Effects of wave-current coupling on dynamic responses of a 15MW spar-type floating wind turbine

Zirui Xin, Xin Li

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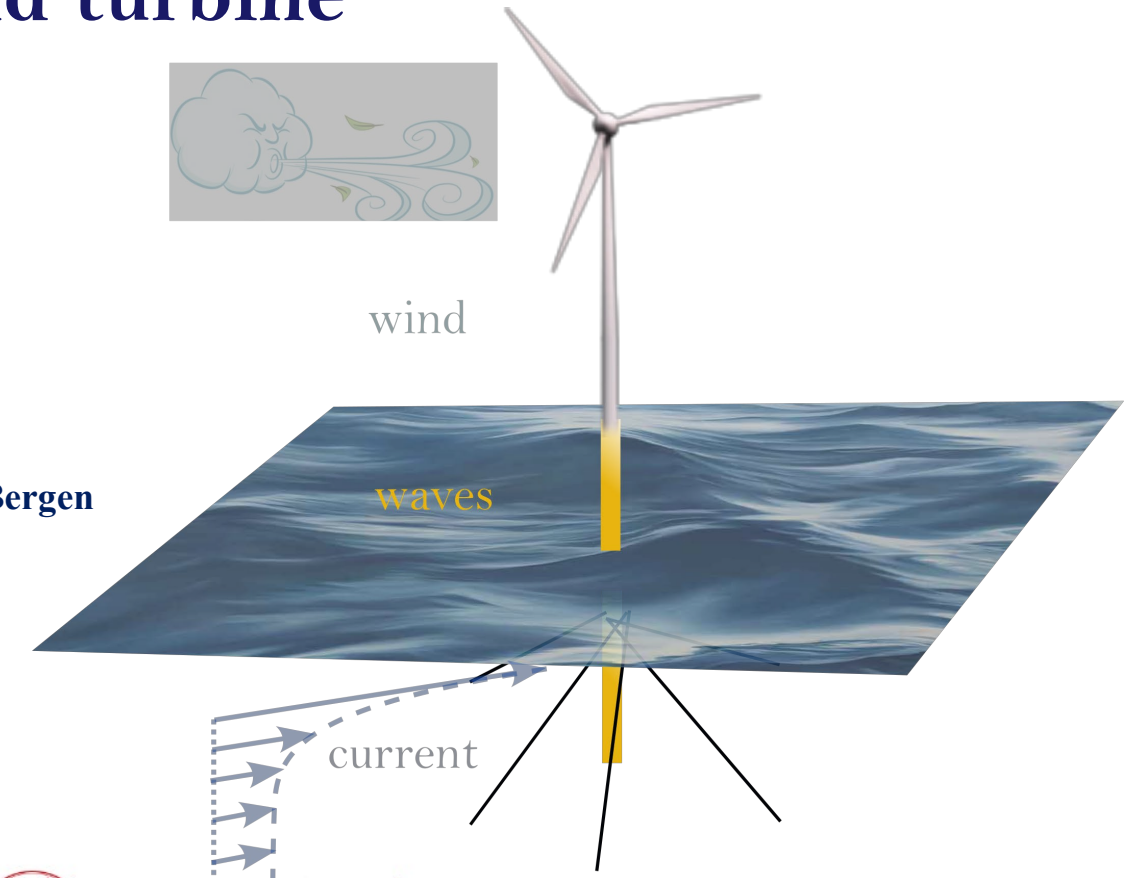

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EERA DeepWind CONFERENCE 2024

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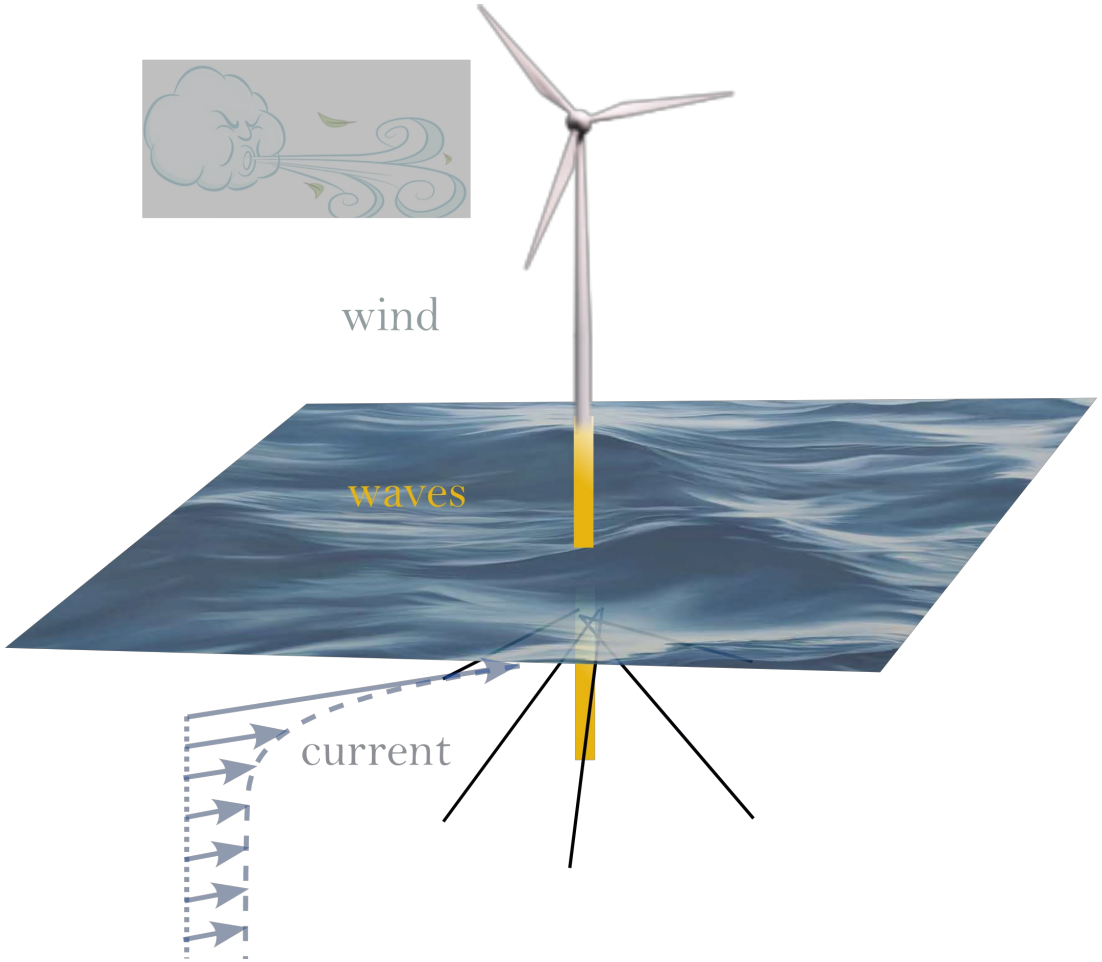
South China Sea

Current speed > 2.5 m/s



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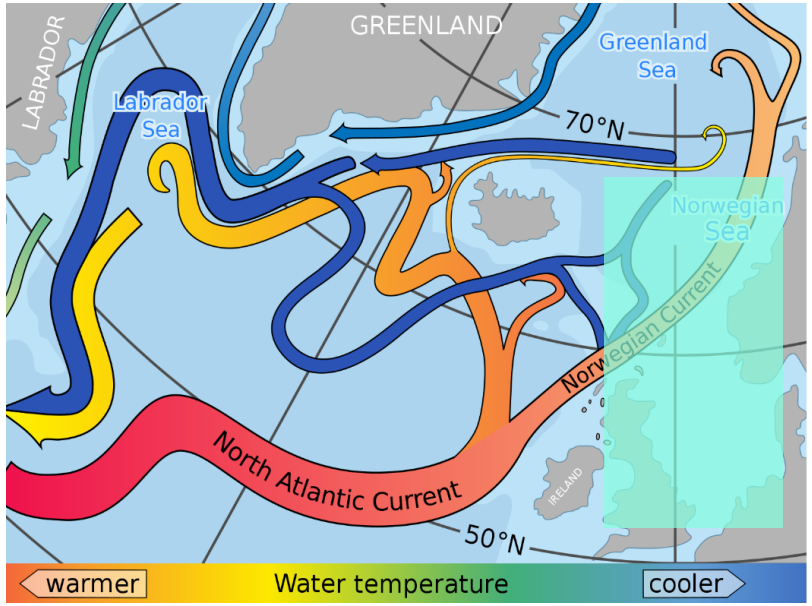
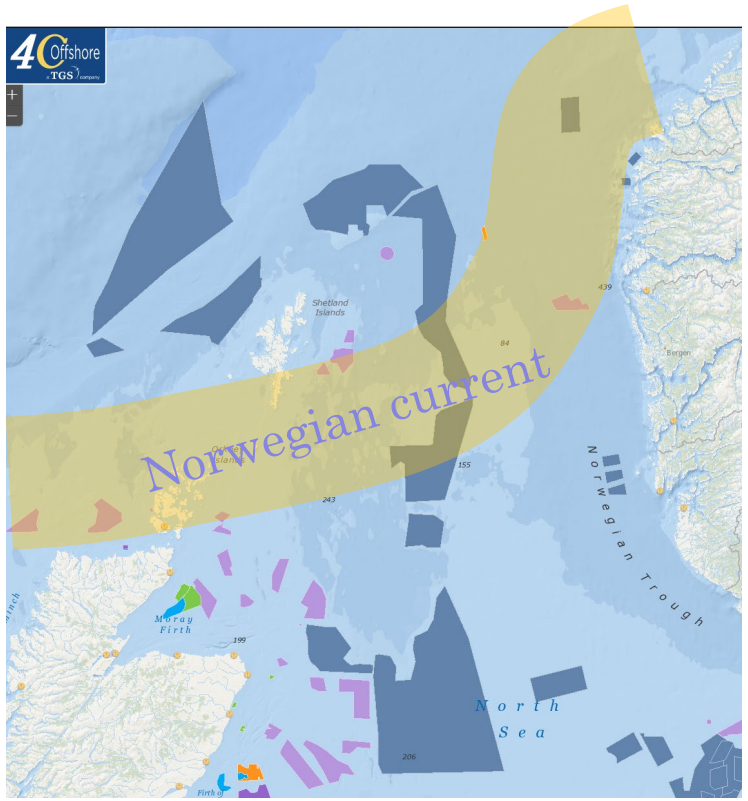
China National Offshore Oil Corporation

Off the coast of Norway



Wikipedia



Norwegian current:

