SPH model of a sea wave powered UUV docking station

Vito Zago, Morteza Derakhti, Curtis J. Rusch, Jim M. Thomson

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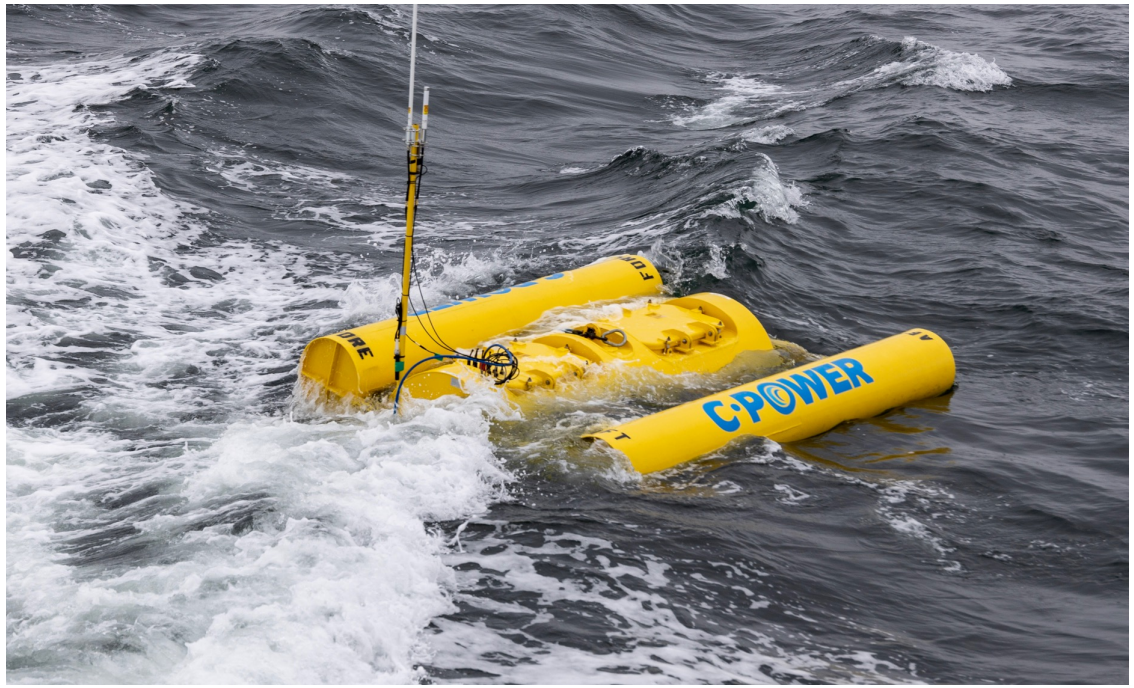
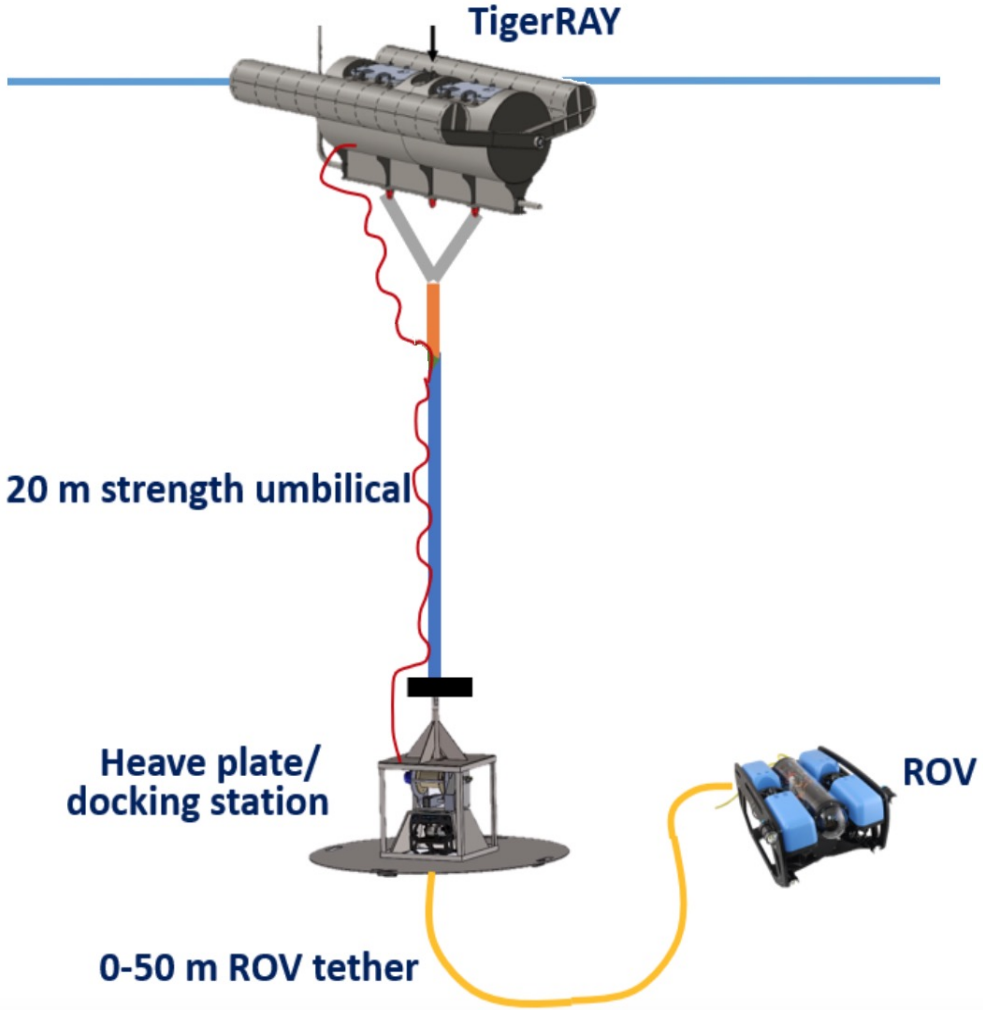
The WEC-UUV system

