OPERANDUM

OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

**EGU21 19 - 30 April 2021**

NH1.4- Nature-based solutions for hydro-meteorological risk reduction 28/04/2021

# Modelling Nature-based Solutions: an application to mitigate coastal erosion

**Unguendoli Silvia**, Valentini A., Biolchi L.G., Umesh P.A., Alessandri J., Pinardi N.

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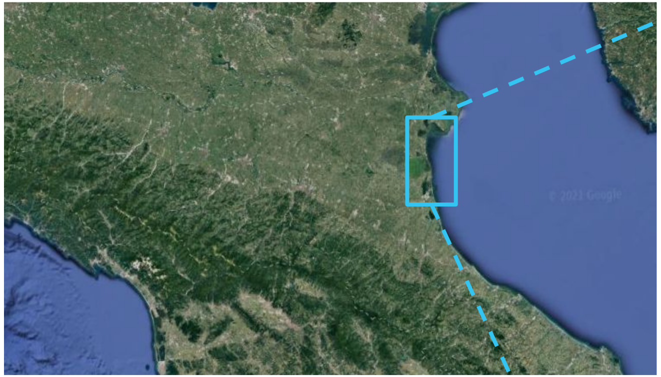
# Introduction

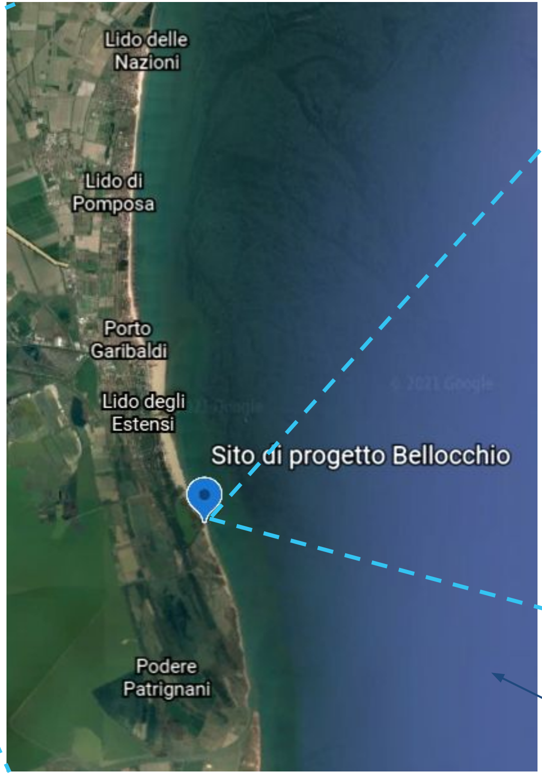
- Nature based solutions (NBSs) address key societal challenges through the protection, sustainable management and restoration of both natural and modified ecosystems.
- In the context of the **OPERANDUM project**, with regards to the Italian experiments, the purpose of the project is the implementation of a **nature based solution** on the Bellocchio beach at Lido di Spina, consisting in an **artificial sand dune** reinforced with a structure of natural material.
- The dune is built in front of a pre-exsisting natural dune with the aim to protect it from erosion and hindering flood phenomena.
- In order to simulate long-term current scenarios (present and future conditions) with and without the NBS a numerical modeling chain has been set-up. The chain is composed of the wave model WAVEWATCH III, the oceanographic model SHYFEM and the morphodynamic model XBeach for the coastal area.
- Long-term morphological simulations require a specific approach. In this work the approach followed for the long-term morphodynamic modelling of the NBS with the XBeach model is presented.

EU funded project
GA no. 776848

# Project Site



Emilia-Romagna littoral, Italy




Bellocchio Beach at Lido di Spina


Adriatic Sea

**The NBS:**

**structure**:
artificial sand dune reinforced with a structure of natural material: wood and coir geotextile.

**aim of NBS:** coastal erosion mitigation

**size:** 100 m long, 8 m large, 3,5 m a.s.l high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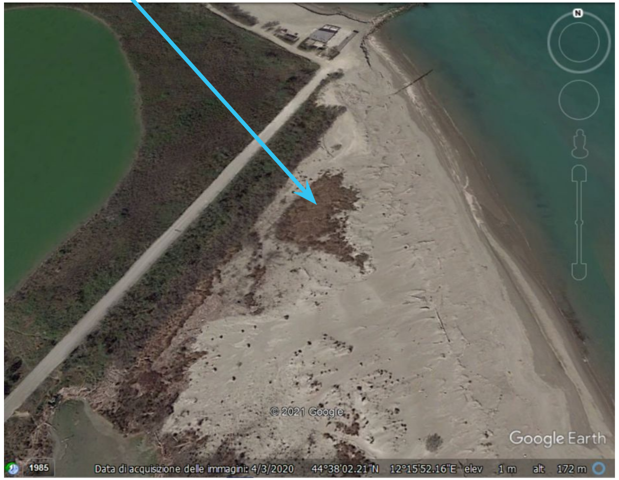
# Project Site

pre-existing natural dune




Occurred erosion phenomena at Bellocchio beach

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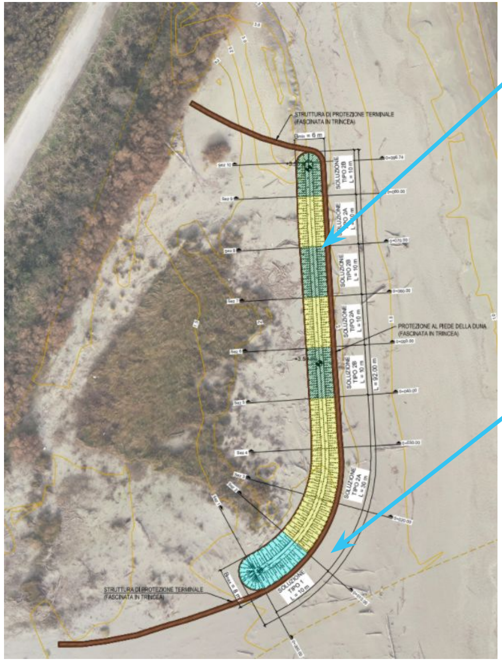
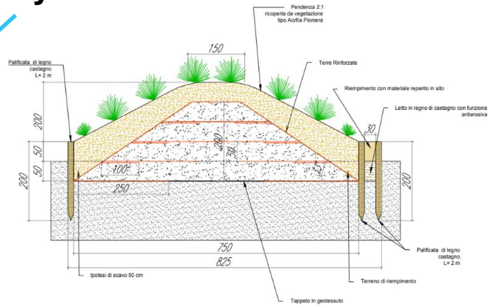
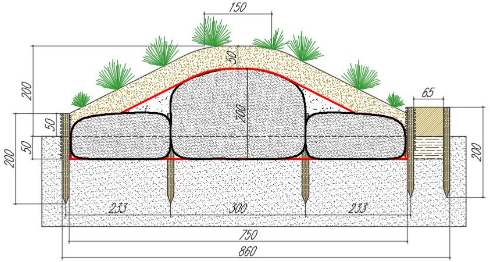
# Artificial dune Layout



