Improving the Accuracy of a Real-Time ADCIRC Storm Surge Downscaling Model

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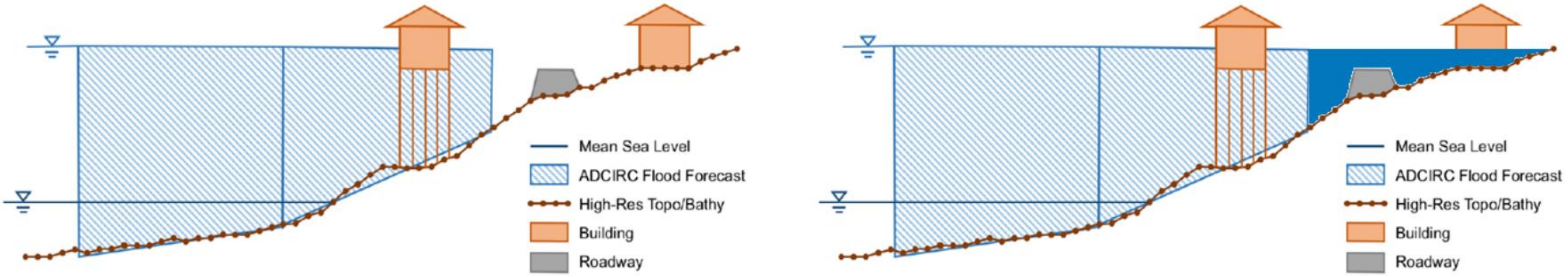
A U.S. Department of Homeland Security Center of Excellence

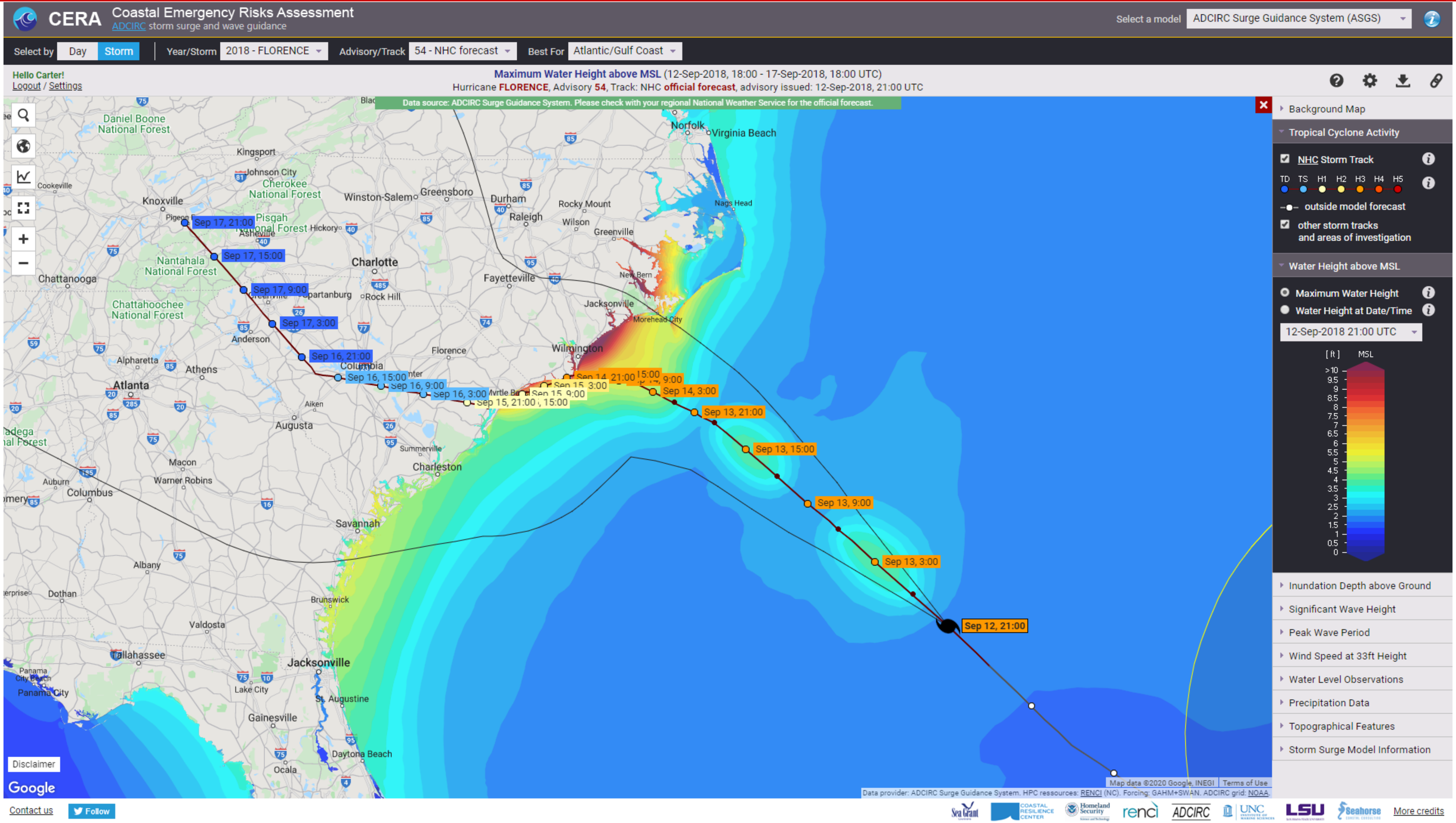


Downscaling ADCIRC water elevations, Tull 2018

Objectives

To achieve the goal of improving the accuracy and applicability of real-time storm surge downscaling methods:

1. Evaluate the accuracy of the existing static downscaling method
2. Increase the applicability of the downscaling code
3. Develop and evaluate a method that downscales water levels using the water surface slope
4. Develop and evaluate a downscaling method that includes head losses due to land cover



Maximum water levels for Hurricane Florence, advisory 54 – visualized on the CERA website

