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

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Introduction

- End-users such as DHS, FEMA, and NCEM rely on storm surge models for decision-making during storms (i.e. hurricanes)
- This research focuses on improving the 1) applicability and 2) physics of a model which downscales, or "enhances the resolution" of a storm surge model
- Downscaling water levels allows emergency managers to analyze flood risk at small-scale features such as buildings and roads
- Typically runs every six hours while a storm is approaching (after each new advisory is released)

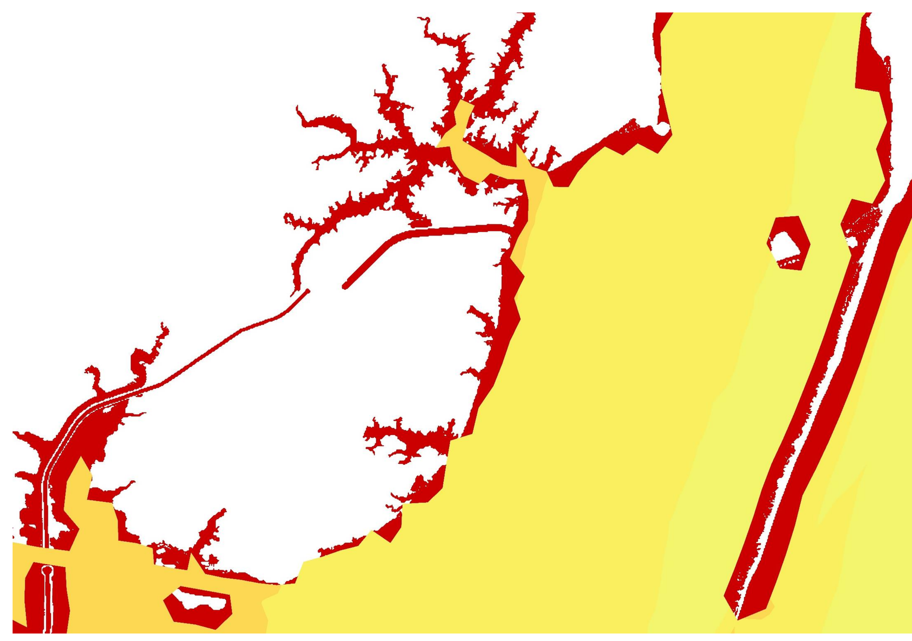

Figure 1. ADCIRC (yellow, orange) vs. downscaled water level extents (red) near Wilmington, NC.

Methods

- Imports a file from ADCIRC (ADvanced CIRCulation model) runs containing data representing the maximum water level experienced by each point in the domain throughout the duration of the storm
- Current downscaling model extrapolates ADCIRC maximum water levels horizontally until reaching an equivalent DEM elevation (Figure 2)
- Typical resolutions used in forecasting:
  - ADCIRC → as fine as 100-200 m
  - DEM used for downscaling → 15 m (or ~50 ft)
- Downscaling process takes 25-35 min (serial); timing is key in emergency management decision-making process

Figure 2. Predicting flood extents at building-sized scale in Charleston, SC.

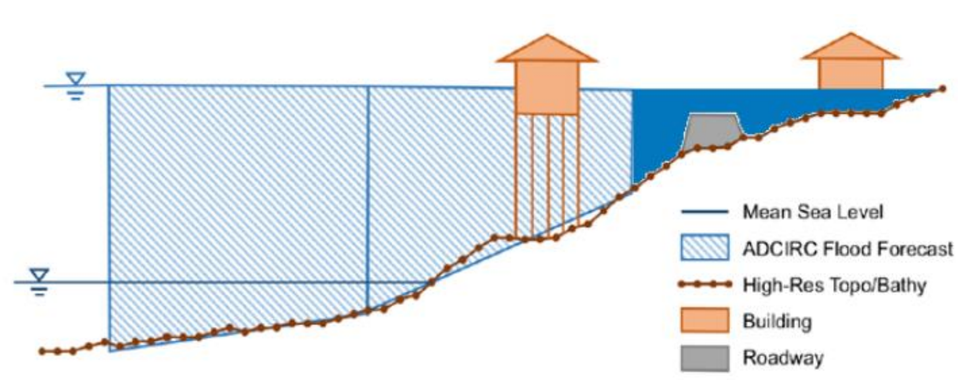

Figure 3. Current downscaling methodology used in forecasting.

