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Author(s)	Oliver Lojek(TUBS), Constantin Schweiger (TUBS), Pieter Rauwoens (KU Leuven), Jianghua Guo (KU Leuven), Mahmoud Abouhalima (UPORTO), Paulo Rosa Santos (UPORTO)
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Cover page

This report is the first deliverable of work package 11 Morphodynamic functioning (D11.1 Numerical demonstrators) in the DuneFront project. DuneFront focuses on better understanding dune-dike hybrid Nature-based Solutions (DD-hybrid NbS) to create sustainable, inclusive, and visually appealing coastal management infrastructure. These innovative solutions aim to integrate biodiversity while addressing significant socio-economic challenges along Europe's densely populated coasts. By studying existing hybrid NbS, this report lays the groundwork for better understanding the design aspects of these systems.

The primary objective of this report is to gather relevant information and data to set up and calibrate numerical XBeach and AeoLiS models for selected demonstrators as a basis for the investigation of their morphodynamic functioning.

The DuneFront project considers 12 Demonstrators across six countries - Portugal, France, Belgium, the Netherlands, Germany, and Sweden – given the complexity of numerical models a selection of demonstrator sites will be modelled with the two open-source software packages

This compilation presents results obtained regarding morphodynamic functioning of select demonstrators using the open-source software packages XBeach and AeoLiS investigating wave driven and wind driven sediment transport volumes, patterns and pathways. This report will be complemented by deliverables D11.1 contributing the initial status and performance of numerical models of select demonstrator sites.

In general, this report provides an overview of model setups and initial results. Complimentary reports D11.2 and D11.3 will advance the morphodynamic understanding of the simulated demonstrator sites by incorporating more details and simulating historic periods (D11.2) as well as project potential future developments (D11.3).

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List of abbreviations

Abbreviation	Explanation
DD	Dune-Dike
DD-Hybrid	Dune Dike-Hybrid
NbS	Nature based Solution
GIS	Geo-Information-System
WP	Work Package
RBMPs	River Basin Management Plans
WFD	Water Framework Directive
PoM	Programs of Management
KTM	key types of measures
NUTS	nomenclature of territorial units for statistics
APSFRs	Assessment of potential significant flood risk
RBD	river basin districts
PRFA	preliminary flood risk assessment
EFAS	European Flood Awareness System
EMODnet	European Marine Observation and Data Network
TWL	total water level
ECFAS	European Coastal Flood Awareness System
RI	Return interval
BSS	Brier-Skill-Score

1. Introduction

1.1 Overview of work package 11 (WP11 – Morphodynamic functioning)

The overarching goal of work package 11 “Morphodynamic functioning” consists of using spatial data researched in other work packages, mainly WP1-4 and WP6, for Europe pertaining to physical, biological and socio-economic boundary conditions and derived morphological signals to setup numerical computer models of select demonstrator sites using XBeach and AeoLiS. These models in a first step must be calibrated in a meaningful way.

1.1.1 Tasks of work package 11

The objective of the first task (Task 11.1) in this work package, consists in obtaining and compiling the necessary source code of the two open-source models XBeach and AeoLiS, which are to be used for setting up demonstrator models. For the demonstrators then the input data must be aggregated and implemented with meaningful boundary conditions to achieve running and physically sound results for further improvement and ongoing research for following tasks (Task 11.2 & Task 11.3).

The objectives for the second task (Task 11.2) within the work package focus on using the setup demonstrator models of Task 11.1 to simulate past periods. This hindcasting will allow for comparisons to observation data and evaluation of model accuracy.

The objectives of the third task (Task 11.3) aims to project potential morphodynamic trends and developments within the demonstrator models. For this, IPCC RCP scenarios will guide literature research on projected developments of implemented boundary conditions (e.g., changes in wind speed and direction or sea level rise and wave climate). Findings will be used by altering prescribed boundary conditions within the demonstrator models to project potential impacts on morphodynamic functioning.

1.1.2 Milestones and Deliverables of work package 11

The key milestone (M11.1) involves the setup of working numerical demonstrator models with AeoLiS and XBeach. This milestone has been met.

The deliverables include:

- **Deliverable D11.1** (this report): Setup of numerical models of select demonstrator sites using open-source software packages XBeach and AeoLiS. Deliverables D6.1 Morphodynamic patterns, D6.2 Vegetation-sediment interactions and D10.2 Assessing plant effect traits are used as data source for setting up the models. A prototype root resistance module for XBeach has been used.

- **Deliverable D11.2:** The numerical models developed in D11.1 are used to hindcast past periods or events to test model performance against available observation data. Vegetation coverage is implemented based on available digital orthophotos (DOP) and identified vegetation coverage.

- **Deliverable D11.3:** The numerical models are used to project potential impacts on morphodynamic functioning stemming from IPCC developed RCP scenarios.

1.2 Aims and objectives of this report

The main objective of this report is to present the numerical demonstrator models setups for XBeach and AeoLiS and achieved initial results.

2. Numerical modelling

In this work package, numerical models (XBeach and AeoLiS) are to be established for the purpose of representative demonstrators. To this end, numerical models of the German demonstrator St. Peter-Ording, the Douro estuary sand spit, Portugal and the Living Lab Raversijde, Belgium will be generated based on the data and findings of WP4, which compiled boundary conditions pertaining to physical boundary conditions such as wave conditions, water levels and topography (WP4.1) as well as the distribution of important species (WP4.2) and socio-economic and administrative boundaries (WP4.3), as well as WP6 (morphodynamic patterns). Within the further course of WP11, these models will be used for morphodynamic hindcasting (WP 11.2) and morphodynamic projections in the context of IPCC RCP scenarios (WP 11.3).

2.1 Modelling approach

Within Workpackage (WP) 11, the two numerical open-source modelling software XBeach and AeoLiS are employed to simulate event-based storm surge impacts on beach and dune systems for select demonstrator sites within the DuneFront project. XBeach is primarily employed to project wave driven beach and dune erosion under storm surge conditions. AeoLiS on the other hand constitutes an aeolian transport model, which is capable of projecting dune growth and morphodynamic evolution. Wihin this report, both models are used to simulate three demonstrator-based field sites for select storm surge events.

XBeach is a process-based numerical model which solves coupled two-dimensional horizontal (2DH) equations for wave propagation, flow, sediment transport and bottom changes due to time varying wave and flow boundary conditions (Roelvink et al. 2009). Within the scope of this study, the surf beat mode was applied using the single-dir option and the default bin size of dtheta_s = 10° (Roelvink 2017). Thus, short-wave motions are solved on the wave-group time scale using a time-dependent (reduced) version of the wave-action balance including the directional distribution of the wave-action density. The dissipation of wave energy, which is used as a source term in a roller energy balance, and the wave-action contribute to wave-induced radiation stresses. The latter serves as an input for the depth-averaged shallow water equations that are used for the calculation of low-frequency and mean flows including infragravity waves and unsteady wave-induced currents. Sediment transport is modeled with a depth-averaged advection-diffusion equation (Galappatti and Vreugdenhil 1985), where accretion or deposition of sediment is determined by the mismatch between the actual depth-averaged sediment concentration and an equilibrium concentration. The former serves as a basis for the calculation of sediment transport rates and, hence, the bed level changes.

AeoLiS is a process-based model for simulating aeolian sediment transport in situations where supply-limiting factors are important, like in coastal environments. Supply-limitations currently supported are soil moisture contents, sediment sorting and armouring, bed slope effects, air humidity and roughness elements. It is based on one-dimensional process descriptions by Vries et al. 2014; Hoonhout and Vries 2016; Hoonhout and Vries 2019 extended the model to be applicable to two-dimensional spatial domains that are relevant to specific management situations. Up until the current work it mainly describes multi-fractional sediment transport and various controls on sediment availability in both one and two spatial dimensions (van IJzendoorn et al. 2023; Hallin et al. 2023). van Westen et al. (2024) extended the model with functionalities that allow for simulations of coastal landforms including the effect of topographic steering on wind shear, avalanching of steep slopes and vegetation processes in the form of growth and wind shear reduction.

2.2 German demonstrator – St. Peter-Ording

2.2.1 Model setup

St. Peter Ording is located at the Eiderstedt peninsula located in North Frisian Wadden Sea in Germany (Figure 1). The demonstrator is characterized by a broad system of multiple dikes and a natural grey dune system. The northern land protection dike, situated at an elevation of 8 m above mean sea level (amsl), serves as the primary line of defense. To the south of the dune system, a regional dike with a tar surface layer provides supplementary protection at an elevation of 6.4 m (amsl). A middle dike, situated behind both the dune system and the regional dike, serves as a secondary line of defence. The natural grey dune system, which varies in height from 6 to 16.5 m (amsl), occupies the space between the northern and southern dikes, thereby enhancing the overall coastal protection by providing a resilient, multifunctional barrier against storm surges and flooding.

From the numerical modelling perspective, the variety of coastal protection features imposes considerable demands on the numerical models to be used. This is due to the presence of aquatic and land-based vegetation (salt marshes, dune vegetation and forest) and hard structures (roads, dike, buildings). These features exert a profound influence on both the hydro- and morphodynamic processes within the model domain, thereby imposing mutual influences.

