HySEA model
Benchmark problems 1, 2, 3, 4 and 5

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# The HySEA model

## Plan for the presentation

1. The HySEA model (in few words)
2. (Previous) Validation
4. Benchmark 2 - Hilo Harbour
5. Benchmark 3 - Tauranga Harbour
6. Benchmark 4 - Seaside (Oregon)
7. Benchmark 5 - Triangular shaped shelf with an island
1. The HySEA model

A family of codes

- Non-linear Shallow Water Equations
- Structured and non-structures meshes (multiGPU)
- UTM and lat/lon coordinates (multiGPU)
- Weakly dispersive (MS model). Beta version.
- Two-Layer Savage-Hutter shallow water system (multiGPU)
- Shallow-Water Exner system on structured and non-structured meshes (bedload transport). GPU
- and others (turbidity currents, coupling biology and hidrodynamics, multilayer,...)

Simulating...

- Earthquake generated tsunamis (**tsunami-HySEA**)
- Submarine and aerial landslide generated tsunamis (**landslide-HySEA**)
- Sediment bedload transport
- Turbidity currents and sedimentary plumes
- Physical-biological coupled processes
- others
1. Tsunami-HySEA

### Numerics: A family of Finite Volume numerical schemes

- **Scenarios:** WAF method (LW+HLL)\(^1\) and higher order
- **TEWS:** hybrid 2s+WAF\(^2\)
- **Laboratory experiments:** higher order methods
- Wet/Dry front treatment\(^3,4,5\)
- Nested meshes and/or AMR (GPU)

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\(^1\) de la Asunción et al. (2012). Efficient GPU implementation of a two waves TVD-WAF method for the two-dimensional one layer shallow water system on structured meshes, *Computers & Fluids*.

\(^2\) Article in progress


1. Tsunami-HySEA

Numerics: A family of Finite Volume numerical schemes

- **Scenarios**: WAF method (LW+HLL)\(^1\) and higher order
- **TEWS**: hybrid 2s+WAF\(^2\)
- **Laboratory experiments**: higher order methods
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Nice properties

- Well-balanced (avoid spurious oscillations)
- Transitions from sub to super critical situations (arrival to coast)
- Positivity (no negative layer thickness)
- Inundation area and runup heights are model outputs
- Discontinuities in data or solutions (no need to smooth bathymetry)

Implementation

- CUDA - GPU/Multi-GPU *(very short computing times)*
### The HySEA model. Validation

<table>
<thead>
<tr>
<th><strong>NOAA benchmarks (Synolakis et al., 2008)</strong> ¹</th>
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<tr>
<td><strong>Analytical solutions</strong></td>
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<td>- Single wave on a simple beach</td>
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<tr>
<td>- Solitary wave on composite beach</td>
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<tr>
<td>- Subaerial landslide on simple beach</td>
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<td><strong>Laboratory benchmarking</strong></td>
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<td>- Solitary wave on a simple beach</td>
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<td>- Solitary wave on a composite beach</td>
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<td>- Solitary wave on a conical island</td>
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<td>- Tsunami runup onto a complex three-dimensional beach. Monai Valley</td>
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<td>- Tsunami generation and runup due to three-dimensional landslide</td>
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<td><strong>Field benchmarking</strong></td>
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<tr>
<td>- Okushiri Island</td>
</tr>
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<td>- Rat Islands tsunami</td>
</tr>
</tbody>
</table>

Benchmark Problem 1

Setup

- Test case SB4.02 in Lloyd and Stansby (1995) Part II
- Steady discharge $U=0.115$ m/s
- Water depth $h=0.054$ m
- Reynolds number $Re = 6210$
- Ratio water depth to island height $h/h_i = 1.10$
- Bathymetry

Domain: $[0, 9.75(84)] \times [0, 1.52]$
Resolution: $\Delta x = \Delta y = 0.0152$ m
Mesh: $642 \times 100$
Benchmark Problem 1. What we have done

Numerical Experiments (112)

