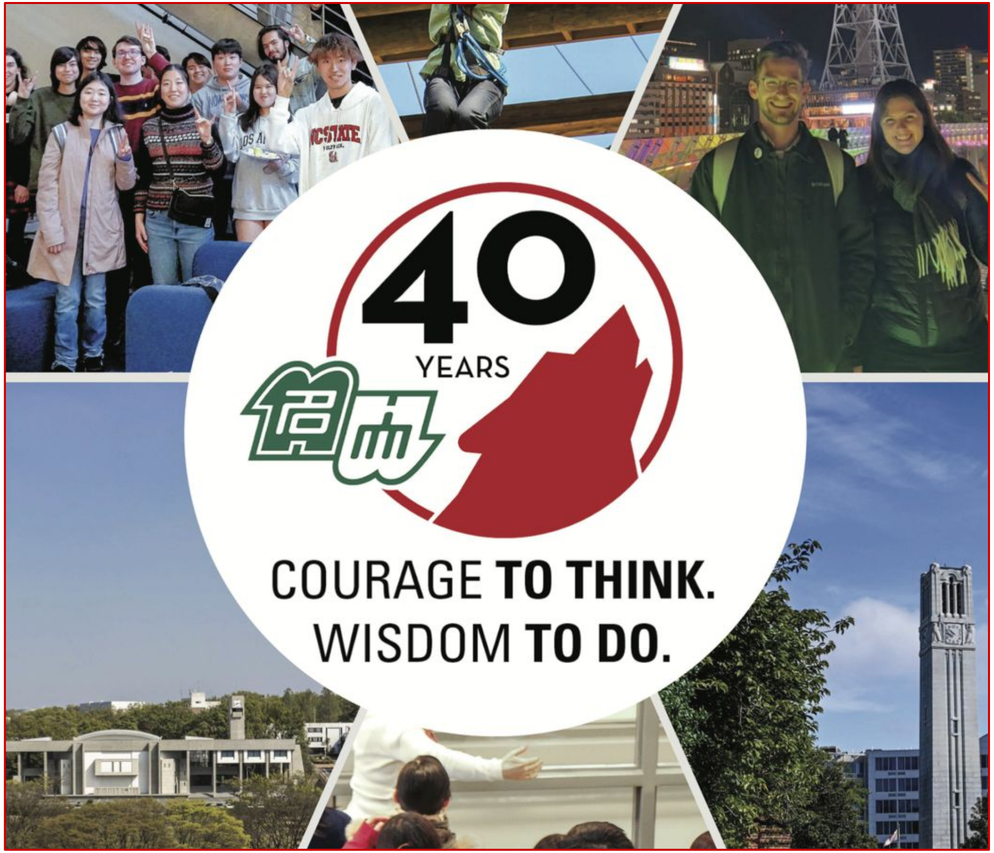
Overview of Coastal Engineering Research at NC State University

Casey Dietrich[1], Jorge San Juan Blanco[1], Ghadir Haikal[1,*]

[1] Dep't of Civil, Construction, and Environmental Engineering; NC State Univ

Dep't of Civil and Environmental Engineering, Nagoya Univ
Seminar, 11 Mar 2025

Nagoya – NC State Partnership



Seed Grant: “Coastal City Resilience: Infrastructure Adaptation for Ship Impact Mitigation in a Changing Climate”

Outline

- Coastal Engineering at NC State
- Flow-Biota Interactions in Coastal Habitats
- Subgrid Corrections for Storm Surge Models
- Progress of Seed Grant Research
- Summary

Coastal Engineering at NC State

NC State University

- 38,400+ students, 2,400+ faculty and 7,100+ staff
- Top 1% of universities worldwide (Center for World University Rankings)
- #6 in research expenditures nationally for universities without a medical school

Dep’t of Civil, Construction, and Environmental Engineering

Civil, Construction, and Environmental Engineering

NC STATE UNIVERSITY

CCEE Faculty

Department of Civil, Construction, and Environmental Engineering

Computing and Systems

Sankar Arumugam ('01) Tufts University
John Baugh ('89) Carnegie Mellon University
Emily Berglund ('05) NC State University
Joe DeCarolis ('04) Carnegie Mellon University
Casey Dietrich ('11) University of Notre Dame
Murthy Guddati ('98) University of Texas at Austin
Ali Hajbabaie ('12) University of Illinois
Kevin Han ('16) University of Illinois
Kumar Mahinthakumar ('95) University of Illinois
Fernando Garcia Menendez ('13) Georgia Tech
Daniel Obenour ('13) University of Michigan
Anderson de Queiroz, ('11) University of Texas
Ranji Ranjithan ('92) University of Illinois

Construction Engineering

Alex Albert ('13) University of Colorado
Kevin Han ('16) University of Illinois
Edward Jaselskis ('88) University of Texas at Austin
Jessica Kaminsky ('13) University of Colorado
Roberto Nunez ('91) MBA University of NC at Chapel Hill
William Rasdorf ('82) Carnegie Mellon University

Environmental Engineering, Water Resources and Coastal Engineering

Katherine Anarde ('19) Rice University
Sankar Arumugam ('01) Tufts University
Tarek Aziz ('10) NC State University
Morton Barlaz ('88) University of Wisconsin
Emily Berglund ('05) NC State University
Douglas Call ('11) Penn State University
Joe DeCarolis ('04) Carnegie Mellon University
Francis de los Reyes ('00) University of Illinois
Casey Dietrich ('11) University of Notre Dame
Joel Ducoste ('96) University of Illinois
H. Christopher Frey ('91) Carnegie Mellon University
Fernando Garcia Menendez ('13) Georgia Tech
Jackie Gibson ('07) Carnegie Mellon University
Andy Grieshop ('08) Carnegie Mellon University
Angela Harris ('15) Stanford **University**
Jeremiah Johnson ('07) Yale University
Detlef Knappe ('96) University of Illinois
Daniel Obenour ('13) University of Michigan
Ranji Ranjithan ('92) University of Illinois
Jacelyn Rice-Boayue ('14) Arizona State University
Jorge San Juan ('21) University of Illinois

Geotechnical/Geoenvironmental Engineering

Ashly Cabas Mijares ('16) Virginia Tech
Mo Gabr ('87) NC State University
Brina Montoya ('11) UC Davis

Mechanics and Materials

Ange Akono ('13) Massachusetts Institute of Technology
Cassandra Castorena ('12) University of Wisconsin
Murthy Guddati ('98) University of Texas at Austin
Tasnim Hassan ('93) University of Texas at Austin
Richard Kim ('88) Texas A&M University
Brina Montoya ('11) UC Davis
Jason Patrick ('14) University of Illinois
Mohammad Pour-Ghaz ('11) Purdue University
Shane Underwood ('11) NC State University

Structural Engineering and Mechanics

Murthy Guddati ('98) University of Texas at Austin
Abhinav Gupta ('95) NC State University
Ghadir Haikal ('09) University of Illinois at Urbana
Tasnim Hassan ('93) University of Texas at Austin
Mervyn Kowalsky ('97) UC San Diego
Gregory Lucier ('12) North Carolina State University
Jason Patrick ('14) University of Illinois
Mohammad Pour-Ghaz ('11) Purdue University
Giorgio T. Proestos ('18) Univ. of Toronto
Rudi Seracino ('00) University of Adelaide
Steve Welton ('92) NC State University
Andy Ziccarelli ('21) Stanford University

Transportation Systems and Materials

Eleni Bardaka ('16) Purdue University
John Baugh ('89) Carnegie Mellon University
Cassandra Castorena ('12) University of Wisconsin
Danjue Chen ('12) Georgia Institute of Technology
Ali Hajbabaie ('12) University of Illinois
Richard Kim ('88) Texas A&M University
George List ('84) University of Pennsylvania
Shane Underwood ('11) NC State University
Billy Williams ('99) University of Virginia

Professional Faculty

George Bonner ('95) M.S. University of Illinois
Meagan Kittle Autry ('13) NC State University
Jonathan Miller ('19) NC State University
Steve Welton ('92) M.S. NC State University

One of the largest CE departments in U.S.

- Undergraduates: 809
- Master’s students: 115
- PhD students: 130

High rankings for degree programs

- *Civil*: undergraduate #21, graduate #25
- *Environmental*: undergraduate #15, graduate #17

Distinguished and productive faculty

- Faculty members: 56
- Research groups: 7
- Annual research expenditures: $25 million

Ghadir Haikal

Ghadir Haikal leads computational research in developing advanced models for **structural integrity and lifetime prediction** in complex structures and materials.

Goal: Simulate load transfer and damage in applications with **interface interactions**

Approach: Novel models to predict stresses and deformations **at multiple scales**

Impact:

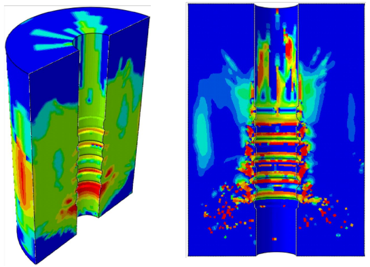
– Multiscale models for bond and damage in composite materials

– Design optimization for novel materials and structural retrofit

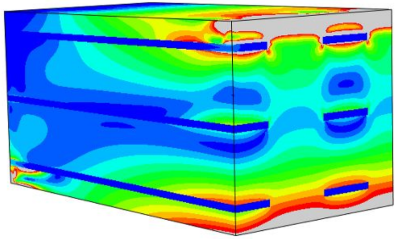
– Enhanced infrastructure resilience

– Renewable energy systems

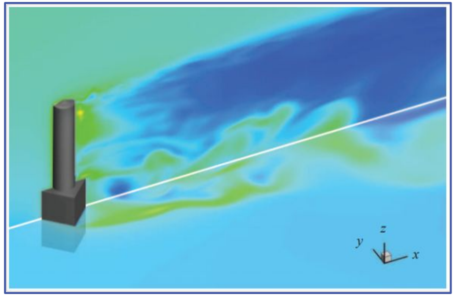
Interface bond/damage models



Digital composites



Offshore energy



Fluid-structure interaction

Coastal Engineering Team

Growing team:

- Core faculty members: 3
- Graduate students: 12
- Postdocs, technicians, undergraduates

Strategic priorities:

- *Engagement with coastal communities*, incorporating stakeholders into research about coastal futures
- *Understanding and prediction of coastal hazards*, enhancing models to be most useful
- *Interactions of fluids, sediments, vegetation & structures in coastal environments*, supporting management of coastal resources

Katherine Anarde

Katherine Anarde leads field research to develop **place-based flood risk information** through deep engagement with underserved coastal communities.