Progress

- Integrated downscaling model with Kalpana, an ADCIRC output visualization tool
- Model was previously hard-coded to a North Carolina-specific ADCIRC mesh and DEM
- Now applicable for any ADCIRC mesh, DEM, and resolution
- User-friendly interface allows the user to download the model and create their own simulation
- Decreased the run time in serial by ~80%
- Hindcasts for Hurricane Dorian were shared with end-users for FL, GA, SC, and NC
  - First time model results have been shared for a state other than North Carolina!

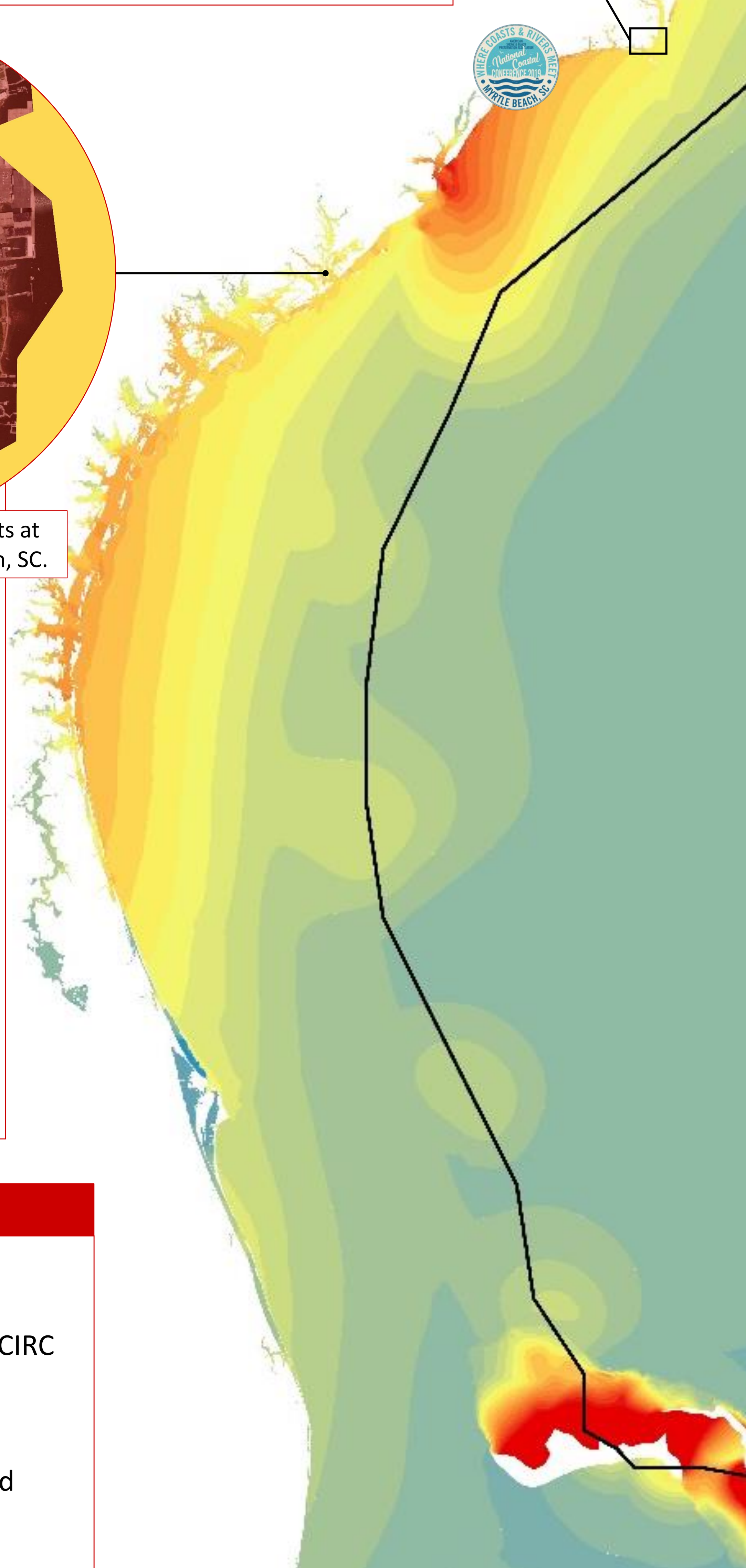

Figure 4. Dorian hindcast results. Hindcast results for Hurricane Dorian (2019) are shown with downscaled results in NC, SC, GA, and eastern FL. The color scale represents maximum water levels experienced throughout the storm where blue=0.5 ft. and red=10+ ft. The black line represents the NHC Best Track path.

