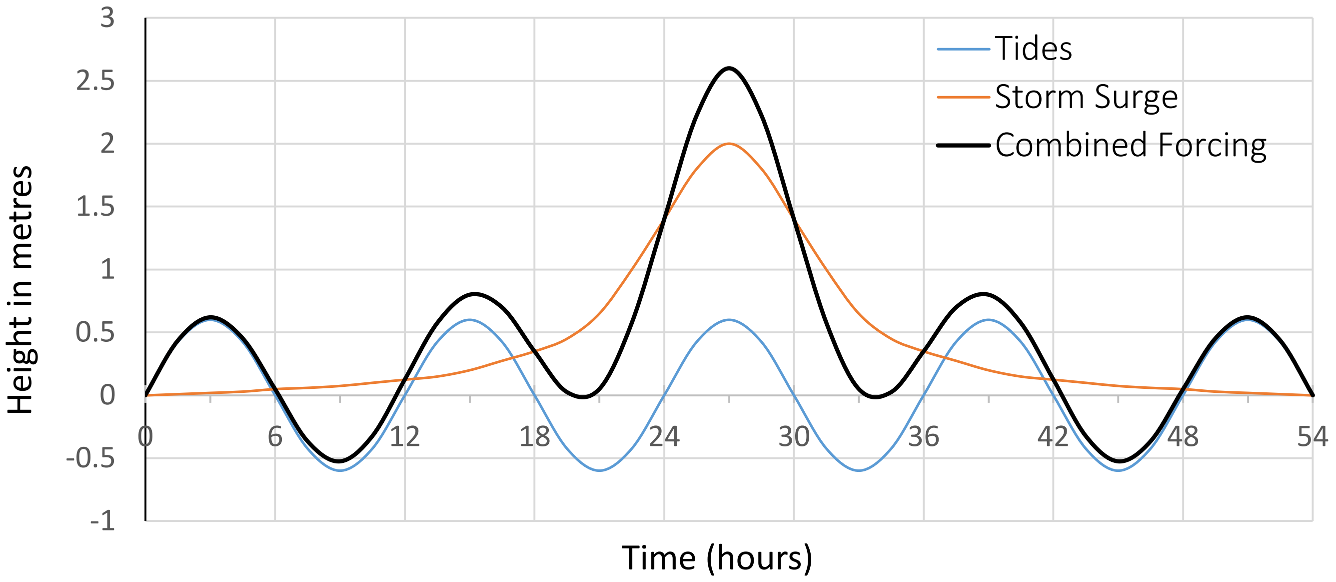
- Scatter at 0.5m resolution
- Average spacing is 20m for coarse and 10m for fine mesh



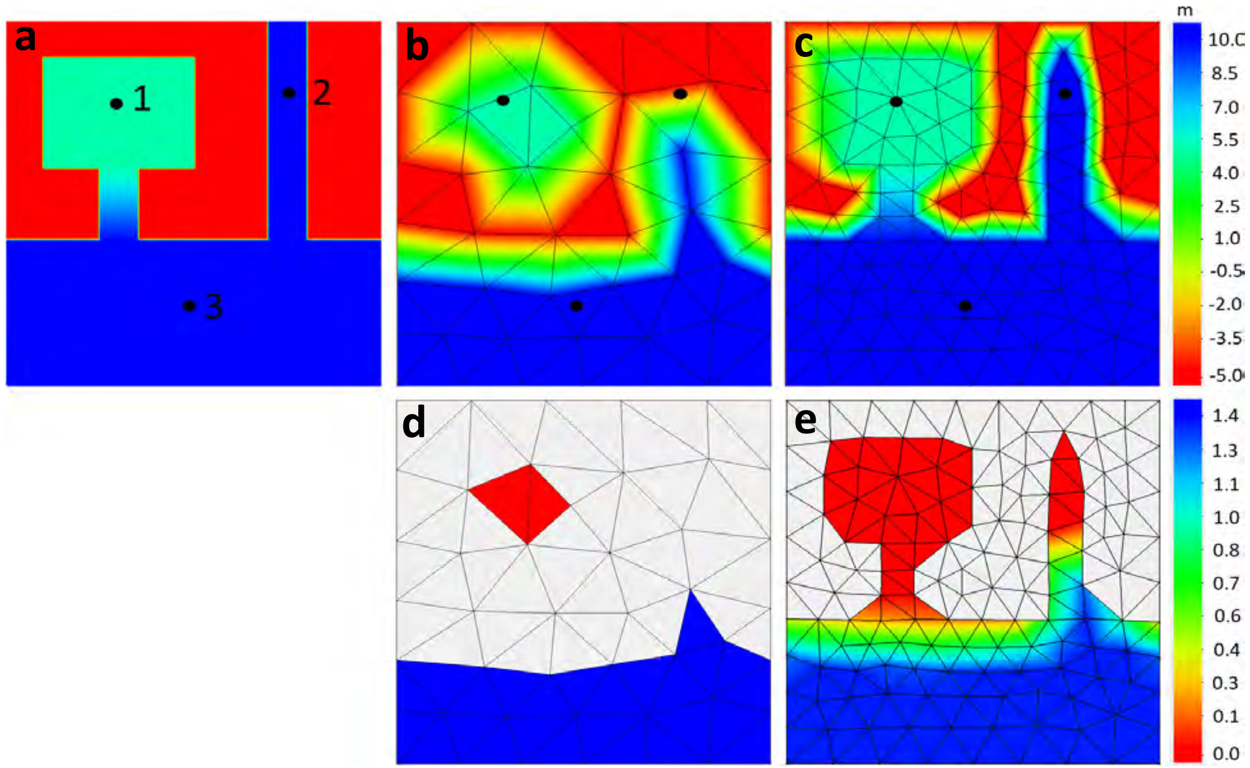
Bathy-topo

Test Case

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

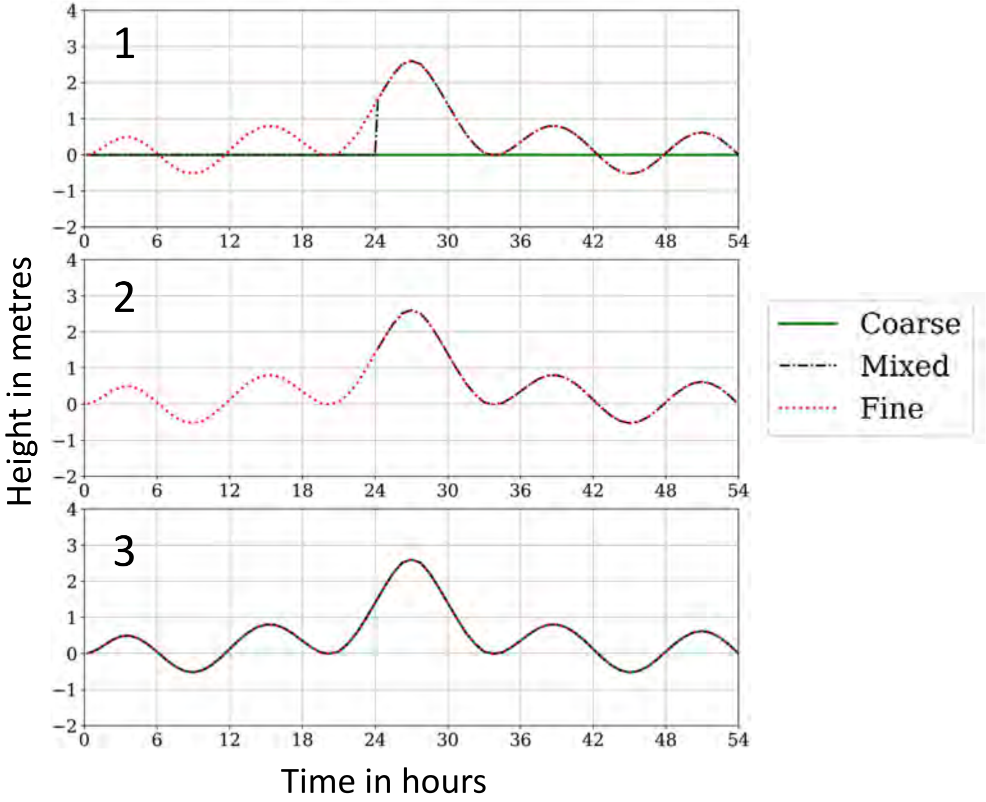


Test Case



WL at end of coarse run

WL at start of fine run



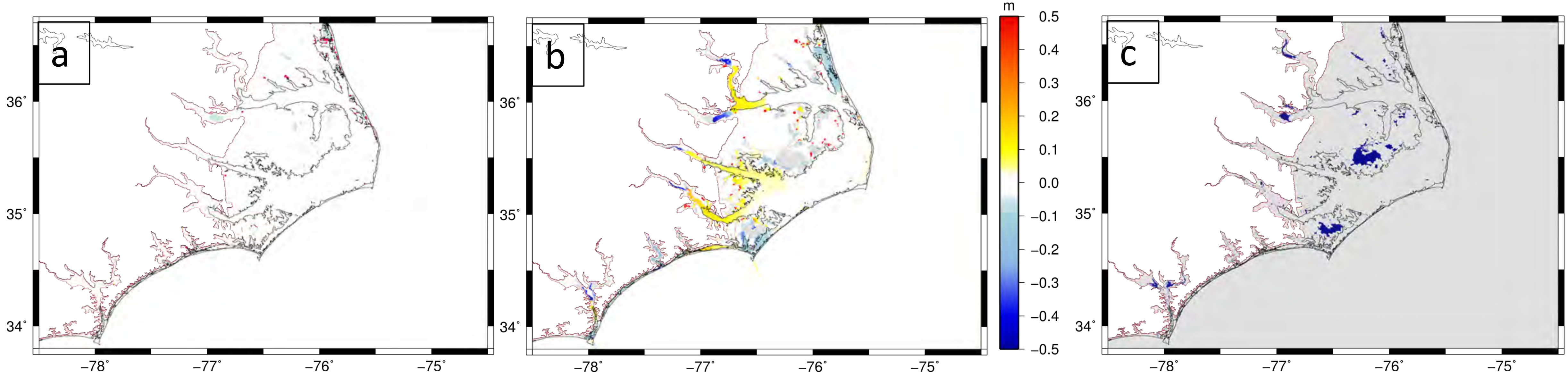
Applying the approach during Matthew and Florence

