Estimating the failure probability of damped harmonic monopiles subject to wave loading

2025 Meeting of the Waves SIG

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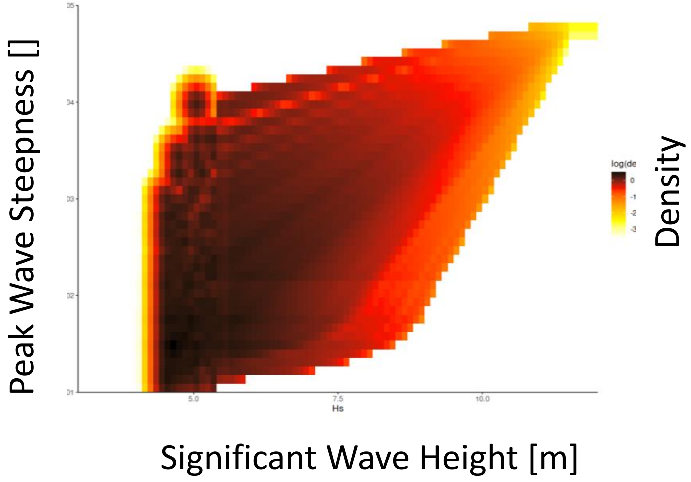
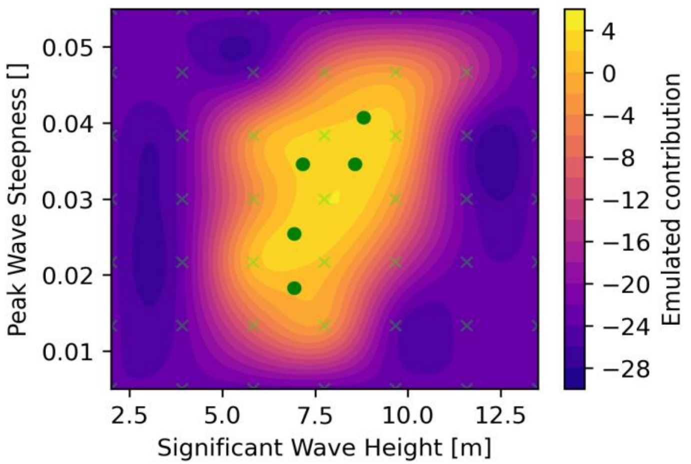
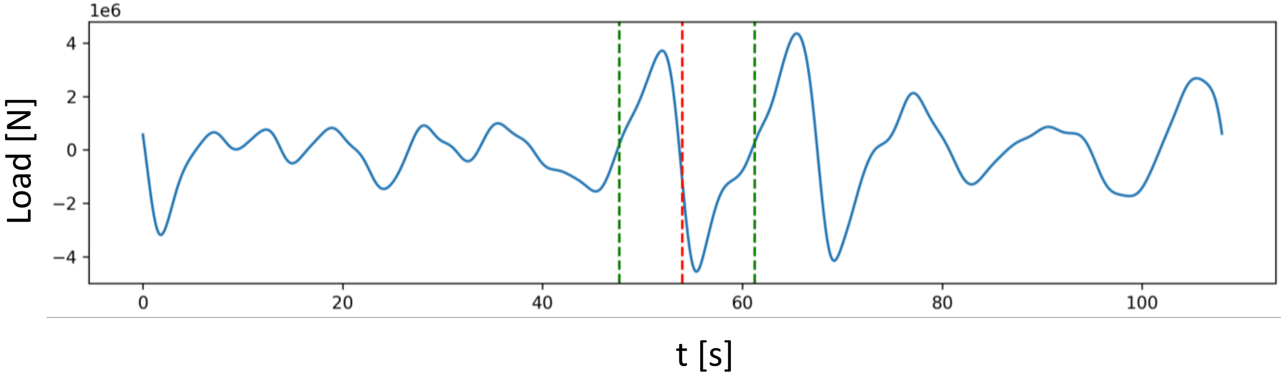






With thanks to:

Supervisors: Jonathan Tawn and Philip Jonathan

Collaborators: Paul Taylor (UWA), Jana Orszaghova (UWA)

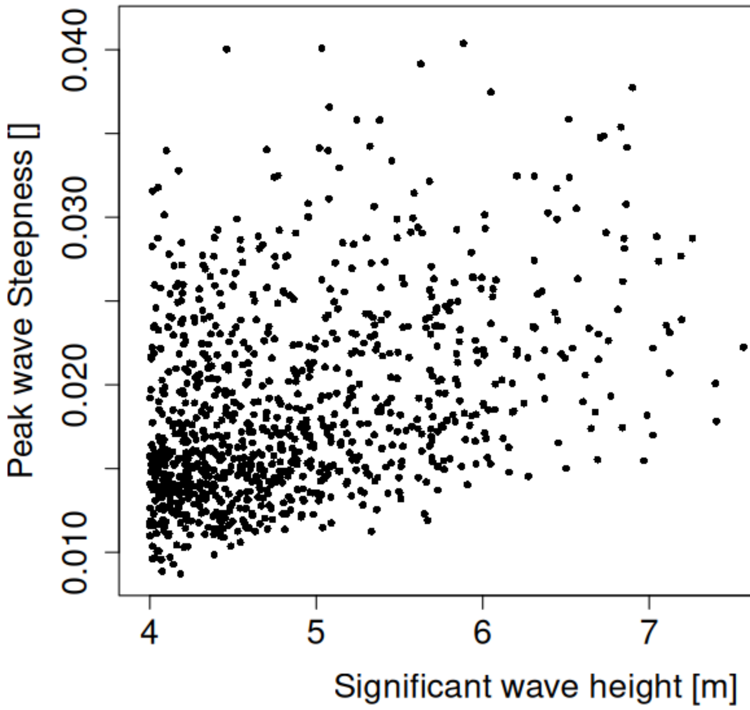
The Problem

- Ocean structures are subject to environmentally induced loading
- Want to assess the risk posed to the structure

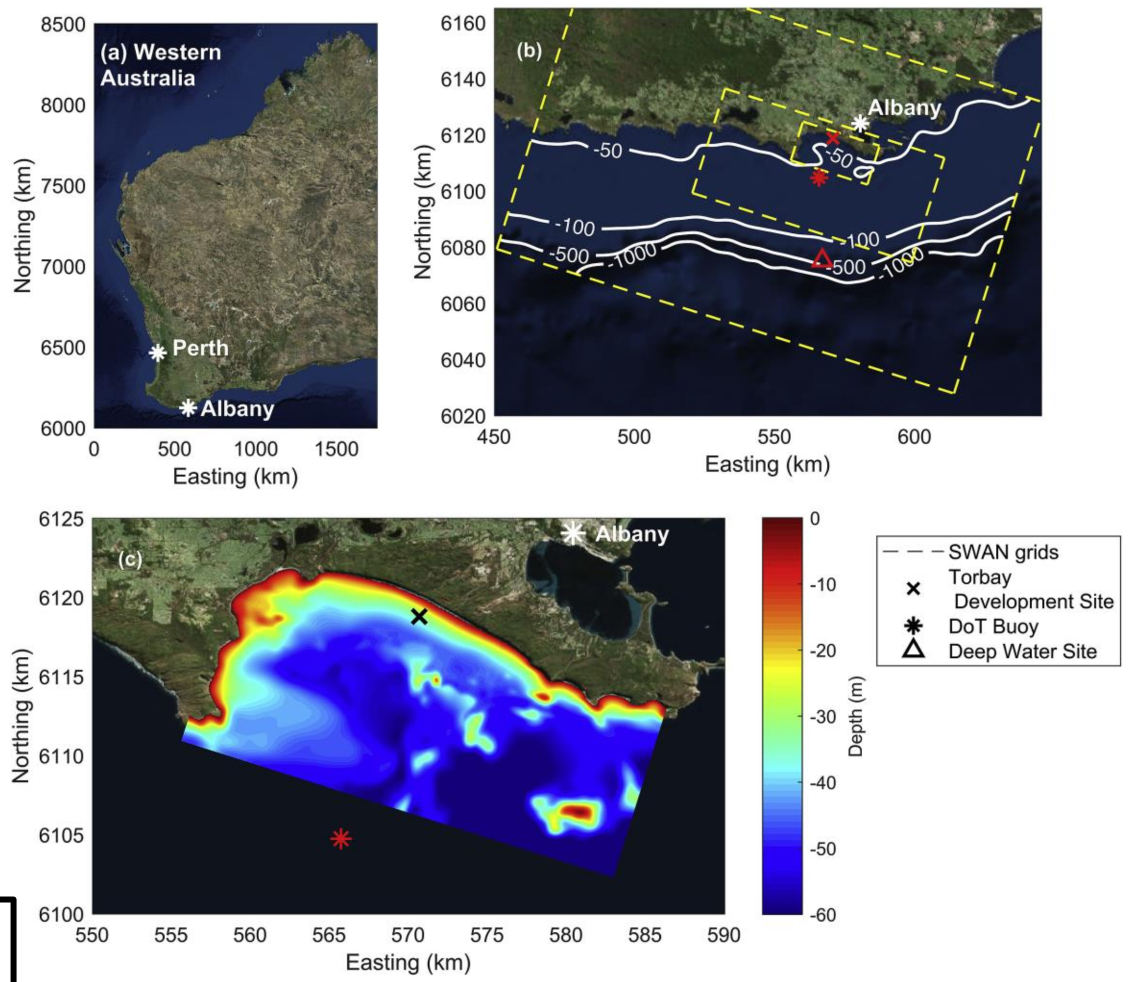
Often ***environmental data is limited*** *and*