Figure 1: Aerial phtoto showing St. Peter-Ording located at the Eiderstedt peninsula in the North Frisian Wadden Sea including grey & green coastal infrastructure (Photograph by Martin Stock)

XBeach

The grid generation for the German demonstrator was based on a digital terrain model from 2016 with a resolution of 10x10 m. Utilizing this data, a 2D grid was generated covering an alongshore distance of 2,500 m and a cross-shore distance of 5,000 m, with orientation normal to the coastline (Figure 2, left). As a result, the offshore boundary is located approx. 3600 m from the coastline at a water depth of -5.5 m (amsl). To prevent incident wave breaking at the offshore boundary, the model was artificially deepened to a water depth of –20 m (amsl) using a slope of 0.5 (Figure 2, right). To reduce the computational cost, a varying grid size was employed in cross-shore direction resulting in dx_{max} = 10 m at the offshore boundary and dx_{min} = 5 m for zb (bed level) > 0 m (amsl). With a constant alongshore grid size of dx = 5 m the grid consists of nx × ny = 741×500 cells. To prepare the grid for MPI applicability, the lateral cross-shore profiles were replaced by their mean for $zb \leq 0.25$ m (amsl). Subsequently, the difference to the actual height was linearly adjusted along five grid cells. This allows the application of cyclic boundaries, where obliquely waves can leave one lateral boundary and to re-enter the model at the opposite site. The initial version of the 2D-model setup is kept simple with respect to the consideration of the aforementioned coastal protection features. In this regard, a constant bed roughness is applied with a manning value of n = 0.022 $s/m^{1/3}$. Additionally, the model setup does not account for hard structures (e.g., roads, dike) and vegetation (salt marshes, dune vegetation).

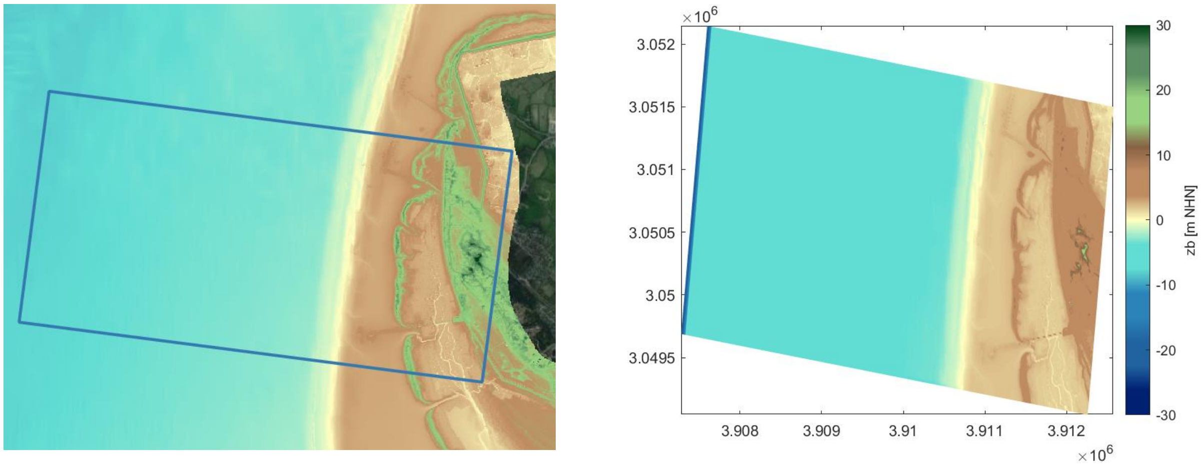

Figure 2: Model domain covering the natural main dune system at the Eiderstedt peninsula (left) as well as final XBeach model grid with artificial deepening at the offshore boundary to zb = -20 m (right)

AeoLiS

Based on the XBeach model of the German demonstrator Sankt Peter-Ording, a complimentary model was setup using AeoLiS Version 3.0.0.rc2 (Vries et al. 2023) to investigate aeolian driven sediment transport. The model domain covers the identical extent as the XBeach model, to render ensuing calculations & projections to be undertaken in D11.2-D11.3 more consistent. The initial bathymetry/topography of the model domain is given in Figure 3.

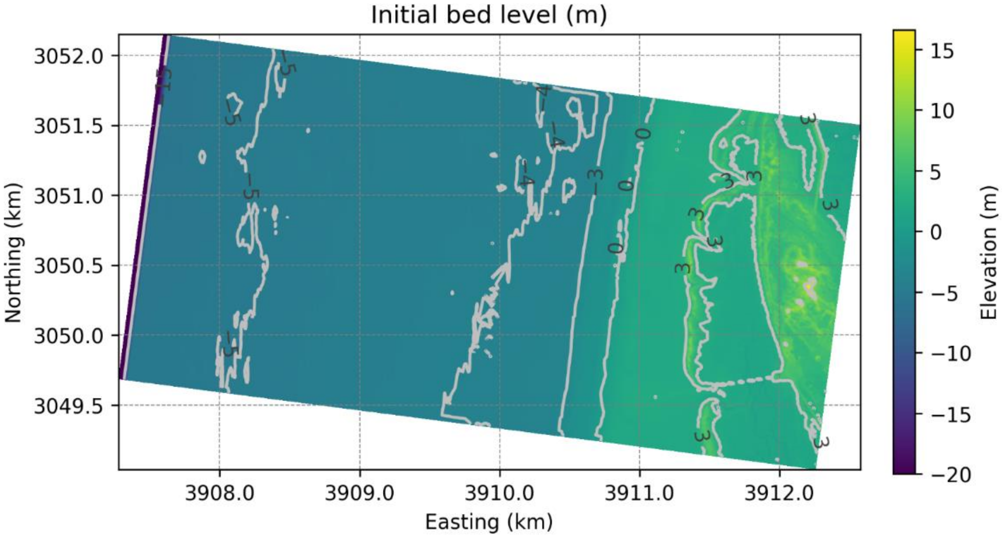

Figure 3: Initial, post-storm and bed level differences (top to bottom) for 2D-model application to the Anatol storm surge at St. Peter-Ording

Analogue to the XBeach boundary definitions, the AeoLiS model has been forced with a storm surge period with a maximum tidal water level of 5.5 m (amsl) depicted in Figure 4.

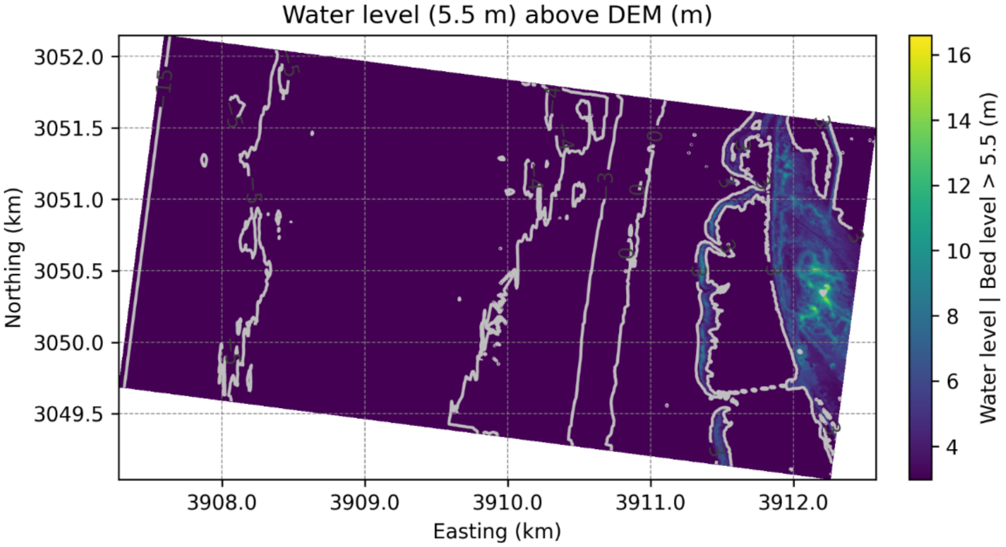

Figure 4: Water level above bed level for peak storm surge water level 5.5 m for the AeoLiS model of St. Peter-Ording with contour iso-lines of the initial bathymetry elevation for identification of the dune belt outlines. Where the water level is equal to 0 m the bed layer is displayed.

Figure 5 showcases the significant wave height distribution within the model domain during peak storm tide level resulting in the prescribed 1.26 m stemming from the upscaled laboratory experiments in turn informed through the coastal protection authority and national wave buoy data and hindcast simulation results. The select storm surge is based on an event from 2013, which occurred December 5th – 7th with a re-occurrence of 20yrs.

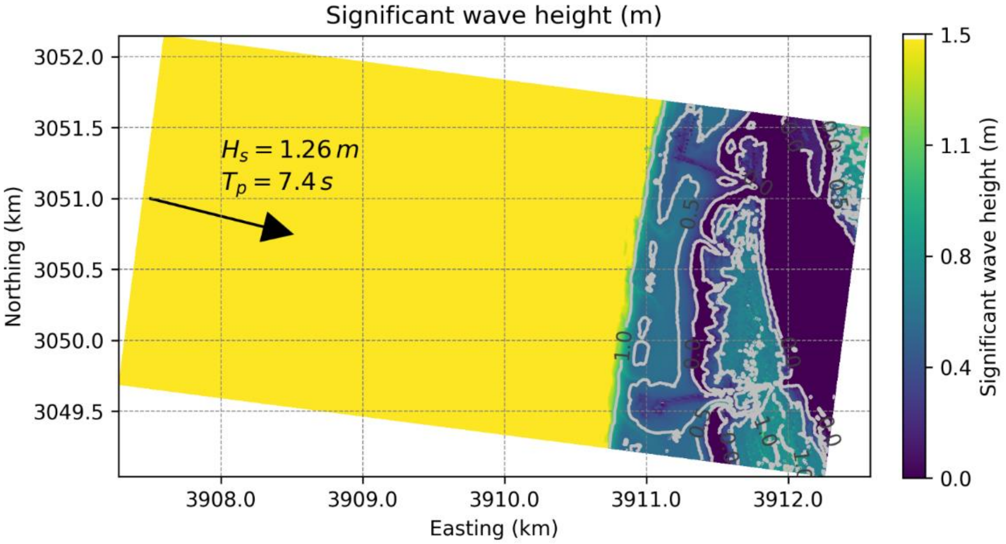

Figure 5: Significant wave height (Hm0) with the dune area protruding out of the inundation and resulting a wave height of 0 m, peak wave period (Tp) of 7.4 s and wave direction of 270° nautical for the AeoLiS model of St. Peter-Ording based on the experimental flume campaign and the XBeach model setup.