- HSOFS when storm is far away
- FEMA-SAB when storm approaches the coastline
- Switching time understood by looking at water levels

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

Results – Global Comparisons of Flooding

- Florence as an example – difference in max water levels



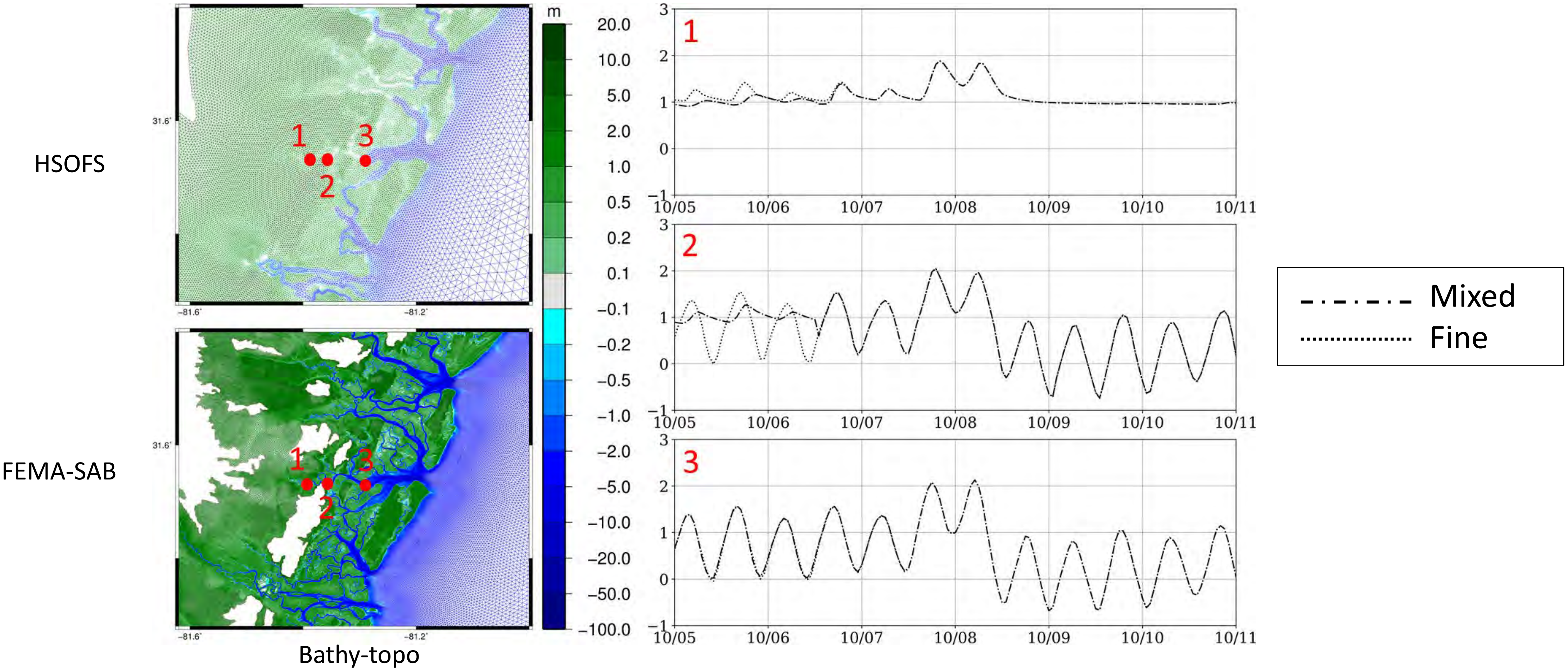
Mixed - Fine

Coarse - Mixed

Extra Flooding Area in *Mixed* as compared to *Coarse*

Results – Comparison at Inland Locations

- Matthew as an example



Results – Comparison to *Fine* Maximum Water Levels

- *Fine* results as truth
- This allows for an evaluation of accuracy throughout the entire region, not only where the observations were collected
- Comparison at nodes that are inland (z<10m) and wetted in both meshes
- FL to NC for Matthew, and NC for Florence
- Mixed approach floods a larger area with gain in accuracy, as compared to *Coarse* results

Error	Matthew		Florence	
	Coarse	*Mixed*	*Coarse*	*Mixed*
Stations	1,981,764	2,664,921	182,289	264,812
Best Fit Slope	0.99	1.00	0.95	1.00
R^2	0.91	0.96	0.86	0.90
ERMS (m)	0.22	0.13	0.22	0.18
B_{MN}	-0.01	0.00	-0.05	0.00

Results – Performance Benefits

- Gains in efficiency in terms of wall-clock time
- All simulations for Matthew and Florence were done on the Stampede2 computing cluster at the Texas Advanced Computing Center, on a total of 532 cores (including 10 writer cores)

Run time in minutes

Storm	*Mixed*				*Fine*	% Save in time
	Coarse	*Adcirpolate*	Fine	Total		
Matthew	29	12	202	243	393	**38**
Florence	37	12	129	178	380	**53**

Summary

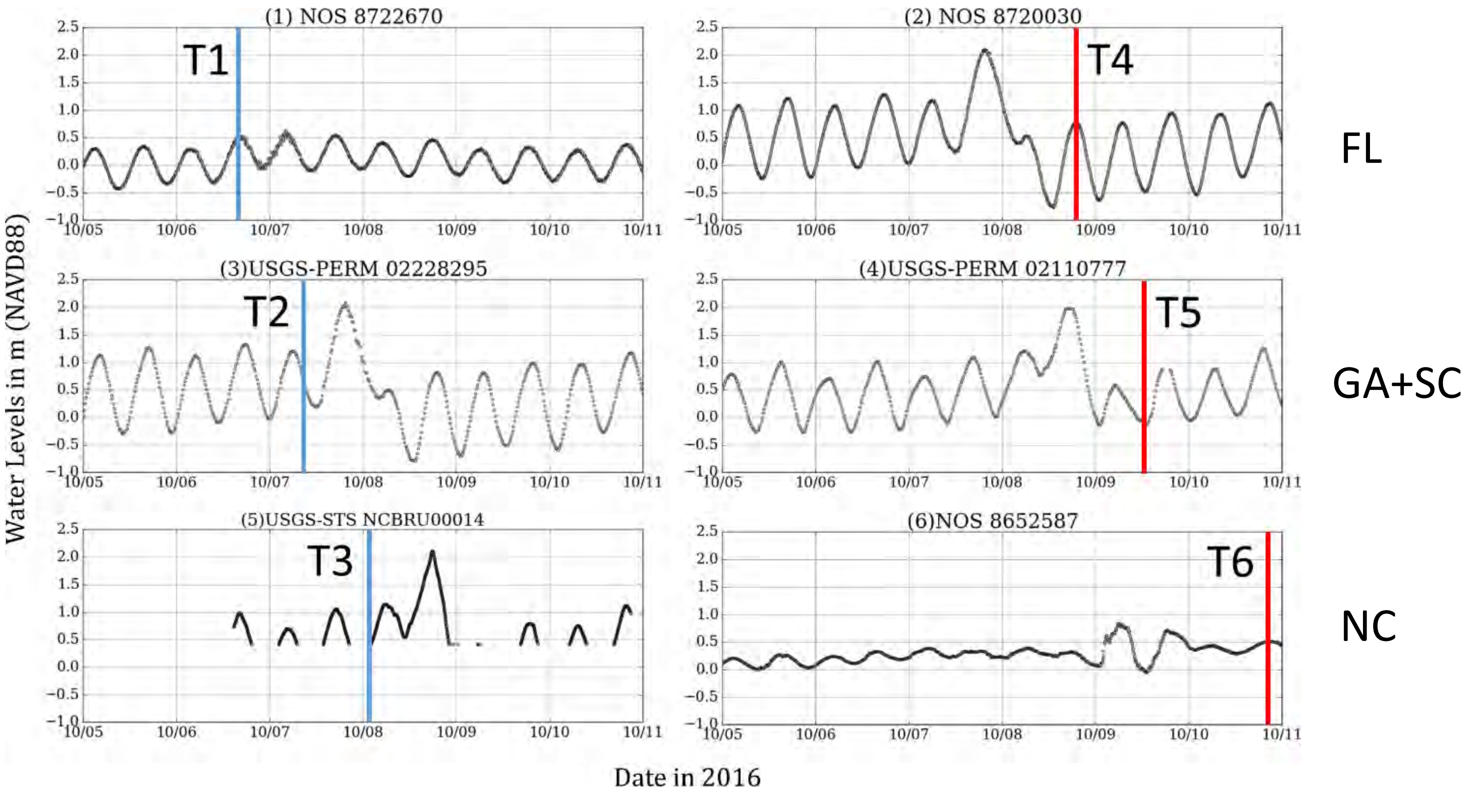
- The Mixed approach retains the accuracy of the *Fine* results, but it floods a larger region as compared to the corresponding *Coarse* simulation
- This extra flooding coverage is at regions like barrier islands, up-stream rivers, etc., where the coarse mesh does not have sufficient resolution to provide the required hydraulic connectivity
- 38 to 53% save in time without compromising on accuracy

