Characterizing flood risk reduction from coral reef engineering designs across scales

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[2]US Geological Survey

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4th International Workshop on Waves, Storm Surges and Coastal Hazards
Incorporating the 18th International Waves Workshop

UC Universidad de Cantabria
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Regional scale >10 km

Hybrid coral reef restoration can be a cost-effective nature-based solution to provide protection to vulnerable coastal populations

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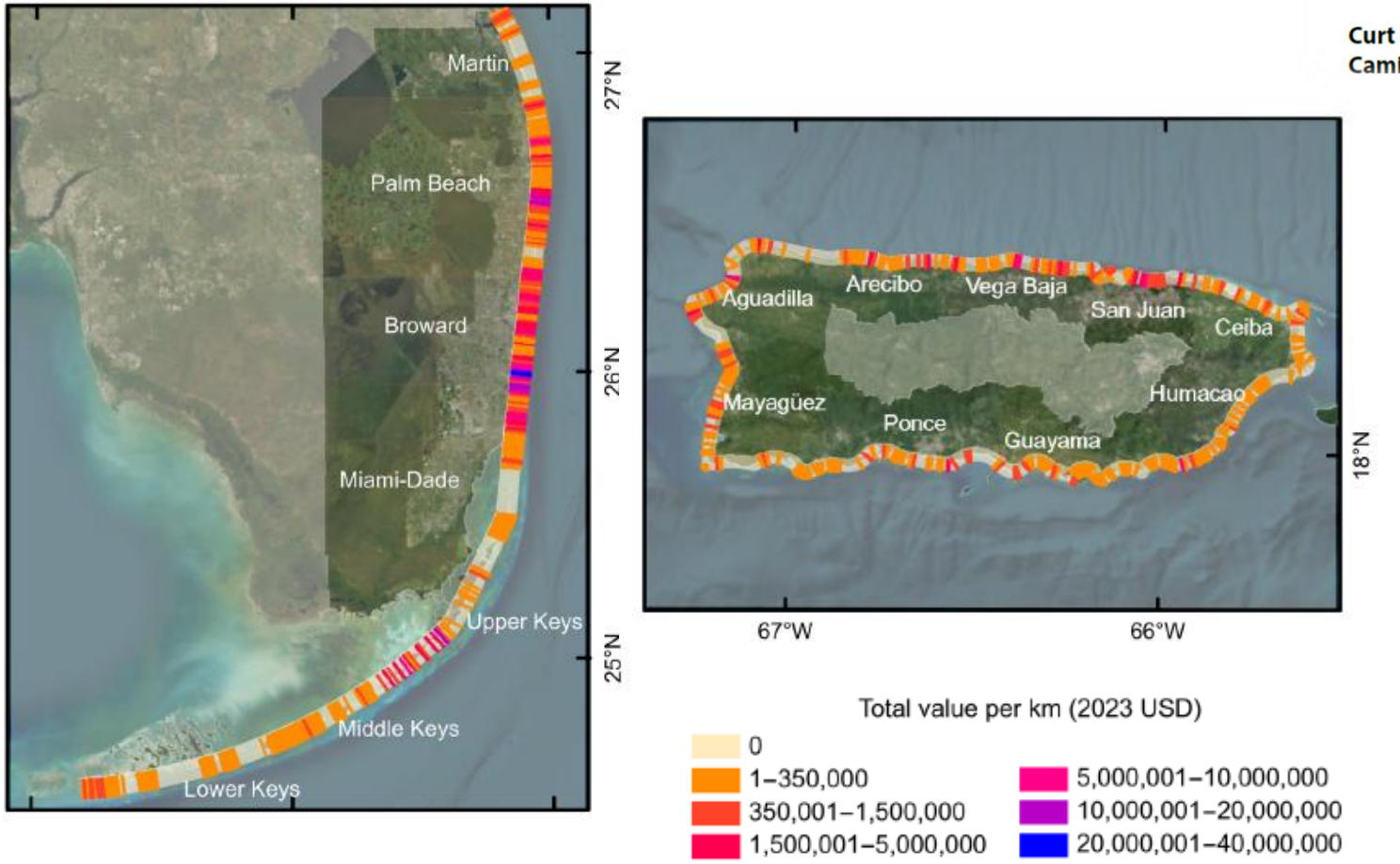
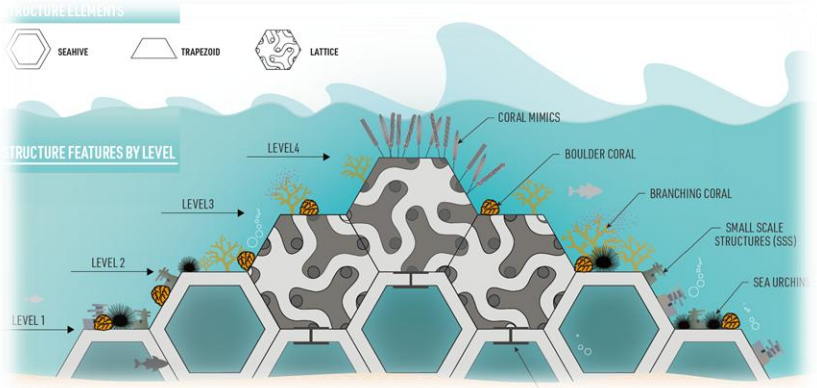
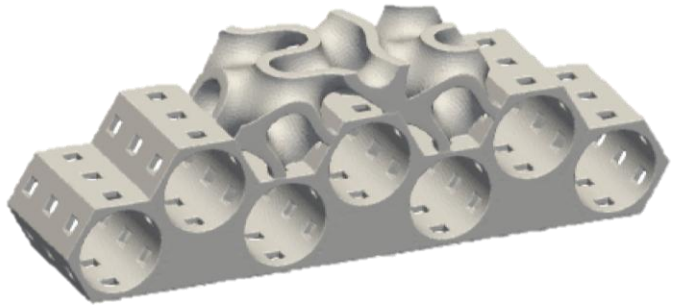
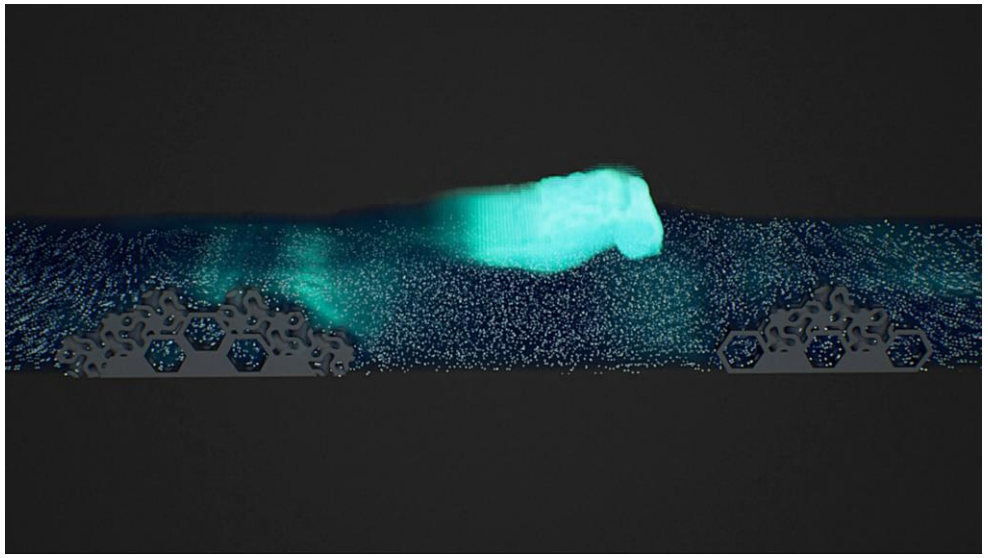




