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Application Of Open Boundaries Within A Two-Way Coupled SPH Model To Simulate Non-Linear Wave-Structure Interactions

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INTRODUCTION

Open Boundaries

Open Boundaries

Potential Flow Solver

Smoothed Particle Hydrodynamics

Potential Flow Solver

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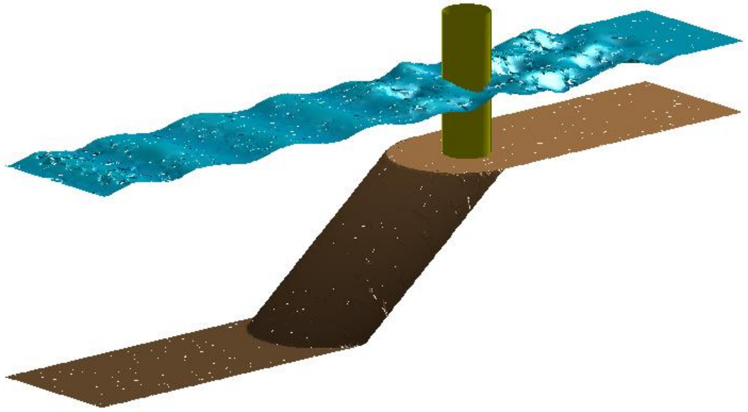
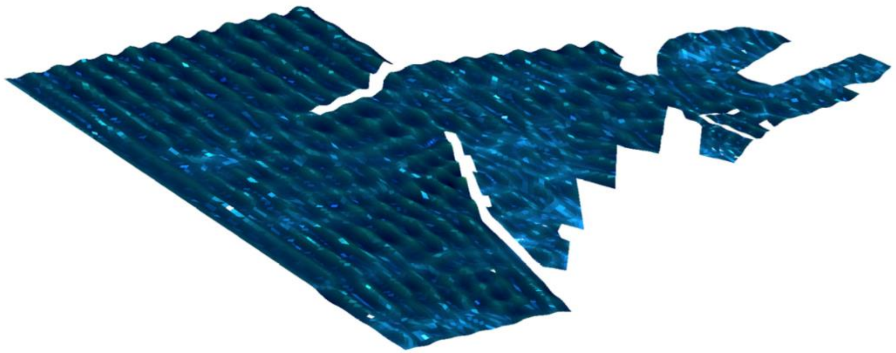
WAVE PROPAGATION MODEL



OceanWave3D



- Fully non-linear potential flow solver
- Flexible-order finite difference
- Fourth-order Runge-Kutta method
- Sigma layers in Z-direction
- Fast calculations

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SPH MODEL

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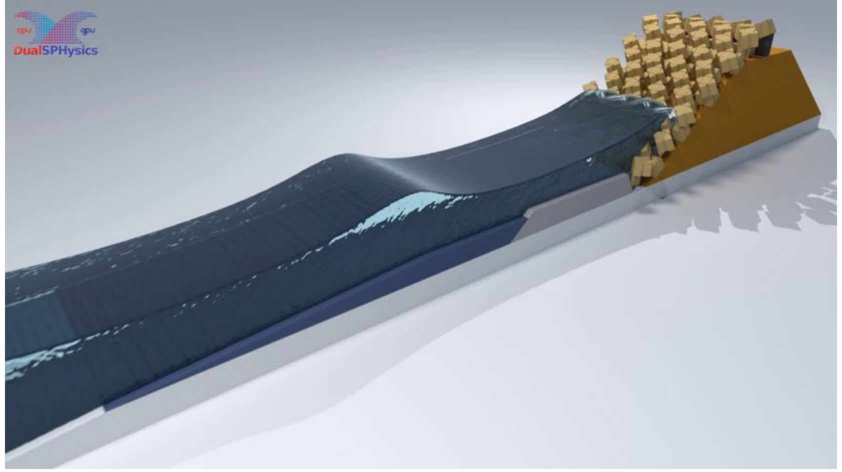
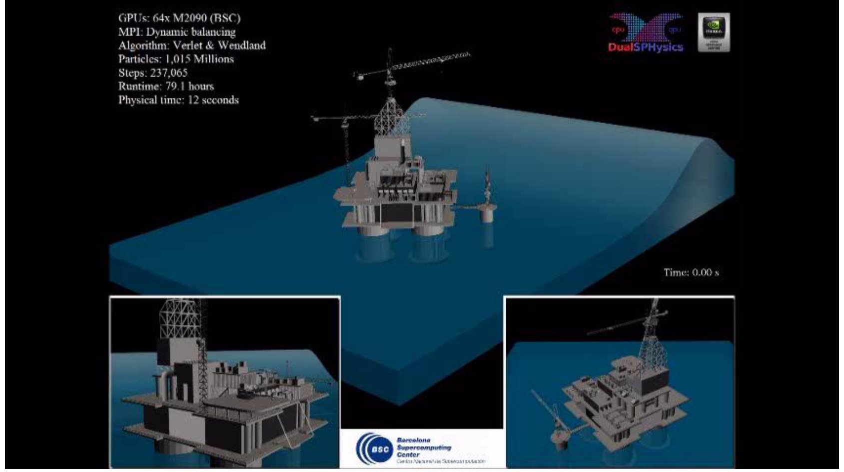
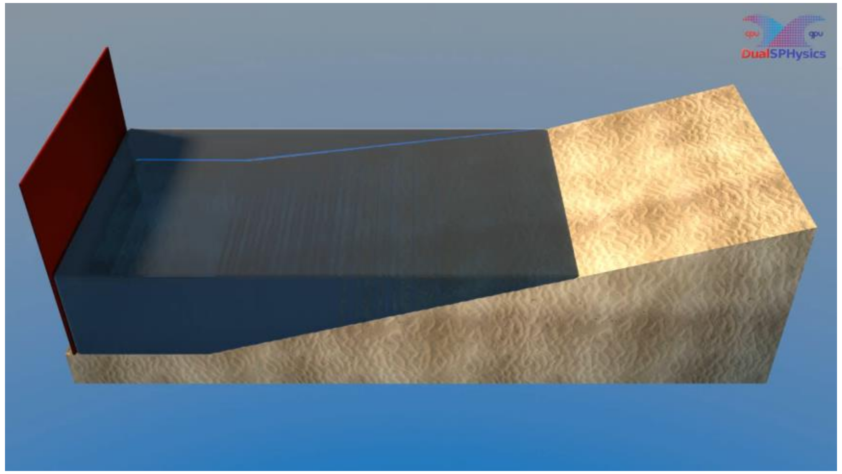




cpu gpu DualSPHysics



- Lagrangian particle method
- Weakly-Compressible SPH
- δ-SPH value of 0.1 (Antuono et al. 2012)
- Particle shifting (Lind et al. 2012)
- Explicit second-order symplectic scheme
- Open Boundaries (Tafuni et al. 2016)

