Netherlands Centre for Coastal Research

Book of Abstracts

These NCK days are supported by:

Contents

Preface

Welcome in Delft for the NCK days 2023, the conference for coastal scientists and engineers in the Netherlands. The NCK conference is each year a benchmark for coastal scientists. It's a place to meet colleagues from other universities, institutes, and companies; to get inspired by new findings; to start your career; to support students and newly started PhDs; to summarize your PhD work.

Coastal engineering changed over the last decades from shortening our coastlines and building barriers to engineering solutions with sand nourishments, rebuilding seagrass meadows and diversifying foreshores. New routes in coastal sciences were further explored and connections were made with other disciplines. This resulted in a coastal management toolbox with more and different types of tools. However, is it already big and diverse enough? Are all tools sufficiently tested? Are new tools needed? Is our knowledge sufficient for applying available tools? These questions led us to the theme of this year: "**Towards more diverse approaches in Coastal Engineering & Sciences**". We aim to explore during the conference where we are and whether we need to further expand strategies and methods.

Two keynote lecturers have been invited to address the theme. Fernando J. Méndez Incera from IH Cantabria will introduce us to the world of big data and data science. How can we improve the predictions of extreme events and what is the effect of El Niño? He will bring in examples from all over the world. Wouter van der Heij from the Waddenvereniging, will bring us to the Afsluitdijk, and especially the hole in the Afsluitdijk. Various stakeholders were brought together, plans were made, and they are now building the Fish Migration River.

This year, we received a massive number of abstracts, resulting in 34 oral presentations and 70 poster presentations. We have contributions from young scientists as well as seasoned researchers. Browse through the abstracts and have a look what NCK2023 has to offer. The program is full, starting with the excursion and icebreaker on Wednesday. Thursday is plenty of presentations ending with a dinner at Knus. Friday is again offering a variety of presentations and we close the conference with the awards for the best poster and oral presentation by a young scientist.

We would like to thank the following organizations for sponsoring the NCK days 2022: JM Burgerscentrum, Arcadis, Boskalis, HKV, Nortek, Svašek Hydraulics, Waddenacademie, RoyalHaskonoing DHV and Waterproof.

We truly hope that you will enjoy these NCK days and that this meeting will reinforce the collaborations within the NCK community and will strengthen the productivity of Dutch coastal research.

The organizing committee,

Anne Ton

Marion Tissier

Sander Vos

Paul Bayle

José A. Á. Antolínez

Bram van Prooijen

About NCK

The Netherlands Centre for Coastal Research is a cooperative network of private, governmental and independent research institutes and universities, all working in the field of coastal research. The NCK links the strongest expertise of its partners, forming a true centre of excellence in coastal research in The Netherlands.

Objectives

The NCK was established with the objectives:

- To increase the quality and continuity of the coastal research in the Netherlands. The NCK stimulates the cooperation between various research themes and institutes. This cooperation leads to the exchange of expertise, methods and theories between the participating institutes.
- To maintain fundamental coastal research in The Netherlands at a sufficient high level and enhance the exchange of this fundamental knowledge to the applied research community.
- To reinforce coastal research and education capacities at Dutch universities;
- To strengthen the position of Dutch coastal research in a United Europe and beyond.

For more than 20 years, the NCK collaboration continues to stimulate the interaction between coastal research groups, which in the past had often worked more isolated. It facilitates a strong embedding of coastal research in the academic programmes and courses, attracting young and enthusiastic scientists to the field of coastal dynamics. Several times a year, the NCK organises workshops and/or seminars, aimed at promoting cooperation and mutual exchange of knowledge. NCK is open to researchers from abroad and exchanges of young researchers are encouraged. Among the active participants we often find people from a lot of different institutes and companies.

NCK Partners

TU Delft — Delft University of Technology

Deltares — Enabling Delta Life

NIOZ — Royal Netherlands Institute for Sea Research

UNESCO — United Nations Educational, Scientific and Cultural Organization | IHE DELFT — Institute for Water Education in partnership with UNESCO

Rijkswaterstaat — Ministerie van Infrastructuur en Waterstaat

UNIVERSITY OF TWENTE.

Universiteit Utrecht

TNO innovation for life

WAGENINGEN UNIVERSITY & RESEARCH

Every partner has a representative in the Programme Committee and the Directory Board.

Organization

The NCK Programme Committee establishes the framework for the activities to be organised by NCK. These include for instance the theme for the annual coastal symposium ("The NCK Days") and the topics for the seminars ("Theme days"). The Programme Committee gathers twice a year. Since 1998 a part-time Programme Secretary has been appointed. The Programme Secretary is also the main contact person for the NCK.

As of March 2022, the NCK Programme Committee consists of:

- B.C. van Prooijen PhD. (Delft University of Technology, Chairman)
- J. Vroom MSc. (Programme Secretary NCK, c/o Deltares)
- G. Ramaekers MSc. (Rijkswaterstaat)
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- M. van der Vegt PhD. (Utrecht University – IMAU)
- S. van Heteren PhD. (TNO Geological Survey of the Netherlands)

The NCK Programme Committee and the Programme Secretary are supervised by the NCK Directory Board. As of March 2022, the Directory Board consists of:

- D.J. Walstra PhD. (Deltares, Chairman)
- J. Vroom MSc. (Programme Secretary NCK, c/o Deltares)
- M.E. Busnach-Blankers MSc. (Rijkswaterstaat)
- prof. S.G.J. Aarninkhof PhD. (Delft University of Technology)
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- prof. K.M. Wijnberg PhD. (University of Twente)
- prof. H. Dolman PhD. (Royal Netherlands Institute of Sea Research NIOZ)
- prof. D. Roelvink PhD. (IHE Delft)
- J. Asjes MSc. (Wageningen Marine Research)
- D. Maljers MSc. (TNO Geological Survey of the Netherlands)