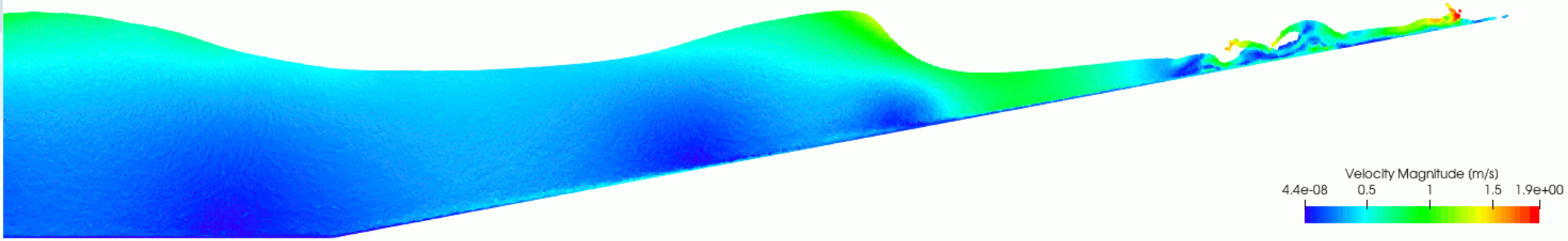
- This system powers an Unmanned Underwater Vehicle (UUV) from sea waves
- Our objective is to simulate the dynamics and kinematics of the WEC, and the effects of the interaction on the surrounding fluid.





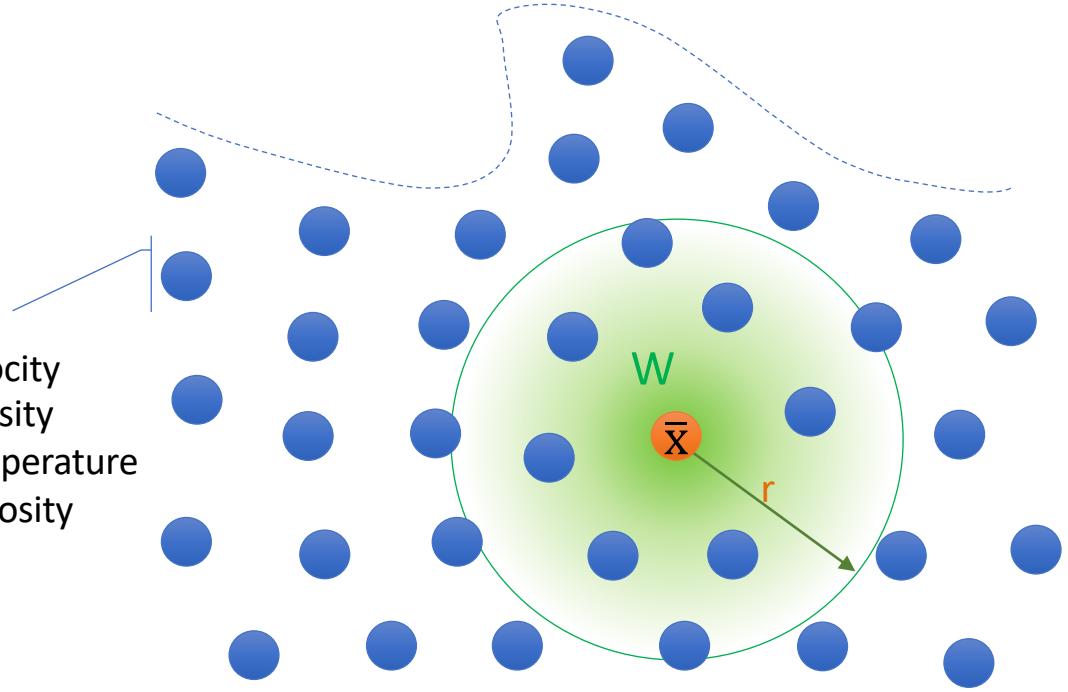
Numerical simulations with SPH

- SPH (Smoothed Particle Hydrodynamics) is a CFD based numerical method;
- It is Lagrangian and mesh-free;
- Unlike analytical or inviscid models, SPH gives a full description of the flow (e.g. pressure field, velocity field, vortex shedding)



Smoothed Particle Hydrodynamics (SPH)

Particles represent a portion of volume, move according to the equations of motion, and carry properties of the fluid.



