LX-ST: INTEGRATED SHORELINE & TOPO-BATHYMETRIC ANALYSIS MODEL

Mohammad Traboulsi, Bureau de Recherches Géologiques et Minières, m.traboulsi@brgm.fr
Déborah Idier, Bureau de Recherches Géologiques et Minières, d.idier@brgm.com
Bruno Castelle, CNRS, UMR 5805 EPOC, bruno.castelle@u-bordeaux.fr
Arthur Robinet, Bureau de Recherches Géologiques et Minières, a.robinet@brgm.fr
Vincent Marieu, CNRS, UMR 5805 EPOC, vincent.marieu@u-bordeaux.fr

INTRODUCTION

In the context of climate change and growing anthropogenic influence on coastal regions, the need for reliable models for long-term (decadal to centennial) shoreline evolution is paramount (Nicholls et al., 2014). Process-based 2D and 3D models incorporate a wide array of physical processes; however, their high computational cost (Zhang et al., 2012) and cascading errors due to their strongly nonlinear nature prevent them from being used to address the long-term morphological changes of wave-dominated beaches, including the effects of climate change.

Reduced-complexity models coupling cross-shore and longshore processes (e.g. CoSMoS-COAST, Vitousek et al., 2017; LX-Shore, Robinet et al., 2018; IH-LANS, Alvarez-Cuesta et al., 2021) offer a relevant framework to simulate shoreline change over large spatial and temporal scales with relatively low computational cost. However, these models typically use the Bruun rule for estimating shoreline changes due to Sea Level Rise (SLR) and therefore cannot reproduce the wealth of shoreface translation modes including the effects of accommodation space (Cooper et al., 2020). Recently, the shoreface translation model ShoreTrans (McCarroll et al., 2021) was developed, considering the effects of SLR on real 2D profiles, encompassing elements like non-erodible layers and seawalls. This tool, however, has been developed for cross-shore profiles (2DV) only. Extending this approach along the longshore direction is challenging but should allow simulating the impacts of climate change on complex coastal morphologies.

In this contribution, we present LX-ST, which is a coupling between the LX-Shore and ShoreTrans models, aimed at simulating medium- to long-term shoreline and nearshore 3D morphology under the effects of sea level rise, coastal structures and longshore processes.

METHOD

Figure 1 illustrates the model coupling. First, in addition to the inputs required by LX-Shore, such as shoreline position, waves, rocky contours, and sea level rise (SLR), LX-ST uses an initial gridded topo-bathymetry. The shoreline at the first iteration in LX-Shore is labeled as 'Base Shoreline'. Then the shoreline evolution under the action of waves is computed with LX-Shore (at a time step Δt_{LX}) over a given time (a coupling time step Δt_{ST}) using the formulation of Larson et al., (2010), resulting in a 'Key Shoreline'. The shoreline evolution between t=0 and t=Δt_{ST} is then converted into longshore transport. A set of transects, orthogonal to the shoreline, is constructed with consistent alongshore spacing guided by normal vectors from the key shoreline. The profiles are then extracted from the topo-bathy grid using these transects. Finally, ShoreTrans is run on these profiles, taking into account the longshore transport, and the effect of SLR over Δt_{ST}.

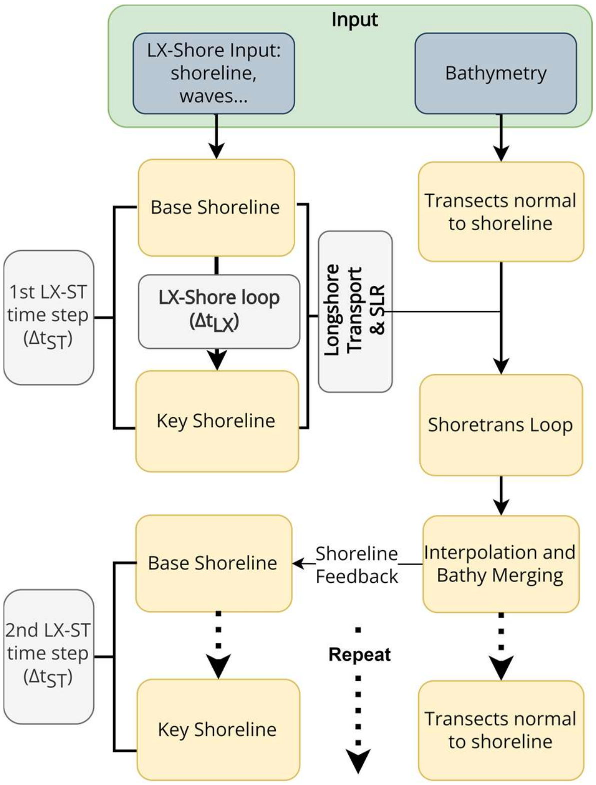

Figure 1 - Flowchart of the coupling between LX-Shore and ShoreTrans

Once the profiles are updated, an interpolation method is used to create a dense point cloud covering the entire domain. This process starts by identifying shoreline points (SPs) and refining the shoreline resolution. Then, using the SPs as starting points, a set of equidistant polylines is constructed, each at a uniform distance (dx) from the shoreline. These equidistant polylines constitute the point cloud, which facilitates the extraction of new transects in the subsequent stages.

To minimize interpolation-induced errors, interpolation is exclusively executed in regions where a certain elevation difference threshold (e.g., 0.05 m) is met. Other parts of the region, where the elevation difference is below the threshold, are sourced from the previous point cloud in a process called 'bathymetry merging'.

