Experimental and CFD Numerical Studies of Wave Attenuation Through Mangrove Forest of Moderate Cross-shore Width

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

Incorporating the 18th International Waves Workshop

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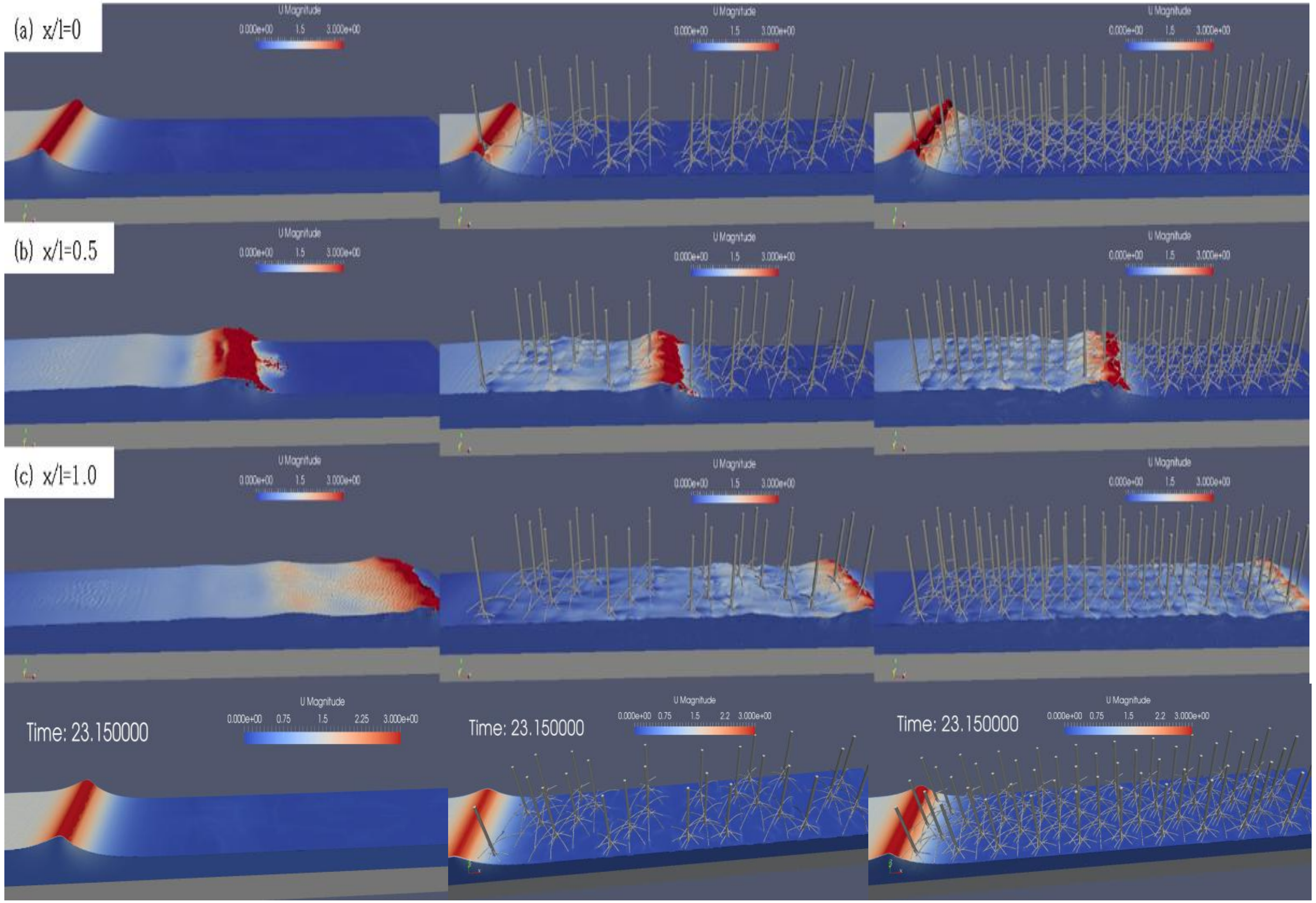
Increasing Flooding Risk

Economic and Human losses

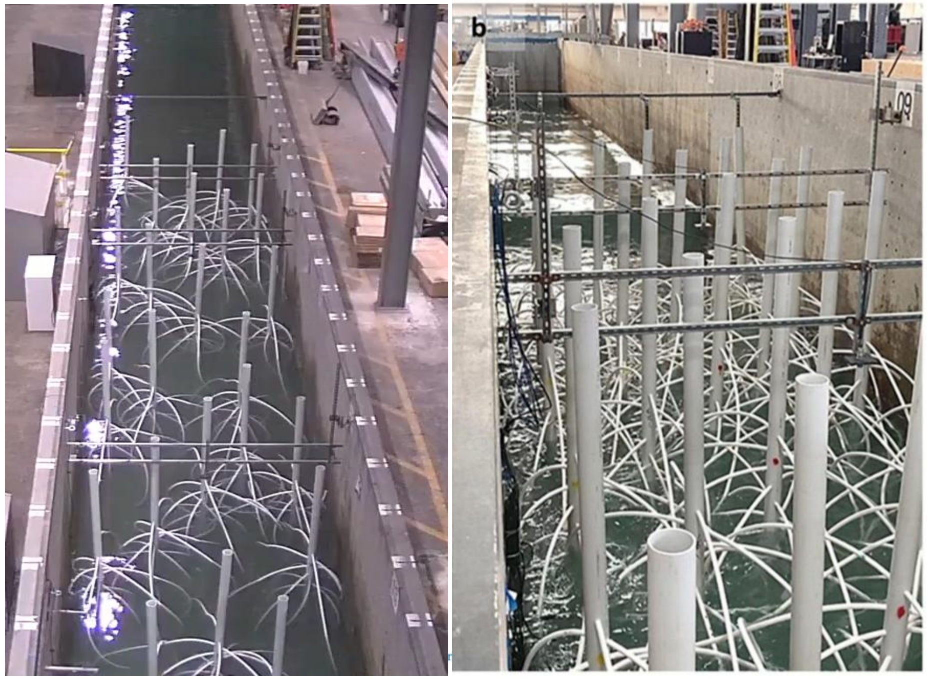
Sustainable Solutions

Risk-prone Coastal Communities

1.2. Previous Works



Investigation on tsunami-like wave attenuation through idealized mangrove forest at moderate width



Contents lists available at ScienceDirect
Coastal Engineering
journal homepage: www.elsevier.com/locate/coastaleng
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Wave hydrodynamics and attenuation in idealized mangrove forest: Large-scale physical and numerical modeling

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I. Motivation and Backgrounds

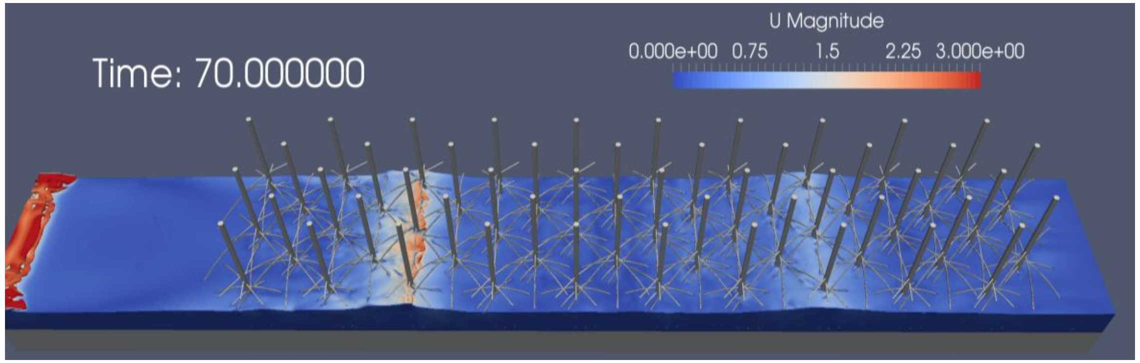
1.3. Research Objectives

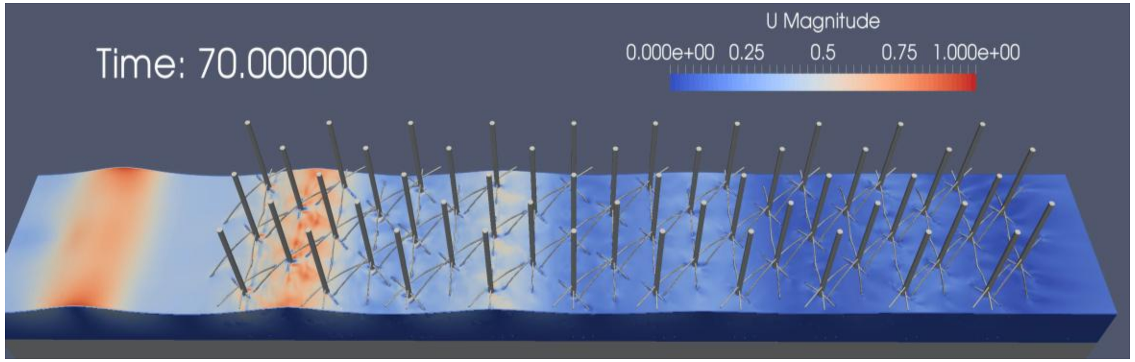
(1) Conduct **prototype-scale physical** and **OpenFOAM-based numerical model**, then **validate numerical results** using experimental results

