NHERI GSC
February General Meeting

2024

Agenda

11:00-11:05 Welcome & Announcements

11:08-11:38 Dr. Aikaterini Kyprioti

11:40-11:58 Q & A

11:58-12:00 Wrap up

NHERI GSC
Graduate Student Council

Welcome New Members

Abigail	Beck	Asma	Iram	Abdulrahman Ahmed	Salah
Benjamin	Zeitlin	Miguel	Angel	Khandker Tarin	Tahsin
Scott	Northedge	Laura	Maalouf	Alireza	Eskandarinejad
Anoop	Tiwari	Mikel	Gordon	Kamrul	Islam
Nisha	Sthapit	Sharfuddin	Ahmed	Sneha	Bhatta
Abdullah	Khan	Wendy	Nathaly	Leo	Martinez III
Sumphoniya	Lanka	Ahmed	Hussain	Xinyue	Huang
Manjari	kothapalli	Prashanna	Mishra	Safoura	Safari
Juan Esteban	Jimenez Pirajan	Claudia Valeria	Calle Müller	Maryam	Pakdehi
Amanda	Voropaeff	Saeid	Ghasemi	Sumon Hossain	Rabby
Mohammadamin	Soltanianfard	Amir Hossein	Moadab	Abdulahi	Opejin
Maziar	Mivehchi	Houssam	Al Sayegh	Bowei	Li
Sudhir	Niroula	Nischal	Kafle	Kayla	Boettcher
Chia	Mohammadjani	Erik William	Benson	Roy	Lan
Jacob Dylan	Murphy	Sai Brindha	Kapalayam VS	Venkata Narendra Kumar	Sykam
Nishat	Tusnime	Azizur	Rahman	Morgan	Sanger
Claudia	Deveaux	Nii Otu	Tackie-Otoo	Hamidreza	Allahdadi
Nasimeh	Rashidi	Islam Mahmoud Ahmed	Radwan		
Michelle	Ruiz	WoongHee	Jung		

*Reach out to Daniel Yahya and Jenny Russell to learn how to get involved!

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FEB
25

NHERI Summer Institute

- Apply for NSF Travel Award to attend by **February 25** bit.ly/2024NHERI_SummerInstitute
- Learn more on NHERI Summer Institute website designsafe-ci.org/learning-center/summer-institute
- Funding is available for 20 early career faculty/post-docs and 5 NHERI GSC members

Apply Today!

NHERI
Natural Hazards Engineering Research Infrastrucure

NSF

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Graduate Student Council

MAR
1

Mini-Conference

Register Today!

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MAR

15

Natural Hazard Workshop

- Register for Natural Hazards Workshop, **July 14-17**: hazards.colorado.edu/workshop/2024/registration
- Submit poster abstract by **March 15**: hazards.colorado.edu/workshop/2024/submission-guidelines

x

- Apply for funding for Natural Hazards Workshop from Natural Hazards Center & NHERI NCO by **March 15**: bit.ly/2024fundingNHW

Apply Today!

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Research Groups

- Join a research group to network with graduate students in your specific area of natural hazards research to discuss research ideas, methods, and resources
- bit.ly/NHERIGSC_Research

Register Today!

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Call for Volunteers!

We are currently looking for dedicated **volunteers to review** abstracts and provide feedback for the NHERI GSC Research Challenge and Mini-Conference.

Look out for the email!

- **Review** up to 5 abstracts
- **Provide** critical and positive feedback
- **Learn** about the reviewer process

NSF

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Workshop!

Feb. 23rd

12:00 pm CT

NHERI GSC *presents*

Transitioning From Ph.D. to Academia

bit.ly/NHERIGSC_TransitionFromPhDToAcademia

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Graduate Student Council

Mohsen Zaker Esteghamati
Assistant Professor, University of Utah

Luis Zambrano Cruzatty
Assistant Professor, University of Maine

Get Involved

Vice Officers
- Vice President
- Vice Secretary
- Vice Treasurer

Vice Chair of Standing Committees
- Membership
- DEI
- Research
- Workshops & Mentoring
- Networking & Community Building
- Social Media & Outreach

Spring Nominations

- Nominations open: **until March 1**
- Confirm nominations: **March 2-3**
- Elections: **March 4-6**

- **Eligibility-** must be member in good standing, attended at least two meetings since August 2023

Speaker Introduction

Dr. Aikaterini P. Kyprioti

Assistant Professor at The University of Oklahoma, Department of Civil Engineering & Environmental Science
akypriot@ou.edu

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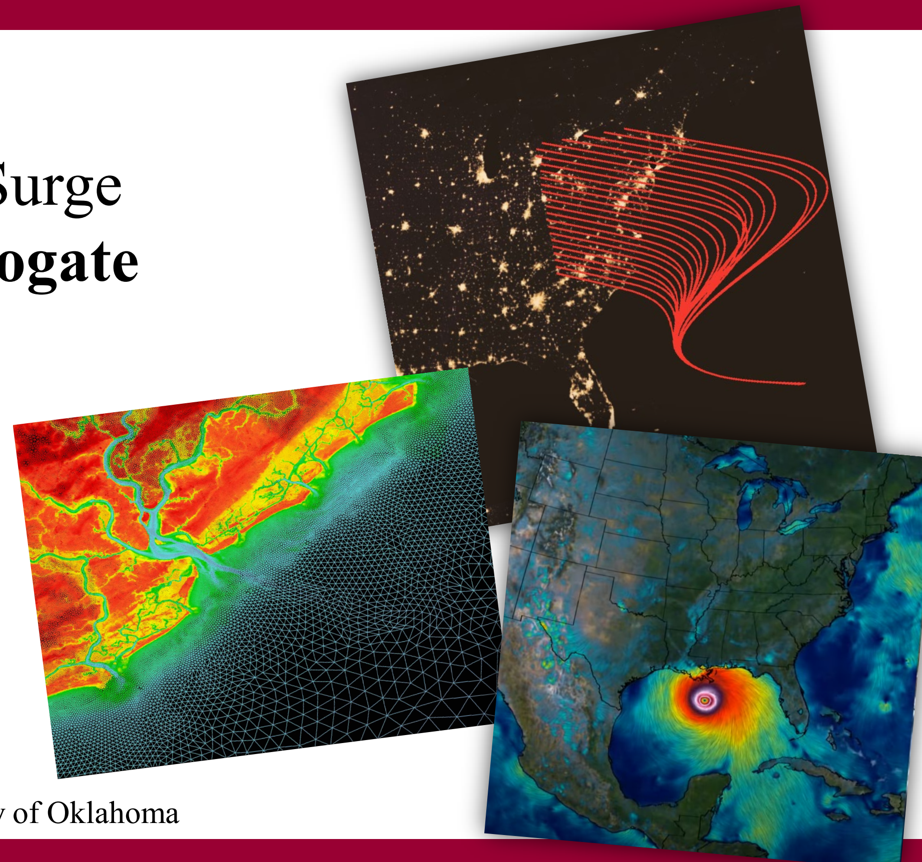
Natural Hazards Infrastructure Resiliency LAB

Revolutionizing Storm Surge Hazard Estimation: **Surrogate Models at our service**



Aikaterini (*Katerina*) P. Kyprioti

Assistant Professor, Civil Engineering, University of Oklahoma

GALLOGLY COLLEGE OF ENGINEERING
SCHOOL OF CIVIL ENGINEERING & ENVIRONMENTAL SCIENCE
The UNIVERSITY of OKLAHOMA

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Outline

- Motivation
- Storm surge fundamentals and surrogate modelling basics
- Storm hazard analysis using surrogate models
- Other Projects - Conclusions

