

Effect of restored reef geometry on sediment retention under different tidal and wave conditions



Authors: Jacopo Composta, Alberto Canestrelli, Rafael O. Tinoco, William Nardin, Piero Ruol, Luca Martinelli, Duncan Bryant, Savanna Barry, Kamil Czaplinski, Stefano Biondi, Daniele Pinton



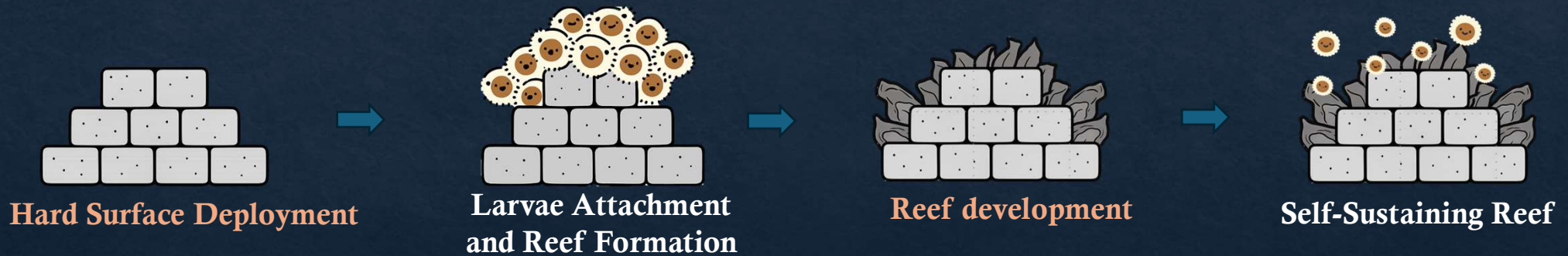
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Why Oyster Reefs?

Oyster reefs reduce wave energy, enhance sediment deposition, stabilize shorelines, and provide key ecological benefits like habitat and water filtration (Scyphers et al., 2011; Coen et al. 2007)



An oyster reef exposed during low tide (Photo credit: Jonathan Wilker/Purdue University)



Submerged reefs may stabilize coasts in some cases but can also induce erosion on both the lee and offshore sides. (Vona and Nardin, 2023; Klonaris et al., 2020, Ranasinghe, R., & Turner, I. L. (2006)

Objective

Quantify how oyster reefs retain sediments and stabilize shorelines under different wave and tide conditions, as well as reef geometries and locations.

Phase 1: Experiments at LSTF (CHL) Scale 1:1 Using Oyster Castles

(Led by Alberto Canestrelli, Rafel Tinoco, William Nardin, Jacopo Composta, Kamil Czaplinski, Stefano Biondi and Daniele Pinton)

Phase 2: Numerical Simulations - Delft3D+SWAN and OpenFOAM

(Led by Jacopo Composta, Alberto Canestrelli, Daniele Pinton and Stefano Biondi)



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Physical experiment at LSTF

Beam in the gap



Beam over the reef



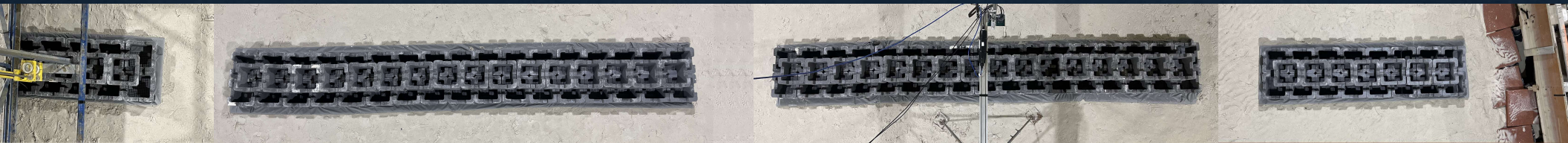
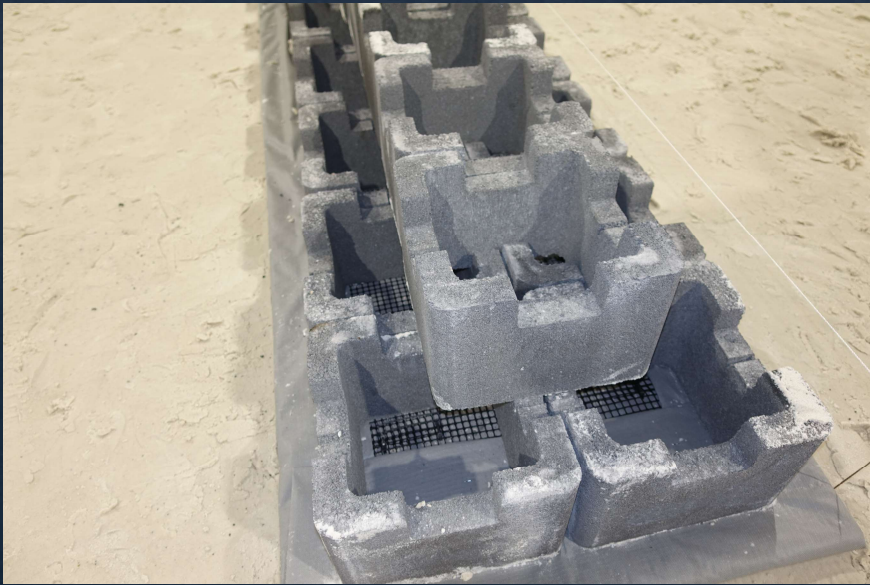
Instruments deployed :

- 17 Wave gauges
- 9 ADVs
- 8 CCP+ (high-resolution near-bed concentration profiles)
- 16 OBS (OpenOBS, suspended concentration)
- 3 ADCP (Nortek Signature 1000).



