Downscaling and Extrapolation of Hurricane Flooding Forecasts to Support Decision-Making

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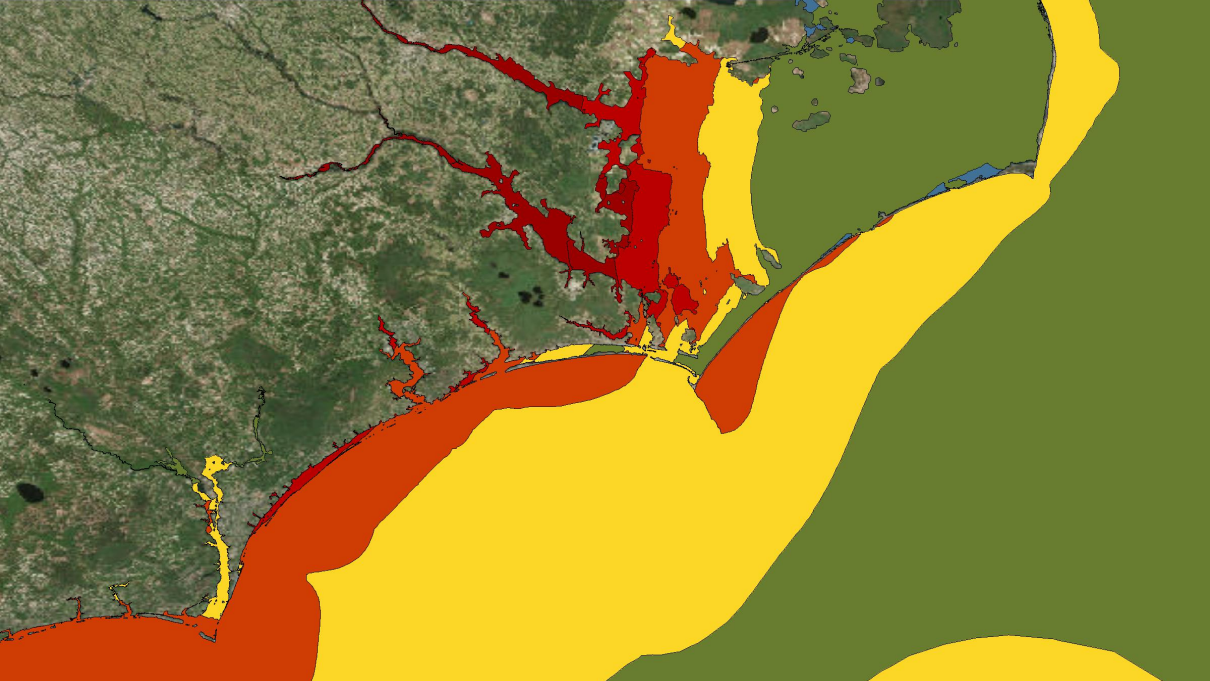
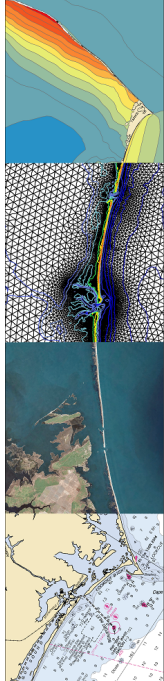
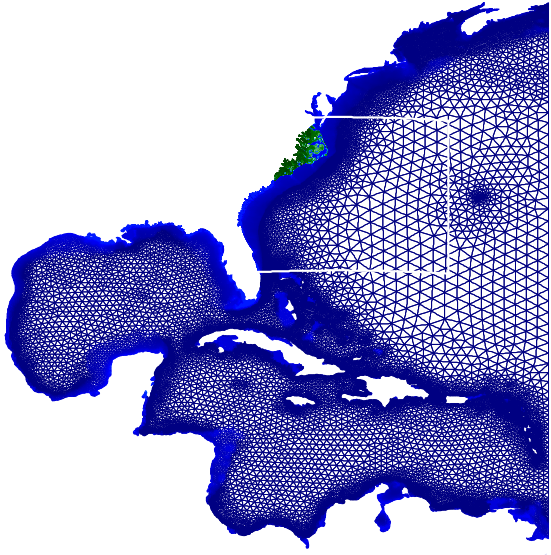
Geospatial Forum, Center for Geospatial Analytics
NC State Univ, 18 October 2018