- **Order of the method**: 1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd}
- **Friction law**:
  - Quadratic (reference value $c_f = 0.006$)
  - Manning ($M_n = 0.01$)
- **Friction coefficient**: inviscid, 0.005 to 0.015 (step 0.001) - 12 cases -
- **3 Boundary conditions** (different implementations of the same BC)
  - ghost cells
  - 1 sponge layer\textsuperscript{1}
  - 2 sponge layer\textsuperscript{1}

\textsuperscript{1} Lavelle and Thacker (2008). Ocean Modelling.
Benchmark Problem 1

Some comments

- Extremely sensitive problem
- 1st order too diffusive (refinement?)
- Any perturbation not leaving the domain will highly interfere the solution
Configuration 1. Quadratic friction with $C_f = 0.006$
1. The HySEA model Benchmark Problem 1 - Boundary Condition 2

Configuration 1. Quadratic friction with $C_f = 0.006$

1 sponge layer – $c=0.006$

![Graphs showing time series data for $u_1$, $v_1$, $u_2$, and $v_2$ with order 2, order 3, and L & S comparison].
Configuration 1. Quadratic friction with $C_f = 0.006$
Benchmark Problem 1 - Boundary Condition 3

Configuration 1. Quadratic friction with $C_f = 0.006$ and Manning $M_n = 0.01$
Configuration 2. Looking for the optimized friction
Configuration 2. Looking for the optimized friction

Second Order – 1 sponge layer

8 (6)
Configuration 2. Looking for the optimized friction
Configuration 2. Looking for the optimized friction
Configuration 2. Looking for the optimized friction

Third Order – 1 sponge layer
Configuration 2. Looking for the optimized friction

Third Order – 2 sponge layers

8 (7.5)
Benchmark Problem 1 - Optimal choice

Just to make an “optimal” choice:

- Amplitude: Order 2 - BC3 - $M_n = 0.01$
- Frequency: Order 3 - BC3 - $c_f$ various (0.01)
1. The HySEA model

Benchmark Problem 1

Benchmark Problem 2

Benchmark Problem 3

Benchmark Problem 4

Benchmark Problem 5

Benchmark Problem 1 - Boundary Condition 1

Configuration 3. Inviscid

0 sponge layer – c=0.0

Time (s)

u1 (m/s)

v1 (m/s)

u2 (m/s)

v2 (m/s)

order 2

order 3

L & S
1. The HySEA model Benchmark Problem 1 - Boundary Condition 2

Configuration 3. Inviscid

1 sponge layer – c=0.0

- $u_1$ (m/s)
- $v_1$ (m/s)
- $u_2$ (m/s)
- $v_2$ (m/s)
Benchmark Problem 1 - Boundary Condition 3

Configuration 3. Inviscid

2 sponge layer – $c=0.0$

$u_1$ (m/s)

$v_1$ (m/s)

$u_2$ (m/s)

$v_2$ (m/s)
Benchmark Problem 1 - Conclusions

About the order
- Forget about 1\textsuperscript{st} order (at least for the given resolution $\Delta x = 0.01$)
- 3\textsuperscript{rd} order not necessarily better (why?)
- Higher the order better the BC must do

About the friction
- High sensitivity for low values
- Low sensitivity for higher values
- Regular, periodic solutions for high friction values
- The better you do (order and BC), sensitivity for higher values increases (frequency)

About the BC
- The implementation of the BC is crucial
- So sensitive that perturbations must leave, if not ...
- But, disappointingly, no one it is the absolute better choice
Benchmark Problem 1 - Sensitivity to friction

High sensitivity to low values

Second Order – 0 sponge layers
Benchmark Problem 1 - Sensitivity to friction

Low sensitivity to high values

Second Order – 0 sponge layers

- $u_1$ (m/s)
- $v_1$ (m/s)
- $u_2$ (m/s)
- $v_2$ (m/s)
Benchmark Problem 1 - Conclusions

About the order
- Forget about 1\textsuperscript{st} order (with the given resolution $\Delta x = 0.01$)
- 3\textsuperscript{rd} order not necessarily better (why?)
- Higher the order better the BC must do

About the friction
- High sensibility for low values
- Low sensibility for higher values
- Regular, periodic solutions for high friction values
- The better you do (order and BC), sensibility for higher values increases
  - for 2\textsuperscript{nd} order 2 sponge layers modify the frequency
  - 3\textsuperscript{rd} order needs 2 sponge layers to homogenize the behaviour

About the BC
- The implementation of the BC is crucial
- So sensitive that perturbations must leave, otherwise ...