~ 20 scenarios (Geometrical Scale 1:1)

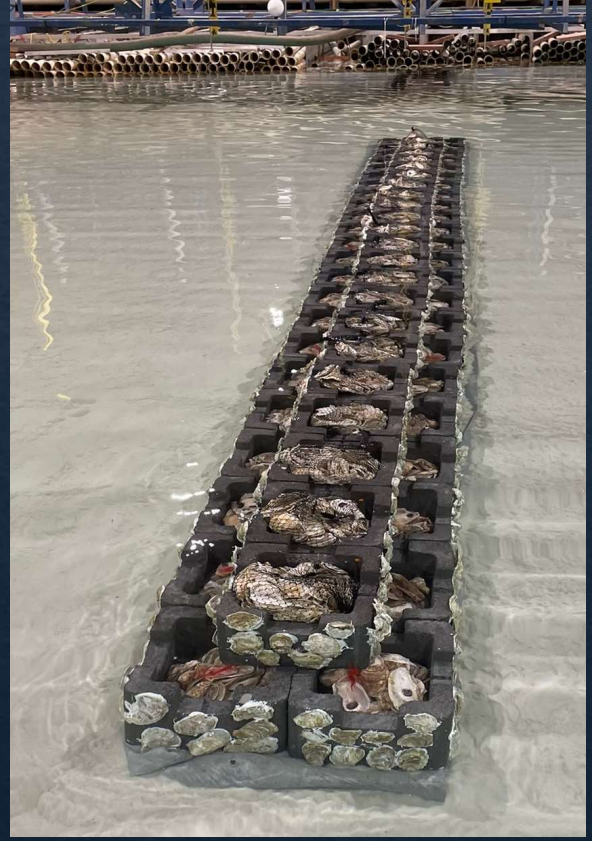
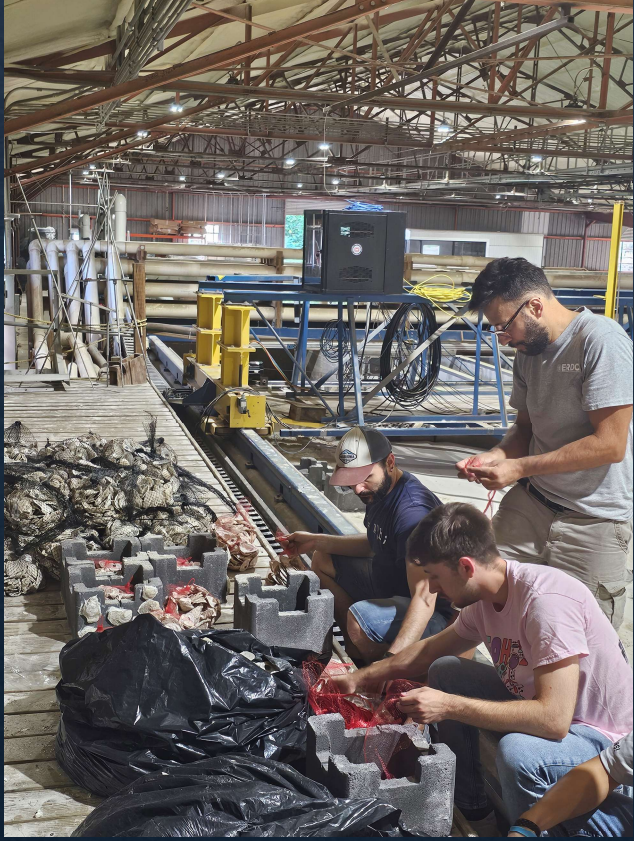
Reef Roughness Configuration 1 – Bare Castles



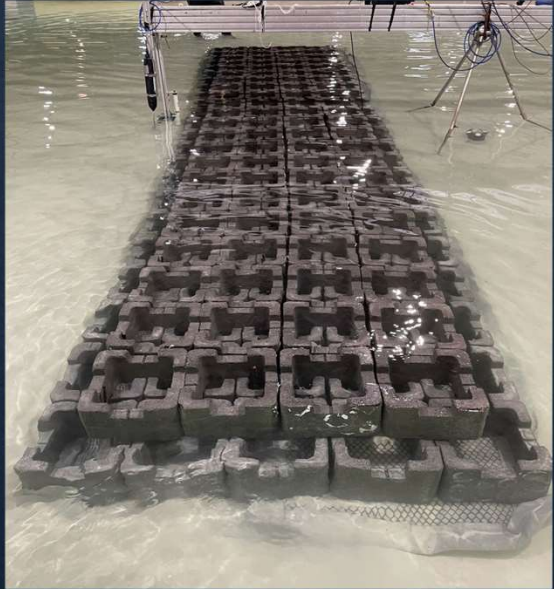
Reef Roughness Configuration 2 – Bare Castles



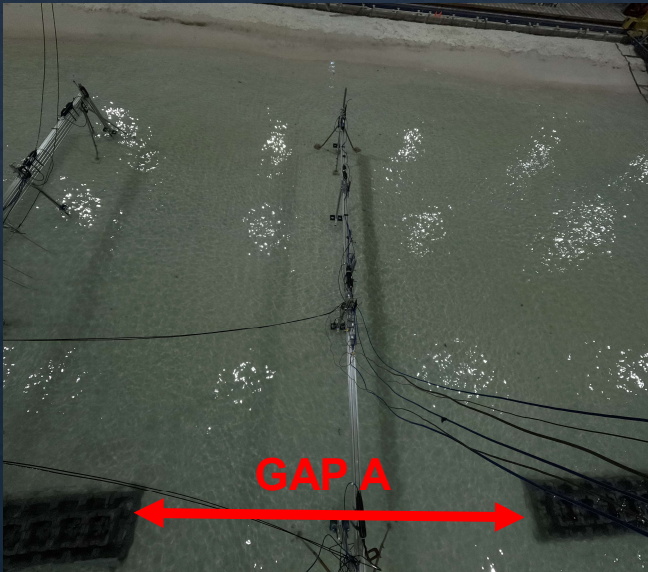
Reef Roughness Configuration 3 – Full Castles



