



WESC-2025

A Novel Methodology for the Definition of Design Wave Groups for Offshore Floating Structures, Using Elementary Gaussian Envelopes

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Project Details

(Twinning for Excellence in Floating Wind Turbines and Hydrogen Systems)

Consortium:

- University of Cyprus (UCY) / **HO**
- University of Florence (UNIFI)
- Aarhus University (AU)
- NEEST



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Details:

- Commencement date: 08/10/2024
- Duration: 36 months

Overview

What?

Methodology using Gaussian Elementary Envelopes to compose 'Design Wave Events' simulating extreme loading events on floating offshore structures.

Why?

Practical and accurate prediction of extreme responses to improve the design process of FOWTs.

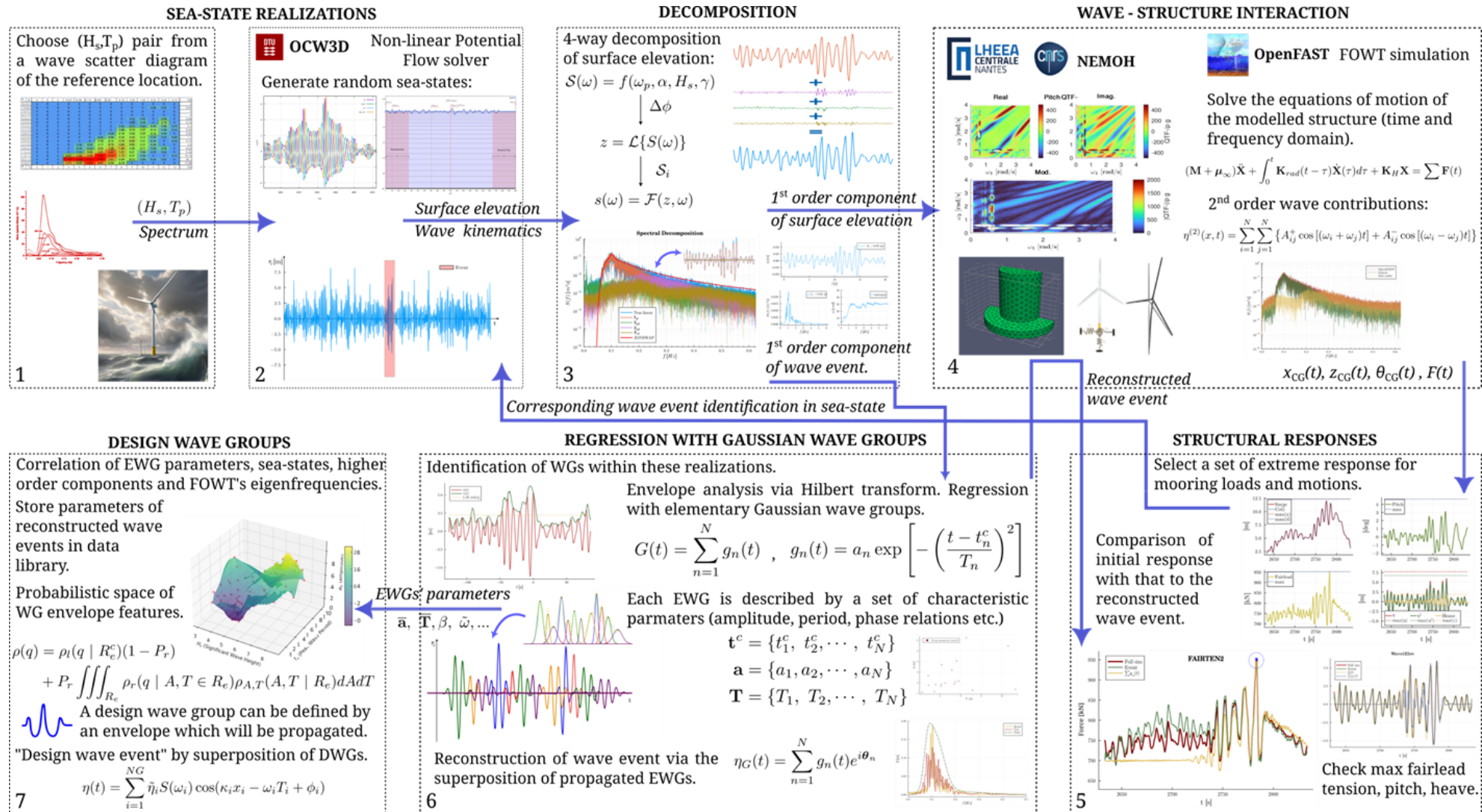
How?

