Advancing Coastal Resilience: Scenario-Based Optimization of Nature-Based Solutions (NBS)

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OceanPredict
Advancing the science of ocean prediction

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Digital Twins of the Ocean - DITTO

An **accessible ocean** with open and equitable access to data, information, and technology and innovation.

Develop a comprehensive digital representation of the ocean.

- **Digital Twins of the Ocean** are a virtual representation of the real ocean and have a two-way connection with it.
- **Digital Twins** will enable users to address **'What if' questions** based on shared data, models and knowledge.
- **Digital Twins** empower ocean professionals, citizen scientists, policymakers, and the general public alike to visualise and explore ocean knowledge, data, models and forecasts.

EDITO-Model Lab Consortium

European ocean numerical modelling expertise

13 partners

8 countries

— Numerical modelling
— Supercomputing
— Artificial intelligence
— Software development
— Operational oceanography
— Design with and for users
— Science communication

A **UN Ocean Decade** Action

EDITO

European Digital Twin Ocean

DITTO

Digital Twins of the Ocean

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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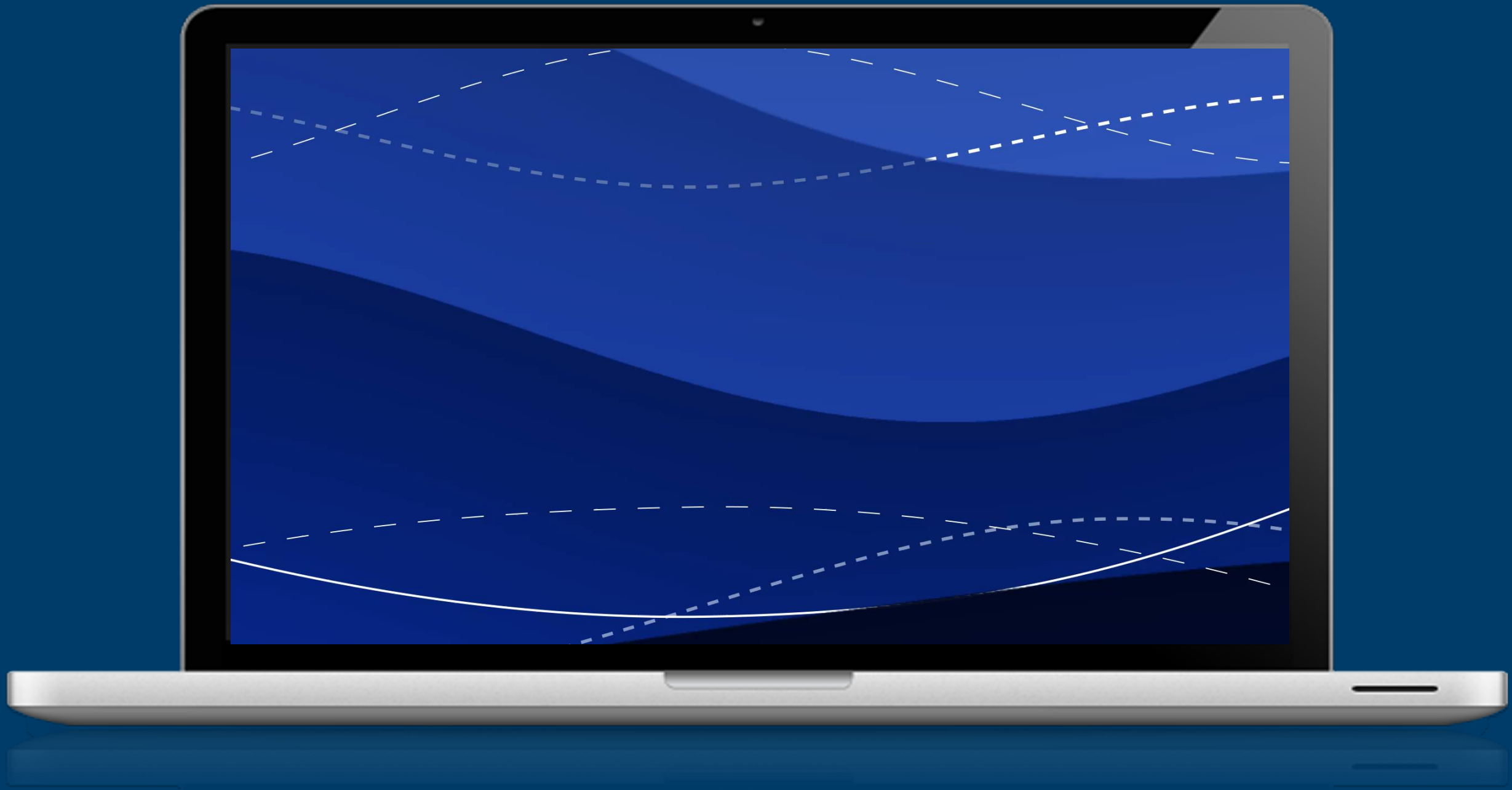

Nature-Based Solutions for Biodiversity & Coastal Hazards

Problems

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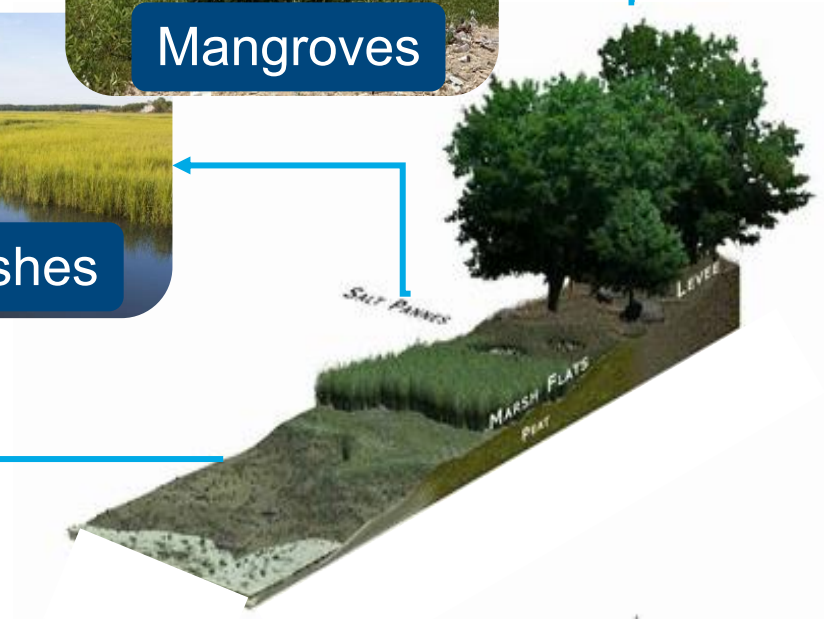
Coastal Protection Measures

NBS- how does it work?

Impact of vegetation



What-if Scenarios for Nature-Based Solutions

Solutions

Nature-based solutions for coastal erosion

? What if we reconstruct vegetation for protecting the coast?

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What-if Scenarios for Nature-Based Solutions

How can they help?