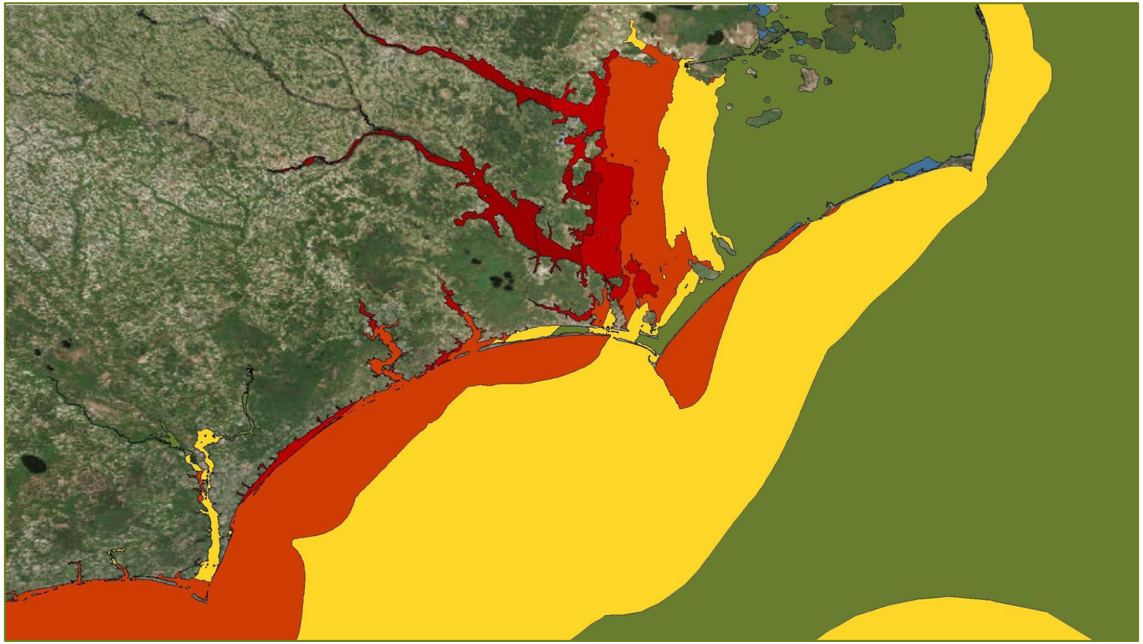
Technician on jet ski

CE 583 field trip

Anarde and student in Netherlands

Casey Dietrich

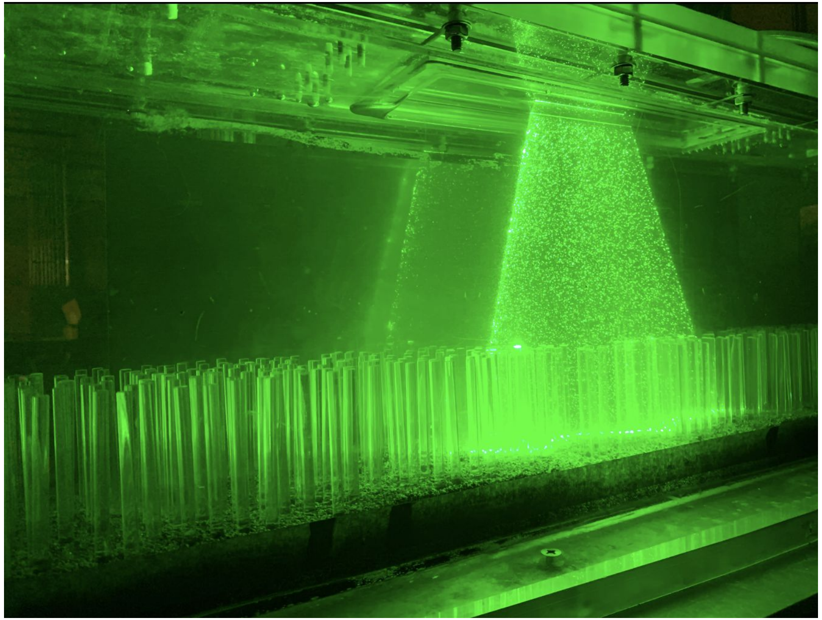
Casey Dietrich leads computational research in the **predictive modeling of coastal hazards**, especially storm surge, flooding, and erosion.

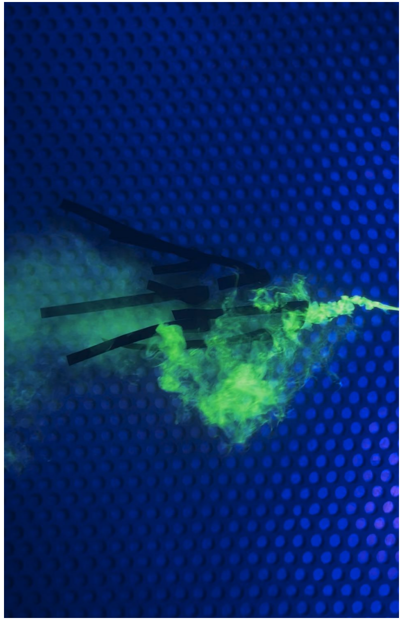


Model prediction of peak water levels during Florence (2018)

Jorge San Juan Blanco

Jorge San Juan Blanco leads laboratory research in **environmental fluid mechanics** to investigate flow and transport processes in coastal habitats.



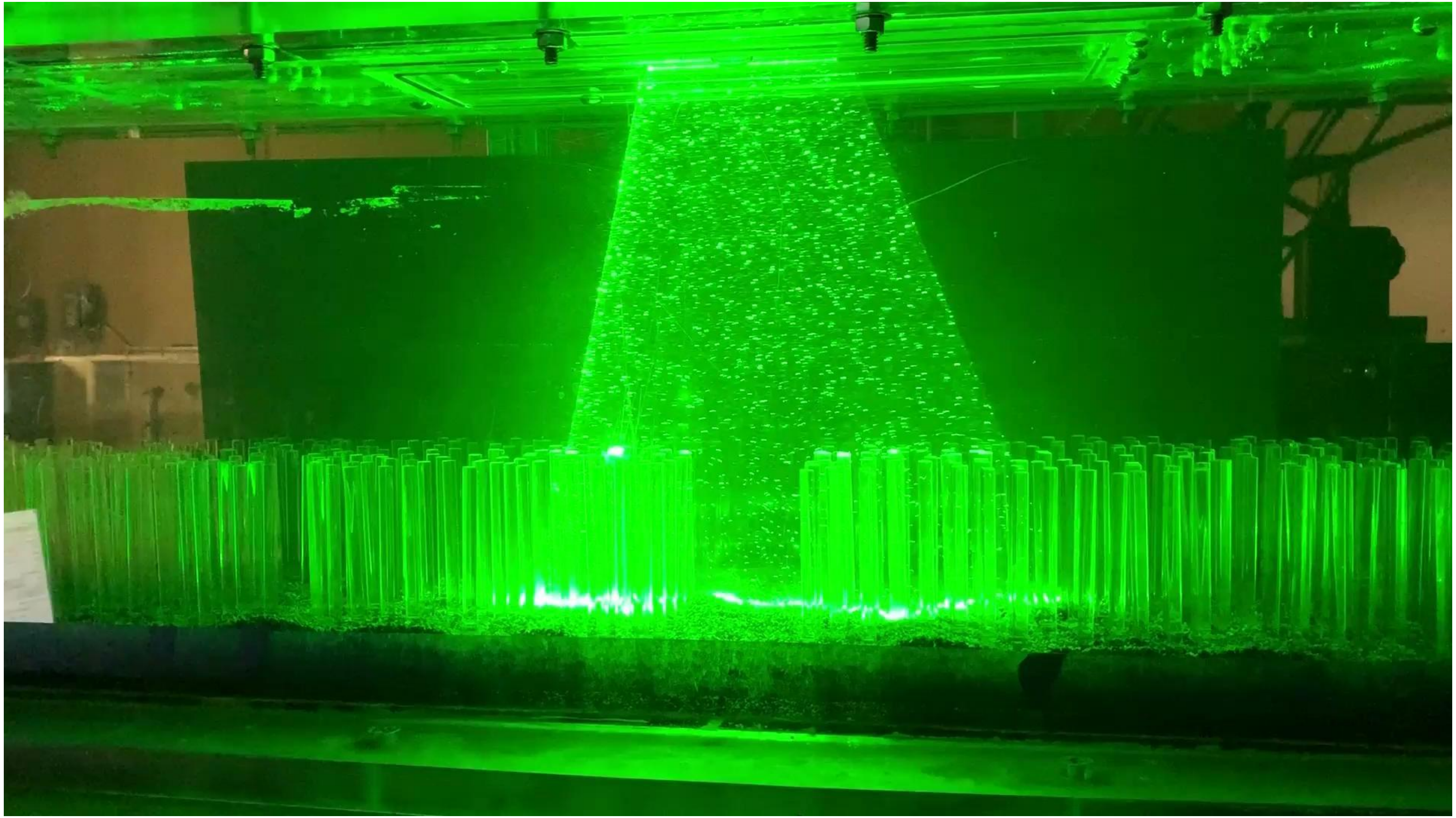


Flow-Biota Interactions in Coastal Habitats

Javier Zumbado González[1], Juan Conde Barrios[1],
Jorge E. San Juan[1]

