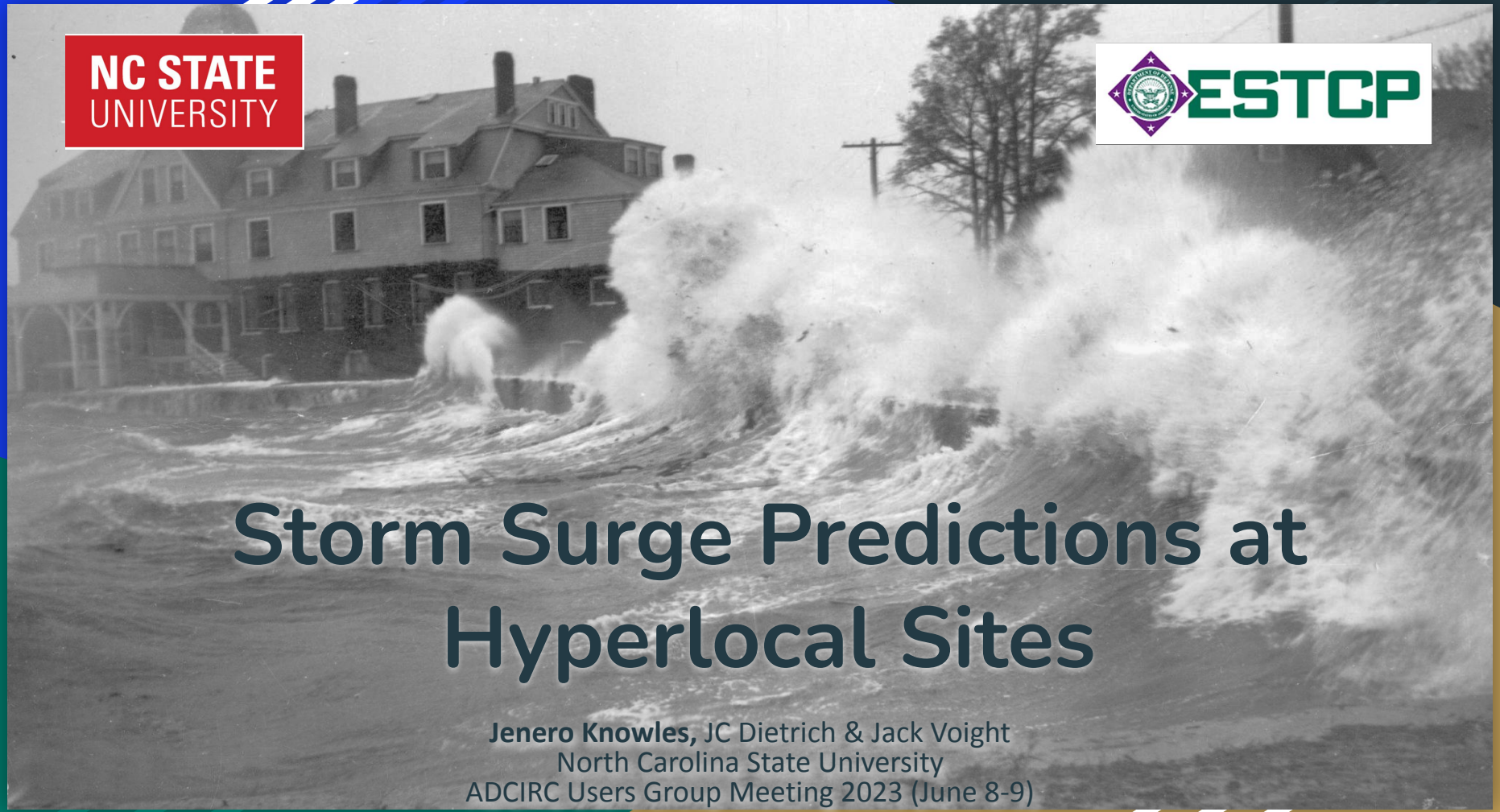
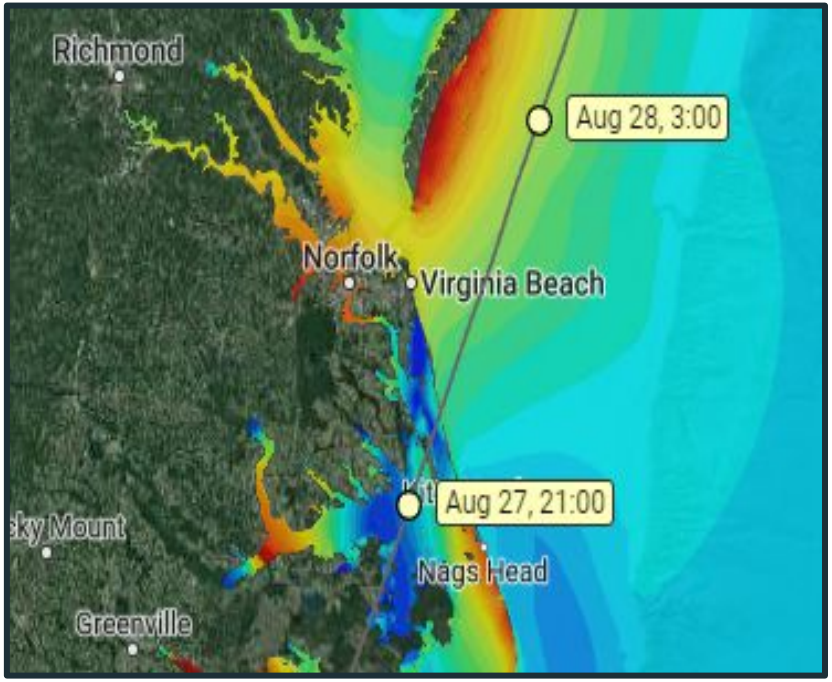