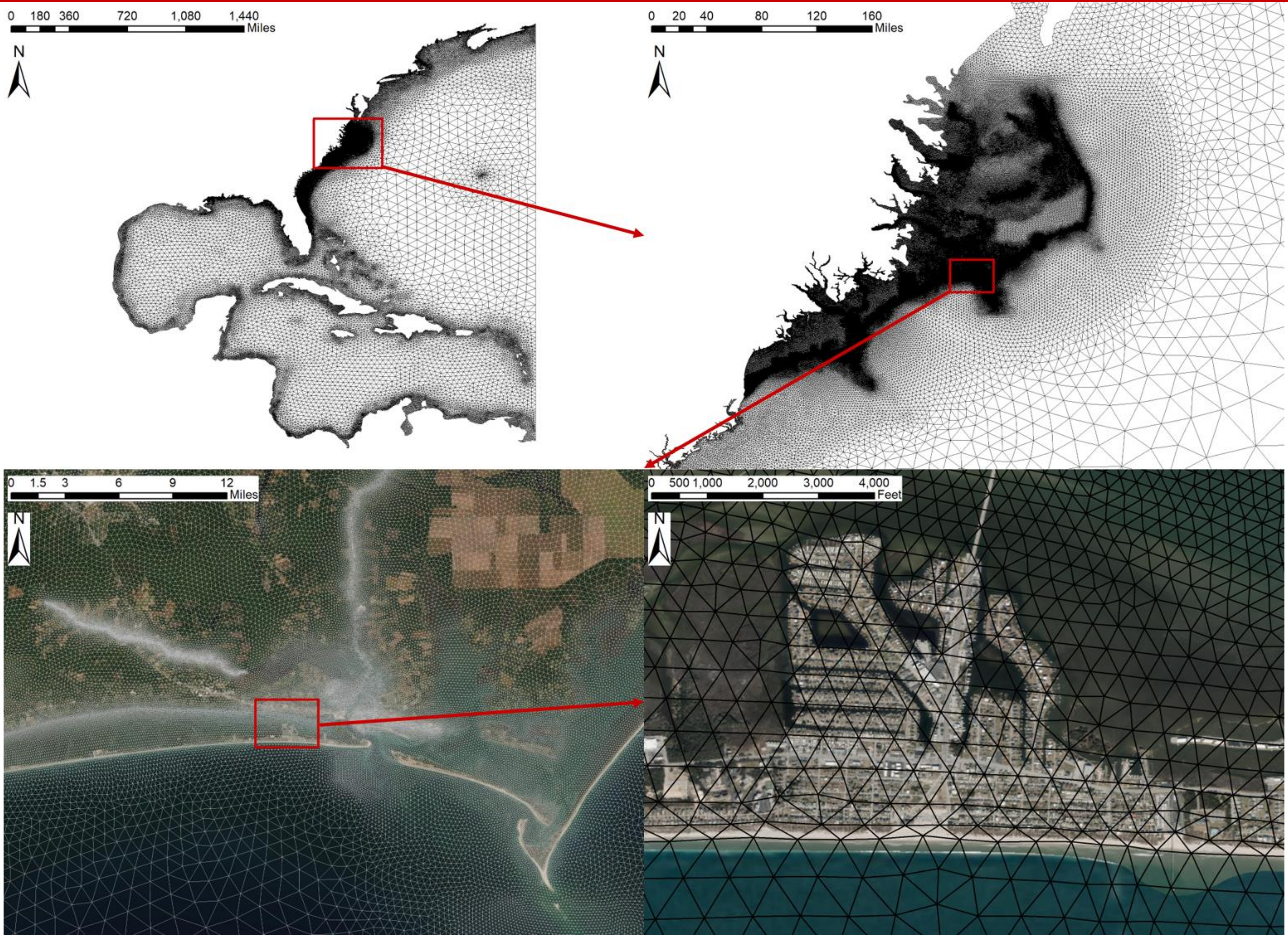
NC9 Mesh

Full NC9 Mesh

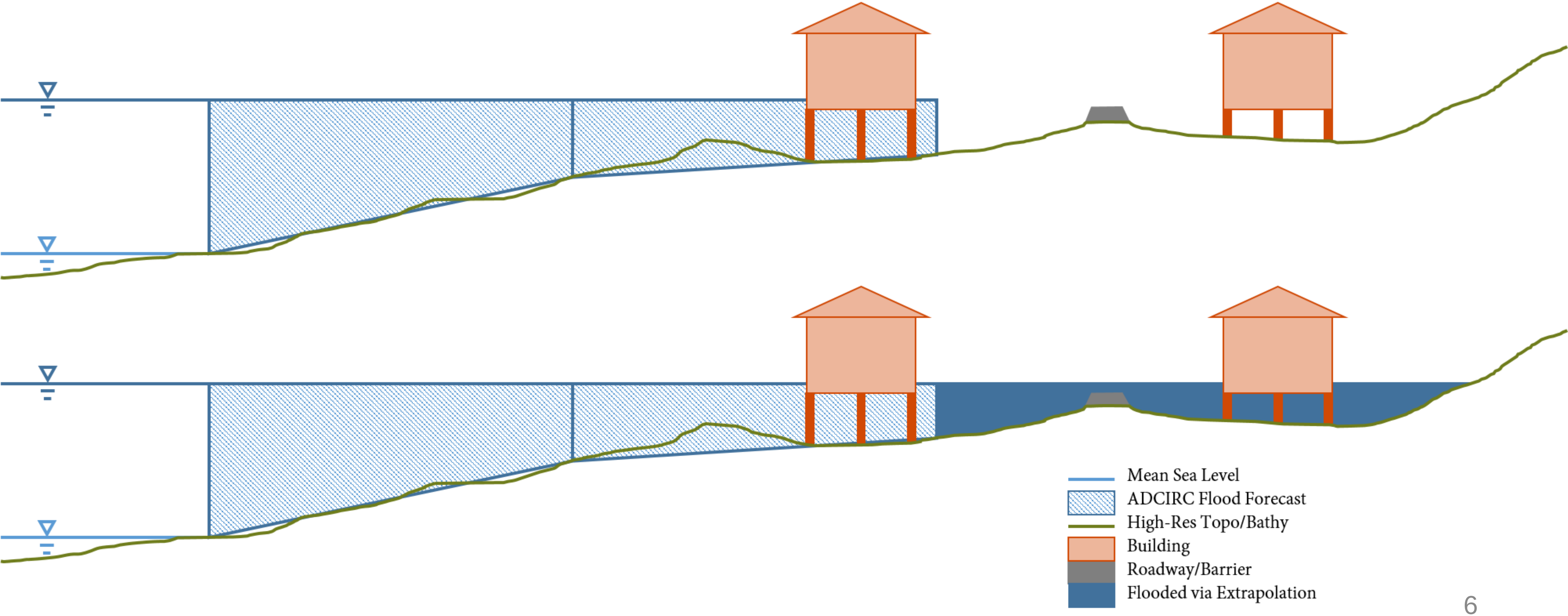
NC9 in North Carolina

Carteret County

Atlantic Beach



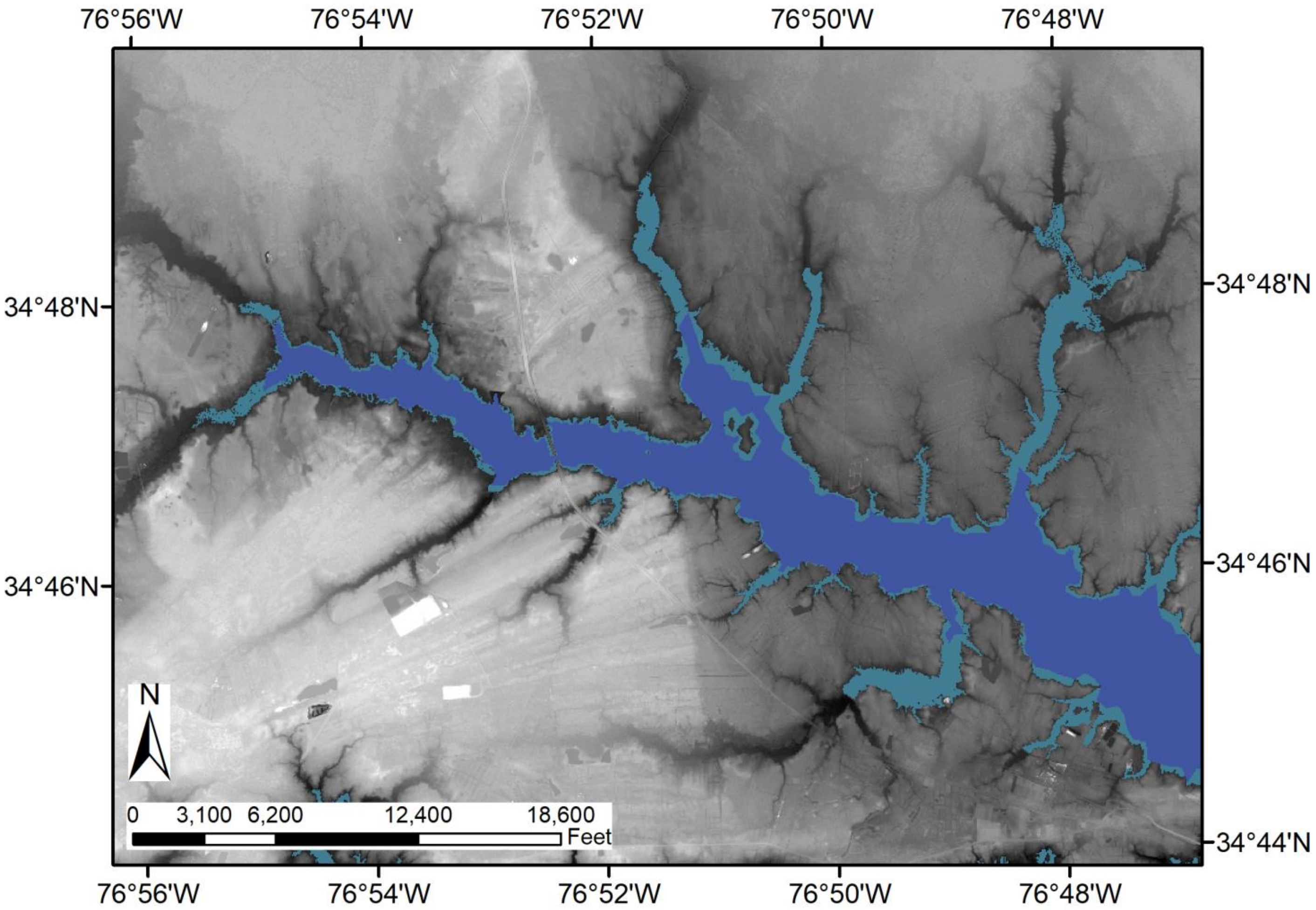
Static Method



Legend

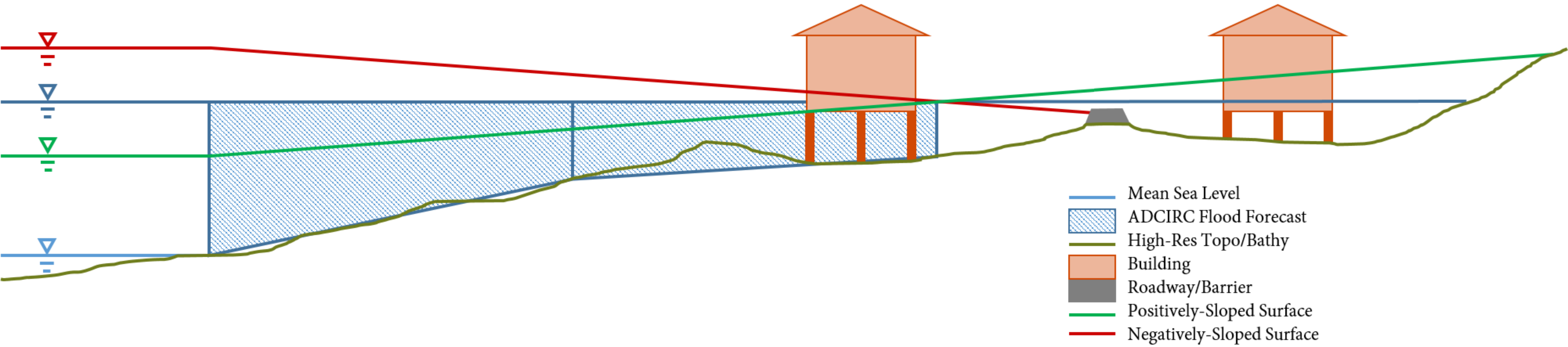
ADCIRC (NC9 mesh)

