Modeling Oyster Reef and Salt Marsh Resilience as a Form of Nature-based Infrastructure in Response to Spatially Varied Hydrodynamic Conditions

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U.S. DEPARTMENT OF COMMERCE

Oyster Reefs as Nature-Based Infrastructure

- Acts as ‘natural breakwaters’[5]
- Promotes sedimentation[1,3]
- Attenuates waves
- Reduces shoreline loss
- Keystone species[4,7]
- Provides ecosystem services[2,6]

https://blogs.ifas.ufl.edu/santarosaco/2016/01/19/panhandle-florida-master-naturalist-graduates-opt-to-use-living-shorelines-to-enhance-habitat-and-protect-their-coastal-properties/

[1] Baggett et al. (2015)
[2] Byers et al. (2017)
[3] Grabowski et al. (2012)
[4] Kennedy et al. (1996)
[5] Meyer et al. (1997)
[6] Newell & Koch (2004)
[7] Zu Ermgassen et al. (2012)

Drivers of Growth and Mortality

Flow Speed

- Growth benefited by higher velocities[2]
- Influenced by reef height and bathymetry[1]

Sediment

- Risk of smothering/mortality[2]
- Reduction in filtering capability[1]
- Influenced by turbulent diffusion[3], reef height[1], and flow speed[2]

https://blog.wfsu.org/blog-coastal-health/2012/03/sounds-of-the-oyster-reef/

[1] Housego & Rosman (2016)
[2] Lenihan (1999)
[3] van Rijn (1993)

Research Objectives

How do oyster reef heights respond to their local hydrodynamic conditions?

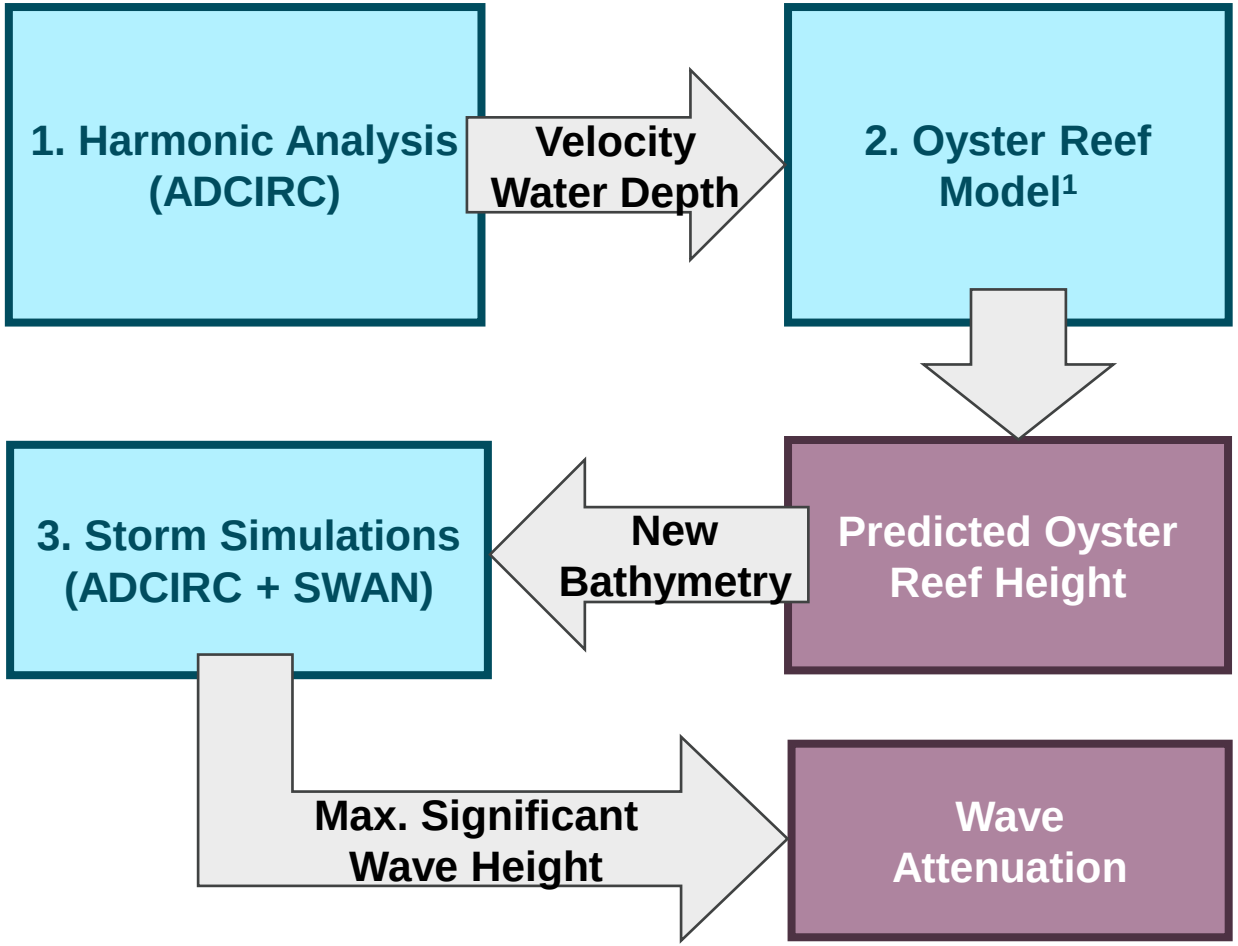
→

What conditions produce the highest final reef height and the greatest longevity of oyster survival?

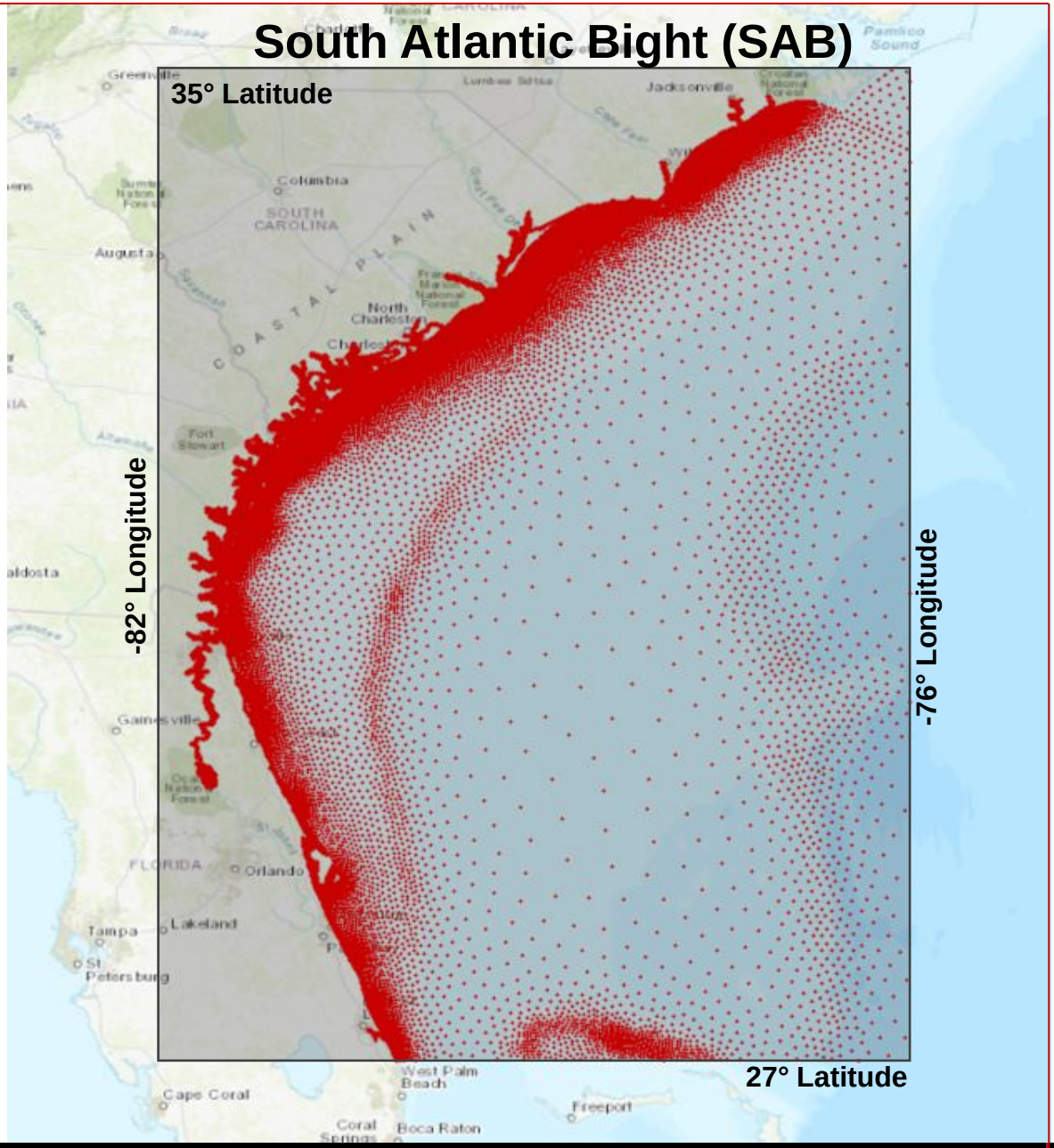
→

What conditions are associated with the greatest amount of wave attenuation?

3-hr timestep over 30 years

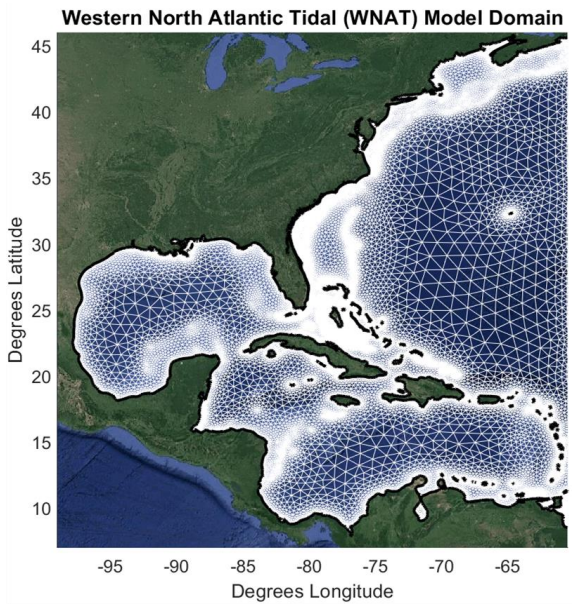


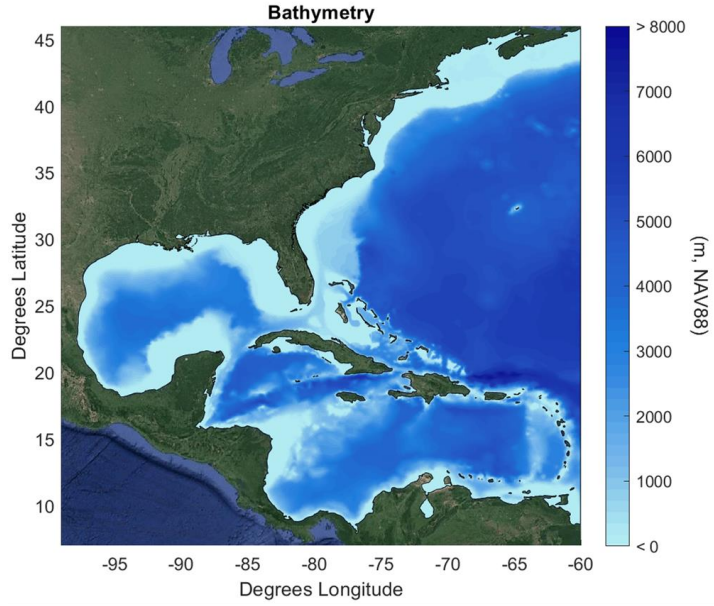
[1] Housego & Rosman (2016)