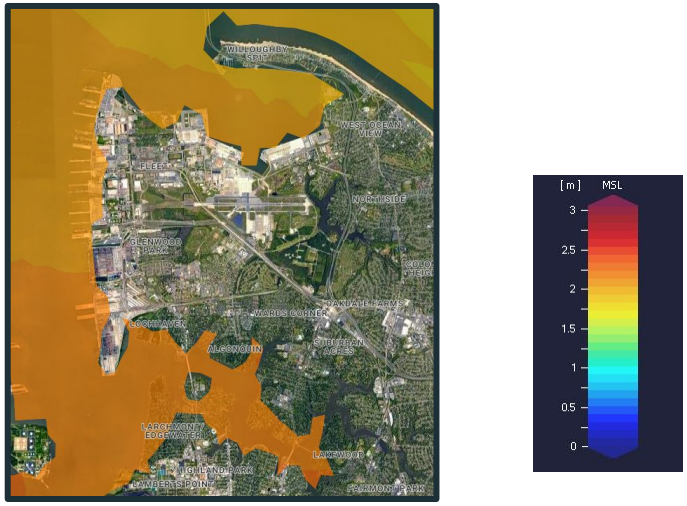
Storm Surge Predictions at Hyperlocal Sites

Jenero Knowles, JC Dietrich & Jack Voight
North Carolina State University
ADCIRC Users Group Meeting 2023 (June 8-9)

Motivation



Storm Track for Hurricane Irene (2011) from CERA

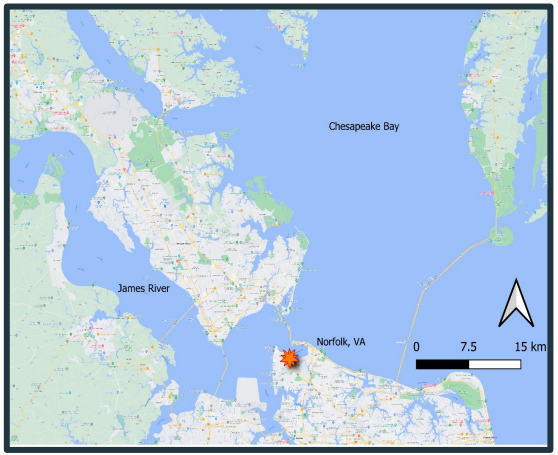


Modeled Water Levels in Norfolk

Local Community in Norfolk

Study Area - Norfolk Naval Station

- Mid - Continental Shelf
- Located on Land Subsidence (Settling Land)
- Surrounded by Narrow Channels and Bulkheads



Location Map of Norfolk Naval Station in Norfolk, VA

Norfolk Naval Station Boundary

Norfolk Naval Station

Study Area - Norfolk

- 96.16% of blocks exposed to coastal flooding [1]
- Increased Inundation Hours [1]
  - 100 hours in 1992 to 275 hours in 2009
- Highest Rate of SLR on east Coast: 4.5mm/year[1]
- Increased Storm Frequency [2,3]

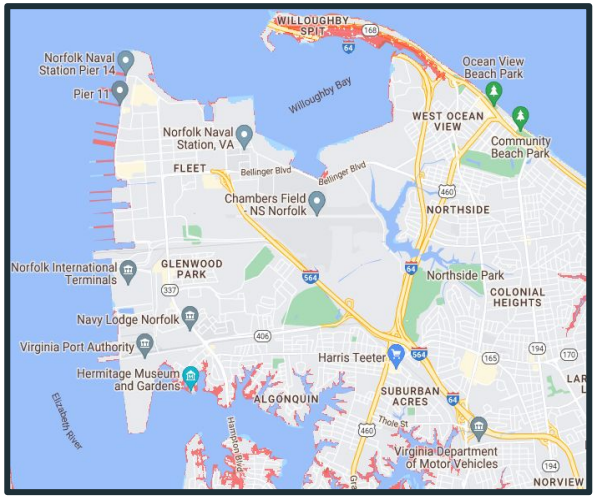
Century	17th	18th	19th	20th	21st
No. of Storms	3	4	17	34	12*

Storm Surge impacts at NNS from Hurricane Irene (2011)

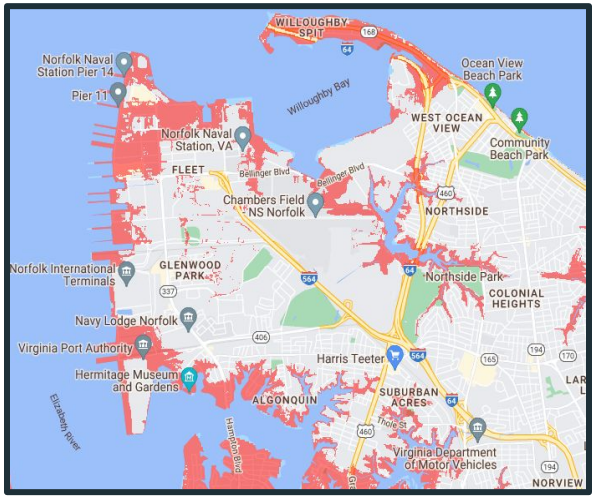
Storm Surge impacts in the city of Norfolk from Hurricane Irene (2011)

