

Mapping and Visualization of Coastal Flood Forecasts for Decision Support

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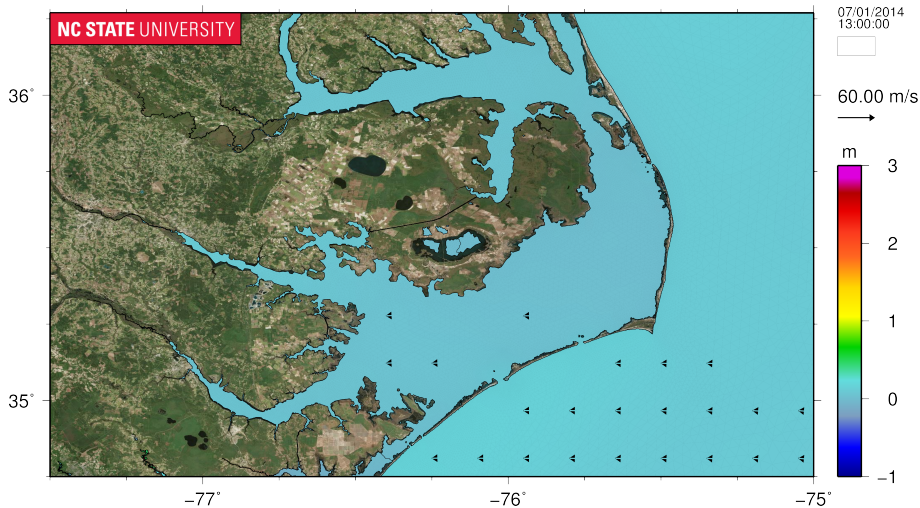
NCDS DataBytes Webinar
6 September 2017



Models for Hurricane Waves and Storm Surge

Example of Coastal Flooding

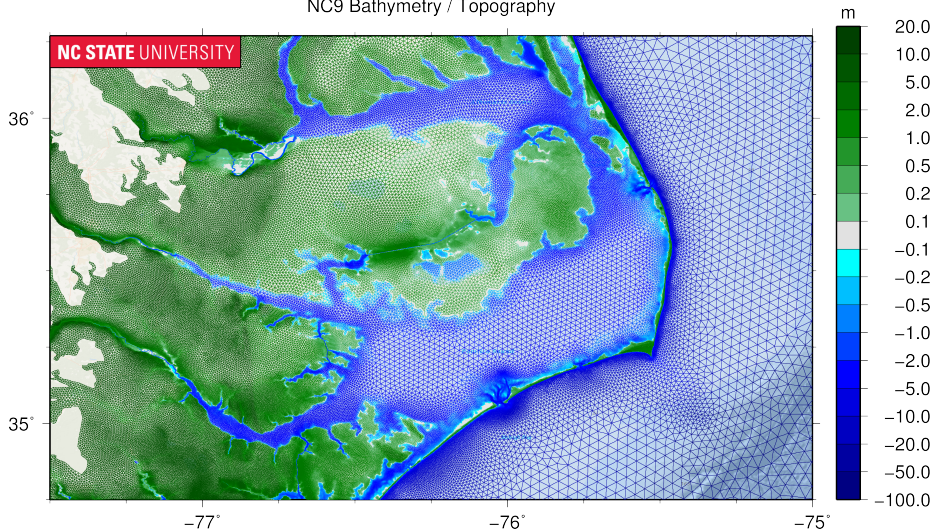
Winds and Storm Surge during Arthur (2014)



Models for Hurricane Waves and Storm Surge

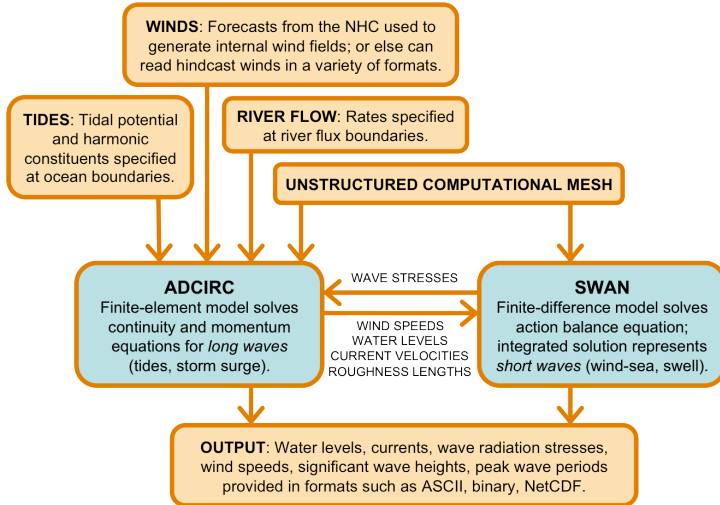
Finite-Element Mesh for NC Coast

NC9 Bathymetry / Topography



Models for Hurricane Waves and Storm Surge

Tight Coupling of SWAN+ADCIRC



Real-Time Forecasting

ADCIRC Surge Guidance System (ASGS)

