

REEF3D : Open-Source Hydrodynamics

Multi-Scale Wave Propagation Modeling for the Norwegian Coast

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Motivation for Wave Modeling



Hirtshals Harbour: Breakwater



Venice Flood Gates: Sea Level Rise



Scheveningen Pier: Local Scour

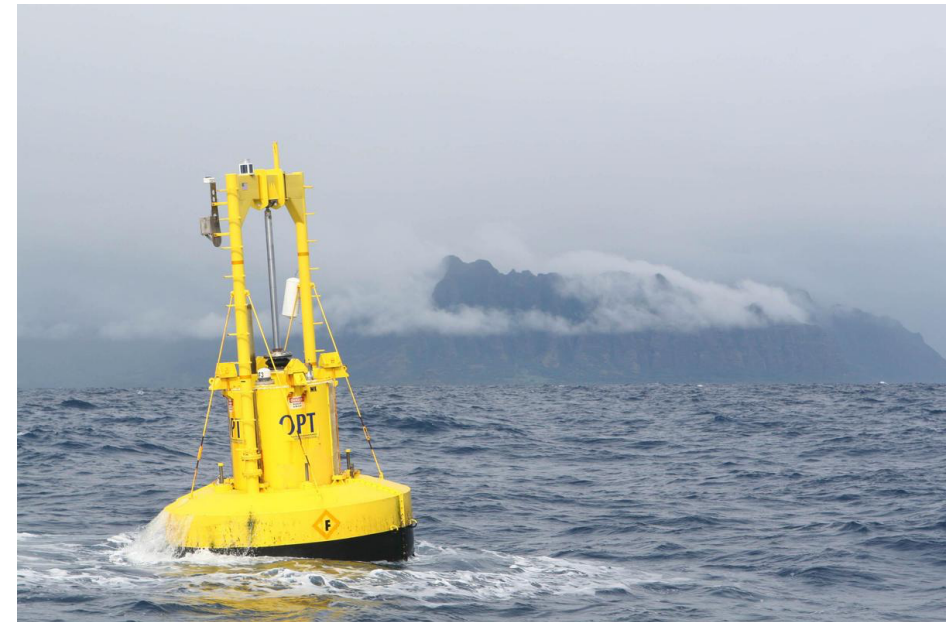


North Sea: Coastal Dynamics

Motivation for Wave Modeling



Offshore Wind Energy: Wave Force, Local Scour



Ocean Wave Energy: Wave Climate, Wave Forces



Offshore Structures: Wave Force, Green Water



Offshore Structures: Floating, Mooring, Ice

Motivation for Wave Modeling



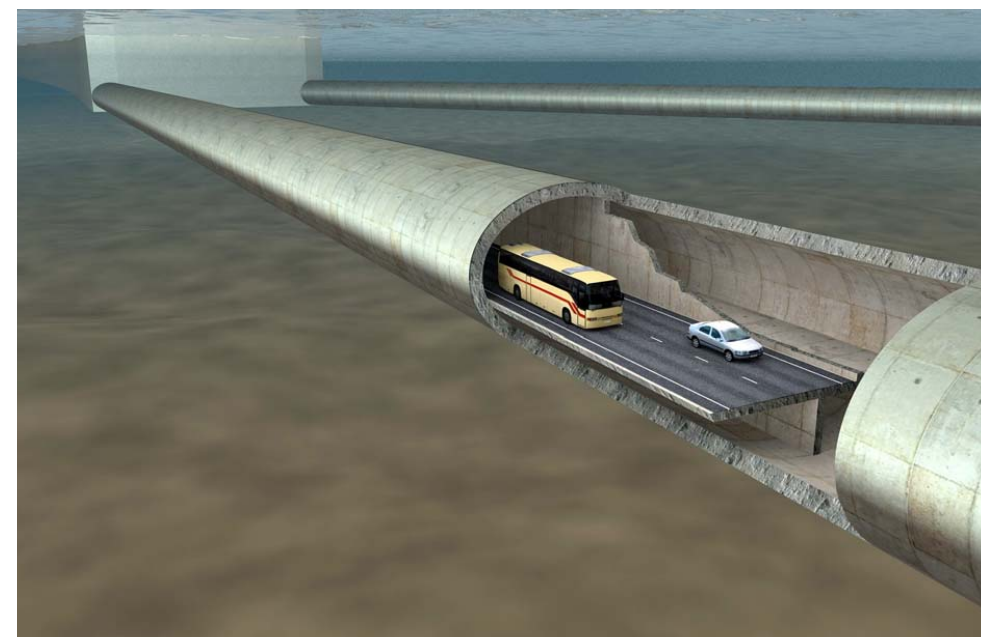
Aquacultures: Floating, Mooring, Forces, Health



Coastal Transportation Infrastructure

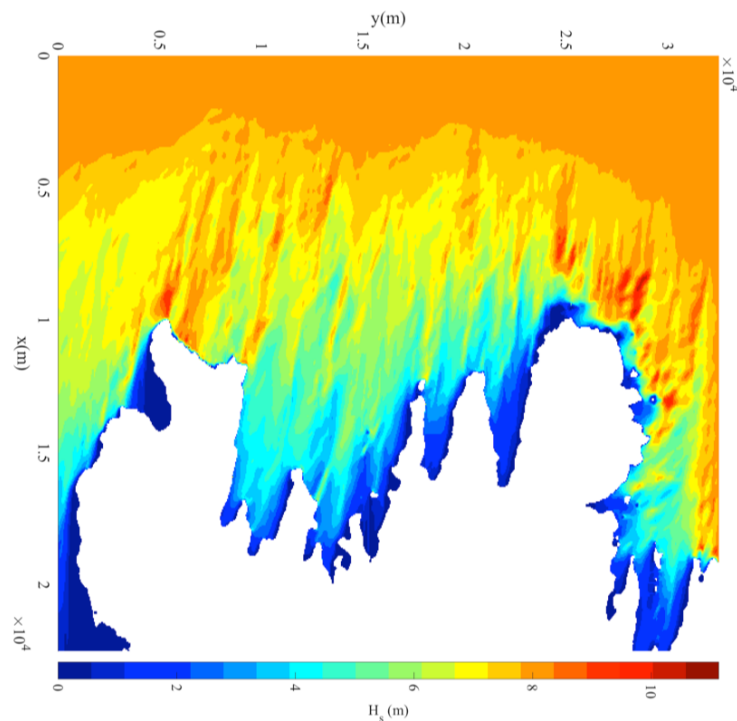


E39: Floating Bridges



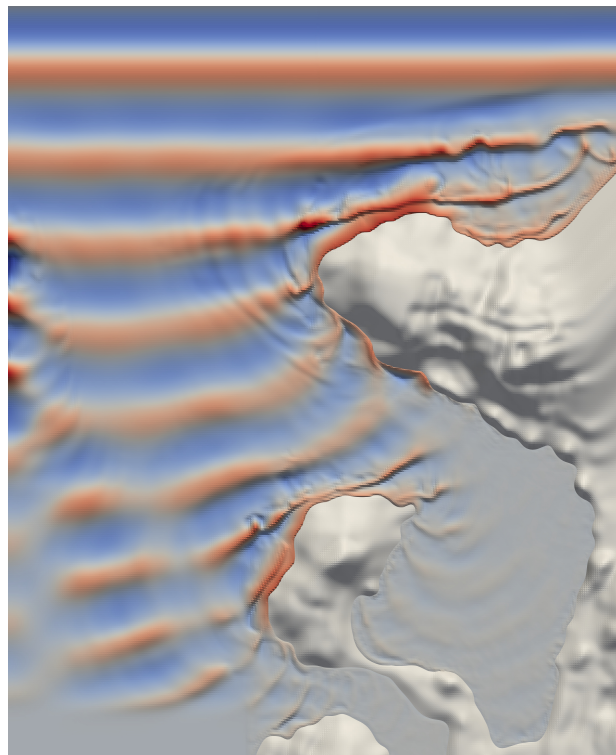
E39: Floating Tunnels

Waves on different scales



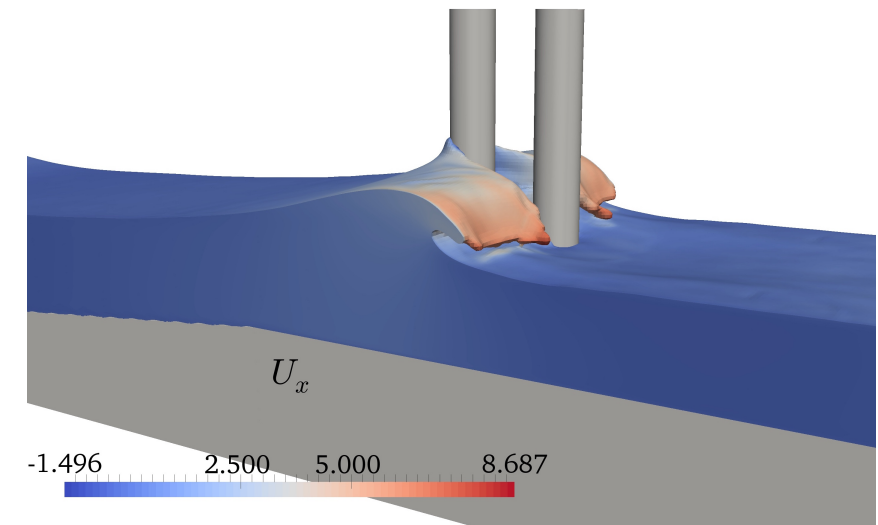
Spectral Wave Model

- Large Scale
- Phase-averaged
- e.g. SWAN



Large Scale Phase Resolved

- Large Scale
- Phase-resolving
- adapted for Norwegian Condition
- REEF3D::SFLOW
- REEF3D::FNPF
- REEF3D::NSEWAVE



Numerical Wave Tank

- Near-field
- Flow resolving
- REEF3D::CFD

REEF3D : Open-Source Hydrodynamics

Resolution ↑ high low	Model	Dimensions	Turbulence	Br. Waves	Speed ↓ low high
	REEF3D : CFD	3D	yes	yes	
	REEF3D : NSEWAVE	3D	yes	no	
	REEF3D : FNPF	3D	no	no	
	REEF3D : SFLOW	2D	yes	no	

REEF3D::CFD

- **Solves:**

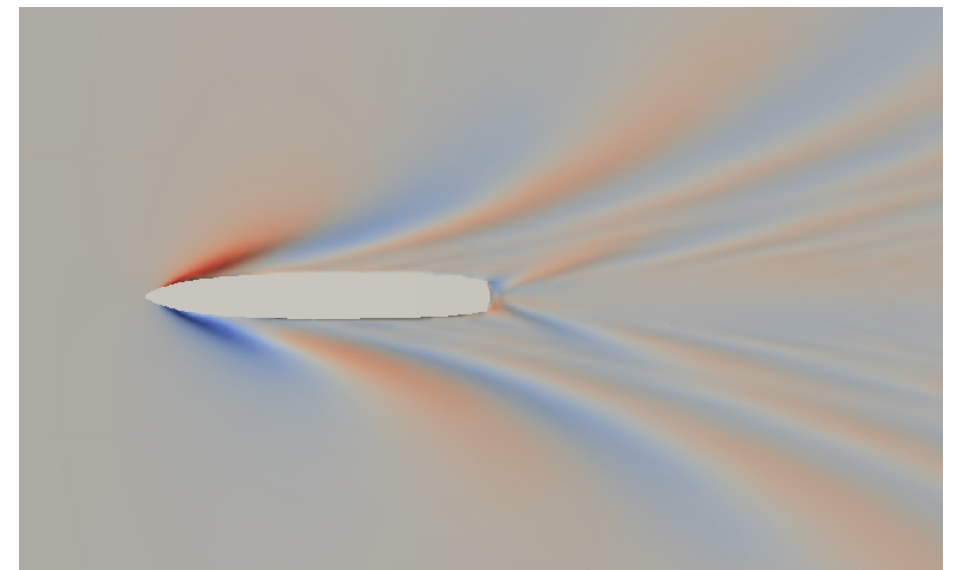
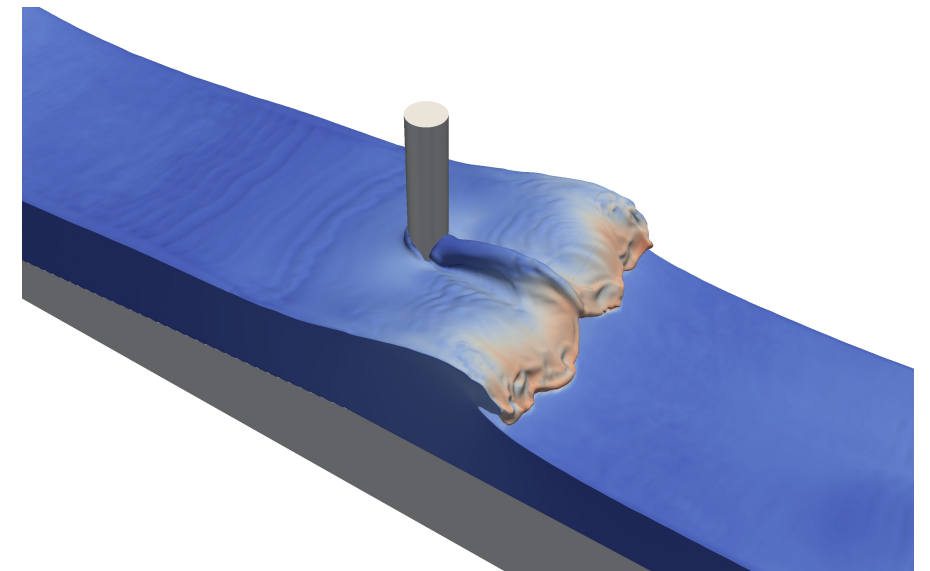
- Full 3D Navier-Stokes Equations
- Free Surface: Two-Phase Flow - Water & Air
- Turbulence

- **Focus on:**

- Free Surface Flows
- Wave Hydrodynamics
- Wave Structure Interaction
- Floating Structures
- Open Channel Flow
- Sediment Transport

- **The Code:**

- C++ (modular & extensible)
- Parallel Computing / HPC
- Open-Source
- Developed at the Department of Civil and Environmental Engineering, NTNU Trondheim

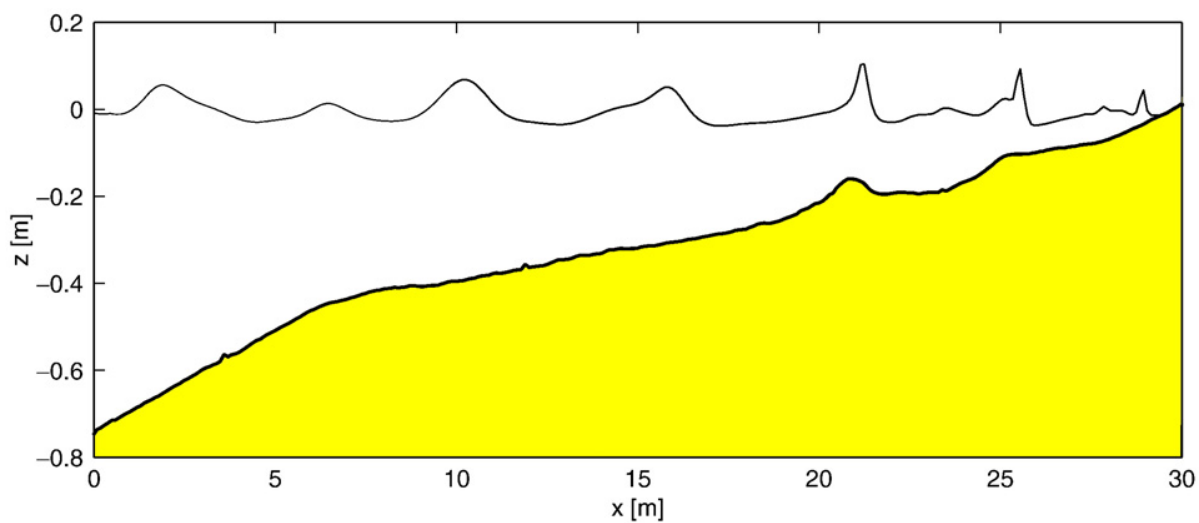


Surf Zone Hydrodynamics (Boers Case)