And finally
- Disappointedly, we do not have a better choice
Benchmark Problem 2 - Hilo Harbor

Description and Aim

- **Field dataset** - Japan 2011 at Hilo Harbour (Hawaii)
- **Primary goal**: assess **model resolution** and **numerics** on the prediction of tsunami currents
  - Level of precision
  - Convergence (at least 3 resolutions: \(\approx 20\) m, \(\approx 10\) m and \(\approx 5\) m or lower)
  - Variation across different models
Benchmark Problem 2 - Hilo Harbor

Setup - Bathymetry
**Benchmark Problem 2 - Hilo Harbor**

**Setup**
- Domain: $[204.90, 204.96] \times [19.71, 19.773]$ (approx $7 \times 7$ km)
- Data Resolution: $1/3$ arcsec ($\approx 10$ m)
- Mesh: $692 \times 701$
- Max depth $30$ m
- Manning coefficient $n = 0.025$ (But also $n = 0.030$ and $0.035$)

**Boundary Condition**
- Offshore simulated free surface elevation
- Control point at $(19.7576, 204.93)$
- Modellers chose the forcing

![Ocean Surface Elevation at Control Point (simulated)](image)
### Benchmark Problem 2 - *What we have done*

1. **Reduced domain** simulations at different resolutions (aim of the benchmark)
   - Three requested resolutions (2/3, 1/3 and 1/6 arcsec)
   - Sensitivity to friction (n=0.025, 0.030, and 0.035)

2. **Complete scenario** simulations at different resolutions (encouraged)
   - Three level nested mesh decomposition
   - Finer mesh of 2/3, 1/3 and 1/6 arcsec
   - Varying coarse meshes
1. Comparison and Sensitivity to Friction

Control Point - [lat,lon] = (19.7576,204.93) - Res 1/6 - Mn=0.025
Benchmark Problem 2 - Free surface elevation at the tidal station

1. Comparison and Sensitivity to Friction

Hilo Tide Station - [lat,lon] = (19.7308,204.9447) - Res 1/6 - Mn=0.025

De-tided Tide Gage Data, Hilo Harbor

De-tided Tide Gage Data, Hilo Harbor – Sensitivity to friction
Benchmark Problem 2 - Depth-average horizontal velocity data

1. Comparison

HA1125, Harbour entrance - [lat,lon] = (19.7452,204.9180) - Res 1/6
1. Sensitivity to Friction

HA1125, Harbour entrance - [lat,lon] = (19.7452,204.9180) - Res 1/6


- **Data**
- **Mn=0.025**
- **Mn=0.030**
- **Mn=0.035**


- **Data**
- **Mn=0.025**
- **Mn=0.030**
- **Mn=0.035**
1. Comparison

HA1126, Inside Harbour - [lat,lon] = (19.7417,204.9300) - **Res 1/6**

- **u (cm/s)**
  - HA 1126:Hilo Harbor – E–W Current Speeds – Res 1/6 – Mn=0.025
  - Data vs Model

- **v (cm/s)**
  - HA 1126:Hilo Harbor – N–S Current Speeds – Res 1/6 – Mn=0.025
  - Data vs Model

The graphs show the depth-average horizontal velocity data over time after the EQ (hours) for HA1126 at Hilo Harbor. The data is compared with the model results for different resolutions and moment magnitudes.
Benchmark Problem 2 - Depth-average horizontal velocity data