- Velocity
- Density
- Temperature
- Viscosity
- etc

Dirac's Delta sampling property

$$f(\bar{\mathbf{x}}) = \int_{\Omega} f(\mathbf{x})\delta(\mathbf{x} - \bar{\mathbf{x}})\, d\mathbf{x}$$

$$f(\bar{\mathbf{x}}) \approx \sum_{\alpha=1}^{N} f(\mathbf{x}_\alpha) W(\mathbf{x}_\alpha - \bar{\mathbf{x}}, h) V_\alpha$$

SPH interpolation

Properties of SPH

- Good for **free-surface** and interfaces.
- Good for highly dynamic flows.
- Intrinsically **parallelizable**: It can be run on high performance parallel computing hardware, like GPUs.

Nvidia V100
Graphic Processing Unit (GPU)

- 5120 calculations at the same time
- 14 Teraflops
- Around 50 millions of particles

GPUSPH is an implementation of the SPH method on GPUs with extension to clusters and grids of clusters.

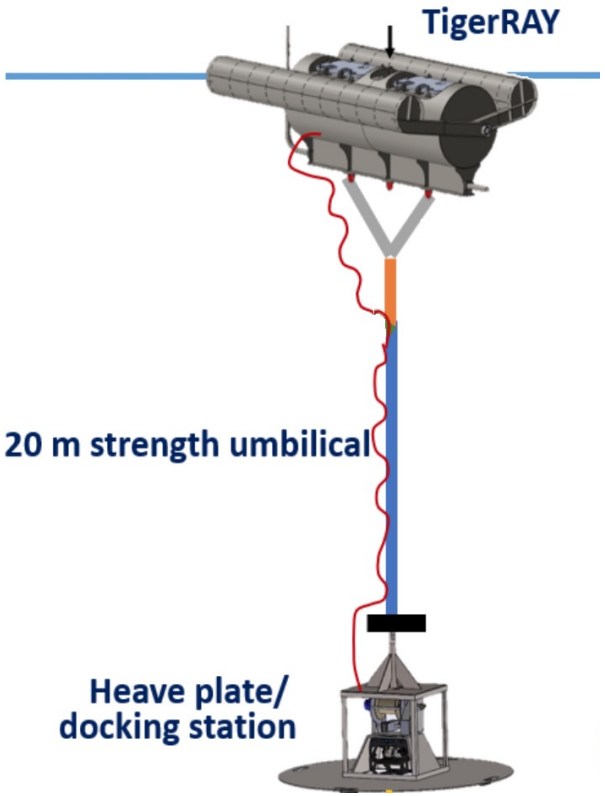
GPUSPH includes the **Project Chrono** engine for rigid body dynamics and FEM, allowing the simulation of fluid-structures interactions.

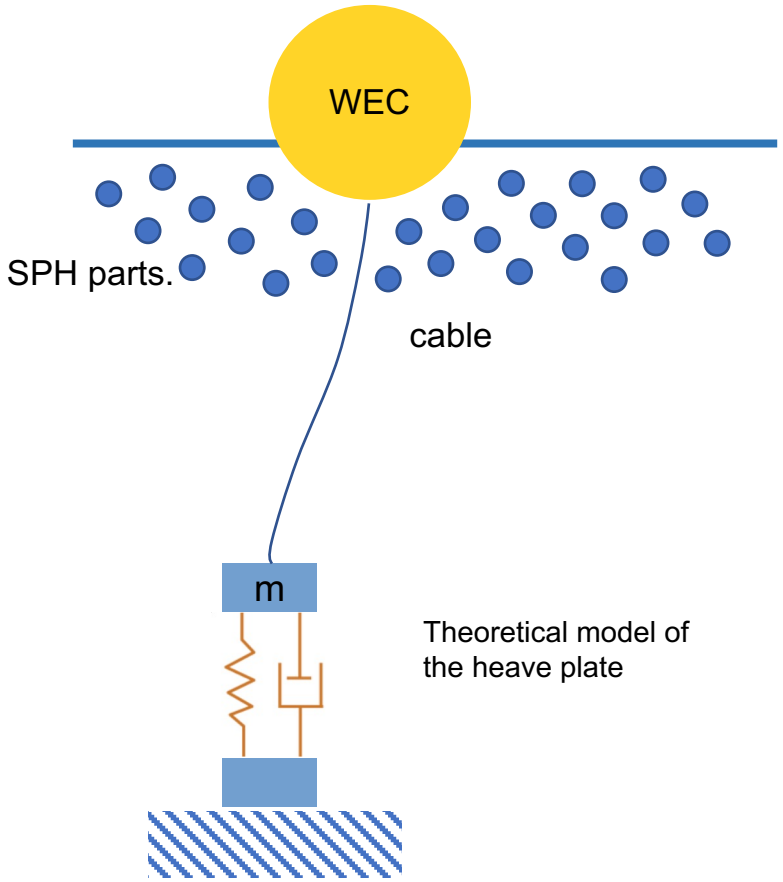
Numerical model of the WEC-UUV system

For computational advantage we divide the domain in two subdomains: WEC and waves, and heave plate.