Tackling societal challenges

- Science-based + AI
- Easy access
- Users co-design

Stakeholders explore risks and solutions

Smarter, informed, more sustainable decisions

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Nature-Based Solutions for Biodiversity & Coastal Hazards

Enhanced Need for Effective Coastal Protection

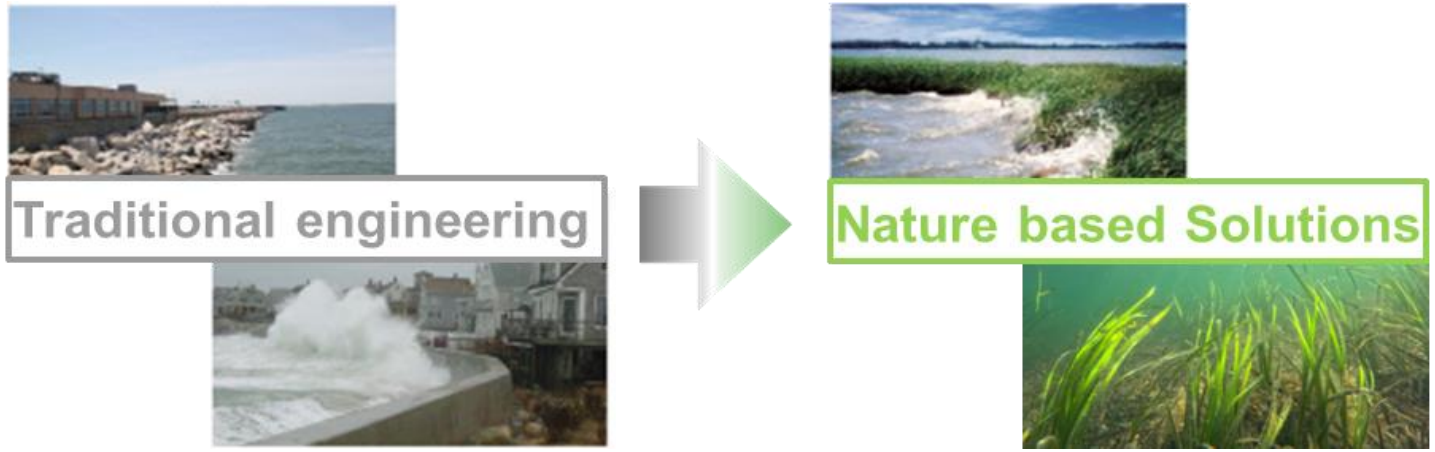
Benefits

- Reduces waves and currents
- Stabilises beaches naturally
- Weakens coastal erosion and flooding
- Protects the environment

NBS in the Wadden Sea

- **UNESCO World Heritage**
  - 73% are protected area
  - 10,000 faunal species
  - 40 fish species
  - 6 million migratory birds

- **Main challenge: Coastal protection with NBS under rising climate uncertainty.**



- **Objectives**
  - A transferable modeling and framework for coastal risk analysis (erosion) that simulates the complex multi-compartment system.
  - Potential improvements for Ecosystem Services (ESS) in the German Wadden Sea.

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Model and Methods

1280 cores

Hydro-model (SCHISM-WWM)

Hydrodynamics

Provides water level, wave spectrum as boundary forcing

Morph-model (XBeach)

Morphodynamics

What if …

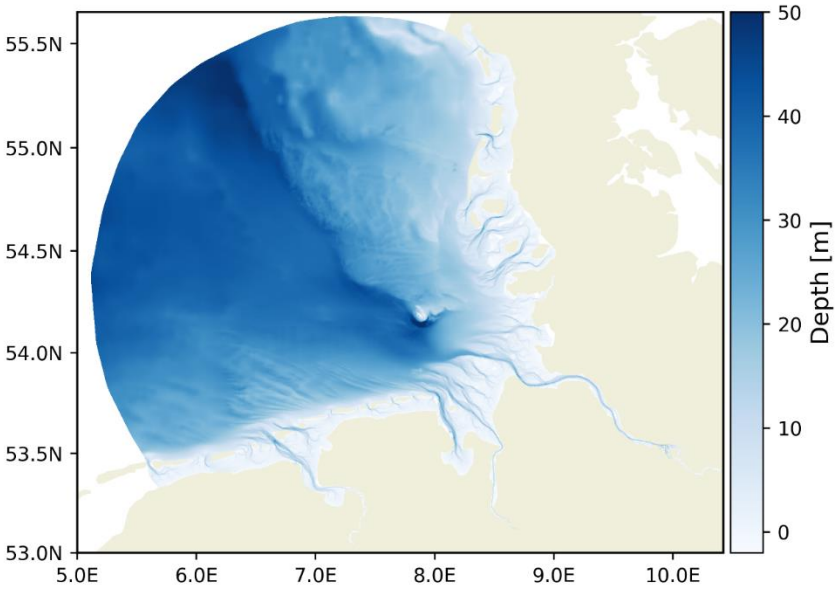
Without seagrass

With seagrass

Different experiment scenarios

Evaluation of Coastal Erosion

SCHISM-WWM model domain



Model and Methods

1280 cores
+
896 cores

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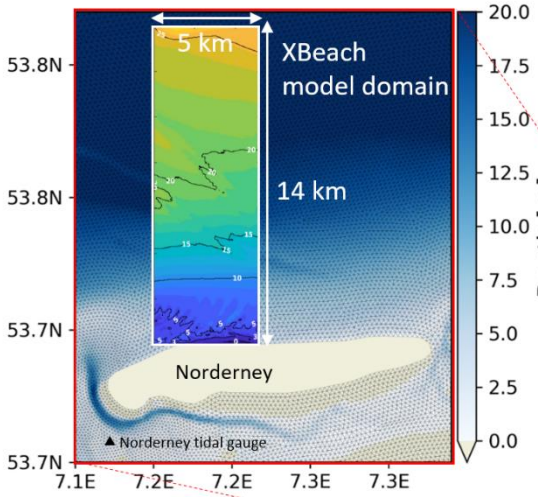
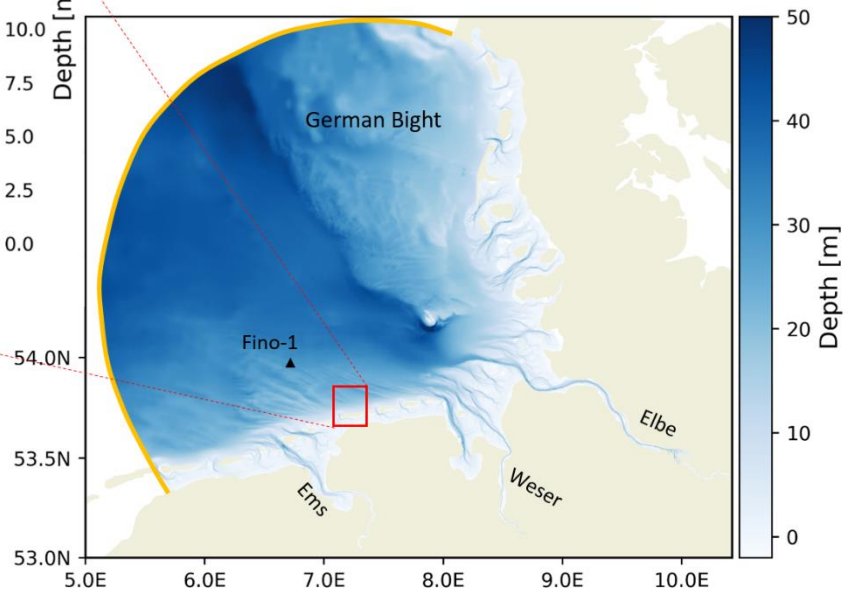