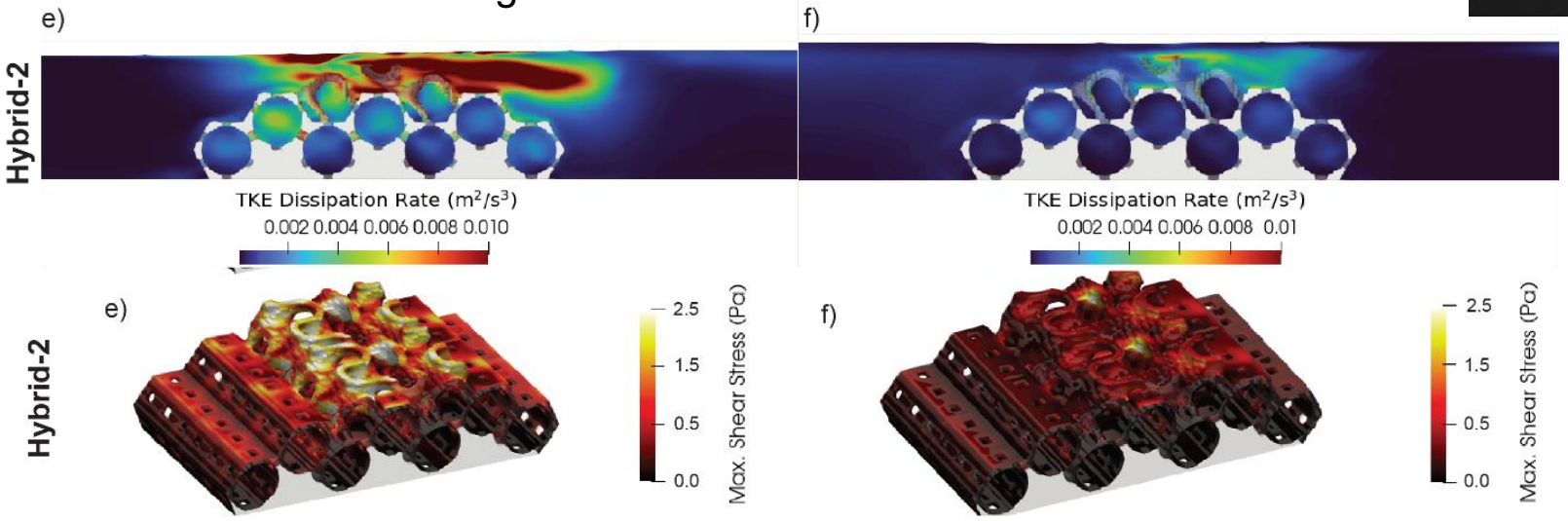
Storlazzi et al. (2025)

Colony scale : 0.1m – 10 m





*Time-averaged values of the maximum shear stress

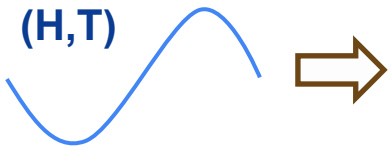


CFD model for hybrid design

Norris et al, 2025, *in preparation*

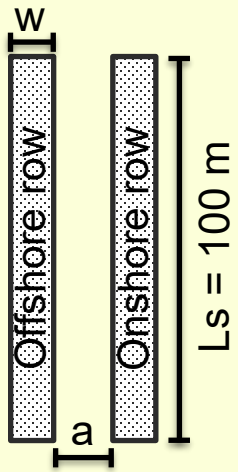
Project scale 10 m – 10 km → Hybrid Reef Layout design

Boundary conditions



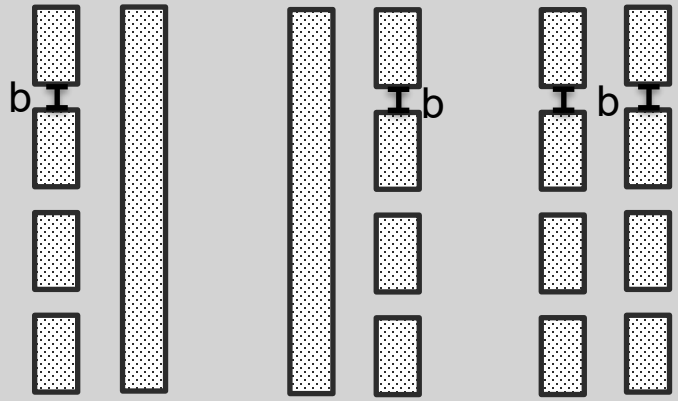
H = 0.25:0.25:2.0 m
T = 4:1:14 s

Test a:
Finding an optimal spacing



a = spacing between structures
a = w, 2*w, 3*w

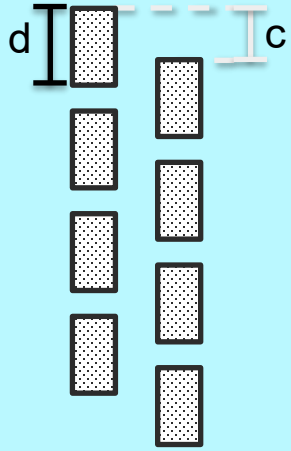
Test b:
Understanding the impact of structure-segmentation