SPH formulation:

- CCSPH[1] for improved energy conservation
- WALE for improved boundary layer representation

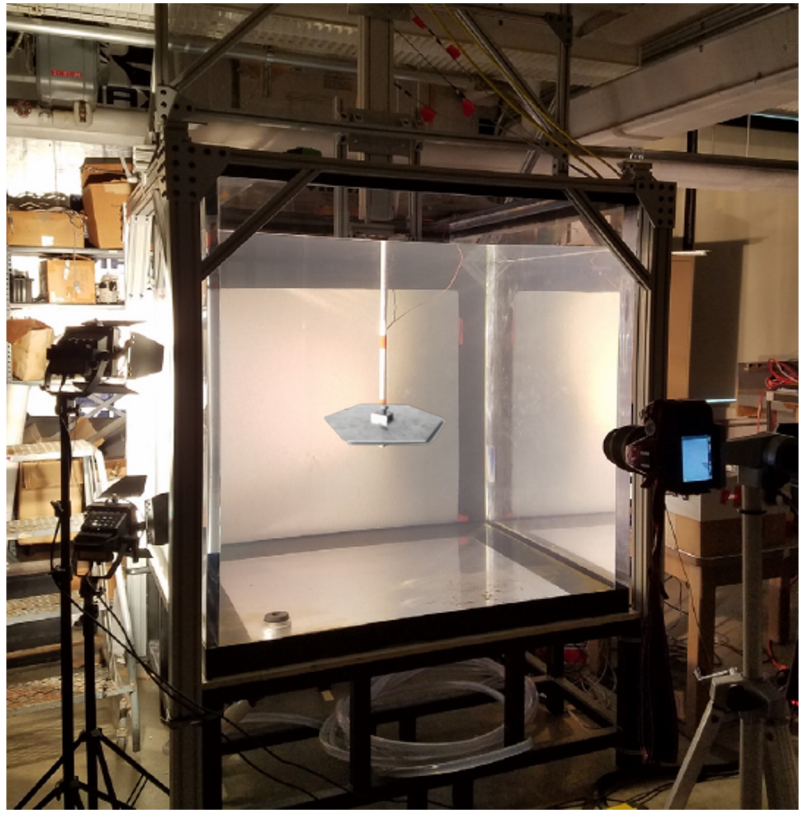




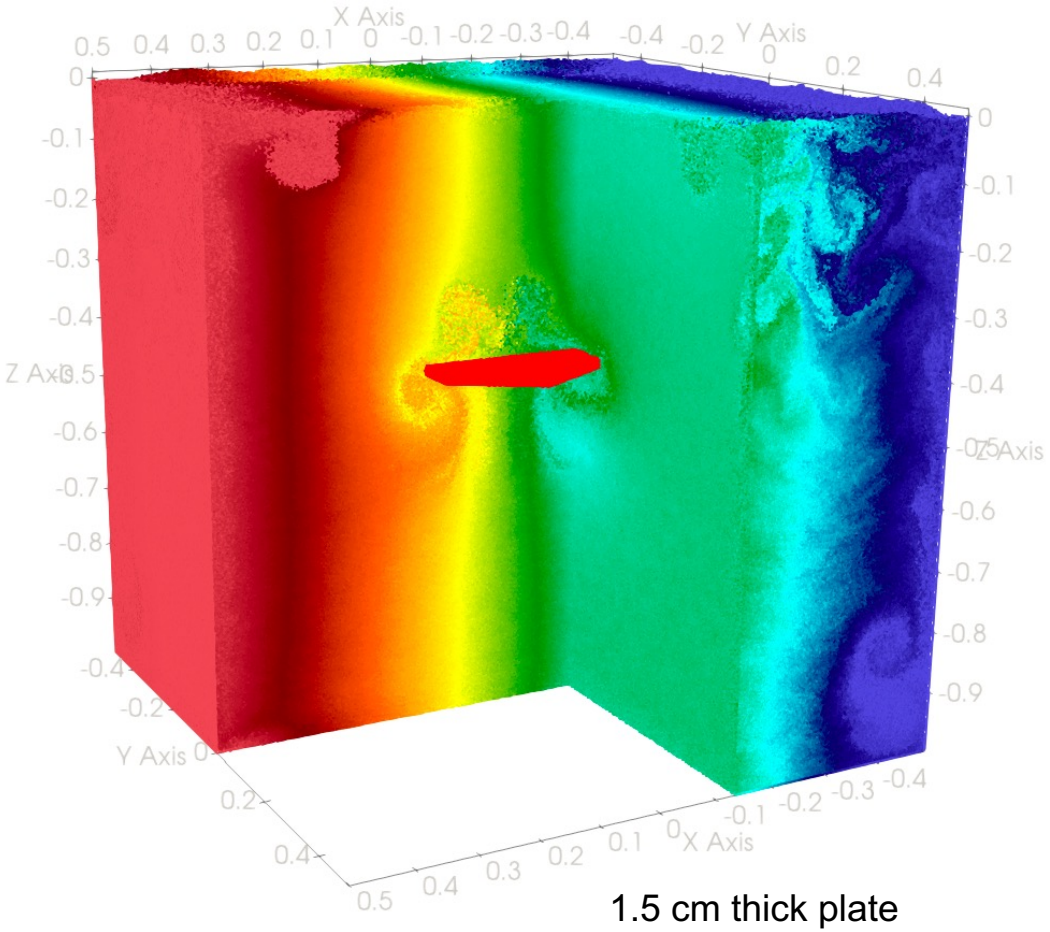
[1] Zago *et al.,(2021),* Overcoming excessive numerical dissipation in SPH modeling of water waves, Coastal Engineering, Volume 170.

SPH simulation of a heave plate

We can use SPH to design and study the heave plate. We refer to a laboratory experiment for model validation.



