Storm Surge Predictions at Hyperlocal Sites

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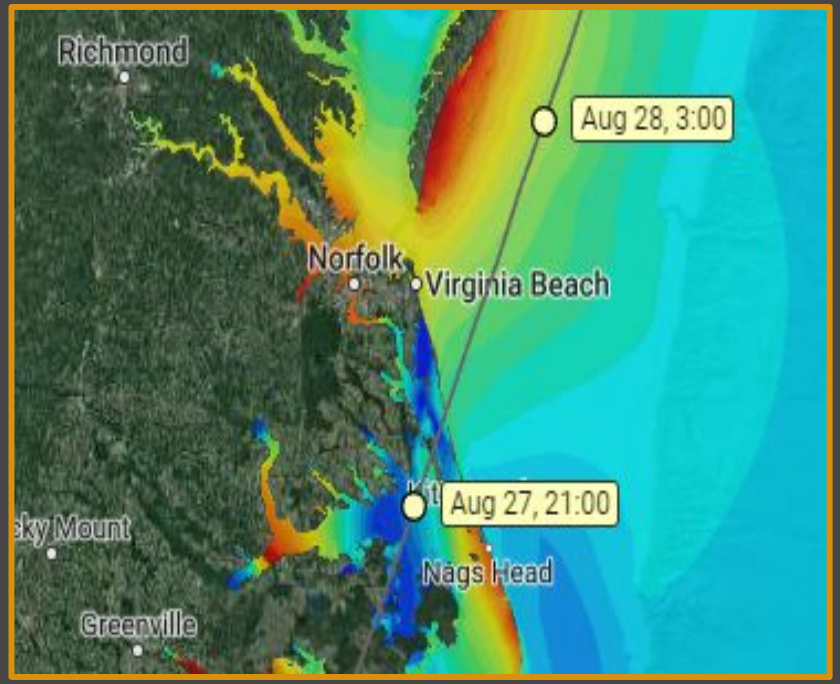
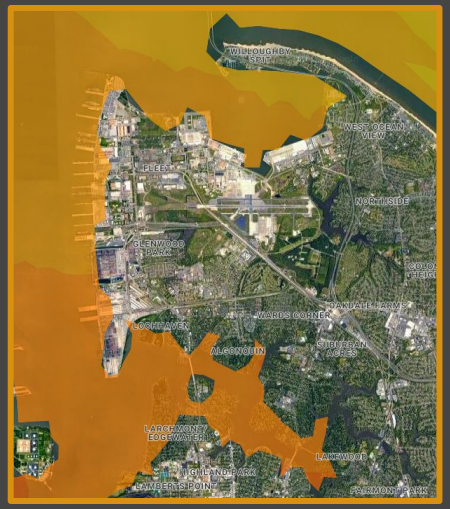
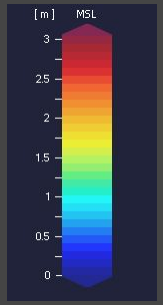