Channels in offshore-row | Channels in onshore-row | Channels in both rows

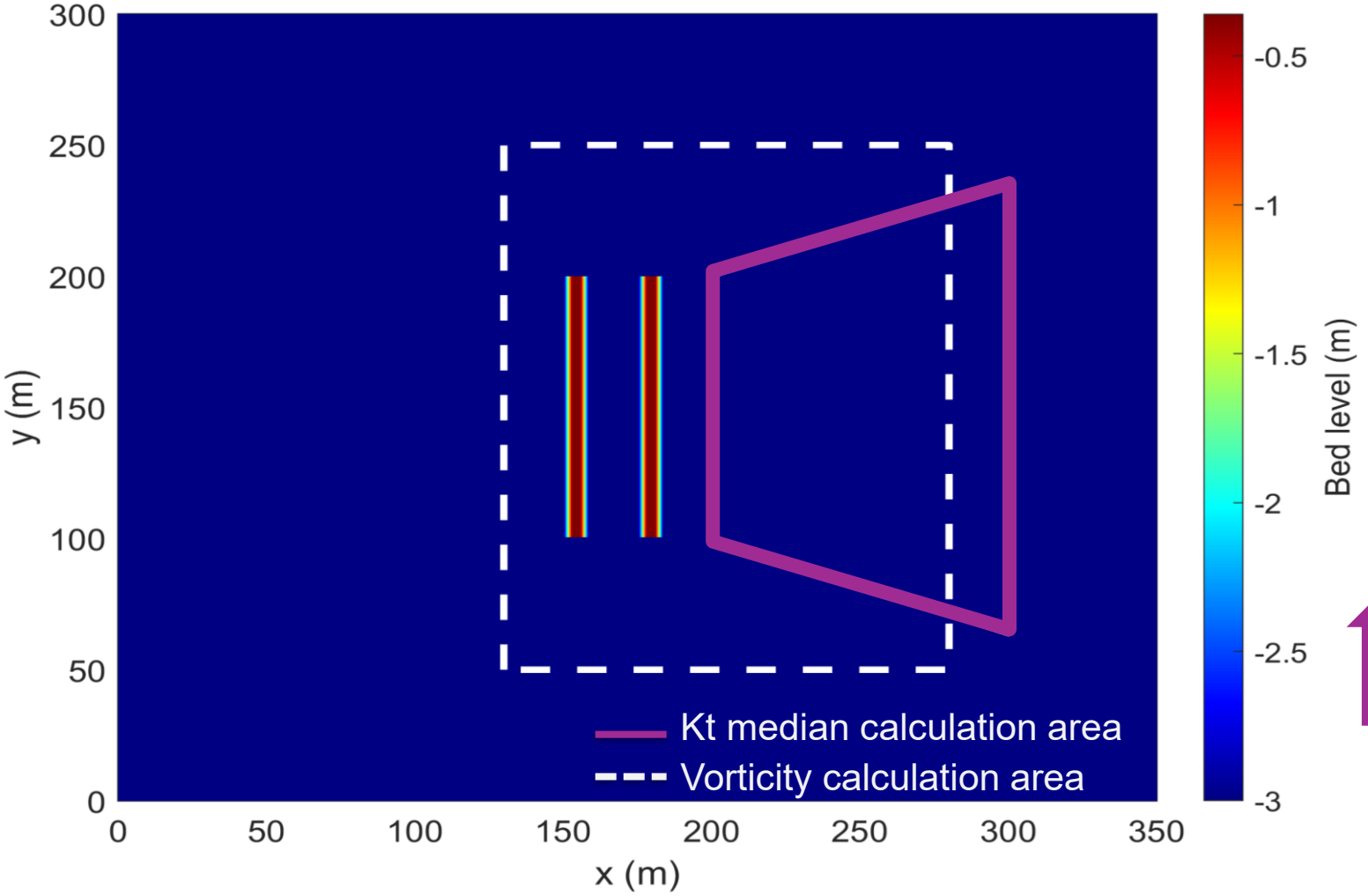
b = channel width
b = 2:2:16 m

Test c:
Understanding the impact of structure-shifting



c = shift (axis)
d = length of the reef unit
c = 0, d/4, d/2,d

XBeach NH model was calibrated with CFD results



$$K_t = Transmission\ coefficient$$

$$K_t = \mathrm{H}_{\mathrm{restoration}}/\mathrm{H}_{\mathrm{norestoration}}$$

$$K_t\ median = \downarrow\ Lower\ Performance$$

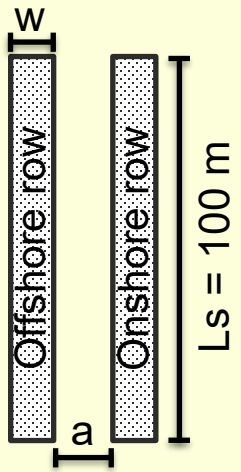
Hybrid Reef Layout design

Boundary conditions

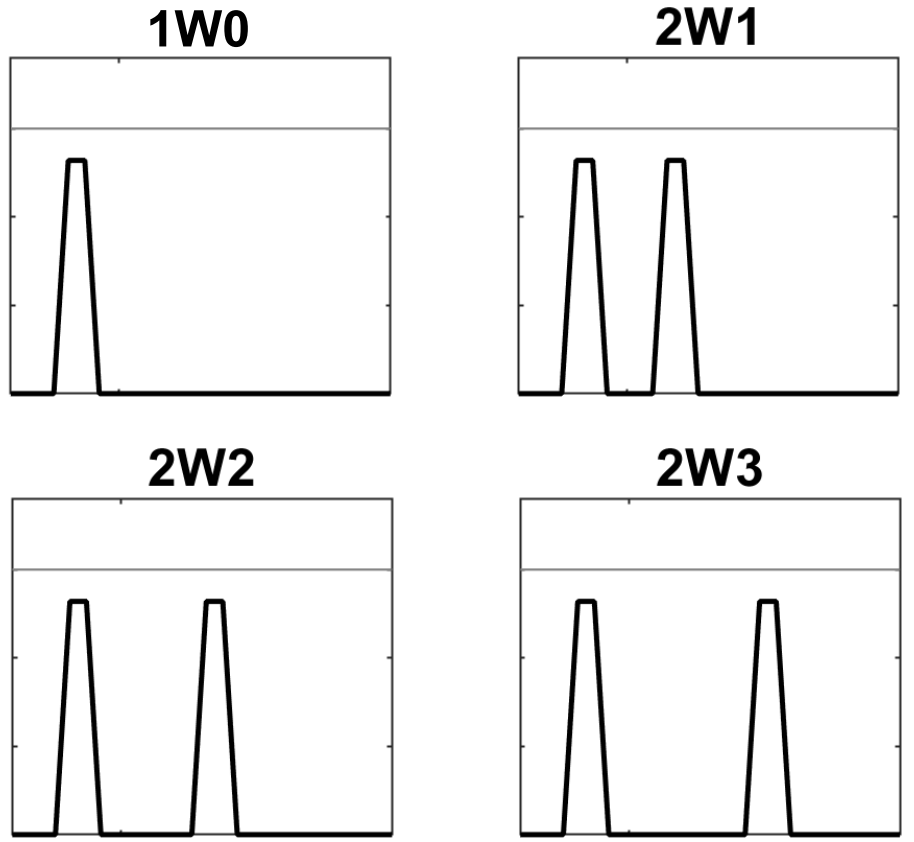
(H,T)