[1] Dep't of Civil, Construction, and Environmental Engineering; NC State Univ

Coastal habitats modify flows and alter transport patterns



Eco-hydrodynamics studies habitat elements and flow

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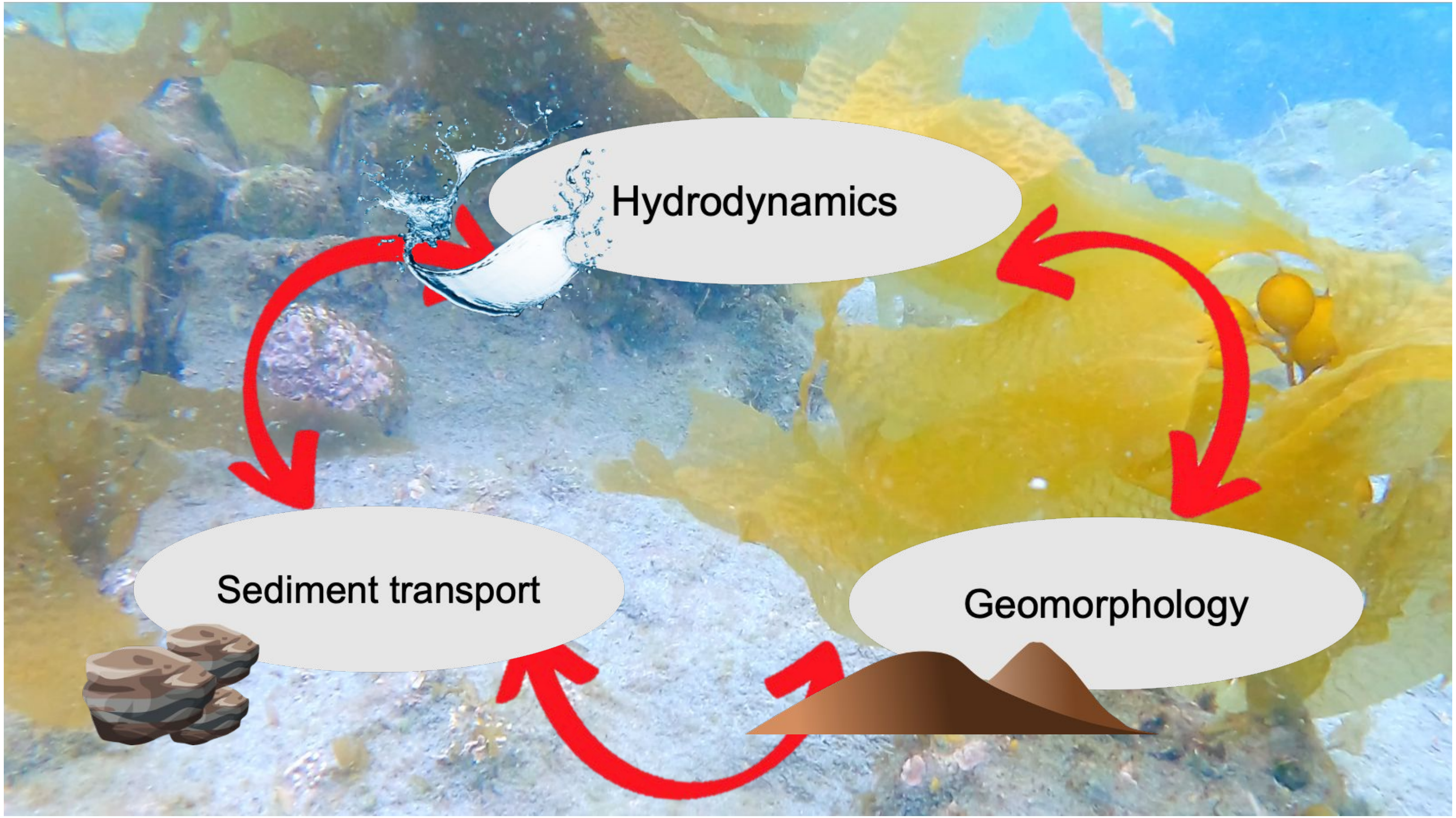
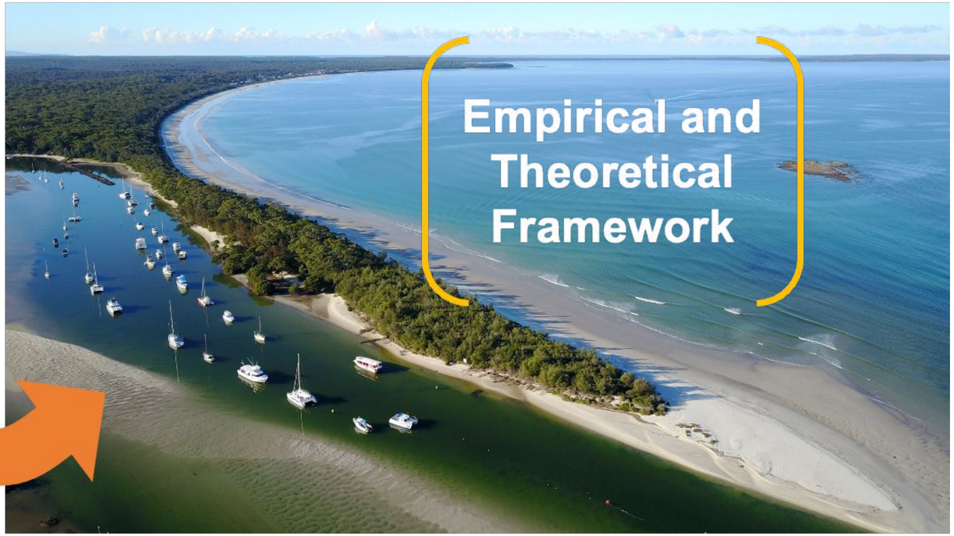


How to translate the small processes into regional changes?



Experimental Research

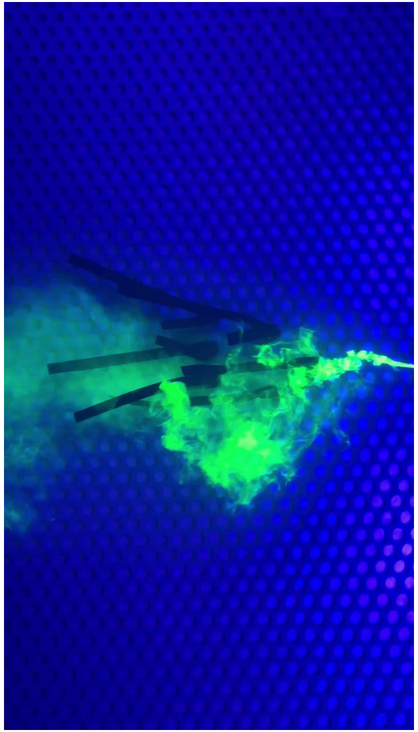
Field-based Research

Numerical Modeling Research

Investigate empirical and theoretical frameworks

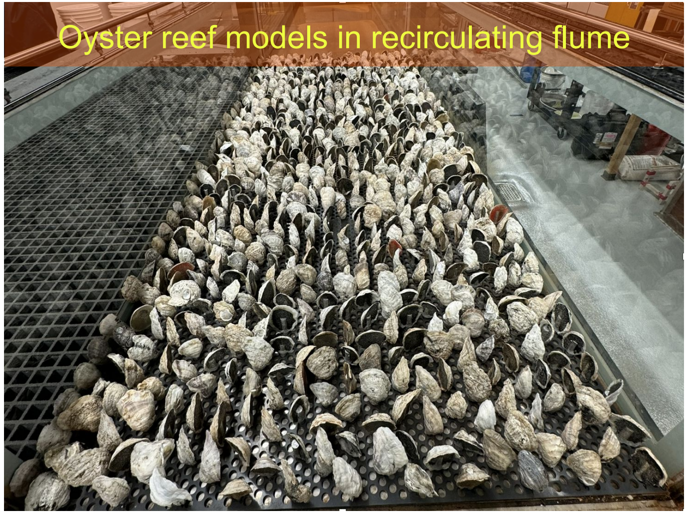
Hydrodynamics in Oyster Reefs

Mixing in Seagrass Beds

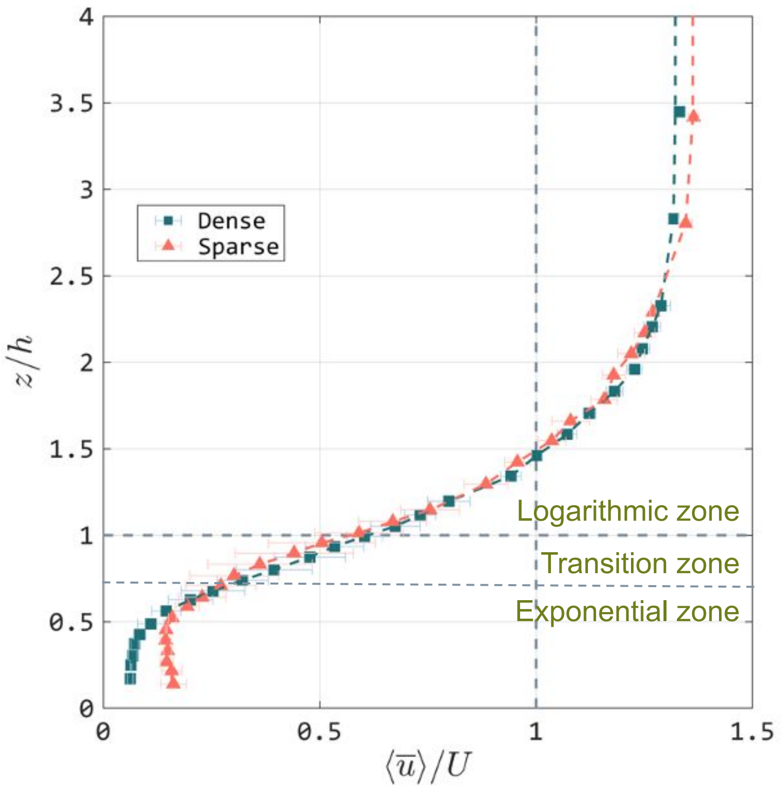


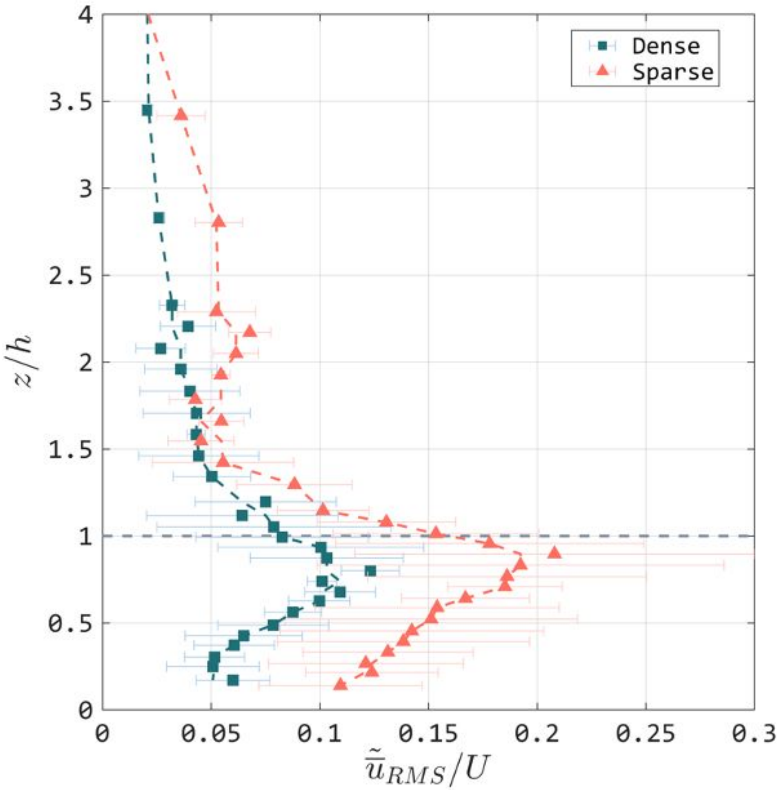
Hydrodynamics in oyster reefs

How do low-relief oyster reefs impact flow and turbulence statistics as a function of hydrodynamic forcing and reef geometric characteristics?