SCHISM-WWM model domain



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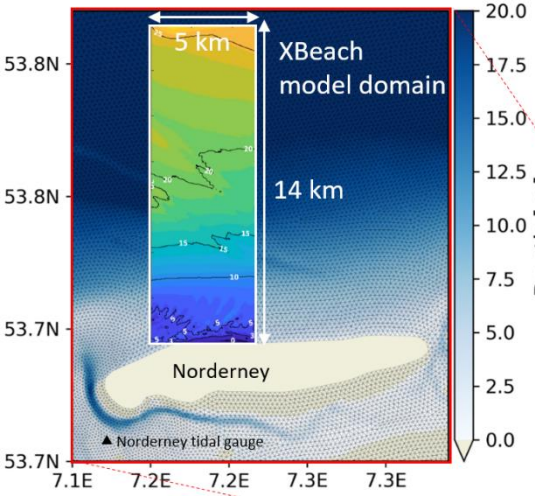
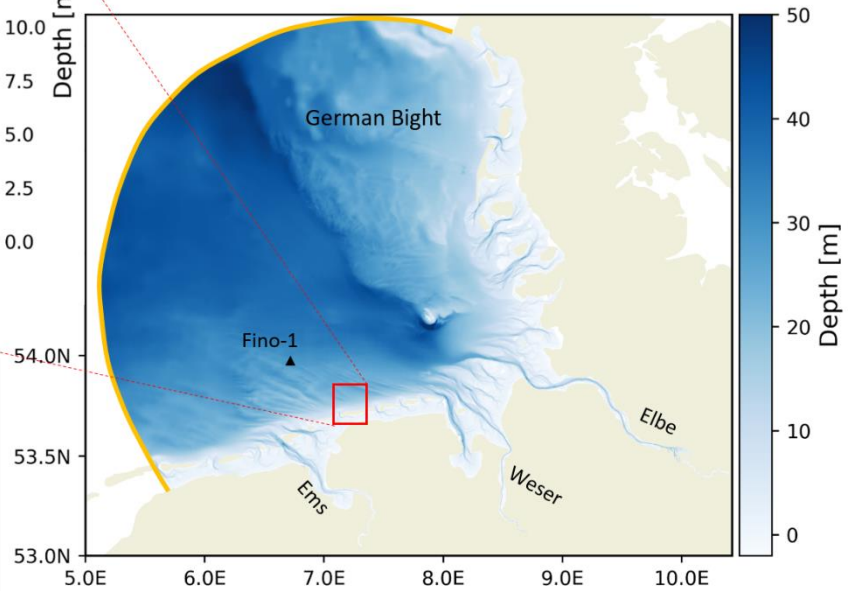


SCHISM-WWM model domain



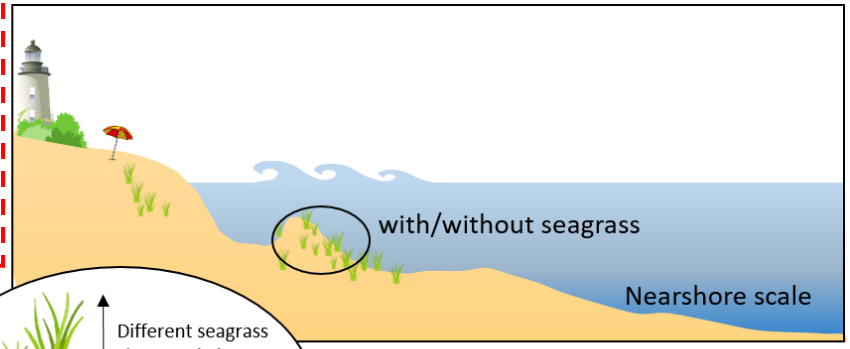
What-if Scenarios (WiS)

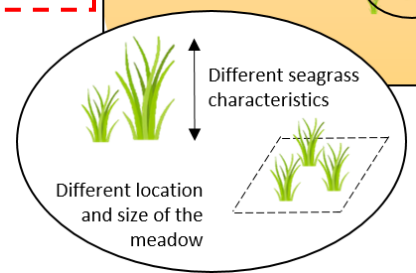
Without seagrass

With seagrass

Different experiment scenarios

Evaluation of Coastal Erosion





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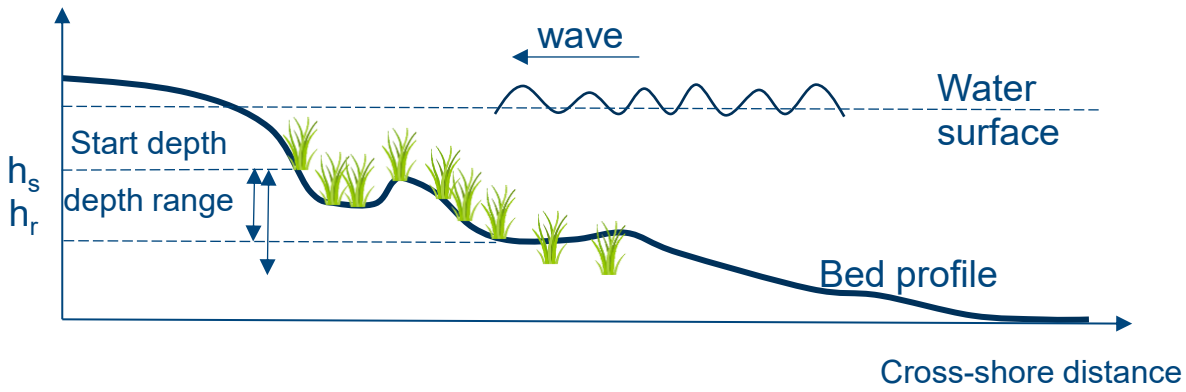
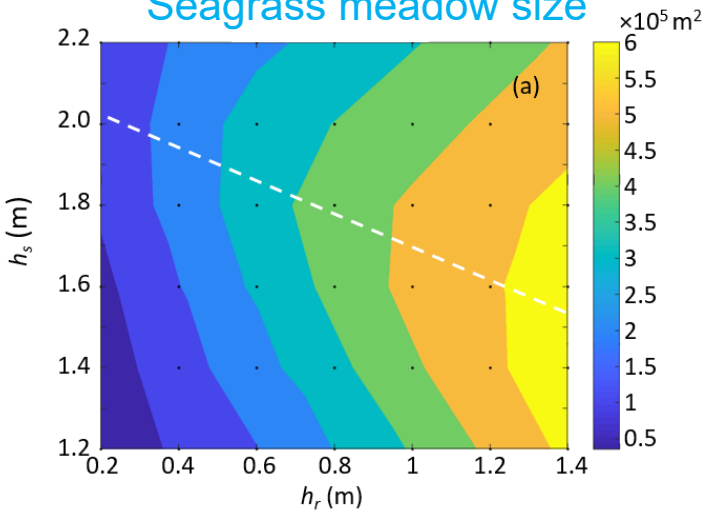
Case I: What-if different seagrass layouts?

