

CLIMATE CHANGE EFFECTS IN ESTUARINE MORPHODYNAMICS: EFFICIENT LONG-TERM MODELING

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INTRODUCTION

Coasts are highly dynamic areas that are particularly sensitive to the effects of climate change (CC) due to their geographical location and the variety of physical processes that shape them. It is well known in the scientific community that CC modifies the characteristics of various marine variables; in particular, the latest IPCC report (AR6, 2022) indicates that, regardless of future greenhouse gas emissions, a global mean sea level rise of between 10 and 25 centimeters is expected by 2050.

In recent years, the modeling capacity of coastal morphodynamics has developed significantly in low-lying sandy beaches; however, these advances have not been directly extended to transitional zones such as estuaries, tidal inlets, or river mouths, mainly due to the difficulty and high computational cost of modeling the multiple physical processes and their interactions (Toimil et al., 2020). Transitional zones promote the proliferation of species and ecosystems of high ecological value; moreover, these areas are under great social and economic pressure, as a significant proportion of the population (e.g., 40% in Spain) lives near the coast.

Therefore, the main objective of this work is to establish a methodology to simulate the morphodynamic evolution of transition zones in the medium and long term, with the aim of evaluating the effects of CC and its associated uncertainty, thus reducing the computational cost. The key step of the methodology is a novel input reduction method called Storm Preservation Schematization (SPS). The methodology is tested and applied to a multi-model ensemble of GCM-RCM wave projections under the RCP8.5 CC scenario to assess changes in morphology through 2050.

METHODOLOGY

The methodology is based on (1) the definition of an idealized geometry, (2) morphodynamic simulations using a process-based numerical model (Delft3D) and the SPS method, and (3) the simulation of different climatic conditions; in particular, the time series of a multi-model ensemble of wave climate projections.

The idealized physical scenario used as the input bathymetry is shown in Figure 1. It corresponds to a straight river flowing into a continental shelf with an equilibrium beach cross-shore profile, where the tidal excursion extends upstream of the outlet, configuring an estuary where river flow, tidal currents, and wind-generated waves interact. The use of an idealized bathymetry has allowed us to implement the interaction of the drivers step by step, achieving a working model with an understanding of the role of each driver on the dynamics of the outlet.

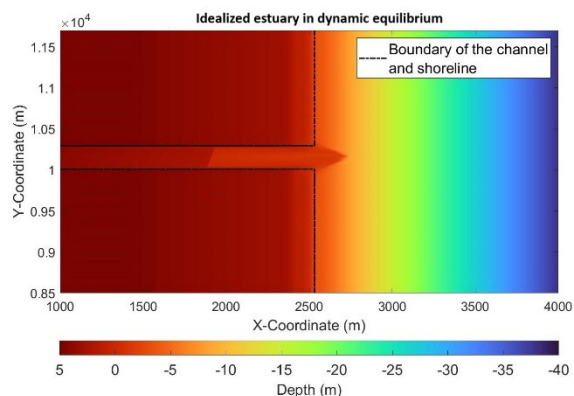


Figure 1 - Idealized river mouth used as input bathymetry.

To reduce the high computational cost, the new input reduction method SPS is defined. It is based on the hypothesis that the major morphological changes occur during the storms; therefore, it preserves the wave chronology by accelerating the calms between extreme events using the Morphological Acceleration Factor (MORFAC) (Lesser et al. 2004), but keeping the storms in real time.

For the morphodynamic simulations, historical wave data from SIMAR points (Puertos del Estado, Spain) on the Andalusian coast are used. They consist of hourly time series of wind and wave parameters obtained from numerical modeling. After the validation of the SPS method, the hindcast wave time series developed by the Metecean Research Group of the University of Genoa (Italy) are used for the long-term simulations (25-30 years). Hourly time series of the main wave climate-integrated parameters from 1979 to 2020 on a 10 km grid for the entire Mediterranean Sea are used. The future wave climate time series correspond to a multi-model ensemble of five GCM and RCM combinations (Table 1) applied in the same area as the hindcast. The wave projections have been obtained with the same setup as the hindcast and have been bias adjusted following the methodology of Lira-Loarca et al. (2023).

The validation of the method is done by comparison of the final morphologies resulting from (1) applying the projection to the initial bathymetry shown in Figure 1 versus (2) applying the projection to a bathymetry already modified by a previous 25-year time series (hindcast, 1995-2020). Thus, the experimental design for the numerical experiments consists of eleven SPS simulations: (i) a 25-year simulation with hindcast information from 1995 to 2020, using the idealized estuary shown in Figure 1 as the input bathymetry; (ii) with this

simulation, a new bathymetry is obtained and then used for the next five 30-year simulations with CC projections (listed in Table 1) from 2020 to 2050; (iii) finally, five more 30-year simulations are performed with the same CC projections from 2020 to 2050, but using the idealized estuary of Figure 1 as input bathymetry.

