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HYDRODYNAMICS LABORATORY

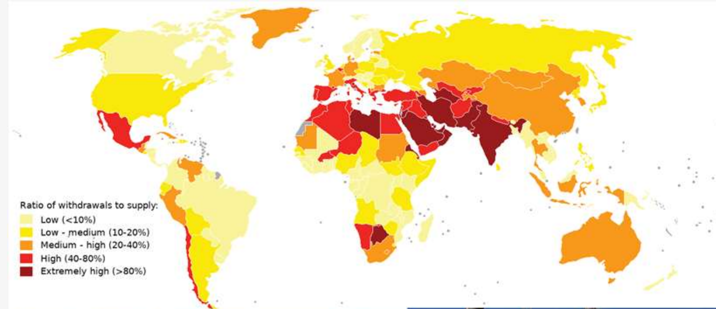
Experimental validation of wave models

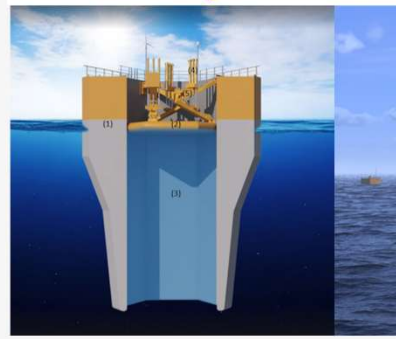
Øystein Lande, Atle Jensen, Thomas B. Johannessen

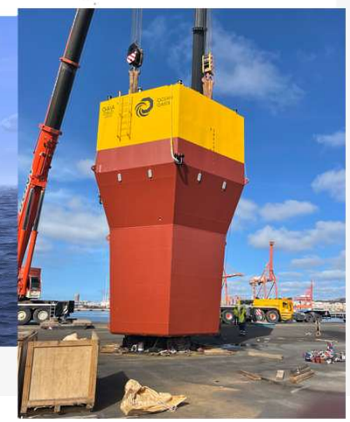
Using wave energy to produce freshwater from the ocean

- Ocean Oasis AS established early 2020
- Wave-powered desalination concept
- Business concept: Build, own and operate to sell water on long-term contracts

Kummu et al."The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability"







Main investors:

GRIEG MARITIME GROUP
ANTLER
UV UNCONVENTIONAL VENTURES
FARVATN venture

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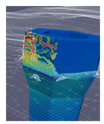
esa
Unión Europea
ICEX
INVEST IN SPAIN
European Innovation Council
Co-funded by the European Union
Cabildo de Gran Canaria
spegc
IMAGINE H2O
The Research Council of Norway

Industrial PhD project

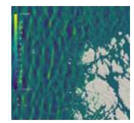
Project title: Computational Fluid Dynamics applied to wave energy extraction in a coastal environment

Funded by Norwegian Research Council & Ocean Oasis AS

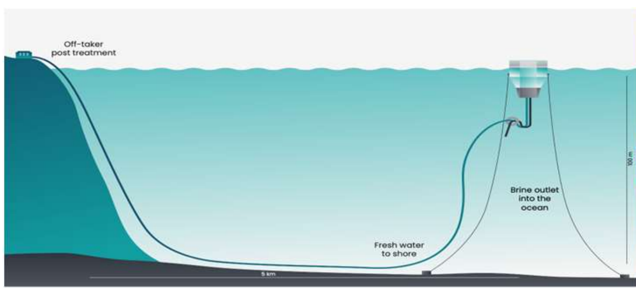
University of Oslo (UiO)

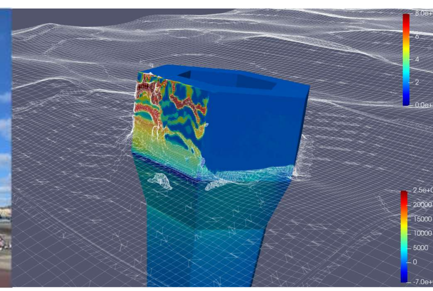


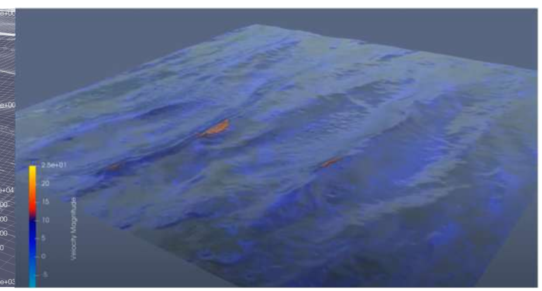
WP 1:
Fluid-structure-interaction



WP 2:
Coastal wave modelling

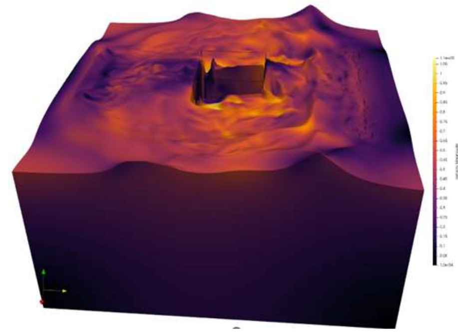




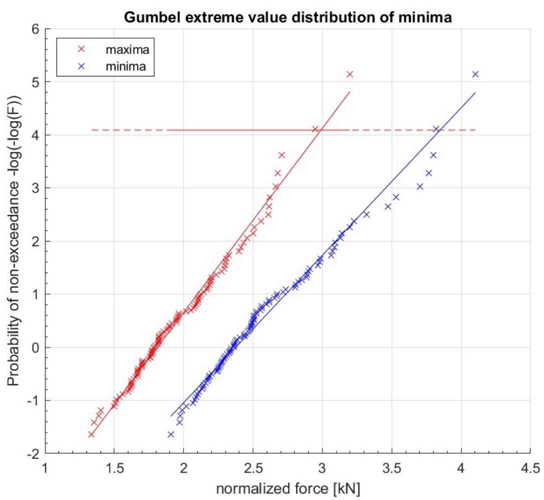


Example1: Near shore coastal wave modelling

Obstacles can be modelled:



- Nonhydrostatic multilayer vertical-Lagrangian solver (Popinet 2020), http://basilisk.fr/src/layered/nh.h
- Efficient -> extract kinematics statistics



