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Wave-resolving Hydro-morphodynamic Modelling of Barred Beaches

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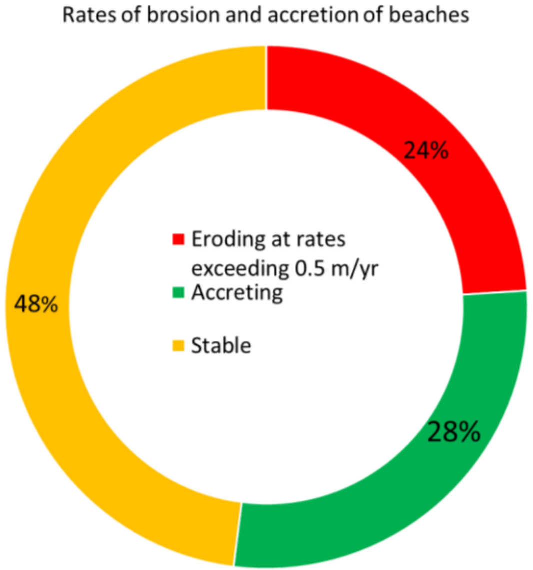
Outline

- Introduction
- Motivation and statement of problem
- Study objectives
- Non-hydrostatic modelling of fixed and mobile barred beaches using XBeach
- Conclusions and Outlook

Introduction (Some statistics)

- 24% of the world's sandy beaches are eroding at rates exceeding 0.5 m/yr and 28% are accreting, while 48% are stable (Luijendijk et al., 2018)
- The number of the people in the low-elevated coastal zones exposed to a 100-year coastal flood will increase up to 950 million in 2030 and 1400 million in 2060
- Therefore, quantitative prediction of beach erosion and recovery is essential to planning resilient coastal communities.



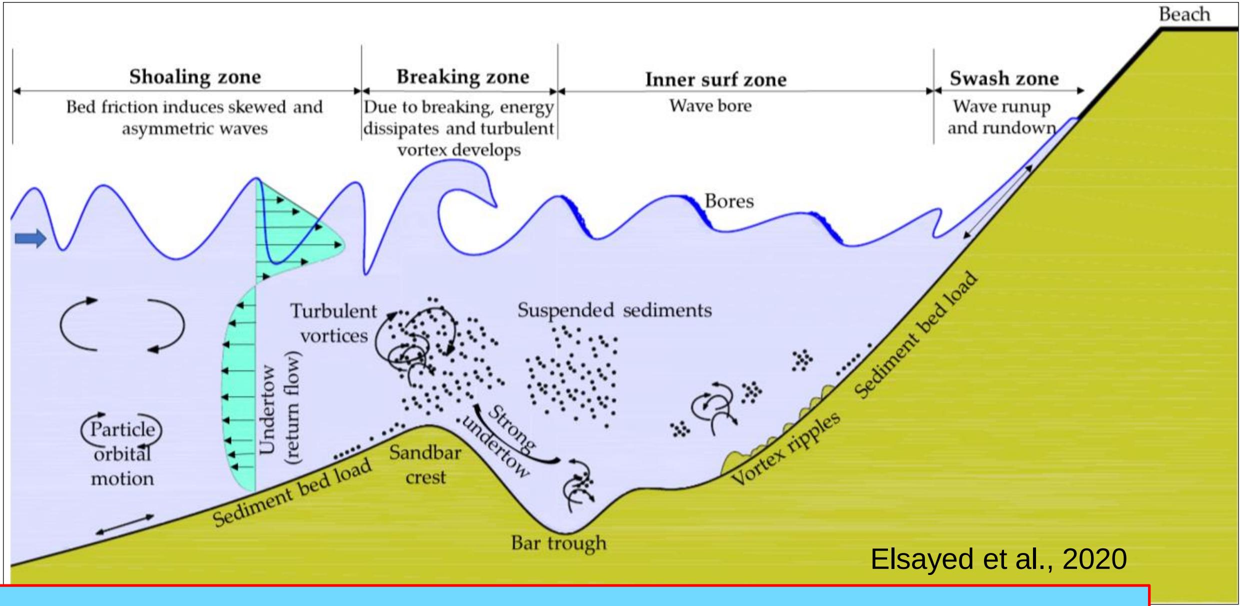
After Luijendijk et al., 2018

Coastal adaptation strategies are currently often assessed using numerical modelling.

Introduction (Selection of a numerical model)

- The selection of a numerical model depends manly on its capability to reproduced the nearshore processes, including shoaling, wave breaking and run up, sediment transport and bed morphology.

- For large demines, 2D models are more practical in order to reduce the computational demand.



