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

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Motivation: Hindcast simulations



Motivation: Real-time forecasting



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Motivation: Risk analysis



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

Motivation: Proposed Workflow



Motivation: Proposed Workflow



Step 1: Dataset of synthetic tropical cyclones Identify a subset of impactful storms



Step 1: Dataset of synthetic tropical cyclones Define an area of influence



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



ADvanced CIRCulation (ADCIRC) model:

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



Step 2: Hydrodynamic modeling with ADCIRC SABv5 – floodplains only NC

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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 \implies 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
 - o NCSU Hazel
 - o Purdue Anvil
 - o TACC Stampede2
- Simulation stats
 - o $1.3M\ \text{cpu}\ \text{hours}$
 - o Wall clock time ranged from 1.2 to 33 hours
 - o Mean wall clock time of 3.7 hours
 - o $\, 17T$ of data











Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Locations of peak storm surge



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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



Rucker et al. (2021)

Downscaled map example. Neuse River, N

CONTRACTOR OF STREET

ADCIRC peak surge extent Downscaled peak surge [ft] 0 - 2 2 - 4 4 - 6 6 - 8

2 km

8 - 10

□ 10 - 12 □ 12 - 14

Downscaled map example. Neuse River, N

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 ADCIRC peak surge extent
 Downscaled peak surge [ft]
 0 - 2
 2 - 4
 4 - 6
 6 - 8

2 km

8 - 10

□ 10 - 12 □ 12 - 14

Step 2: Hydrodynamic modeling with ADCIRC Downscaled map example, Neuse River, NO

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Step 2: Hydrodynamic modeling with ADCIRC Downscaled DEM to greyscale image



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Image: A image: A

Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Peak storm surge stats



Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Peak storm surge stats



Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Peak storm surge stats



Postprocessing simulations - Exceedance probability distribution at New Bern, NC



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Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Where to buy a beach house in NC?



Step 2: Hydrodynamic modeling with ADCIRC Postprocessing simulations – Where to buy a beach house in NC?



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.