The foreshore and beach area are inundated, and the cells are rendered inactive for aeolian transport during this phase. Through the blowouts and behind the foredune belt, a propagation of storm surge water level and waves can be observed comparing overall elevation of the used digital elevation model (DEM) with the prescribed water level and wave conditions to designate model grid cells either wet or dry during a simulation, rendering either a source for aeolian transport or not.

AeoLiS allows for the simulation of aeolian transport within sandy domains. For the initial setup, field sampling of surface sediment was conducted along beach and dune transects for the demonstrator. From these sieve curves and overall sediment characterization was derived for model fraction definition. Furthermore, the sediment data was contextualized by researching national and federal data bases for the simulated scenario regarding wind and pressure fields m/s, equalling Beaufort 8 (34–40 kn; 17,2–20,7 m/s or 62–74 km/h) for the stormy conditions simulated for the storm surge event. The wind direction was set to 270° nautical, coming from west, an initial ramp-up from 0 to 18 m/s over the course of 2 hours was prescribed to mitigate potential model artifacts.

The initial surface sediment inventory contains one bed layer with 1.5 m thickness and a single grain size fraction with a median grain size diameter of 0.2 mm with the local distribution of D_{50} ranging from 0.2 – 0.25 mm according to federal data bases and locally sourced surface samples (MDI-DE 2017). The final surface elevation changes computed over the course of the storm surge peak (Figure 6) reveals magnitudes of –0.65 m (red), with increases of up to 0.83 m (blue). The overall patterns reveal a surface elevation change along the foredune chain, where the crest was eroded by up to –0.65 m, and the seaward dune toe area of both, the foredune chain and the main coastal protection dune were elevated by the eroded material.

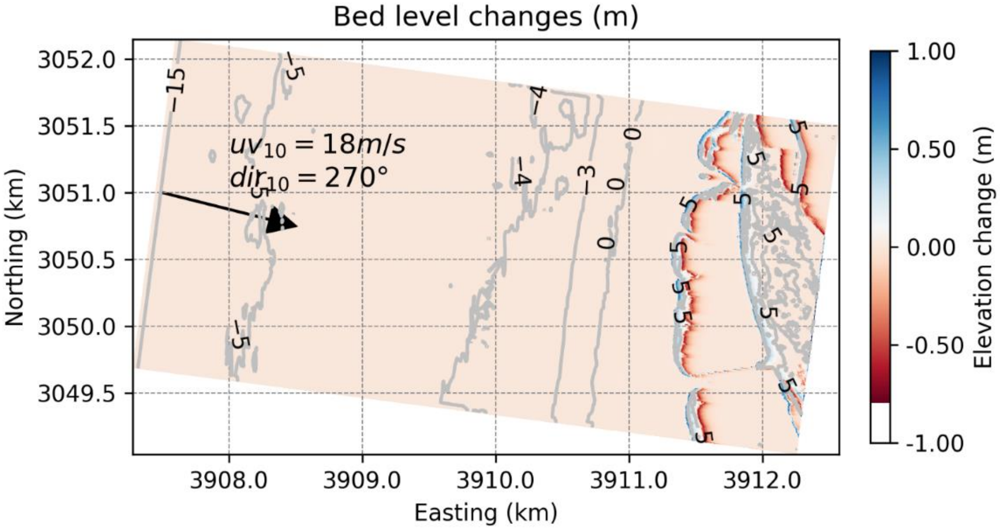

Figure 6: Selected boundary conditions time series including water level, wave height (Hm0), peak wave period (Tp) and wave direction (top to bottom) for the three representative storm events for the XBeach model of St. Peter-Ording

Given that aeolian erosion and sedimentation are both present in the model, the dune toe area elevation increase might well be connected to the wave driven swash zone dynamics, rendering the elevated dune toe area accessible to transport processes, whereas the inundated cells are excluded from the calculation. Erosion of the dune crests is likely connected .

The aeolian erosion volume appears to be too large for the duration and wind speed prescribed. This is most likely due to the facts that no precipitation was prescribed, which would limit aeolian transport significantly during storm surge events. Furthermore, present vegetation on the foredune and ensuing coastal protection dune where not taken into consideration at this stage of the model setup due to a lack of data, which has been acquired during a field survey in April 2025 and is currently being evaluated for future incorporation into the AeoLiS model of the Demonstrator.

2.2.2 Model results

XBeach

The German demonstrator St. Peter-Ording was the basis for an extensive experimental flume study with a Froude length scale of 7 (Mehrtens et al. 2025). In addition, the flume experiments were utilized to setup a 1D-XBeach model with the x-grid size varying between 0.4 m ≤ dx ≤ 0.05 m (Figure 3, left). Furthermore, morphodynamic model parameters were adjusted to smaller scale with *depthscale* = 7. Hydrodynamic boundary conditions included two constant water levels of zs_0 = 0.5 m and zs_0 = 0.56 m and a JONSWAP spectrum with a significant wave height of H_s = 0.18 m and a peak wave period of T_p = 2.8 s. The test duration was 113 minutes.

Within the scope of calibration, including the *bermslopetransport* with *bermslope* = 0.2 led to a substantial enhancement of the model-predicted dune erosion, resulting in a Brier-Skill-Score of BSS = 0.9, Figure 7 right) and, thus, an excellent agreement according to the classification of van Rijn et al. (2003). The calibrated model was then used to conduct further investigations, including the influence of coastal foredune on storm-induced secondary dune erosion (Bölker et al. 2025) also achieving a good agreement between model and measurement with respect to the temporal development of wave-induced foredune erosion.

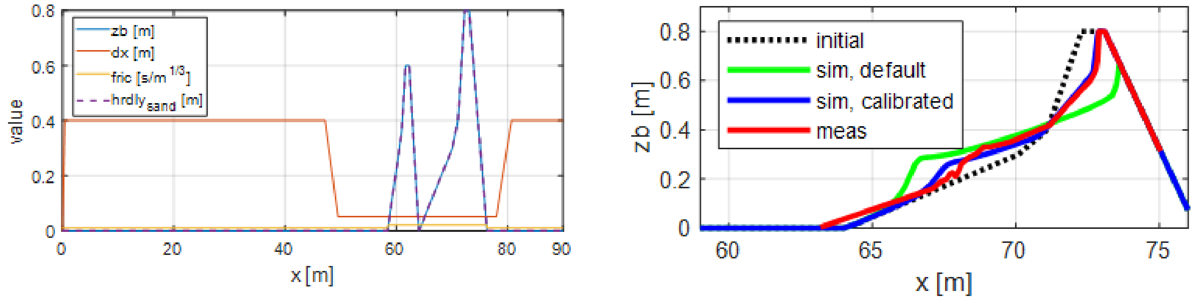

Figure 7: 1D-XBeach model of the German demonstrator St. Peter-Ording (left) and post-storm dune profiles for defaulg settings (green) and after calibration (blue) in comparison to the measured (red) data (right)

Following the XBeach model calibration based on flume experiment data without a foredune and subsequent validation, including flume experiment data with different foredune configurations, the 1D-grid was upscaled and input parameters adjusted to larger scale (*depthscale* = 1). Hydrodynamic parameters were scaled resulting in a significant wave height of $H_s = 1.26$ m, a peak wave period of $T_p = 7.4$ s and a constant water level of $zs_0 = 5.5$ m. This is the result of the upscaled water level ($zs_{0,small\text{-}scale} \times 7$) plus the mean beach elevation at St. Peter-Ording of 1.9 m (see Mehrtens et al. 2023 for the details). This was done in order to apply the calibrated model at prototype scale to selected cross-shore profiles within the 2D-model domain of St. Peter-Ording for the purpose of comparing the individual 1D simulations with the 2D-simulation. In this regard, seven cross-shore profiles located at an alongshore distance between 500 m and 2,000 m (see Figure 8) were selected as input for 1D-simulations.

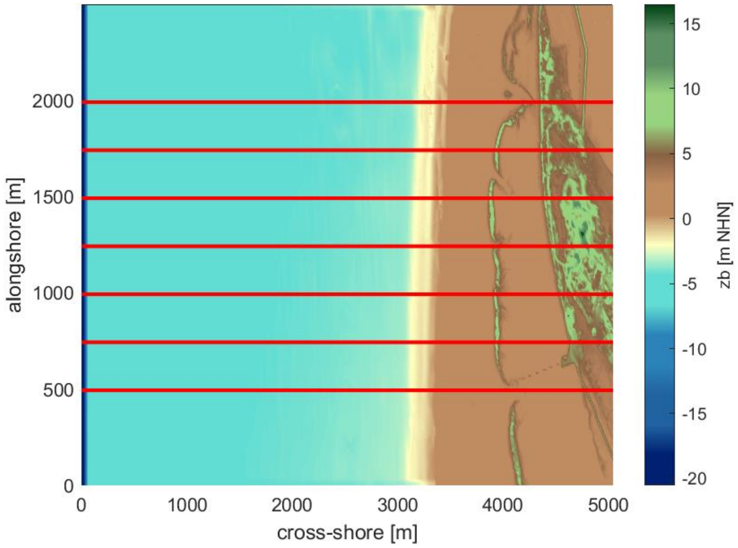

Figure 8: XBeach 2D-model domain including selected 1D profiles between 500 m and 2,000 m (bottom to top) for the purpose of comparison between 1D and 2D simulation