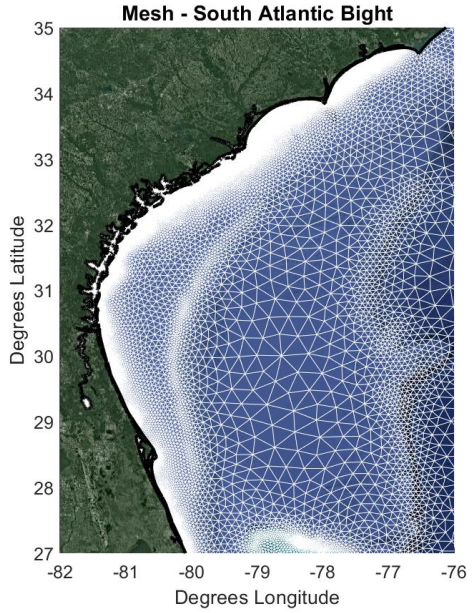


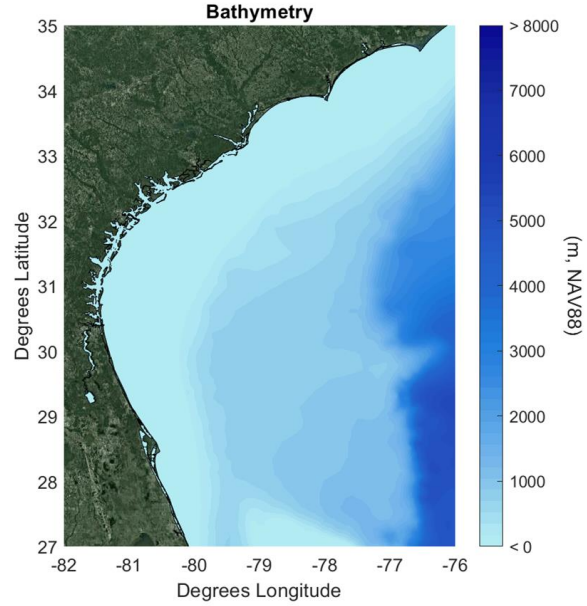
ADCIRC – **AD**vanced **CIRC**ulation Model[3]

- Calculates water depth and depth-averaged velocity using shallow water equations[2,3]
- Mesh includes intertidal zones of estuaries of South Atlantic Bight
- Resolution increases closer to shore[1]









[1] Bacopoulos et al. (2011)
[2] Kolar et al. (1994)
[3] Luettich & Westerink (2004)

1. Harmonic Analysis (ADCIRC)

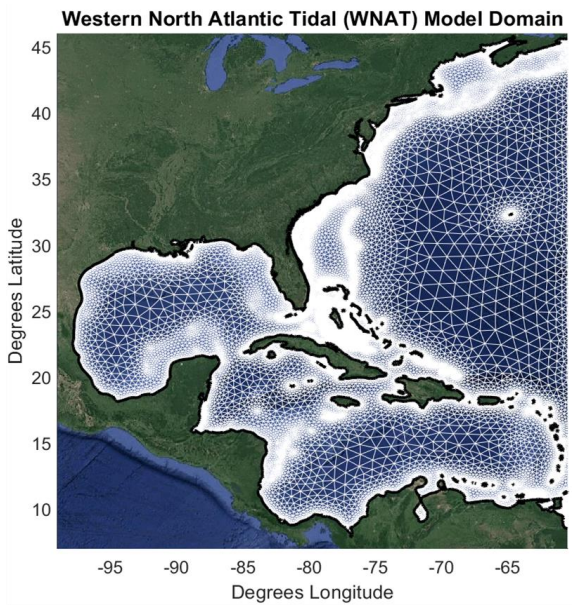
- 230 day total run time
- 1 second timestep
- Harmonic analysis performed from day 45-230

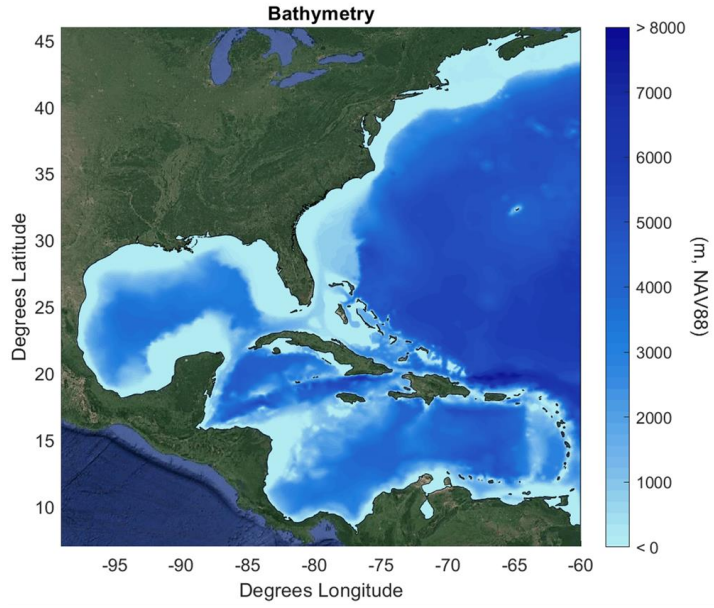
Model Forcing – Tidal Constituents

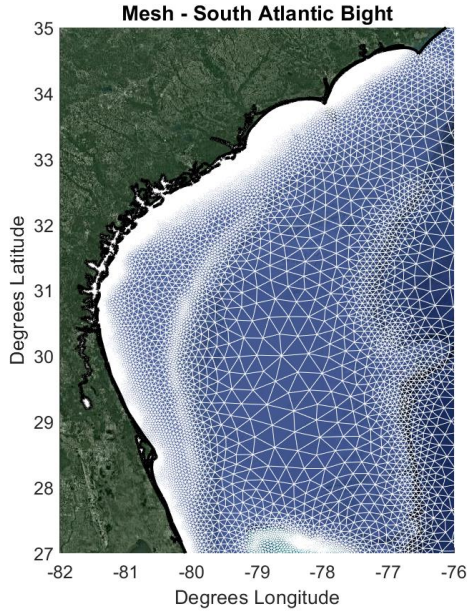
Diurnal: O_1 K_1 Q_1

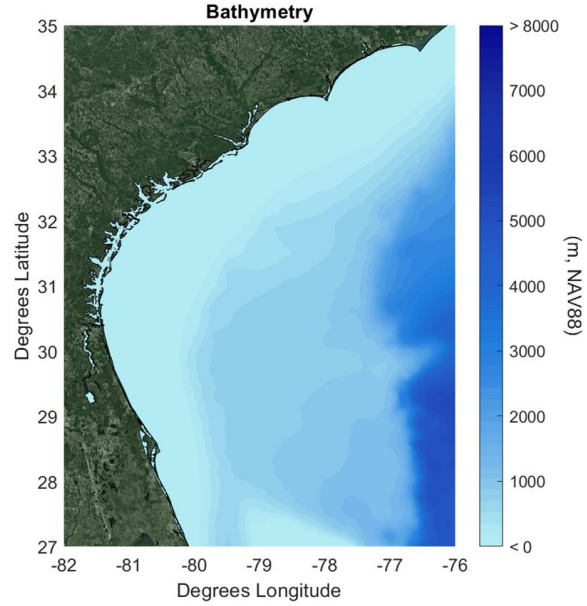
Semidiurnal: M_2 N_2 S_2 K_2

Amplitude (a_i), phase angle (α_i), and frequency (ω_i) values for each tidal constituent (i) were recorded at each node