fluid loading calculation is expensive

Albany Dataset



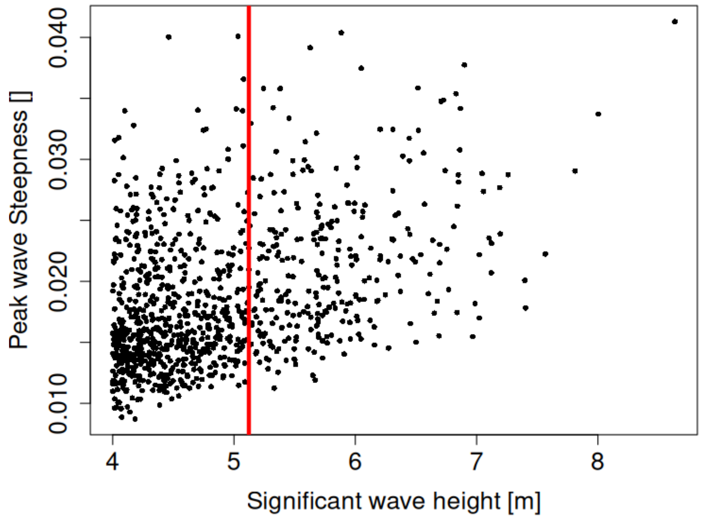
$$S_2 = \frac{2\pi H_S}{g T_2^2}$$

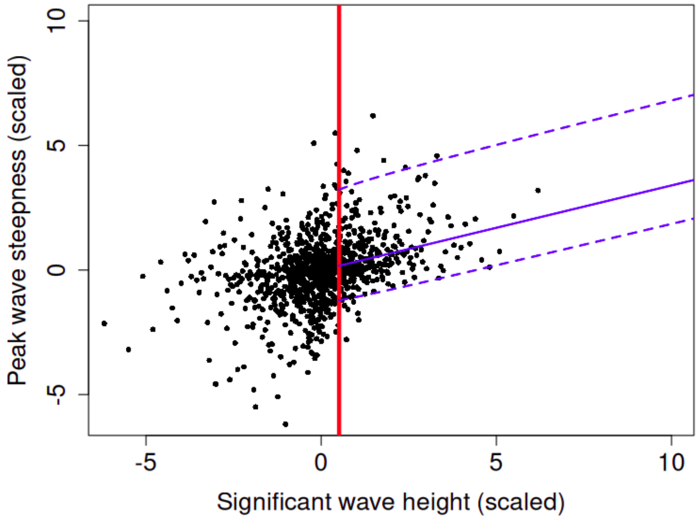


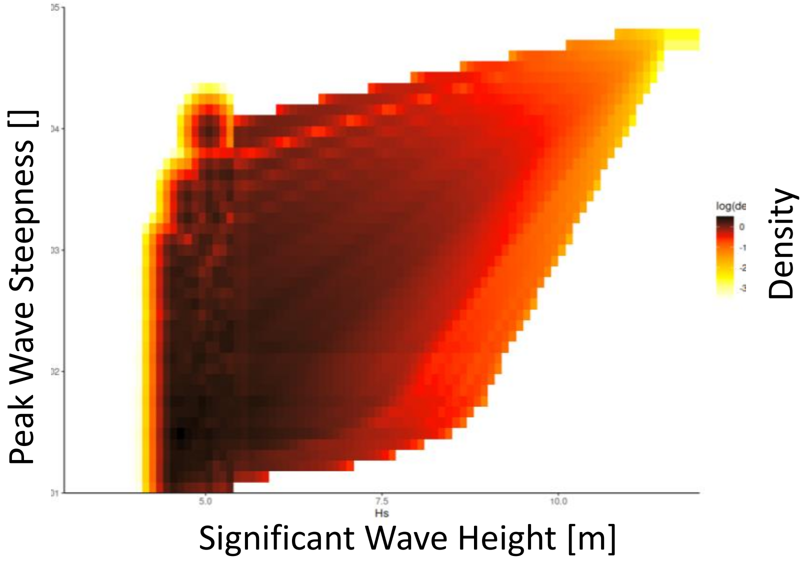