Variability: 0.2 – 1 m/s

Average: 0.5 m/s

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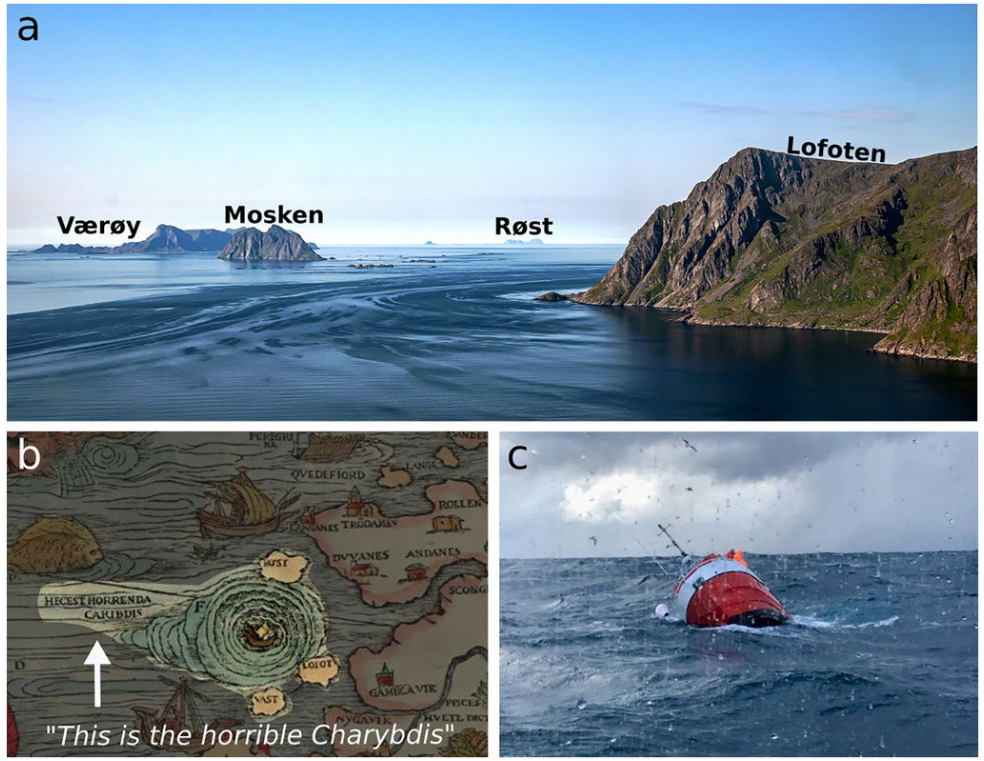
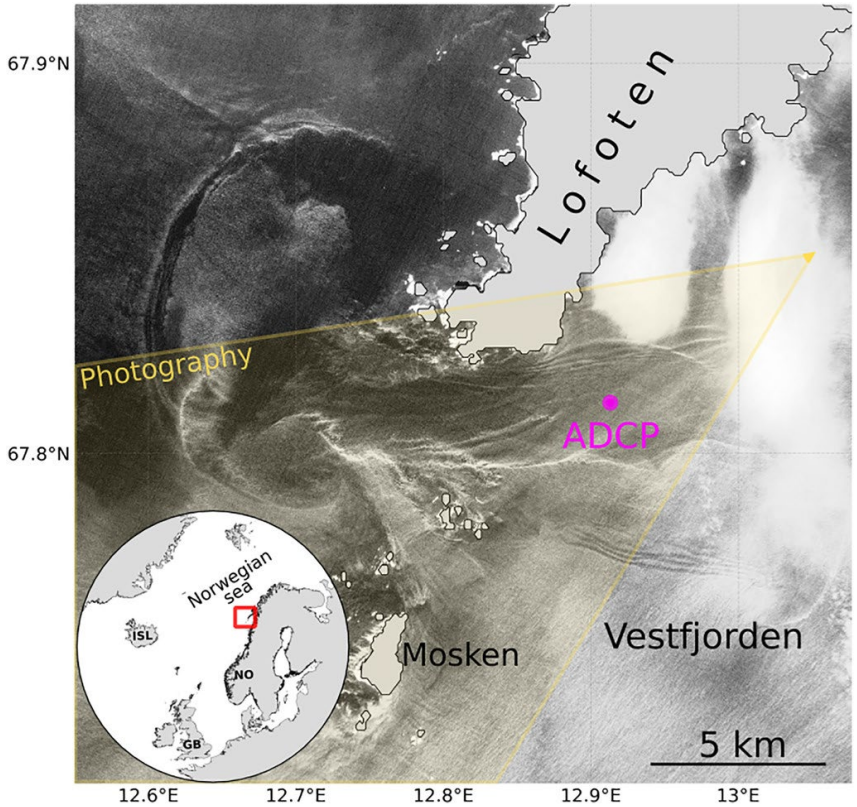


Saetra, *et al.* 2021, *J. Phys. Oceanogr.*



current: speed up to 5 m/s

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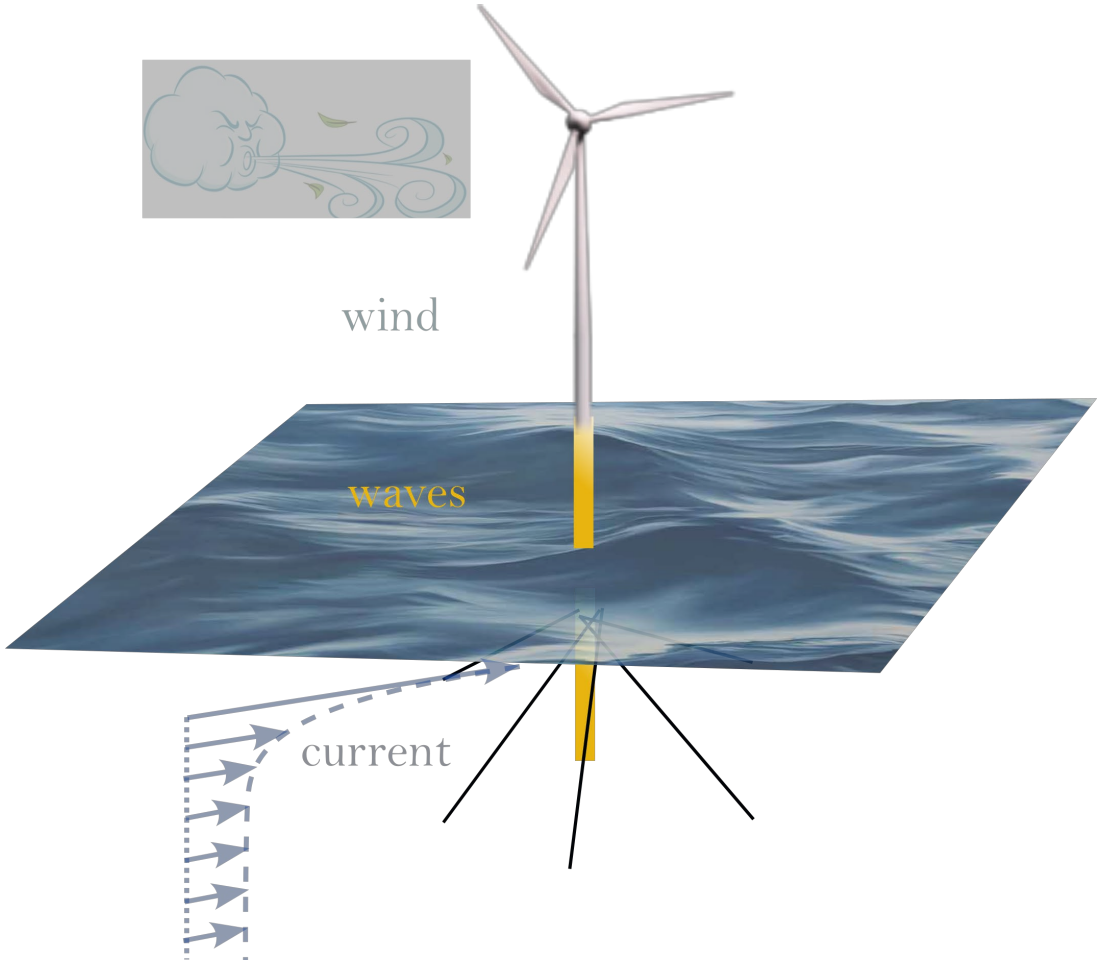
A general goal of the on-going works

To understand how the wave and current coupling affects the general performances of offshore wind turbines



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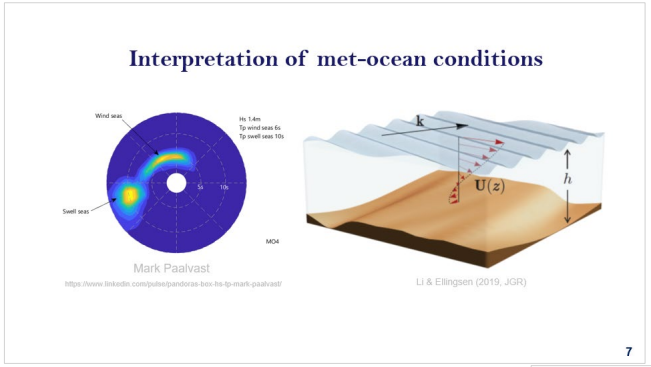
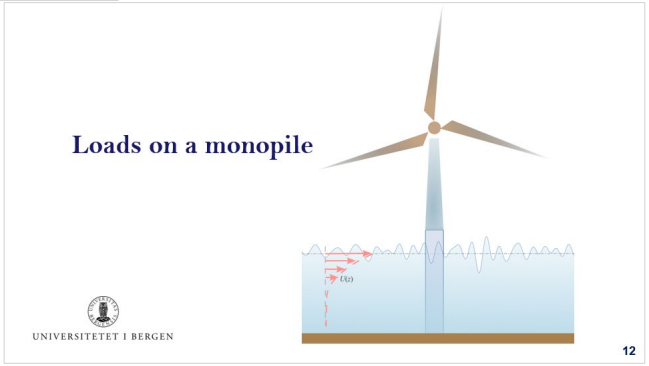
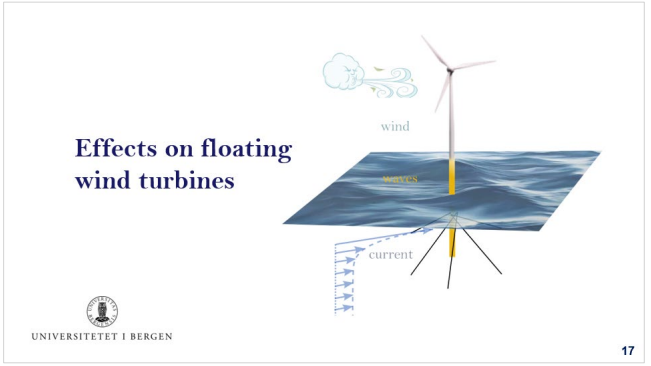
Open research questions

How to

- interpreter met-ocean data
  (e.g., swell & wind waves; tidal currents + wind waves)
- accurately and efficiently estimate excitation loads and responses on OWTs
- examine aerodynamic and hydrodynamic coupled effects?
- ……







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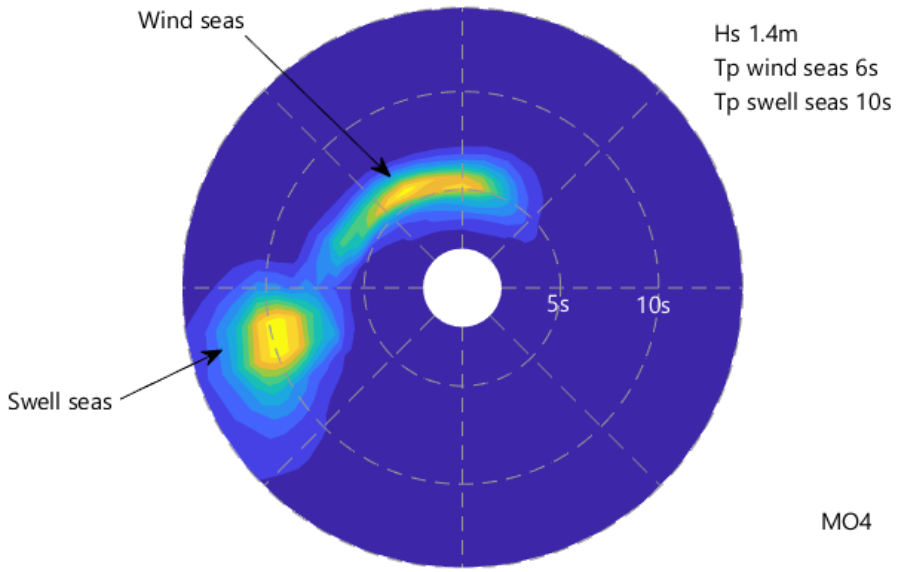
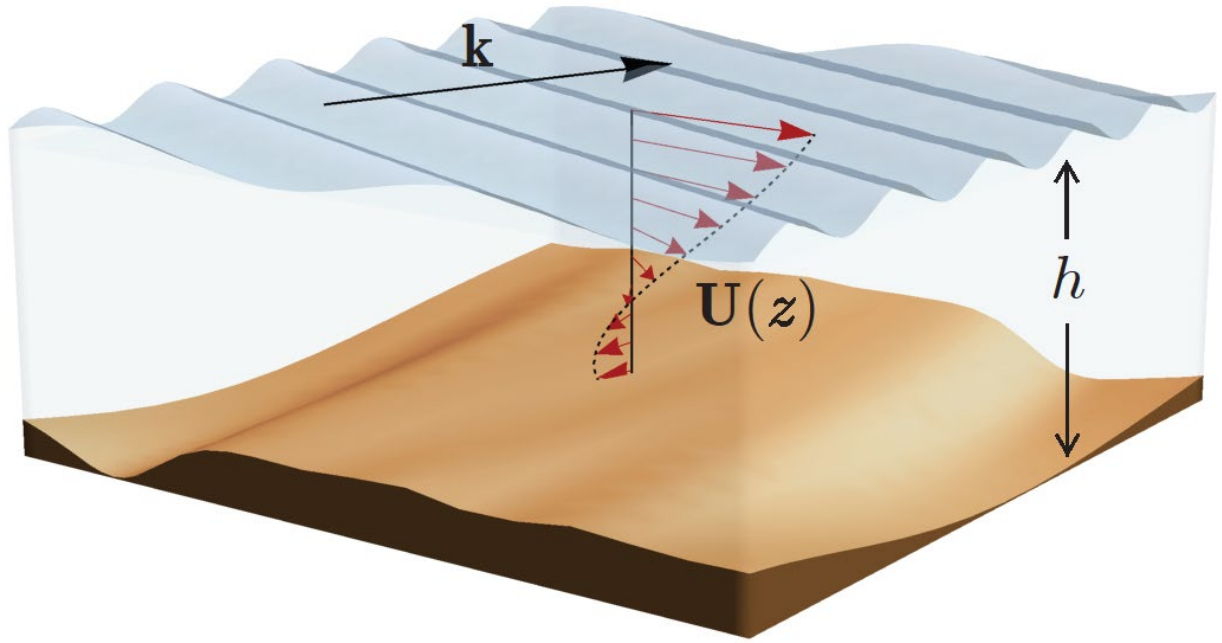
Interpretation of met-ocean conditions



