Prediction of High-resolution Maps of Storm-driven Coastal Flooding Using Deep Learning

Tomás Cuevas-López[1], Brandon Tucker[1], Casey Dietrich[1] & Dylan Anderson[2]

[1]Department of Civil, Construction, and Environmental Engineering, NC State University
[2]Coastal Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Duck, NC, USA

3rd International Workshop on Waves, Storm Surges, and Coastal Hazards
Oct 2023

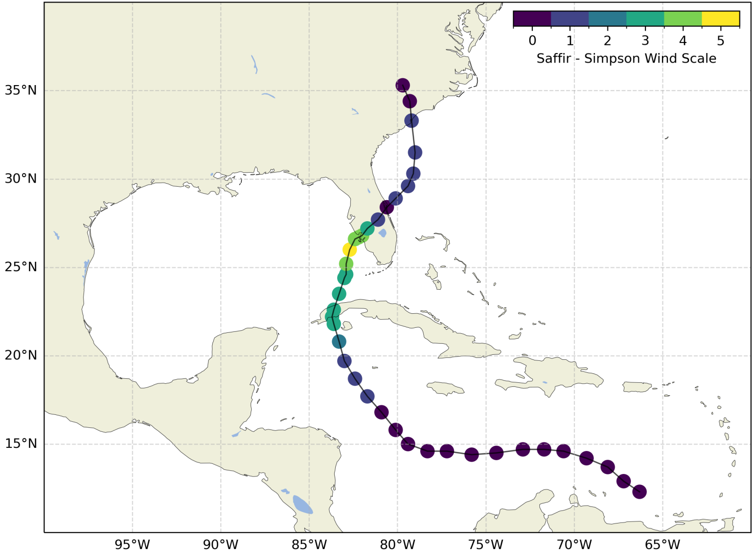
Agencia Nacional de Investigación y Desarrollo
Ministerio de Ciencia, Tecnología, Conocimiento e Innovación
Gobierno de Chile

COASTAL RESILIENCE CENTER

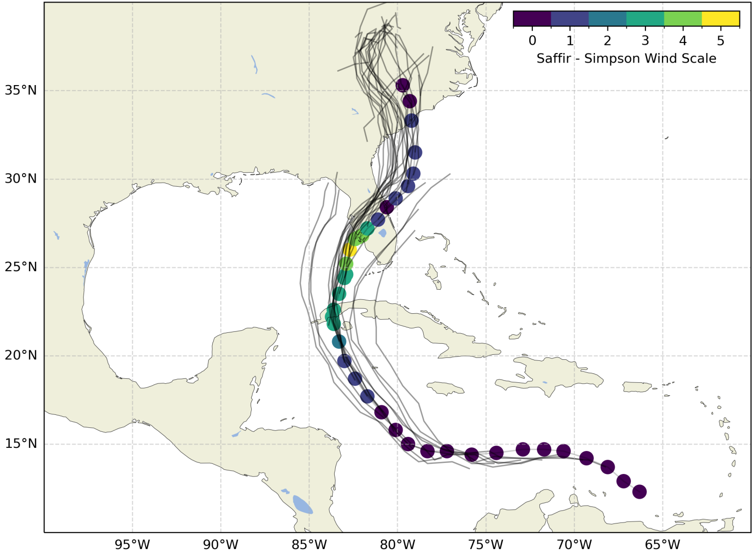
~~Prediction of High-resolution Maps of Storm-driven Coastal Flooding Using Deep Learning~~

Library of High-resolution Maps of Storm-driven Coastal Flooding for Training a Neural Network

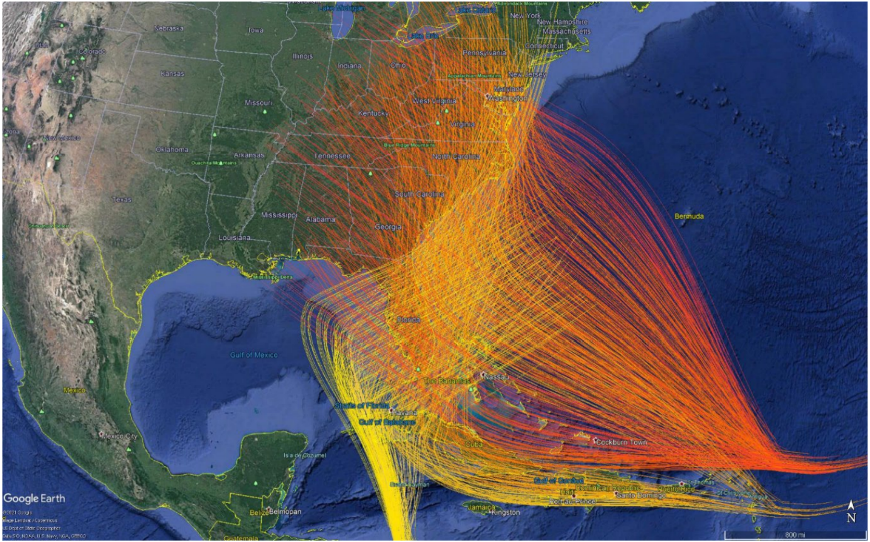
Motivation: Hindcast simulations



Motivation: Real-time forecasting uncertainty



Motivation: Risk analysis uncertainty

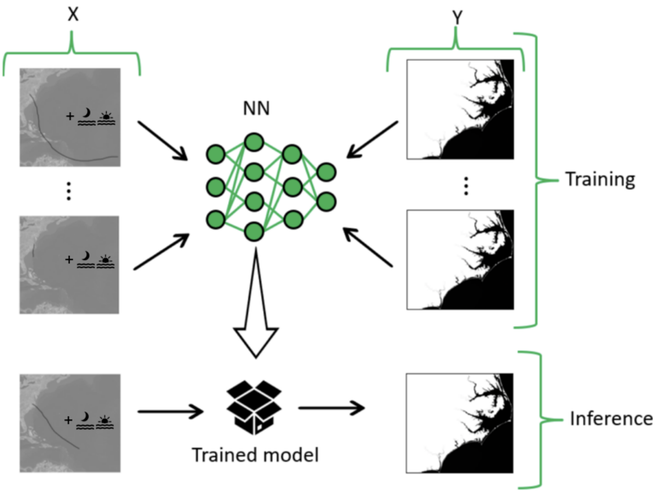


U.S. Army Corps of Engineers (2021)

GOAL: Create a large library of ADCIRC simulations with random astronomical tides for training a neural net to predict high-res maps of storm-driven coastal flooding