Figure 9 shows the comparison of seven individual 1D-simulations with the 2D simulation of St. Peter-Ording as well as the post-storm bed level differences between the 1D simulation with the corresponding cross-shore profile of the 2D-simulation (bottom right). With the exception of cross-shore profiles y = 500 m and y = 2,000 m, the height of the foredune exceeds the imposed constant water level of $zs_0 = 5.5$ m. Consequently, wave-induced erosion is restricted to the area of the foredune as no dune overwash is computed except for y = 1,000 m. Conversely, the natural foredune gaps in the vicinity of cross-shore profiles y = 500 m and y = 2,000 m (see Figure 4) enable direct wave impact on the main dune at a cross-shore distance of approx. 4,800 m. The lowest vertical post-storm bed level differences can be observed at profile y = 500 m with $-0.42 \text{ m} \leq \Delta zb \leq 0.43 \text{ m}$ and at y = 750 m with $-0.25 \text{ m} \leq \Delta zb \leq 0.5 \text{ m}$. In contrast, vertical bed level differences of $-1.86 \text{ m} \leq \Delta zb \leq 1.23 \text{ m}$ can be observed at y = 1,750 m and $-0.36 \text{ m} \leq \Delta zb \leq 2.91 \text{ m}$ at y = 2,000 m. For the remaining 1D-simulations, whose profiles are situated in an alongshore undisturbed section of the coastal foredune, a higher agreement between 1D and 2D simulation can be observed. In summary, the comparison of the extracted cross-shore results of the 2D simulation with the corresponding independent 1D-simulations indicates that the results of the 2D simulation are reasonable. However, given the high complexity of the coastline at St. Peter-Ording with multiple soft and hard coastal protection features, the results of the 2D simulation appear to be more reliable. This is primarily due to the incorporation of alongshore sediment transport and, thus, the relocation of sediments within the model domain and its influence on local hydro- and morphodynamic processes. In this regard, it is crucial to note that the present version of the 2D model is simplified with respect to the consideration of soft and hard coastal protection features. Therefore, model improvements will be targeted in the further course of this work package, e.g., the consideration of aquatic and land-based vegetation, hard structures or a higher spatial resolution in the beach/dune area. Furthermore, the comparison with measured post-storm data is essential and will be pursued as soon as the opportunity arises to survey actual post-storm data.

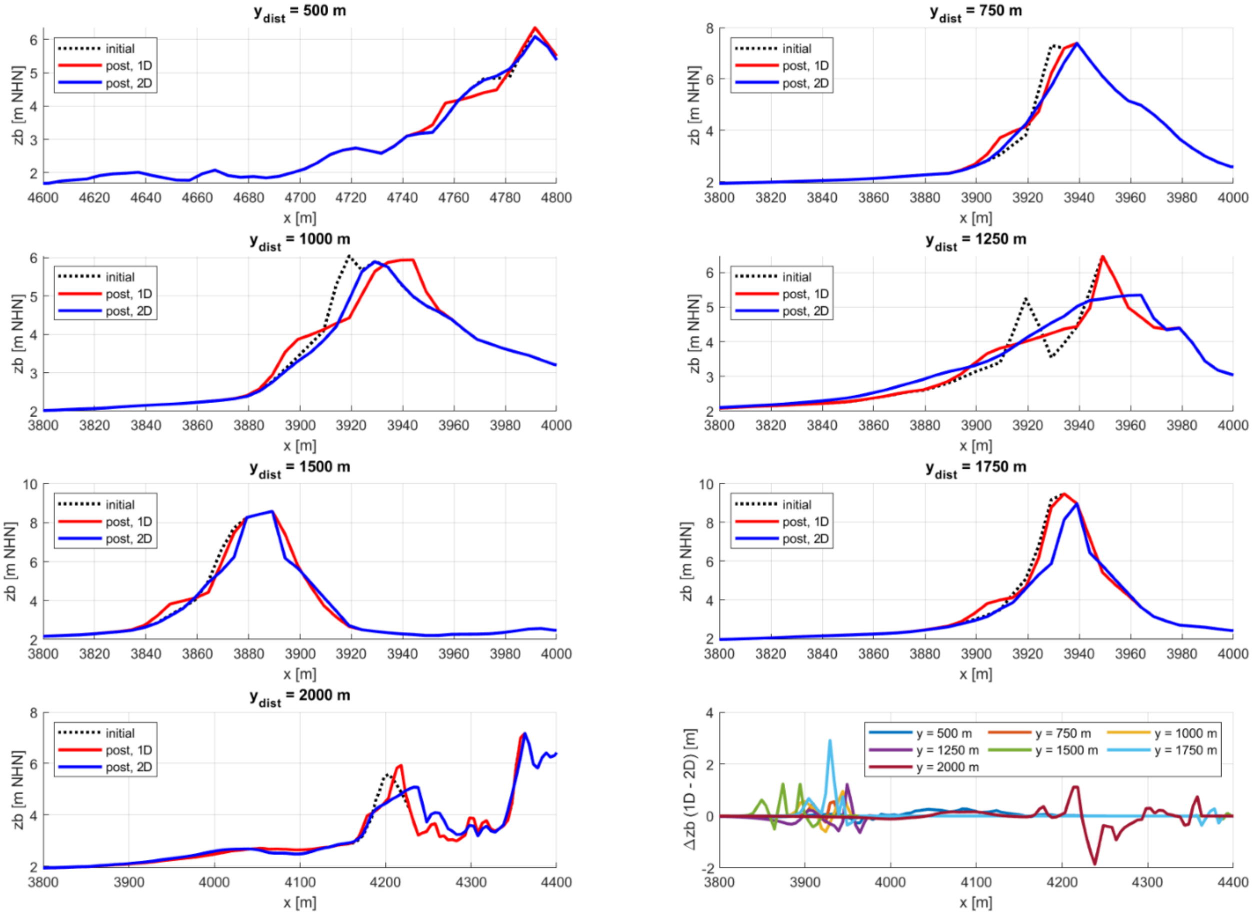

Figure 9: Comparison of post-storm dune profiles between 1D- (red) and 2D- (blue) XBeach simulation at selected cross-shore profiles (subplot titles) as well as post-storm bed level differences between 1D and 2D model applications (bottom right)

Following the comparison between the 1D and the 2D simulations, the 2D model was applied to three representative storm events by utilizing *XBeach Halloween version 1.24.6057* in MPI mode. In this regard, the storm events Anatol (03.-04.12.1999), Tilo (08.-09.11.2007) and a south-westerly storm event were chosen. Figure 10 presents the time series of the water level, H_{m0} wave height, peak wave period T_p and wave direction over a duration of 6 h. With respect to the almost westerly oriented coastline (~270° *w.r.t. north*), the Tilo storm surge approached the coast from a north-westerly direction (mean wave dir. = 315°), whereas the other two surges approached the coast from a south-western direction (SW: mean wave dir = 196°, Anatol: mean wave dir = 228°).

As an example, Figure 11 displays the pre- and post-storm bed levels as well as the bed level differences (post-pre) of the model application to the Anatol storm surge. The comparison of the pre- and post-storm bed levels reveals two distinct areas of erosion in the vicinity of the natural gaps at x ~ 500 m and x ~1,500 m, respectively. Due to the natural gaps and the resulting locally low initial beach elevation, water is able to enter the section between the fore- and the main dune once the water level reaches the foredune foot. As a result, the inflow is restricted to these two areas, resulting in locally high flow velocities and bed shear stresses. This is emphasized by Figure 12, which shows the instantaneous Eulerian velocities in x- (u) and y- (v) direction at t = 4.25 h with Eulerian flow velocities of up to u = 4 m/s and v = 2.9 m/s.

Next steps involve the incorporation of hard structures (piers, dike, roads) and vegetation (salt marshes, dune vegetation) as these features alter local hydrodynamic and morphodynamic processes, which are likely to affect the propagation of the inflowing water through the foredune and the final inundation area in the model domain.

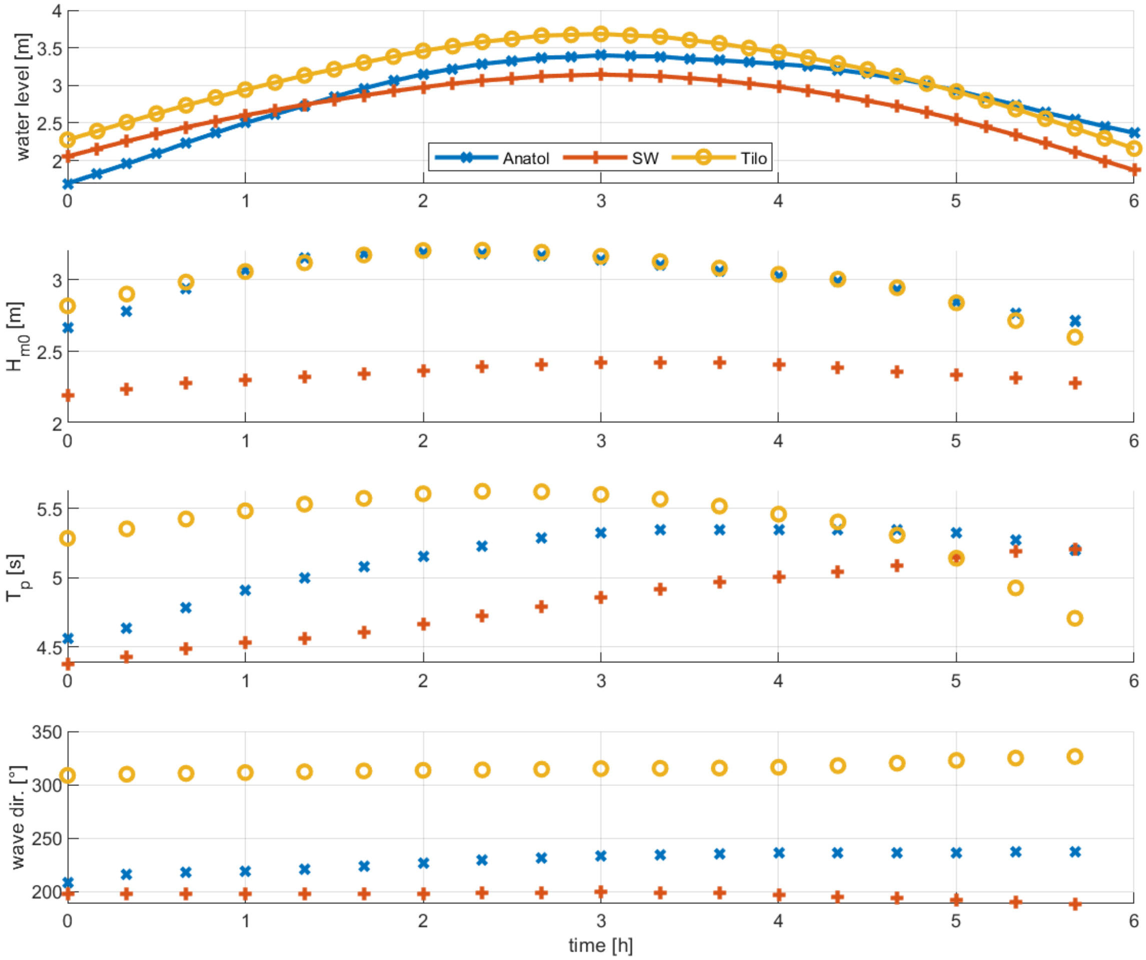

Figure 10: Selected boundary conditions time series including water level, wave height (Hm0), peak wave period (Tp) and wave direction (top to bottom) for the three representative storm events for the XBeach model of St. Peter-Ording