Program

Wednesday 29 March 2023		
Excursion to Maasvlakte and Springertduinen		
11:45	Meeting at *Stevinweg 1, Civil Engineering, Delft University of Technology*.	
12:00	Bus departs from Stevinweg 1 car park	
12:45	Excursion Maasvlakte	
14:15	Bus departs for the second excursion stop	
14:45	Excursion Springertduinen	
16:15	Bus return to TUDelft	
17:00	Arrival at *Stevinweg 1, Civil Engineering, Delft University of Technology*	
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Conference locations

Icebreaker

Mooie Boules

Professor Schermerhornstraat 9
2628 PZ Delft
Netherlands

Website: https://mooieboules.nl/delft/

Conference venue

Theater de Veste

Asvest 1
2611P Delft
Netherlands

Website: https://www.theaterdeveste.nl/

Conference diner

Knus

Zavelpad 3
2616 LH Delft
Netherlands

Website: https://www.knus.nl/

Excursion

Windmiles in the surfzone and bulldozing/digging in the dunes. What is going on along the South Holland coast? Join us on the NCK 2023 excursion on Wednesday 29 March 2023 and learn more about these particular cases from the specialists who worked on these field cases. Bas van Leeuwen from Svasek will inform us about interesting facts of the 2e Maasvlakte and Yede Bruinsma from Waterboard Hollandse Delta will show us how to give dunes more space go grow.

Field excursion:

Start/Endpoint:

Civil Engineering
Stevinweg 1, 2628 CN Delft

Duration: 12:00 till 17:00.

12:45-14:15: Excursion 2e Maasvlakte

14:45-16:15: Excursion Springertduinen

Lunch included

Keynote speakers

Fernando J. Méndez Incera

Incorporating Data Science and Climate in Coastal Engineering

This work integrates the "Big data in Oceanography", the "Data Science" and the "Climate Science" to solve coastal engineering problems, such as the probabilistic design of maritime works, the risk of flooding and erosion of the coast, or the impact of climate change on the coast. Specifically, we deal with studies of extreme value analysis of oceanographic variables (how often will be the 1953 storm in Netherlands?), study of wave climate on the coast (what is the probability of a 10 m wave height arriving to Sardinero beach?), global-scale wave climate variability (how does the El Niño phenomenon affect the "surf" resource in California?), multivariate analysis of wave data (how can I synthesize millions of wave data measured by satellite to predict storm surge from tropical cyclones?), coastal flooding (what will be the flooding risk in Kwajalein atoll in the Marshall Islands in the year 2100?), or coastal erosion (How was the historical wave time series that affected the beaches of North Carolina, in the United States in the last 140 years?).

Fernando Méndez is Full Professor of Coastal Engineering at University of Cantabria. He is Head of the research group "Geomatics and Ocean Engineering Group". His research lines are focused on building knowledge to incorporate CLIMATE and DATA SCIENCE in COASTAL ENGINEERING (databases of marine variables, statistical models of extremes, data mining, statistical downscaling, climate variability, climate change, dynamical downscaling, flooding and coastal erosion).

Wouter van der Heij

What happens when a fish ecologist and a civil engineer start talking about a hole in the Afsluitdijk?

The 30 km long Afsluitdijk, constructed between 1927 and 1932, can be seen from space. A more than formidable achievement underlining the Dutch as master dike builders worldwide. On the other hand the Afsluitdijk is nationally seen as the biggest ecological disaster. Destroying a complete ecosystem and still causing unprecedented effects on marine life.

Making restoring the ecological connection and softening the hard barrier between saline and fresh water one of the major goals when plans were made for a new, stronger Afsluitdijk between 2006 - 2011. Budget cuts however put all this ambition aside and a bare reinforcement of the dike was chosen. Nature organizations, anglers and commercial fishermen grabbed the invitation of incorporating add-ons and presented the idea of a Fishmigration river. More than ten years later the Afsluitdijk is being reinforced but at the same time a hole is made in that same dike to let fish like salmon, eel and sturgeon pass.

Wouter van der Heij is a marine ecologist working at the NGO Waddenvereniging. He is determined to restore the Swimway function of the UNESCO World Heritage Site Wadden Sea for fish. Convinced that the connecting ecology and engineering is key in a time of sea level rise and biodiversity loss, he was one of the initiators of the Fishmigration River. An innovative, 4 kilometer long, winding fish-passage through the iconic Afsluitdijk reconnecting the Wadden Sea and lake IJssel for migratory fish.

Abstracts of Oral presentations

Integrated coastal management strategy for the Saint-Louis region, Senegal

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Introduction

The Senegal river delta is vulnerable to inundation during the rainy season. To avoid widespread inundation in 2003 of the region's capital city Saint-Louis (UNESCO-heritage site), the authorities decided to expel the surplus of river water by creating an artificial breach 7 km south of the city, through the Langue de Barbarie sand spit (Figure 1). This avoided large-scale inundations of the city, but the artificial breach grew uncontrollably during the subsequent years and became the new river mouth. This altered the dynamics of the lower river delta and continuous to affect local villages, fishery activities, agriculture, and nature reserves. With the natural southward migration of the river mouth at a pace of ~500 m/yr, the population subject to flood risk by 2050 is estimated at 178,300 inhabitants for a 100-year flood. The Government of Senegal has asked the consortium Egis Eau - Deltares to propose a sustainable and long-term management strategy for the lower Senegal river delta. Here, the project approach and results are presented.