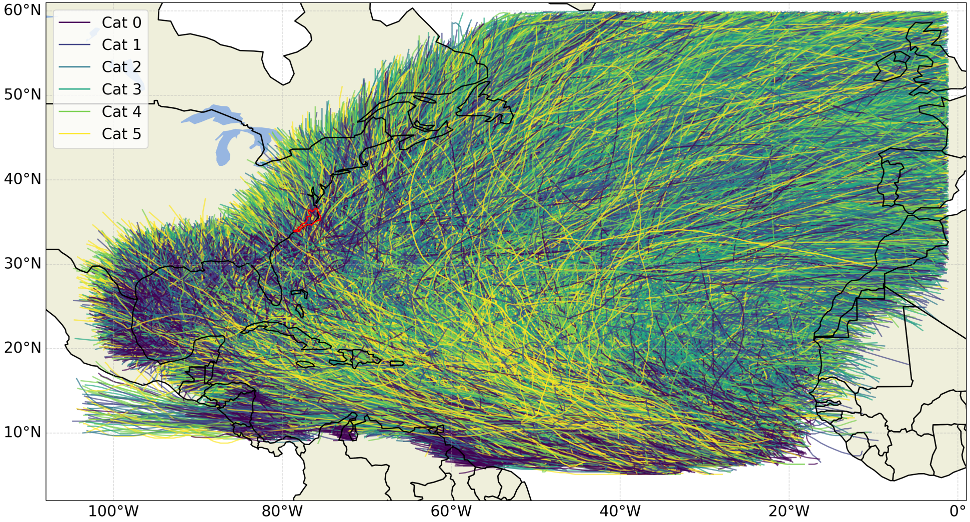
What is new?

- Tropical cyclones library:
  - o Tracks from a probabilistic model
  - o Random astronomical tides
  - o High-resolution maps as outputs
- Neural network:
  - o Tide as input
  - o Tracks of variable length
  - o Prediction of high-resolution maps



Step 1: Dataset of synthetic tropical cyclones

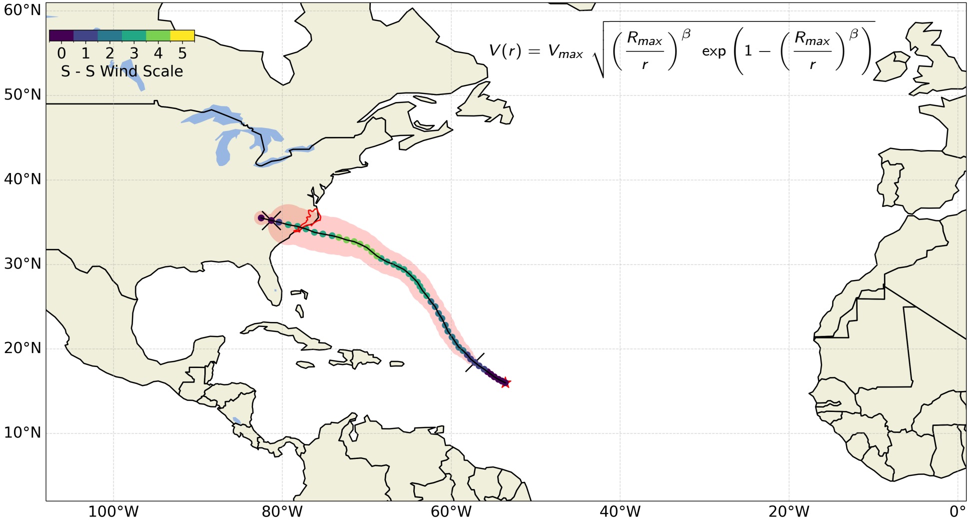
Identify a subset of impactful storms



Bloemendaal et al. (2020)

Step 1: Dataset of synthetic tropical cyclones

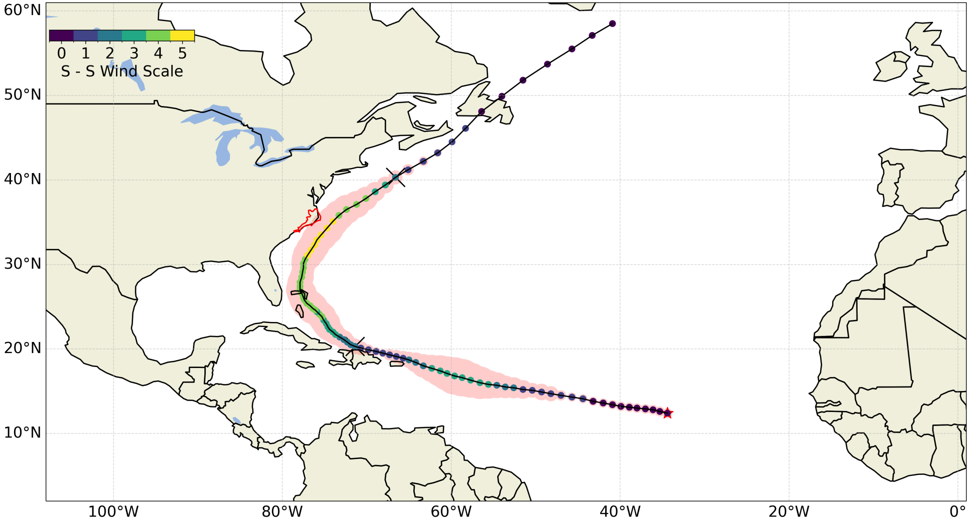
Define an area of influence



Holland (1980)

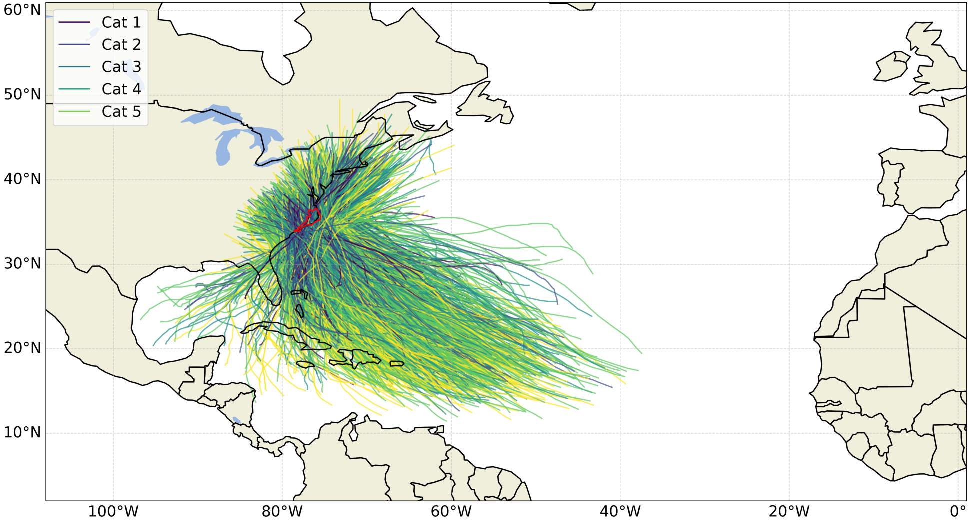
Step 1: Dataset of synthetic tropical cyclones