Cuttler et al. (2020)

Extraplation of joint sea state variables

Using extreme value modelling

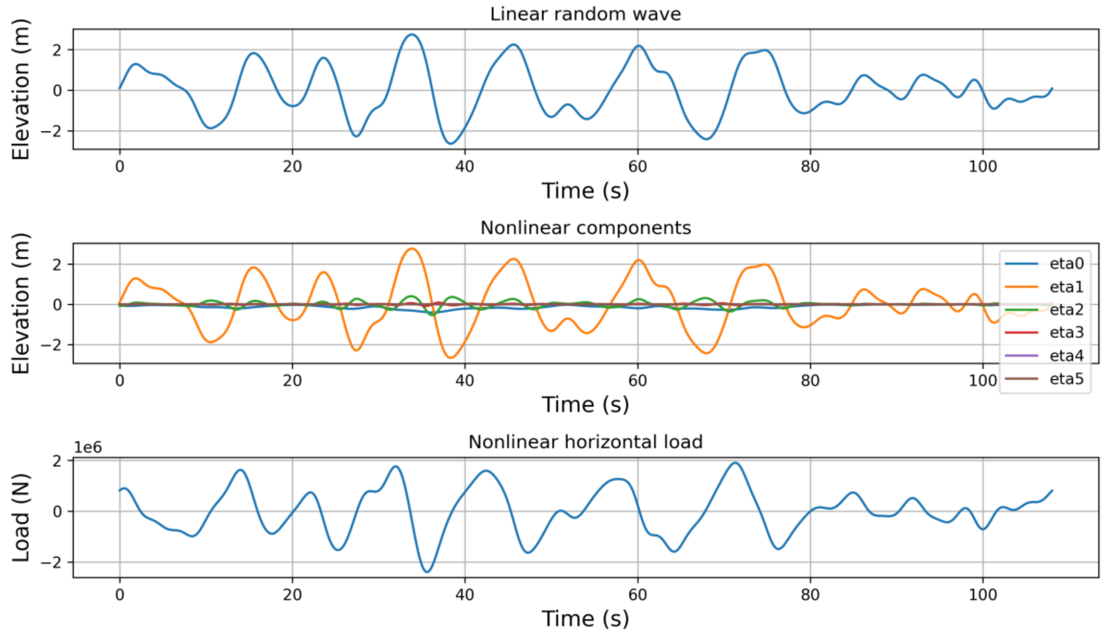






Fluid loading and structural response simulation

Using TFNV (Taylor et al., 2024)