(2) Examine the **wave evolution modes** and **kinematic patterns inside the mangrove forest** when waves passing through mangrove forest

(3) Investigate the influence of varying **mangrove properties** and **wave parameters** on **wave attenuation coefficients**

(4) Propose **empirical formula** to estimate **wave attenuation coefficients** using MNLR model and deep learning regression model





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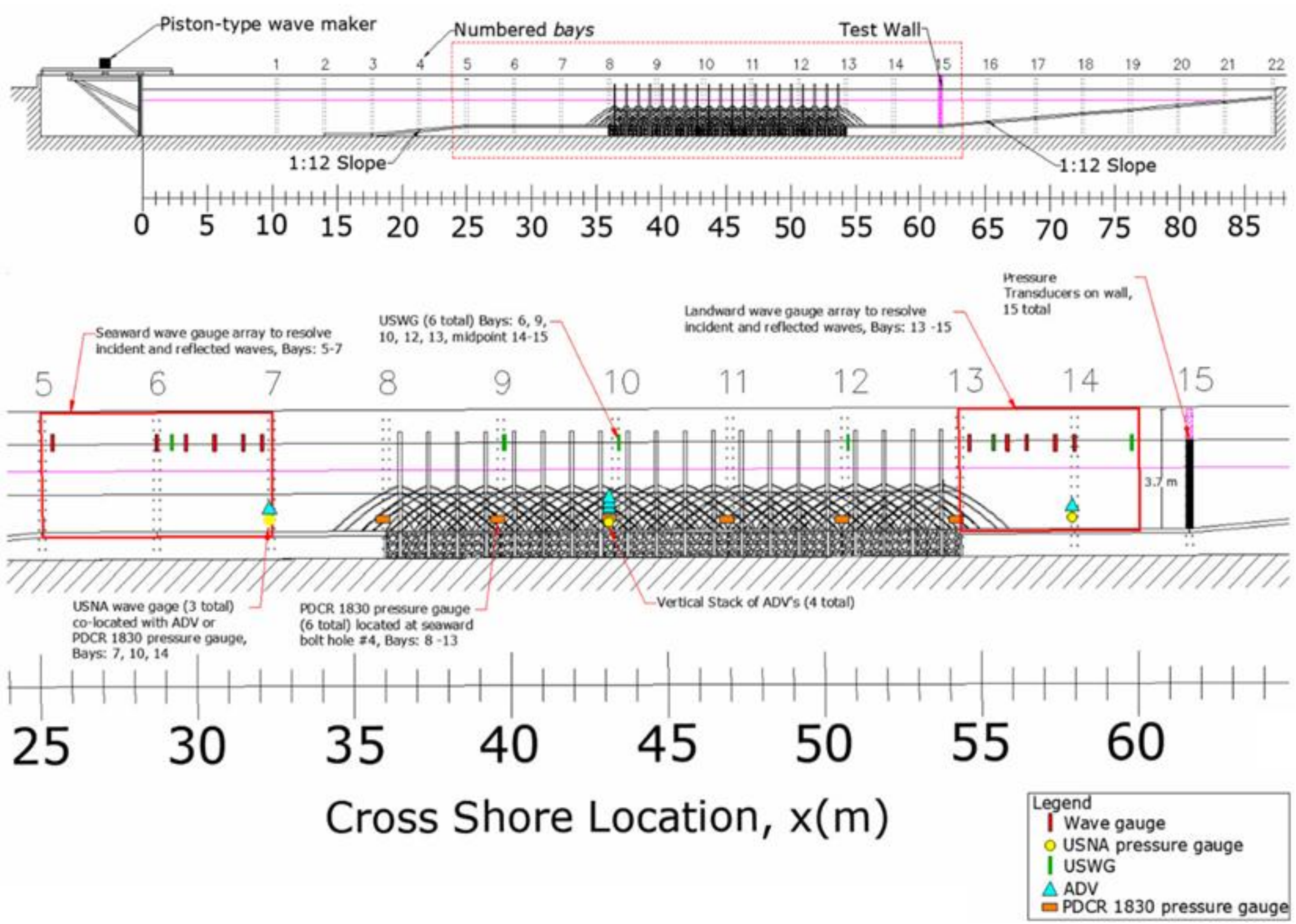
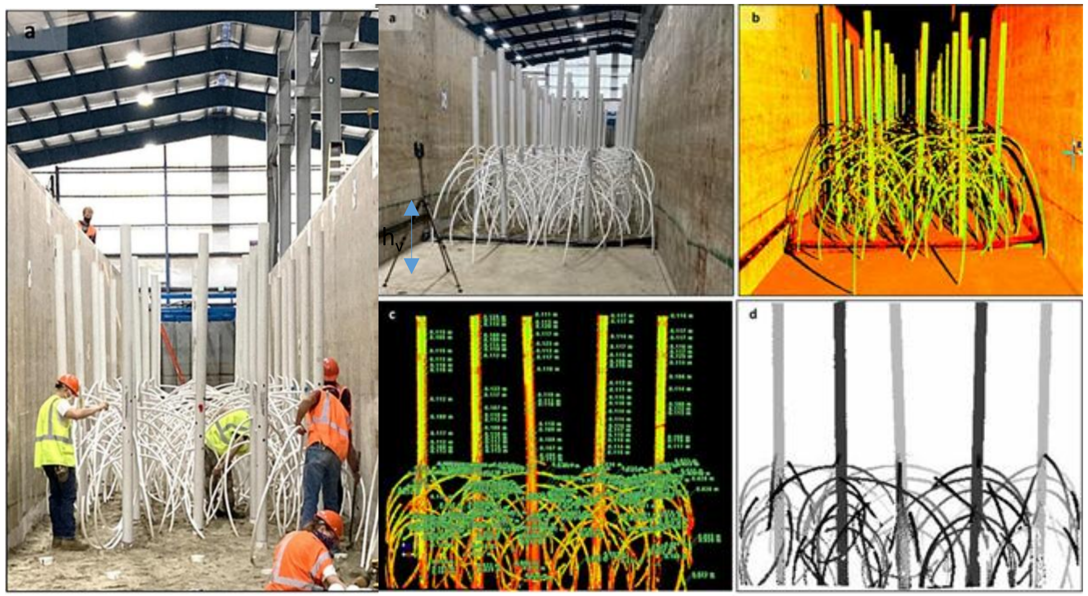
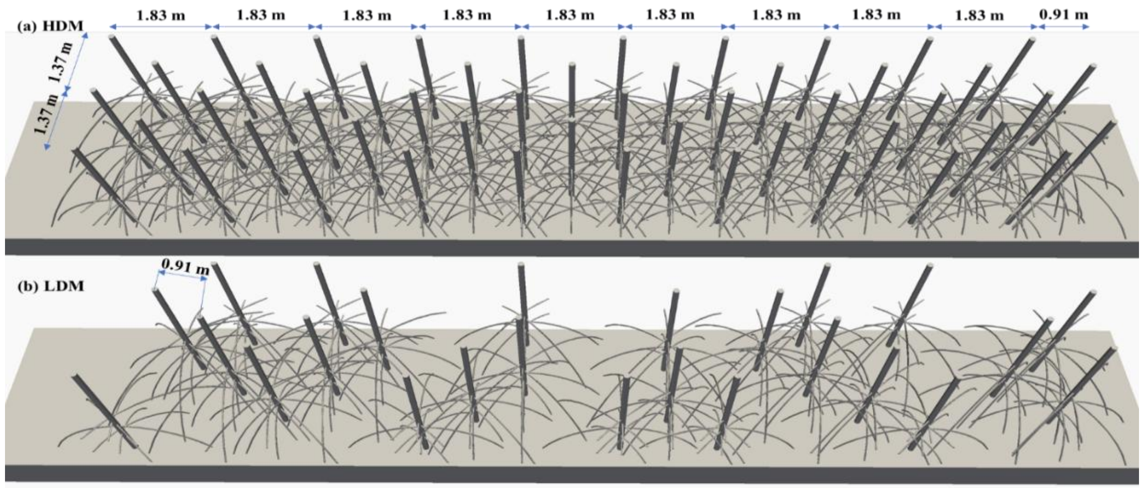
II. Experimental Description