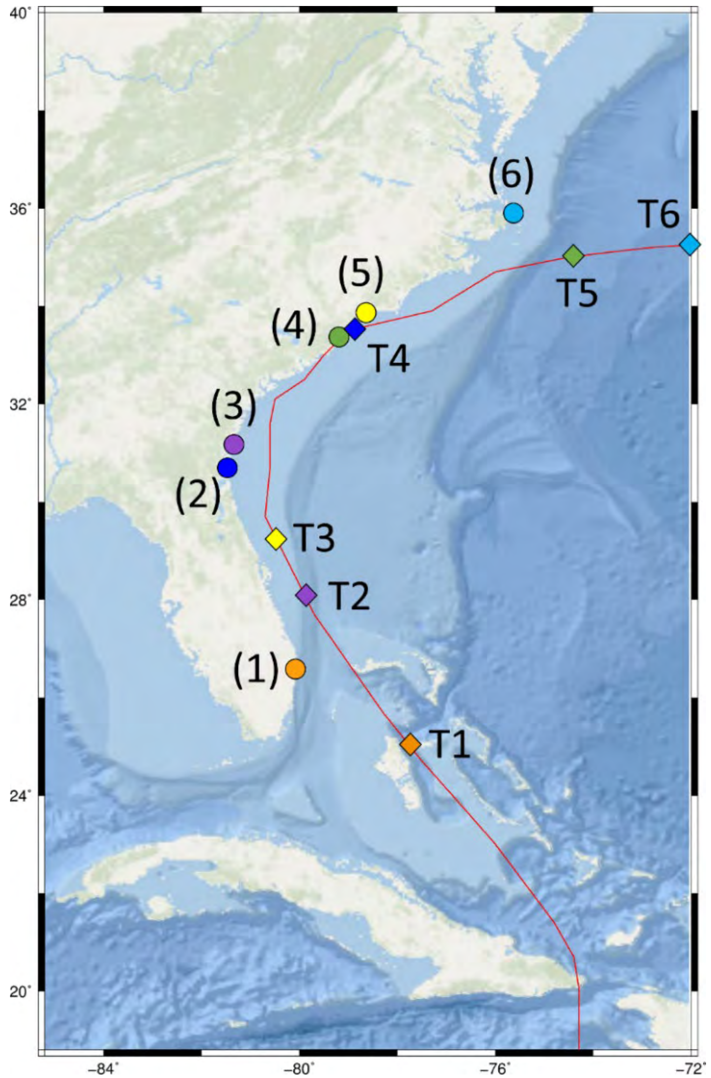
Multi-Resolution Approach

- Part I – Application of the approach to Hurricanes Matthew and Florence
- **Part II – Optimizing the approach for accuracy and efficiency during Matthew**

Motivation

- Matthew
  - Shore-parallel storm moved from south-to-north
  - But it did not impact this entire region at the same time
  - Southeast coast divided into 3 regions: FL, GA+SC, NC



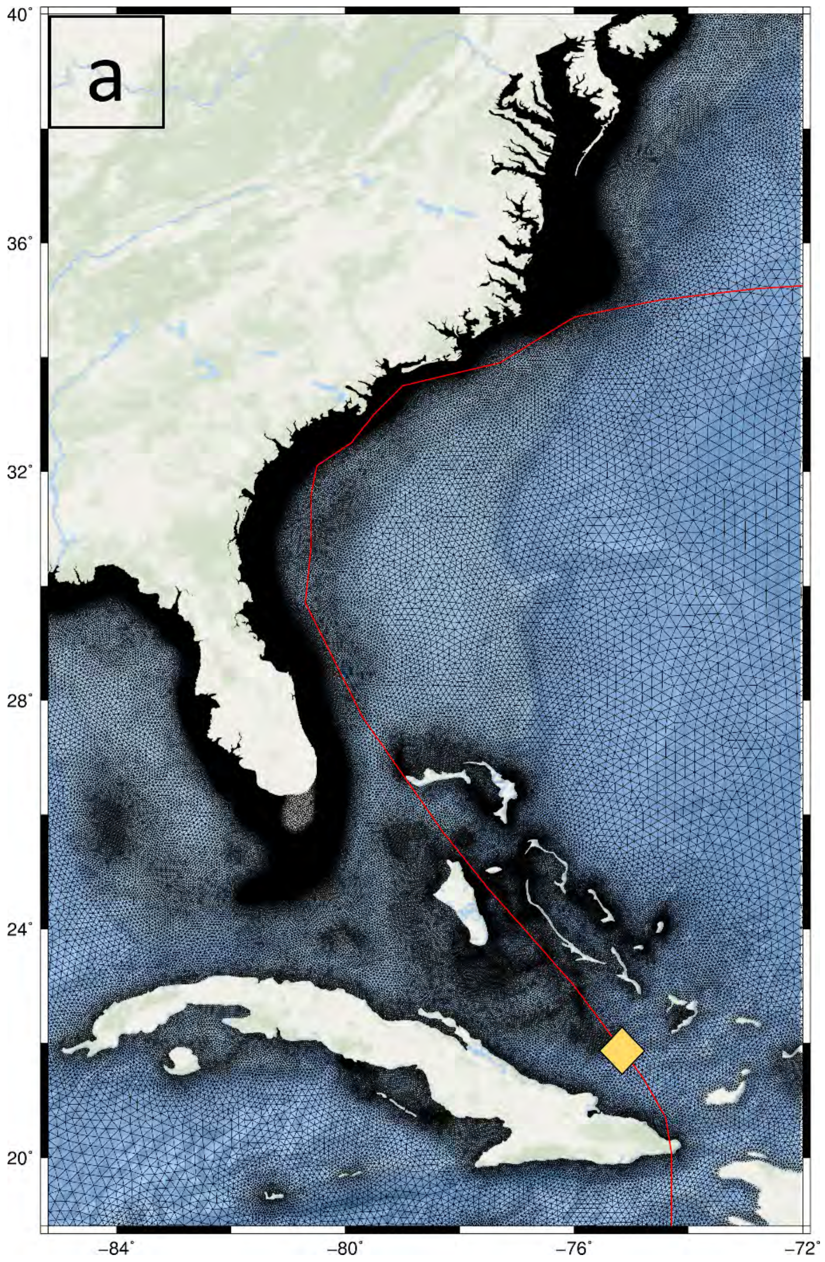


Research Hypothesis and Objectives

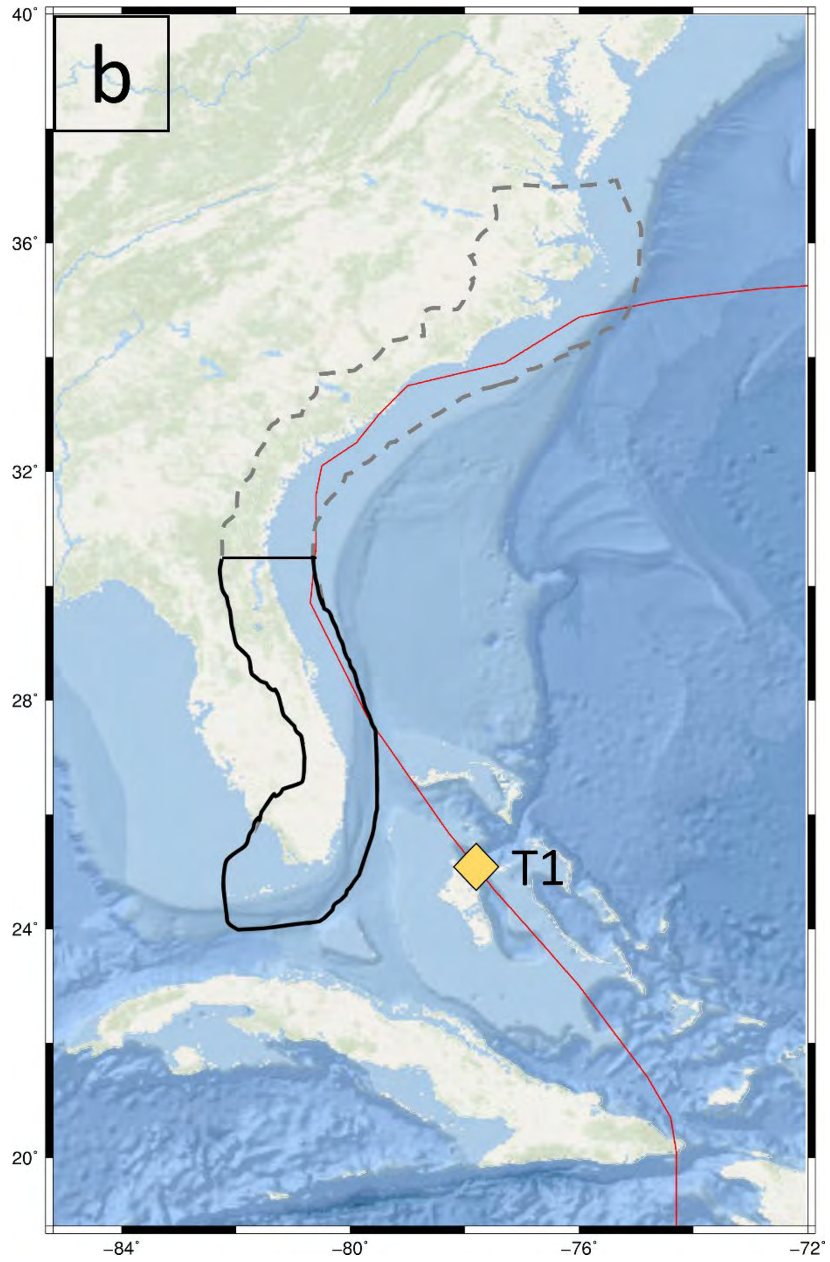
- Hypothesis
  - By applying smaller high-resolution meshes that describe specific regions of the U.S. southeast coast as they are affected by Matthew, the predictions can be further improved in both accuracy and efficiency
- Objectives
  - Identify the optimal number of segments along the U.S. southeast coast, to represent the variation in water levels during Matthew without excessive switching between meshes
  - Evaluate the storm information available during the storm, as possible triggers for switching between meshes
  - Quantify the benefits in accuracy and efficiency of the multi-resolution approach, via comparisons with a single simulation on the FEMA-SAB mesh

