Twenty-years forecast of coastline evolution on sandy coastal stretches in mainland Portugal

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Introduction

- Notable increase of erosion and consequent overtopping events.
- Lost of around 13.3 km^2 of coastal territory during 63 y (APA, 2022)
- Efforts on the development of prediciton tools.
- Numerical models appear as a useful tool.

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Objectives

I) Obtaining a full calibrated shoreline evolution model for the Portuguese western coast.

II) Implementing new design scenarios into the numerical model.

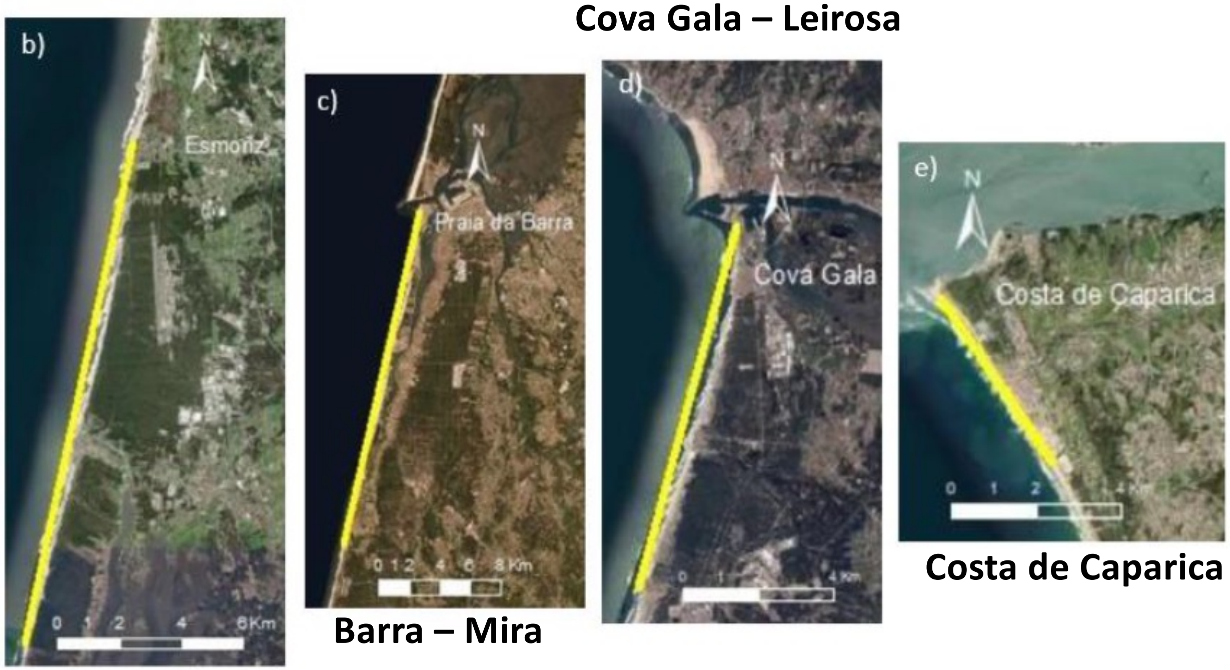
III) Performing a 20 y forecast of coastline evolution for the Portuguese western coast considering a do-nothing scenario.

Study area

- Portugal western coast
- Erosive trend
- Highly interventioned coastal stretches

Esmoriz – Torrão do Lameiro

Cova Gala – Leirosa



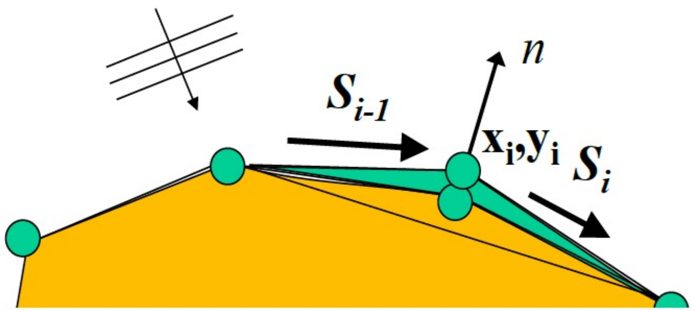
Barra – Mira

Costa de Caparica

ShorelineS[1] numerical model

Model description

- One-line numerical model: seaward/landward displacement are due to longshore sediment transport gradients
- Open source (Matlab-based)
- Vectorized model: efficient for complex shorelines
- Applicable to spatial scale on the order of tens of km and years to decades



