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Sand-mud interaction effects on the decadal morphodynamics of the Scheldt estuary

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ABSTRACT

The Scheldt estuary is a key waterway that connects to major ports between the Netherlands and Belgium. Its morphodynamic evolution has been studied under tides, waves, and dredging influences, yet the contribution of cohesive sediments and waves remain poorly quantified. This study aims to evaluate how sand-mud interactions shape the large-scale development of the estuary, with an emphasis on intertidal areas. A 3D process-based model will be applied to represent sand-mud effects in erosion and bed roughness. The outcomes will be a hindcast of the Scheldt estuary morphodynamics between 1955 and 2020, and will be expected to highlight the role of cohesive sediment in estuarine morphodynamics, and will identify the dominant natural or anthropogenic drivers.

1. Introduction

The Scheldt estuary, located on the border between the Netherlands and Belgium, is a vital navigational waterway providing access to the ports of Vlissingen, Terneuzen, Ghent, and Antwerp. Since the 1960s, intensive dredging has been required to maintain these navigational channels, making the estuary a focus of management efforts balancing navigational access, flood protection, and ecological integrity. The bathymetry of the estuary (Fig 1; Röbke et al., 2025) reflects the system of channels and shoals shaped by both natural and human influences.

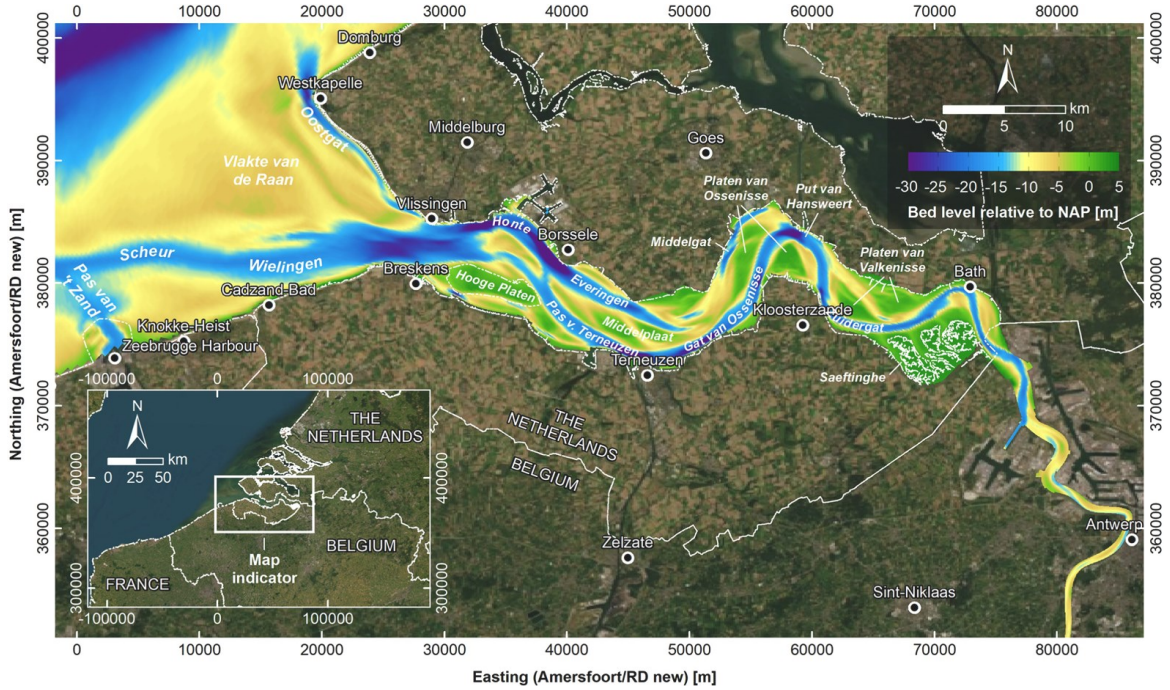

Fig 1. Bathymetric map of the Scheldt estuary annotated with key features (Röbke et al., 2025)

Numerous studies have investigated the morphodynamic development of the Scheldt estuary. Dam (2025) developed a morphodynamic model reproducing the sediment budget of Dam et al. (2022). This model introduced a novel representation of sand-mud interactions in erosion behavior to simulate the cohesive and non-cohesive sediment transport. To account for human interventions, van der Wegen & Roelvink (2012) both implemented dredging and dumping modules to reproduce the morphological impact of navigation maintenance. More recently, Röbke et al. (2025) and Elmilady (2025) examined the estuary's response to sea level rise, with the former focused on sand transport and channel-shoal migration and the latter analyzing intertidal evolution without sand-mud interaction.

Dam (2025) simulated the effect of sand-mud interaction on the erosion rate of mixed sediments under tidal and river discharge forcing. However, his study did not account for wind and wave forcing, which are key drivers of sediment transport in the intertidal areas. Colina Alonso et al. (2023) applied a sand-mud interaction framework to an idealized tidal basin. This framework captured both the cohesive influence on erosion rates and its effect on bed roughness, yet this formulation has not been tested in a real estuary. The knowledge gap lies in quantifying how sand-mud interactions affect estuarine morphodynamics within a 3D, process-based model. The present study, therefore, investigates how cohesive sediment influences morphological development of the Scheldt estuary under natural forcings (tides, waves, and wind) and anthropogenic drivers (dredging and dumping).

2. Methodology

To address this gap, the present study will develop a 3D process-based morphodynamic model to simulate the decadal evolution of the Scheldt estuary under the combined influence of tides, waves, wind, and dredging and dumping activities. The research will examine the influence of the sand-mud interaction module (both erosion interaction and bed roughness) implemented on the morphological and compositional evolution, with particular focus on the intertidal area. The model performance will be calibrated and validated through a hindcast of the estuary's evolution from 1955 to 2020. In addition, a series of sensitivity analyses will be performed to evaluate how variations in forcing magnitude affect the predicted bed levels and sediment composition.

3. Expected results

The expected results of the study include a significant improvement in the modeled reproduction of bed levels and sediment composition, particularly in the intertidal areas, compared with previous studies that used sand-only or non-interacting sediment fractions. The sensitivity analyses will identify the dominant natural or anthropogenic forcings governing the morphological evolution of the Scheldt estuary. This new knowledge will inform the estuarine management strategies by enhancing the predictive capability of morphodynamic models, providing a valuable tool for evaluating future dredging and disposal scenarios.

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