## Layout 1 with reinforced soil




## Layout 2 with with tubular module + hinge system (patented by RINA C)




For a detailed description of duna layout see the presentation:

## Design and pre-assessment of NBS for coastal erosion and marine flooding:

## a case study

### EGU 28/04/2021

NH1.4- Nature-based solutions for hydro-meteorological risk reduction


Margherita Aguzzi, Maurizio Bacci, Nunzio De Nigris, Laura Sandra Leo, Maurizio Morelli, Beatrice Pulvirenti, Paola Robello, Paolo Ruggieri, Fabrizio Tavaroli, Silvia Unguendoli, Andrea Valentini, Carlo Cacciamani



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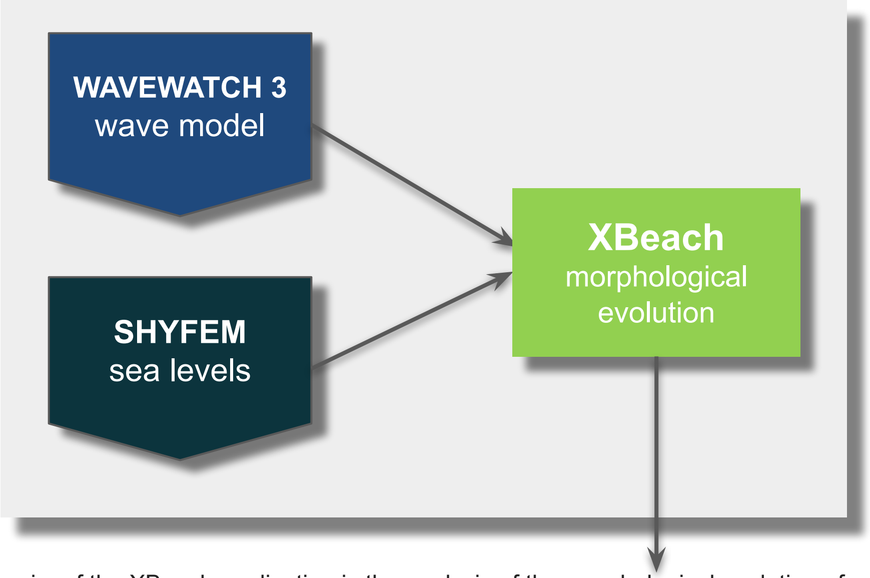
# Numerical Modelling

## NUMERICAL MODELING CHAIN:




The aim of the XBeach application is the analysis of the morphological evolution of the beach with and without the NBS. In order to analyze **current** and **future scenarios** the analysis consists in **long-term simulations.**

## Scenario Simulations (long-term)

| Present climate (2010-2019) | Future climate (2040-2049) |
|---|---|
| Control simulation (current scenario) | Control simulation (current scenario) |
| NBS simulation (post-implementation) | NBS simulation (post-implementation) |

The XBeach model is forced with sea level inputs provided by the model SHYFEM and waves input provided by WAVEWATCH 3 model.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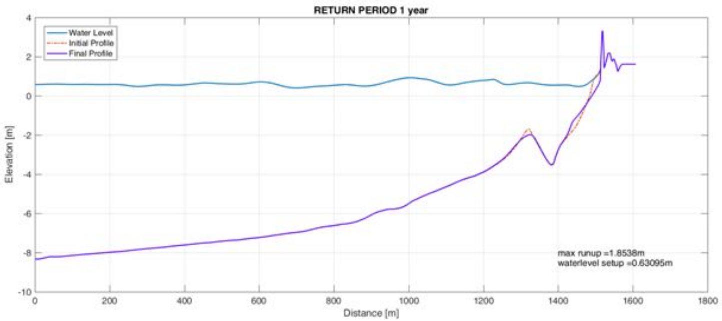
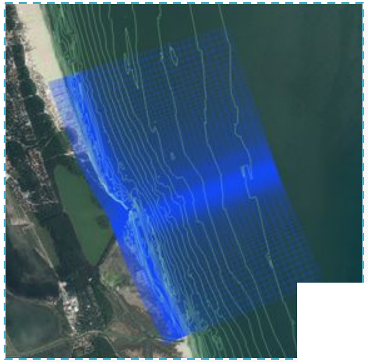
# Morphological model XBeach

## 1D XBeach simulations
dune design and sizing




Model simulations with input forcing (sea levels and waves) at 3 different return period (2, 10 and 25 years)

## 2D XBeach model
long-term simulations with and without NBS

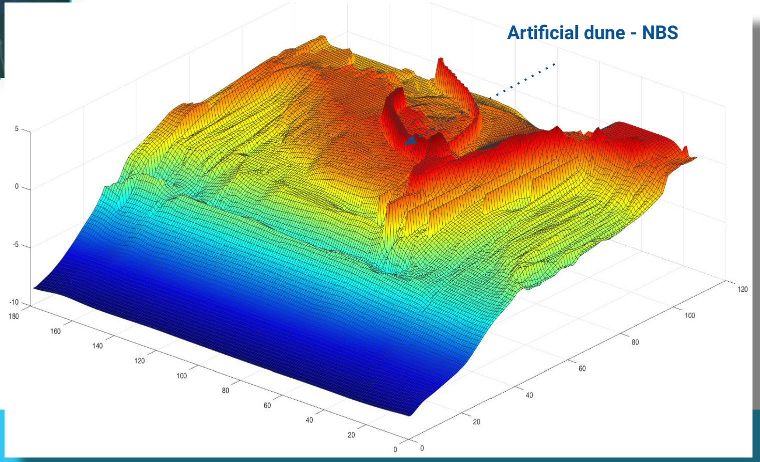


Grid domain

Grid Domain and bathymetry generation.