Downscaled using static method

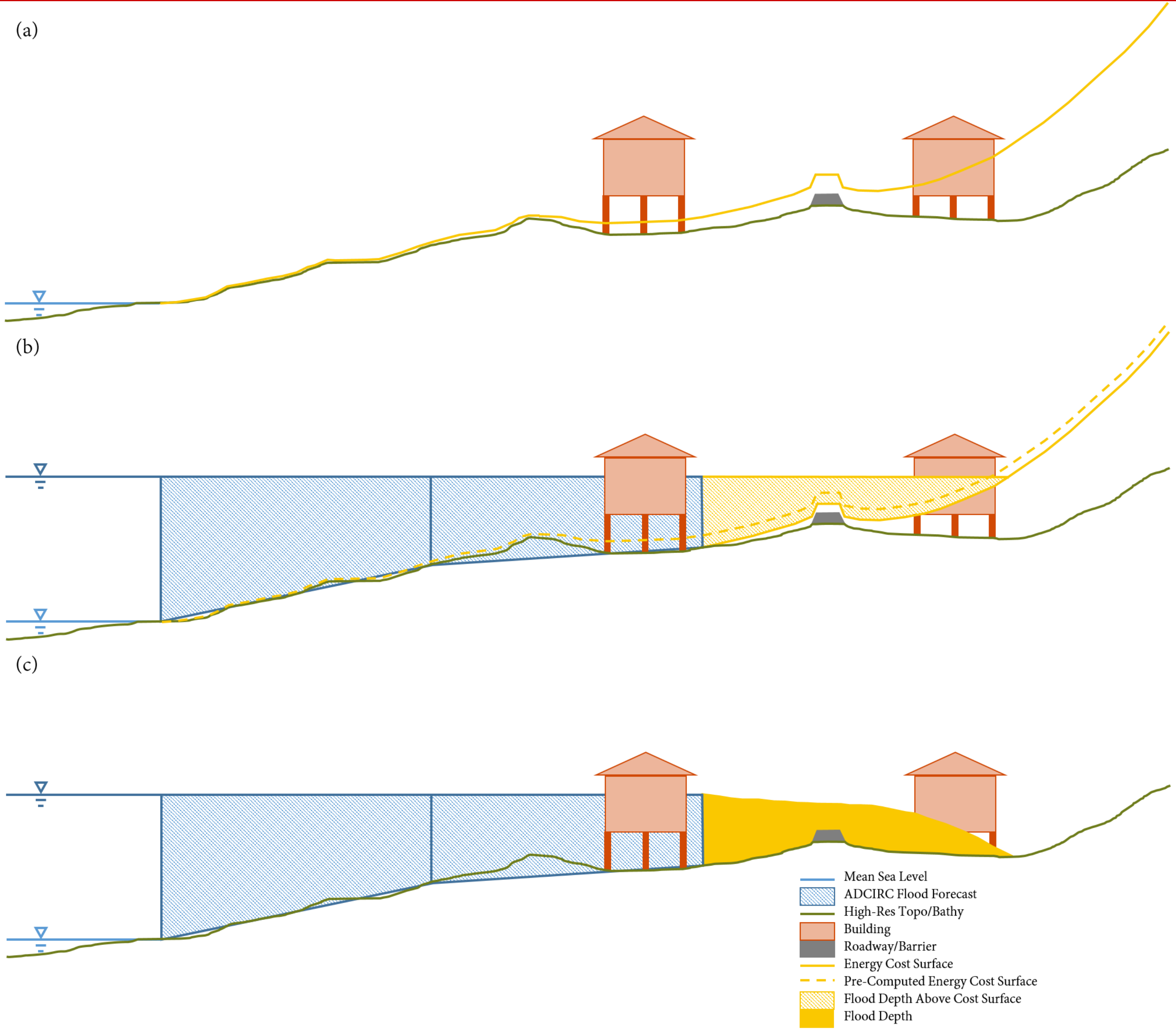


ADCIRC (NC9) results vs. downscaled results using the static method for Hurricane Florence (2018).

Slopes Method



$$\zeta_{slopes} = \zeta_{static} \pm c(m_x \Delta x) \pm c(m_y \Delta y)$$


(a)
(b)
(c)
Mean Sea Level
ADCIRC Flood Forecast
High-Res Topo/Bathy
Building
Roadway/Barrier
Energy Cost Surface
Pre-Computed Energy Cost Surface
Flood Depth Above Cost Surface
Flood Depth

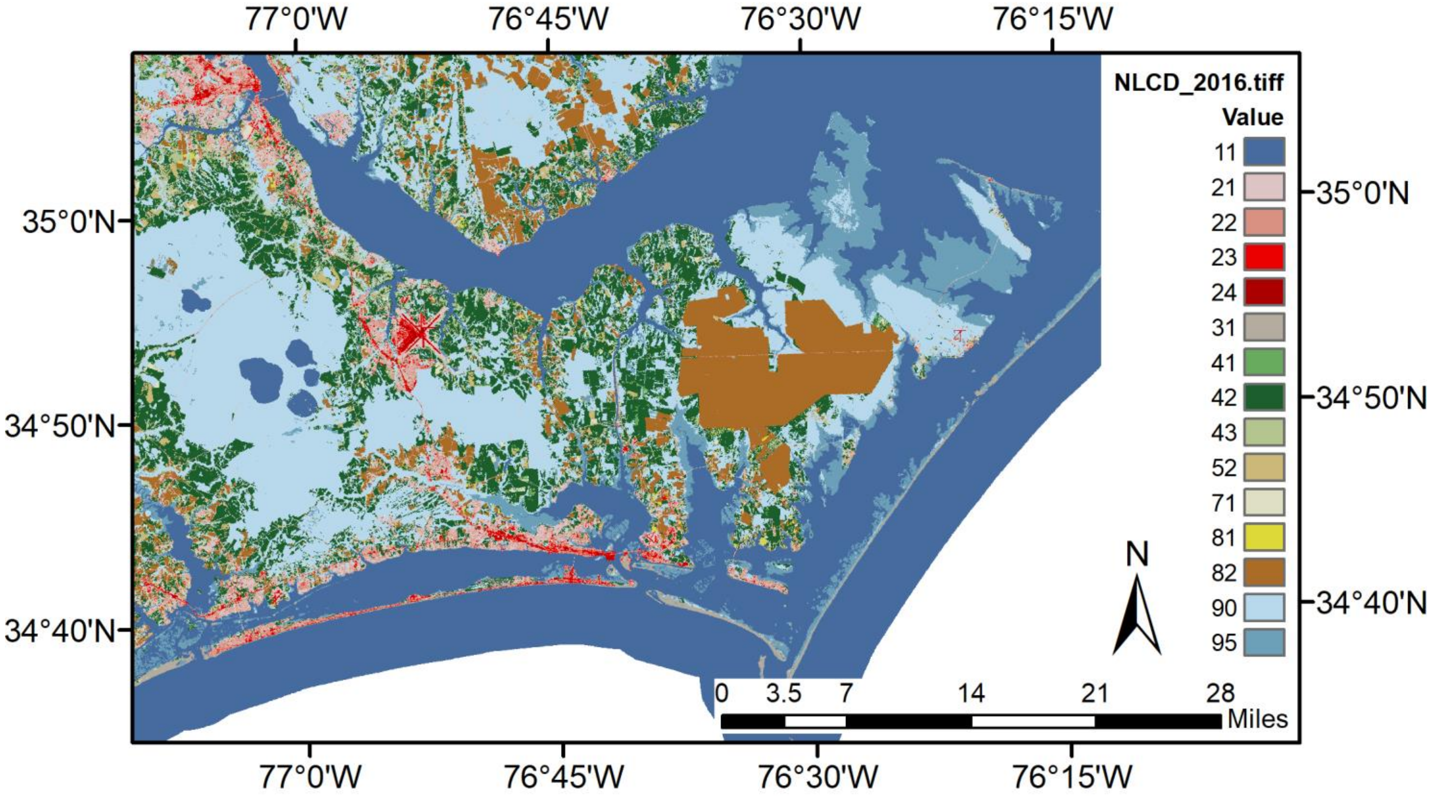
Head Loss Using Manning's Equation

- Manning's Equation:

$$U = \frac{k}{n} R^{2/3} S^{1/2}$$

- *S* = slope of energy grade line ≈ h_L/L
- Head loss:

$$h_L = L \left(\frac{n * U}{k * R^{2/3}} \right)^2$$



Land Cover	Description	Manning's n
11	Open water	0.001
21	Developed, open space	0.0404
22	Developed, low intensity	0.0678
23	Developed, medium intensity	0.0678
24	Developed, high intensity	0.0404
31	Barren land	0.0113
41	Deciduous forest	0.36
42	Evergreen forest	0.32
43	Mixed forest	0.40
52	Shrub/scrub	0.40
71	Grassland/herbaceous	0.368
81	Pasture/hay	0.325
82	Cultivated crops	0.037
90	Woody wetlands	0.086
95	Emergent herbaceous wetlands	0.1825

