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The State of the Art and Science of Coastal Engineering

NNBF Short Course: Reefs and Vegetation



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Motivation

Coastal Wave Impacts:

- Runup / Overtopping
- Drive nearshore currents
- Move sediment
- Damage infrastructure

Reefs and Vegetation:

- Attenuate waves
- Reduce water levels & currents
- Reduce coastal erosion



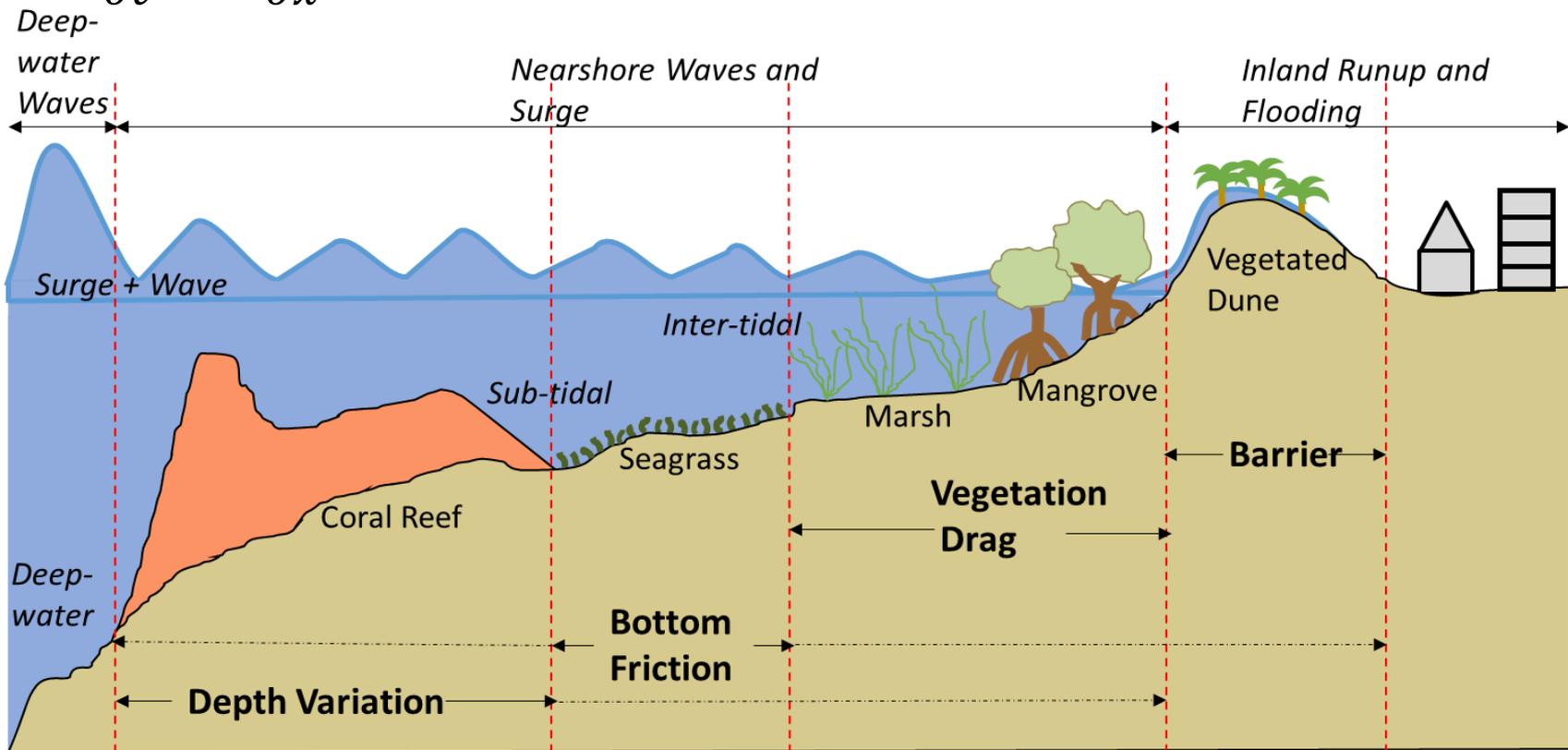
Modeling Nearshore Waves

Model Features	Phase – Averaged	Phase - Resolved
Key Equations	Energy Flux	Boussinesq-type
Wave Linearity	Linear	Non-linear (3-way interactions)
Wave Breaking	Depth-limited	Empirical
Reflection & Diffraction	Neglected	Included
Dissipation & Transmission Within Reef	Neglected	Neglected
Examples	SWAN	XBEACH



Wave Height Reduction Across Coastal Habitats

$$\frac{\partial N}{\partial t} + \frac{\partial C_{g,x}N}{\partial x} = -\mathbf{D} = -(\mathbf{D}_b + \mathbf{D}_f + \mathbf{D}_{veg})$$



