Predicting extremes in the ocean

a data-driven approach

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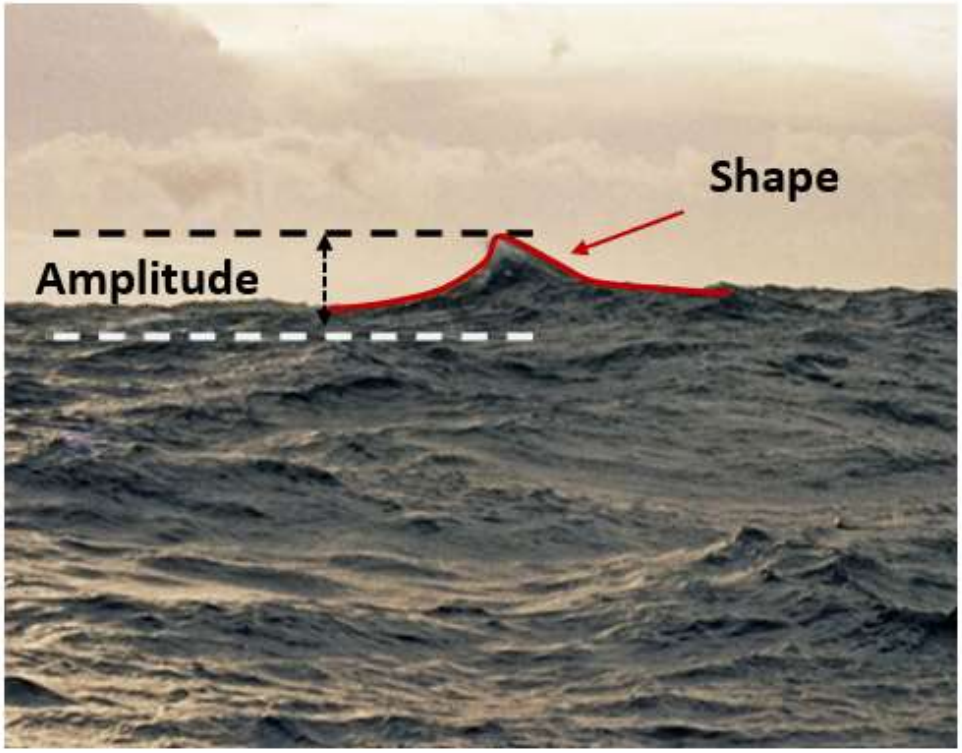
Rogue waves

- Offshore wind
- Offshore floating solar
- Wave energy
- Transportation
- Autonomous marine vehicle

…

What do we want to know about the rogue wave?

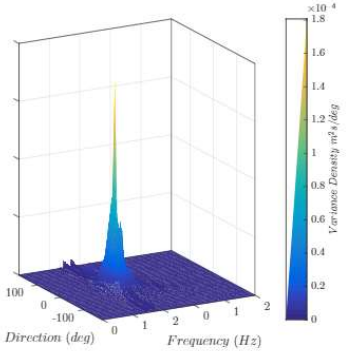


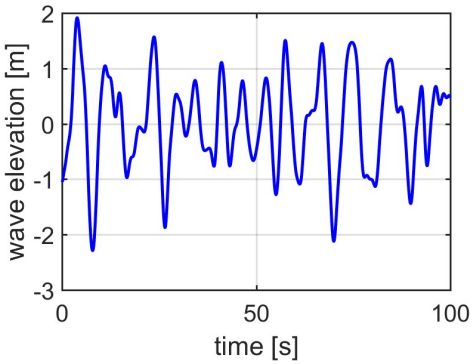
- Wave crest **amplitude** statistics
- Most probable **shape** of extreme waves
- **Physics** behind extreme waves

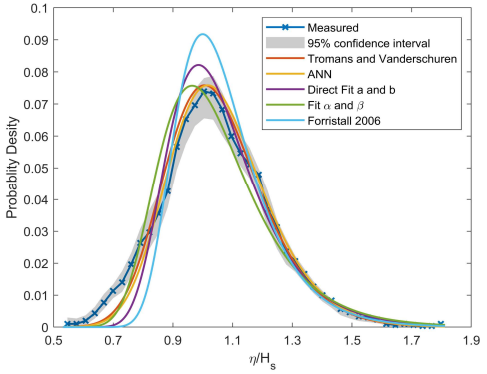
The challenge

- Complexity in the nonlinear physics (Benjamin-Feir instability, wave breaking, wave-current interactions, wind-wave interactions…)
- Balance between in the numerical model accuracy and computation resources available

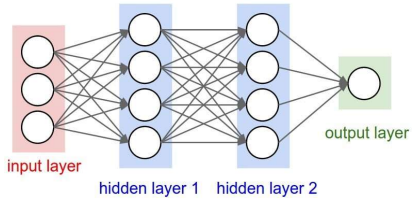
Wave spectrum → **Time series** → **Probability distribution**





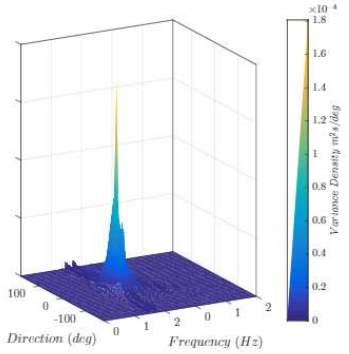


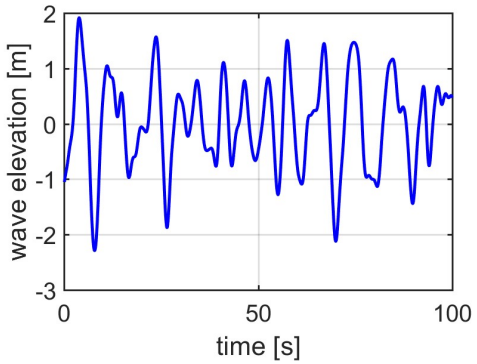
The challenge

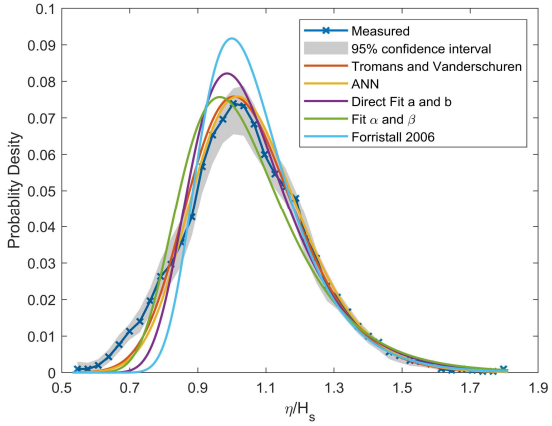


Machine Learning?