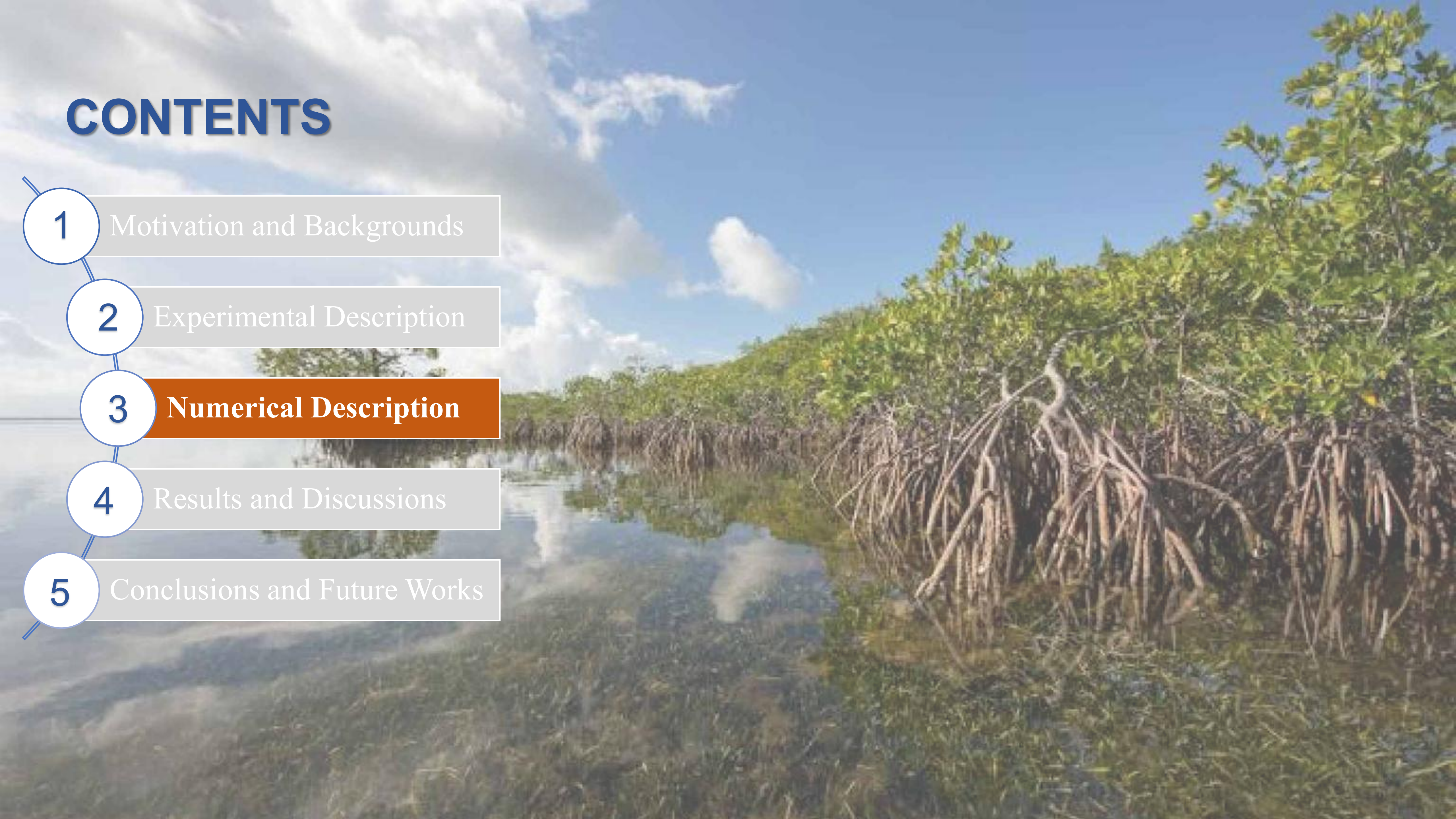






Two mangrove densities HDM (0.75 stem/m^2) and LDM (0.35 stems/m^2)

Kelty et al., 2022



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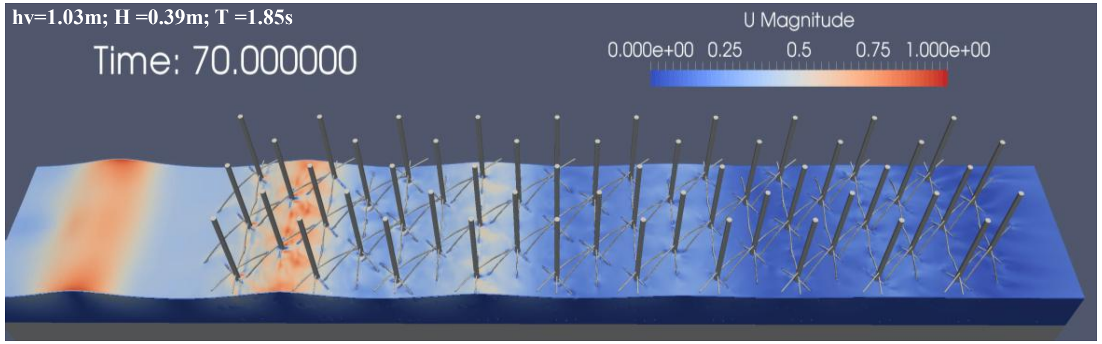
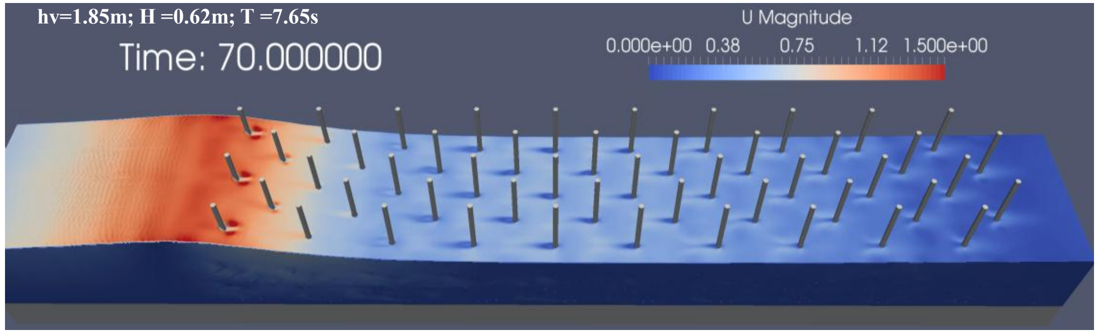
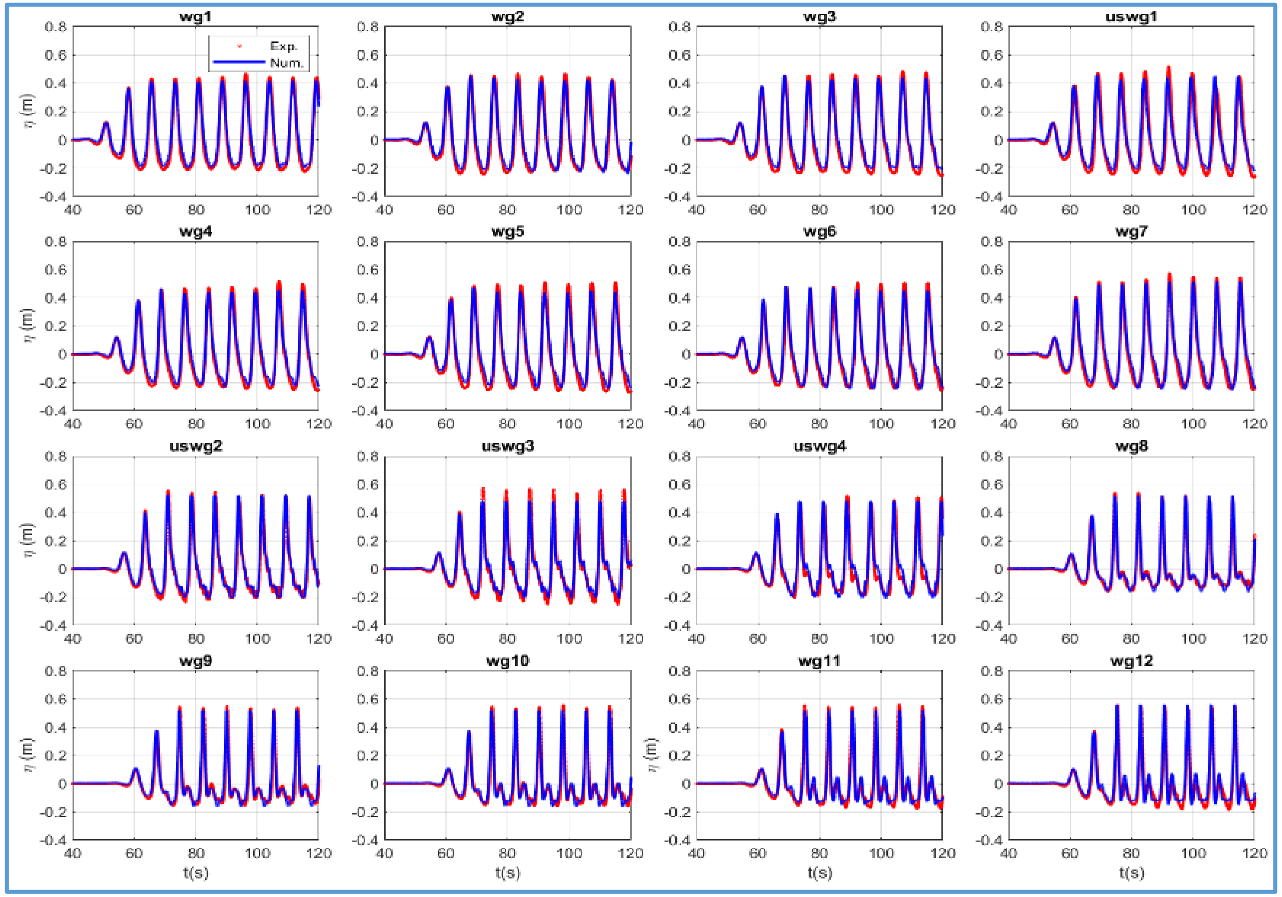
III. Numerical Description