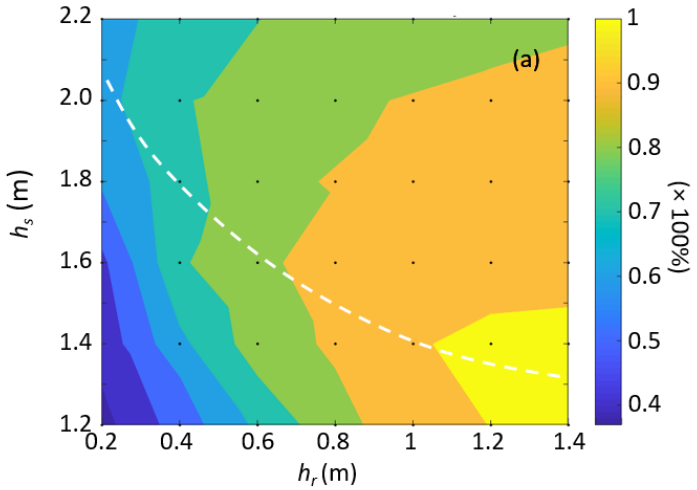


➢ **Different meadow layouts, depending on parameterizations, yield varied erosion volumes.**

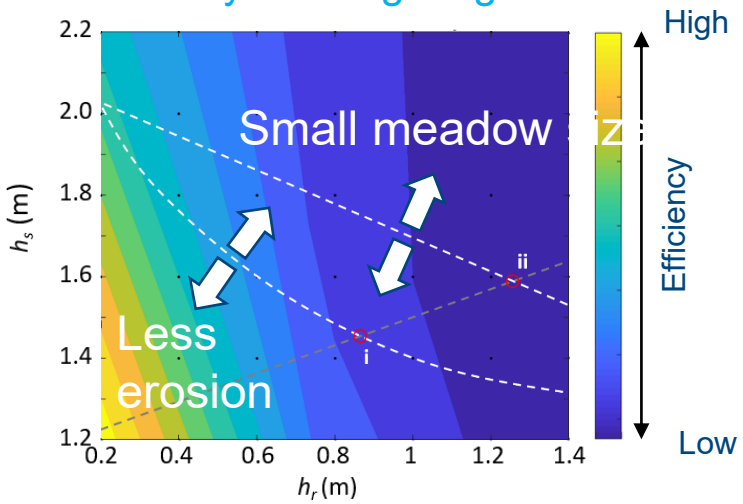
Seagrass meadow size



Reduced erosion volume



Efficiency on mitigating erosion



Jacob et al., Ocean Dyn. (2023); Chen et al., Sci. Total Env. (2024)

