A hybrid monitoring-modelling analysis on the storm induced sediment dynamics of a structure-controlled beach

João Nuno C. Oliveira§†*, Filipa S. B. F. Oliveira†, Paula Freire†, and António A. Trigo-Teixeira§

MOTIVATION, STUDY SITE AND GOAL

The Portuguese west coast was classified as having a high index of exposure to coastal erosion and flooding. The rise of the mean sea level and the expected increase of frequency and intensity of maritime storms increase this risk.

The study site is located in the Portuguese sandy coastal stretch of Cova-Gala (Fig. 1), critical regarding erosion-flooding risks despite the interventions of coastal protection with a groin field (5 groynes), seawalls and nourishment. It is subjected to a high energy wave climate, with average significant wave height 2.15 m and reference potential sediment drift 1 million m³/yr, despite the high interannual and seasonal variations.

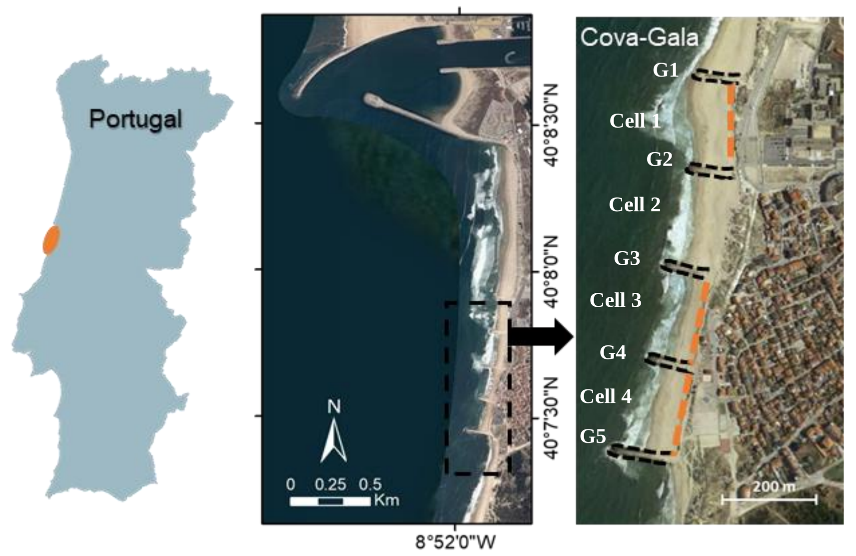

Fig. 1 - Cova-Gala location in the Portuguese West Coast and detail of the existing defence scheme.

METHODOLOGY

The XBeach numerical model was applied to investigate the sediment dynamics and morphological evolution of the study site from August 2018 to February 2019, for a period of average hydrodynamic conditions, followed by an energetic storm event (storm Helena) and the following recovery period.

Two modelling approaches using both observed (obs.) and numerical (num.) topo-bathymetric data were considered based on: the hydro-morphological evolution of a topo-bathymetric cross-shore profile frequently monitored, in 1D mode; and the hydro-morphological evolution of the overall active zone of the study site in 2DH mode, using a digital terrain model (DTM) built from a topo-bathymetric area-survey performed annually (Fig. 2). The morphological response was assessed for a sequence of hydrodynamic conditions as presented in Fig. 3.