Wave spectrum → **Time series** → **Probability distribution**

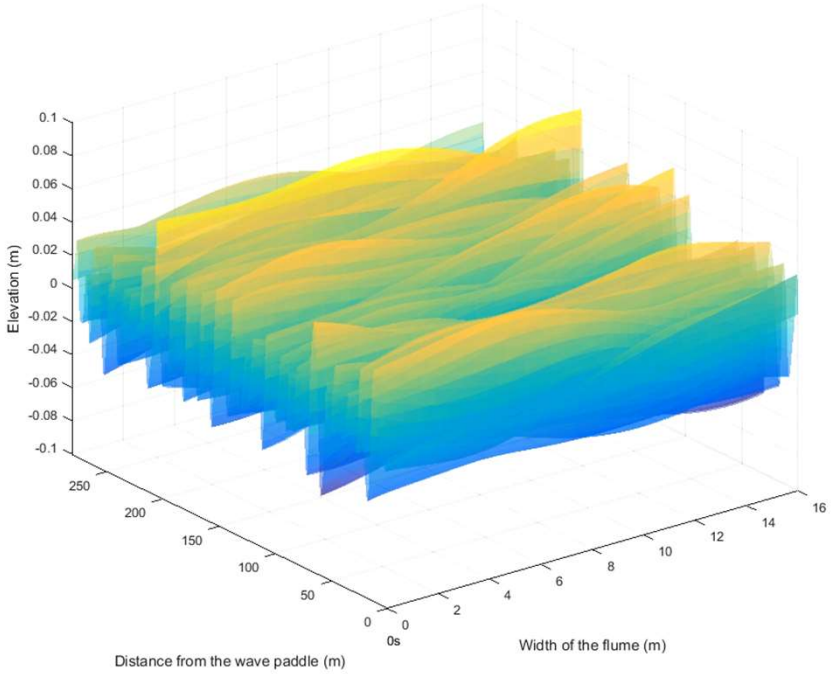


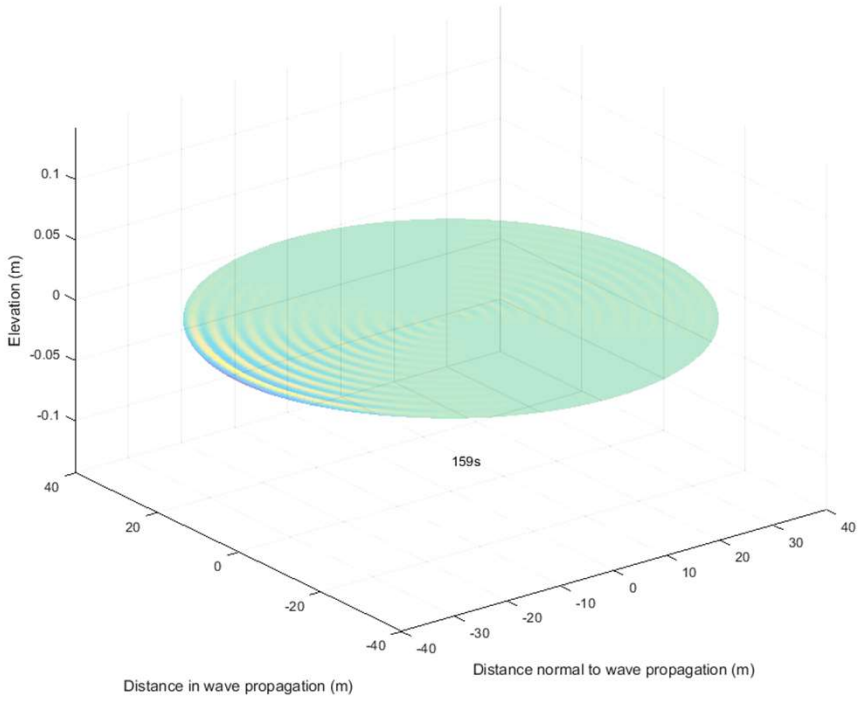




- It is computationally impractical to obtain sufficient **statistically stable** training data with high fidelity numerical model