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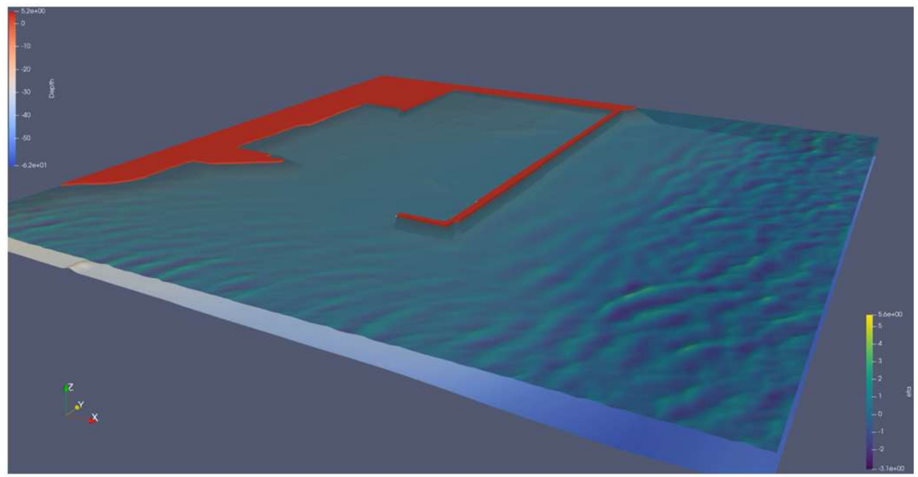
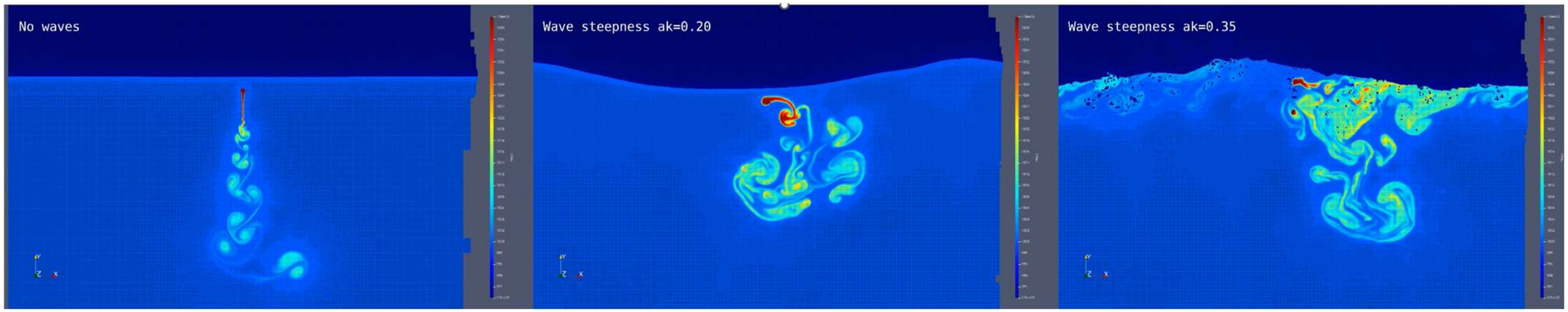


Example2: Brine dispersion

- Brine (water with high salt content)
  - biproduct of desalination
  - Hazard for the environment in high concentration
- Dispersion critical for environment

Basilisk VoF Navier Stokes solver

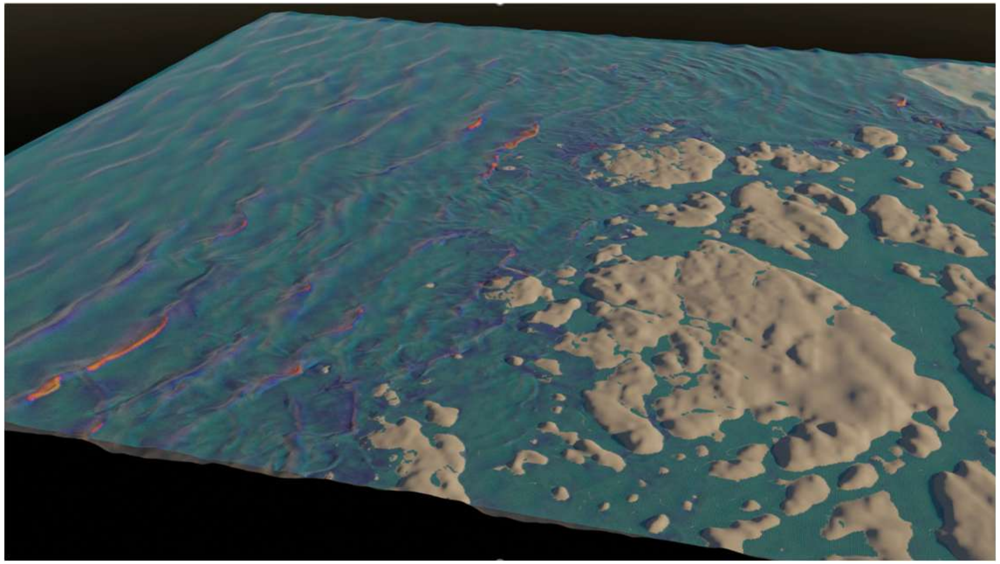


Wave model requirements:

- Dispersion – inhomogeneous conditions, deep -> shallow water
- Reflection, diffraction
- breaking, overtopping?
- Energy dissipation
  (post breaking)