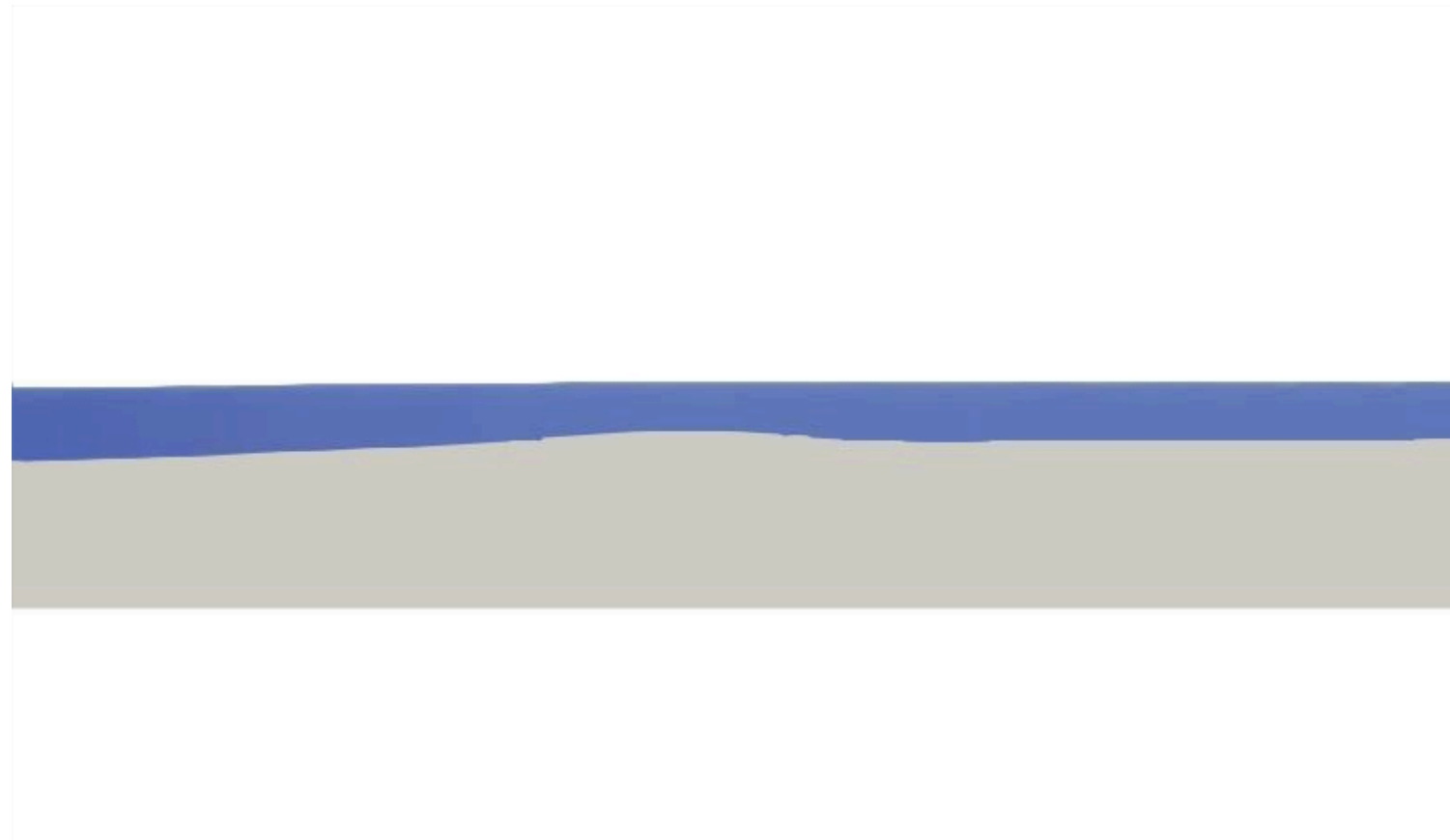
Irregular Waves

$H = 0.1 \text{ m}$

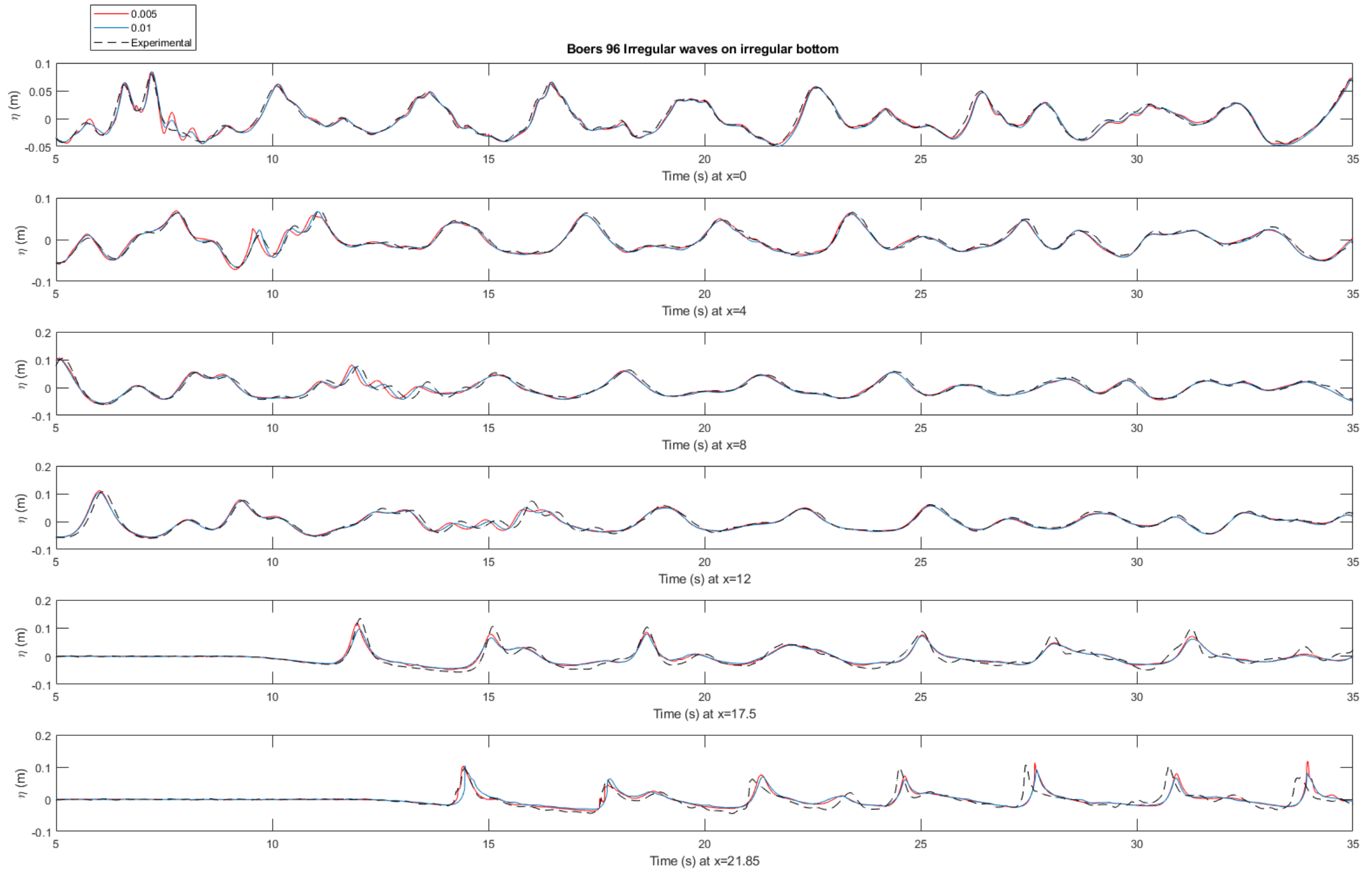
$T = 3.3 \text{ s}$



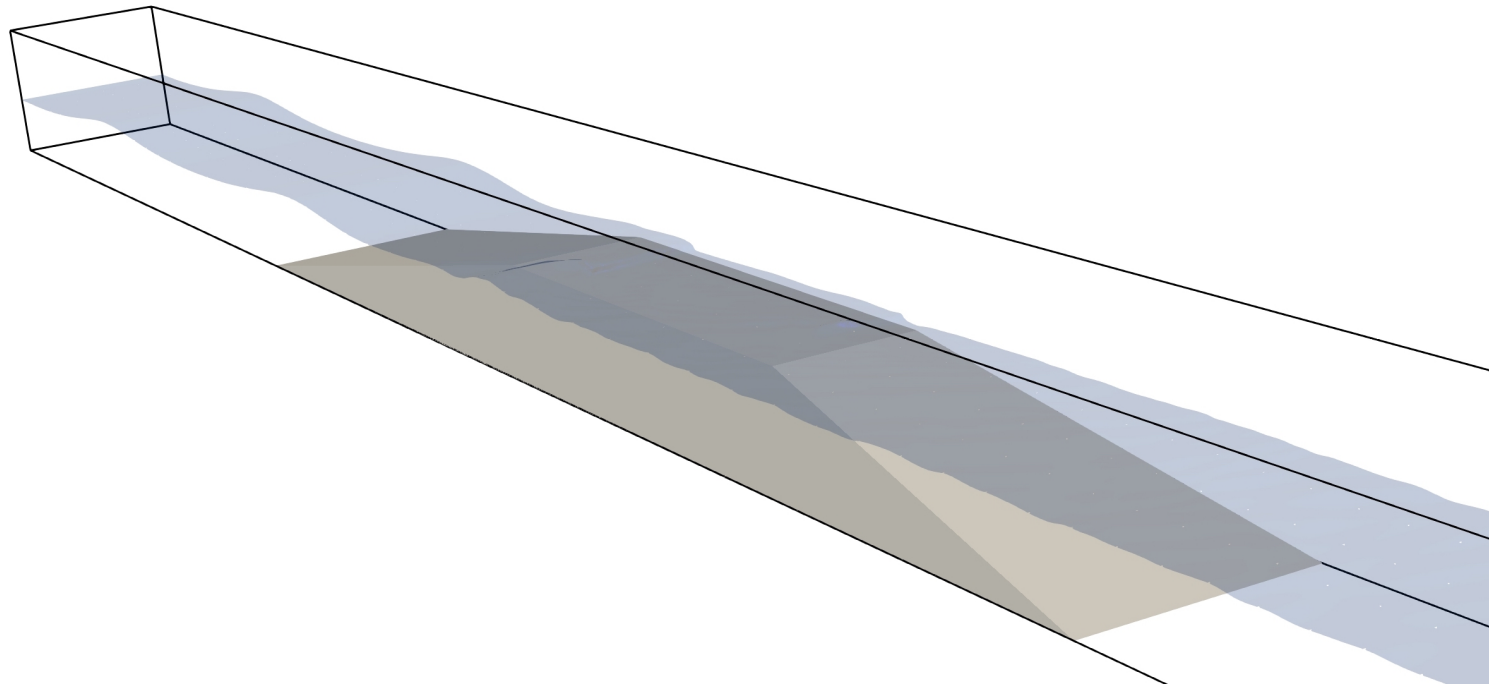
[ongoing MSc-thesis at NTNU]



Surf Zone Hydrodynamics (Boers Case)