1 – Kramer (2016)
2 – Glen Allen Weather (2016)
3 – Kossin et. al. (2020)

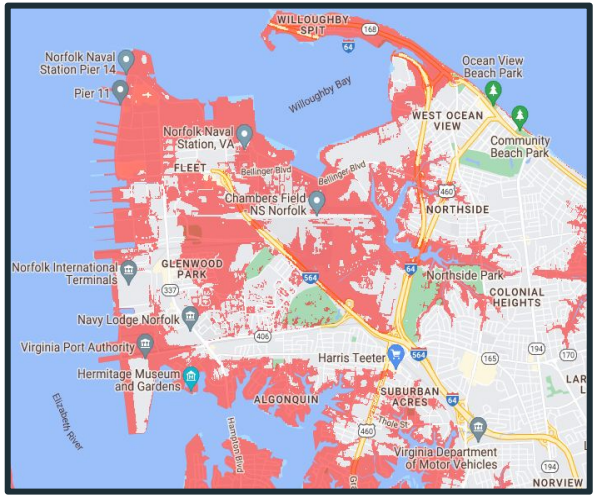
Study Area - Norfolk



1.1m Sea Level Rise Projection for 2080 on Medium Rate[1]



2.2m peak storm surge from Hurricane Irene (2011)[2]



2.7m peak storm surge from Hurricane Isabel (2003)[3]

1 - Sweet et. al. (2022)
2 - Availa (2011)
3 - Hovel et. al. (2004)

Research Questions

How can we optimize for storm surge predictions at a hyperlocal site?

- How does this change the mesh development, if we only care about the solution accuracy for a few square kilometers near Norfolk Naval Station (NNS)?
- How does this change the other modeling choices?

This is a work in progress!

Research Objectives

Mesh Development

- Process DEMs to use in the mesh development for the NNS
- Produce Meshes to focus elements on NNS

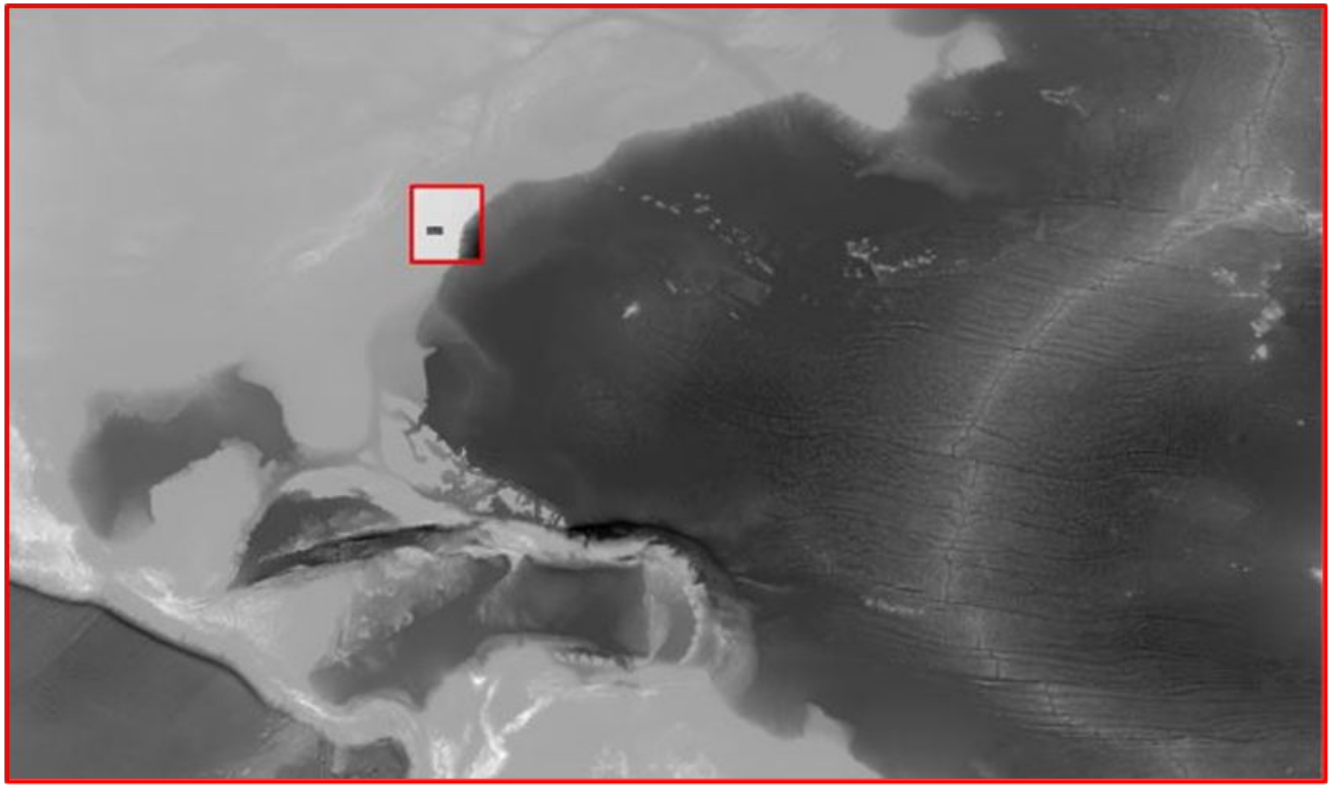
Storm Simulations

- Validate mesh and model with historic storms
- Run various Hurricane simulations with on various meshes

Model Collaboration

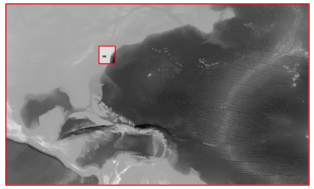
- Compare predictions with larger ESTCP team

Mesh Development – What DEMs to use?