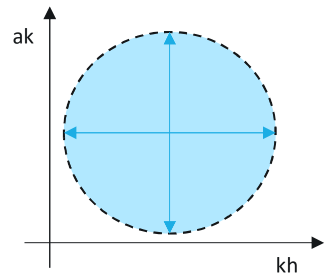
- Validation is needed

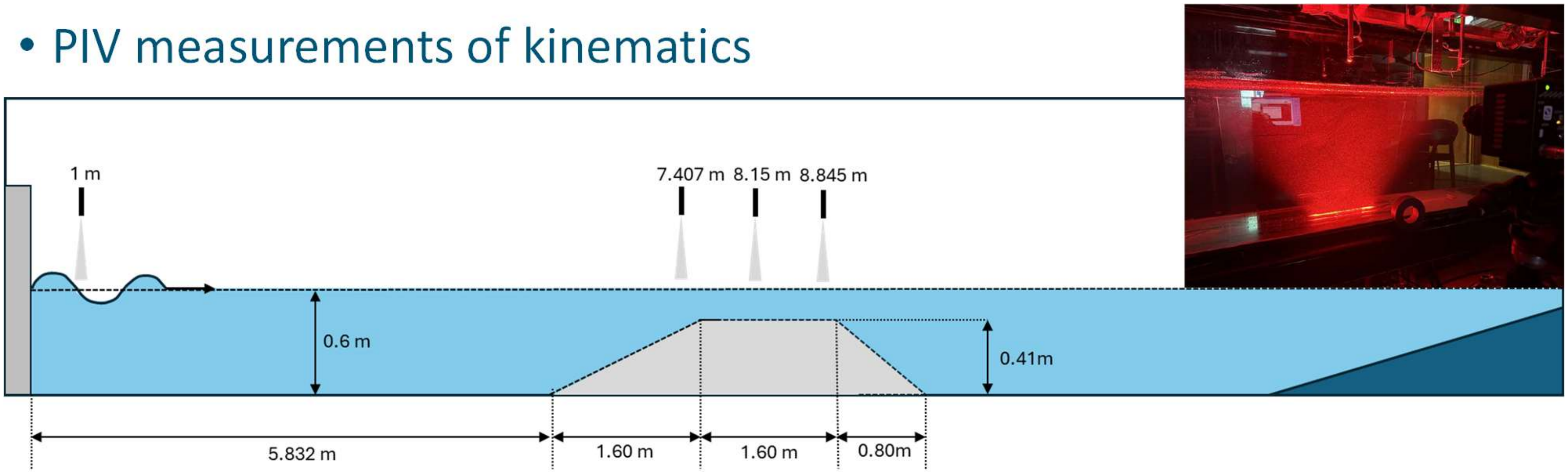
Basilisk multilayer solver (http://basilisk.fr)



Validation project - Experimental setup

- Dispersive waves over constant and variable depth
- Cover a broad range of steepness and water depth
- 4 acoustic wave gauges
- PIV measurements of kinematics





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Benchmark set of 8 focused waves

$$\eta(x,t) = \sum_{i=1}^{N} a_i cos\left(k_i(x - x_f) - \omega_i(t - t_f)\right)$$

- Amplitude spectrum definition as (Baldock 1996 & Johannessen 1997)

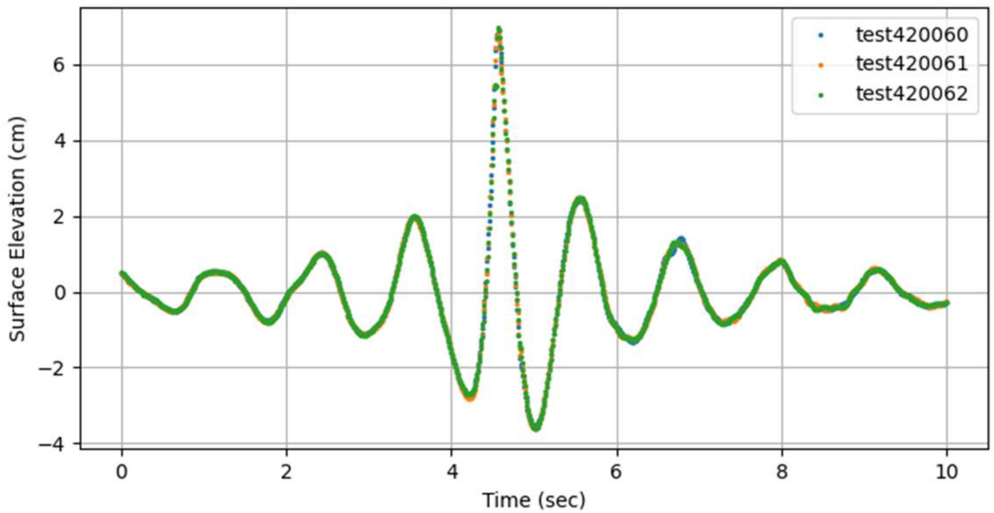
$$a_i = A_{targ}\frac{\omega_i^{-2}}{\sum_j \omega_j^{-2}} \qquad \omega_i = \frac{2\pi}{64}i \qquad \text{where } i = 46 - 106$$

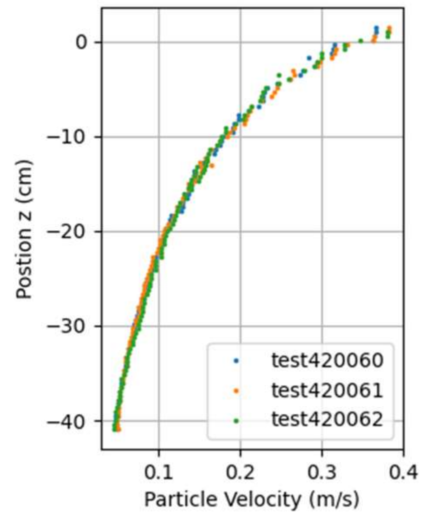
ID	RUNID	Depth	Linear focus point	Linear Steepness ak	Description	PIV
Wave1	C01A07F01	0.6	8.1	0.04	linear	no
Wave2	C01A25F01	0.6	8.1	0.16	nonlinear	yes
Wave3	C01A45F01	0.6	8.1	0.29	at the point of spilling	yes
Wave4	C01A65F02	0.6	7.1	0.41	breaking	yes
Wave5	C02A07F01	0.19-0.6	8.1	0.04	linear	no
Wave6	C02A25F01	0.19-0.6	8.1	0.16	nonlinear	no
Wave7	C02A45F01	0.19-0.6	8.1	0.29	breaking	no
Wave8	C02A65F02	0.19-0.6	7.1	0.41	breaking	no