The input bathymetry for model simulations were generated by means the elaboration of available topo-bathymetric survey of the interest area.

2D bathymetry



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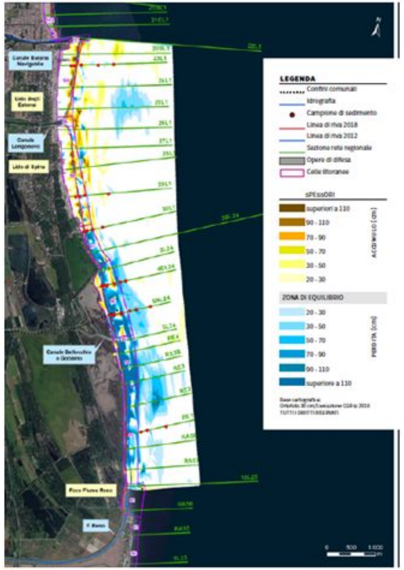
# XBeach Calibration

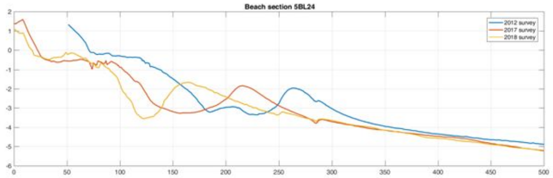
- Regional Topo-bathymetric Network surveys was used to calibrate the model performance.
- averaged annual shoreline retreat 5-10 m
- A seit of XBeach simulations with varied parameter values were carried out. Forecasted shoreline movement has been compared with available measurements (year trend of shoreline retreat).

| parameter | description | range |
|---|---|---|
| **facua** | Calibration factor time averaged flows due to wave skewness and asymmetry | 0-1 |
| **lws** | Switch to enable long wave stirring | 0-1 |
| **wetslp** | Critical avalanching slope under water (dz/dx and dz/dy) | 0.1 - 1.0 |
| **gamma** | Breaker parameter in baldock or roelvink formulation | 0.4 - 0.9 |
| **fw** | bed friction coefficient | 0 -1 |
| **CFL** | Maximum courant-friedrichs-lewy number | 0.1 - 0.9 |
| **eps** | Threshold water depth above which cells are considered wet | 0.001 - 0.1 |
| **smax** | Maximum shields parameter for equilibrium sediment concentration | -1.0 - 3.0 |

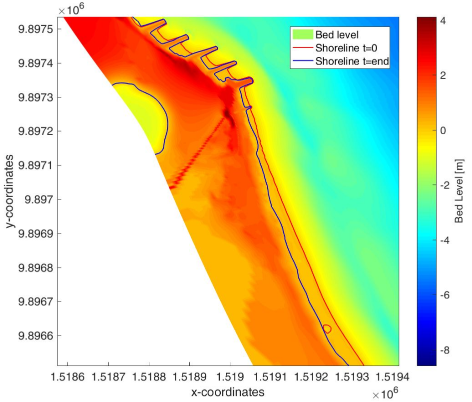



**Best parameter setting:**

CFL=0.8, facua=0.15, smax=0.8, eps=0.01, fw =0.1




shoreline retreat analysis:

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M2 and K1 constituent

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# Input-schematization

Input reduction is **imperative to long-term morphodynamic** simulations to avoid excessive computation times.

Input reduction was applied both to **seal level** and **wave inputs** provided by SHYFEM and WAVEWATCH3 respectively.

**Sea Levels** → Selection of representative tide(s); morphological tide.
Approach of **Latteux (1995)**

**Waves** → Schematization of the wave climate
Approach of **Walstra et al. 2013**.

***Bibliography***

- *Latteux, B., 1995. Techniques for long-term morphological simulations under tidal action. Marine Geology 126, pp 129-141*
- *Walstra, D.J.R., Hoekstra, R., Tonnon, P.K., Ruessink, B.G., 2013. Input reduction for long-term morphodynamic simulations in wave-dominated coastal settings. Coast. Eng. 77, 57–70. https://doi.org/10.1016/J.COASTALENG.2013.02.001*

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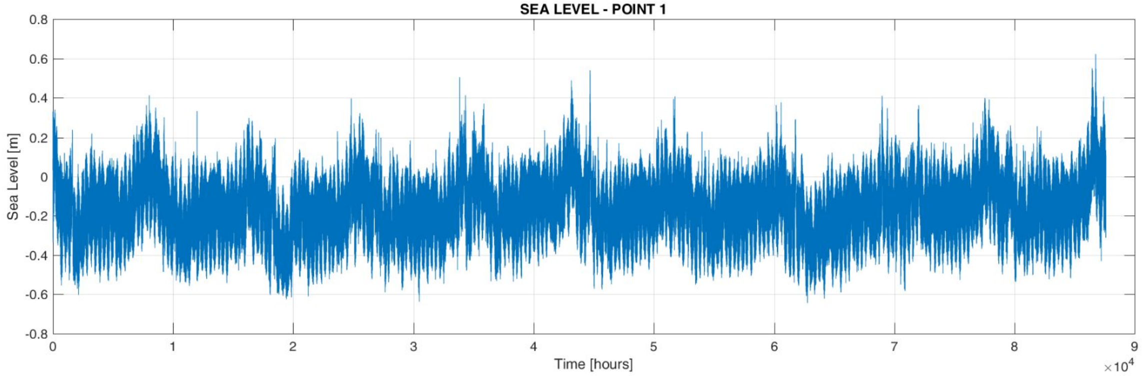
# Sea level original dataset