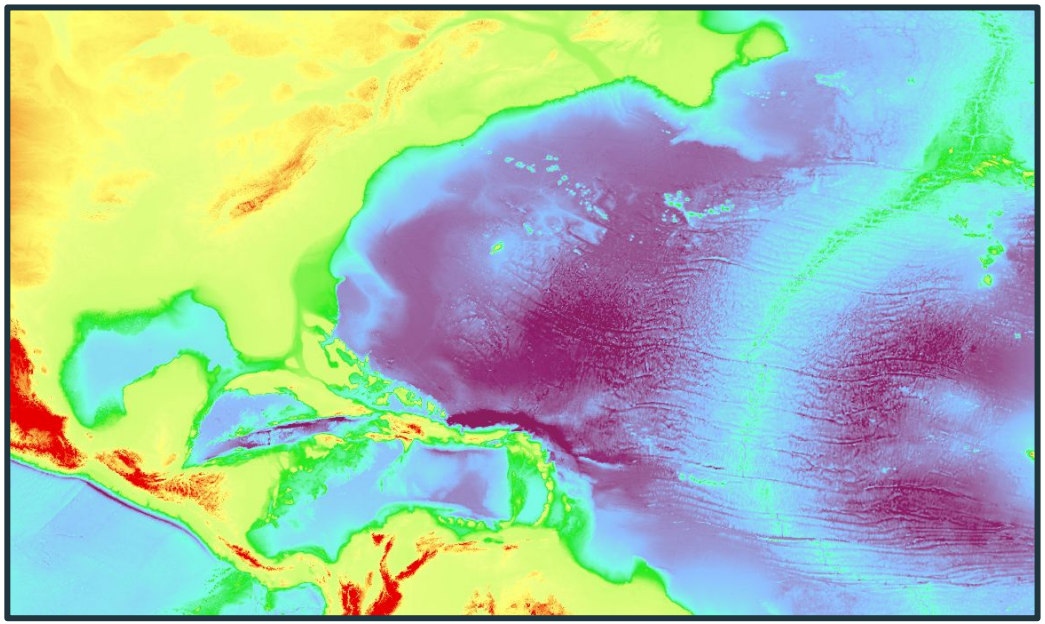


Nested DEMs

Mesh Development – Full Domain

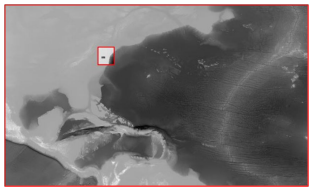


500m - 2018 Shuttle Radar Topography Mission (SRTM)

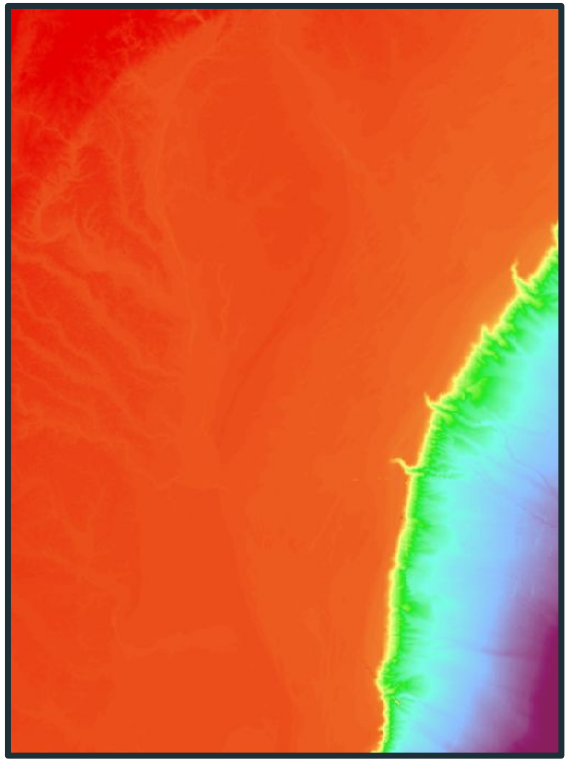


- Covers Atlantic Ocean
  - West Atlantic and Caribbean
- Min. resolution at 500m
- Coordinate Ranges
  - 5° N to 50° N.
  - 25° W to 101° W.