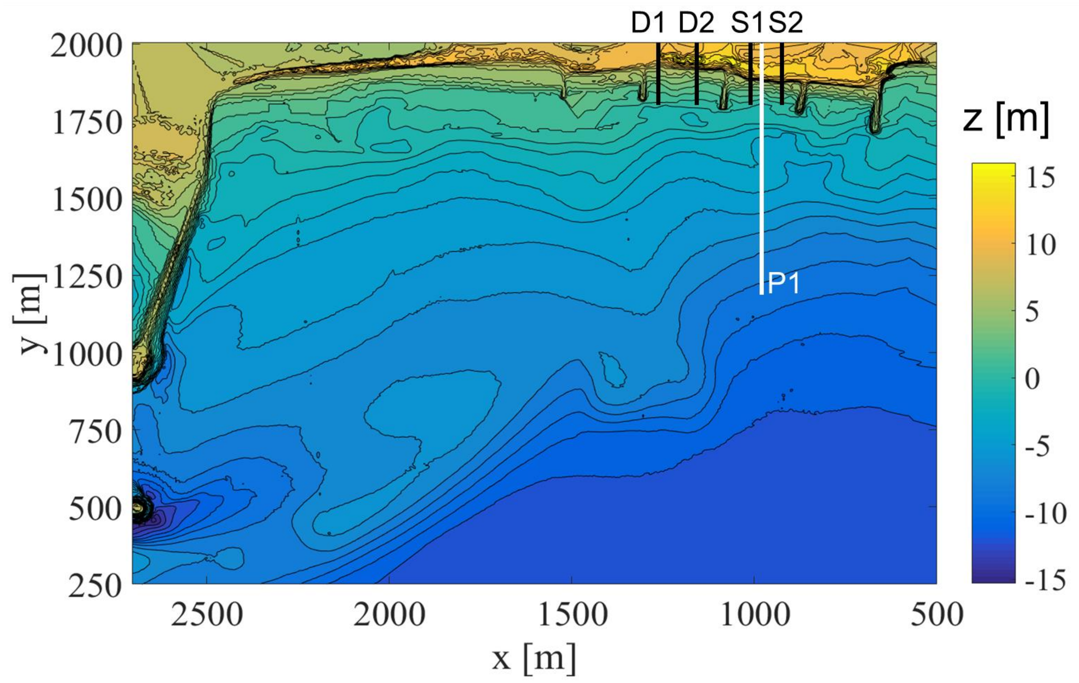

Fig. 2 - Study site DTM in 01.08.2018. Monitored topo-bathymetric profile P1 and topographic profiles D1, D2, S1 and S2.

The 1D approach consisted in simulating: i) the evolution of profile P1 observed in 15.11.2018 to obtain a numerical P1 in 04.02.2019 [1]; ii) the evolution of P1 observed in 04.02.2019 to obtain a numerical P1 in 11.02.2019 [2]; and iii) the evolution of [1] to obtain a numerical P1 in 11.02.2019 [3]; all forced with the respective period hourly synoptic hydrodynamic conditions.

The 2DH approach consisted in simulating: i) the evolution of the complete DTM in 01.08.2018 to obtain a numerical DTM in 01.02.2019 [4], after six months of average hydrodynamic conditions; ii) the evolution of sedimentological cells 2 and 3 in [4], between the groins G2 and G4 of the Cova-Gala defence scheme (Fig. 1), to obtain a numerical 2 cells DTM in 04.02.2019 [5], forced with the hourly synoptic hydrodynamic conditions of the Helena storm; and iii) the evolution of [5] to obtain a numerical 2 cells DTM in 11.02.2019 [6], forced with the period hourly synoptic hydrodynamic conditions.

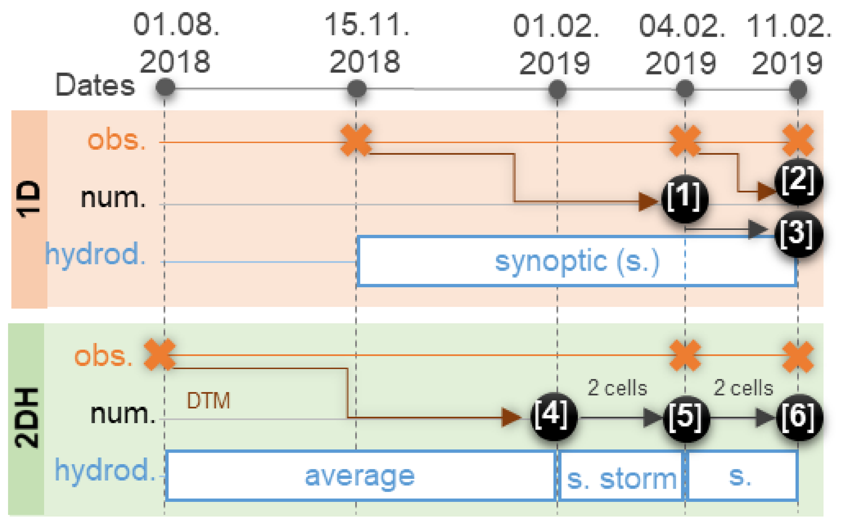

Fig. 3 - Scheme of the conceptual model adopted for the XBeach application.