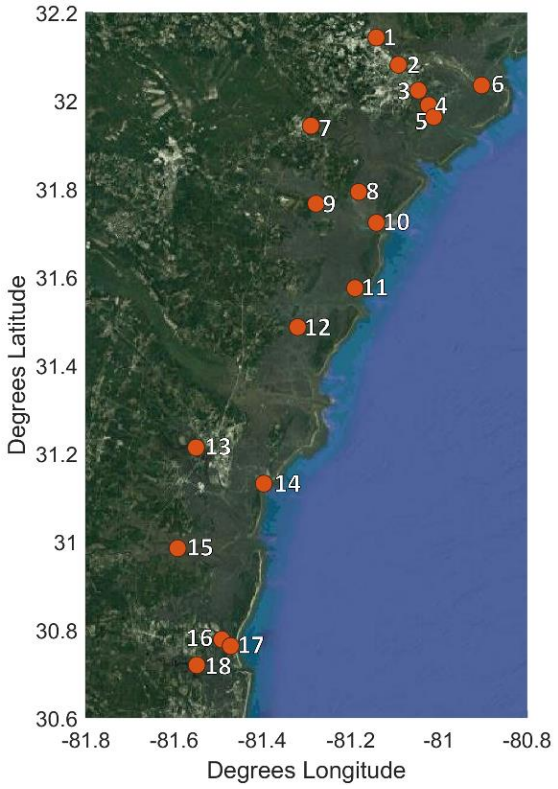


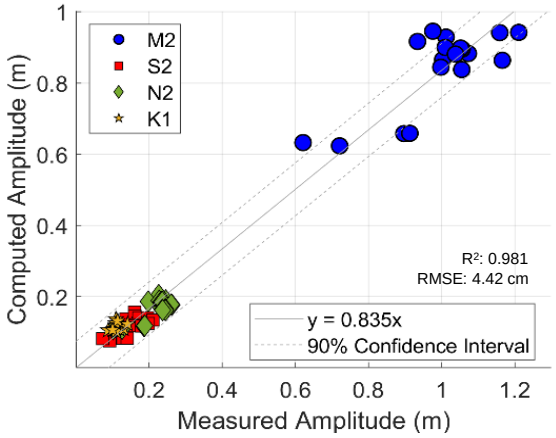


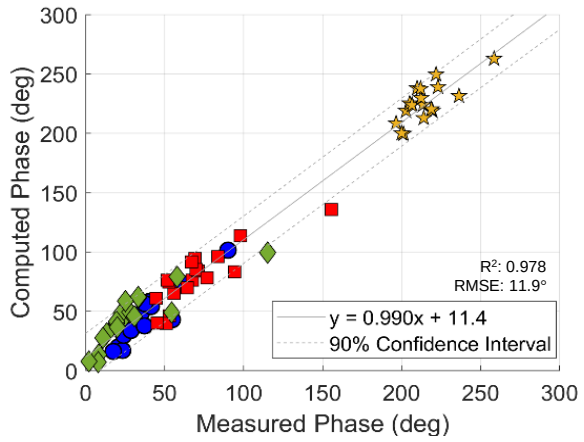


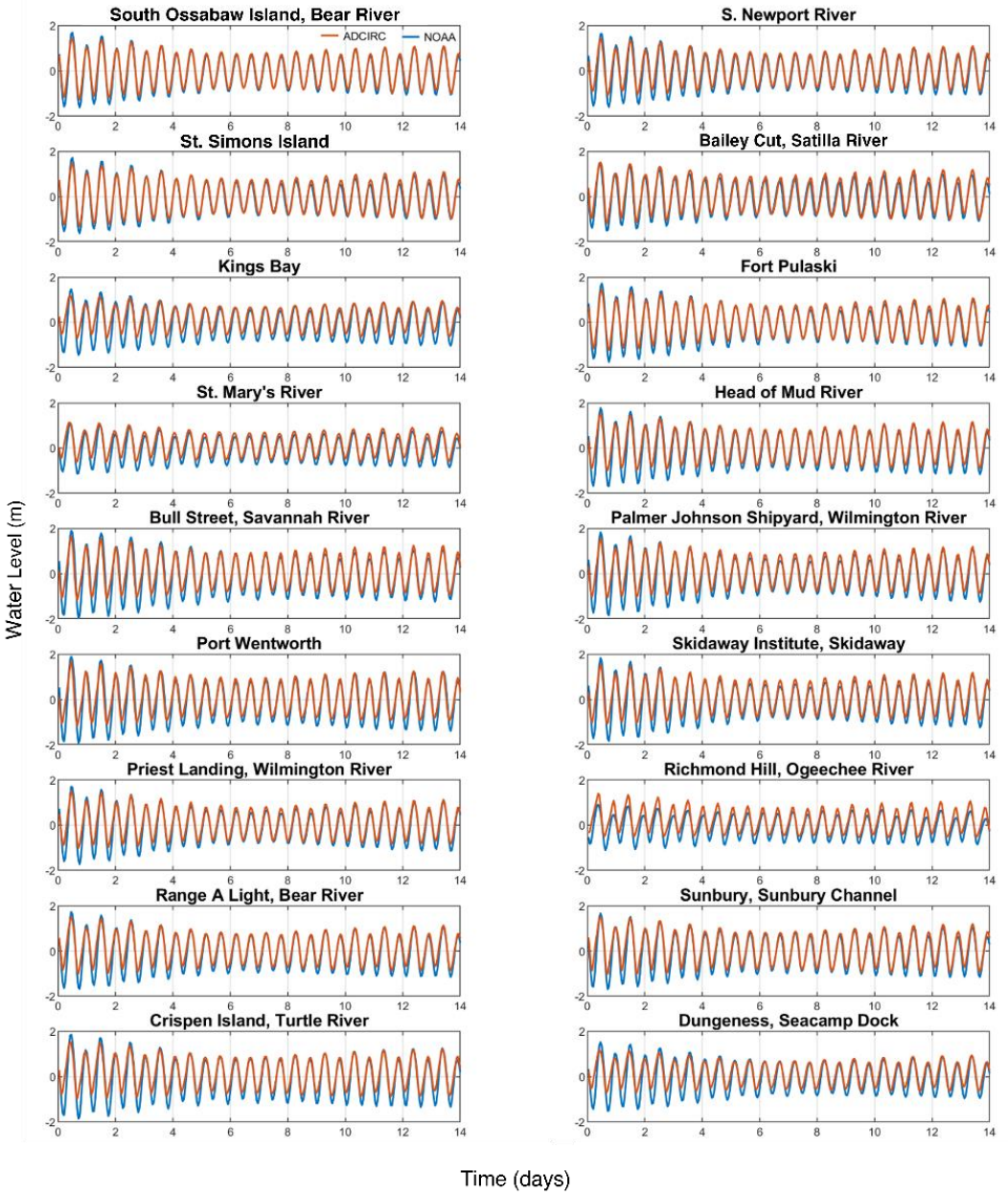
1. Harmonic Analysis (ADCIRC)

Tide Resynthesis



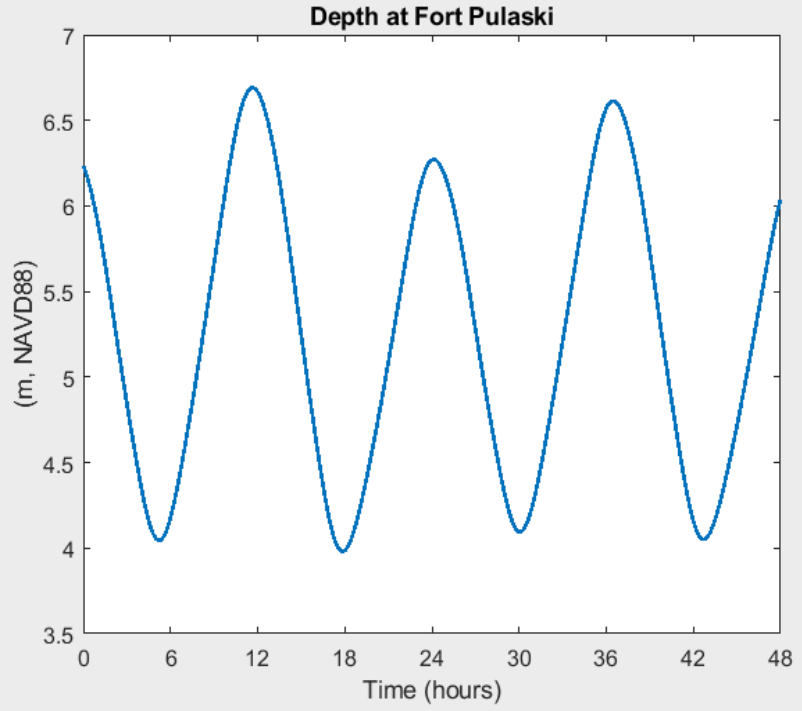




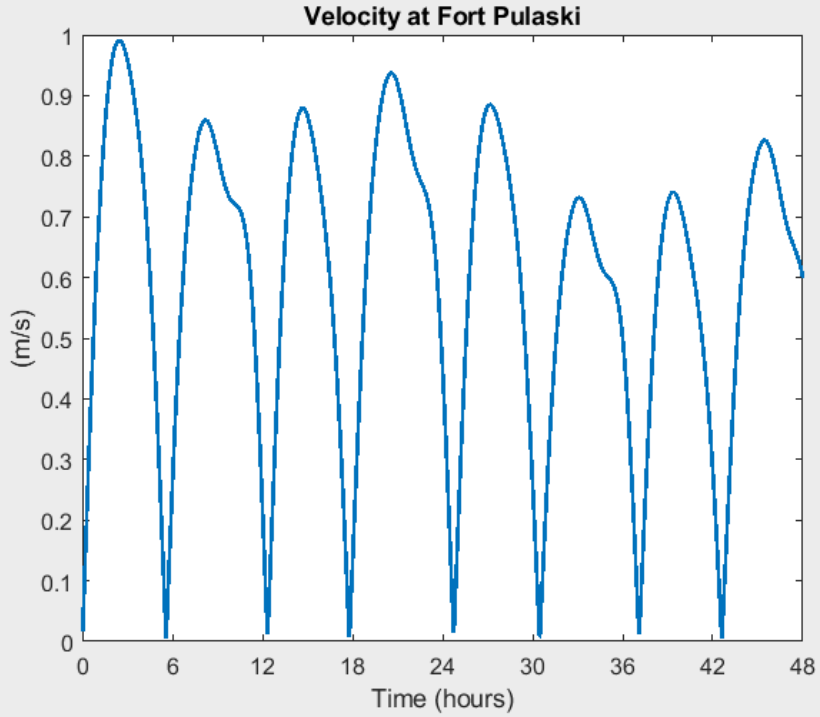


1. Harmonic Analysis (ADCIRC)

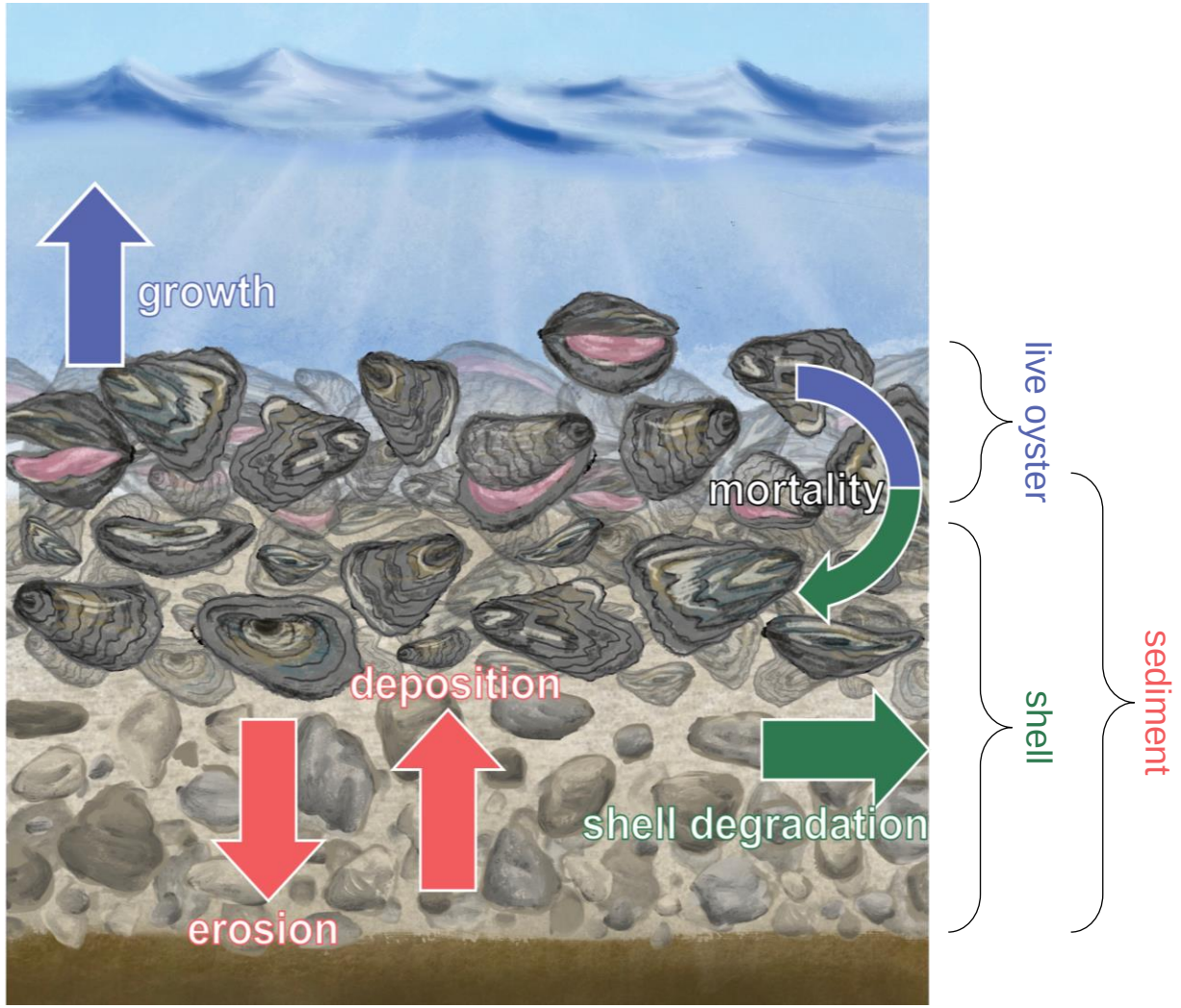
$$H = h + \sum_{i=1}^{I} a_i \cos(\omega_i t + \alpha_i)$$



$$U_{x,y} = \sum_{i=1}^{I} a_i \cos(\omega_i t + \alpha_i) \qquad U = \sqrt{{U_x}^2 + {U_y}^2}$$



1. Harmonic Analysis (ADCIRC) → **Velocity Water Depth**



Velocity
Water Depth

2. Oyster Reef Model[1]

Oyster Layer Volume

$$\frac{\partial O}{\partial t} = \underbrace{\frac{b_1 f O}{b_2 O + 1}}_{growth} - \underbrace{[\mu f + \varepsilon(1-f)]O}_{mortality}$$

Shell Layer Volume

$$\frac{\partial B}{\partial t} = \underbrace{[\mu f + \varepsilon(1-f)]O}_{mortality} - \underbrace{\gamma B}_{degradation}$$

Sediment Layer Volume

$$\frac{\partial S}{\partial t} = \underbrace{(C \cdot W_s)}_{deposition} - \underbrace{E}_{erosion}$$

Equations from Housego & Rosman (2016)

[1] Housego & Rosman (2016)

Model Assumptions

- Constant temperature, salinity, dissolved oxygen, density, etc.
- No land subsidence
- No change in hydrodynamic conditions experienced by the oysters with elevation on reef or orientation towards flow
- van Rijn sediment concentration profile (van Rijn, 1993)
- Sediment concentration profile *does not change* when water meets the reef