Reducing track length to reduce computation – Key asumption 1



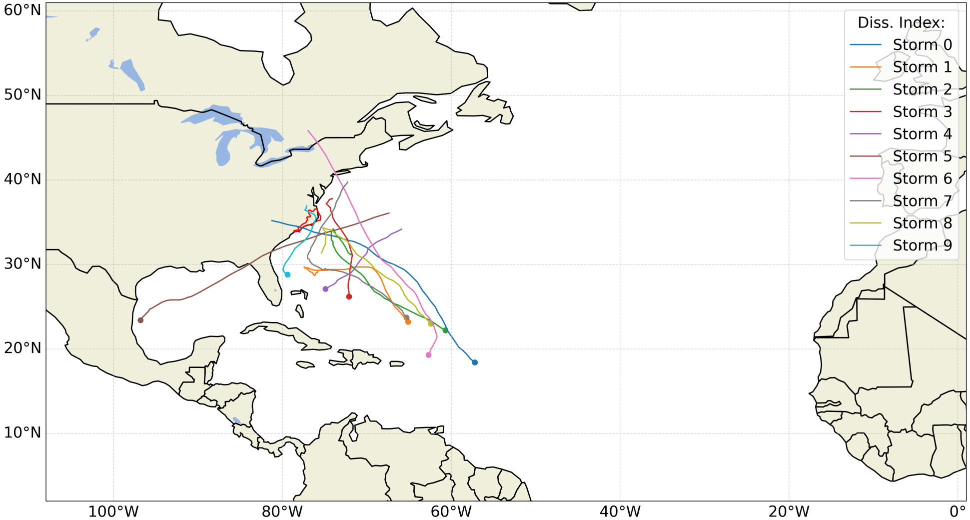
Step 1: Dataset of synthetic tropical cyclones

Subset of 1813 tracks that affect North Carolina



Step 1: Dataset of synthetic tropical cyclones

Maximum dissimilarity algorithm to sort the tracks based on dissimilarity

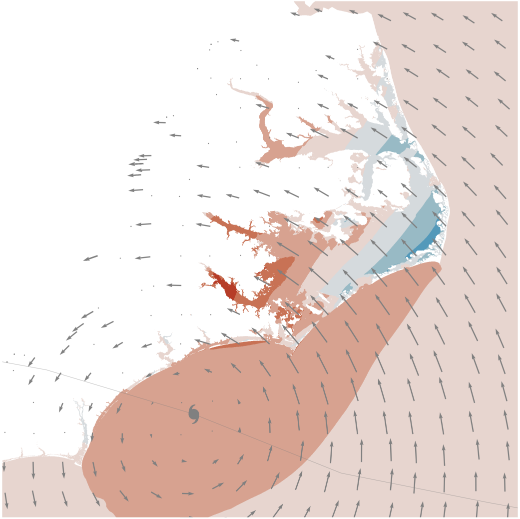


Camus et al. (2011)

Step 2: Hydrodynamic modeling with ADCIRC

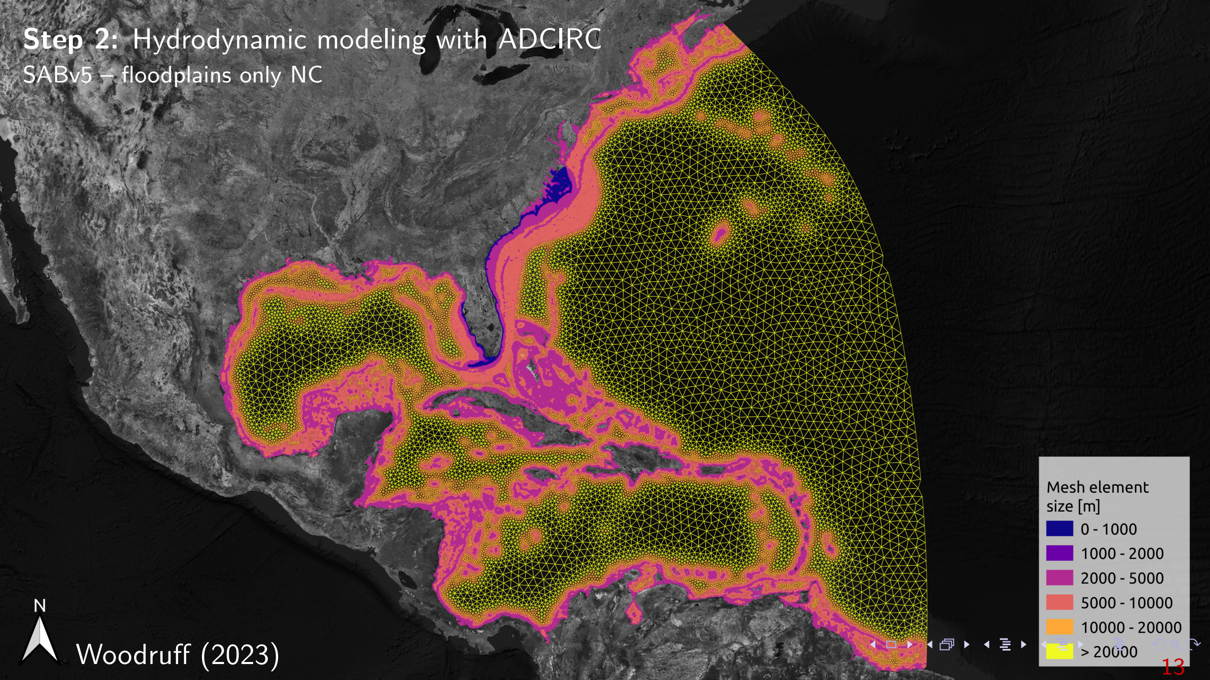
ADvanced CIRCulation (ADCIRC) model:

- Unstructured, variable resolution meshes
- Finite element in space and finite differences in time
- Solve the Generalized Wave Continuity Equation
- Well validated in the U.S. Gulf and Atlantic coasts



Step 2: Hydrodynamic modeling with ADCIRC

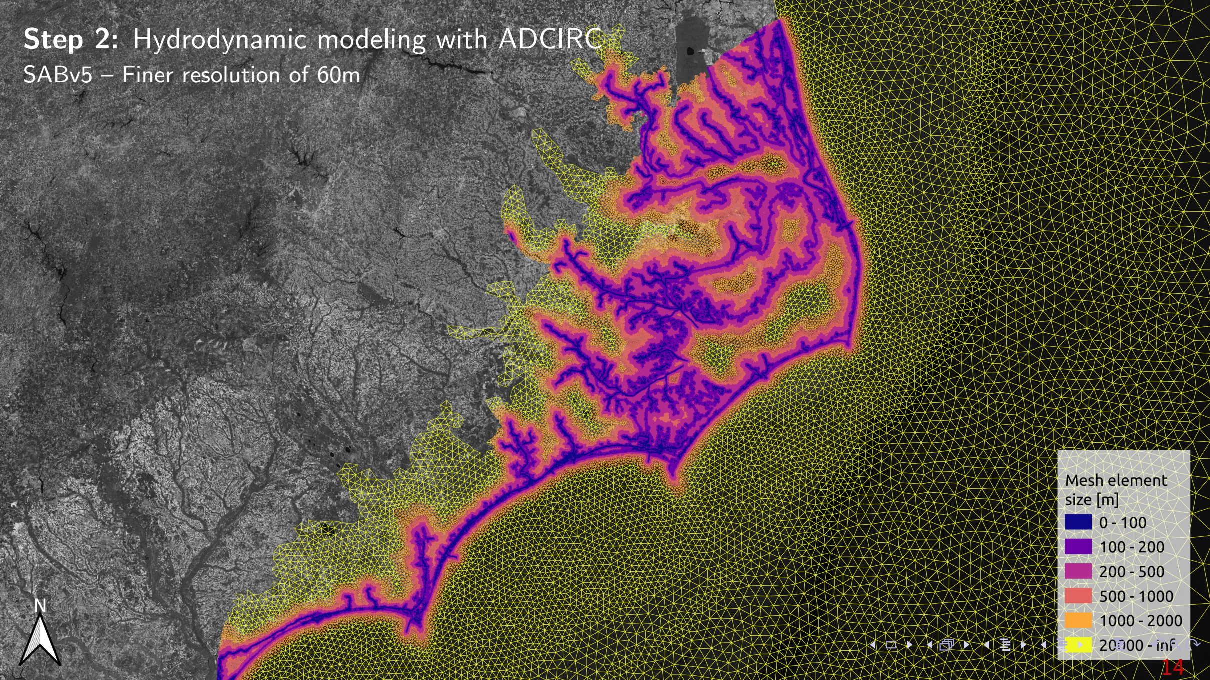
SABv5 – floodplains only NC



Woodruff (2023)

Step 2: Hydrodynamic modeling with ADCIRC

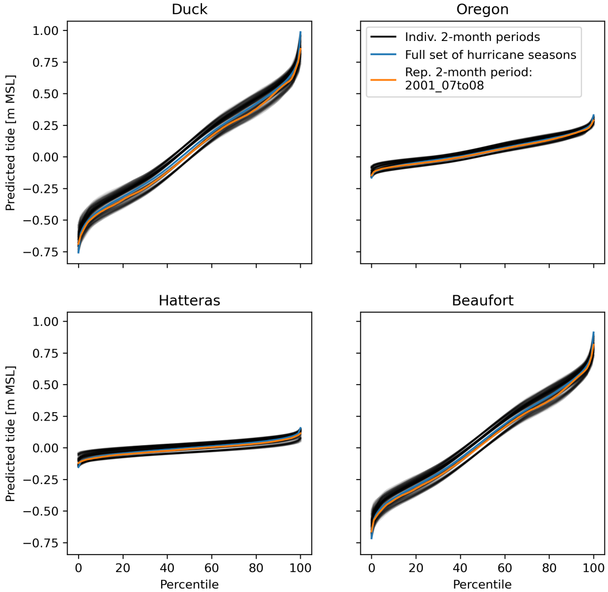
SABv5 – Finer resolution of 60m



Step 2: Hydrodynamic modeling with ADCIRC

Simulations setup

- Same mesh and nodal attributes
- Almost the same configuration
  - o 2-month representative period (Key assumption 2)
  - o Random date $\Longrightarrow$ random tide
- Wind field: Symmetric Holland Model
  - o No need to compute extra parameters
  - o Coords, WS, P, and RMW
- 3-days spin-up

