NC STATE UNIVERSITY

# Mapping and Visualization of Coastal Flood Forecasts for Decision Support


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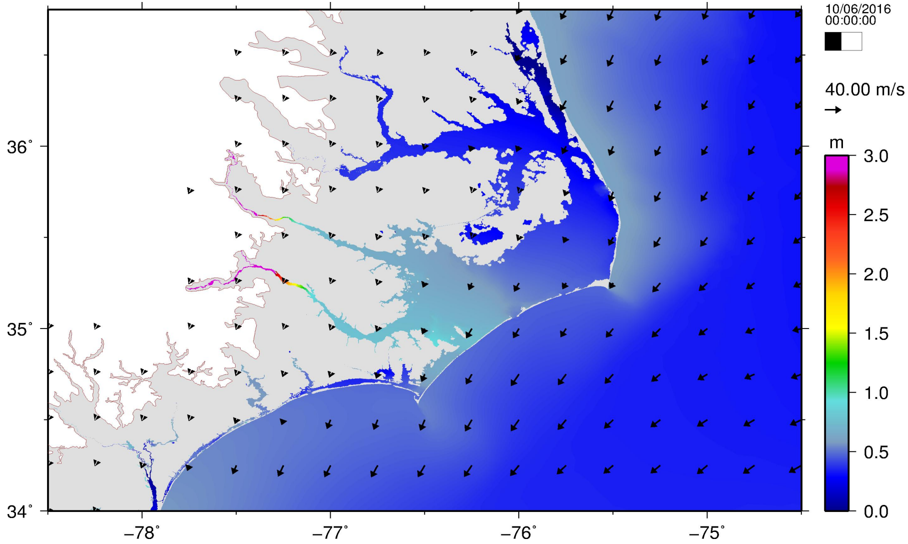
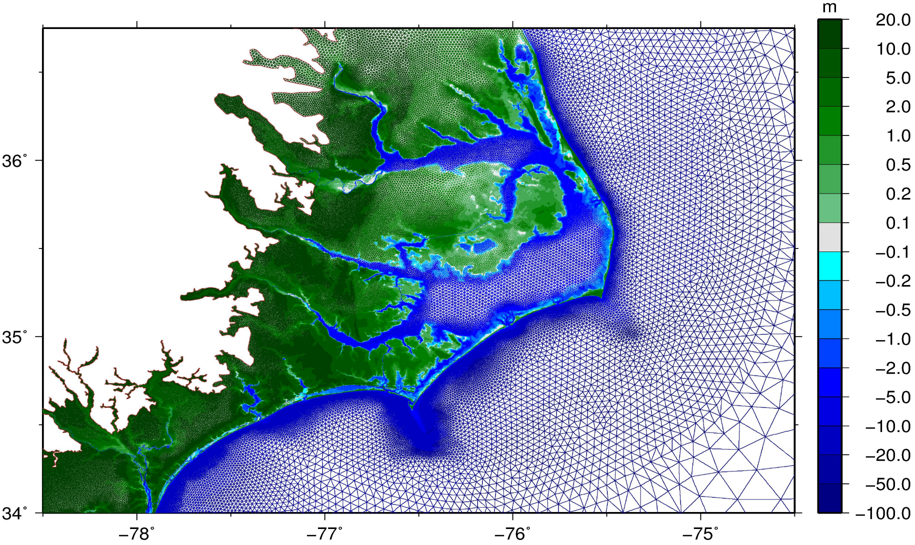
# Models for Hurricane Waves and Storm Surge

## Hurricane Matthew (2016) – Water Levels in North Carolina



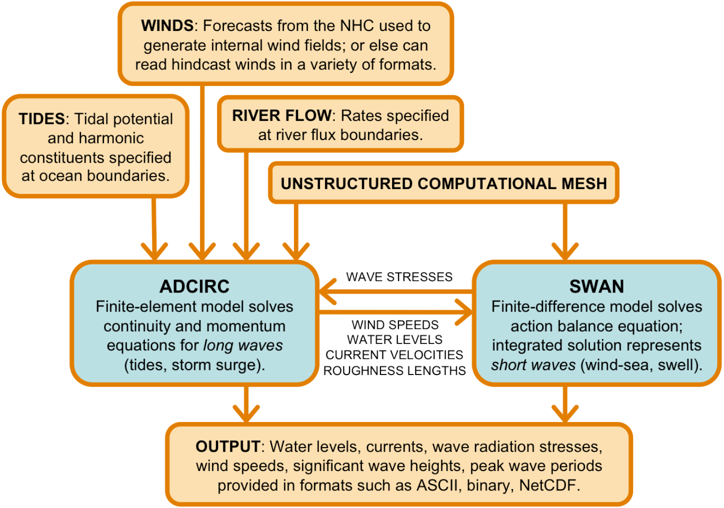
# Models for Hurricane Waves and Storm Surge