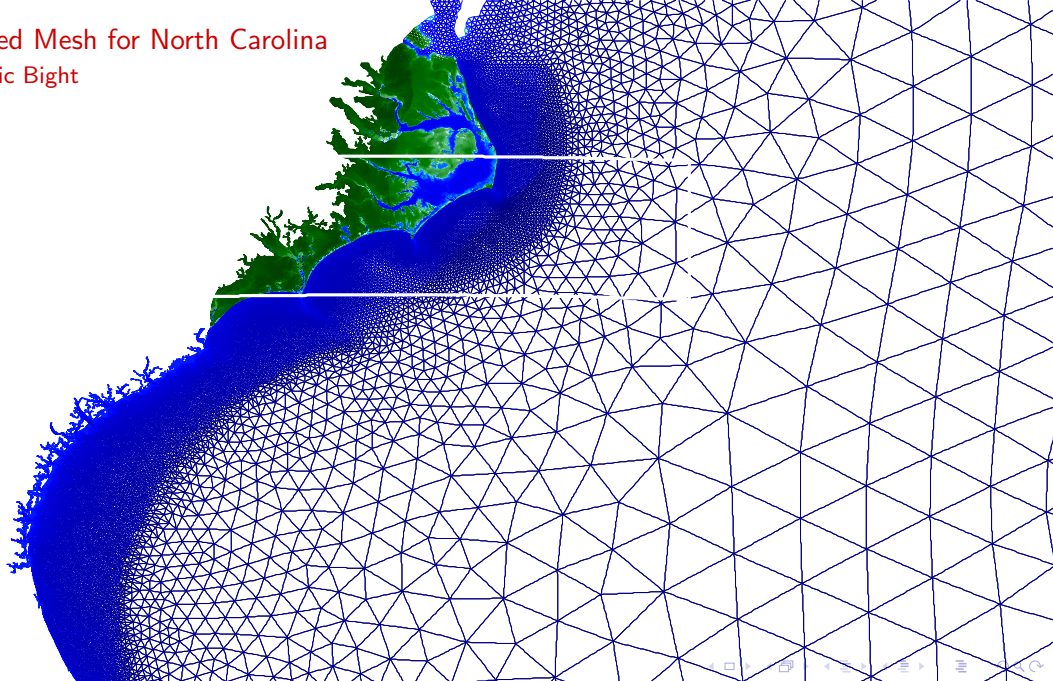
Unstructured Mesh for North Carolina

Western North Atlantic Ocean



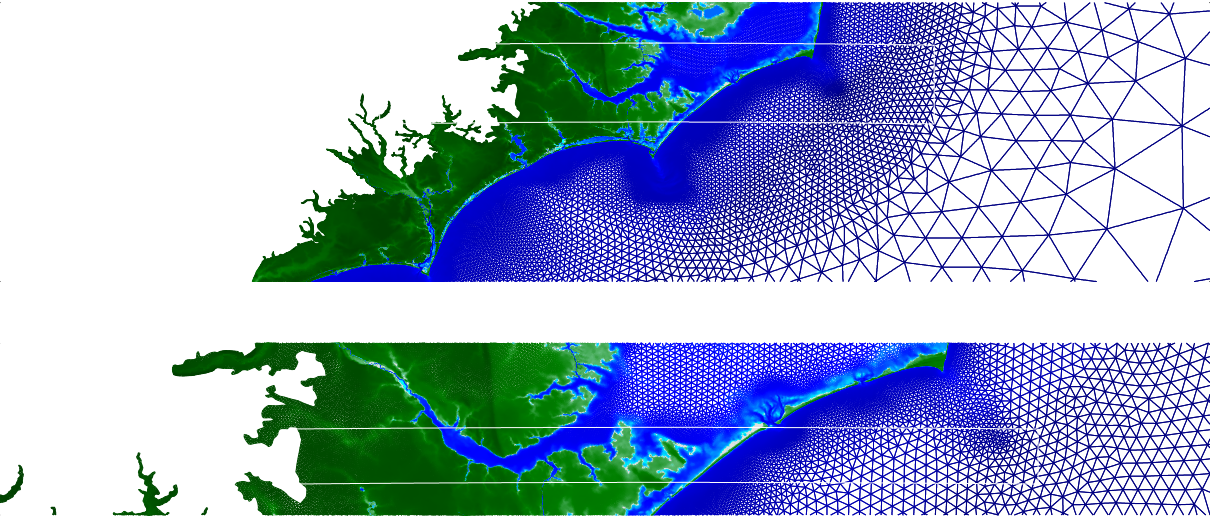
Unstructured Mesh for North Carolina

South Atlantic Bight



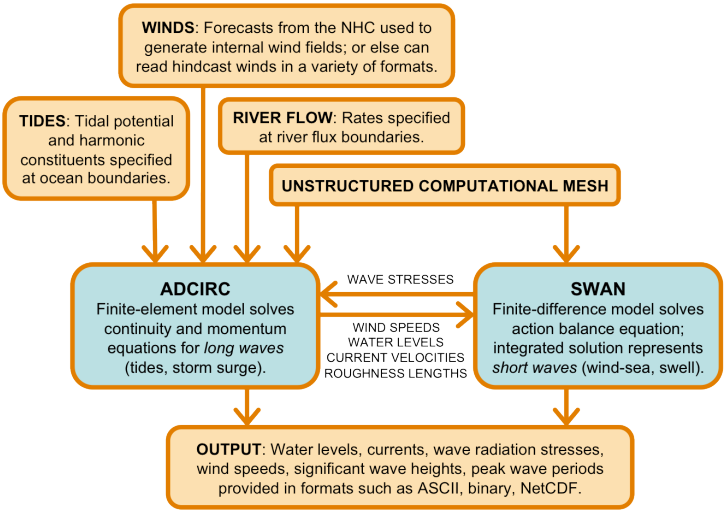
Unstructured Mesh for North Carolina

Outer Banks & Neuse River Estuary



Models for Hurricane Waves and Storm Surge

Tight Coupling of SWAN+ADCIRC



SWAN+ADCIRC can be employed in real-time

- **Everything happens automatically**
  - Models are initialized, run, and processed by Perl scripts

