Wave-Current Interactions Representation by Coupling Spectral Wave and Coastal Hydrodynamics Models

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1. Introduction

Wave-current interactions occur in coastal waters affecting a plethora of applications, from port navigation to sediment transport to weather predictions. Water levels and currents affect

- wave propagation and
- the location of wave breaking

The currents and water levels are in turn influenced by

- the radiation stress caused by wave transformation and
- the circulation and vertical mixing induced by wind-driven waves

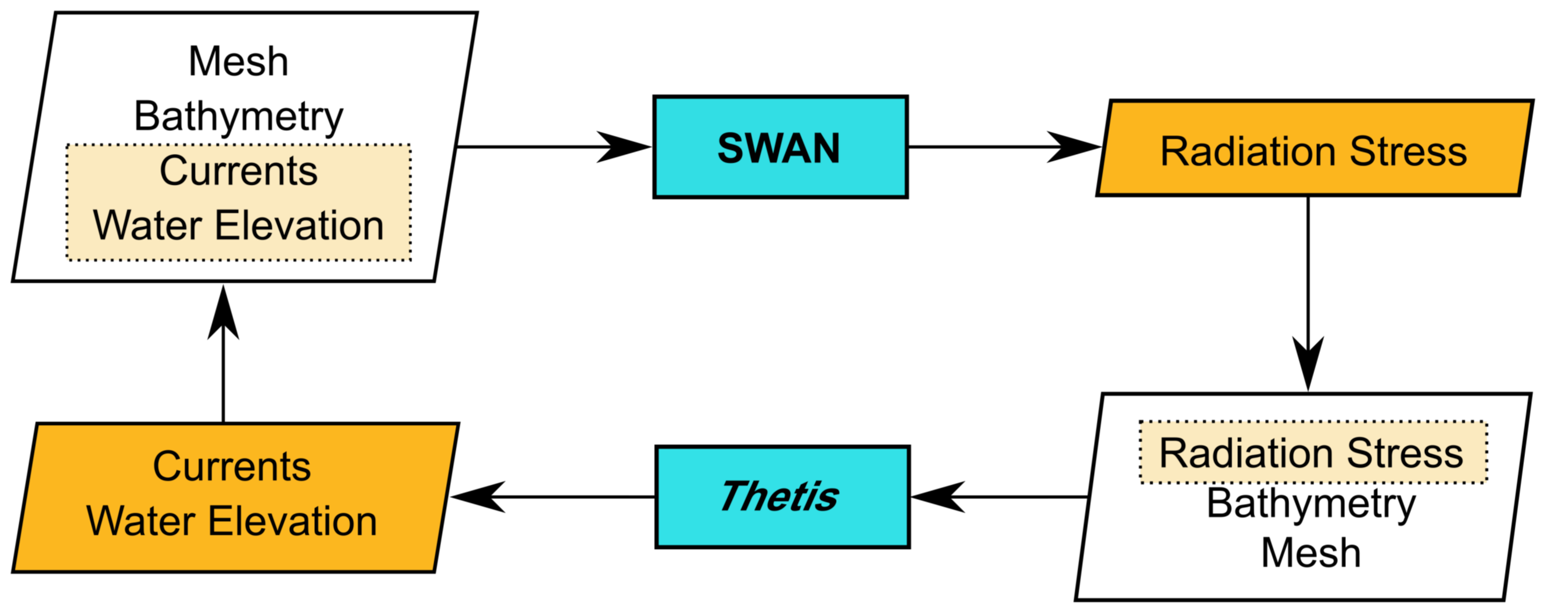
2. Aim

Development of a versatile parallelized unstructured wave-current interaction model that couples the spectral wave model, SWAN [1], with the 2D hydrodynamic model, *Thetis* [2], to investigate wave-current interactions in coastal waters at a regional scale.

3. Coupled Model : SWAN + *Thetis*

SWAN (Simulating Waves Nearshore) is a spectral wave model based on the action density equation containing various source-terms accounting for deep- and shallow-water phenomena.