Liu et al. [2018] and Kalyanapu et al. [2009]

Head Loss Method

Pre-Forecasting

- Before receiving input from ADCIRC
- Computation time is **not** important
- Goal: Create energy cost surface to use in forecasting
- Have: DEM, Manning's n

Forecasting

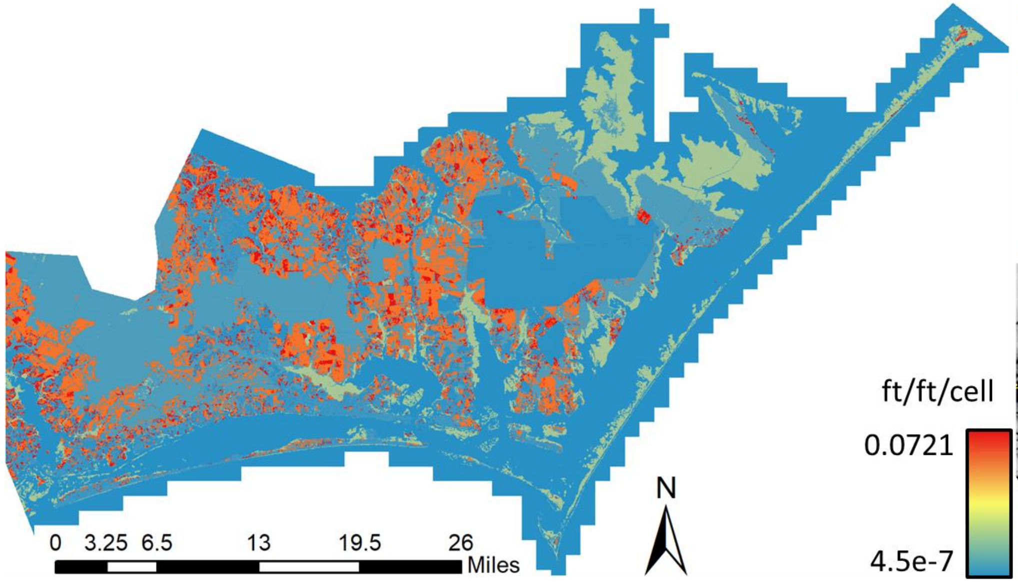
- After receiving input from ADCIRC
- Computation time **is** important
- Goal: Downscale ADCIRC results and distribute to emergency managers
- Have: Cost surface, ADCIRC water elevations

Pre-Forecasting r.walk Steps

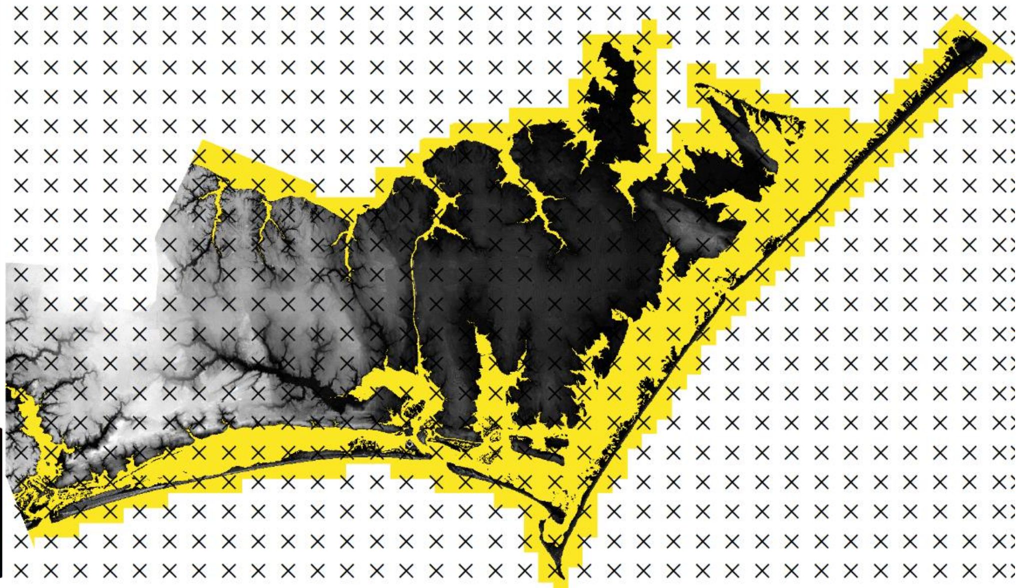
- Paths are entrained using the **r.walk** GRASS module
- **Least energy cost** from MSL to each endpoint using:

$$cost_{total} = \Delta z + \sum L \left(\frac{nU}{kR^{2/3}}\right)^2$$

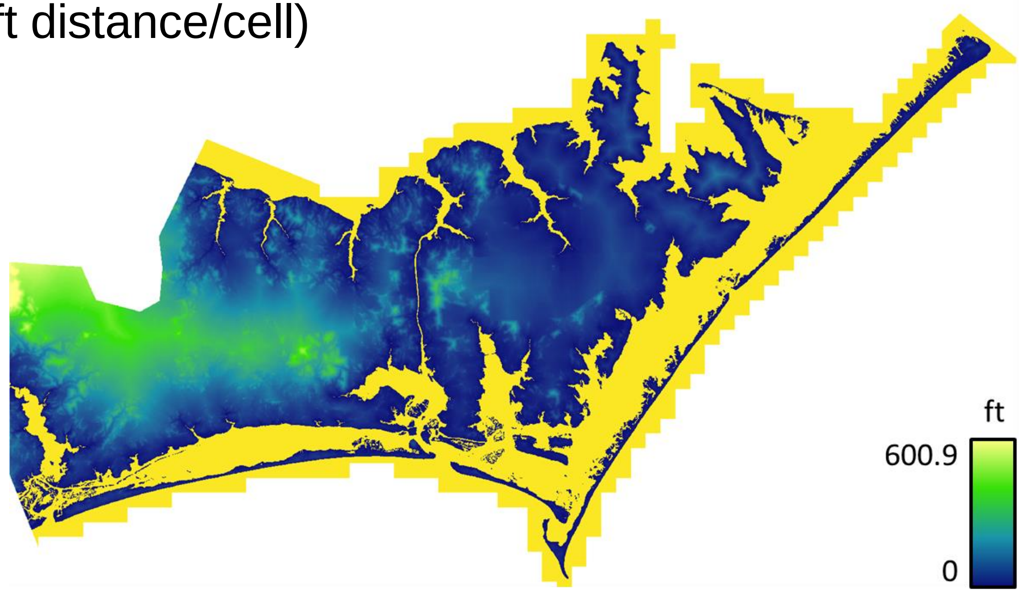
- Synthetic value $\boldsymbol{UR_{const}}$ used in pre-forecasting; equal to $U/R^{2/3}$



Unit Head Loss (ft h_L/ft distance/cell)



MSL (yellow, cost=0) and r.walk endpoints



Final cost surface; least cost of traveling from MSL to any raster cell

Head Loss Method

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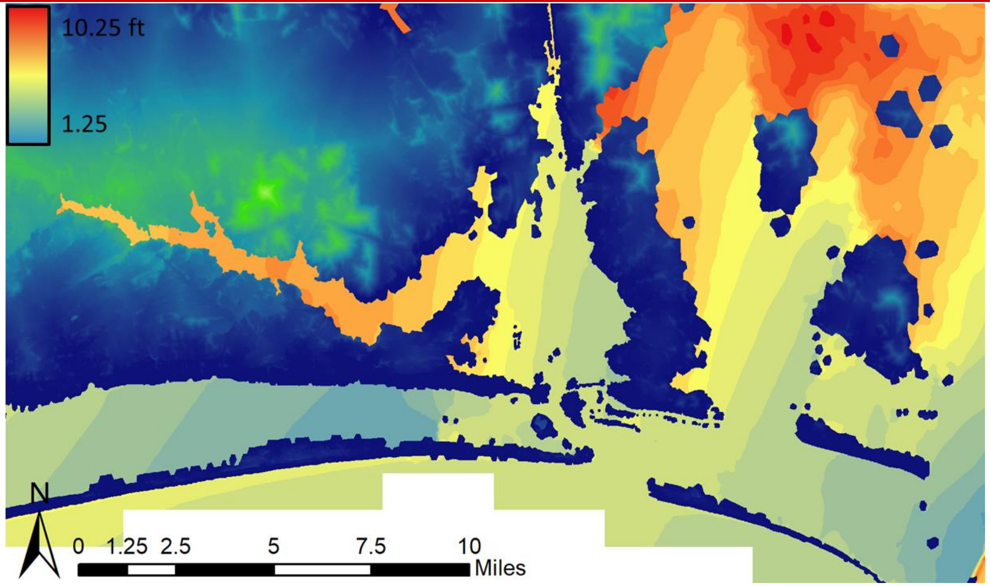
Forecasting with Head Loss