Wave Energy Proportional to H^2

From Narayan et al. 2016



Reefs

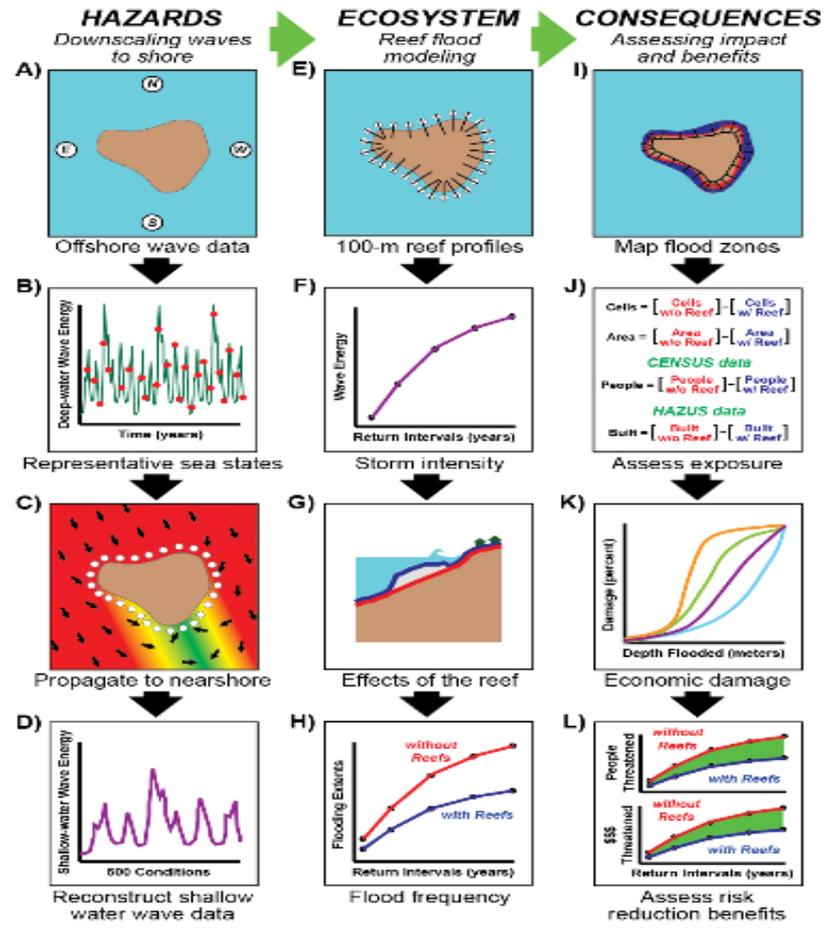
Natural and artificial reefs provide wave dissipation to reduce wave impact on the shoreline

Reef Types

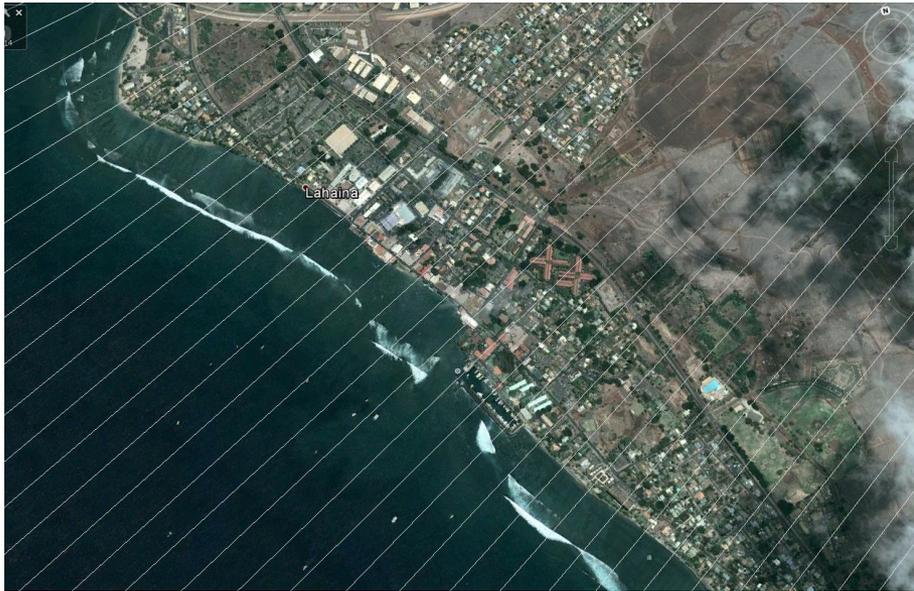
- Natural Reef
 - Coral
 - Rock
- Artificial Reef Structures
 - Submerged
 - Emergent
- Others
 - Oyster



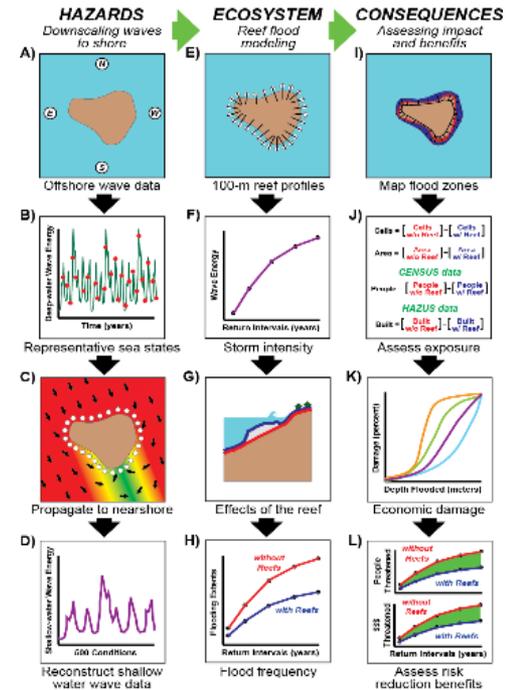
Modeling Waves on Reefs: Example From the USA