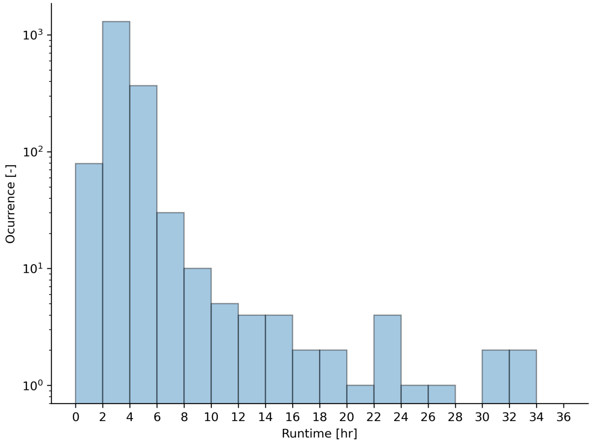


Step 2: Hydrodynamic modeling with ADCIRC

Running and postprocessing simulations

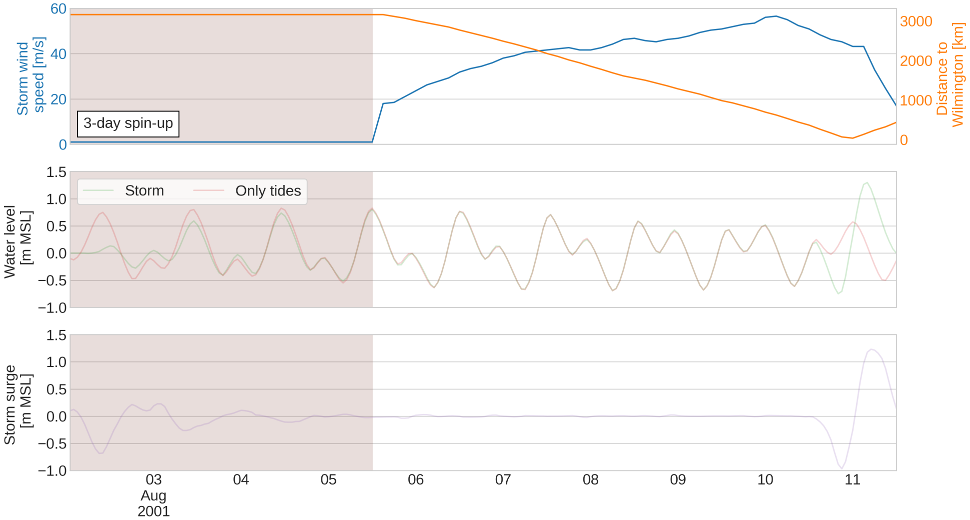
- HPC systems
  - NCSU Hazel
  - Purdue Anvil
  - TACC Stampede2

- Simulation stats
  - **1.3M** cpu hours
  - Wall clock time ranged from 1.2 to 33 hours
  - Mean wall clock time of 3.7 hours
  - **17T** of data



Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Time series at Wilmington NOAA tide gauge, storm 0



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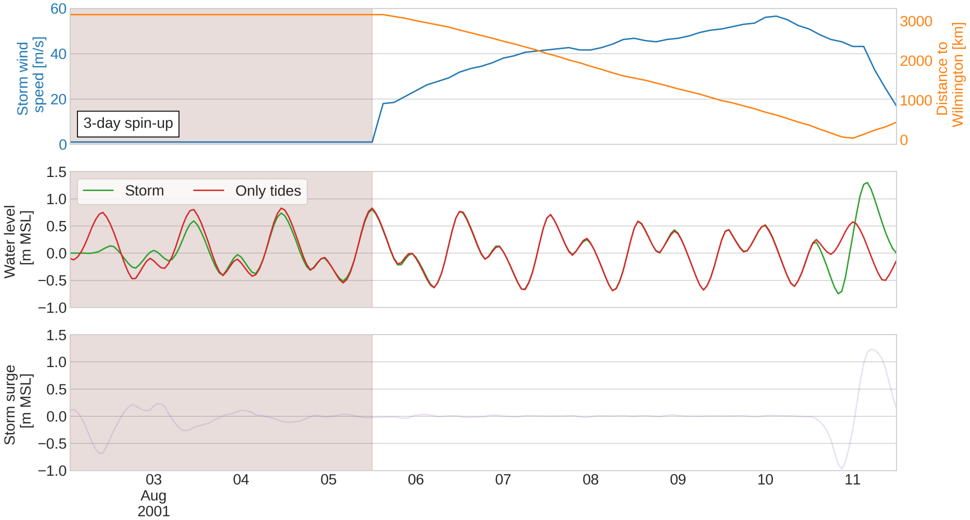

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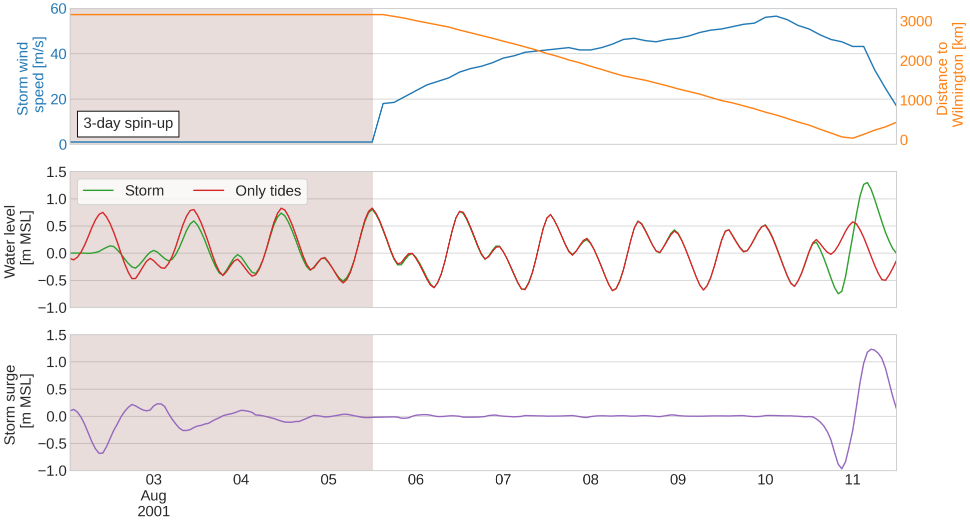
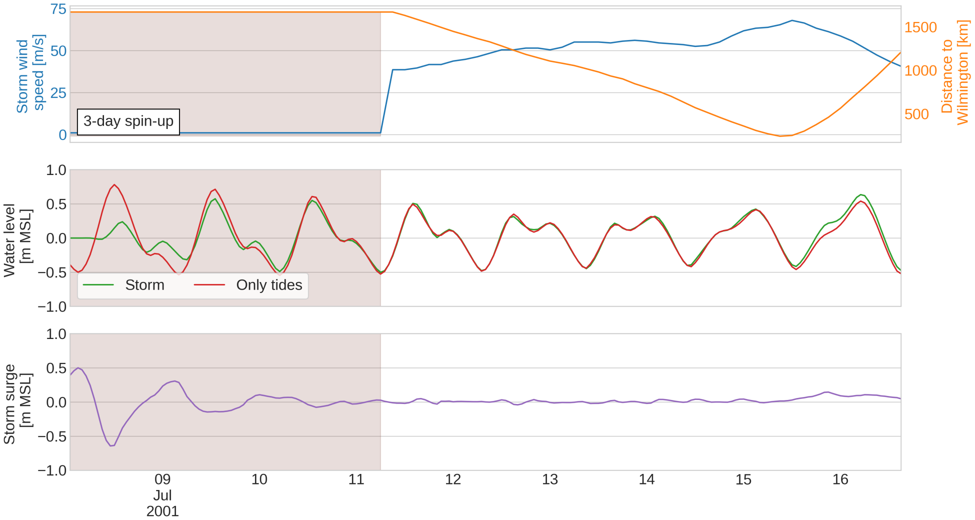