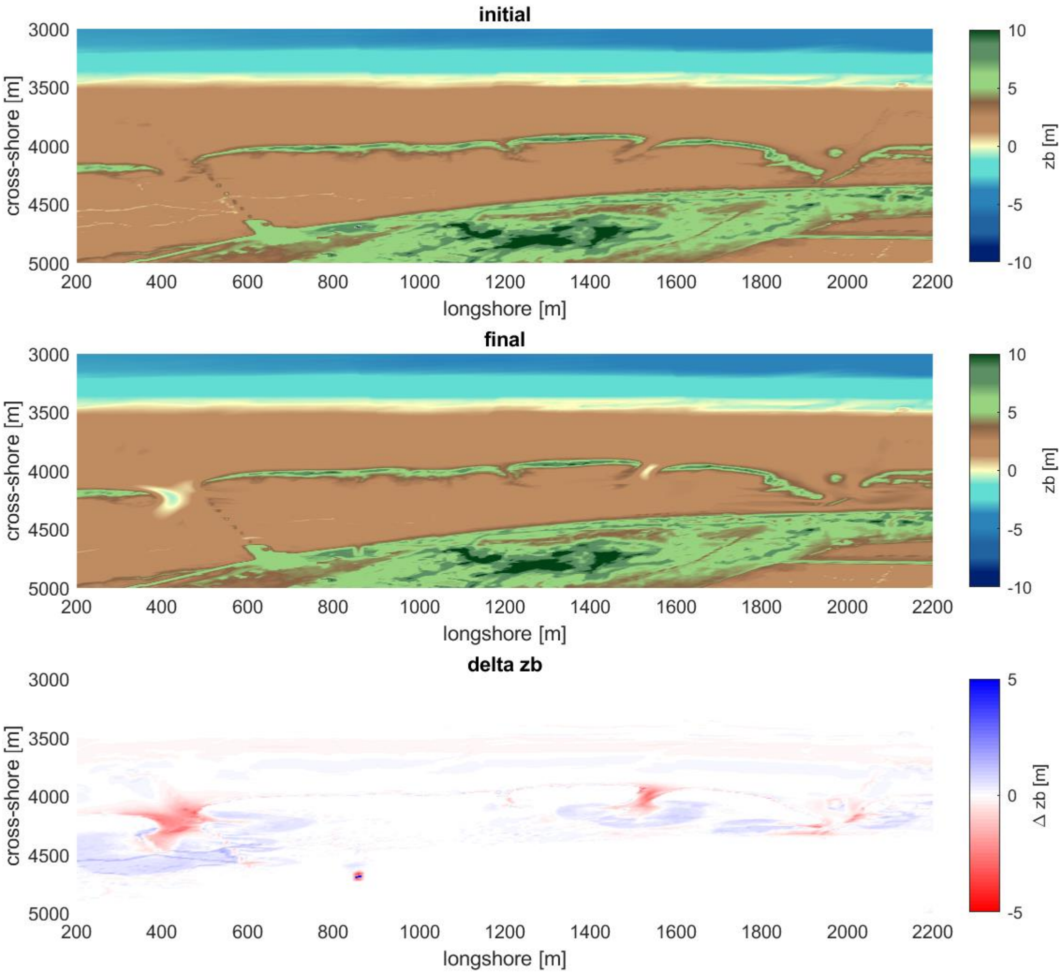

Figure 11: Initial, post-storm and difference between post- and pre-storm bed levels (top to bottom) for 2D-model application to the Anatol storm surge at St. Peter-Ording

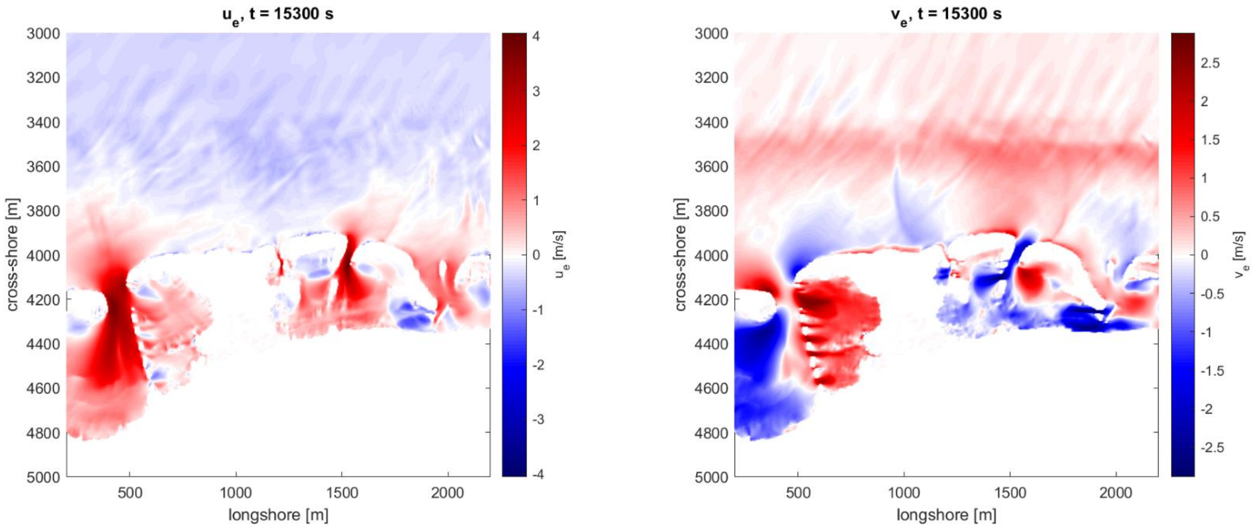

Figure 12: Instantaneous Eulerian velocities in x- (u, left) and y- (v, right) direction for the Anatol storm surge with positive values indicating cross-shore and longshore directions, respectively.

AeoLiS

Calibrating the wind driven model renders impossible at this stage of the project, as no available data regarding aeolian transport rates or wind speed profiles within the dune system are available to date. Correspondingly, a first field survey has been undertaken from the 26th – 29th of March 2025 to acquire necessary episodic aeolian transport rates and wind profiles at multiple points within the model domain (Figure 13). Data is currently being processed for potential calibration. Surface soil samples and surface soil moisture data was acquired. Additionally, aeolian trap measurements were performed for a 24-hour cycle to map episodic transport rates. Supported by the Technical University of Berlin (TU Berlin), UAV based measurements and orthophoto coverage of the complete dune area were acquired. Supplemental vegetation plots were installed and vegetation trait measurements conducted by the TU Berlin. This data will also be used within the numerical modelling efforts within Work Package 11 as soon as they have been processed.

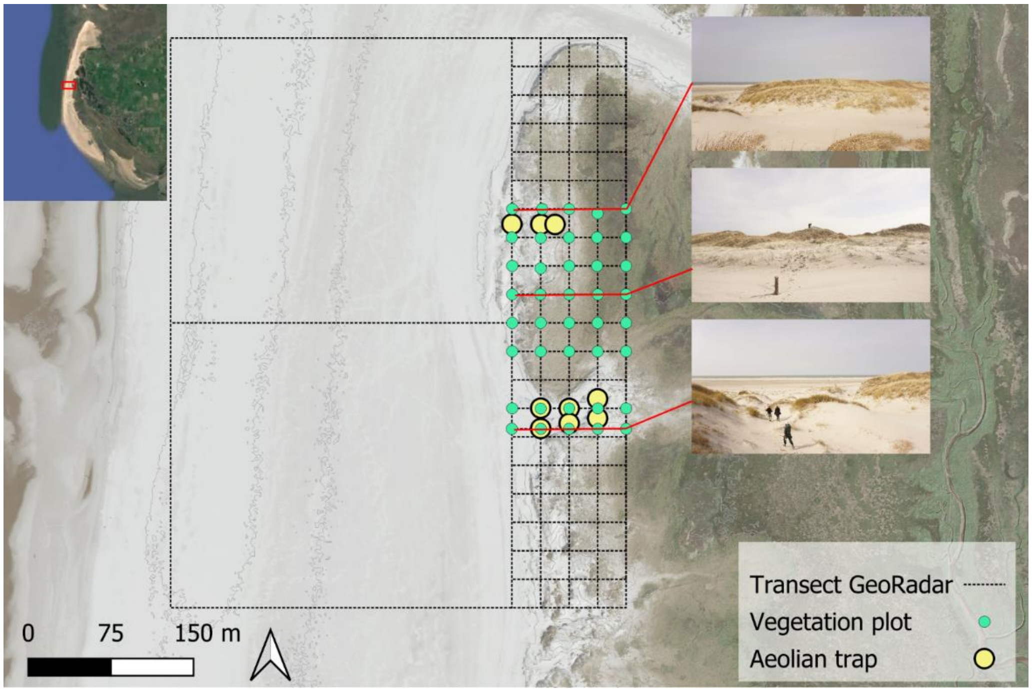

Figure 13: Measurement grid for ground penetrating radar and UAV coverage, sample sites for vegetation plots and aeolian sediment traps at St. Peter-Ording. Field campaign conducted 03/2025 with impressions from the field.