Modeling Waves on Reefs: Example From the USA



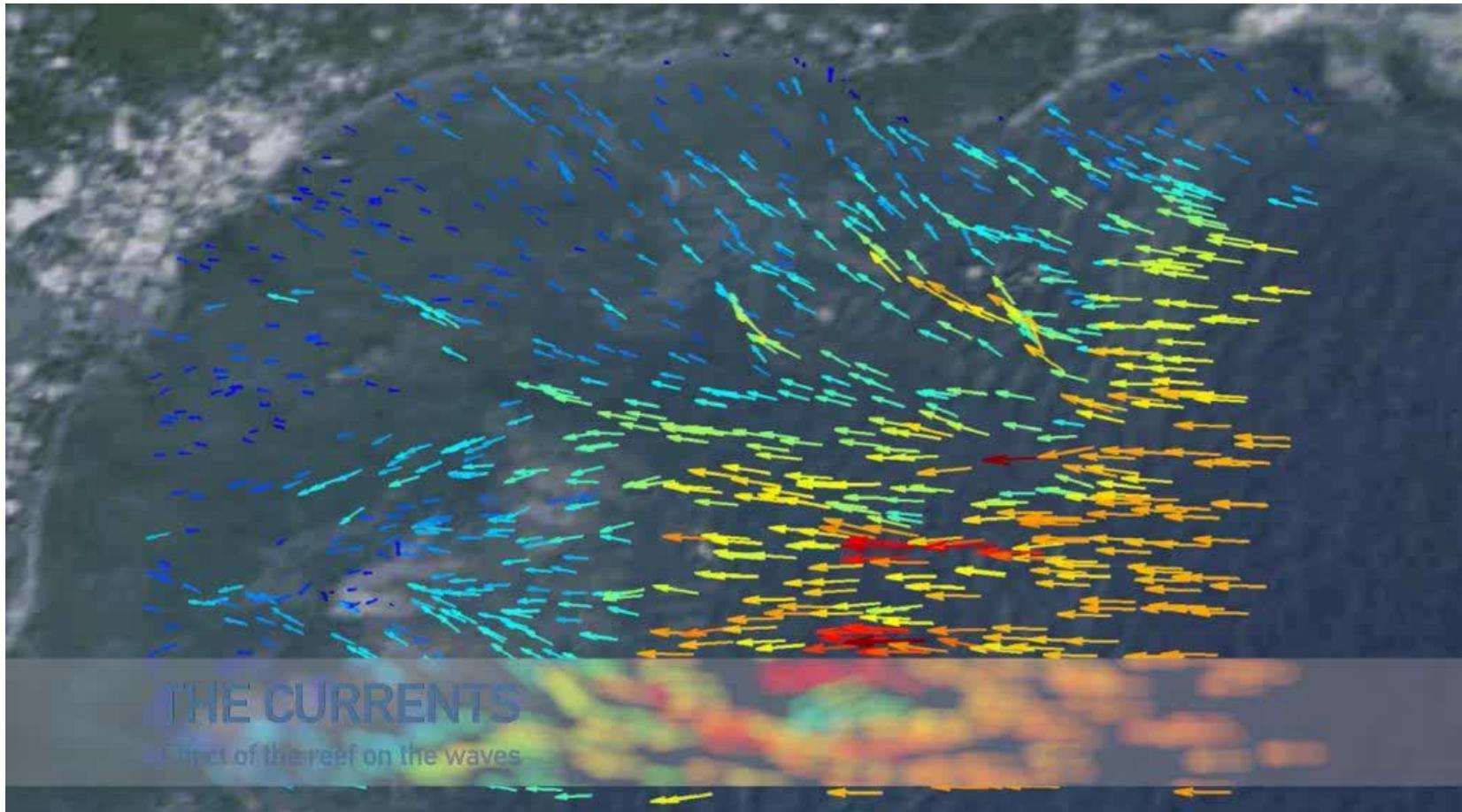
- Transects every 100 m (30,167 total)
- Non-linear wave model XBeach
 - Wave propagation
 - Long waves
 - Sediments and Currents
- Originally for sandy beaches – configured for coral reefs



A Coastal Problem Due To Reef Loss: Grenville Bay, Grenada

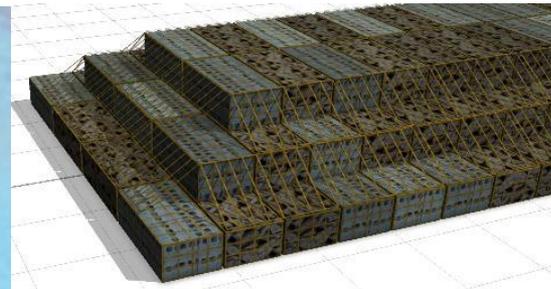


Designing Reef Restoration for Coastal Resilience: Grenada



Designing Reef Restoration for Coastal Resilience: Grenada

2-tier pilot submerged breakwater structure (this one with blocks) with corals from the nursery placed along their sides



Designing Reef Restoration for Coastal Resilience: Grenada



Coral transplants have stabilized or the rate of loss has decreased



Fish usage is high, and continues to attract attention from the local fishers



Oyster Reefs For Shoreline Stabilization: MacDill Air Force Base



Benefit #1: Shoreline stabilization – reduce wave energy; trap sediment

Benefit #2: Water Quality Improvement

Benefit #3: Habitat Enhancement – diversity, encourages marsh /mangrove recruitment

Limitation #1: Porous, less effective than coral reefs

Limitation #2: Prefer low wave-energy environments

From Kirkpatrick, 2013.

<http://www.oyster-restoration.org/wp-content/uploads/2013/02/9.-Jason-Kirkpatrick.pdf>



Field Studies



Lab Studies of Waves on Reefs



Reef Summary

- Empirical, numerical, and lab tools to evaluate wave dissipation by reefs
- Research needs:
 - Characterize stability
 - Characterize porosity (dissipation/transmission)
 - Field and Lab Studies for Validation
 - General Parameters for Simplified Models
 - Design guidance
 - Quantify additional environmental benefits



Vegetation

Vegetation provides wave dissipation to reduce wave height as a function of:

- Stem height
- Stem diameter
- Stem density
- Length of vegetation field
- Stiffness of the vegetation
- Submergence depth
- Wave parameters
- Drag coefficient

Morison-type equation

$$D = \frac{g^2}{16\sqrt{\pi}} C_D b_v N \left(\frac{T_p}{L} \right)^3 \frac{\sinh^3 kah + 3 \sinh kah}{3k \cosh^3 kh} H_{rms}^3$$

Dalrymple (1984)

