

Estuarine morphodynamics: simulating schematic configurations with a process-based 3D model with focus on the evolution of tidal marshes under climate change

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Context and objectives

Among the impacts of climate change in estuarine systems, one of the most difficult to tackle is the possible morphological evolution of estuaries, either due to sea level rise downstream, or to changes in both liquid and solid upstream river inputs. In large European estuaries, channel systems are most often constrained by navigation criteria, so that dredging is commonly undertaken in order to maintain the channel depth. On the other hand, lateral zones - especially intertidal flats and tidal marshes - are likely to be strongly impacted by climate change, mainly for two reasons:

- estuarine cross-profiles are essentially convex, so that the upper intertidal flats, most often vegetated (marshes), are only inundated during spring tides high water level; in case of sea level rise, the rate of inundation can increase tremendously, and generate new constraints on the natural marsh ecosystem or on its anthropic use, for instance for extended breeding;
- the tidal marshes elevation depends on the sedimentation rate which is both related to the previously mentioned inundation rate and to the suspended sediment concentration (SSC) in the upper water column in front of marshes; this concentration is strongly dependent on the proximity of the turbidity maximum, the location and intensity of which is related to the river regime.

Methodology

In order to test the estuaries morphological response to climate change and possibly characterize an equilibrium state, a process-based hydrodynamics and sediment transport numerical model, with morphological coupling is applied to schematic geometrical configurations. The morphological coupling requires a rather high horizontal resolution, while the simulation of realistic turbidity maximum location and good range of SSC in the upper layers requires some vertical discretization, so that the interest of schematic cases does not imply any saving in computing time, but an easier interpretation of results, according to the geometry of the estuary, the tidal range and the river regime.

The numerical code is a morphodynamic version of the MARS hydrodynamic code coupled with multilayered bed models. Navier-Stokes equations are solved under the Boussinesq approximation and hydrostatic assumption. Only suspended sediment transport is accounted for, with the possibility of mixing several sand and mud particle classes (Le Hir *et al.*, 2011). The typical horizontal resolution is 100-300m, while the vertical resolution remains crude in order to save computing time. A morphodynamic factor is used to speed up the sediment evolution for given mass exchanges between the bed and the water column. In order to allow meandering and channels divagation or intertidal flats extension, lateral erosion has been implemented for dry cells: lateral erosion is proportional to the tangent velocity components in neighbouring cells. In addition, the deposition of fine suspensions above a given cell can be spread to deeper neighbouring, in order to account for the actual sliding of fluid mud according to the bottom slope. In order to reduce possible artefacts induced by the use of a morphological factor, sediment processes have been strongly simplified: sand and mud have similar erosion behaviours and are mainly distinguished by their settling velocity, which allows for the simulation of sorting processes.

Results

First, the capacity of the model to simulate the long term evolution of an estuary (up to 800 years) has been tested: depending on the upstream sediment input, an equilibrium can be reached, or the estuary evolves into a delta. The banks most often exhibit steep slopes in the lower intertidal zone, while upper flats develop at elevations of realistic marshes. Secondary channels (creeks) can form throughout the marshes provided they are still regularly flooded.

Accounting for sea level rise (SLR=1cm/year during 100 years) leads to strongly non uniform marshes elevation. In the case illustrated on Fig. 1, the SLR is likely to enhance hydrodynamics within the estuary, and then generate meandering.

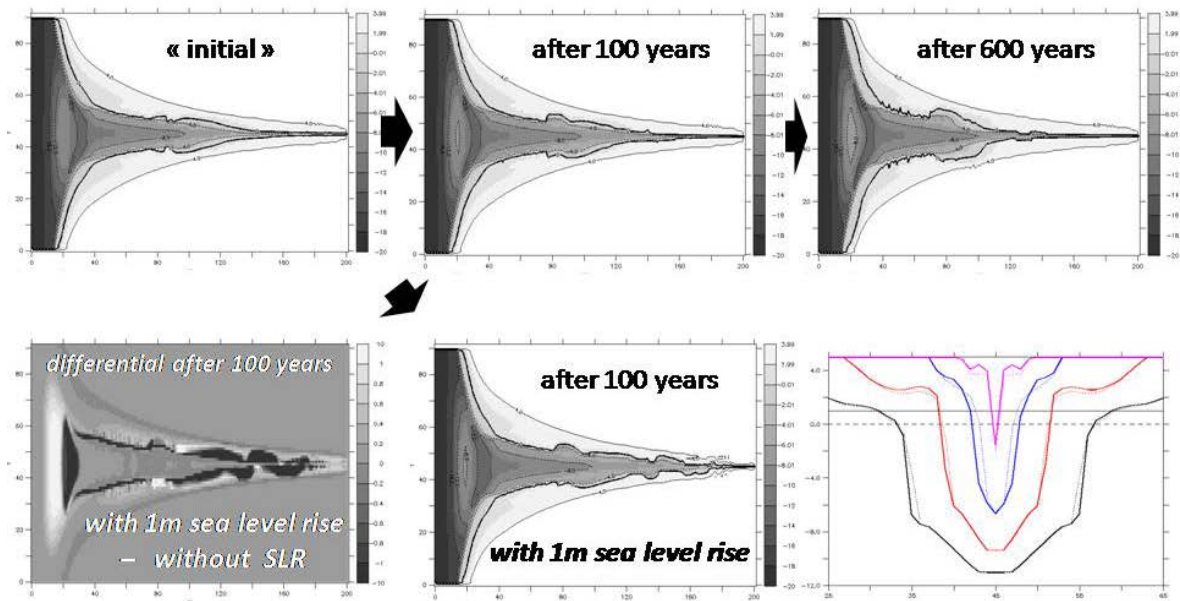


Fig. 1. Topo-bathymetric evolution of a 50km long estuary, with an upstream input of $40\text{m}^3\cdot\text{s}^{-1}$ and $\text{SSC}=0.05\text{kg}\cdot\text{m}^{-3}$. Lower right picture shows cross-sections with and without SLR after 100 y.

Confirming previous results from the literature, it appears that the change of river regime can affect the sedimentation rate on tidal marshes and their response to any sea level rise. In given circumstances the marsh elevation may follow the sea level rise if sedimentation is enough, while in other cases the inundation rate is likely to increase, and lead to other configurations with creeks formation, inducing different vegetation cover and influencing habitats (*e.g.* Temmerman *et al.*, 2012).

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References

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