[1]Roelvink, D., Huisman, B., Elghandour, A., Ghonim, M. and Reyns, J. (2020). "Efficient modeling of complex sandy coastal evolution at monthly to century time scales". Frontiers in Marine Science, 7:535

Model implementations

- **Spatial variation of bathymetry orientation** along the computational domain
- Shoreline change with a **time-varying mean sea level**
- Possibility to consider **several artificial beach nourishments** with **different volumes** along the coastal domain
- Implementation of **submerged (nearshore) beach nourishment**
- New methodology to determine the sediment transport near the groynes (**bypass**) and along seawalls

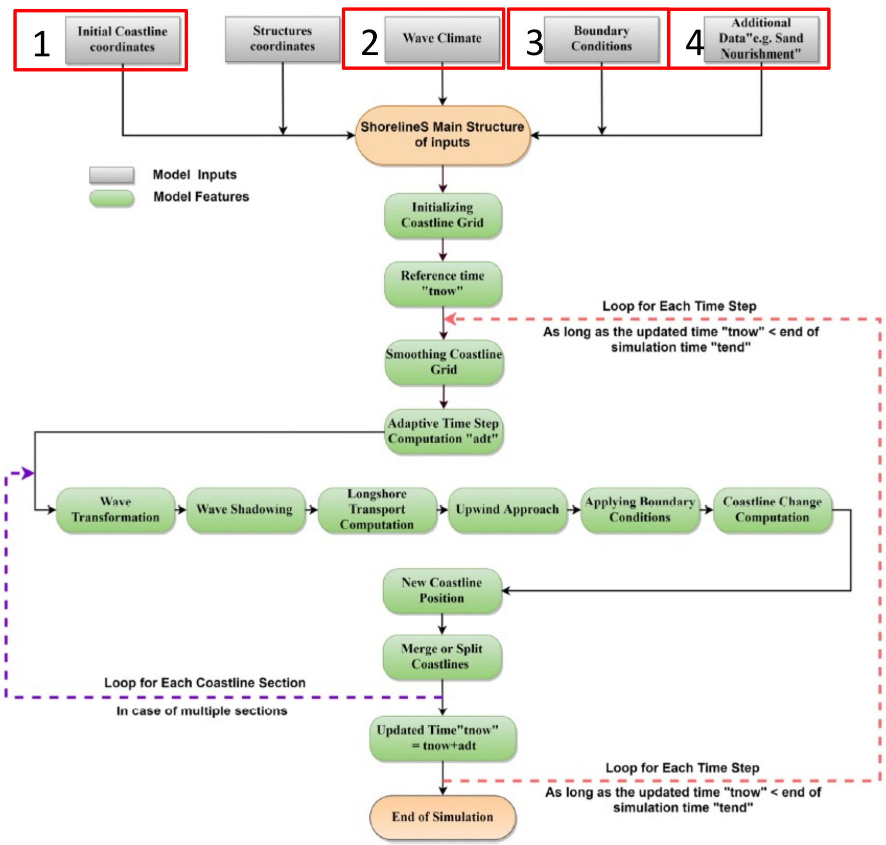
General ShorelineS set up

1. Initial coastline: + 3.0 mCD from the LIDAR 2011(DGT) survey.

2. Wave Climate: offshore wave data at 50 m water depth (CMEMS[1] – 1993 to 2021).

3. Boundary conditions: Neumann (gradient = 0)

4. Additional data: beach nourishment at Costa da Caparica (2019).



From Roelvink et al. (2020)

[1]Copernicus Marine Environment Monitoring Service

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Model calibration

- According to Kamphuis (2020), the longshore sediment transport (Q) is equal to the potential transport (Q_{CERC}) multiplied by a factor (**qs_{calc}**), i.e:

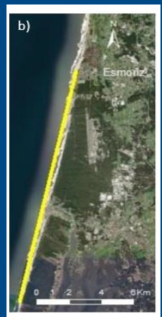
$$Q = Q_{CERC} \times \mathbf{qs_{calc}}$$

- According to Roelvink et al (2020), the **active profile height** (berm height D_B + closure depth D_C) can also be used as a calibration parameter

$$\frac{\partial y}{\partial t} + \left(\frac{\partial Q}{\partial x} + q\right) / (D_B + D_c) = 0$$