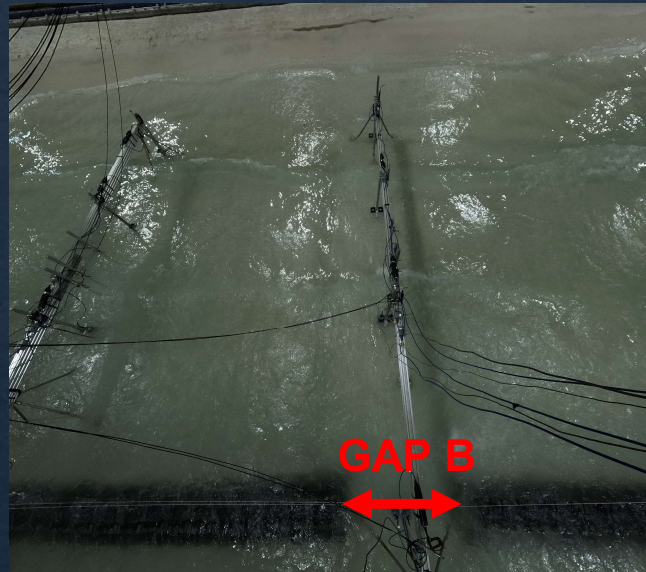
Effect of different width



Effect of different Gaps



$$L_G / L_R = 1$$



$$L_G / L_R = 1/3$$



$$L_G / L_R = 1/2$$

L_R = Reef length reef

L_G = gap length

Effect of shore distance



$S_D = 6 \text{ m}$



$S_D = 10 \text{ m}$

S_D = distance from the shoreline

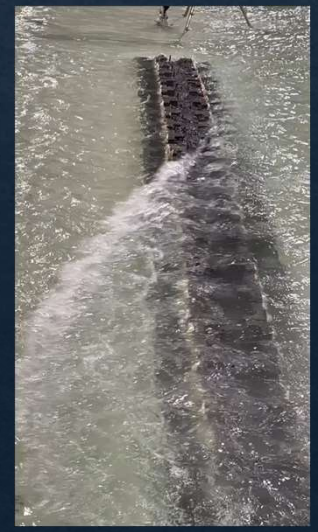
Different Wave Conditions

Irregular waves, 20° angle, TMA spectrum ($H_s = 0.25\text{m}$ $T_p = 2.3\text{s}$)

Hs [m]	0.25, 0.19, 0.17
Tp [s]	2.3, 1.9
Direction [°]	20, 0
Tidal range [m]	0.10
Tidal current	20% wave current
Wave spectrum	Regular, Irregular
Directional spreading (n)	2, 4



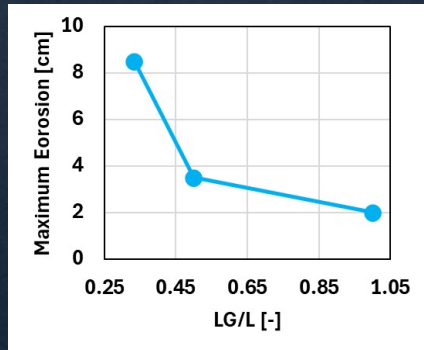
Recirculation pumps



Preliminary Results: morphology

TEST → TMA spectrum ($H_s = 0.25$ m, $T_p = 2.3$ s), $W_{DIR} = 0^\circ$, Gap C ($L_G / L_R = 1/2$)