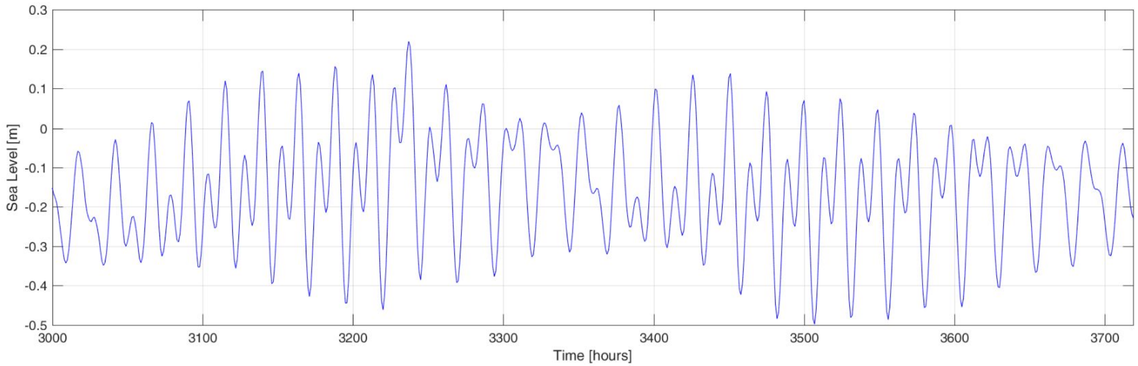
## SHYFEM model

sea levels
10 years dataset

original time series forecasted by the SHYFEM model (2010-2019)




original time series forecasted by the SHYFEM model (spring-neap period)

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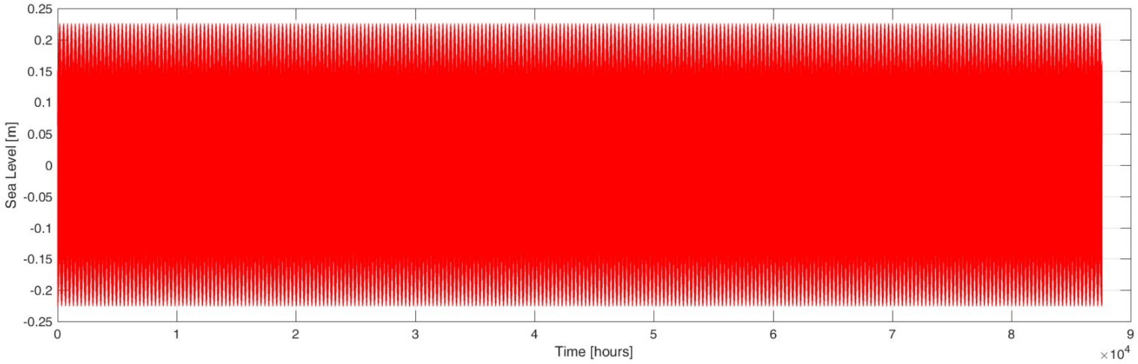
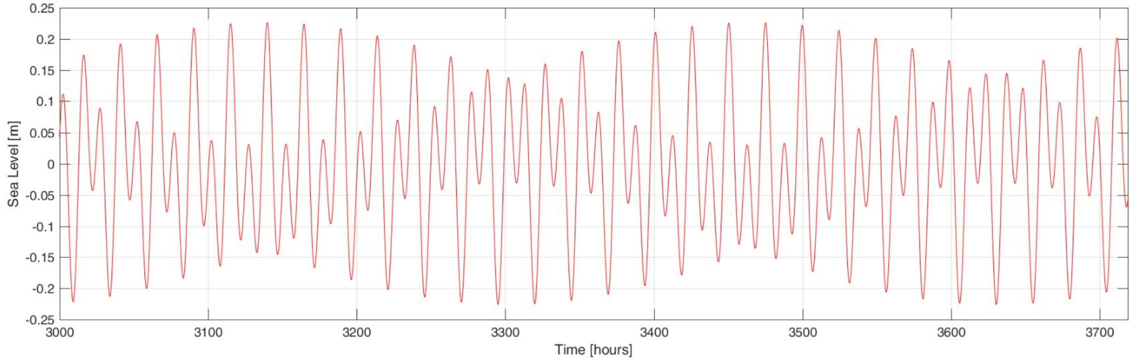
# Sea level schematization

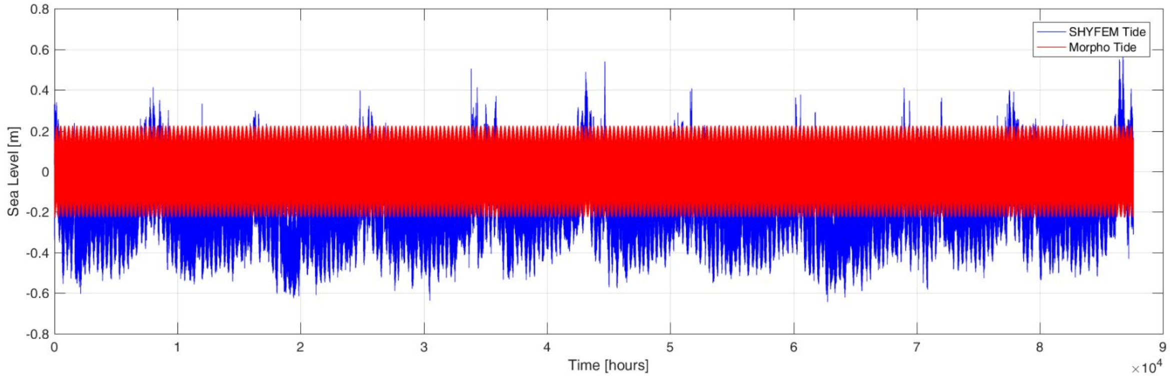
**Morphological tide:**
morphological tide was generated on the basis of K1 and M2 signal constituents considered the most representative for the Adriatic basin