Storm Track for Hurricane Irene (2011) from CERA covering regional domains

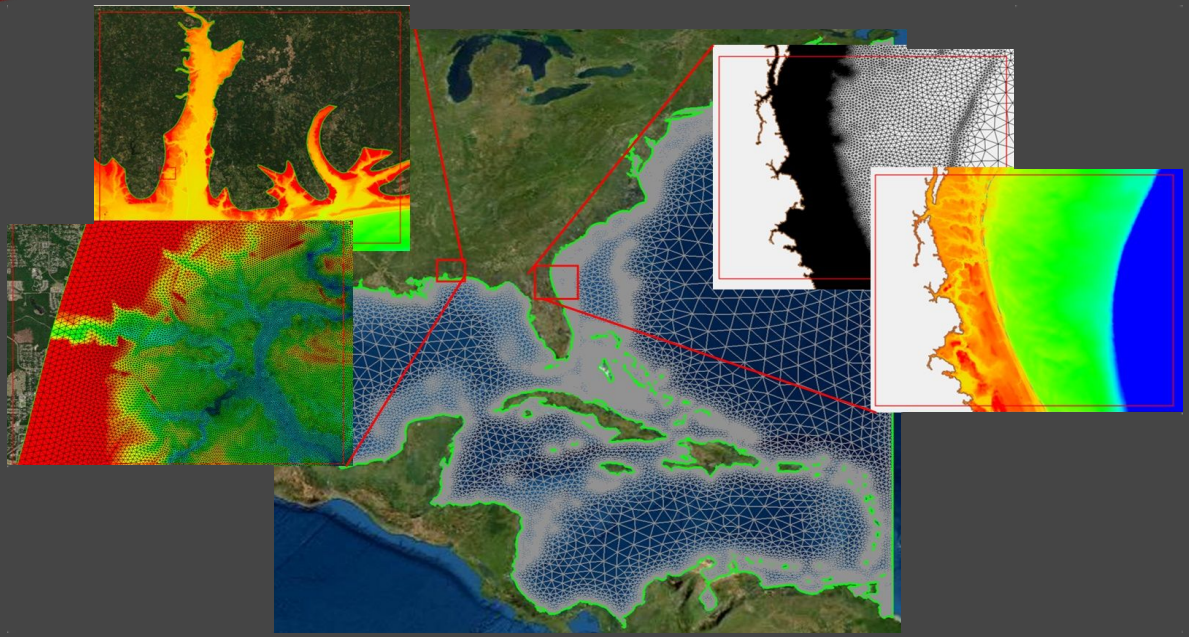




Modeled Water Levels in Norfolk

Local Community in Norfolk

ADCIRC + SWAN

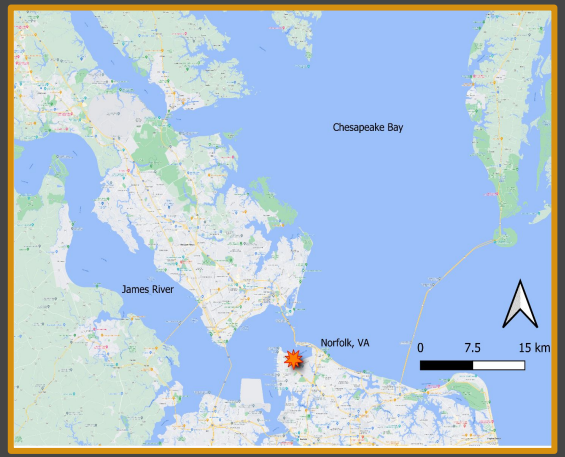


ADCIRC Model showing resolution details and bathymetry

- Uses finite element unstructured grids
- Solves Generalized Wave Continuity Equation (GWCE)
- Resolves Tides and Storm Surges
- Successfully used for forecasts by NOAA, DHS and USACE

NAVAL STATION NORFOLK (NSN)

- Located on Land Subsidence (Settling Land)
- Surrounded by bulkheads and many water bodies
- Highest Rate of SLR on east Coast: 4.5mm/year[1]



Location Map of NSN in Norfolk, VA

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

Naval Station Norfolk

1 – Kramer (2016)

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)
4 – NOAA Sea Level Rise Viewer (https://coast.noaa.gov/slr/#/layer)

RESEARCH QUESTION & OBJECTIVES

What is the worst-case scenario for a storm at NSN?

Mesh

Mesh Development

- Develop high resolution mesh(es) for NSN.