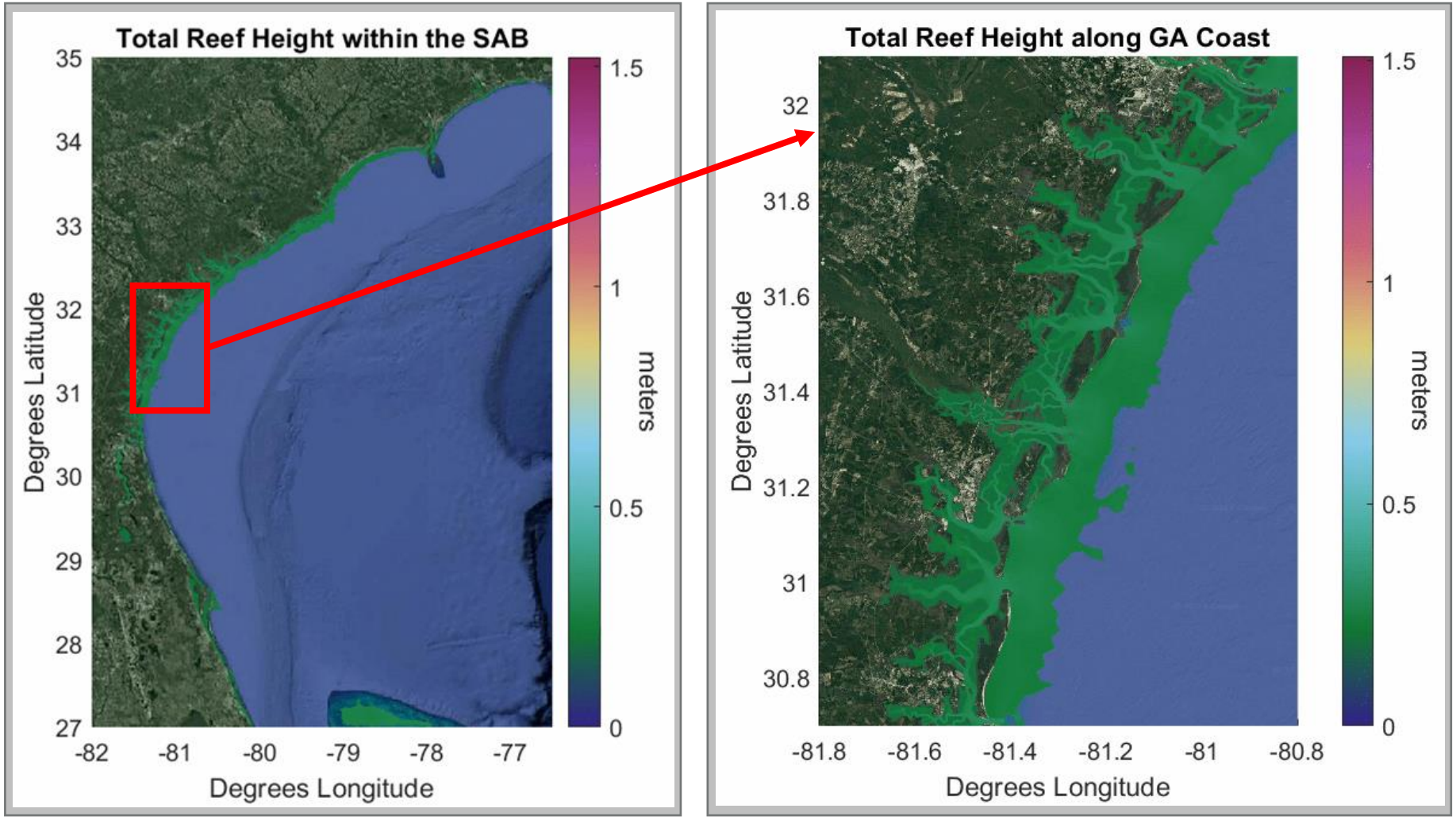
2. Oyster Reef Model[1]

Results

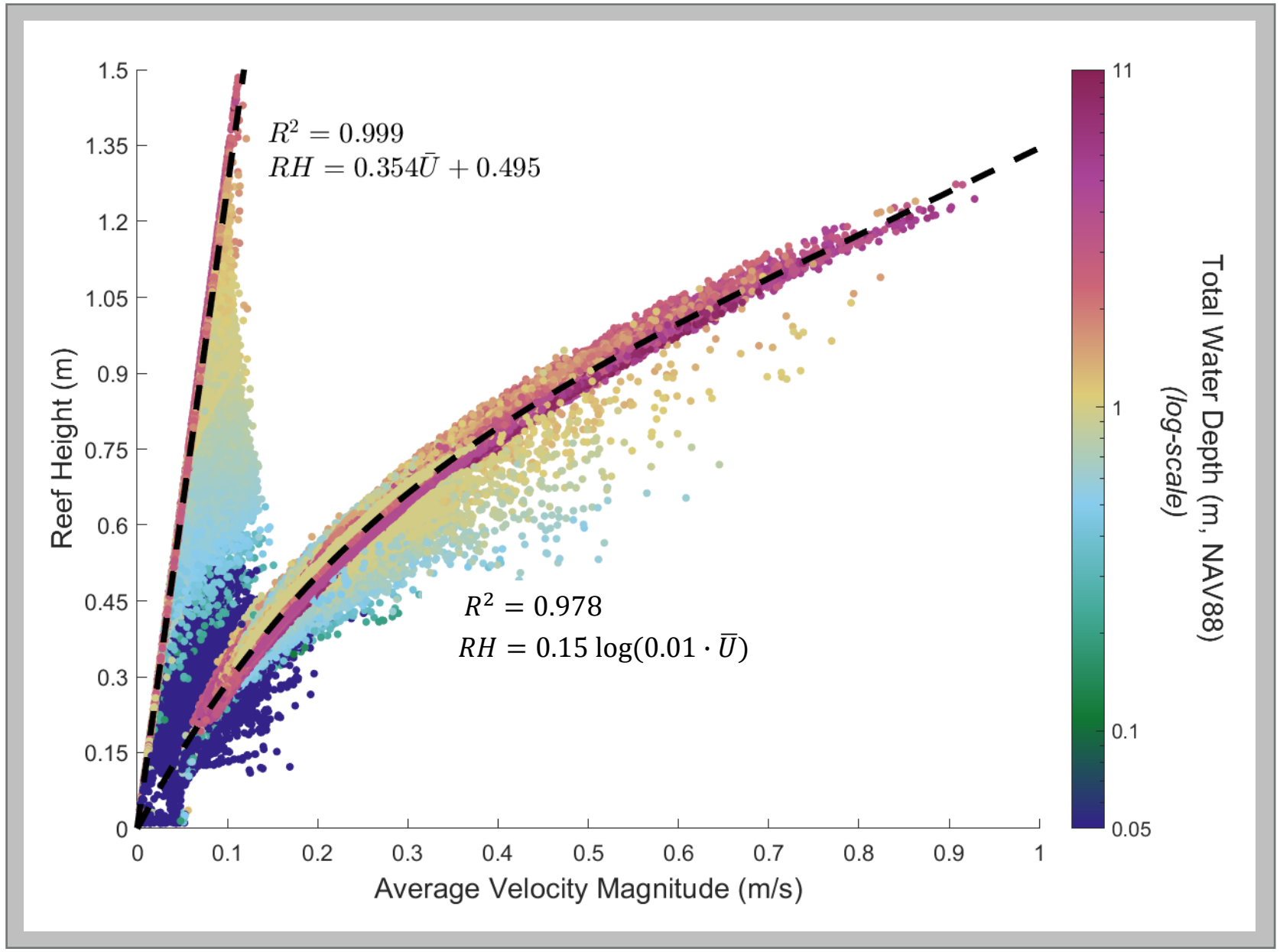
2. Oyster Reef Model[1]