$$\chi(f) = \frac{1}{1 - (f/f_r)^2 + i2c(f/f_r)^2}$$

$$f_r = 0.1s^{-1}$$
$$c = 0.1$$

Integrating statistical and physical models

See e.g. Speers et al. (2024)

Extreme value statistics

Simulation from physical models

Transfer function

Long term environment
$\mathbf{X}_{\mathrm{LT}}$
Sea state variables H_S, S_2

→

Short term environment
$\mathbf{X}_{\mathrm{ST}}|\mathbf{X}_{\mathrm{LT}}$
Kinematics & surface elevation

→

Hydrodynamics loading
$L|\mathbf{X}_{\mathrm{ST}}$
e.g., Horizontal loading

→

Structural response
$R|L$
e.g., Structural resonances

Probability of failure (in a sea state)

$$\Pr(R > r_F) = \int_{\mathbf{x}_{\mathrm{LT}}} \Pr(R > r_F | \mathbf{X}_{\mathrm{LT}} = \mathbf{x}_{\mathrm{LT}})\, f_{\mathbf{X}_{\mathrm{LT}}}(\mathbf{x}_{\mathrm{LT}})\mathrm{d}\mathbf{x}_{\mathrm{LT}}$$

for failure response r_F, where $\mathbf{X}_{\mathrm{LT}} \sim f_{\mathbf{X}_{\mathrm{LT}}}$.

Integrating statistical and physical models

See e.g. Speers et al. (2024)

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Transfer function

Long term environment $\mathbf{X}_{\mathrm{LT}}$
Sea state variables H_S, S_2

$\rightarrow$

Short term environment $\mathbf{X}_{\mathrm{ST}}|\mathbf{X}_{\mathrm{LT}}$
Kinematics & surface elevation

$\rightarrow$

Hydrodynamics loading $L|\mathbf{X}_{\mathrm{ST}}$
e.g., Horizontal loading

$\rightarrow$

Structural response $R|L$
e.g., Structural resonances

Replace these steps with Gaussian Emulation

Probability of failure (in a sea state)

$$\Pr(R > r_F) = \int_{\mathbf{x}_{\mathrm{LT}}} \Pr(R > r_F | \mathbf{X}_{\mathrm{LT}} = \mathbf{x}_{\mathrm{LT}}) f_{\mathbf{X}_{\mathrm{LT}}}(\mathbf{x}_{\mathrm{LT}}) d\mathbf{x}_{\mathrm{LT}}$$

for failure response r_F, where $\mathbf{X}_{\mathrm{LT}} \sim f_{\mathbf{X}_{\mathrm{LT}}}$.