Wind fields from two sources:

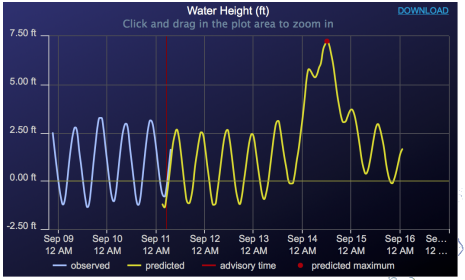
- Under normal conditions:
  - Downloaded from NAM model output by NOAA/NCEP
  - Converted into format compatible with SWAN+ADCIRC
- Under storm conditions:
  - Download advisories from NOAA/NHC
  - Generate wind fields using parametric model (Holland, 1980)

Guidance can be shared in multiple formats:

- Send directly to stakeholders (NC Emergency Management)
- Share publicly via web service (`http://www.adcirc.org`)

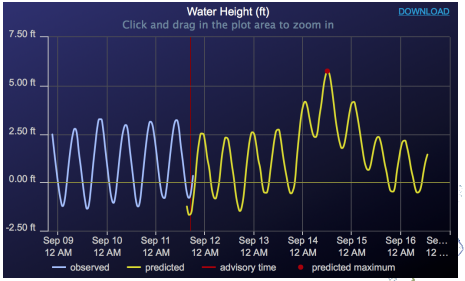
Real-Time Forecasts

Adv 48 – Sep 11 Tue 5am



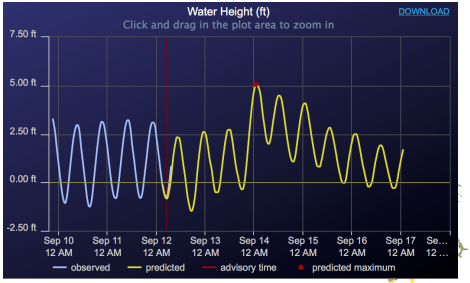
Real-Time Forecasts

Adv 50 – Sep 11 Tue 5pm



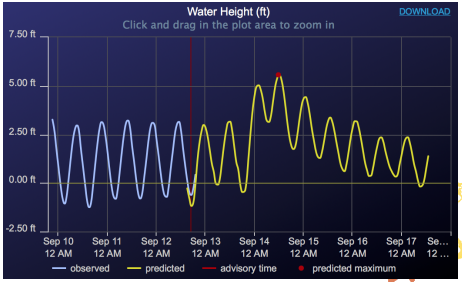
Real-Time Forecasts

Adv 52 – Sep 12 Wed 5am



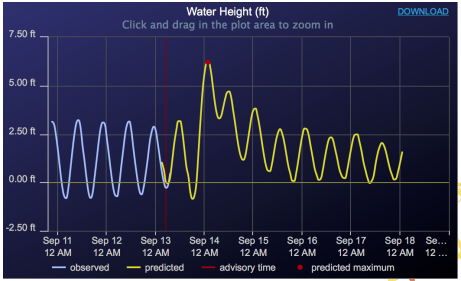
Real-Time Forecasts

Adv 54 – Sep 12 Wed 5pm



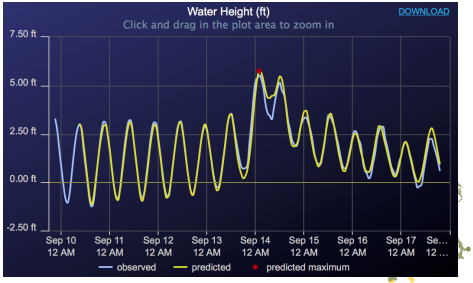
Real-Time Forecasts

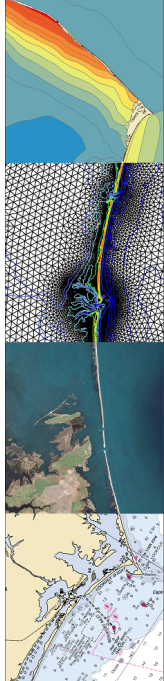
Adv 56 – Sep 13 Thu 5am



Real-Time Forecasts

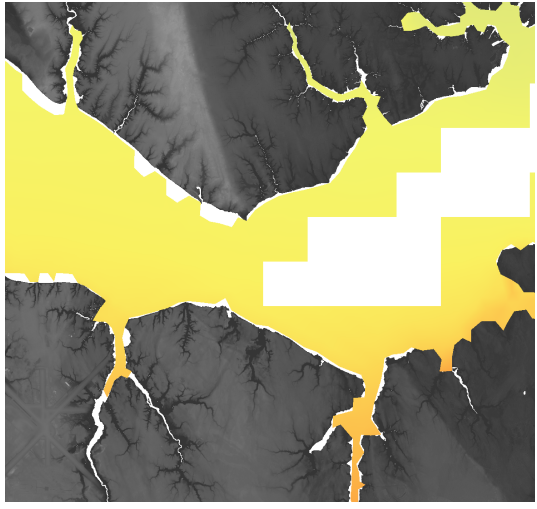
Best-Track Hindcast





Motivation for Research Project

So .. What is the Problem?