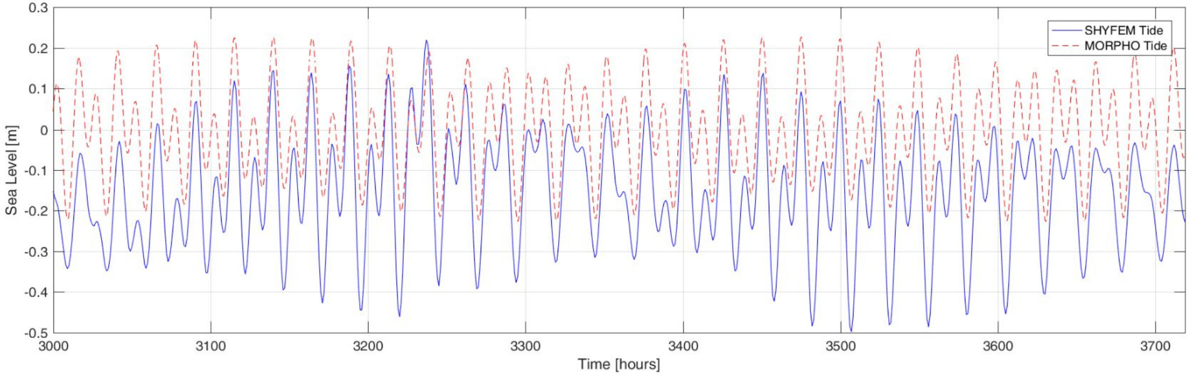


# Sea level comparison

**Comparison**
morphological tide (dashed red line) and original dataset (blu line)

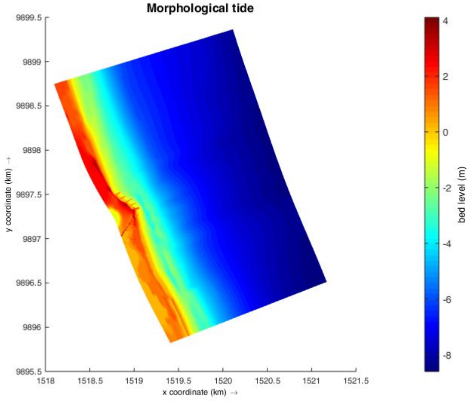


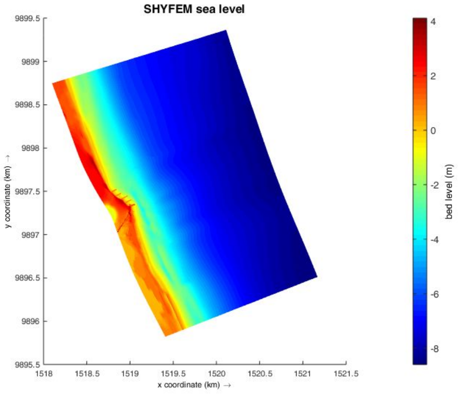



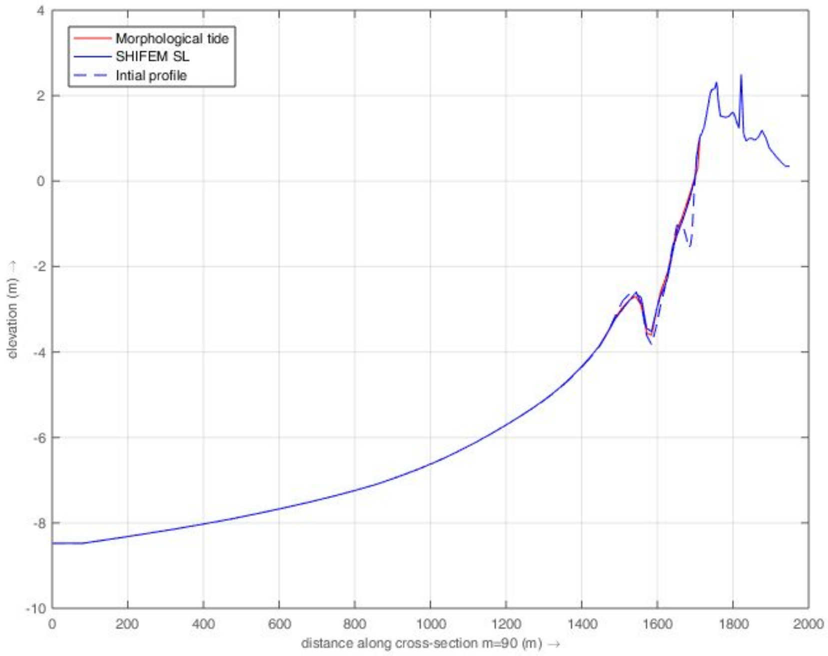
# Results of sea level reduction

## Comparison of model results

model results for XBeach simulations forced with the morphological tide and the original dataset (SHYFEM data) are in good agreement