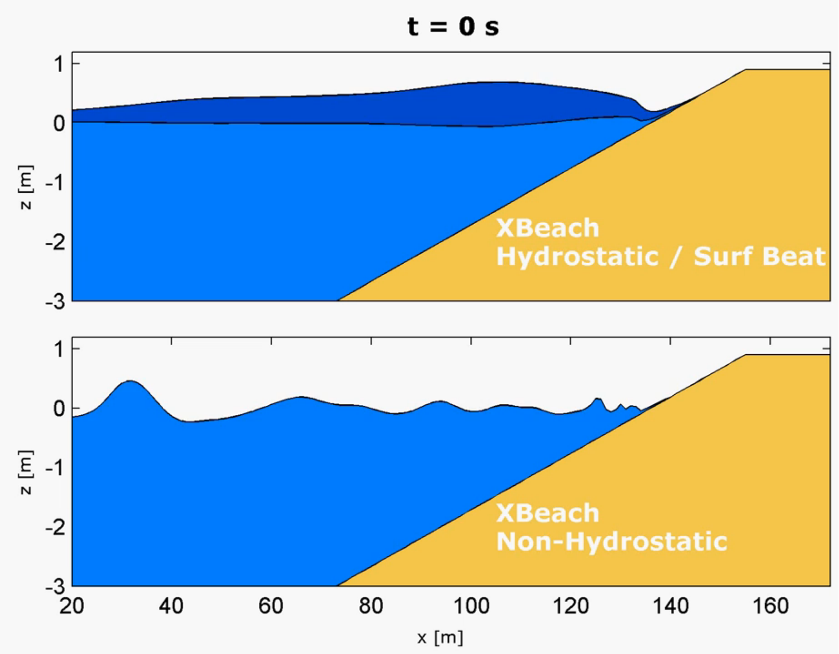
Elsayed et al., 2020

XBeach is a widely used model to simulate nearshore hydrodynamics and coastal erosion

Introduction (two hydrodynamic modes)

XBeach modes

- Non-hydrostatic/wave-resolving mode
  - Hydrodynamic Module (non-hydrostatic)
    - Solves the NLSWEs, including a non-hydrostatic pressure.
    - Intra-waves processes (e.g. wave asymmetry and skewness) are resolved
    - Wave breaking is resolved, but overturning is omitted
  - Morphodynamic Module
- Hydrostatic/surf-beat/ wave averaged mode
  - Morphodynamic Module
    - Calculates sediment entrainment, accretion and subsequent bathymetric changes
    - Calculates slopes avalanching and bank instabilities
  - Hydrodynamic Module (Hydrostatic)
    - Solves the long waves based on the NLSWEs
    - Short waves are considered on the wave group scale (short wave envelope) by wave action balance, then their effect is embedded in the NLSWEs
    - Intra-waves processes (e.g. wave asymmetry and skewness) are approximated

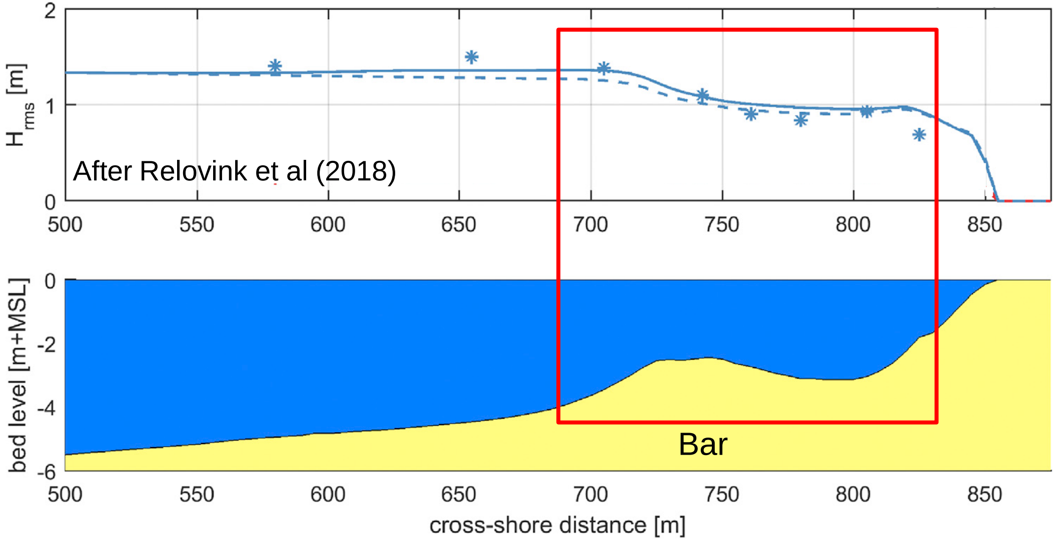


By Deltares

XB-SB is suitable for dissipative beaches while XB-NH is more suitable for reflective beaches.

Motivation and Statement of Problem

- Submerged Sandbars are one of the possible means to dissipate wave energy through depth-induced breaking.
- Thus, they affect wave transformation processes in the surf zone.
- In addition, they reduce the wave period by non-linear dispersive wave transformation.

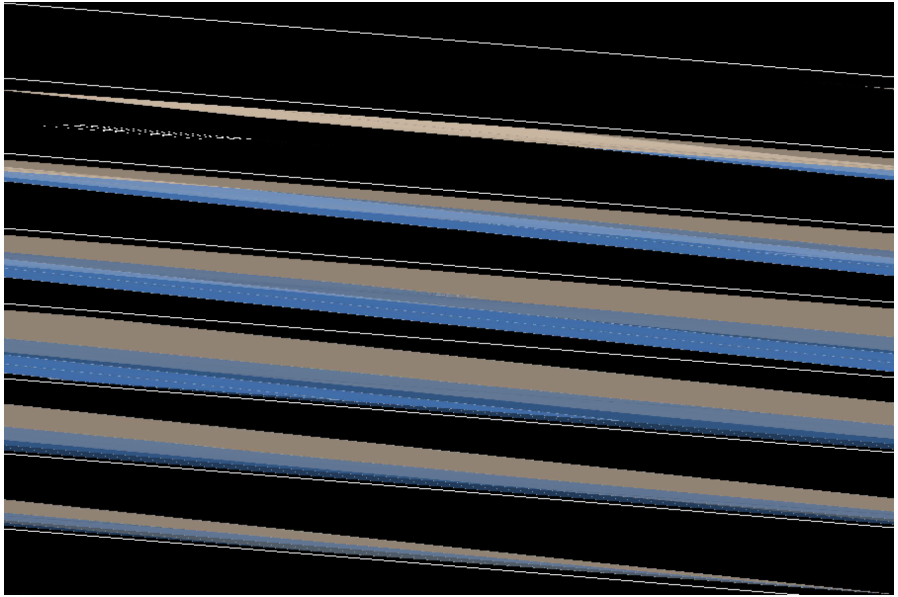


- Therefore, they influence the cross-shore sediment transport and support in reducing rates of coastal erosion.