1. Sensitivity to Friction

HA1126, Inside Harbour - [lat,lon] = (19.7417,204.9300) - Res 1/6


2. Convergence: Mesh Refinement

Sea Surface Elevation - Control Point and Hilo Tide Station

Ocean Surface Elevation at Control Point – Convergence

De-tided Tide Gage Data, Hilo Harbor – Convergence
2. Convergence: Mesh Refinement

Currents at HA1125, Harbour entrance


HA 1125: Approach to Hilo Harbor – N–S Current Speeds – Convergence
2. Convergence: Mesh Refinement

Currents at HA1126, Inside Harbour

HA 1126:Hilo Harbor – E–W Current Speeds – Convergence

HA 1126:Hilo Harbor – N–S Current Speeds – Convergence
Benchmark Problem 2 - Maximum Speed Maps

3. Convergence for Maximum Velocity

Maximum Speed Map
3. Convergence for Maximum Velocity

Maximum Speed Map
Benchmark Problem 2 - Maximum Speed Maps

3. Convergence for Maximum Velocity

Maximum Speed Map

![vmax 5m resolution](image_url)
3. Convergence for Maximum Velocity

Maximum Difference Speed Maps

differences 5m-20m resolutions
differences 5m-10m resolutions
Benchmark Problem 2 - **Complete scenario**

2. **Complete scenario** simulations at different resolutions (encouraged)

- Three level nested mesh decomposition
- Coarse ambient mesh 128/3 arc sec
- Intermediate 8/3 arc sec mesh
- Finer meshes of 2/3, 1/3 and 1/6 arcsec (three resolutions)
- But also varying in resolution coarse and intermediate meshes (256/3 and 16/3)
- Two sources (from NOAA and GeoClaw)

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**Computational domain** $[130, 206] \times [19.35, 43]$

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Resolution</th>
<th># of cells in lat</th>
<th># of cells in lon</th>
<th># of cells</th>
<th>cell size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>128/3 arc-sec</td>
<td>6,414</td>
<td>1,996</td>
<td>12,802,344</td>
<td>1,280</td>
</tr>
<tr>
<td>B</td>
<td>8/3 arc-sec</td>
<td>672</td>
<td>672</td>
<td>451,584</td>
<td>80</td>
</tr>
<tr>
<td>C1</td>
<td>2/3 arc-sec</td>
<td>360</td>
<td>352</td>
<td>126,720</td>
<td>20</td>
</tr>
<tr>
<td>C2</td>
<td>1/3 arc-sec</td>
<td>720</td>
<td>704</td>
<td>506,880</td>
<td>10</td>
</tr>
<tr>
<td>C3</td>
<td>1/6 arc-sec</td>
<td>1,424</td>
<td>1,392</td>
<td>1,982,208</td>
<td>5</td>
</tr>
</tbody>
</table>
Benchmark Problem 2 - Complete scenario

Nested meshes spatial extension

- Three level nested mesh decomposition
- A : $[130, 206] \times [19.35, 43]$ (128/3 arc sec)
- B : $[204.5, 204.97] \times [19.52, 20]$ (8/3 arc sec)
- C : $[204.9, 204.965] \times [19.711, 19.773]$ (2/3, 1/3 and 1/6 arcsec)
Benchmark Problem 2 - Complete scenario

Nested meshes spatial extension
1. Sensitivity to mesh refinement - Inner Mesh

Control Point - [lat,lon] = (19.7576,204.93)
1. Sensitivity to mesh refinement - Inner Mesh

Hilo Tide Station - [lat,lon] = (19.7308,204.9447)

- De-tided Tide Gage Data, Hilo Harbor
- E–W Current Speeds at Hilo Harbor
- N–S Current Speeds at Hilo Harbor
1. Sensitivity to mesh refinement - Inner Mesh

HA1125, Harbour entrance - [lat,lon] = (19.7452,204.9180)
1. Sensitivity to mesh refinement - Inner Mesh