RESULTS AND DISCUSSION

Regarding the 1D approach results (Fig. 4), the onshore bar movement measured in P1 for the first simulation period is the result of a sediment flux that the model was not capable of reproducing. The longer the modelling period, the more the beach profile is smoothed, converging to the average morpho-hydrodynamic conditions of the simulation.

The features of the measured post-storm profile were not modelled correctly since the numerical profile at the beginning of the storm was smoothed by several weeks simulation time.

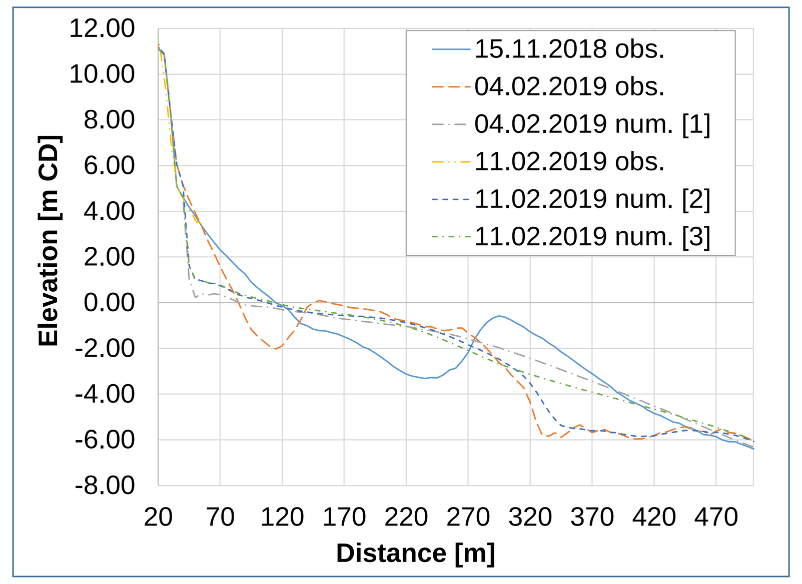

Fig. 4 - Morphological evolution of P1 (cell 3) from 15.11.2018 to 11.02.2019: obs. and num. profiles in the 1D simulation approach.

Data assimilation to estimate initial conditions for the model from field observations is very important to prevent the profile features from being lost by the smoothing effect of long simulation periods.

The modelled six months 2DH morphological evolution depicts an overall erosion scenario (Fig. 5), intrinsic of the study site energetic hydrodynamic conditions. The morphological evolution of a cell with a dune backshore rather than a seawall backshore is more accurately simulated by the model in storm conditions (Fig. 6). The model repeatedly over-estimates the erosion in the seawall toe.

The morphological response to the storm is more accurately simulated using hydrodynamic synoptic data in the 2DH approach than in the 1D mode, and features such as a post-storm berm crest in the north side of cells 2 and 3 can be predicted in this approach.