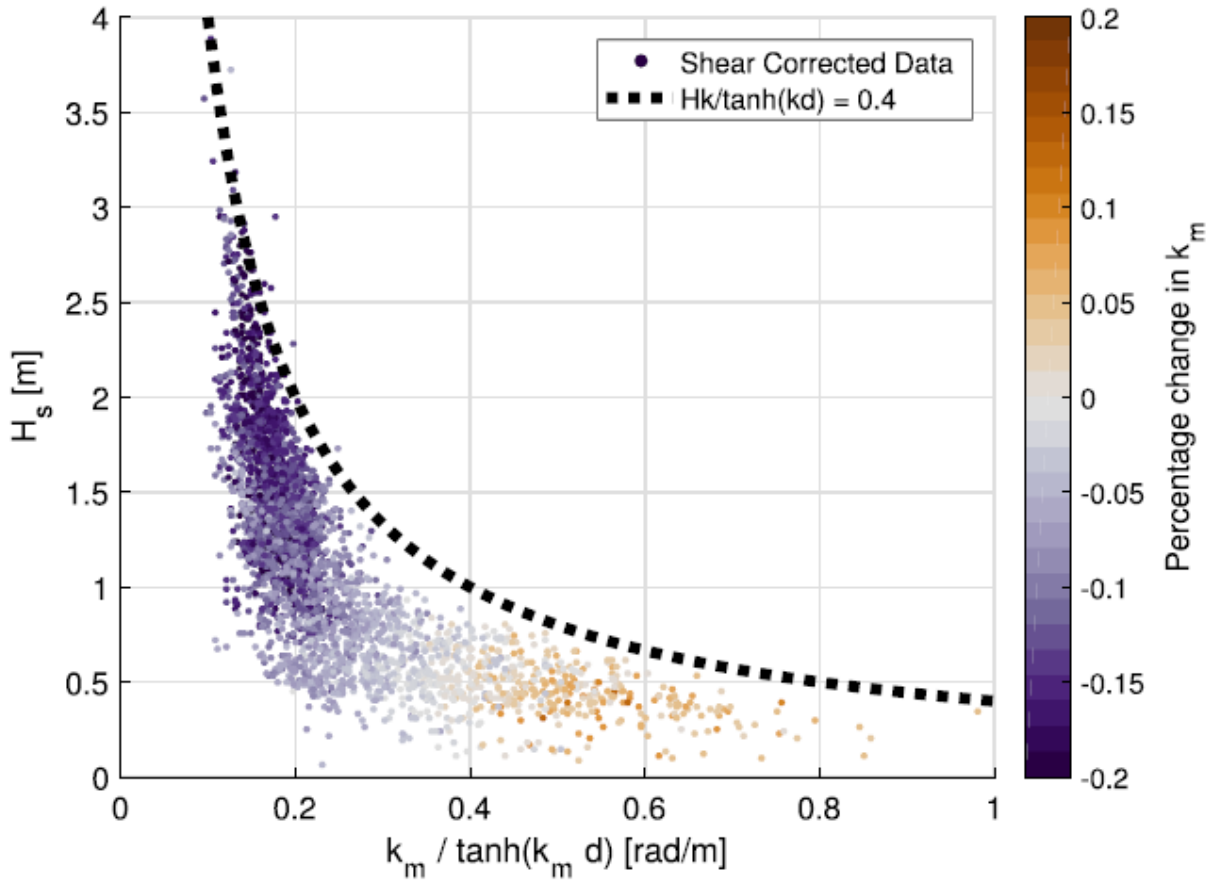
Mark Paalvast

https://www.linkedin.com/pulse/pandoras-box-hs-tp-mark-paalvast/



Li & Ellingsen (2019, JGR)

Interpretation of met-ocean conditions



Zippel & Thomson(2017, *JGR*)

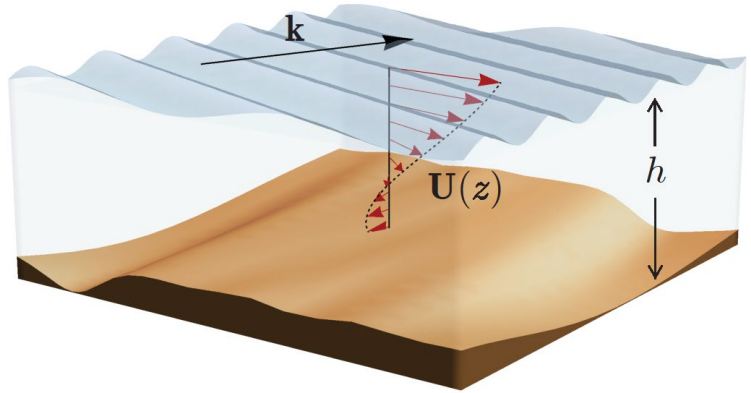
Interpretation of met-ocean conditions

- Shear-current modified dispersion relation
  (Ellingsen & Li 2017, JGR)

$$\omega \approx \sqrt{g|\mathbf{k}|\tanh|\mathbf{k}|h}\left(1+\varepsilon_U\right) \equiv \mathbf{k}\cdot\mathbf{U}_0 + \sqrt{g|\mathbf{k}|\tanh|\mathbf{k}|h}\left(1-\delta_S\right)$$

$$\varepsilon_U = \int_{-h}^{0} \frac{2\mathbf{k}\cdot\mathbf{U}(z)}{\sqrt{g|\mathbf{k}|\tanh|\mathbf{k}|h}} \frac{\cosh 2|\mathbf{k}|(z+h)}{\sinh 2|\mathbf{k}|h}|\mathbf{k}|\mathrm{d}z,$$

$$\delta_S = \int_{-h}^{0} \frac{\mathbf{k}\cdot\mathbf{U}'(z)}{\sqrt{g|\mathbf{k}|\tanh|\mathbf{k}|h}} \frac{\sinh 2|\mathbf{k}|(z+h)}{\sinh 2|\mathbf{k}|h}\mathrm{d}z$$



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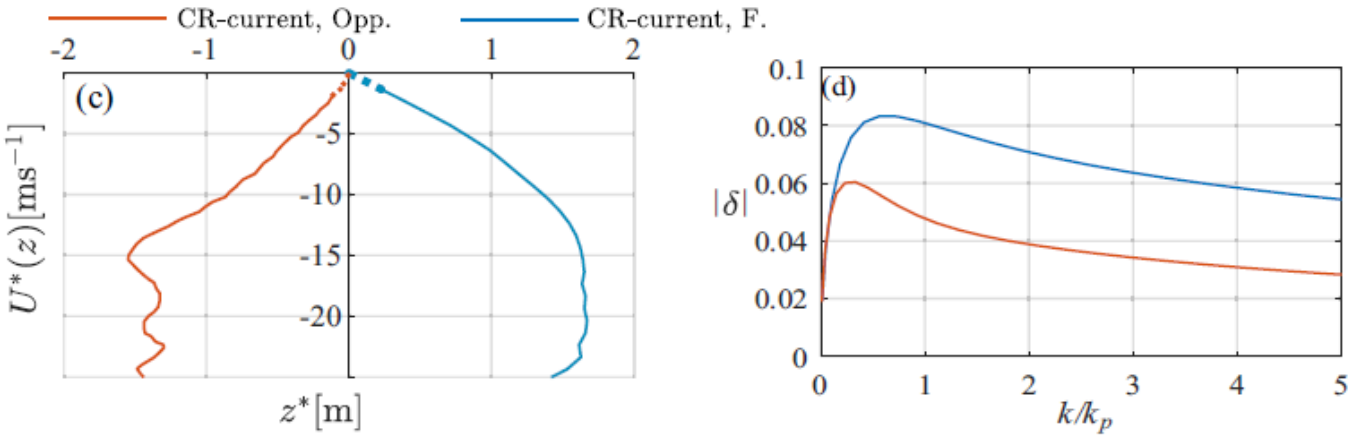

Zheng *et al.* (2022, *Phys. Rev. Fluids*)

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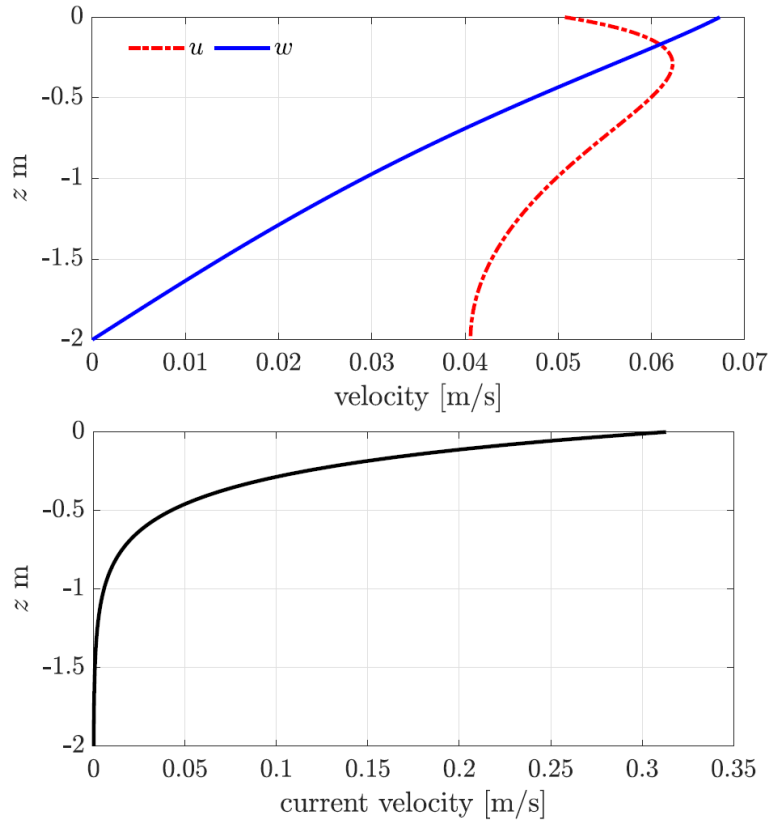
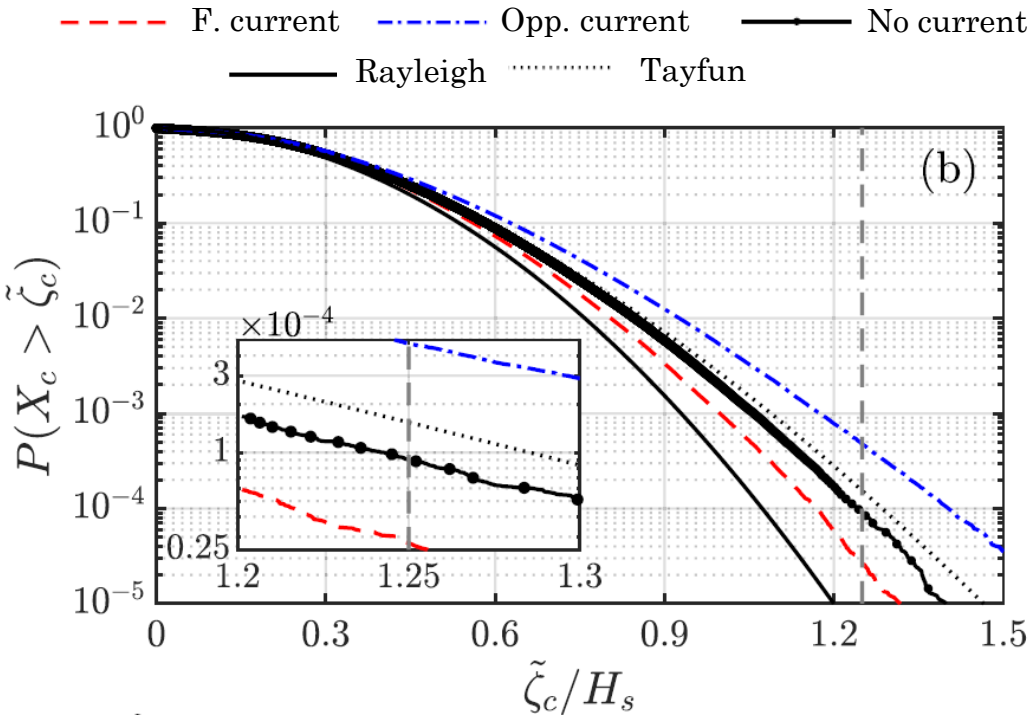
Current-modified wave properties