We want to enhance the flooding guidance we provide to NCEM

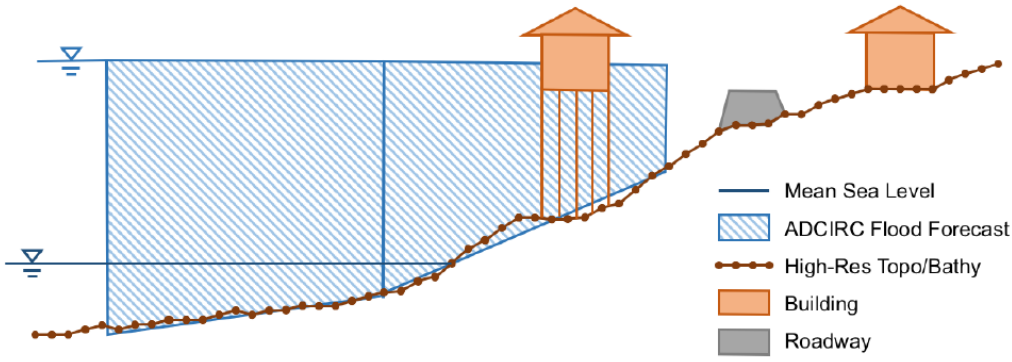
- Now we provide water levels at our model resolution
  - Use an unstructured *mesh* with unequal spacings
  - More than 600K points
  - Minimum spacing of about 50 to 100 m
- NCEM wants to combine with other datasets
  - Use a structured *raster* with equal spacing
  - More than 400M cells
  - High-resolution topography with spacings of 50 ft (or smaller!)

Need to do two things:

1. *Downscale* – Increase resolution to match their high-resolution topography datasets
2. *Extrapolate* – Extend our flooding guidance into small-scale coastal regions that cannot be represented by our model

Motivation for Research Project

Downscaling and Extrapolating the Coastal Flood Forecasts



Goal:

- Enable data-driven decision-making for coastal communities during storm events

Objectives:

- Extrapolate ADCIRC results to intersect higher resolution DEM
- Create fully-automated process to be run during real-time forecasting
- Enable process to run in 10-20 minutes for each forecast
- Use open-source software for transferability
- Share enhanced guidance with NCEM

We used the Geographic Resources Analysis Support System (GRASS):

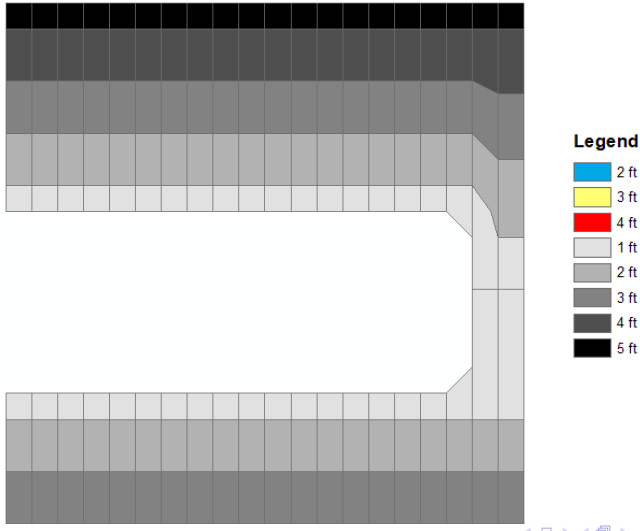
- Available as open-source software (`https://grass.osgeo.org`)
- Developed by Prof. Mitasova and researchers in the Center for Geospatial Analytics
- Extremely fast for raster processing

Then the general steps were:

- Interpolate ADCIRC points to raster at resolution of DEM (50 ft)
- Extrapolate water levels into small-scale channels and floodplains
  - Expand the raster outward only where the water levels are higher than the ground
  - Remove isolated (not hydraulically-connected) cells
- Convert the new "grown" raster to polygon format for distribution

