

FACTORS CONTROLLING THE EQUILIBRIUM SEDIMENT COMPOSITION IN SAND-MUD TIDAL BASINS

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INTRODUCTION

Bed sediments in estuaries and tidal basins often consist of sand and mud, which can be deposited as uniform mixtures or as layers with varying mud content. Segregation between muddy and sandy areas is usually observed over large spatial scales (with sandy outer areas gradually fining in the landward direction), but also over small spatial scales. These small spatial scales are characterized by abrupt transitions of the sediment composition over relatively short distances.

Understanding where sand and mud prevails is crucial to understand and predict coastal evolution and biological activity. Recent research (Colina Alonso, et al., submitted) has shown that the mud content in tidal basins tends to be bimodally distributed, revealing the existence of two stable equilibrium conditions (see Figure 1). Their theoretical framework suggests that both the existence of multiple equilibrium conditions, as well as their values, are controlled by the spatial dependence of sand and mud deposition. Field data of the Wadden Sea (The Netherlands and Germany) support these findings.

Colina Alonso, et al (submitted) argue that this spatial dependence is most likely influenced by mud availability and the probability of sand to be transported towards muddy parts of the system. We advance on their contribution by further quantifying these relationships through exploratory modelling, with the specific aim to explore mechanisms responsible for bimodality using a schematized tidal basin.

METHODS

We have developed a depth-averaged (2DH) Delft3D morphodynamic model of a schematized tidal basin (see Figure 2). The model domain consists of a tidal inlet in-between two islands and a back-barrier basin with dimensions of 15 x 10 km. The rectangular computational grid has a resolution of 100 x 100 m. We work with a stratified bed with an active transport top layer with a thickness of 0.1 m and 20 layers of 1 m underneath.

Starting from a linearly sloping bed with a uniform sediment composition, we model 50 years of morphological evolution under tide- and wave-forcing for several scenarios with: 1) varying mud availability (boundary conditions, and initial bed composition), 2) varying hydrodynamic forcing (average wave heights, storm occurrence, and tidal prism) and 3) varying grain sizes of the sand fraction (D_{50}). We subsequently analyze the simulated bed evolution, the spatial sediment composition in the upper bed and most importantly, its bimodality.

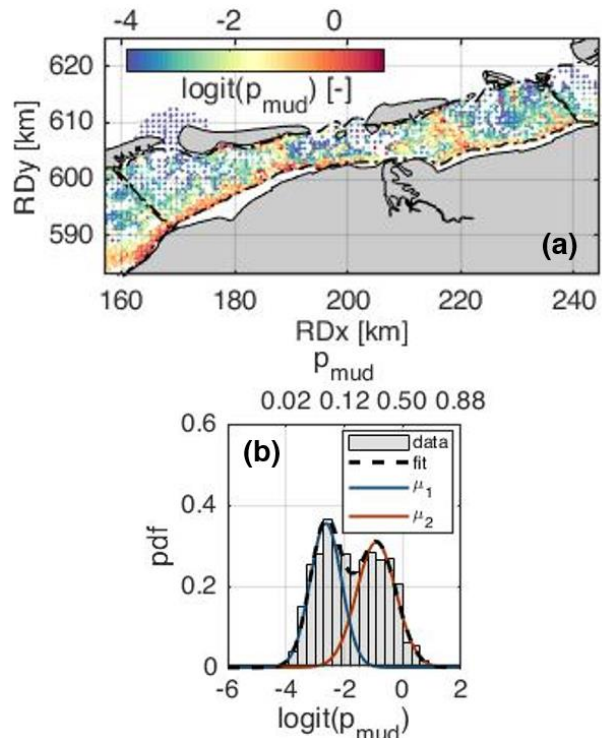


Figure 1 - (a) Mud content in the Wadden Sea sediment bed (logit -transformed) and (b) its bimodal distribution.