Numerical Parameters	Mesh Resolution Types (Regular Waves)		
	Type 1 (coarse)	Type 2 (medium)	Type 3 (fine)
dx (m)	0.1~0.025	0.1~0.015	0.1~0.01
dy (m)	0.025	0.015	0.01
dz (m)	0.05~0.025	0.05~0.015	0.05~0.01
Cell Number	~28 million	~52 million	~89 million
Courant Number	0.5	0.5	0.5
Turbulence Closure	k-ω SST	k-ω SST	k-ω SST
Duration (s)	200	200	200
Initial Time Step (s) at $t = 0$	0.01	0.01	0.01
Processor (cores)	24	24	24
Averaged Computation Time (days)	3	9	20



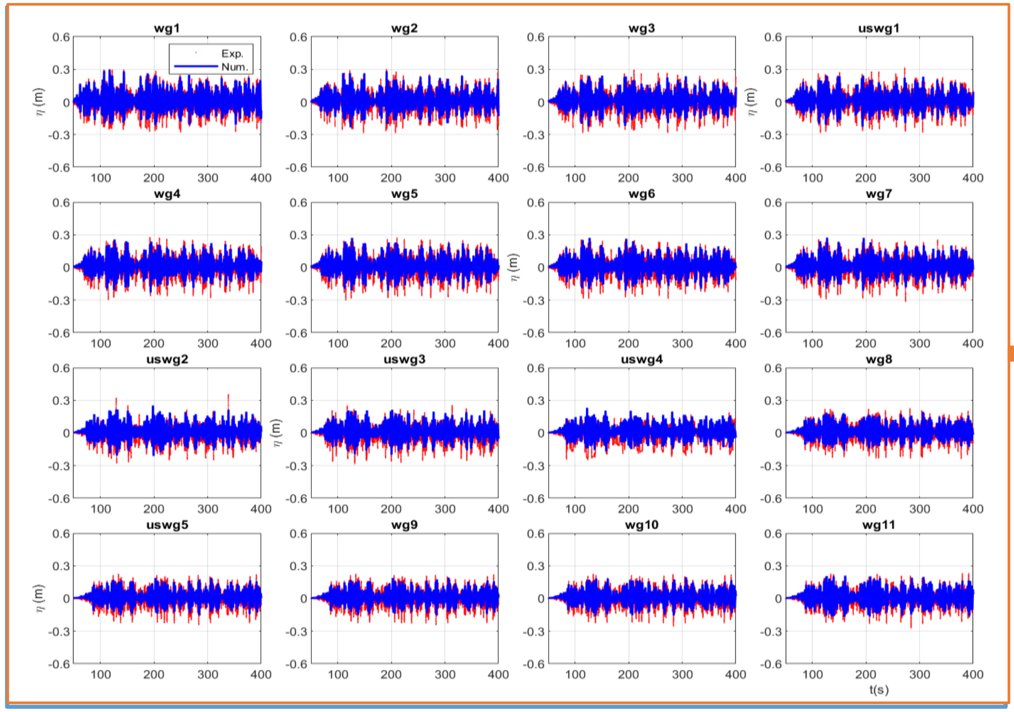


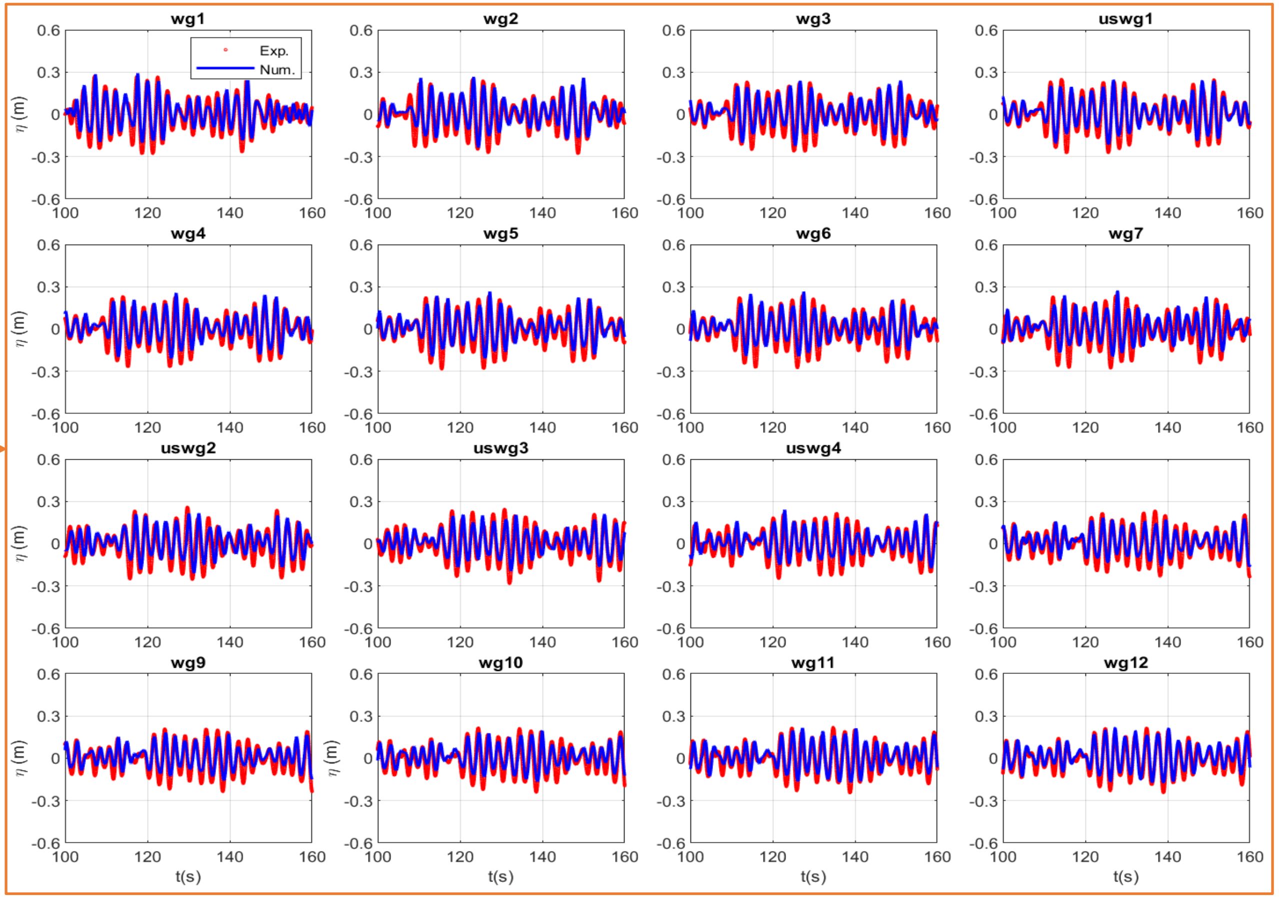


Comparison of measured and simulated surface elevations in REG waves

III. Numerical Description

Numerical Parameters	Mesh Resolution Types (Random Waves)		
	Type 1 (coarse)	Type 2 (medium)	Type 3 (fine)
dx (m)	0.1~0.025	0.1~0.015	0.1~0.01
dy (m)	0.025	0.015	0.01
dz (m)	0.05~0.025	0.05~0.015	0.05~0.01
Cell Number	~28 million	~52 million	~89 million
Courant Number	0.5	0.5	0.5
Turbulence Closure	k-ω SST	k-ω SST	k-ω SST
Duration (s)	400	400	400
Initial Time Step (s) at $t = 0$	0.01	0.01	0.01
Processor (cores)	24	24	24
Averaged Computation Time (days)	5	14	28