Methods

During the project, in-depth technical analyses were integrated with social, economic, financial and environmental analyses. To understand the natural system in detail, at the start of the project extensive measurement campaigns were realized. High-resolution bathymetry and topography were acquired, together with information on physical processes such as water level variations, currents, waves and salinity levels in the river. Various numerical (morpho)dynamic models of river- and coastal dynamics were developed and calibrated with the newly acquired field data, to evaluate various scenario's and help in the preparation of an intervention plan.

Results

It is recommended to maintain the natural functioning of the lower delta, while attenuating the negative impact of the southward migrating river mouth. To avoid inundation of Saint-Louis after horizon 2050, whenever a peak (> 1/10-year return period) river discharge is measured upstream at the hydrological station of Bakel, an artificial breach should be created through the sand-spit a few kilometers south of the town of Degouniaye (23 km south of Saint-Louis). This ensures protection against flooding of Saint-Louis up to a 100-year flood level by the year 2100, without large-scale negative impacts. In addition, a package of urgent "no-regret" protection measures is recommended.

Figure 1: The Langue de Barbarie sandspit in Senegal just before, and the years following, the creation of the artificial breach (Source: Google Earth).

How to explore the solution space of sandy strategies under accelerated sea-level rise

R. de Winter[1]*, M. Haasnoot[1,2], W. van de Lageweg[3], V. Bax[3], T. van der Heide[4,5], E. Lansu[4], S. Hover[4,5], A. Luijendijk[1,6], T. Kettler[6], A. van Oudenhoven[7], H. Geukes[7], M. de Schipper[6]
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Introduction

The sandy coastal zone of the Netherlands hosts a wide range of functions; it provides safety against flooding, is important for recreation and has high nature values. The sandy coast is regularly nourished to compensate for erosional losses and to allow for growing with a rising sea level. It is expected that nourishment volumes will increase in the future under accelerated sea-level rise (SLR). In this study, we explore how the solution space for nourishment strategies could be explored when multiple functions of the coastal zone are considered.

Methods

Since there is not yet a model that considers all relevant processes and indicators needed for a multi-objective assessment of nourishments, we combine the Dynamic Adaptive Policy Pathways (DAPP; Haasnoot et al. 2019) with the XLRM framework (Lempert et al. 2019). This combination enables us to evaluate how nourishment strategies affect a range of objectives under changing conditions. The resulting model is the first to consider all processes and indicators relevant for our multi-objective assessment of pathways. With the combined framework we can explicitly link the objectives to the different functions and the system characteristics these functions need. The result can then be evaluated for different futures and adaptation pathways using a set of outcome indicators (Figure 1). To test this novel approach, we applied it to a limited set of objectives (coastal safety, functional coastal ecosystem and recreation) and assessed the possibilities of the method with established outcome indicators that support the objectives. Total nourishment volumes are directly related to future SLR-rates; however, they can vary in frequency and type of nourishment, resulting in different adaptation strategies.

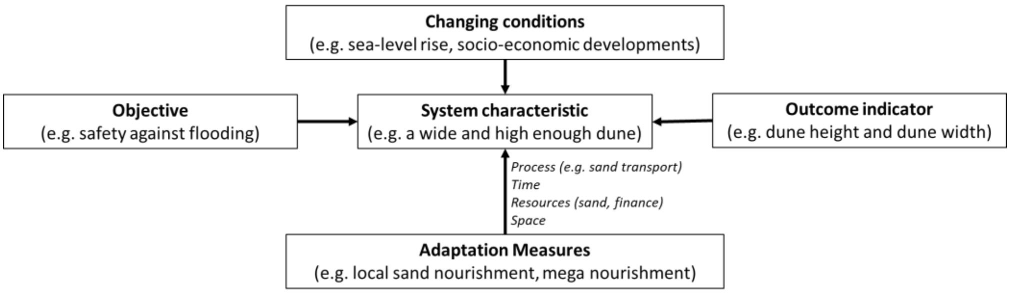

Figure 1: Relation between policy objective, the system characteristic that supports this objective and the outcome indicator that describes the state of the system. Changing conditions and adaptation measures impact the system characteristic.

Results and Conclusion

We found that the solution space of sandy strategies under lower SLR-rates is relatively, with a large range of possible sandy strategies. However, as SLR-rates and nourishment volumes increase, the solution space becomes smaller as strategies with small scale and/or infrequent nourishments become less feasible. The strategies therefore converge in nourishment volume and frequency. For the chosen objectives a literature assessment shows that indicators are known that determine under which set of conditions it would be preferable (for that specific objective) to switch strategies. We argue that this integrated approach allows us to evaluate how an attractive multifunctional coast can be maintained when moving towards higher nourishment volumes under accelerating SLR-rates.

References

Lempert, R.J. (2019). Robust Decision Making (RDM). In: Marchau, V., Walker, W., Bloemen, P., Popper, S. (eds) Decision Making under Deep Uncertainty. Springer, Cham.
Haasnoot et al. 2019. Dynamic Adaptive Policy Pathways. In: Marchau, V., Walker, W., Bloemen, P., Popper, S. (eds) Decision Making under Deep Uncertainty. Springer, Cham.