- Due to refraction effects on the propagation from offshore to the coast, a shift in the wave incident angle was also tested (**d_θ**)

Model calibration

Parameter	Description	Esmoriz – Torrão do Lameiro (2011-2018) 	Barra - Mira (2011-2018) 	Cova Gala - Leiros a (2011-2021) 	Costa de Capari ca (2018-2020) 
D_θ [º]	Shift in wave direction	0	0	0	-50
AP_H [m]	Active profile height	10	16	18	10
h_n [m]	Nearshore water de pth for refraction	15	20	20	15
qs_{calc}	Sediment transport calibration factor	0.3	0.325	0.31	0.1
dx [m]	Initial space step	40	40	40	30

Best compromise between sediment transport rates and line to line comparision!

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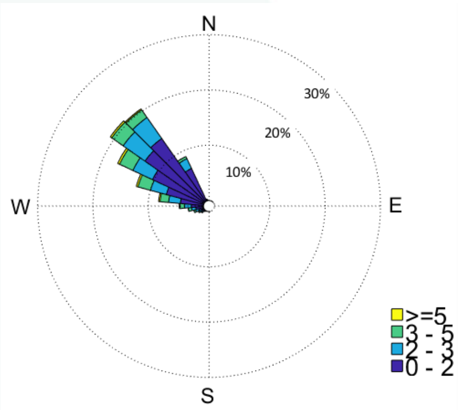
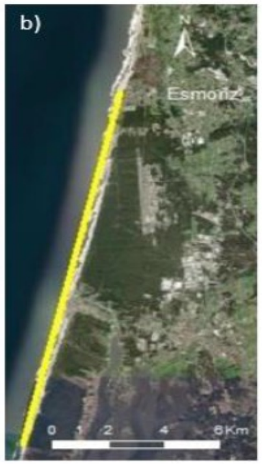
Wave conditions

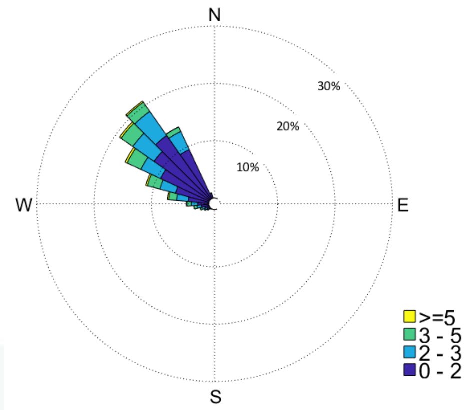
- Wave Climate: offshore wave data at 50 m water depth (CMEMS) between 1993-2021.

Esmoriz-Torrão do Lameiro





Barra-Mira



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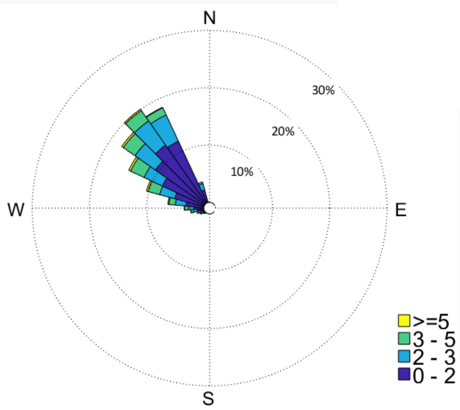
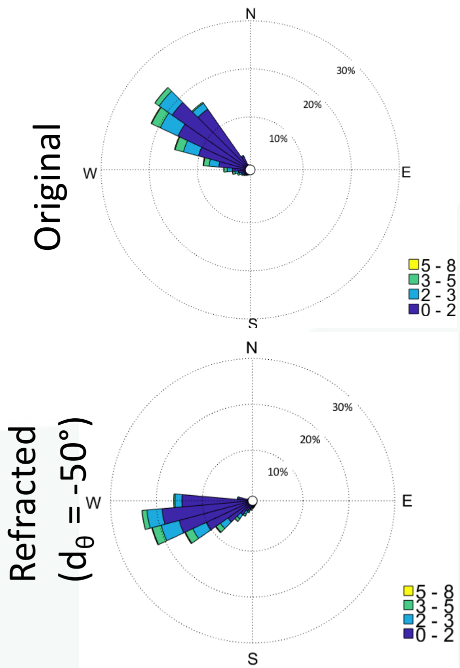
Wave conditions

- Wave Climate: offshore wave data at 50 m water depth (CMEMS) between 1993-2021.

