PREDICTING SEDIMENT PATHWAYS ACROSS THE NEARSHORE-DUNE SYSTEM

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INTRODUCTION

Coastal zones worldwide are densely populated and feature many developments and essential infrastructure, providing numerous services to local coastal communities. Central to the efficacy of the entire coastal system in providing these services, is the presence and movement of sediment. The intricate movement of sediment throughout the system, or sediment pathways, is influenced by a combination of natural processes and (un)intentional human interference, making understanding them critical for optimizing the design of coastal (Nature-based) solutions and coastal management decisions. Recognizing this, our study focuses on the role of human impact on sediment movement throughout the coastal system.

The Delfland coast in the Netherlands is a densely populated coastal region. Beyond the inherent value in providing water safety, recreation, and natural values, this coastal region has seen a range of human interventions aimed at harnessing and enhancing the provided services. These vary from the construction of breakwaters aiding harbour navigation to systematic nourishments, including the Sand Engine mega nourishment.

Our goal is to examine sediment connectivity along the Delfland coast, revealing interactions, primary sediment pathways, and the impacts of human interventions. Hereto we made improvements to an existing coupled modelling framework focusing on the nearshore-dune system (Westen et al., 2023) in combination with a Lagrangian transport model (SedTRAILS; Pearson et al., 2020), enabling us to track individual sand particles within our evaluation domain and to map the primary sediment pathways along the Delfland coast, crossing the dry-wet interface.

METHOD

For our analysis, we use SedTRAILS fed by results from an integrated nearshore-dune simulation, thereby tracing sediment particles across the Delfland coast. First, we simulate the morphodynamic changes in both the subaqueous and subaerial domains, serving dual objectives: i) validation to evaluate model performance, and ii) calibrating SedTRAILS' particle velocities. The coupled model is extended from van Westen et al. (2023), in which the process-based models Delft3D Flexible Mesh (FM), SWAN and AeoLiS are coupled to simulate marine morphodynamics, waves and supply-limited aeolian transport, respectively (Figure 1). We examine the morphodynamic outcomes to validate the model's ability to simulate the integrated development of the coastal system. Afterwards, sediment pathways and system connectivity are analyzed based on morphostatic simulations for the morphological state of different years.

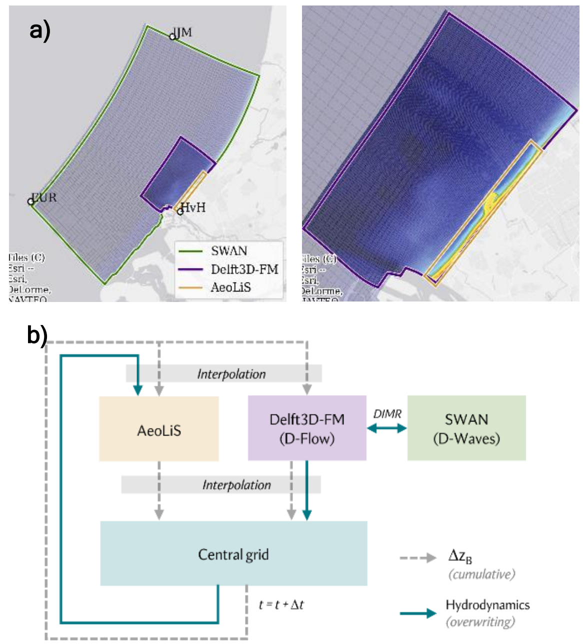

Figure 1 - a) Spatial coverage of the computational domains of SWAN (green), Delft3D FM (purple) and AeoLiS (yellow) and b) the parameter exchange between these model components.

COUPLED MODEL VALIDATION

To evaluate the coupled model's ability to predict sediment pathways across the nearshore-dune system, we compare its outcomes with observed morphodynamic development over a 12-year period (2011-2023), focusing on the nearshore, beach, and dunes. Results show that the alongshore redistribution of sediment can be captured well by the model (Figure 2). Along accretive sections of the domain, beach width increase is observed in both observations and model results. In these accretive situations, marine-driven transport provides the sediment supply for aeolian pickup and duneward aeolian transport. As a result, largest growth rates occur along more accretive locations, whereas reduced dune growth is observed at locations where sediment supply is limited. The model is able to reproduce part of these observed alongshore patterns in dune growth, indicating the model's ability to simulate sediment transport across the wet-dry interface. The ability of the model to reproduce 12 years of integrated morphodynamics allows us to apply it for the analysis of sediment pathways and system connectivity using SedTRAILS.