A numerical flume for the pressures on clay erosion profiles for the Wide Green Dike

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Introduction

With the increasing threads against the coastal zones and the nature (stronger wave conditions and sea level rise), the world demands solutions that comply with safety and climate adaption as well as nature preservation. One pilot project developed in the Netherlands that satisfies both needs is the Wide Green Dike project. The Wide Green Dike consists of a gradually sloping dike that smoothly transitions into the salt marshes and is located along the Ems-Dollard estuary. The dike is constructed with clay made from locally dredged sediment that is ripened to clay near the dike. Due to the innovative layout and materials used in the construction of the dike, physical tests were carried out in the Delta Flume on a real scale to assess the safety of the dike against high wave loads (up to 2 m) and to study the erosion rate of the clay. To extend the study and gain a better understanding on the process of clay erosion, an analysis of the pressures along the profiles of erosion of clay is desired.

Methods

The numerical flume consists of a CFD model OpenFOAM coupled with a potential flow solver OceanWave3D. The offshore wave conditions from the wave paddle are the input values in OceanWave3D, which then passes the water elevations □(x,t) to the OpenFOAM model, which simulates the wave-structure interaction. In this way, the physical tests are replicated in the numerical flume. The dike geometry is based on the subsequent clay erosion profiles measured during the physical modelling campaign. The numerical model is used to determine the pressures during the physical model experiments, since the pressure due to wave impacts is the main driver of erosion. Next, a relationship between the modelled pressure and the observed erosion is developed for the wave conditions during the physical experiment. Finally, the dataset is extended using the numerical model to simulate the pressures for different wave conditions, such as variation in wave steepness, with which the erosion could be calculated with the erosion-pressure relation.

Results

A relation between the observed erosion, the modelled pressures and the wave conditions is determined that can be used in the safety assessment of these innovative flood defences. Moreover, the numerical flume provides insights into the important hydrodynamic processes that occur during extreme events and will be developed further to help improve our understanding of the erosion process on flood defences.

Figure 1: Wide Green Dike under wave attack. Left: Physical flume. Right: Numerical flume.

Acknowledgement

This study has been performed in cooperation with the Waterboard Hunze en Aa's and Sweco. Especially the contributions of Henk van Norel, Marco Veendorp and Jos van Zuylen are acknowledged.

Simulating impacts of nourishment scenarios on decadal cross-shore dynamics

Tosca Kettler[1]*, Matthieu de Schipper[1], Arjen Luijendijk[1,2], Stefan Aarninkhof[1]
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Introduction

Projections of high rates of sea level rise have stimulated proposals for adaptation strategies with increasingly high nourishment volumes. A widely accepted perception is that coastal profiles respondto nourishment by rapid equilibration to a (new) equilibrium shape including the added sand volume.The validity of this viewpoint depends on the rate and extent of sediment redistribution over the nourished site. The profile shape may undergo significant deformation when high volumes ofnourishment are applied. Analysis of the impact of nourishment scenarios on decadal cross-shore dynamics requires a level of detail that can typically not be obtained from (semi-)empirical models, while process-based models are too complex for robust decadal analysis. Therefore, we introduce the numerical, diffusion-type model *CROCODILE* (CROss-shore COastal DIffusion-type Long-term Evolution model), which combines inductive assumptions on dynamic profile response and current state-of-the-art knowledge of nourishment behavior in a predictive tool.

Methods

In this work, *CROCODILE* is introduced and applied to case study locations that vary in morphological setting and nourishment history. The model computes an 'instantaneous' profile response with a time-dependent profile evolution approaching a 'dynamic' equilibrium profile. Changes in the coastal system (e.g. SLR, erosion, or implementation of nourishment(s)) lead to horizontal and vertical translation ofthe dynamic equilibrium profile as given by a sediment volume balance. The nourishment shape is added to the 'instantaneous' profile, and the time-dependent evolution is calculated following a diffusion-type approach inspired by Stive et al. (1991). Hereby, the rate and extent of sediment dispersion are calculated as the sum of four components that depend on the scale of the nourishment relative to the static profile; cross-shore diffusion (fig 1B), background erosion (fig 1C), nourishmentlateral loss (fig 1E), and aeolian loss (fig 1F). The simulated cross-shore profile shape is then translatedto different coastal state indicators (e.g. profile volume (fig 1A,D), coastline position, and beach width).

Results

Hindcast results show that *CROCODILE* is able to reproduce the time-varying response of different coastal state indicators to the implementation of nourishments. This approach can provide a more comprehensive understanding of the impacts of shore nourishment scenarios in different coastal settings, with special attention to sea level rise.

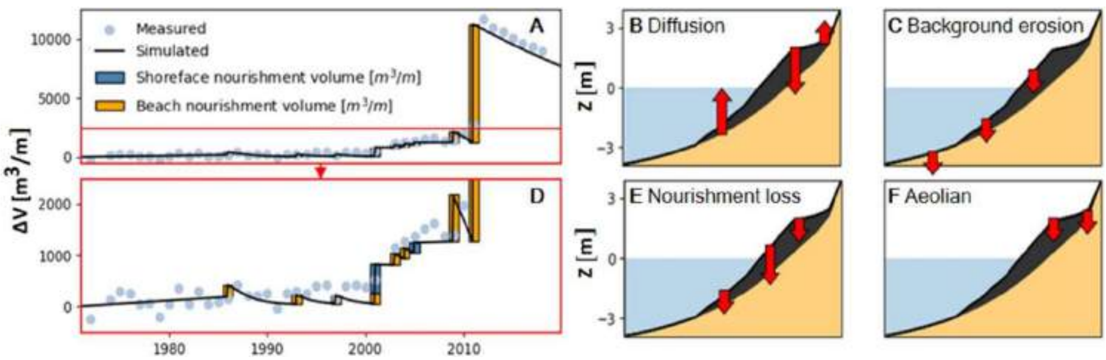

Figure 1 – (A,D) CROCODILE hindcast and observations of profile volume ΔV at Monster. Panel D isan enlargement of panel A. (B,C,E,F) The instantaneous profile of the first nourishment (black), the direction and magnitude of the red arrows indicate its time-dependent evolution.