H = 0.25:0.25:2.0 m
T = 4:1:14 s

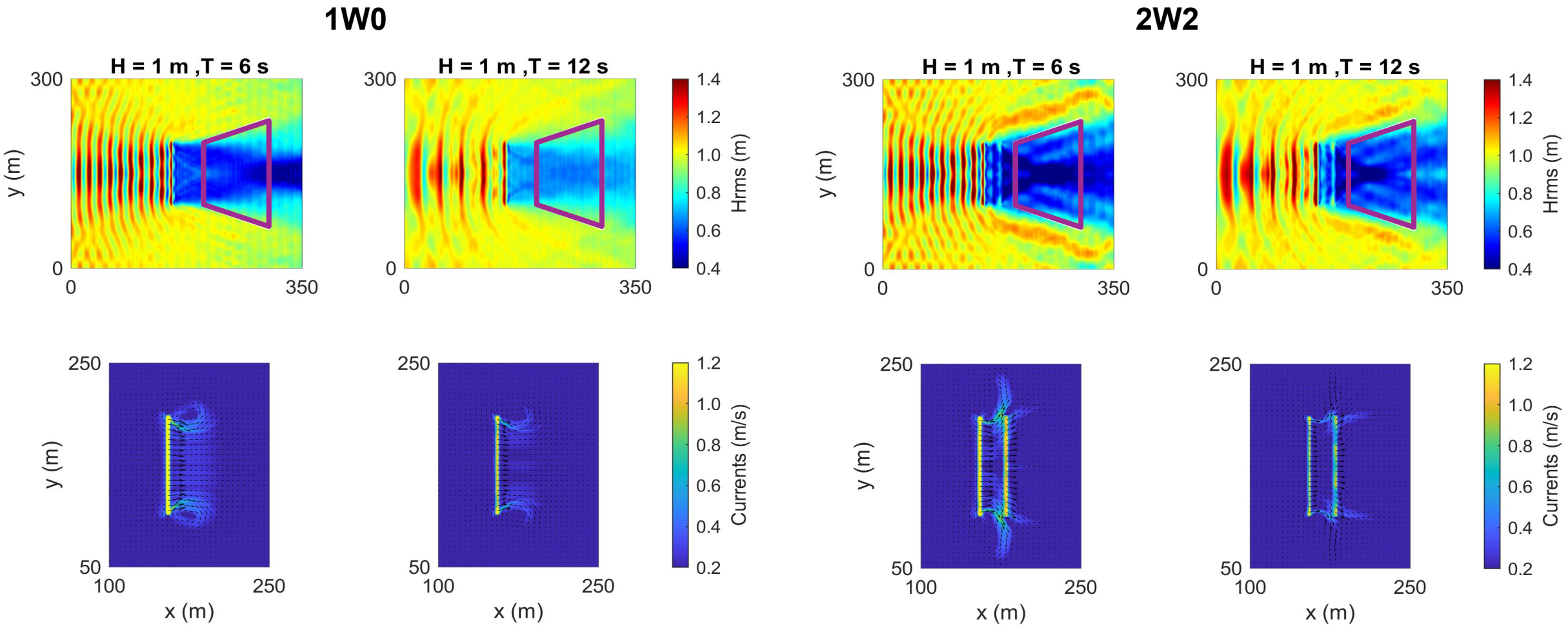
Test a:
Finding an optimal spacing



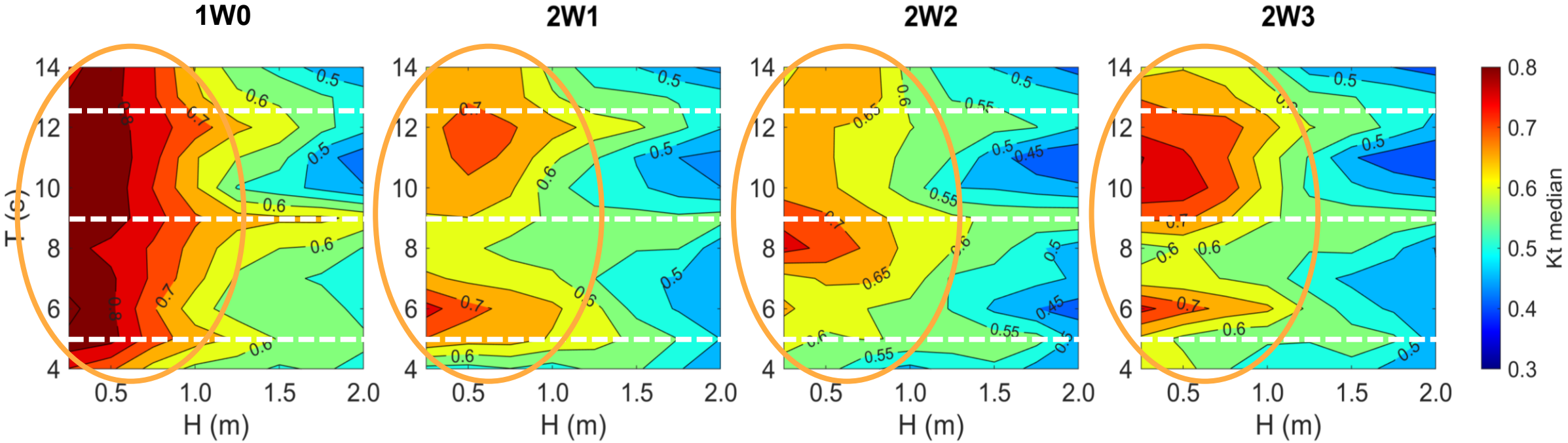
a = spacing between structures
a = w, 2*w, 3*w



Finding an optimal spacing



Higher waves = higher performance, but there are peaks of lower performance under certain periods



Best performance

Hybrid Reef Layout design

Boundary conditions

(H,T)

H = 0.25:0.25:2.0 m
T = 4:1:14 s

Test a:
Finding an optimal spacing

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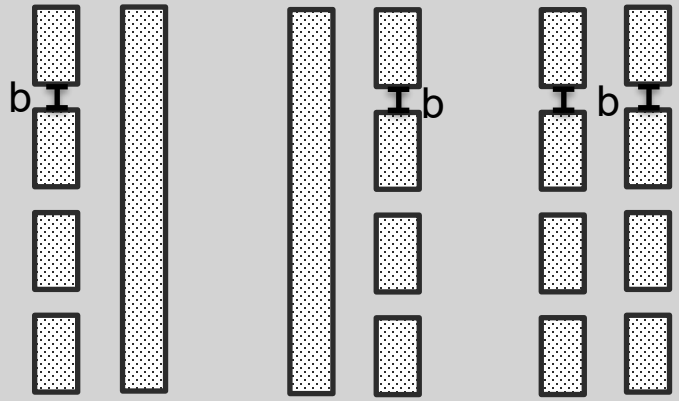
Test b:
Understanding the impact of structure-segmentation