0.32 cm thick plate

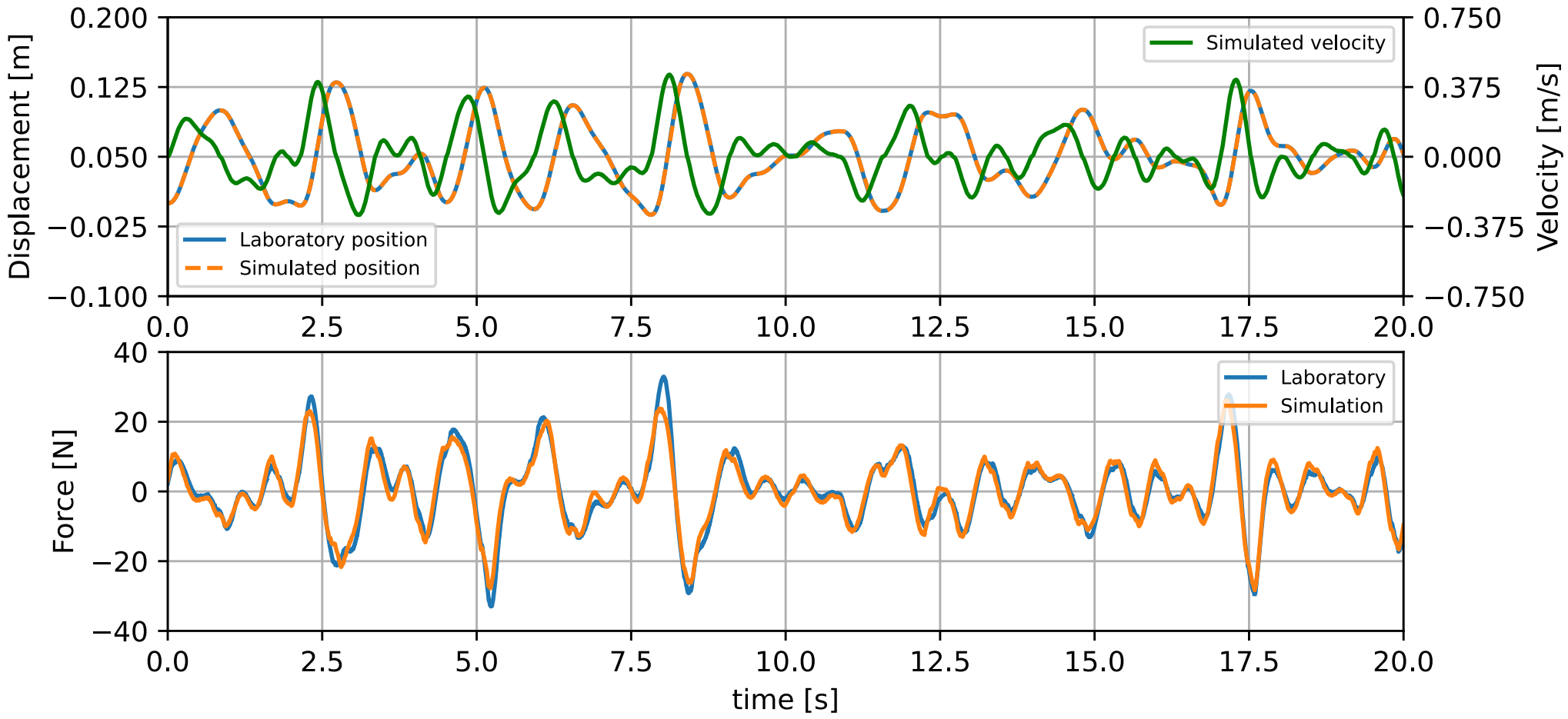


1.5 cm thick plate

[1] Rusch *et al.*, (2021) Influence of heave plate topology on reaction force, Ocean Engineering, Volume 241.