Thetis is a hydrodynamic model that can be employed with either a 2D or 3D configuration. It considers the non-conservative form of the shallow-water equations. Its repository is https://github.com/thetisproject/thetis



The coupled model follows an iterative procedure, which is initialized by SWAN. SWAN provides the radiation stress for *Thetis*, while *Thetis* calculates the water elevation of depth and currents for SWAN. The models are run in sequence either serially or in parallel.

4. Case Study : Gradually Varying Bathymetry

In a gradually varying bathymetry, the radiation stress causes

- an increase of the water level near the shoreline (set – up) and
- a decrease of the water level near the breaking point (set-down)

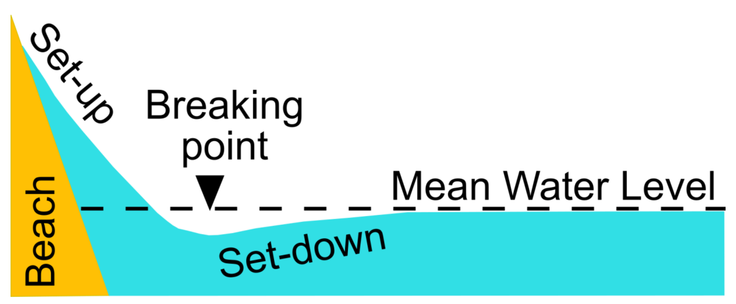


*Figure is shown in distorted scales

5. Analytical solution

Longuet-Higgins and Stewart in 1964 [3] studied the case of wave setup on a gradually varying bathymetry. They provided an analytical solution in two zones, defined by the point x_B, which denotes the surf zone.

i) Outside the surf zone $(x \geq x_B)$ the water elevation η is:

$$\eta = -\frac{\alpha^2 k}{2\sinh(2kd)}$$

where α: the wave amplitude, k: the wavenumber, d: the water depth.

ii) Inside the surf zone $(x \leq x_B)$, the water elevation is:

$$\eta = \frac{1}{1+\frac{2}{3\beta^2}}(d_B - d) + \eta_B$$

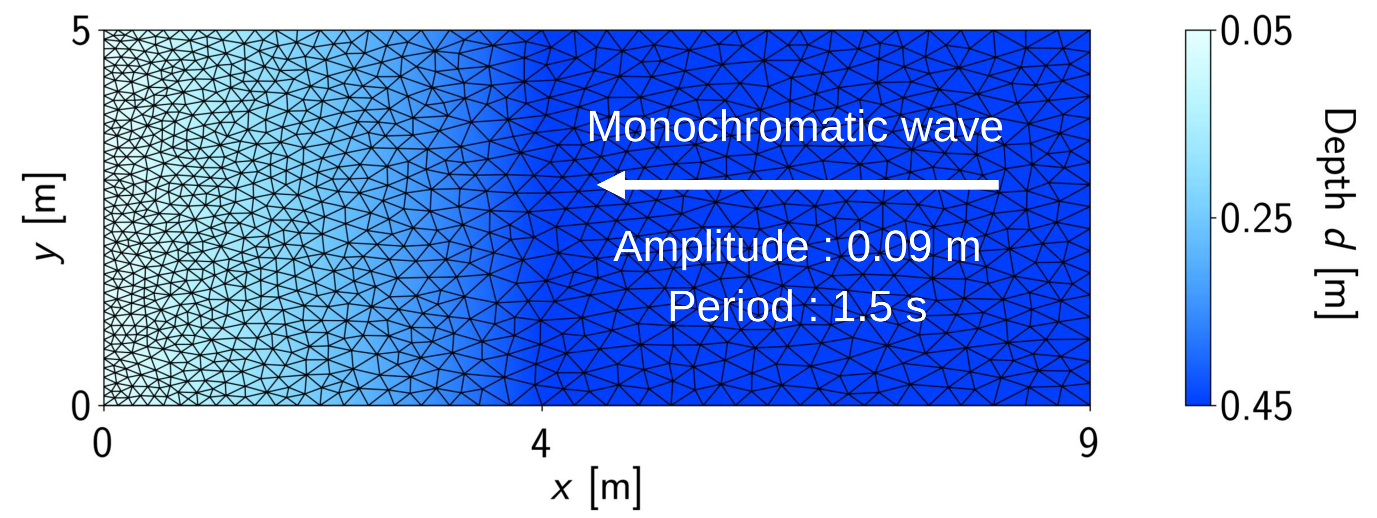
where β: a wave breaking constant, equal to 0.415 [5]; the subscript B denotes quantities at $x = x_B$.