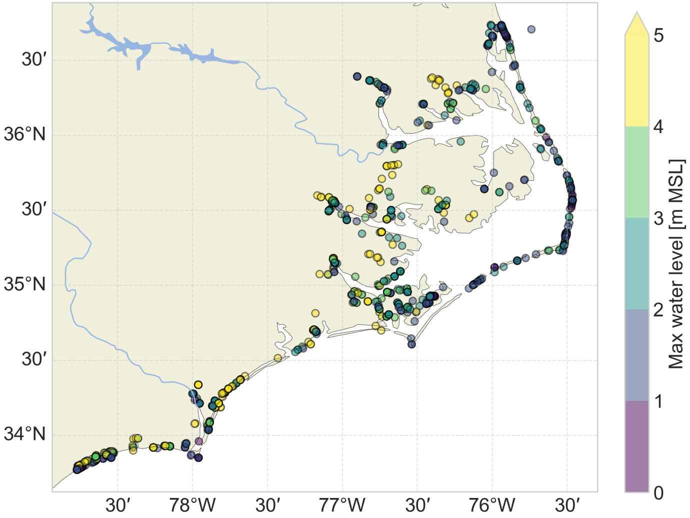
Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Time series at Wilmington NOAA tide gauge, storm 11



Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Locations of peak storm surge

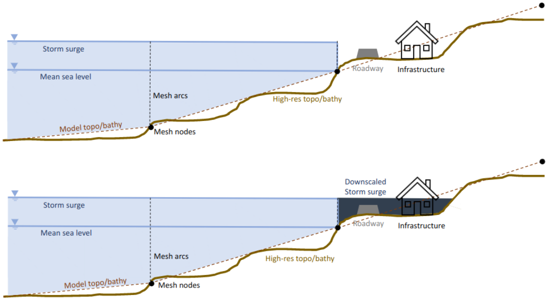


Step 2: Hydrodynamic modeling with ADCIRC

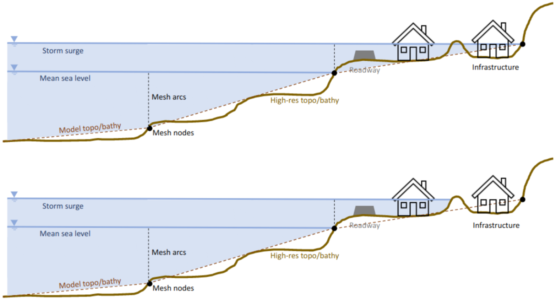
Peak storm surge output to high-res rasters with Kalpana's Static Downscaling method

Use of a high-resolution topo DEM to increase ADCIRC resolution and to expand or shrink the inundation extent[1]

Expand inundation



Shrink inundation

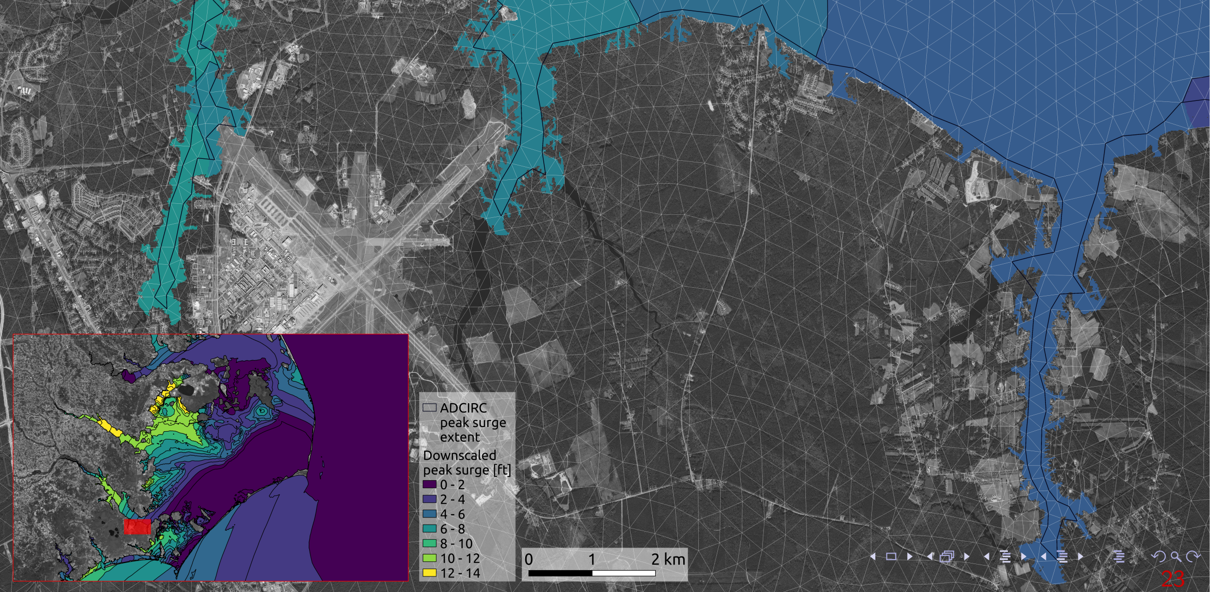


github.com/ccht-ncsu/Kalpana

Rucker et al. (2021)

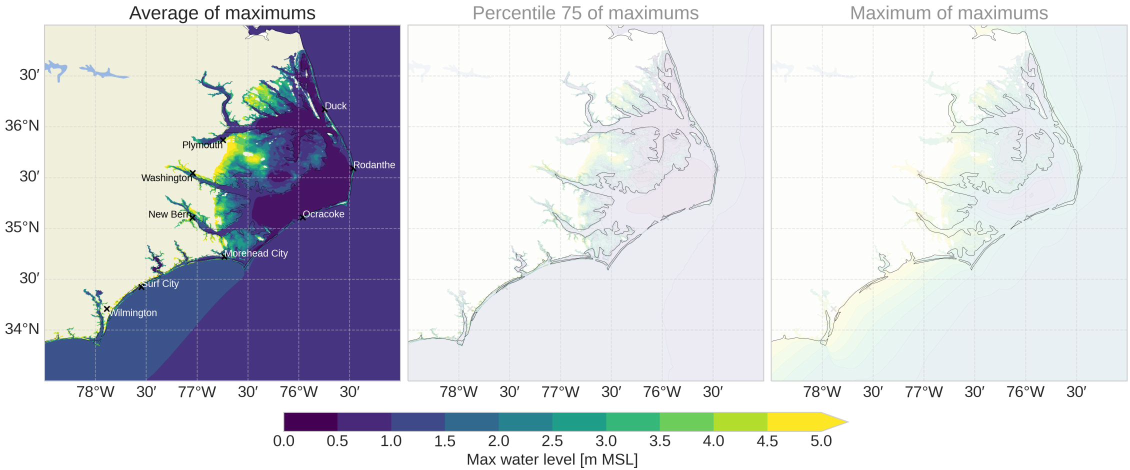
Step 2: Hydrodynamic modeling with ADCIRC