OPEN BOUNDARIES

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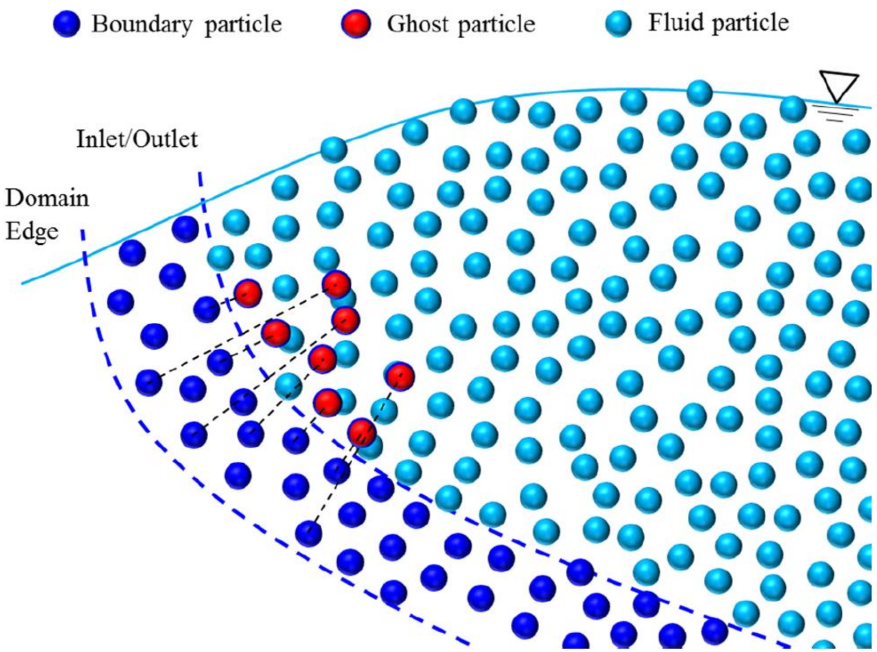
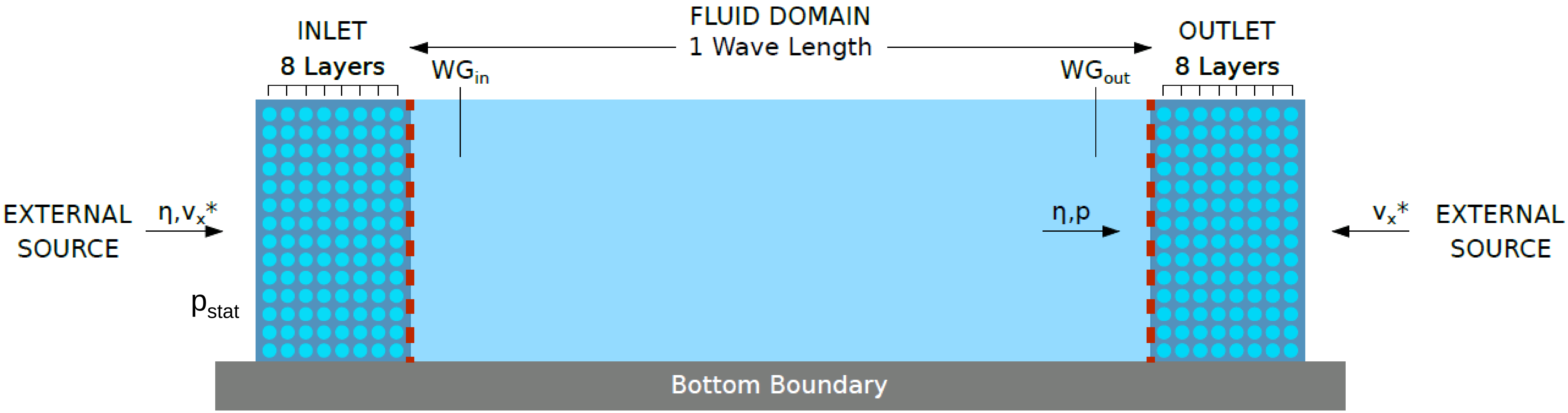
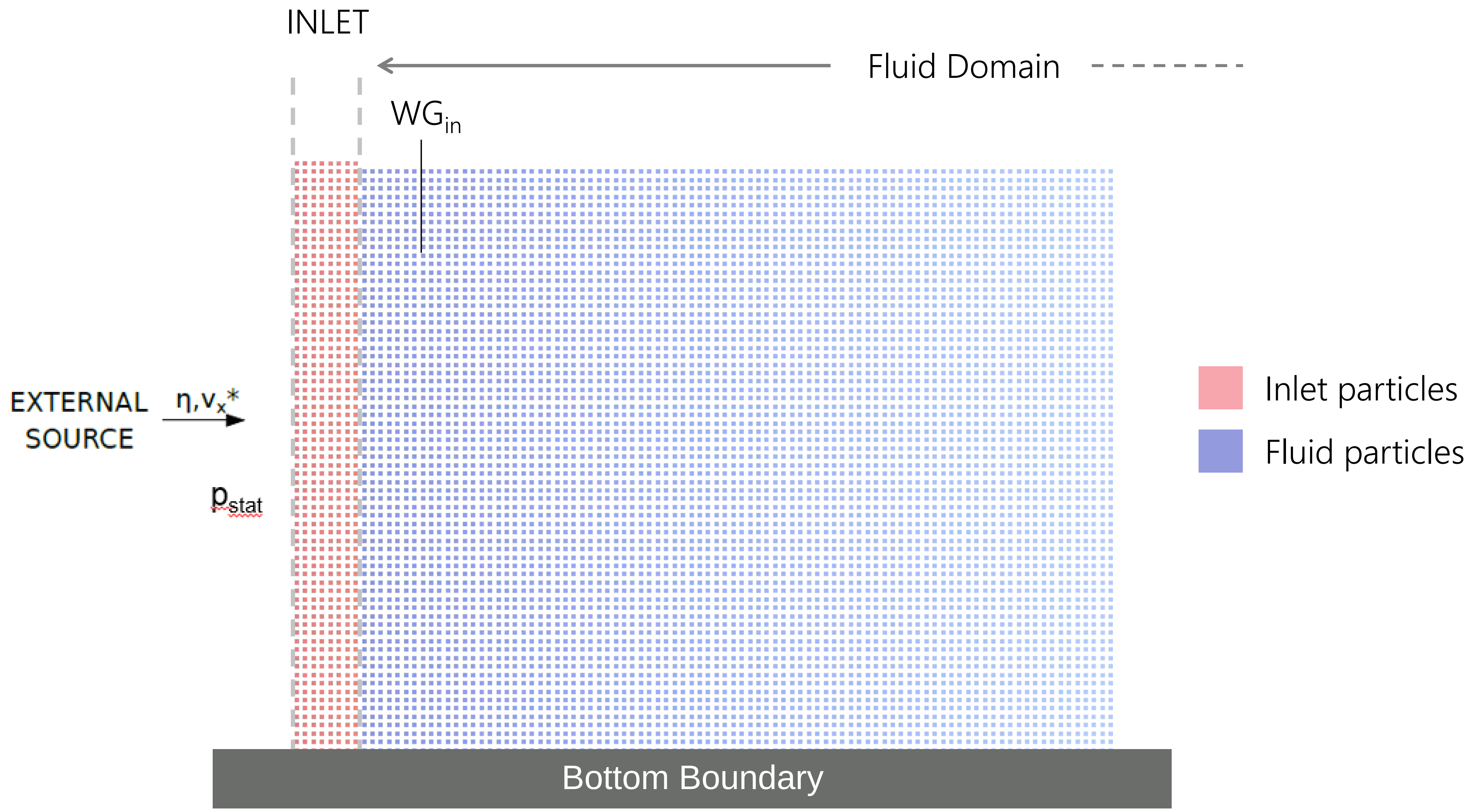
- Impose physical quantities
- Extrapolate from fluid domain using ghost nodes