Current-modified wave kinematics



Li *et al.* (2024)

Current-modified exceedance probability



Zheng *et al.* (2022, *Phys. Rev. Fluids*)

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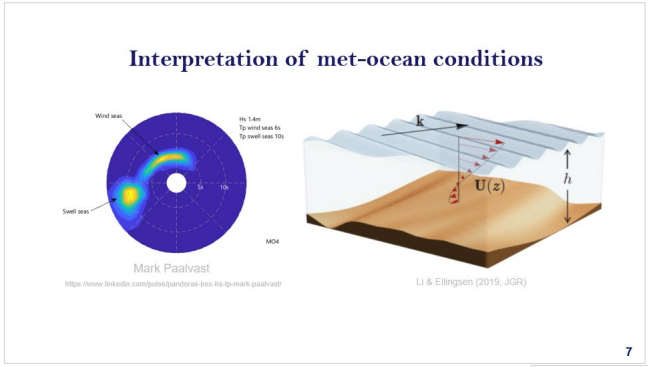

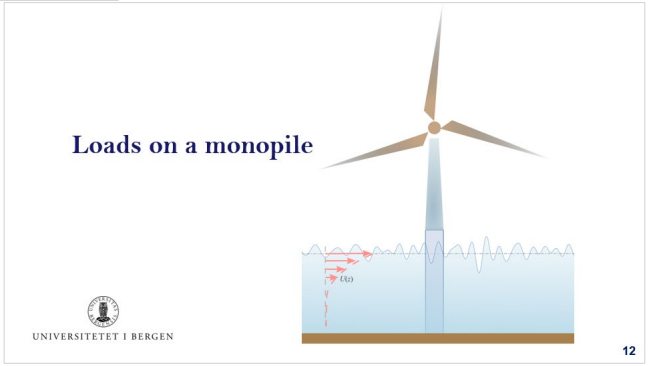

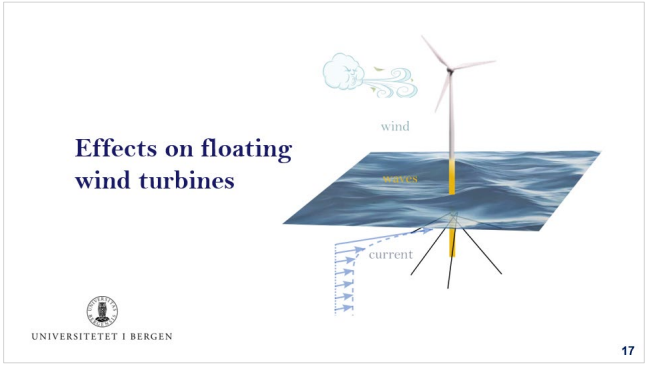

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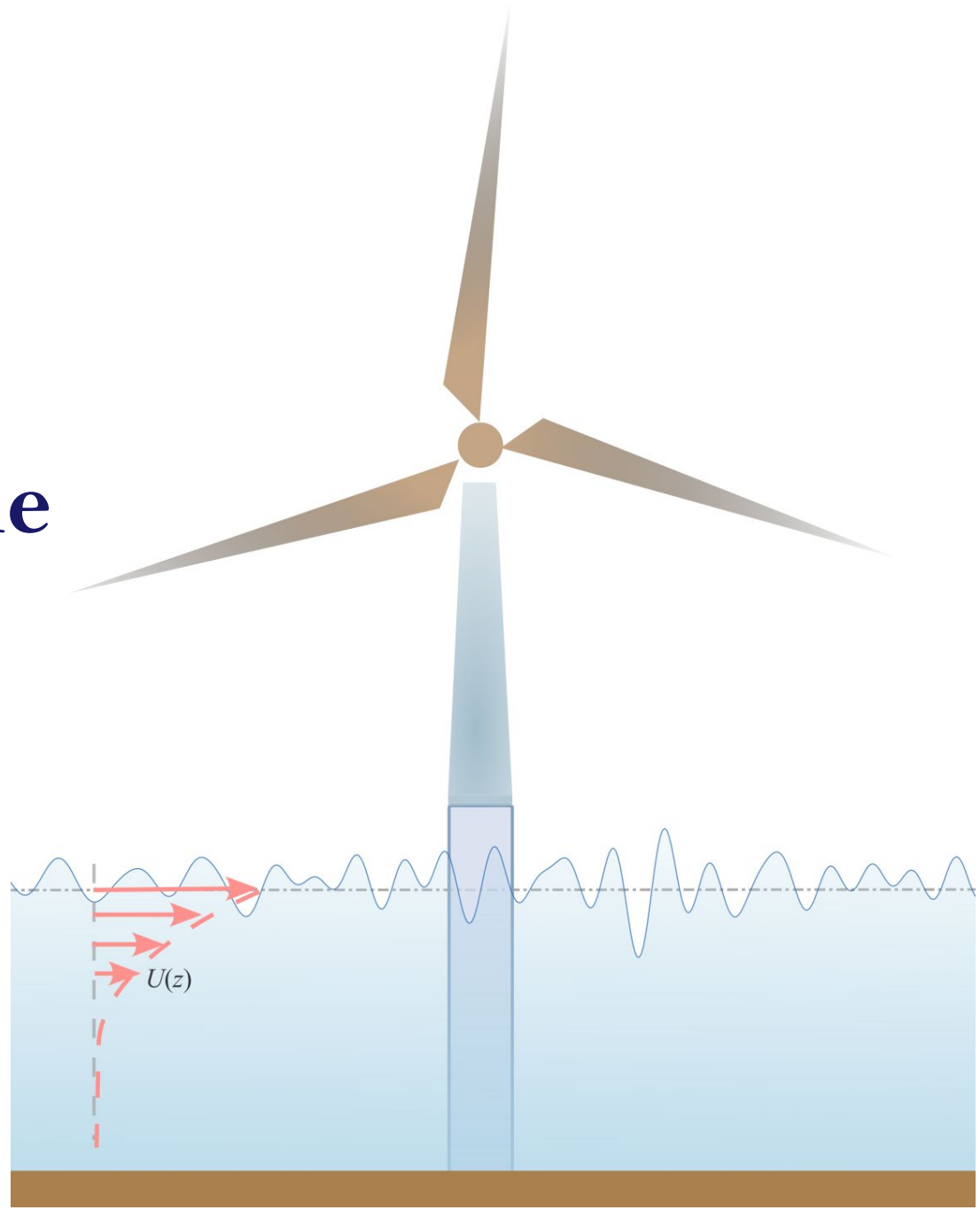
Loads on a monopile



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Predictions of loads

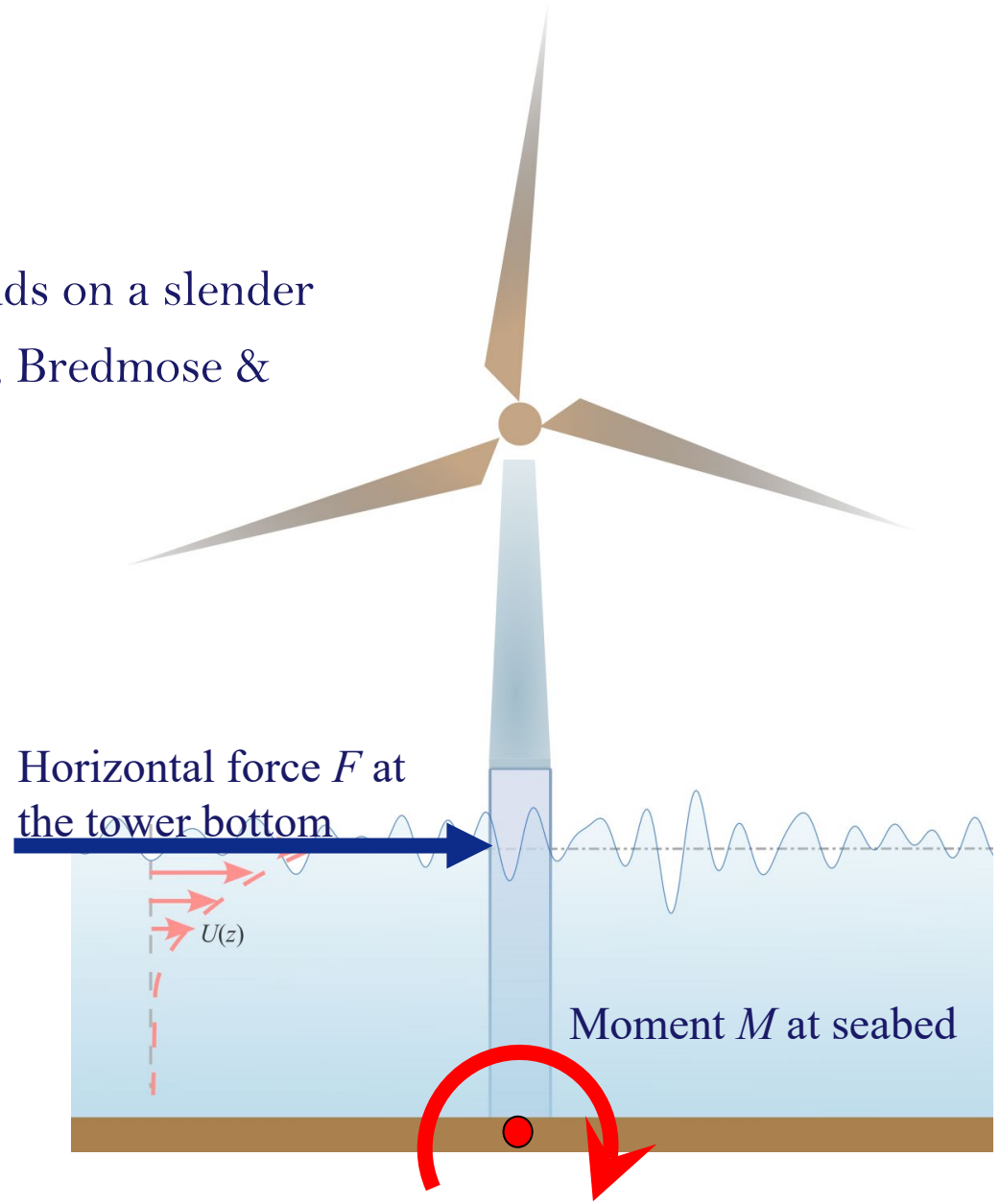
Modified Morison equations for the loads on a slender structure in various sea states (see, e.g., Bredmose & Pegalajar-Jurado, 2021)

Comparisons of *F* and *M*:

coupled

versus

de-coupled



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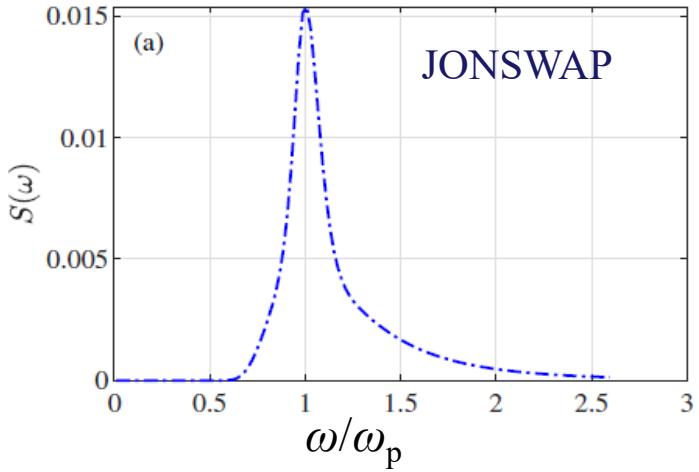
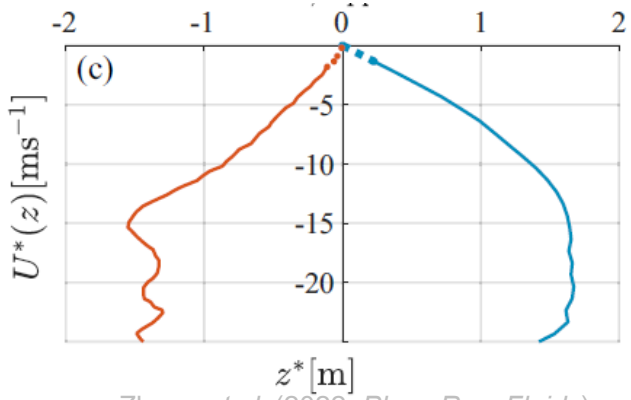
Extreme waves in different currents