Smart coastal management takes sandbar positions into account

Statement of Problem

- XB-NH can only capture the macro-scale effects of wave breaking on hydrodynamics in the surf zone, where propagating waves are allowed to steepen until the front face is almost vertical.
- Processes such as wave overturning, subsequent turbulence generation are absent so far.
- Omitting such detailed processes of breaking affect the predictions of bed evolution and bar migration.



Estimating the effect of approximating the breaking process on bed morphology is a crucial issue.

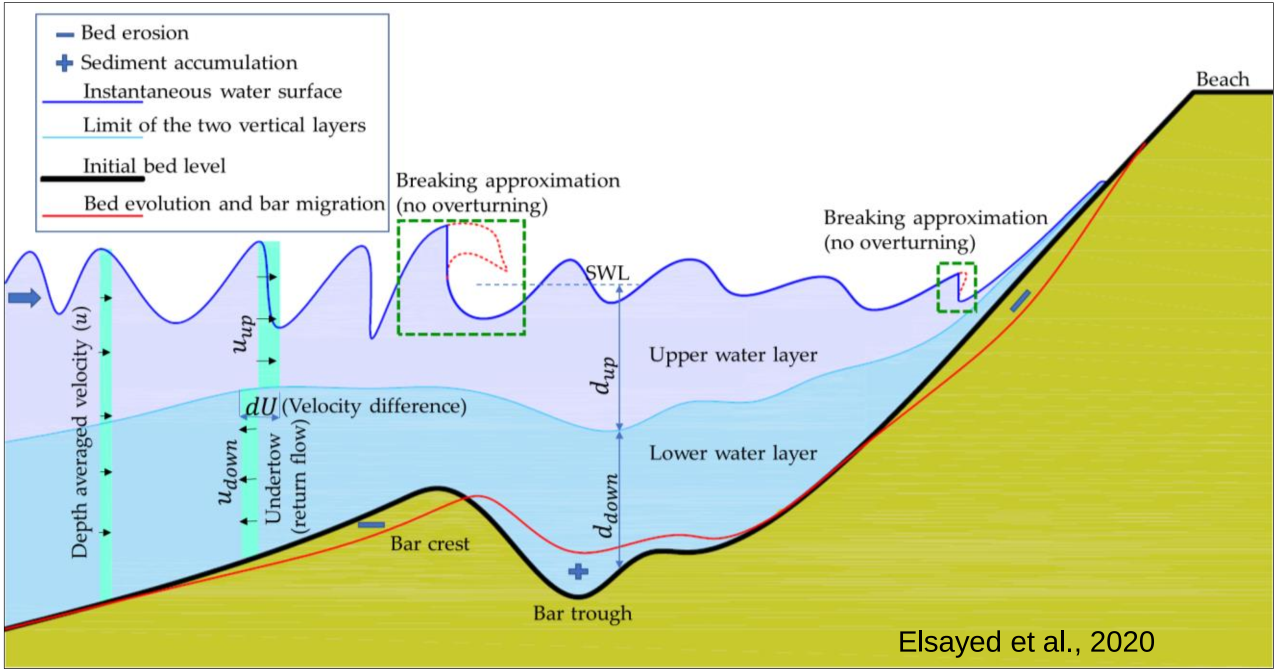
Objectives

Main Objective: To provide a new validation of XB-NH using the large-scale dataset of SINBAD, considering the option of quasi-3D computations, provided by considering two water layers.

Specific Objectives:

(i) To investigate the effect of the approximated wave breaking on the hydrodynamics near the sandbar and related implications for bar evolution.

(ii) To investigate the capability of the quasi-3D computations in XB-NH to reproduce the undertow and the associated sediment transport