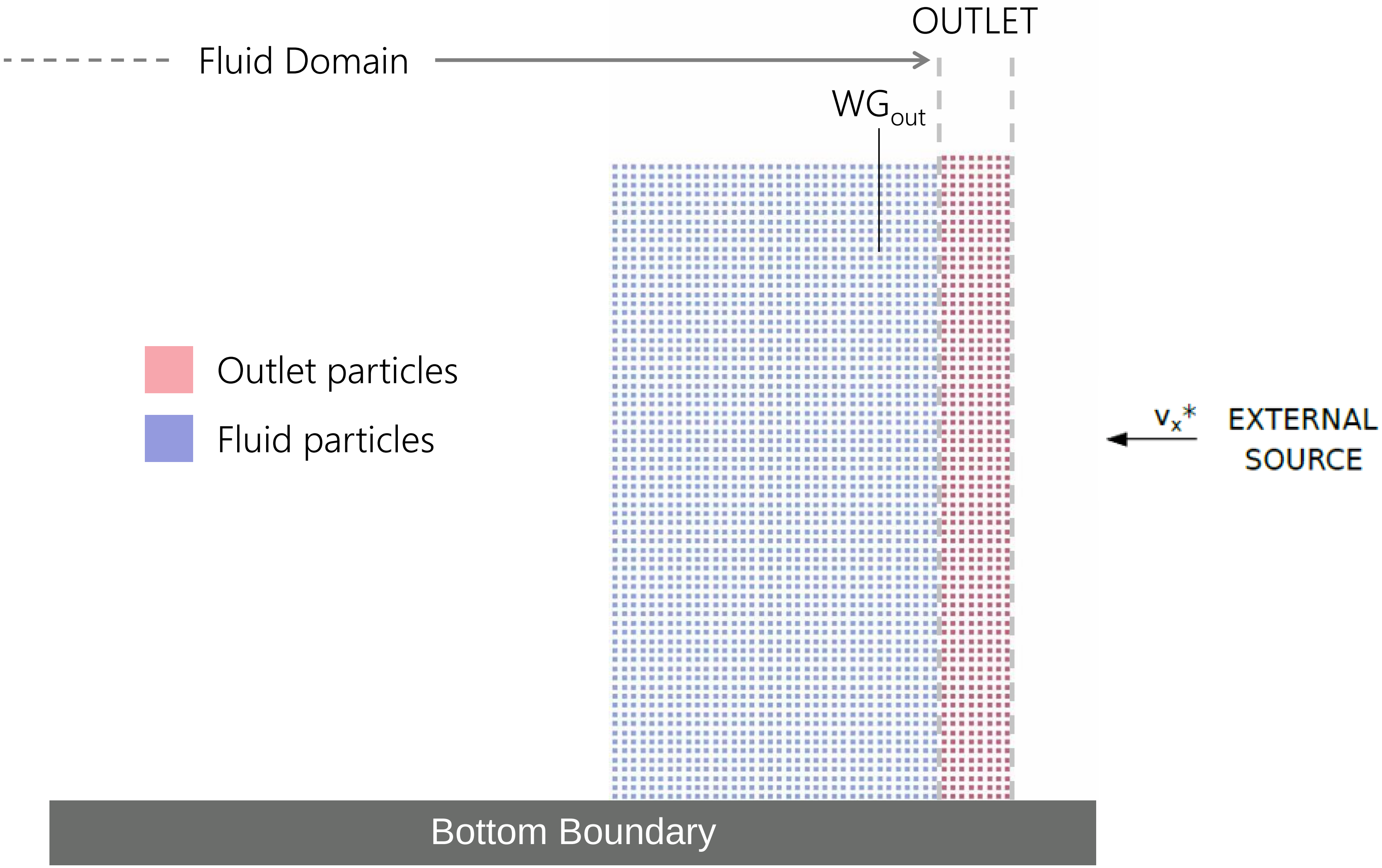
Tafuni, A., Dominguez, J.M., Vacondio, R., Crespo, A.J.C., 2017. Accurate and efficient SPH open boundary conditions for real 3-D engineering problems, in: Proceedings of the 12th SPHERIC International Workshop, June 13-15, Ourense, Spain.



Quantity	X-Velocity	Z-Velocity	Surface Elevation	Pressure
INLET	Imposed	/	Imposed	Hydrostatic
OUTLET	Imposed	/	Extrapolated	Extrapolated



INLET
Fluid Domain
WG$_{in}$
EXTERNAL SOURCE
η, v_x^*
p_{stat}
Inlet particles
Fluid particles
Bottom Boundary



OUTLET
Fluid Domain
WG$_{out}$
Outlet particles
Fluid particles
v_x^*
EXTERNAL SOURCE
Bottom Boundary

Inlet Correction:

$$v_{x,in}(z,t) = v_{x,theory}(z,t) - [\eta_{WG,in} - \eta_{theory}] \cdot \sqrt{\frac{g}{d}}$$

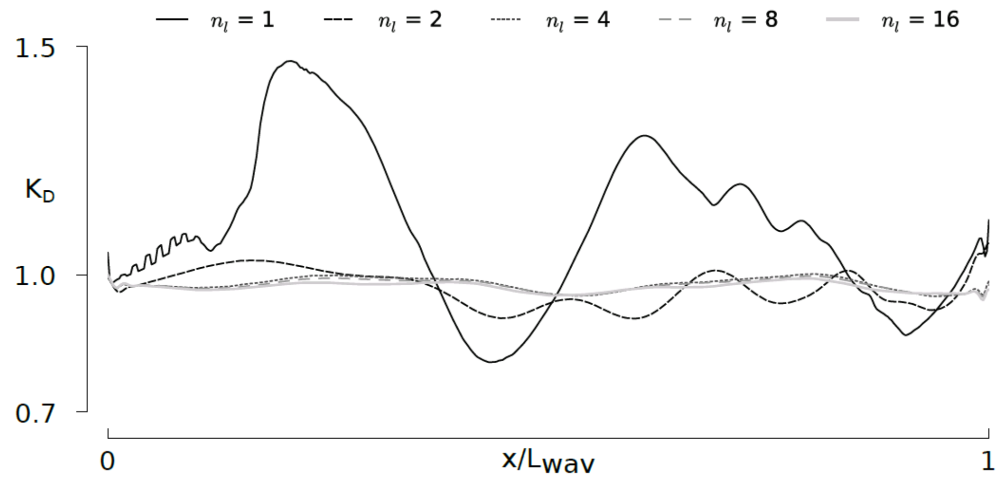
Outlet Correction:

$$v_{x,out}(z,t) = v_{x,theory}(z,t) - [\eta_{theory} - \eta_{WG,out}] \cdot \sqrt{\frac{g}{d}}$$

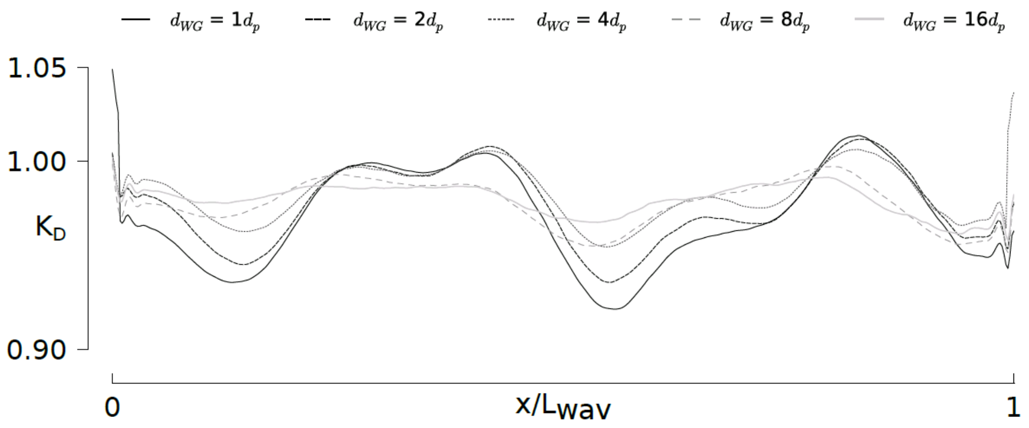
= Active wave absorption based on shallow water approximation

Altomare, C., Domínguez, J. M., Crespo, A. J. C., González-Cao, J., Suzuki, T., Gómez-Gesteira, M., & Troch, P. (2017). Long-crested wave generation and absorption for SPH-based DualSPHysics model. COASTAL ENGINEERING, 127, 37–54.