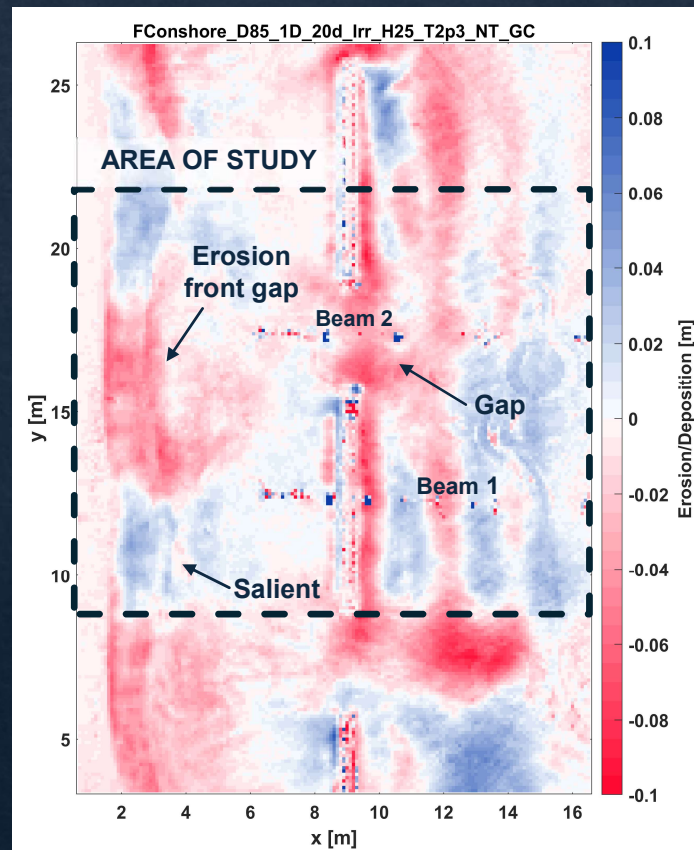
Full Castle → oysters + bags



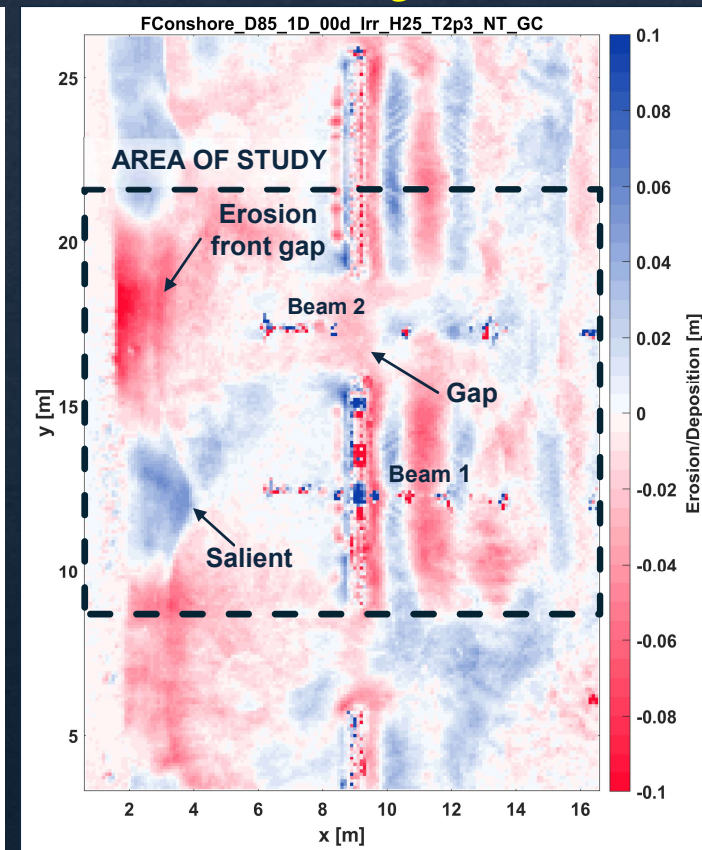
Smaller Gap
↓
LARGER GAP
EROSION



Inclined 20°

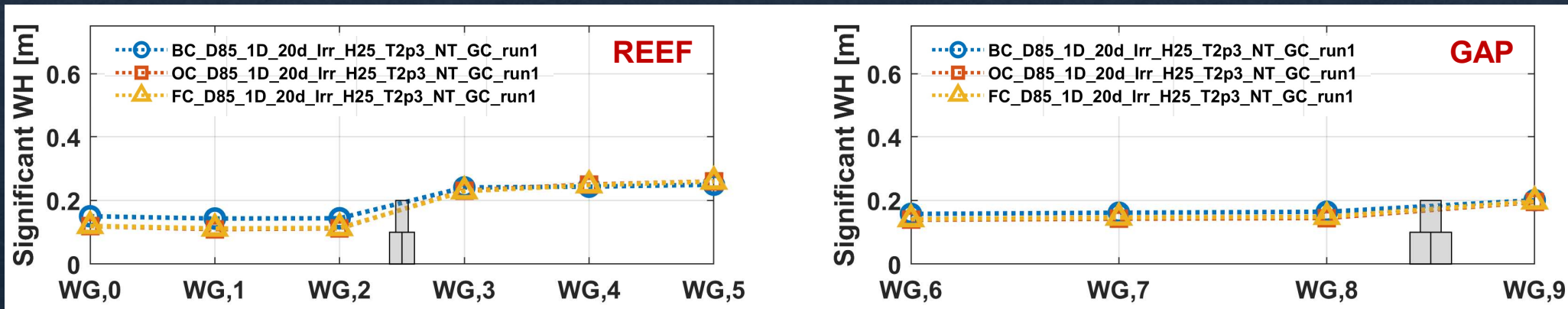


Orthogonal



Preliminary Results: Effect of Roughness and Porosity on Dissipation

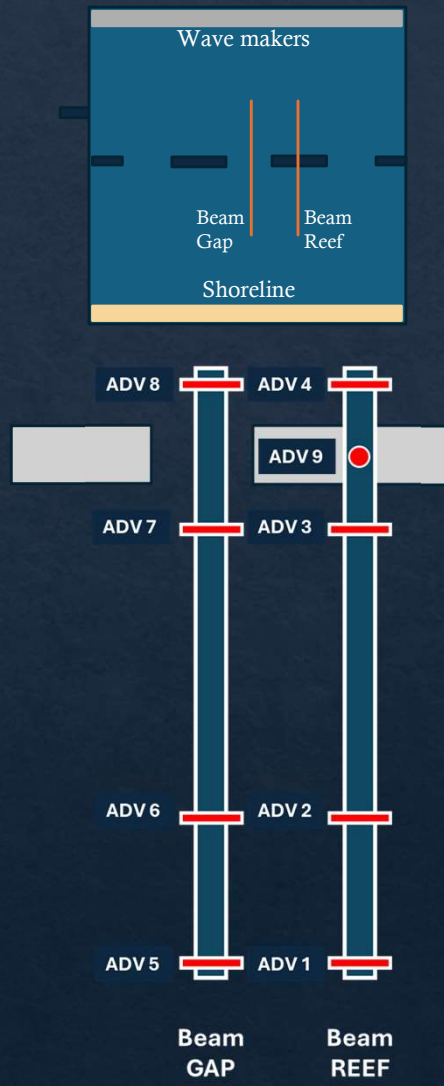
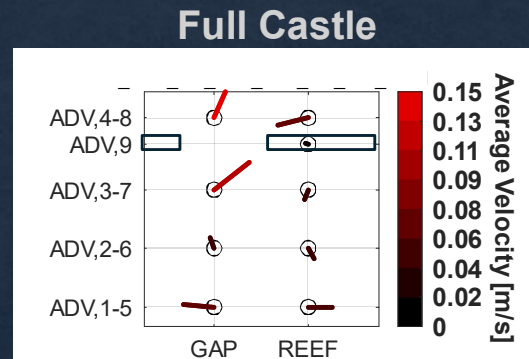
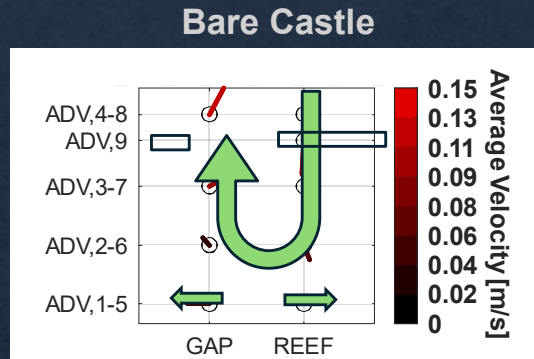
TES → TMA spectrum ($H_s = 0.25$ m, $T_p = 2.3$ s), $W_{DIR} = 20^\circ$, Gap C ($L_G / L_R = 1/2$)



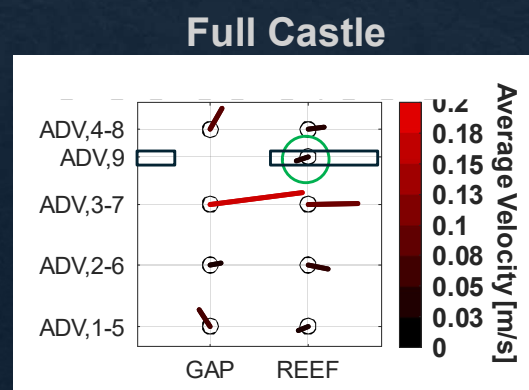
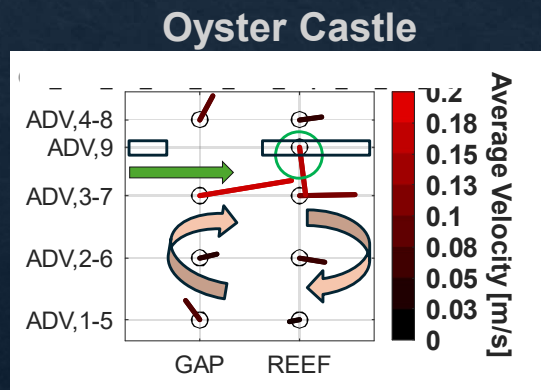
- Wave height reduced by 40% (from ~24 cm offshore to ~14 cm inshore)
- Shell roughness decreases transmissivity ($= \frac{H_{S,T}}{H_{S,I}}$) notably (0.49 with shells vs. 0.60 without shells)
- This decrease in transmissivity is observed also in the gap (0.75 with shells t vs. 0.82 without shells)
- The addition of oyster bags inside the oyster castles doesn't significantly change the transmissivity

Preliminary Results: Hydrodynamics

TMA spectrum ($H_s = 0.25$ m, $T_p = 2.3$ s), $W_{DIR} = 0^\circ$, Gap C ($L_G / L_R = 1/2$)



TMA spectrum ($H_s = 0.25$ m, $T_p = 2.3$ s), $W_{DIR} = 20^\circ$, Gap C ($L_G / L_R = 1/2$)