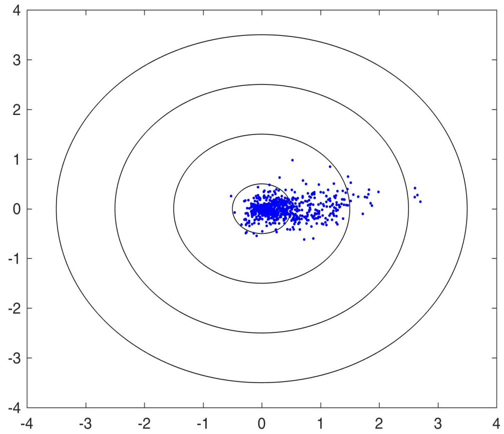


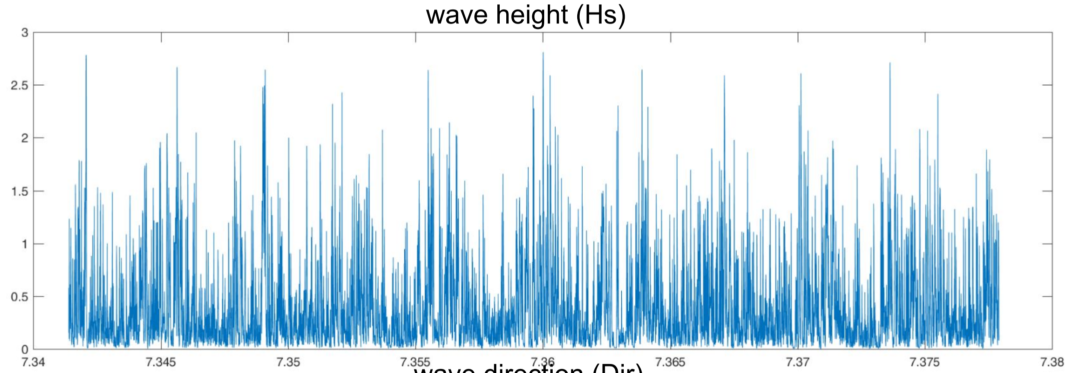



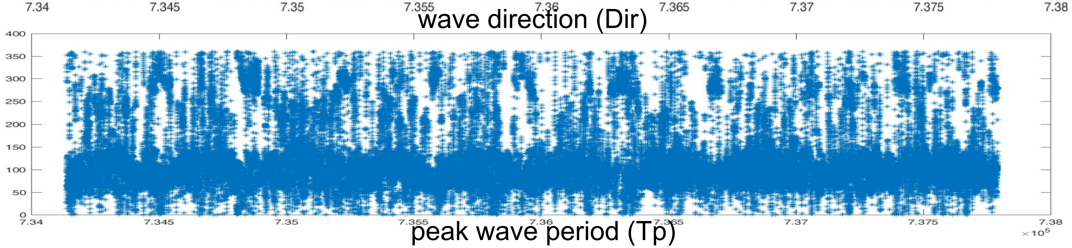



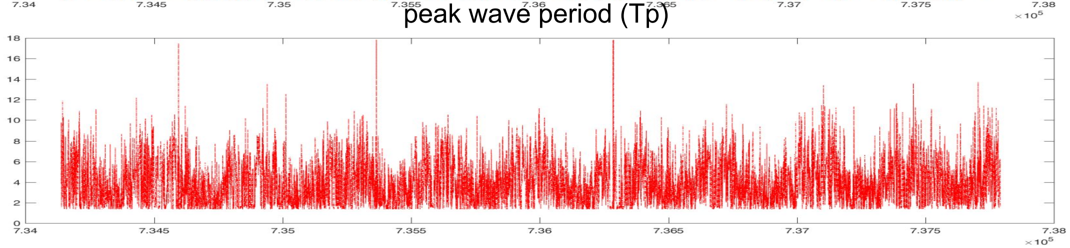
# Waves original dataset

**WAVEWATCH3**
10 years dataset (2010-2019)
original time series of waves



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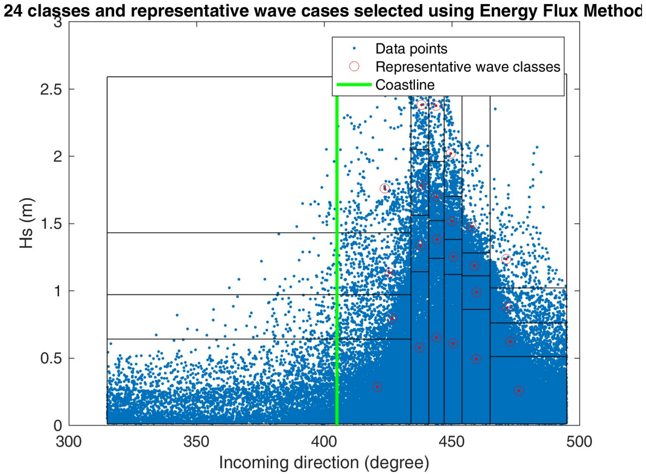
# Waves schematization

Wave schematization methodologies consist in dividing a wave time-series into directional and wave height classes, and calculating a representative sea state for each class.

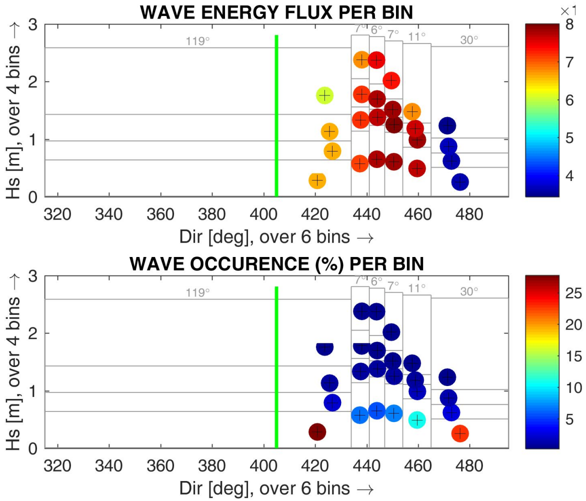



**Wave climate:**
Based on the original datasets provided by the WW3 model a wave climate was generated.

**Energy Flux Method**

Wave climate consists in a sequence of 24 wave classes featured by a significant wave height, peak wave period and mean wave direction.

Duration of each class depends on the cumulative frequency of occurrence.



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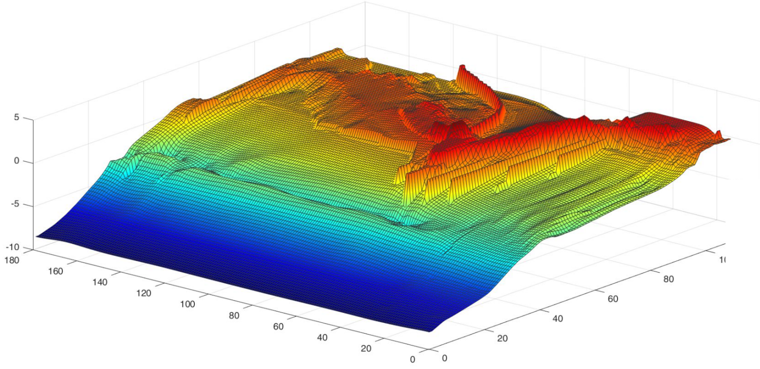
# Results of waves schematization