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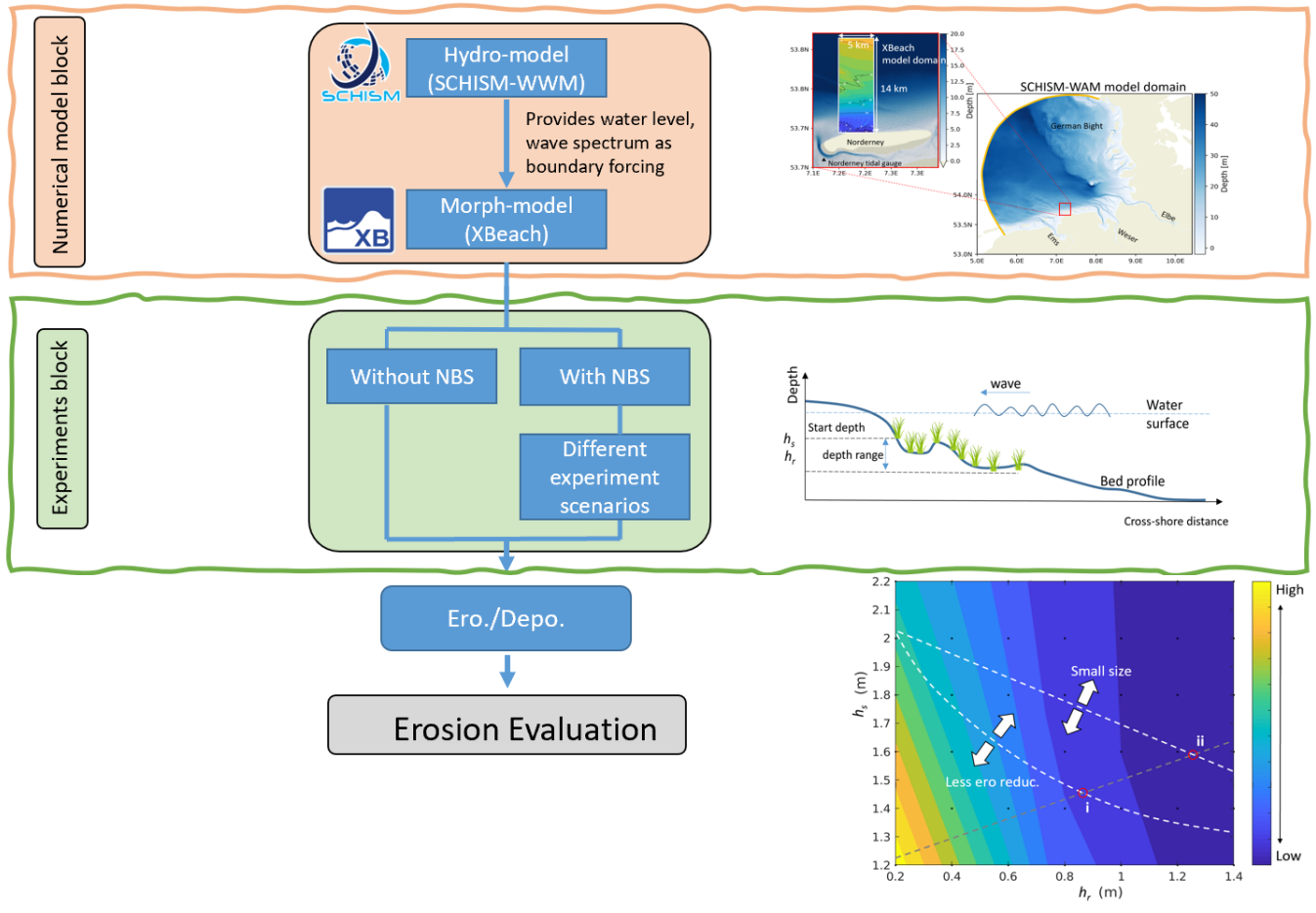
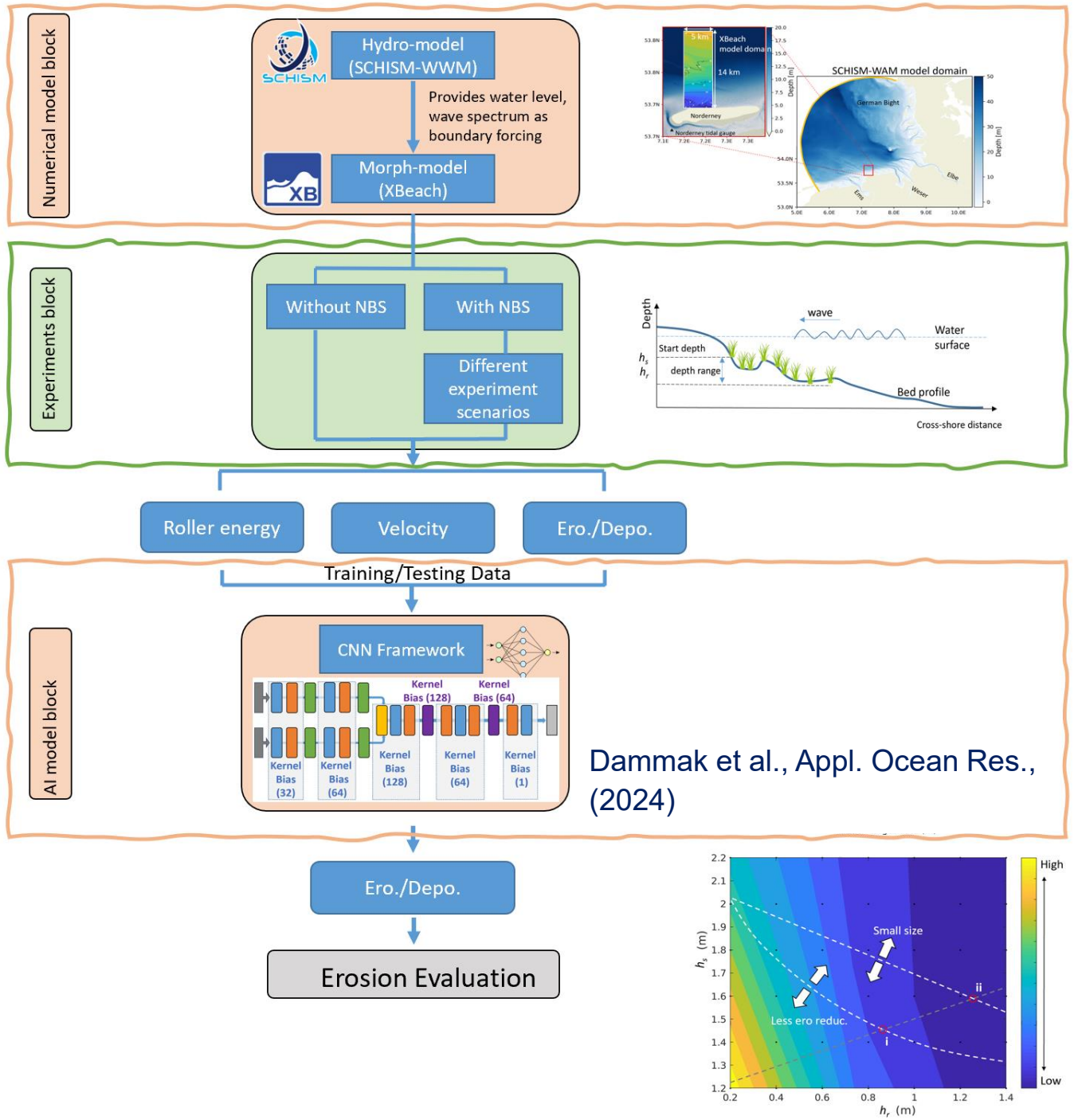

Numerical model block
Hydro-model (SCHISM-WWM)
Provides water level, wave spectrum as boundary forcing
Morph-model (XBeach)
5 km
XBeach model domain
14 km
Norderney
Norderney tidal gauge
SCHISM-WAM model domain
German Bight
Ems
Weser
Elbe
Experiments block
Without NBS
With NBS
Different experiment scenarios
Depth
wave
Water surface
Start depth
depth range
Bed profile
Cross-shore distance
Ero./Depo.
Erosion Evaluation
Small size
Less ero reduc.
i
ii
High
Low
h_s (m)
h_r (m)

AI & Physics-based numerical hybrid model framework



Dammak et al., Appl. Ocean Res., (2024)

- High level of precision in the AI model's prediction
- Can reduce experiment numbers by 70% while keeping sufficient accuracy!

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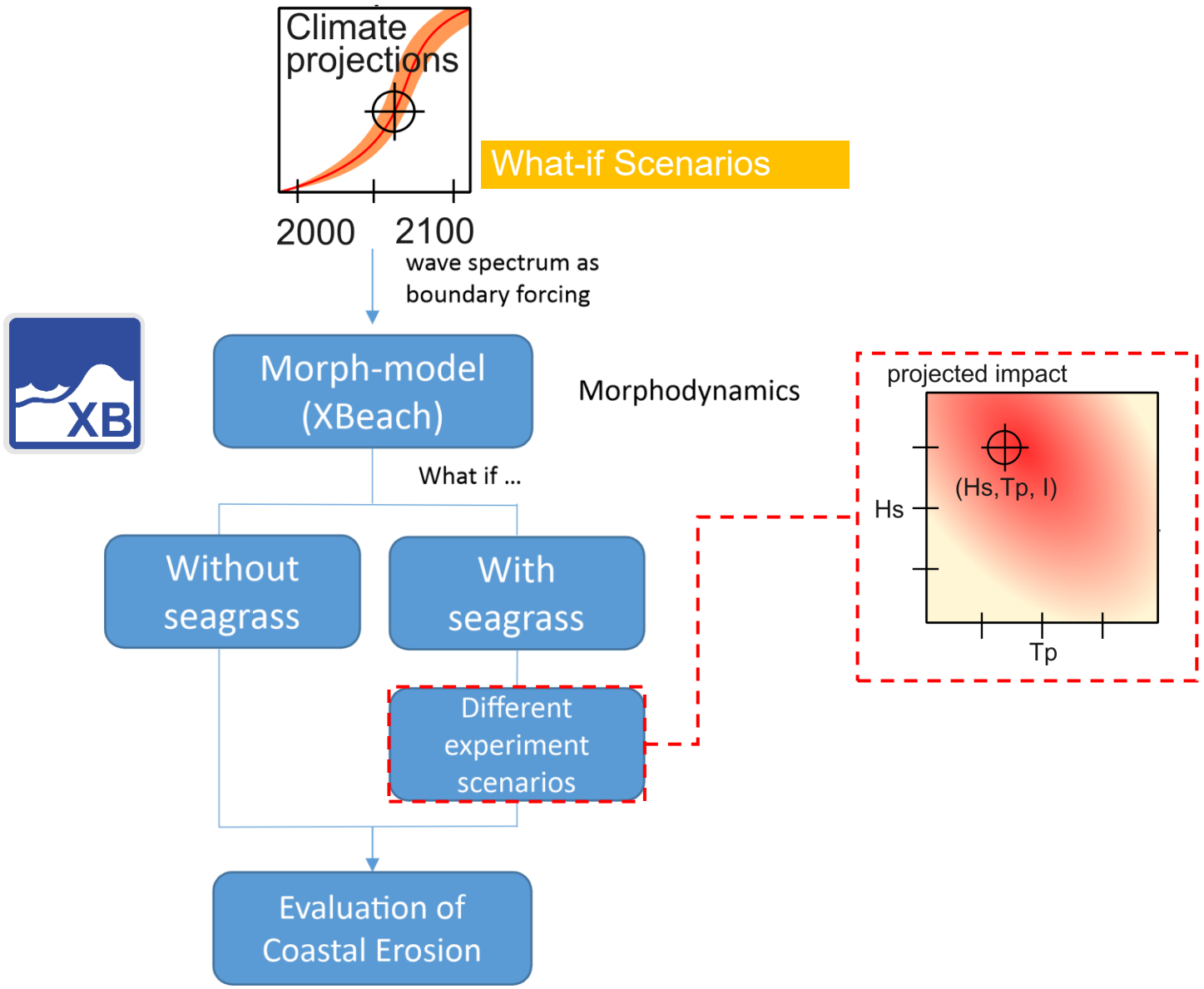
Case II: What-if different wave features?