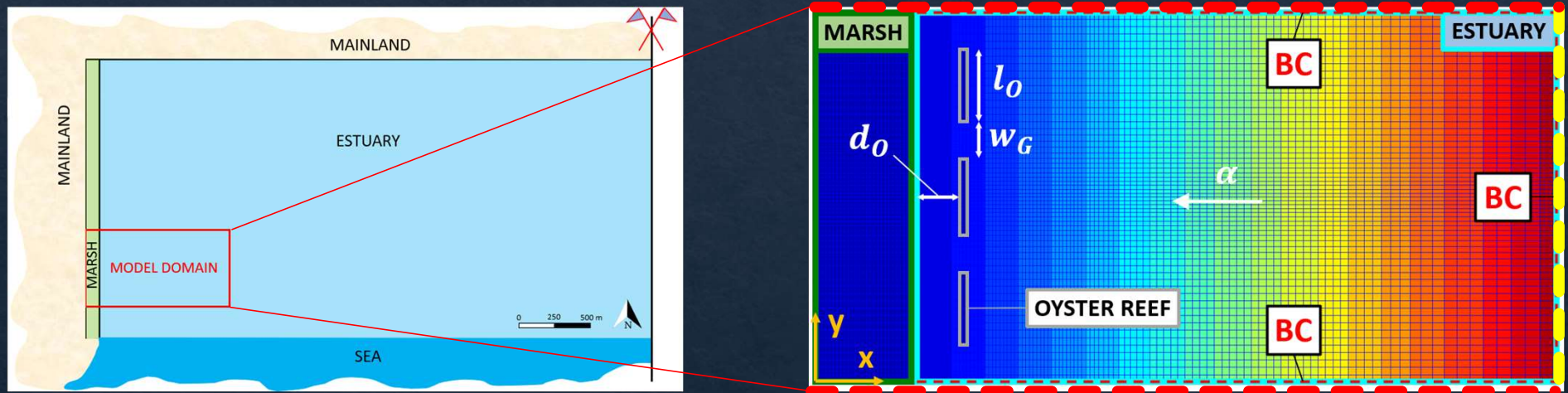


Conclusion

- The oyster reef system produced **substantial wave attenuation**, with wave height decreasing by approximately **40%** from offshore to inshore conditions.
- The presence of **shell roughness significantly reduced wave transmissivity**, indicating enhanced wave energy dissipation relative to the configuration without shells.
- The inclusion of **oyster bags within the oyster castles did not result in a measurable additional decrease in transmissivity**.
- Formation of the **salient** with both orthogonal and inclined waves.
- **Smaller gaps** lead to higher **scour** within the gap.
- **Longshore current** diffuses morphological features

Numerical Simulations - Delft3D+SWAN

Model set-up and description

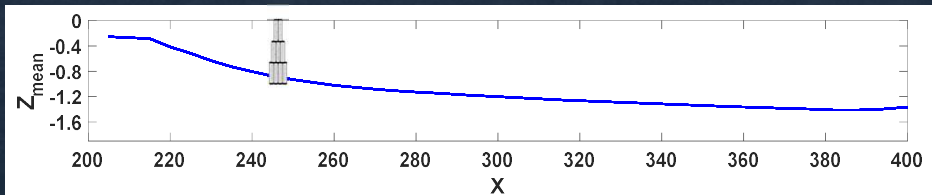


- - - Wave height and period are estimated using the semi-empirical relationships of Young & Verhagen, c (1996) as in Mariotti & Fagherazzi, (2013).
- - - Semidiurnal tide

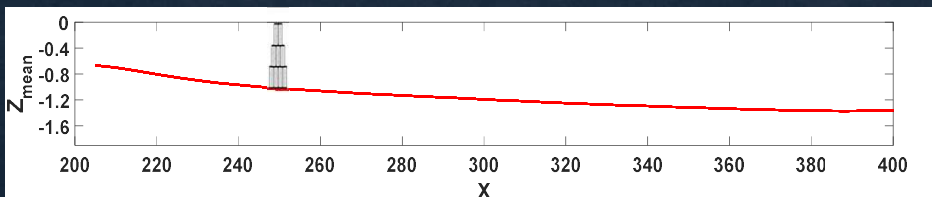
Numerical Simulations - Delft3D+SWAN

Equilibrium profiles

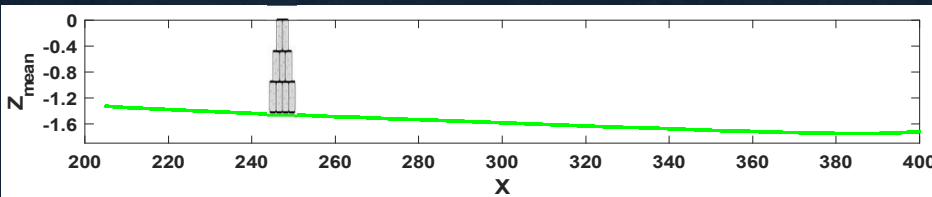
EQ1) $a = 0.6$ m, $w_s = 0.5$ mm/s, $Q = 30$ m³/s, angle = 45°, $H_s = 0.08$ m, $c = 0.03$ kg/m³



EQ2) $a = 0.6$ m, $w_s = 0.5$ mm/s, $Q = 60$ m³/s, angle = 0°, $H_s = 0.09$ m, $c = 0.03$ kg/m³



EQ3) $a = 0.6$ m, $w_s = 0.5$ mm/s, $Q = 60$ m³/s, angle = 90°, $H_s = 0.09$ m, $c = 0.03$ kg/m³



OYSTER REEF CHARACTERISTICS

Length [m]	50		
Aspect ratio (length/width)	5	10	
Shoreline distance [m]	50	100	
Number of reefs	1	2	3
Gap/length	0.5	1	2
Reef top elevation [m]	0		

HYDRODYNAMIC AND MORPHODYNAMIC PARAMETERS

Settling velocity [mm/s]	0.5	
Tidal amplitude [m]	0.6	
Mean significant wave height [m]	0.08	0.09
Sediment concentration [kg/m ³]	0.03	