$f_p \sim 0.08$ Hz; $T_p \sim 12$ s

Profiles of current

Wave propagation direction



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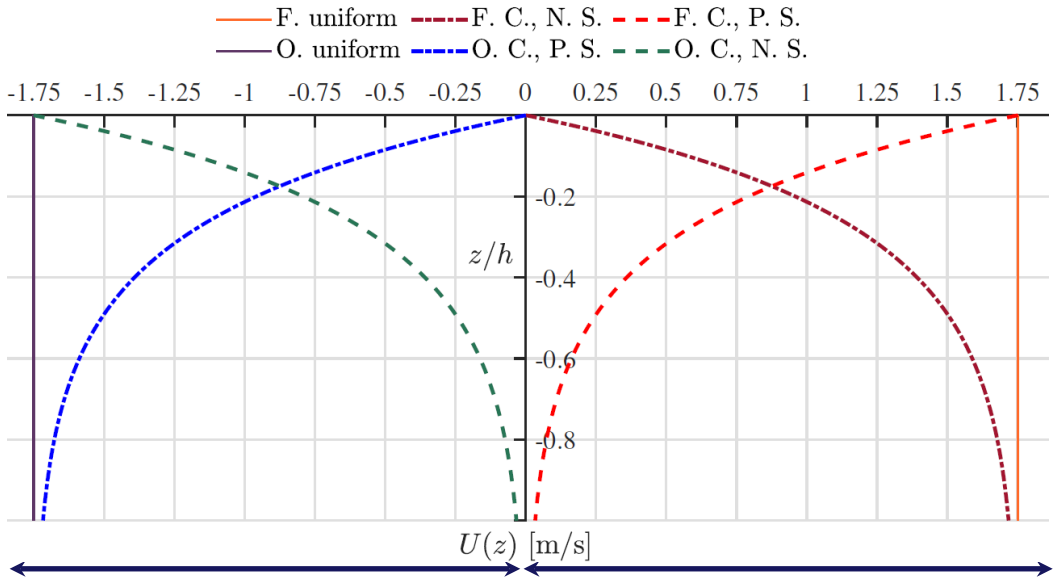

Opposing Currents | Following Currents

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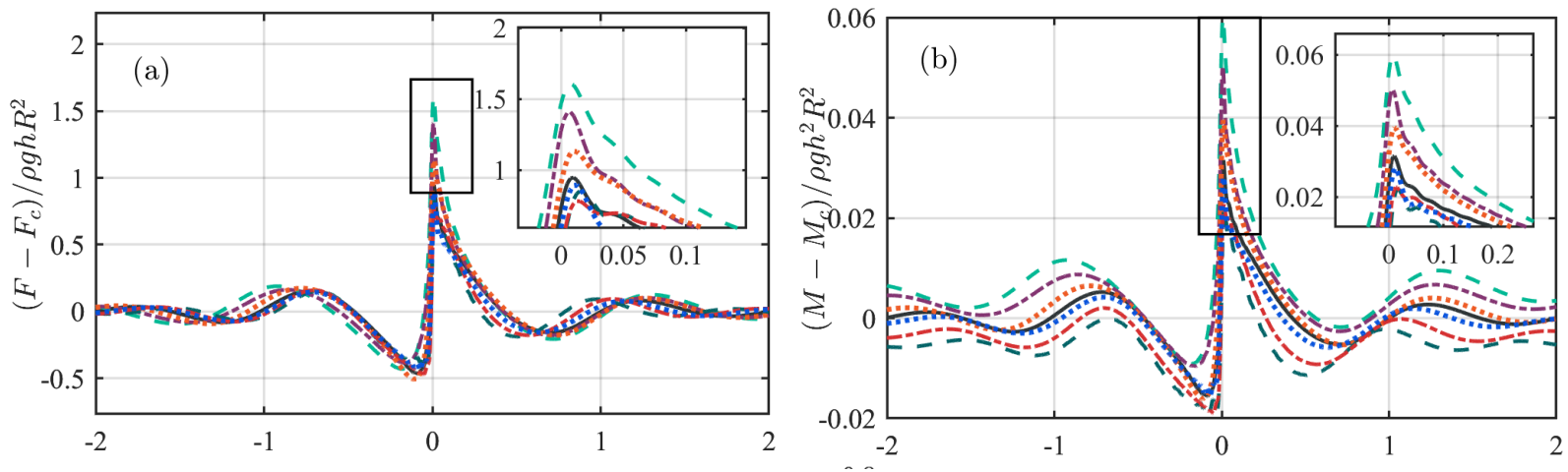
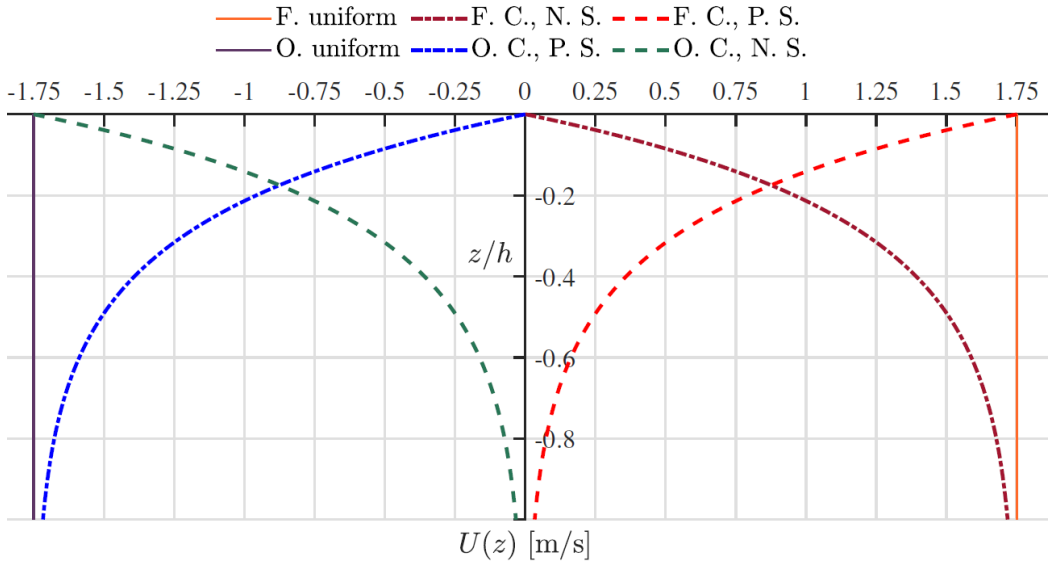
Two takeaways (Xin, *et al. Coastal Eng.* 2023)





Opposing Currents → Following Currents

- Wave-current coupling should **NOT** be neglected in extreme load cases
- Uniform currents set up upper/lower bounds of responses analysis

Open research questions

How to

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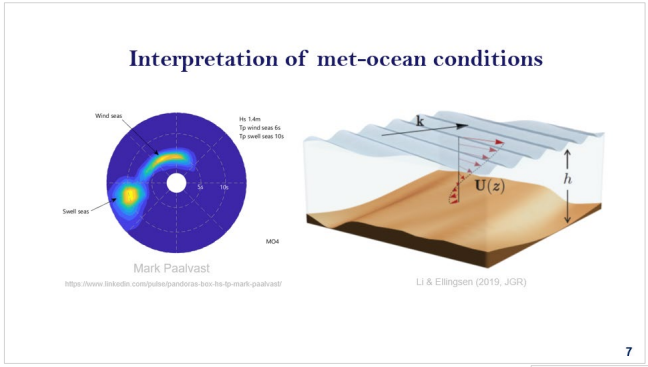
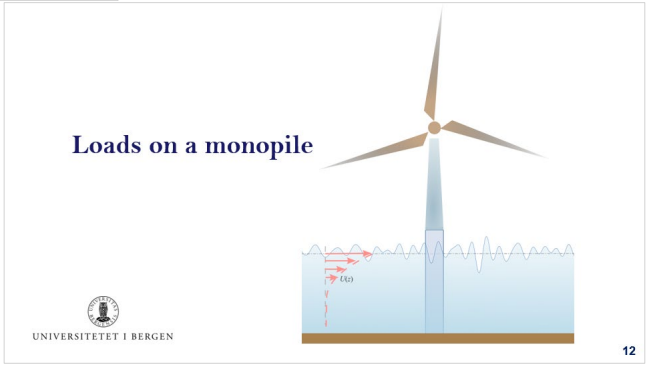
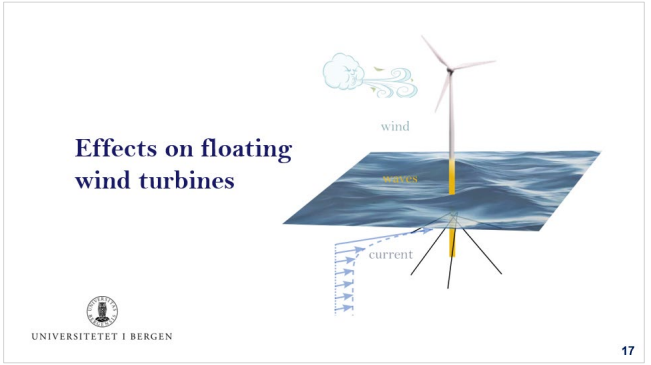
- ……







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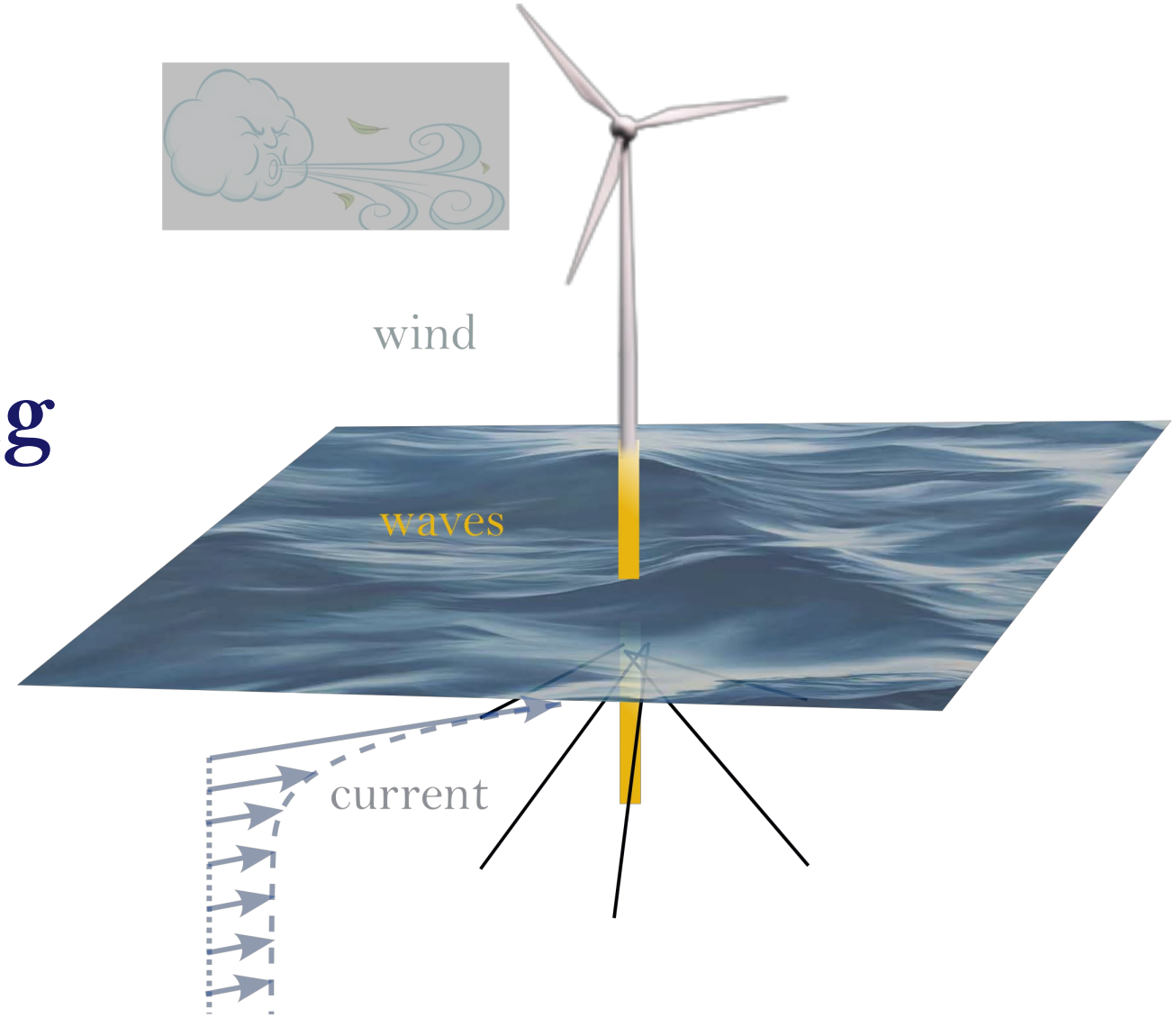
Effects on floating wind turbines