# of Layers

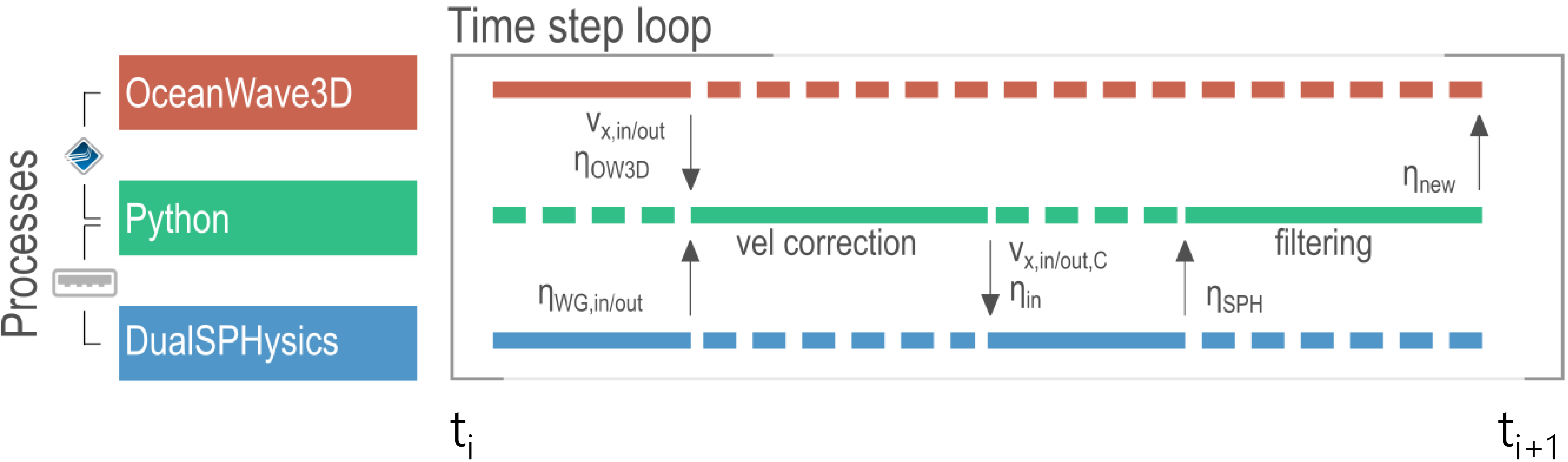


WG distance

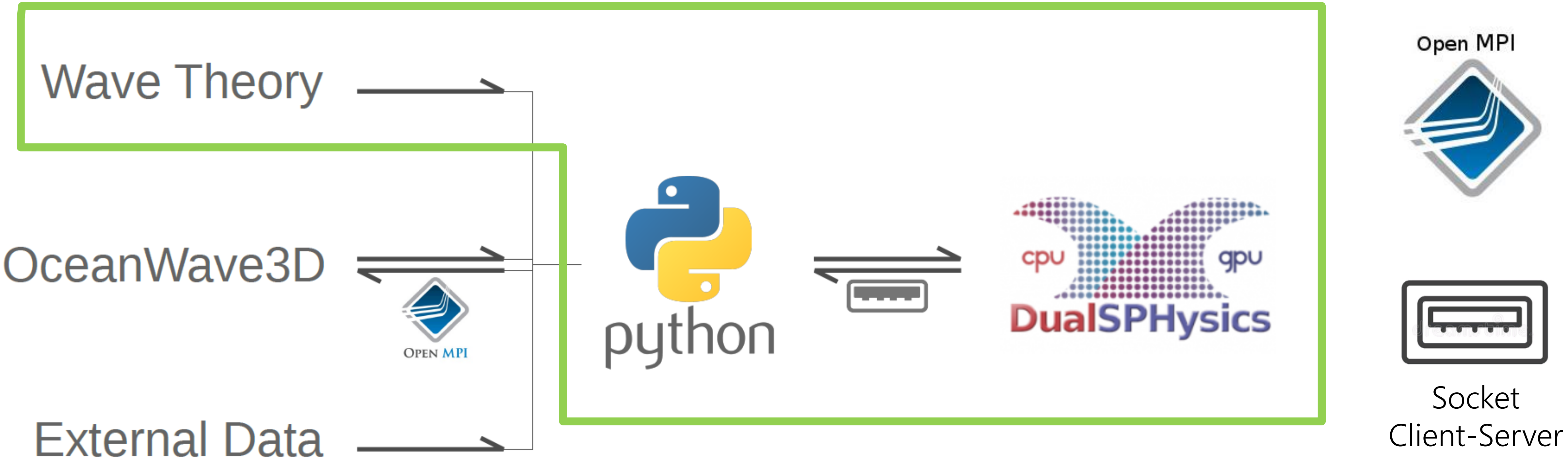


COUPLING METHODOLOGY


Wave Theory
OceanWave3D
OPEN MPI
External Data
python
cpu
gpu
DualSPHysics
Open MPI
Socket
Client-Server


Time step loop
Processes
OceanWave3D
Python
DualSPHysics
$v_{x,in/out}$
η_{OW3D}
η_{new}
vel correction
filtering
$\eta_{WG,in/out}$
$v_{x,in/out,C}$
η_{in}
η_{SPH}
t_i
t_{i+1}