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)

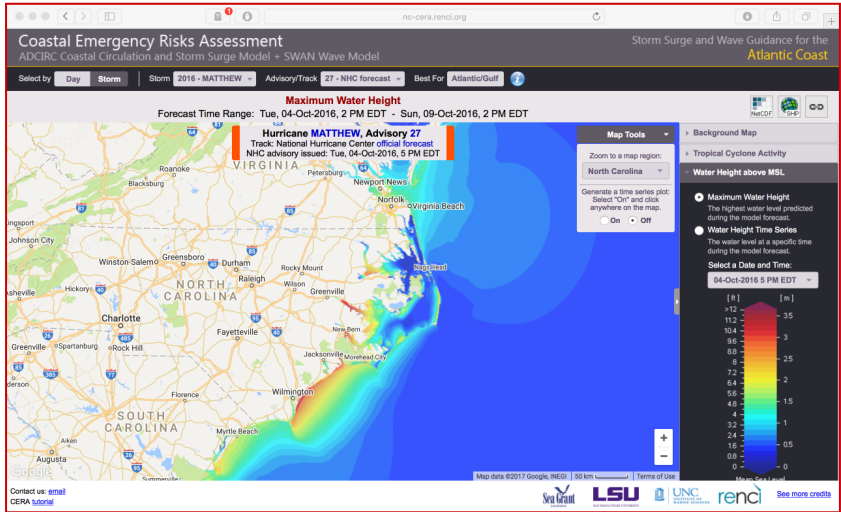
Guidance can be shared in multiple formats:

- 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>)

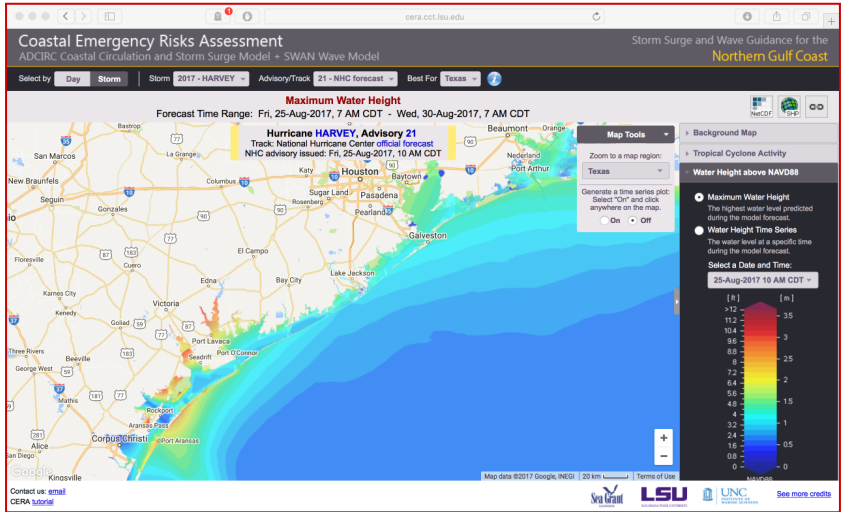
Hurricane Matthew (2016) Advisory 27 - Consensus



Real-Time Forecasting

Coastal Emergency Risks Assessment (CERA, <http://www.adcirc.org>)