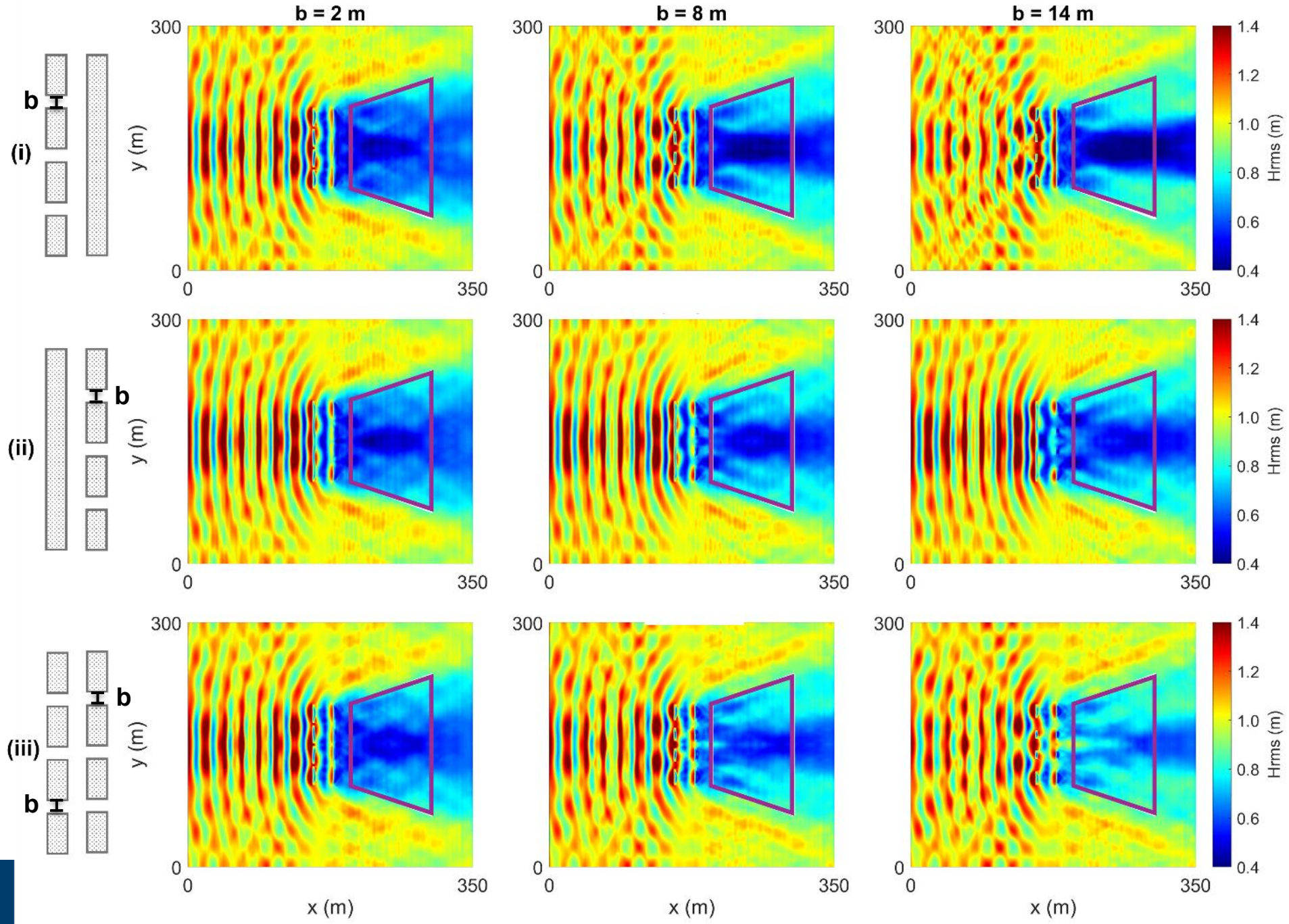


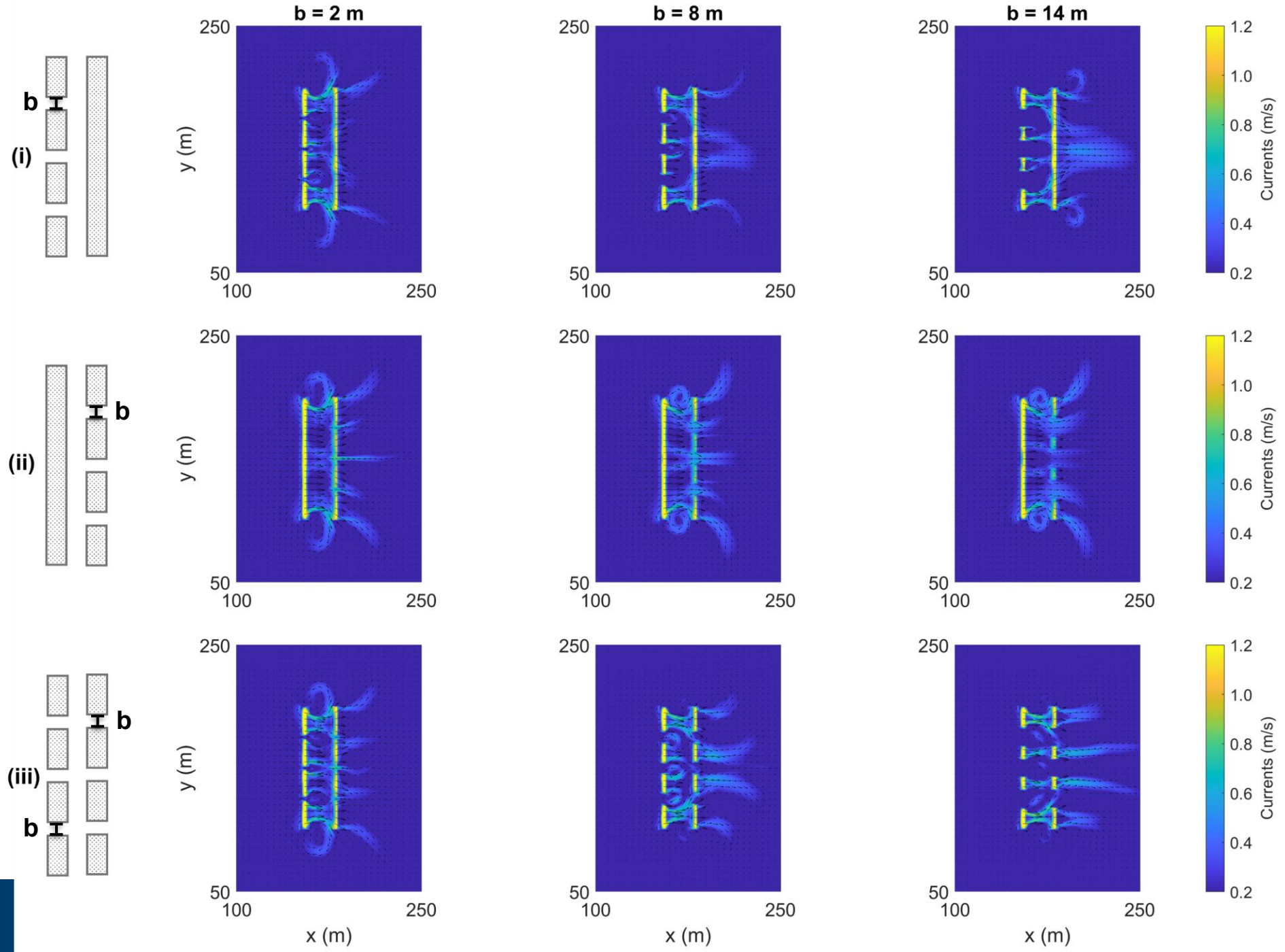
Channels in offshore-row | Channels in onshore-row | Channels in both rows

b = channel width
b = 2:2:16 m

Test c:
Understanding the impact of structure-shifting

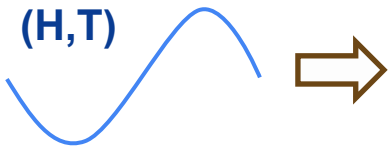
c = shift (axis)
d = length of the reef unit
c = 0, d/4, d/2,d


b = 2 m
b = 8 m
b = 14 m
(i)
(ii)
(iii)
b
b
b
y (m)
x (m)
300
0
350
Hrms (m)
1.4
1.2
1.0
0.8
0.6
0.4


b = 2 m
b = 8 m
b = 14 m
(i)
(ii)
(iii)
b
b
b
y (m)
x (m)
250
50
100
250
1.2
1.0
0.8
0.6
0.4
0.2
Currents (m/s)

