OPTI-MORPH, a new model for sandy beach dynamics by wave energy minimization

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Introduction

- A new coastal dynamics morphodynamic model, Opti-Morph, has been developped based on constrainted energy minimization.
- The model adapts to either basin or open sea settings and only requires two hyper-parameters (the sand abrasion and the maximal slope threshold).
- To validate the model, Opti-Morph is compared to wave-flume experimental data and XBeach numerical simulations.

Model description

1. Cost function

The evolution of the seabed is assumed to be driven by the minimization of a **cost function** J. Here, we assume the shape of the seabed ψ is determined by the minimization of the **potential energy of shoaling waves**:

$$J(\psi, t) = \frac{1}{16}\int_{\Omega_S} \rho_w g H^2(\psi, x, t)dx \quad [J.m^{-1}]$$

- Ω_S: shoaling zone $[m]$
- ρ_w: water density $[kg.m^{-3}]$
- g: gravitational acceleration $[m.s^{-2}]$
- H: significant wave height $[m]$

2. Governing equations

In order to describe the evolution of the seabed, we assume that the seabed ψ, in its effort to minimize J, verifies the following dynamics:

$$\begin{cases} \psi_t = -\Upsilon \Lambda d \\ \psi(t=0) = \psi_0 \end{cases}$$

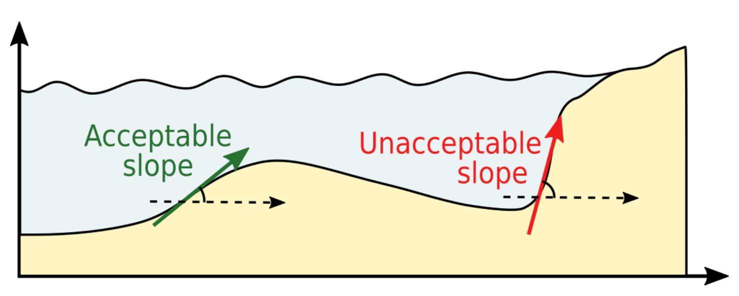
- ψ_t: evolution of the seabed over time $[m.s^{-1}]$
- Υ: abrasion of sand $[m.s.kg^{-1}]$
- Λ: excitation of the seabed by the water waves
- ψ_0: initial seabed elevation $[m]$

In unconstrained circumstances, $d = \nabla_\psi J$. Additional constraints alter the value of d. Constraints are added to the model to incorporate more physics and deliver more realistic results.

3. Two examples of constraints

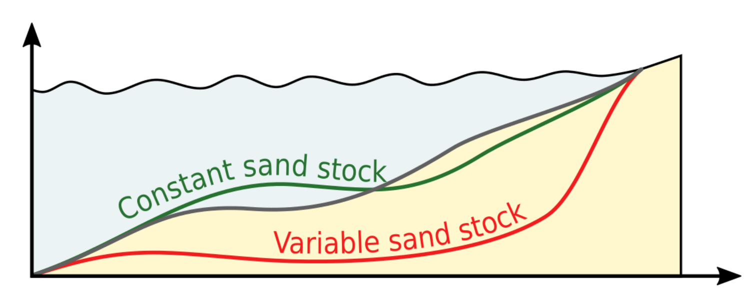
The slope of the seabed is bounded by a grain-dependent threshold M_{slope}:

$$\left|\frac{\partial \psi}{\partial x}\right| \leq M_{\text{slope}}$$

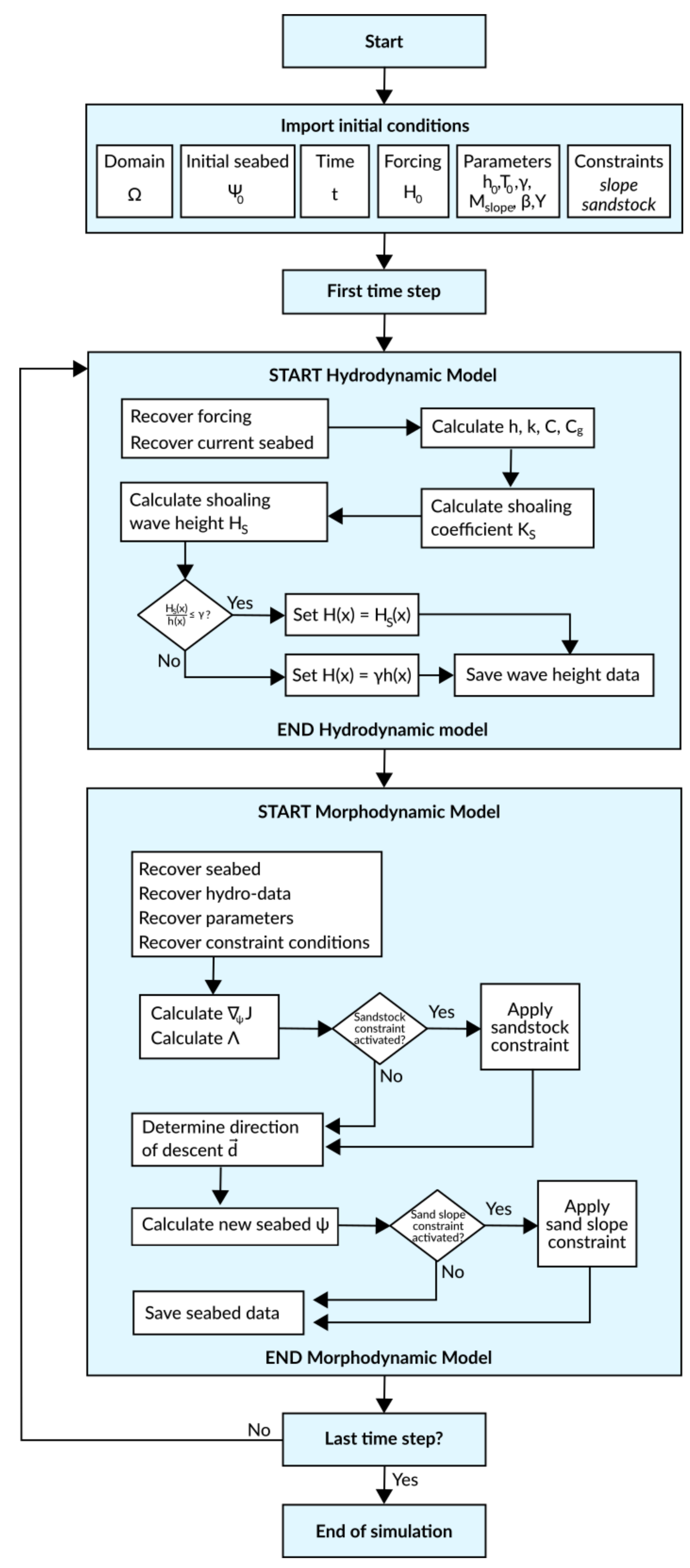


In the case of an experimental flume, the quantity of sand in a flume must be constant over time:

$$\int_\Omega \psi(t,x)dx = \int_\Omega \psi_0(x)dx \qquad \forall t \in [0,T]$$



Workflow



Numerical results

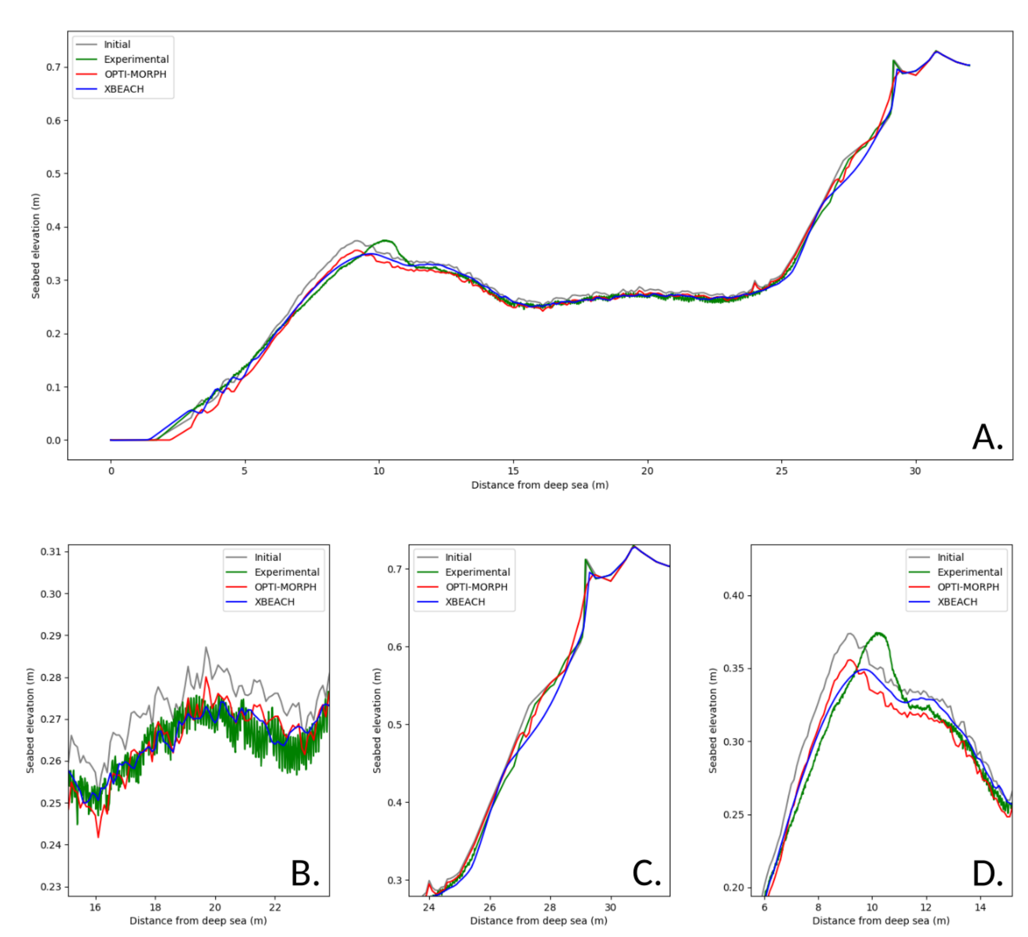


Figure 1: ***A.*** *Results of the numerical simulation calculated over the initial seabed (black) using the XBeach morphodynamic module (blue) and the Opti-Morph model (green). These are compared with the experimental data (orange).* ***B.*** *Zoomed in view of the plateau section.* ***C.*** *Zoomed in view at the shoreline.* ***D.*** *Zoomed in view of the sandbar.*

Opti-Morph was applied to a flume configuration and was compared to **experimental data** and a well-established numerical morphodynamic model, XBeach.

Figure 1 shows a general **quantitative agreement** when compared to the experimental data, especially at the coast and the plateau. However, neither numerical model was able to predict the advancing of the sandbar.

Further studies include the **long-term behavior** of Opti-Morph and XBeach (Figure 2) and the **robustness** of the hyper-parameters (Figure 3).

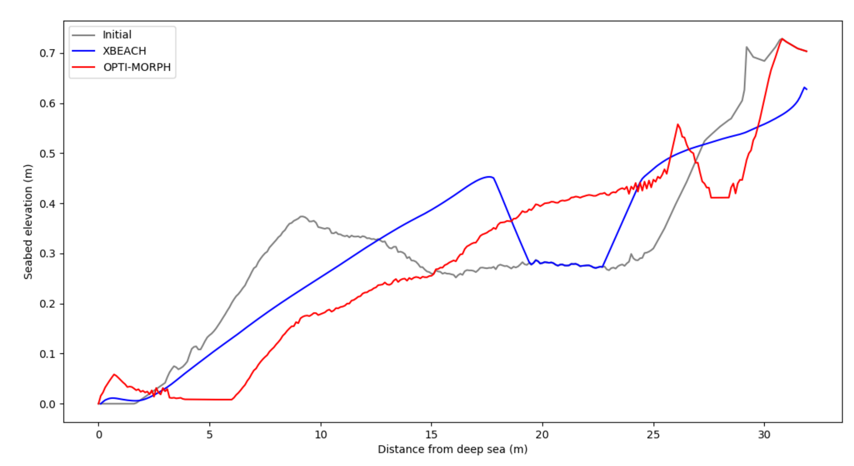


Figure 2: *Comparison of seabeds produced by Opti-Morph and XBeach over a longer time series.*