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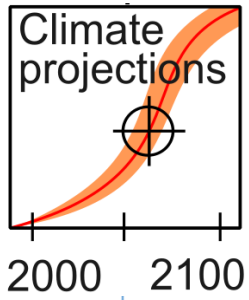


What-if Scenarios

wave spectrum as boundary forcing

Morph-model (XBeach)

Morphodynamics

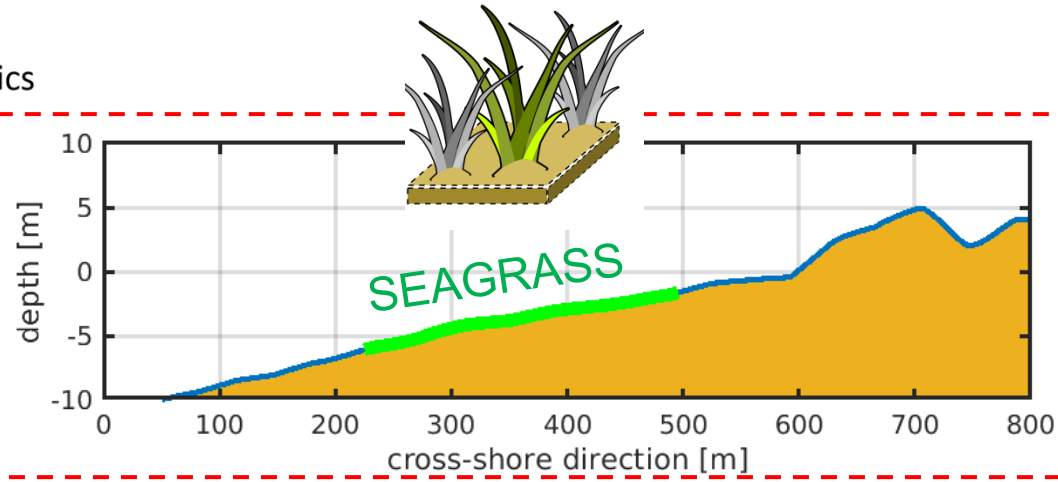
What if ...

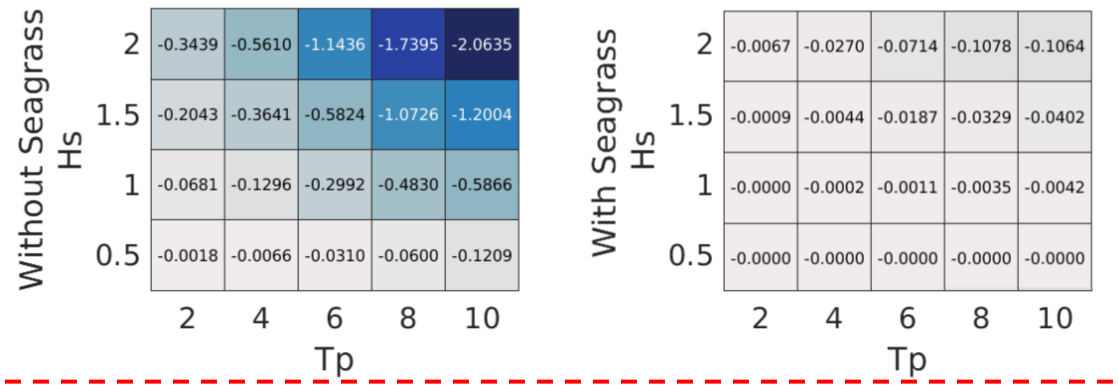
Without seagrass

With seagrass

Different experiment scenarios

Evaluation of Coastal Erosion





Vieira da Silva et al. (submitted)

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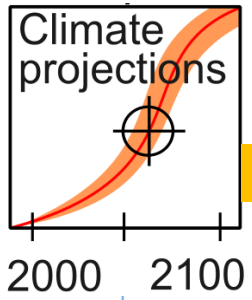
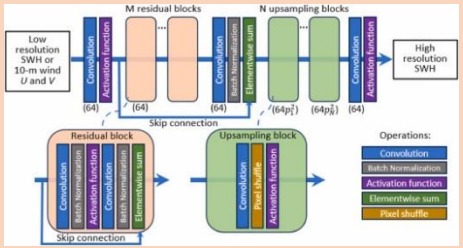


Regional wave data

What-if Scenarios (WiS)

wave spectrum as boundary forcing

Downscaling AI



Global ERA5 dataset

Yuan et al., Ocean Eng. (2025)

Refer to the talk Tuesday during Theme 5: AI/ML applications

XB

Morph-model (XBeach)

Morphodynamics

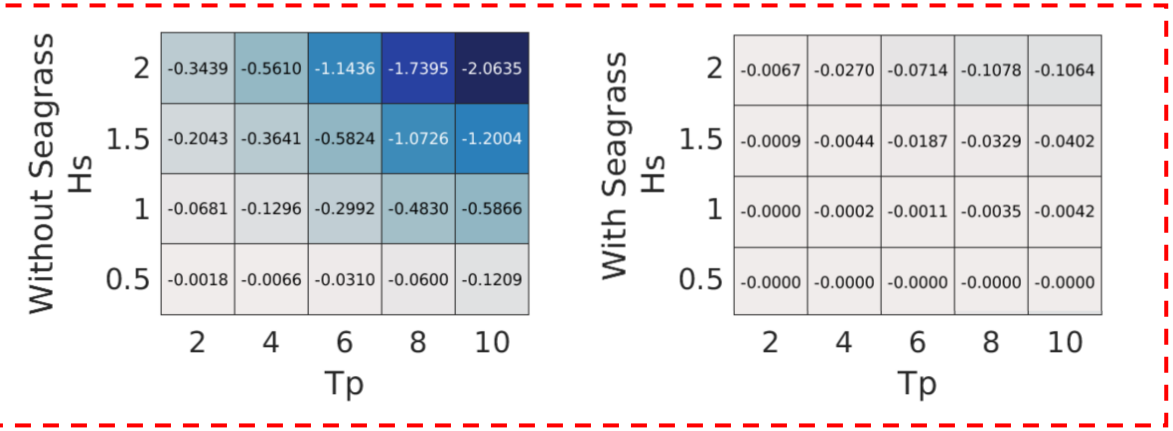
What if ...