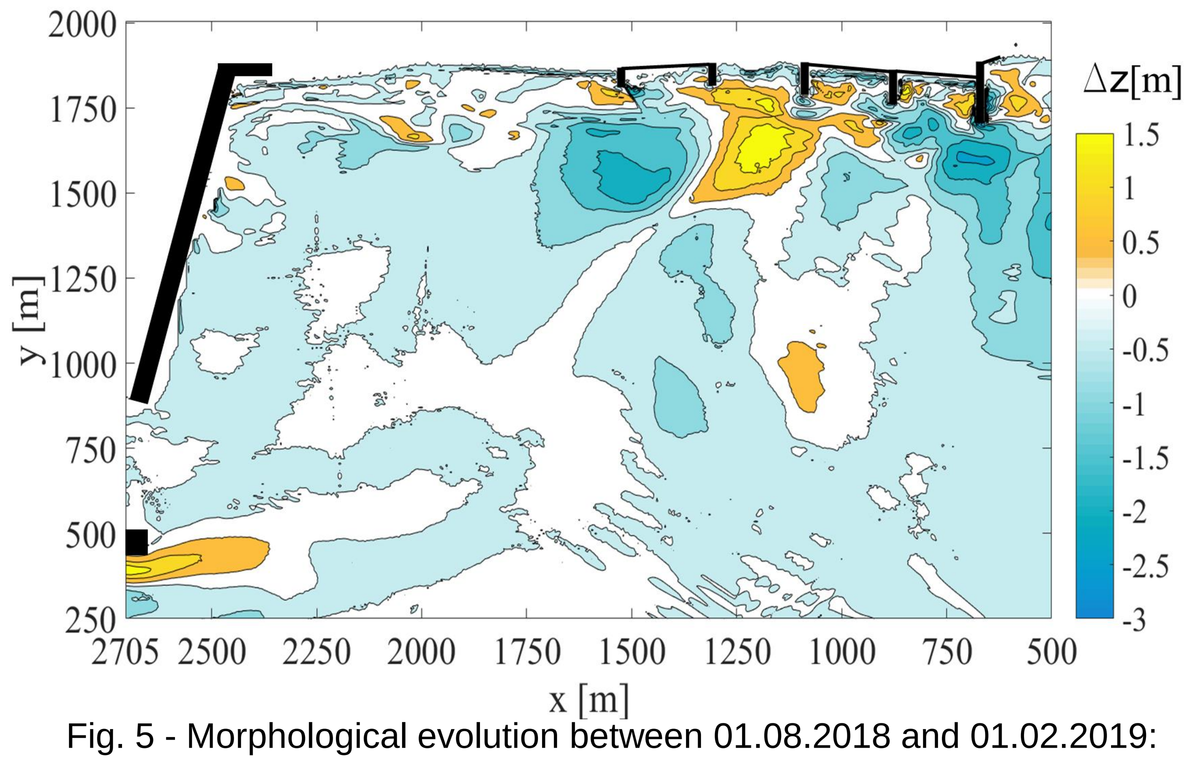

Fig. 5 - Morphological evolution between 01.08.2018 and 01.02.2019: elevation differences. Negative values show erosion.