Systematic processing of critical wave events described by few variables \Rightarrow data library for statistical analysis.

Concept:

Sub-harmonic waves, wave-grouping (nonlinear wave-wave interactions) \Rightarrow Resonance with structural motions \Rightarrow Extreme responses \Rightarrow Properties of responsible wave groups can be identified to reproduce critical wave events.

Methodology



Critical Wave Events – Identification & Isolation

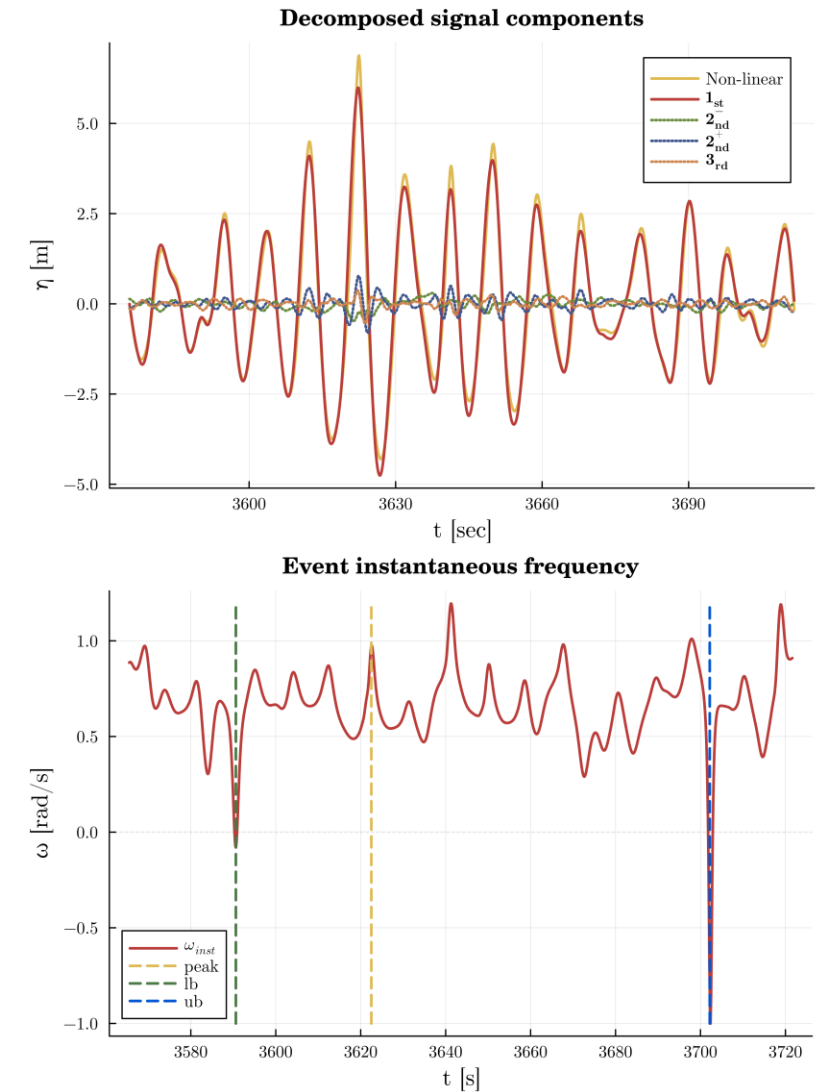
- Extreme structural responses \Rightarrow Identify corresponding part of the sea-state
- Critical wave events selected based on the "instantaneous" frequency:

$$\omega_{inst} = \dot{\theta}$$

(θ : phase angle from Hilbert transform)