Cova Gala - Leirosa



Costa de Caparica



Model verification

Esmoriz – Torrão do Lameiro

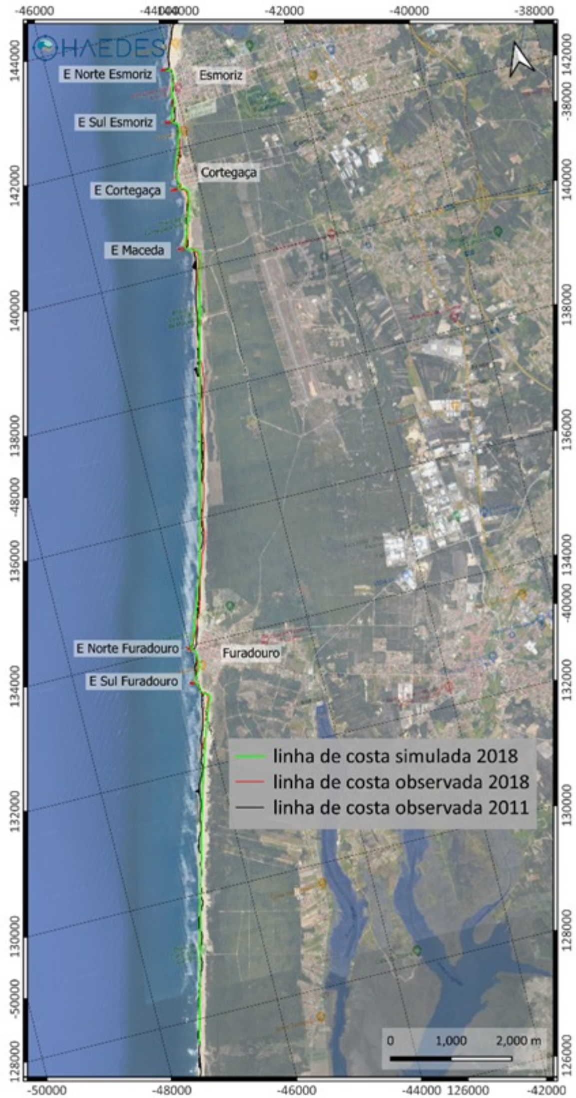
- **Reference values:**

(I) GTL - Duarte Santos et al. (2017)[1]
-1.1×10^6 m^3/yr

- **Model**

$-0.5\text{x}10^6$ m^3/yr

$-1\text{x}10^6$ m^3/yr



Coastal section	Bias [m]	RMSE [m]
Esmoriz/Cortegaça	-1	20
Furadouro	8	28

[1] Duarte Santos, F., Mota Lopes, A., Moniz, G., Ramos, L., Taborda, R. (2017). Grupo de Trabalho do Litoral: Gestão da Zona Costeira: O desafio da mudança. Filipe Duarte Santos, Gil Penha Lopes e António Mota Lopes (Eds). Lisboa (ISBN: 978-989-99962-1-2).