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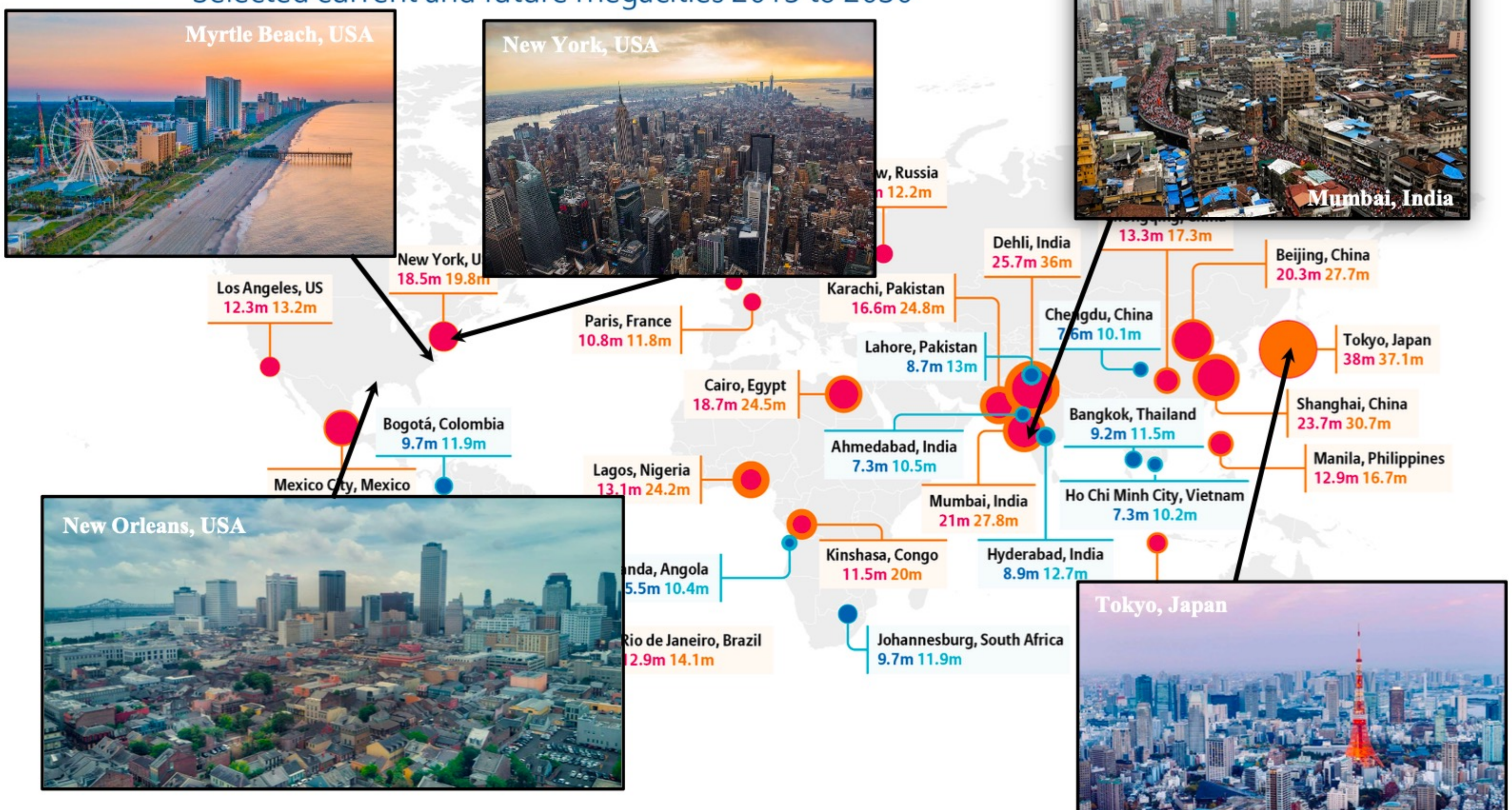
Vulnerability to Natural Hazards I

Selected current and future megacities 2015 to 2030



Source: World Urbanization Prospects: The 2014 Revision

Vulnerability to Natural Hazards II

- Fatalities: 1,833
- $125 billion

10 Typhoons & 23 total storms for 2020: $4.06 billion

…s & …al storms fo… 2020: >$51.114 billion

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Vulnerability to Natural Hazards III

Global Cost of Natural Disasters Rose to $280 billion in 2021, from $210 billion in 2020 and $166 billion in 2019
(Munich RE)

Necessity: ► **Take proactive measures**
► **Offer well-informed emergency response management**

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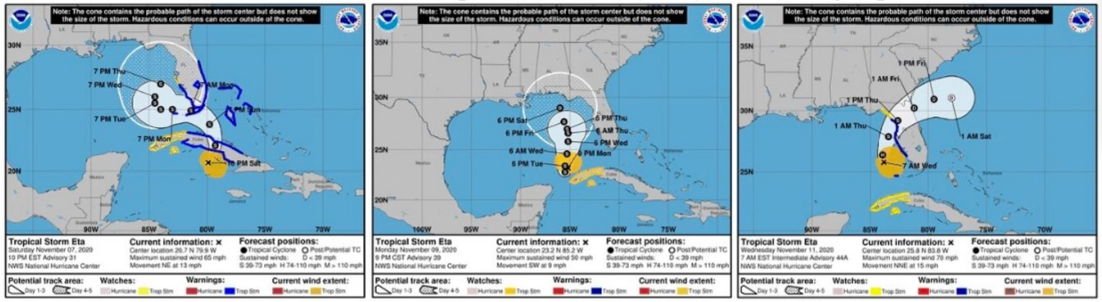
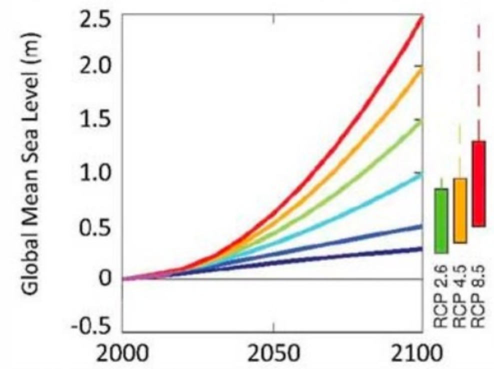
Uncertainty ➡ Risk

Exposure to Natural Hazards is **directly related** to **uncertainty** and therefore **risk**

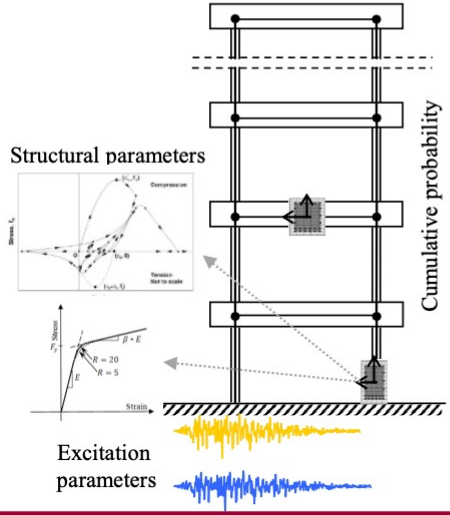
NOAA advisories from tropical storm Eta (2020) within 4 days apart

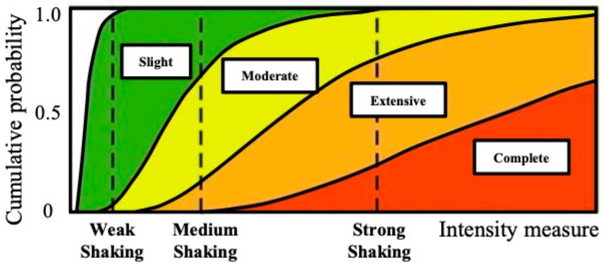


NOAA Mean Sea Level Scenarios



Source: Modified from Sweet, et al. 2017

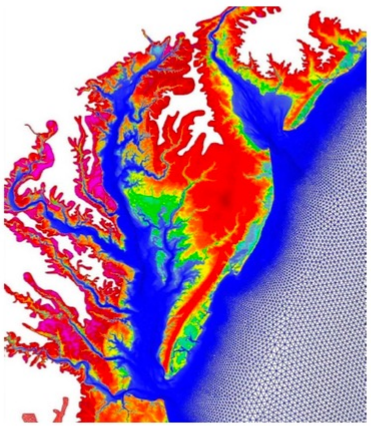


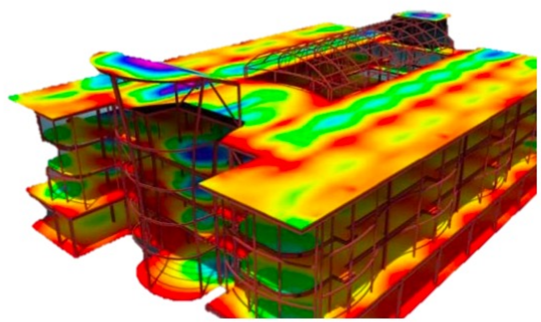


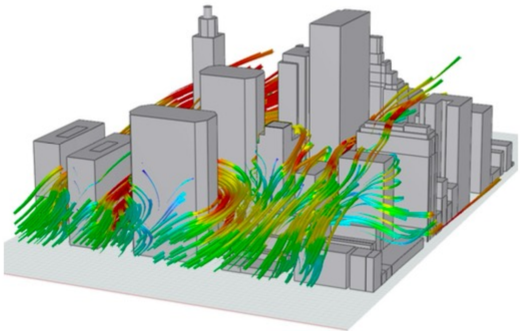
Risk estimation

- Complexity of natural hazards as physical phenomena
- Interdependencies in infrastructure systems and socio-economic factors