- Limits defined by discontinuities:

$$\omega_{inst}(t) \leq 0$$



Gaussian Regression of Wave Events

- Surface elevation $\eta(t) \rightarrow$ Hilbert transform ($\eta = ue^{i\theta}$):

$$u(t) = |\mathcal{H}\{\eta(t)\}|, \theta = \angle\mathcal{H}\{\eta(t)\}$$

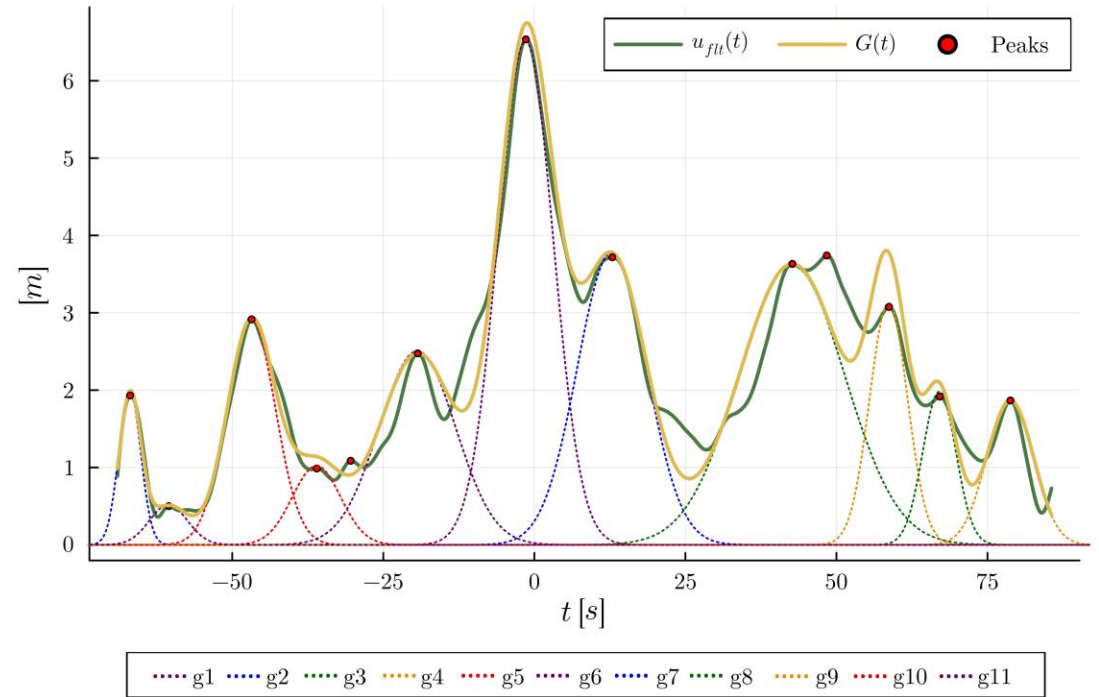
- Approximation of envelope:

$$u(t) \approx G(t) = \sum_{n=1}^N g_n(t)$$

- Elementary Gaussian Envelope (EGE):

$$g_n(t) = a_n \exp\left[-\left(\frac{t - t_n^c}{T_n}\right)^2\right]$$

- N EGEs $\rightarrow N$ triplets: α_n, T_n, t_n^c



- Calculation of \mathbf{T} is a minimization problem:

$$J(\mathbf{T}) = \frac{1}{2} \int_0^{t_e^E} (G(t) - |u(t)|)^2 dt$$

Systematic Processing of Wave Events

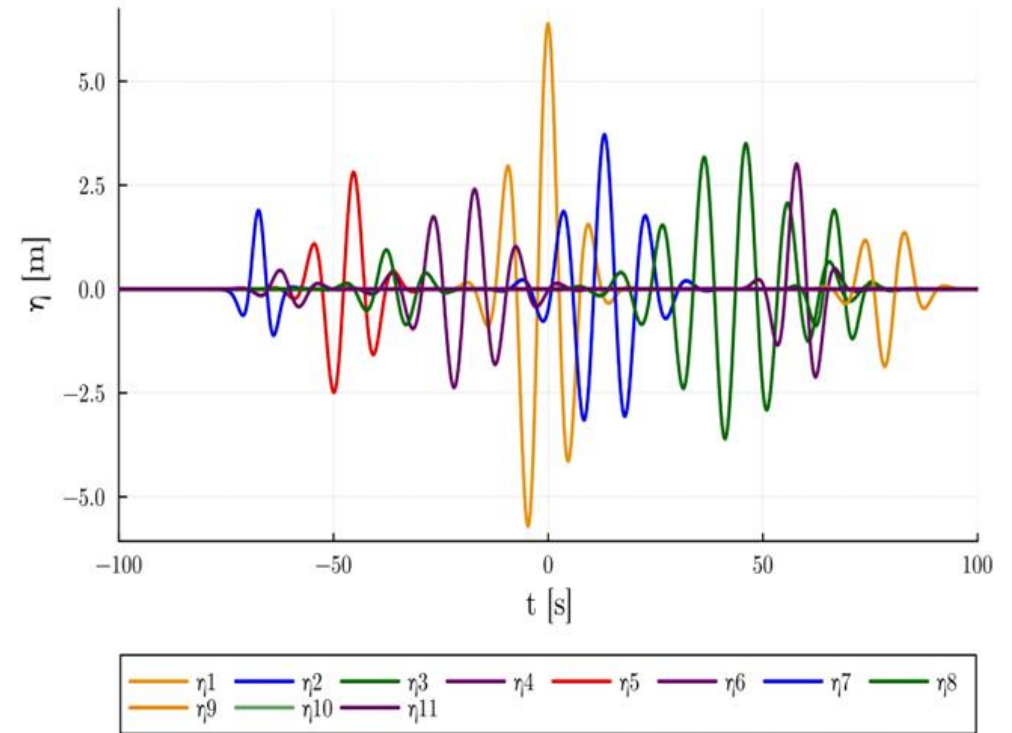
- Summarise phase information:

$$\eta_G(t) = \left[\sum_{n=1}^N g_n(t) \right] e^{i\theta} = \sum_{n=1}^N g_n(t) e^{i\theta_n}$$

A solution is:

$$\left. \begin{aligned} e^{i\theta} &= e^{i\theta_n} = e^{-i\omega_n t} e^{i\phi_n} \\ \phi_n &= \omega'_n t + \beta_n \\ \tilde{\omega} &\equiv \omega'_n - \omega_n \end{aligned} \right\} e^{i\theta} = e^{i\tilde{\omega} t} e^{i\beta_n}$$