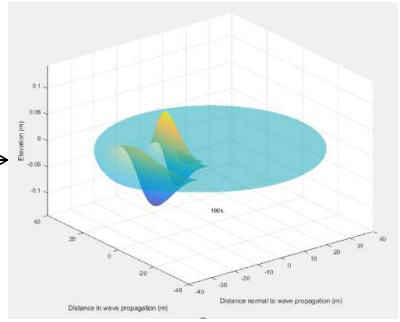
Random time series vs. Wave groups



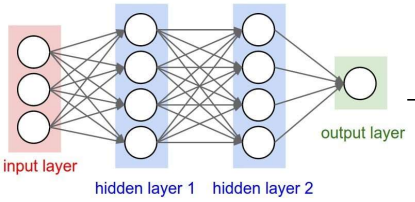


A framework describing extremes

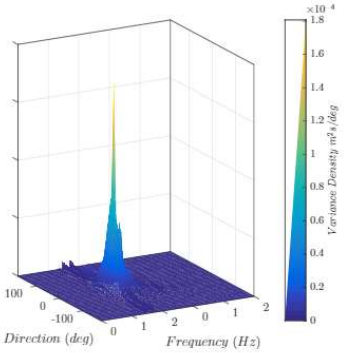
Wave groups

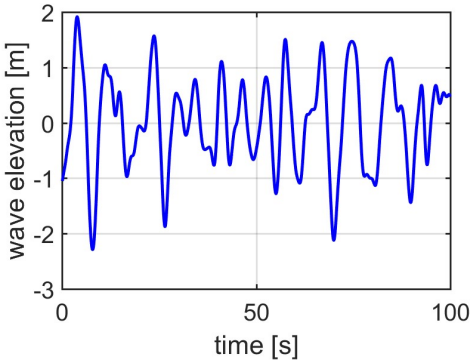


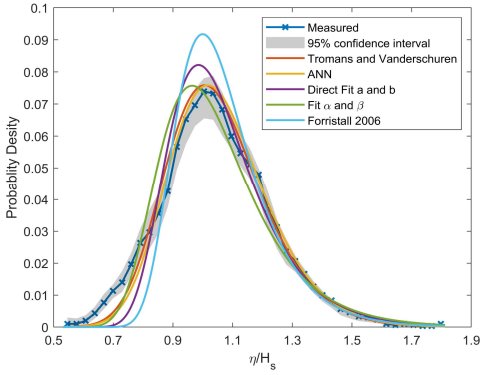
Data-driven methods



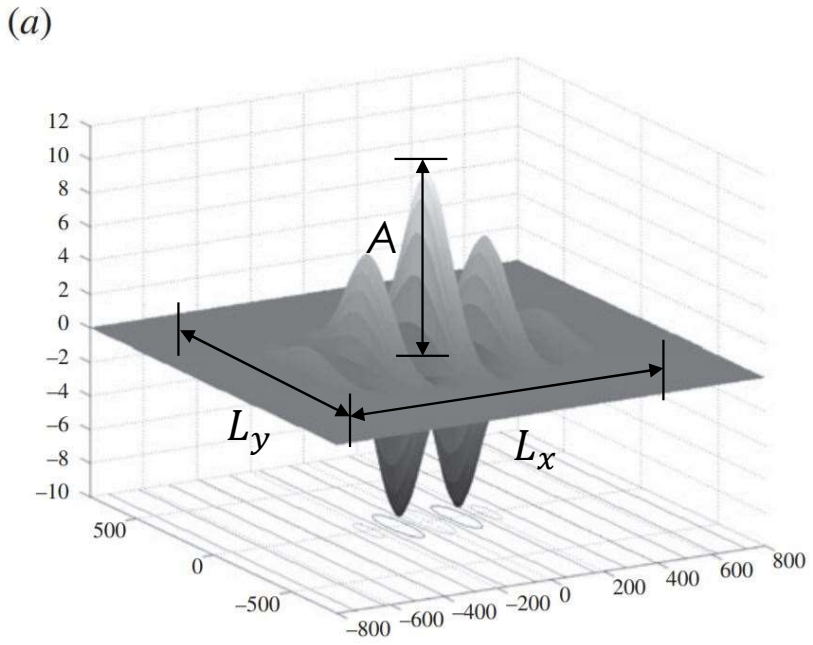
Wave spectrum → **Time series** → **Probability distribution**







Gaussian wave groups



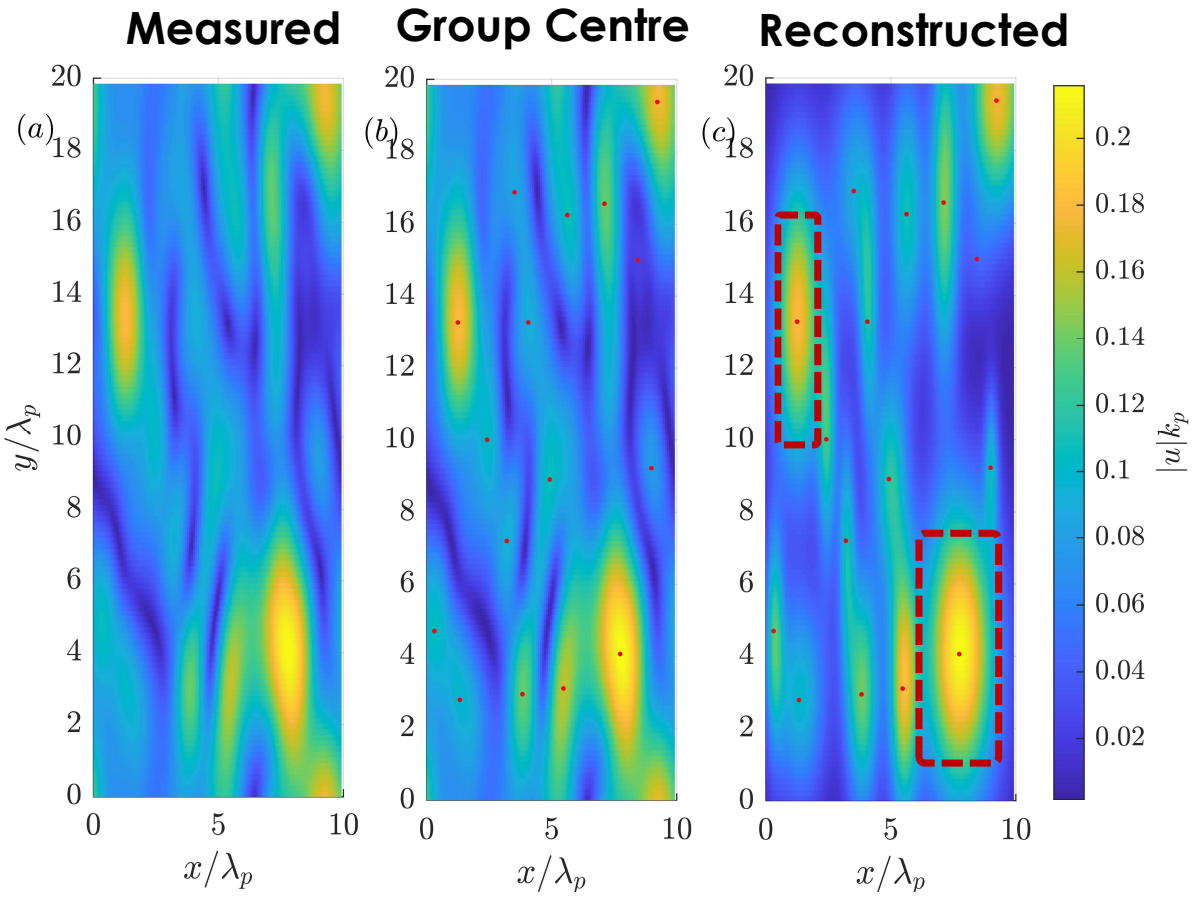
$$u_0(x,y) = A\exp\left[-\frac{x^2}{L_x^2} - \frac{y^2}{L_y^2}\right],$$