High fidelity models can *faithfully* capture such processes and map interconnections







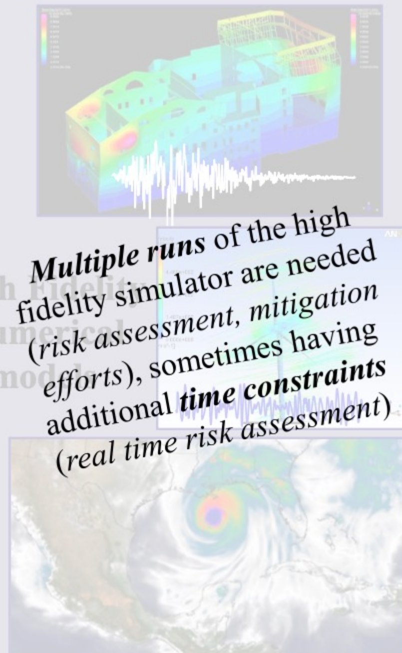
High fidelity models:
- ***high computational cost***
- ***expert knowledge*** → **Unavailable for critical decision making at lower administration levels**

Vulnerability assessment using high fidelity models

Assess the ***vulnerability*** (**risk**) using:

Uncertainties
hazard + infrastructure

High Fidelity Numerical model



Multiple runs of the high fidelity simulator are needed (*risk assessment, mitigation efforts*), sometimes having additional ***time constraints*** (*real time risk assessment*)

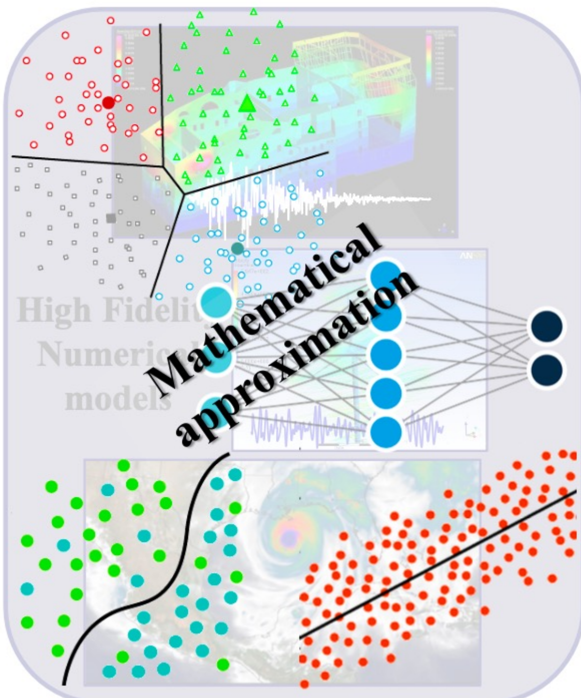
Estimation of the *hazard* and/or the structural *response* with high accuracy

Computationally very expensive
(regarding the time and the memory requirements)

How can we ***integrate*** these **computationally expensive tools** in *uncertainty quantification* without **increasing the computational burden**???

Machine learning-aided predictions I

Input
x



Output
y(x)

Advances in ***computational statistics*** allow the solution of such computationally intensive problems, ***faster*** maintaining ***<u>similar accuracy</u>***

Computational efficiency in *risk assessment* and *emergency response management*

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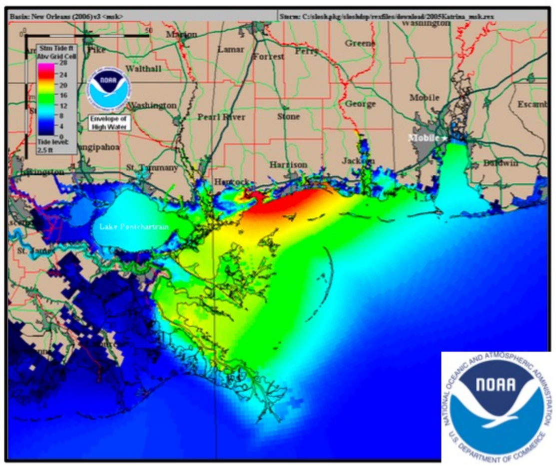
Outline

- Motivation
- Storm surge fundamentals and surrogate modelling basics
- Storm hazard analysis using surrogate models
- Incorporation of Sea Level Rise in storm surge surrogate modeling
- Other Projects - Conclusions

High fidelity models

SLOSH model
(computational efficiency, low accuracy)

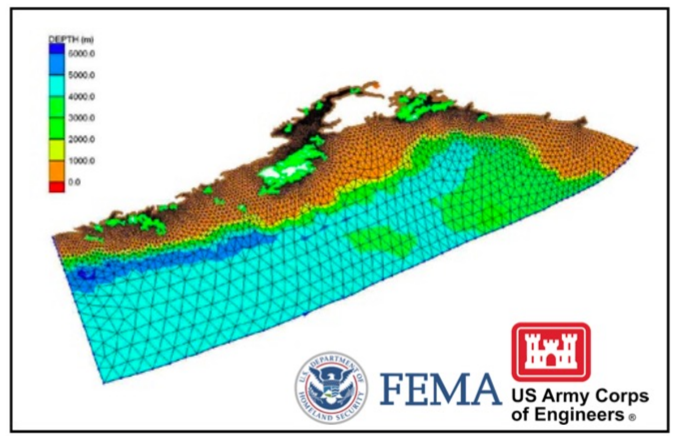
- Established NOAA approach
- Large errors at shallow waters (where it matters!)



Relatively ***simplified*** model that sacrifice ***accuracy*** over ***simulation time***

ADCIRC
(high accuracy, large computational burden)

- USAGE & FEMA approach for regional flood studies
- Dense grid with high accuracy onshore and shallow water
- Coupled surge/wave/current simulations and ability to provide diverse outputs.
- Simulation of each storm scenario → **Thousands of CPU hours**.



High accuracy with ***detailed results*** across the grid, ***large simulation time***

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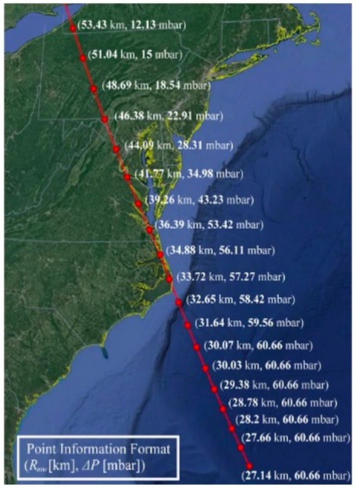
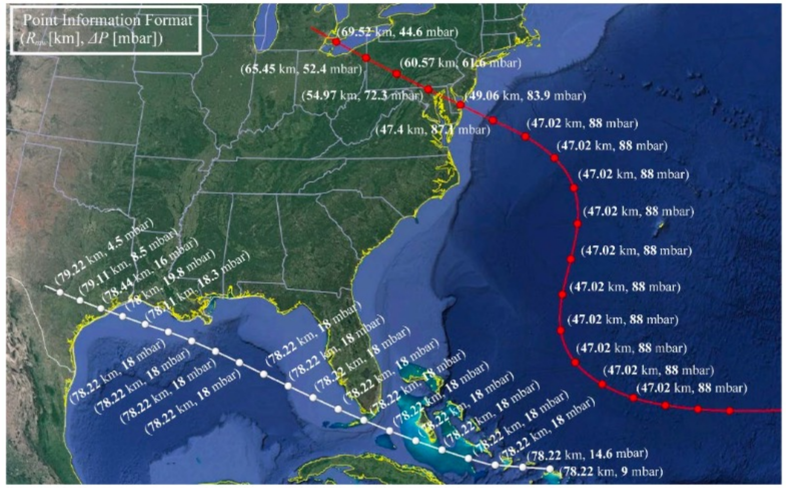
Databases from Regional flood studies