Comparison of measured and simulated surface elevations in RAN waves

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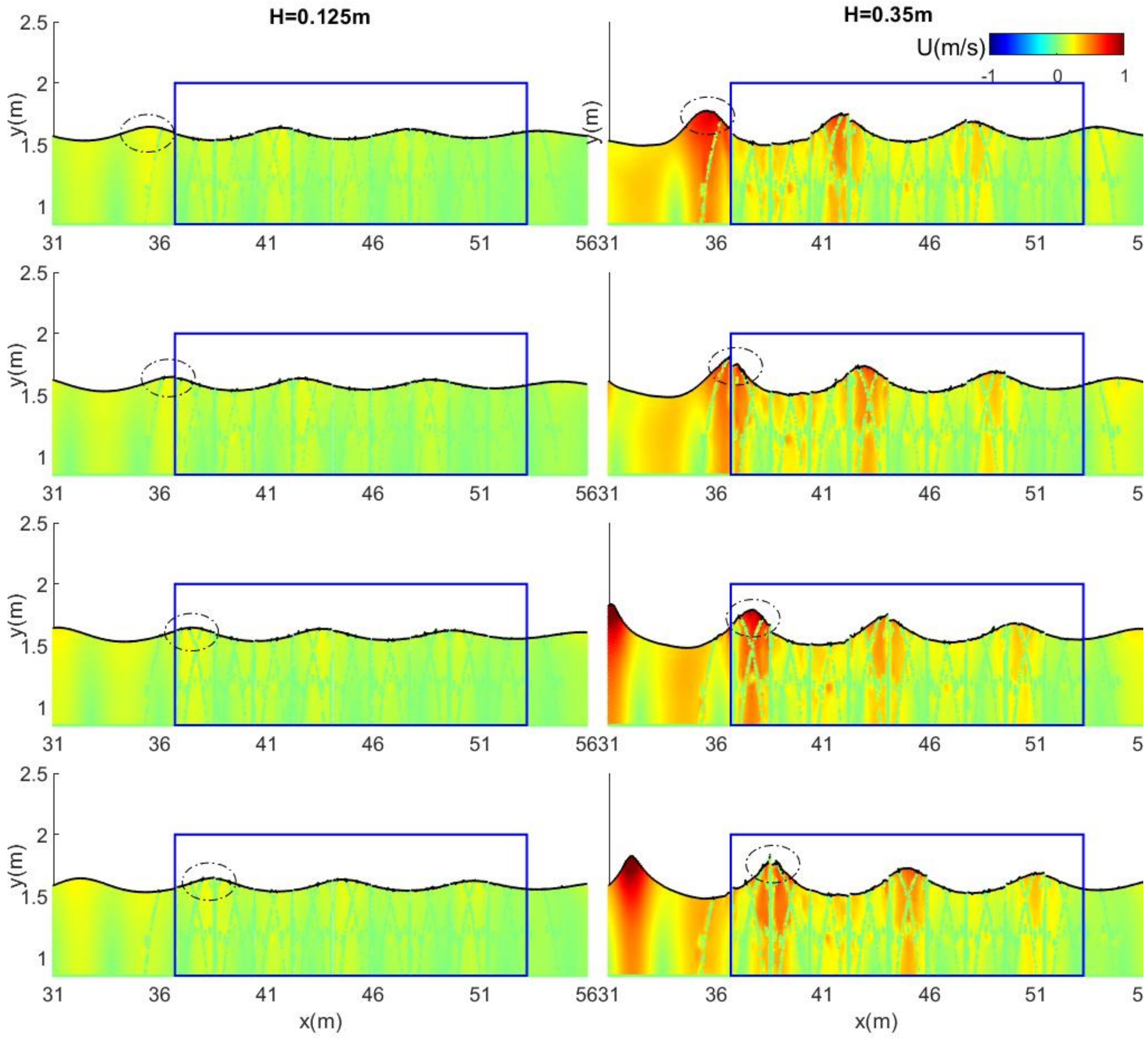
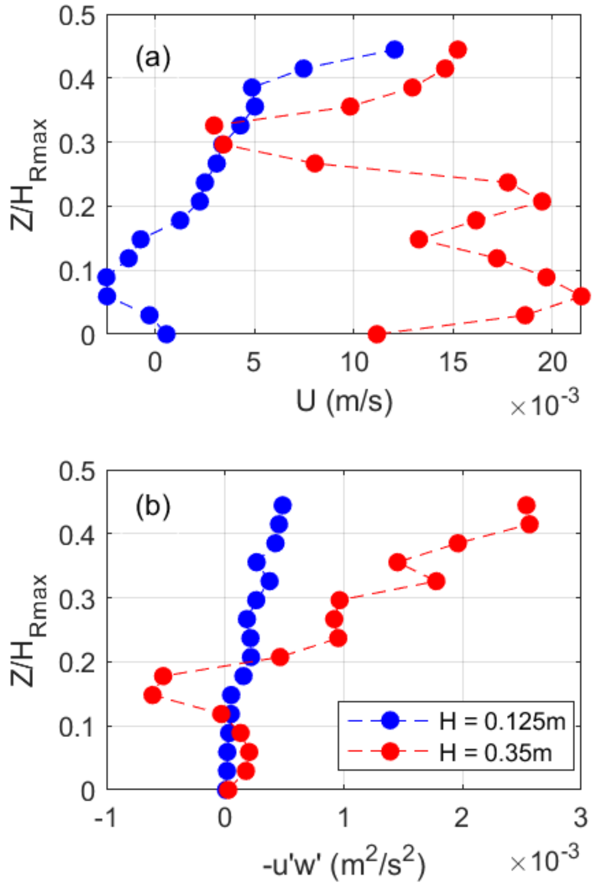
4.1. Hydrodynamic Patterns



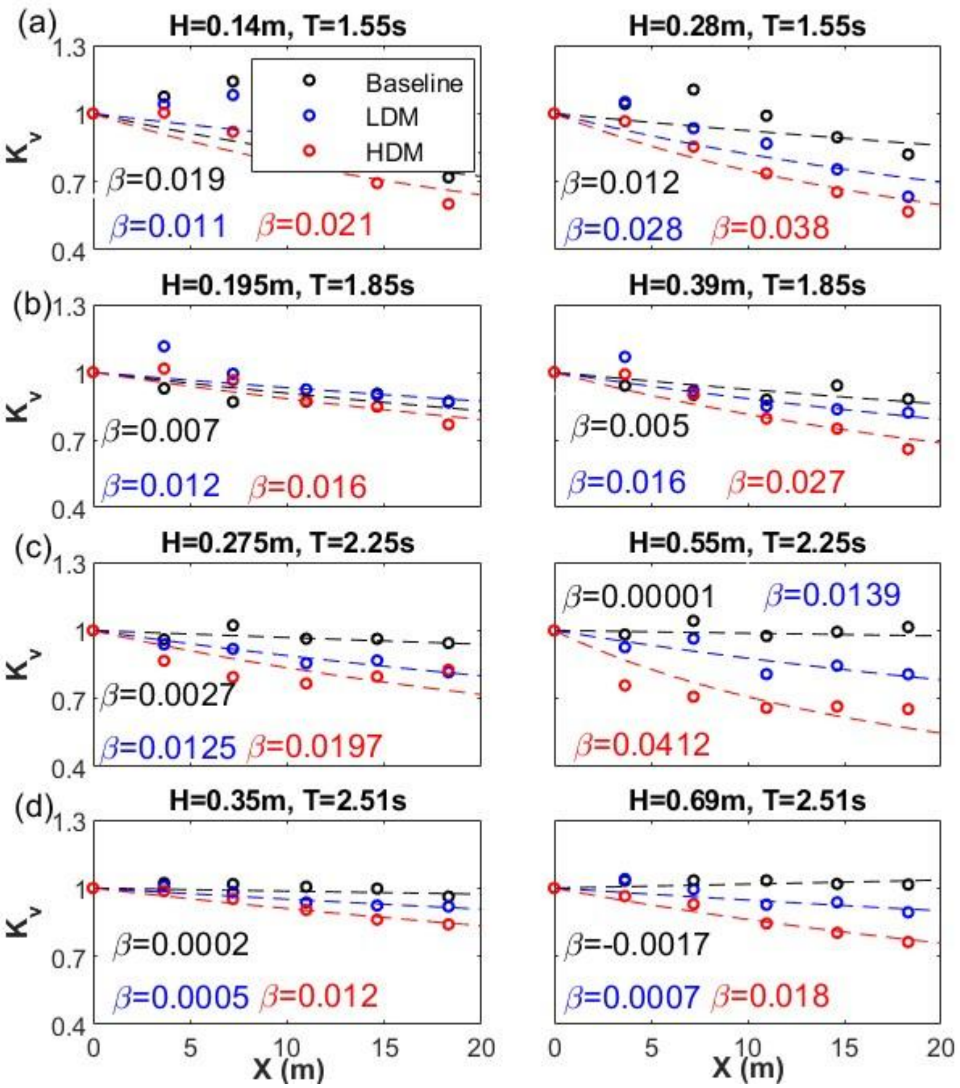
Effects of wave heights on flow fields



- Increasing wave height induced higher mean velocity and stronger turbulence, inducing more significant wave energy dissipation

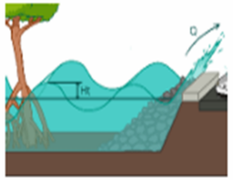
IV. Results and Discussions

4.2. Wave Attenuation Coefficients



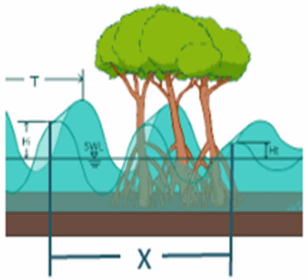
Representative transmission coefficients versus distance

Transmitted Wave Height

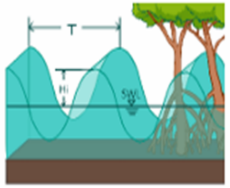


$$K_v = \frac{H_t}{H_i} = \frac{1}{1 + \beta x}$$

Distance along the "x-axis"