Table 1. Combinations of EUROCORDEX RCM and driving GCM and notation selected.

Institution	RCM	GCM	Notation
SMHI	RC4	NCC-NorESM1-M	RCA4-NorESM1-M
SMHI	RC4	MOHC-HadGEM2-ES	RCA4-HadGEM2-ES
SMHI	RC4	ICHEC-EC-EARTH	RCA4-EC-EARTH
DMI	HIRHAM5	NCC-NorESM1-M	HIRHAM5-NorESM1-M
DMI	HIRHAM5	MOHC-HadGEM2-ES	HIRHAM5-HadGEM2-ES

PRELIMINARY RESULTS AND FINAL REMARKS

To evaluate the performance of the SPS method, we have compared its results with those obtained by simulating a complete year without applying any input reduction method. To obtain a quantitative value of the goodness of the results, we use the Brier Skill Score (BSS) value defined by Sutherland et al. (2004):

$$BSS = 1 - \frac{(Z_m - Z_{end})^2}{(Z_0 - Z_{end})^2} \quad (1)$$

Where Z_m is the bathymetry obtained with the SPS method, Z_{end} is the target bathymetry (one real year) and Z_0 is the initial bathymetry.

We have carried out several different simulations to validate the SPS method using the climate corresponding to a location from the Andalusian Mediterranean coast. Three different years have been used, with different ranges of mean wave energy flux per crest unit (2):

$$E = \frac{\rho g^2}{64\pi} H_s^2 T_p \quad (2)$$

Where ρ is the density of water, g is the acceleration of gravity, H_s is the significant wave height and T_p is the peak period. The BSS values obtained during the validation are shown in Table 2.

Table 2. Classification of the morphodynamic simulations.

Year	Mean energy (kW/m)	BSS	Classification
1 st	1,6647	0,7491	Good
2 nd	1,4854	0,5783	Reasonable
3 rd	2,1132	0,6041	Good

The results obtained for the 1st year are depicted in Figure 2, showing the bathymetry obtained after one year of simulation with the real climate and the bathymetry obtained with the validated SPS method. A BSS between 0.6 and 0.8 is defined as good by Sutherland et al. (2004). In this example, we have reduced the number of days from 365 (one year) to 61 days, which is a reduction of 1/6 of the computational cost.

According to the results shown in Table 2, the SPS method is a promising efficient tool for simulating long-term

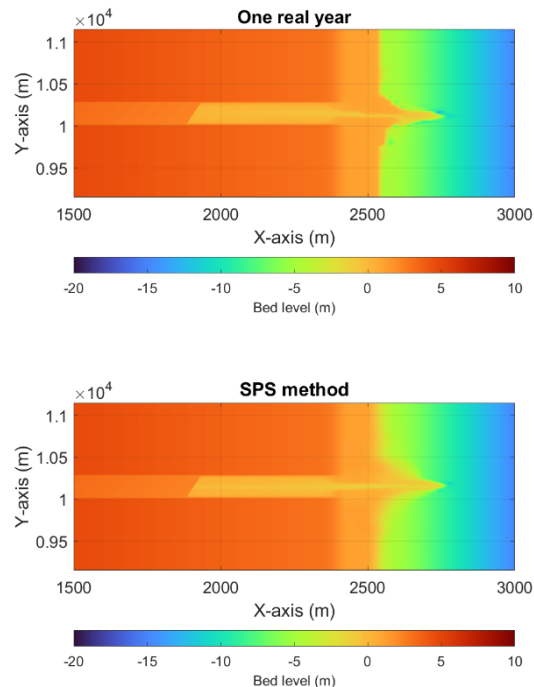


Figure 2 - Final bathymetry obtained after one real year simulation (above) and one virtual year simulation using SPS method (below) for the 1st year.

morphodynamics to study the role of CC on transitional waters. We have already optimized the model in the idealized study area, and thanks to the new input reduction methodology, the computational time has been reduced between 1/6 and 1/5 in the 3 simulated years. This allows us to compare the morphodynamic response between different CC projections without the large computational effort that was previously required. Once the 11 simulations are completed, morphological parameters will be defined to assess the effects of CC. These parameters include the change in delta volume and the position of the shoreline. These additional results will be presented at the conference.

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