- Without seagrass
- With seagrass
- Different experiment scenarios

Evaluation of Coastal Erosion

AI & Physics-based numerical hybrid model framework

- Capability to downscale regional 10km-resolution data to 100m scale



Vieira da Silva et al. (submitted)

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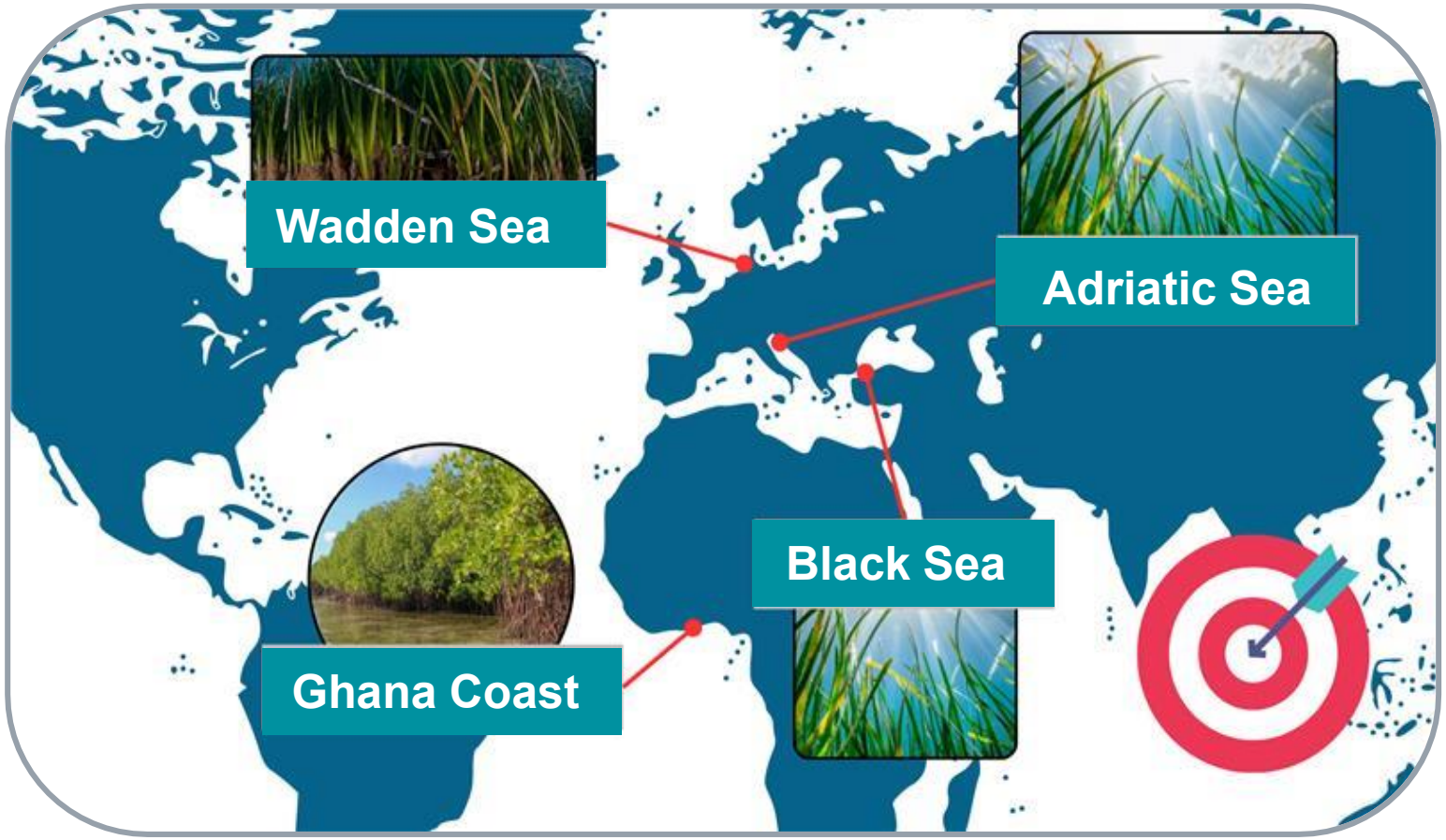
Nature-Based Solutions for Biodiversity & Coastal Hazards

Regional Applications



13 CLIMATE ACTION

14 LIFE BELOW WATER

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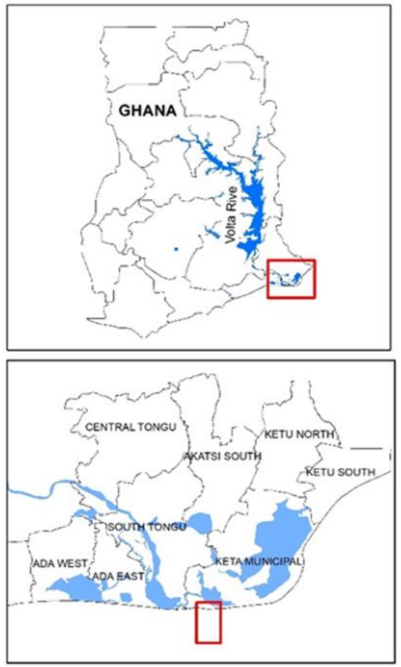
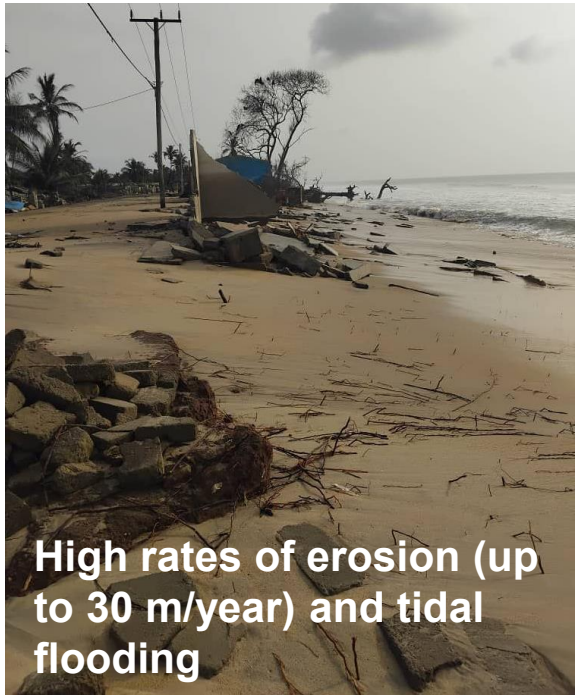
NBS in Ghana