- $\tilde{\omega}$: constant for all $g_n \Rightarrow$ wave event characteristic frequency
- β_n : phase angle, additional parameter for each g_n



- Normalization:

$$\bar{a} = \frac{a}{H_s} \quad \bar{T} = \frac{T}{T_p} \quad \bar{t}^c = \frac{t^c}{T_p} \quad \Omega = \frac{\tilde{\omega}}{\omega_p}$$

Reconstruction of Wave Events

- Carrier signal $e^{-i\tilde{\omega}t}$ modulated by each g_n
- Resulting variance spectrum:

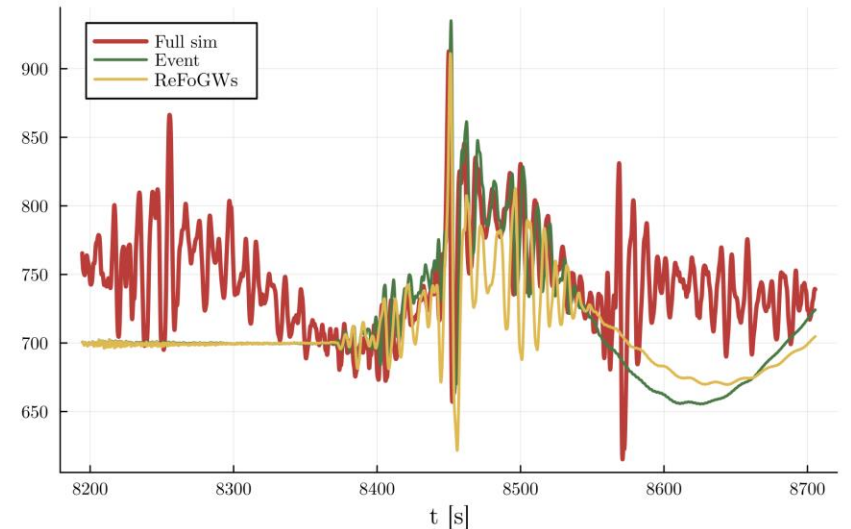
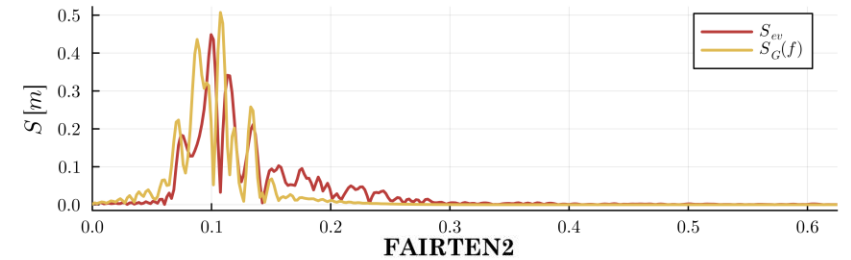
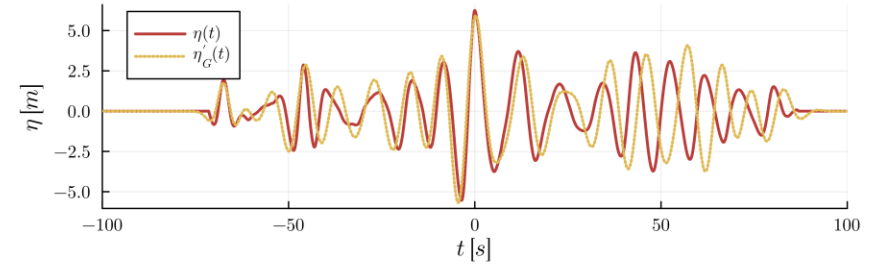
$$P_n(f) = \frac{1}{2} \frac{|S_n(f)|^2}{\Delta f}$$