A: Envelope amplitude at linear focus

L_x: Length scale in x direction

L_y: Length scale in y direction

Parameterization of random wave fields

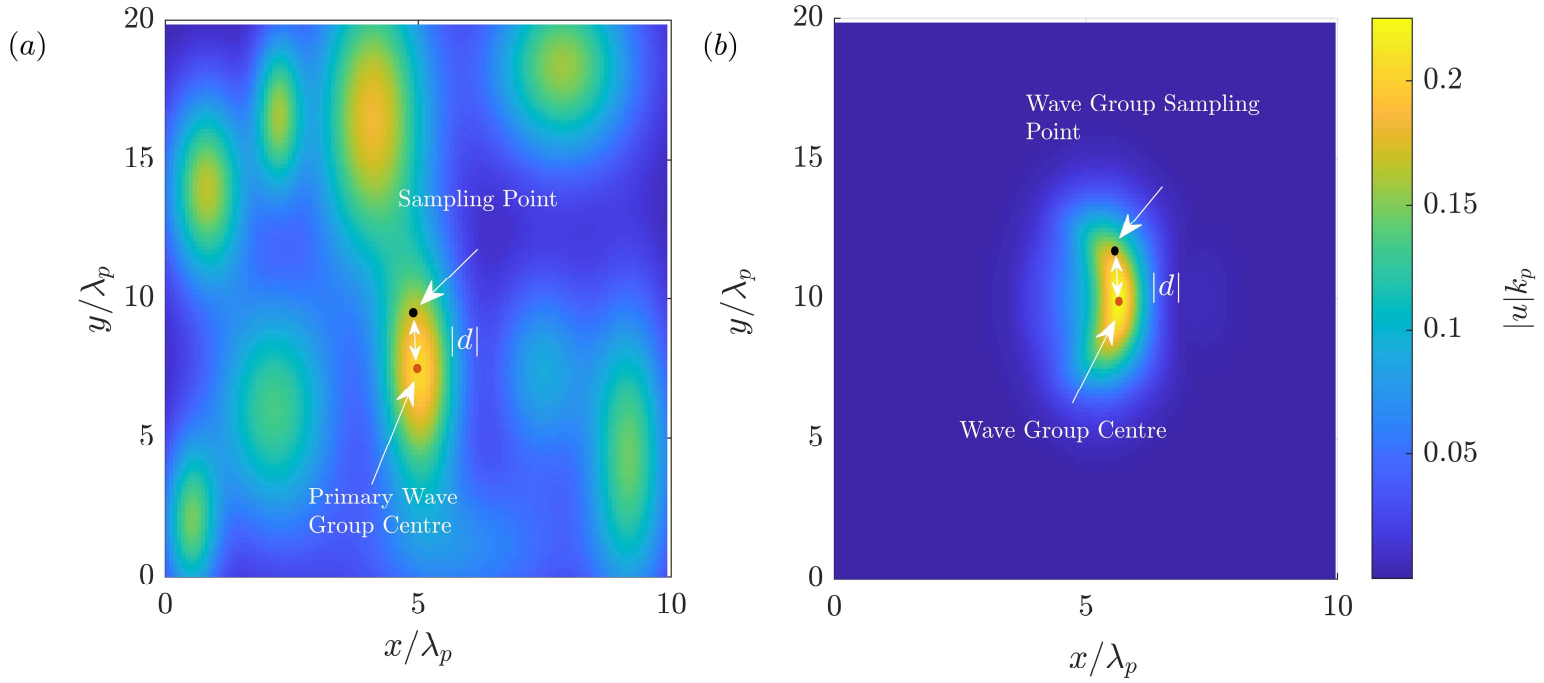


Step 1: Determine the envelope peak

Step 2: Determine the length scale parameters with optimization algorithm

$$u_0(x,y) = A\exp\left[-\frac{x^2}{L_x^2} - \frac{y^2}{L_y^2}\right],$$

Recreate the formation of extreme events