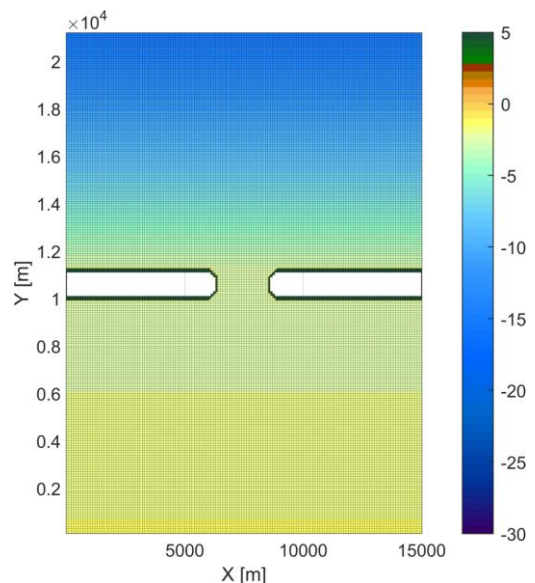


Figure 2 - Domain and initial bathymetry (in m) of the Delft3D model.

PRELIMINARY RESULTS

Our models generate an intricate pattern of tidal channels and flats, in which, overall, the mud content increases in landward direction. The model reproduces the bimodal character of the mud content in the sediment bed when sand-mud erosion interaction is accounted for. The computed morphology, including the distribution of the mud content, is strongly steered by several numerical model input parameters explored, which are briefly discussed below.

Mud availability

The distribution of the mud content is, within the range of our parameter settings, most strongly affected by the availability of mud (both initially in the bed and prescribed along model boundaries). With decreasing mud availability more intertidal areas move from a muddy (cohesive) state to a sandy (non-cohesive) state (i.e., the second mode in the bimodal distribution becomes more prominent compared to the first mode, see Figure 3). Additionally, the value of the second mode in the bimodal distribution increases with increasing mud availability (i.e., muddy areas become muddier). Bimodality is observed for a wide range of conditions. However, when the mud availability is very large (by increasing the offshore mud concentrations from 5 mg/l to over 100 mg/l), the bimodal character disappears, and only muddy intertidal flats evolve.

Varying the initial mud content in the bed has a stronger effect on the model results than varying the suspended mud concentrations along the boundary. This is probably because the channel configuration is strongly influenced by the initial morphological developments at the start of the simulation. During these conditions the mud availability in the model domain is largely controlled by erosion and less by advection from the model boundaries (as it takes a significant amount of time for the suspended mud to reach the basin and contribute to its morphodynamics).

Note that the mud availability not only affects the composition of the bed, but also largely its bathymetric evolution: with increasing availability small shoals merge into larger ones, resulting in a final bathymetry with large shoals and a larger total intertidal area.

Hydrodynamic forcing

Next, we explore the effects of varying wave and tidal forcing on basin evolution. Waves are simulated as local wind-generated waves. Increasing the wind velocities with a factor of 1.3 does not lead to any clear changes in the morphodynamic evolution (Figure 4). Increasing the wind velocity with a factor of 2 does lead to notable changes, consisting of 1) a smoother bathymetry and 2) a more pronounced bimodality (representing a sharper segregation between sandy ($p_{\text{mud}} \approx 0.02$) and muddy areas ($p_{\text{mud}} > 0.5$)), and less areas with a mud content in-between the two dominant modes. Especially the first mode (representing the sandy areas) is more pronounced and larger. A reason for this is that increased wave forcing results in a larger transport capacity of sand.