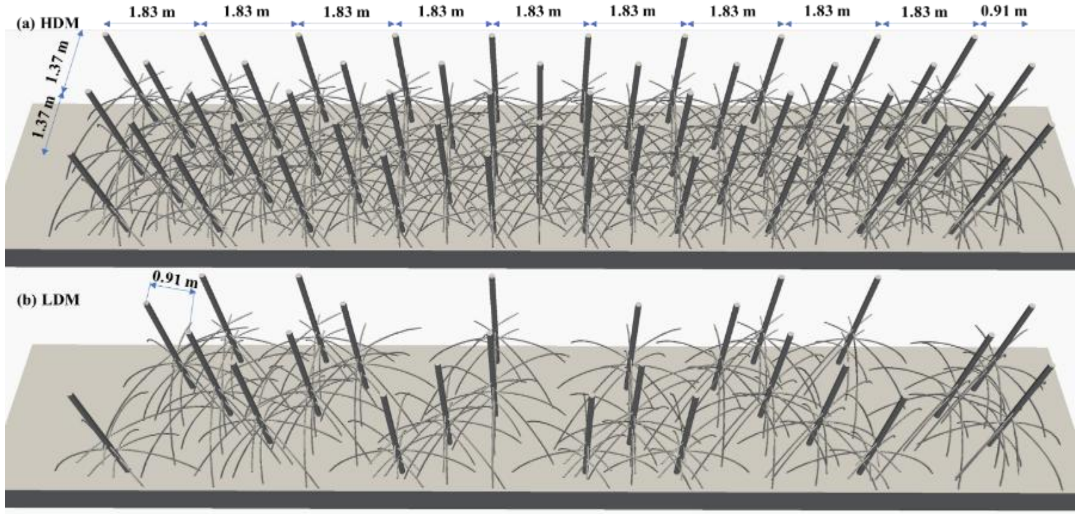
Incident Wave Height

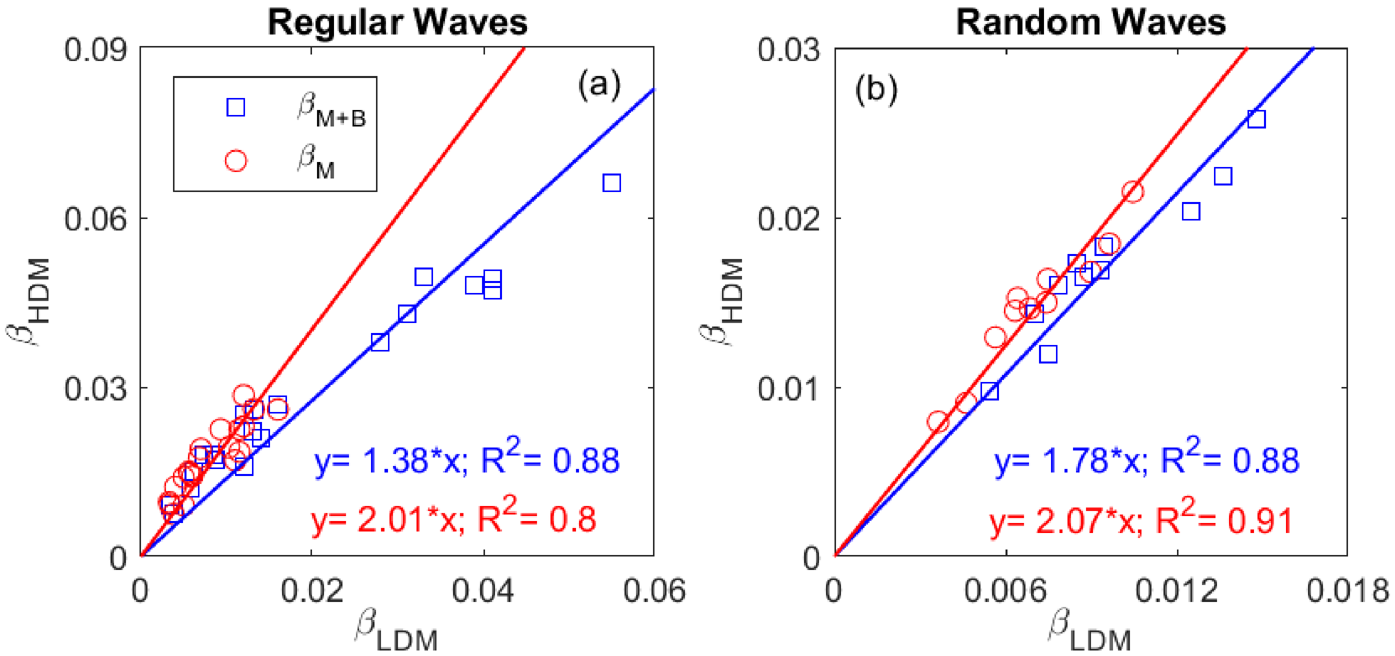


Wave Height Attenuation Coefficient

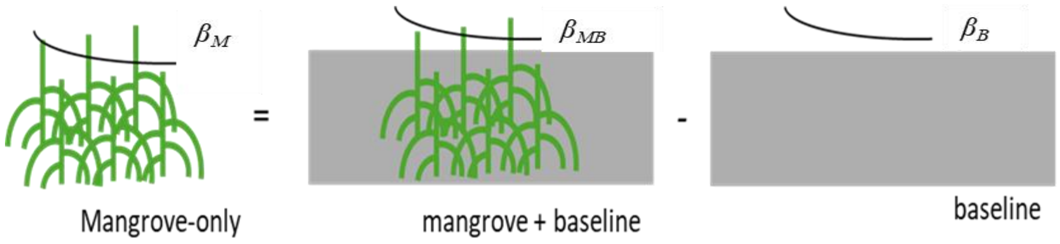
- Increasing wave heights and mangrove densities generally resulted in greater wave attenuation coefficients

4.2. Wave Attenuation Coefficients





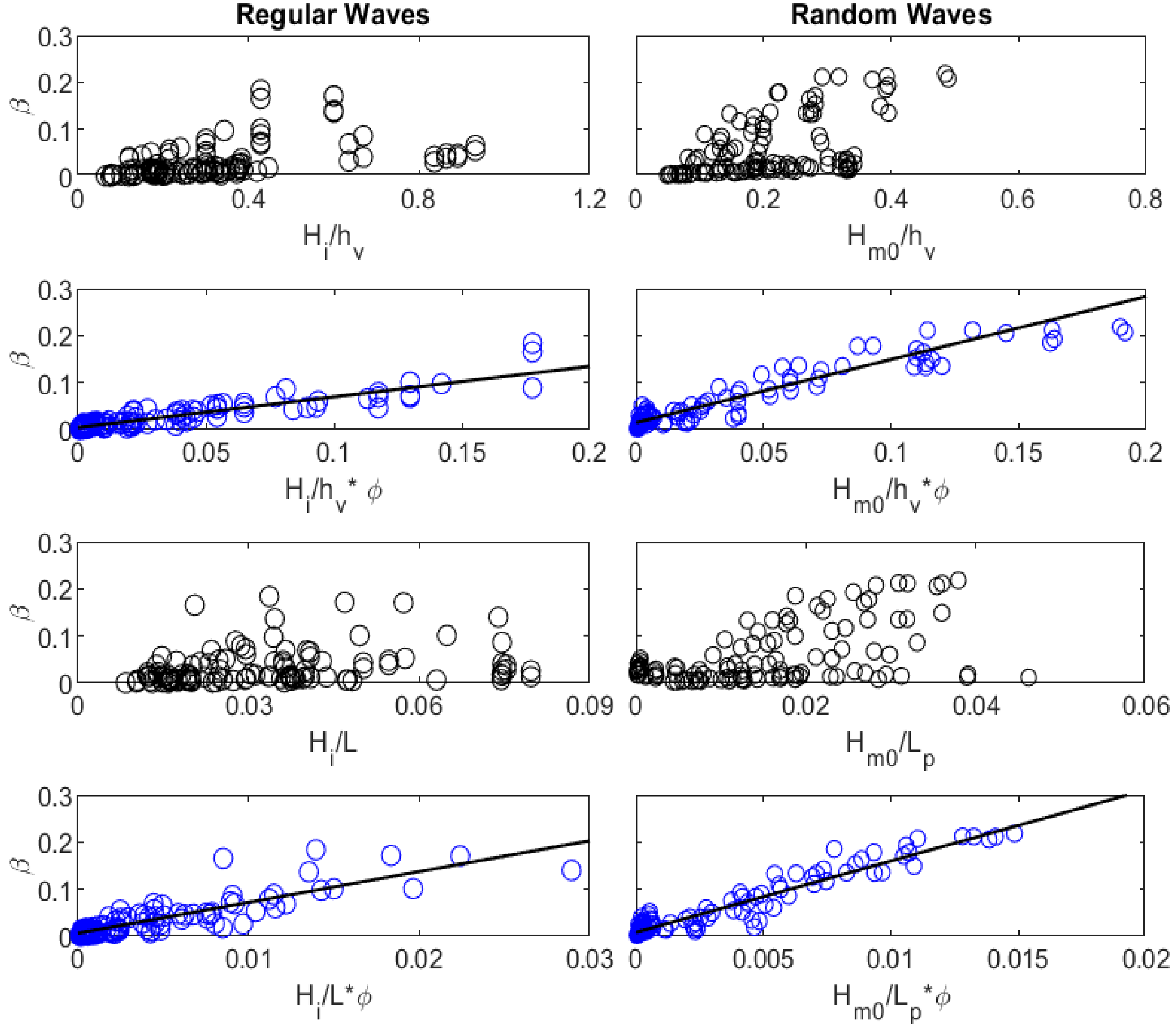
Effects of mangrove densities on wave attenuation coefficients