Predicted Oyster Reef Height

Year 1

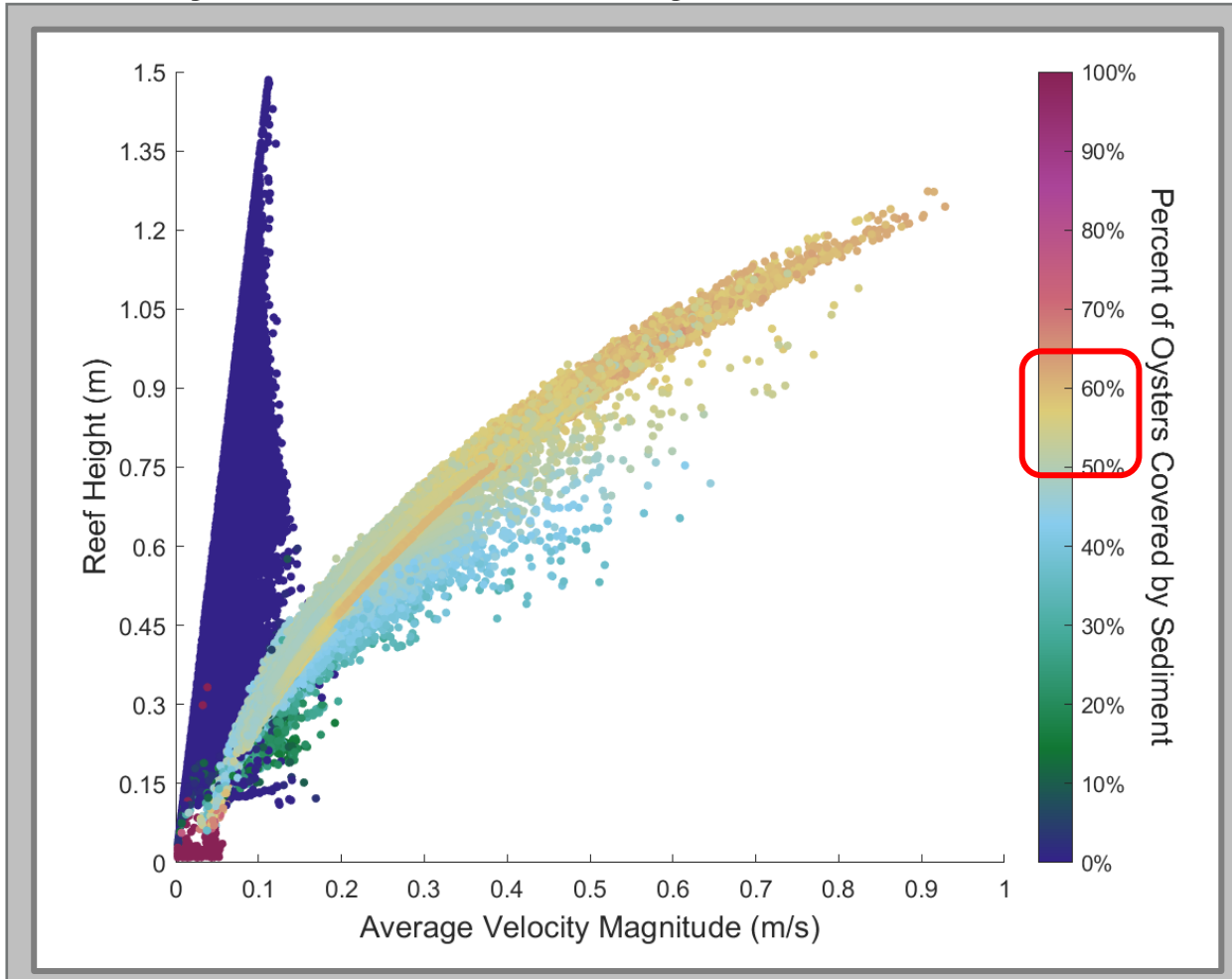


$$reefheight = oysterheight + shellheight$$

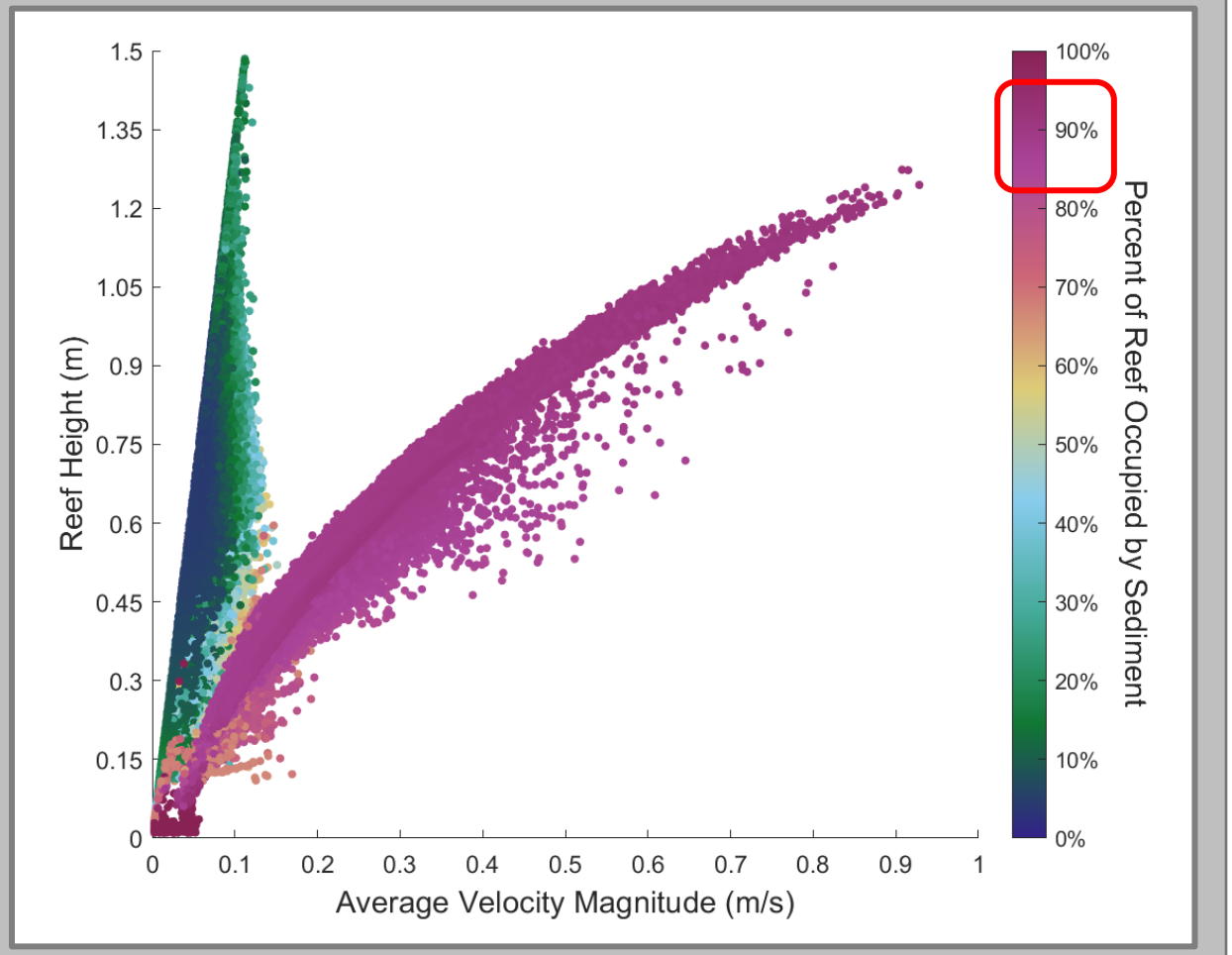


Predicted Oyster Reef Height

Oysters Covered by Sediment

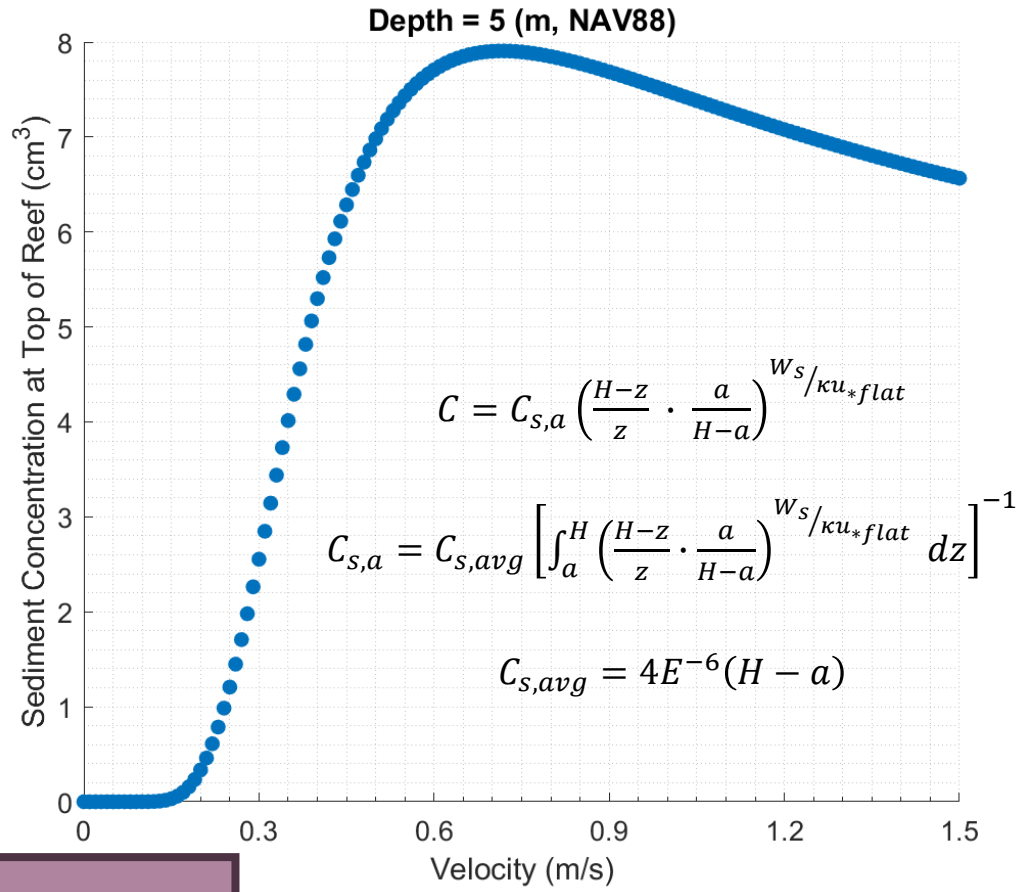


Reef Covered by Sediment



Predicted Oyster Reef Height

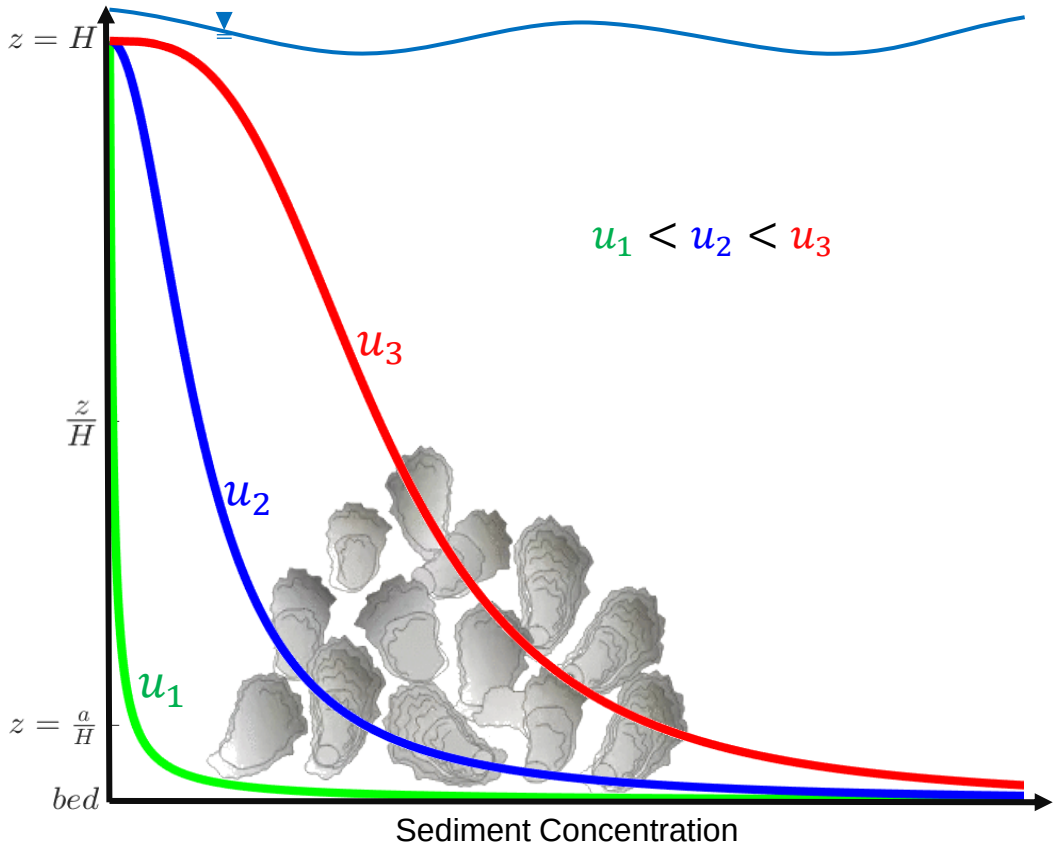
van Rijn Sediment Concentration Profile



$$C = C_{s,a}\left(\frac{H-z}{z}\cdot\frac{a}{H-a}\right)^{W_s/\kappa u_{*flat}}$$

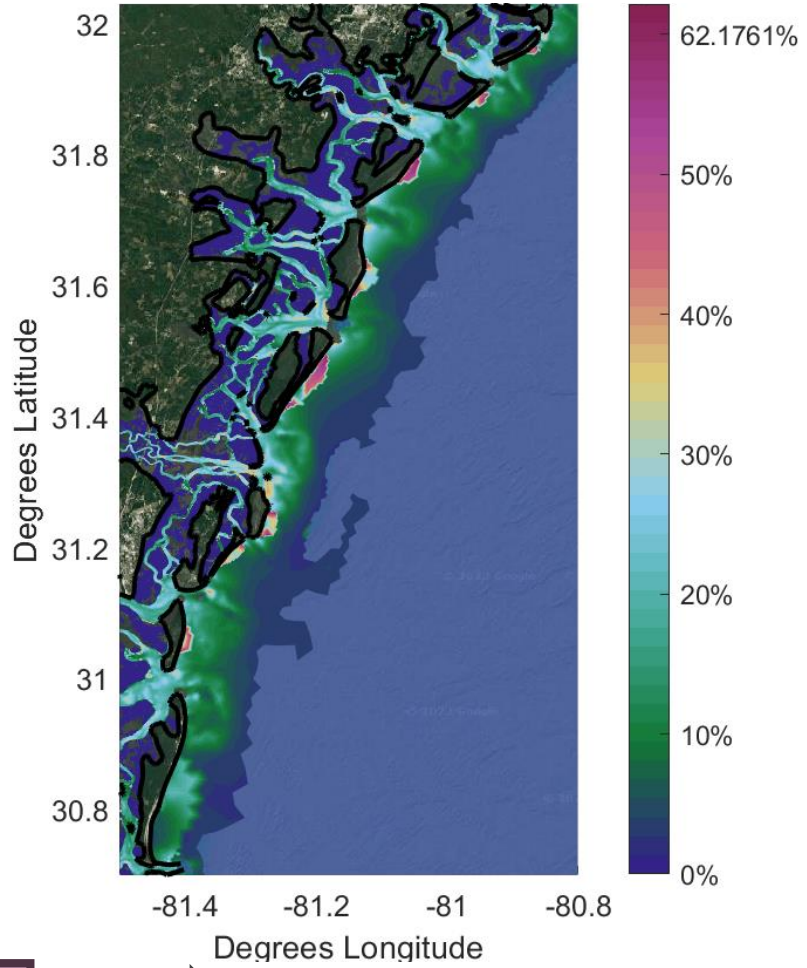
$$C_{s,a} = C_{s,avg}\left[\int_a^H \left(\frac{H-z}{z}\cdot\frac{a}{H-a}\right)^{W_s/\kappa u_{*flat}} dz\right]^{-1}$$