Hybrid Reef Layout design

Boundary conditions



H = 0.25:0.25:2.0 m
T = 4:1:14 s

Test a:
Finding an optimal spacing

a = spacing between structures
a = w, 2*w, 3*w

Test b:
Understanding the impact of structure-segmentation

Channels in offshore-row | Channels in onshore-row | Channels in both rows

b = channel width
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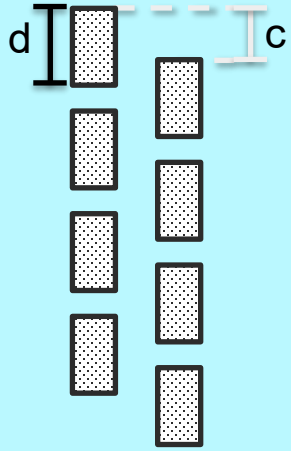
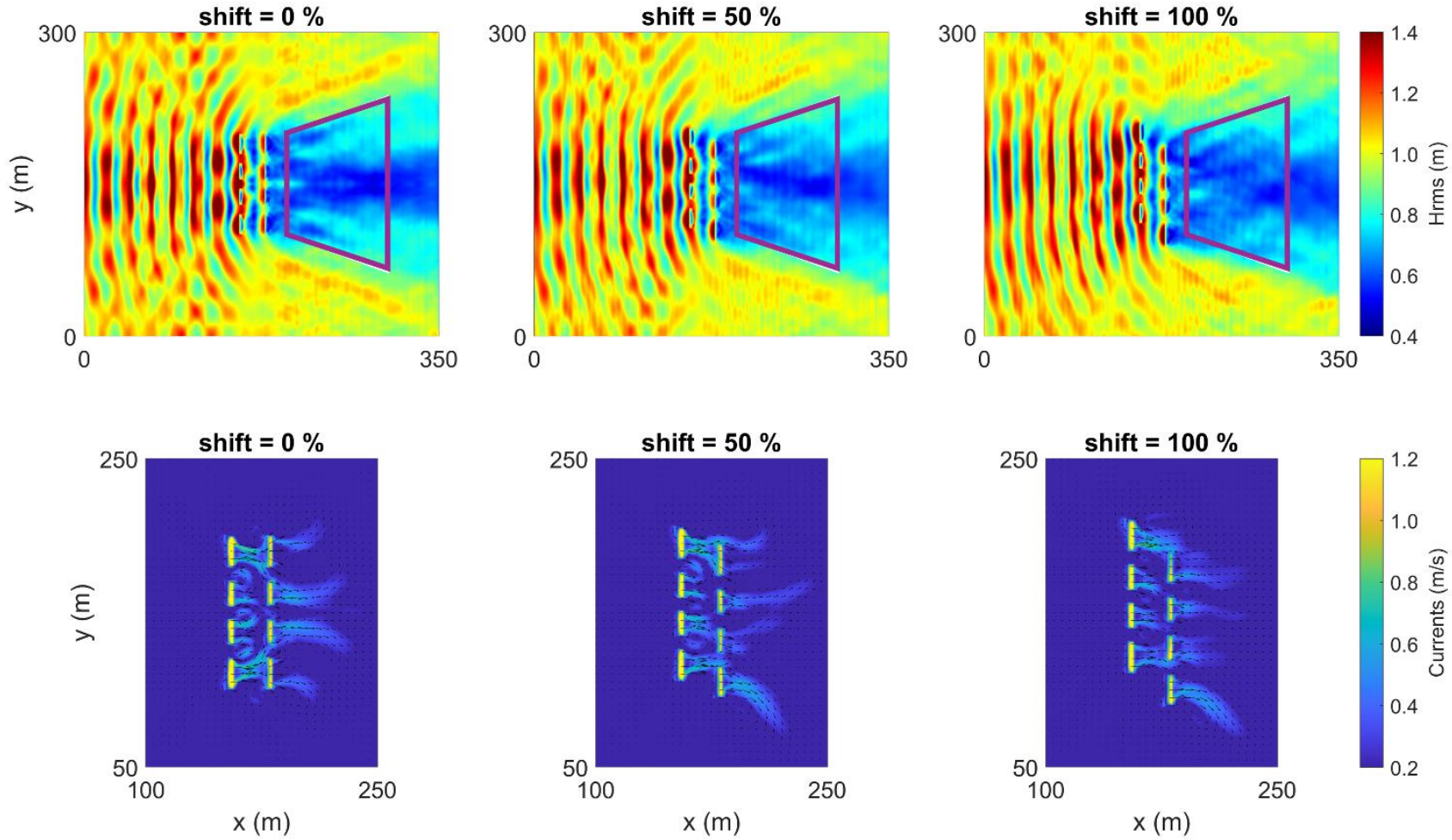
Test c:
Understanding the impact of structure-shifting



c = shift (axis)
d = length of the reef unit
c = 0, d/4, d/2,d

Shifting the structures can help to extend the alongshore protection and decrease vorticity



Discussion & Conclusion

- The wave energy reduction performance of the restoration layout highly depends on the wave climate. Overall, performance tends to increase with increasing wave heights; however, specific wave periods can generate a peak in wave energy transmission, lowering its performance.

- Two rows of hybrid structures spaced by two times their width gave the lowest transmission coefficient and more contained low-performance peaks.

- Segmenting the offshore structure gives the highest performance over all the segmentation strategies; however, it focuses the wave energy dissipation and leads to complex current patterns, which can have environmental and safety caveats.

- Shifting of the structure helps reduce vorticity and defocus the energy dissipation to have a higher performance in a larger area.

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Thank you!

Questions?