VALIDATION


Wave Theory
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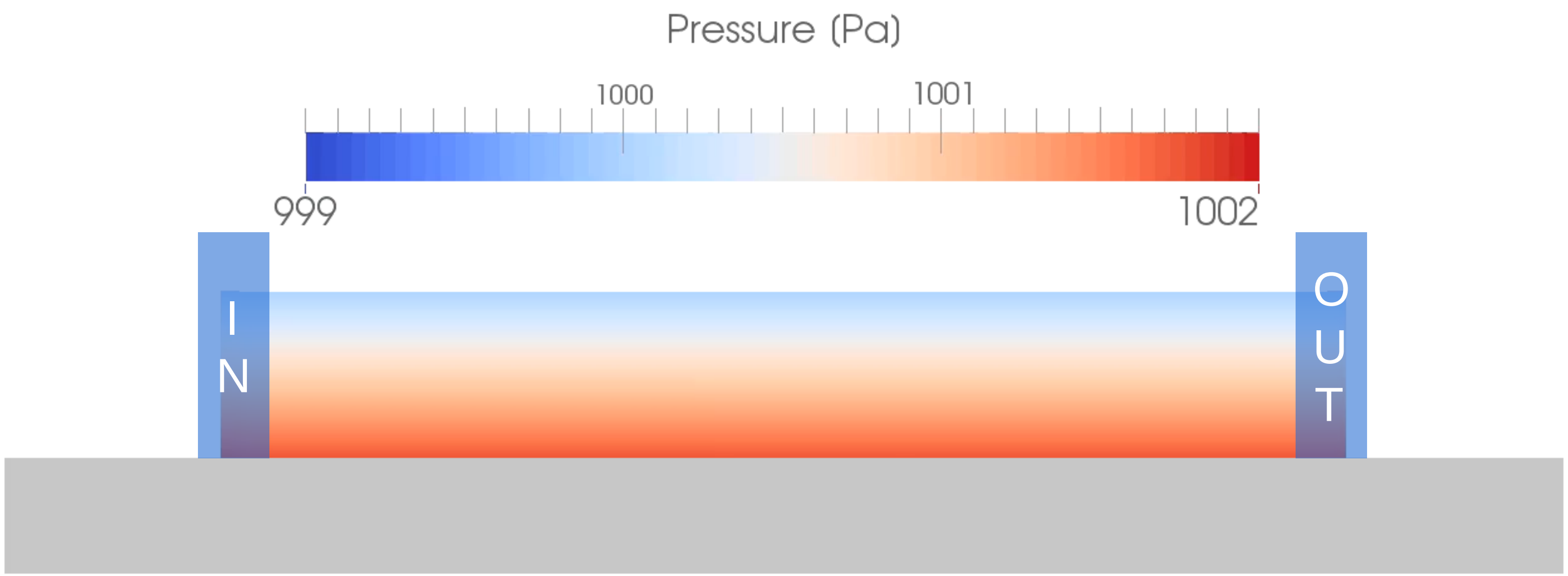
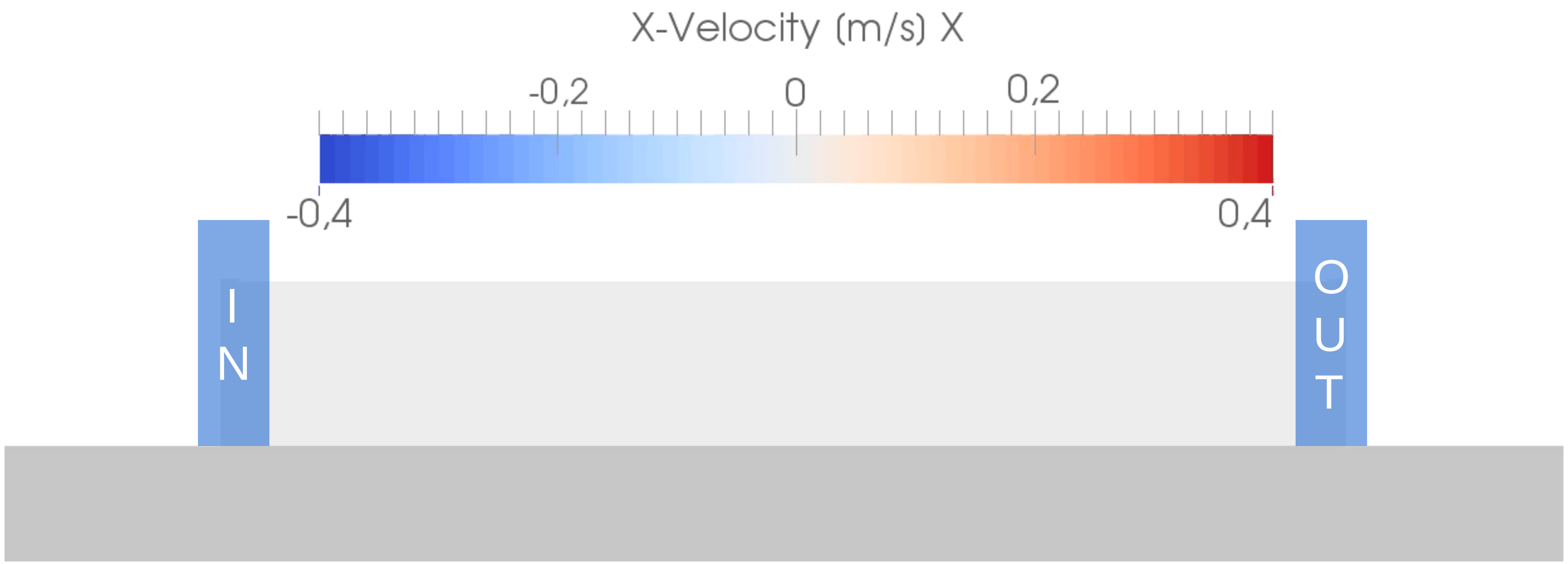
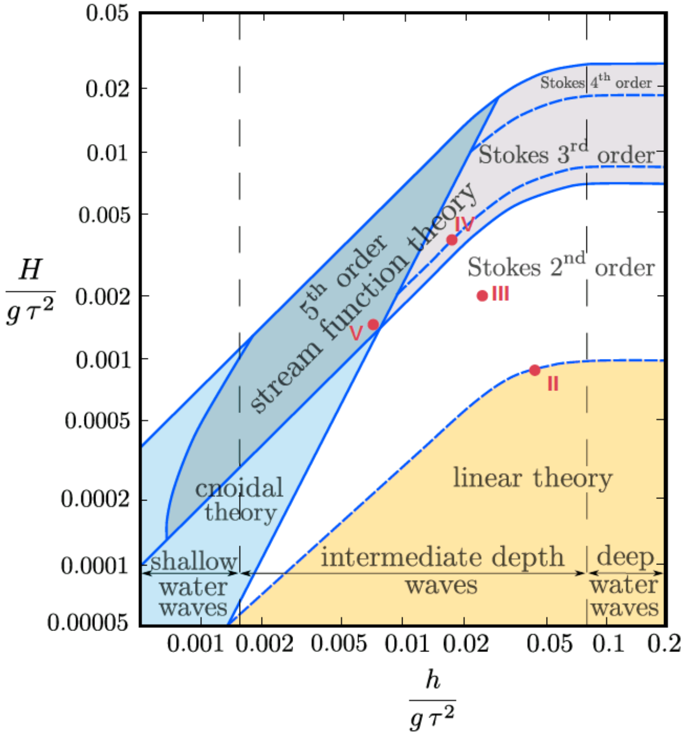
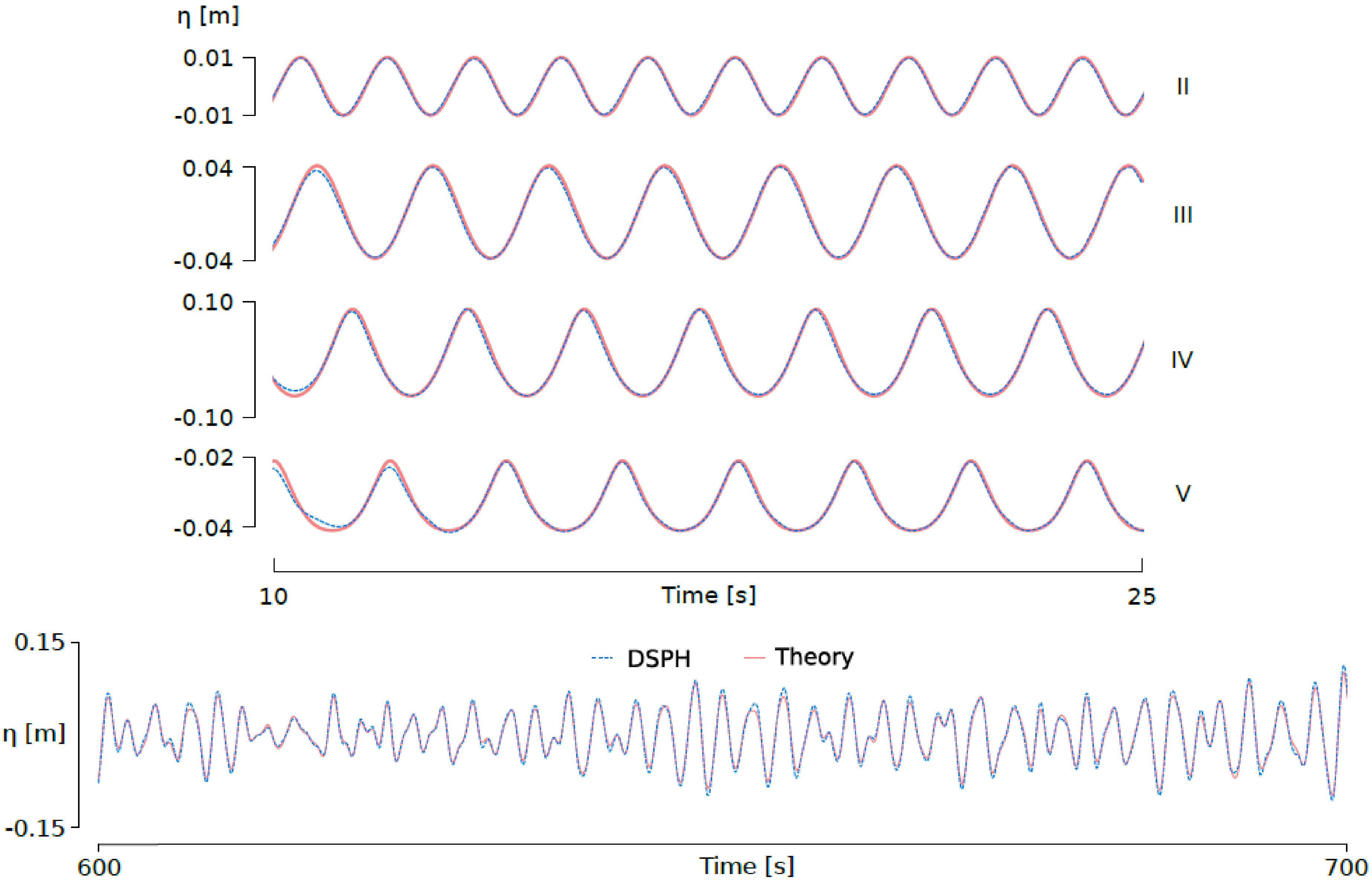

Pressure (Pa)
1000
1001
999
1002
IN
OUT


X-Velocity (m/s) X
-0,2
0
0,2
-0,4
0,4
IN
OUT



Test Number	Wave Theory	Wave Height $H_{(s)}$ [m]	Wave Period $T_{(m)}$ [s]	Water Depth d [m]	Wave Length L [m]	Particle Size d_p [m]
I	Standing	0.15	2.0	0.7	4.62	0.020
II	Linear	0.02	1.5	1.0	3.35	0.0020
III	Stokes 2^{nd}	0.08	2.0	1.0	5.22	0.010
IV	Stokes 3^{rd}	0.15	2.0	0.7	4.62	0.010
V	Stream Function	0.06	2.0	0.3	3.26	0.005
VI	Irregular Wave	0.15	2.0	1.0	/	0.01