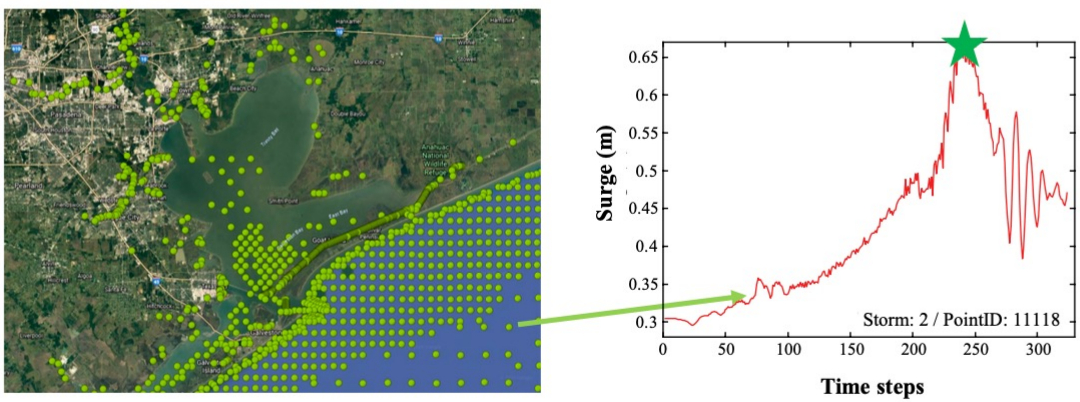




Storm Input

corresponds to the ***time evolution of the storm input*** $\mathbf{q}_{st}(t)$ including:

- ***track*** (latitude and longitude of storm center),
- ***intensity*** (pressure difference between storm center and ambient temperature),
- ***size*** (radius of maximum winds)



Surge Output

corresponds to the ***surge*** $\zeta(t,s)$ provided at different discrete times and locations (nodes), and frequently the output is further simplified by obtaining the **peak surge** instead of the time-series. Other outputs are: wave height, current velocities, etc.

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Database formulation for the surrogate model development

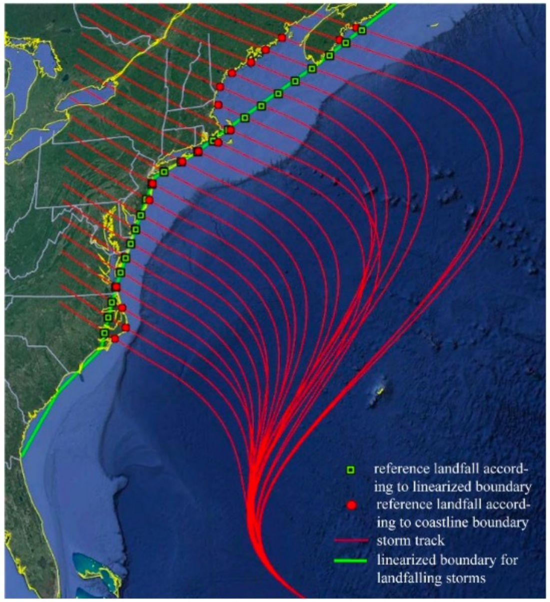
Need to establish an ***appropriate parametrization*** for the synthetic storm database

- ✓ Capture all important features that distinguish the different storms
- ✓ Remain simplistic enough to avoid over-parametrization
- ✓ Express the temporal variability across their entire track history with a small number of parameters, corresponding to some specific instance typically at landfall or "reference landfall" or at peak strength

Features related to both the storm *intensity/size/speed* and to the *track* should be included:

- Landfall location x_{lat}, x_{long}
- Heading direction θ
- Central pressure deficit ΔP
- Forward speed v_f
- Radius of maximum winds R_{mw}

$$\mathbf{x} = \begin{bmatrix} x_{lat} \\ x_{long} \\ \theta \\ \Delta P \\ R_{mw} \\ v_f \end{bmatrix}$$



replacement of $\mathbf{q}_{st}(t)$ with some n_x dimensional vector $\mathbf{x}$ that serves as the input of the surrogate model

Experiment (input) matrix:

$$\mathbf{X} = [\mathbf{x}^1 \ \ldots \ \mathbf{x}^n]^T \in \Re^{n \times n_x}$$

Observation (output) matrix:

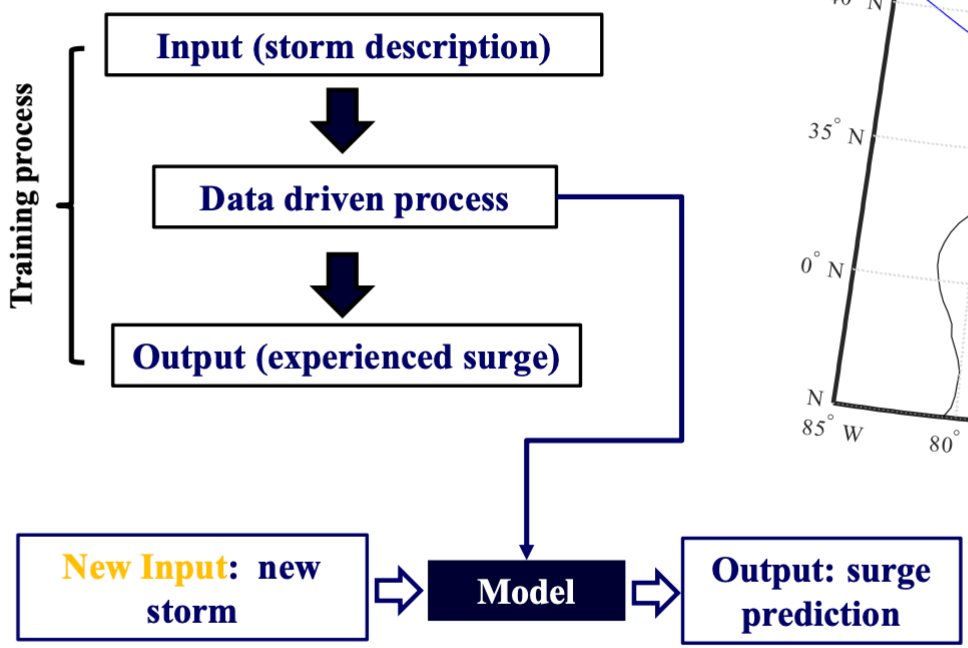
$$\mathbf{Z} = [\mathbf{z}^1 \ \ldots \ \mathbf{z}^n]^T \in \Re^{n \times n_z}$$

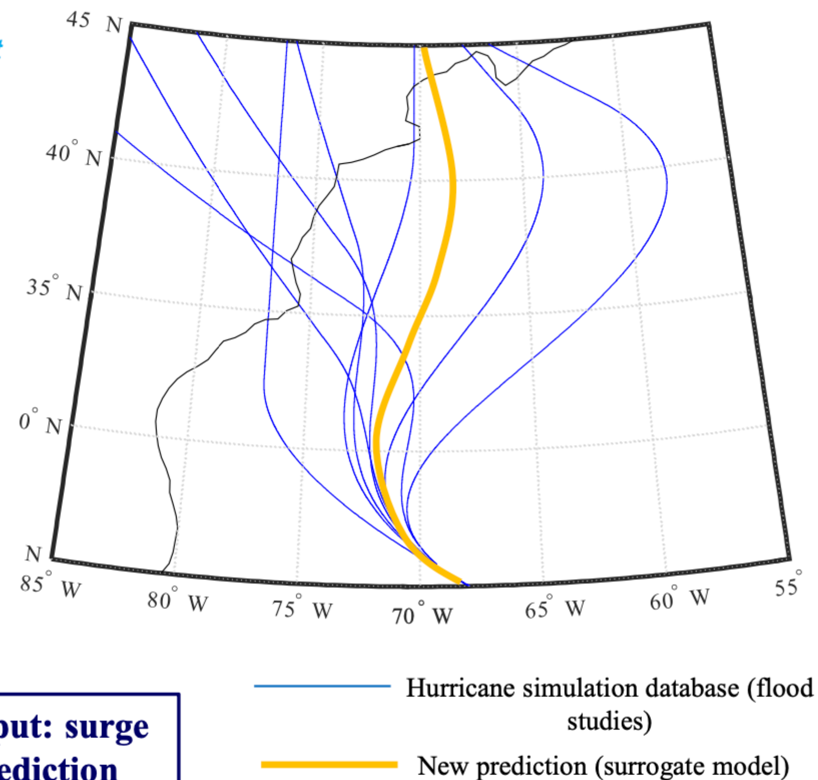
Characteristics of surrogate model formulation

n_x: input dimension (storm parameters)
n_z: output dimension (storm surge)
n: number of experiments (storm scenarios)