Model Validation

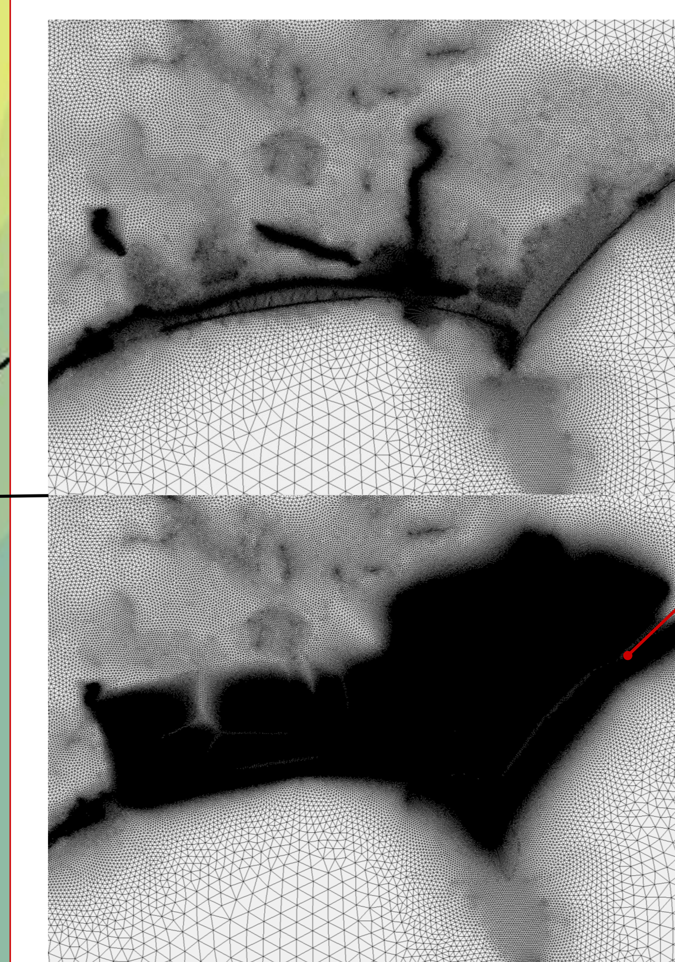

Figure 5. Comparing lower resolution ADCIRC mesh to high resolution. (Top) Lower resolution mesh used in forecasting. (Bottom) High resolution mesh used for downscaling model validation.

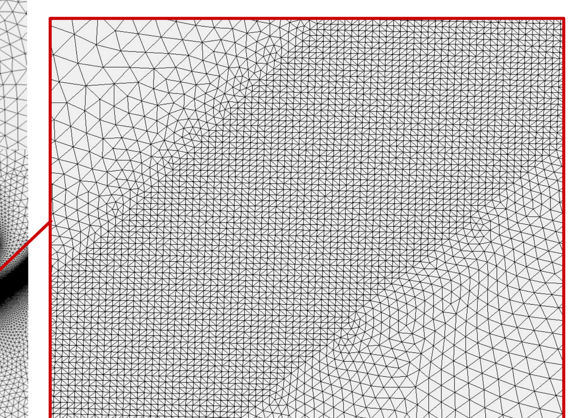

Figure 6. High resolution mesh over barrier island. (Above) High resolution mesh set with nodes aligning to each raster cell in Carteret County, NC.

- Validated using a high resolution ADCIRC mesh
- The high resolution mesh is developed using an existing mesh (referred to as NC9) which was made to provide the best accuracy throughout the North Carolina coast
- All elements are kept the same between NC9 and the high resolution mesh except the node spacing has been adjusted to 15 m throughout Carteret County, NC (aligned with each raster cell)
  - Increase in total mesh nodes from 623,000 to 6,772,000
  - High resolution mesh is feasible for validating downscaling model but not for forecasting
- The high resolution model is not yet prepared, so model validation has not yet taken place

Proposed Methods for Improving Model Physics

Method 1: Extrapolation by Slopes

- Rather than horizontally extrapolating water levels, this model takes into account the slope of the water surface
- Calculated using the following equation:

$$new\ water\ level = horizontal\ extrapolation$$
$$\pm slopedx * EWresolution * (x_{ADCIRC} - x)$$
$$\pm slopedy * NSresolution * (y_{ADCIRC} - y)$$

- Once the high resolution ADCIRC results are prepared, the model can be calibrated by altering:
  1. Slope interpolation methods
  2. Implementing slope exaggeration factors
  3. Using various slope smoothing or averaging techniques