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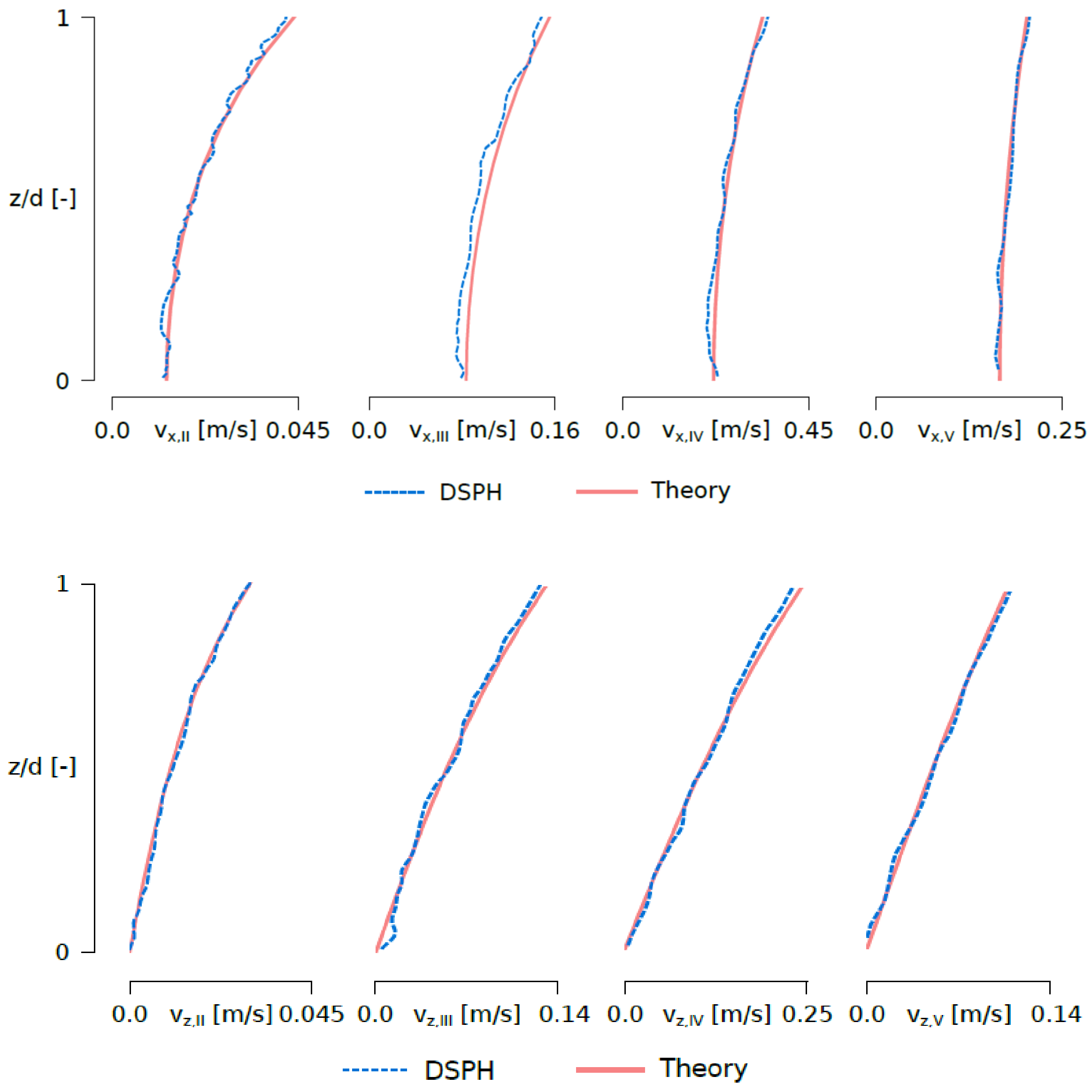
Validation