Downscaled map example, Neuse River, NC



Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Peak storm surge stats



Step 2: Hydrodynamic modeling with ADCIRC

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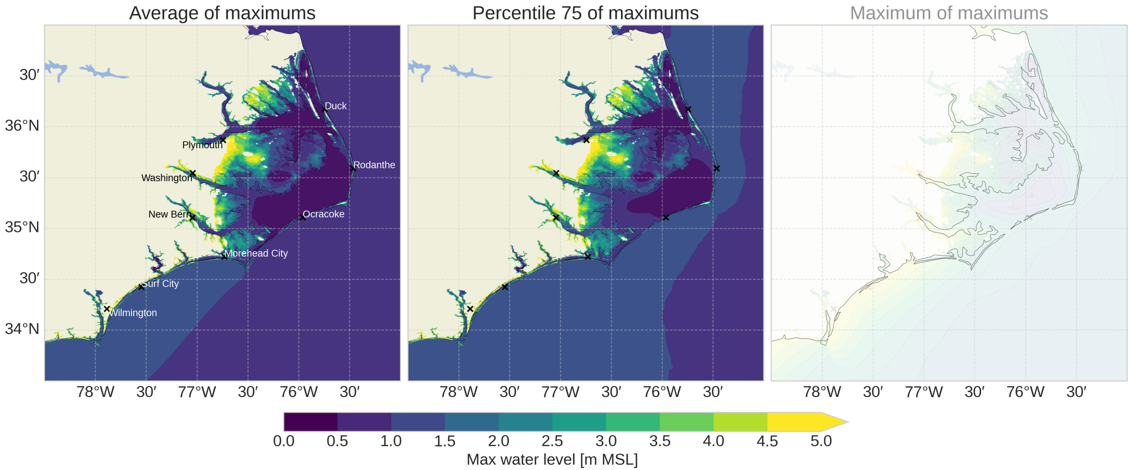

Step 2: Hydrodynamic modeling with ADCIRC

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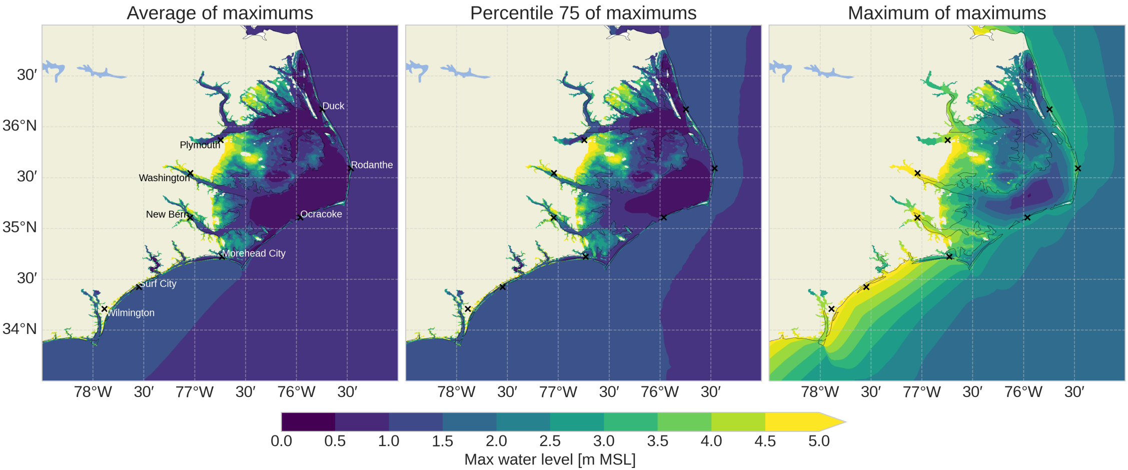
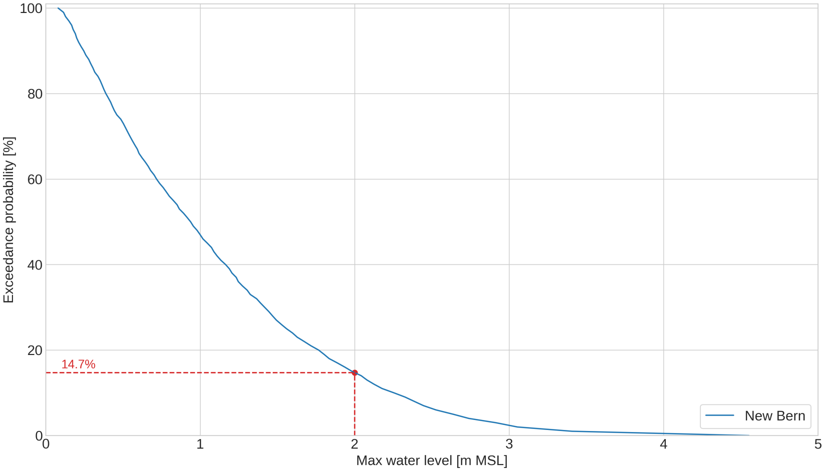


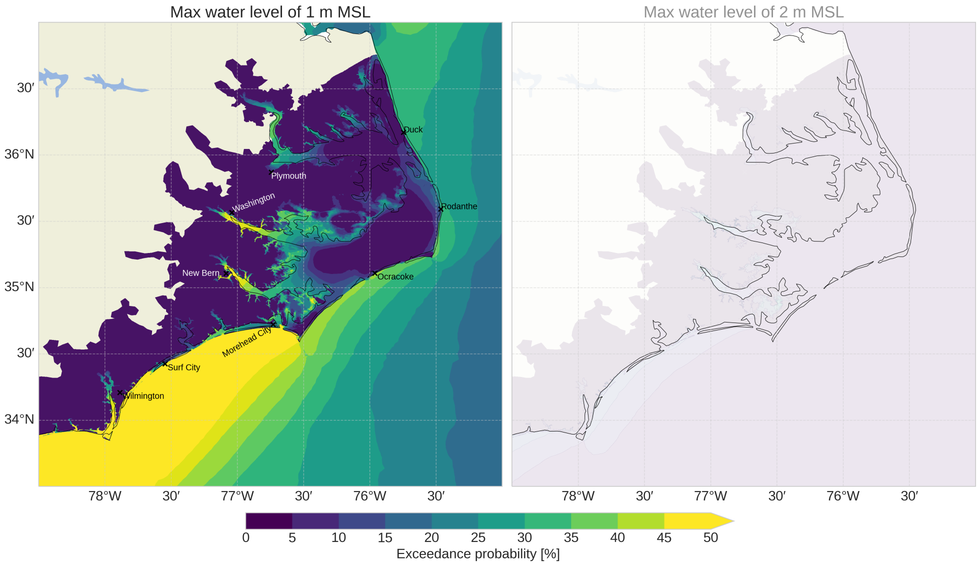
Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Exceedance probability distribution at New Bern, NC



Step 2: Hydrodynamic modeling with ADCIRC

Postprocessing simulations – Where to buy a beach house in NC?