Test on HSOFS Sub-meshes

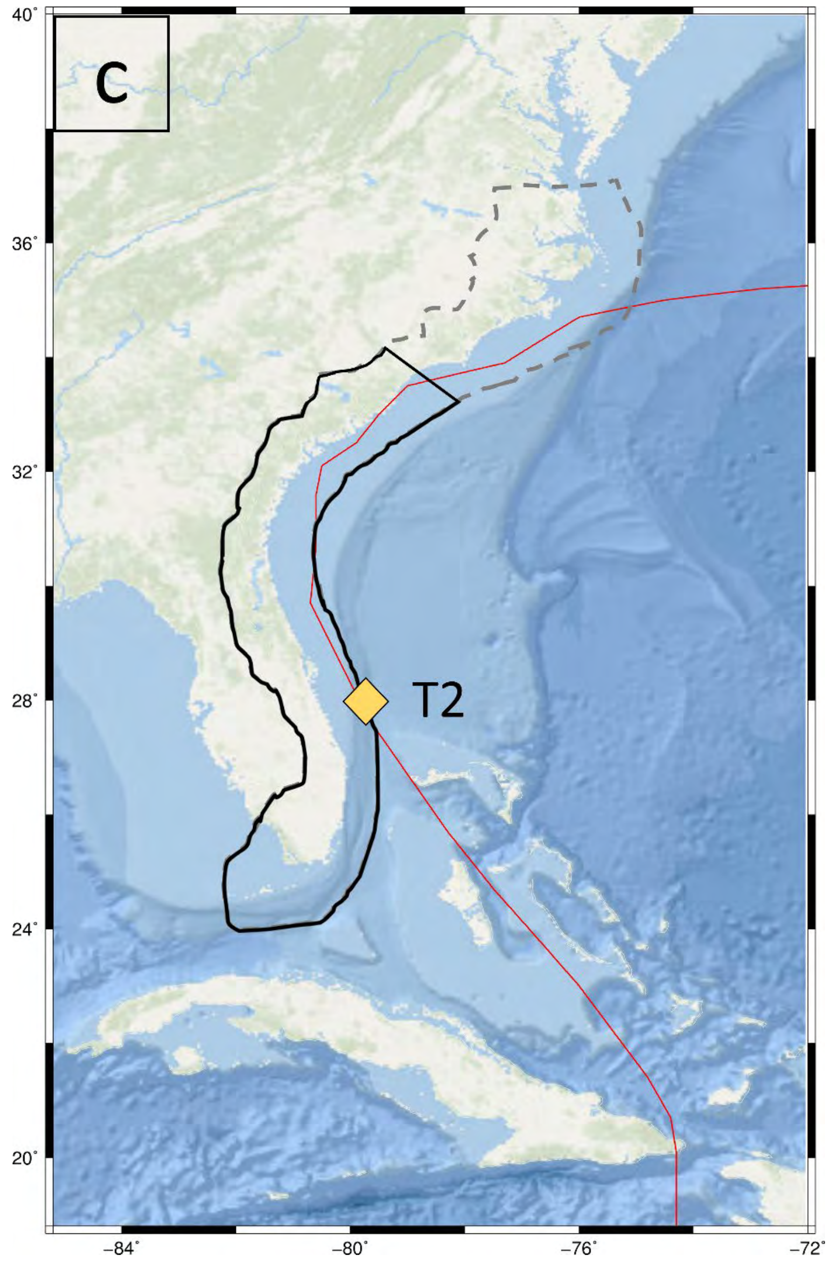
- Sub-meshes were created from HSOFS using state-line boundaries