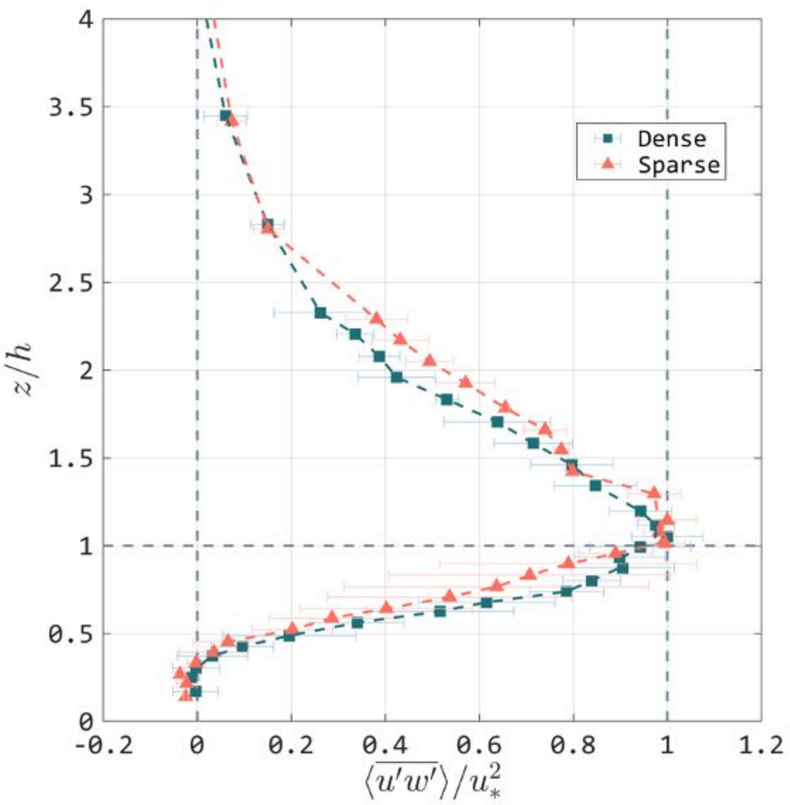


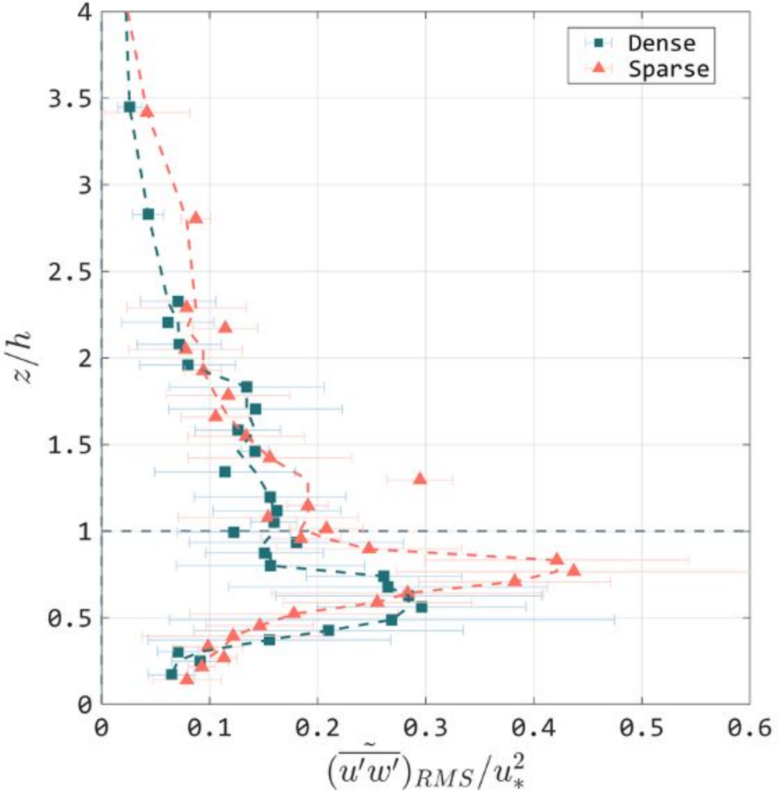
Complex reef geometry leads to spatial variation of the flow



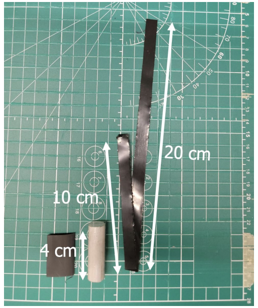


Temporal and spatial variation of the flow drives transport





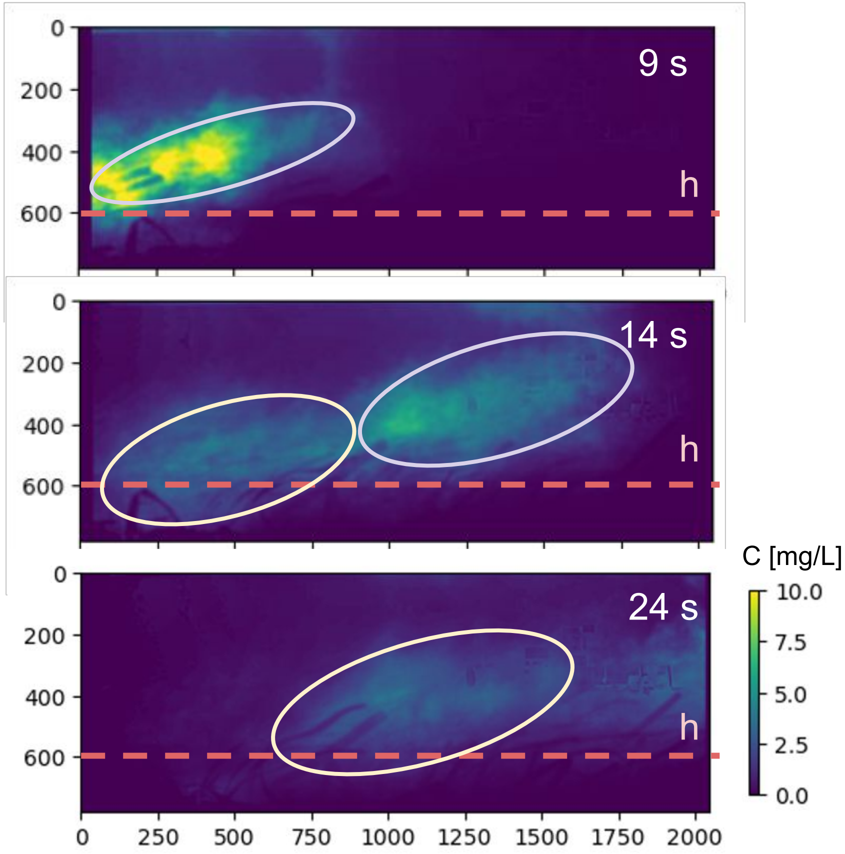
Mixing in seagrass beds

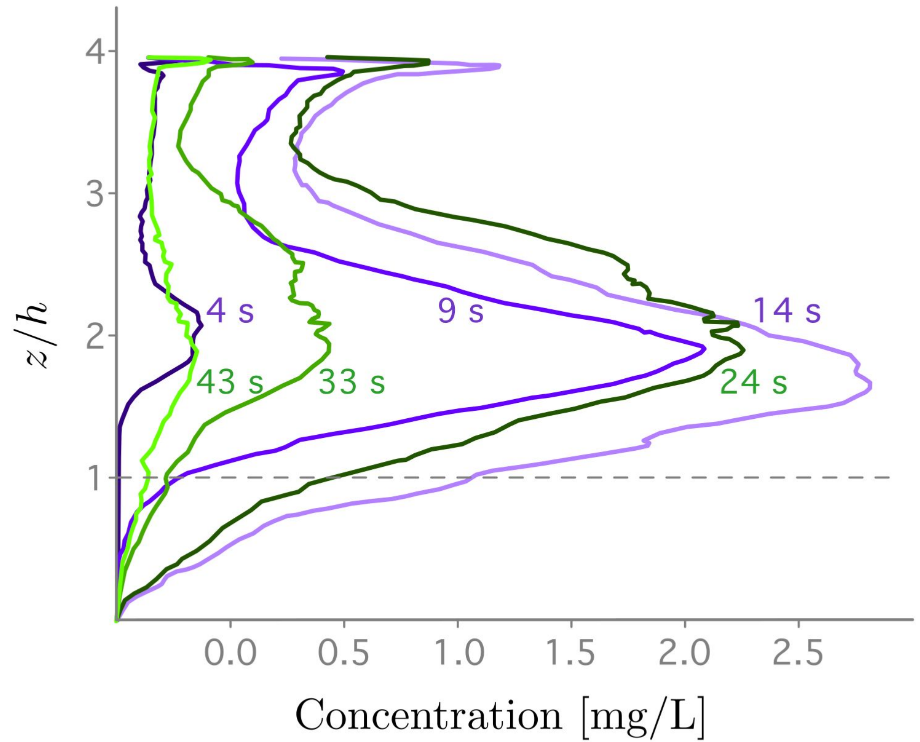


What is the effect of vertical dispersion on the residence time of solutes in seagrass beds?

Fluorescence as proxy for concentration

Seagrass can cause lagging in residence time





Subgrid Corrections for Storm Surge Models

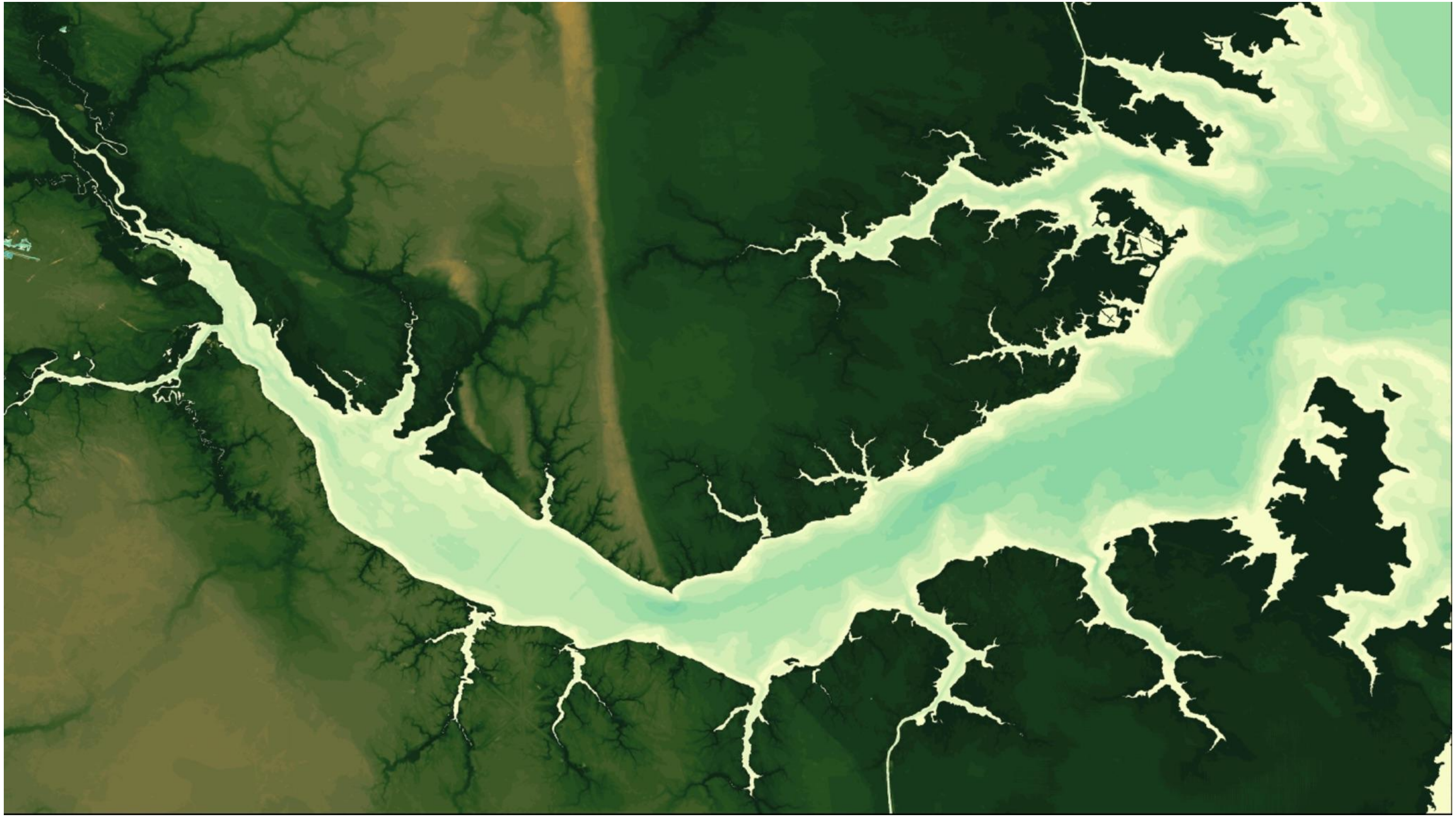
Johnathan Woodruff[1], Casey Dietrich[1],
D Wirasaet[2], AB Kennedy[2], D Bolster[2]