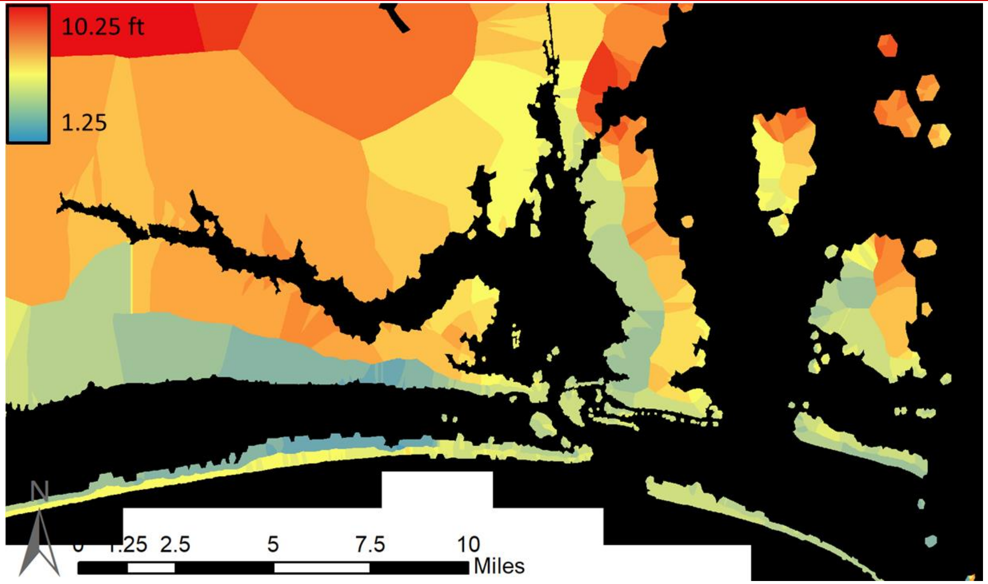
- Use ADCIRC water elevations to calculate R_{avg}

$$R_{avg} = \frac{1}{2}\left(\left(\zeta_{ADCIRC} - z_{DEM}\right)_{overland} + \left(\zeta_{ADCIRC} - z_{DEM}\right)_{MSL}\right)$$

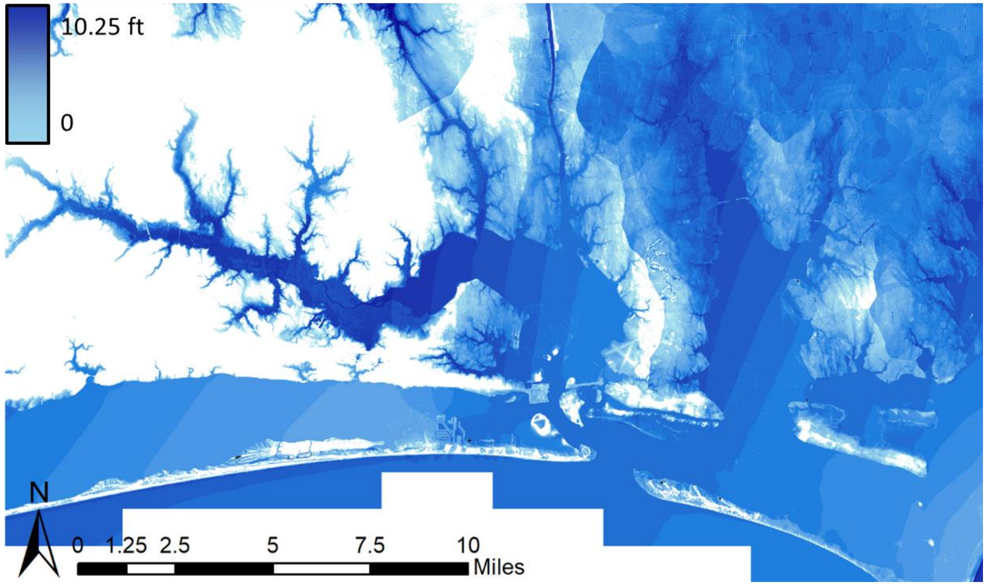
- No-flow condition exists in ADCIRC at wet/dry boundary; velocities at this divide cannot be used for extrapolation
- A constant value is used for *U*; for simplicity, this research uses *U*=1