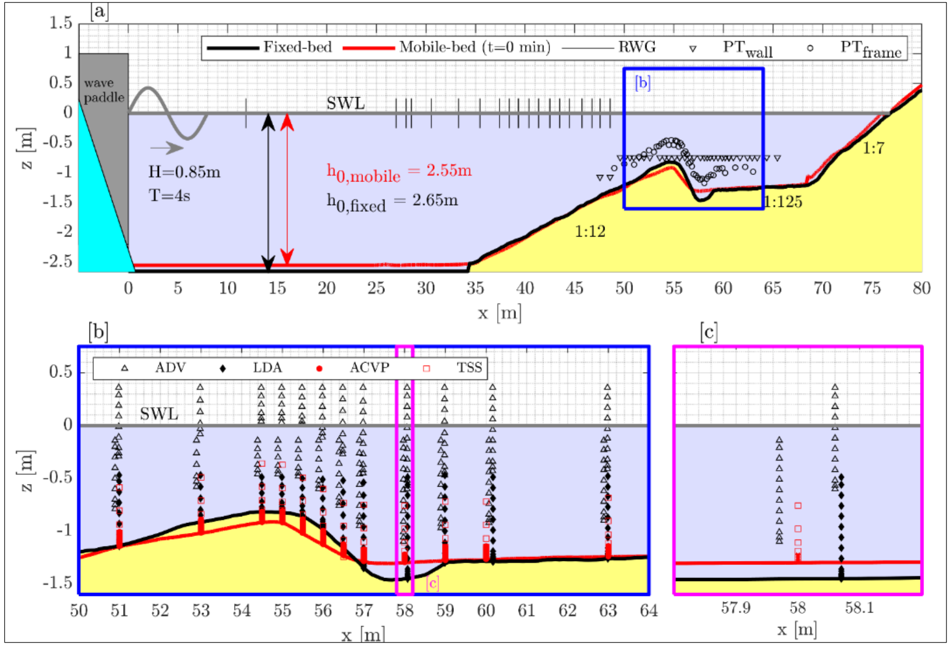


Elsayed et al., 2020

Non-hydrostatic modelling of barred beaches: Dataset

- SINBAD was performed in the Maritime Research and Experimentation Wave Flume (CIEM) at Universitat Politècnica de Catalunya (UPC), Barcelona
- It represents two similar experiments of1) a mobile bed and 2) fixed bed.

Parameter	Fixed bed	Mobile bed
No of tests (physical runs)	123	12
Water depth	2.65 m	2.55m
Wave parameters	H= 0.85 m and T= 4s (regular waves)	H= 0.85 m and T= 4s (regular waves)
Run time	38 min = 2280 s	90 min = 5400 s (6 x 15 min)
No of generated waves	570	1350 (6 x 225)
Equilibrium time	400 s (6.67 min) i.e. after 100 waves	300 s (5 min) i.e. after 75 waves



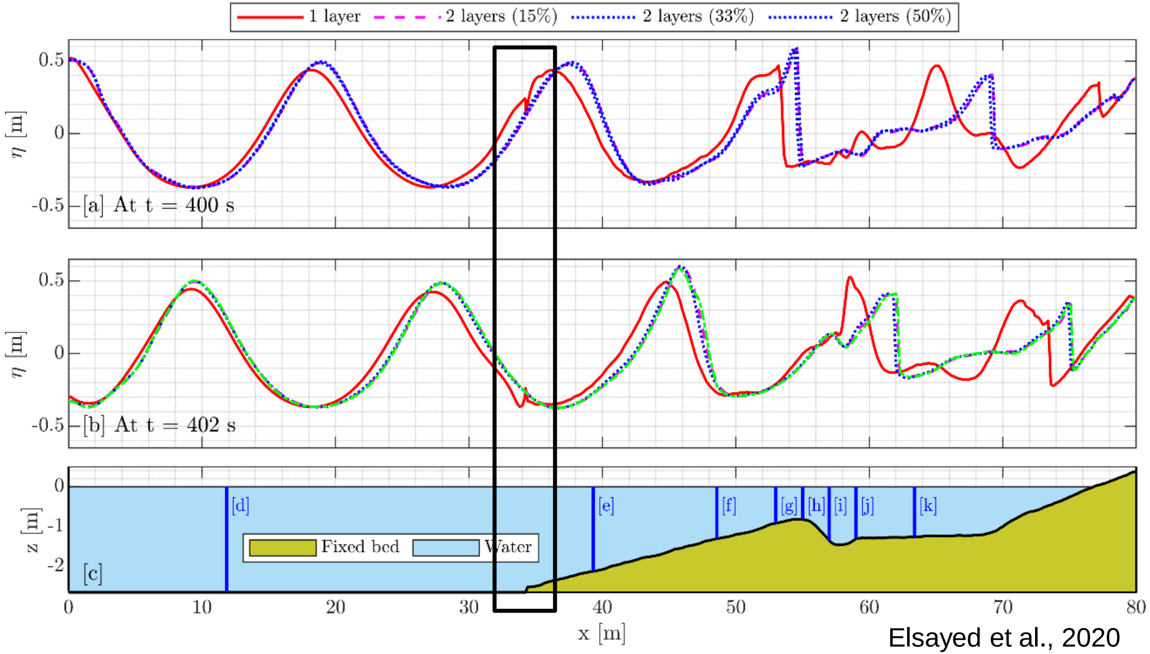
After van der A et al (2017) and van der Zanden et al (2017c, 2017d, 2016).

The Fixed and mobile bed experiments are used respectively to validate the model hydrodynamically and mophodynamically.

Non-hydrostatic modelling of barred beaches: Results

Wave propagation

- It is clear that the wave overturning is not simulated.
- Locations of breaking points is sensitive to the number of layers.
- Wave propagation is insensitive to the layer fraction but to number of water layers.
- Onshore of the bar, wave propagation changes with the number of water layers