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Research for Coastal Policy and Practice – a case study on the policy process and the role of conceptual models

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Introduction

Many of us work on our coast on a daily basis. We draft research proposals, do research, write papers and reports, and teach new generations of coastal scientists, practitioners and policy makers. Often our aim is to advance on all aspects: deliver great science, robust policy, and innovative practice. However achieving this is difficult, especially achieving impact on policy and practice from science. Achieving impact on policy and practice requires bringing together science and policy in a meaningful and effective way. Connecting science to policy is seen, not without reason, as one of the top challenges for sustainability in the 21th century (UNEP, 2012). In the Dutch situation, however, there is a long history within Coastal Flood and Erosion Risk Management of an established link between science and policy. This makes the Dutch policy-driven research approach an intriguing object of study.

Method: Case Study Coastal Genesis 2

At present the Dutch coast is maintained using a dynamic conservation strategy (also referred to as dynamic preservation), developed using the results from the Coastal Genesis (Kustgenese) research programme from the nineteen eighties and –nineties. With accelerating sea level rise this management strategy could require a significant increase in nourishment volumes in the future, raising questions regarding the sustainability of the strategy. Accordingly, Rijkswaterstaat initiated the Coastal Genesis 2 (Kustgenese 2) research programme in 2015 aimed at developing a robust and sustainable long-term coastal management strategy. We analyse the policy-driven Coastal Genesis 2 research programme, identifying the process that was followed in its initiation, in determining the research agenda and in synthesizing and communicating the results. We assess the role that conceptual models play in achieving impact on policy and practice (Figure 1).

Results

Our analysis highlights that synthesising new scientific insights into shared conceptual models is critical to achieving impact in policy and practice. In the context of Coastal Genesis 2, a new shared conceptual model of the long-term sediment demand of the Dutch coast enabled the development of potential nourishment strategies. In 2021, the Minister of Infrastructure and Water Management officially articulated her intention to adopt the advised nourishment strategy from 2024 onwards in a letter to parliament.

Figure 1: The 'Research for Policy' cycle to support coastal policy development in the Netherlands (Lodder and Slinger 2022) CC 4.0

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Visualising past landscapes to combat shifting baselines

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Introduction

Sea level rise is threatening coastal populations the world over, requiring adaptive measures such as coastal defences to be installed. An increasing number of these measures involve nature-based adaptations, relying on the evolutionary adaptations of coastal ecosystems such as salt marshes to protect human populations and infrastructure. In the Netherlands, this often requires the de-embankment of polders, a proposal which is regularly met with fierce resistance from many local residents. An important factor in this resistance is what is known as “shifting baseline syndrome” – the human tendency to assume that the way things are when you are young is the way things should be, and any change can only be for the worse. In the Dutch case, the present-day landscape is dominated by polders and dikes. But many modern settlements that are now surrounded by dikes began in the Middle Ages as simple, dike-free farms or villages on open salt marshes.

We utilize 3D panoramas of the landscape around the village of Wemeldinge, in Zeeland, as it would have been in the mid 12th century, following a scientific reconstruction. We present these to the public in a number of formats, in an attempt to open minds and hearts to the idea that an exposed salt marsh can be just as safe, or even safer than a massive dike.

Methods

We made use of previous geological and historical studies of Wemeldinge’s past in combination with our own numerical model of salt marsh self-organization to reconstruct the landscape around the village prior to the systematic embankment of the region in the late 12th century. Using the 3D modelling software Blender, we apply 3D models of plants, animals, people, and buildings, to create photorealistic panoramic views of this landscape.

Results

We present our 3D images in a mobile app, allowing locals and visitors to Wemeldinge to view the past while standing on the same spot in the present-day landscape. These will also be available in local visitors’ centres as a virtual reality experience, giving users the feeling that they are standing in the actual medieval landscape.

Figure 1: Life on the marshes of 12th century Zeeland.

Coastal engineering benefits of sand nourishments at the shores of Walcheren (Southwest delta, the Netherlands)

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Introduction

For decades, sand nourishments have been executed along the coastline of peninsula Walcheren (SW Netherlands) with the goal of improving coastal safety, widening beaches for recreation and reducing the impact of coastal erosion. While the coastal engineering benefits of sand nourishments have become clear, it remains challenging to understand the economic rationale of these nourishments compared to the alternative coastal defence strategy of dike construction and reinforcement. There is demand for direct comparisons between 'soft' *building with nature* methods like sand nourishments and traditional 'hard' coastal engineering methods such as dike construction. This demand is only heightened by the expectation of rising costs due to sea level rise.

Methods

Beach and dune development at Walcheren since 1965 were derived from the JARKUS database.. First, the historical trends in volume and position of individual coastal transects were determined over the pre-sand nourishment period 1965-1978. Second, the estimated erosion or accretion trends were applied to the momentary coastline (MCL) to model a 'what-if' scenario in which the sand nourishments had not occurred over the period 1979-2019. Third, dune safety in the what-if scenario was assessed through the identification of weak points, using Dutch flood risk standards in MorphAn. Finally, a comparison was made between on the one hand the costs of 'hard' coastal defences at these weak points (estimated from dike/dune reinforcement costs at Dishoek in 2008) and on the other hand the costs of the conducted sand nourishments (estimated from local sand nourishment costs in the period 2000-2020).