HA1126, Inside Harbour - [lat,lon] = (19.7417,204.9300)
Benchmark Problem 2 - Complete scenario - Time series at control point

2. Sensitivity to mesh refinement - Ambient and Intermediate Meshes

Control Point - [lat,lon] = (19.7576,204.93)

Ocean Surface Elevation at Control Point – CI NOAA

E–W Current Speeds at Control Point

N–S Current Speeds at Control Point
2. Sensitivity to mesh refinement - Ambient and Intermediate Meshes

Hilo Tide Station - [lat,lon] = (19.7308,204.9447)
2. Sensitivity to mesh refinement - Ambient and Intermediate Meshes

HA1125, Harbour entrance - [lat,lon] = (19.7452,204.9180)

Graphs showing:
- Ocean Surface Elevation at HA 1125: Approach to Hilo Harbor – CI NOAA
- HA 1125: Approach to Hilo Harbor – N–S Current Speeds
Benchmark Problem 2 - Complete scenario - Time series at HA1126

2. Sensitivity to mesh refinement - Ambient and Intermediate Meshes

HA1126, Inside Harbour - [lat,lon] = (19.7417,204.9300)
Benchmark Problem 2 - Complete scenario - Initial Conditions

3. Two Sources as Initial Condition (NOAA and GeoClaw)
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3. Two Sources as Initial Condition (NOAA and GeoClaw)

Hilo Tide Station - \([\text{lat,lon}] = (19.7308,204.9447)\)
3. Two Sources as Initial Condition (NOAA and GeoClaw)

HA1125, Harbour entrance - [lat,lon] = (19.7452,204.9180)
3. Two Sources as Initial Condition (NOAA and GeoClaw)

HA1126, Inside Harbour - \([\text{lat,lon}] = (19.7417,204.9300)\)

Ocean Surface Elevation at HA 1126:Hilo Harbor – Res 1/3

HA 1126:Hilo Harbor – E–W Current Speeds

HA 1126:Hilo Harbor – N–S Current Speeds
Benchmark Problem 3 - Tauranga Harbour

Description and Aim

- **Field dataset** - Japan 2011 in Tauranga Harbour (New Zealand)
- **Aim:** Attempt to include effects of tides

Observed Data
Benchmark Problem 3 - Tauranga Harbour

Setup - Bathymetry
## Benchmark Problem 3 - Tauranga Harbour

### Setup

- **Domain:** \([0, 40000] \times [0, 20000]\) in meters (rotated) - 40 km \(\times\) 20 km
- **Data Resolution:** 10 m
- **Numerical resolution:** 20 m \((a \times b)\)
Setup - Boundary Condition

- Use most offshore measured free surface elevation data (ABeacon tide gage)
Benchmark Problem 3 - Free surface elevation at the 4 tidal stations

**Tsunami-Only signal**

- **Extracted Tsunami Signal ABeacon**
- **Extracted Tsunami Signal Tug Berth**
- **Extracted Tsunami Signal Sulfur Point**
- **Extracted Tsunami Signal Motu**
Benchmark Problem 3 - Free surface elevation at the 4 tidal stations

**Tsunami + Tide signal**

- **Total Recorded Signal ABeacon**
- **Total Recorded Signal Tug Berth**
- **Total Recorded Signal Sulfur Point**
- **Total Recorded Signal Motu**
Benchmark Problem 3 - Free surface elevation at the 4 tidal stations

Tide-Only signal

Extracted Tidal Signal ABeacon

Extracted Tidal Signal Tug Berth

Extracted Tidal Signal Sulfur Point

Extracted Tidal Signal Motu
Benchmark Problem 3 - Depth-Average Horizontal Velocity data

ADCP: \([\text{lat,lon}] = (-37.6307, 176.18377) - [x,y] = (29250, 14660)\) (rotated)

ADCP Data: (Filtered) Tide Signal Only

ADCP Data: (Filtered) Tsunami Signal Only

ADCP Data: Measured (Complete) Signal
Benchmark Problem 4 - Seaside (Oregon)