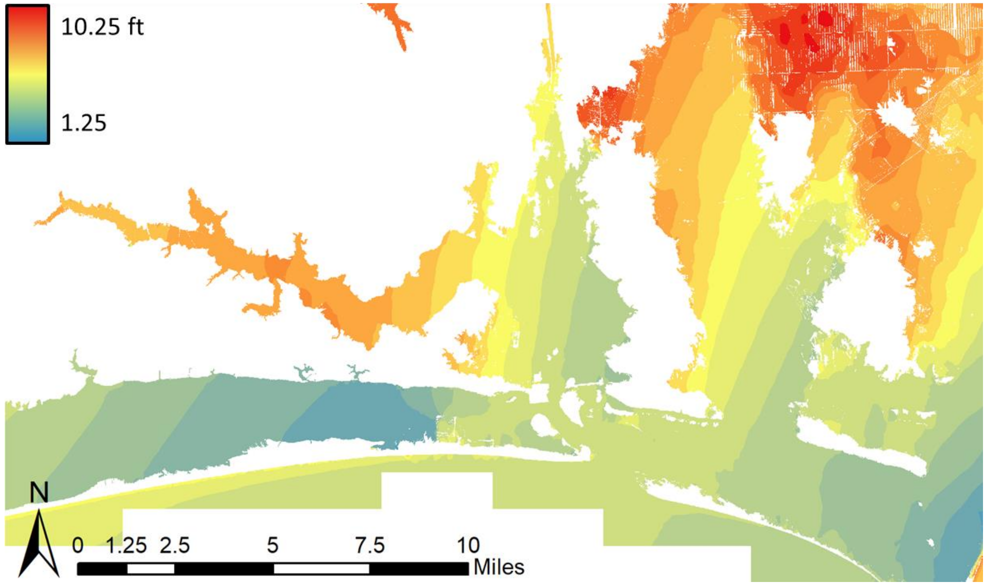
Cost raster and ADCIRC water levels



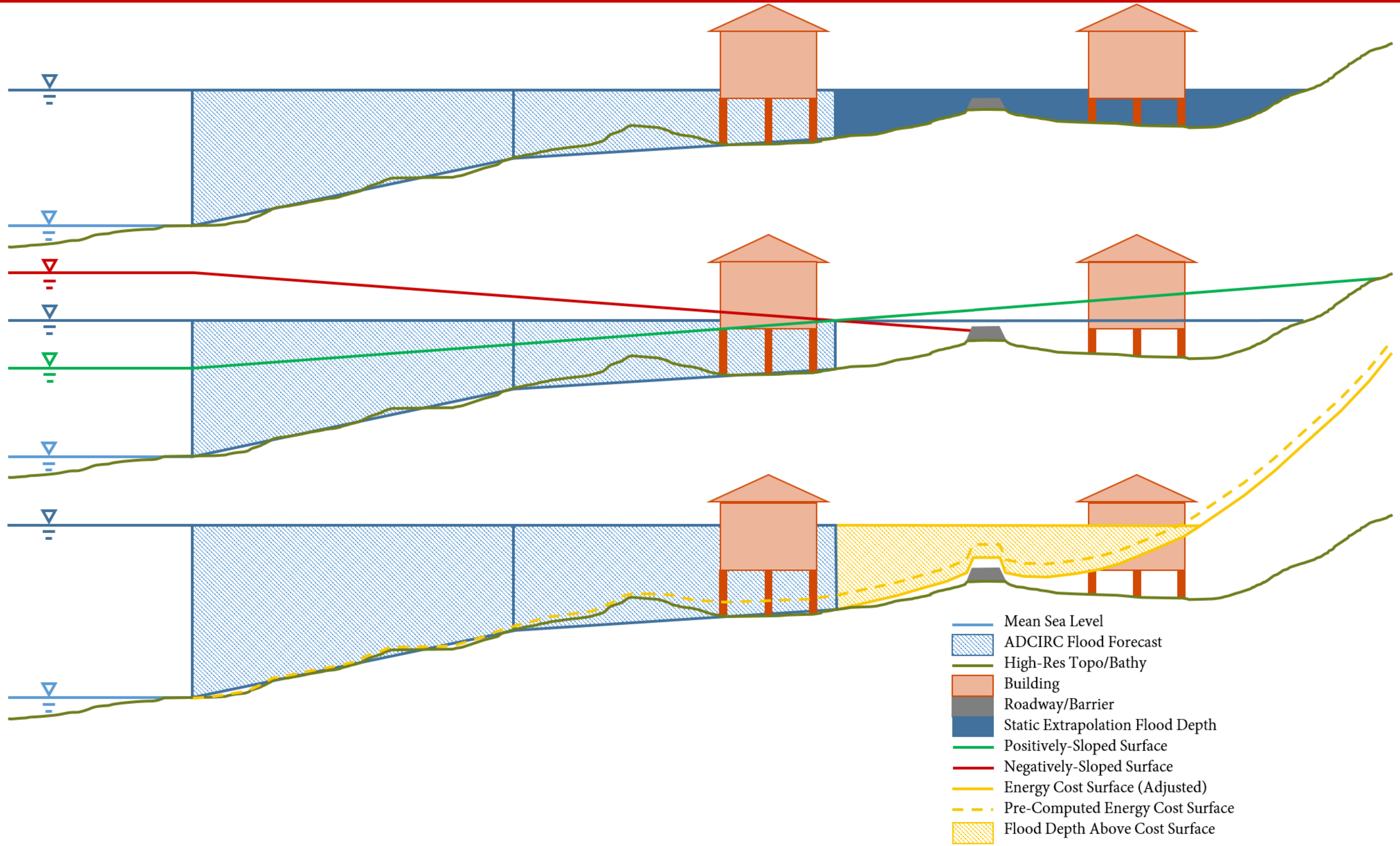
ADCIRC water levels, extrapolated



R_{avg}

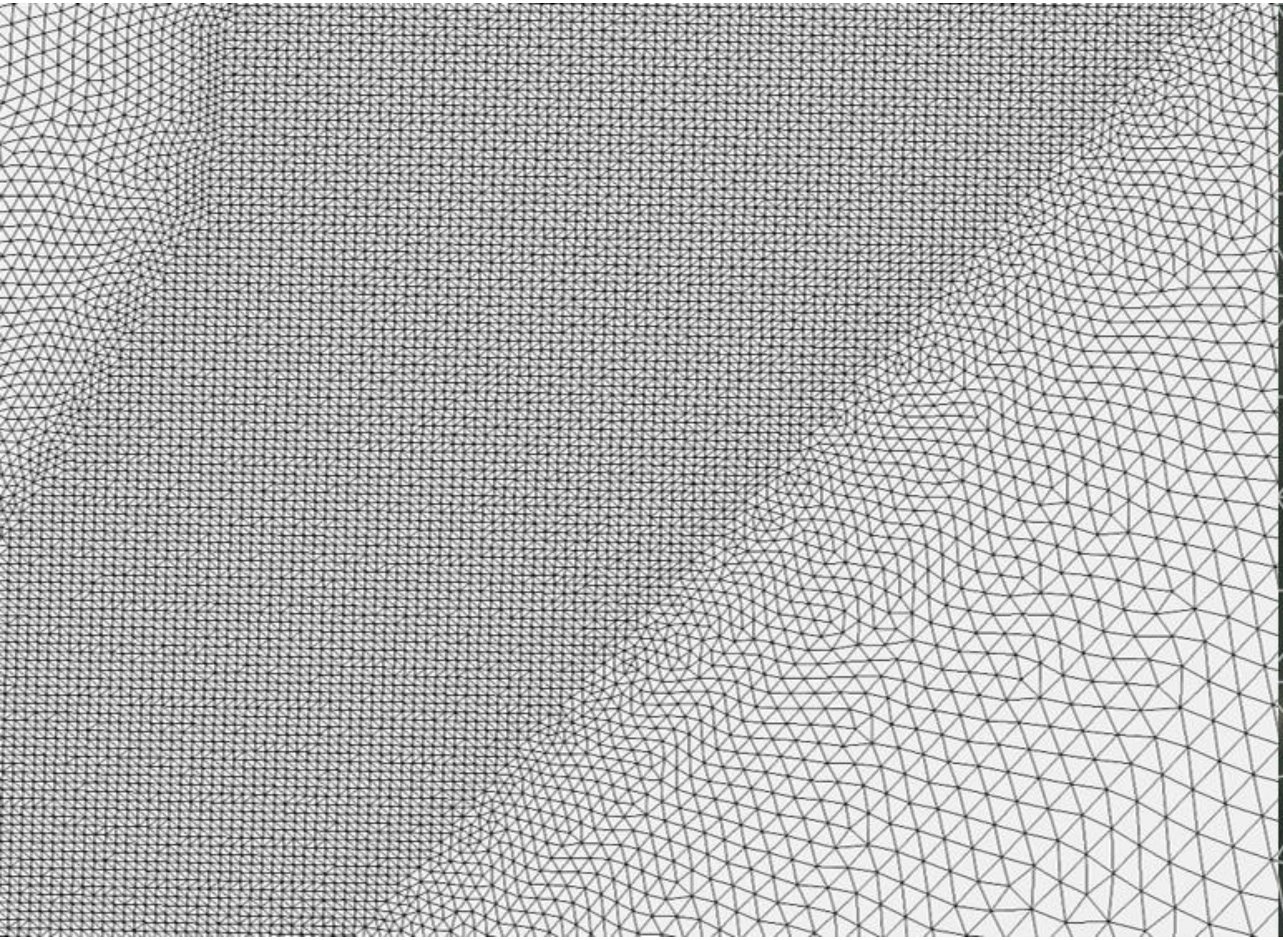


Downscaled water levels

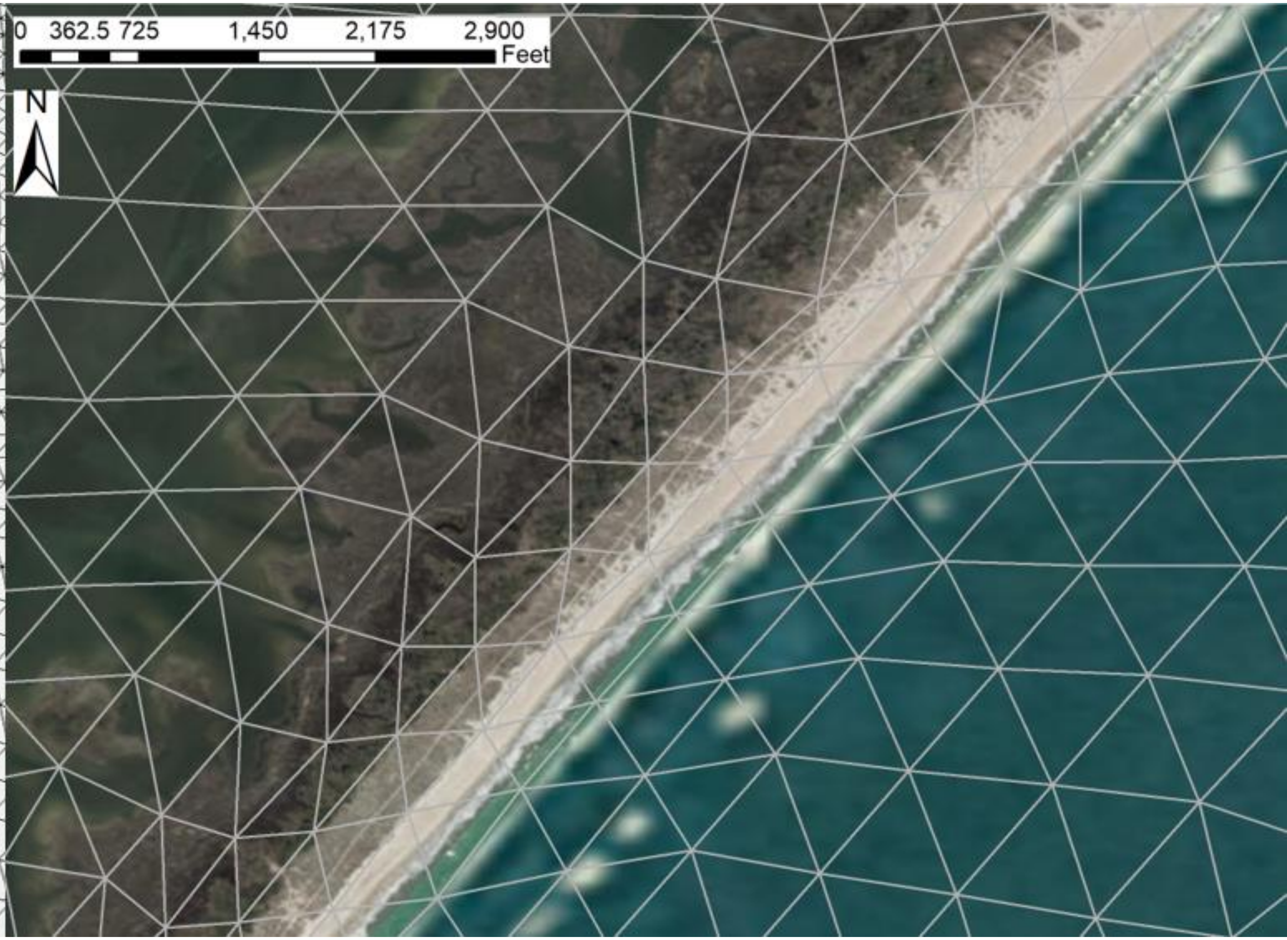

Mean Sea Level
ADCIRC Flood Forecast
High-Res Topo/Bathy
Building
Roadway/Barrier
Static Extrapolation Flood Depth
Positively-Sloped Surface
Negatively-Sloped Surface
Energy Cost Surface (Adjusted)
Pre-Computed Energy Cost Surface
Flood Depth Above Cost Surface