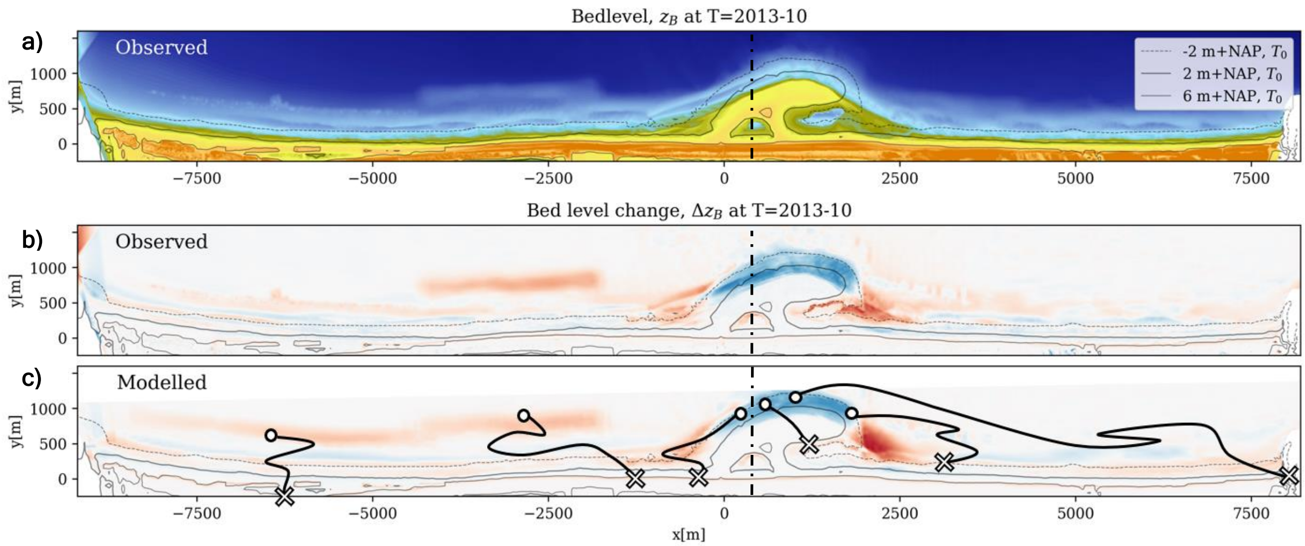

Figure 2 – The observed bed level along the Delfland coast in October 2013 (a). Contour lines show the morphological state in August 2011. The observed and modelled bed level change between August 2011 and October 2013 (blue=erosion, red accretion, b-c). Conceptual sediment pathways shown by the solid black lines. Starting point of the pathways given by the open circles, final point by the crosses.

SEDIMENT PATHWAYS

SedTRAILS is used to trace thousands of grains through the nearshore-dune system, creating a conceptualized map of predominant sediment pathways (see Figure 2-c and Figure 3 for possible outcomes). The orientation of sediment trajectories varies in space (e.g., at larger water depths with respect to higher elevations in the profile), reflecting differences in the balance between forcings. Analyzing the origin and destination of the individual particles provides useful insights to clarify the feeding range for different nourishments and the probability for individual particles to be transported from the subaqueous into the subaerial domain. These sediment pathways are further quantified by segmenting the system into nodes, capturing the interconnections within the system in its primary longshore and cross-shore subsections. These systematically labelled nodes visualize the system's internal connectivity as revealed by the connection strengths between nodes and particle residence times within each node.

OUTLOOK

Our work with the combined application of an innovative coupling framework and Lagrangian transport model SedTRAILS, shows how one can map sediment pathways crossing the nearshore, beach and dune domains. Our findings into the connectivity between different regions of the system, the residence time of particles within certain regions or the connecting role of certain nodes can prove useful in assessing the efficiency of existing human interventions and thereby support in optimizing future coastal solutions. This model-derived pathway technique brings new opportunities for explaining the (complex) interconnectivity in the coastal domain to coastal engineers and decision-makers.

REFERENCES

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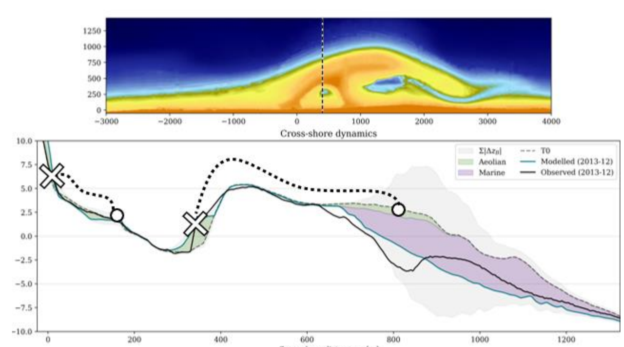

Figure 3 – The modelled (blue line) and observed (black line) cross-shore development over a 2-year period. The marine-(purple) and aeolian-driven (green) bed level changes are shown by the colored patches. The starting point of the pathways is given by the open circles, the final point by the crosses.