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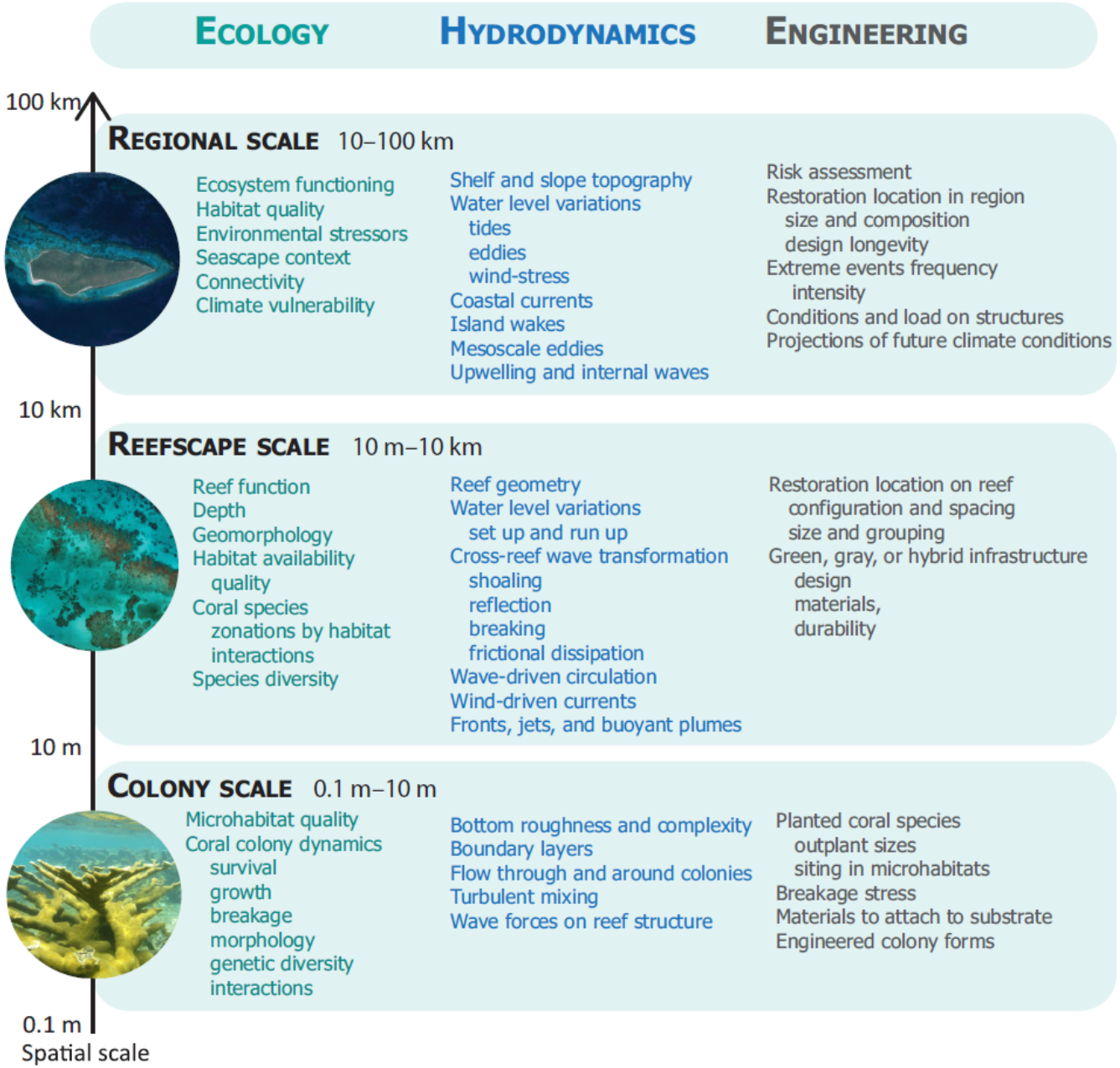
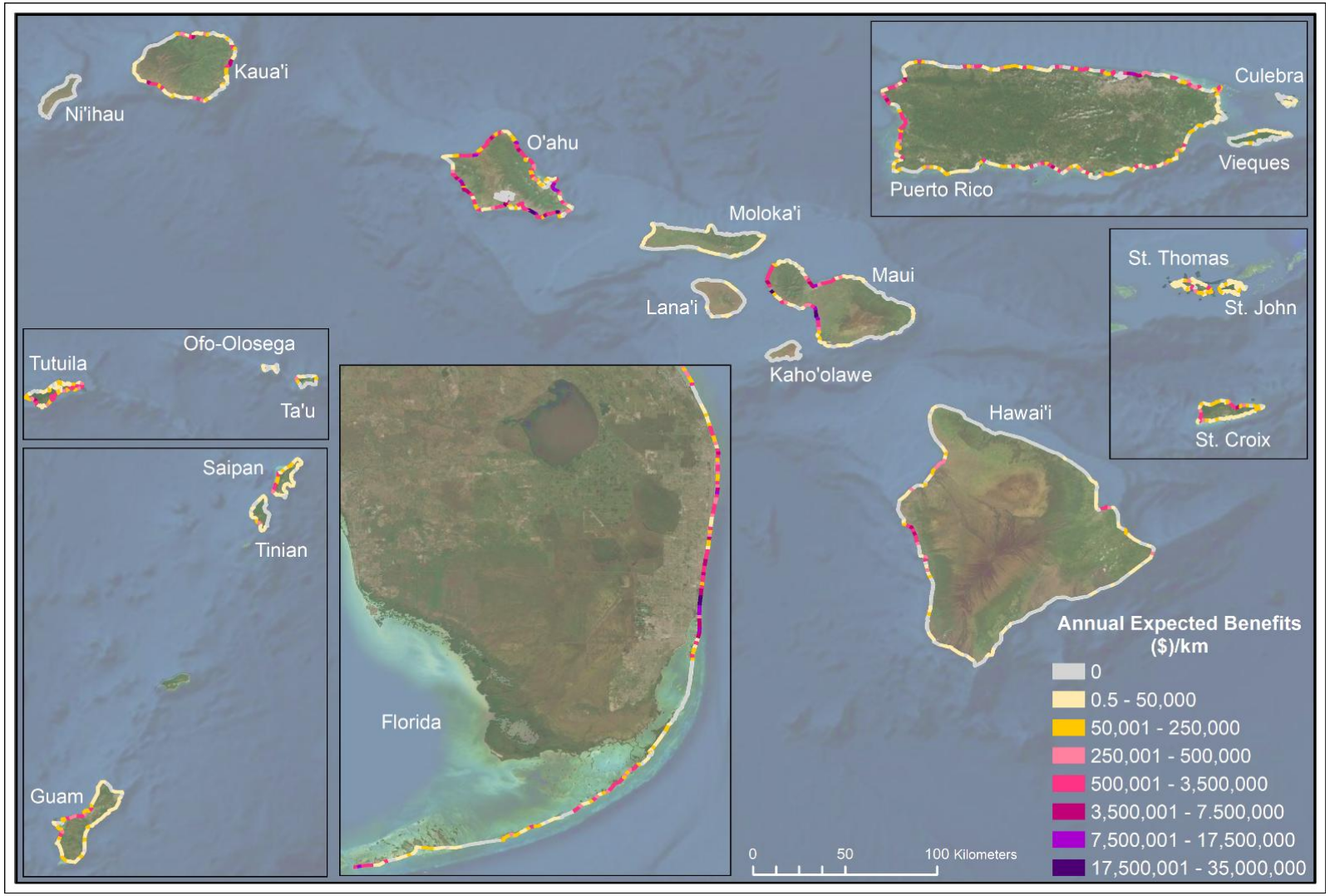


Reef restoration at multiple scales

Viehman et al. (2023) Coral restoration for coastal resilience: Integrating ecology, hydrodynamics, and engineering at multiple scales. *Ecosphere*