Numerical Simulations - Delft3D+SWAN

Gap size effect

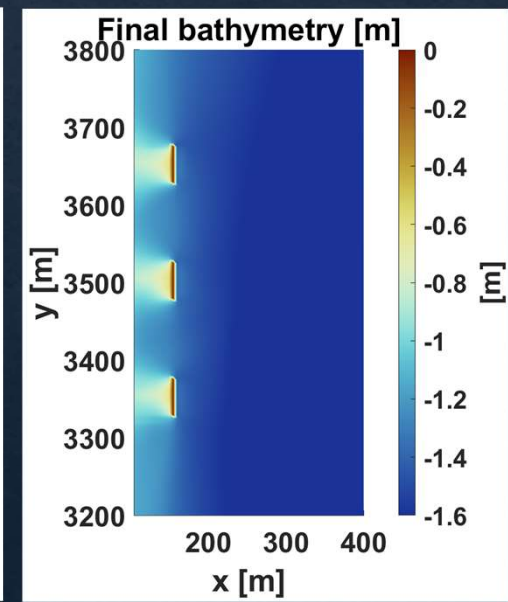
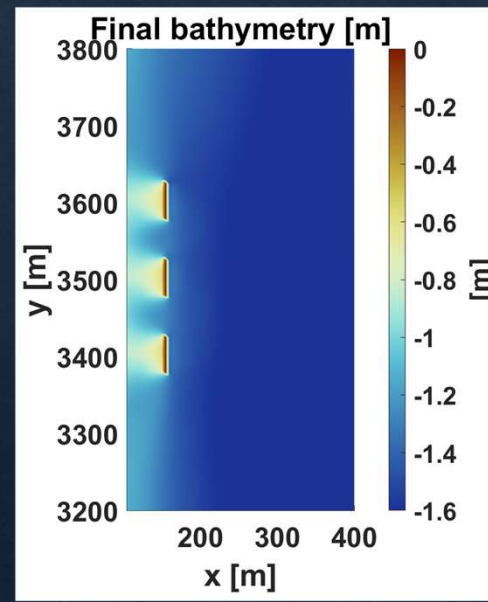
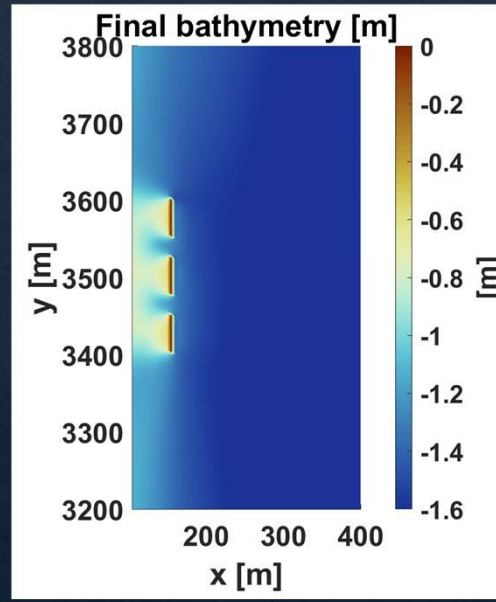
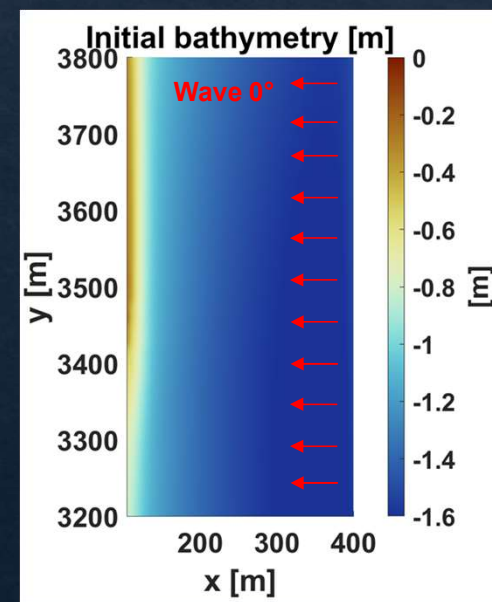
EQ2) $a = 0.6$ m, $w_s = 0.5$ mm/s, $Q = 30$ m³/s, angle = 0°, $H_s = 0.09$ m, $c = 0.03$ kg/m³

REEF	Length [m]	50
	Aspect ratio (length/width)	10
	Shoreline distance [m]	50
	Number of reefs	3

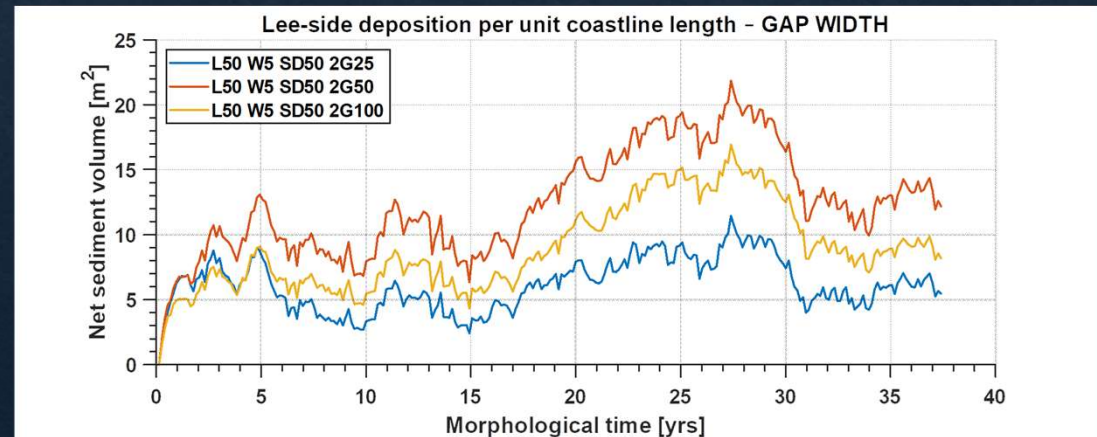
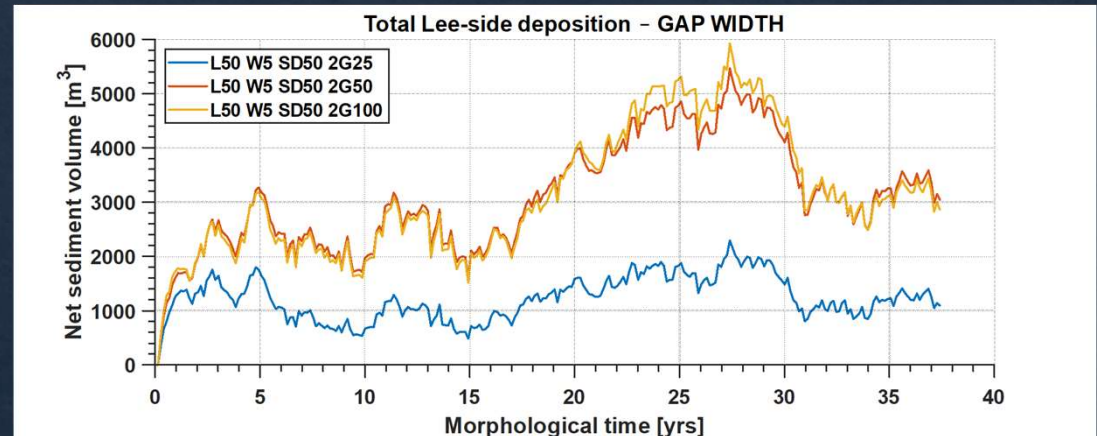
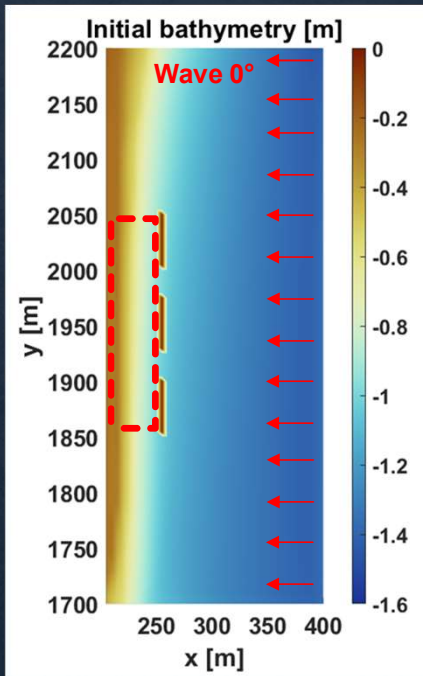
GAP = $L_{\text{REEF}}/2 = 25$ m