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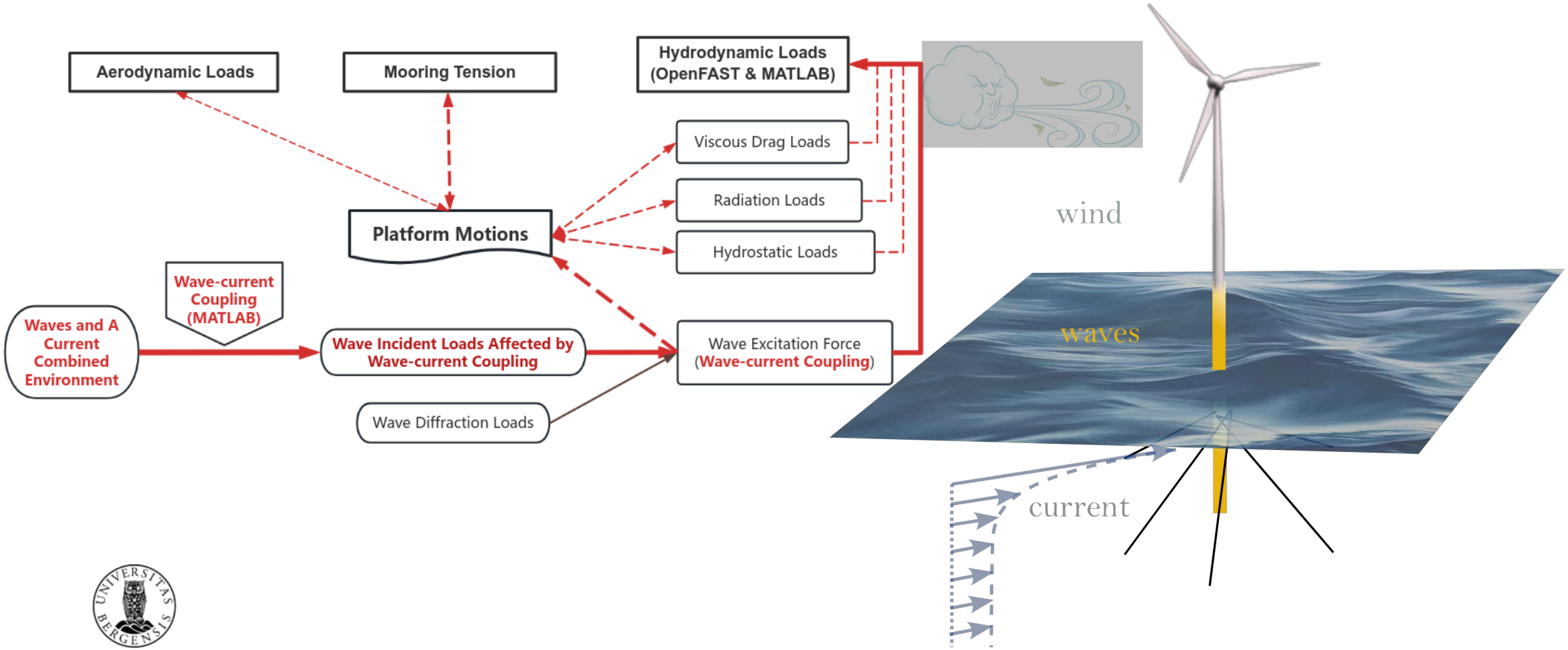
OpenFast & Matlab



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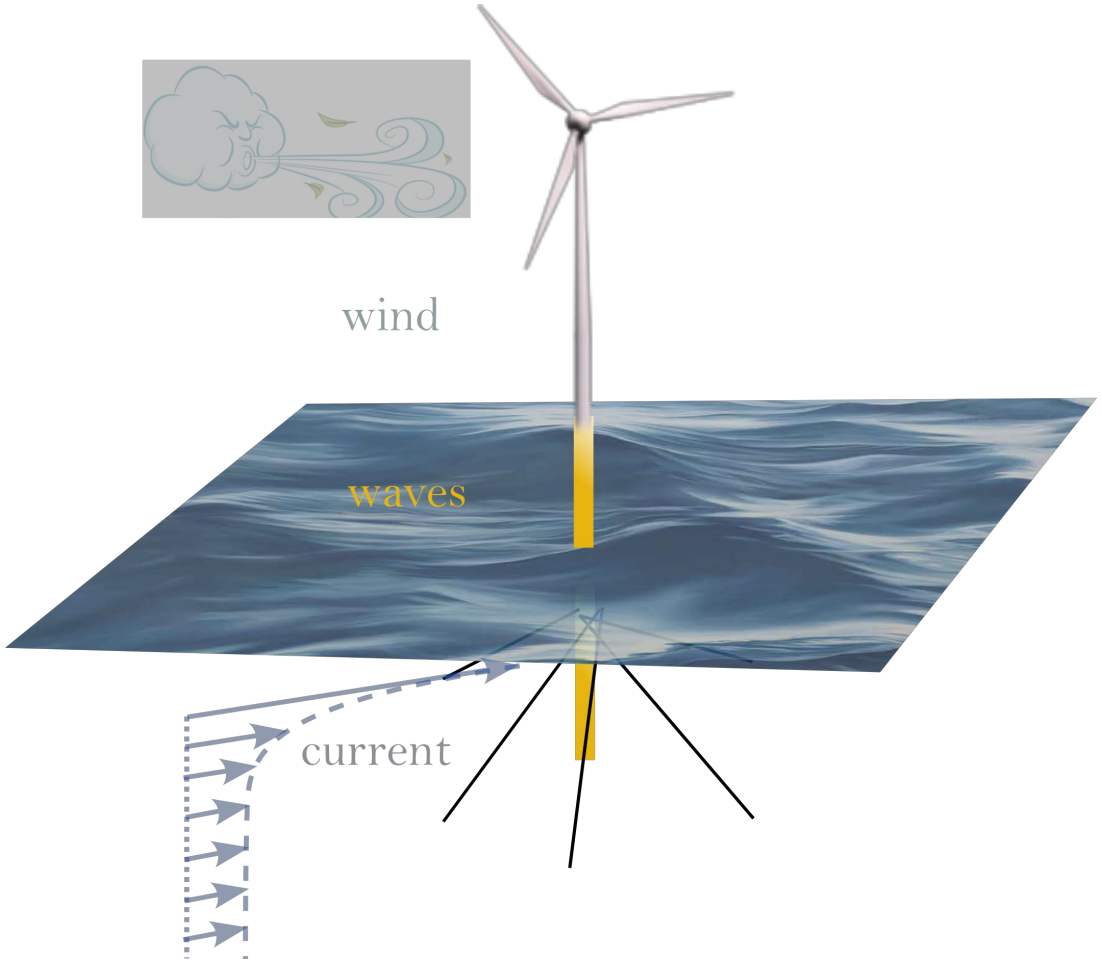
Offshore wind turbine model

- IEA 15MW reference wind turbine
- **Floater**: WindCrete Spar
- **Site conditions**: west coast of Norwegian sea



Severe site condition: a return period of 50 years

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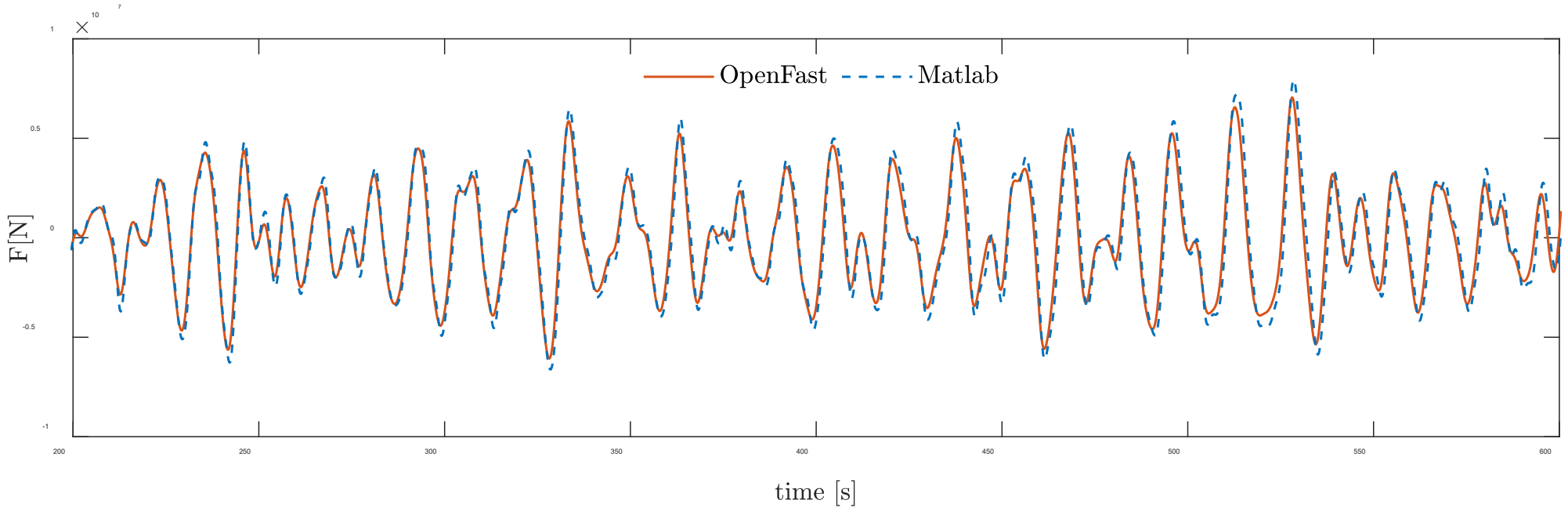
Input differences by construction

- Second-order wave effects in incident wave induced loads



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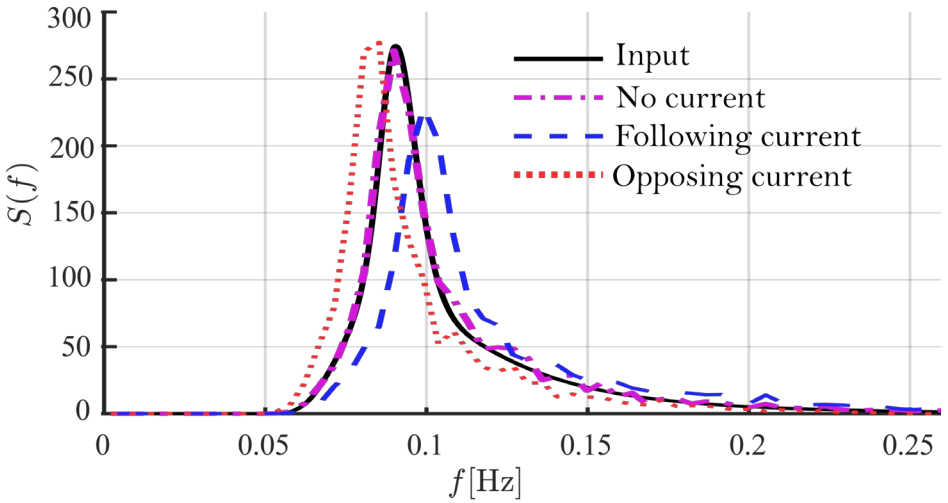
Input differences by construction

- Second-order wave effects in incident wave induced loads
- Modified wave spectra due to wave-current coupled effects