Mendez and Losada (2004) ~ irregular waves



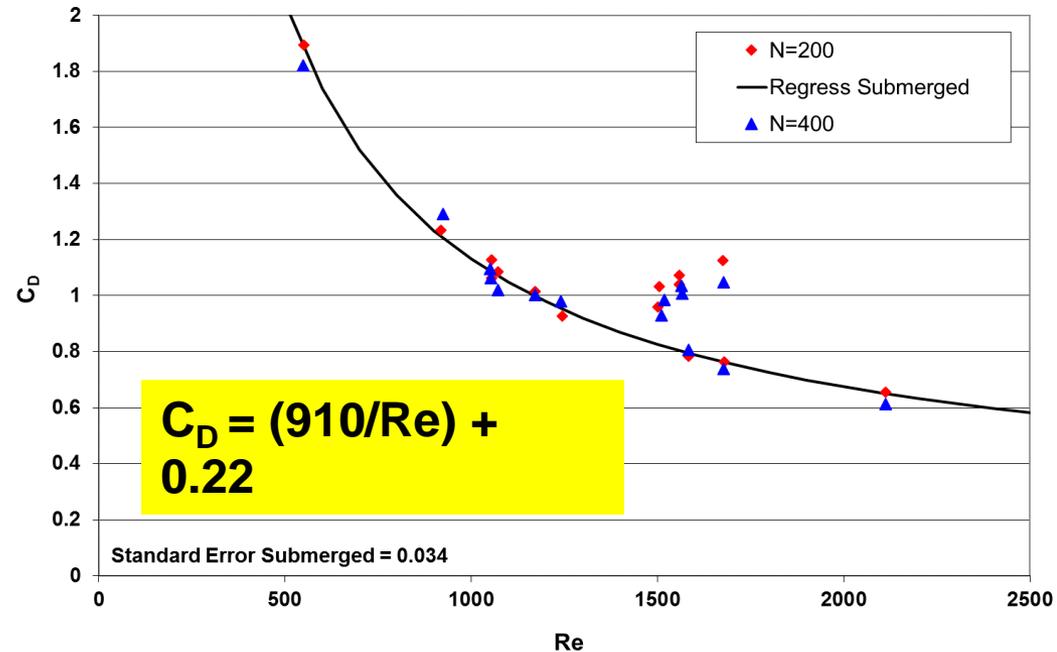
Bulk Drag Coefficient C_D

Drag coefficient parameterized based on lab or field data

- Reynolds number
- Keulegan-Carpenter number
- No comprehensive formulation for C_D
 - Vary with season
 - Vary with depth/submergence
- >70 parameterization in literature (mostly lab based)

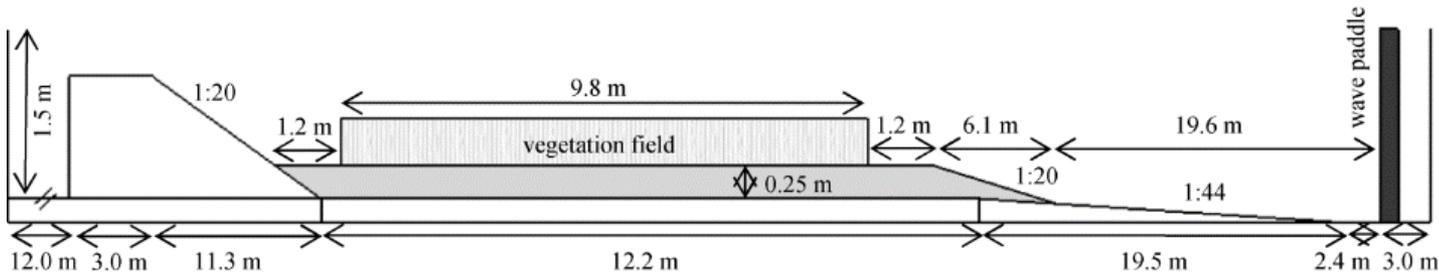
$$Re = \frac{u_c d}{\nu}$$

$$KC = \frac{u_c T_p}{b_v}$$



u_c ~ characteristic velocity, d ~ depth, ν ~ kinetic viscosity, T_p ~ peak wave period, b_v ~ stem diameter

Lab Experiments (Anderson & Smith 2014)



Three water depths (h):

30.5 cm, 45.7 cm, 53.3 cm

▶ correspond to l_v/h ratios of
1.0 (emergent), 0.91, 0.78

Irregular waves

▶ $T_p \sim 1.25$ s to 2.25 s

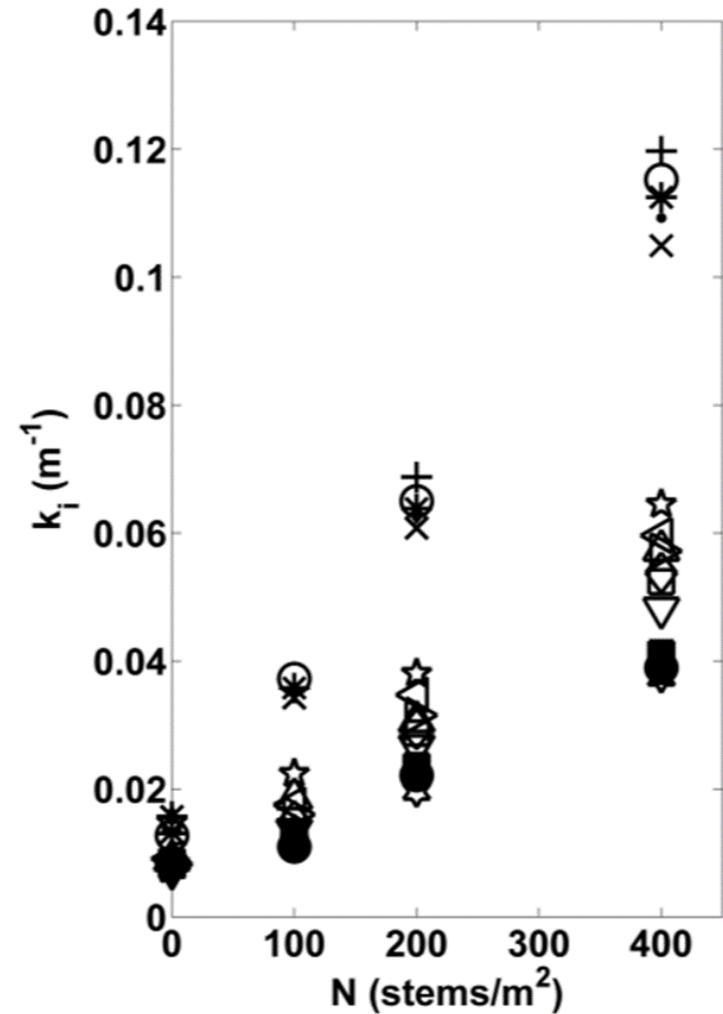
▶ $H_{m0} \sim$ ranging from 5.0 cm to
19.2 cm