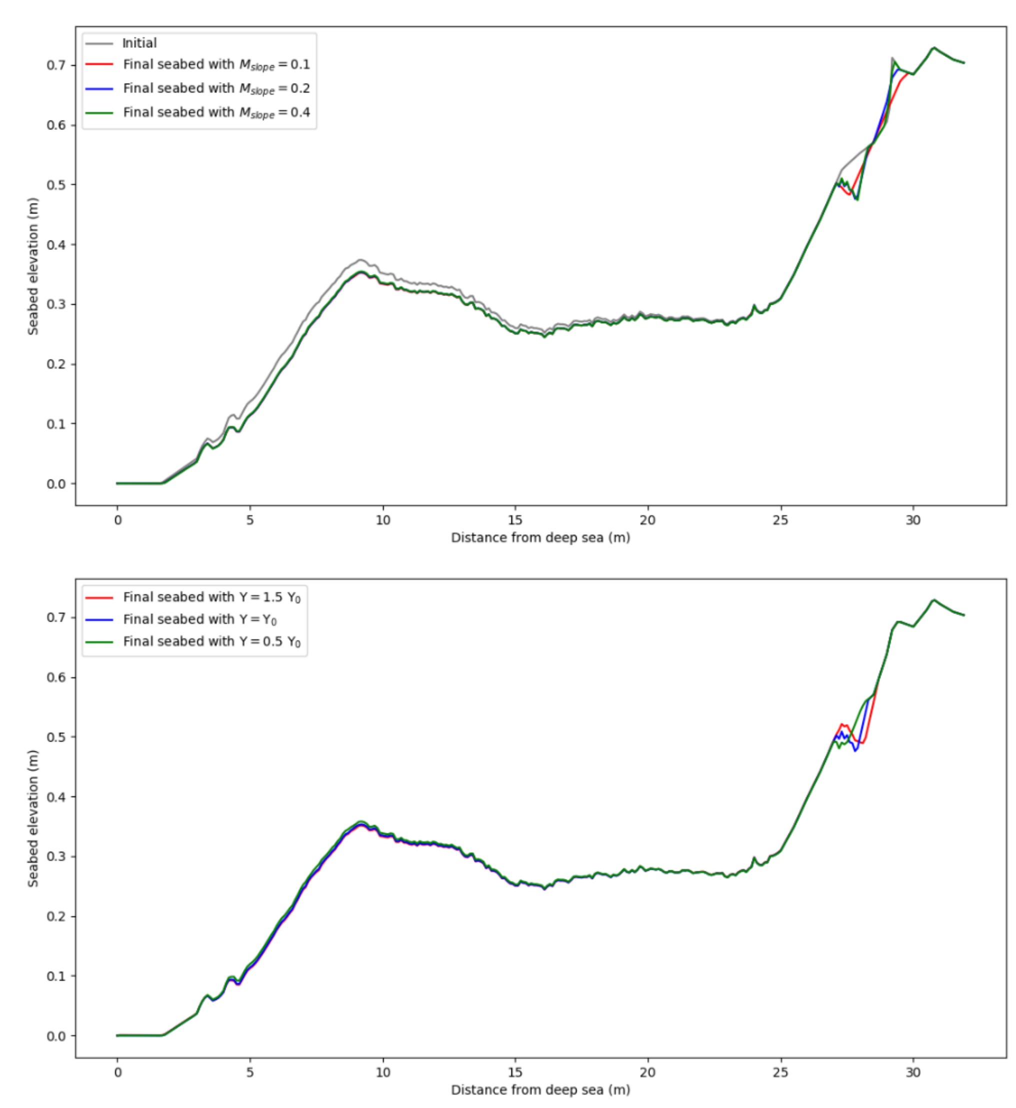


Figure 3: ***Top:*** *Seabeds produced by Opti-Morph with different values of the maximal slope parameter* M_{slope}*.* ***Bottom:*** *Seabeds produced by Opti-Morph with different values of the mobility parameter* Υ*.*

Conclusion

- Opti-Morph shows potential as a **fast**, **robust** and **low complexity** morphodynamic model involving only **two hyper-parameters**.
- Numerical simulation based on an optimization theory reproduces certain **natural coastal mechanisms**, such as the formation of **sandbars** and **coastal erosion** during severe weather conditions.
- These results demonstrate the **potential** of a constrained **energy minimization** morphodynamic model.

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