Emulation of contribution to failure

Fit a Gaussian Process to the integrand of failure estimate

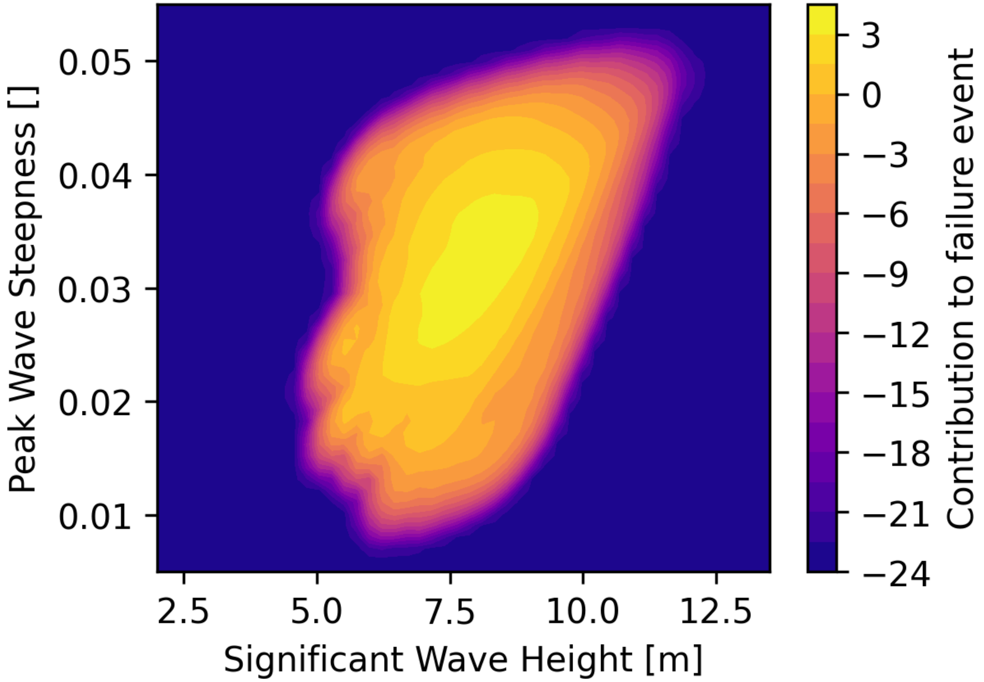
$$\Pr(R > r_F) = \int_{\mathbf{x}_{\mathrm{LT}}} \boxed{\Pr(R > r_F \mid \mathbf{X}_{\mathrm{LT}} = \mathbf{x}_{\mathrm{LT}})\, f_{\mathbf{X}_{\mathrm{LT}}}(\mathbf{x}_{\mathrm{LT}})}\, \mathrm{d}\mathbf{x}_{\mathrm{LT}}$$

$$\Pr(R > r_F \mid \mathbf{X}_{\mathrm{LT}} = \mathbf{x}_{\mathrm{LT}})\, f_{\mathbf{X}_{\mathrm{LT}}}(\mathbf{x}_{\mathrm{LT}}) \sim \mathcal{GP}(\mathbf{x}_{\mathrm{LT}})$$

This allows us to:

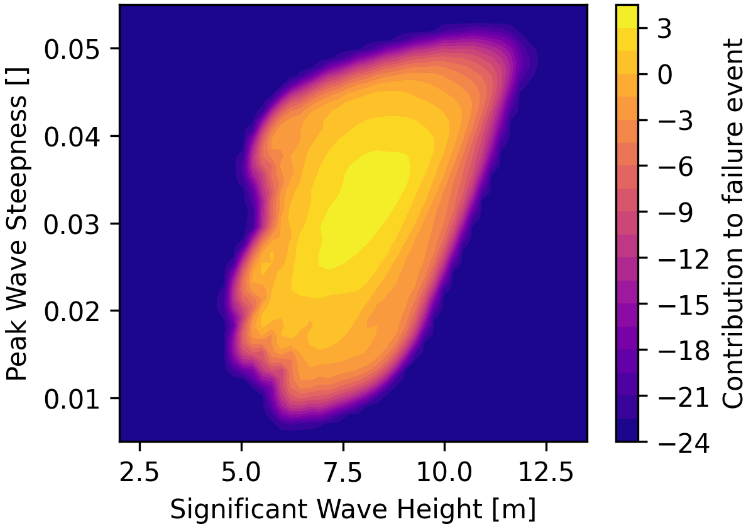
- Estimate failure probability

- Select new sea states at which to run simulations

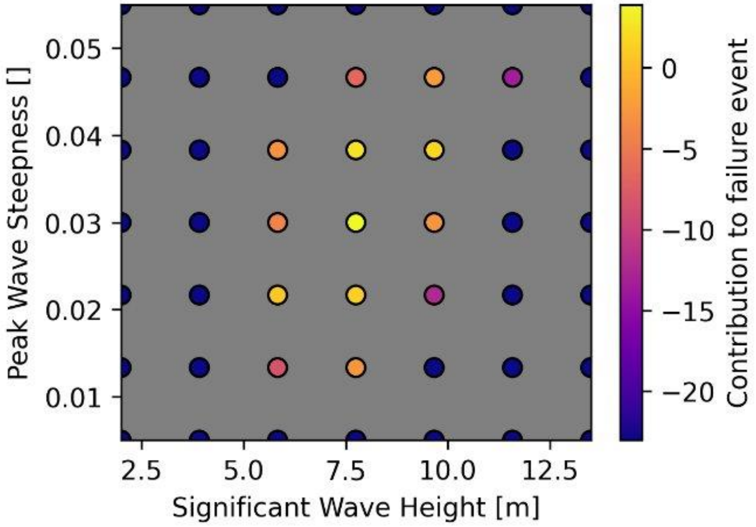


$$\Pr(R > r_F \mid \mathbf{X}_{\mathrm{LT}} = \mathbf{x}_{\mathrm{LT}})\, f_{\mathbf{X}_{\mathrm{LT}}}(\mathbf{x}_{\mathrm{LT}})$$

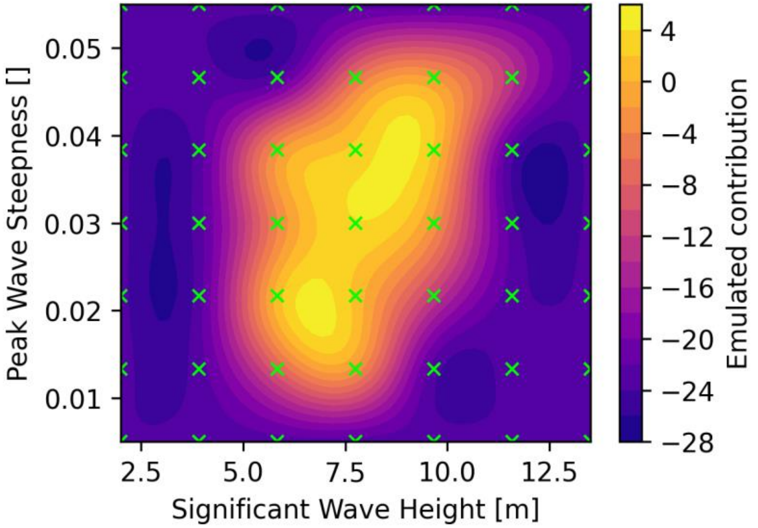
Emulation of contribution to failure



Target



Training Points



Emulator

Ongoing work

- Working with Paul Taylor and Jana Orszaghova to use this methodology with their monopile model
- Paper on arxiv soon about the emulation of response on damped harmonic oscillating monopiles
- Previous paper here:

ELSEVIER
Ocean Engineering
Volume 311, Part 1, 1 November 2024, 118754

Research paper

Estimating metocean environments associated with extreme structural response to demonstrate the dangers of environmental contour methods

Matthew Speers [a], David Randell [b], Jonathan Tawn [a], Philip Jonathan [a c]