## Finite-Element Mesh for NC Coast



# Models for Hurricane Waves and Storm Surge

## Tight Coupling of SWAN+ADCIRC




JC Dietrich, et al. (2011). Modeling Hurricane Waves and Storm Surge using Integrally-Coupled, Scalable Computations. *Coastal Engineering*, 58, 45-65, DOI:10.1016/j.coastaleng.2010.08.001.

SWAN+ADCIRC can be employed in real-time via the ASGS

- **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 hurricane conditions:
  - Download advisories from NOAA/NHC
  - Generate wind field using parametric model (Holland, 1980)

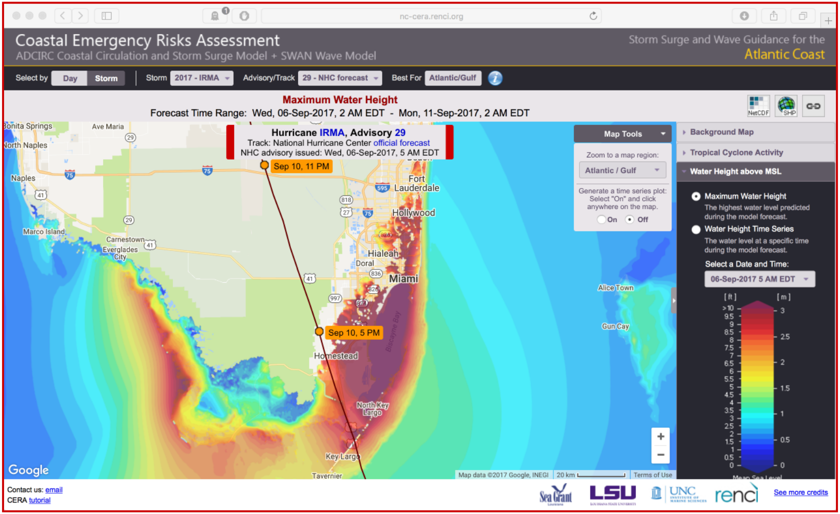
Guidance can be shared in multiple formats:

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

# Real-Time Forecasting

## Coastal Emergency Risks Assessment (CERA, `http://www.adcirc.org`)

### Hurricane Irma (2017) Advisory 29 - Consensus



## Differences in Horizontal Resolution

We want to enhance the flooding guidance we provide to NCEM

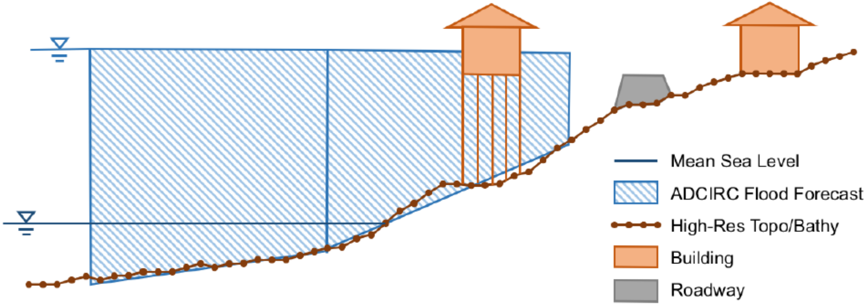
- Now we provide water levels at our model resolution
  - Use an unstructured *mesh* with unequal spacings
  - More than 600K points
  - Minimum spacing of about 50 to 100 m
- NCEM wants to combine with other datasets
  - Use a structured *raster* with equal spacing
  - More than 400M cells
  - High-resolution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