GAP = $L_{\text{REEF}} = 50$ m

GAP = $L_{\text{REEF}}/0.5 = 100$ m



Numerical Simulations - Delft3D+SWAN



An intermediate gap configuration maximizes sediment volume deposition per unit of coastline in the lee of the reef

Numerical Simulations - Delft3D+SWAN

Gap size effect

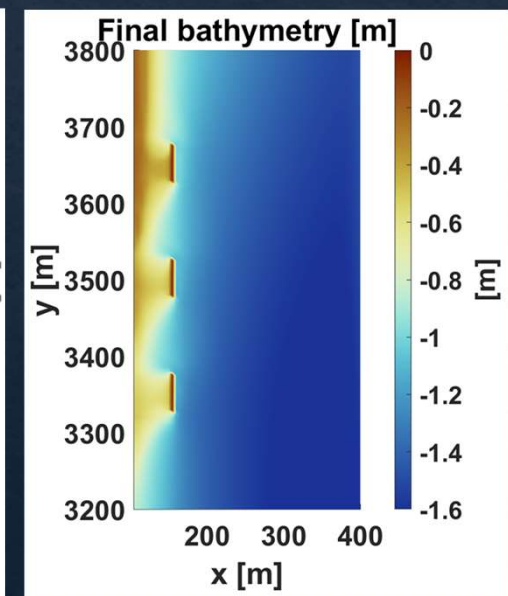
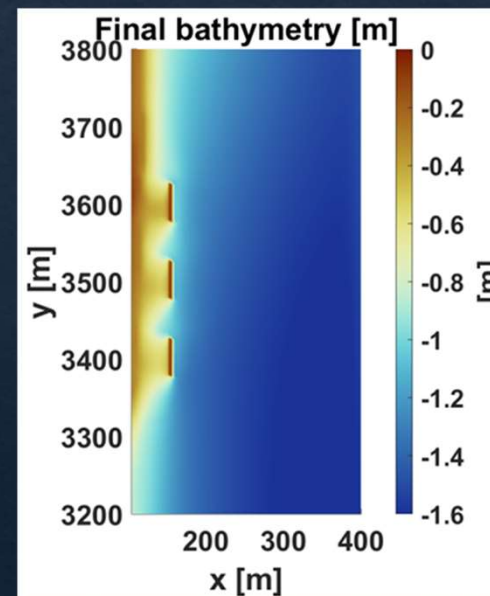
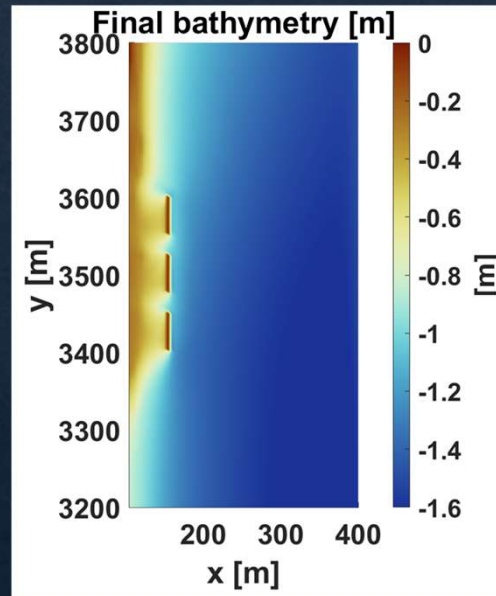
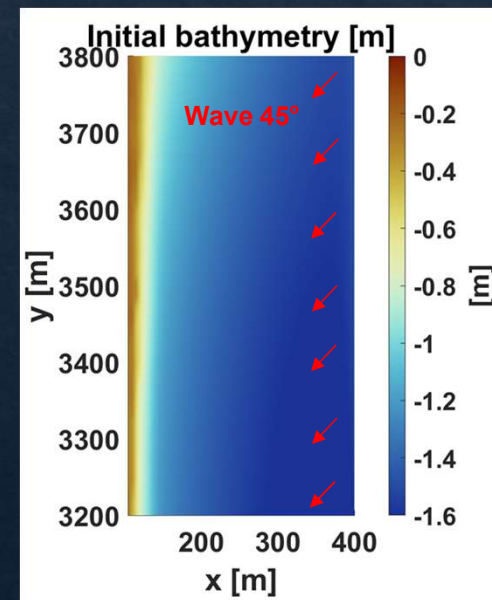
EQ1) $a = 0.6$ m, $w_s = 0.5$ mm/s, $Q = 60$ m³/s, angle = 45°, $H_s = 0.09$ m, $c = 0.03$ kg/m³

REEF	Length [m]	50
	Aspect ratio (length/width)	10
	Shoreline distance [m]	50
	Number of reefs	3