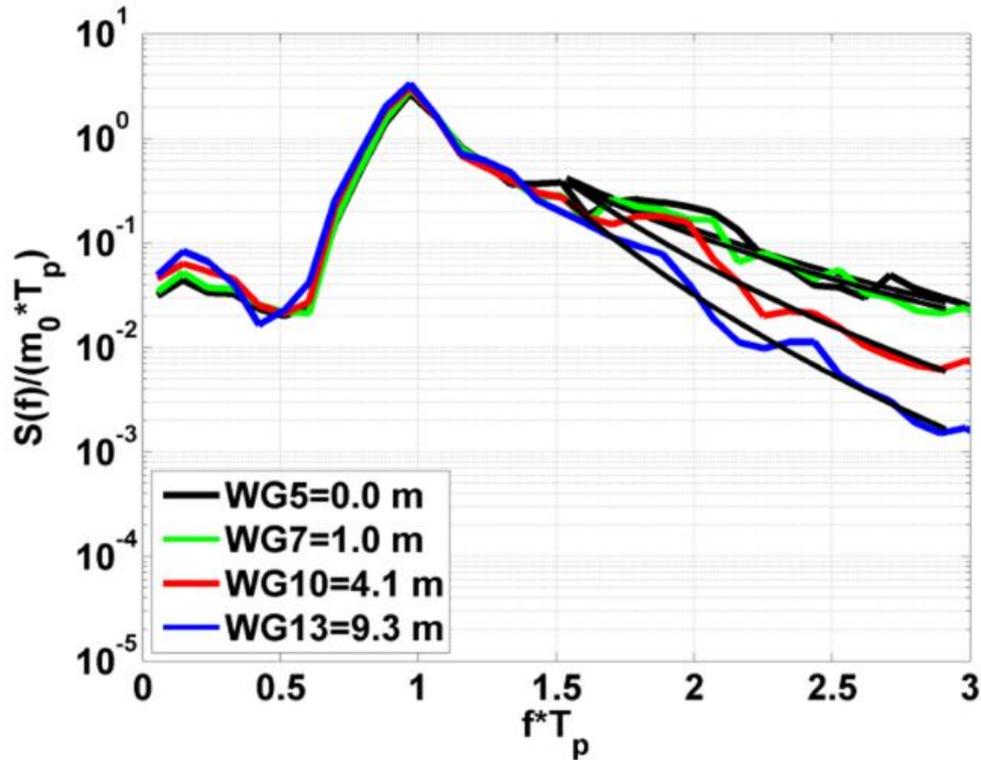
Trends in Wave Attenuation

Wave attenuation was found to:

- increase with stem density
- increase with submergence ratio
- slightly increase with incident wave height
- marginally decrease with longer waves during emergent conditions



Wave Spectra

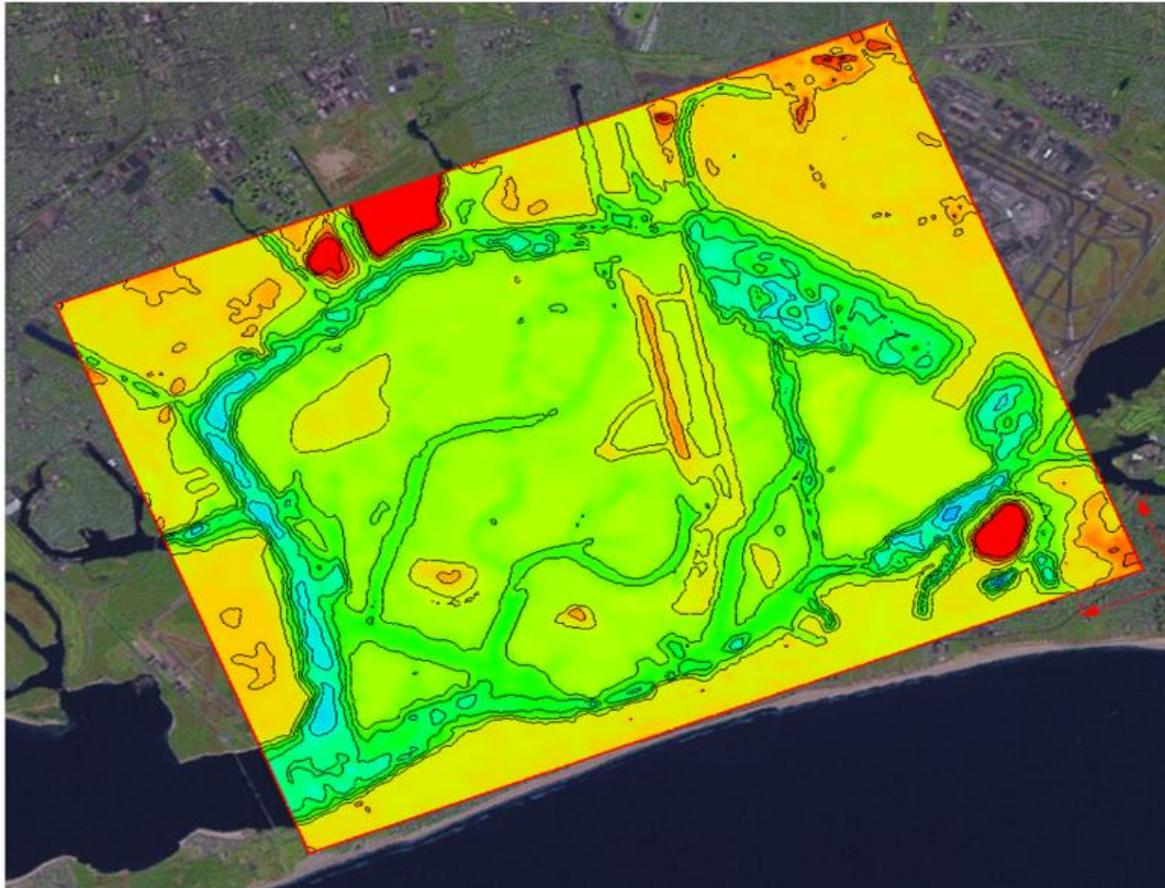
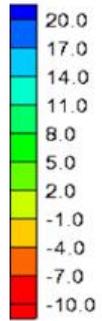