# Downscaling and Extrapolation

## Raster Method

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

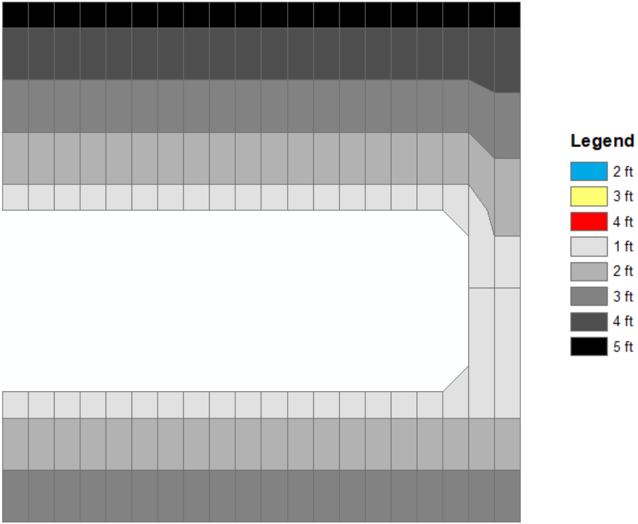
- Available as open-source software (`https://grass.osgeo.org`)
- Developed partly by Prof. Mitasova and others in the NCSU Center for Geospatial Analytics
- Extremely fast for raster processing

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 ADCIRC water levels are greater than the ground surface
  - Remove isolated (not hydraulically-connected) cells
- Convert the new "grown" raster to polygon format for distribution

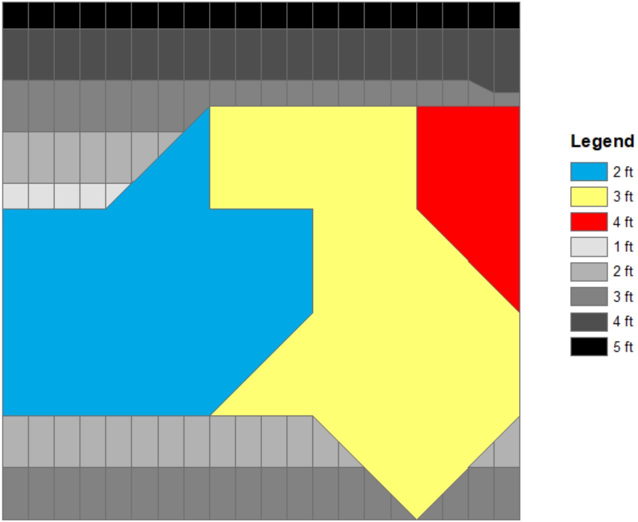
# Downscaling and Extrapolation

## Example with Simple DEM and Water Levels



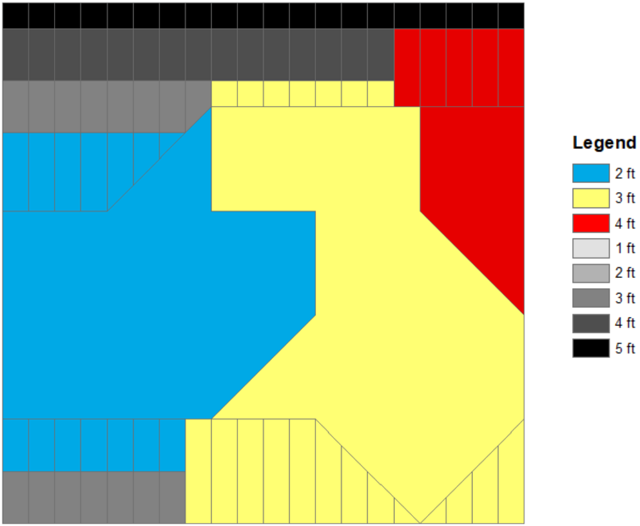
# Downscaling and Extrapolation

## Example with Simple DEM and Water Levels



# Downscaling and Extrapolation

## Example with Simple DEM and Water Levels



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

# Downscaling and Extrapolation

## Details on Process – Modifications within GRASS

We made some changes within the GRASS software:

- Normally, the `r.grow` function expands a raster outward
  - Fills surrounding null 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