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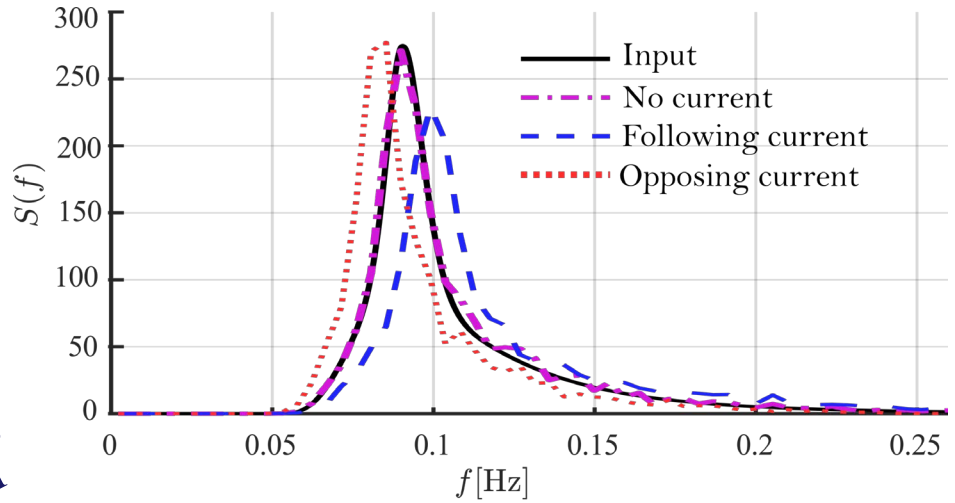
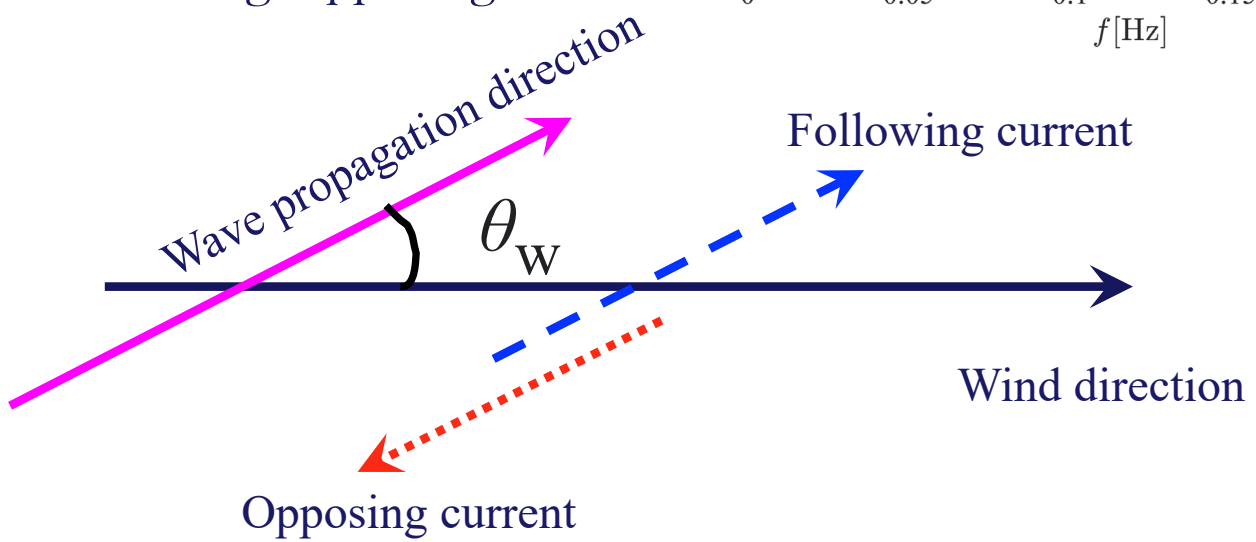
Input differences by construction

- Second-order wave effects in incident wave induced loads
- Modified wave spectra due to wave-current coupled effects
- Uniform current following/opposing waves





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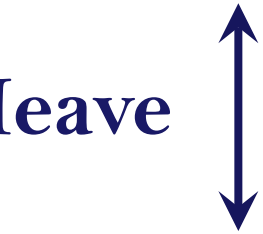
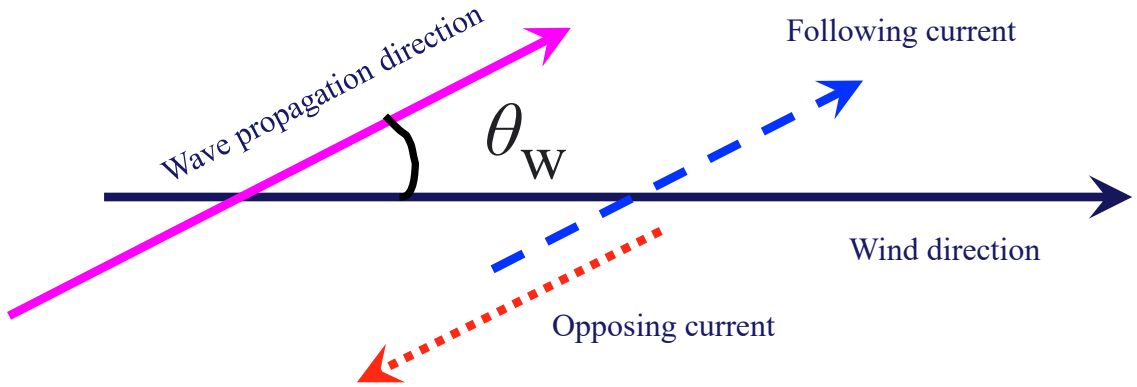
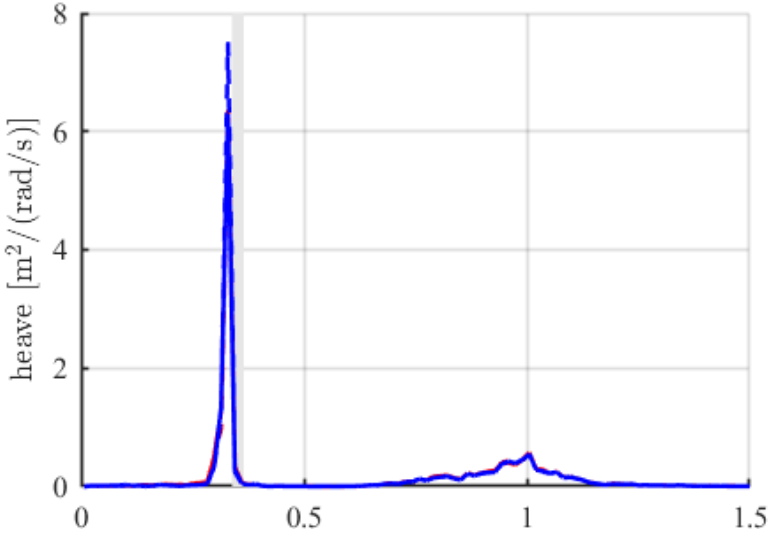
Heave

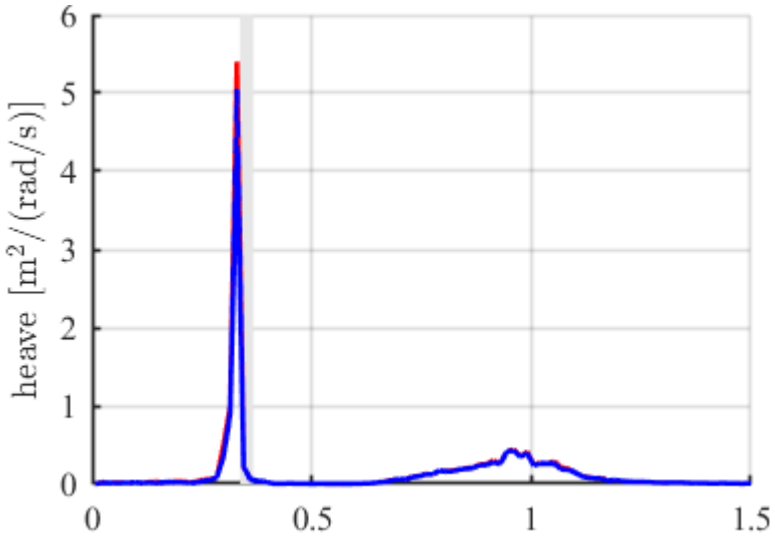


following, decoupled
following, coupled
opposing, decoupled
opposing, coupled

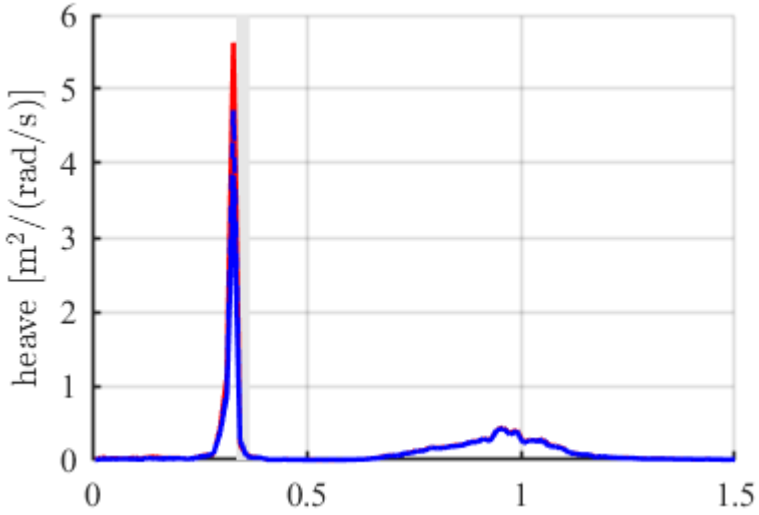




θ_w = 0 degree



θ_w = 30 degrees



θ_w = 60 degrees

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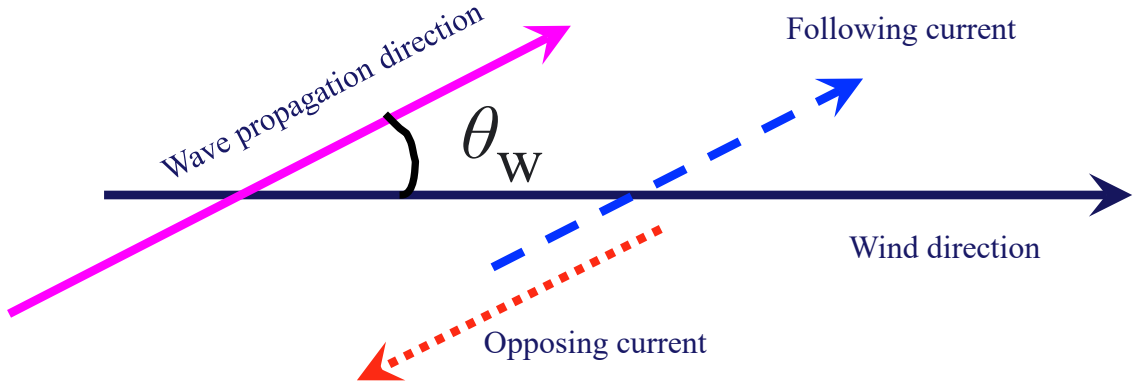
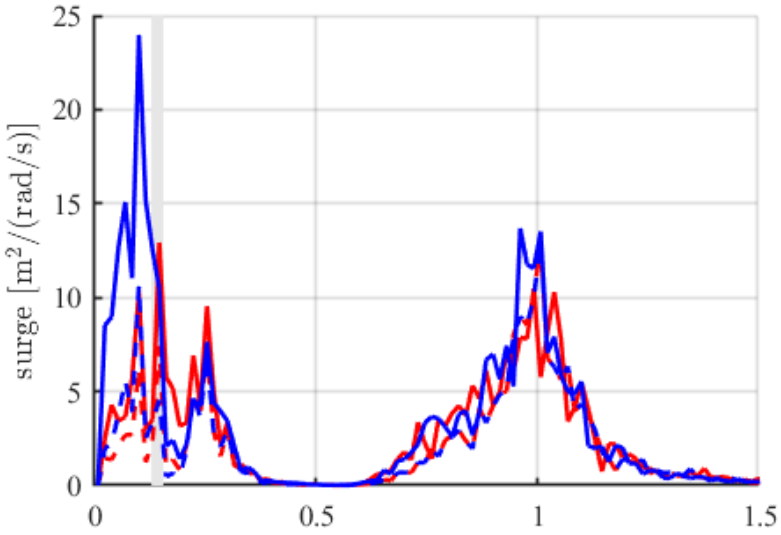
Surge

following, decoupled
following, coupled
opposing, decoupled
opposing, coupled





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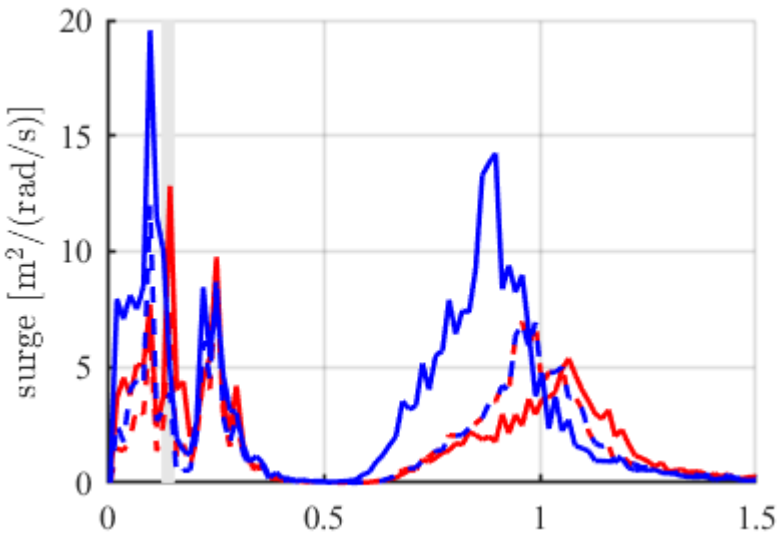