Storm

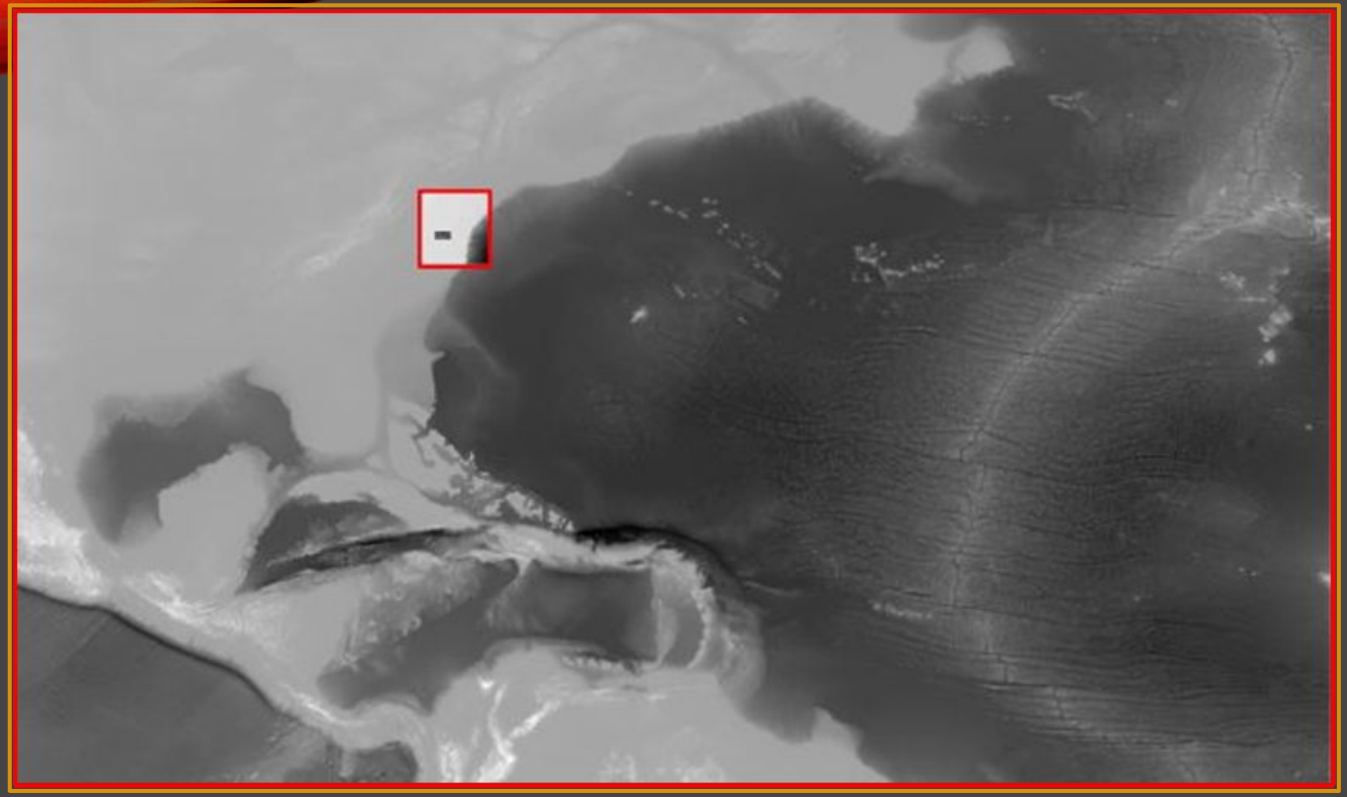
Storm Simulations

- Examine sensitivity to mesh resolution.

Model

Model "Inter-Comparison"

- Examine sensitivity to storm scenarios with other models.
  - Sea Level Rise
  - Storm Track