Results

Over the period 1979-2019 some 70 separate nourishments have been executed on the shores of Walcheren at an estimated total cost of €180 million. The sand nourishments resulted in coastal advance along 70% of the 33 km long coastline with an average gain of 48-66 m. This indicates that not only are sand nourishments preventing erosion but are meaningfully expanding the dunes and beaches.

The model simulations indicate that in the absence of sand nourishments over 40 years, volume trends result in a decrease in dune safety. In consequence, a growing length of the coastline would require dike reinforcement. Given a unit price of approx. € 13 million per km, the reinforcement costs are estimated at € 132-155 million. The additional cost of coastal maintenance without sand nourishments of € 0.78 million/y was added to the reinforcement costs over the model period, leading to a cost of €163-186 million. These total costs resulting from the retrospective analysis of a scenario without sand nourishments compares well to the expenditure on the executed sand nourishments for Walcheren over the period 1979-2019.

In conclusion, the overall societal business case of the sand nourishments looks to be very positive as they advanced most of the coastline substantially, reduced reactive maintenance, and increased beach area for recreation at a similar expenditure as 'hard' coastal defences.

Salt intrusion in the Rhine-Meuse Delta under different river discharge scenarios

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Introduction

The Rhine-Meuse estuary is a heavily engineered estuarine delta in the Western Netherlands.
Recent summer droughts have shown that salt intrusion in this system is a topic of concerns and deserves further study. As part of the SALTISolutions project, our aim is to better understand and quantify the dependence of salt intrusion to various physical forcings such as river discharge for this system.

Methods

An idealized model of the Rhine-Meuse Delta will be presented. This model solves the simplified momentum balances, coupled with the salt balance, for currents and salinities in estuarine deltas. The new elements with respect to the one developed in Biemond et al. (2022) are the explicit solutions for tidal flow and tidally varying salinity and the geometry of a complicated channel network.
Salinity observations from Rijkswaterstaat are used to calibrate the model. Afterwards, the salt intrusion is calculated for different river discharge scenarios.

Results

After calibration, the salinity values from the model agree fairly well with the observed salinity values (Fig. 1). The river discharge scenarios indicate that different channels have a different sensitivity to changes in river flow. To gain a better understanding of the spatial heterogenous response, the salt transport in the model is decomposed into different contributions, and for each channel separately the dominant salt transport process is established. In strongly stratified channels, the density-driven current is the dominant salt import process, but in weaker stratified channels tidal pumping and horizontal diffusion is more important.

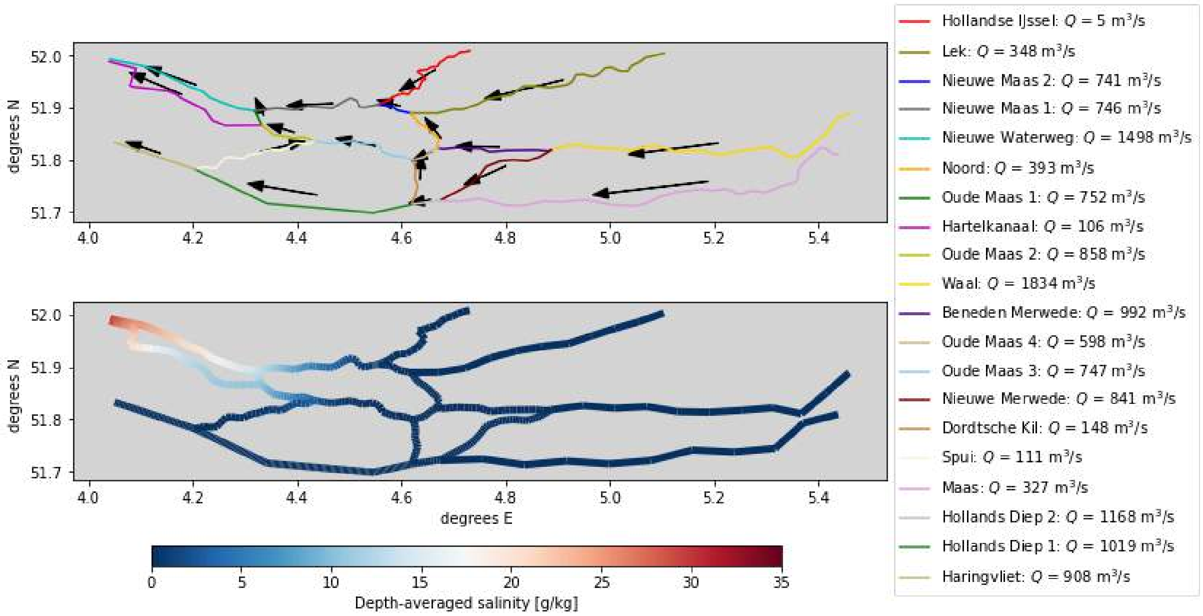

Figure 1: An example of the model results for salt intrusion in the Rhine-Meuse Delta. (a) Discharge in the different branches. (b) Depth and tidally averaged salinity in the different branches.

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Improving morphodynamic modelling using sand-mud interaction and morphologic metrics

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Human interventions and climate change are progressively influencing the state of coastal systems. Especially climate change impacts coastal evolution over long time scales, and such long-term changes are typically studied and forecasted using highly schematised low-complexity models. Initially, these studies focused on the dynamics of sandy coasts only. Later, follow-up studies were extended with mud-sized sediment to improve the prediction of large-scale delta evolution. Herein, sand and mud were largely treated as independent fractions, despite overwhelming evidence that the sediment dynamics of sand and mud is mutually coupled.