- Deviations of slope of spectral tail, $1.5f_p$ to $3f_p$
- Preferential dissipation of higher frequencies
- dissipation of higher frequencies dependent on stem density and submergence ratio



Example: Jamaica Bay, NY

Depth [m]



Bathymetry



Simulations with Spectral Wave Model (STWAVE)

Three wind & water level combinations

18.5 m/s winds, 1.3 m WL

22.1 m/s winds, 2.0 m WL

26.0 m/s winds, 2.9 m WL

Four vegetation states

No vegetation, existing bathymetry

Existing vegetation and bathymetry

Moderate vegetation w/ modified bathymetry

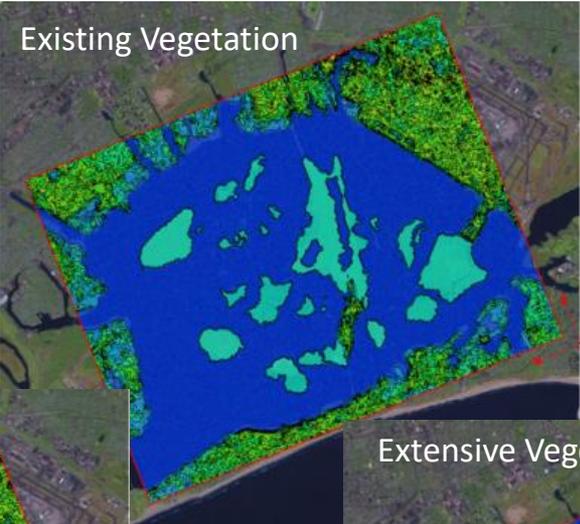
Extensive vegetation w/ modified bathymetry

Spartina alterniflora in the low marsh, *Spartina patens* in the high marsh, and *Phragmites*

$C_D \sim 0.35$, $N = 400$, $b_v = 0.6$ cm

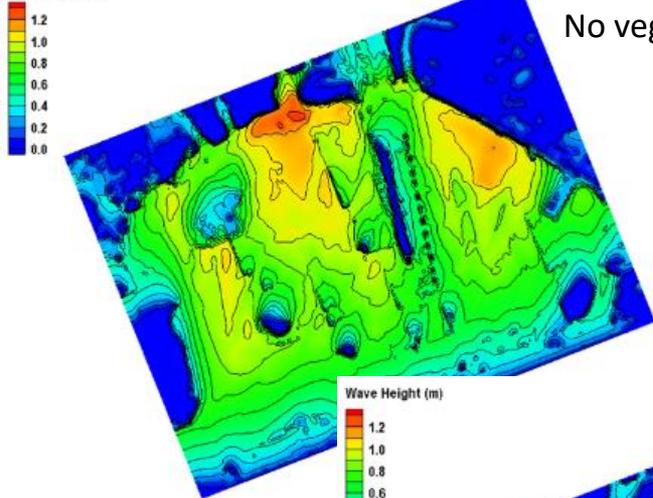


Vegetation States



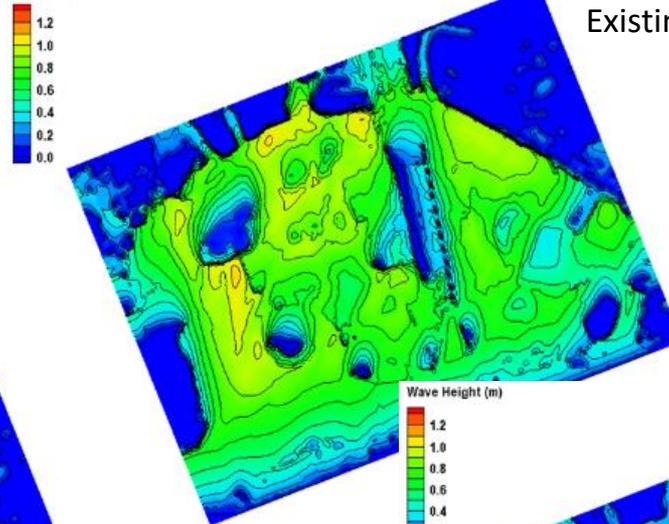
26 m/s winds, 2.9 m WL

Wave Height (m)