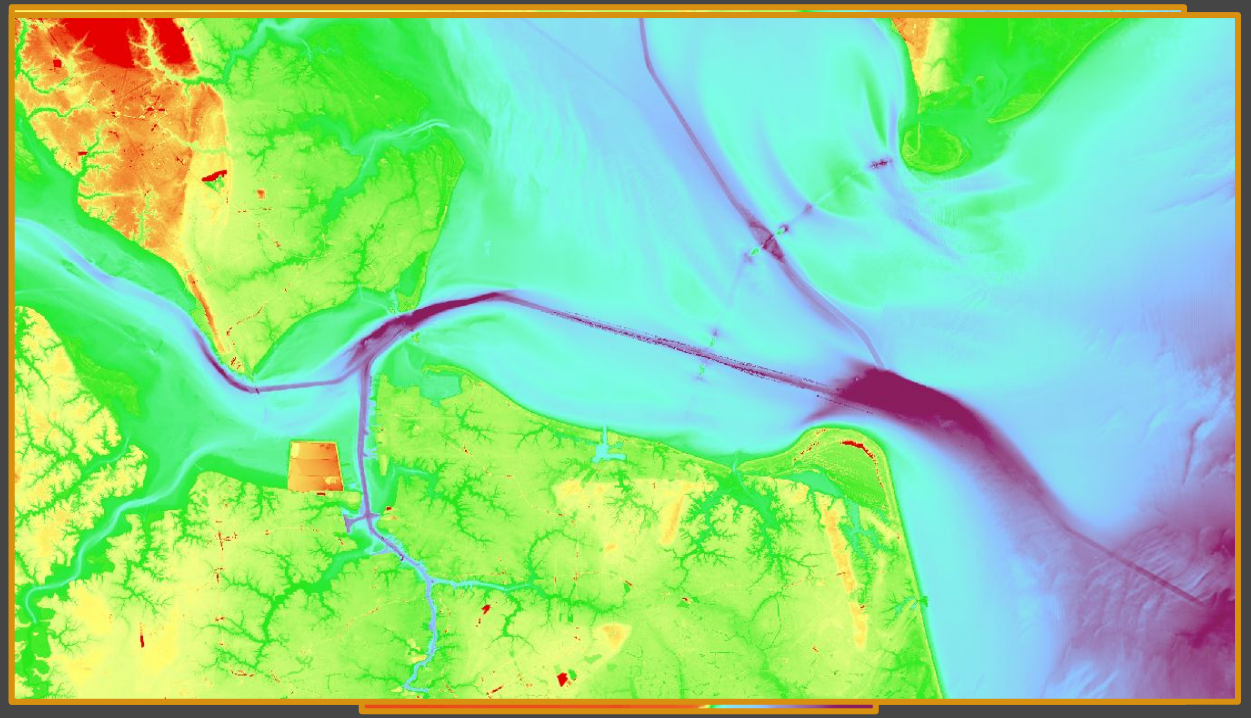


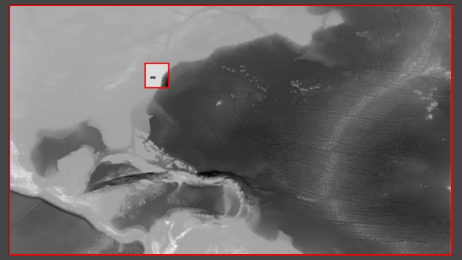
MESH DEVELOPMENT – WHAT DEMS TO USE?

500m - 2018 Shuttle Radar Topography Mission (SRTM)

10m - Nested 2014 LiDAR DEM

30m - Nested 2014 DEM



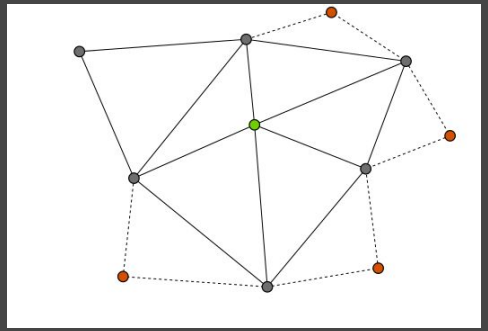


OCEANMESH2D

- Creates the Delaunay Triangulation
- Refines the Triangulation Iteratively

$$Element\ quality = \ q_E = 4\sqrt{3}A_E\left(\sum_{i=1}^{3}(\gamma_E^2)_i\right)^{-1}$$

Where:
A_E = area of the element
$(\lambda_E)i$ = length of the ith edge of the element



Example of Delaunay Triangulation

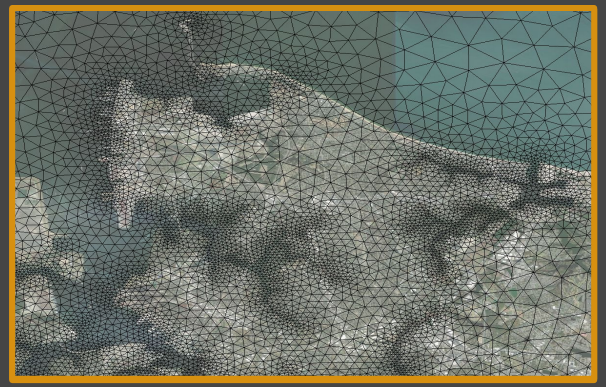
GeoProcessing	Mesh Building	Mesh Generation	Mesh Data
Sets ocean and land boundaries using DEMs and coastline shapefiles.	Ensures the mesh will be stable by bounding Courant number to under 0.5.	Distributes mesh resolution in 2D space within the domains.	Builds input files for a simulation.