$$C_{s,avg} = 4E^{-6}(H-a)$$

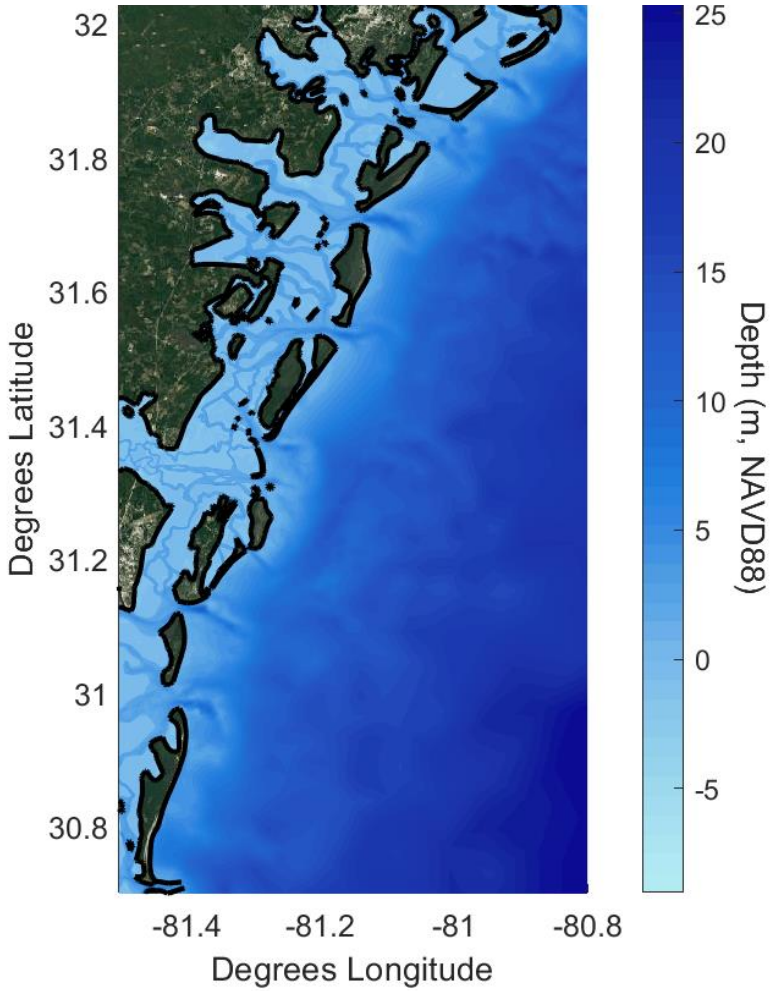


Predicted Oyster Reef Height

Reduction in Water Column Depth Along GA Coast



Adjusted Bathymetry Along GA Coast



Predicted Oyster Reef Height → **New Bathymetry**

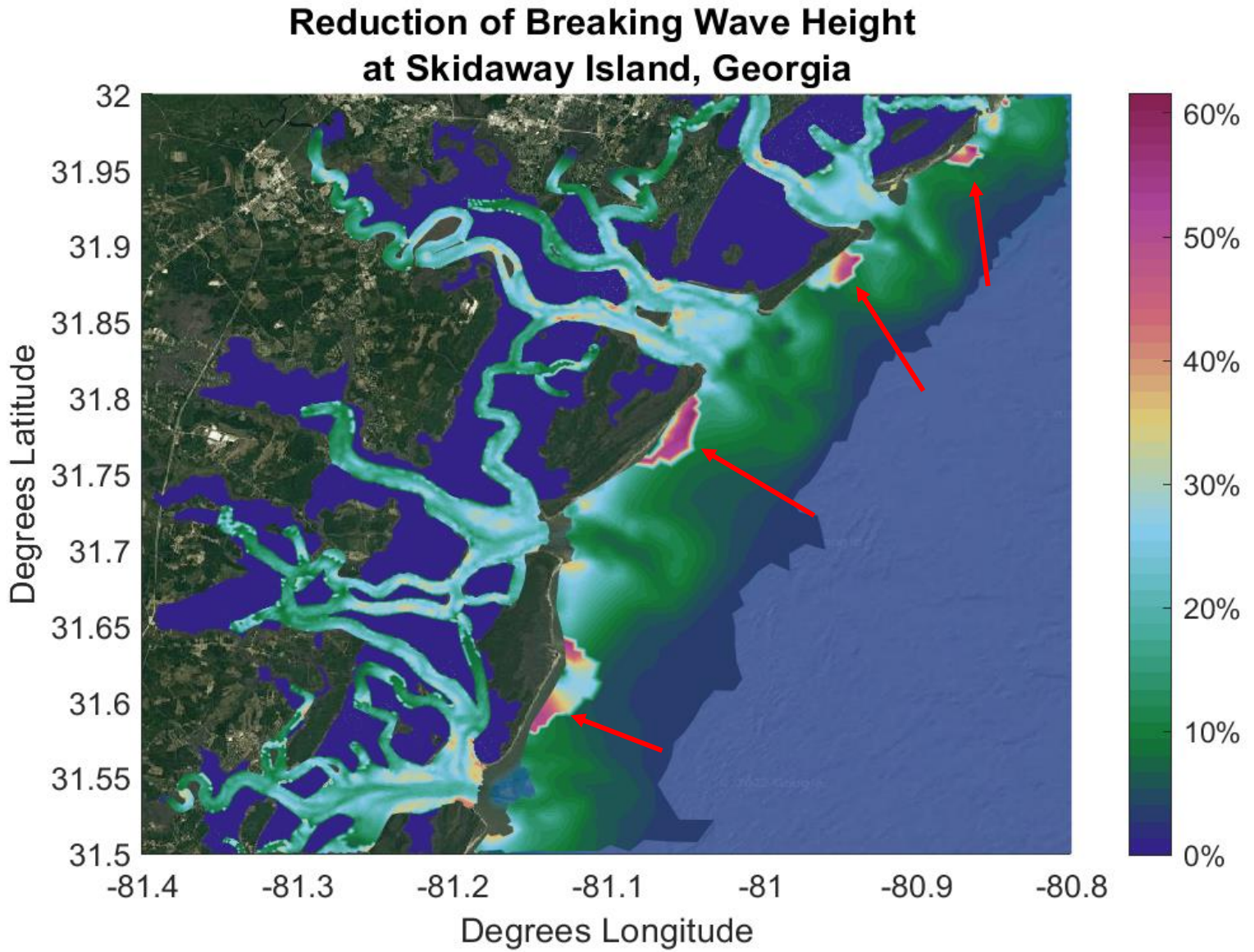
Shoreline Protection

$$H_b = \gamma h_b$$

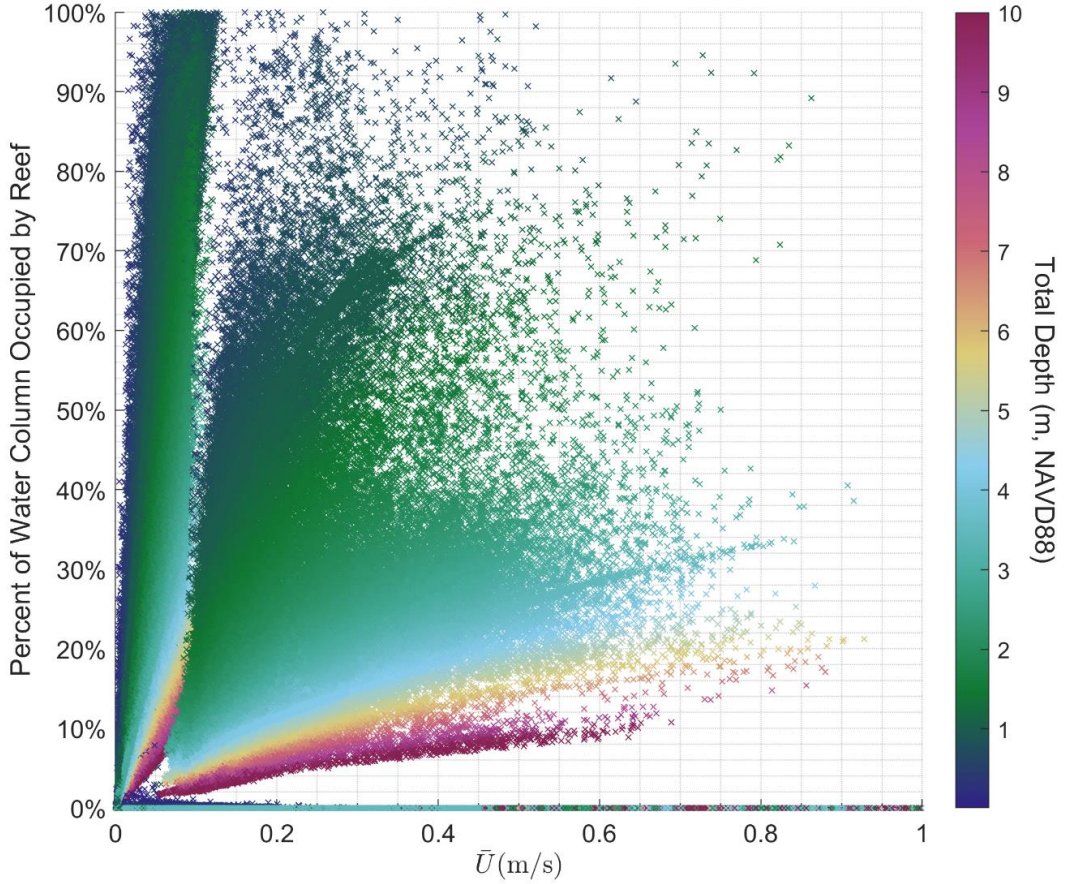
H_b: breaking wave height

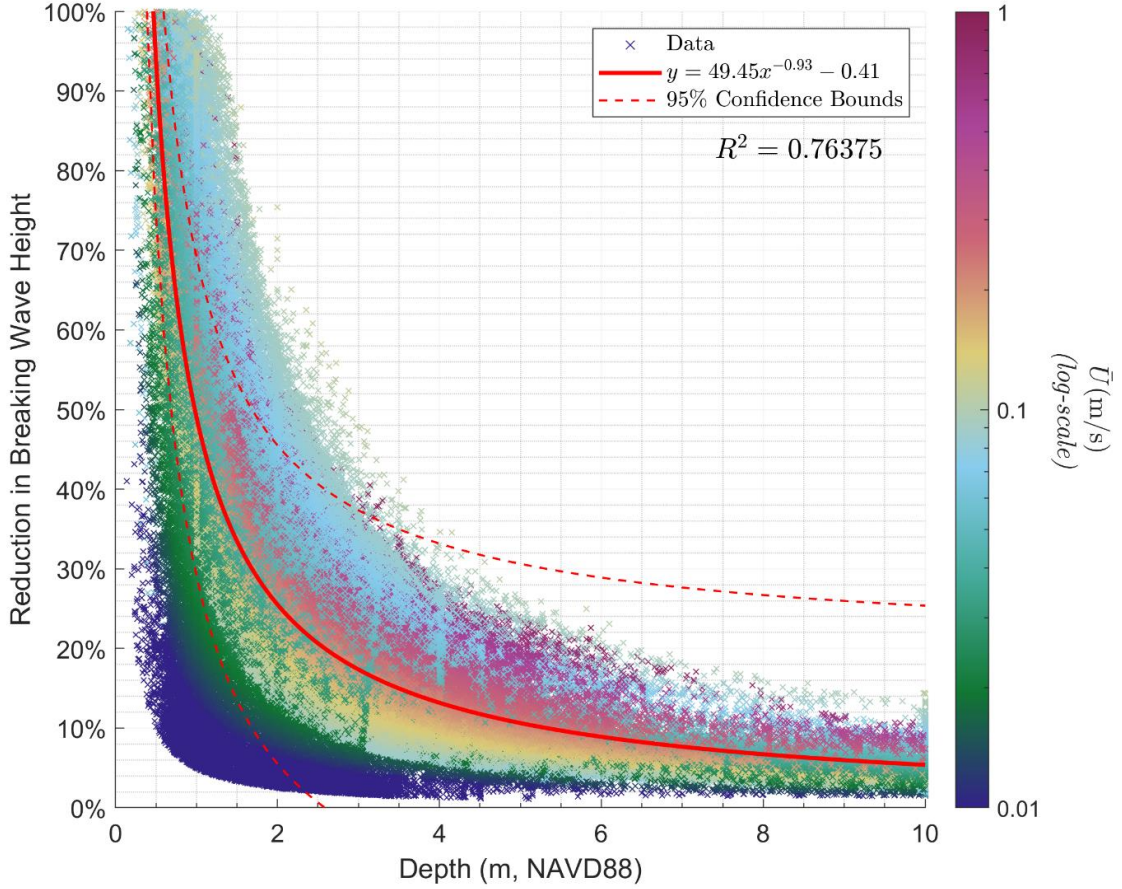
γ: breaker index (~0.78)