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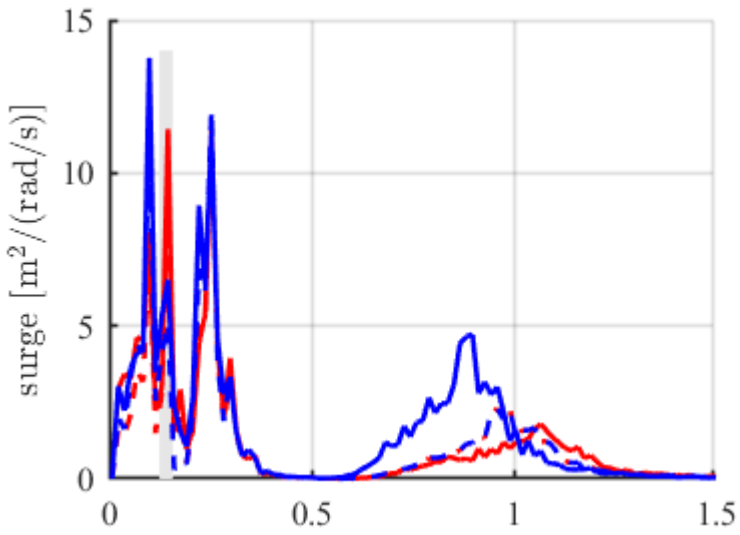

θ_w = 60 degrees

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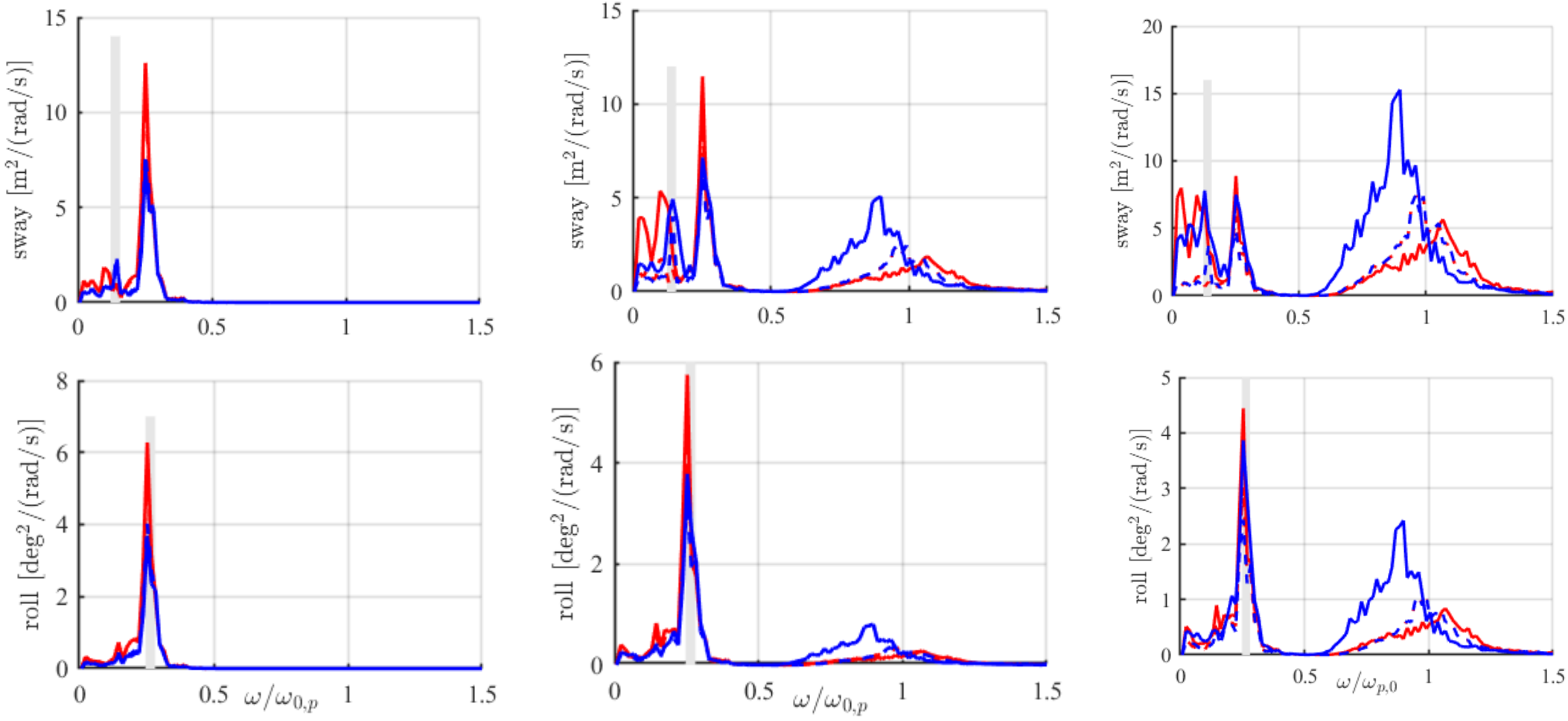
Sway

Roll



θ_W = 0 degree

θ_W = 30 degrees

θ_W = 60 degrees

following, decoupled
following, coupled
opposing, decoupled
opposing, coupled

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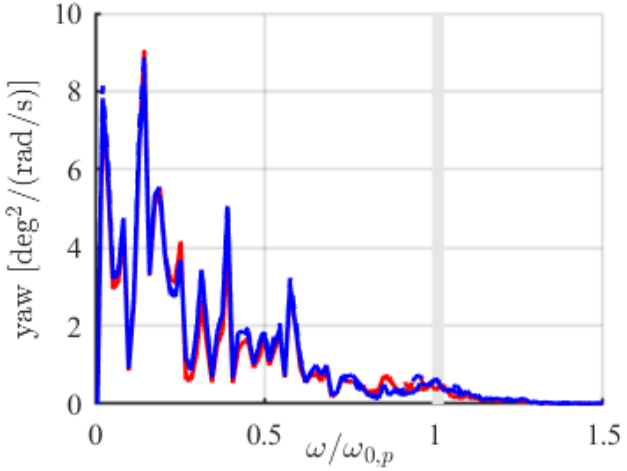
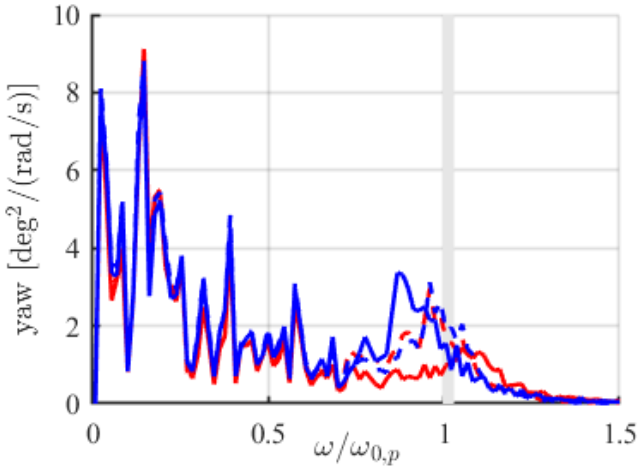
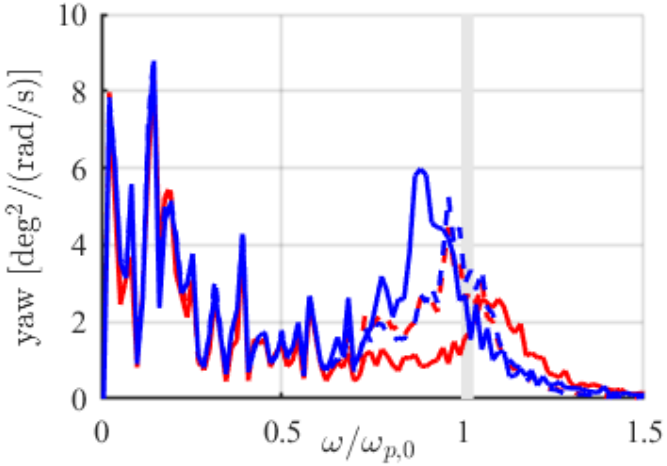
Yaw

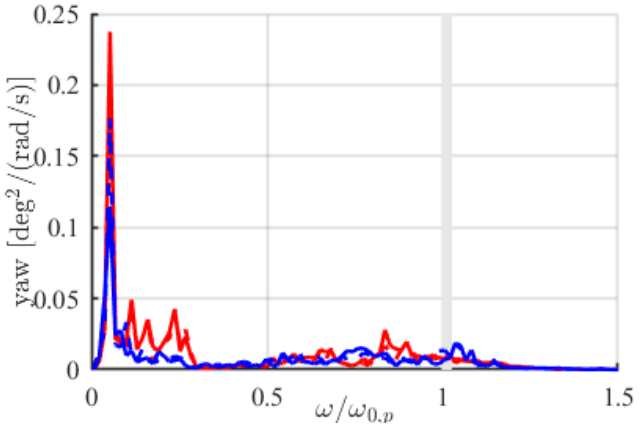
wind cut-out

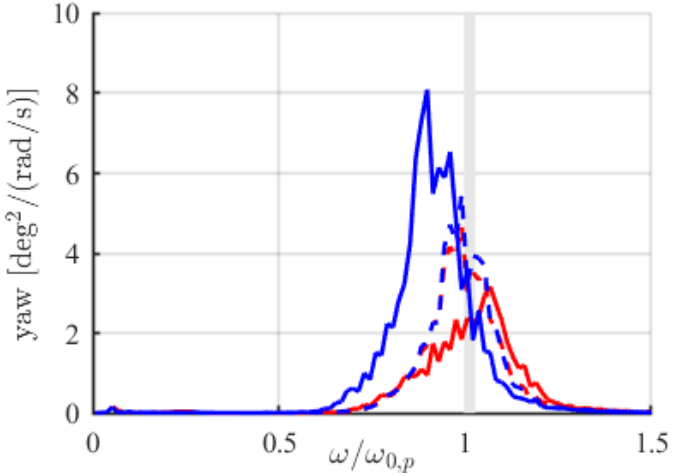


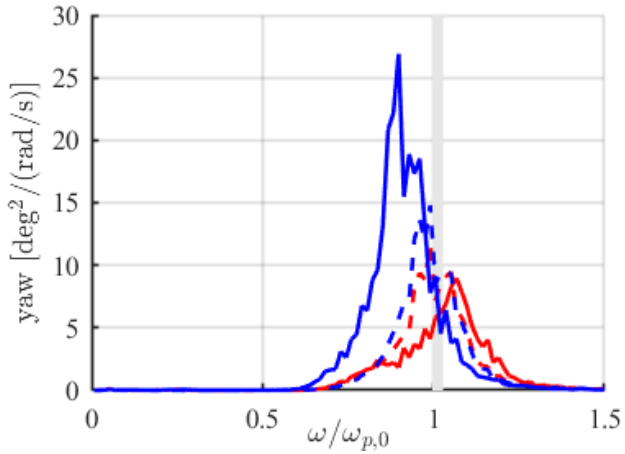




idling







θ_W = 0 degree

θ_W = 30 degrees

θ_W = 60 degrees

following, decoupled
following, coupled
opposing, decoupled
opposing, coupled

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Conclusions and outlook

I. The **coupling** between waves and a background current (WCC) can have significant effects on the interpretations of met-ocean data

II. Much amplified motion responses but heave due to WCC, especially for load cases of a current opposing waves in **oblique** seas.

III. **Strong coupling** between aerodynamic and hydrodynamic loads in Yaw

- wind cut-out speed leads to higher yaw responses in the **low-frequency** domain for oblique seas than idling
- and therefore, **extra damage** to mooring lines for the wind cut-out speed load cases

IV. Future steps:

- Manuscript in preparation
- further study on a **semisubmersible** floating wind turbine