[1] Dep't of Civil, Construction, and Environmental Engineering; NC State Univ
[2] Dep't of Civil and Environmental Engineering and Earth Science, Univ of Notre Dame

ADvanced CIRCulation (ADCIRC) model for Florence (2018)

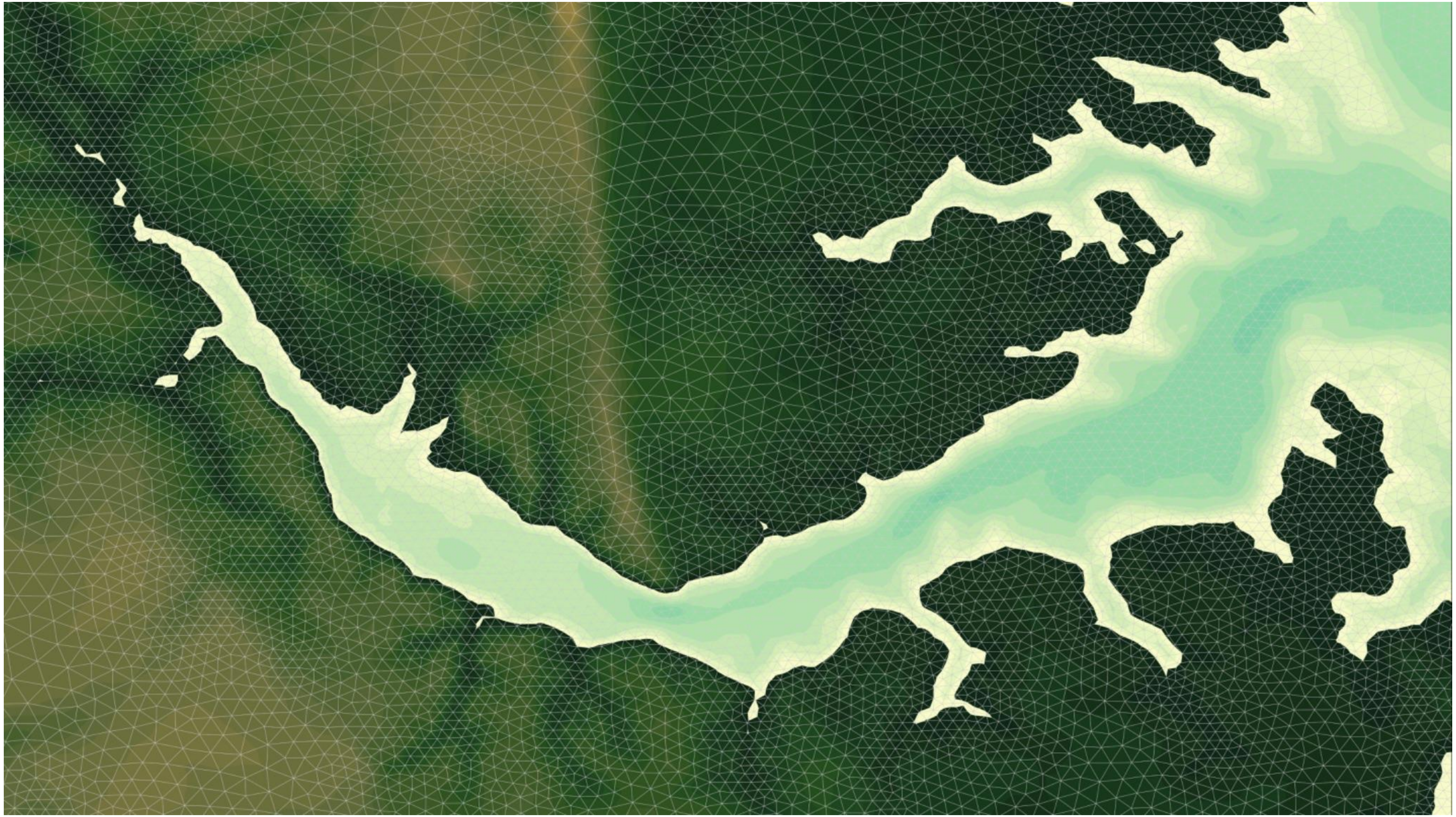
ADCIRC uses unstructured, finite-element meshes

Coastal regions have a wide range of spatial scales …

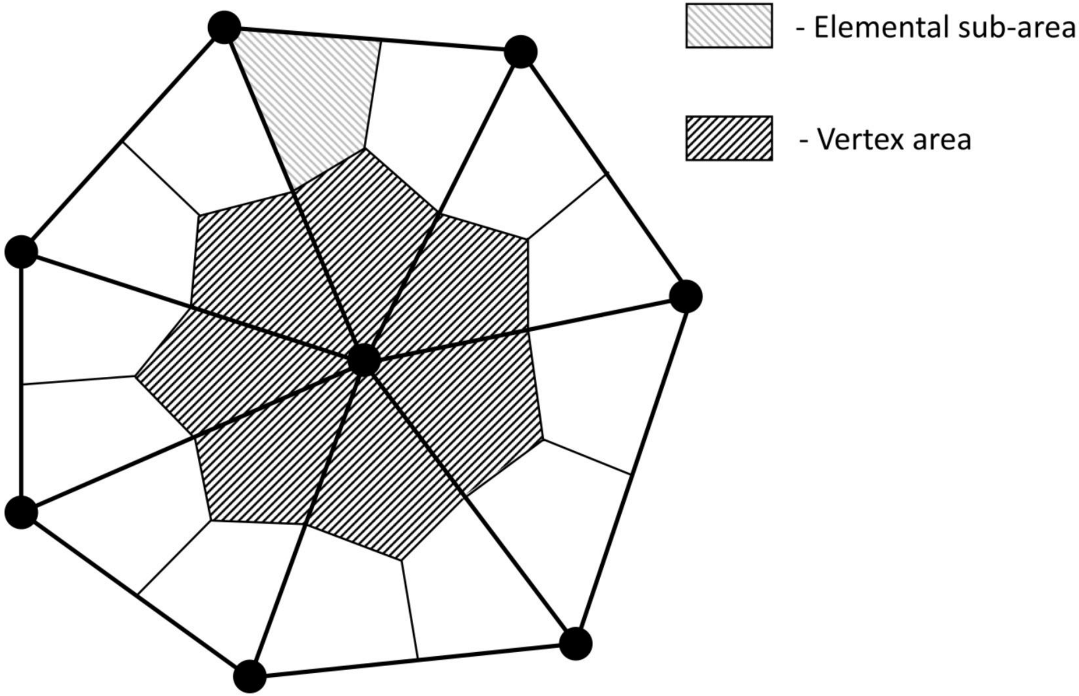


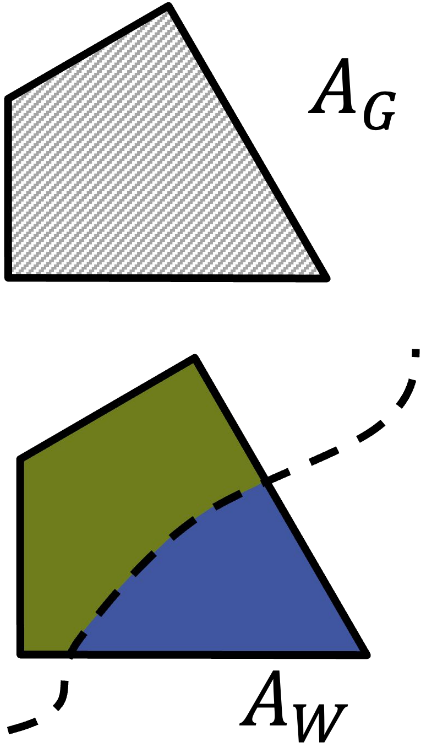
… and we can represent a lot of scales with our meshes …

… but we alias the smallest flow pathways and barriers



Implementation requires definitions of averaging areas





We averaged the governing equations for ADCIRC

We apply averaging rules to every term in the governing equations

– Example of momentum conservation in *x*-direction:

$$\frac{\partial \langle UH \rangle_G}{\partial t} + \frac{\partial C_{UU} \langle U \rangle \langle UH \rangle_G}{\partial x} + \frac{\partial C_{VU} \langle V \rangle \langle UH \rangle_G}{\partial y} - f \langle VH \rangle_G$$

$$= - g C_\zeta \langle H \rangle_G \frac{\partial \langle \zeta \rangle_W}{\partial x} - g \langle H \rangle_G \frac{\partial P_A}{\partial x} + \phi \langle \frac{\tau_{sx}}{\rho_0} \rangle_W$$

$$- C_{M,f} \frac{|\langle \mathbf{U} \rangle| \langle UH \rangle_G}{\langle H \rangle_W} + \frac{\partial}{\partial x} \tilde{E}_h \frac{\partial \langle UH \rangle_G}{\partial x} + \frac{\partial}{\partial y} \tilde{E}_h \frac{\partial \langle UH \rangle_G}{\partial y}$$

in which the red coefficients are new closure terms

– Similarly for momentum conservation in *y*-direction, mass conservation

Closures and averaged values can be stored in look-up tables

Following variables depend on subgrid information:

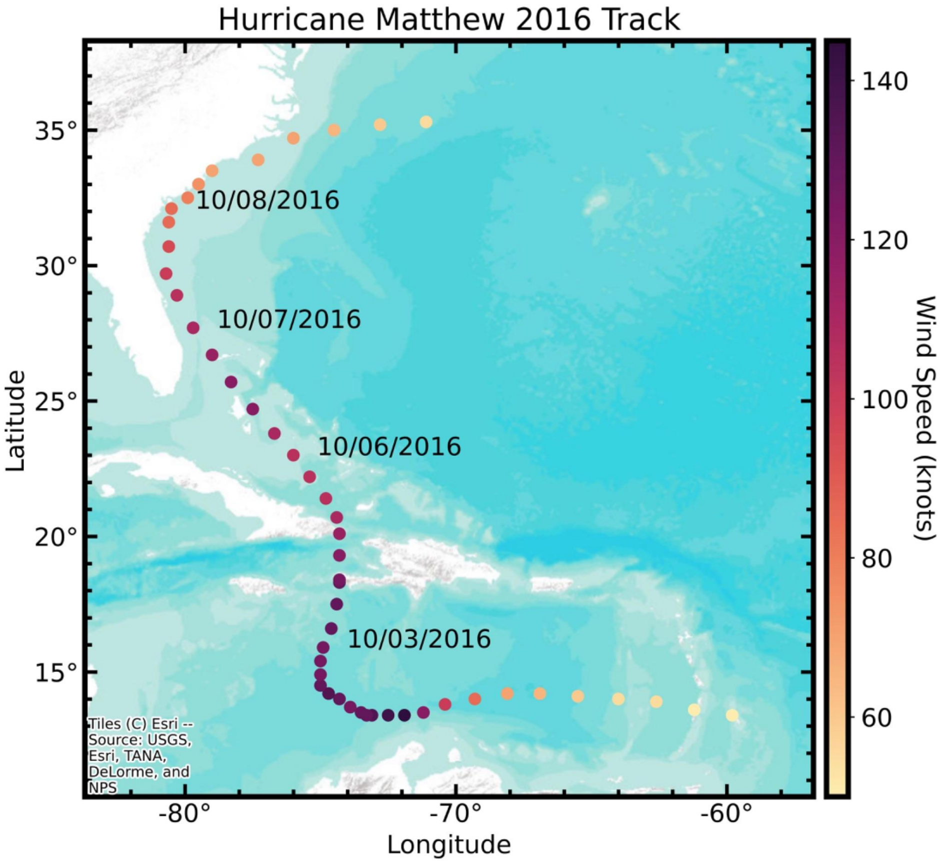
- Elements: $\langle H \rangle_G$, C_{UU}, C_{VU}, C_{UV}, C_{VV}, ϕ
- Vertices: $\langle H \rangle_G$, $\langle H \rangle_W$, $C_{M,f}$, ϕ

We can pre-compute these variables:

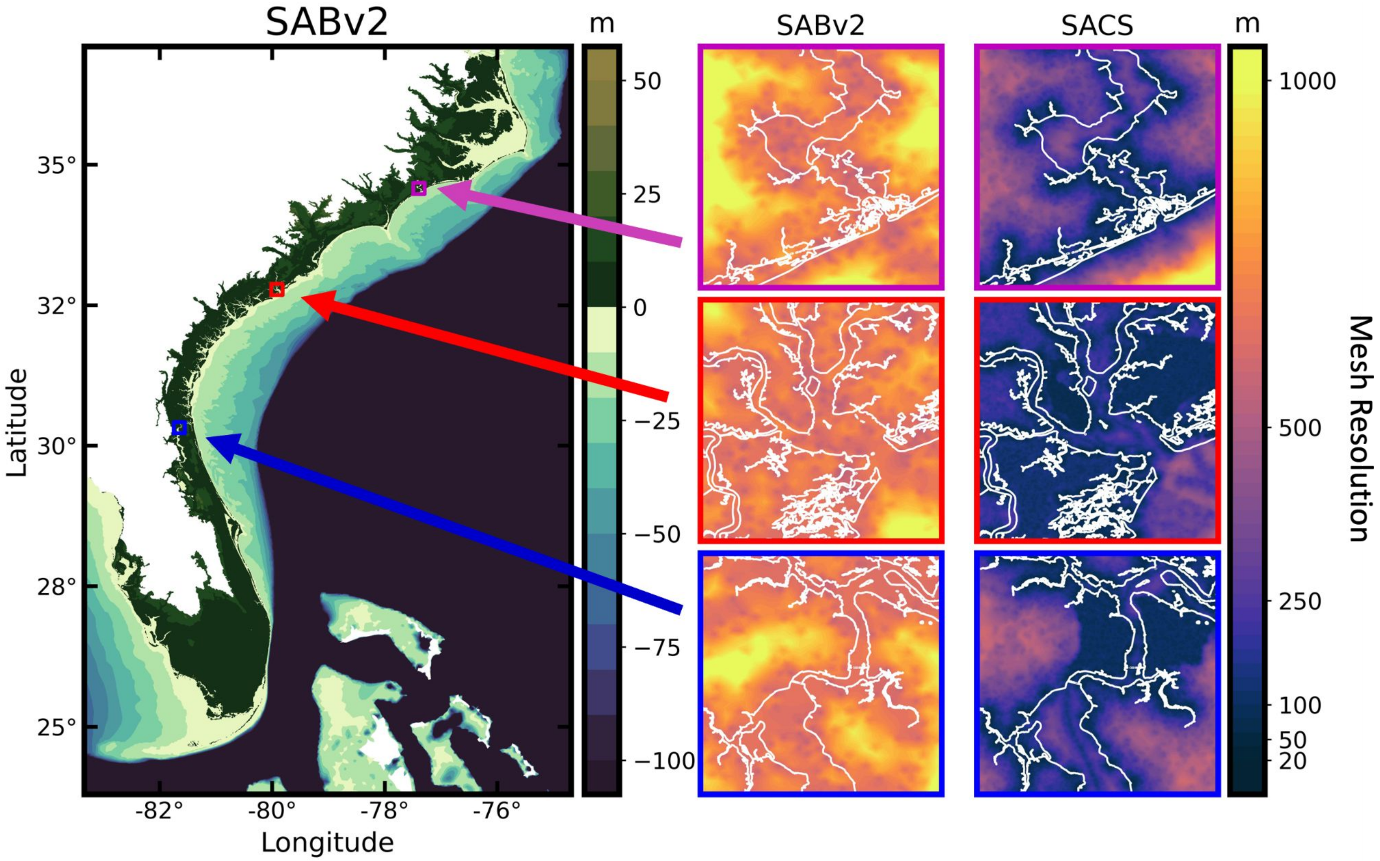
- Pick a range of possible water levels, e.g. $\langle \zeta \rangle_W$ = – 5 to 5 m
- For each possible $\langle \zeta \rangle_W$, compute other variables based on high-resolution elevation and landcover raster datasets
- Store variables in look-up tables for use during the simulation

We reduced file sizes by using a range of possible wet-area fractions, ϕ = 0 to 1