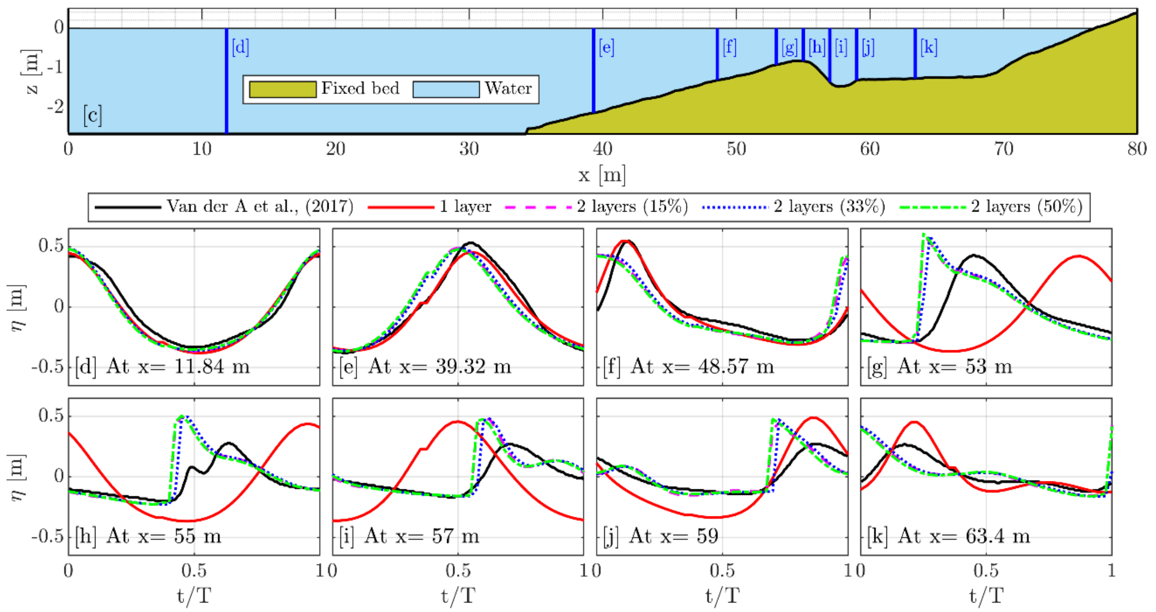
Elsayed et al., 2020

Model instability is overcome using the 2 layers, due to the improved modelling of the frequency dispersion

Non-hydrostatic modelling of barred beaches: Results

Water surface elevation

- XB-NH accurately predicted the phase-resolved water surface elevation offshore of the bar, but its predictive capability decreased above the bar crest.
- The predictive capabilities of XB-NH in terms of the water surface predictions are enhanced by the two-layer option.



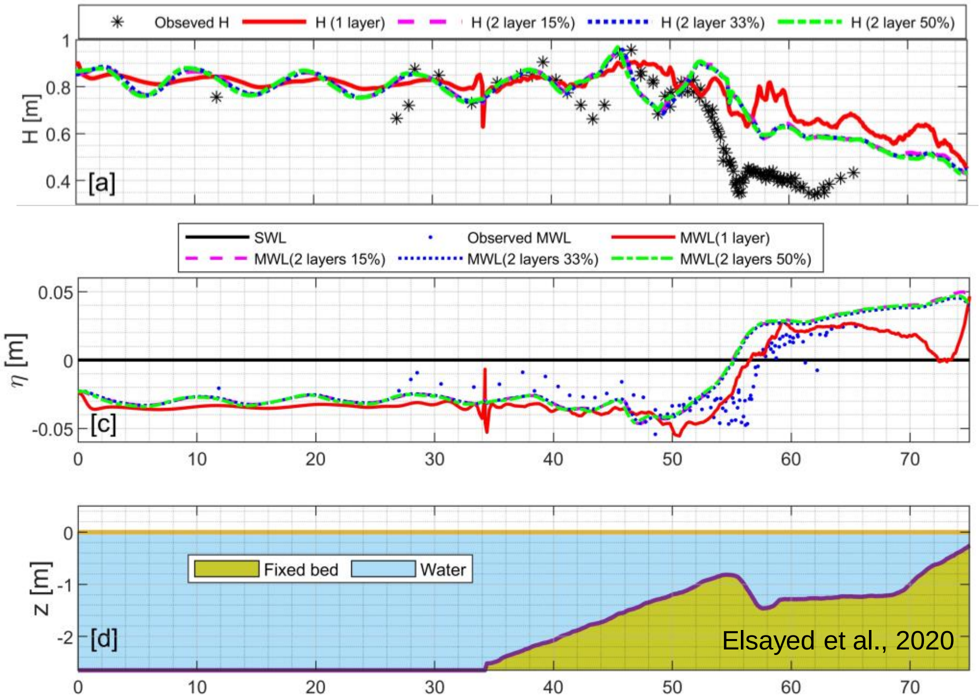
Elsayed et al., 2020

The 2 water layers option enhances the predictive capability of XB-NH, due to the improved modelling of the frequency dispersion

Non-hydrostatic modelling of barred beaches: Results

Wave heights and setup

- XB-NH predicted the wave height accurately between the wave maker and the bar.
- The wave heights top and landward of the bar are overestimated due to the underestimation of the energy dissipation .
- Layer fraction does not affect the predicted wave heights and wave setup.
- XB-NH is generally capturing the wave setup and set down.



The simplified representation of the wave breaking process leads to underestimation of the energy dissipation and hence overestimated wave heights.