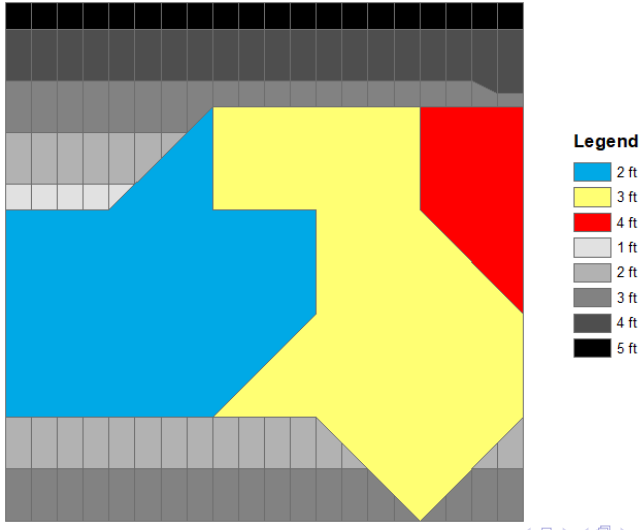
Downscaling and Extrapolation

Example with Simple DEM and Water Levels



Downscaling and Extrapolation

Example with Simple DEM and Water Levels



Downscaling and Extrapolation

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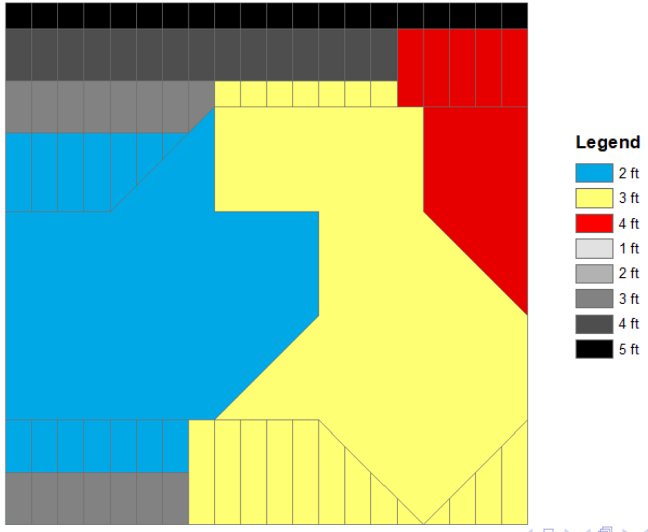


The first interpolation step is costly

- Need to take water levels from the ADCIRC mesh vertices
  - About 600,000 vertices for NC
- And interpolate water levels onto 50-ft raster DEM
  - About 28 million cells for Carteret County
  - About 434 million cells for NC
- This process is slow
  - We use a file with pre-computed, inverse-distance weights
  - It still takes 5 min for each forecast

The new raster is imported into GRASS:

- Raster is extrapolated using a modified version of the module "`r.grow`"
- Only hydraulically-connected, flooded cells are retained

We made some changes within the GRASS software:

- Normally, the `r.grow` function expands a raster outward
  - Fills surrounding cells with values taken from the outermost cells of the original raster
  - A radius in number of cells is specified
- Our modified version allows for expanding into null cells **only if** the ADCIRC cell value is greater than the value of the DEM
  - Water level must be higher than ground surface
- After "growing" by a sufficiently large radius, isolated cells are removed if they do not overlap with any part of the original raster
  - Enforce a hydraulic connectivity

Then we convert back to polygons

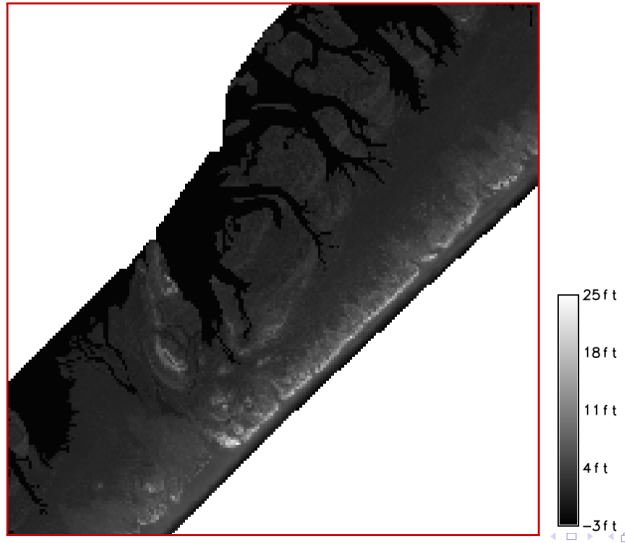
- Expanded water surface is binned into 0.5-ft intervals
- Enhanced guidance is saved as a shapefile

Consider the enhanced guidance on Carteret County

- One of 32 NC coastal counties that includes at least some part of the ADCIRC mesh
- Chosen for its complexity; contains barrier islands, estuaries, low-lying topography

Examples in Carteret County

Zoom of Cape Lookout National Seashore



Examples in Carteret County

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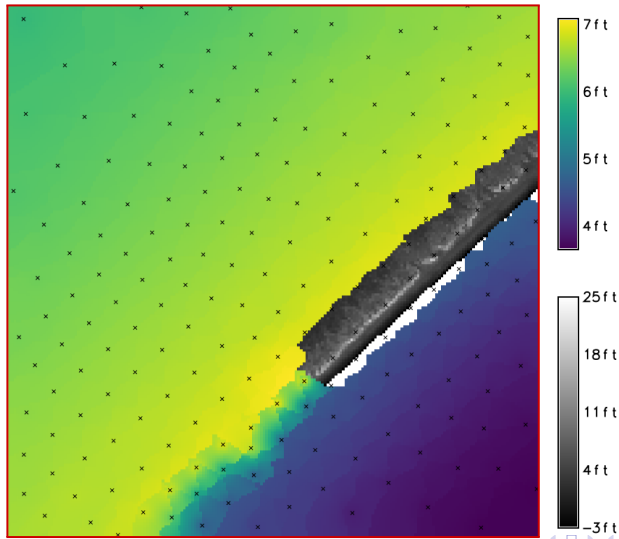