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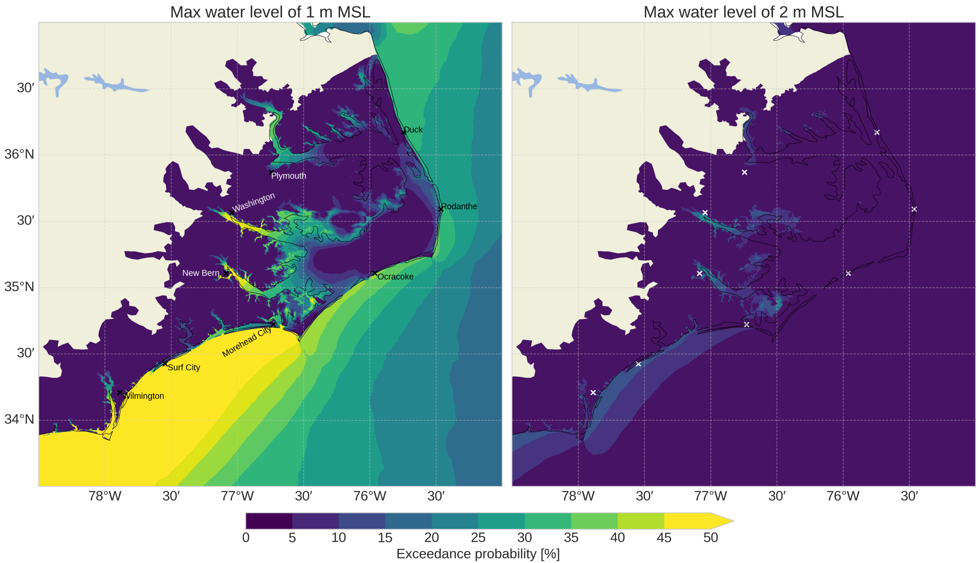
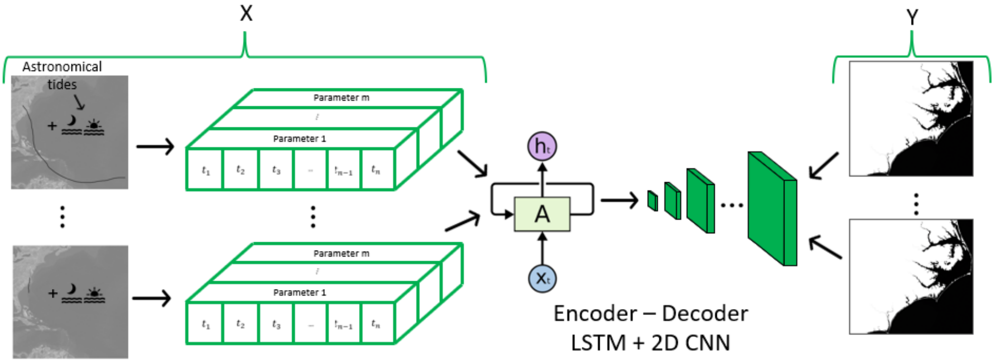


Step 3: Neural network development

NN architecture: Long short-term memory and 2D transposed convolution layers



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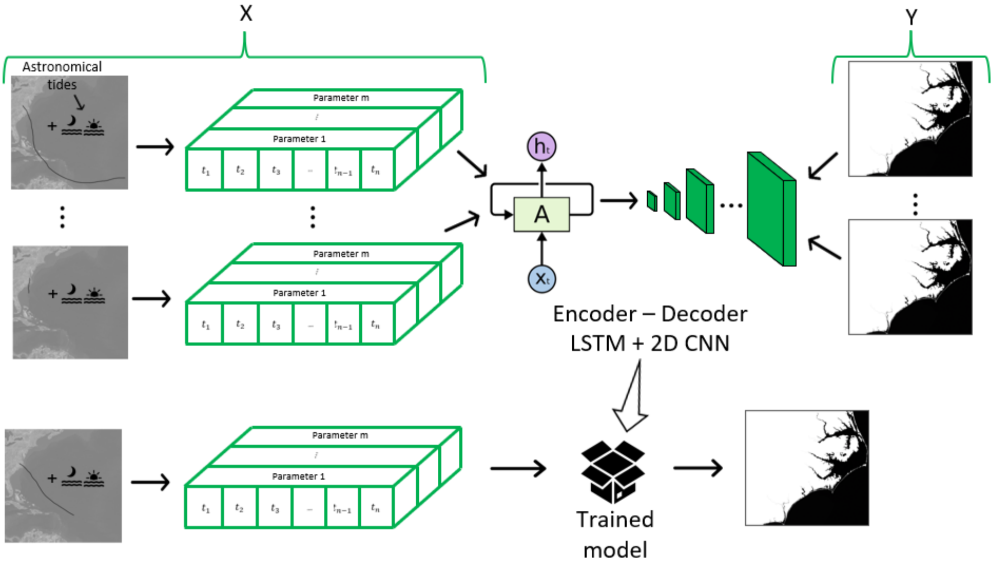

Summary and Ongoing Work

Library of High-resolution Maps of Storm-driven Coastal Flooding for Training a Neural Network

- Selected a set of tracks that represents the max and avg of the tropical cyclone conditions in NC
- 1813 ADCIRC simulations with random astronomical tide using $\approx$ 1.3M cpu hours.
- Ran a 2-month tides-only simulation to isolate the storm surge.
- Downscaled the peak surge output to produce high and constant-resolution maps with and without the tide effect.

Ongoing work:

- Developing an NN based on an **LSTM** to process storm track and astronomical tides time series and a **CNN** with transpose convolution layers to generate the maps.
- Define how to incorporate the astronomical tide in the inputs.
- Define the error metric.