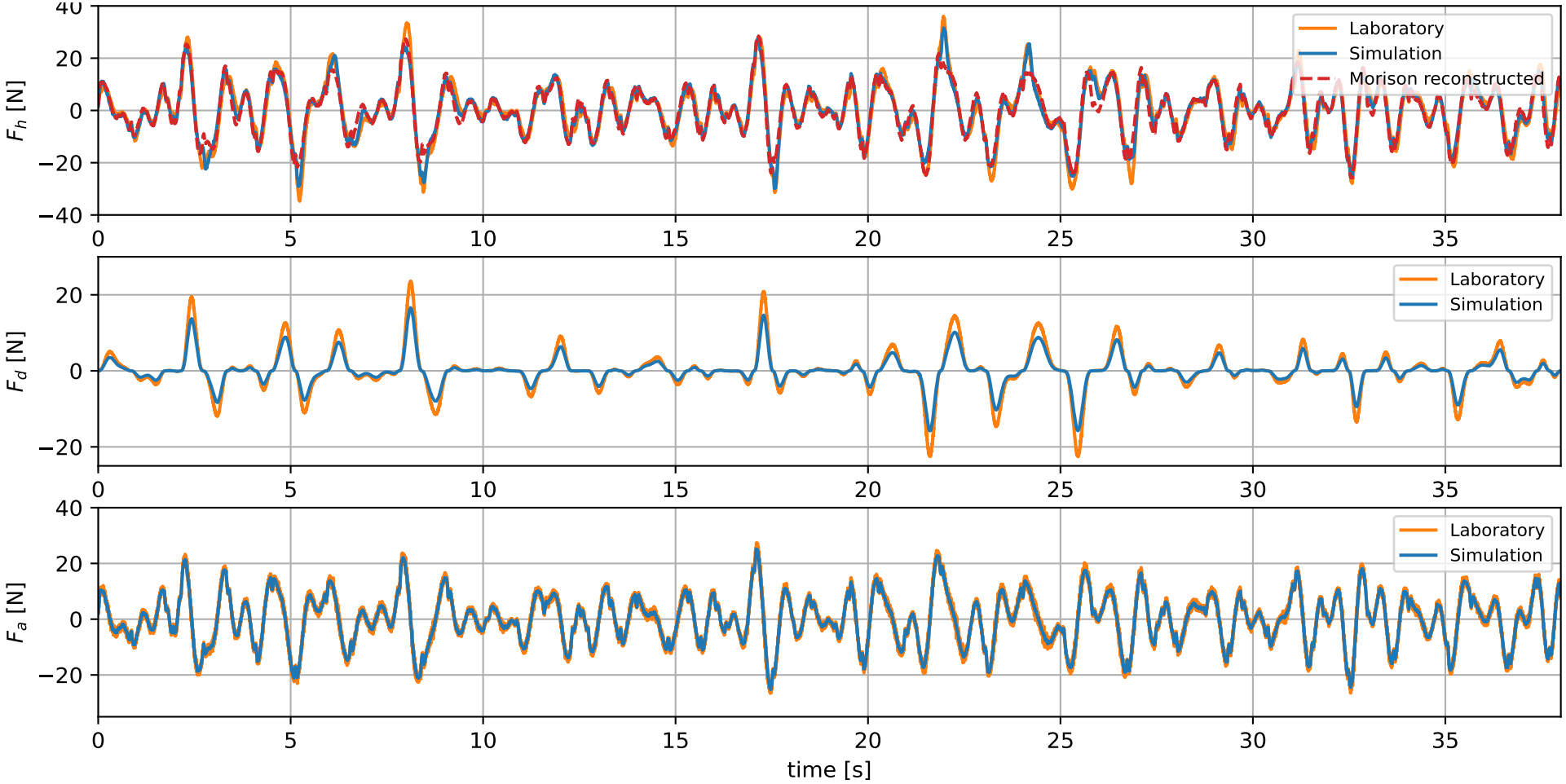
Validation of the heave plate model

The plate is moved with H_s = 20 cm, T = 2 s and we look at the hydrodynamic reaction forces.



Estimation of hydrodynamic coefficients

Knowing the motion and the hydrodynamics of the plate we can characterize the heave plate with its hydrodynamic coefficients, such as C_D and C_A.



[1] Rusch *et al.*, (2021) Influence of heave plate topology on reaction force, Ocean Engineering, Volume 241.

Simulating the WEC-UUV system in GPUSPH

We initially characterize the field-size heave plate from simulation. We simulate a flat circular plate with the diameter *D* of the real model (*D = 2.4* m*)*. Thickness *t* is chosen so to have the *D/t* ratio used during validation.

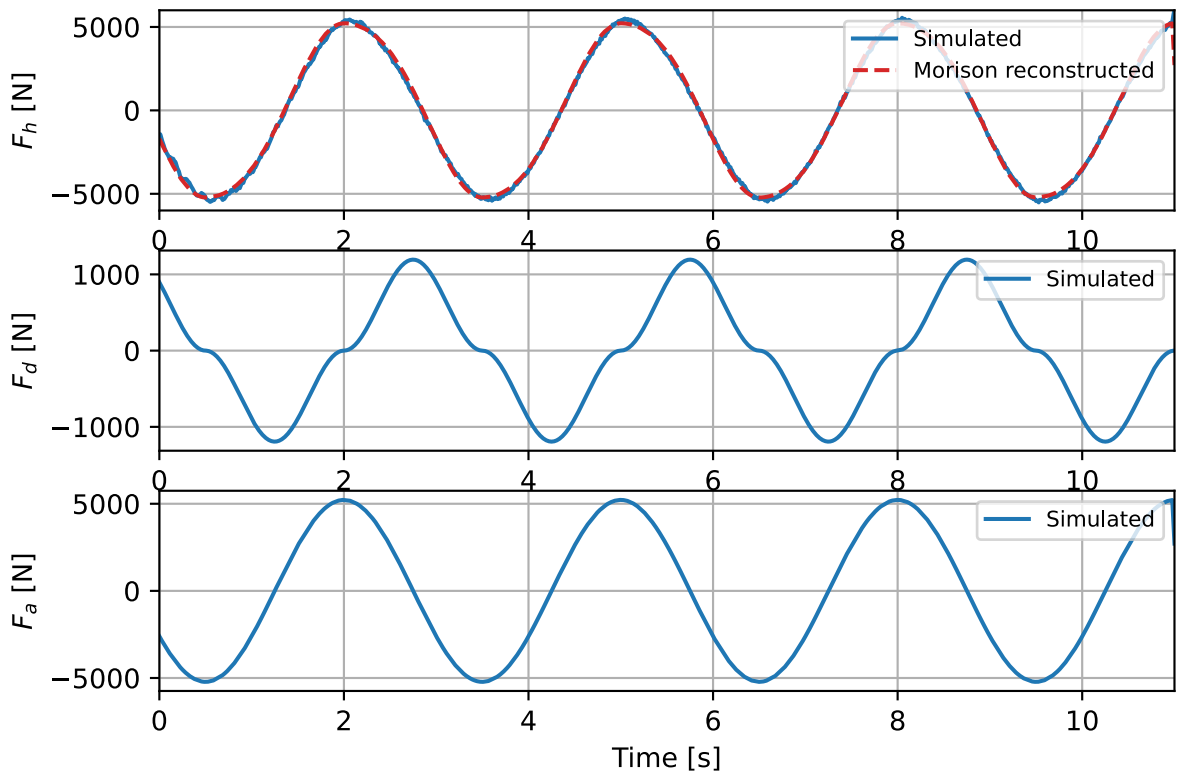
We apply a sinusoidal motion with:

H = 0.38 m and T = 3s (KC = 0.5).