Examples in Carteret County

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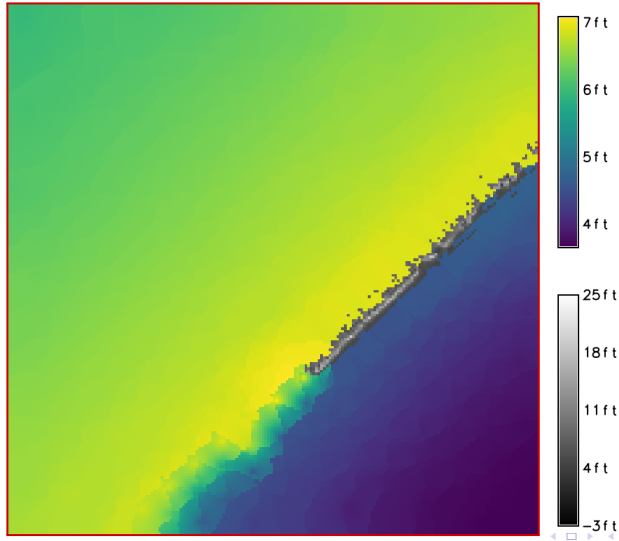
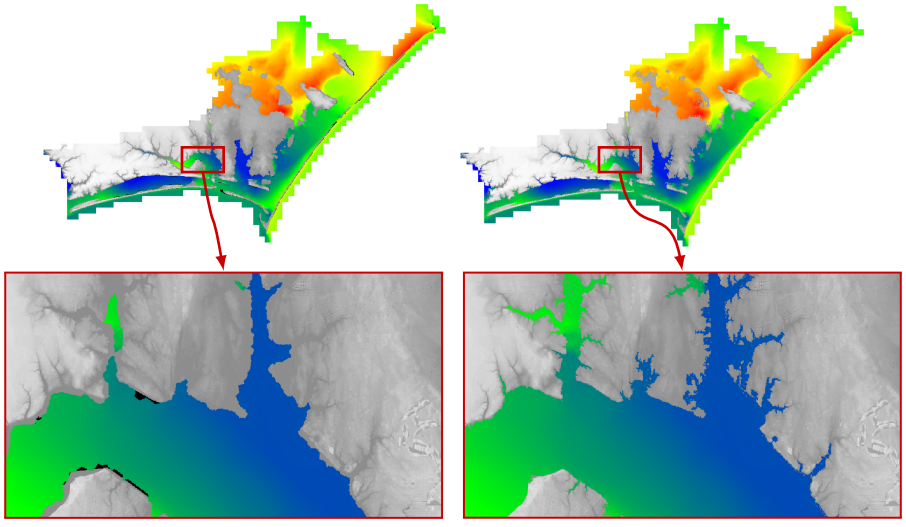


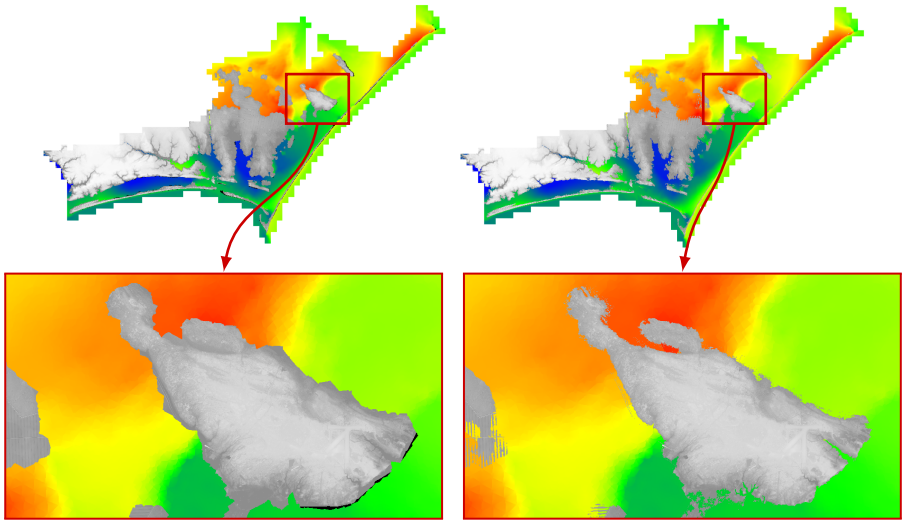
Examples in Carteret County

Newport River



Examples in Carteret County

Cedar Island

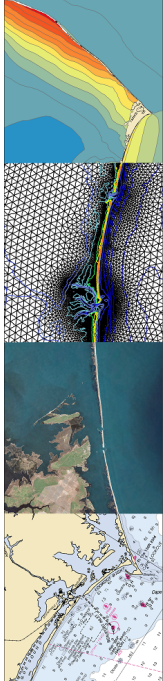


We can intersect the flooding guidance with known buildings

- NCEM has compiled a database of infrastructure in every NC county
- Building footprint, first floor elevation, etc.
- Used for their planning during and after storm events