Model verification

Barra-Mira

- **Reference values:**

(I) Pinto et al. (2022)[1]:
-0.75 x 10^6 m^3/yr

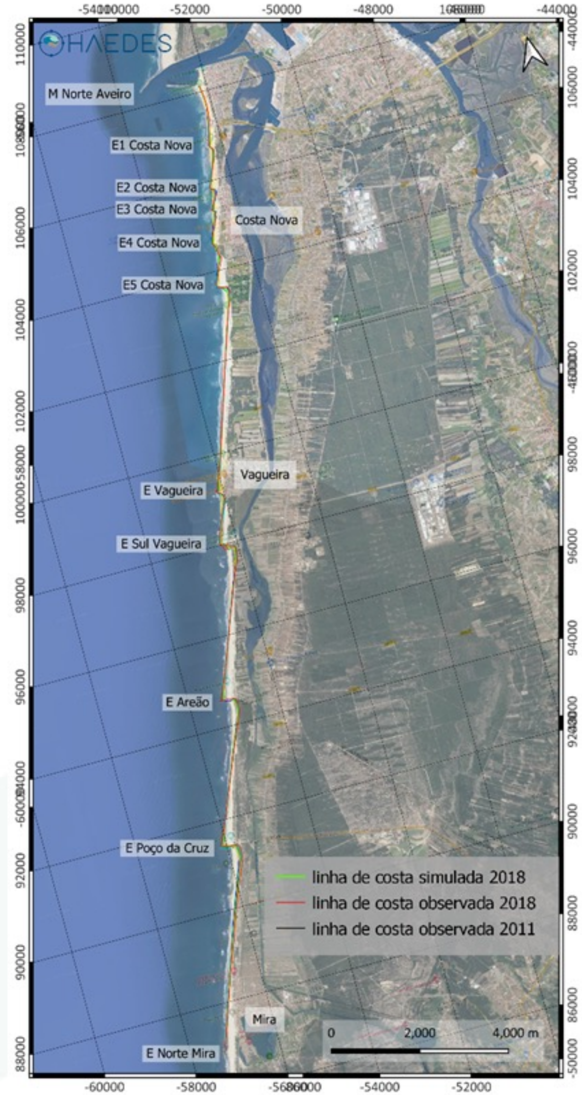
(II) GTL - Duarte Santos et al. (2017)
-1.1 x 10^6

Coastal section	Bias [m]	RMSE [m]
Costa Nova	-10	41
Vagueira	2	47

- **Model**

-0.5x10^6 m^3/yr

-0.8x10^6 m^3/yr



[1]Pinto, C. A., Taborda, R., Andrade, C., Baptista, P., Silva, P. A., Mendes, D., & Pais-Barbosa, J. (2022). Morphological development and behaviour of a shoreface nourishment in the Portuguese western coast. JMSE, 10 (2), 146.

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Model verification

Cova Gala - Leirosa

- **Reference values:**

(I) Oliveira (2016)[1]:
-0.6 x 10⁶ m³/yr to -1.5 x 10⁶ m³/yr

(II) GTL - Duarte Santos et al. (2017)[2]
-1.1 x 10⁶

Coastal section	Bias [m]	RMSE [m]
Cova Gala	-4	20
Costa de Lavos	-3	53

- **Model**

$+0.1 \times 10^6$ m³/yr

-0.5×10^6 m³/yr

[1]Oliveira, J. N. C. (2016). Modelação do impacte do prolongamento do molhe northe da embocadura do rio Mondego nas praias adjacentes a sul. Dissertação de Mestrado. Instituto Superior Técnico.
[2] Duarte Santos, F., Mota Lopes, A., Moniz, G., Ramos, L., Taborda, R. (2017). Grupo de Trabalho do Litoral: Gestão da Zona Costeira: O desafio da mudança. Filipe Duarte Santos, Gil Penha Lopes e António Mota Lopes (Eds). Lisboa (ISBN: 978-989-99962-1-2 .

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Model verification

Costa de Caparica

- **Reference values:**

(I) Sancho (2023)[1]:

+0.05 x 10^6 to +0.1 x 10^6 m^3/yr (S.J. Caparica)

(II) Dodet et al. (2013)[2]

-0.2 x 10^6 m^3/yr

Coastal section	Bias [m]	RMSE [m]
S.J. da Caparica	-12	19
Southward E7		

+0.1 x 10^6 m^3/yr

-0.2 x 10^6 m^3/yr

[1] Sancho, F. (2023). Evaluation of Coastal Protection Strategies at Costa da Caparica (Portugal): Nourishments and Structural Interventions. Journal of Marine Science and Engineering,11(6),1159.
[2] Dodet, G. (2013). Morphodynamic modelling of a wave-dominated tidal inlet: the Albufeira Lagoon. PhD Thesis, La Rochelle University, 181 pp

Shoreline evolution (2043)