Mesh Development – Regional Domain

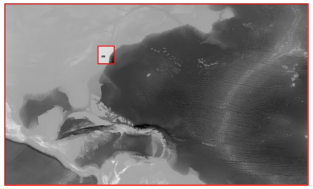


30m - Nested 2014 CUDEM

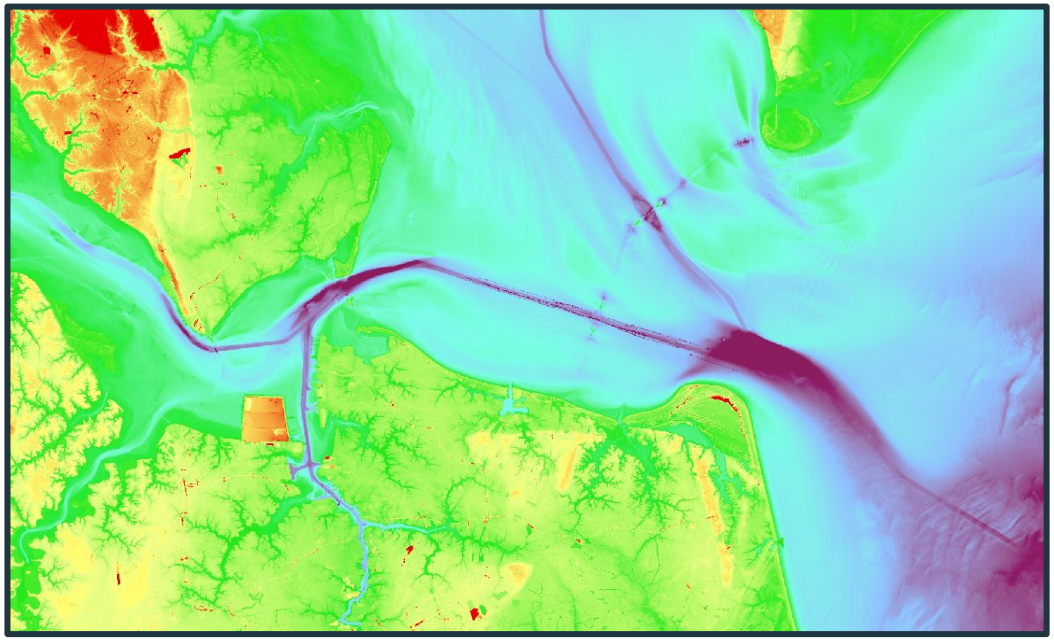


- Covers Mid- Atlantic Region
  - Virginia, Maryland and Delaware
- Min. resolution at 30m
- Coordinate Ranges
  - 35.4° N to 39.7° N.
  - 77.5° W to 73.5° W.

Mesh Development – Local Domain

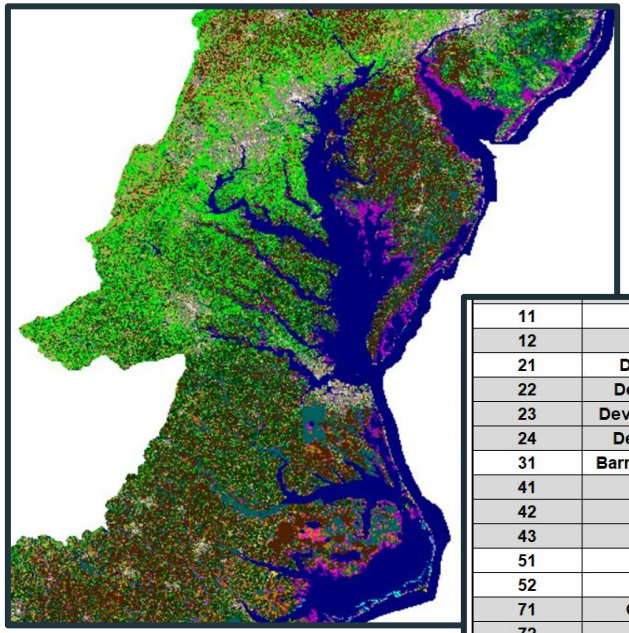


10m - Nested 2014 CUDEM



- Covers Southeast Virginia
  - Chesapeake Bay and Norfolk Region
- Min. resolution at 10m
- Coordinate Ranges
  - 36.8º N to 37.2º N.
  - 76.6º W to 75.8º W.

Mesh Development – Land Use and Land Cover



The 2016 Coastal Change Analysis Program (CCAP)

11	Open Water	0.025 - 0.05
12	Perennial Ice/Snow	N/A
21	Developed, Open Space	0.03 - 0.05
22	Developed, Low Intensity	0.06 - 0.12
23	Developed, Medium Intensity	0.08 - 0.16
24	Developed, High Intensity	0.12 - 0.20
31	Barren Land (Rock/Sand/Clay)	0.023 - 0.030
41	Deciduous Forest	0.10 - 0.20
42	Evergreen Forest	0.08 - 0.16
43	Mixed Forest	0.08 - 0.20
51	Dwarf Scrub*	0.025 - 0.05
52	Shrub/Scrub	0.07 - 0.16
71	Grassland/Herbaceous	0.025 - 0.05
72	Sedge/Herbaceous*	0.025 - 0.05
73	Lichens*	N/A
74	Moss*	N/A
81	Pasture/Hay	0.025 - 0.05
82	Cultivated Crops	0.020 - 0.05
90	Woody Wetlands	0.045 - 0.15
95	Emergent Herbaceous Wetlands	0.05 - 0.085

- Covers Mid-Atlantic Region
- Coordinate Ranges
  - 36.8° N to 37.2° N.
  - 76.6° W to 75.8° W.
- Min. resolution at 30m
- Use for Wind Reduction Factors and Canopy Coefficient
- Includes 24 classifications [1]

1 – US Army Corps of Engineers (2021)

Mesh Development – Using OceanMesh2D

Pre- Processing

No NaNs and
Project to WGS84

GeoProcessing → Mesh Building → Mesh Generation → Mesh Data

Sets ocean and land boundaries using DEMs and coastline shapefiles.