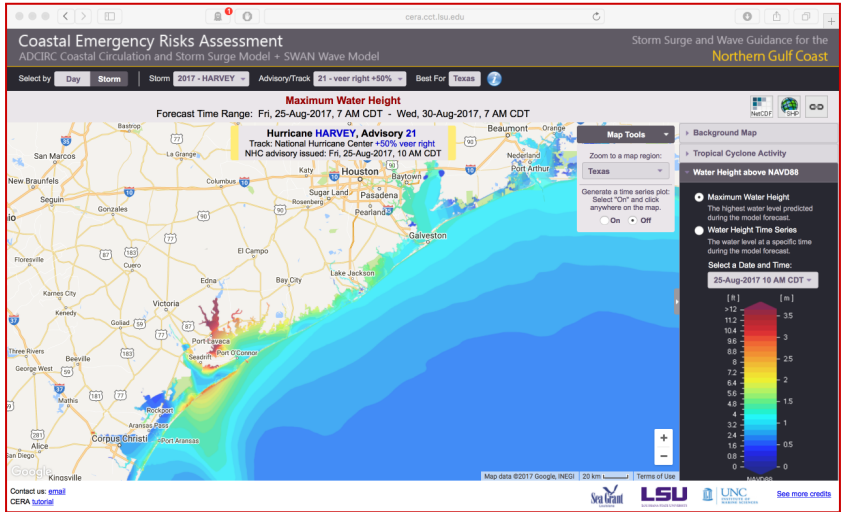
Hurricane Harvey (2017) Advisory 21 - Consensus



Real-Time Forecasting

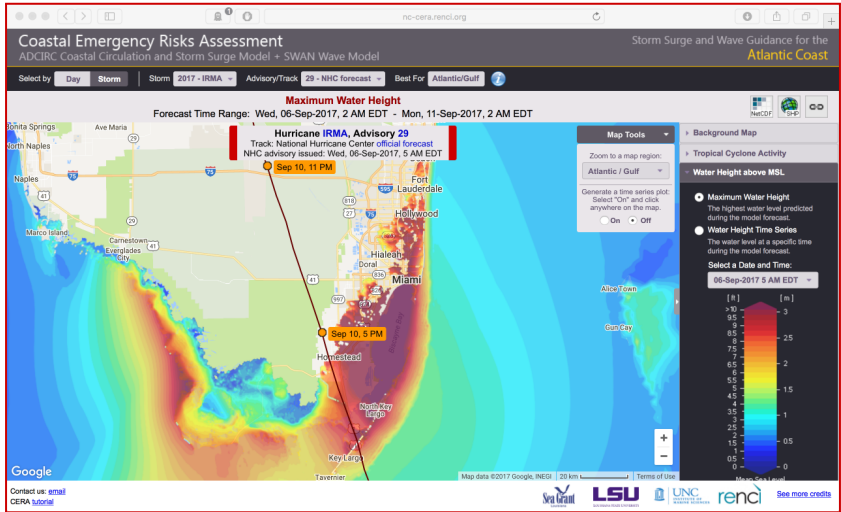
Coastal Emergency Risks Assessment (CERA, <http://www.adcirc.org>)

Hurricane Harvey (2017) Advisory 21 - Veer Right 50%



Coastal Emergency Risks Assessment (CERA, <http://www.adcirc.org>)

Hurricane Irma (2017) Advisory 29 - Consensus



Expanding Guidance for End Users

Conversion of Output Products to Other Formats

Some partners prefer guidance in other formats:

- ▶ Polygon-based formats:
 - ▶ Shapefiles and ancillary files for GIS
 - ▶ KML files for Google Earth
- ▶ These files can be overlaid with information from other sources

We developed Python-based scripts to convert SWAN+ADCIRC output

- ▶ Based on older scripts from BO Blanton, RA Luettich
- ▶ Expanded to consider time series information, KML formats

Now sharing guidance in these formats with partners at North Carolina Emergency Management (NCEM), NWS offices, state and local emergency management teams

- ▶ **Guidance products are generated and shared automatically**

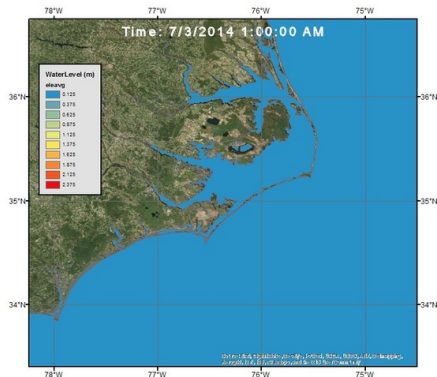


Expanding Guidance for End Users

Introducing *Kalpana*

Our Python-based script is called *Kalpana*:

- ▶ Visualizes guidance in GIS and Google Earth formats
- ▶ Example of water levels during Arthur (2014):



Expanding Guidance for End Users

Key Features of *Kalpana*

Kalpana has been developed with a range of capabilities:

- ▶ Utilizes specialized Python libraries:
 - ▶ Reading from *netCDF4*
 - ▶ Create contours with *matplotlib*
 - ▶ Convert to polygons with *shapely*
 - ▶ Write guidance products with *fiona* or *simplekml*
- ▶ Polygons that represent user-defined contour levels
 - ▶ No loss of resolution at extreme zoom levels
- ▶ Compatible with range of ADCIRC outputs:
 - ▶ Water levels, wind speeds
 - ▶ Wave height, mean wave period, peak wave period, etc.
- ▶ Compatible with single time step (maxima) or full time series
- ▶ Creates products in *.shp* and *.kmz* formats compatible with ArcGIS and Google Earth, respectively

Motivation for Research Project

Differences in Horizontal Resolution

We want to enhance the flooding guidance we provide to NCEM

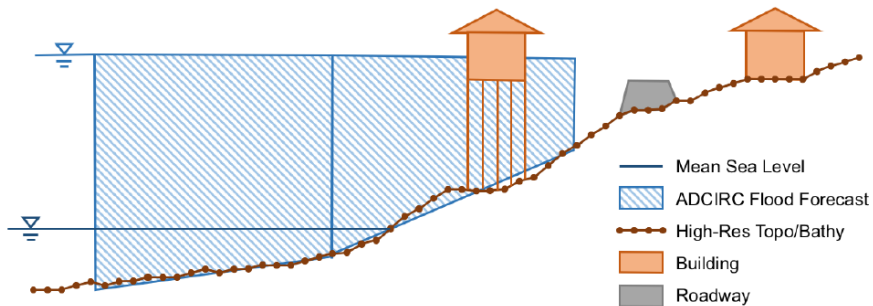
- Now we provide water levels at our model resolution
 - Use an unstructured *mesh* with unequal spacings
 - More than 600K points
 - Minimum spacing of about 50 to 100 m
- NCEM wants to combine with other datasets
 - Use a structured *raster* with equal spacing
 - More than 400M cells
 - High-resolution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



Motivation for Research Project

Goal and Objectives

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):

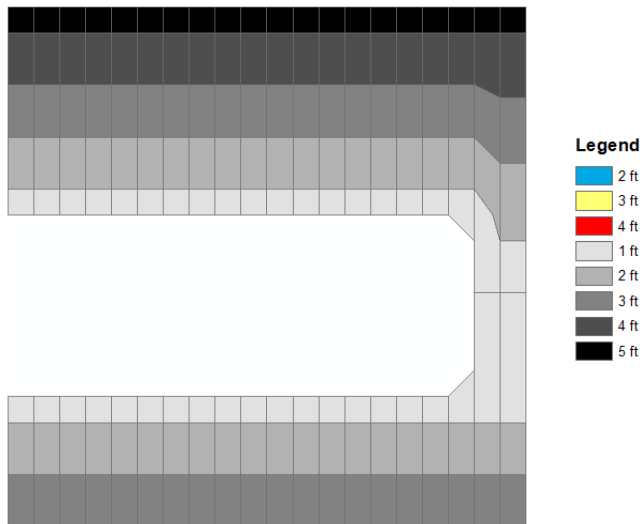
- Available as open-source software (<https://grass.osgeo.org>)
- Developed partly by Prof. Mitsova and others in the NCSU Center for Geospatial Analytics
- Extremely fast for raster processing