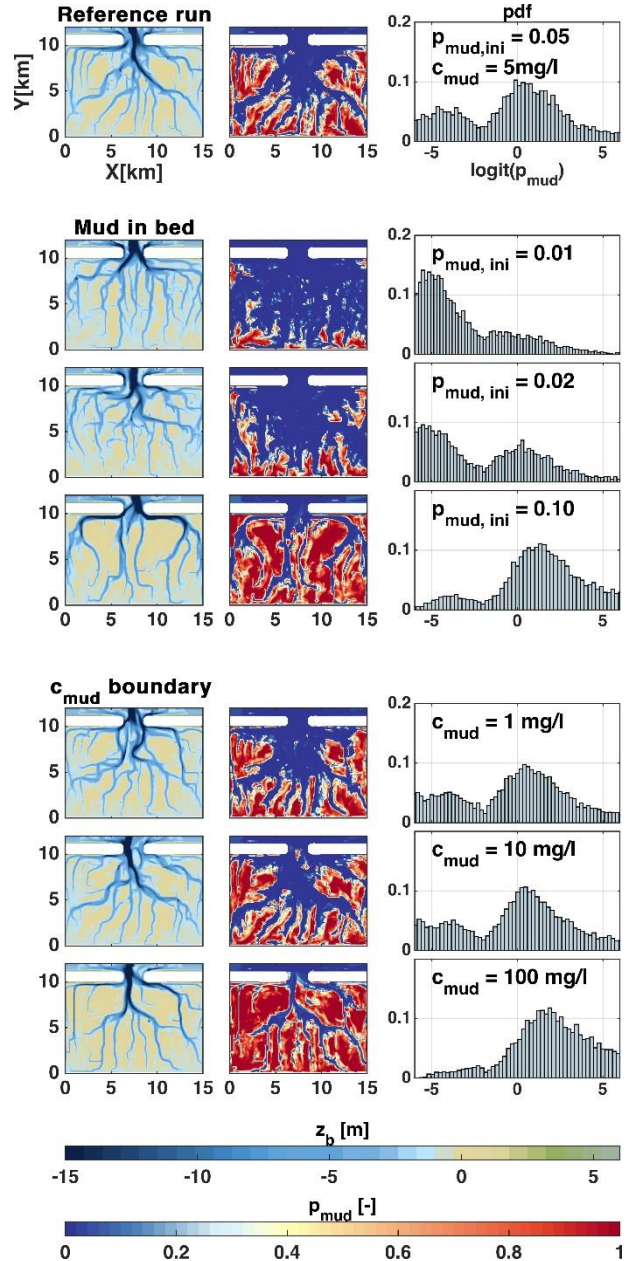


Figure 3 - Model results for scenarios with different mud availability by varying the initial mud content in the bed or the suspended mud concentration at the model boundary. Left panels: bathymetry. Middle panels: mud content in upper bed. Right panels: pdf of the (logit-transformed) mud content.

Increasing the tidal prism results in sandy areas becoming muddy and the muddy areas becoming muddier, despite the fact that an increased tidal prism may also increase velocities and thus the sand-transport capacity. Note that the results with increased tidal prism are very similar to the results with increased mud availability (Figure 3), especially regarding the bathymetric evolution.