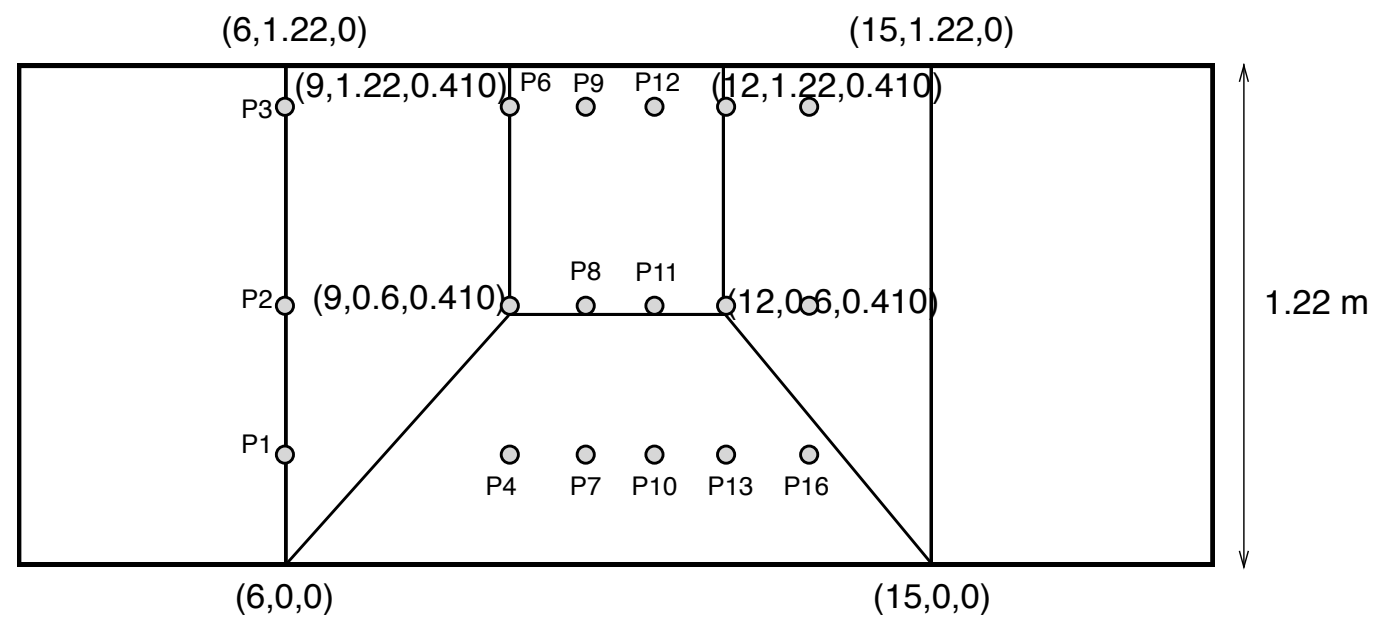


3D Breaking Waves on Reef



Collaboration with Prof. Seiffert,
Florida Atlantic

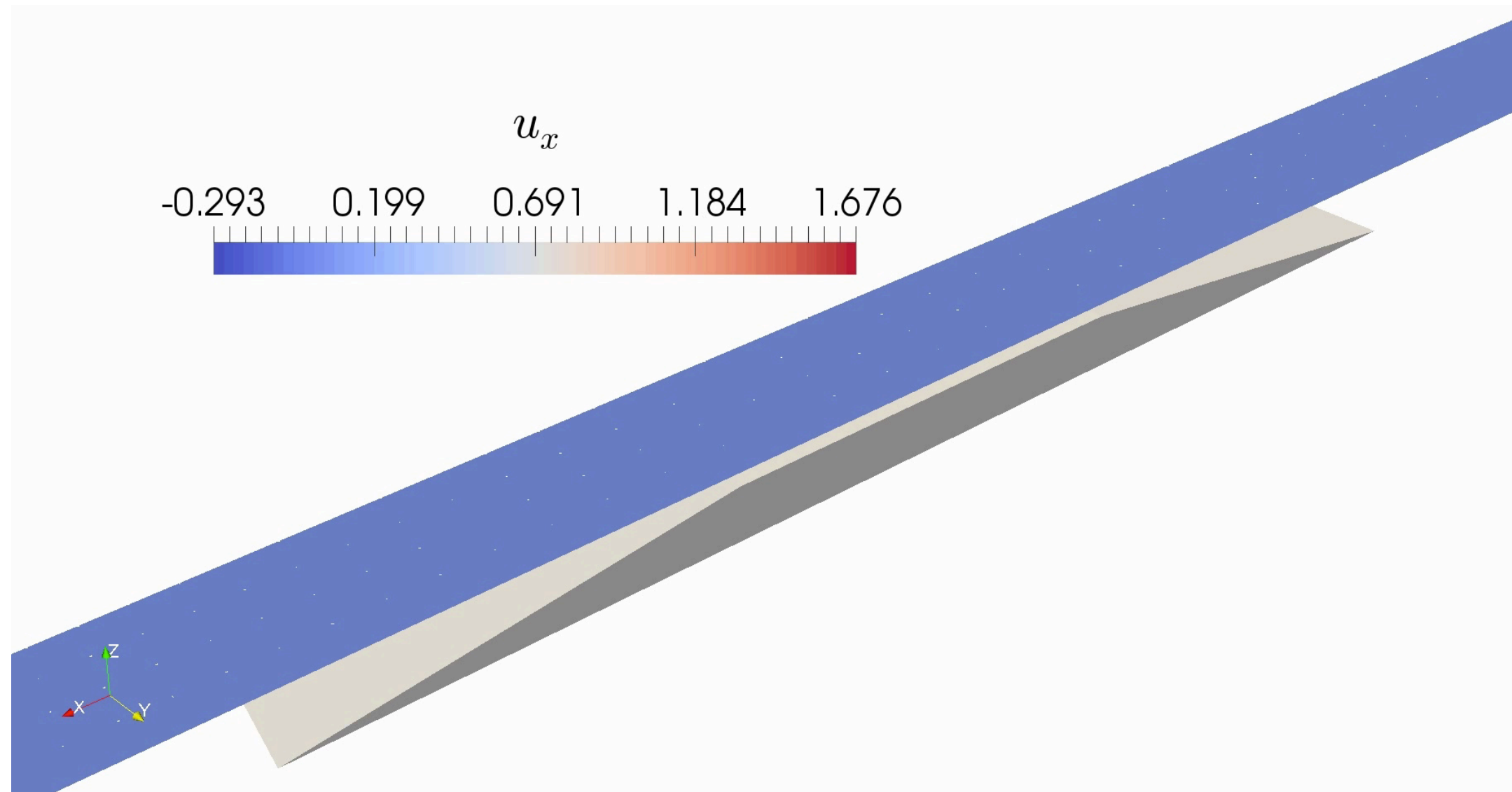
Experiments design based on
CFD input



all dimensions in m

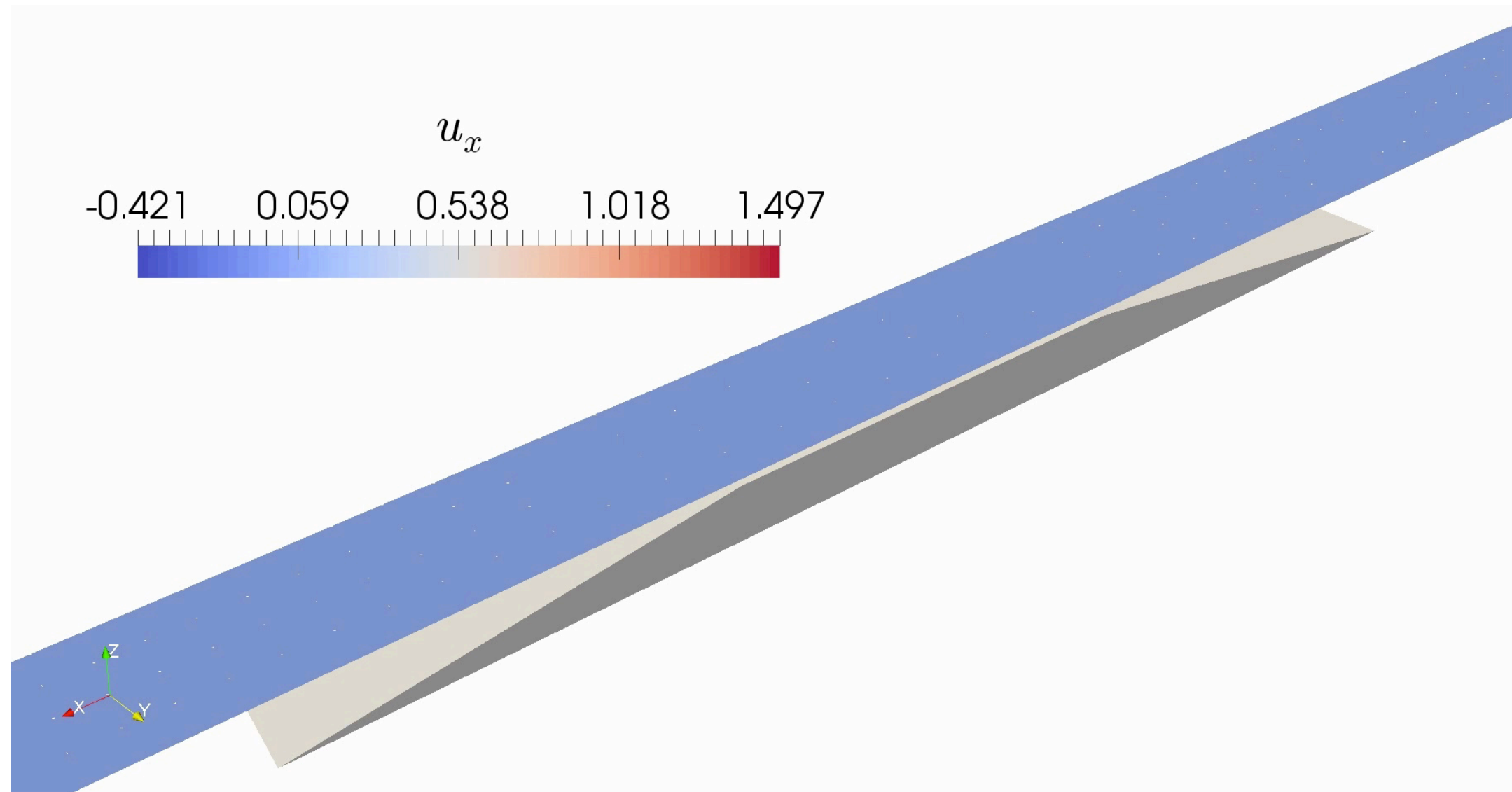
Reef Case 12

H 0.07m, L 3 m, d=0.530

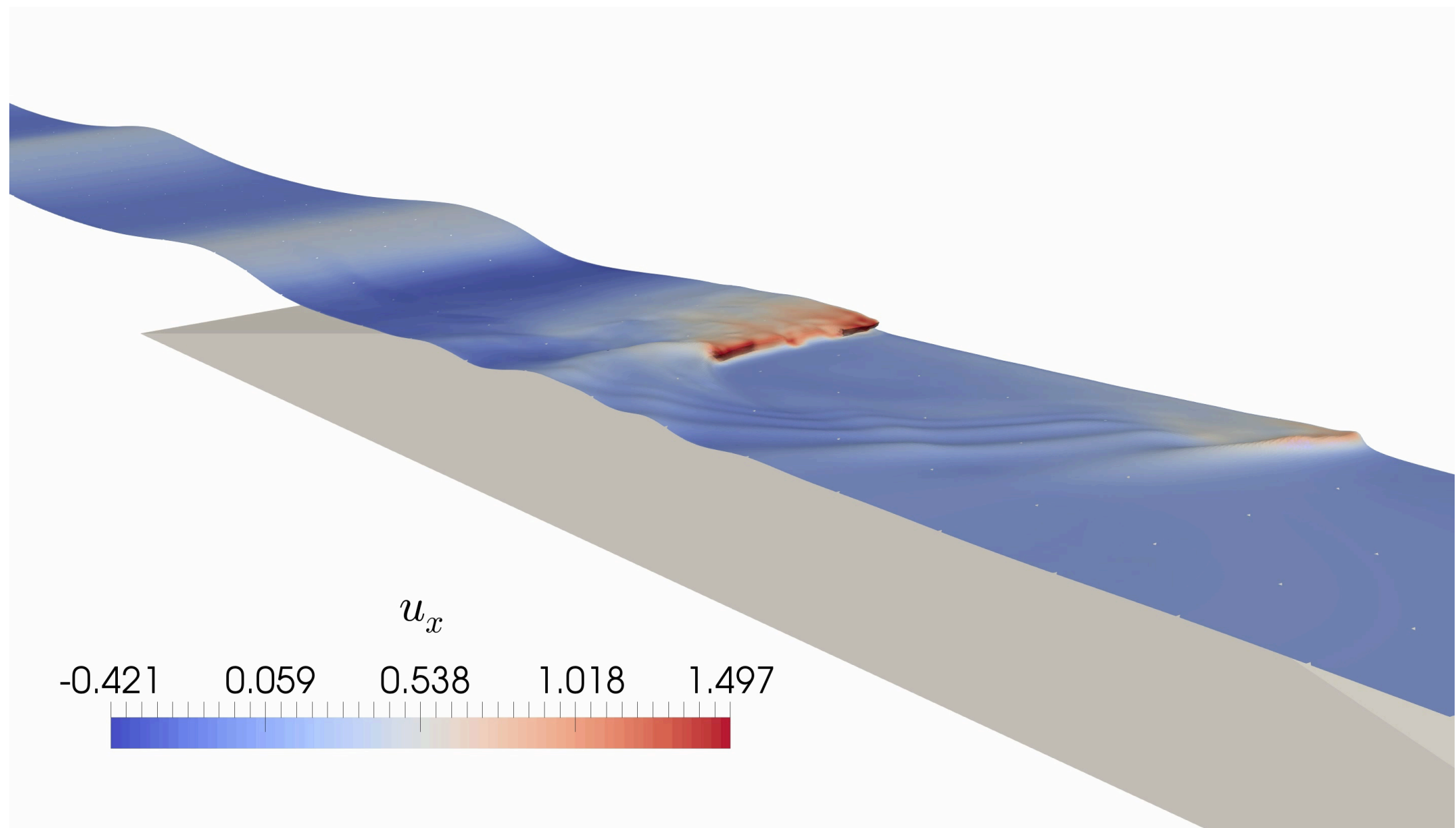


Reef Case 13

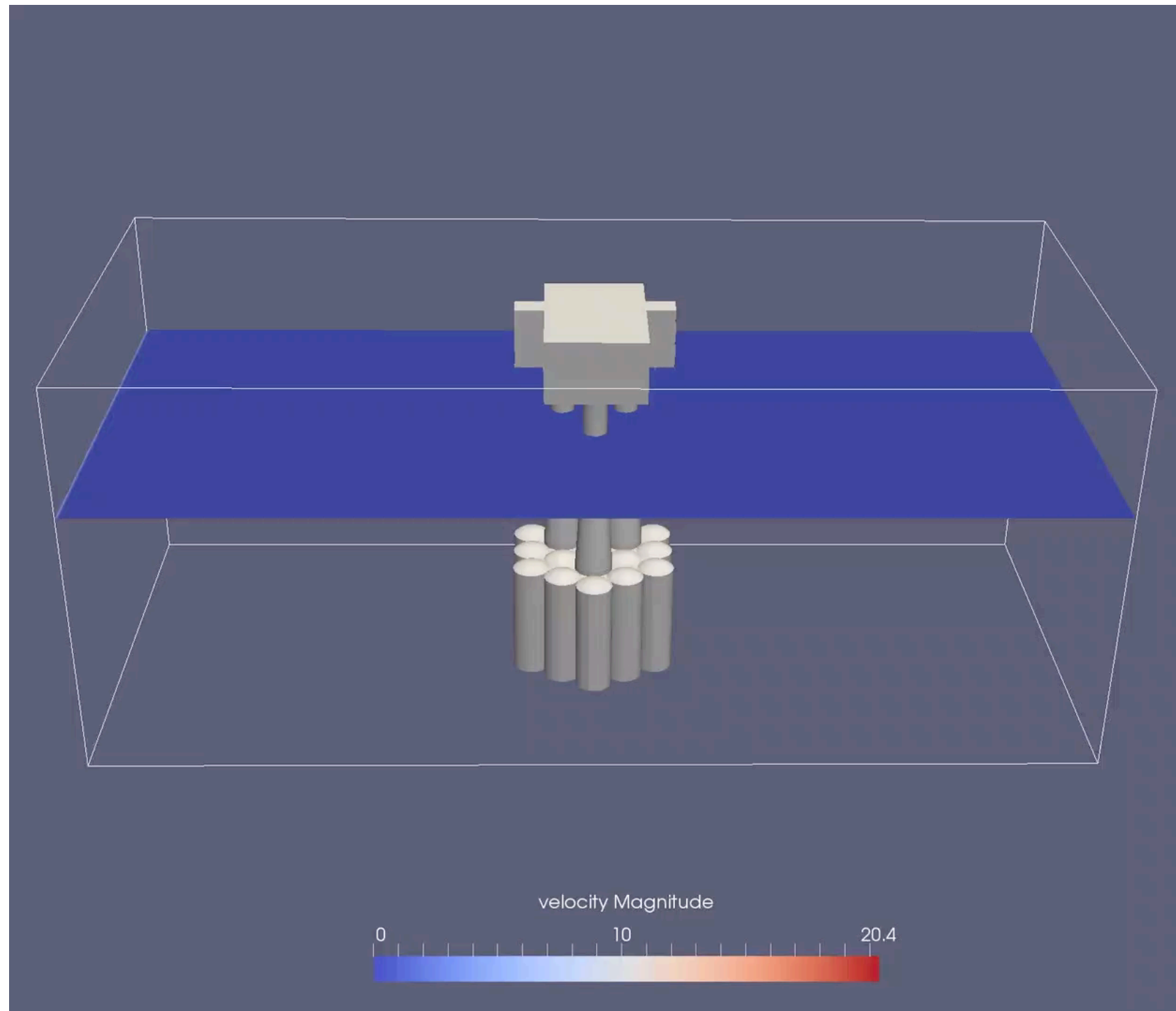
H 0.10, L 4m, d=0.460



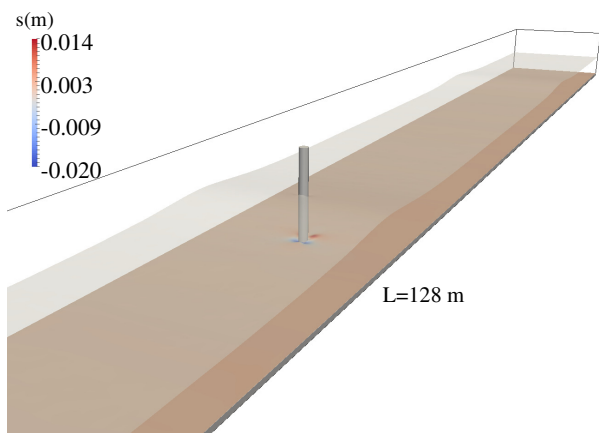
Reef Case 13 - Close-Up



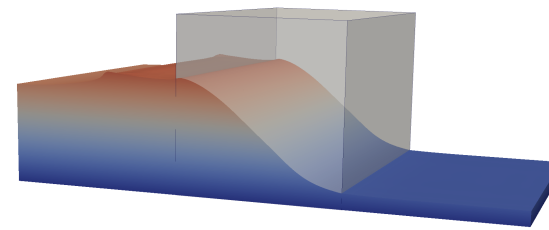
Offshore Hydrodynamics / SINTEF Collaboration