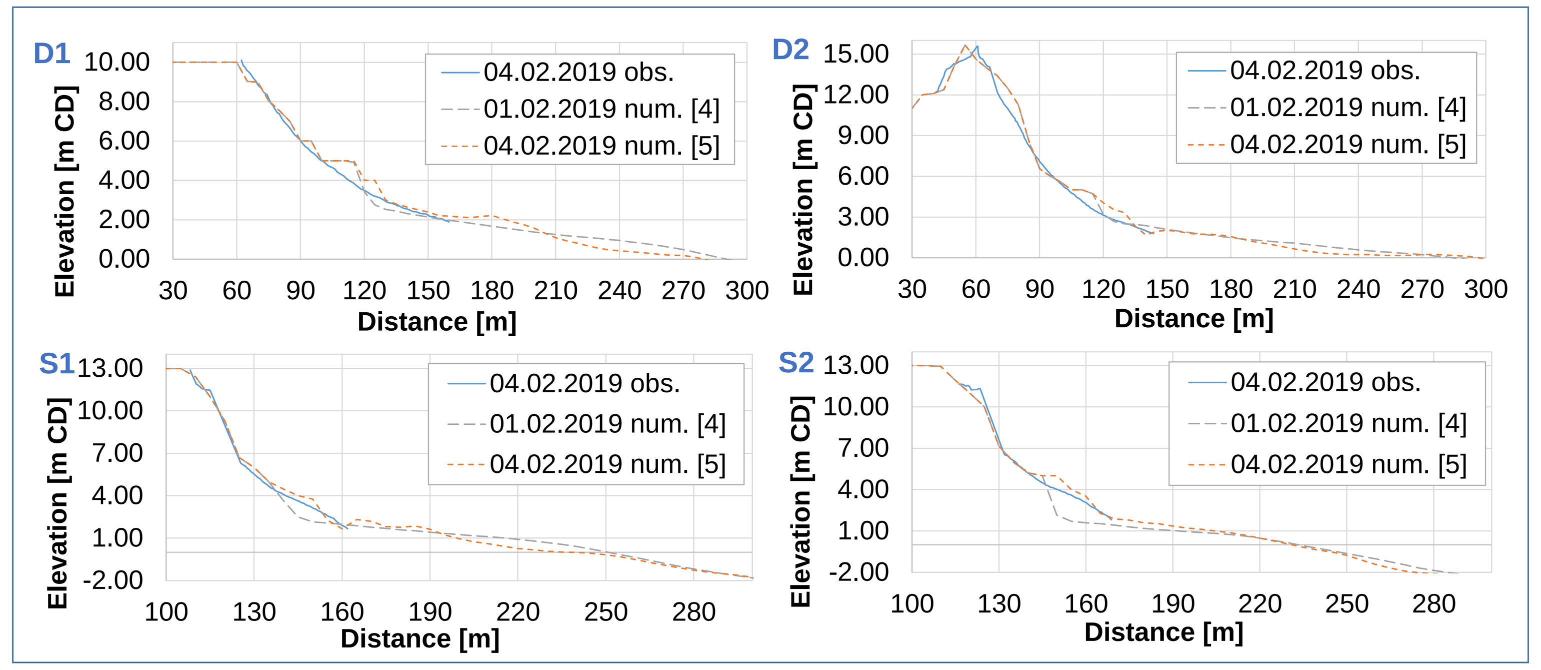

Fig. 6 - Morphological evolution of the profiles D1 and D2 (cell 2), and S1 and S2 (cell 3) from 01.02.2019 to 04.02.2019.

To analyse how the model simulates a recovery period the numerical 1D and 2DH approaches are compared (Fig. 7), using the same synoptic forcing conditions but different modes and morphologies as the starting point.

The model tendency to over-estimate the erosion in the seawall toe and to smooth the overall numerical profile is evident in both the 1D and 2DH approaches. The 1D approach maintains the observed profile features assimilated with the observed data available at the beginning of this period.

The lack of hydrographic data for the breaking zone, which is a challenge to gather, makes it difficult to validate the complete post-storm profile.

Even though the starting morphology is very different for the two approaches, the evolution tendency simulated by the model is similar in the upper beach face: extreme erosion in the seawall toe.

It should be emphasized that the role of the aeolian transport in this process of profile recovery remains unknown and is not accounted for the model .

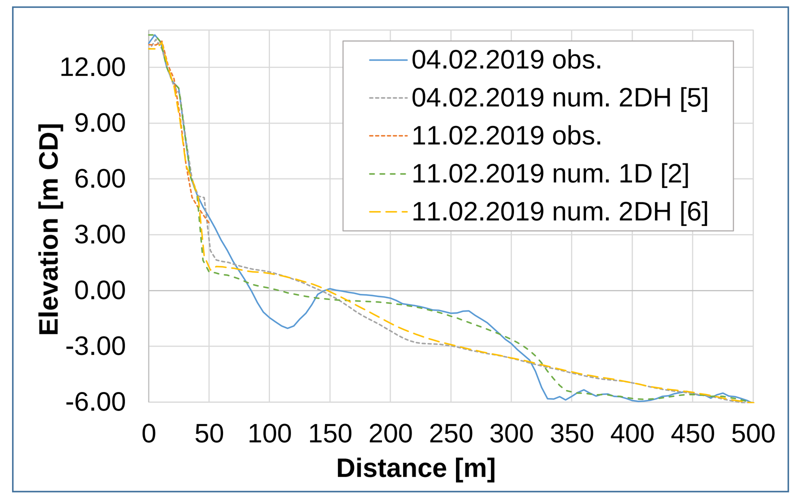

Fig. 7 - Morphological evolution of P1: obs. and num. profiles in the 1D and 2DH simulation approaches.

CONCLUSIONS

The overall medium-term erosion scenario depicted by the results is characteristic of a southward directed sediment flux in a site where the average wave energy is high and sediment supply is low, creating critical erosion hotspots at different scales.

The model performance for a storm event is better in the 2DH mode than 1D mode, and the beach face morphological evolution of a dune backshore typology beach is more accurately modelled than that of a seawall backshore typology.

Although field data in the nearshore may be scarce and the model can run on average representative conditions to provide morphological evolution tendencies, data assimilation of the geometrical features of the actual morphology from field observations is crucial for more realistic model results.

ACKNOWLEDGEMENTS

Funding Fundação para a Ciência e a Tecnologia – FCT, Ph.D. Grant PD/BD/128508/2017, CYTED Grant 2017-PE-PROTOCOL, Project MOSAIC.pt (PTDC/CTA-AMB/28909/2017). The authors are grateful to the Spanish State Port Authority, Puertos del Estado, the Portuguese Environment Agency, Luís Simões Pedro, Maria João Henriques and Hugo Silva for the data acquisition contribution.

*Corresponding author: joao.c.oliveira@tecnico.ulisboa.pt
† Hydraulics and Environment Department, National Laboratory for Civil Engineering, Lisbon, Portugal
§ CERIS, Instituto Superior Técnico, Lisbon University, Lisbon, Portugal