- Record wave paddle position

Repeatability

- 3 repetitions of each condition
- Good repeatability -> focused waves

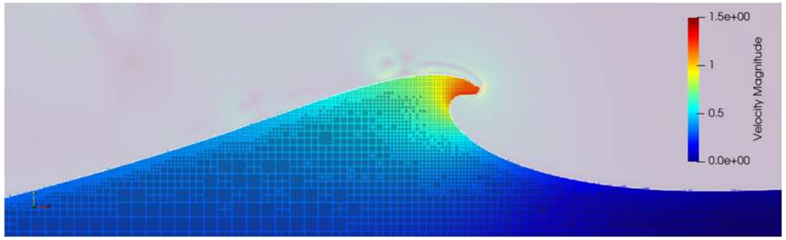




Deterministic recreation

1. VoFAMR wave model

- src/navier-stokes/centered.h
- 2D simulation, 25m long basin
- Maxlevel basecase : lvl 14
- Cost: high, speed: slow



http://basilisk.fr/src/navier-stokes/centered.h

2. Linear wave theory (reference case)

- Low-end wave model
- No breaking or nonlinear effect
- Cost: neglectable, speed: instant

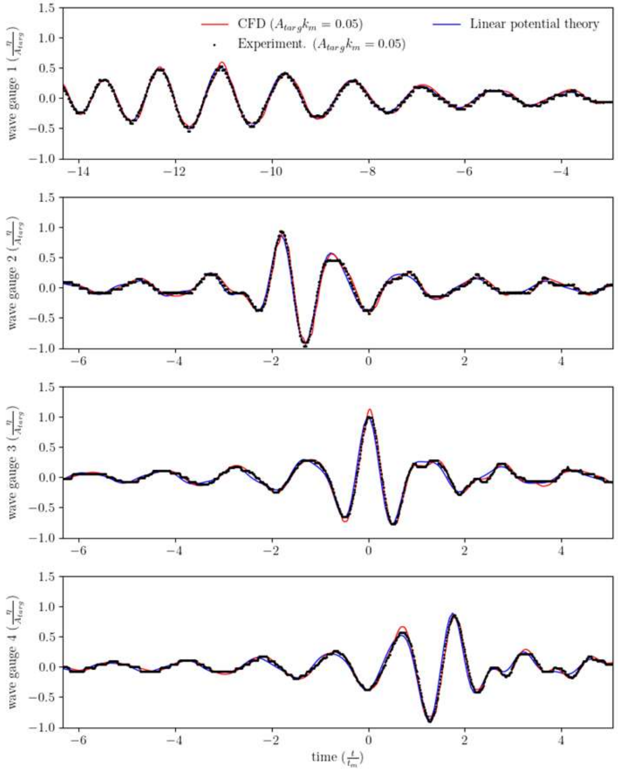
3. Non-hydrostatic multilayer model

- 2D simulation nx: 16384, nl: 44
- Theta_h: 0.5

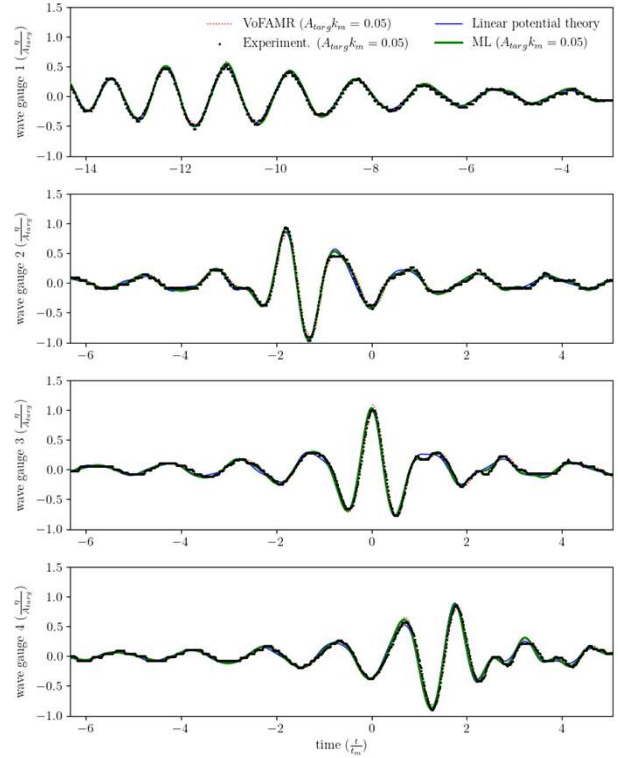
Wave paddle velocity used at the inflow boundary – no tuning!