Surrogate models

- ***Regional flood studies*** provide databases of ADCIRC high-fidelity runs
- Exploit them to develop ***rapid risk assessment tools***





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Kriging surrogate modeling I

Experiment matrix:

$$\mathbf{X} = [\mathbf{x}^1 \ \ldots \ \mathbf{x}^n]^T \in \Re^{n \times n_x}$$

Observation matrix:

$$\mathbf{Y} = [\mathbf{y}^1 \ \ldots \ \mathbf{y}^n]^T \in \Re^{n \times n_y}$$

Characteristics of surrogate model formulation

n_x: input dimension

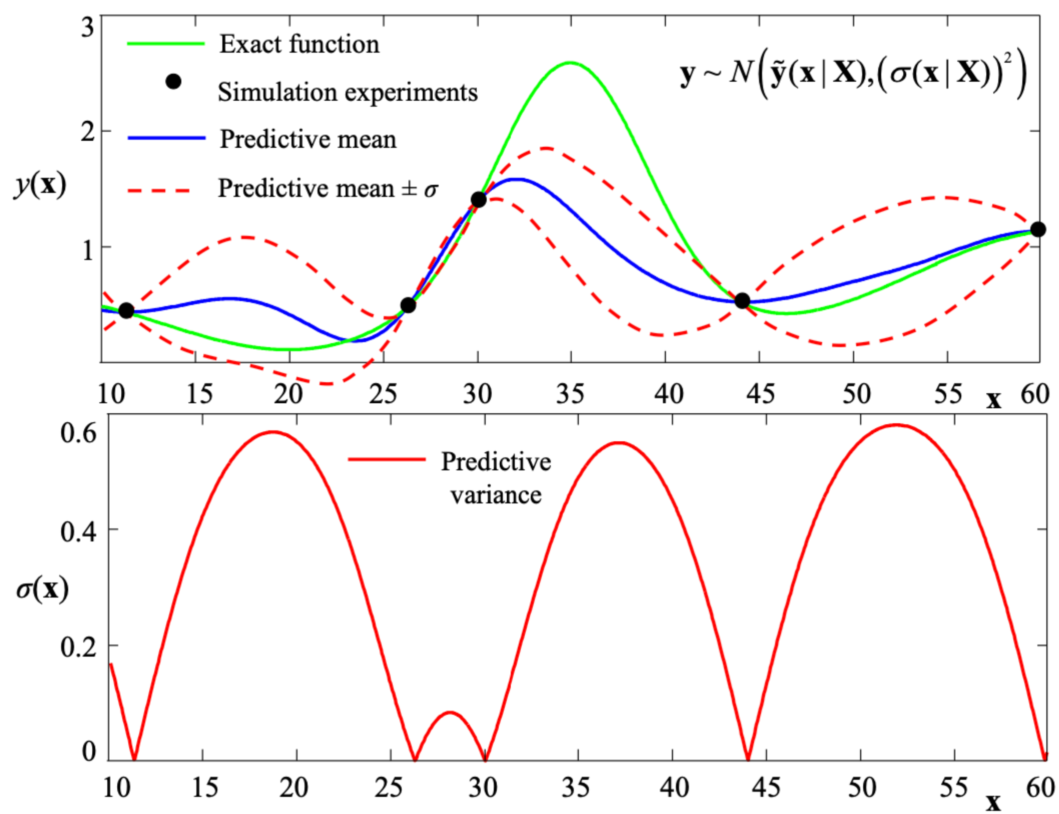
n_y: output dimension

n: number of experiments

Kriging metamodel provides ***quantifiable uncertainty*** in ***predictions*** that is not constant across the input ($\mathbf{x}$) space

Kriging surrogate modeling

Kriging approximates the ***true response*** as a *realization of a stochastic Gaussian Process* (GP) $Z(\mathbf{x})$ with an *underlying linear regression trend.*



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Kriging surrogate modeling

- Predictions are very efficient (simple matrix manipulations that can be vectorized).
- Metamodel provides quantifiable uncertainty in predictions that is not constant across the input (**x**) space.
- Multi-output high fidelity processes can be accommodated (Parallel GPs).
- Database formulation is of major importance for the accuracy of the surrogate model, as well as the optimization of the hyper-parameters (selection of the objective function).
- Number of training points n has to remain low (Recall the matrix inversion that is required which will be of $O(n^3)$ computational cost).This typically means that the input dimensionality has to be low.

Outline

- Motivation
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Database description for North Atlantic

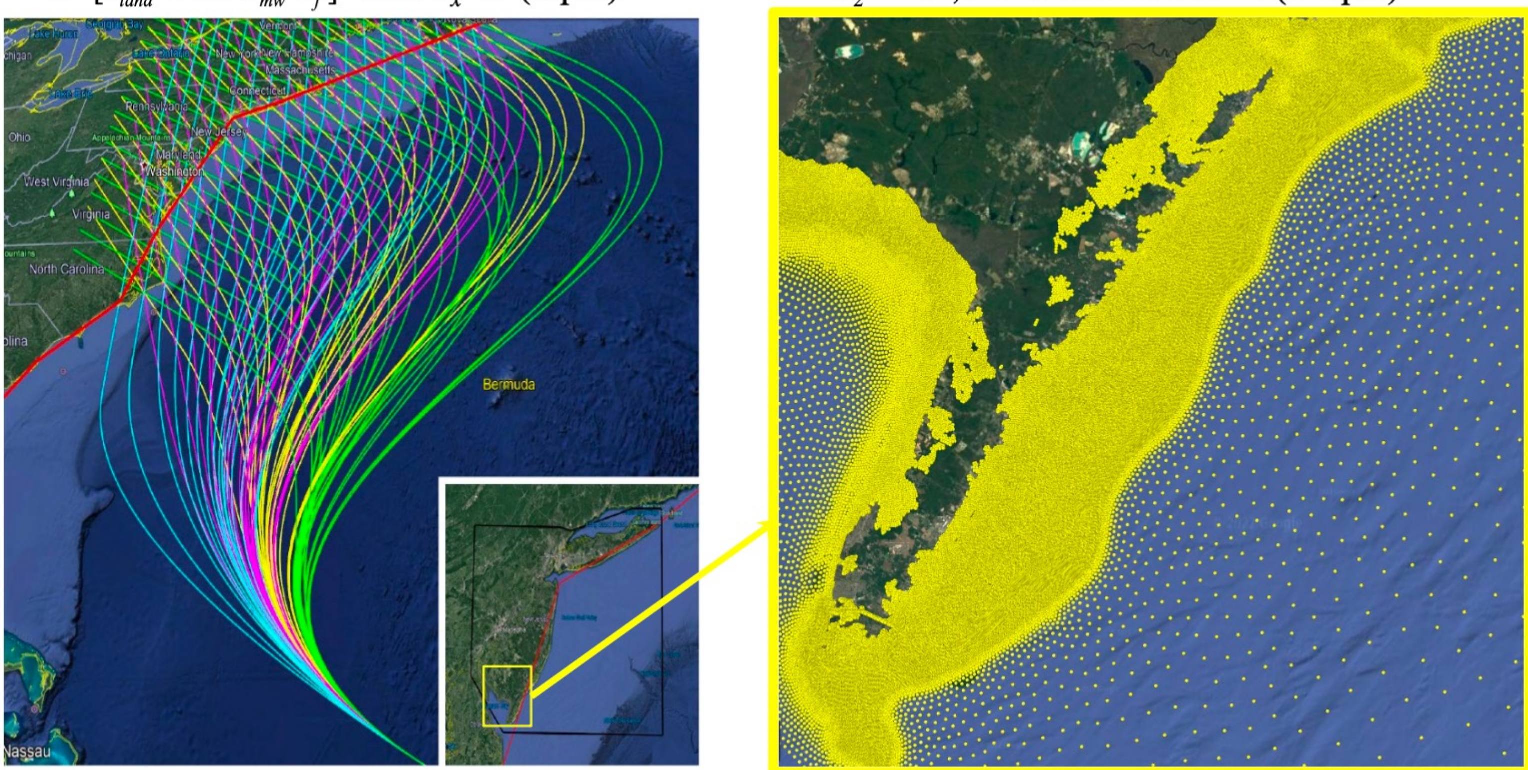
US Army Corps of Engineers®

<u>North Atlantic Coast Comprehensive Study (**NACCS**) database</u>

n=595 landfalling storms

$\mathbf{x} = [x_{land} \;\; \theta \;\; \Delta P \;\; R_{mw} \;\; v_f]$ with n_x=5 (Input)

n_z= **684,607** nodes of interest (Output)