6. Domain

The mesh is unstructured with resolution 0.125 at x = 0 m & 0.400 m at x = 9 m

Number of nodes : 1135

Number of cores : 1



Physical processes:

✗ Bottom friction

✓ Wave breaking

Boundary Conditions

- SWAN : Monochromatic wave
- *Thetis* : Elevation from analytical solution

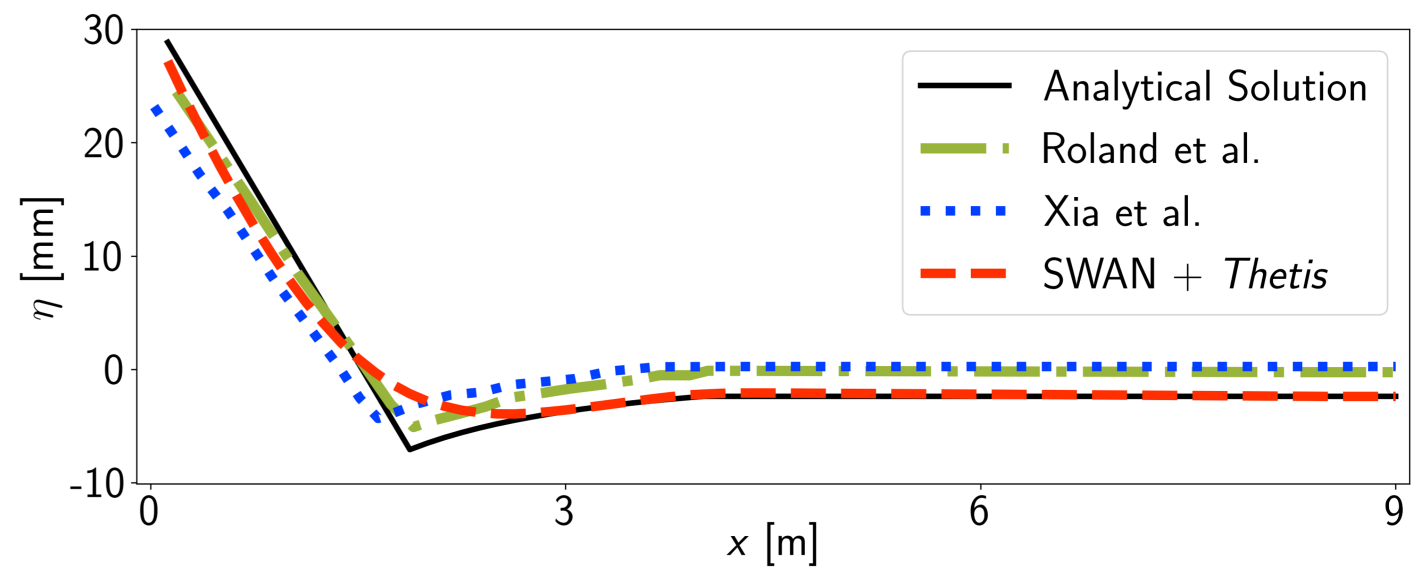
7. Numerical studies

Results from previous studies are used for comparison against the developed model. Some key characteristics of the models' configuration for the case study are briefly outlined.