In this research we aim at a better understanding of the effects of including abiotic small-scale sand-mud interaction on modelled large-scale morphodynamics of tidal basins. We study long-term tidal basin evolution with a schematised model inspired by the basins in the Dutch Wadden Sea, in which two sand-mud interaction mechanisms (*erosion*- and *roughness interaction*, Colina Alonso et al., submitted) have been implemented. Our results show that sand-mud interaction substantially impacts tidal basin evolution. Channel patterns, intertidal flat shape and size, and sediment composition widely vary with mud erodibility settings, but equally with the considered interaction mechanisms (see Figure 1). Including sand-mud interaction in morphodynamic models provides a better representation of the physical processes and it may consequentially be used to optimise the morphodynamic model evolution.

An important limitation of schematised model configurations (such as the one that we use) is the difficulty to relate simplified model layouts to the real world. This introduces the key challenge on how to capture the fundamental aspects of real-world systems in low complexity models, and how to quantitatively validate the schematised model performance. We therefore introduce metrics describing the morphology in data and model results, such that they can be compared (see e.g., Figure 1 b-d). We strongly advocate the use of such morphological validation metrics as part of future work.

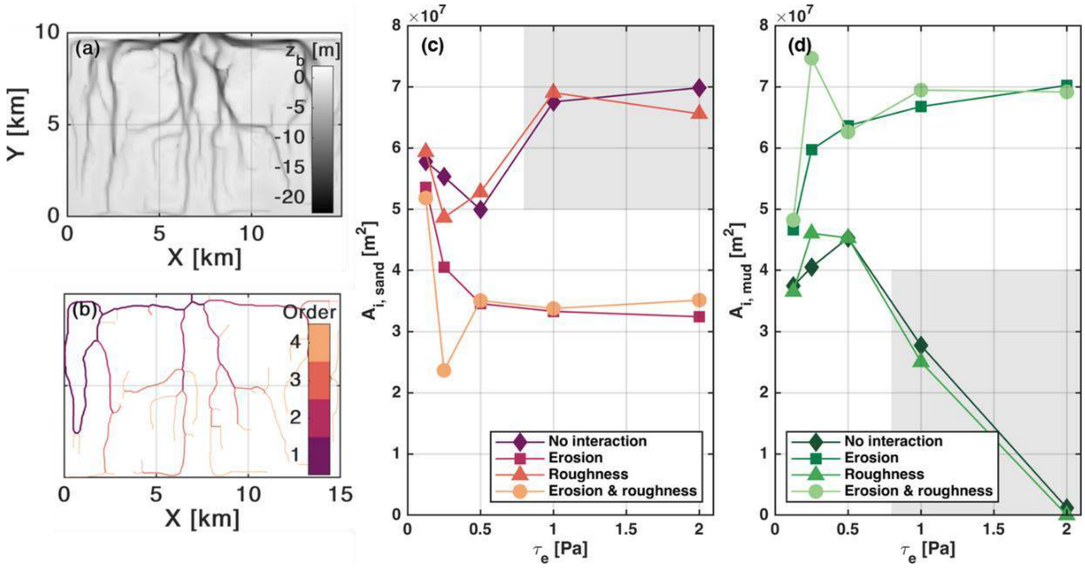

Figure 1: (a) Modelled basin evolution for 1 sand-mud interaction scenario. (b) Extracted reversed Strahler Order of the channel patterns for further analysis. (c-d) Development of the sandy and muddy intertidal areas, depending on the sand-mud interaction settings.

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Unravelling the morphodynamic and ecological functioning of tidal flats

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Introduction

Tidal flats are valuable ecosystems that support biodiversity and contribute to coastal defence. Unfortunately, these dynamic ecosystems are globally declining and may lose their ecological value if their morphodynamics change. Preserving and restoring these habitats requires an understanding of how physical processes drive *i)* the short- and long-term tidal-flat morphodynamics, *ii)* the ecological value of tidal flats and *iii)* thereby the tidal-flat response to environmental changes.

Physical drivers of morphodynamics

Newly developed statistical descriptors of *Surface Elevation Dynamics* (SED) and *MorphoDynamic Signatures* (MDS) based on the measured daily sediment dynamics explain the sensitivity of individual tidal flat morphodynamics to specific wind conditions and specific tides. Such descriptors provide managers insight into the sensitivity of specific tidal flats to changes in wind climates (e.g., more storms vs. increase in average winds) and anthropogenic measures (e.g., increasing vs. reducing tidal currents). We subsequently studied how the spatiotemporal variability in SED and MDS may offer a more mechanistic categorisation of tidal flats as low vs. high dynamic habitats (rather than using the current velocity of 60 cm/s ad divide).

Physical drivers of the ecological significance of tidal flats

We obtained in-depth insight into how physical factors drive the ecological value of tidal flats by combining observational field data (e.g. SED-sensors) with mechanistic experimental studies (e.g. flumes). The presence of specific macrobenthic communities was found to be closely related to daily sediment dynamics, with mobile species increasing in dominance in more dynamic areas. Compared to mobile species, immobile benthic communities are more affected by frequent wave-induced disturbances of the bed-level, although non-indigenous species struggle more than native species.

Outlook

Tidal flats are increasingly facing challenges from human interventions and sea level rise. Adopting alternative technologies, such as the SED and MDS indicators, can lead to a more comprehensive understanding of tidal flats morphodynamics, ecological value and their response to environmental changes, ultimately resulting in improved coastal management strategies.