Ensures the mesh will be stable by bounding Courant number to under 0.5.

Distributes mesh resolution in 2D space within the domains.

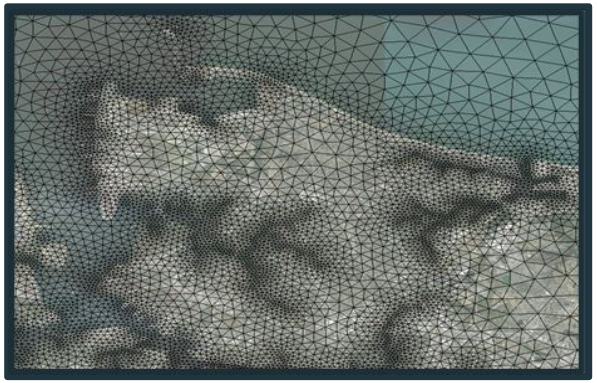
Builds input files for a simulation.

Mesh Development – Meshes Created!!

Coarse (500m)

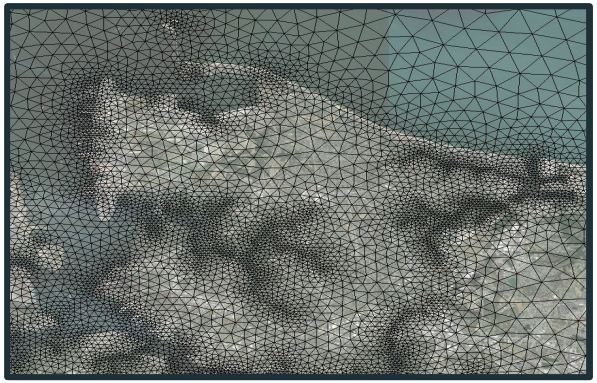
- HSOFS Mesh
- 1.8M Elements
- 50km max in open ocean
- 10m Floodplains in CONUS
- Natural Coastline

Medium (100m)



- Produced in OceanMesh2D
- 775k Elements
- 30km max in open ocean
- 10m Floodplains in VA only
- No barrier islands in NC

Fine (20m)



- Produced in OceanMesh2D
- 856k Elements
- 10km max in open ocean
- 10m Floodplains in VA only
- No barrier islands in NC

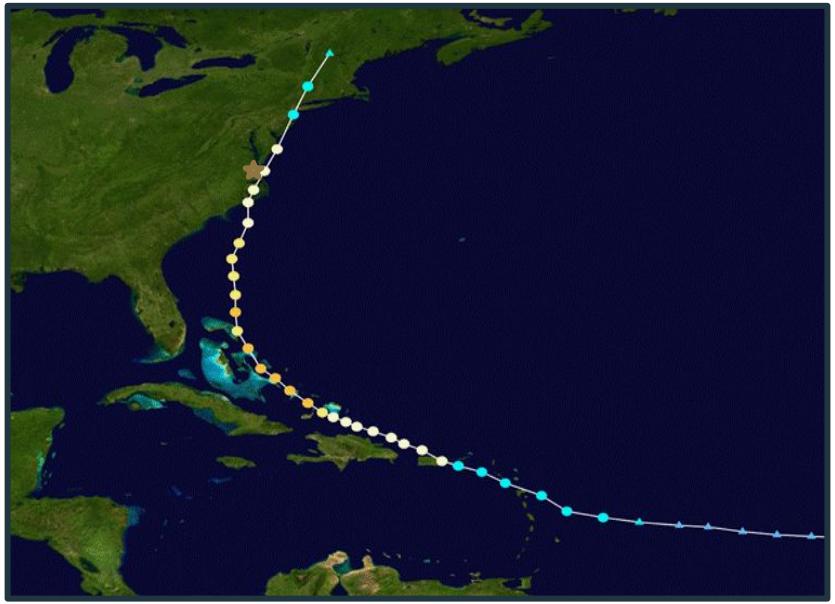
Storm Simulation - Hurricane Irene (2011)

Tides

- Major 8 Tidal Constituents
  - K1, O1, Q1, P1, M2, N2, K2, and S2
- 18 day spin up (8/6/2011 to 8/24/2011)