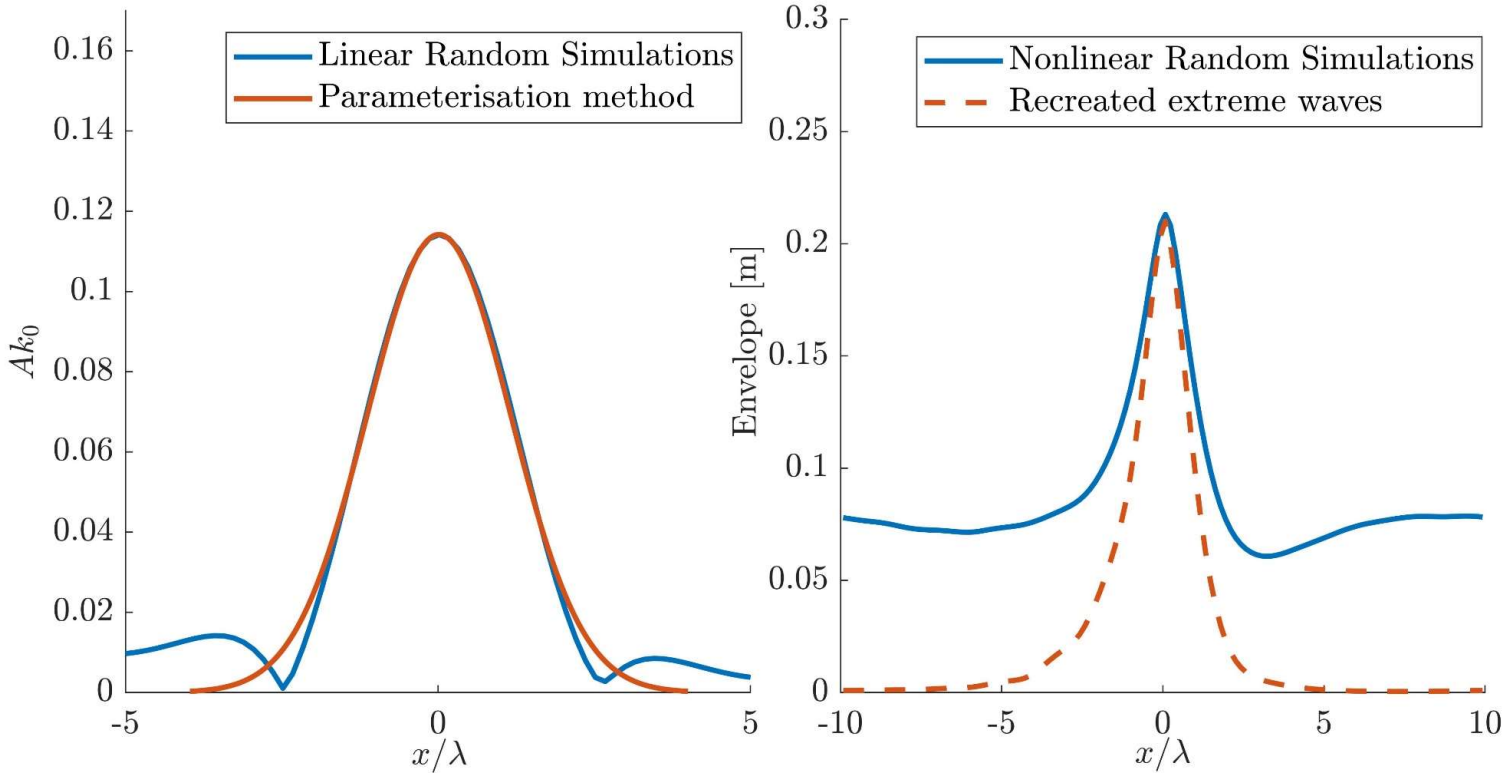


Reconstructed wave field (Linear)

Isolated extreme events (Nonlinear)

Can we predict the most probable **shapes** of rogue waves?

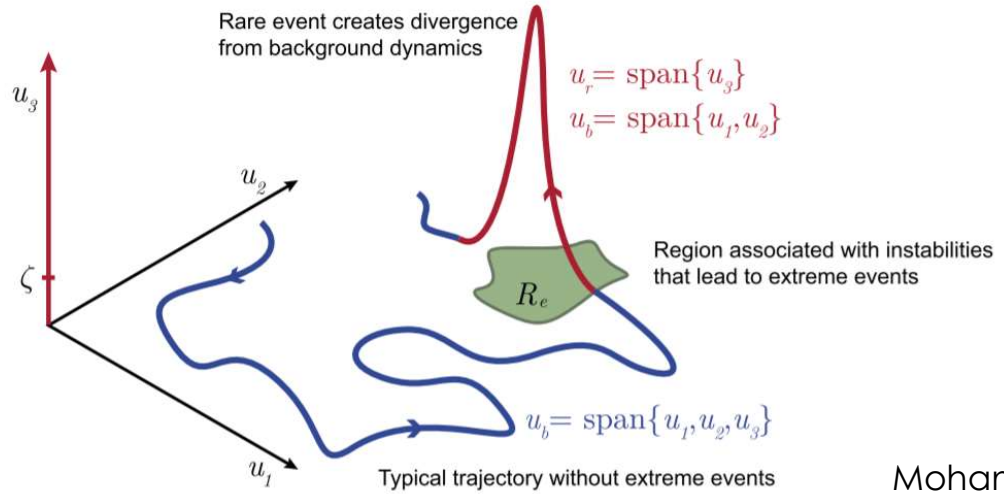
Averaged shape of extreme events



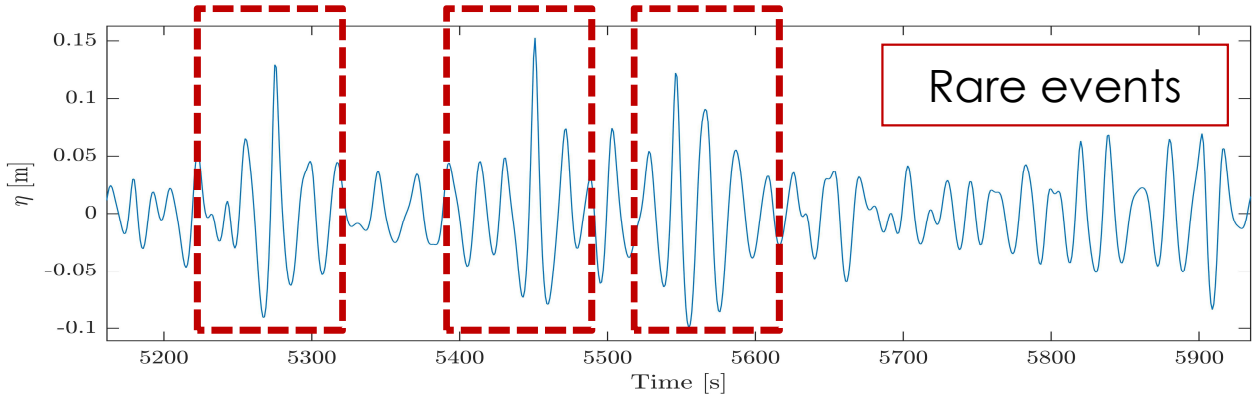
- The proposed parameterization and recreation method can accurately **isolate** the extreme events and predict the **nonlinear changes**.