Wave 1 linear wave

Surface elevation - VoFAMR

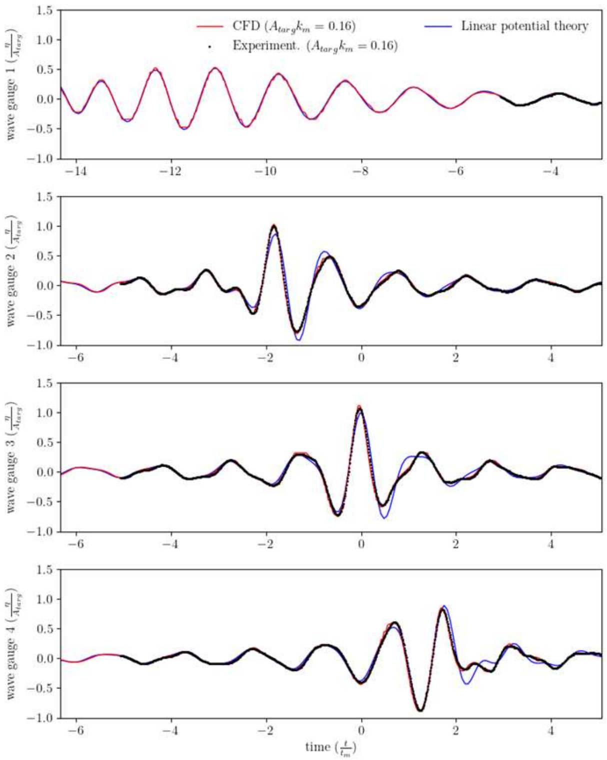


Surface elevation – NHmultilayer

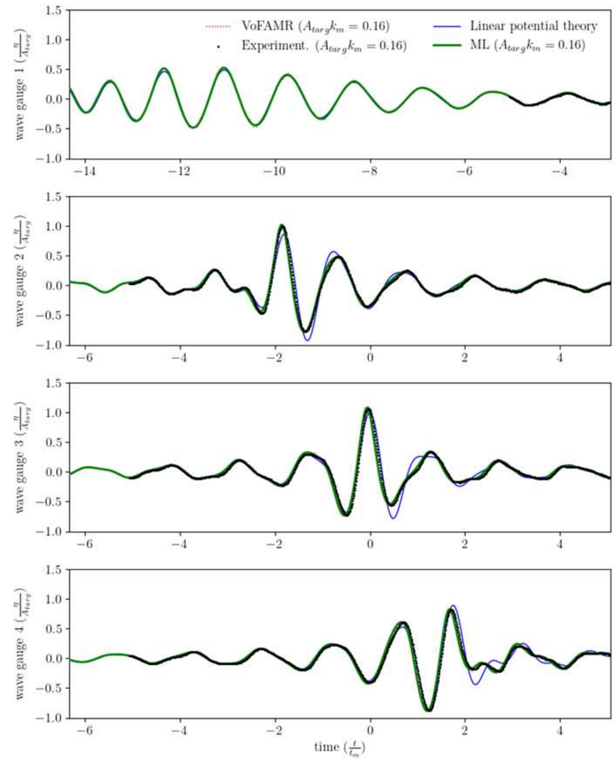


Wave 2 Non linear, non breaking

Surface elevation - VoFAMR

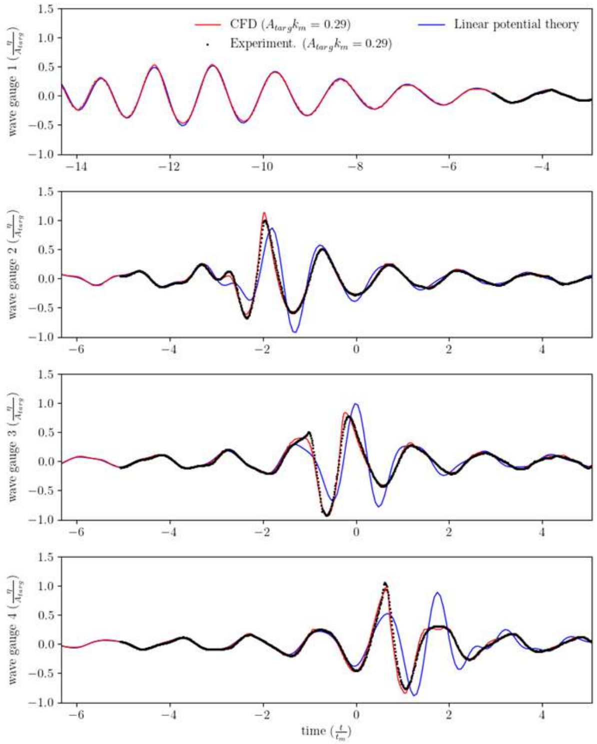


Surface elevation – NHmultilayer

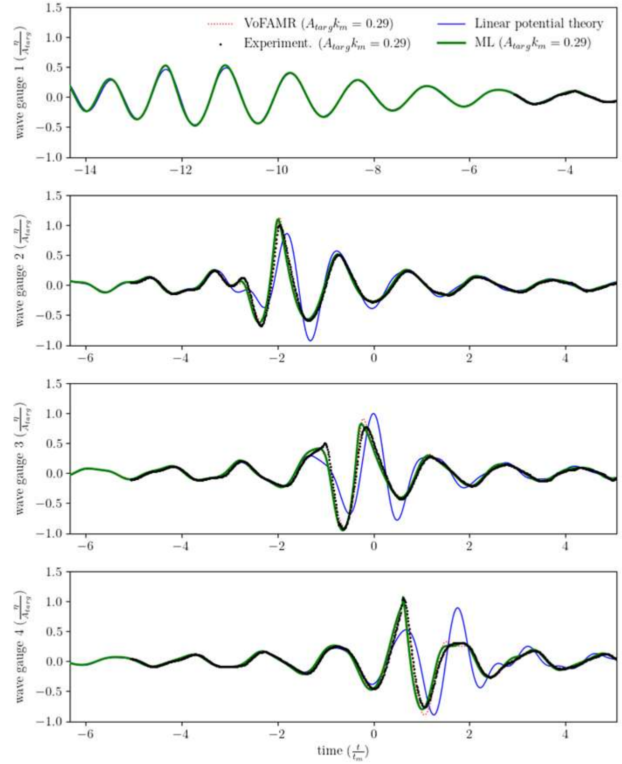


Wave 3 - At the limit of spilling