Characteristic	SWAN + *Thetis*	Roland et al. [4]	Xia et al.[5]
2D Hydrodynamic Model	✓		
3D Hydrodynamic Model		✓	✓
Spectral Wave Model	✓	✓	✓
Structured mesh		✓	✓
Unstructured mesh	✓		
Mesh resolutions [m]	[0.125, 0.400]	0.125	0.125
Timestep [s]	1.5	0.050	0.002

8. Results

The proposed model approximates the analytical solution well with R^2= 96.50% and $RMSE$ = 1.5 mm



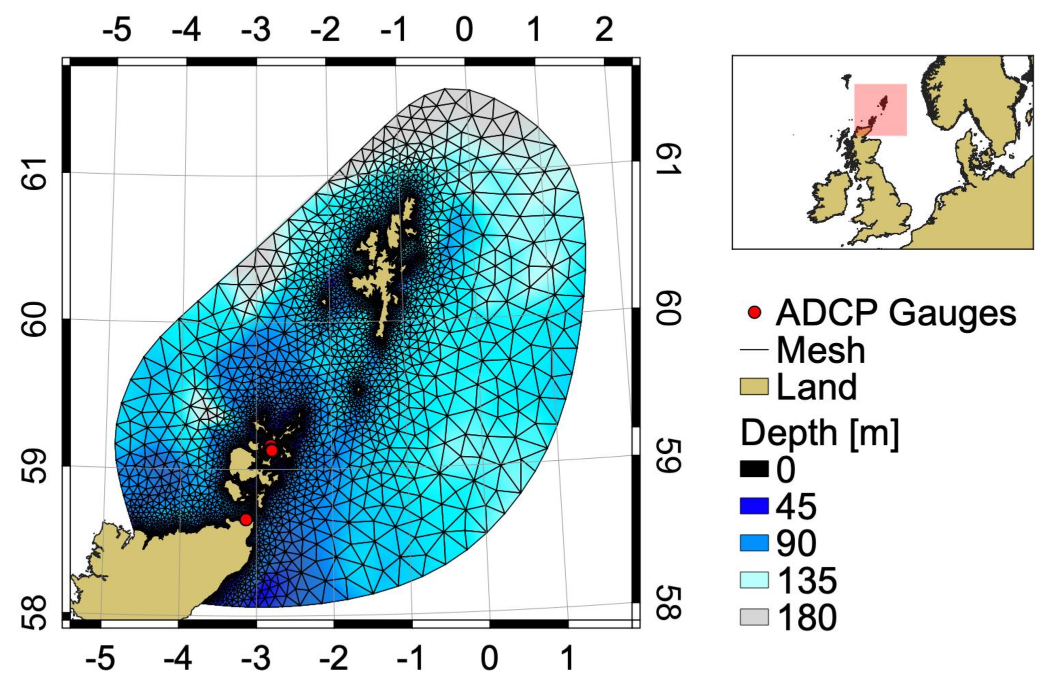
The solution converges at 26 timesteps, while Roland et al.'s converged at roughly 43200 timesteps [4].
To see the water levels' evolution, scan the code on the left.

9. Conclusions

- Fully coupled SWAN – *Thetis* model.
- Accurate representation of the wave setup occurring in gentle slopes.
- Higher accuracy compared to other models.
- Developed model converges 1660 times faster compared to [4].
- Less computational cost compared to other models.

10. Future Work

- Concurrent rather than sequential simulation of SWAN and *Thetis.*
- Wave-current interactions in the case of a submerged breakwater.
- Wave-current interactions in a realistic scenario: Orkney-Shetland waters.



Orkney-Shetland waters: suitable for wave and tidal energy extraction. Both energy forms are influenced by wave-current interactions. Thus, the inclusion of these interactions are crucial for an accurate estimation of energy characterization.

Scan the code on the left to watch the hydrodynamics of Orkney-Shetland islands for the period 01/08/2017 – 15/08/2017.

References: [1] Booij et al. (1999). https://doi.org/10.1029/98JC02622; [2] Kärnä et al. (2018). https://doi.org/10.5194/gmd-11-4359-2018; [3] Longuet-Higgins & Stewart, (1964). https://doi.org/10.1016/0011-7471(64)90001-4; [4] Roland et al., (2012). https://doi.org/10.1029/2012JC007952; [5] Xia et al., (2004). https://doi.org/10.1016/j.coastaleng.2004.03.003