We can analyze the number of buildings covered by our flooding prediction for a Hurricane Matthew hindcast

- Before enhancement: **2,435 buildings**
- After enhancement: **3,886 buildings**
- This is an increase of 60 percent

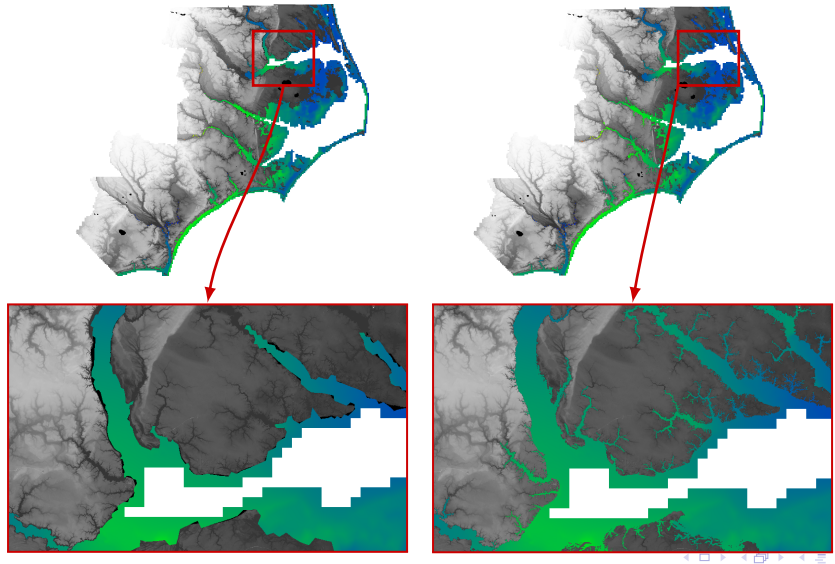


We need the method to be *fast*:

- Interpolation of ADCIRC points to raster format is most time-consuming part of process, even with precomputed weights
- Entire process was taking **30-40 minutes** at first, and clearly needed to be parallelized:
  - Scripts were tweaked to allow for parallel processing on up to 16 CPUs
  - DEM was divided into horizontal strips with overlap of 500 cells
- Some aspects cannot be parallelized
  - Final conversion into 0.5-ft polygons
- With parallelization, the entire process now takes **12-15 minutes** to run on the NCSU computing cluster

Enhanced Real-Time Guidance

Albemarle Sound



We are now providing the enhanced guidance to NCEM

- During hurricane season, we use an automated script on our cluster at NCSU:
  - Detects when ADCIRC results are posted to the archive
  - Downloads the maximum water levels
  - Runs the enhanced-resolution process
- Recent storms:
  - 2017 – Harvey & Irma
  - 2018 – Florence & Michael

Future work – Integrate this script into the ADCIRC Surge Guidance System (ASGS)

Comparisons with High-Resolution ADCIRC

Evaluating Accuracy using a Refined Mesh

Our process does not incorporate physics

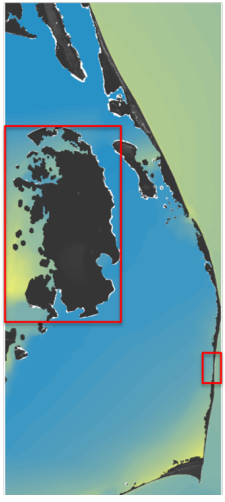
- If we could run ADCIRC at a similar 15-m resolution, then how would the results compare?

To answer this, we developed a refined mesh for Dare County, NC

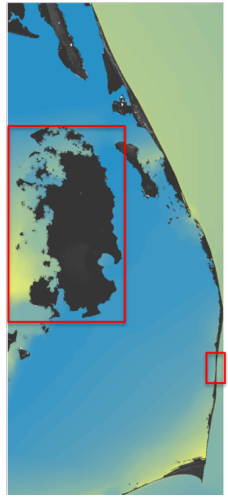
- Modified from our existing mesh
- Overland vertices in Dare County correspond exactly to DEM cells via a 1-to-1 conversion
- Contains 5.7 million vertices

Comparisons with High-Resolution ADCIRC

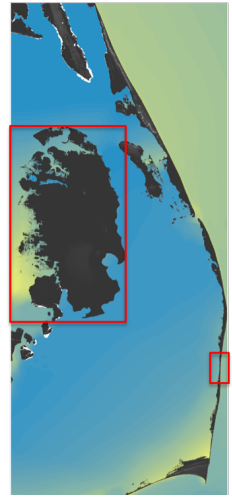
Enhanced Resolution vs Refined Mesh



Base



Enhanced



Refined

Comparisons with High-Resolution ADCIRC

Flooding Comparison in Dare

We can compare the flooding extents:

	Area, km^2 (%)
Base	185 (18.6)
Enhanced	291 (29.2)
Refined	133 (13.4)

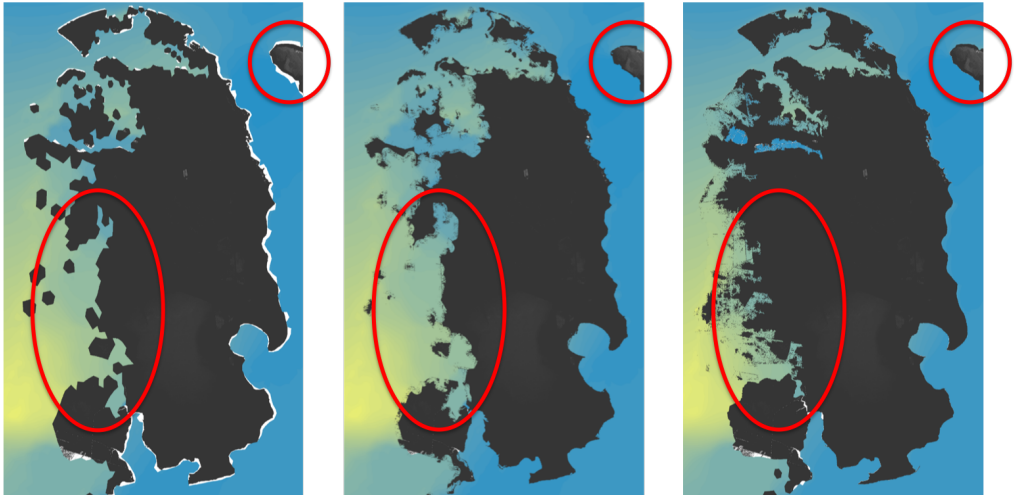
which lead to some interesting findings:

- *Base* is already over-predicting!
- *Enhanced* is making it worse!

What is happening here?

Comparisons with High-Resolution ADCIRC

Inland Dare Comparison

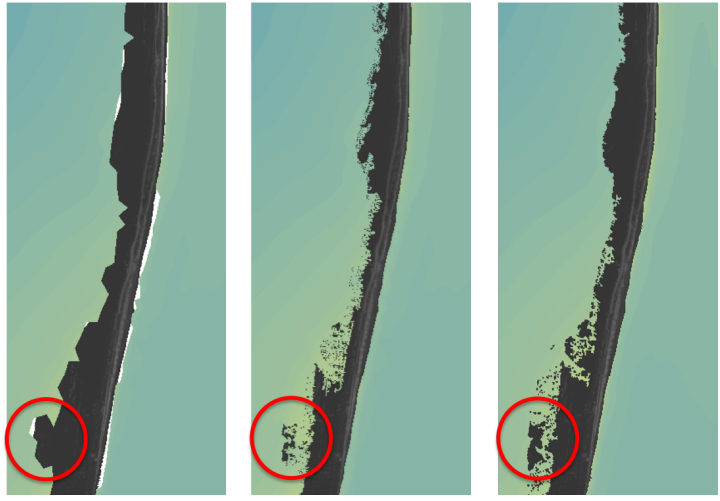


Base *Enhanced* *Refined*

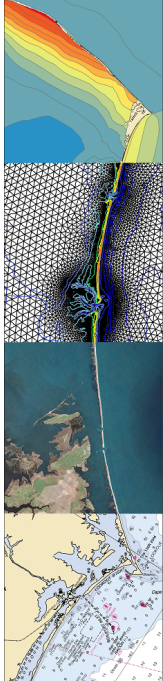
Comparisons with High-Resolution ADCIRC

Hatteras Island Comparison

	Area, km^2 (%)
Base	0.6 (2.2)
Enhanced	3.8 (14.4)
Refined	3.0 (11.5)



Base *Enhanced* *Refined*

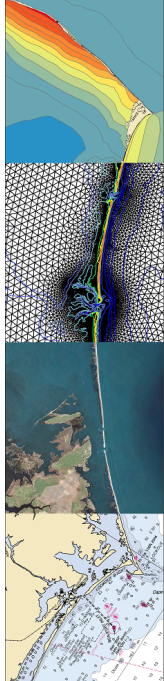


Summary and Future Work

Predictive Models for Storm Surge and Flooding Risks

Real-time forecasting for coastal North Carolina:

- Available at: `www.adcirc.org`
- Matthew (2016), Harvey & Irma (2017), Florence & Matthew (2018)
  - Providing guidance for multiple states
  - Every advisory and perturbations
- Working with NCEM to support their decision-making
  - Downscale our model results to 50-ft DEM
  - Extrapolate into small-scale channels and floodplains
  - Provide automatically as GIS shapefiles
- Investigating ways to improve our enhanced-resolution technique



Sea Grant North Carolina

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