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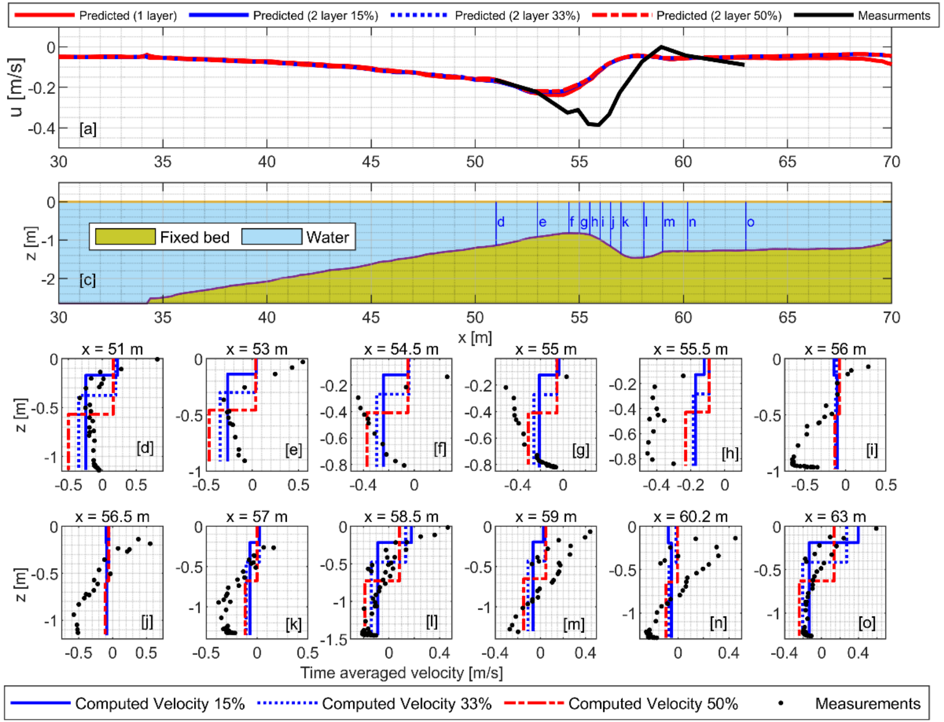
Non-hydrostatic modelling of barred beaches: Results

Flow velocities

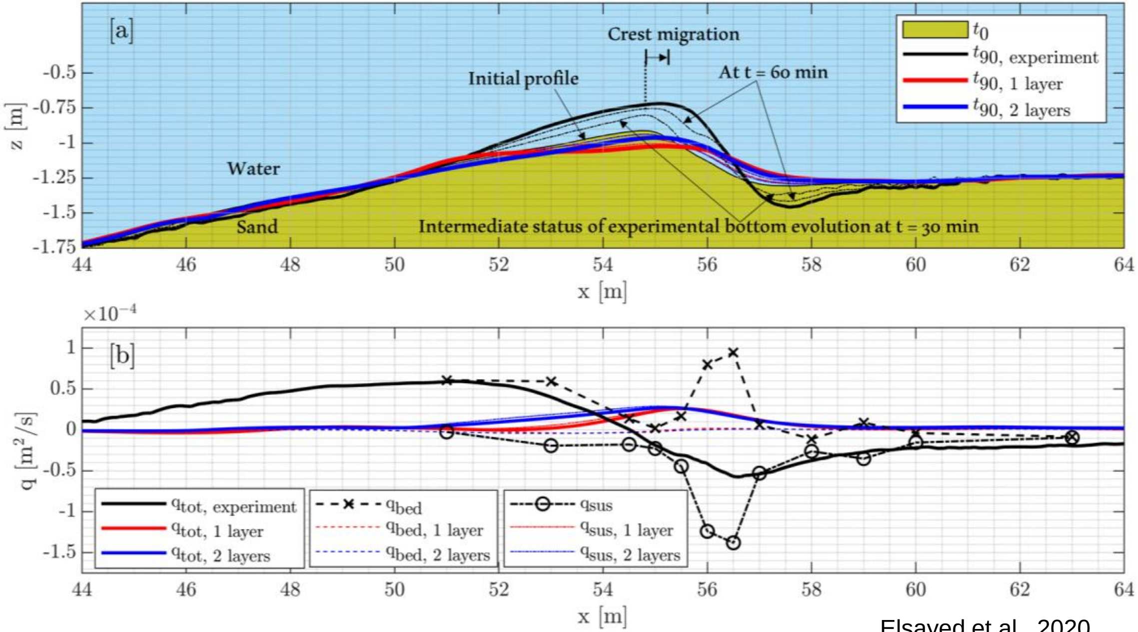
- The negative values of mean velocity indicate the dominating offshore directed flow, practically on the sandbar.
- XB-NH computes the depth-averaged velocity very precisely offshore of the bar and fails to predict the strong undertow on the bar.
- Depth-resolved velocities are properly predicted, where the depth-averaged velocity is correctly predicted, but with varying layer fractions.



The position of the neutral axis (point of zero flow velocity) varies from one section to another

Bed Morphology and bar migration

- During the mobile-bed experiment, the sandbar volume increases due to increasing bar crest elevation and deepening of the bar trough.
- The increase in bar crest was fed from one side by the dominant onshore directed bedload on the outer bar slope and from the landward side by the negative suspended load directed offshore due to the strong undertow.