Can we predict the **Statistics** of rogue waves?

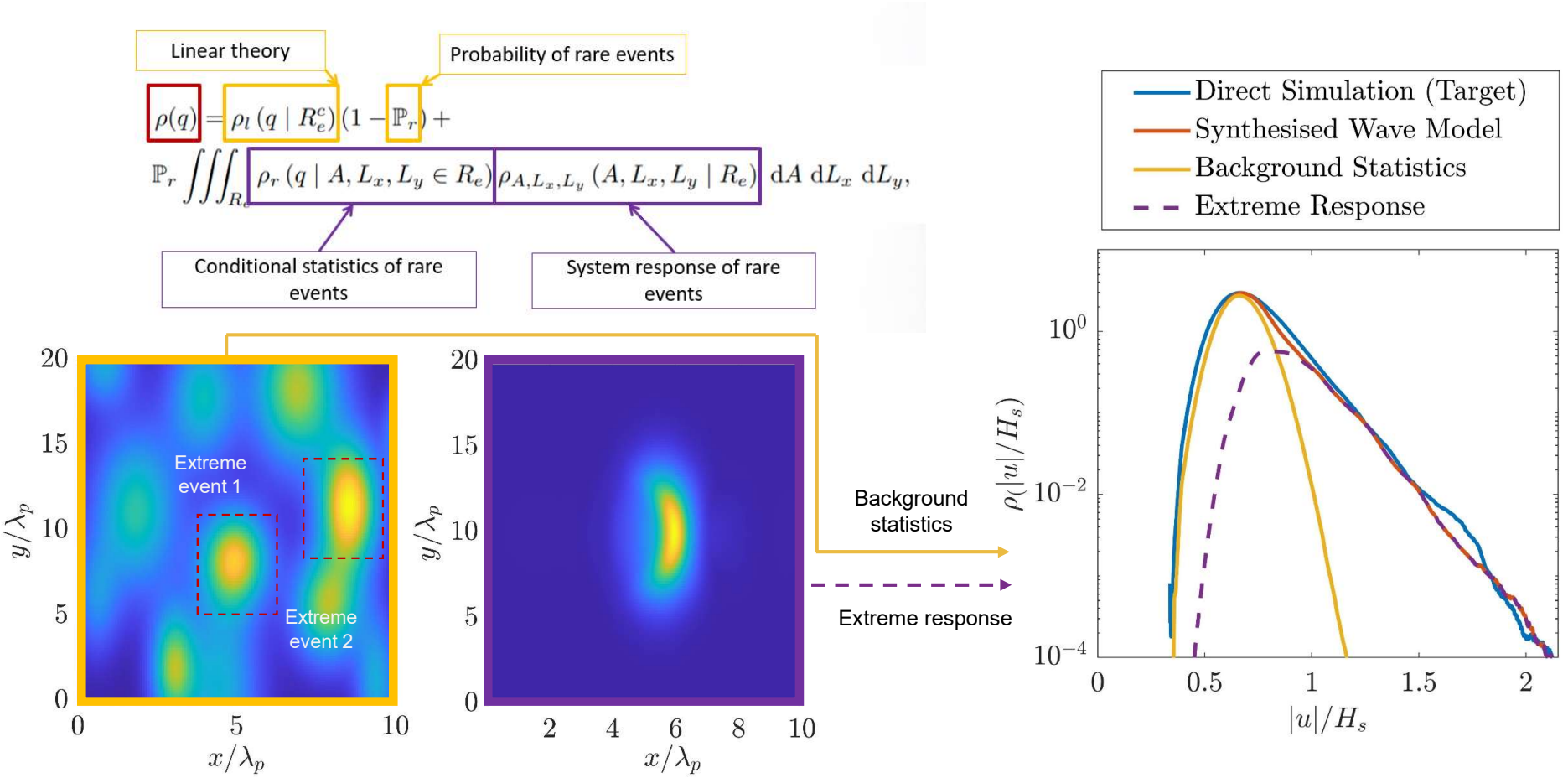
Probability of extreme events



Mohamad et. al. (2016)