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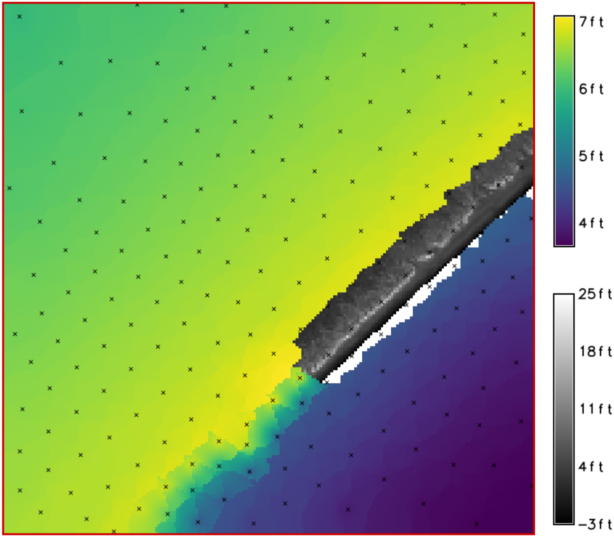
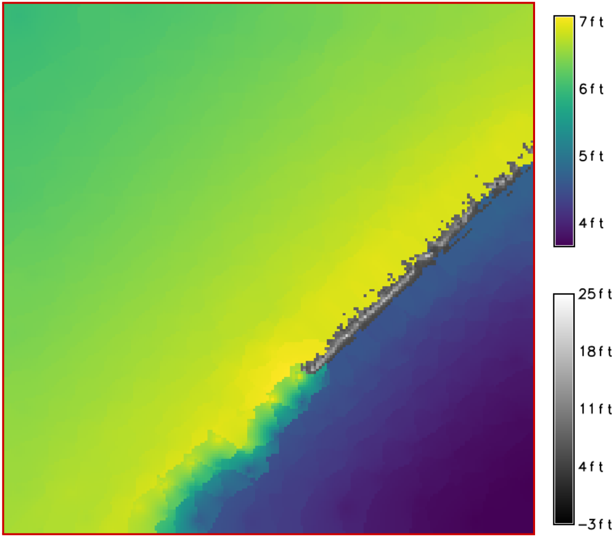
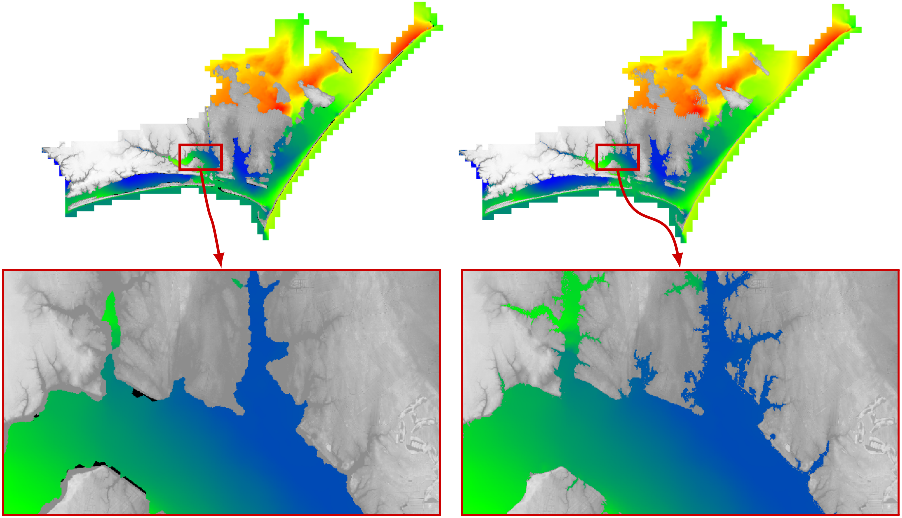