2.3 Belgian Demonstrator – Oostende/ Raversijde-Mariakerke

Initial model efforts are for the Belgian demonstrators are focused on two locations along the North Sea Coast (Figure 23) For Mariakerke-Raversijde, located West of Ostend, an XBeach model has been set up. For Oostende-Oosteroever, East of Ostend, an AeoLiS model has been finetuned.

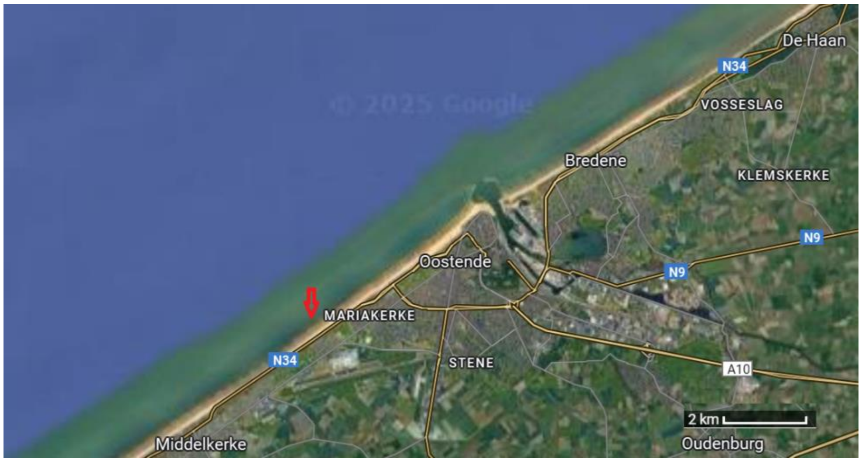

Figure 14: Demonstrator location

2.3.1 Model setup

Xbeach

The XBeach models are taken from the well validated sources used for the *coastal safety assessment 2021* (Witteveen + Bos 2023). These models are used to determine the beach and dune erosion, according to the Belgian Safety Standards. We report shortly on their use and set-up, which will be changed later for hindcast and forecast simulations of the demonstrators.

Grid generation

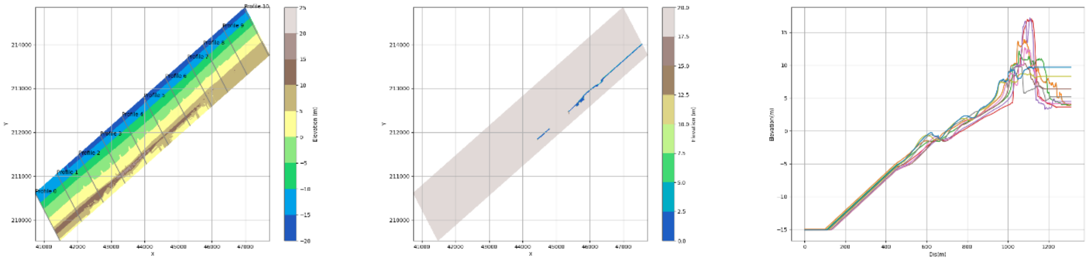

Figure 15: Computational domain(left), non-eroded bed(middle) and dectional view(right)

The computational Domain which covers an area of 1310m cross-shore by 7543m along shore is as shown in Figure 15(left), and the non-erodible area is demonstrated in the middle of Figure 15. Ten cross-sections were selected to illustrate the onshore topography. In the local coordinate system, the x and y directions are divided into 708 and 522 grids, respectively. A zoomed-in view of the grid is shown in the Figure 16. In the x direction, the grid size ranges from 0.56 m to 5.6 m, while in the y direction, it ranges from 4.48 m to 8.41 m, as shown in Figure 16. In the area with significant terrain variations or regions of interest, the refinement was done, as a typical profile was plotted (in orange colour).

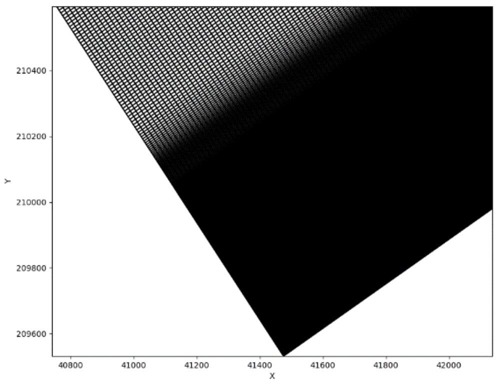

Figure 16: Grid size (a zoomed-in view)

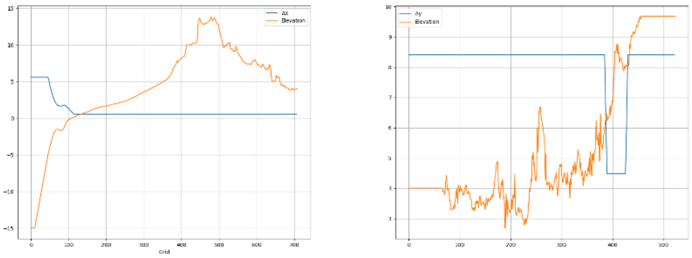

Figure 16: Grid size (left: x-direction, right: y-direction)

Open Boundary

For the time being, the tidal water level and the wave height and period is designed based on a return period of 1000 years. Wave information from 18 points was used as the BCs for the open boundary, which were marked as red dots on Figure 17 (left).

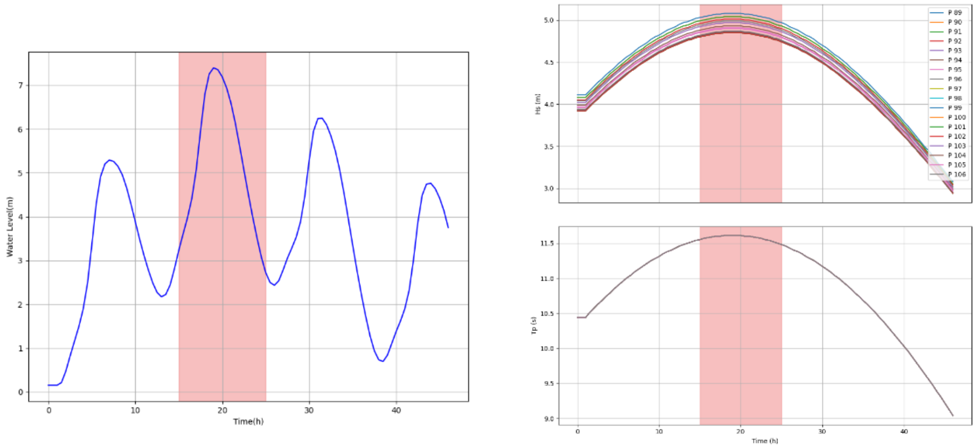

Figure 17: Tidal level(left) and wave boundary condition(right)

Model settings

The flow boundary condition are as follows: Front and back: *abs_2d,* left and right: *neumann*. Bed shear stresses were parametrized using Manning formulation, where the friction coefficient was set to .0200. The sediment transport model was set as the Van Thiel-Van Rijn transport equations (*vanthiel_vanrijn*). The D_{50} *and* D_{90} *of the bed composition was* 0.229 mm *and* 0.345 mm, respectively. The critical slope for dry (*wetslp*) was 0.1. The calculation start and end time are 54000 s and 90000 s, respectively, as shown in the Figure 17.

AeoLis

The initial topography in the computational domain is shown in Figure 18. A structured computational grid with a cell size of 1 m is used in both the x and y directions.

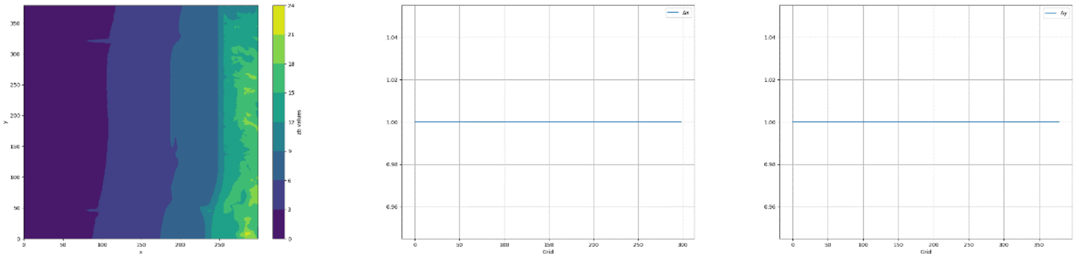

Figure 18: Computational domain and grid size in the x and y directions.

The tidal and wave boundary conditions, wind rose, and vegetation distribution are all shown in the Figure 19.