Matthew (2016) affected the U.S. Atlantic coast



‘Forecast-grade’ mesh with minimum resolution of 500 m

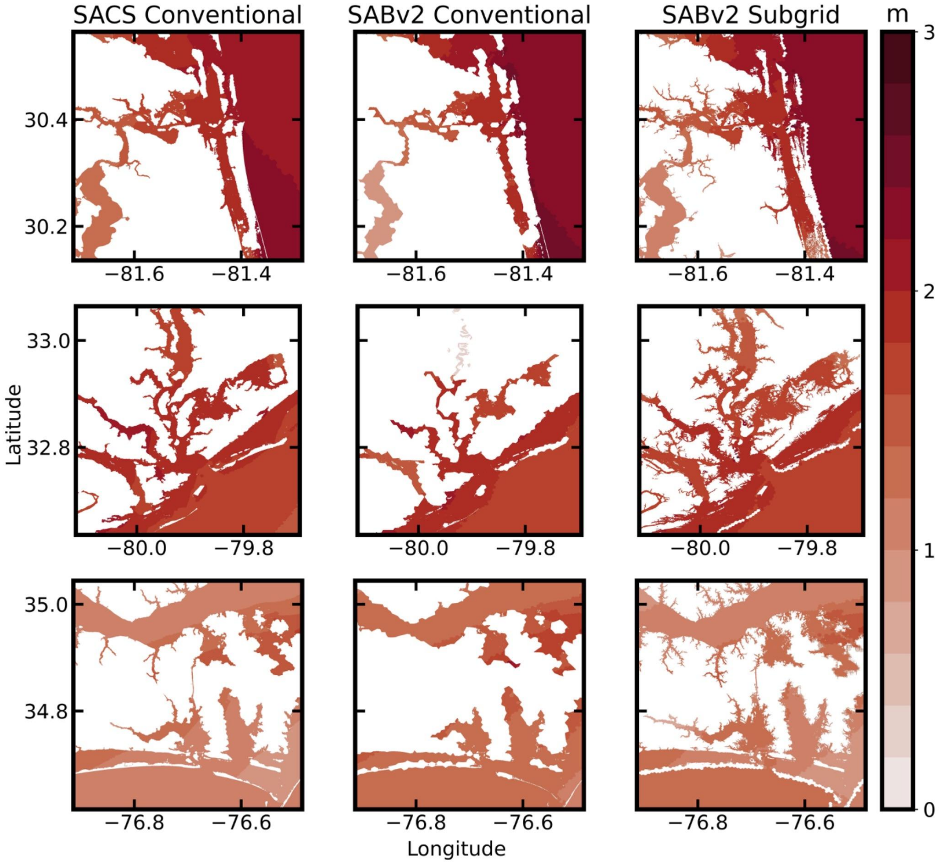


Flooding extents are similar to mesh that is 15 times larger

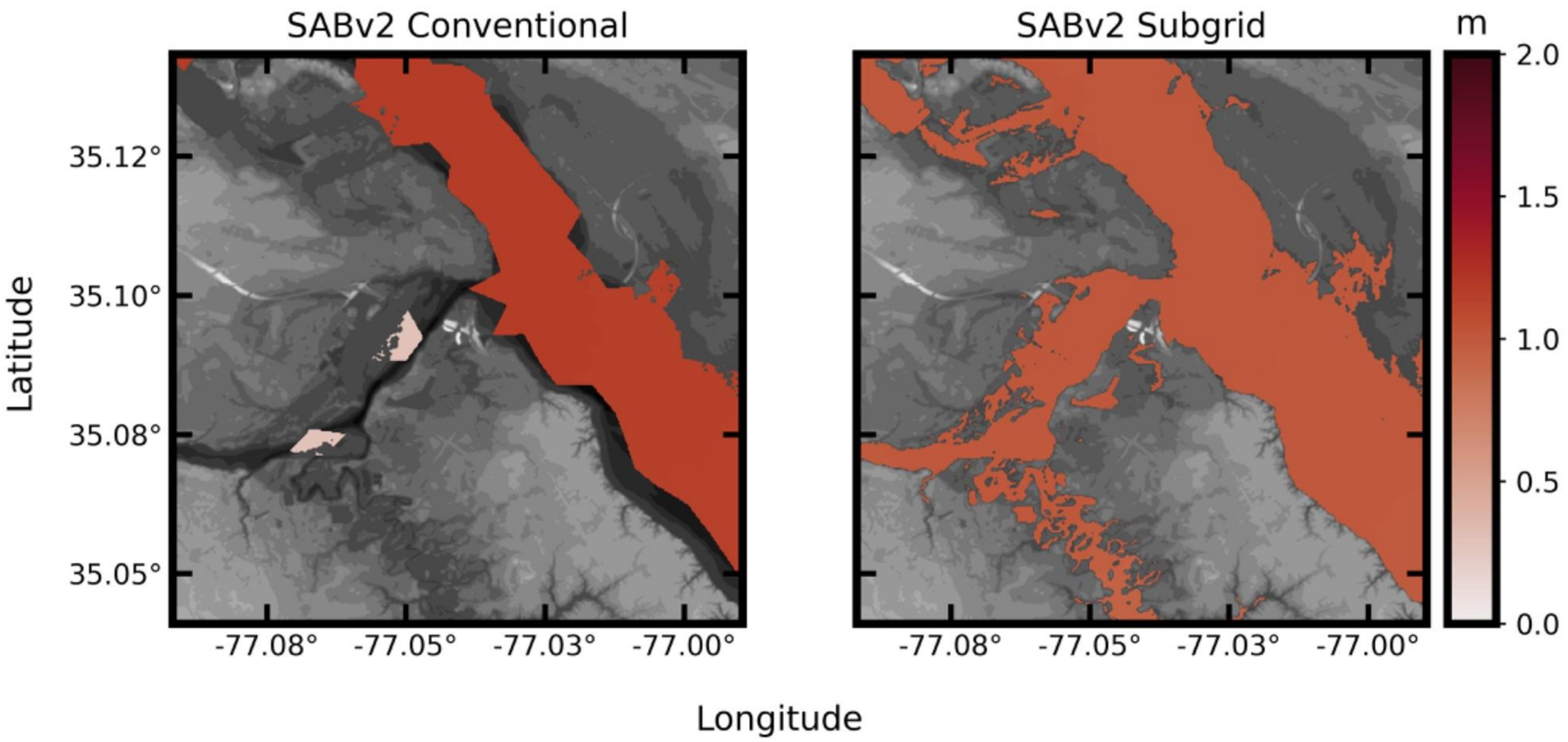
Jacksonville FL

Charleston SC

Morehead City NC



Improved connectivity to far-inland regions like New Bern NC

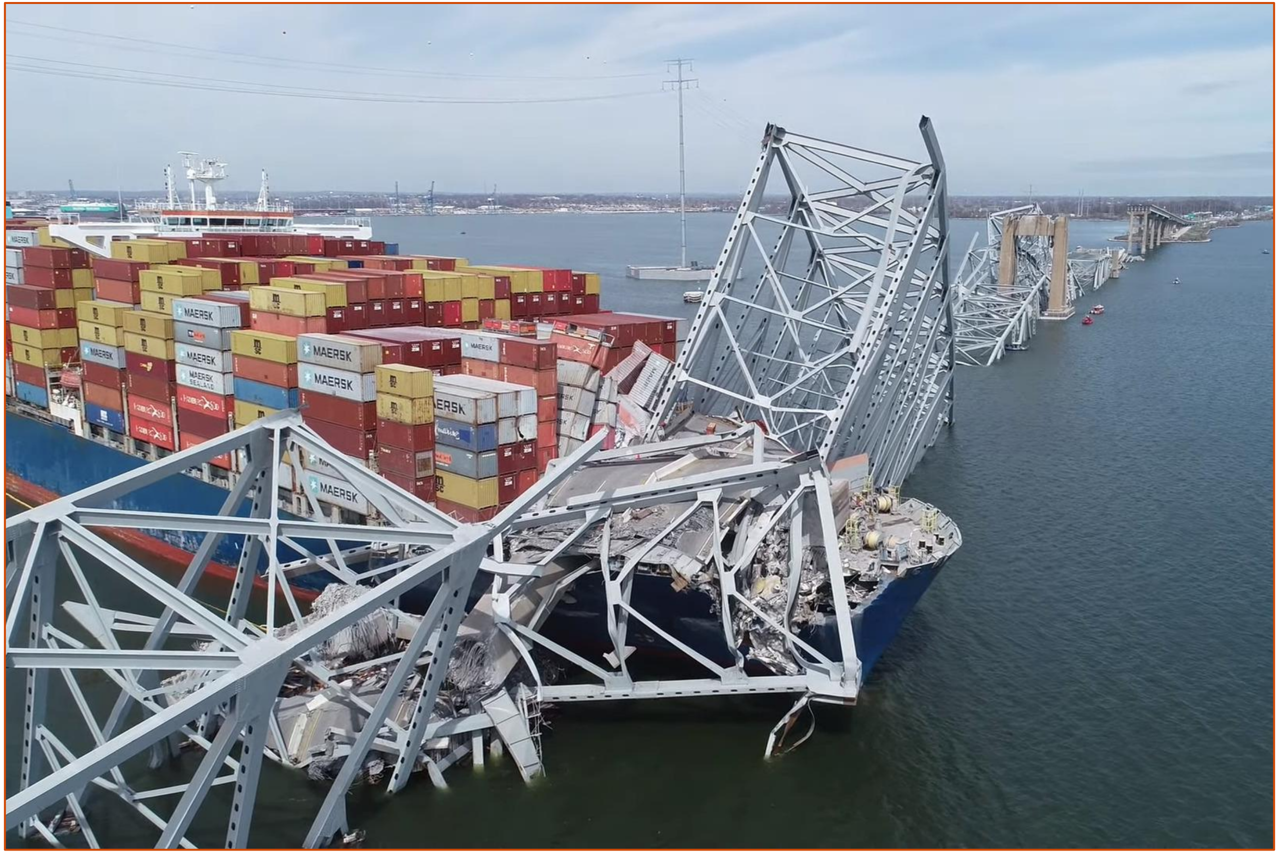


Progress of Seed Grant Research

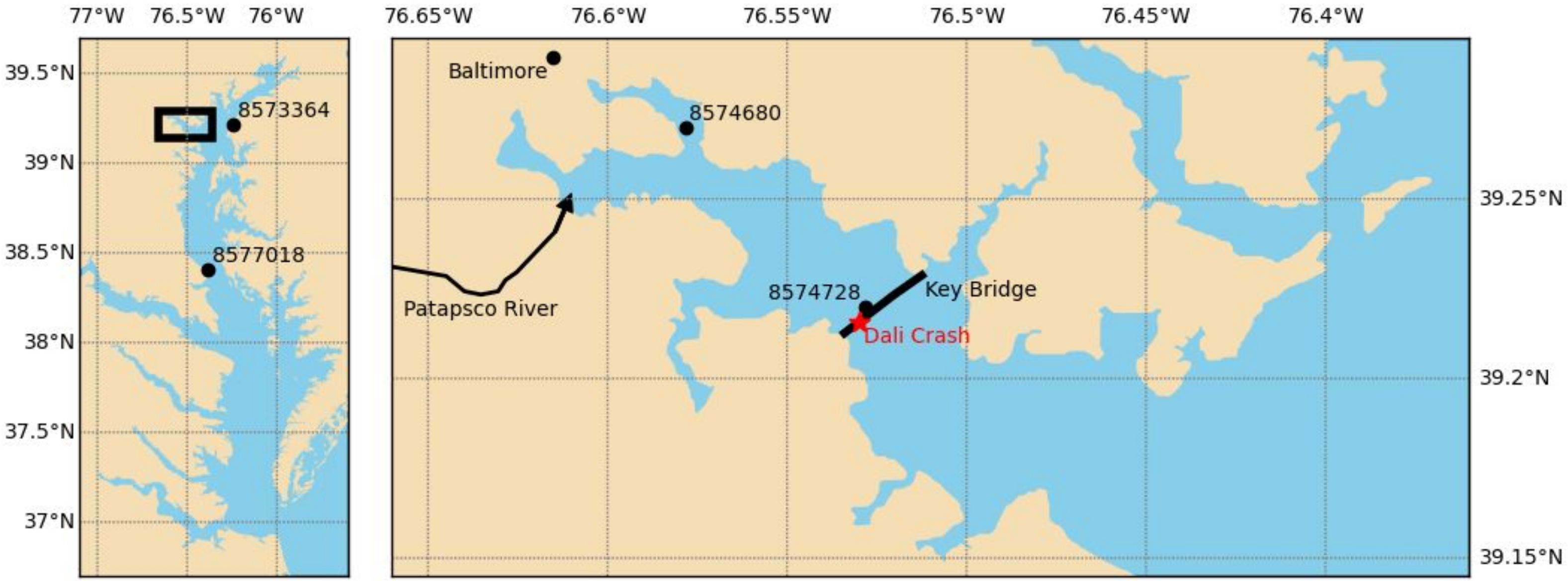
Tomoaki Nakamura[2], Casey Dietrich[1],
Yonghwan Cho[2], Jorge San Juan Blanco[1], Ghadir Haikal[1]

[1] Dep't of Civil, Construction, and Environmental Engineering; NC State Univ
[2] Dep't of Civil and Environmental Engineering, Nagoya Univ

We are motivated by the *Dali* crash into the Key Bridge …



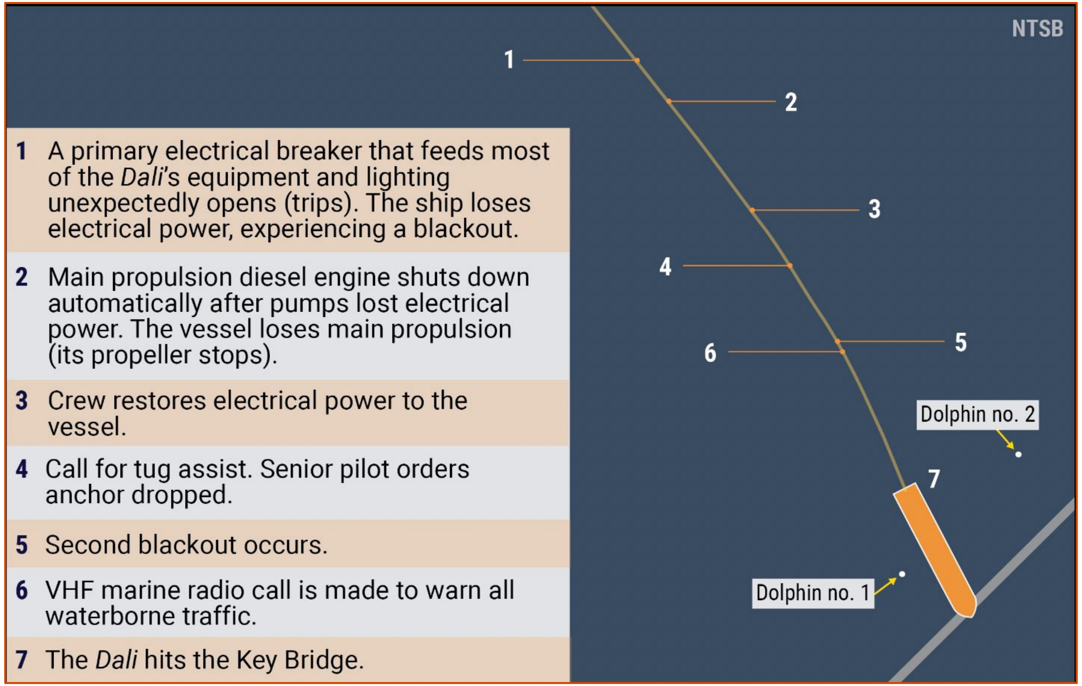
… which disrupted highway and ship traffic for a major port …



Disruptions to Port of Baltimore:

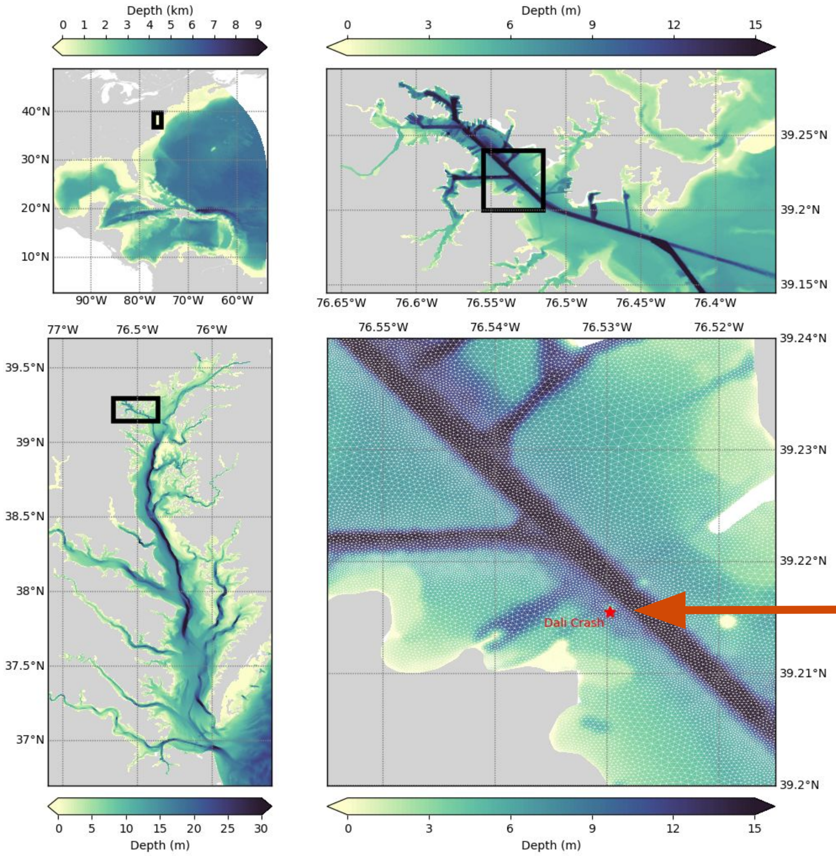
– Highway traffic, more than 34,000 vehicles per day across the bridge
– Ship traffic, 52.3 million tons of foreign cargo valued at $80 billion per year

… and which was affected by local hydrodynamics?



- How was the *Dali* affected by the real currents in the Patapsco River as it approached?
- What is the best-possible prediction of the ship's impact force on the Key Bridge?

We developed an ADCIRC model for Baltimore Harbor …



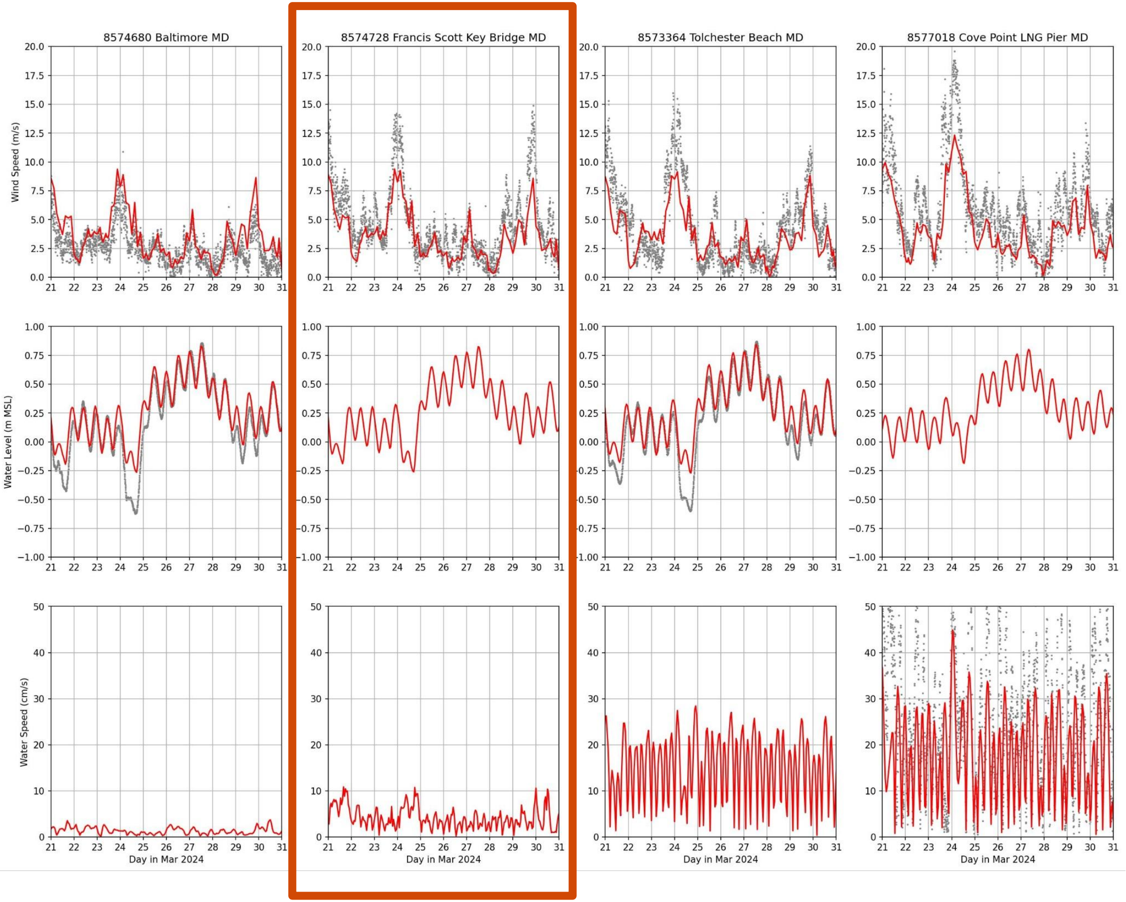
Resolution of about 30 m near the crash location

… with good predictions, including at the bridge

Winds ➤

Water Levels ➤

Currents ➤

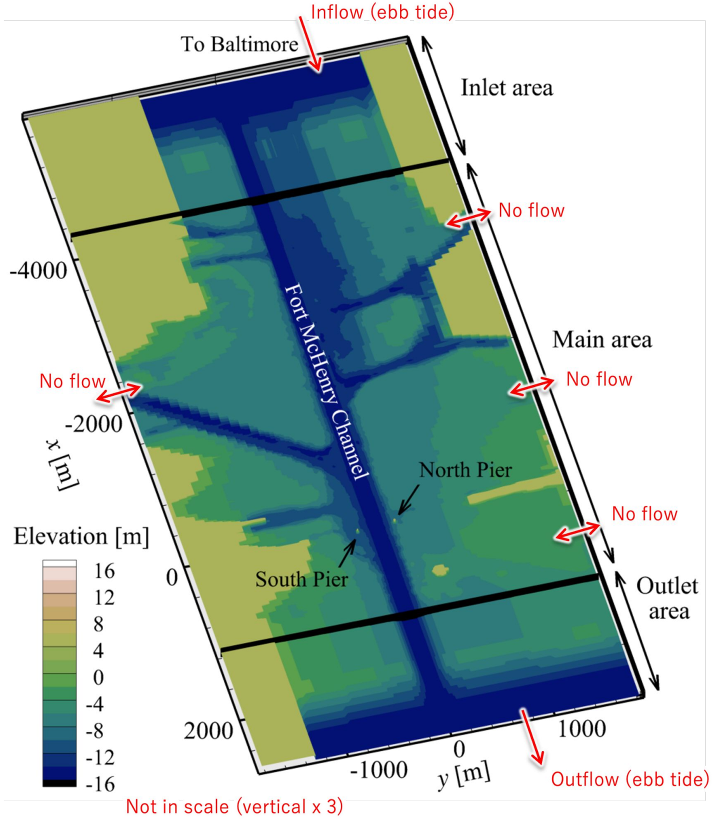


Prof. Nakamura built a high-resolution model near the bridge …

ADCIRC
(Dietrich)

Upstream:
- **Flux**

At the bridge:
- **Water levels**
- **Currents**



… and approximated the *Dali*'s dimensions and density …

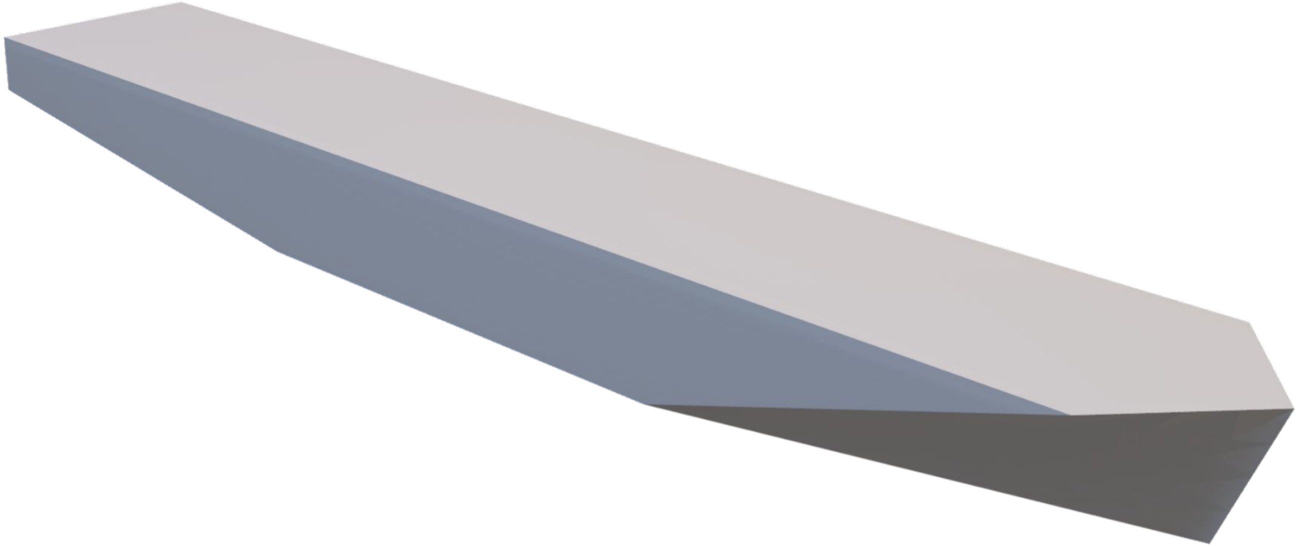
"The Dali, a [289-m]-long, steel-hulled general cargo vessel (containership), was built by HD Hyundai Heavy Industries Co., Ltd. in 2015. The vessel's draft on departure was [12.1 m] fore and aft, with a cargo of 4,680 containers (56,675 metric tons of containerized cargo). The ship and cargo displaced 112,383 metric tons as loaded at departure." (NTSB)

Dimensions:

- Length: 300 m
- Width: 48.2 m
- Height: 24.8 m
- Draft: 12.16 m

Density:

- 448.5 kg/m^3



… and with good predictions of ship motion and crash

Summary

Summary

Coastal Engineering at NC State	NC State has a growing team of coastal engineers and scientists – Eager to collaborate!
Flow-Biota Interactions in Coastal Habitats	Biota can modify flow structure in space and time: – Geometric variations lead to space and time flow variations – Flow variations control mixing processes
Subgrid Corrections for Storm Surge Models	ADCIRC can correct for small-scale flow pathways and barriers – Better predictions of flooding into upland regions – Similar to models with much higher resolution (and cost)
Progress of Seed Grant	Investigation of hydrodynamic effects on *Dali* ship crash – Coupling of simulations by ADCIRC and FS3M – Early predictions are promising!

Thanks for your attention!