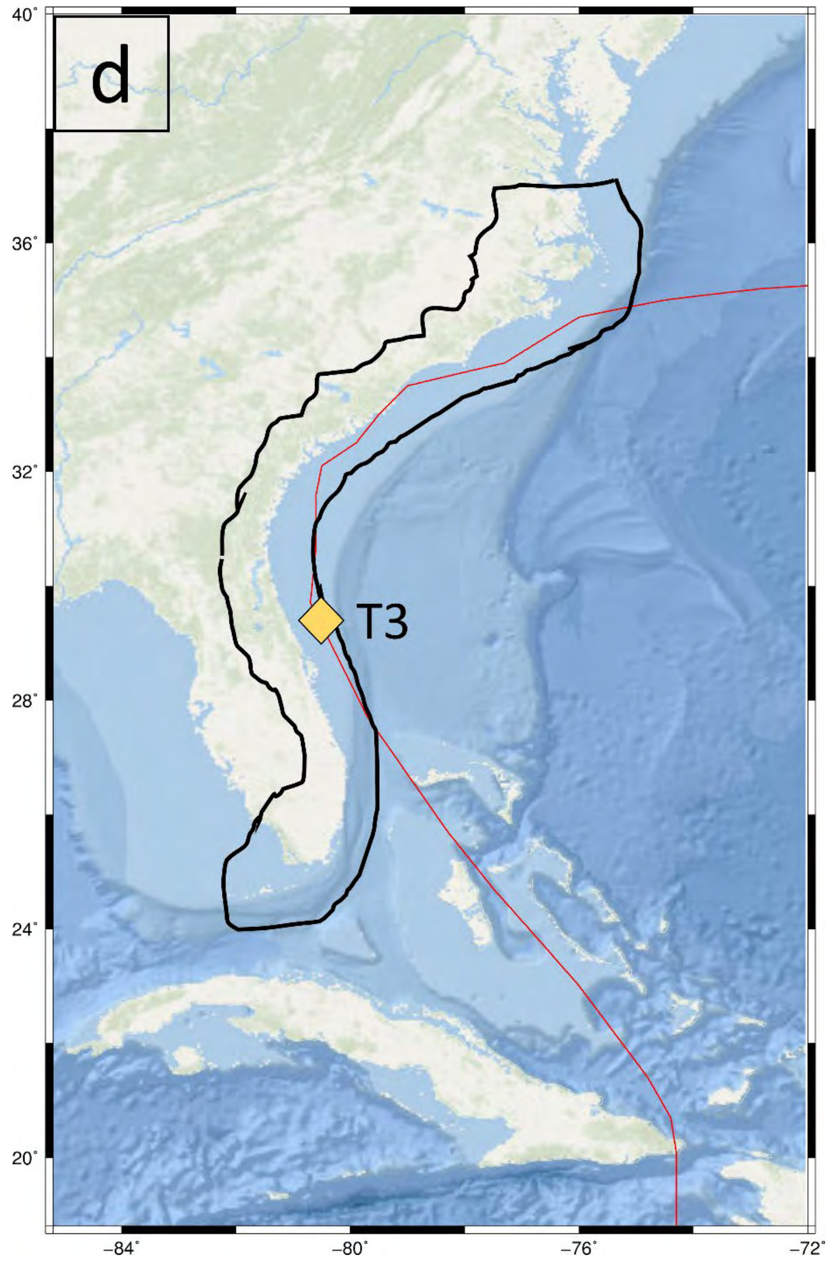
Test on HSOFS Sub-meshes



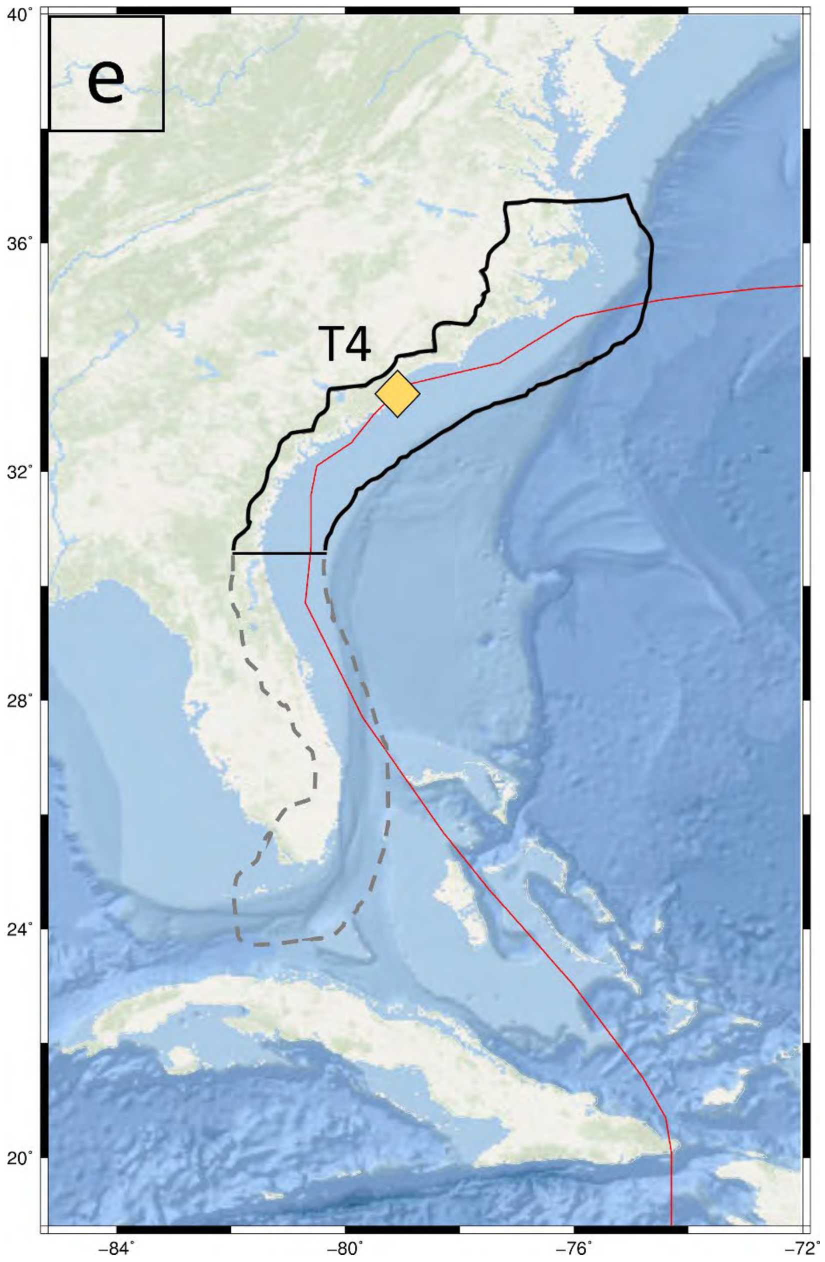
Test on HSOFS Sub-meshes



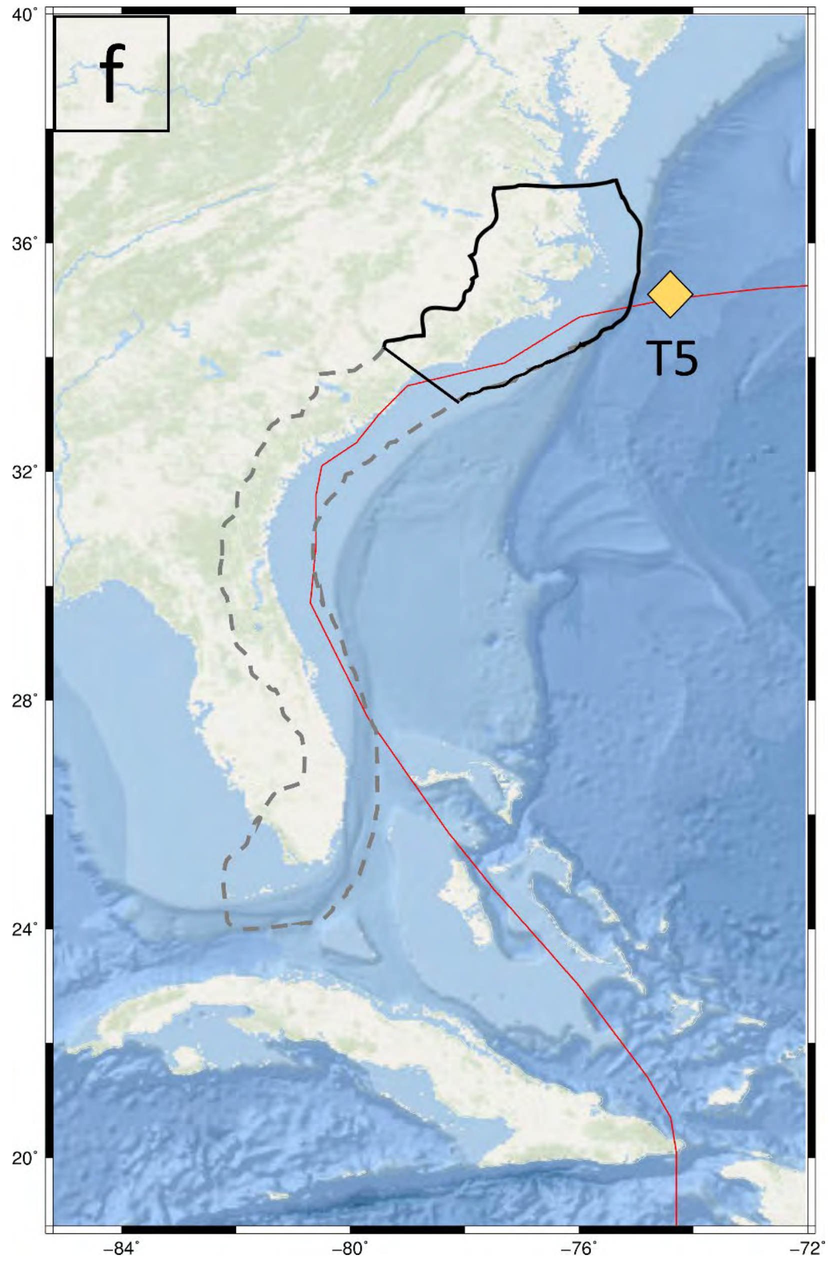
Test on HSOFS Sub-meshes



Test on HSOFS Sub-meshes



Test on HSOFS Sub-meshes

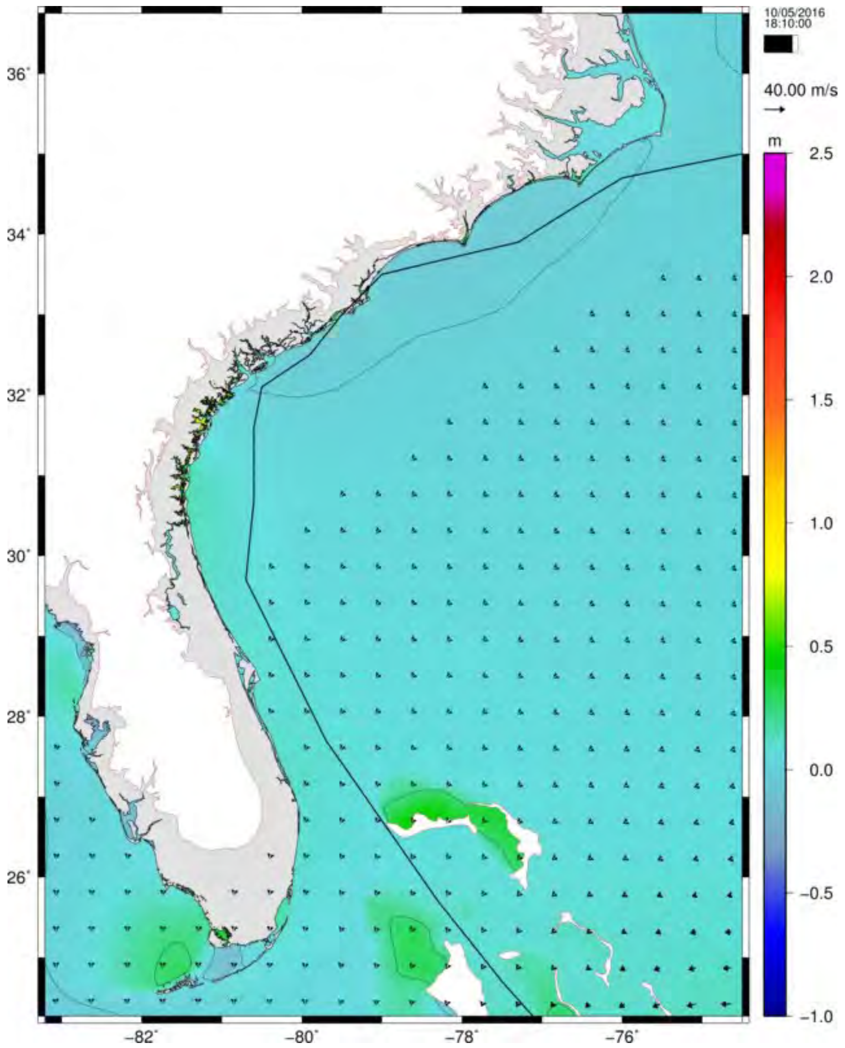


Test on HSOFS Sub-meshes

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

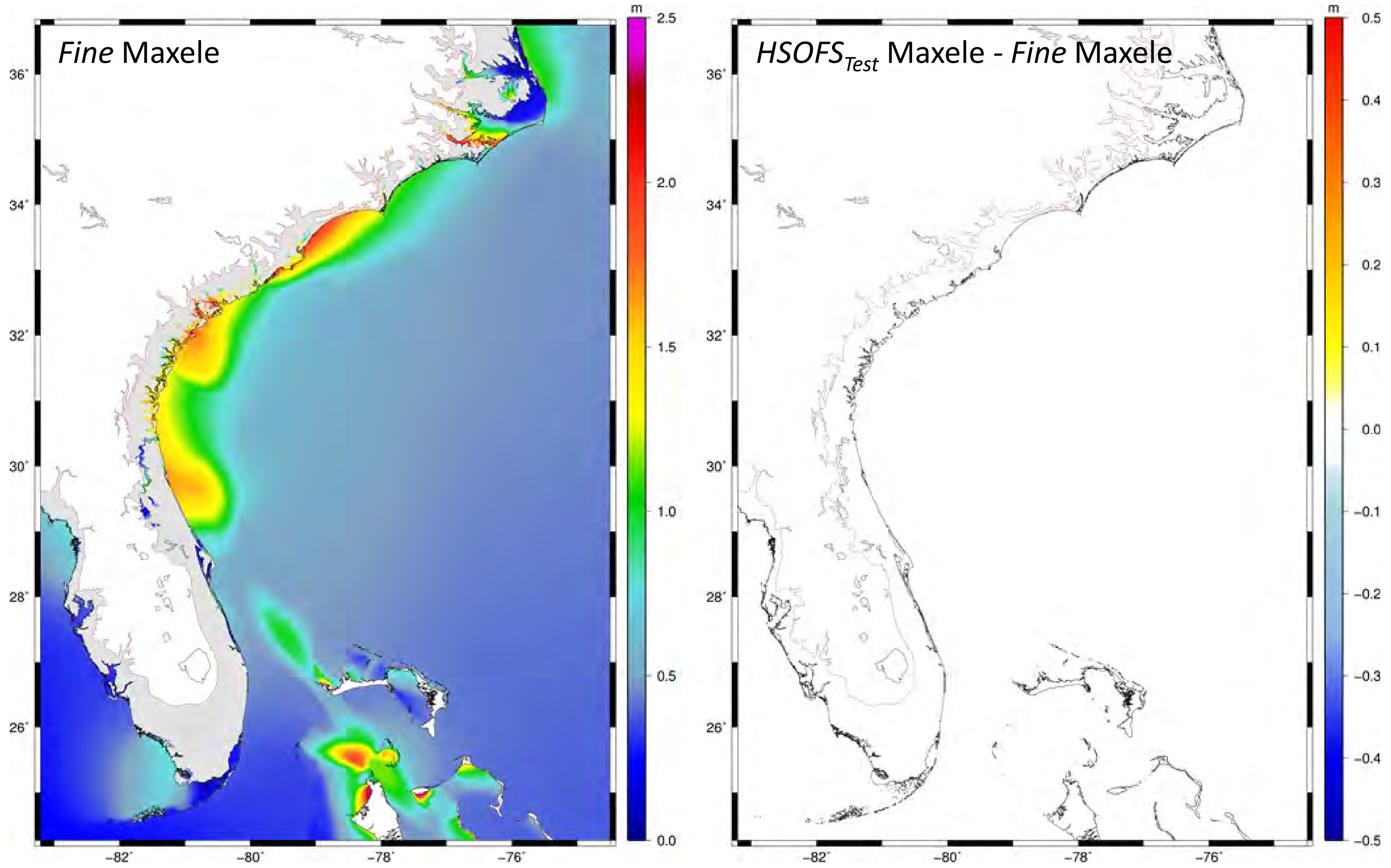
Test on HSOFS Sub-meshes

- Water Levels



Test on HSOFS Sub-meshes

- Comparison to Fine maximum water levels



Test on HSOFS Sub-meshes

- Timing Comparison

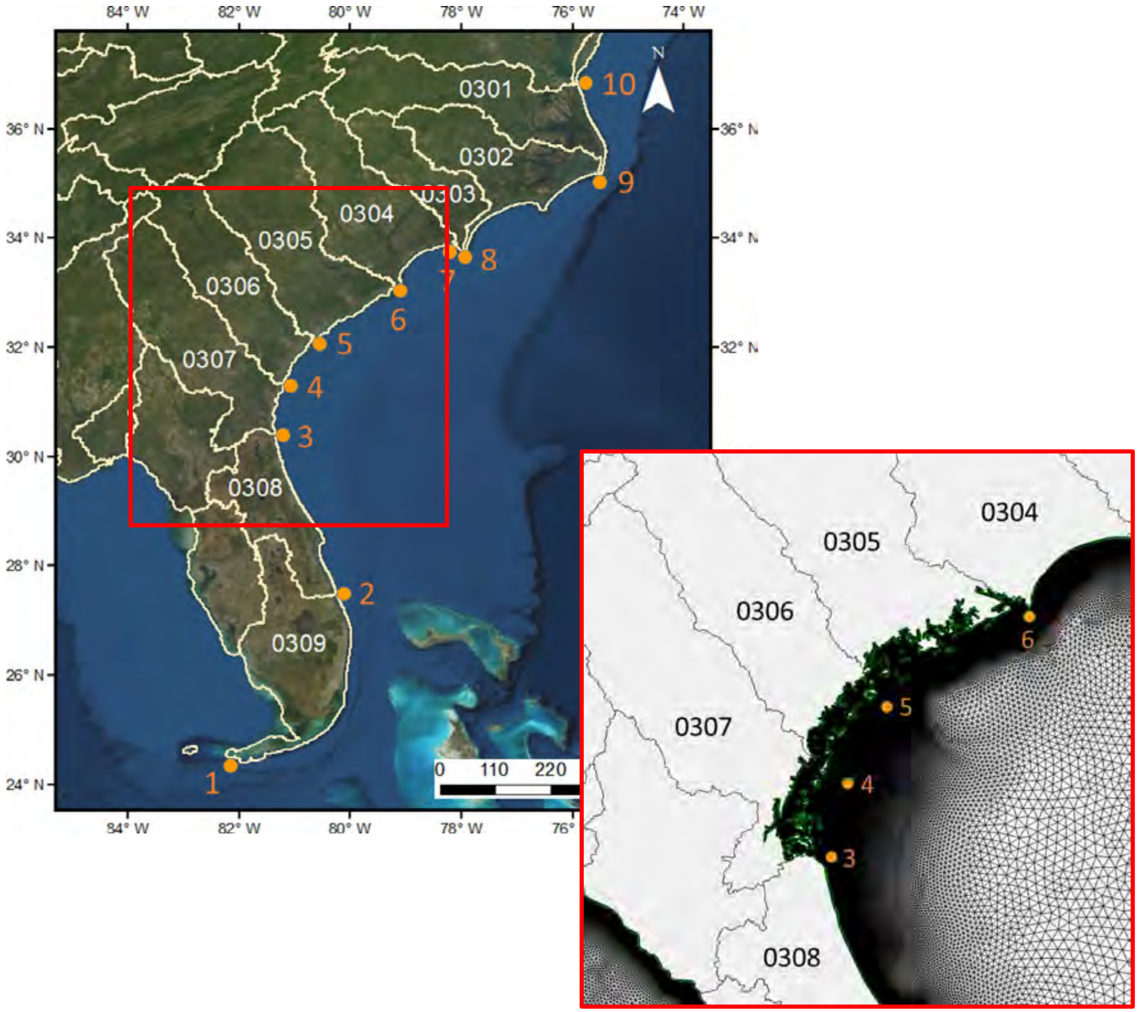
Mesh	No. of Nodes	Days	Run Time on 532 Cores (min)	
HSOFS	1,813,443	4.5	34	
HSOFS_FL	804,964	0.75	3	2
HSOFS_FL+GA+SC	942,427	0.75	3	2
HSOFS_FL+GA+SC+NC	1,057,880	0.75	4	3
HSOFS_GA+SC+NC	886,565	0.75	3	2
HSOFS_NC	784,911	1.5	6	2

Total = 64 mins

HSOFS for the entire storm = 67 mins

Simulations Using FEMA-SAB Sub-meshes

- Creating sub-meshes
  - Watershed boundary dataset from USGS
  - Hydrologic units represents regions that drain to a portion of stream network
  - U.S. southeast coast – South Atlantic-Gulf ‘region’ (03), ‘sub-regions’ (0301-0318)



$WSB_{307+306+305}$

Error Metrics

- Accuracy
  - E_{RMS}, B_{MN}, R^2, m
- Efficiency
  - Actual Speedup $S_{actual} = \frac{T_{fine}}{T_{mixed}}$
  - Theoretical Speedup $S_{theoretical} = \frac{N\,T}{\sum_{i=1}^{n} N_i T_i}$
  - T_{fine} is the total wall-clock time for the *Fine* simulation in days
  - T_{mixed} is the total wall-clock time for the approach including the times for switching in days
  - *N* is the number of vertices in the Fine mesh