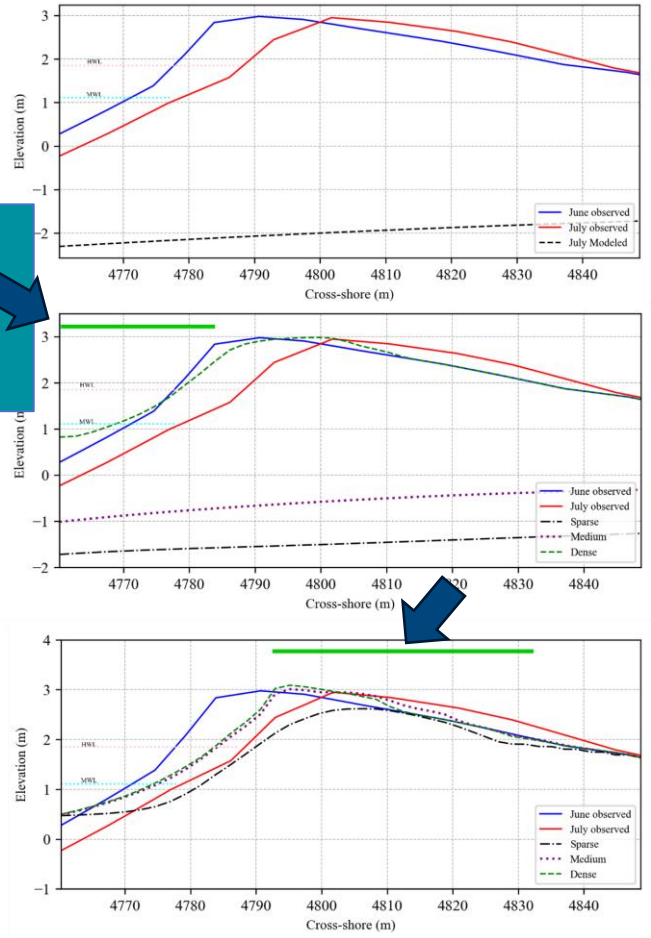


High rates of erosion (up to 30 m/year) and tidal flooding



https://newsghana.com.gh/relocation-is-essential-for-tidal-wave-victims-coda-ceo/

What-if Mangroves here?



Mangroves will reduce the impact of sea level rise (2040 scenario) by up to 99%.

Jayson-Quashigah, et al. (2025)

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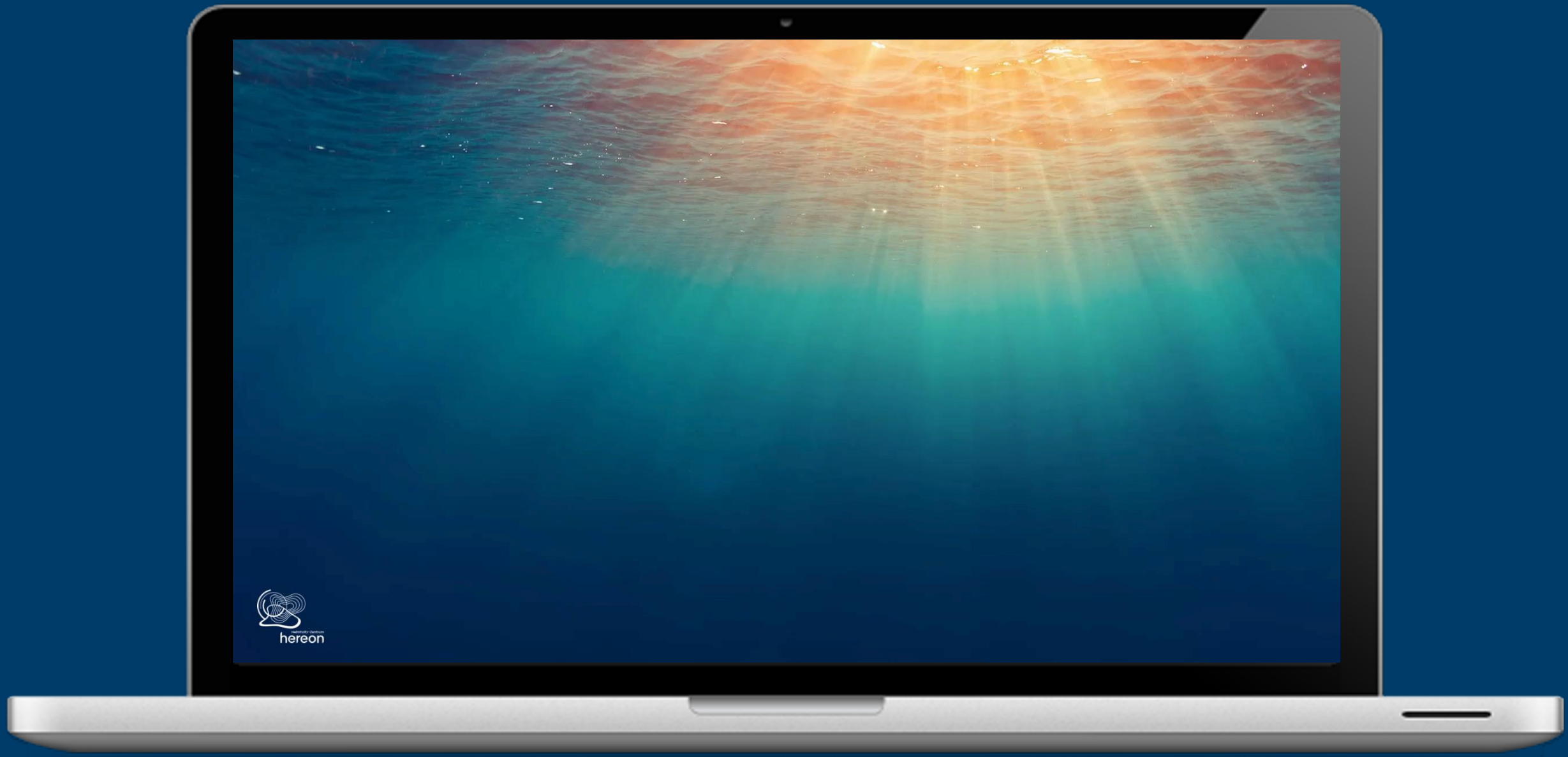
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- Vieira da Silva, D., Chen, W., Jacob, B., Gramcianinov, C., Pham, N. T., Ricker, M., Johnson, K., & Staneva, J.(submitted). Projections of Coastal Morphodynamics of a Small Sandy Beach under What-If Scenarios and Nature-Based Solutions: A Case Study for Ropotamo Beach (Bulgaria)

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