From force decomposition we get:

C_D = 3.3 and C_A = 0.86.

In this regime, Morison's decomposition can faithfully reconstruct the total force.



Simulating WEC-UUV

We simulate the WEC with floats in free-wheel.

A FEM-modeled cable is used to connect the WEC to the model of the heave plate

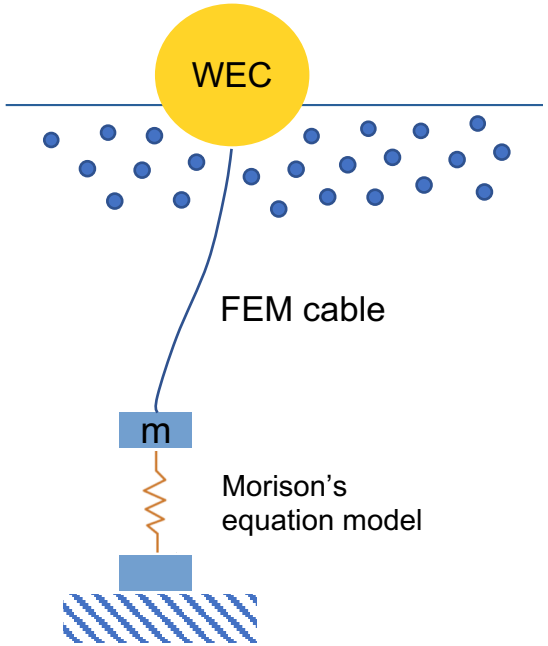
Field measurement:

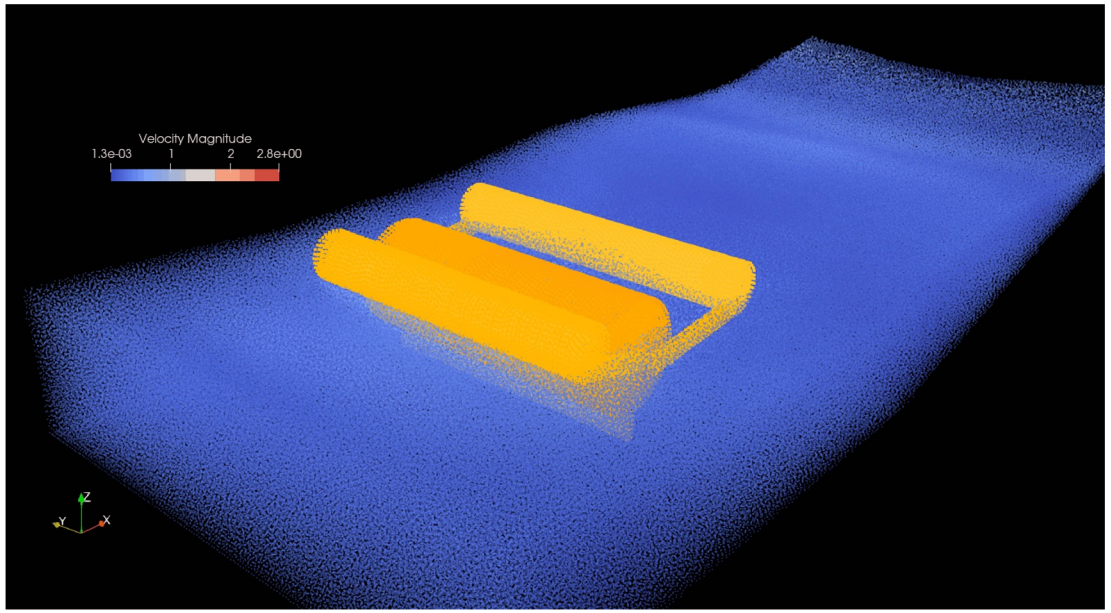
H_s = 0.35 m, T = 2.5 s

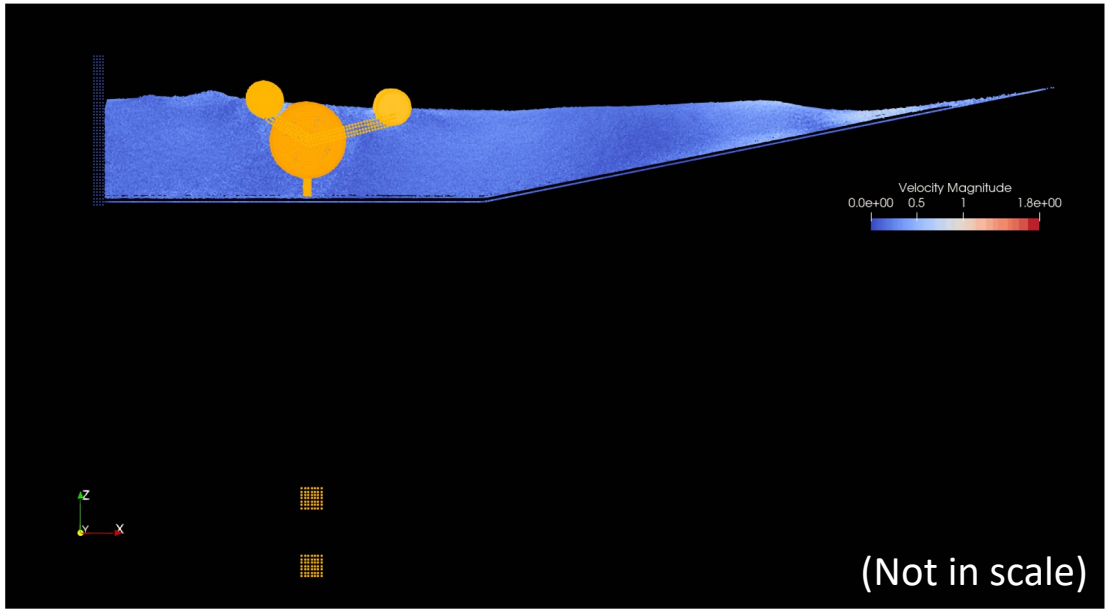
Simulation:

Monochromatic, with

H = 0.35 m, T = 2.5 s.

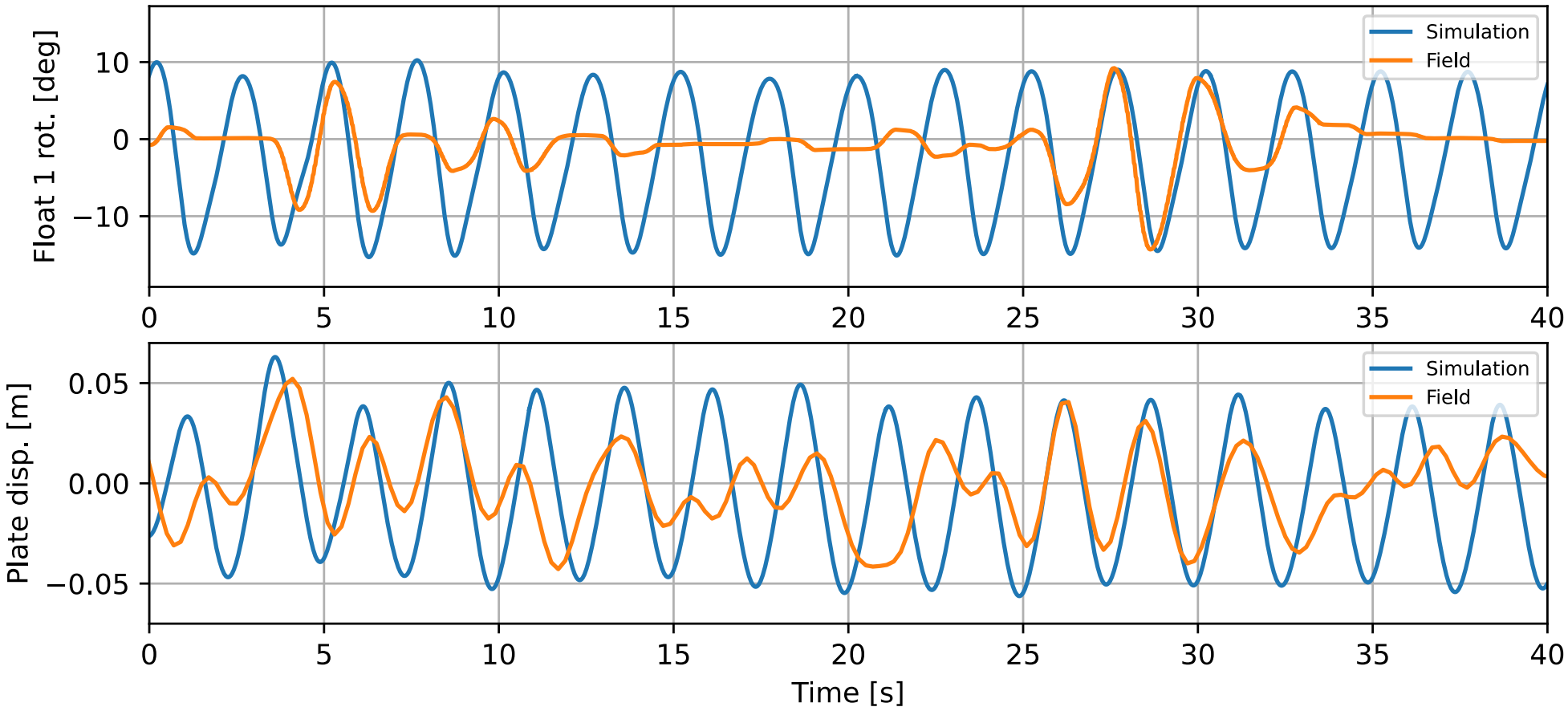






Comparison with field measurements

Signals from the field come from irregular waves, so they are not directly comparable to those obtained with a monochromatic wave. Good matching is achieved when wave conditions are comparable.



Conclusions and future perspectives

- We used GPUSPH to simulate a complex WEC application;
- We defined an SPH formulation that can reproduce the hydrodynamics of a heave plate;
- We reproduced the kinematics of the WEC;

- Modeling the Power-Take-Off system will allow to simulate power production.