MESHES CREATED

Coarse (500m)

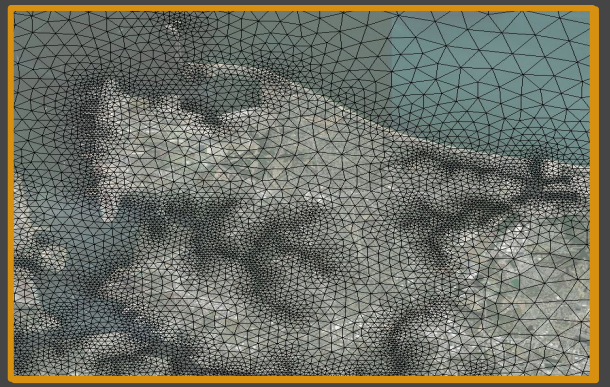
- Off-the-shelf-Model
- **1.8M Elements**
- 50km max in open ocean
- 10m Floodplains on coast

Medium (100m)



- Produced in OceanMesh2D
- **775k Elements**
- 30km max in open ocean
- 10m Floodplains in VA only

Fine (20m)



- Produced in OceanMesh2D
- **856k Elements**
- 10km max in open ocean
- 10m Floodplains in VA only

STORM SIMULATION

Tides

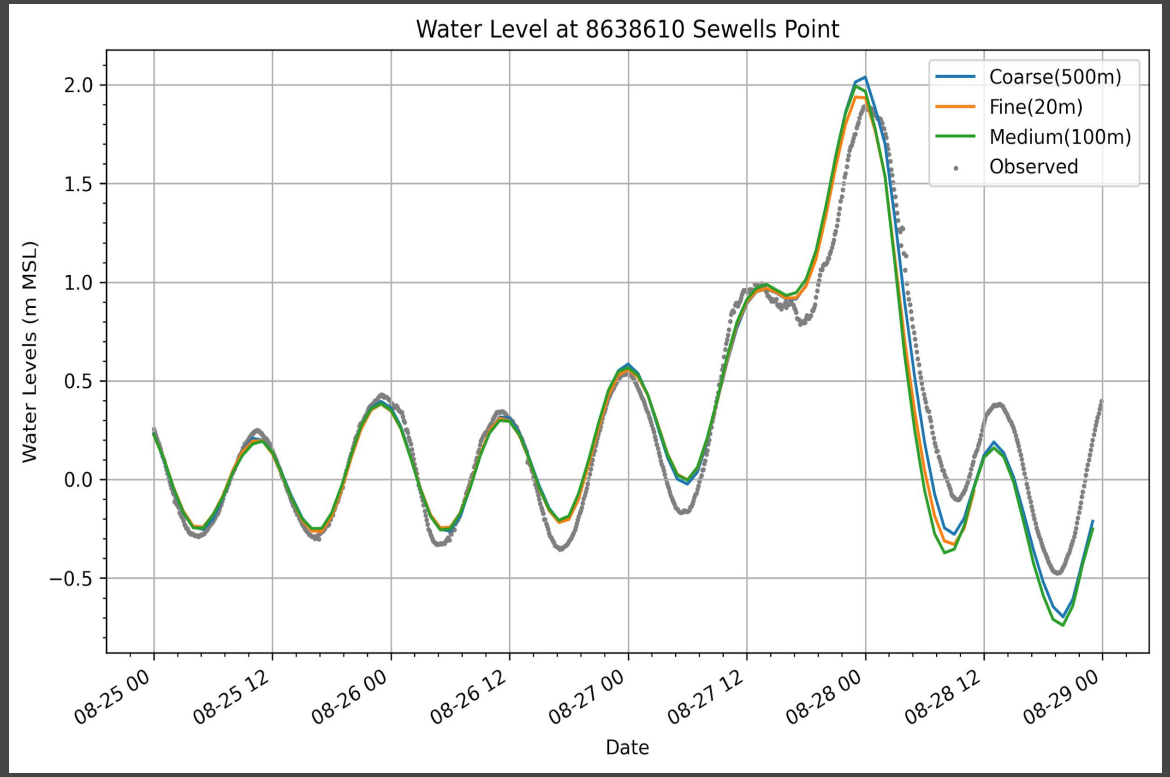
- Major 8 Tidal Constituents
  - K1, O1, Q1, P1, M2, N2, K2, and S2
- 18-day spin up (8/6/2011 to 8/24/2011)