# Examples in Carteret County

## Zoom of Cape Lookout National Seashore

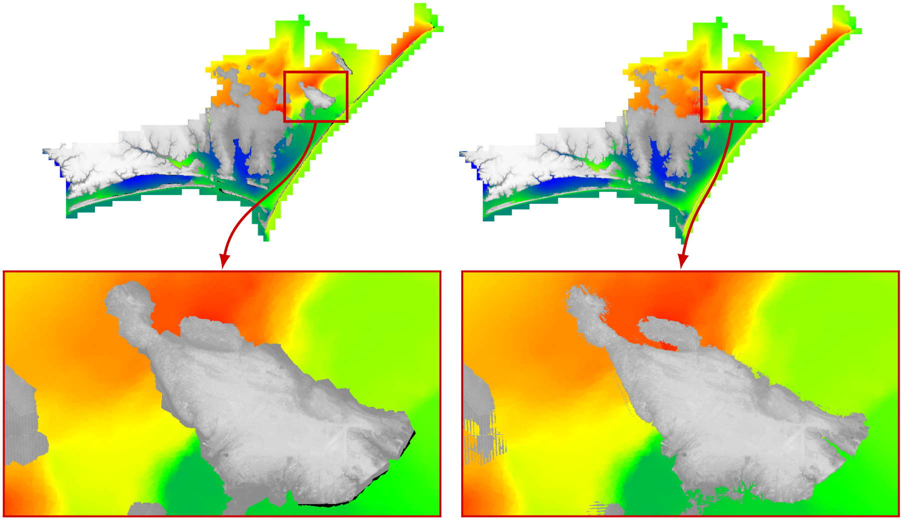


# Examples in Carteret County
## Newport River



# 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

This is not a perfect comparison

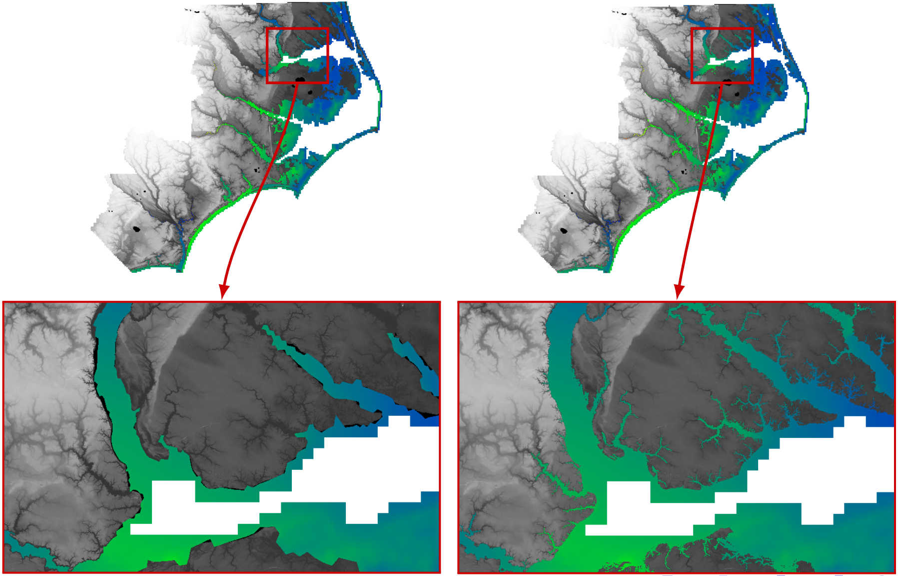
- Future work – compare with flood insurance claims

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 Guidance for Entire NC Coast

## Albemarle Sound



We are now providing the enhanced guidance to NCEM

- For the current hurricane season, we use an automated email script that is running on our cluster at NCSU
- This script:
  - Detects when ADCIRC results are posted to the archive
  - Downloads the maximum water levels
  - Runs the enhanced-resolution process
- We produced results for Hurricane Harvey, and are beginning to produce results for Hurricane Irma
- We will be working to incorporate this script into the ADCIRC Surge Guidance System (ASGS)

Future work:

- **Hypothesis** – If we were using the same resolution in our ADCIRC model, then it would push water into those small-scale regions
- We can test this hypothesis:
  - Refine our unstructured mesh to match the 50-ft raster DEM
  - Compare with downscaled and extrapolated water surface
- Is the enhanced guidance still physically accurate?

Implications:

- How to balance the modeling and post-processing?
- Can we coarsen our unstructured mesh, and thus speed up the forecast simulation?

# Summary and Future Work

## Predictive Models for Storm Surge and Flooding Risks

Real-time forecasting for coastal North Carolina:

- Available at: `www.adcirc.org`
- Hurricanes Matthew (2016), Harvey and Irma (2017)
  - Providing guidance for multiple states
  - Every advisory and perturbations
- Working with NCEM to add to their workflow
  - Downscale our model results to 50-ft DEM
  - Extrapolate into small-scale channels and floodplains
  - Provide automatically as GIS shapefiles