Surface elevation - VoFAMR

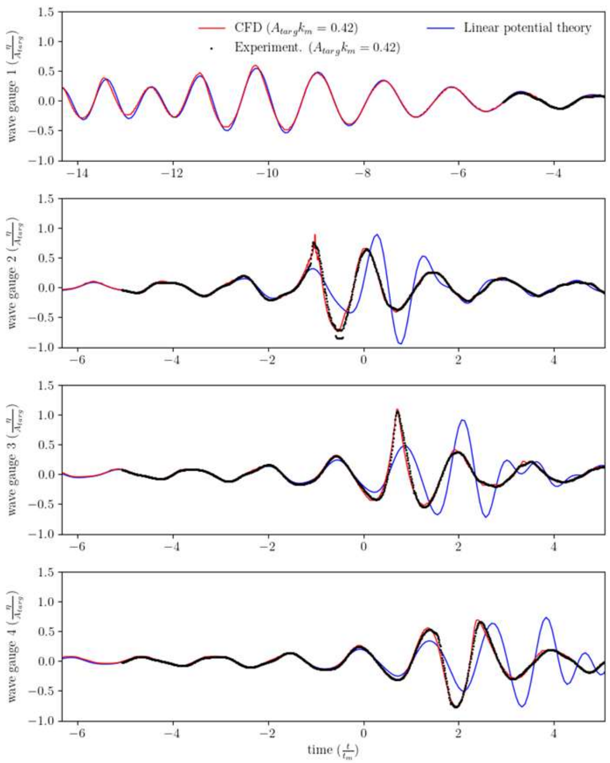


Surface elevation – NHmultilayer

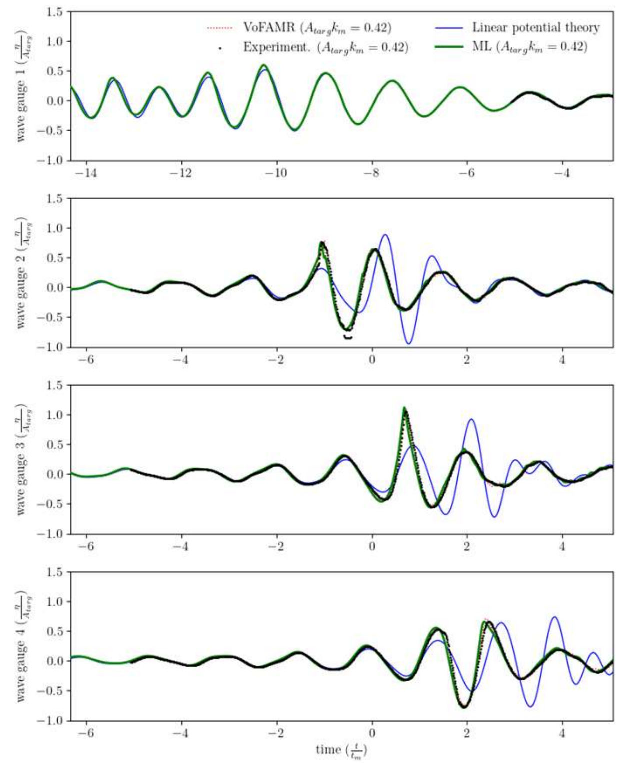


Wave 4 – Breaking (severely)

Surface elevation - VoFAMR

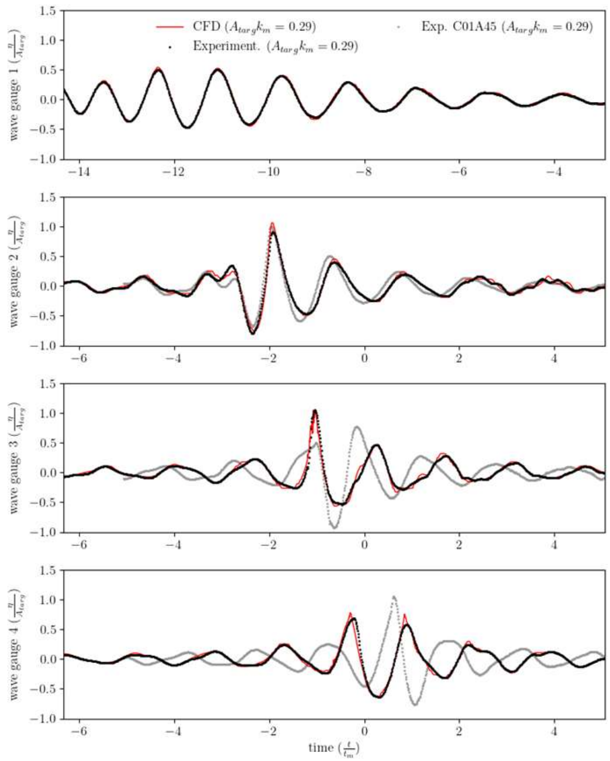


Surface elevation – NHmultilayer

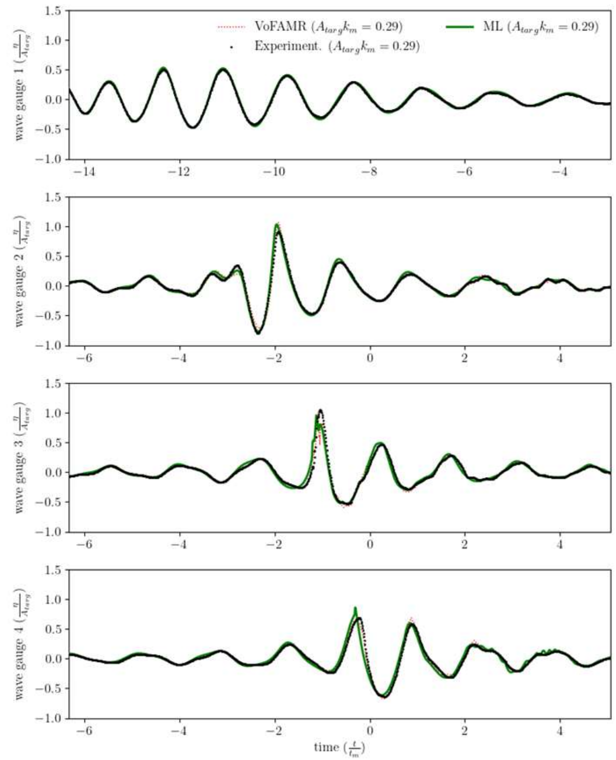


Wave 7 – breaking (over a shoal)