- HDM induced wave attenuation coefficients of approximately 2 times compared to LDM configuration for both regular and random wave conditions

IV. Results and Discussions

4.2. Wave Attenuation Coefficients



Relationships between the β values for vegetation models and H/h and H/L

Φ: submerged solid vegetation fraction

$$\Phi = \frac{V_m}{V_w}$$

V_m *submerged vegetation volume*

V_w *water volume in 18–m forest length*

- A linear relationship between wave attenuation coefficient and relative wave height and steepness
- Highlighting the importance of mangrove density in wave attenuation coefficient

IV. Results and Discussions

4.3. Predictive Models for Wave Attenuation Coefficients

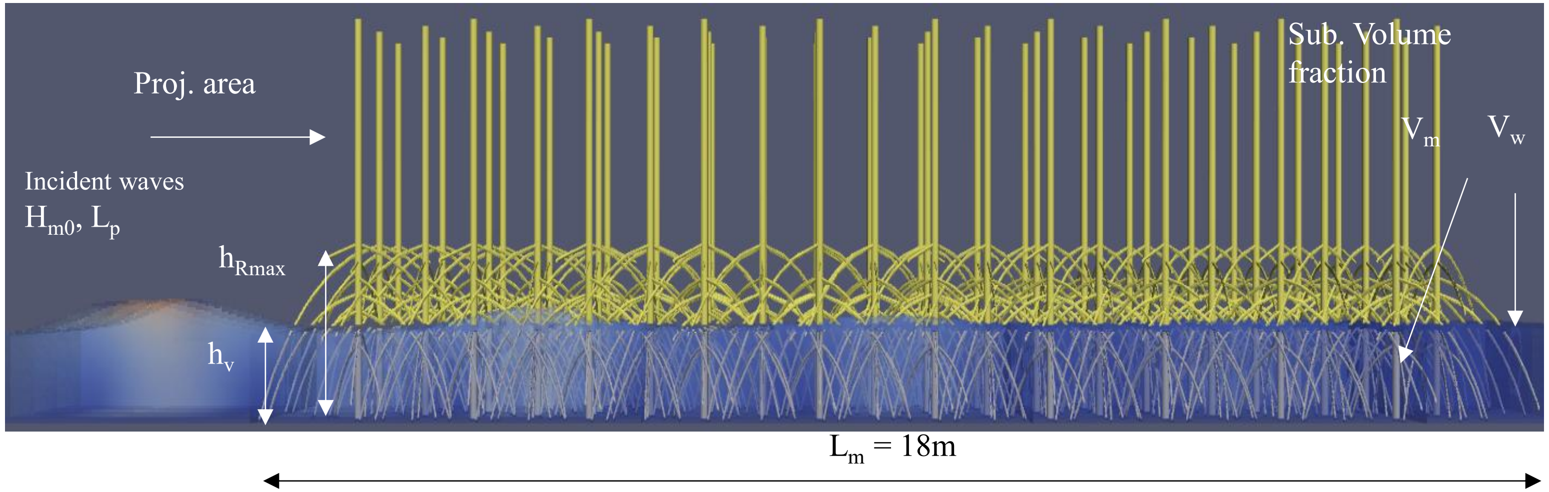
Symbol	Expression	Dimensionless Parameters
RA	$\frac{H_{m0}}{h_v}$	Relative Wave Height
RS	$\frac{H_{m0}}{L_p}$	Wave Steepness
ϕ	$\frac{V_m}{V_w}$	Solid Volume Fraction
AR	$\frac{A_m}{A_w}$	Relative Projected Area
RB	$\frac{L_p}{L_m}$	Relative Forest Width
α	$\frac{h_{Rmax}}{h_v}$	Relative Mangrove Height

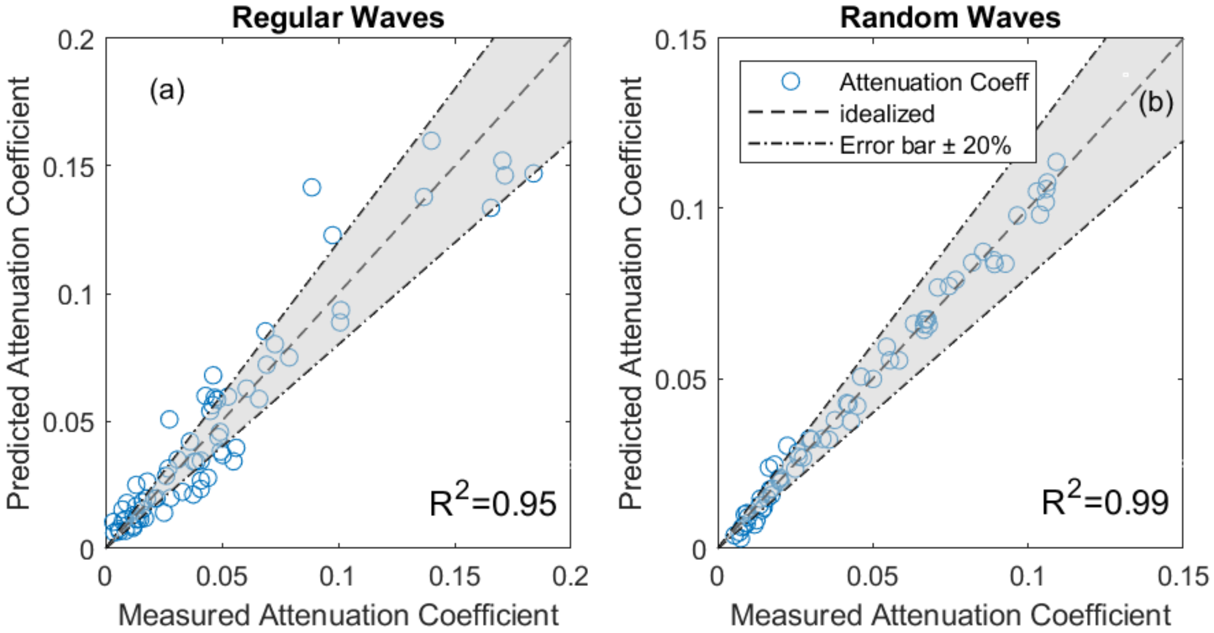
Regular waves ($R^2 = 0.95$)

$$\beta = 0.08 R_A^{0.56} R_S^{0.46} (\Phi)^{-0.05} (A_R)^{-0.85} R_B^{0.27} \alpha^{-1.32}$$

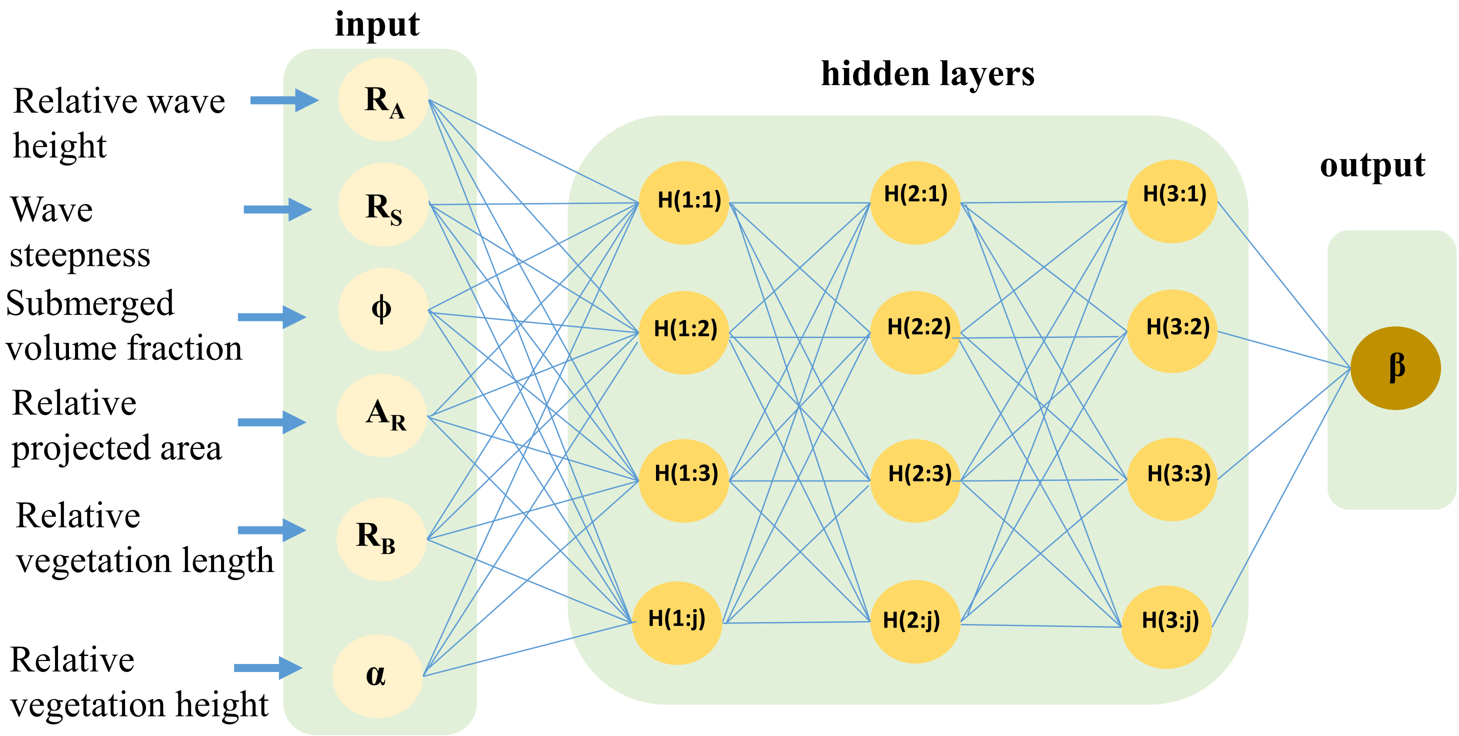
Random waves ($R^2 = 0.99$)