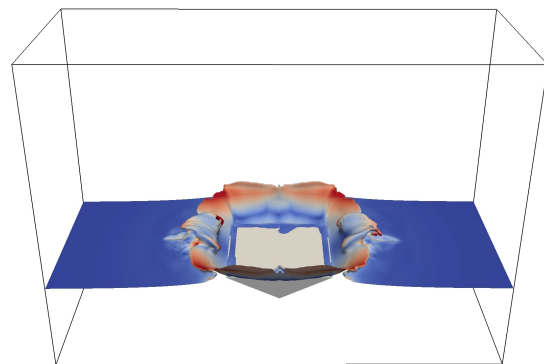
REEF3D::CFD Multiphysics Extensions



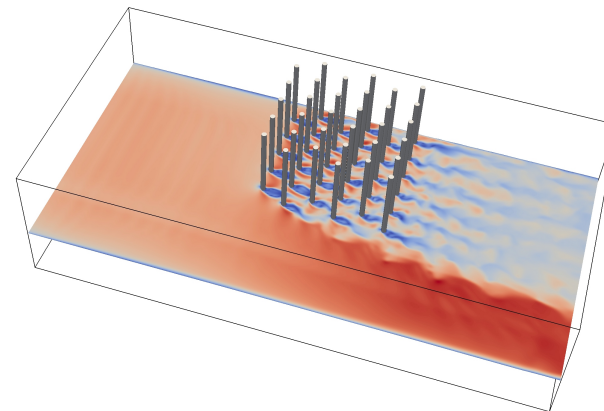
Sediment Transport
Local Scour
Arctic Erosion



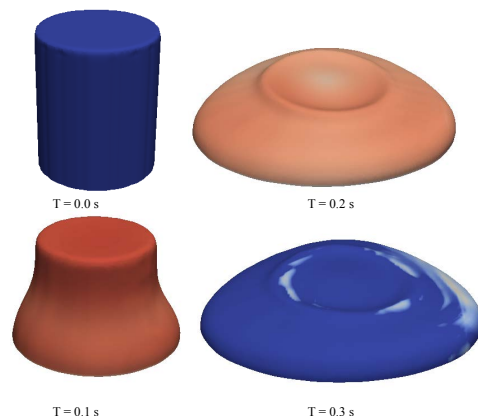
Porous Structures



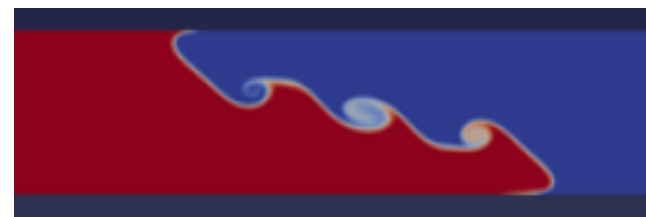
Floating Structures
6DOF
Mooring



Vegetation

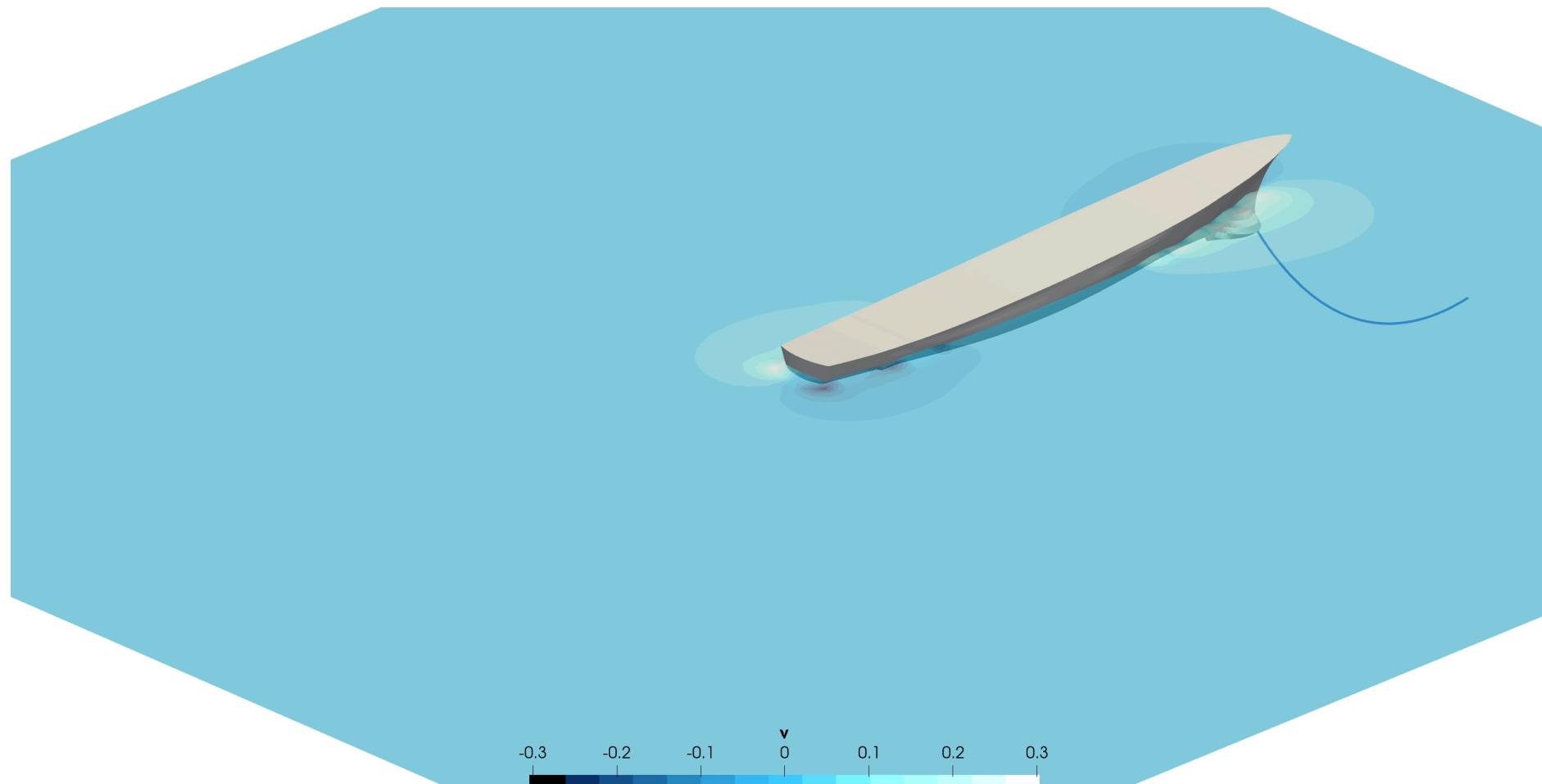


Debris Flow
Granular Flow



Stratified Flow

Multiphysics: 6DOF Algorithm



Equations of Motion:

$$[m(\dot{u} - vr + wq)] = X$$

$$[m(\dot{v} - wp + ur)] = Y$$

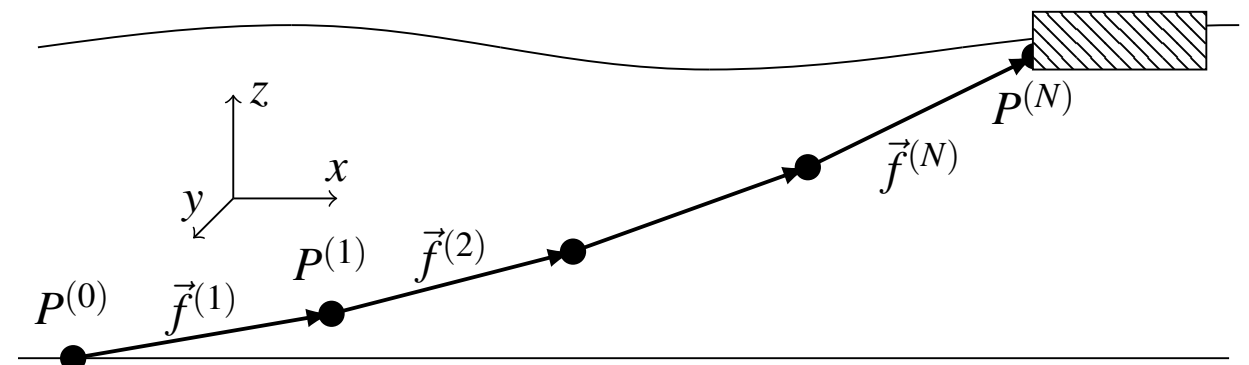
$$[m(\dot{w} - uq + vp)] = Z$$

$$[I_x \dot{p} + (I_z - I_y)qr] = K$$

$$[I_y \dot{q} + (I_x - I_z)rp] = M$$

$$[I_z \dot{r} + (I_y - I_x)pq] = N$$

Element Based
Mooring Model



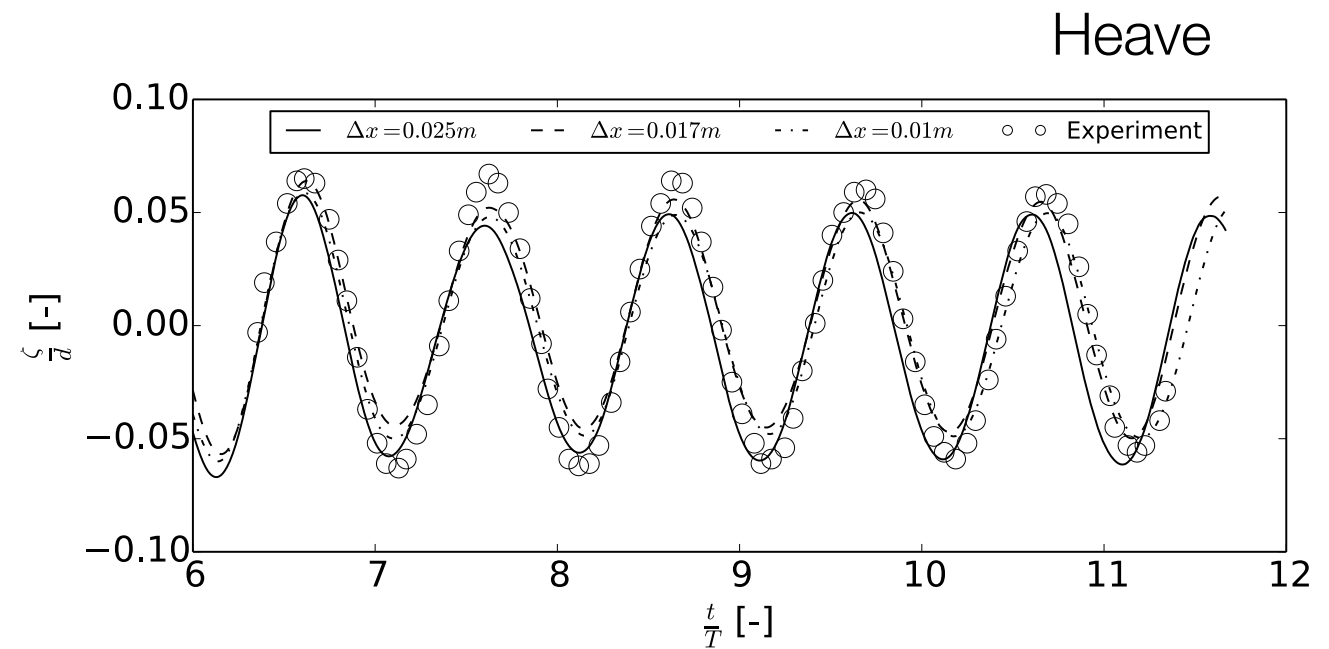
Motion of a 2D Moored-Floating Barge

2D Barge:

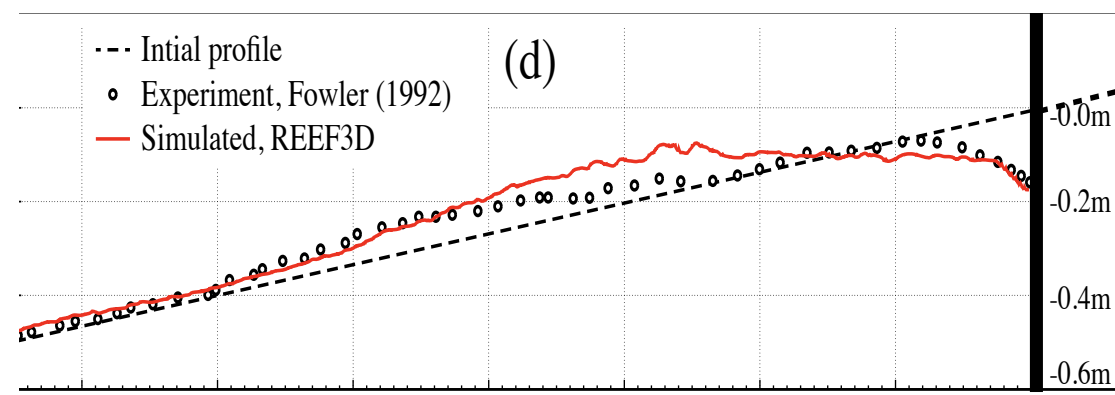
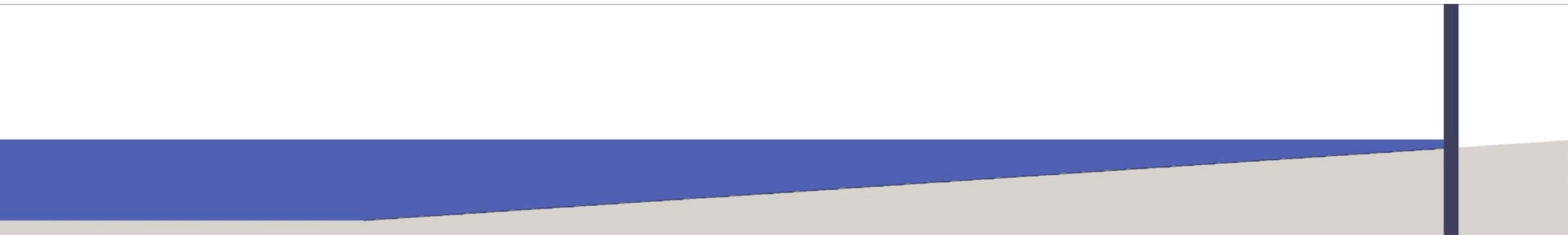
- $\rho_{\text{barge}} = 500 \text{ kg/m}^3$
- $H_{\text{barge}} = 0.2 \text{ m}$
- $L_{\text{barge}} = 0.3 \text{ m}$

Waves:

- $\lambda = 1.936 \text{ m}$
- $H = 0.04 \text{ m}$
- $T = 1.2 \text{ s}$



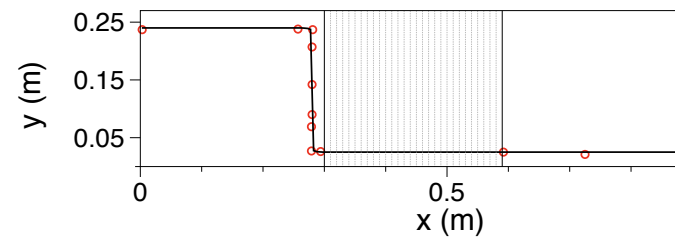
Multiphysics: Sediment Transport



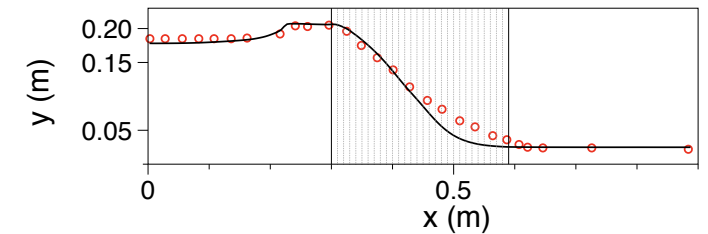
Multiphysics: Porous Structures

VRANS-equations

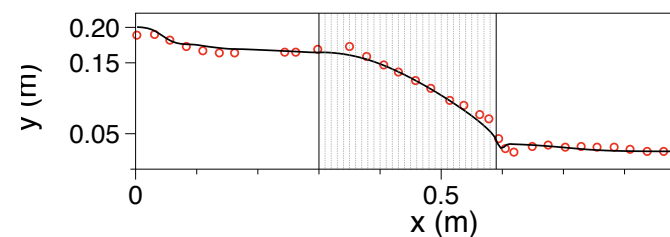
- adapted for level set method
- adapted for staggered grid