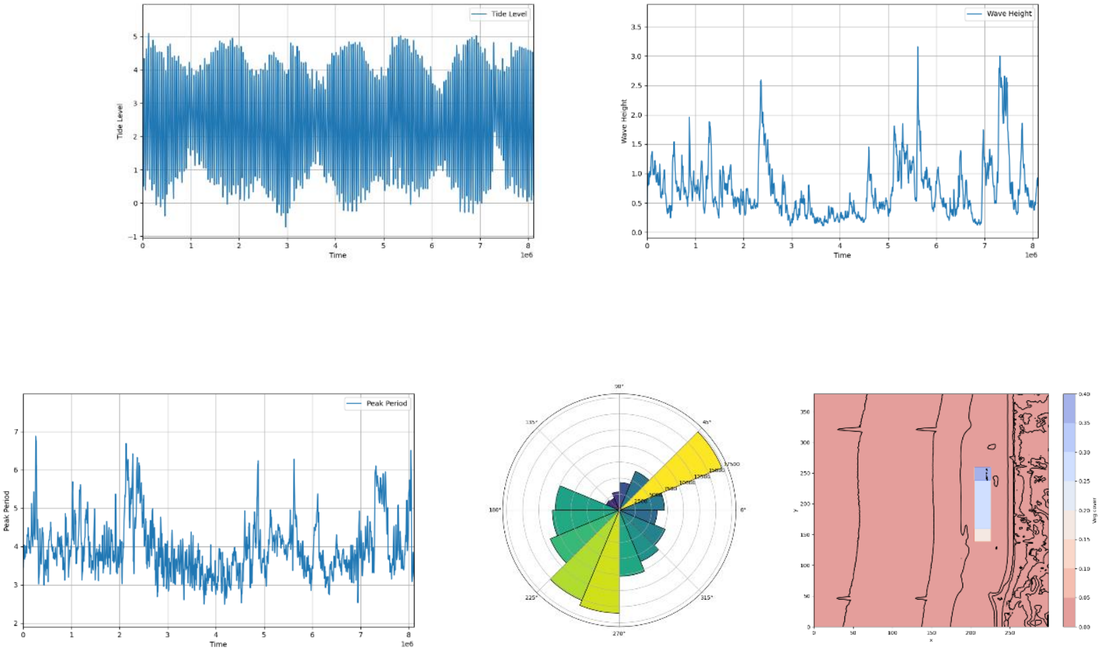

Figure 19: Overview of model boundary conditions (note: all units are SI units).

More detailed information on the model set-up can be found in (Stryptseen Glenn et al. 2024).

2.3.2 Model results

XBeach

Figure 20 shows the final terrain and elevation change. The main erosion area is located at around (43000, 211000). The eroded sediment was transported offshore flattens the dune. Each cross-section has varying degrees of erosion, as illustrated in Figure 21.

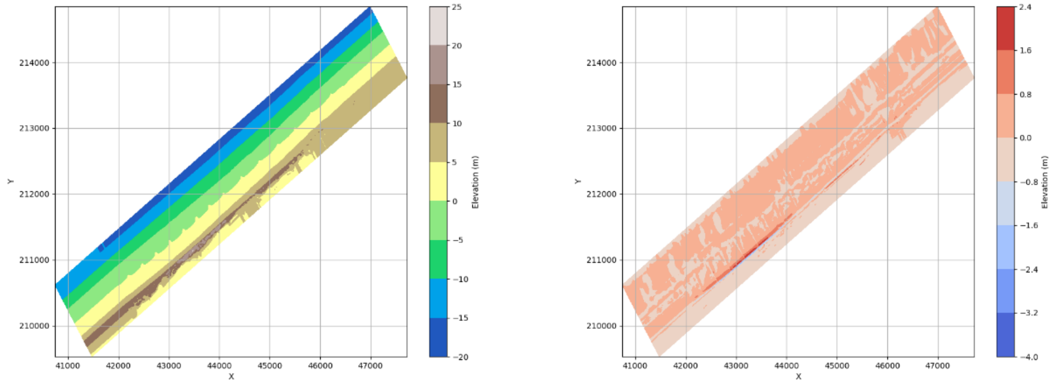

Figure 20: Final terrain(left) and Elevation Change (Δz m) (right)

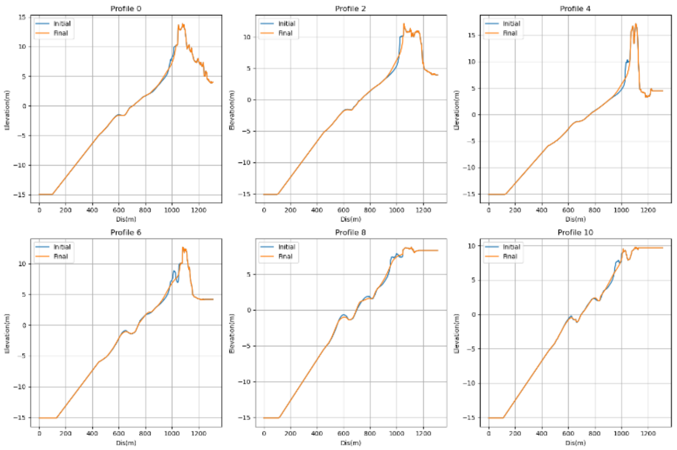

Figure 21: Comparison of the Initial and Final Cross-sections

AeoLis

Figure 22 shows the terrain change, with a significant increase in elevation observed in areas covered by vegetation. However, on the seaward side, the elevation increase is more pronounced, while on the landward side, wind erosion occurs instead. This can also be observed from the cross-section at y = 190 m (fig).

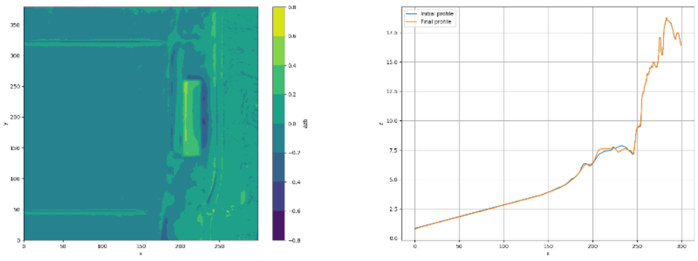

Figure 22: Top view of terrain change (left) and cross-sectional view (right)

Dune volume changes are well predicted. However, vegetation dynamics proved to be crucial for good model results.

2.4 Portuguese Demonstrator - Douro

The Douro sandspit is situated at the mouth of Douro River, between the cities of Porto and Vila Nova de Gaia, Figure 23, exposed to the Atlantic Ocean. The Douro River has the largest watershed in the Iberian Peninsula, with a total area of nearly 100.000 km^2. The sandspit protects inland margins and the natural reserve of São Paio Bay from storms. In 2004, a detached rubble-mound breakwater was constructed in front of the sandspit to stabilise the estuary's bank and inlet and to improve navigation safety. Since then, the sandspit has been growing in area and volume, with the exception of some eroding events related to heavy storms. On average, the sandspit has grown by 68.000 m^3 per year since the construction of the breakwater has finished, in 2008. The dune reaches a maximum height of around 8 m above the mean sea level.

The Douro sandspit is a complex morphological case considering the different drivers that affect it. This location is influenced by an interaction of wave action, fluvial discharge, and aeolian processes, in addition, the effects that the breakwaters have on the hydrodynamics. This makes numerical modelling particularly challenging.

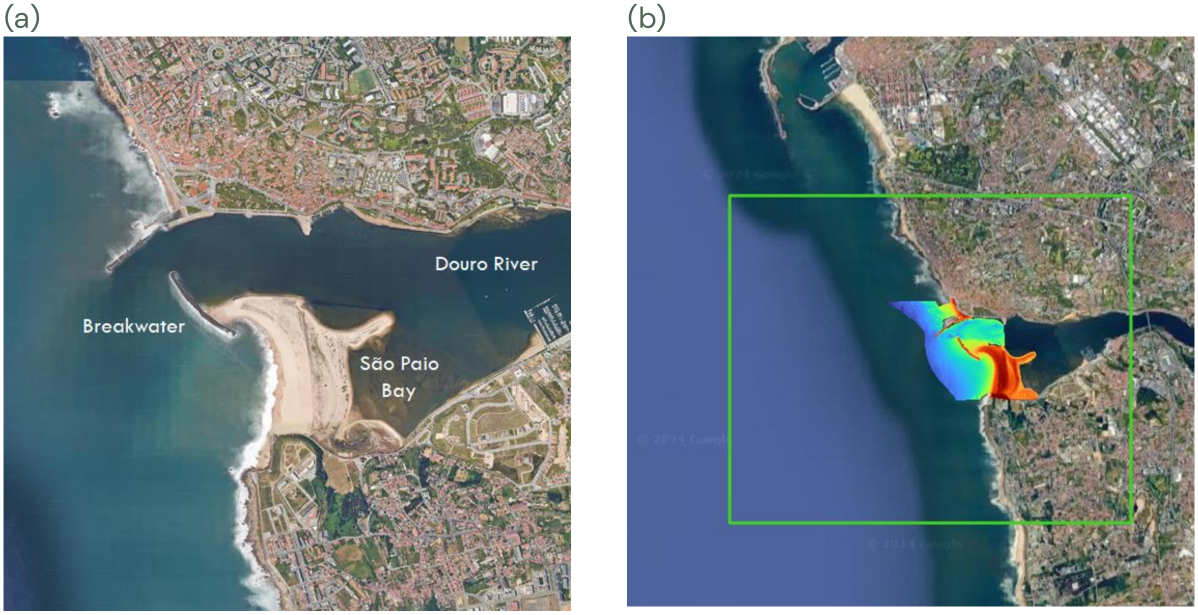

Figure 23. (a) Douro sandspit showing the breakwaters and the São Paio Bay. (b) Domain area along with the demonstrator's high-resolution DEM.

2.4.1 Model setup

The preparation of the XBeach surfbeat model is based on a bathymetric survey of the area of interest conducted in 2018 with a DEM of resolution 30 cm, Figure 23 (b). The computational domain covers an area of 5100 m (cross-shore) by 6250 m (along shore). The remainder of the area was assimilated from other lower-resolution bathymetries.