- Generate focused wave group:

$$\eta_n(t) = \frac{a_n}{\sum P_n \Delta f} \sum_{i=1}^{N_f} P_n(f_i) \Delta f \cos[-\omega_i(t - t_n^c) + \beta_n]$$

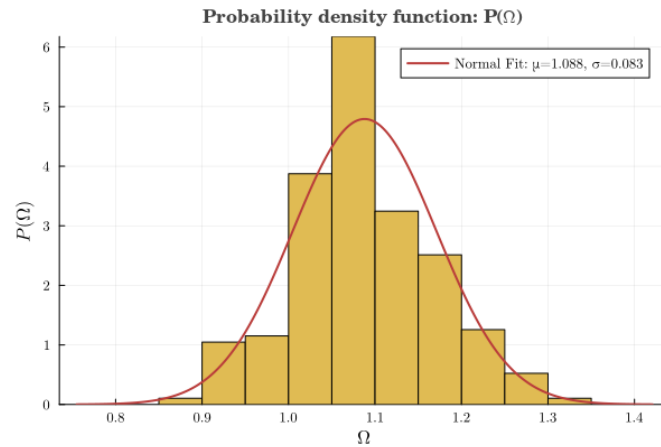
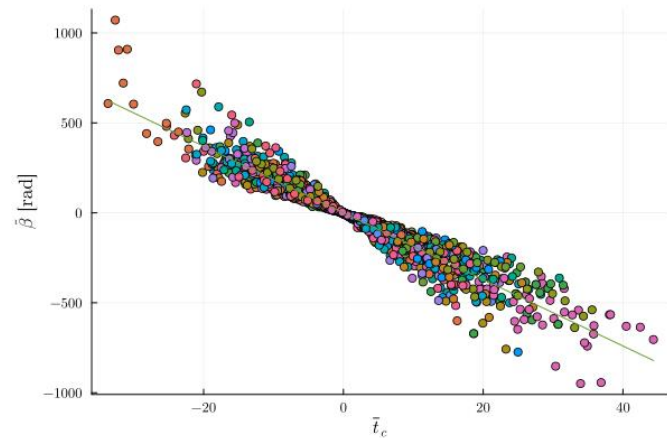
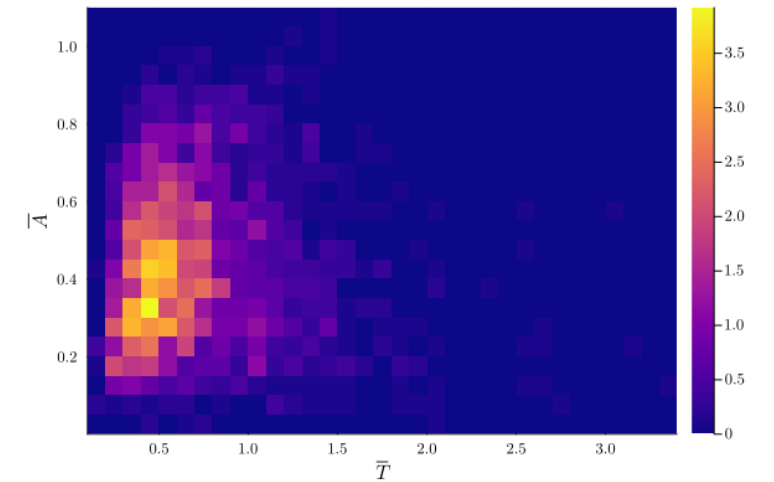
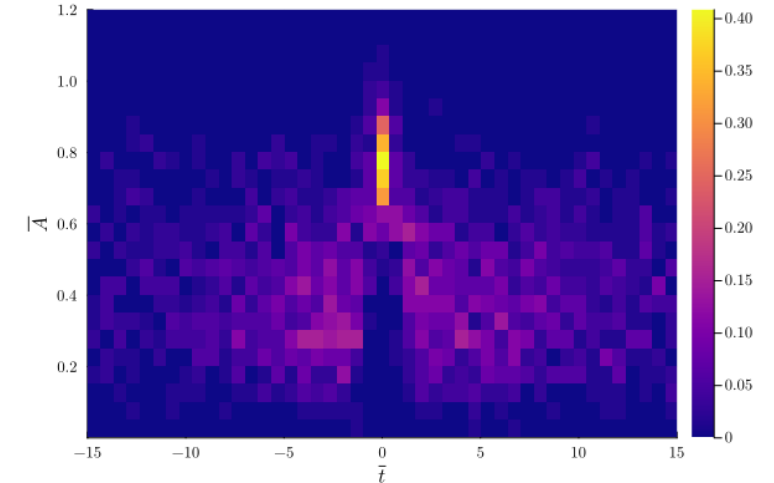
- Reconstructed surface elevation:

$$\eta_G(t) = \sum_{n=1}^N \eta_n(t)$$



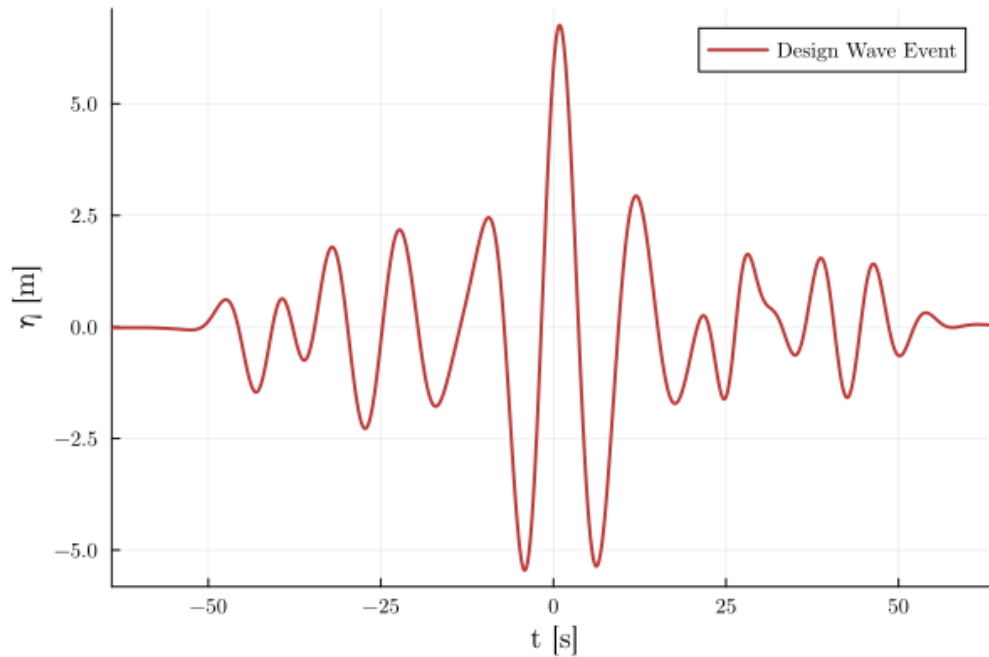
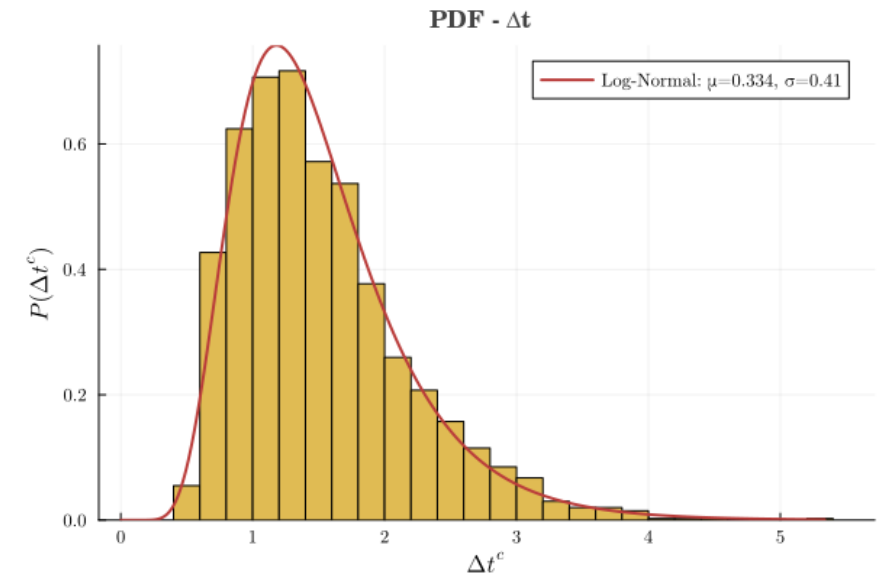
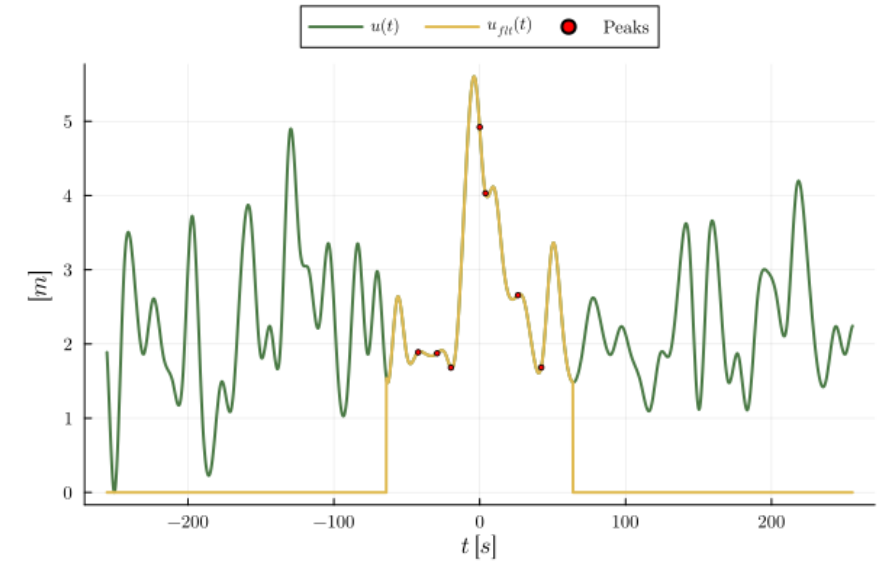
Statistical Processing

- Per H_S, T_p pair \Rightarrow 10s of critical wave events in ≥ 20 sea-state simulations
- Statistics of elementary envelopes / wave events
- Identification of variable distributions and correlations



Design Wave Events

- Draw random set of EGEs from probability distributions $T, \Delta t^c, \Omega$
- Reconstruct design wave event



Conclusions

- Extreme responses (e.g. mooring tension) not solely determined by wave amplitude but also the interplay of wave groups and low-frequency resonance effects
- Reliable reproduction of critical events justifying the identification/isolation and Gaussian regression approaches
- Structural dynamics are involved (wave event duration, interval between wave groups)
- Practical/cost-efficient tool for iterative design and experiments

Thanks for your attention!



This project has received funding from the European Union's Horizon research and innovation program under Grant Agreement No 101159567.

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