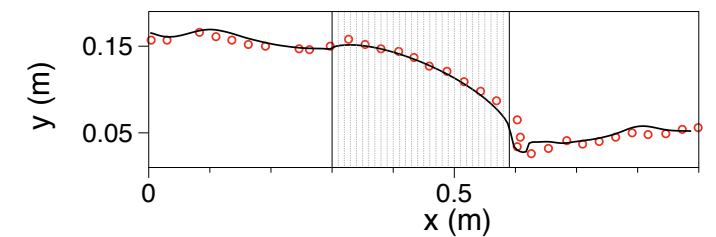
(a) 0.0 s



(c) 0.4 s



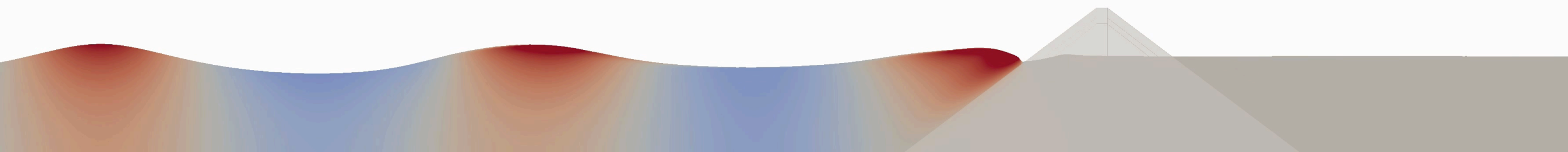
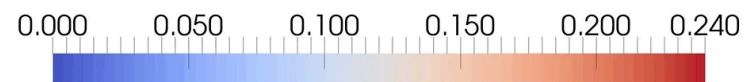
(e) 0.8 s



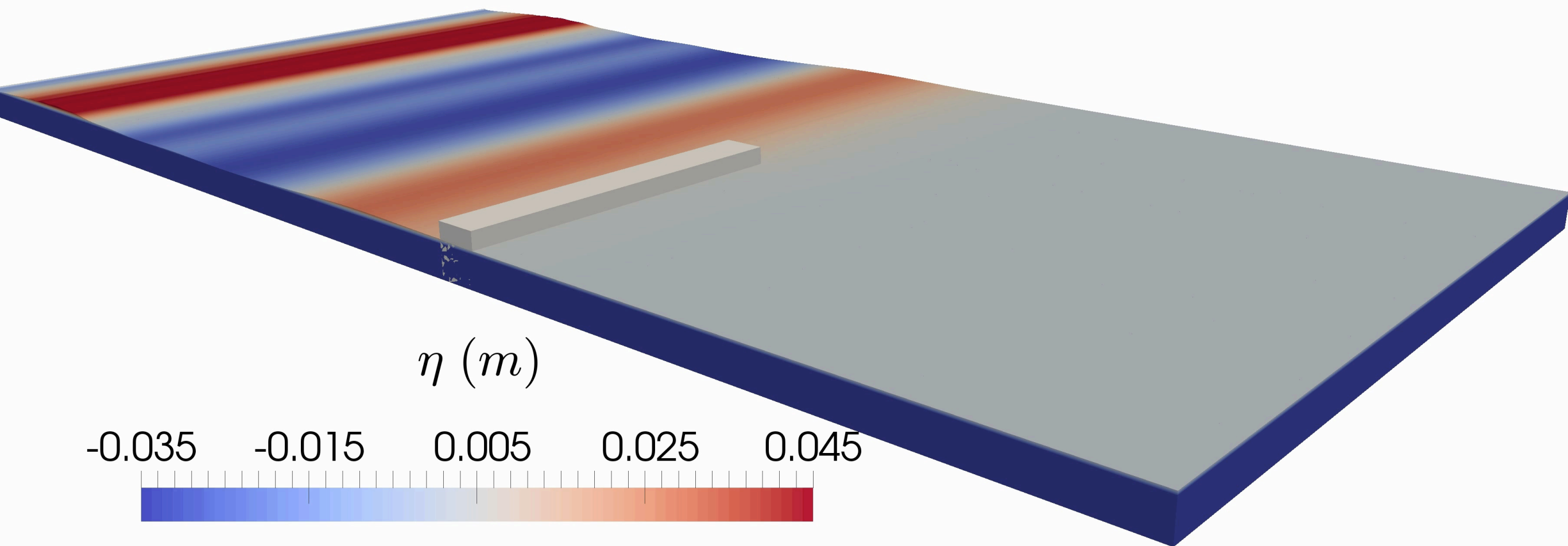
(h) 1.4 s



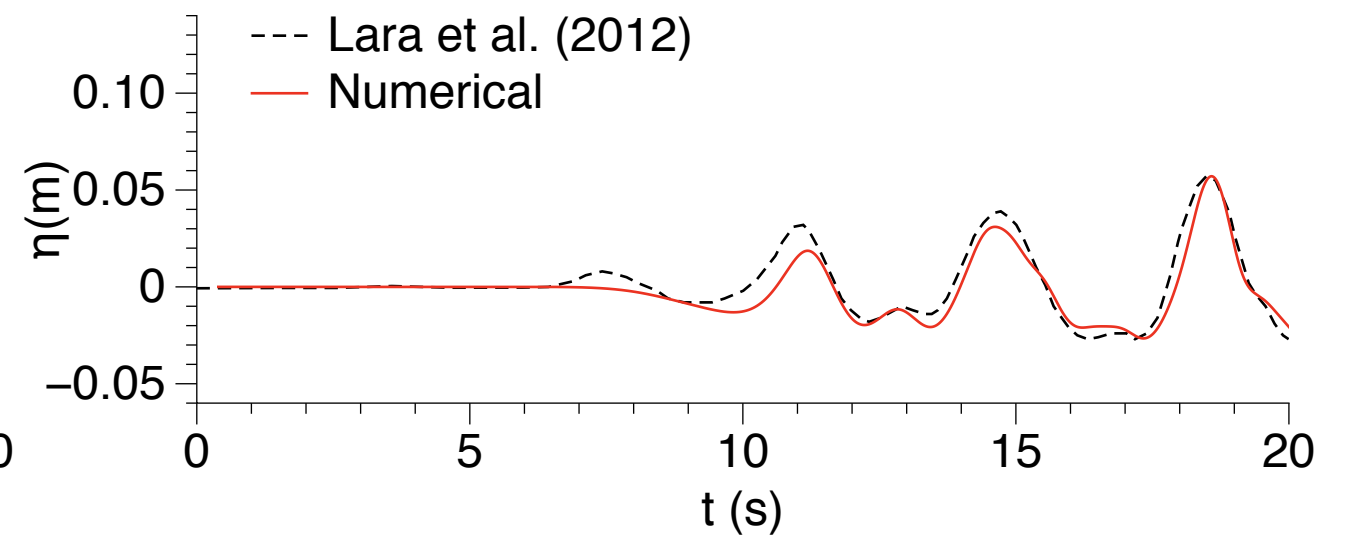
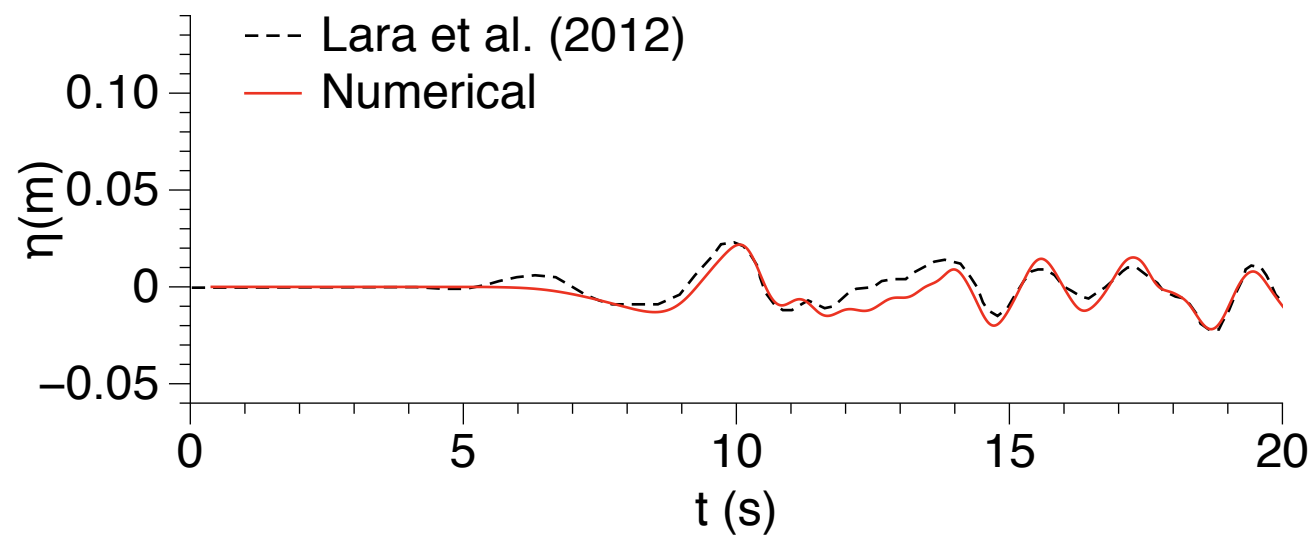
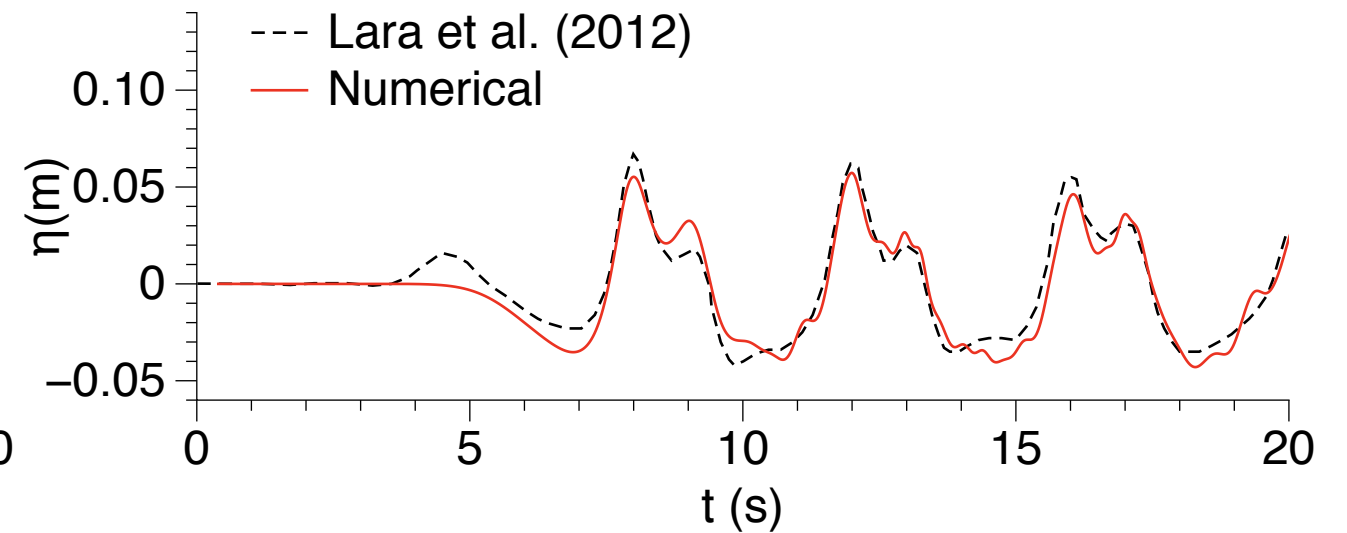
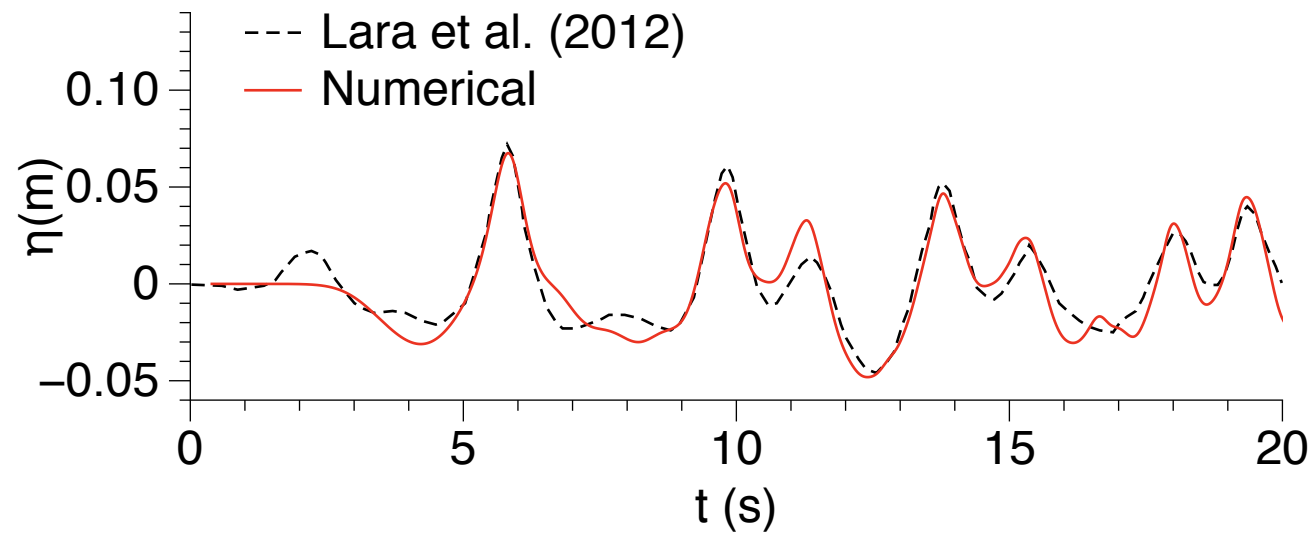
Elevation (η)



Coastal Structures: Regular waves



Porous media flow: Regular waves



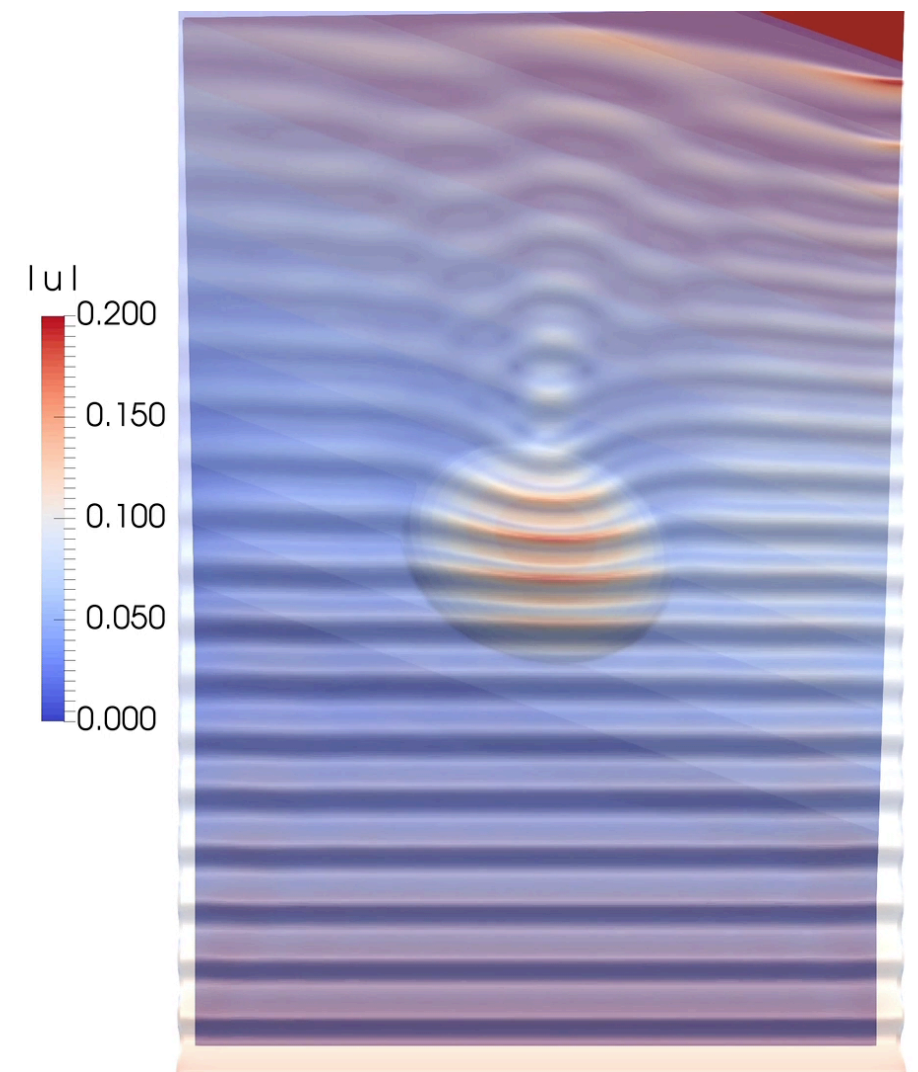
REEF3D::SFLOW

- Solves:

- Shallow-Water Equations (i.e. 2D)
- Non-hydrostatic pressure
- wetting-drying
- parallel computing
- Physics:
 - diffraction
 - refraction
 - reflection
 - shoaling
 - breaking
 - current

- Focus on:

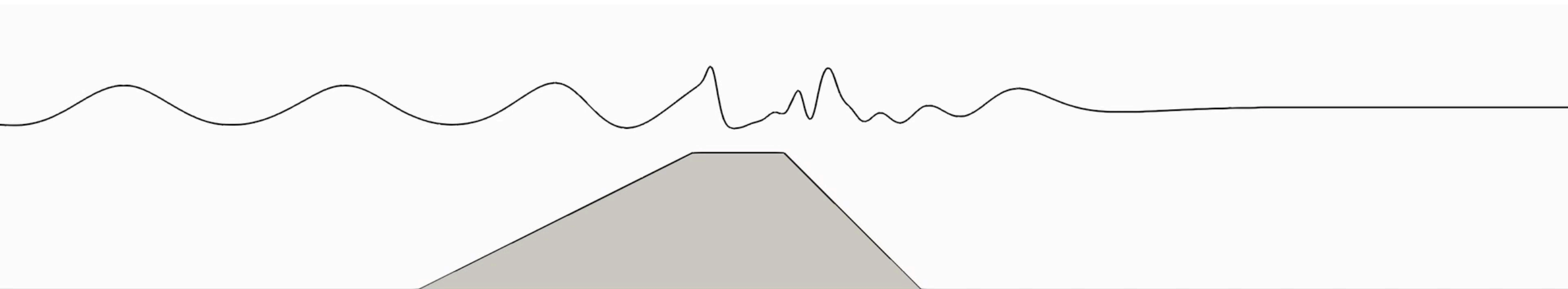
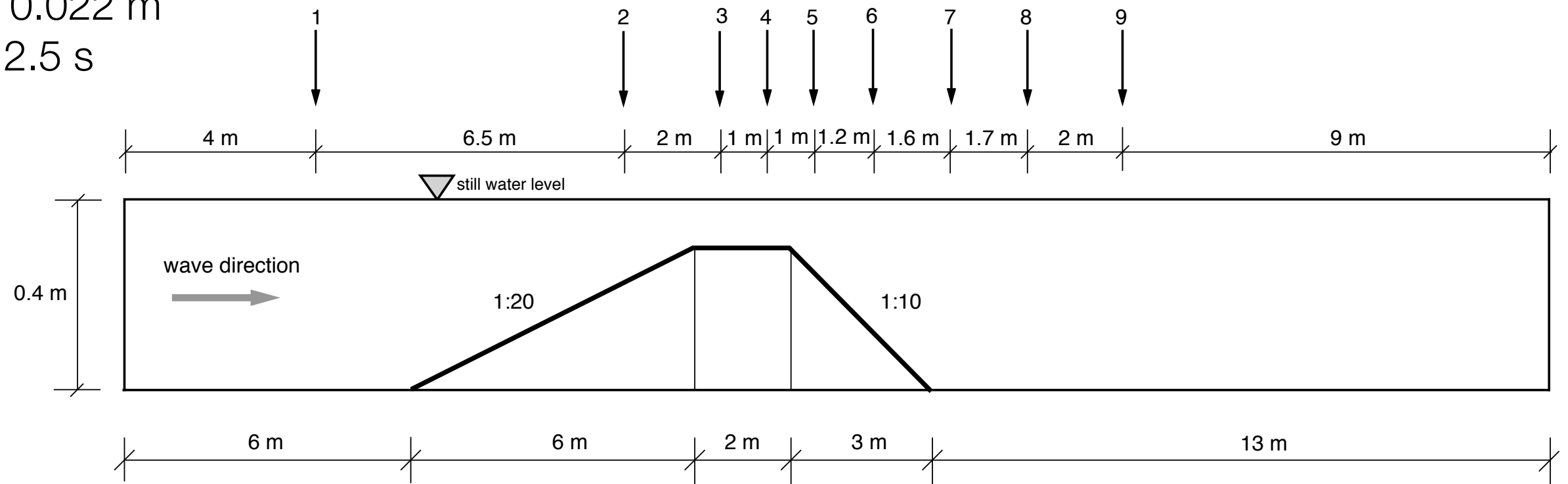
- Phase-Resolved Wave Modeling
- Wave Hydrodynamics
- Open Channel Flow
- Sediment Transport



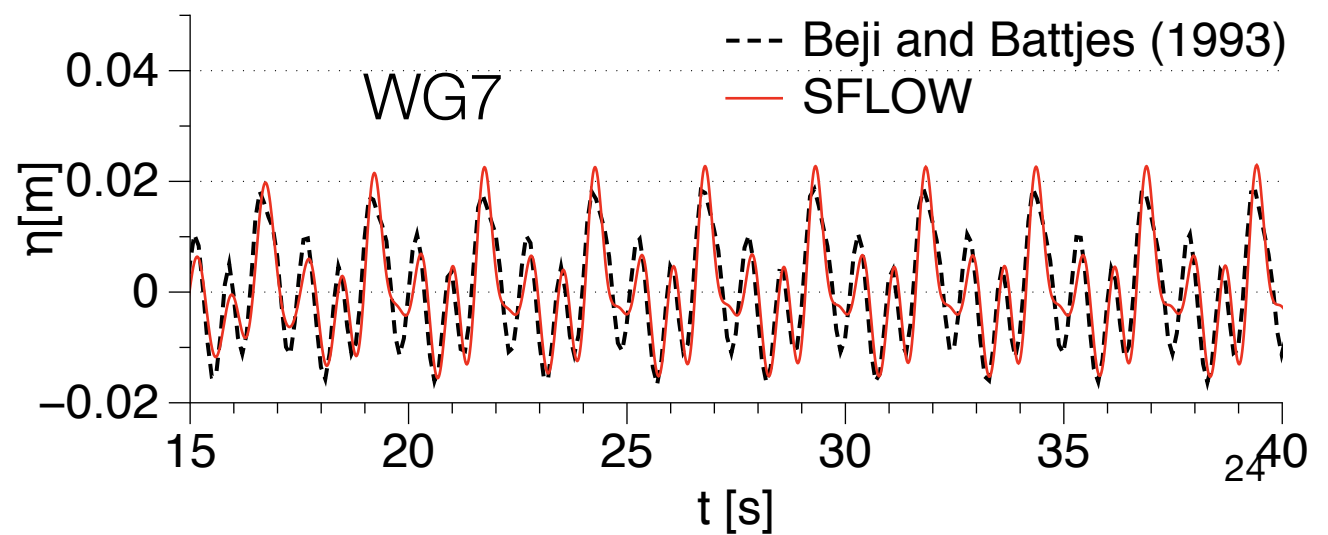
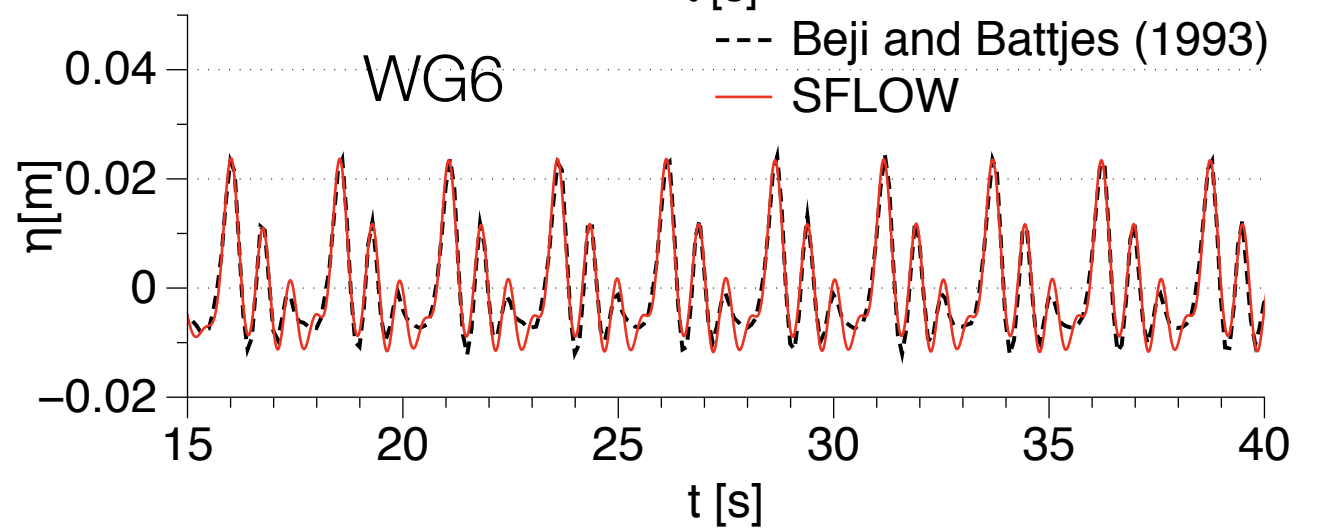
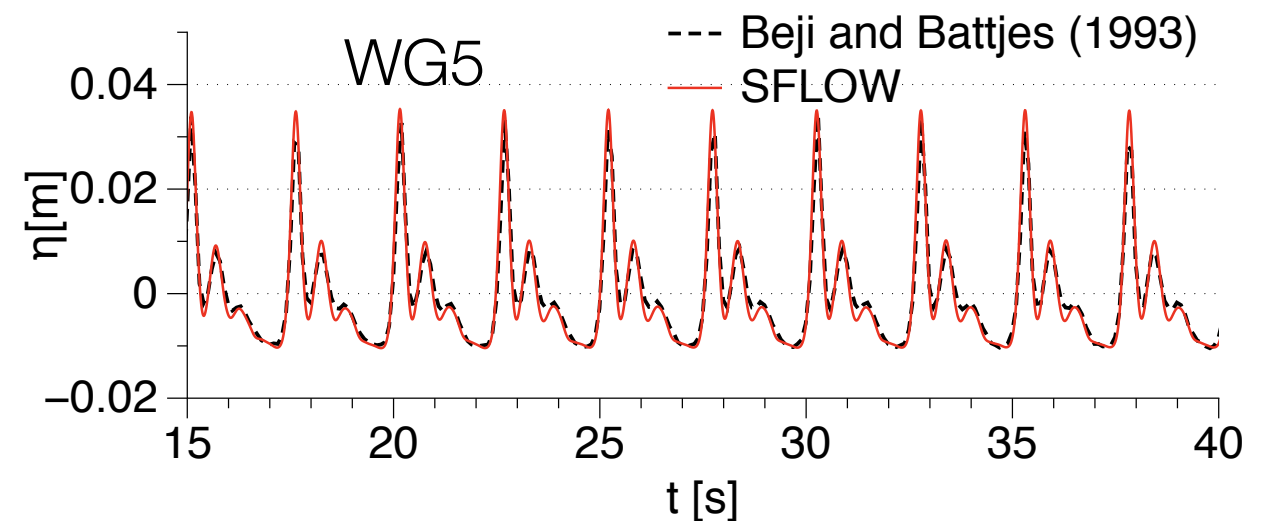
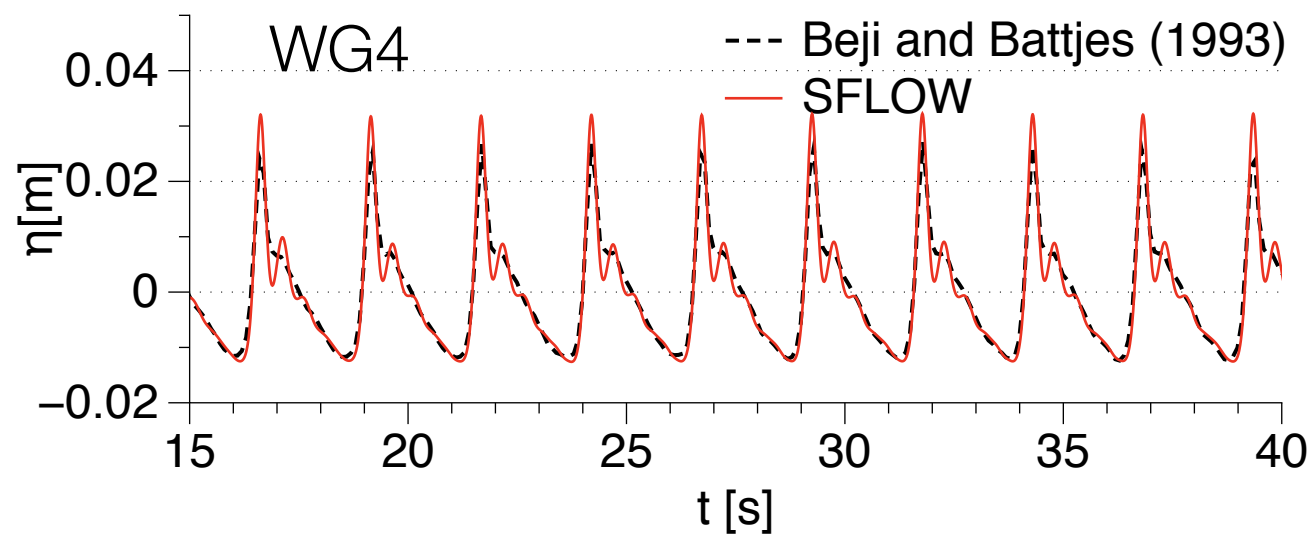
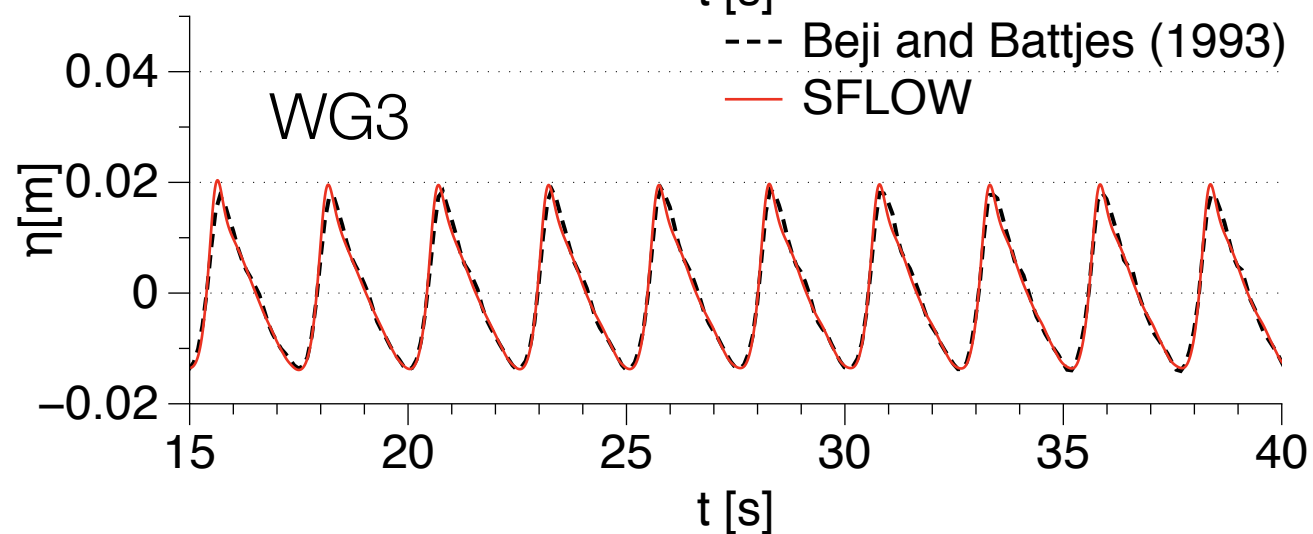
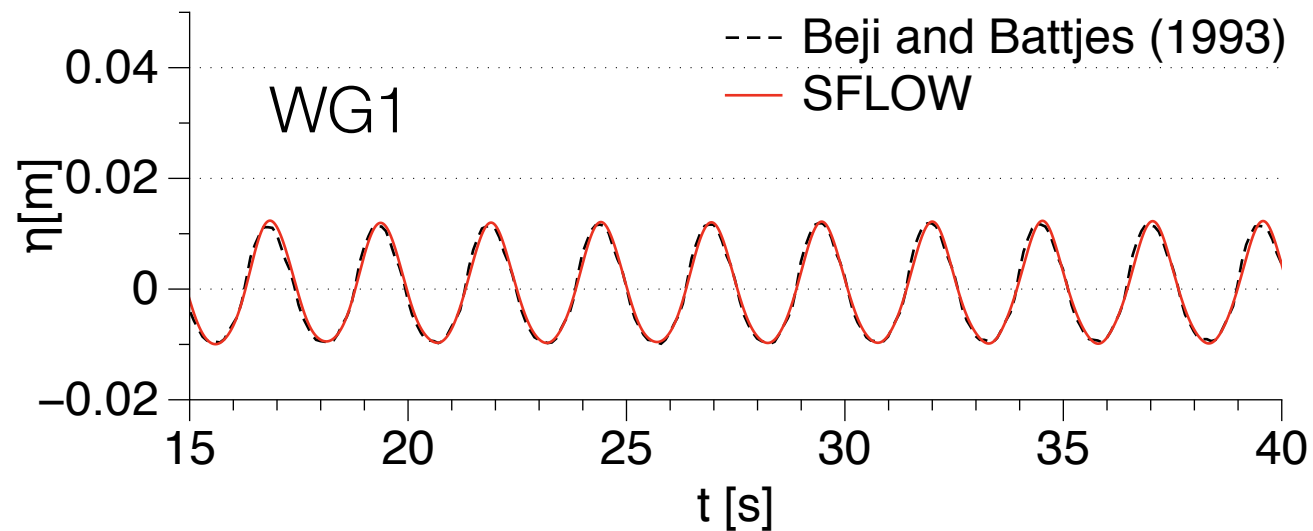
SFLOW Validation : Beji & Battjes