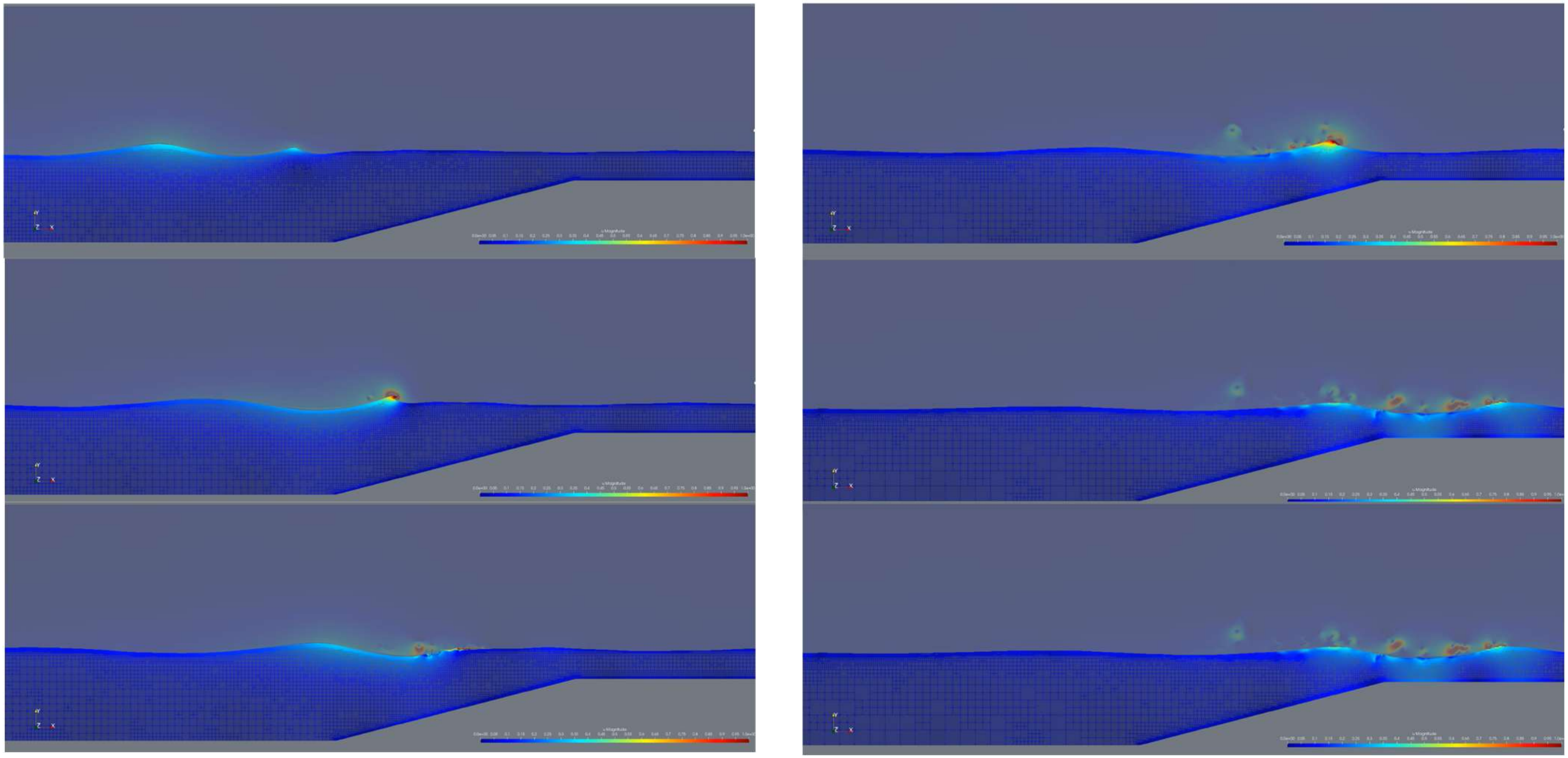
Surface elevation - VoFAMR



Surface elevation – NHmultilayer



Wave 7 - simulation



Wave 8 – Breaking (over a shoal)

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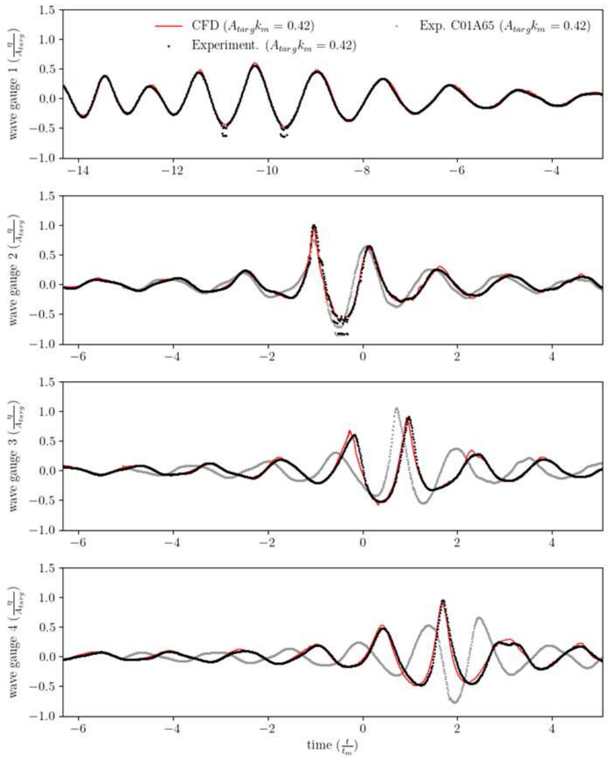
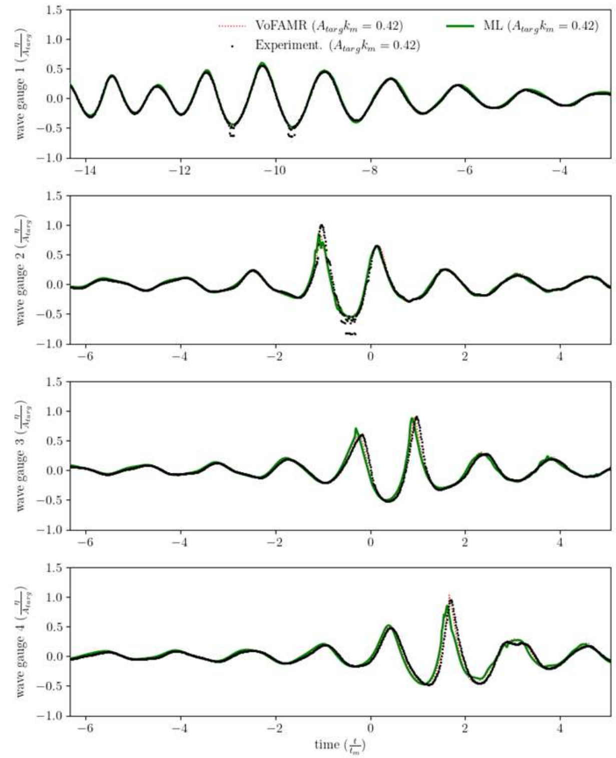
Surface elevation - VoFAMR



Surface elevation – NHmultilayer



Benchmark

Weighted least square error of surface elevation

$$\varepsilon = \sum_{i=1}^{N} w_i(\eta_i^{exp} - \eta_i^{model})^2$$

Level of refinement	Basin length [m]	smallest cell size [mm]	cells pr mean wavelength
12	25	6.10	161
13	25	3.05	321
14	25	1.53	642
15	25	0.76	1285