To stabilize the propagation of waves at the offshore boundaries, a constant depth of −25 m was assumed for nearly 160 m Figure 24 (a). Also, to prevent having significant wave shadow areas, the domain was oriented towards the global X-direction, instead of being perpendicular to the shoreline as is typically favored. This was chosen since orienting the grid slightly to the south would cause many North-Western waves to exit the domain from the bottom lateral before reaching the shoreline, resulting in a larger shadow area at the upper lateral boundary. Then, a varying grid resolution was chosen to decrease the computational effort. A grid size of 5x5 m was chosen to the area of interest and gradually increased towards the boundaries. In the cross-shore direction, dx varied from 5 m to 10 m Figure 24 (b). While in the along-shore direction, dy varied from 5 m to 20 m. The total grid consists of 841 x 553 mesh cells. Several cells were marked as non-erodible to correspond to the real case as closely as possible, Figure 24 (c). These cells represent the breakwaters, the riverbanks, and several rocky patches along the coastline.

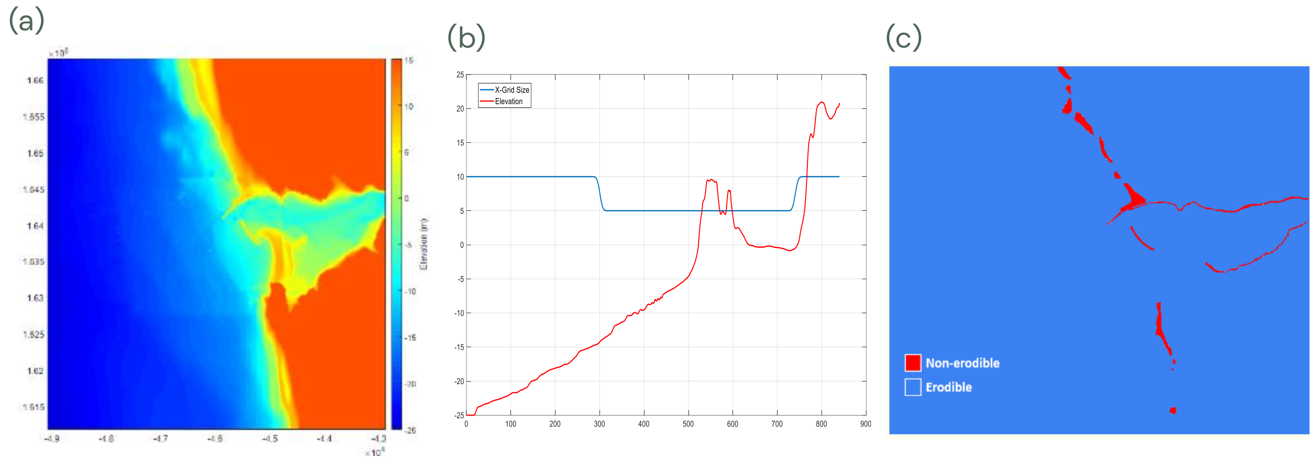

Figure 24. (a) XBeach model bathymetry with artificial offshore depth of -25m. (b) Grid size in cross-shore direction, dx, along with the bed profile. (c) Non-erodible regions (red) covering the river banks, breakwaters, and rocky spots along the coast.

The lateral boundaries of the domain were assumed to be Neumann for the hydrodynamics and wavecrest for the waves. Front and back boundaries were set to abs_2d. Implementing a cyclic boundary condition resulted in an erroneous behaviour because the bathymetries at either end of the domain are completely different, which does not allow a smooth reentering of the waves from one side to the other. For the offshore boundary, a time-varying spectral wave condition was defined along with a wind time series, which had a one-hour temporal resolution. Additionally, a daily averaged timeseries of river discharge was applied from the onshore direction. Sea level variations were implemented using astronomical tide components with a temporal resolution of half an hour and a tidal range of 3.75 m. The sediment transport module was set to the VanThiel_VanRijn equations, and the D_{50} was set to 2.91 mm. Other parameters were kept as simple as possible, and many coefficients remained as Xbeach's recommended default values.

As for the Aeolis model, a similar grid resolution to the XBeach model was chosen, i.e., 5x5 m, to ensure smooth translation between the models and ease the work of coming deliverables. Nonetheless, the domain area was reduced to give attention to the sandspit region, discarding the offshore and side land parts, Figure 25. Tide, wind, and wave conditions are kept the same as XBeach simulations. Values of wind speeds and directions are adapted from a weather station in Port Leixões, north of the demonstrator site.

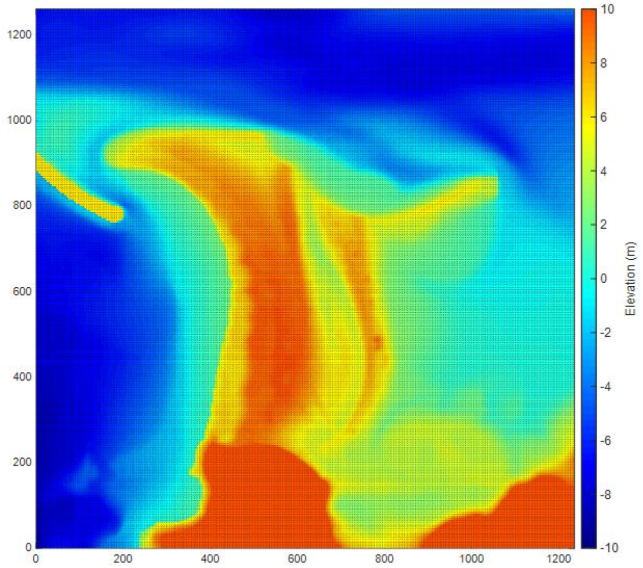

Figure 25. Aeolis model domain focused on the dune area. Grid size is 5m x 5m.

2.4.2 Model results

The XBeach and Aeolis models for the Douro Sandspit are currently being validated with available data. Therefore, model results are still under investigation. Nevertheless, Figure 26 presents preliminary results of the XBeach model regarding waves and bed change. These initial outputs indicate areas of erosion and accretion along the coastline, particularly around the breakwaters and the river mouth. Although the results are inconclusive, they can give a qualitative representation. Further calibration and comparisons with field surveys will refine these predictions and provide a reliable predictive tool.

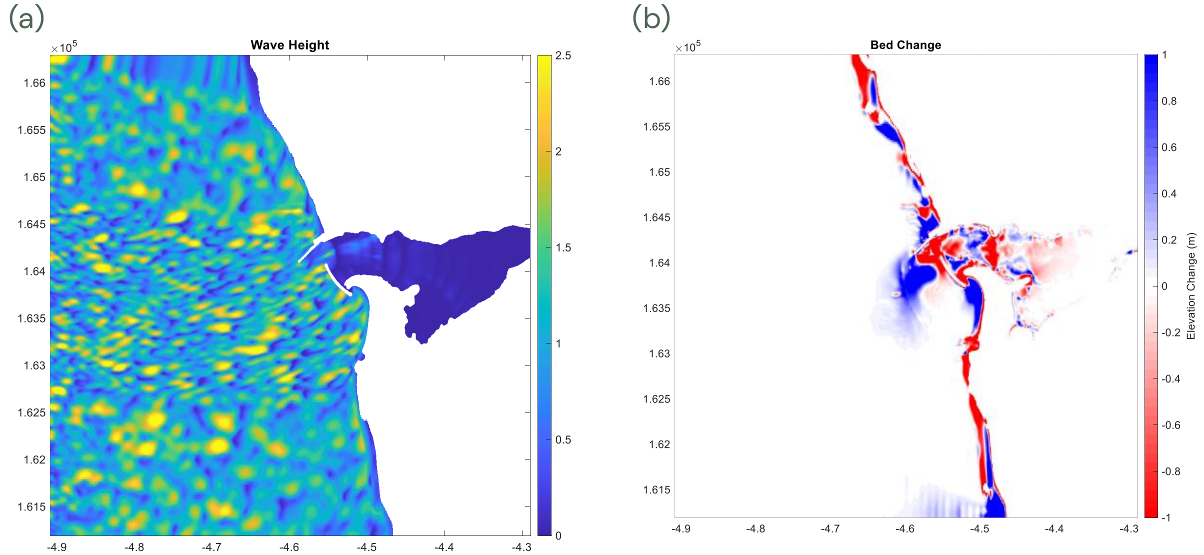

Figure 26. (a) Wave field of the surfbeat model in XBeach. (b) The bed change variation of XBeach only after 10 days.

3. Conclusions

This report showcases the numerical models developed for select demonstrator sites within Work Package 11.1 for the simulation of morphodynamic functioning using available data from D6.1, D6.2 and D10.2 as well as complimentary or more recent data provided/obtained from government agencies.

Numerical models have been setup for demonstrator sites of Sankt Peter-Ording, Germany, the Douro estuary sand spit, Portugal and the Living Lab Raversijde, Belgium. Further advances and development will be the subject of research in the following two reports in Work Package 11.

The models exhibit varying degrees of fidelity, depending on the data availability. Calibration was only possible at this stage for the Belgian models, since these are part of a larger national modeling framework and has been previously published.

The XBeach model of the German demonstrator has been calibrated based on extensive physical laboratory campaign data and shows no numerical artifacts or physically unsound results. This leads the authors to conclude that this approach is valid and the model can be considered calibrated. A scientific standalone publication is currently under review regarding this model. The AeoLiS model of the German demonstrator is based on field sampling data and national weather data. Calibration of this model renders difficult at this moment, since detailed on site data is not available. Therefore, dedicated surveys are conducted throughout 2025 to assess wind profile data and aeolian transport volumes within episodic campaigns.

The Portugese models yield insights into local processes and may well serve the advancement of the morphodynamic functioning of the demonstrator. These models are no mandatory part of WP11.1 but are a well received addition to the work carried out in WP11.

4. Data availability statement

The demonstrator base models for the German demonstrator are archived on Zenodo with their base settings and model boundaries, along with a copy of this report (https://doi.org/10.5281/zenodo.15795904).

The demonstrator base models for the Portuguese demonstrator can be made available by the authors upon reasonable request.

The demonstrator base models for the Belgian demonstrator can be made available by the authors upon reasonable request.

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