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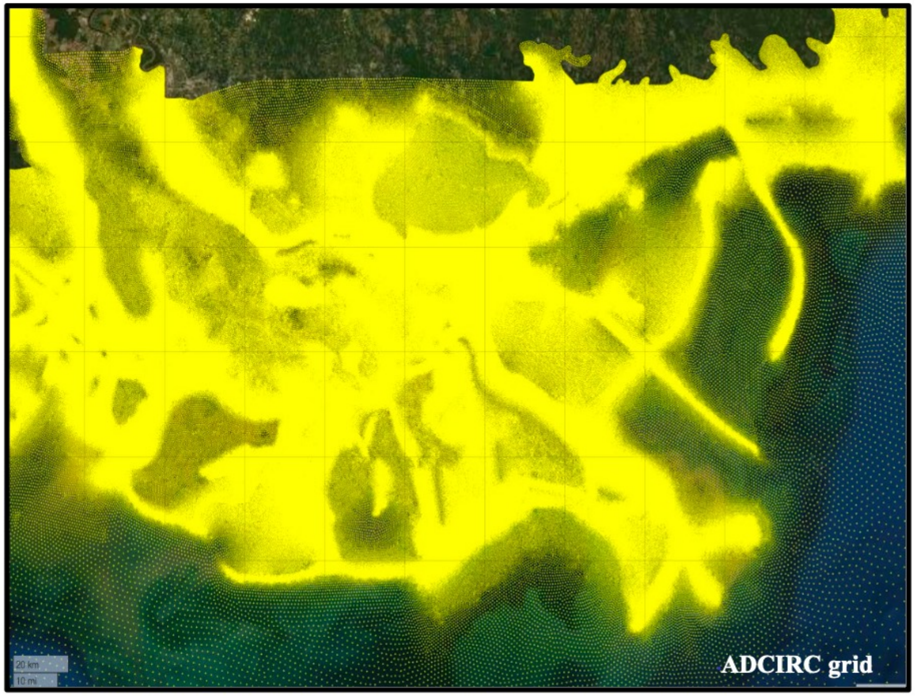
High output dimensionality implications

- What is *one of the* ***challenges*** for the development of the surrogate model?

  High **output** dimensionality > hundreds of thousands of locations of interest

  → *How is this tackled* in the surrogate model calibration stage?

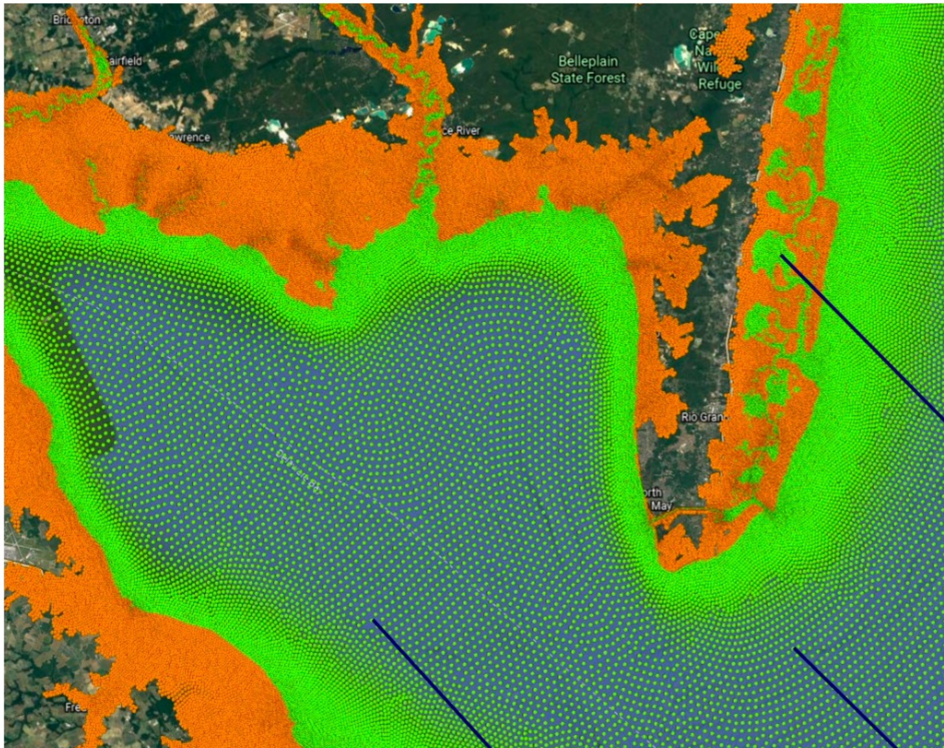


To accommodate the large dimension of the database ***two alternative approaches*** :

- calibrate ***one kriging surrogate model*** to offer predictions across the entire database (parallel surrogate model implementation)
- use ***principal component analysis*** (PCA) as a dimensionality reduction technique and then consider separate surrogate models for the individual latent components (or for groups of them)

higher accuracy

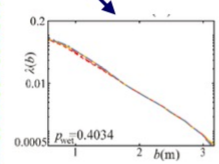
Storm hazard analysis using surrogate models over extended geospatial grids

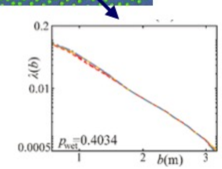


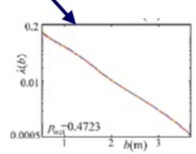
Hazard/risk estimation performed using the trained surrogate model **cannot** be performed in the **latent space**

↓

Original high dimensional output needs to be considered for each storm within the MC framework → **significant computational burden**





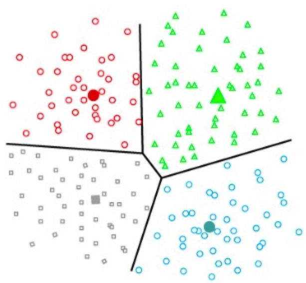


Kyprioti, Aikaterini P., Alexandros A. Taflanidis, Norberto C. Nadal-Caraballo, and Madison Campbell. "Storm hazard analysis over extended geospatial grids utilizing surrogate models." *Coastal Engineering* 168 (2021): 103855.

Coastal hazard risk estimation

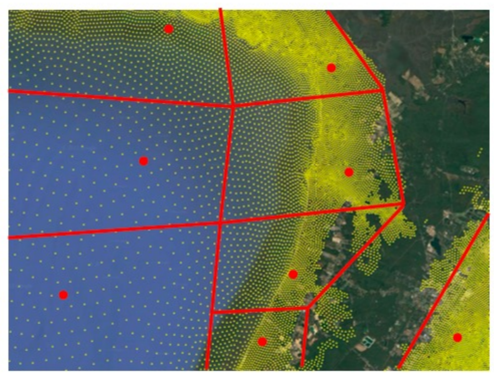
Main Idea:

Reduce the number of points we wish to provide the hazard curves for → HOW? → Maybe provide them for a group of "*important nodes*" → From those important nodes *interpolate* to retrieve the full domain

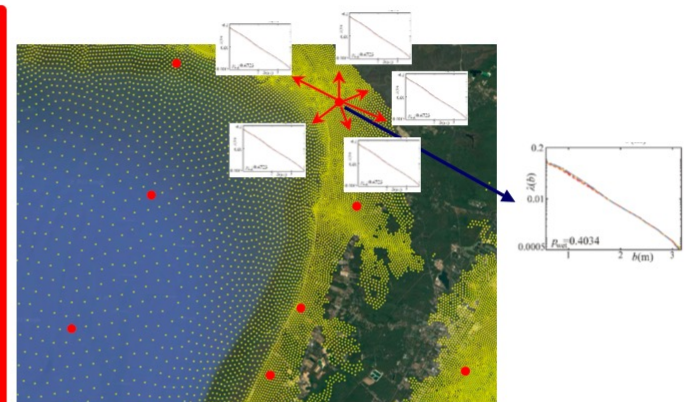


Clustering algorithm *K*-means

Computational burden: number of clusters × grouping features



Identify *cluster centroids* that the hazard curves will be provided for.