Evaluation Using High Resolution ADCIRC Mesh

- **High resolution ADCIRC mesh was used as "truth"**
- Developed using the NC9 mesh, which is input for downscaling
- Completely identical, except high resolution mesh vertices align with each cell in the DEM raster for Carteret County, NC
  - NC9 mesh: **622,946** vertices, 1,230,430 elements
  - High resolution mesh: **6,772,170** vertices, 13,528,879 elements
- Both models were run for Hurricane Florence (2018)
- Each model uses the same exact input parameters



High Resolution Mesh



NC9 Mesh

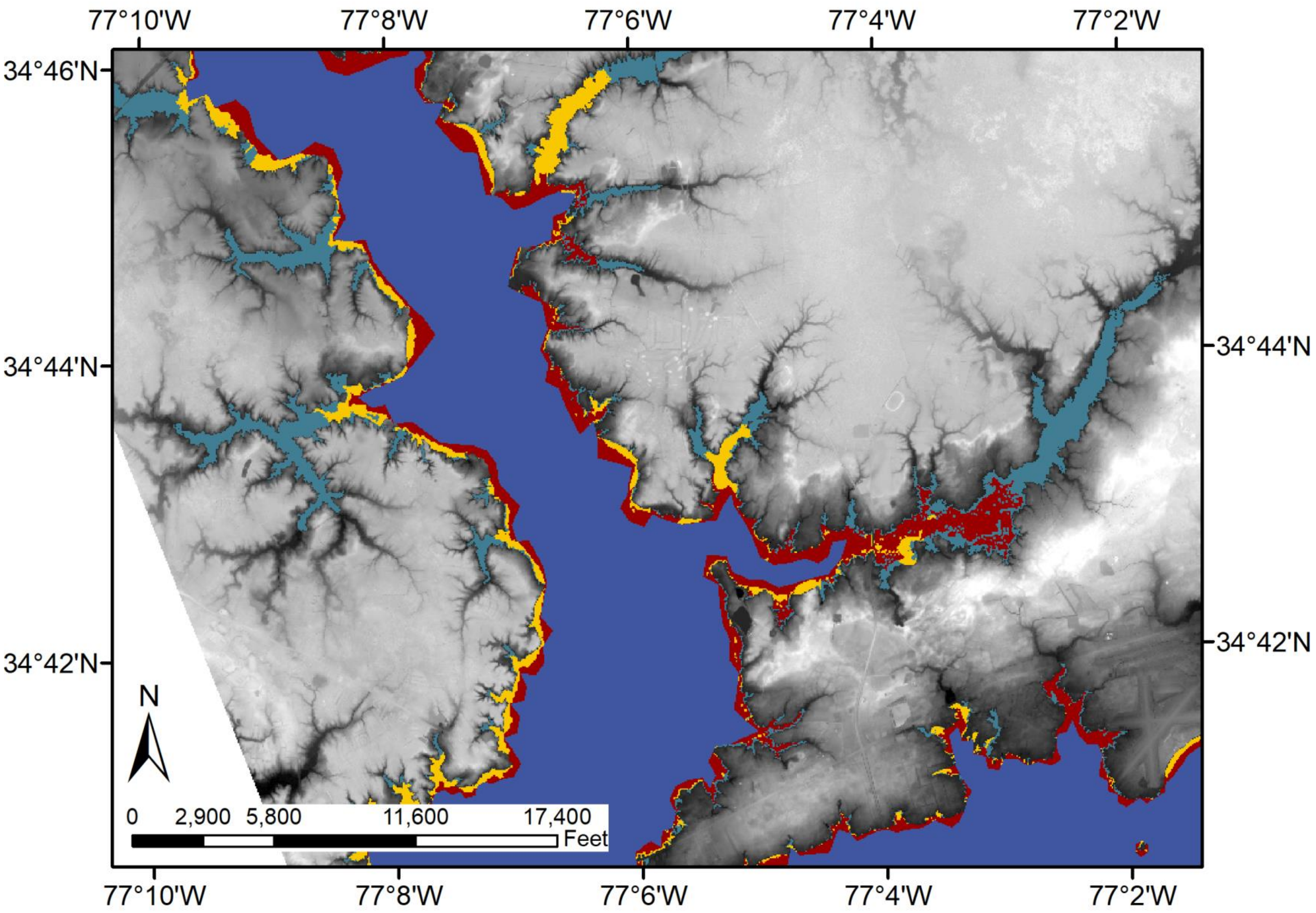
Legend

ADCIRC (NC9)

ADCIRC (high resolution)

Head loss method

Static method



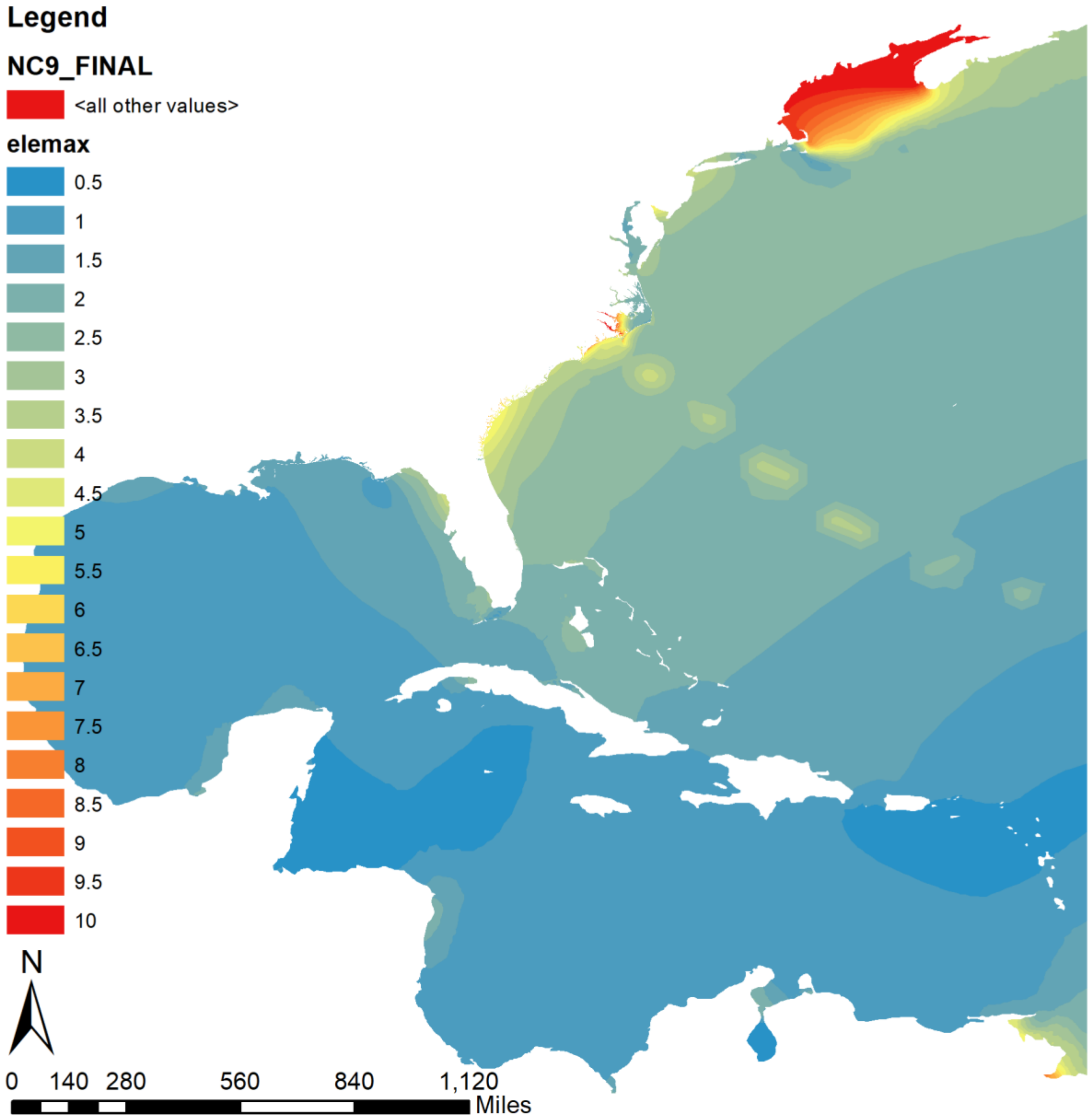
Mesh	Downscaling Method	Flooded (acres)	Flooded, outside NC9 (acres)	Over-estimation, outside NC9 (acres)	Under-estimation, outside NC9 (acres)
NC9	---	157,314	---	---	---
NC9	Static	174,203	**23,324**	13,989	79
NC9	Slopes	175,358	**24,006**	14,655	62
NC9	Head Loss	162,579	**11,729**	5,573	3,258
High Resolution	---	126,593	**9,414**	---	---