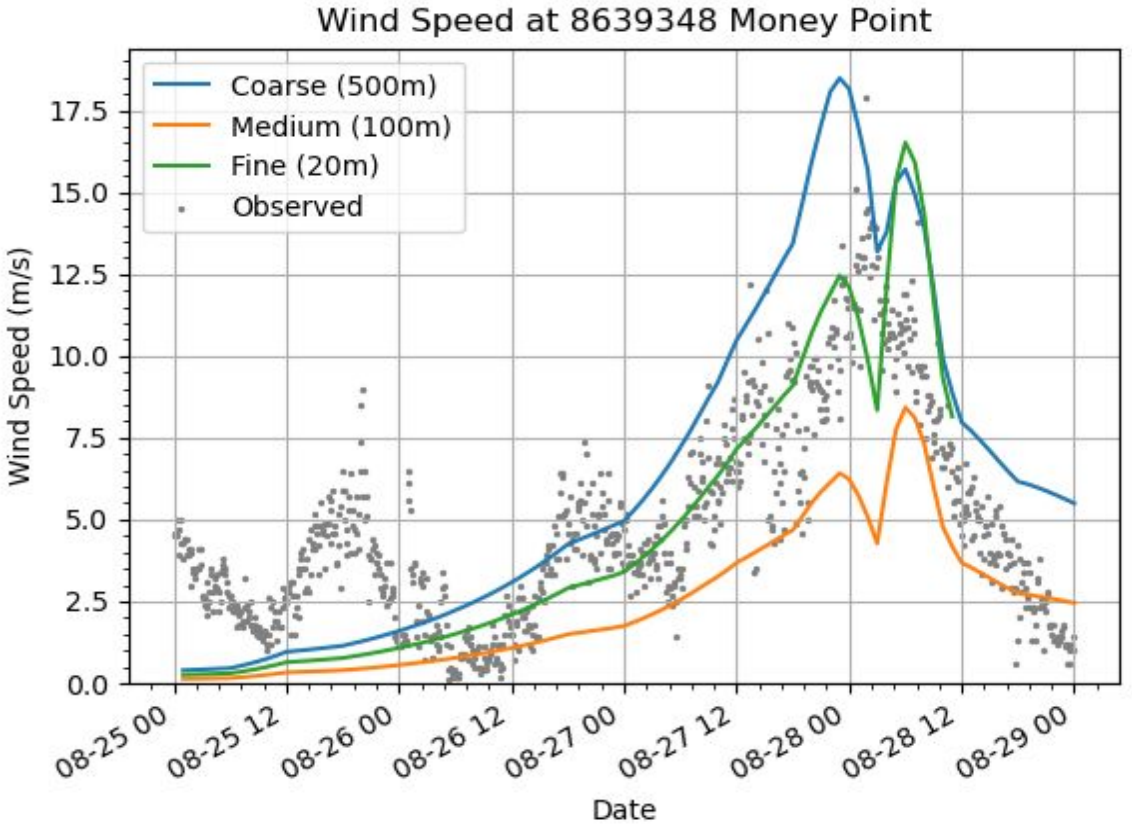
Storm

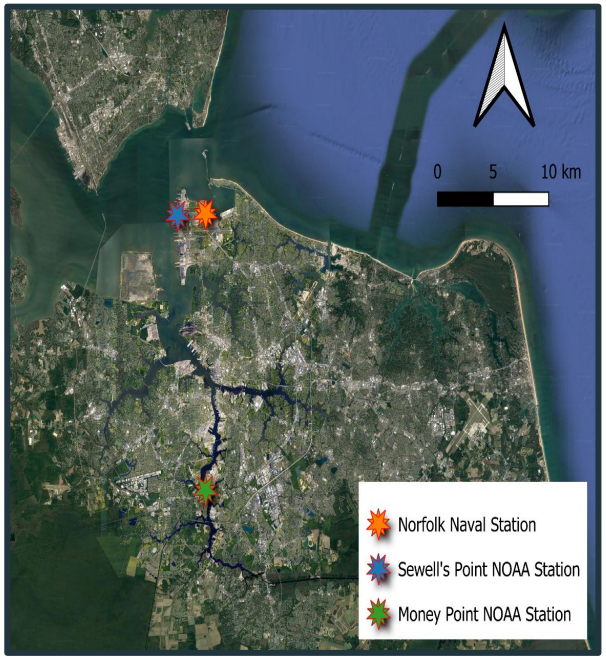
- Hurricane Irene (2011)
- GAHM (NWS=20) with NHC best-track
- 6 day winds (8/24/2011 to 8/30/2011)
  - Landfall Date = 8/27/2011