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

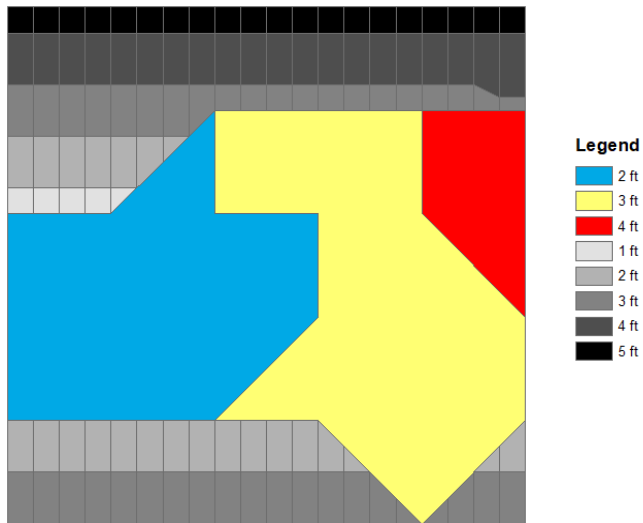
Downscaling and Extrapolation

Example with Simple DEM and Water Levels



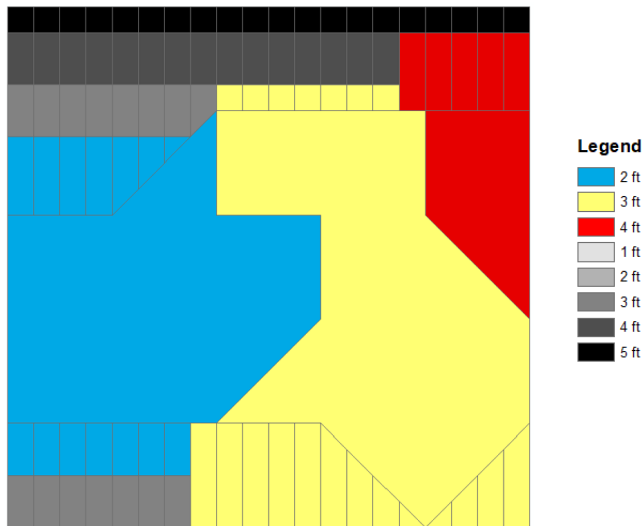
Downscaling and Extrapolation

Example with Simple DEM and Water Levels



Downscaling and Extrapolation

Example with Simple DEM and Water Levels



Downscaling and Extrapolation

Details on Process – Interpolation into GRASS

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

Examples in Carteret County

Testing in a Realistic Setting

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



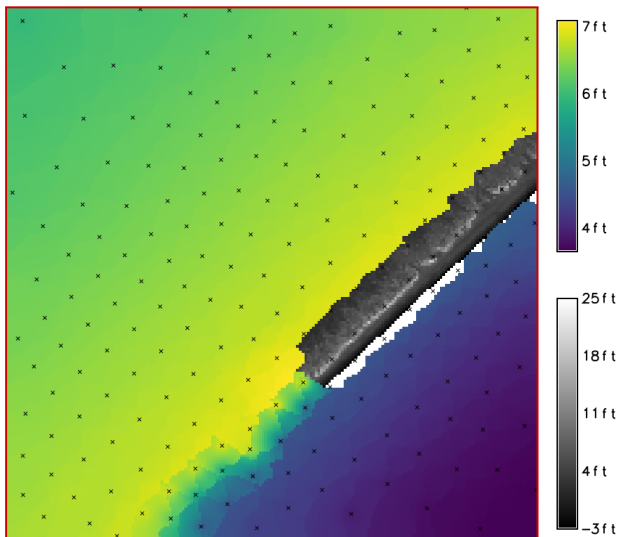
Examples in Carteret County

Zoom of Cape Lookout National Seashore



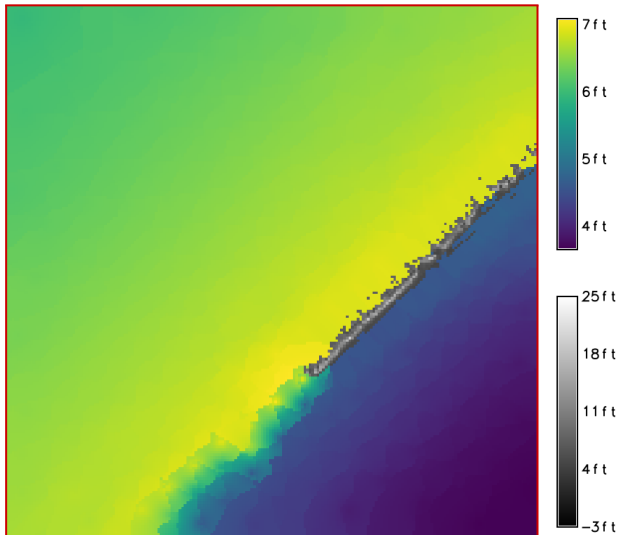
Examples in Carteret County

Zoom of Cape Lookout National Seashore



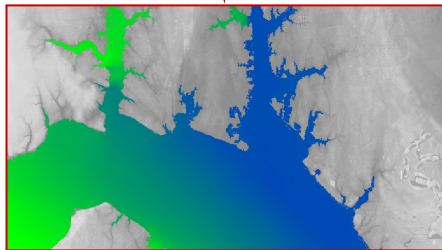
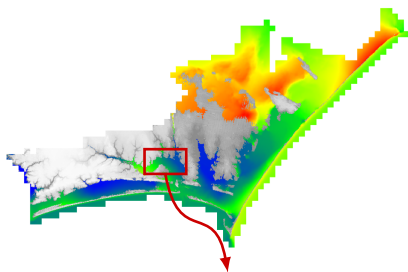
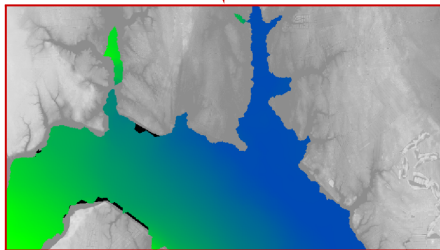
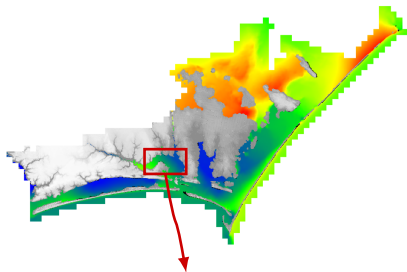
Examples in Carteret County