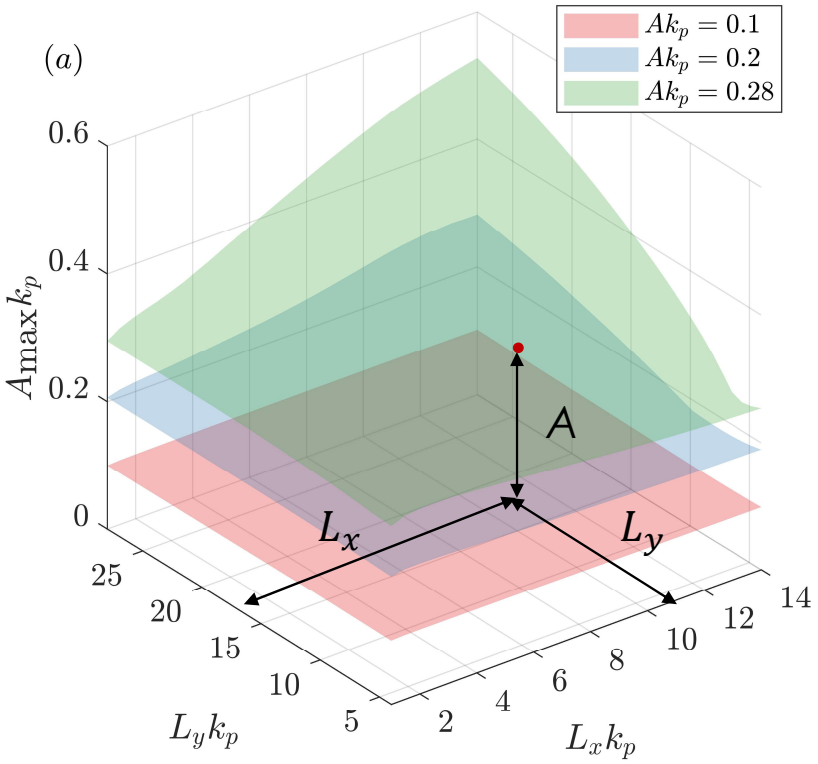


Probability of extreme events



Can we establish a wave group database without simulating thousands of wave groups?

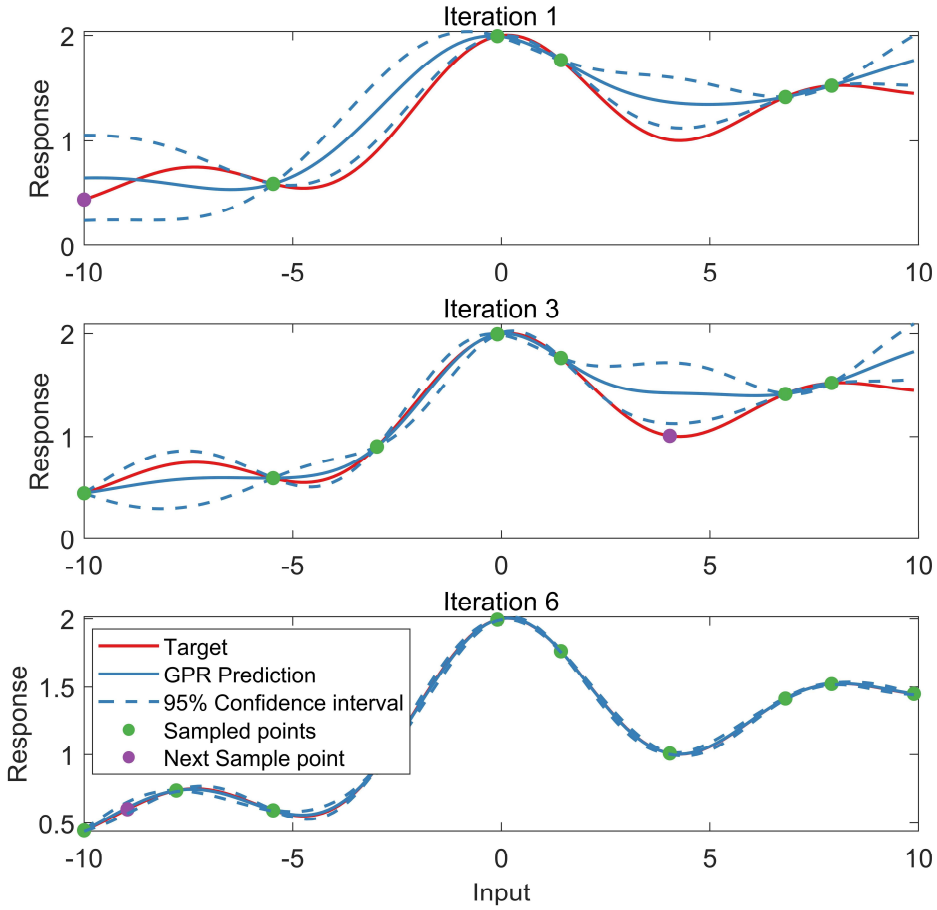
Database assimilated Gaussian Process



$$\text{Extreme Response} \equiv \text{GP}(L_x, L_y, A)$$

- A gaussian process regression is used to interpolate the extreme responses.
- For new combination of inputs, the high-fidelity numerical model results can be reused.