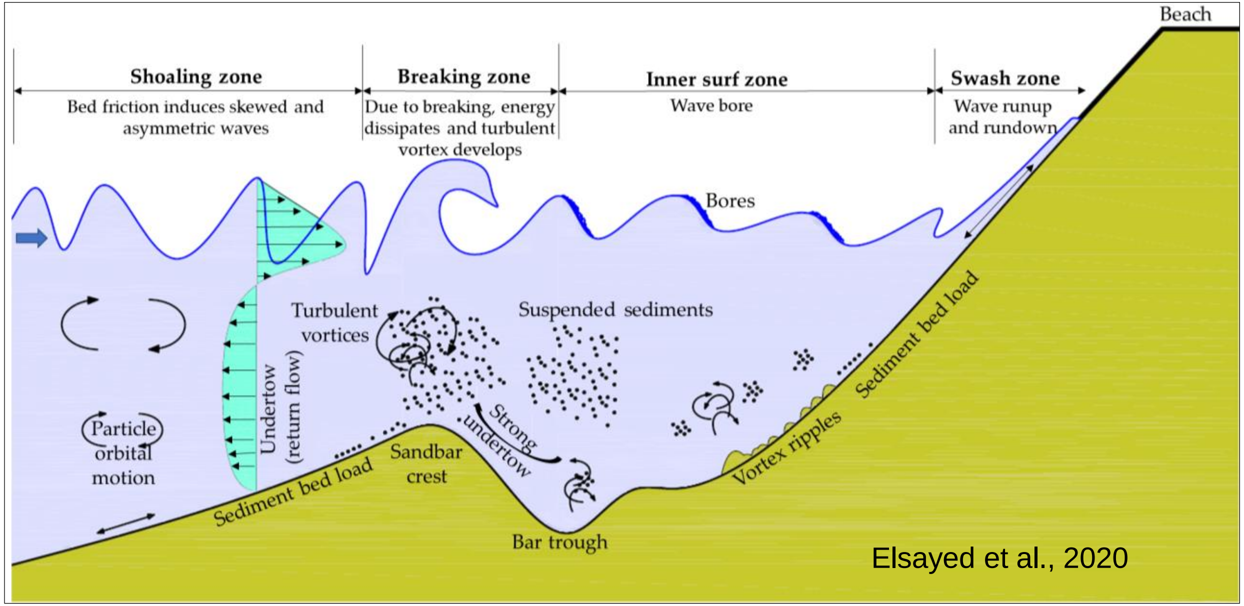


Elsayed et al., 2020

XB-NH showed 'bad' performance in predicting bar formation and migration

Non-hydrostatic modelling of barred beaches: Results

Bed Morphology and bar migration



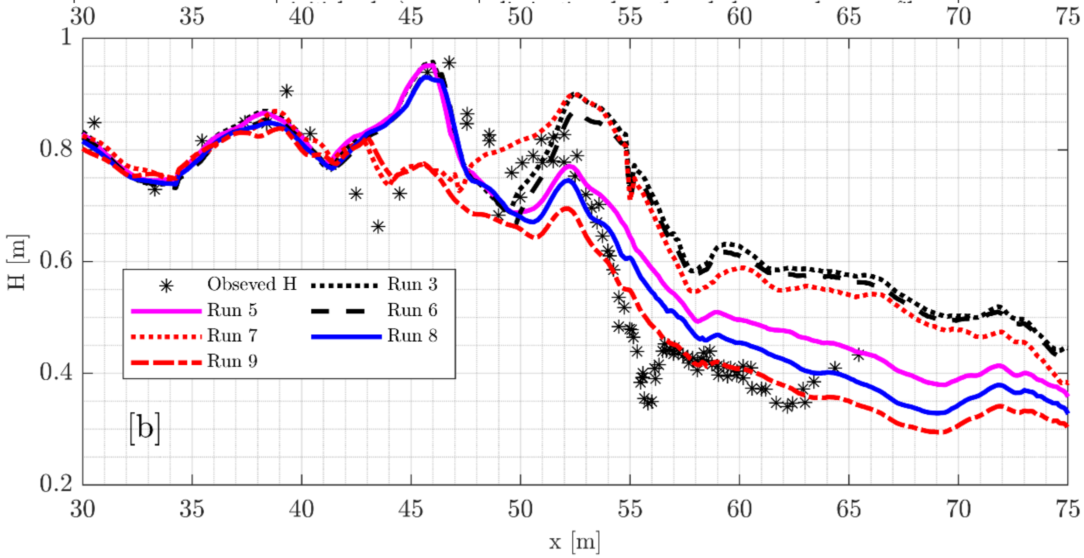
Skewed waves on offshore side of the bar enhances the onshore-directed bedload and strong undertow increases the offshore-directed sediment transport.

Non-hydrostatic modelling of barred beaches: Results

Tuning of breaking parameters

- The main breaking parameters are further examined to enhance the modelling of breaking.
- The parameters of the most significant influence on the energy dissipation were Cs and ß, which are measures of the turbulence viscosity.

Run	Investigated parameter (s)	Default/ initial value	New value (s)	Reason of investigation
Run 5	ß	1.5	3 (max. value of ß in XB-NH)	Increasing the viscosity during breaking might lead to larger energy dissipation.
Run 6	n	0.025	0.05 (double of the	Increasing the bed friction leads to more energy
Run 7	δ			
Run 8	C_s			
Run 9	ß, δ and C_s			