Use *geospatial interpolation* for the hazard curves across the whole domain

***efficiency*: MC process only performed for the cluster centroids**

Kyprioti, Aikaterini P., Alexandros A. Taflanidis, Norberto C. Nadal-Caraballo, and Madison Campbell. "Storm hazard analysis over extended geospatial grids utilizing surrogate models." *Coastal Engineering* 168 (2021): 103855.

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Clustering algorithm *K*-means
Computational burden: number of clusters × grouping features

→ Identify *cluster centroids* that the hazard curves will be provided for.

→ Use *geospatial interpolation* for the hazard curves across the whole domain

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Kyprioti, Aikaterini P., Alexandros A. Taflanidis, Norberto C. Nadal-Caraballo, and Madison Campbell. "Storm hazard analysis over extended geospatial grids utilizing surrogate models." *Coastal Engineering* 168 (2021): 103855.

Metamodel-aided storm surge risk assessment over large domains

US Army Corps of Engineers ®

<u>North Atlantic Coast Comprehensive Study (**NACCS**) database</u>

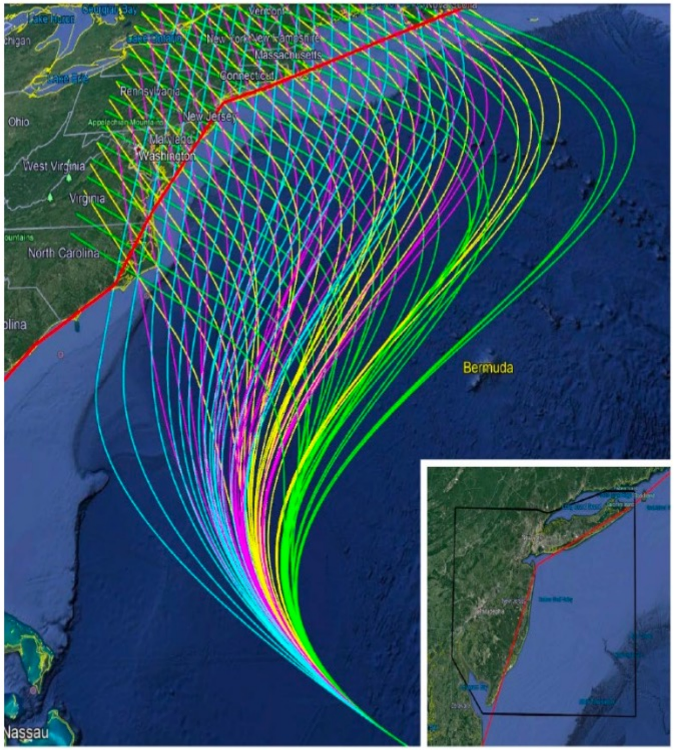
$\mathbf{x} = [x_{land}\ \ \theta\ \Delta P\ R_{mw}\ \ v_f\ ]$ with n_x=5

n=595 landfalling storms

n_z= 684,607 nodes

(imputation step is performed)

57.8% have been inundated for all 595 storms in the database
42.2% have remained dry for at least one of the storms (*offshore*)
35.0% have remained dry for at least 70% of the storms (*nearshore*)
18.0% have remained dry for at least 90% of the storms (*onshore*)



Percentage of storms for which a node has remained dry is an indicator of how close to the shore this node is

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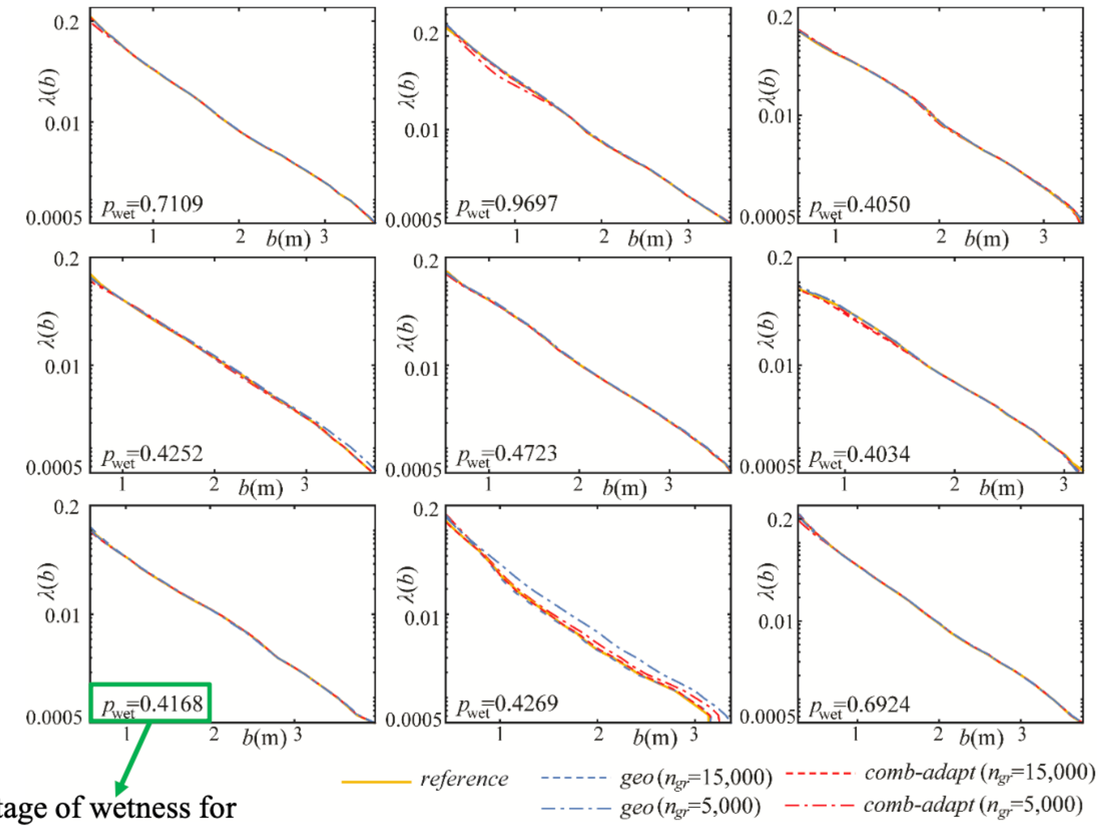
Metamodel-aided storm surge risk assessment over large domains

Results for individual nodes:



Percentage of wetness for the examined location

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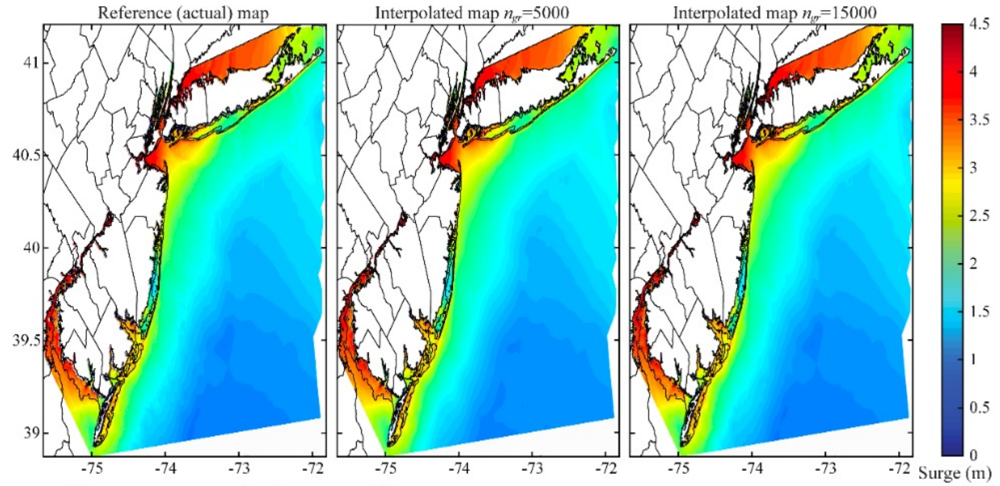
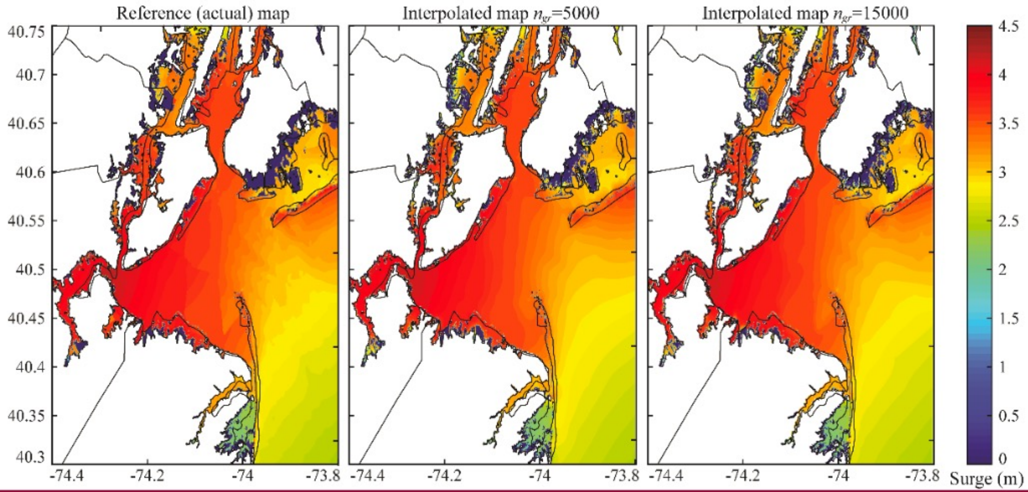
Metamodel-aided storm surge risk assessment over large domains