h_b: mean water depth at point of breaking



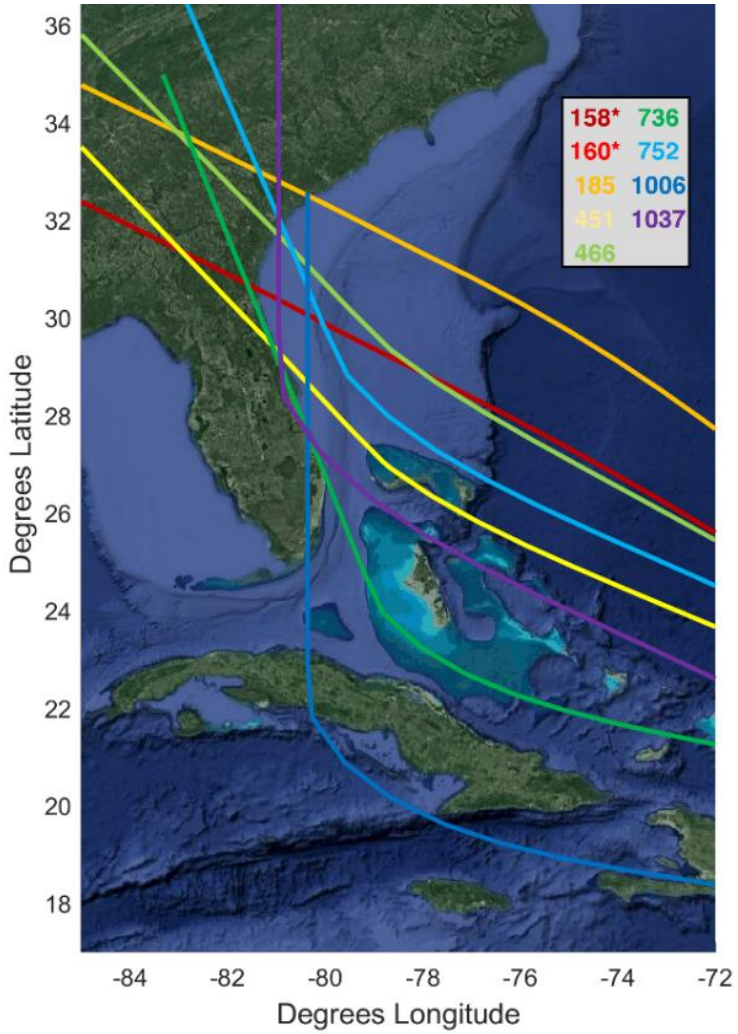
Predicted Oyster Reef Height → **New Bathymetry**



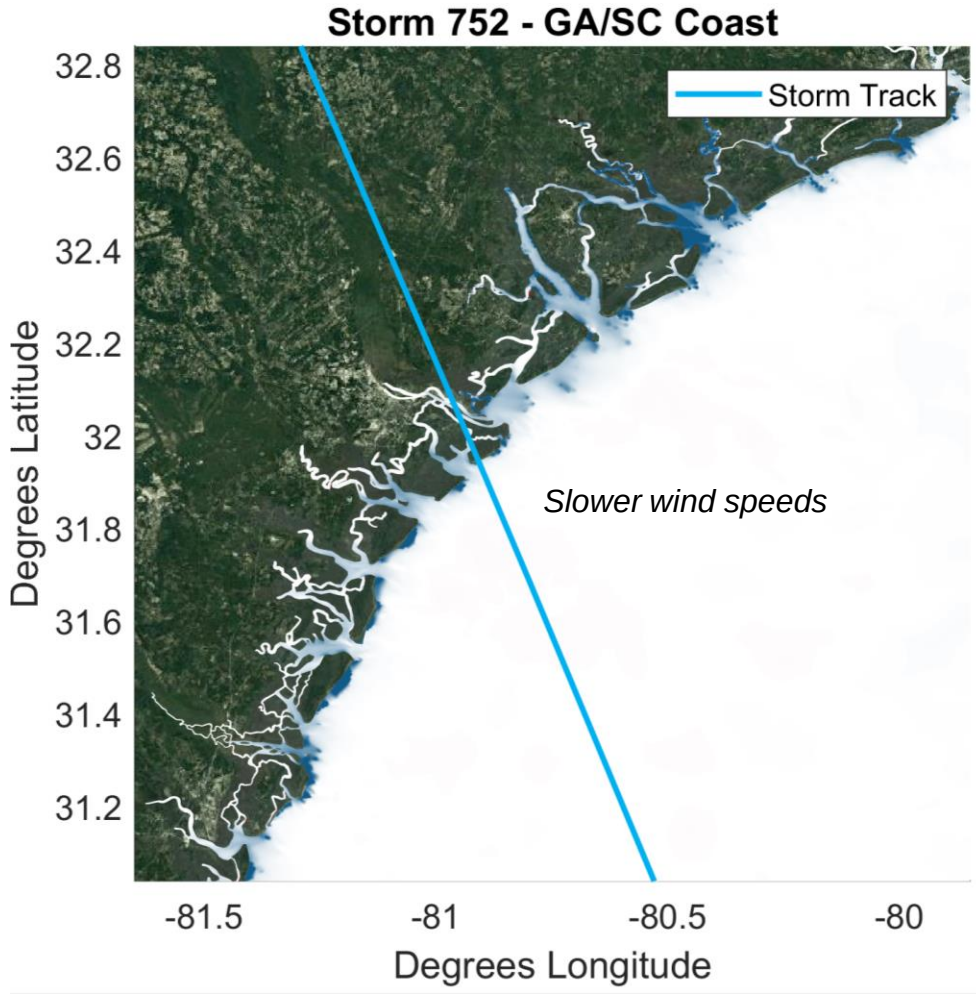


Predicted Oyster Reef Height → **New Bathymetry**

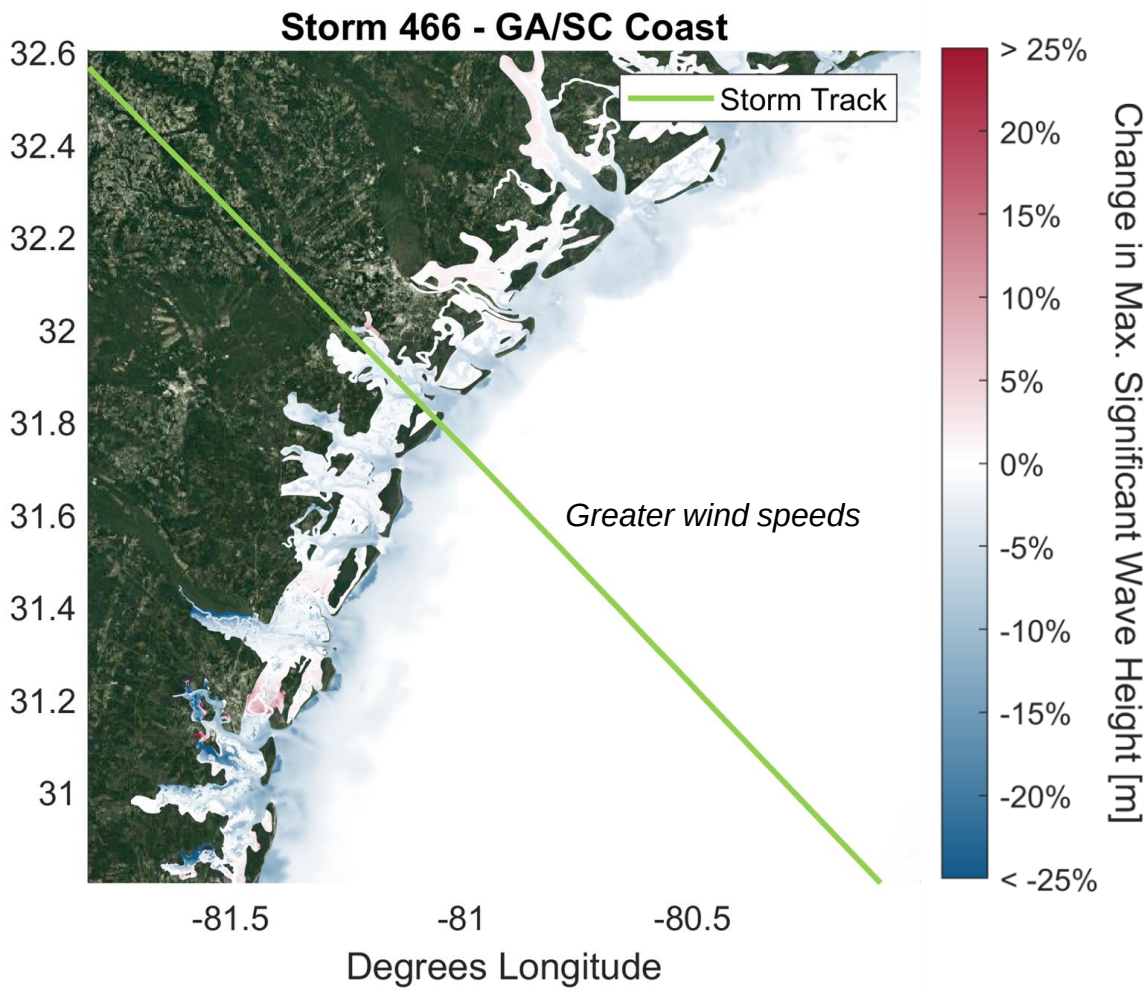
Depth-limited, not speed-limited!