Zoom of Cape Lookout National Seashore



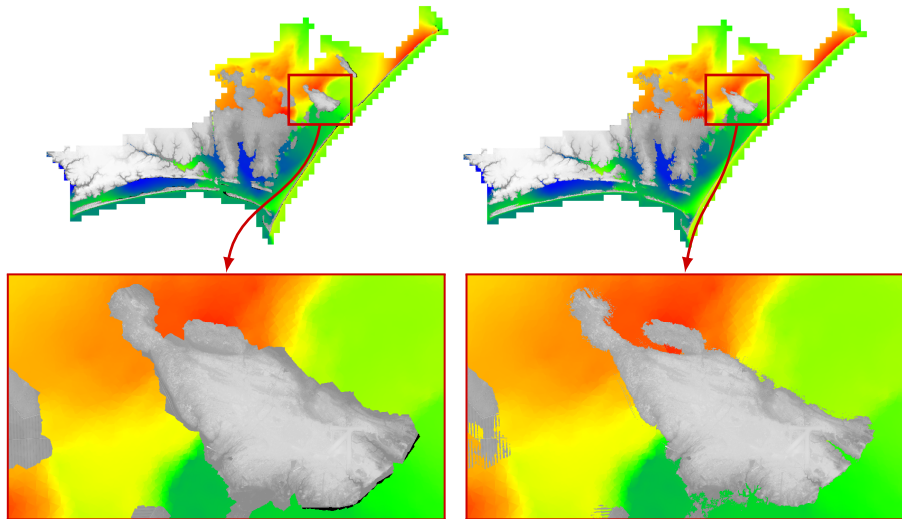
Examples in Carteret County

Newport River



Examples in Carteret County

Cedar Island



Examples in Carteret County

Analysis of Impacted Buildings

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

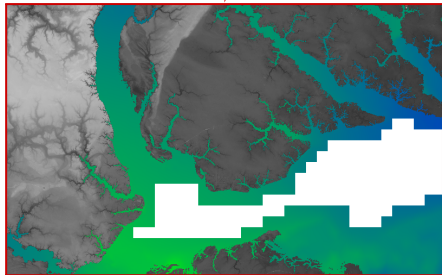
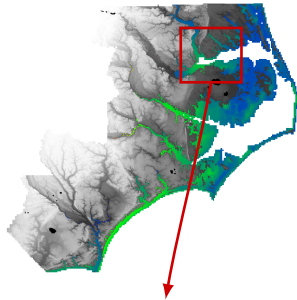
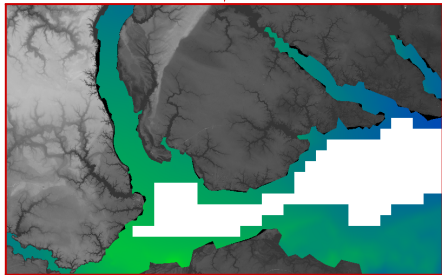
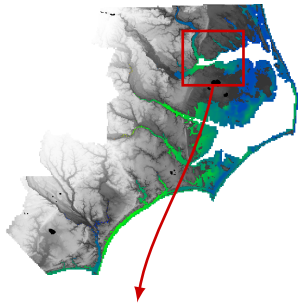
Enhanced Guidance for Entire NC Coast

Parallel Script for Fast Execution

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



Enhanced Guidance for Entire NC Coast

Automation for Real-Time Guidance

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)

Enhanced Guidance for Entire NC Coast

Implications for the Future

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?



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Summary and Future Work

Predictive Models for Hurricane Waves and Coastal Flooding

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