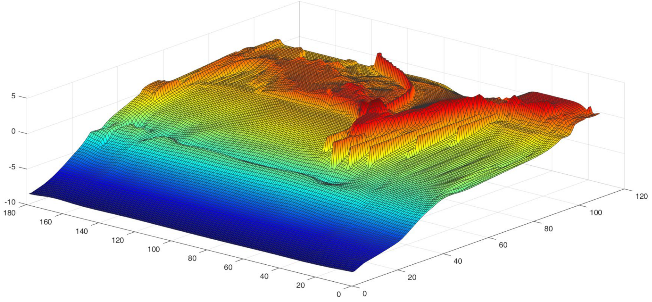
Wave reduction performance and definition of wave climate duration

### Target simulation (1 year)



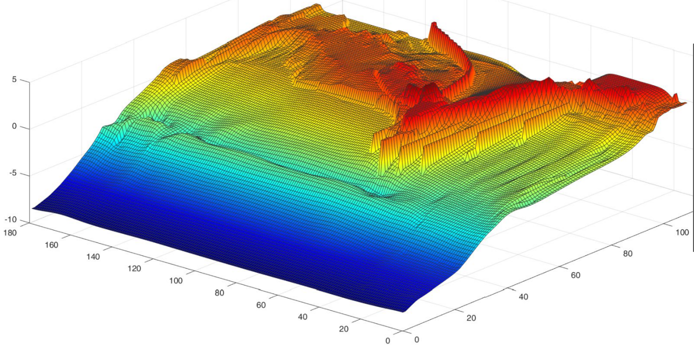
Simulation with a wave climate composed by 24 wave representative classes, repeated for 0.8 times shows the best performance and a good agreement with target.

### Wave climate reduced (24 classes)



| | |
|---|---|
| **r2** | 0.95 |
| **sci** | 0.07 |
| **relbias** | -0.01 |
| **bias** | -0.05 |
| **rmse** | 0.25 |
| **bss** | -0.32 |

### 0.8 Wave climate reduced (24 classes)



| | |
|---|---|
| **r2** | 0.98 |
| **sci** | 0.04 |
| **relbias** | 0.00 |
| **bias** | -0.02 |
| **rmse** | 0.14 |
| **bss** | 0.60 |

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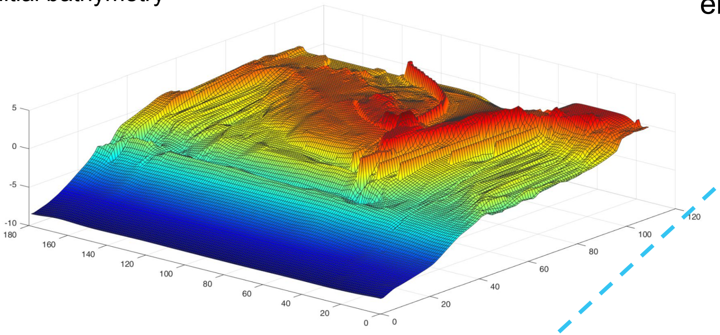
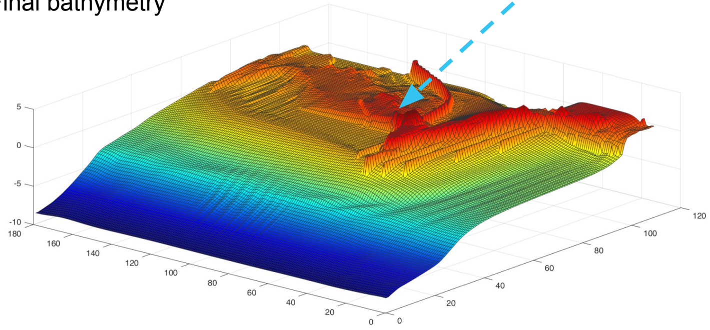
# 2010-2019 simulation
## current scenario

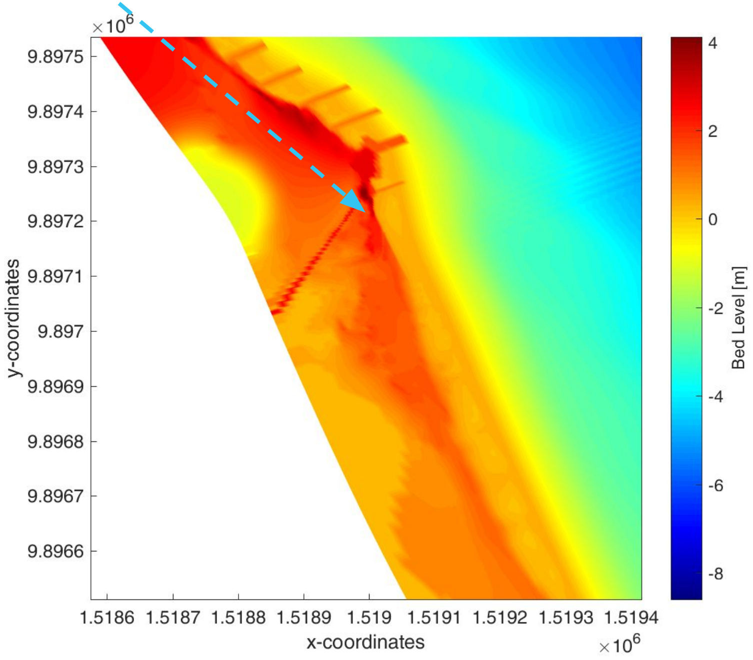
Initial bathymetry




Final bathymetry




erosion of the pre-existing natural dune

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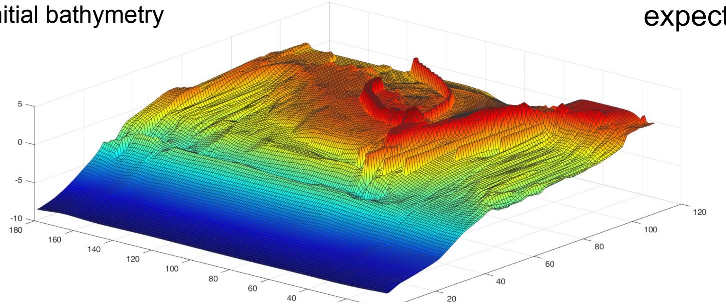
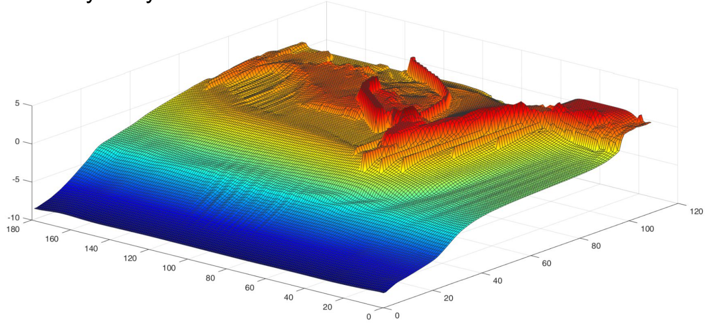
# 2010-2019 simulation
## post-implementation scenario