Wave gauge 3

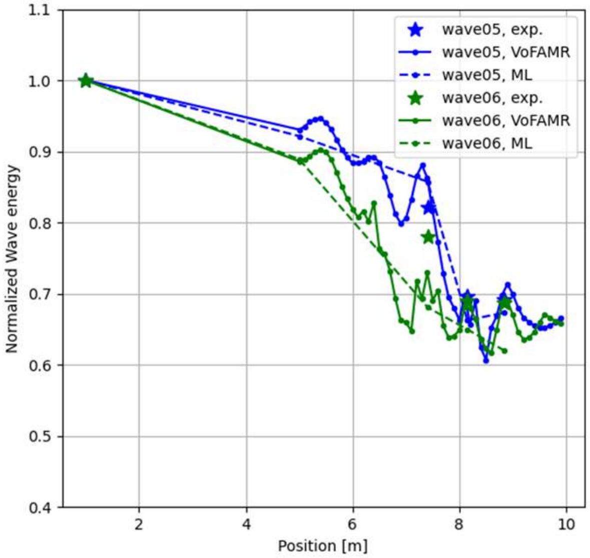
ID	ID	Description	gauge3 (x=8.15m)					
			Navier-stokes/centered				Linear waves	Multilayer
			Level 15	Level 14	Level 13	Level 12		16384 (lvl14 eq)
Wave01	C01A07F01	linear	0.205051	0.2159	0.263868	2.081042	0.4528	0.3171
Wave02	C01A25F01	nonlinear	0.10787	0.1158	0.118696	0.139915	1.2430	0.8212
Wave03	C01A45F01	spilling (marginally	0.601825	0.5669	0.589352	0.660804	10.9006	0.9681
Wave04	C01A65F02	breaking (severly)	0.302018	0.2578	0.283181	0.209404	14.0966	0.8819
Wave05	C02A07F01	linear	0.579656	0.5307	0.407946	1.504514		0.4529
Wave06	C02A25F01	nonlinear	0.481379	0.5273	0.545321	0.486363		0.3794
Wave07	C02A45F01	breaking	1.58309	0.5117	0.880954	0.619378		1.2595
Wave08	C02A65F02	breaking (severly)	0.7053	0.8472	0.957785	1.488423		2.5057

Wave gauge 4

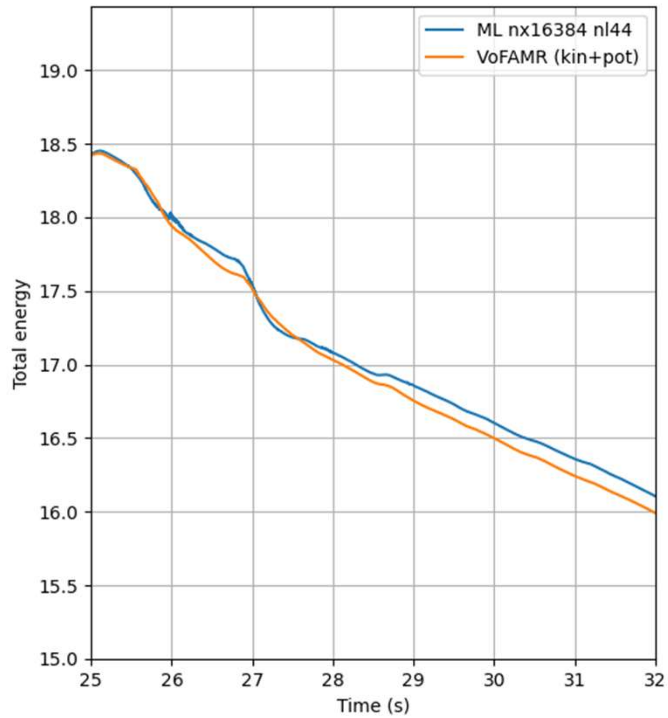
ID	ID	Description	gauge4 (x=8.845m)					
			Navier-stokes/centered				Linear waves	Multilayer
			Level 15	Level 14	Level 13	Level 12		16384 (lvl14 eq)
Wave01	C01A07F01	linear	0.20711	0.2193	0.300228	1.521317	0.5227	0.4544
Wave02	C01A25F01	nonlinear	0.126783	0.1376	0.148996	0.183235	0.9684	0.8023
Wave03	C01A45F01	spilling (marginally	0.463103	0.5157	0.455876	0.465116	11.7451	1.4311
Wave04	C01A65F02	breaking (severly)	0.283105	0.3105	0.297538	0.253901	12.0169	0.5890
Wave05	C02A07F01	linear	0.452143	0.4227	0.335138	1.382911		0.3033
Wave06	C02A25F01	nonlinear	0.389056	0.4266	0.443883	0.444154		0.3426
Wave07	C02A45F01	breaking	0.333126	0.5945	0.64826	0.752927		1.3300
Wave08	C02A65F02	breaking (severly)	0.409504	0.4181	0.657991	0.893044		2.9256

Energy assessment

Potential wave energy comparison
(integrated sq(eta))



Integrated total energy of wave flume (models only)



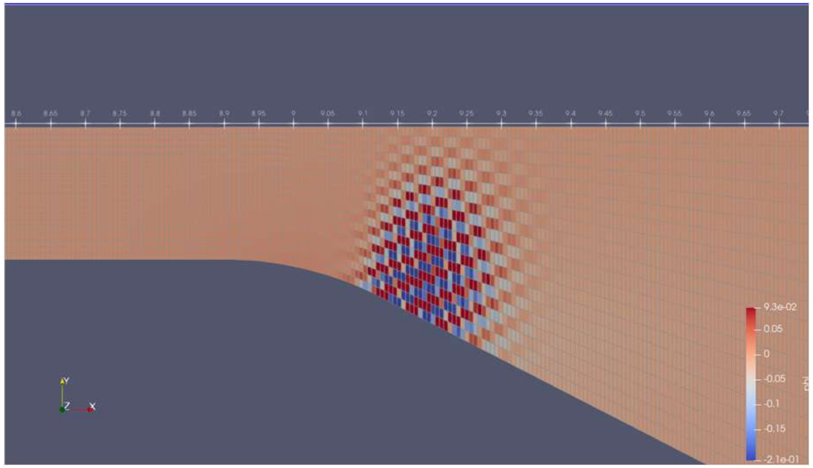
Summary & conclusion

- Wave experiment carried out with purpose of validating numerical wave models
  - Linear -> nonlinear -> breaking
  - Constant and variable water depth
  - Dataset will be published open access
- Multilayer model capable of reproducing wave events almost as good as the navier-stokes/centered solver

Not only a sunshine story…

- Challenge with stability of ML model in cases of variable bathymetry and steep waves
- Can be suppressed by
  - Increasing theta_h
  - local spatial filtration (inspired by Engquist. Et al. 1989)

  (Not ideal solutions….)



- Contact: oystein@oceanoasis.co