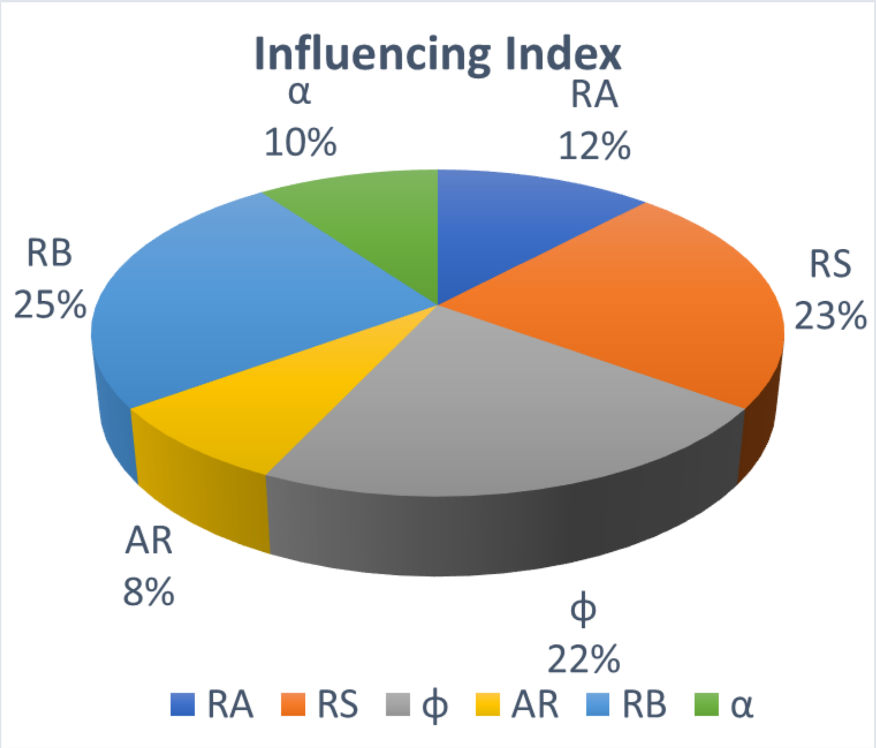
$$\beta = 5.16 R_A^{-0.09} R_S^{0.06} (\Phi)^{0.99} (A_R)^{0.44} R_B^{0.26} \alpha^{-0.29}$$





4.3. Predictive Models for Wave Attenuation Coefficients

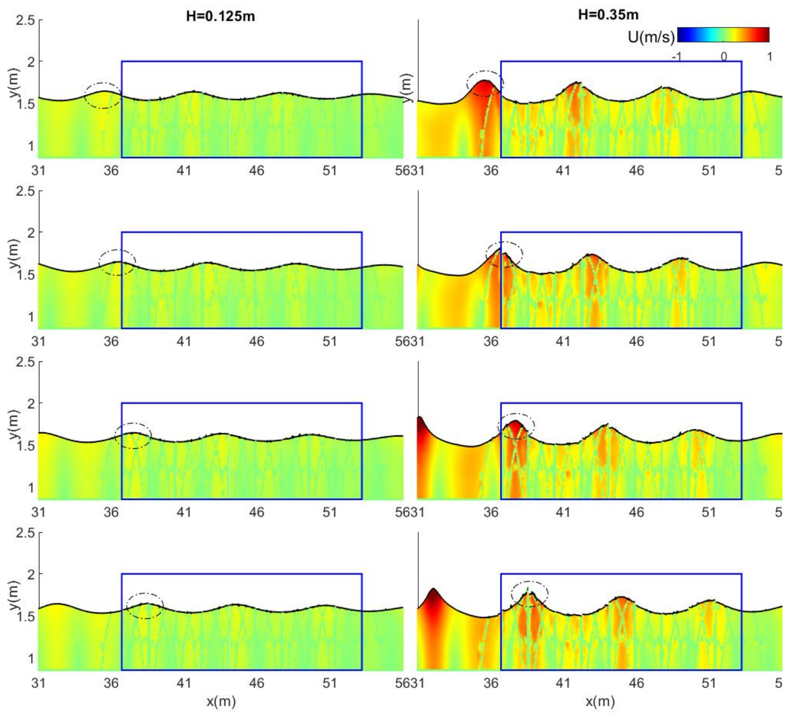


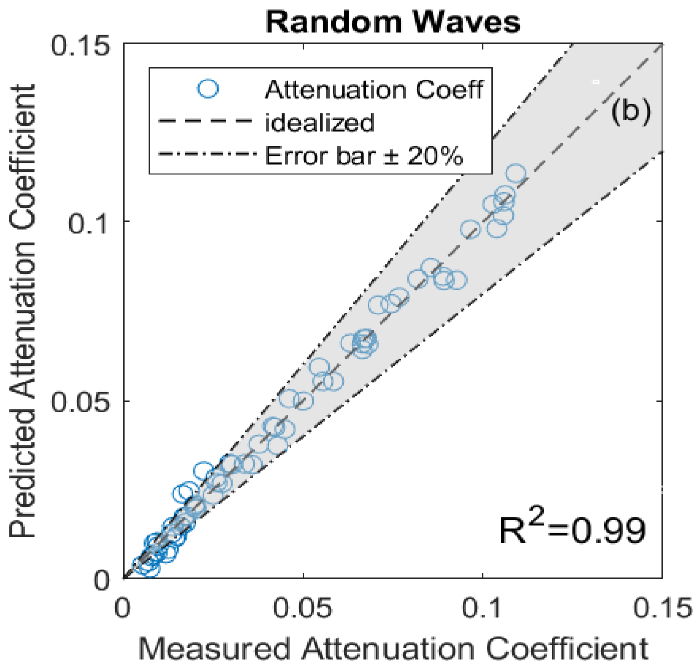


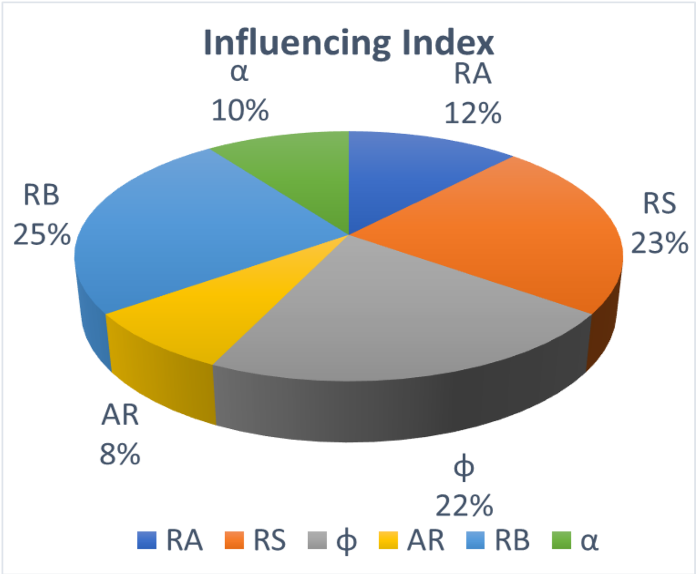
- Wave steepness, density, and cross-shore width of mangrove forest are dominant parameters, achieving 70% contribution on β

V. Conclusions

- Influences of wave parameters and mangrove densities have been investigated on flow patterns inside mangrove forests
- Wave attenuation coefficients increase with increasing relative wave height and wave steepness
- Fraction of mangrove densities is equal to the fraction of wave attenuation coefficients
- Empirical equations derived using MNLR were proposed for estimating the wave attenuation coefficients
- Wave steepness, forest length, and density are determined as key factors influencing β using Artificial Neural Network







THANK YOU FOR YOUR ATTENTION!

BIG Thanks to

Prof. Pedro Lomonaco

Prof. Dan Cox

Prof. Tori Tomiczek

Mr. Kierman Kelty