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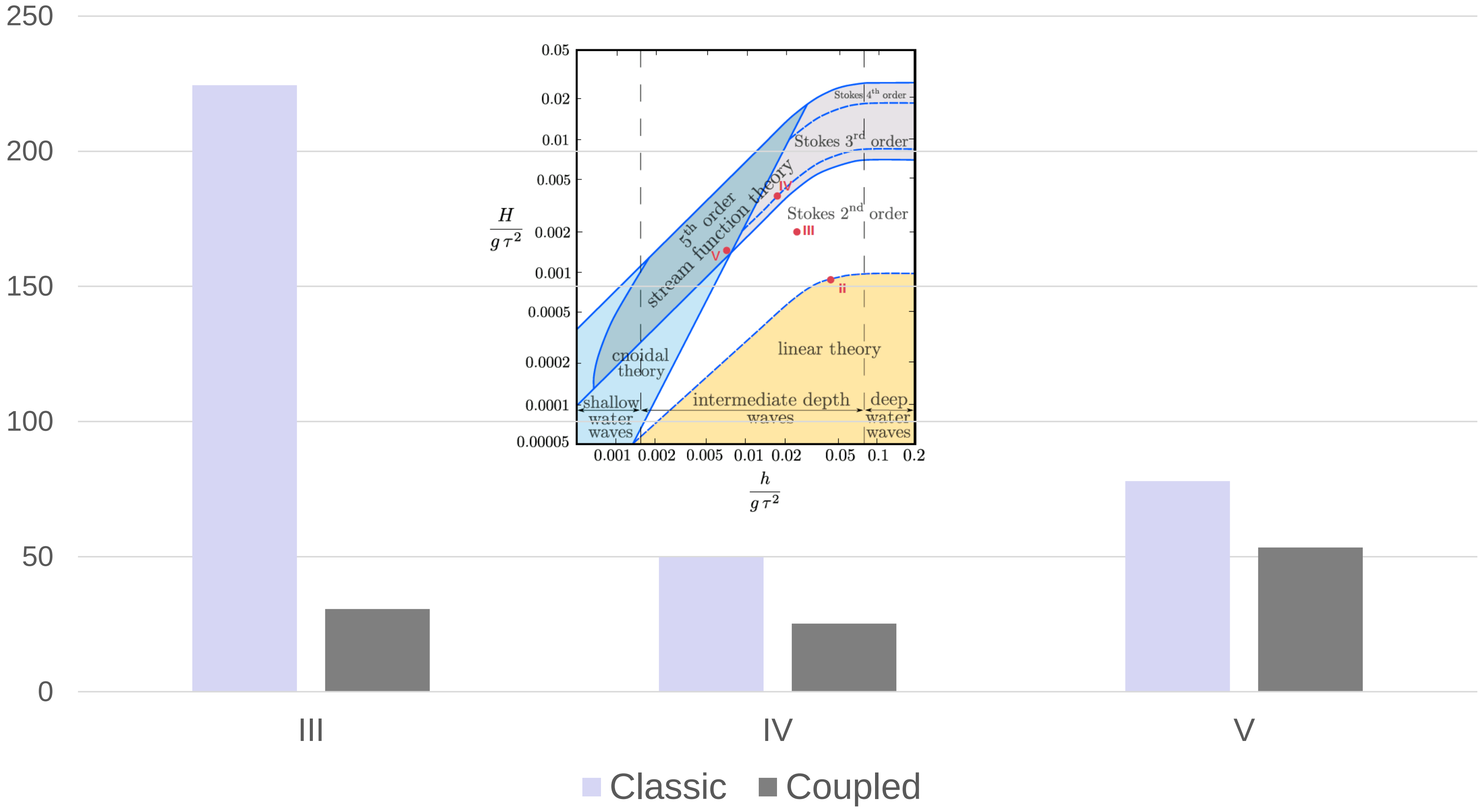
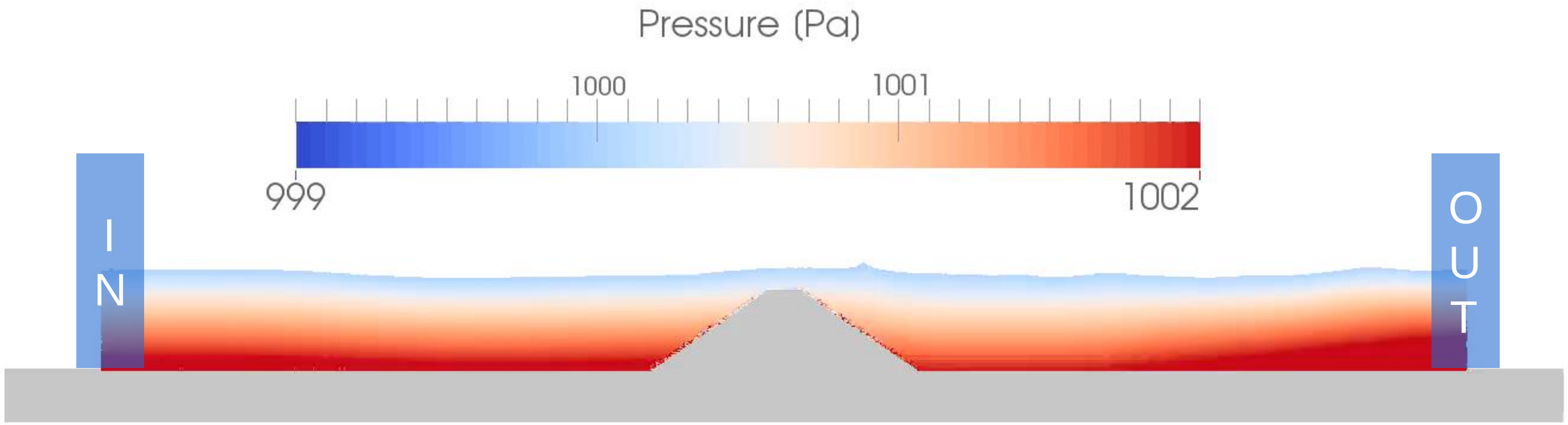
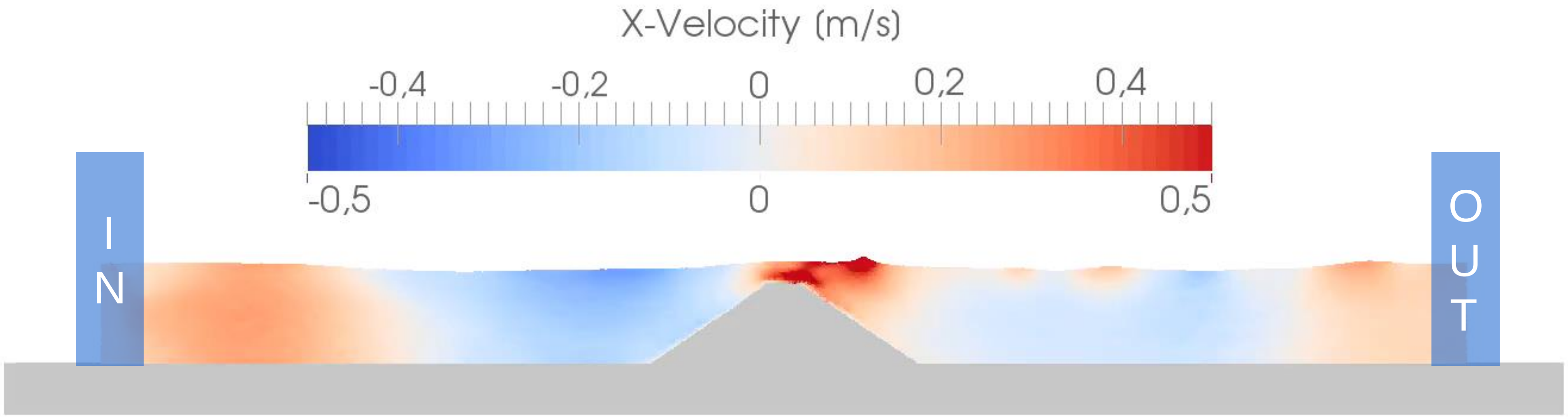
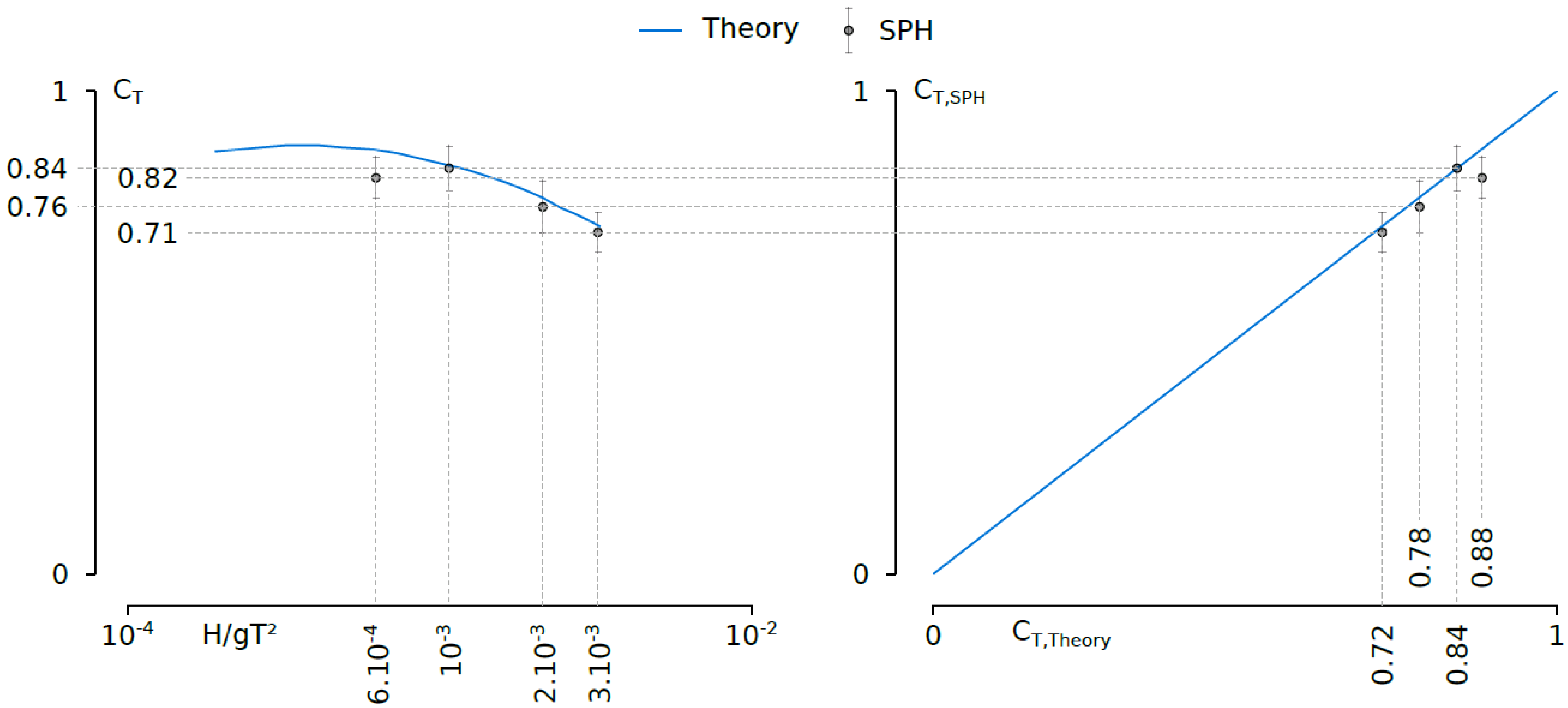
Simulation Time in Minutes