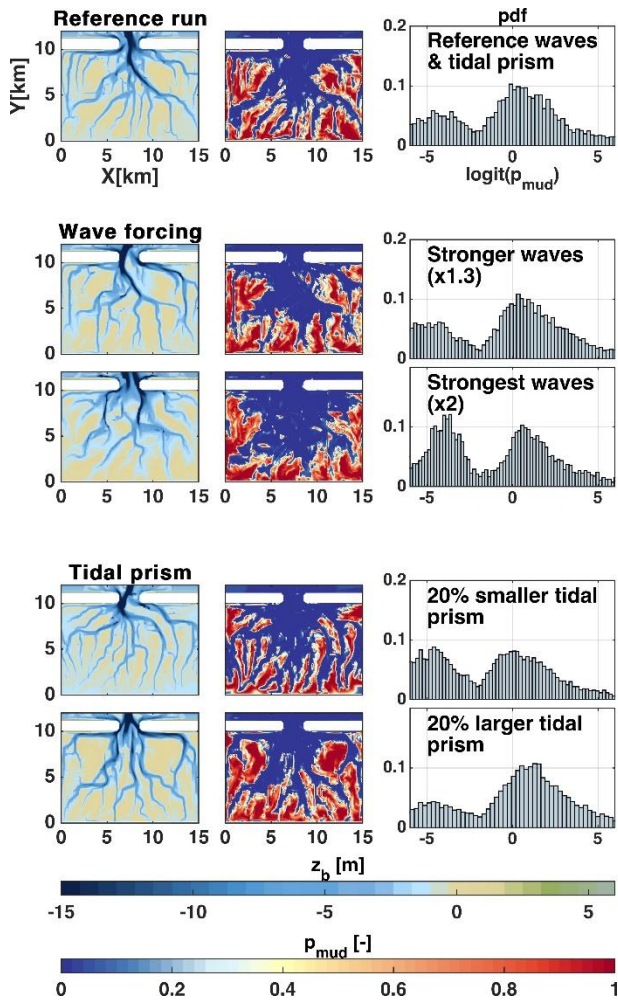


Figure 4 - Model results for scenarios with different forcing (waves and tides).

Sand grain size

Our model results show that intertidal flats become slightly more sandy with a decrease in the D_{50} of sand, because the increased mobility of sand enables transport to relatively calm conditions (Figure 5). This results in a shift in the proportion of the sandy and the muddy areas. Simulations with $D_{50, \text{sand}} = 300 \mu\text{m}$ have approximately 10% less sandy shoal area compared to simulations with $D_{50, \text{sand}} = 150 \mu\text{m}$. A change in D_{50} does not necessarily lead to a shift in the modes of the bimodal distribution. This implies that the sand grain size influences the extent of muddy areas, but the muddy areas will not necessarily be more/less muddy.

CONCLUSION AND OUTLOOK

We have shown that the bimodal character of the mud content, that has previously been observed in the tidal basins of the Wadden Sea, can be reproduced with numerical models. It is important to correctly reproduce the bimodal distribution of the mud content, since this indicates a correct representation of the bed sediment composition in the modelled system. Consequently, this distribution could be used as a model calibration metric.

We have explored three main factors influencing basin evolution and more specifically, the distribution of the sediment composition in the upper bed. Increasing the mud availability results in more muddy intertidal areas. This can be parameterized by either increasing the suspended mud concentration at the boundary, or by increasing the initial mud content in the sediment bed. The latter has a stronger effect on the model results. Increased wave forcing results in a larger transport capacity of sand and therefore more sandy areas, whereas an increased tidal prism has the opposite effect. We believe this may be because the latter can also largely increase the net mud flux into the basin. Lastly, we have shown that intertidal flats become progressively less sandy for increasing sand grain size.

We aim at further exploring the factors that control the equilibrium sediment composition in sand-mud tidal basins by further 1) quantifying their relative contributions and 2) analyzing the physical processes that play a role when changing these factors.

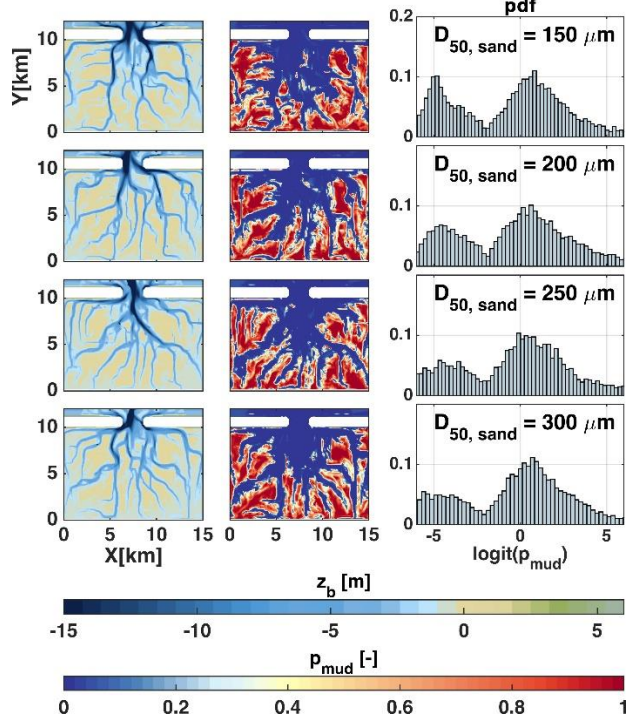


Figure 5 - Model results for scenarios with sand size (D_{50}).

REFERENCES

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