Description
- Single long-period wave
- Piecewise linear slope and small scale model of Seaside (Oregon)
- Free surface information
- Velocity information

Setup - Bathymetry
Benchmark Problem 4 - Seaside (Oregon)

**Setup**

- Domain: $[0.012, 43.633] \times [-13.261, 8.549]$ in meters ($43.621 \times 21.81$ meters)
- Data Resolution: 0.01 m
- Mesh: $4363 \times 2182$

**Physical Model**

![Physical Model Diagram]
Benchmark Problem 4 - Seaside (Oregon)

Setup - Boundary Condition

- **Wavemaker**
  - Wavemaker Displacement Time Series – REAL DATA. Can use this to drive a moving wall BC
  - ![Graph showing wavemaker displacement time series](image)

- **Incident wave time series at x=5m**
  - Incident-only Wave Time Series at X=5m – SIMULATED DATA. Can use this to drive a stationary input wave BC at X=5m
  - ![Graph showing incident wave time series](image)
Benchmark Problem 4 - Seaside (Oregon)

Water surface elevation at WG3

Simulated vs Measured Data @ X=18.618m, Y=0m – Control Point
Benchmark Problem 4 - Seaside (Oregon)

Measured Data at B1, B4, B6, B9 (Flow Depth - Velocity - Specific Momentum Flux)

- **Flow Depth Data**
  - Location B1: (33.721, −0.588)
  - Location B4: (35.176, −0.406)
  - Location B6: (36.635, −0.229)
  - Location B9: (40.668, 0.269)

- **Cross-Shore Velocity Data**
  - Location B1: (33.721, −0.588)
  - Location B4: (35.176, −0.406)
  - Location B6: (36.635, −0.229)
  - Location B9: (40.668, 0.269)

- **Cross-Shore Specific Momentum Flux Data**
  - Location B1: (33.721, −0.588)
  - Location B4: (35.176, −0.406)
  - Location B6: (36.635, −0.229)
  - Location B9: (40.668, 0.269)
Benchmark Problem 4 - Seaside (Oregon)

What we have done

- Numerical Resolution: 1 and 2 cm
- Numerical scheme: Order 1, 2 and WAF (Order 2 presented)
- Varying friction (from 0.01 to 0.035)
- Spatial variability (4 cm distance)

Spatial Variability
Benchmark Problem 4 - Seaside (Oregon)

What we have done

- Numerical Resolution: 1 and 2 cm
- Numerical scheme: Order 1, 2 and WAF (Order 2 presented)
- Varying friction (from 0.01 to 0.035)
- Spatial variability (4 cm distance)

Spatial Variability

[Graph showing spatial variability with a color scale from 0 to 1.4]
Benchmark Problem 4 - Seaside (Oregon)

Flow Depth Spatial Variability for all the “B1” points

Simulated vs Measured Flow Depth Data – Location B1 (33.721, −0.588)

Simulated vs Measured Flow Depth Data – Location B1_1 (33.721, −0.640)

Simulated vs Measured Flow Depth Data – Location B1_2 (33.721, −0.680)

Simulated vs Measured Flow Depth Data – Location B1_3 (33.721, −0.720)
Benchmark Problem 4 - Seaside (Oregon)

Flow Depth Spatial Variability for all the “B4” points

Simulated vs Measured Flow Depth Data – Location B4 (35.176, −0.406)

Simulated vs Measured Flow Depth Data – Location B4_1 (35.176, −0.440)

Simulated vs Measured Flow Depth Data – Location B4_2 (35.176, −0.480)
Benchmark Problem 4 - Seaside (Oregon)

Flow Depth Spatial Variability for all the “B6” points

Simulated vs Measured Flow Depth Data – Location B6 (36.635, -0.229)

Simulated vs Measured Flow Depth Data – Location B6_1 (36.635, -0.270)

Simulated vs Measured Flow Depth Data – Location B6_2 (36.635, -0.310)
Benchmark Problem 4 - Seaside (Oregon)