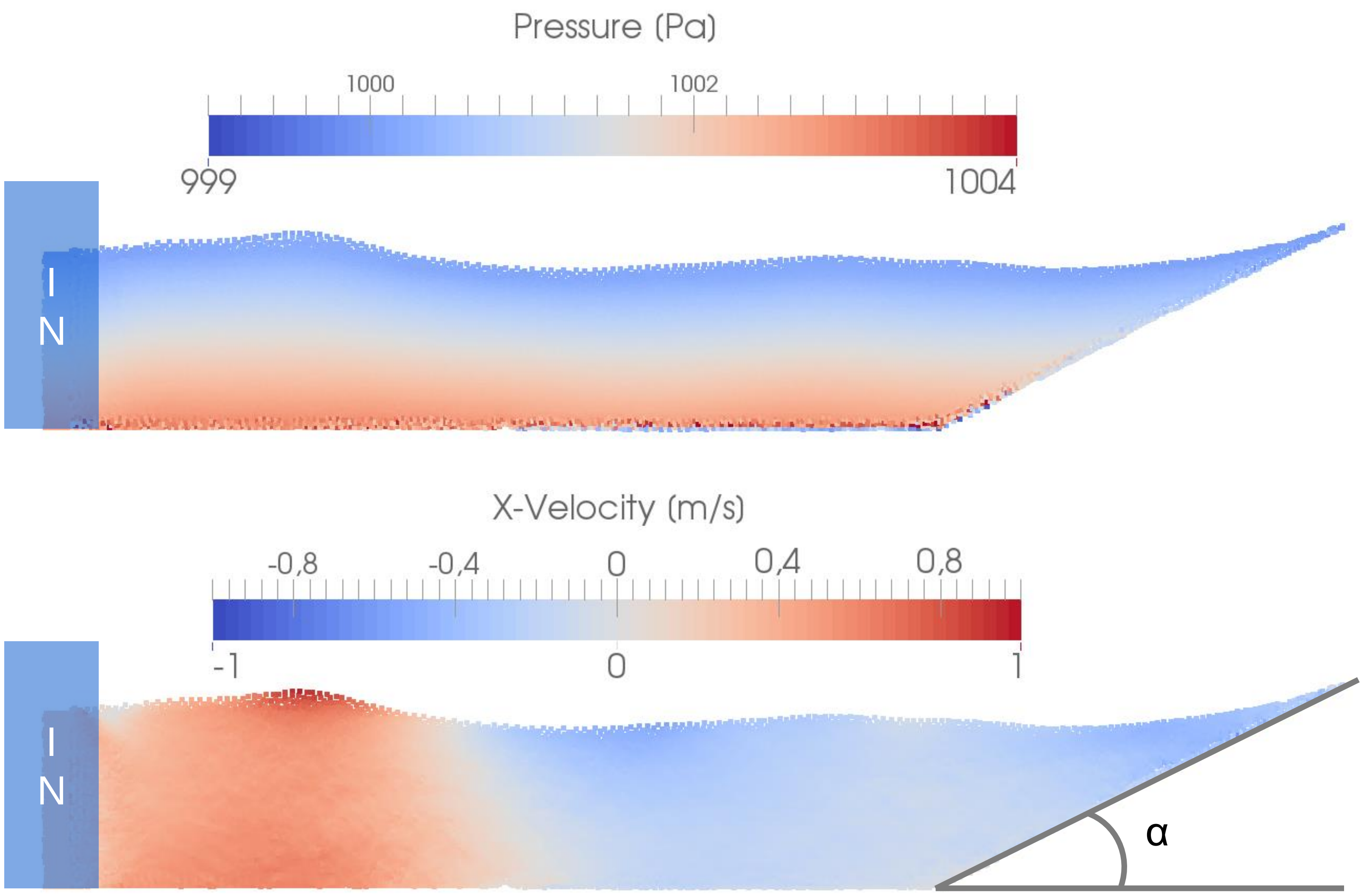


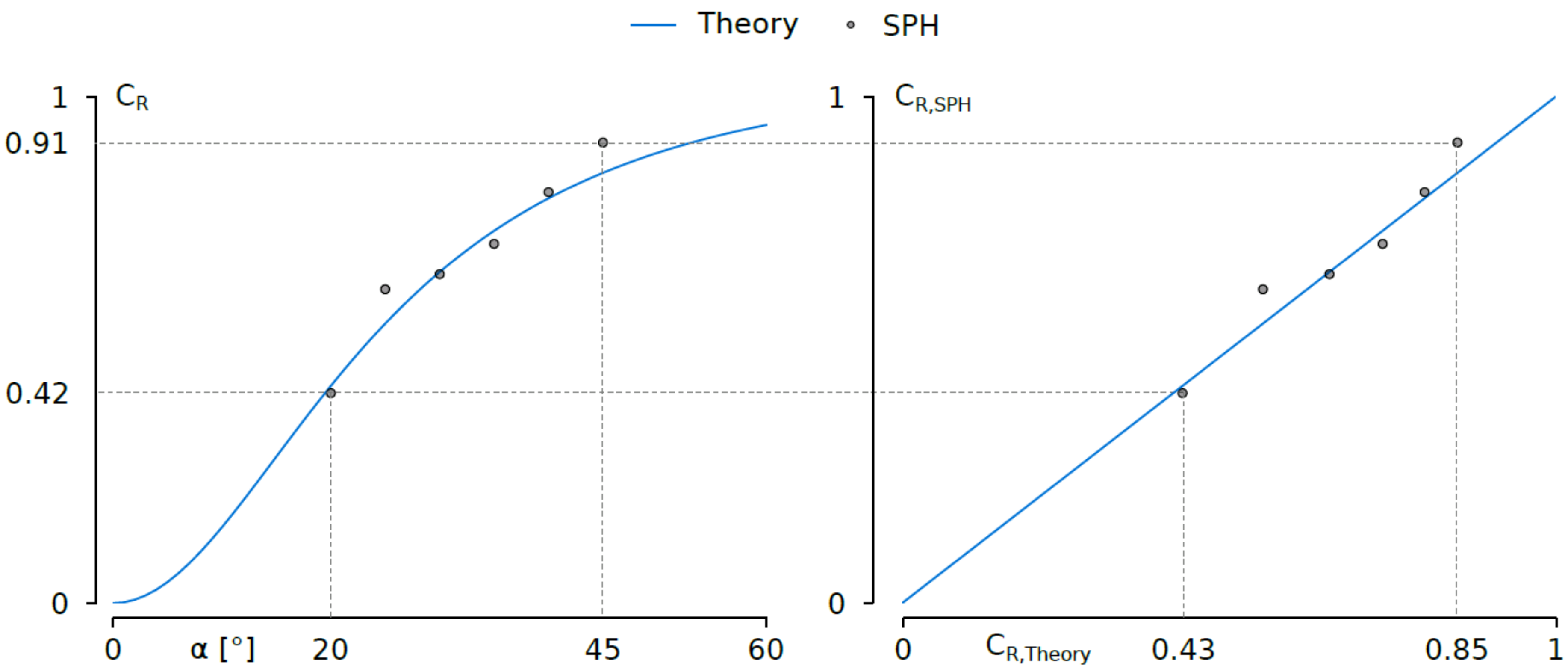

Pressure (Pa)
1000
1001
999
1002
IN
OUT


X-Velocity (m/s)
-0,4
-0,2
0
0,2
0,4
-0,5
0
0,5
IN
OUT



Seelig, W. N., 1980. Estimation of wave transmission coefficients for overtopping of impermeable breakwaters. Tech. rep., COASTAL ENGINEERING RESEARCH CENTER FORT BELVOIR VA.


Pressure (Pa)
1000
1002
999
1004
IN
X-Velocity (m/s)
-0,8
-0,4
0
0,4
0,8
-1
0
1
IN
α



Seelig, W., 1983. average reflection from coastal structures. Proceedings of coastal structures 1983 Conference. Arlington, USA, ASCE, New York, pp. 961-973.

CONCLUSIONS

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- Open boundaries are ideal for accurate wave generation/propagation/absorption
- 2-way coupling is applied to calculate velocity corrections
- 2-way coupling with fast wave propagation models is possible
- Both socket client-server protocol as well as MPI protocol can be used for communication

FUTURE WORK

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Wave Theory
OceanWave3D
OPEN MPI
External Data
python
cpu
gpu
DualSPHysics
Open MPI
Socket
Client-Server

3D Validation of Heaving Cylinder with overtopping