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

PRELIMARY RESULTS - WATER LEVEL



Location Map showing NOAA Station to NNS

MAX FLOODING FROM PRELIMARY RESULTS

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

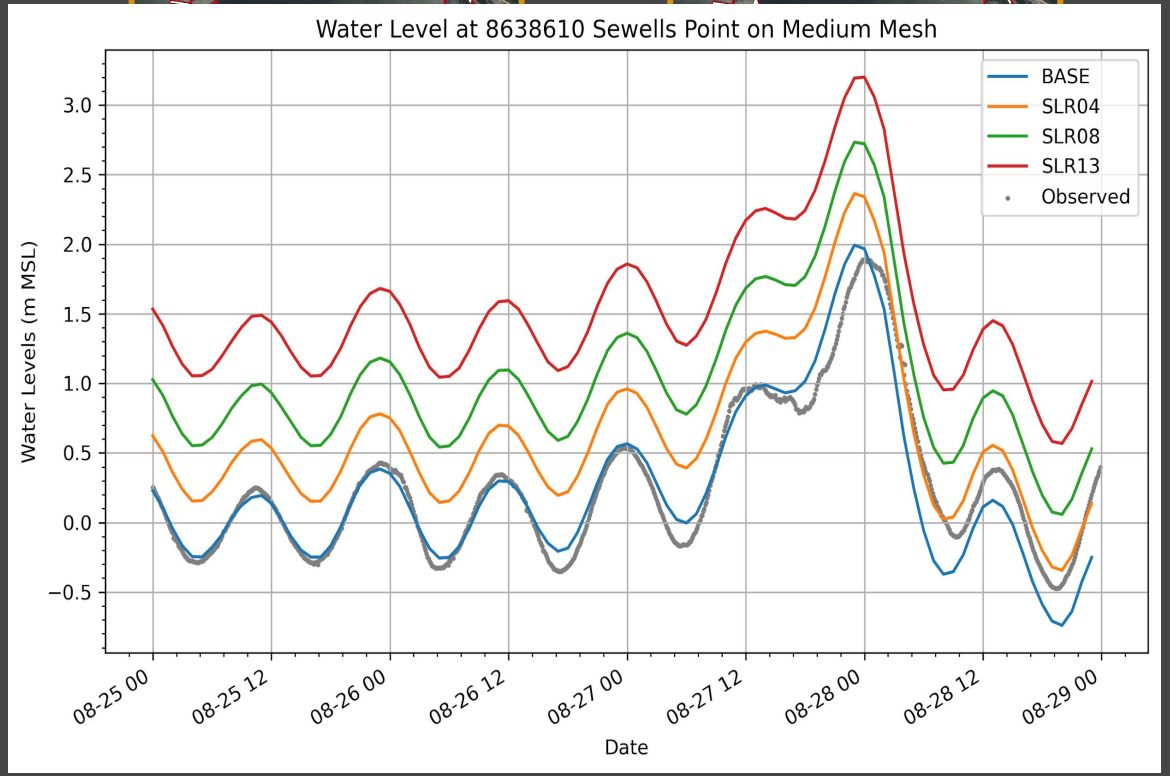
Norfolk Open Data:

- 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	Water Levels (Peak = 1.89m)			Computational Cost
	RMSE (m)	Peak (m)	Reported Floodings Models (%)	Hours (hr.)
Coarse (500m)	0.19	2.04	0	3612
Medium (100m)	0.27	1.99	69	398
Fine (20m)	0.22	1.94	85	838