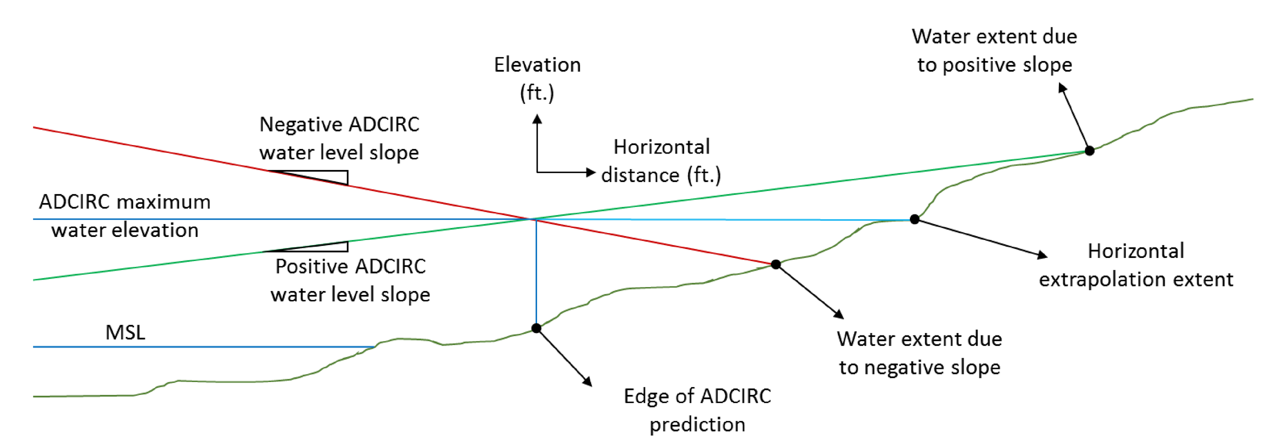

Figure 7. Extrapolation by slopes schematic. ADCIRC water levels with a downward slope will create a reduced flooding extent as compared to an upward slope in water levels.

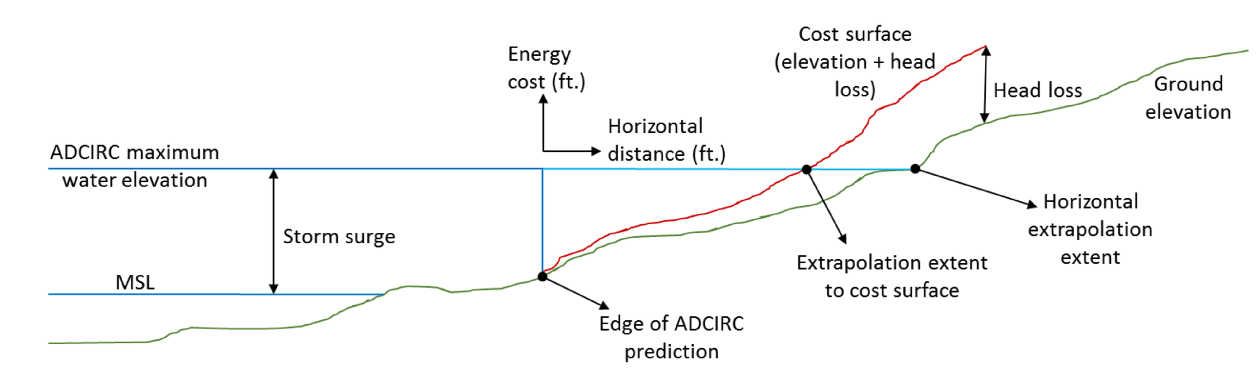

Figure 8. Extrapolation with head loss schematic. ADCIRC water levels are extrapolated horizontally until reaching an equivalent energy cost surface.

Method 2: Extrapolation with Head Loss due to Land Cover

- Water is extrapolated horizontally but rather than extrapolating the water levels until they are equivalent to the DEM surface, the water levels are extrapolated until they reach an energy cost surface
- The energy cost surface is calculated by adding elevation to cumulative head loss:

$$total\ cost = \Delta elevation + \sum \Delta horiz.distance \left(\frac{n * U}{k * R_H}\right)^2$$

where n=Manning's n, U=depth-averaged velocity, k=conversion factor, R_H=hydraulic radius

- Treated as cumulative energy required to reach a certain point
- Difficult to implement because the flow paths are unknown

Summary

- Goal: Create a model which "enhances the resolution" of relatively coarse ADCIRC maximum water level output
- This model will provide real-time high resolution results to end-users which will assist in decision making in the event of an emergency
- The model's code has been integrated to allow it to be used with any ADCIRC mesh or DEM, rather than just in North Carolina
- Next steps:
  - Complete high resolution ADCIRC simulation
  - Complete workflow for the 1) extrapolation by slopes method and 2) extrapolation with head loss method
  - Use the high resolution ADCIRC results to validate and calibrate each model