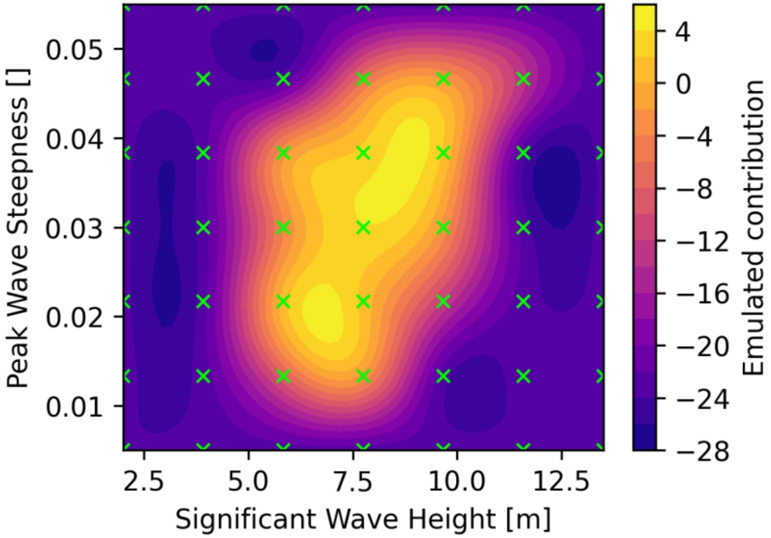
References

Cuttler, M.V., Hansen, J.E. and Lowe, R.J., 2020. Seasonal and interannual variability of the wave climate at a wave energy hotspot off the southwestern coast of Australia. Renewable Energy, 146, pp.2337-2350.

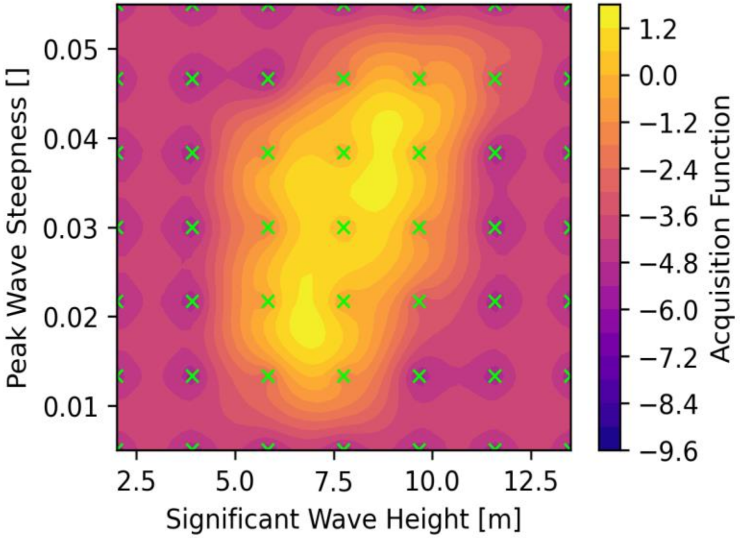
Taylor, P.H., Tang, T., Adcock, T.A. and Zang, J., 2024. Transformed-FNV: Wave forces on a vertical cylinder—A free-surface formulation. Coastal Engineering, 189, p.104454.

Speers, M., Randell, D., Tawn, J. and Jonathan, P., 2024. Estimating metocean environments associated with extreme structural response to demonstrate the dangers of environmental contour methods. Ocean Engineering, 311, p.118754.

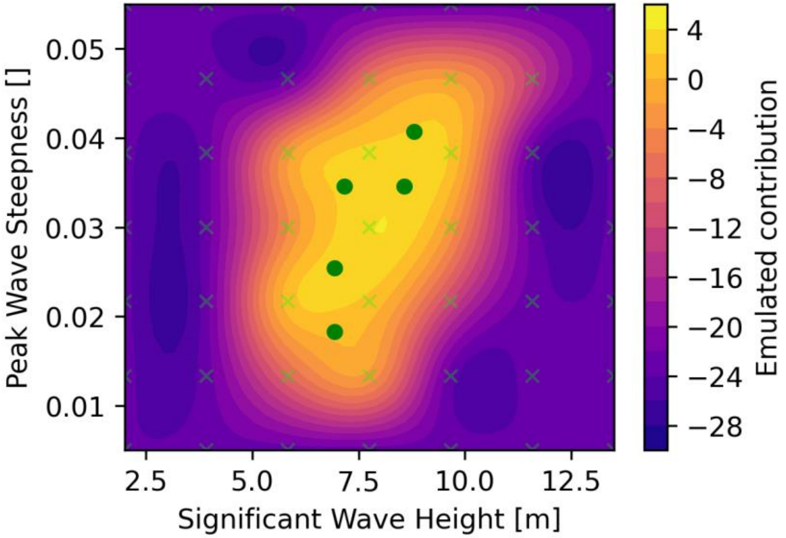
Improving the emulator



Emulator



Utility Function



Updated Emulator