$H = 0.022 \text{ m}$

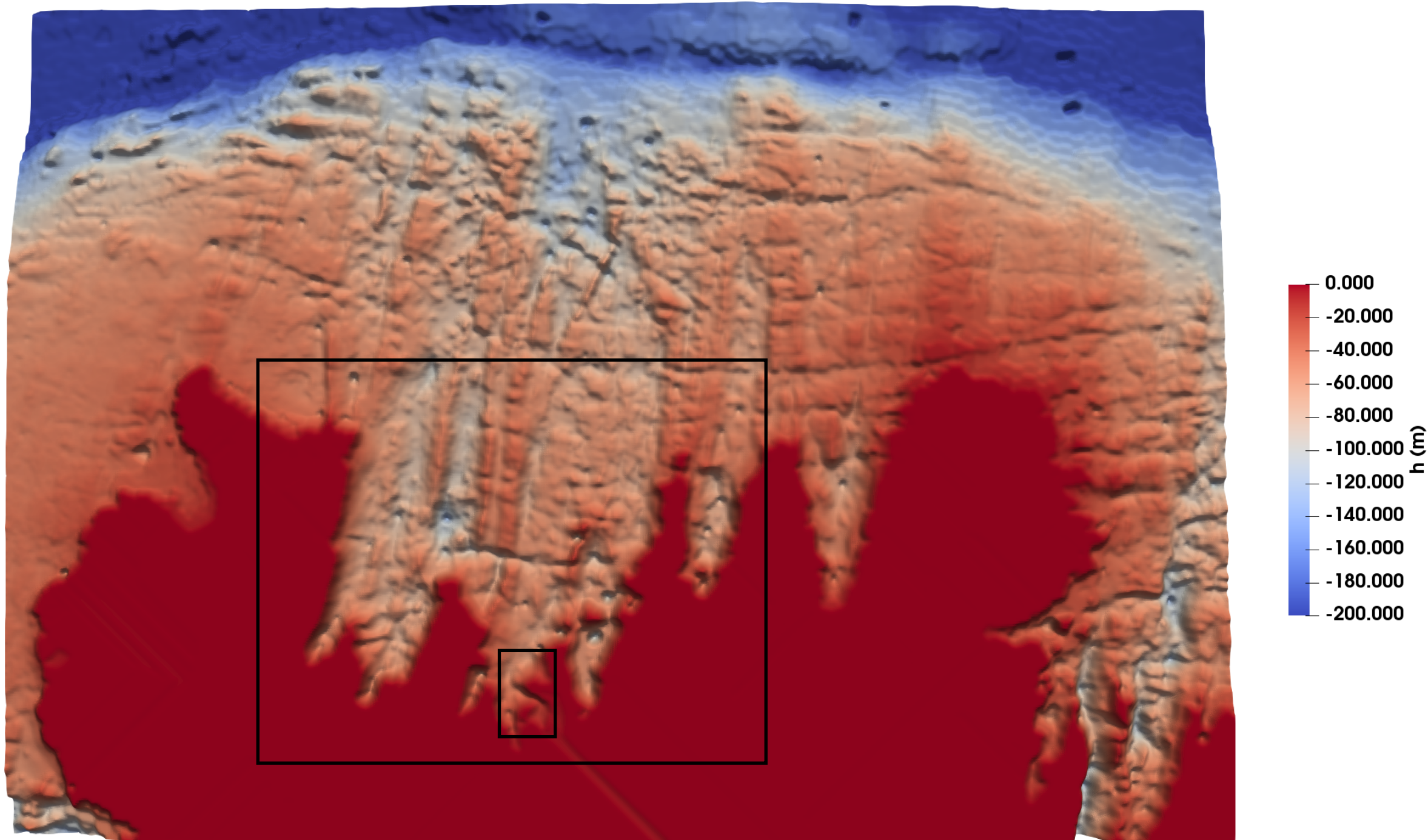
$T = 2.5 \text{ s}$



Beji & Battjes



Mehamn Topography



The continental shelf near Mehamn Harbour

Mehamn Continental Shelf Scale - SWAN

Input wave:

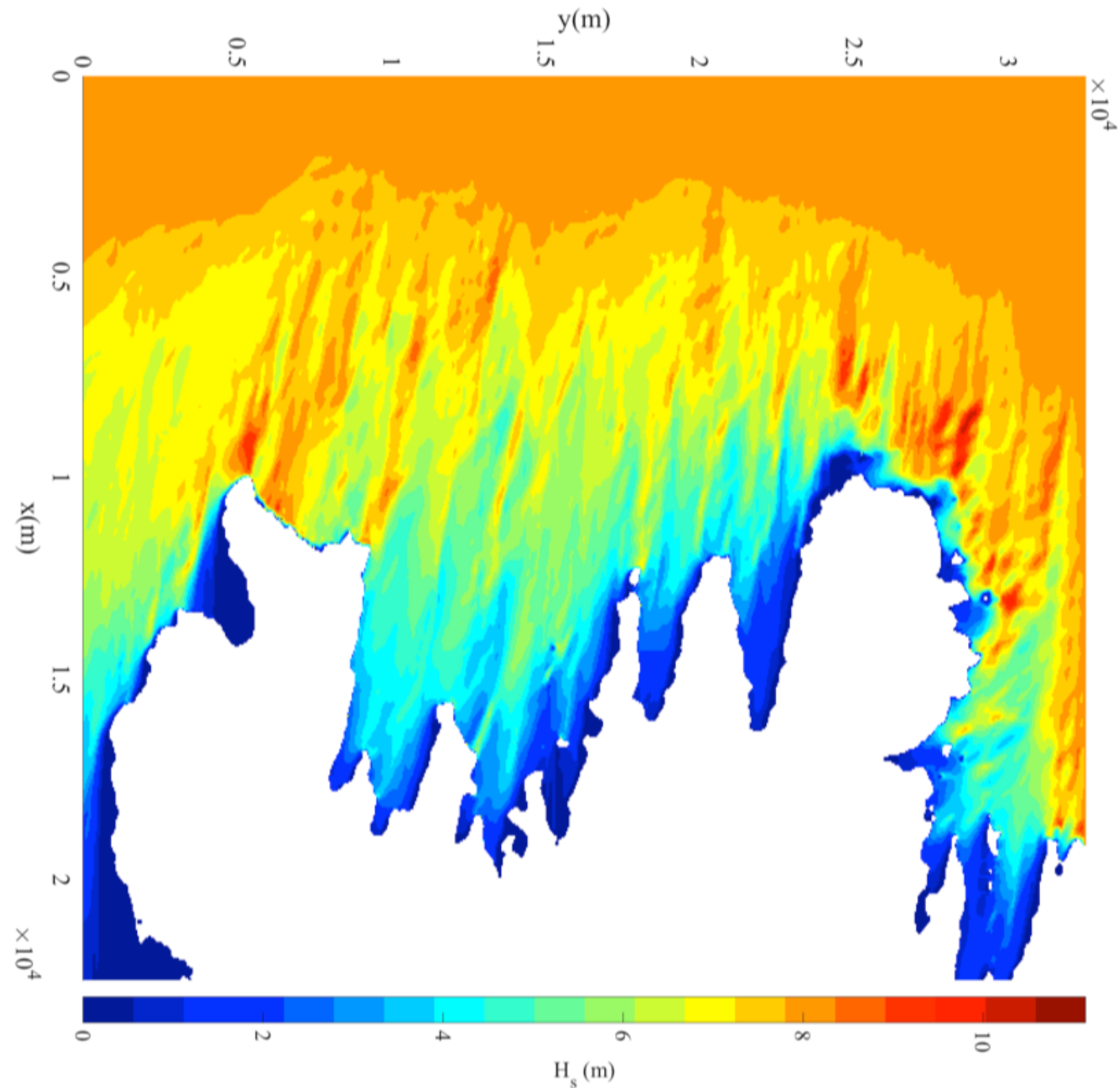
$H_s = 11.4$ m

$T_p = 15$ s

Spectrum:

JONSWAP

Cos-2s



Mehamn Large Scale - SFLOW

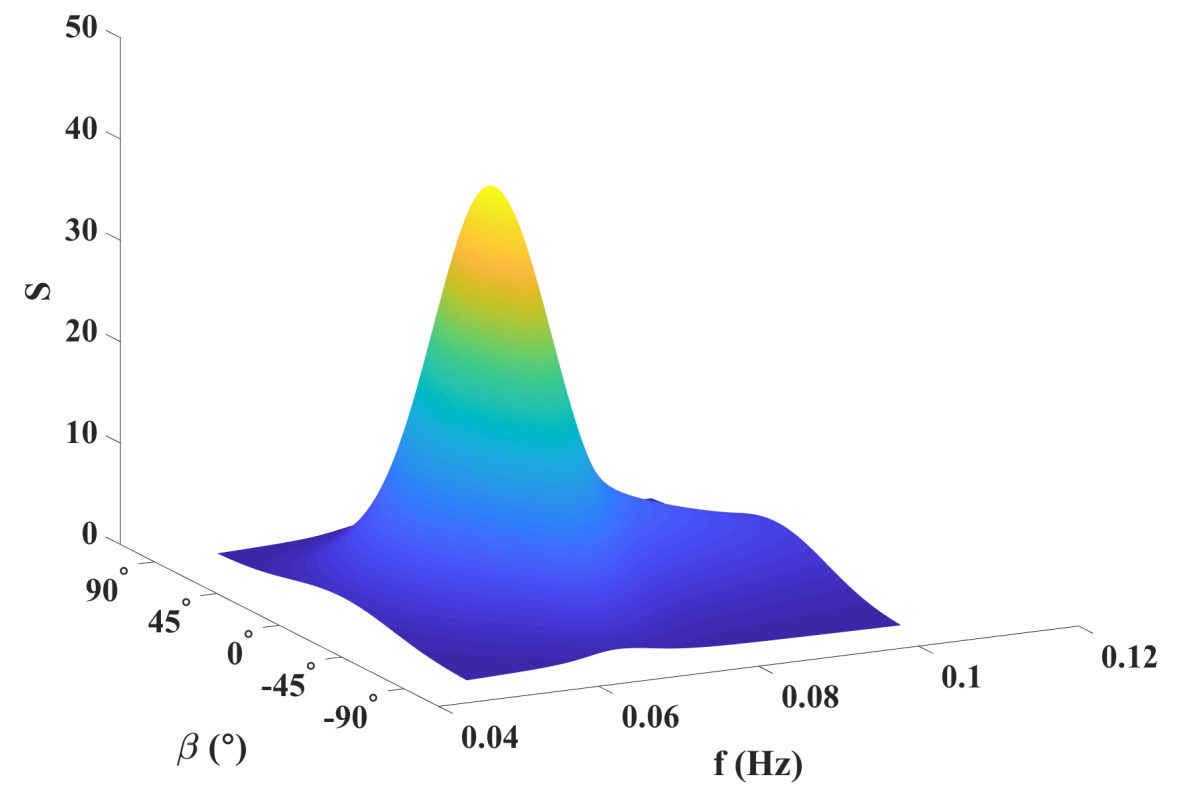
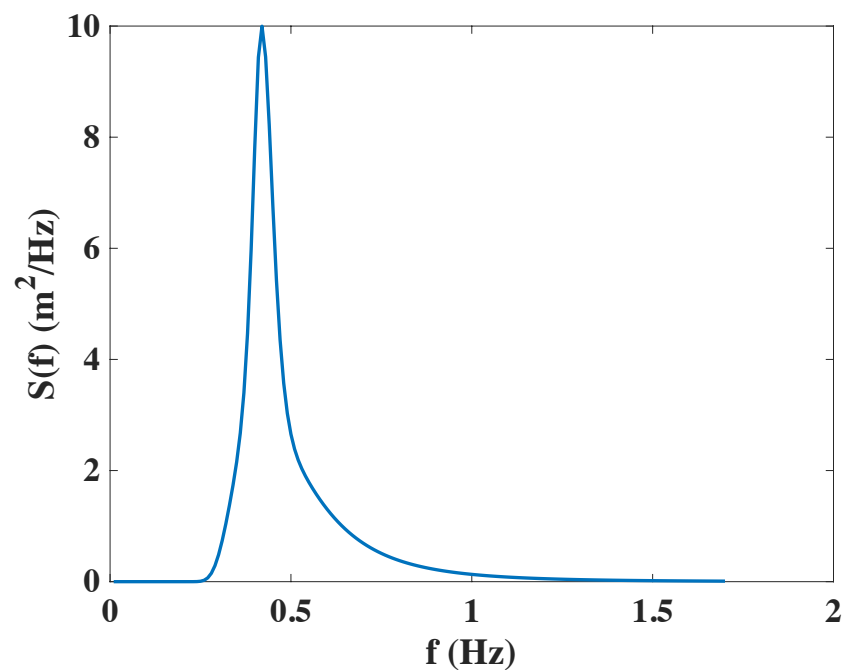
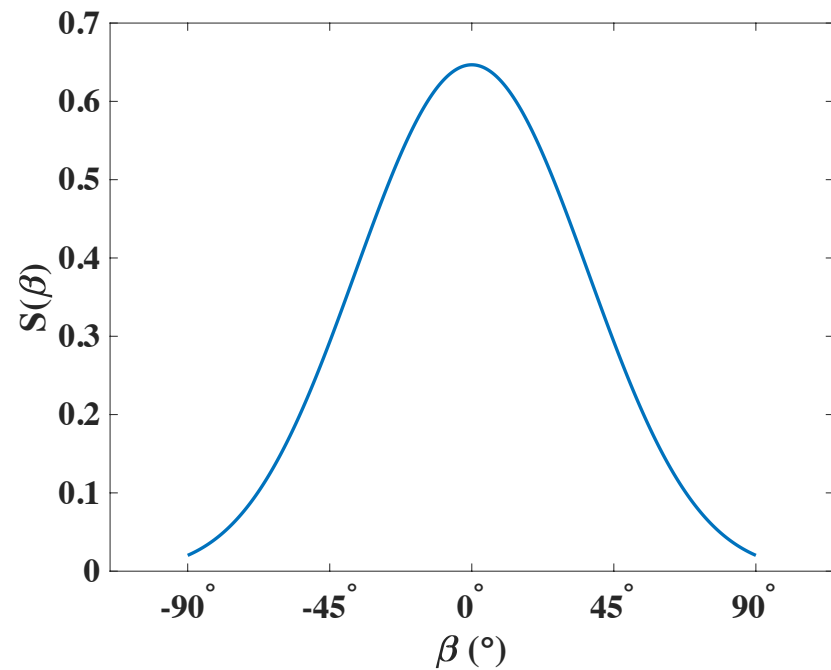
Input wave:
 $H = 9$ m
 $T = 15$ s
Regular wave