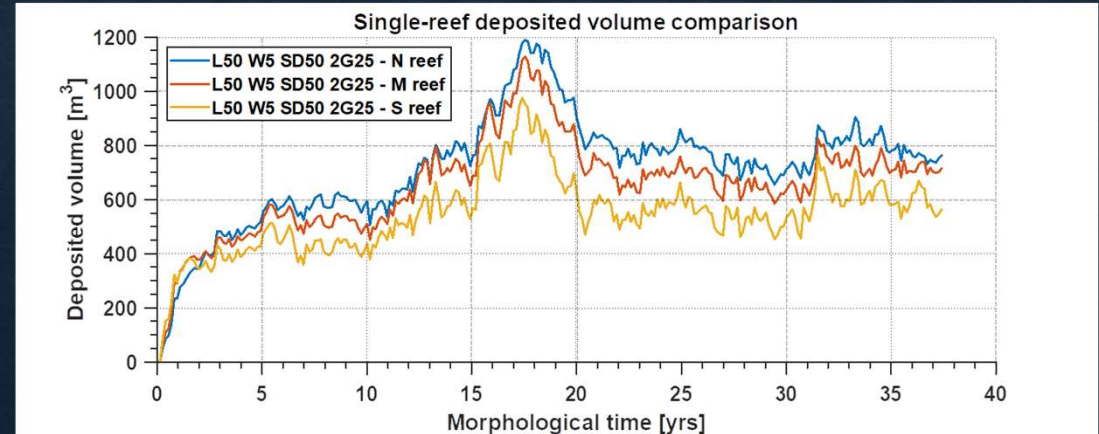
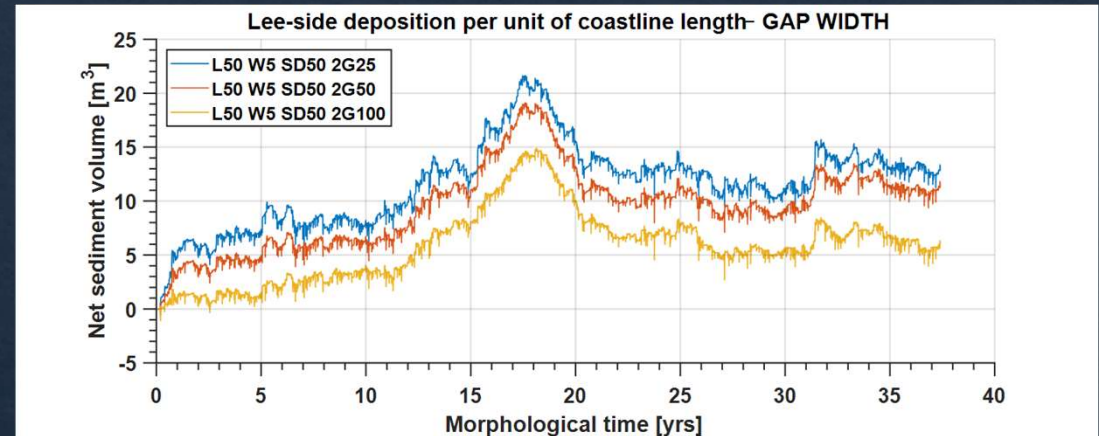
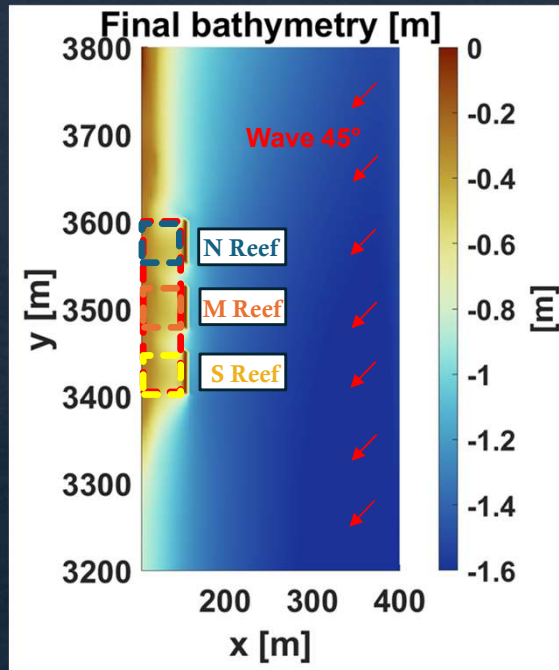
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GAP = $L_{\text{REEF}} = 50$ m

GAP = $L_{\text{REEF}}/0.5 = 100$ m



Numerical Simulations - Delft3D+SWAN



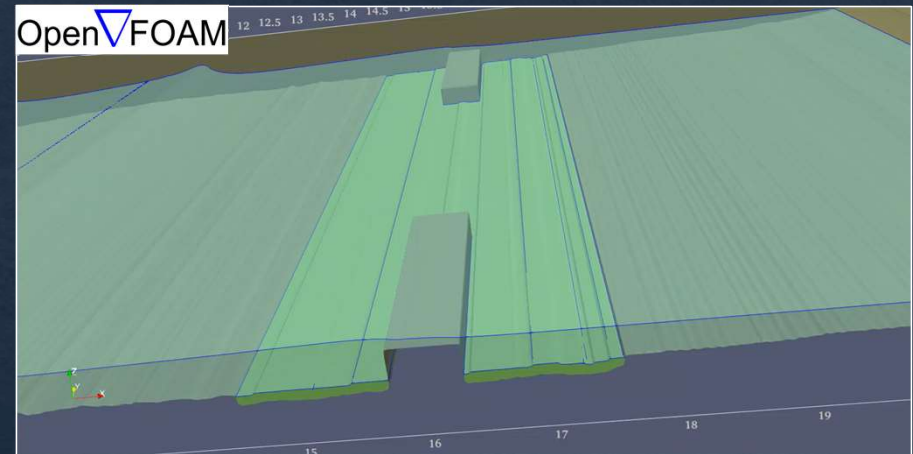
- Sediment deposition on the lee side of the reef decreases toward the south.
- The northern reef acts as a groin, intercepting longshore sediment transport.

Delft3D+SWAN – Limitations and Preliminary Conclusion

- ◇ Phase not resolved
- ◇ Diffraction approximated
- ◇ No structural porosity, and so no infiltration



Assess **Delft3D's** limitations through comparison with LSTF and OpenFOAM, and **develop parameterizations for missing processes**



collab. with the University of Delaware

- **Oyster reefs promote shoreline progradation**, driving the system toward a **new equilibrium shoreline** position.
- For **shore-normal waves**, an **optimal gap** width may exist that balances lee-side sediment retention and shoreline protection
- For **oblique waves**, the northern reef behaves like a **groin**, trapping longshore sediment transport and **reducing southward deposition**

Thank you!