- **Potential scenarios:**

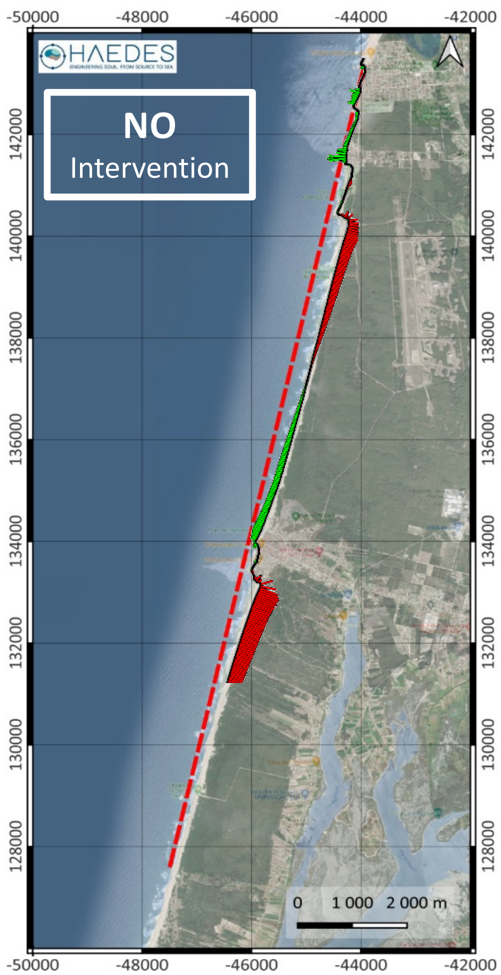
I) Beach nourishment (single or multiple)

II) Shoreface nourishment (single or multiple)

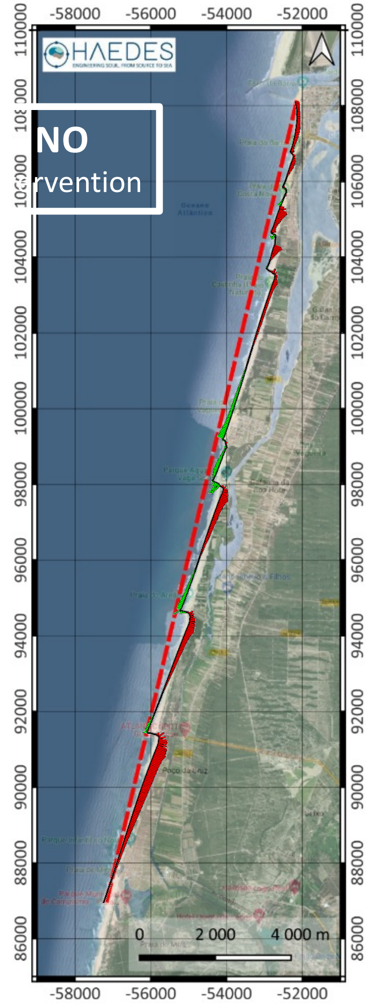
III) Adding/removing groynes

IV) Detached breakwater

Esmoriz-Torrão do Lameiro



Barra - Mira



Accretion

Erosion

Modeling domain

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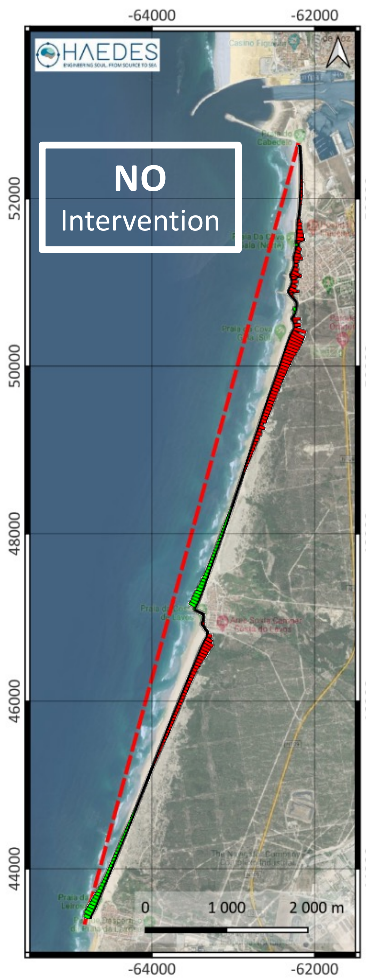
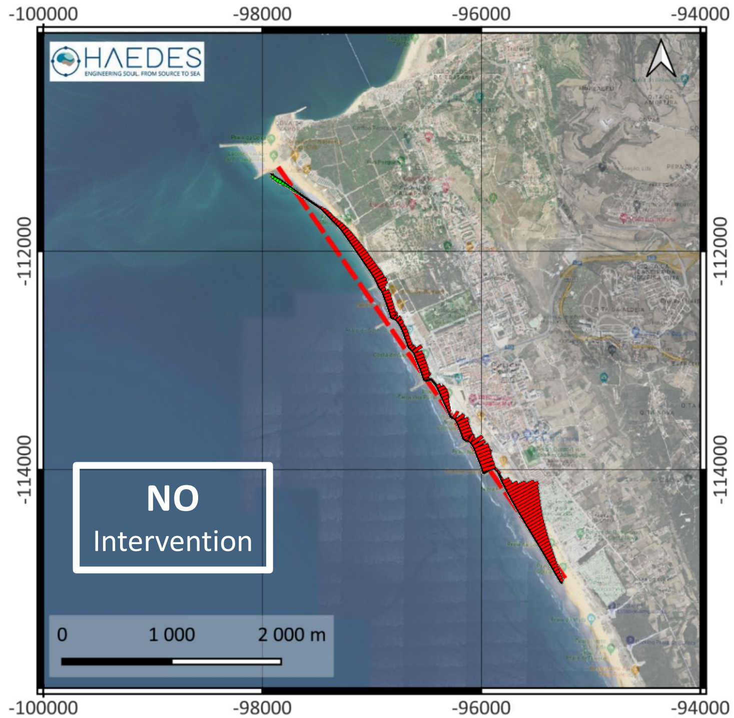