After this step, the change in shoreline position at each transect is used to update the sediment fraction grid (F) in LX-Shore. This results in a modification of the key shoreline, which becomes the new base shoreline for the next LX-ST iteration. In the subsequent ST time step (Δt_{ST}), the simulation continues from the new base shoreline: a new key shoreline is computed and then updated using ShoreTrans (with the interpolation phase). This operation is repeated until the end of the simulation.

TEST CASES

Two academic test cases have been selected to demonstrate the model capabilities and to challenge the coupling procedure using an idealized beach-dune profile: 1) diffusion of a shoreline bump under shore-normal waves; 2) effect of an alongshore seawall under obliquely incident waves (Figure 2).

Test Case 1 consists of an initial shoreline bump (Figure 2a) exposed primarily to normal waves and SLR of 1 m within 5 years. Unrealistic SLR is used to have similar coastal response magnitude due to SLR or longshore processes, challenging thus the coupling. As a result, the shoreline bump rapidly diffuses because of longshore processes. By the end of the simulation using rollover shoreface translation (McCarroll et al., 2021), the shoreline is straight but the dune is not anymore uniform alongshore. Interestingly enough, final dune field strongly depends on the shoreface translation mode (not shown).

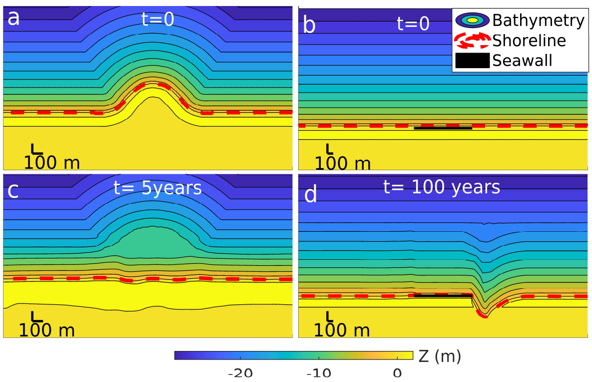

Figure 2 - Initial (a,b) configuration and final results (c,d) of test cases 1 (bump, panels a and c) and 2 (seawall, panels b,d)."

Test Case 2 consists of a straight shoreline including and alongshore a seawall (Figure 2b) exposed to low incidence waves (30 degrees from the shore normal direction) and SLR of 1 m within 100 years. In the absence of SLR, waves induce minimal changes to the straight shoreline. By introducing SLR, there is a significant erosion at the downdrift of the seawall edge as sediment is eventually trapped at the updrift side (Figure 2d). This is associated with a lowering of the upper profile facing the seawall, a phenomenon called the 'wall effect' (McCarroll et al., 2021). Additional simulations have been conducted, demonstrating the sensitivity of the shoreline evolution (and bathymetry) to the position of the seawall and the dune profile.

DISCUSSION AND CONCLUSION

The LX-ST model provides new perspectives for analyzing the long-term effects of SLR on sandy coasts with computational efficiency (the 100-year simulation of test case 2 takes about 8 hours on a standard computer). This model has an edge over others, such as IH-LANSloc (Álvarez et al., 2023), in its capability to simulate intricate scenarios involving shoreline curvature and rotation, such as regional-scale sand spit and cuspate.

However, the absence of a robust sediment conservation procedure and the interpolation method can lead to accumulating errors, particularly on highly curved shorelines. LX-ST still requires validation through real world observations and satellite data. While the test cases were simulated using Larson's (2010) formulation, LX-Shore also offers an alternative for solving wave conditions through its coupling with the spectral wave model SWAN (Booij et al., 1996), thereby providing the capability to handle more complex cases.

Future efforts will focus on applying the model to diverse coastlines to assess its full potential.

REFERENCES

Álvarez-Cuesta, Losada, Toimil (2023): A nearshore evolution model for sandy coasts: IH-LANSloc, Environmental Modelling & Software, vol. 169, pp. 105827.
Booij, Holthuijsen, Ris (1996): The "SWAN" wave model for shallow water, In Coastal Engineering 1996, pp. 668-676.
McCarroll, Masselink, Valiente, Scott, Wiggins, Kirby, Davidson (2021): A rules-based shoreface translation and sediment budgeting tool for estimating coastal change: ShoreTrans, Marine Geology, vol. 435, pp. 106466.
Larson, Hoan, Hanson (2010): Direct formula to compute wave height and angle at incipient breaking. J. Waterw. Port, Coast. Ocean Eng. 136, 119-122.Nicholls, Hanson, Lowe, Warrick, Lu, Long (2014): Sea-level scenarios for evaluating coastal impacts, Wiley Interdisciplinary Reviews: Climate Change, vol. 5, pp. 129-150.
Peng, Guan, Tang, et al. (2020): Towards a multiscale crop modelling framework for climate change adaptation assessment, Nat. Plants, vol. 6, pp. 338-348.
Robinet, Idier, Castelle, Marieu (2018): A reduced-complexity shoreline change model combining longshore and cross-shore processes: The LX-Shore model, Environmental Modelling & Software, vol. 109, pp. 1-16.
Vitousek, Barnard, Limber, Erikson, Cole (2017): A model integrating longshore and cross-shore processes for predicting long-term shoreline response to climate change, Journal of Geophysical Research: Earth Surface, vol. 122, pp. 782-806.
Zhang, Schneider, Harff (2012): A multi-scale hybrid long-term morphodynamic model for wave-dominated coasts, Geomorphology, ELSEVIER, vol. 149, pp. 49-61.