Flow Depth Spatial Variability for all the “B9” points

Simulated vs Measured Flow Depth Data – Location B9 (40.668, 0.269)

Simulated vs Measured Flow Depth Data – Location B9_1 (40.668 0.230)

Simulated vs Measured Flow Depth Data – Location B9_2 (40.668 0.310)
Benchmark Problem 4 - Seaside (Oregon)

Simulated vs Measured Data comparison at B1

Simulated vs Measured Flow Depth Data – Location B1 (33.721, -0.588)

Simulated vs Measured Cross–Shore Velocity Data – Location B1 (33.721, -0.588)

Simulated vs Measured Cross–Shore Momentum Flux Data – Location B1 (33.721, -0.588)
Benchmark Problem 4 - Seaside (Oregon)

Simulated vs Measured Data comparison at B4

Simulated vs Measured Flow Depth Data – Location B4

Simulated vs Measured Cross–Shore Velocity Data – Location B4

Simulated vs Measured Cross–Shore Momentum Flux Data – Location B4
Benchmark Problem 4 - Seaside (Oregon)

Simulated vs Measured Data comparison at B6

**Simulated vs Measured Flow Depth Data – Location B6**

**Simulated vs Measured Cross–Shore Velocity Data – Location B6**

**Simulated vs Measured Cross–Shore Momentum Flux Data – Location B6**
Benchmark Problem 4 - Seaside (Oregon)

Simulated vs Measured Data comparison at B9

Simulated vs Measured Flow Depth Data – Location B9

Simulated vs Measured Cross–Shore Velocity Data – Location B9

Simulated vs Measured Cross–Shore Momentum Flux Data – Location B9
Simulated vs Measured Data comparison at B9

1. **Simulated vs Measured Flow Depth Data**
   - **Location B9**
   - Data points for different flow depths are shown over time.

2. **Simulated vs Measured Cross-Shore Velocity Data**
   - **Location B9**
   - Data points for different velocities are shown over time.

3. **Simulated vs Measured Cross-Shore Momentum Flux Data**
   - **Location B9**
   - Data points for different momentum fluxes are shown over time.
Setup

- Single solitary wave
- Triangular shaped shelf with an island
- Free surface information
- Velocity information
Benchmark Problem 5

Setup - Bathymetry

Bathymetric Data

- Approx. Domain: $[-0.1, 44.6] \times [-13, 13]$ in meters ($43.744 \times 26.554$ m)
- Data Resolution: $\Delta x = 0.0438$ m - $\Delta y = 0.0266$ m
- Mesh: $1,000 \times 1,000$
Benchmark Problem 5

Model Set-up

- Extended domain $[-9, 44.6] \times [-13, 13]$
- Initial Condition:
  - Imposed surface elevation (soliton) from Tonelli and Petti (2009):
    \[
    \eta(x, t = 0) = A \text{sech} \left[ (x - x_0) \sqrt{3A/(4H^3)} \right]
    \]
  - Velocity Correction:
    \[
    u(x, 0) = \eta(x, 0) \sqrt{gH/H}
    \]
    with $x_0 = -3.3$ m; $A = 0.39$ m; $H = 0.78$ m; $g = 9.81$ m/s.
- Initial condition:
  - $h(x, y, 0) = \eta(x, 0) + 0.78$
  - $q_x(x, y, 0) = h(x, y, 0) u(x, 0)$
  - $q_y = 0.0$
- Time of simulation: 20 s
Benchmark Problem 5

Setup - Initial Condition

Initial Surface Elevation

Initial Velocity
Benchmark Problem 5

What we have done

- SW non-dispersive
  - Test order (2\textsuperscript{nd} and 3\textsuperscript{rd})
  - Mesh resolution (2.5 cm, 5 cm, 10 cm)
  - Friction (from 0.005 to 0.035)
- SW Dispersive (beta version)
  - 3\textsuperscript{rd} order
  - Resolution 10 cm (490×260)
  - Friction (from 0.005 to 0.035)