Quantifying the US coral reefs flood protection benefits

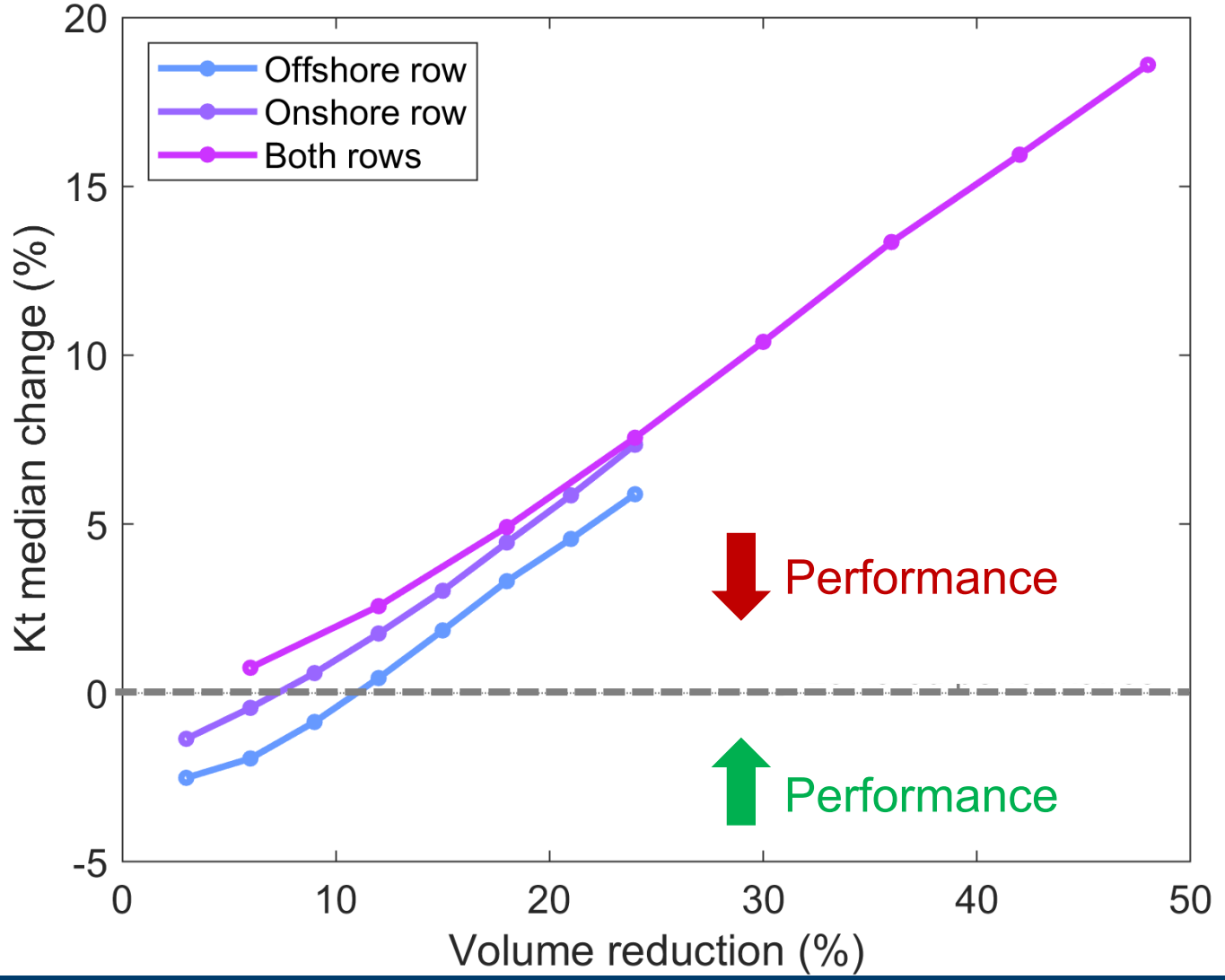


+ $1.805 billion / year
(2010 USD)

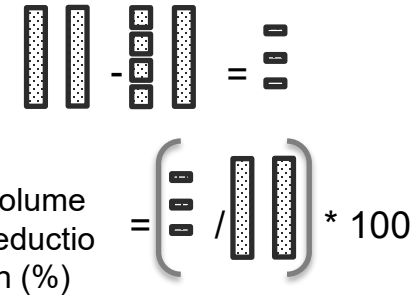
+ 18,000 people / year
(2010 census)

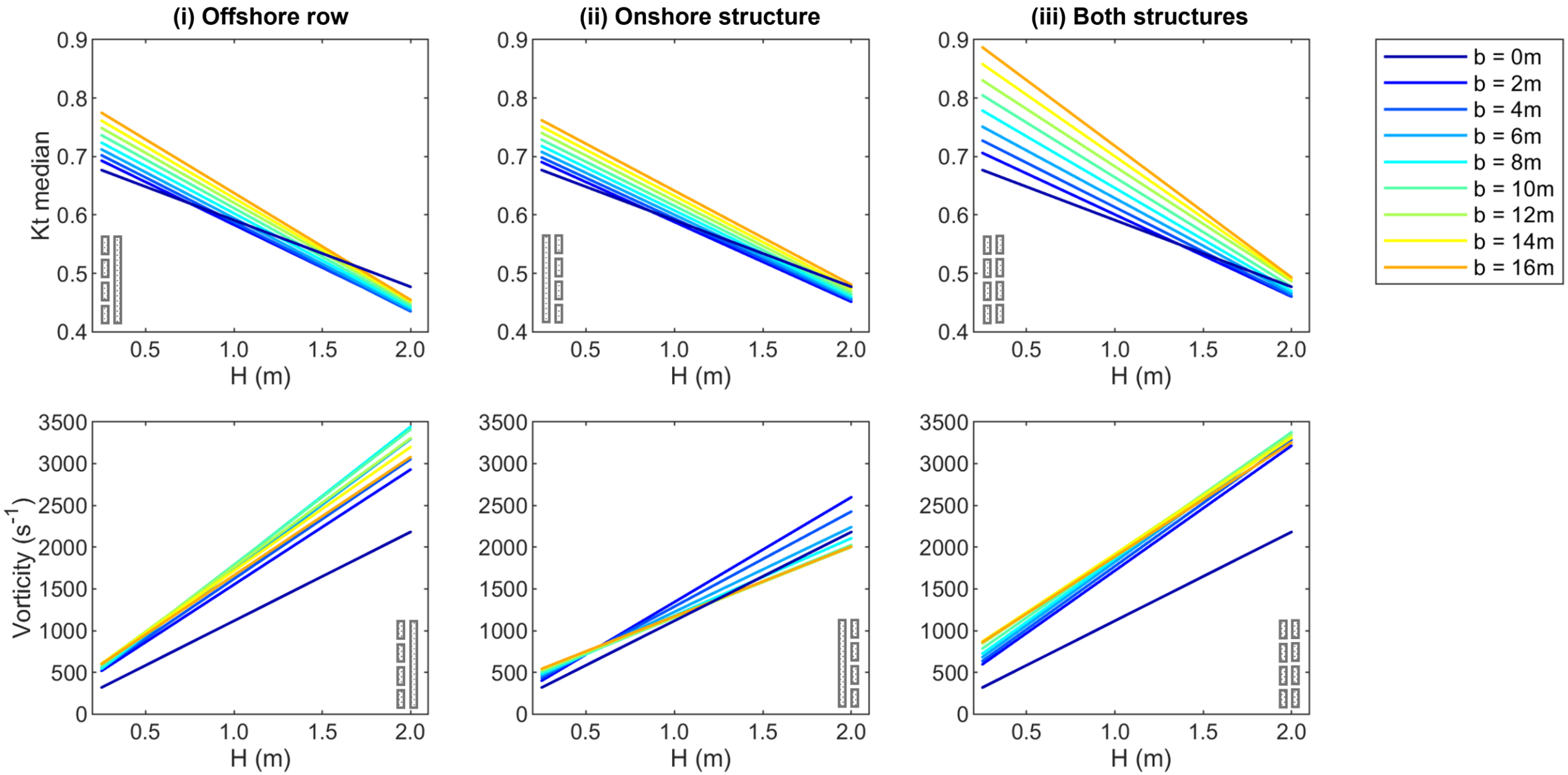
Reguero et al. (2021) The value of US coral reefs for flood risk reduction. *Nature Sustainability*

Trade off: Cost reduction vs Performance



EXAMPLE VOLUME REDUCTION CALCULATION




(i) Offshore row
(ii) Onshore structure
(iii) Both structures
Kt median
Vorticity (s-1)
H (m)
b = 0m
b = 2m
b = 4m
b = 6m
b = 8m
b = 10m
b = 12m
b = 14m
b = 16m

Structure shifting