Results for a specific threshold p=1/500:





Outline

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- Other Projects - Conclusions

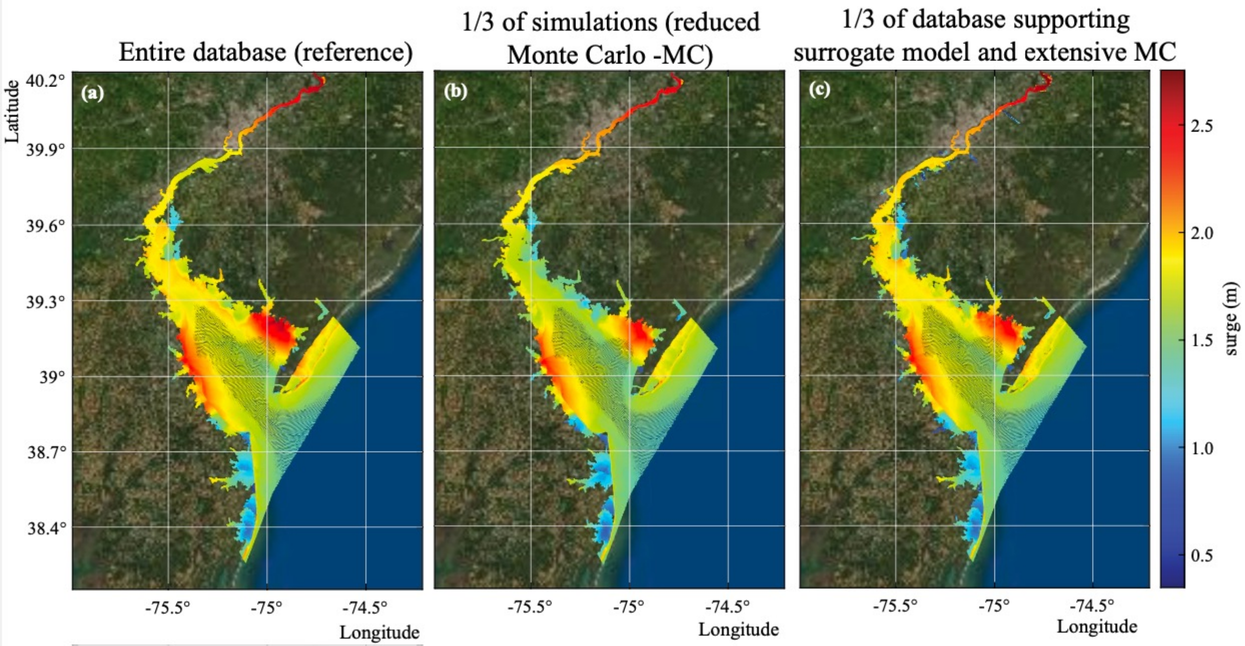
Other projects - contributions

Investigation of Coastal *Probabilistic* Hazard Analysis in order to ***replace*** the current **FEMA V-Zone**

FEMA

FEMA Region III Database

Hazard map for storm surge with a 100-year return period



- Development of a ***secondary classification surrogate model*** to enhance ***predictive capabilities of inland nodes***
- Investigation quality of hazard maps established with different approaches under a ***limited computational budget***.

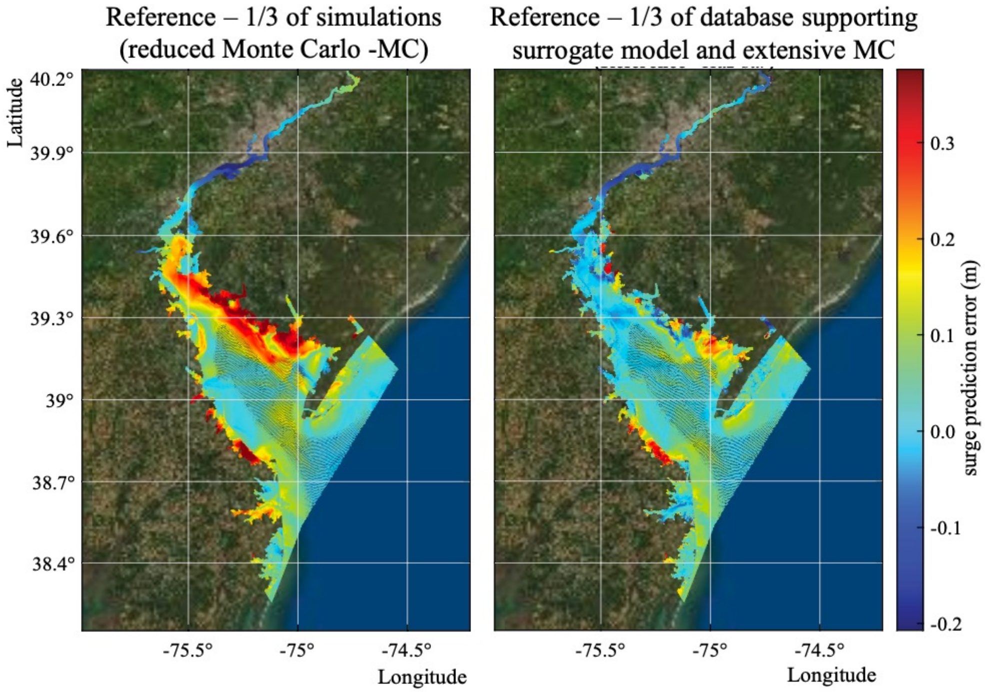
Kyprioti, Aikaterini P., Alexandros A. Taflanidis, Matthew Plumlee, Taylor G. Asher, Elaine Spiller, Richard A. Luettich, Brian Blanton, Tracy L. Kijewski-Correa, Andrew Kennedy, and Lauren Schmied. "Improvements in storm surge surrogate modeling for synthetic storm parameterization, node condition classification and implementation to small size databases." Natural Hazards 109, no. 2 (2021): 1349-1386.

Other projects - contributions

Investigation of Coastal *Probabilistic* Hazard Analysis in order to ***replace*** the current **FEMA V-Zone**

FEMA Region III Database

Error map for storm surge with a 100-year return period



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Conclusions

- ***Machine Learning tools*** can be tailored to engineering problems, surpassing the computational cost that detailed models numerical models have. They can offer useful insights for long term regional planning along the coastlines, and assist in real time risk estimation

- An ***efficient coastal hazard risk assessment framework*** using *surrogate models* was established for *large areas of interest*, taking into consideration ***accuracy***, ***computational*** and ***memory requirements*** throughout the process.

- All the *computationally intensive processes* were performed ***offline***, allowing for the framework application to be executed in a fast and efficient way

- ***Sea Level Rise*** was successfully incorporated in surrogate models, tackling any challenges that rose related to the calibration and validation stages.

- ***Insights*** for the ***generation of future databases*** were offered through a thorough investigation of the allocation of numerical analyses across different SLR scenarios.

Thank You!

Graduate Student Council

Future Meeting Date

3rd Friday of every month at 11:00am CST

Graduate Student Council