Some preliminary conclusions

- Dispersion is mandatory
- Friction is mostly felt in the points behind the obstacle (more if just behind)
Benchmark Problem 5. Mesh resolution

SW non-dispersive - **Three resolutions** (2.5 cm, 5 cm, 10 cm) - 3\textsuperscript{rd} order - Fric 0.025
Benchmark Problem 5. Mesh resolution

SW non-dispersive - **Three resolutions** (2.5 cm, 5 cm, 10 cm) - 3\(^{rd}\) order - Fric 0.025
Benchmark Problem 5. Mesh resolution

SW non-dispersive - **Three resolutions** (2.5 cm, 5 cm, 10 cm) - 3rd order - Fric 0.025

![Graphs showing FSE at X=25m, Y=0m, Y=5.0m, Y=10.0m for different mesh resolutions](image-url)
Benchmark Problem 5 - Sensitivity to friction

**SW non-dispersive - 3rd order - Res 10 cm - Varying friction**

![Graphs of FSE at different positions with varying friction](image-url)
Benchmark Problem 5 - Sensitivity to friction

SW non-dispersive - 3rd order - Res 10 cm - Varying friction

The figure shows three graphs, each representing the time evolution of the free surface elevation (FSE) at different locations: X=7.5m, Y=5.0m, X=13.0m, Y=5.0m, and X=21.0m, Y=5.0m. The graphs illustrate the variation of FSE over time for different friction values, ranging from 0.005 to 0.035.

The x-axis represents time in seconds, and the y-axis represents the free surface elevation in meters. The graphs display the data for each friction value, allowing for the comparison of the response under varying friction conditions.
Benchmark Problem 5 - **Sensitivity to friction**

**SW non-dispersive** - 3rd order - Res 10 cm - Varying friction

- **FSE @ X=25m, Y=0m**
- **FSE @ X=25m, Y=5.0m**
- **FSE @ X=25m, Y=10.0m**

![Graphs showing depth (m) vs. time (sec) for different friction coefficients](image-url)
Benchmark Problem 5. Dispersion - Sensitivity to friction

**SW non-dispersive** - 3rd order - Res 10 cm - Varying friction

![Graph showing ADV @ x=13m, y=0m](image)
Dispersion model - Madsen and Sorensen (1992)

- Dispersion coefficient: 1/21
- Breaking wave criteria (based on Kazolea, Delis and Synolakis, 2014).
  Dispersion is locally applied when:
  - \( h_i > h_{\text{eps}} \) and
  - \( |\partial_t \eta_i| < \gamma \sqrt{g h_i} \) with \( \gamma = 0.65 \)
  - \( (\partial_x \eta_i)^2 + (\partial_y \eta_i)^2 < \tan^2(\phi_c) \) with \( \phi_c = 33^\circ \)
Benchmark Problem 5. Dispersion - Sensitivity to friction

Dispersive SW - 3\textsuperscript{rd} order - Res 10 cm - Varying friction

![Graph showing dispersion over time with varying friction for X=7.5m, Y=0m, X=13.0m, Y=0m, X=21.0m, Y=0m.](image)

Data points and curves represent different friction values: fric 0.005, fric 0.01, fric 0.015, fric 0.02, fric 0.025, fric 0.03, fric 0.035.
Benchmark Problem 5. Dispersion - Sensitivity to friction

Dispersive SW - 3rd order - Res 10 cm - Varying friction

FSE @ X=7.5m, Y=5.0m

FSE @ X=13.0m, Y=5.0m

FSE @ X=21.0m, Y=5.0m
Benchmark Problem 5. Dispersion - Sensitivity to friction

Dispersive SW - 3\textsuperscript{rd} order - Res 10 cm - Varying friction

![Graphs showing dispersion sensitivity to friction](image-url)
Benchmark Problem 5. Dispersion - Varying friction

Dispersive SW - 3rd order - Res 10 cm - Varying friction

ADV @ x=13m, y=0m

Mean U component (m/s)

Mean V component (m/s)

Time (sec)