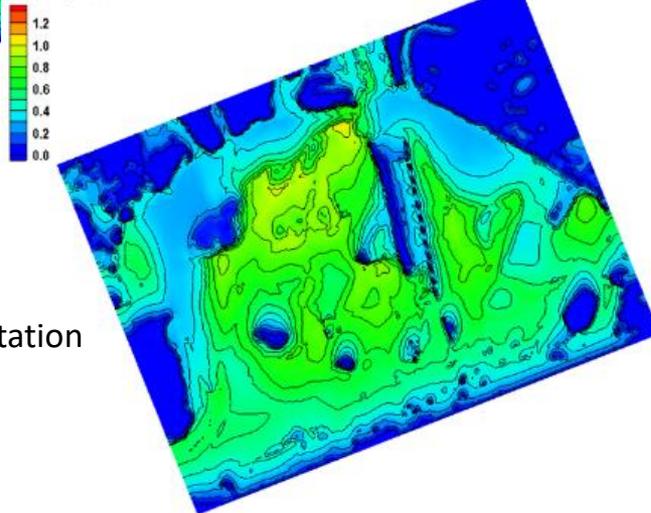
No vegetation

Wave Height (m)



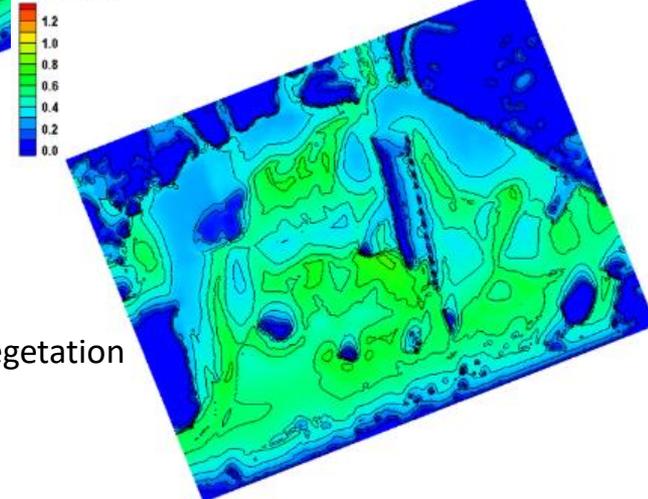
Existing vegetation

Wave Height (m)



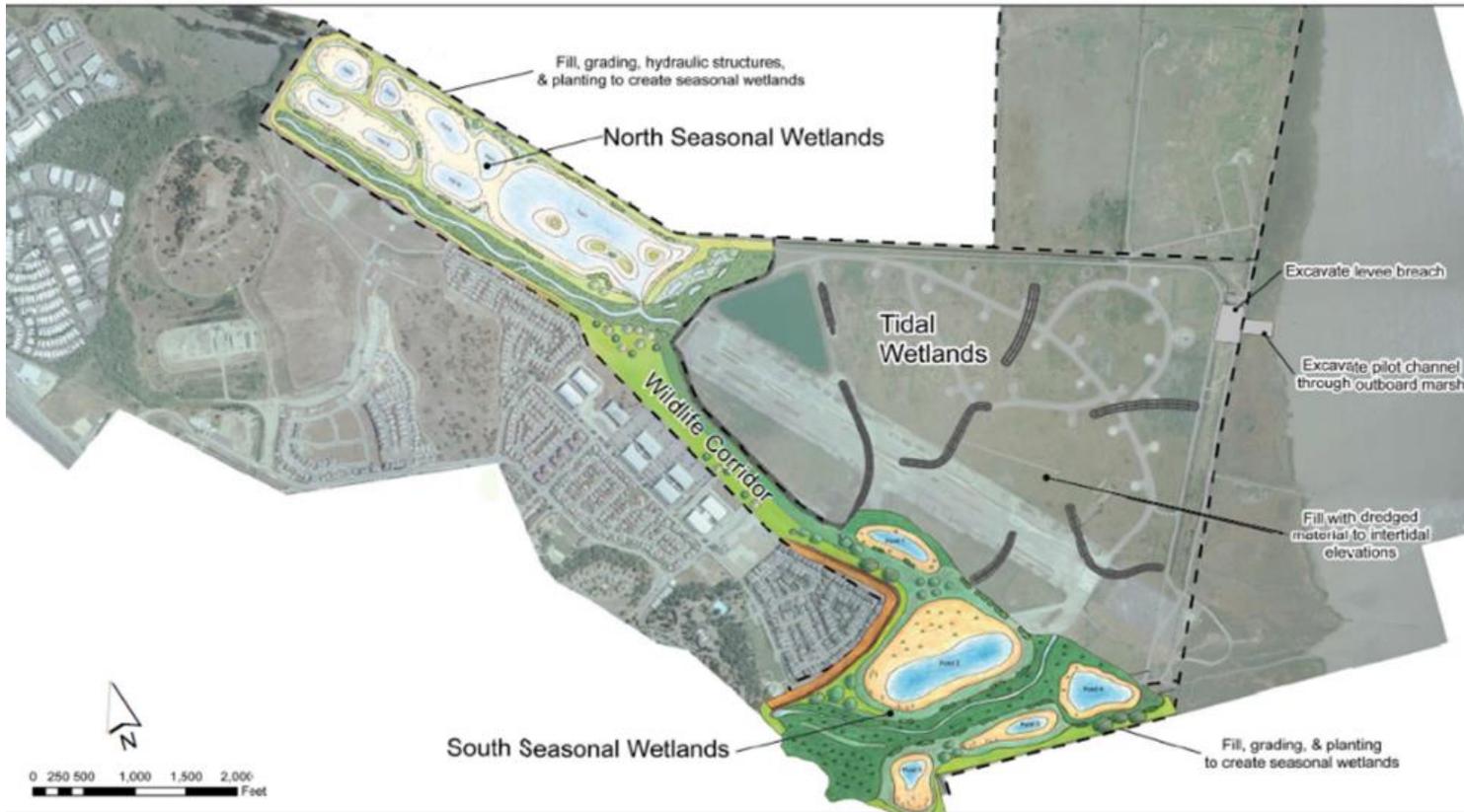
Moderate vegetation

Wave Height (m)