Costa de Caparica



Accretion

Erosion

Modeling domain

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Discussion and Final remarks

- The required modification (proposed by Kamphius[1]) in the sediment transport factor (qs_{calc}) accounts for differences between the potential and efective longshore sediment transport.

- Also, this modification is likely to incorporate uncertainties associated with:

  - The use of wave linear theory (for wave propagation and transformation)

  - The use of semi-empirical longshore sediment transport (CERC formula)

[1]Kamphuis (2020). Introduction to Coastal Engineering and Management, World Scientific, 544 pp.

Discussion and Final remarks

- The coastal design implementations performed in the model allow a **wider application** of ShorelineS.
- The inclusion of **spatial variation of bathymetry orientation** and **time-varying mean sea level** allow for more realistic simulations.
- Also, **new methodologies for calculating sediment transport near groynes and along sea walls** induces a better performance of the model.
- The **lack of** quantitative information on the **errors associated with shoreline modeling in similar works** prevents a further comparison on model performance.
- A full-calibrated model was obtained for four coastal stretches along the Portugal western coast with both **line to line** and **sediment transport calibration.**

Acknowledgements

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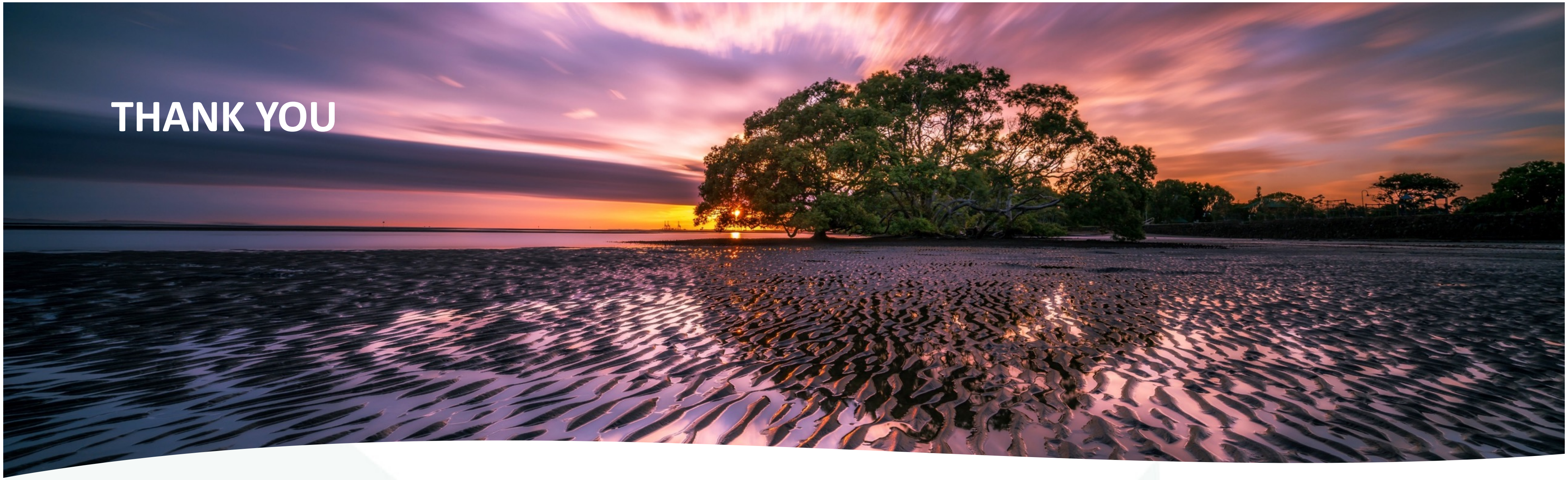