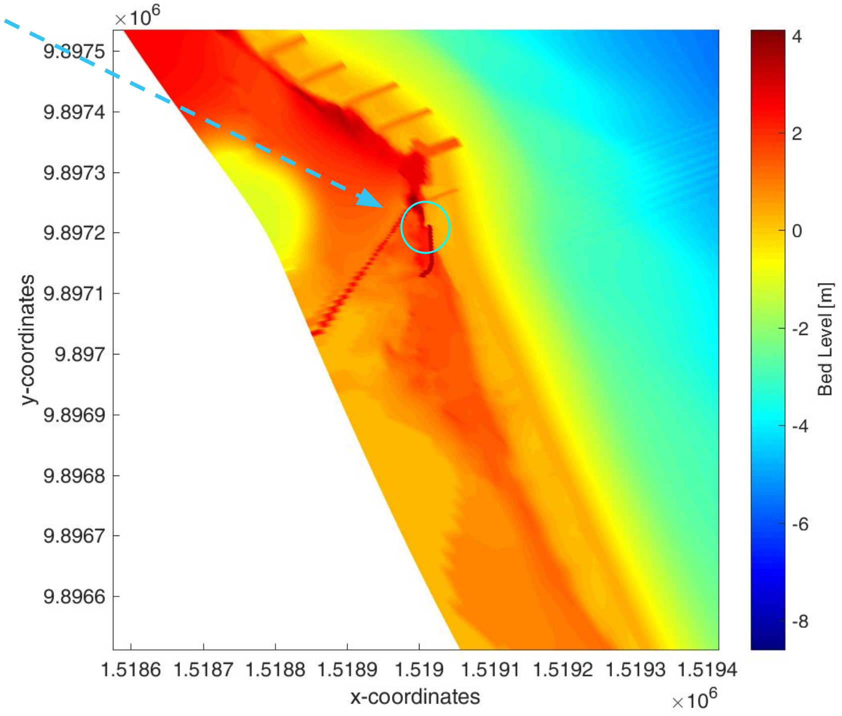
Initial bathymetry




Final bathymetry




expected erosion at dune foot



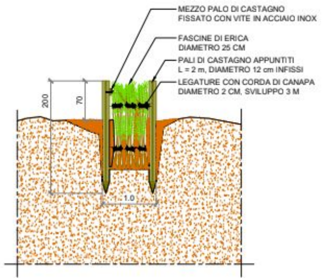

- NBS protects the pre-existing natural dune from erosion

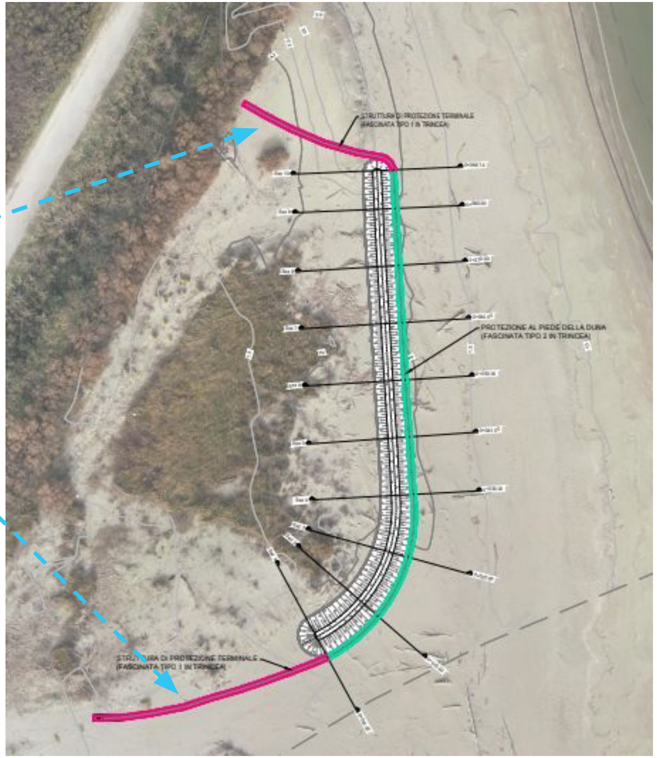
# 2010-2019 simulation
## post-implementation scenario

As expected, simulation results show a **local erosion in the northern part of the dune** (around the dune head)

The dune project includes the implementation of a **bundles of wood vertical in trench** on the dune sides in order to avoid this erosion process.

Due to its structure and porosity features this type of structure is not well representable through the model and then was not included in numerical runs.



# Conclusions

- This work presented an application of morphological model XBeach to simulate A Nature-based Solution performance for long-term scenarios.
- The NBS analyzed consists in an artificial sand dune reinforced with a structure of natural material: wood and coir geotextile built in front of a pre-exsisting natural dune with the aim to protect it from erosion and hindering flood phenomena.
- The study presented the methodology followed to simulate long-term scenarios with XBeach  model and demonstrated it applicability to an NBS implementation.
- The input-reduction is necessary for long-term simulations with morphological model.
- Simulations for period 2010-2019 confirmed the NBS efficacy in hindering the erosion of the pre-existing natural dune .
- Long term simulations for future conditions (2040-2049) are ongoing.

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# Thanks for your attention!

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OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

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agenzia prevenzione ambiente energia emilia-romagna

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