  - *T* is the total days of Fine simulation
  - n is the number of component meshes used in the approach
  - N_i and T_i are the number of vertices and days of simulation for the component meshes

Simulations Using FEMA-SAB Sub-meshes

1. *FEMA-SAB$_{ACC}$*
   - aimed at getting maximum accuracy out of the approach
   - 1.1 times the tidal maxima was used as trigger to add or remove regions

Mesh	Vertices	Days
HSOFS	1,813,443	3
WSB$_{309+308}$	3,813,463	1.5
WSB$_{309+308+307+306}$	5,013,281	0.75
WSB$_{309+308+307+306+305+304}$	5,263,482	0.75
FEMA-SAB	5,584,241	0.75
WSB$_{307+306+305+304+303+302+301}$	3,229,413	0.75
WSB$_{304+303+302+301}$	1,853,662	1.5

Simulations Using FEMA-SAB Sub-meshes

2. *FEMA-SAB$_{OPT}$*
   - aimed at an optimum prediction of water levels (both accuracy and performance)
   - 1.2 times the tidal maxima was used as trigger to add or remove regions

Mesh	Vertices	Days
HSOFS	1,813,443	3
WSB_{309}	2,803,323	2
$WSB_{309+308+307+306+305}$	5,181,167	1
$WSB_{307+306+305+304}$	2,910,982	0.25
$WSB_{306+305+304}$	2,246,580	0.25
$WSB_{306+305+304+303+302+301}$	2,565,008	0.5
$WSB_{302+301}$	1,681,994	2

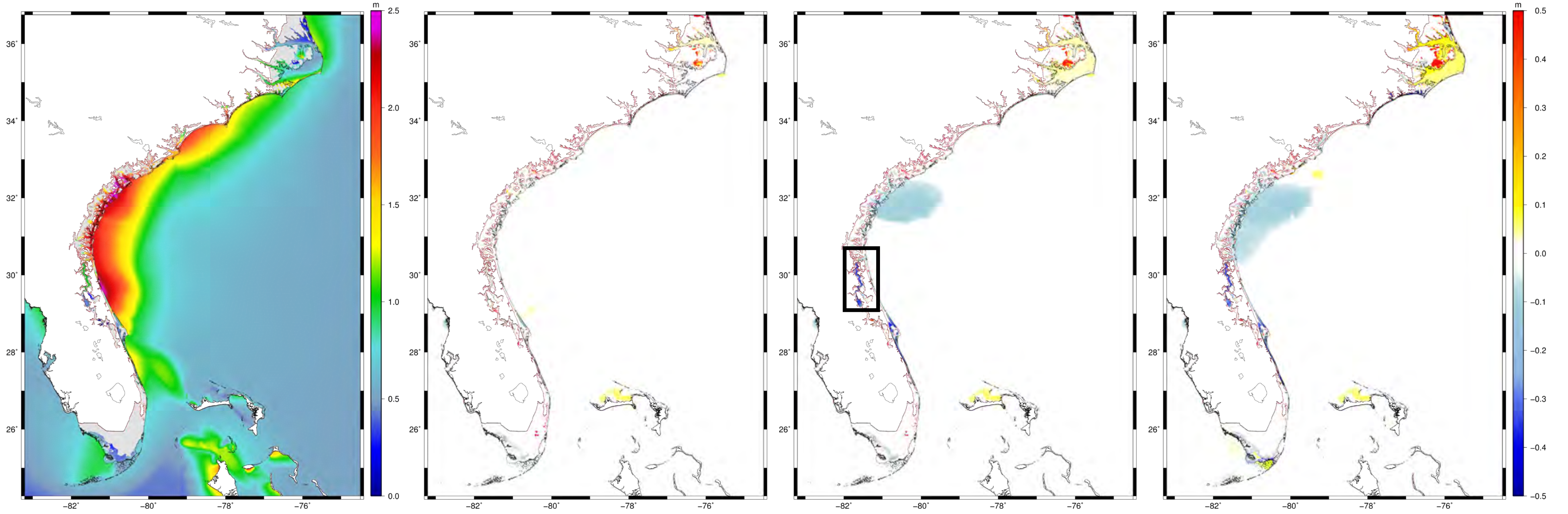
Simulations Using FEMA-SAB Sub-meshes

3. *FEMA-SAB$_{EFF}$*
   - aimed for maximum efficiency
   - 1.4 times the tidal maxima was used as trigger to add or remove regions

Mesh	Vertices	Days
HSOFS	1,813,443	4.5
WSB$_{309}$	2,803,323	0.5
WSB$_{308}$	2,471,130	0.5
WSB$_{308+307+306}$	3,670,946	0.5
WSB$_{306+305}$	2,164,263	0.5
WSB$_{305+304+303}$	1,808,744	0.25
WSB$_{304+303}$	1,632,726	0.25
WSB$_{302+301}$	1,681,994	2