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ShorelineS numerical model

Sediment transport

$$\frac{\partial n}{\partial t} = -\frac{1}{D_c}\frac{\partial Q_s}{\partial s} - \frac{c}{\tan\beta} RSLR + \frac{1}{D_c}\sum q_i$$

- Sediment transport rate (CERC):

$$Q = K\frac{\rho\sqrt{g/\gamma_b}}{16(\rho_s-\rho)(1-n)} H_{sb}{}^{5/2} sen(2\theta_b)$$

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Model implementations

- Determination of k in eq. (I) according to Mil-Homens[1]

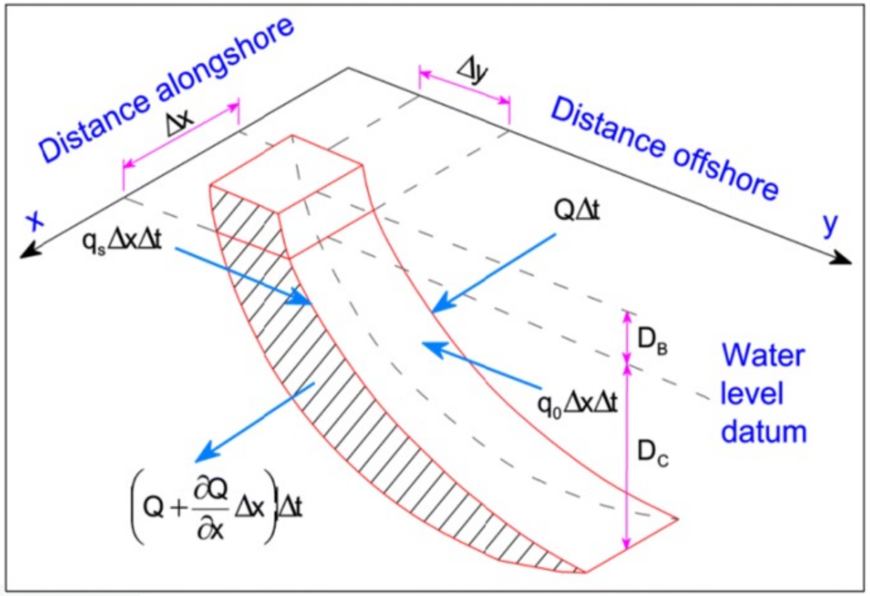
(I) $$Q = K \frac{\rho_w \sqrt{g}}{16(\rho_s - \rho_w)(1-n)\sqrt{\gamma}} H_b^{5/2} \sin(2\alpha_b) \qquad K = \frac{1}{2232{,}7\left(\frac{H_b}{L_0}\right)^{1{,}45} + 4{,}505}$$

- New methodology to determine the sediment transport near the groynes (**bypass**) and along seawalls

[1]Mil-Homens, J., Ranasinghe, R., de Vries, J. V. T., & Stive, M. J. F. (2013). Re-evaluation and improvement of three commonly used bulk longshore sediment transport formulas. *Coastal Engineering*, *75*, 29-39.

One-line numerical models

- Seaward or landward displacement of the shoreline position in time (dy/dt) is due to longshore sediment transport gradients (dQ/dx)
- If Q is very large between two adjacent cells but dQ/dx = 0, there will be no seaward/landward shoreline displacement!
- If Q is very small between two adjacent cells but dQ/dx ≠ 0, there will be a seaward/landward shoreline displacement!
- The model is driven by gradients in the longshore sediment transport



$$\frac{\partial y}{\partial t} + \left(\frac{\partial Q}{\partial x} + q\right) / (D_B + D_c) = 0$$

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