Extensive vegetation

Example: Hamilton Wetland, California



Example: Hamilton Wetland, California

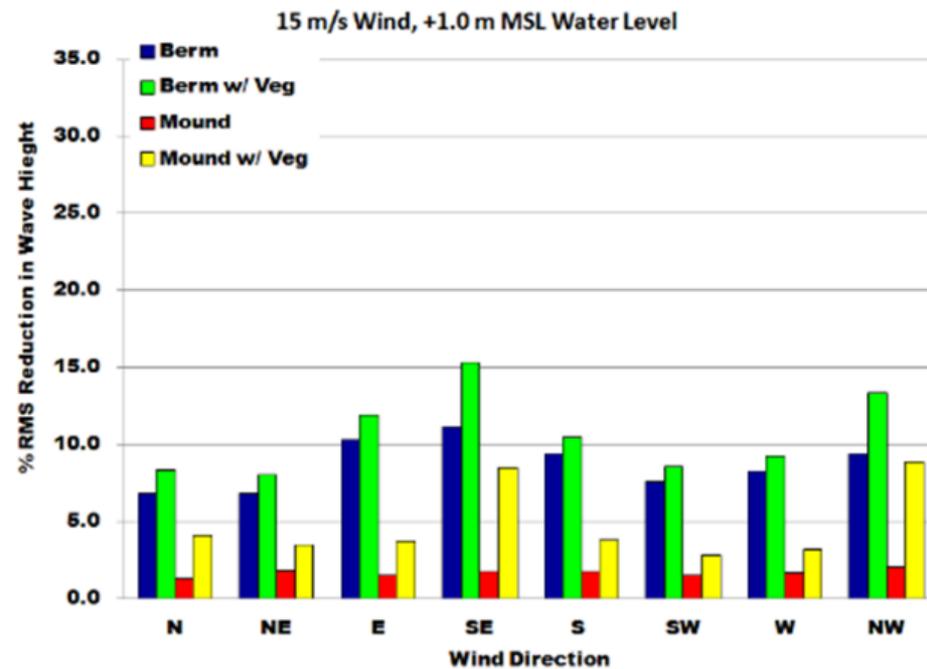
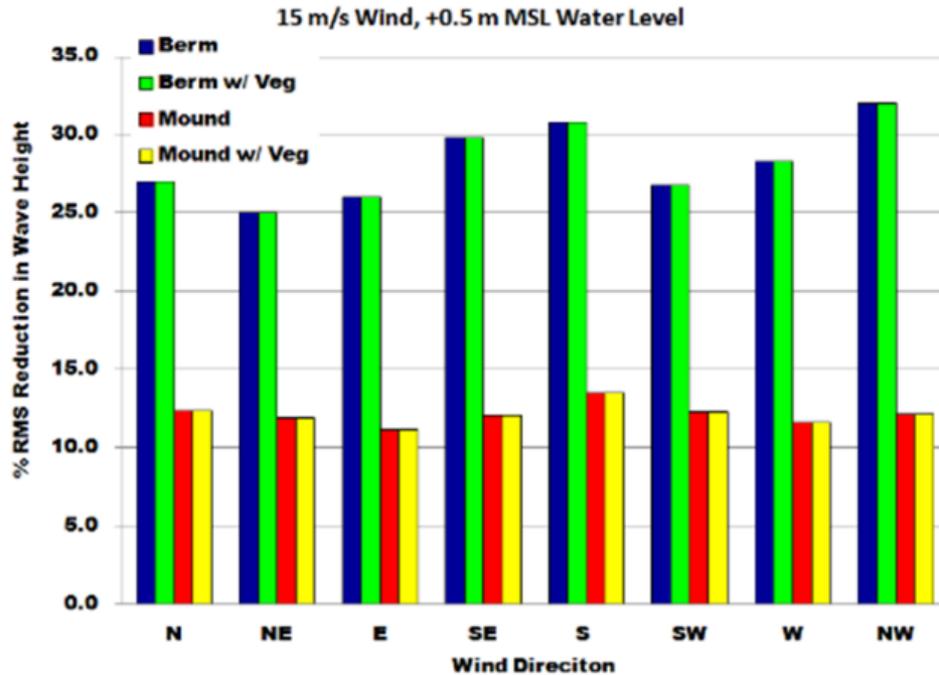
Compare wave reduction for Berms (linear feature) vs. Mounds (circular feature)

Numerical simulations:

- Winds of 15 and 20 m/s (14-yr wind record at Richmond, CA)
- Water levels of + 0.5 and +1.0 MSL
- 8 wind directions (N, NE, E, SE, S, SW, W, NW)
- With and without vegetation
 - Pickleweed
 - Within depth range of +0.4-0.95 m MSL
 - $C_D = 0.1$, stem height=0.6 m, density = 300/m² diameter = 0.01 m (Northwest Hydraulic Consultants 2011)



Example: Hamilton Wetland, California



Linear berms produced a greater reduction in wave height than circular mounds:

25-32% at 0.5m MSL Berms versus 11-14% at 0.5m MSL Mounds

Wave height attenuation by berms AND mounds decreases significantly once they are submerged (75% reduction 1m v. 0.5m MSL)

Vegetation increases wave height reductions (when vegetation is submerged), vegetation impact greater for circular mounds



Vegetation Summary

- Wave dissipation is key, but other factors may come into play for reducing currents and sediment transport
- Need sufficient “space” for dissipation
- Research needs:
 - Better characterization of vegetation types and C_d
 - Understanding of resilience to storms (breakage, failure, recovery)
 - Seasonal variability
 - Validation
 - Design guidance



Thank You

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Photo credit: Metthea Yepsen, TNC