Mehamn Large Scale - SFLOW

Input wave:
 $H_s = 4.5$ m
 $T_p = 15$ s

Spectrum:
JONSWAP
Mitsuyasu



Mehamn Large Scale - SFLOW

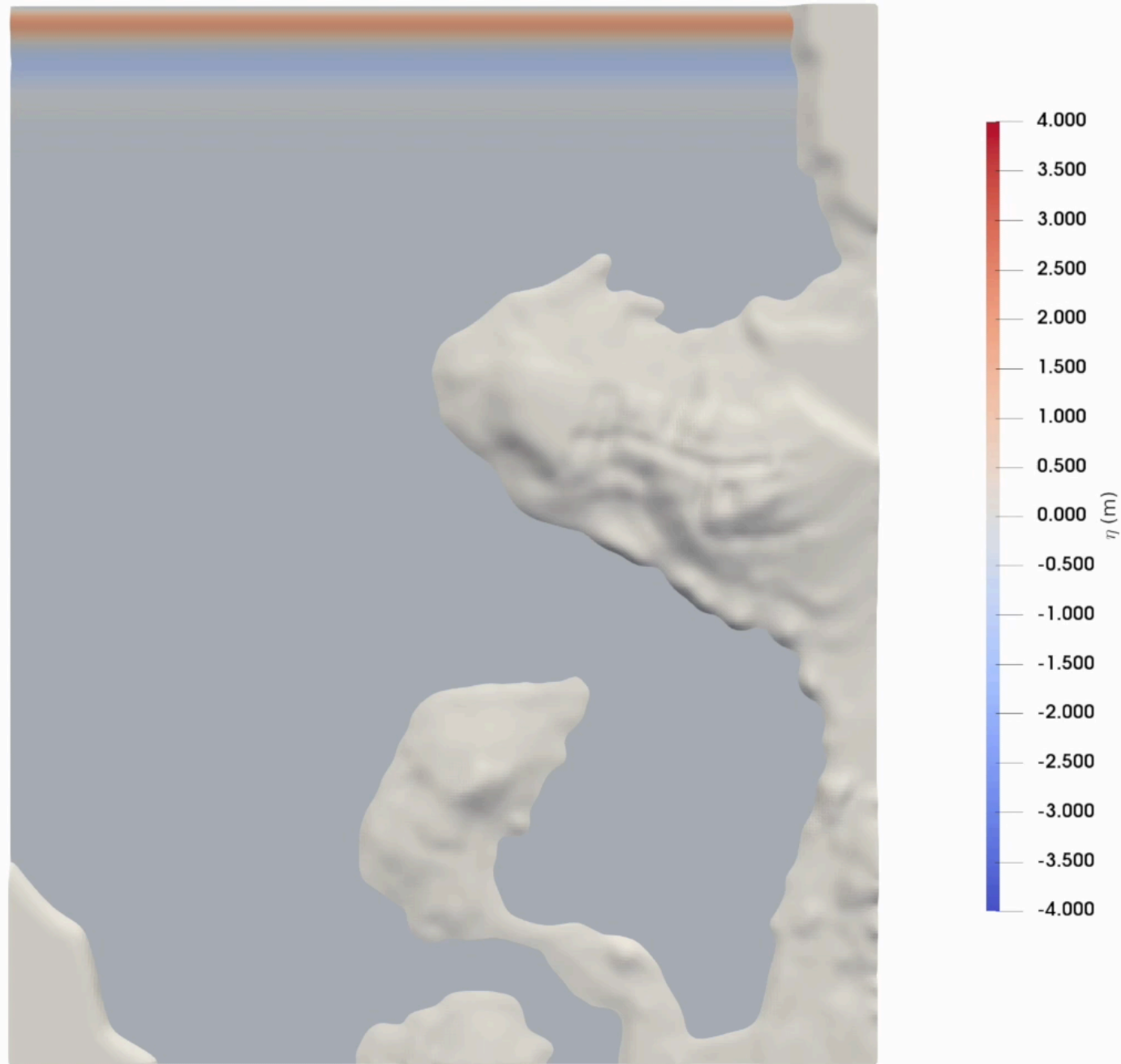
Input wave:
 $H_s = 4.5$ m
 $T_p = 15$ s

Spectrum:
JONSWAP
Mitsuyasu



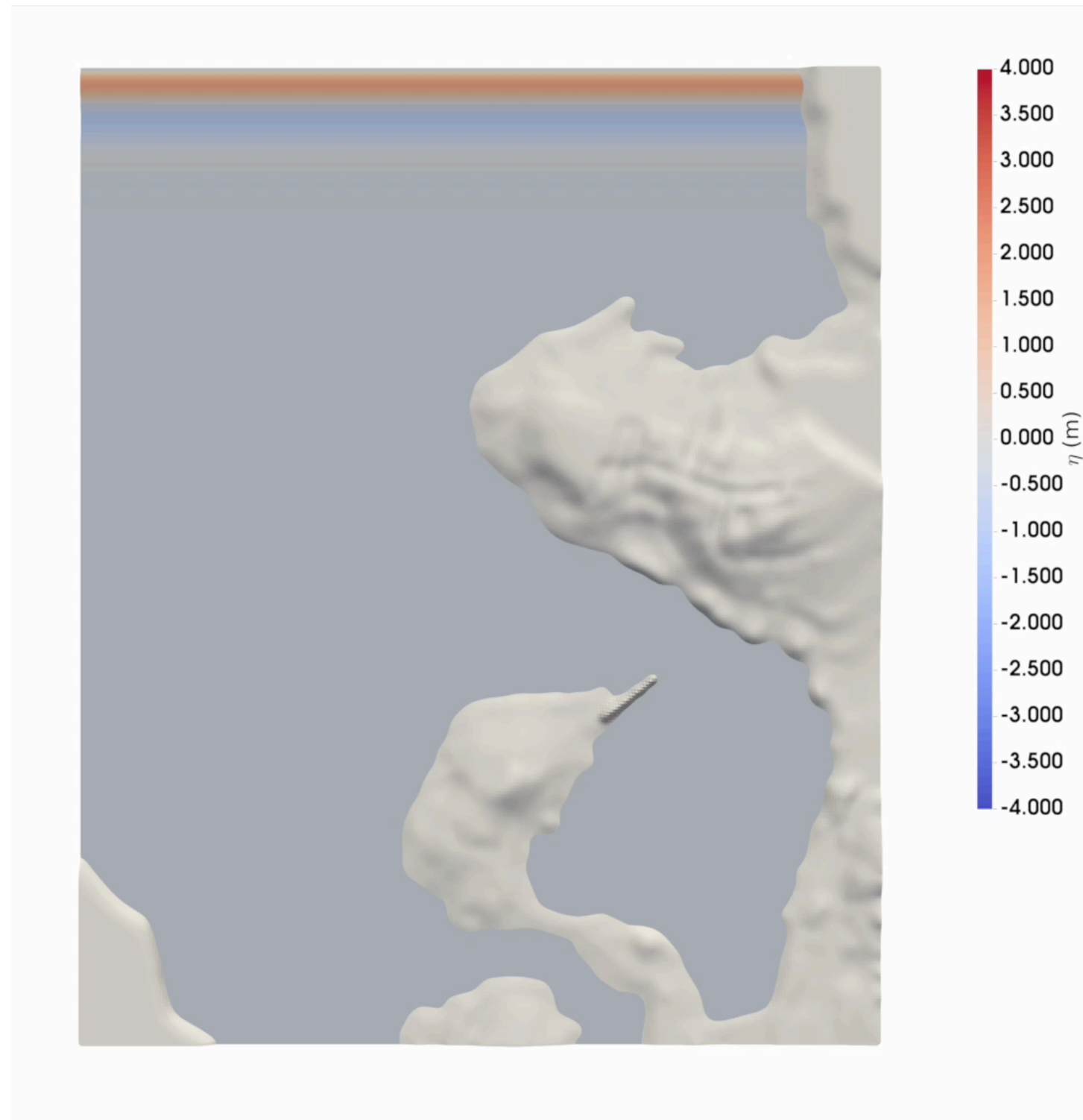
Mehamn Harbour scale - SFLOW

Input wave:
 $H = 3.5$ m
 $T = 9.5$ s
Regular wave



Mehamn Harbour scale - SFLOW

Input wave:
 $H = 3.5 \text{ m}$
 $T = 9.5 \text{ s}$
Regular wave

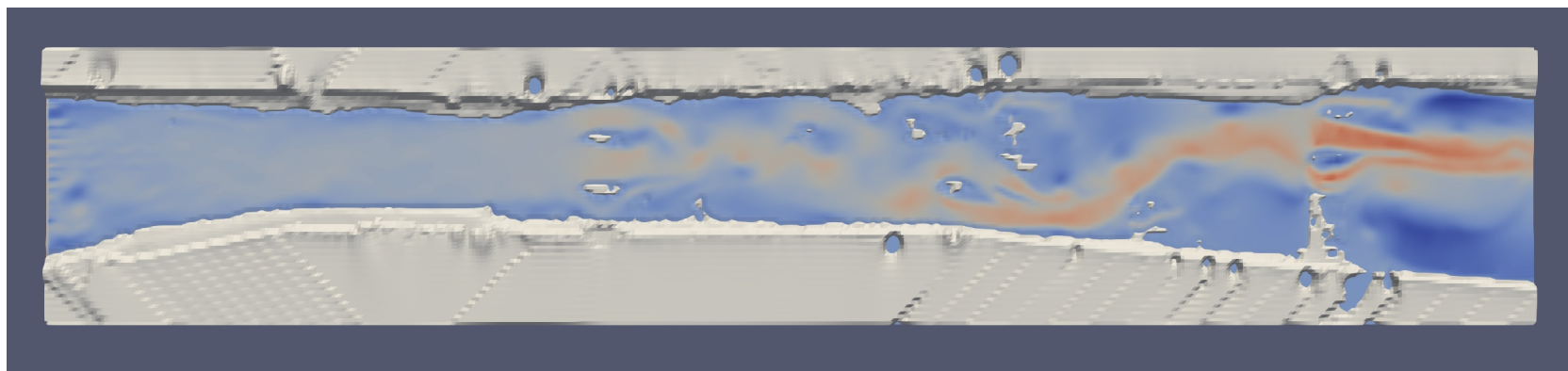


River and Environmental Engineering Flows 3D

Arno, Firenze:

- high hydraulic risk during floods
- several (old) bridges
- weirs
- narrow river corridor
- numerical investigation:
 - CFD: Bridges&Weirs
 - SFLOW: River Hydraulics

[ongoing MSc-thesis at NTNU]

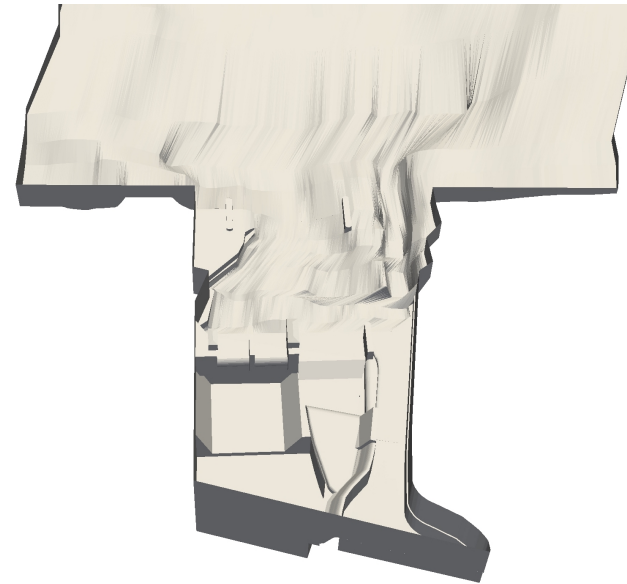


REEF3D::SFLOW (preliminary)

River and Environmental Engineering Flows 3D



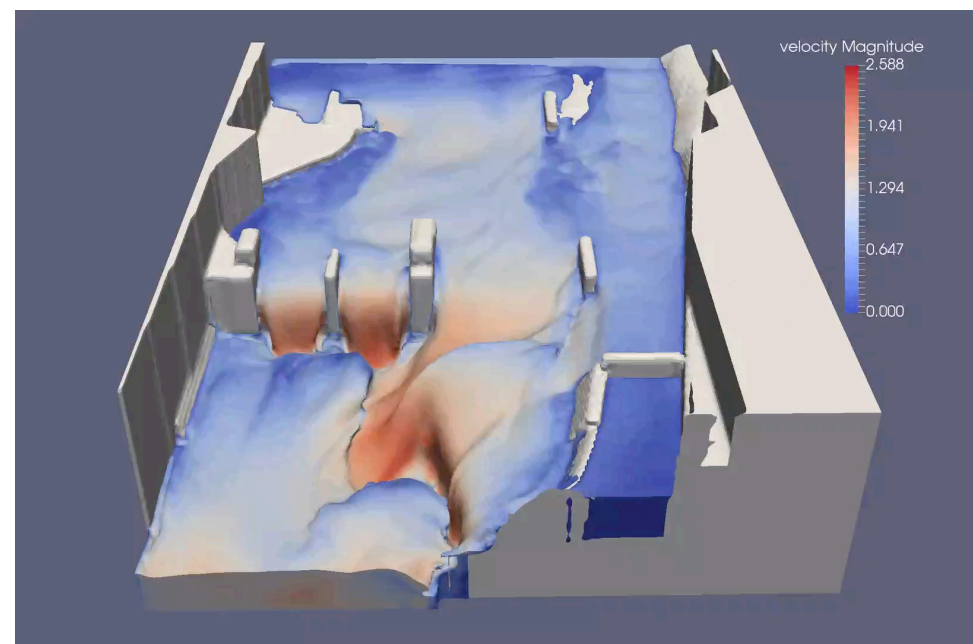
Sarpfossen Hydropower Plant



CAD Model: STL



Laboratory



REEF3D::CFD

Conclusions

- **REEF3D Open-Source Hydrodynamics :**
 - > Phase-resolved Waves on all Scales
- Coastal / Marine / Hydraulic Engineering
- Multiphysics Extensions
 - Floating
 - Sediment
 - Coastal Structures
 - Vegetation
 - Stratified Flow
 - Debris Flow