Simulations Using FEMA-SAB Sub-meshes

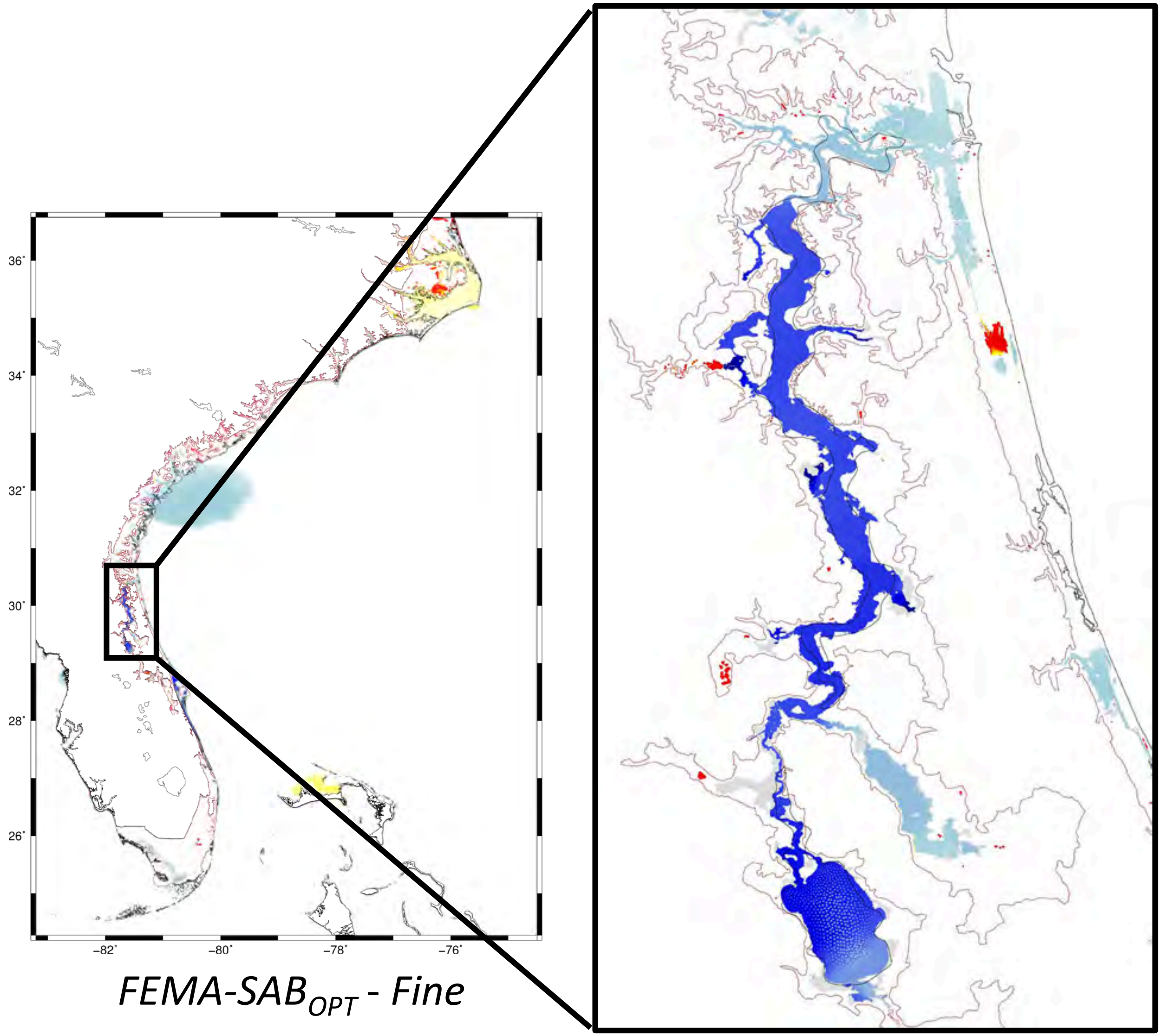
- Results - Maximum water levels



Fine | *FEMA-SAB$_{ACC}$ - Fine* | *FEMA-SAB$_{OPT}$ - Fine* | *FEMA-SAB$_{EFF}$ - Fine*

Simulations Using FEMA-SAB Sub-meshes

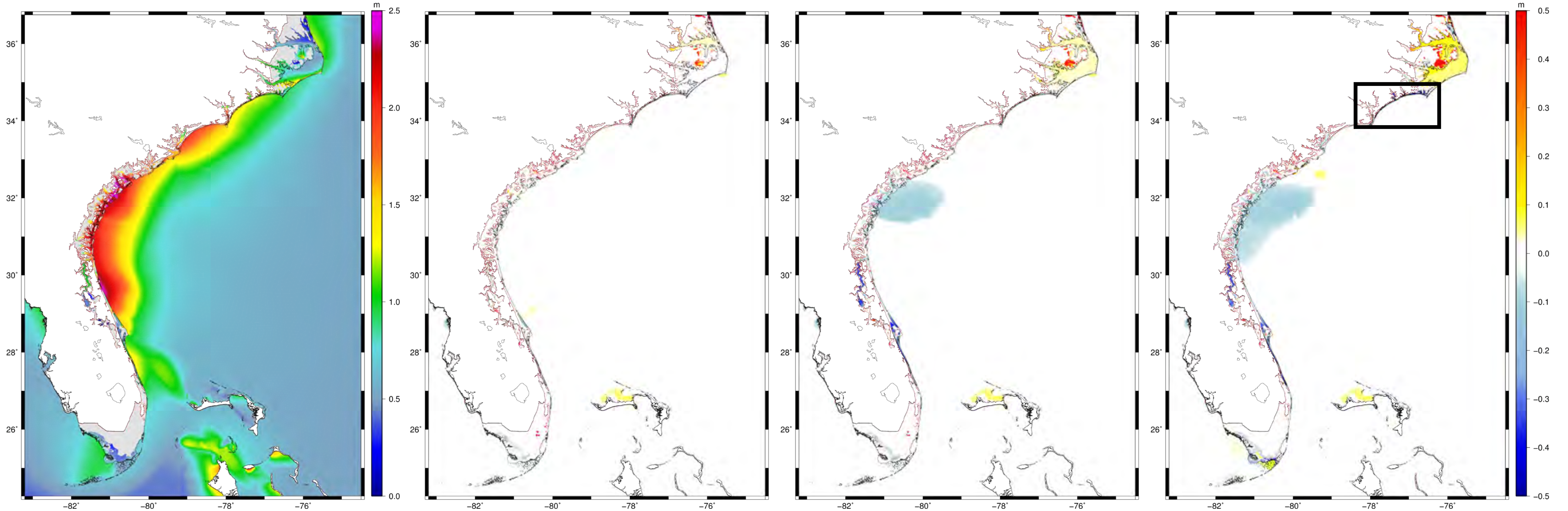
- Results - Maximum water levels



FEMA-SAB$_{OPT}$ - Fine

Simulations Using FEMA-SAB Sub-meshes

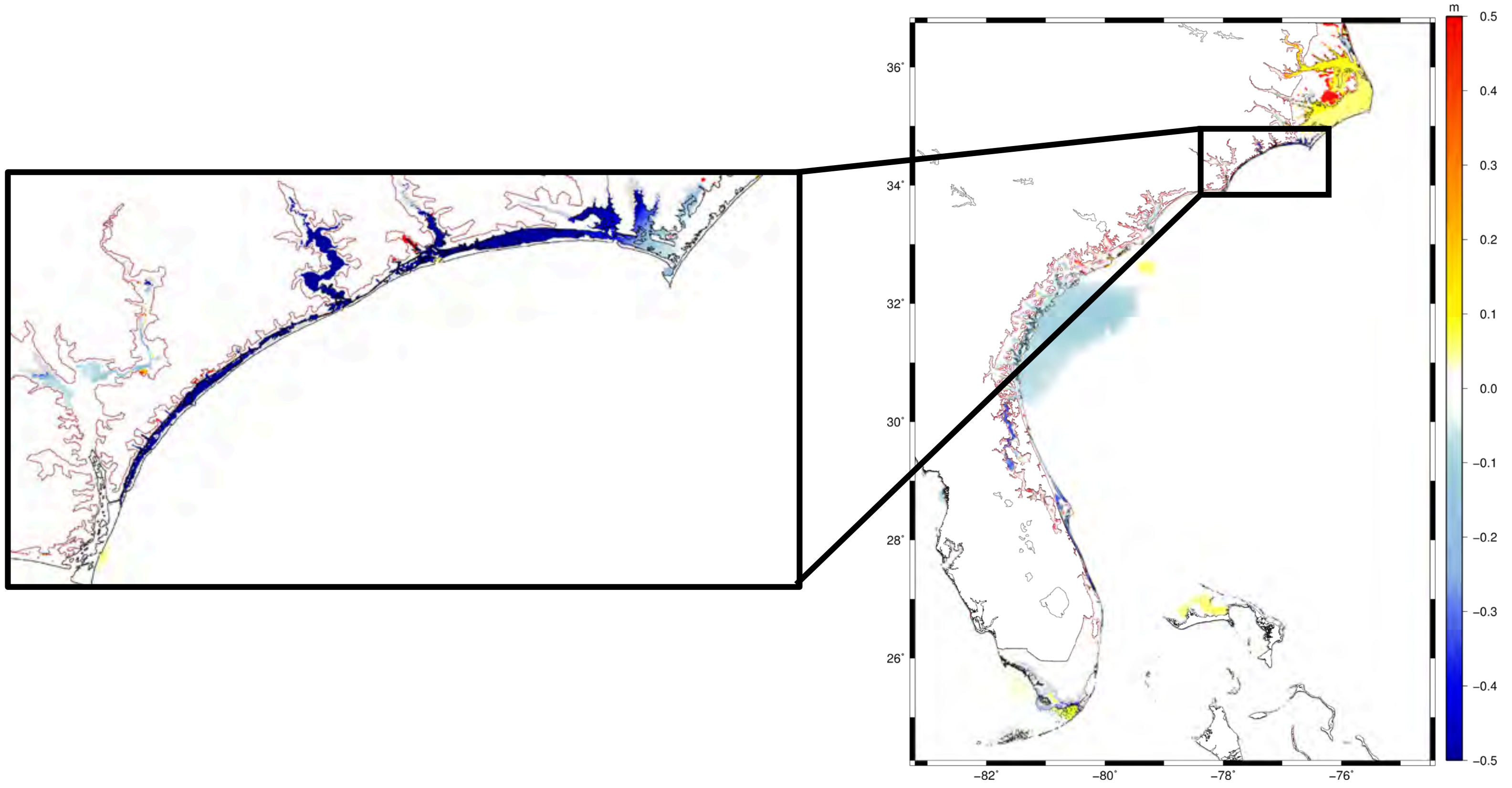
- Results - Maximum water levels



Fine | *FEMA-SAB$_{ACC}$ - Fine* | *FEMA-SAB$_{OPT}$ - Fine* | *FEMA-SAB$_{EFF}$ - Fine*