Storm Track for Hurricane Irene (2011) from National Hurricane Center

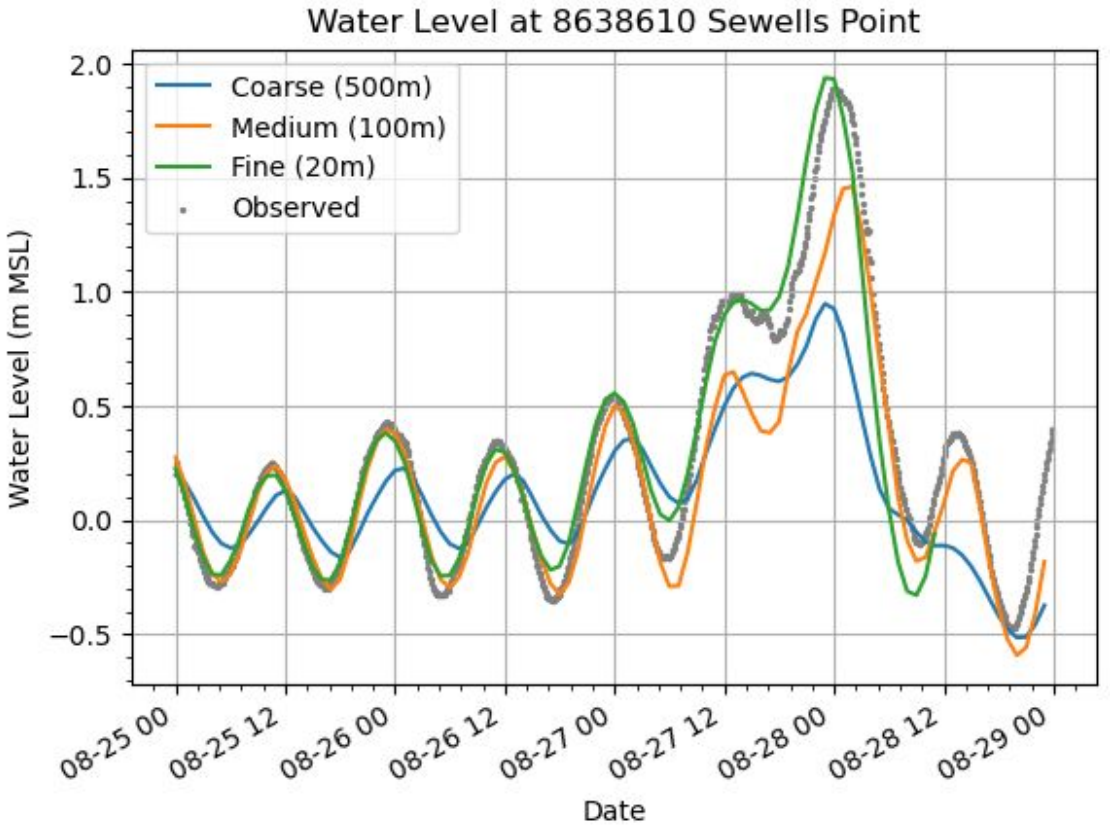
Storm Simulation - Wind Speed Results





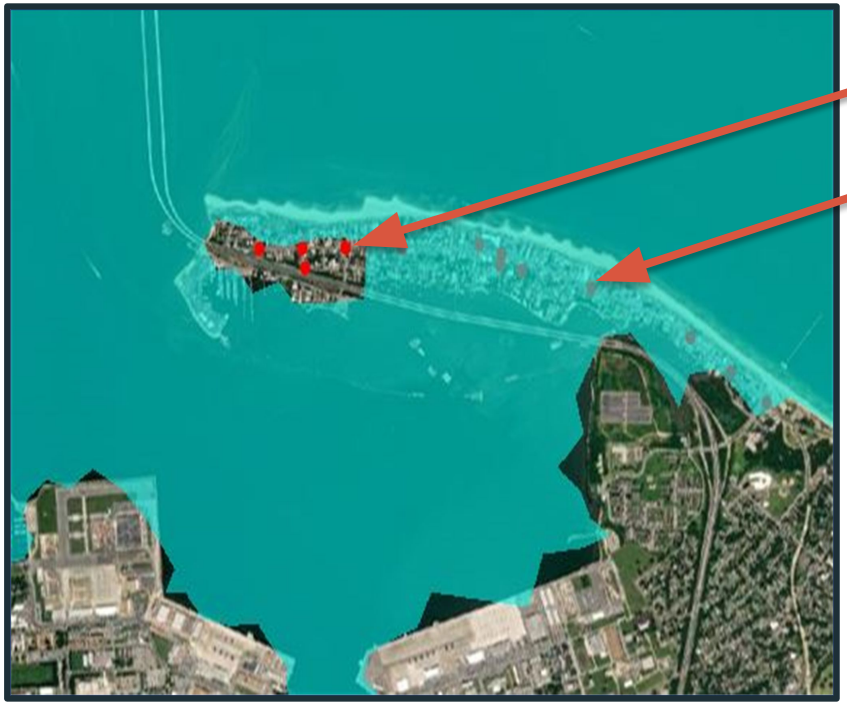
Location Map showing NOAA Station to NNS

Storm Simulation - Water Level Results



Location Map showing NOAA Station to NNS

Storm Simulation- Max Flooding Results on Medium Mesh



Reported flooding from Norfolk Open Data compared againt Medium Mesh Max Flooding

Norfolk Open Data:

- Surveyed Residents Reports
- Report Type:
  - Flooded Streets (13 Reported) ←
  - Traffic Signal Issues
  - Down Power Lines
  - Date and Event
- Address and location of reported

Storm Simulation - Summary of Results

Mesh	Wind Speeds	Water Levels		
	RMSE (m/s)	RMSE (m)	Peak Diff. (m)	Reported Floodings Models (%)
Coarse (500m)	5.65	0.56	-0.94	0
Medium (100m)	4.01	0.33	-0.43	69
Fine (20m)	3.46	0.23	+0.05	85

Main Conclusions

- Mesh and Model optimization is achieved by focusing the elements on the mesh to the hyperlocal site.
  - Improves the accuracy of max wind speeds **by reducing the RMSE by 2.19m/s**.
  - Imporves the accuracy of predicted water levels **by reducing the RMSE by 0.33m**.
  - Improves the max peak water level from **-0.99m to +0.05m**.
  - Shows **85% more reported flooding** results.

On-going/Future Work

- Optimizing storm surge predictions at hyperlocal sites.
  - ❑ Changes in mesh development??
    - ❑ Produce more meshes.
    - ❑ Vary domain and minimum mesh resolutions.
  - ❑ Affects of Modeling Choices??
    - ✔ Investigate Wind Models. □ **Will need to run simulations!**
      - ✔ Convert NetCDF wind file to readable ADIRC files (NWS=13).
      - ✔ Update input files for OWI Standards.
- Model Collaboration.
  - ❑ Modify storm parameters.
  - ❑ Conduct model degradation studies.
  - ❑ Determine worst case scenario for NNS.


Thank
You