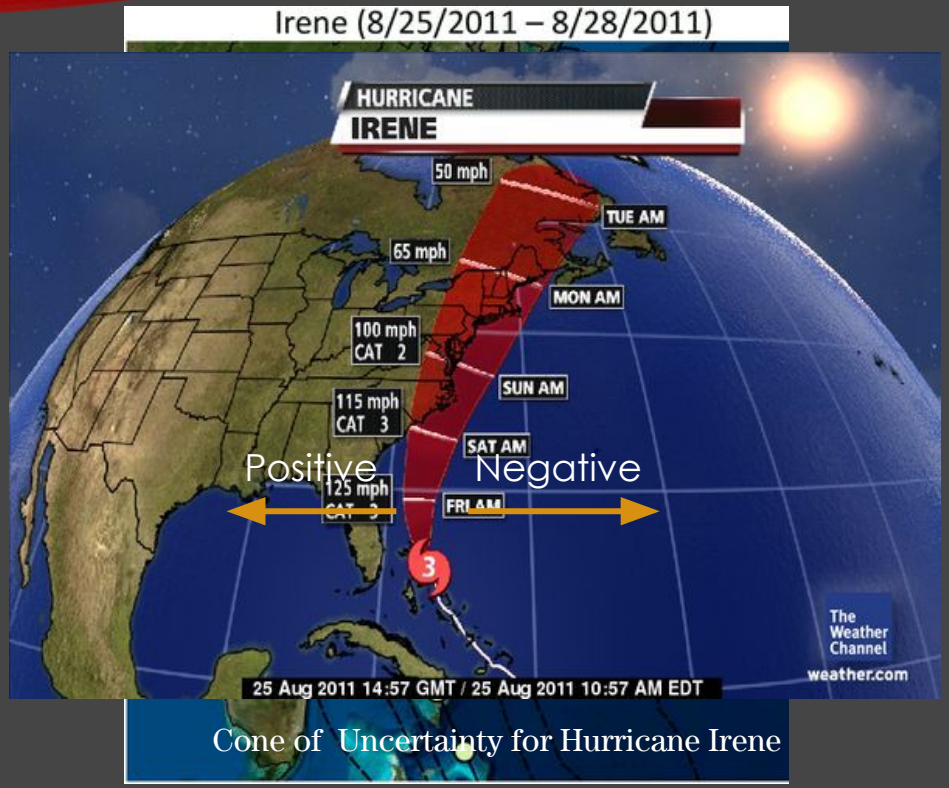
SEA LEVEL RISE SCENARIO



Sea Level Rise Comparison

Sea Level Rise (m)	Peak Water Levels (m)	Flooded Area (sq. km)
0.0	1.99	0.70
0.8	2.73	4.00

STORM TRACK DEVIATION SCENARIO

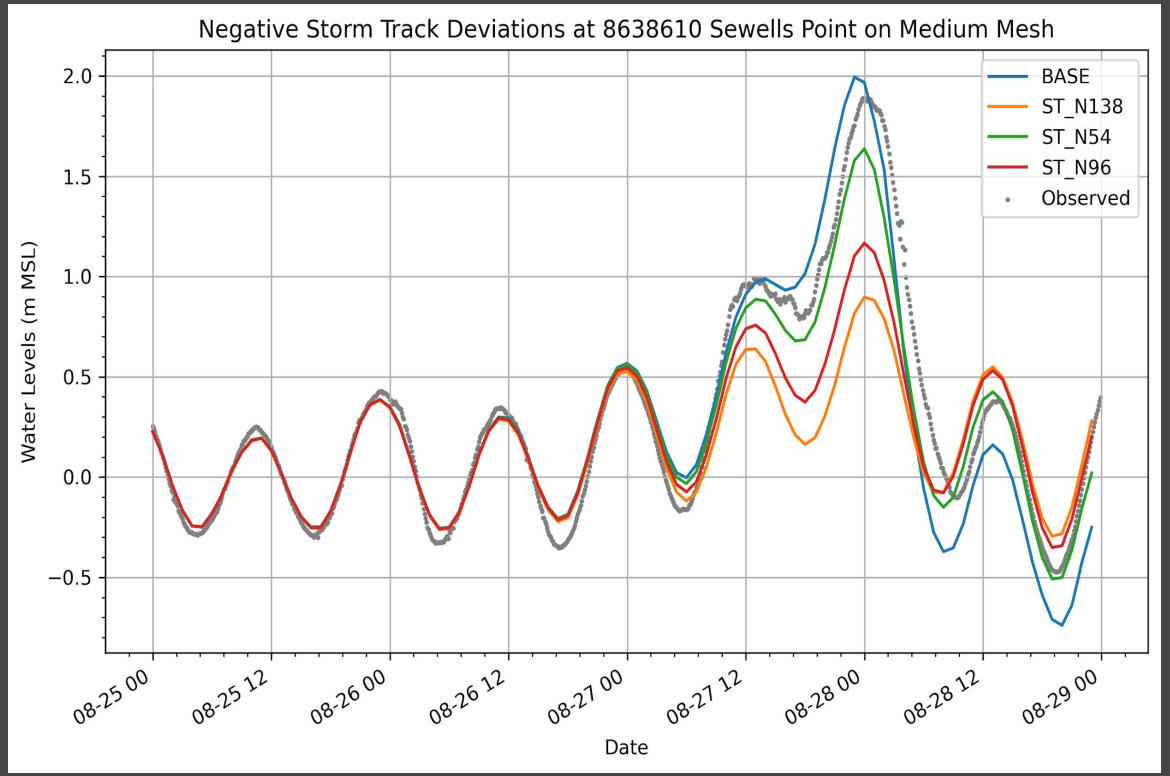


Storm Track Deviations

Storm Track Deviations of Hurricane Irene

Deviation (°)	Deviation (km)	Deviation (n mi.)
± 0.9	± 99.9	± 53.5
± 2.3	± 255.3	± 137.9