Simulations Using FEMA-SAB Sub-meshes

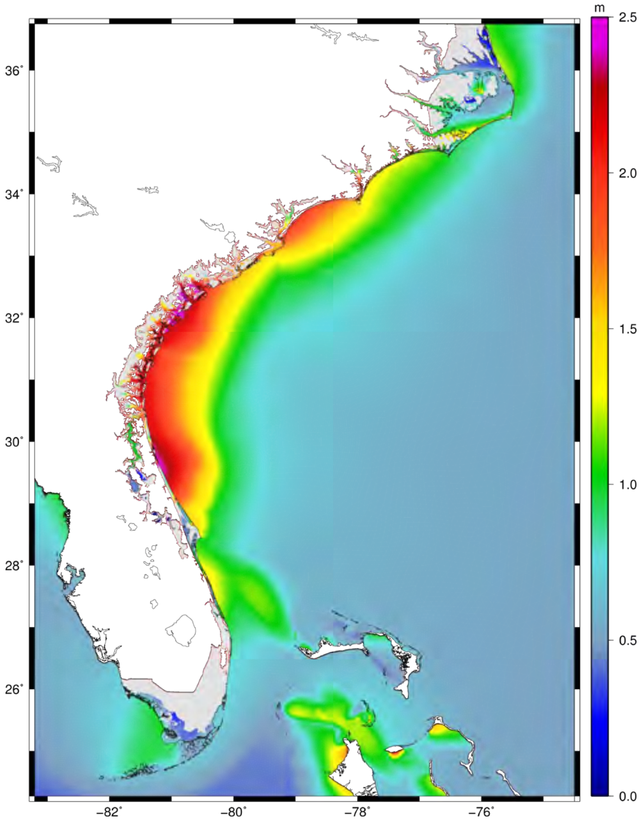
- Results - Maximum water levels



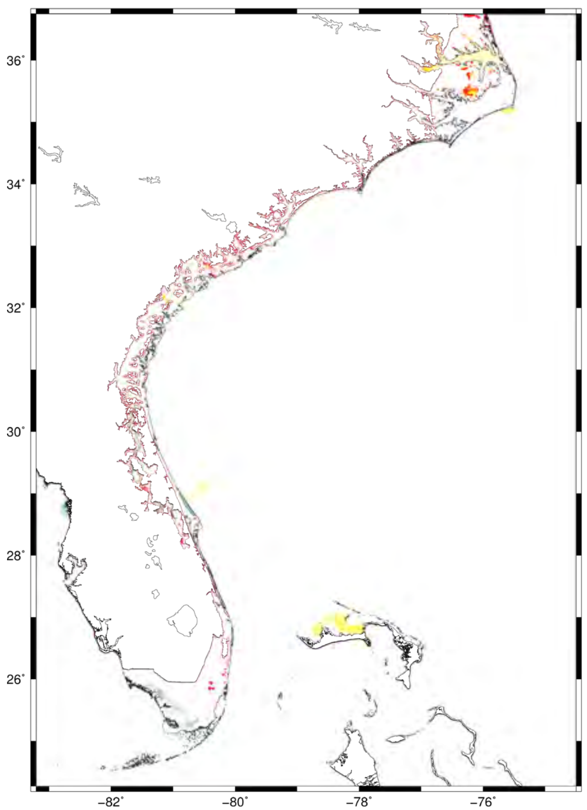
FEMA-SAB$_{EFF}$ - Fine

Simulations Using FEMA-SAB Sub-meshes

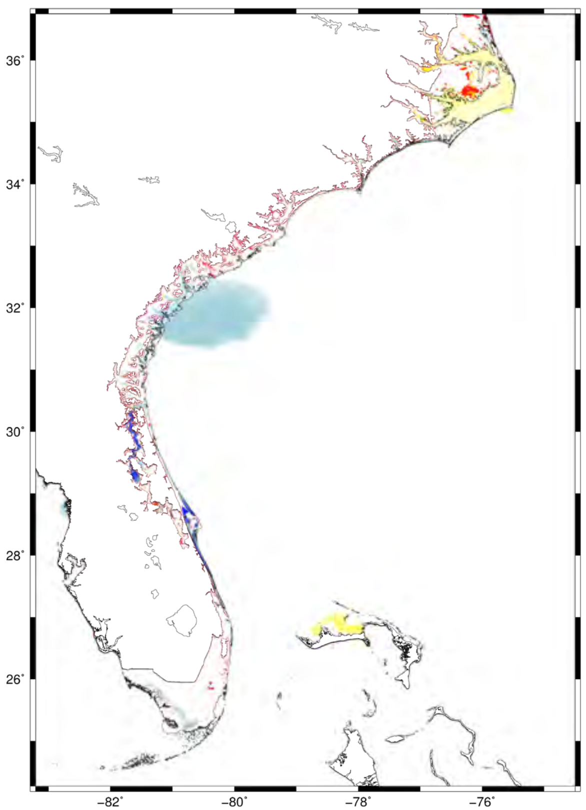
- Results - Maximum water levels



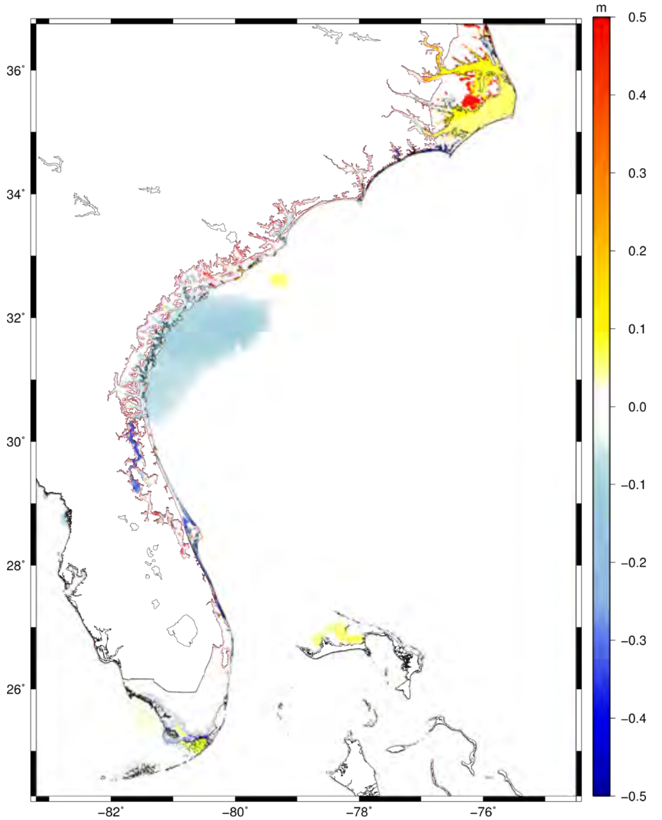
Fine



FEMA-SAB$_{ACC}$ - Fine



FEMA-SAB$_{OPT}$ - Fine



FEMA-SAB$_{EFF}$ - Fine

Simulations Using FEMA-SAB Sub-meshes

- Results – Comparison to *Fine* water levels

Error	$FEMA\text{-}SAB_{ACC}$	$FEMA\text{-}SAB_{OPT}$	$FEMA\text{-}SAB_{EFF}$
Stations	2,665,697	2,618,907	2,571,024
Best Fit Slope	1.00	0.96	0.95
R^2	0.98	0.96	0.94
ERMS (m)	0.08	0.15	0.18
B_{MN}	-0.003	-0.050	-0.070

Simulations Using FEMA-SAB Sub-meshes

- Results – Wall-clock times

Error	Time in minutes				Save in time (%)	S_{actual}	$S_{theoretical}$
	Fine	Approach					
		ADCIRC	*Adcirpolate*	Total			
FEMA-SAB$_{ACC}$	393	215	64	279	29.01	1.41	1.78
FEMA-SAB$_{OPT}$	393	153	50	203	48.35	1.94	2.27
FEMA-SAB$_{EFF}$	393	107	45	152	61.32	2.59	2.80

Summary

- The approach was the applied to three simulations of Matthew with sub-meshes created out the FEMA-SAB mesh using watershed boundaries as guidelines
- Different levels of accuracy and efficiency can be achieved out of the multi-resolution approach, by using different combinations of smaller high-resolution meshes
- By targeting only the major peaks in the total water levels, maximum efficiency (61%) can be achieved, although this would compromise on accuracy at different locations

Outline

- Introduction
- Case Study
- Background and Motivation
- FEMA-SAB Mesh Development and Validation
- Multi-Resolution Approach
- **Summary and Conclusion**

Summary and Conclusion

Case-Study

- The ADCIRC+SWAN model does a remarkable job of capturing Matthews's impacts even when applied on the relatively coarse HSOFS mesh

FEMA-SAB Mesh

- Developed by merging five FEMA regional meshes onto an open-water mesh
- 5,584,241 vertices and 11,066,018 elements (3 times that of the HSOFS mesh)
- Resolution is less than 100 m along the U.S. southeastern coastline at most locations
- Validation for Hurricanes Matthew and Florence indicate the FEMA-SAB mesh out-performing the HSOFS mesh especially at inland locations

Summary and Conclusion

Multi-Resolution Approach

- Allows switching from a coarse- to a fine-resolution mesh during a simulation without having to do a cold-start
- The approach was applied during Hurricanes Matthew and Florence, and results indicated gains in accuracy and efficiency as compared to results from single simulations on coarse- and fine-resolution meshes
- Instead of using just one switch between the coarse HSOFS mesh and the fine FEMA-SAB mesh, multiple smaller higher resolution meshes can be used to further improve efficiency gains
- Different levels of accuracy and efficiency can be achieved out of the multi-resolution approach, by using different combinations of smaller high-resolution meshes

Summary and Conclusion

Future Work

- Improve stability of the FEMA-SAB mesh without using restrictive attributes
- Add NetCDF capabilities
- Extend it to SWAN model
- Automation

Thank You!