Sequential sampling method

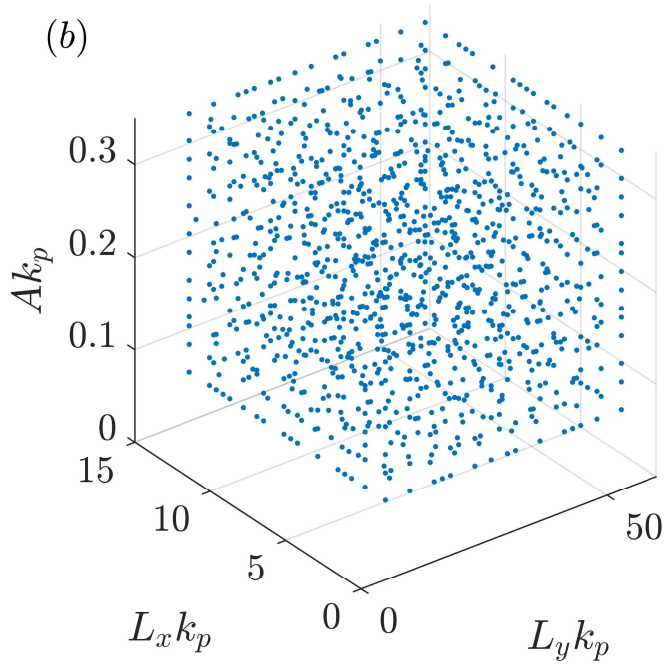


Step 1: Predict the response based on current observations with GPR

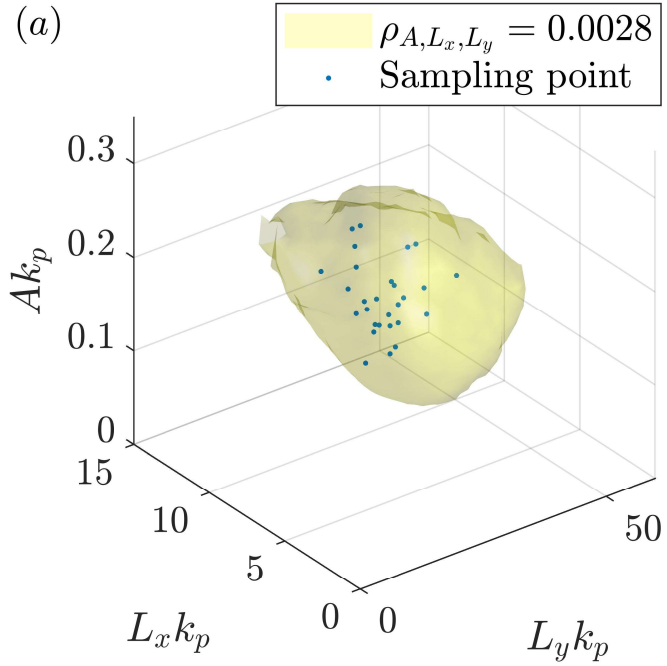
Step 2: Determine the next best sampling point based on the information gain

Step 3: Sample the system response at the best sampling point and repeat the process

Sequential sampling method

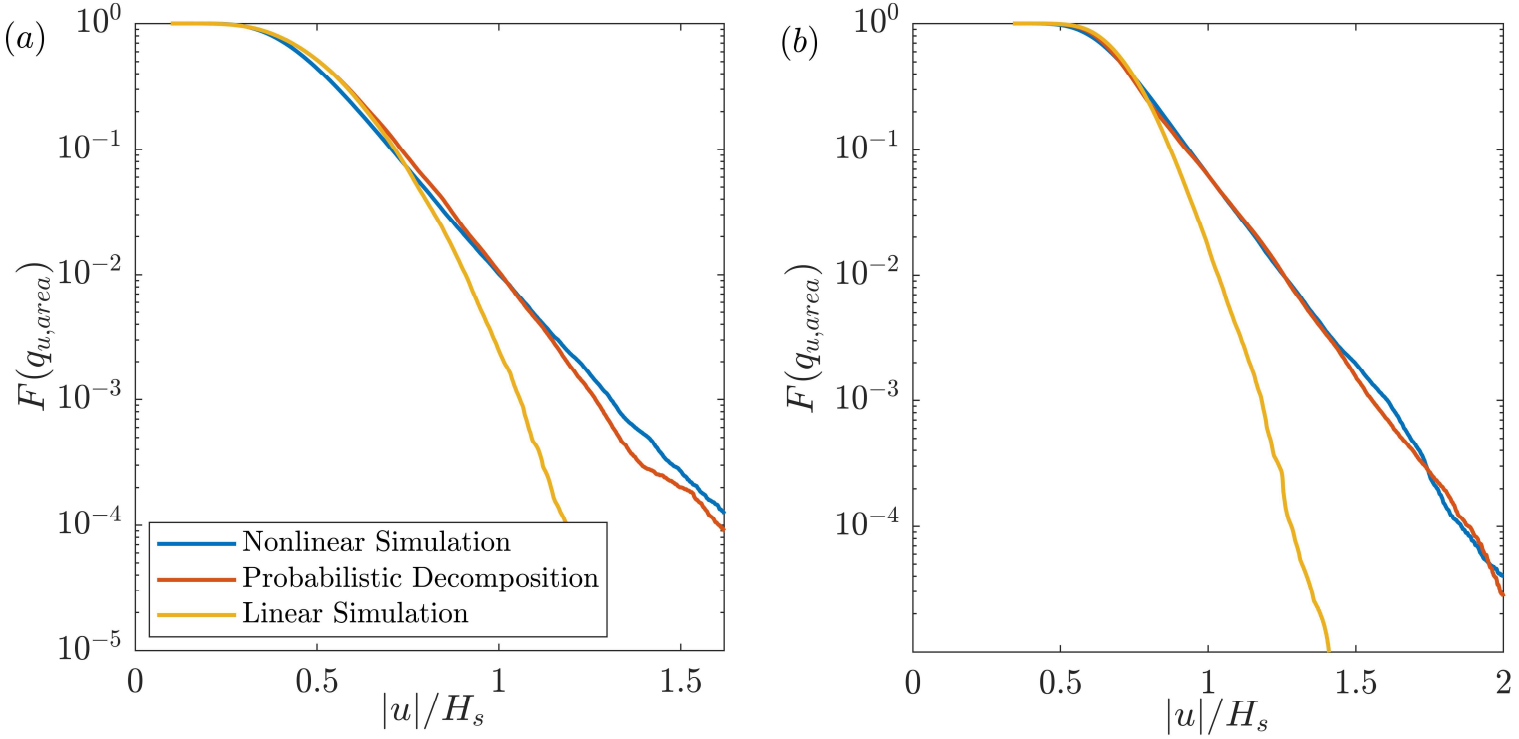


Random search sampling method



Sequential sampling method

Probability of extreme events



- The proposed probabilistic decomposition method can provide accurate estimation for space-time wave statistics for test cases without random time series simulations.

Tang & Adcock (2022) Applied Ocean Research

Conclusions

- A data-driven method is presented for parameterizing the random wave fields with deterministic wave groups.
- The nonlinear simulation of individual wave groups can capture the nonlinear changes of in the averaged shape of largest events.
- The probabilistic decomposition method can provide accurate estimation for space-time wave statistics for test cases without random time series simulations.
- The proposed sequential sampling method can significantly reduce the number of wave group simulation used in the model.

Current & Future work

- Apply the proposed framework to extreme force predictions.
- Include more non-linear physics (e.g., wave-current interactions, wind-wave interactions…).


Thank you!