Conclusions

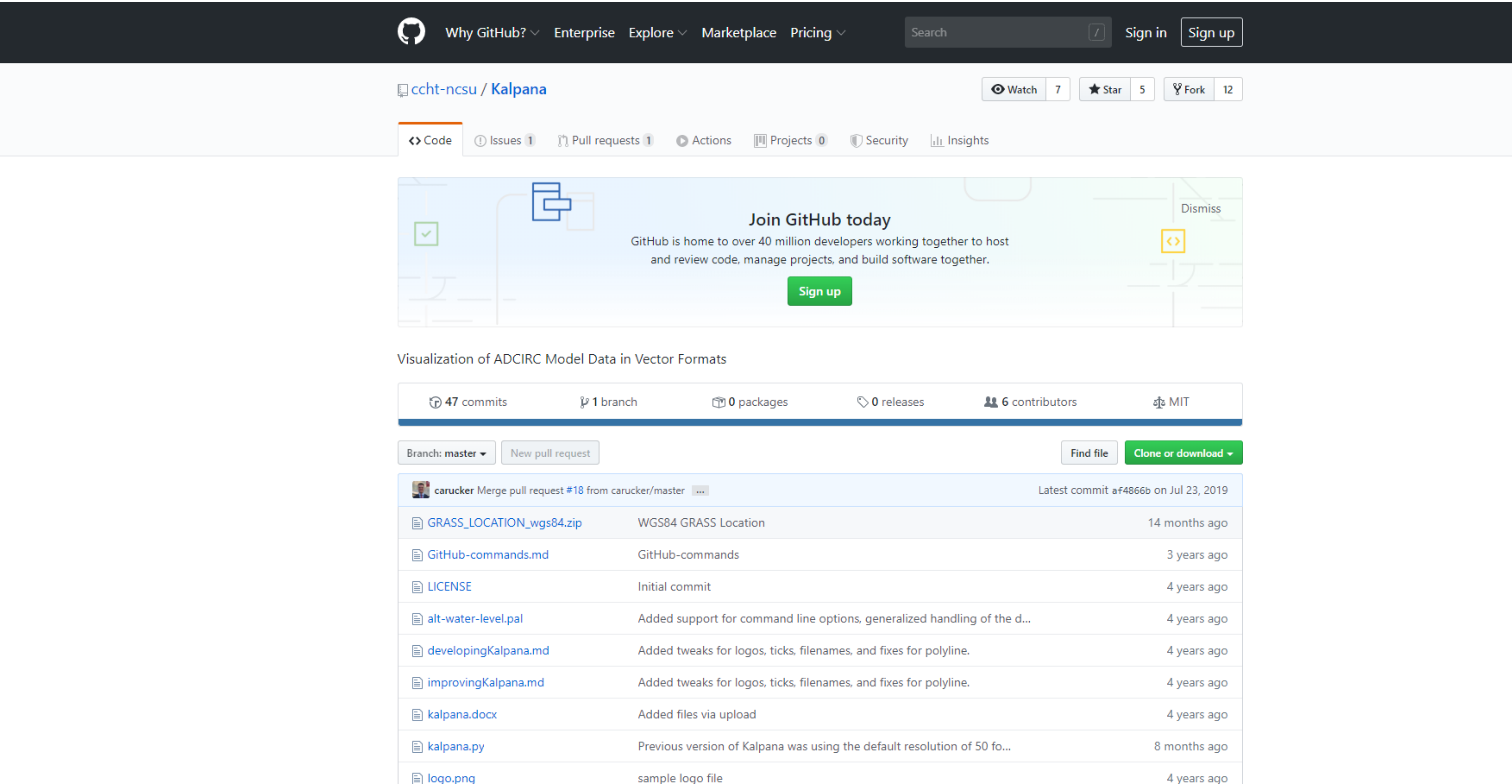
1. The static method over-predicts water level extents
2. The slopes method did not improve the downscaling simulations
3. The head loss method performed best and allows for the most flexibility

Kalpana

- Originally designed as a Python code for visualizing ADCIRC output in GIS
- Kalpana has now been integrated with the static method
- Can now visualize ***and*** downscale ADCIRC results in Kalpana



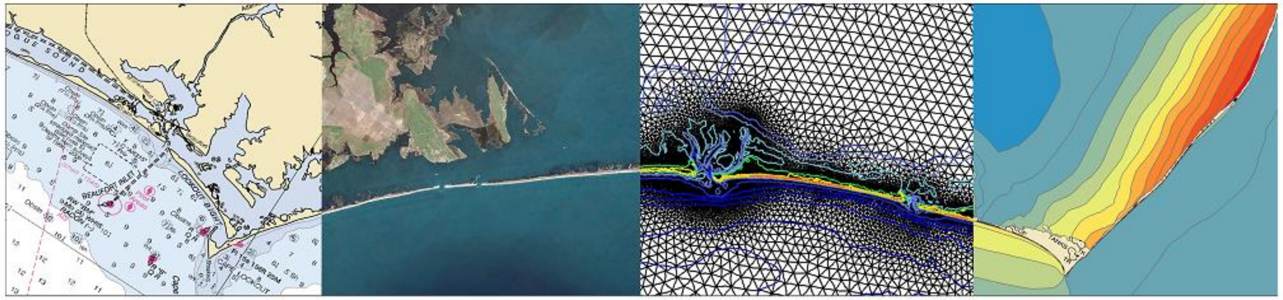
Maximum water elevations, visualized as an ESRI shapefile using Kalpana github.com/ccht-ncsu/Kalpana



ccht.ccee.ncsu.edu/kalpana

NC STATE UNIVERSITY

Coastal & Computational Hydraulics Team



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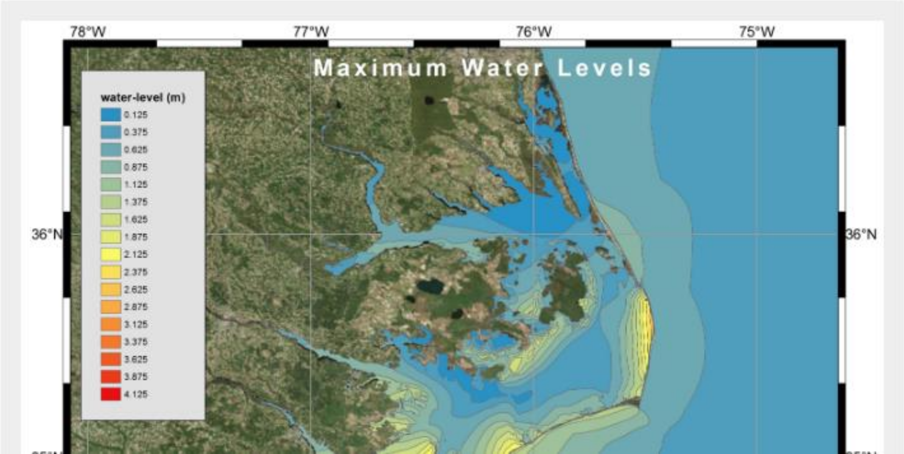
Kalpana

Kalpana is a Python script that converts ADCIRC output files to ArcGIS compatible shapefiles and Google Earth compatible KMZ files. The code accepts NetCDF formatted ADCIRC outputs for maximum water levels, wind speeds, wave heights and peak wave period and converts these to polyline/polygon shapefiles and polygon KMZ files. The code is also capable of converting timeseries ADCIRC outputs for water levels, wind speeds and wave heights into polygon shapefiles.



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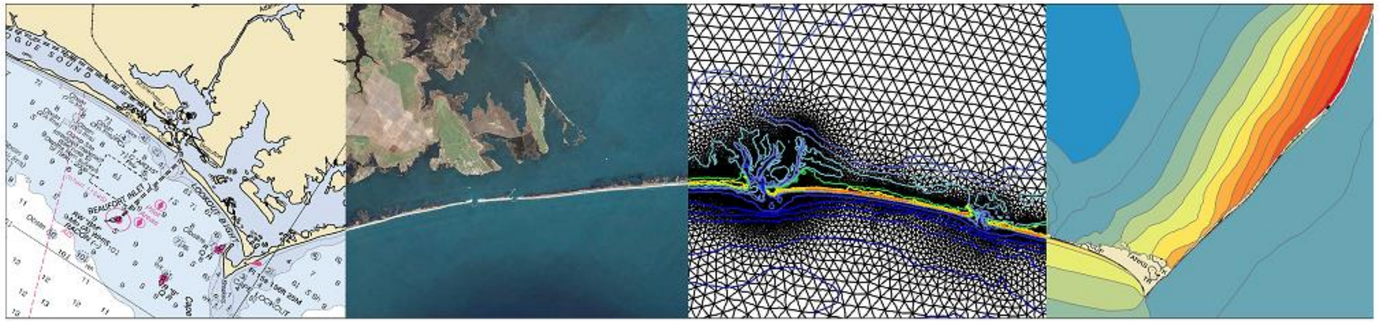

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Downscaling ADCIRC Flooding Inundation Extents Using Kalpana

The ADCIRC modeling system is used often to predict coastal flooding due to tropical cyclones and other storms. The model uses high resolution to represent the coastal environment, including flow pathways (inlets, man-made channels, rivers) and hydraulic controls (barrier islands, raised features). However, due to the use of large domains to represent hazards on coastlines in an entire state or multiple states, the highest resolution is typically about 20 to 50 m in coastal regions. Thus, there is a potential gap between the flooding predictions and the true flooding extents. We have developed a geospatial software to downscale the flooding extents to higher resolution.

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Questions?