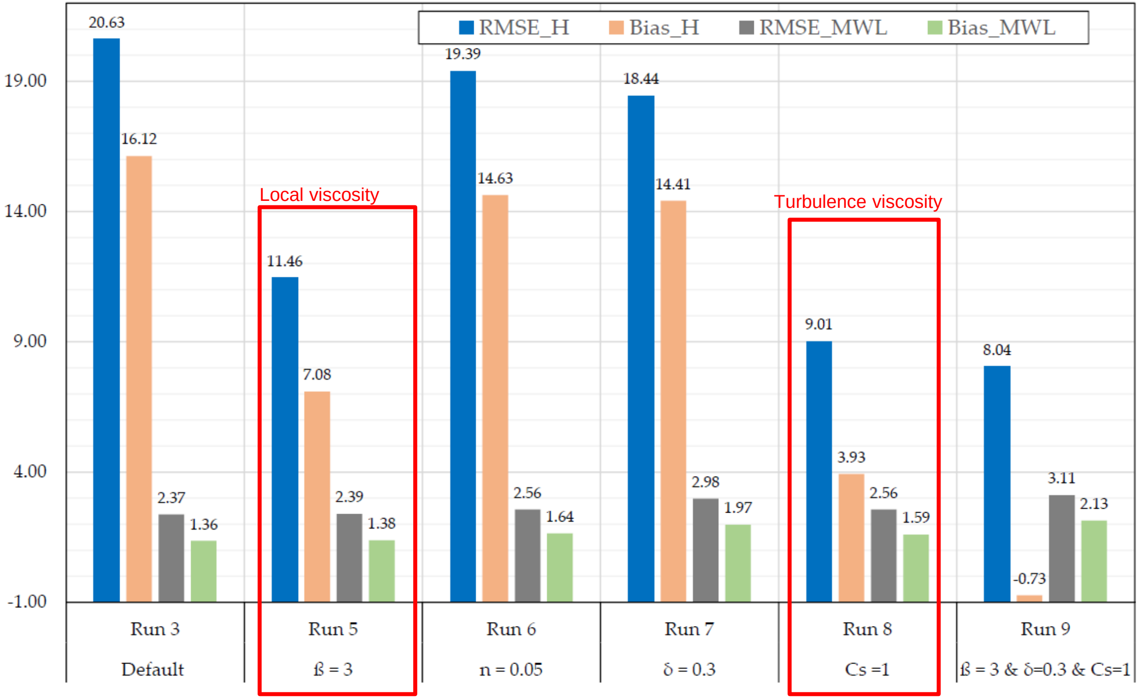


Tuning the breaking parameters may enhance the predictivity of wave heights by XB-NH

Non-hydrostatic modelling of barred beaches: Results

Tuning of breaking parameters

- Increasing the local viscosity during breaking and the turbulent viscosity increase the energy dissipation and reduce the overestimated wave heights onshore of the bar.
- Therefore, tuning them provide the lowest RMSE and Bias of the wave heights and MWL.

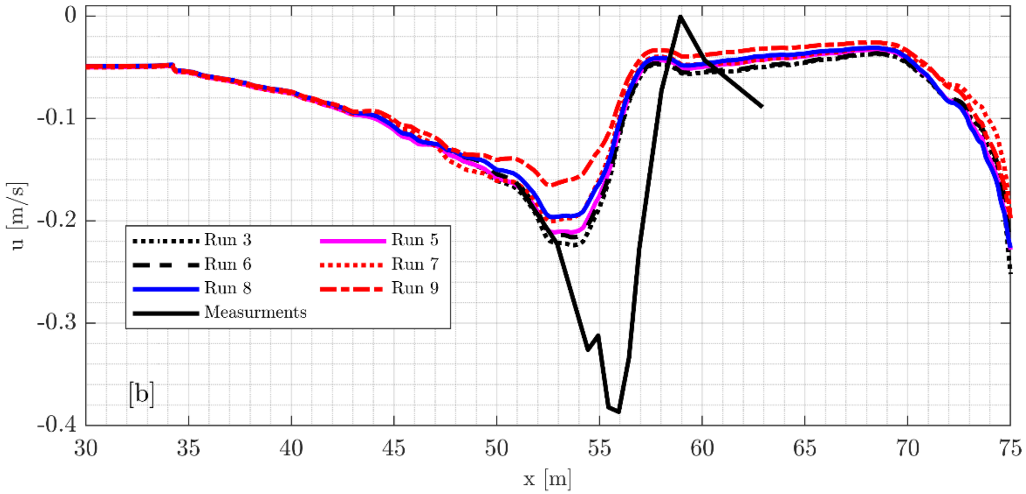


Underestimated energy dissipation is certainly duo to unconsidered vertical turbulence induced by vertical penetration of the plunging waves

Non-hydrostatic modelling of barred beaches: Results

Toward improved morphodynamics

- Sediment transport is based on the depth averaged velocity .
- Thought parameters tuning may improve the productivity of the wave heights, it does not enhance the velocity predictions.
- Therefore, morphological evolution of the sandbar is negatively affected



The key step toward improved predictive capabilities of morphodynamics should start with improving the hydrodynamic capabilities

Outlook (How to improve)

- Increasing the number of water layers in XB-NH so that the over depth variability of flow velocity could be better captured, but demanding big Computational efforts.

- Rather than tuning the turbulence parameters, the vertical mixing need to be modelled to account for the plunging induced vertical penetration and its influence in water circulation.

- XB-NH would require an improved sediment entrainment prediction in cases of large turbulent vortices in addition to an improved prediction of their effect on keeping sediment in suspension.

Conclusions (Take home messages)

- Underwater sand deposits reinforce our coastlines as they dissipate wave energy through depth-induced wave breaking.
- The limited representation of the wave-breaking process in XB-NH has several implications for the simulation of surf zone processes.
- The model with two depth water layers showed slightly better results, due to the more accurate computation of the frequency dispersion.
- Two water layers are not sufficient to resolve the significant variations of velocities along the depth.
- The planning of coastal protections requires deep investigation of the physical processes and a proper selection of the modelling tool.

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Prof. Dr Dronkers, 2018

Thank you for your kind attention!

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