New Bathymetry → **3. Storm Simulations (ADCIRC + SWAN)**

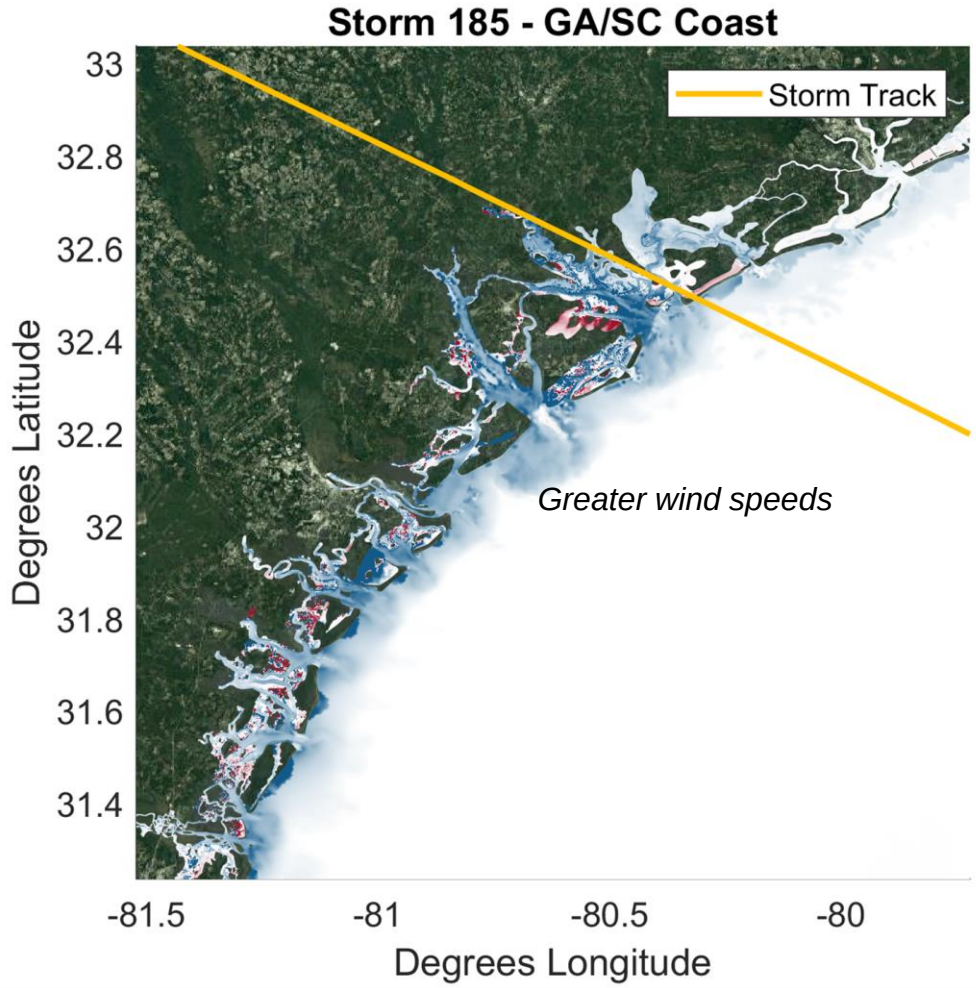


θ	∂P	r_{max}	$v_{w,max}$
-20°	8 hPa	82.9 km	37.89 mph

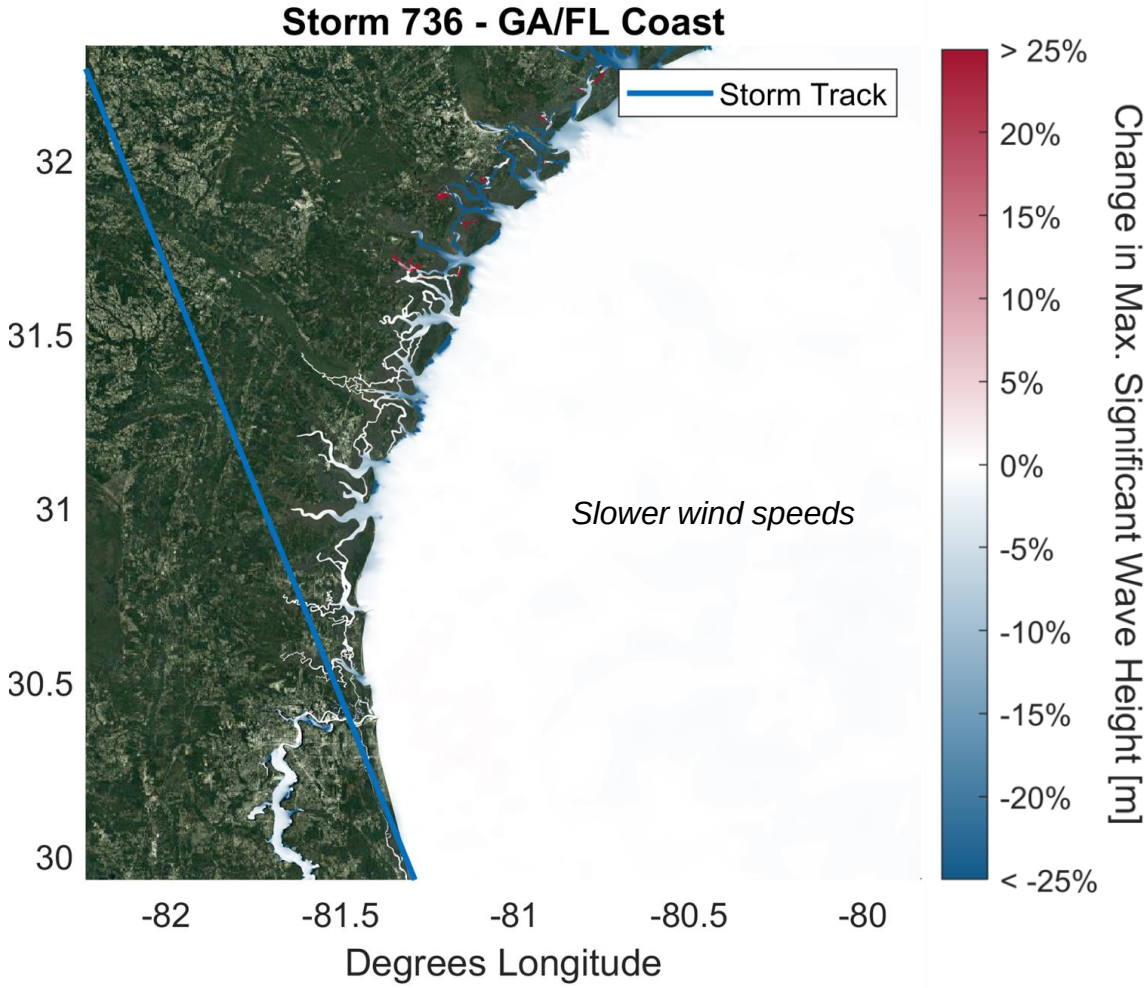


θ	∂P	r_{max}	$v_{w,max}$
-40°	138 hPa	43 km	120.5 mph

Max. Significant Wave Height → **Wave Attenuation**



θ	∂P	r_{max}	$v_{w,max}$
-60°	48 hPa	26 km	77.93 mph



θ	∂P	r_{max}	$v_{w,max}$
-20°	8 hPa	142.3 km	29.01 mph

Max. Significant Wave Height → **Wave Attenuation**

Conclusions

Oyster response to hydrodynamic conditions

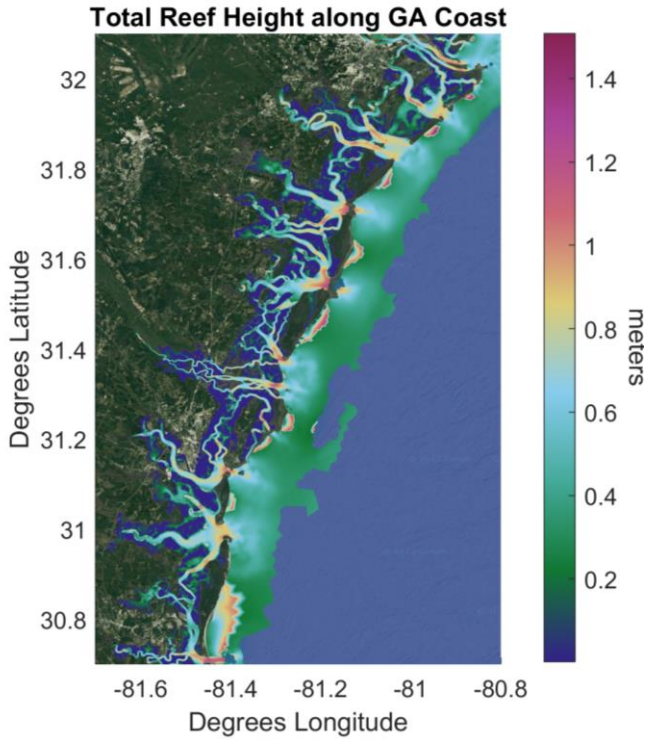
- Total reef height has strongest correlation with flow speed

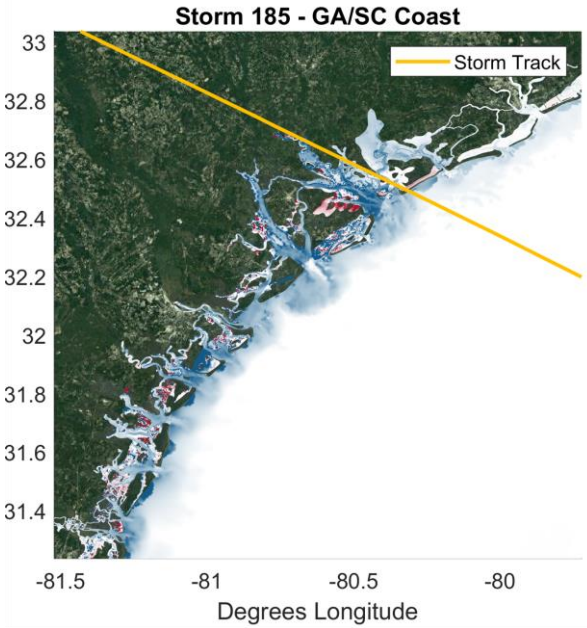
Conditions associated with greatest final height

- Highest steady-state reef height achieved at the greatest flow speed that does not result in sediment deposition onto the reef

Wave Attenuation

- Overall reduction of max. significant wave height across all simulated storms





Current/Future Work

Hydro-MEM: Integration of MEM (Marsh Equilibrium Model - Morris et al., 2002) and ADCIRC (Hagen et al., 2013)

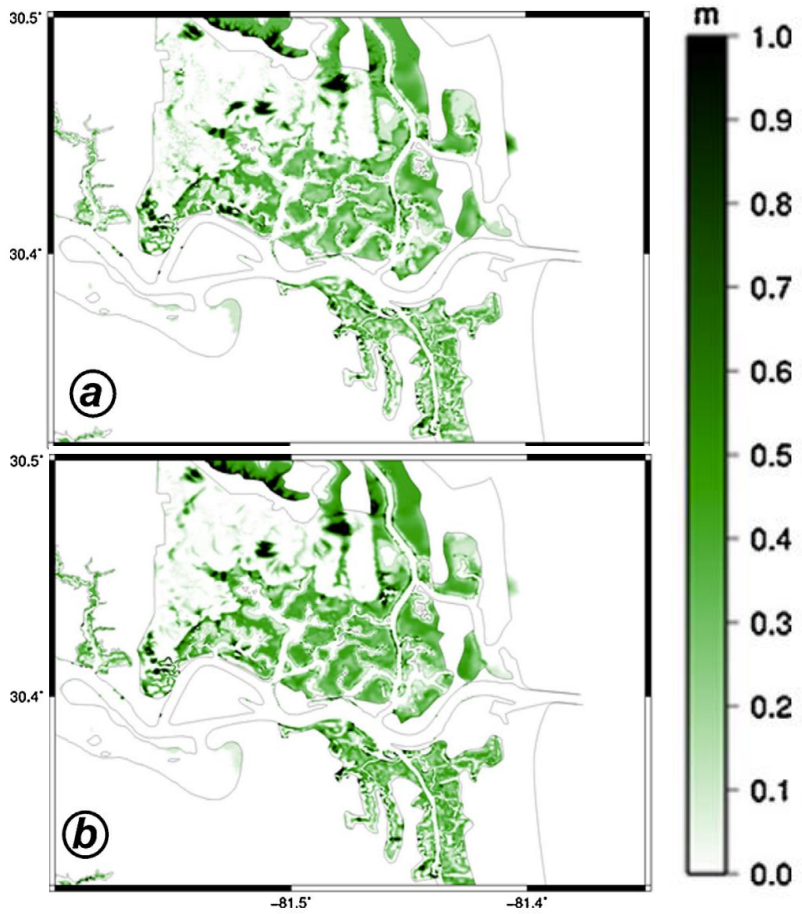
- Examines SLR impact on salt-marsh productivity

Current Hydro-MEM Adaptations (Alizad et al., 2016):

- Spatially dependent marsh platform accretion
- Manning's *n*
- Biophysical feedbacks between biomass density and hydroperiod

Future Work

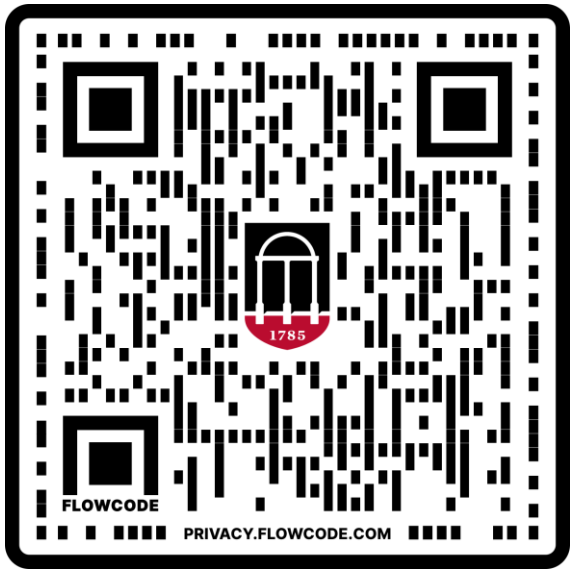
- Is there a better way to obtain MLW in a marsh other than interpolation?
- What level of stream order optimizes accuracy of results vs. computational expense?
- Expansion of model domain to South Atlantic Bight



Adapted from K. Alizad et al., (2016)

Thank you!

COAST Lab:



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