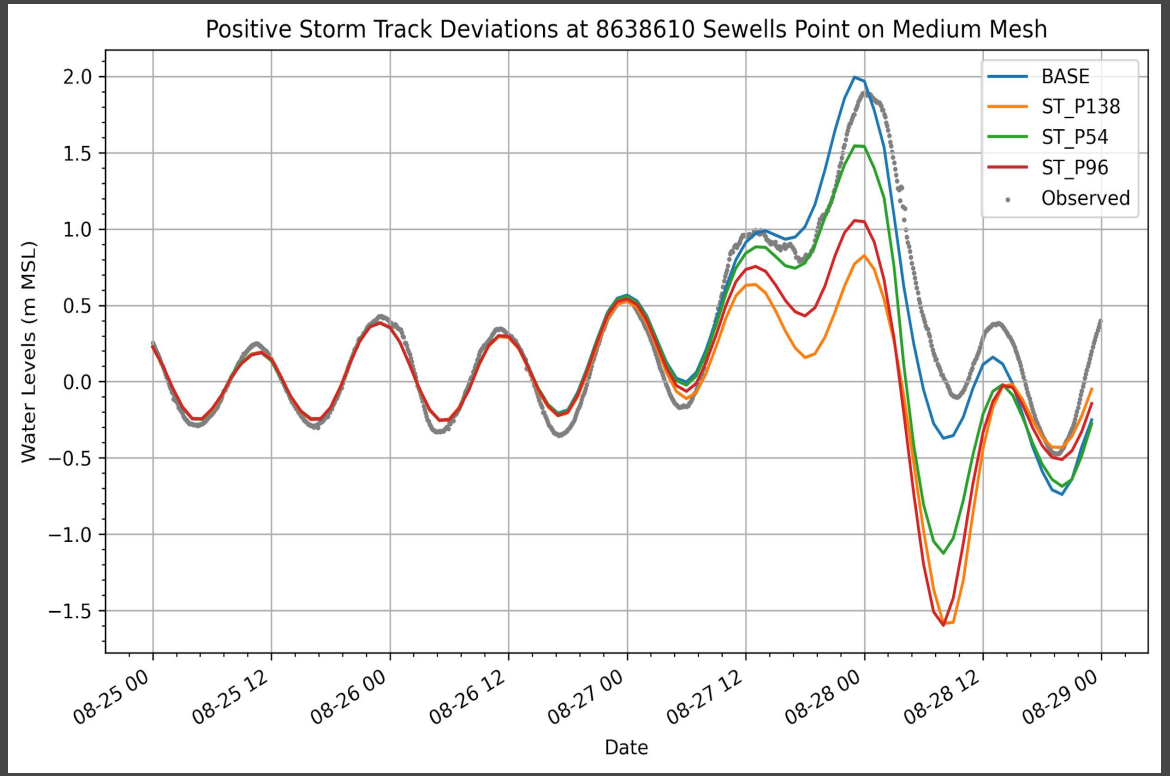
STORM TRACK DEVIATION SCENARIO



Negative Storm Track Deviations

Name	Storm Deviation (km)	Peak Water Level (m)
Base	0.00	1.99
N96	177.6	1.17

STORM TRACK DEVIATION SCENARIO



Positive Storm Track Deviations

Name	Storm Deviation (km)	Peak Water Level (m)
Base	0.00	1.99
P96	177.6	1.05

MAIN CONCLUSIONS

- Mesh and Model optimization is achieved by focusing the elements on the mesh to the hyperlocal site.
  - Improves the max peak water level from **2.04m to 1.94m**.
  - Shows **85% more reported flooding** results.

- Further storm perturbations will be needed to determine the worse case for NSN.
  - Sea level rise has a linear relationship to the peak flood.
  - Parallel deviations do not give worse scenario from Hurricane Irene.

Thank You

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