Figure 1: Monitoring short-term sediment dynamics with an acoustic SED-sensor during storm conditions in the Westerschelde (image courtesy: T. Grandjean).

Dutch Wadden Sea as an Event-driven System: A Numerical Perspective

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Introduction

The Dutch Wadden Sea (DWS) is an ecologically important multi-inlet water body between the North Sea and the Dutch mainland. The dynamics of this region is mainly modulated by the tidal action, variability of wind regime and the freshwater discharge. The present study aims to comprehend the hydrodynamics of the DWS on a multi-decadal timescale (35 years), both from a Lagrangian and Eulerian perspective. The fundamental objective of the current work is to quantify the transport time scales (e.g., age, flushing time, and residence duration) and their spatial and temporal variability, which likely govern key biological processes occurring in this area. Previous studies have quantified the tidal-residual characteristics of the DWS within the intertidal basins (Donatelli et al., 2022; Duran-Matute et al., 2014), that could impact the flushing of nutrient and pollutant to the adjacent sea. The present study attempts to estimate the local transport time scales (age and residence time) and the basin-wide integrated transport time scale (flushing time), in order to understand the decadal variability with variable wind and extreme events which could eventually impact the water quality and habitat niche.

Methods

Numerical simulations were carried out using the General Estuarine Transport Model (GETM) for a period of 35 years in the Dutch Wadden Sea. Eulerian approach was adopted to quantify the flushing time of the system. Eulerian passive tracers were also used to track the freshwater dispersal and to determine the residual circulatiion.

Results

The simulation results show that winds are the most important factor in net water transport processes and their variability. Tidal activity controls the system's salinity variations over the short term, whereas long-term anomalies are linked to wind variability and extremes therein. The system's flushing characteristics exhibit spatiotemporal variability, with the least flushing occurring close to the tidal mudflats during low wind conditions.

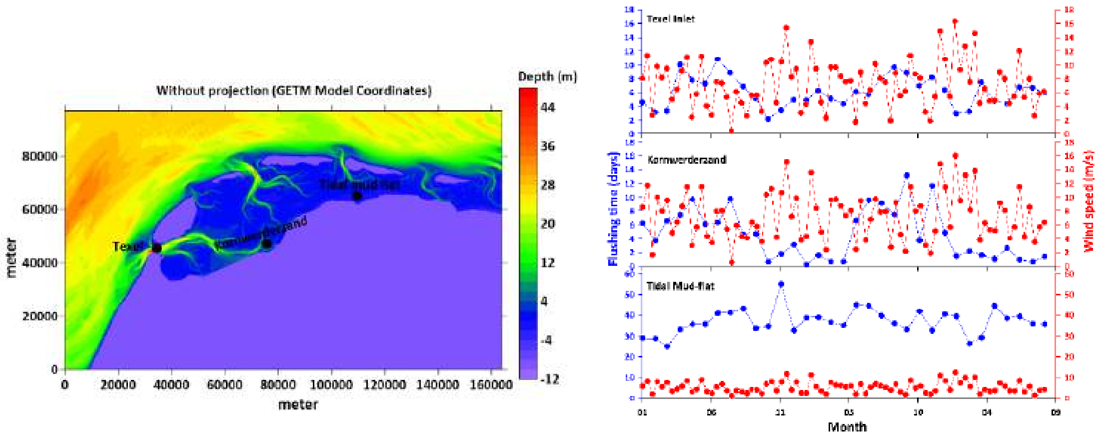

Figure 1: Bathymetry and local flushing time at three different regions of the Dutch Wadden Sea

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New concept of inlet connectivity helps understand role of tidal divides in double inlet systems

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Introduction

The extent to which the inlets in a mesotidal barrier coast, e.g. the Wadden Sea, morphodynamically influence one another is of both theoretical and practical interest. For example, dredging operations in one inlet may lead to sedimentation at another inlet. Based on Escoffier's (1940) principle, past studies have focused on the cross-sectional stability of an inlet system, i.e. whether the system returns to equilibrium after perturbing one or more inlets (e.g., Roos et al. 2013). However, *inlet stability* does not address the extent to which inlets influence each other morphodynamically, a new concept which we shall refer to as *inlet connectivity*. Inlet connectivity is likely to depend on various characteristics such as basin geometry, inlet spacing and tidal divides. The goal of this study is twofold: (i) to introduce and quantify this new concept of inlet connectivity, and (ii) to implement and analyse it in an exploratory double inlet model, that includes a tidal divide (Fig.1a).

Methods

Starting from a stable equilibrium in a multiple inlet system, consider the system's return to equilibrium after perturbing one of the inlets, while leaving the other(s) unaffected. The *connectivity quotient* C_{jq} measures the maximum cross-sectional change experienced by the (initially unperturbed) inlet j, divided by the initial perturbation of inlet q's cross-section (Fig.1b). Large values of $|C_{jq}|$ suggest strong connectivity, whereas $C_{jq}\approx 0$ implies weak connectivity. We then implement this in a new double inlet model, based on Roos et al. (2013), that includes tidal divides using a stepped topography (Fig.1a).

Results

Model results demonstrate how increasing the tidal divide's height or width either may turn an unstable inlet system into a stable one, or reduces connectivity if it is already stable (Fig.1c). All our simulations reveal negative values of the connectivity quotient: the system's return to equilibrium after an increase (decrease) in the cross-section of inlet 1 is attended with a decrease (increase) in inlet 2, and vice versa. Further model results will be presented and the implications for the Western Wadden Sea (Texel inlet, Vlie inlet and Eijerlandse Gat system) will be discussed.

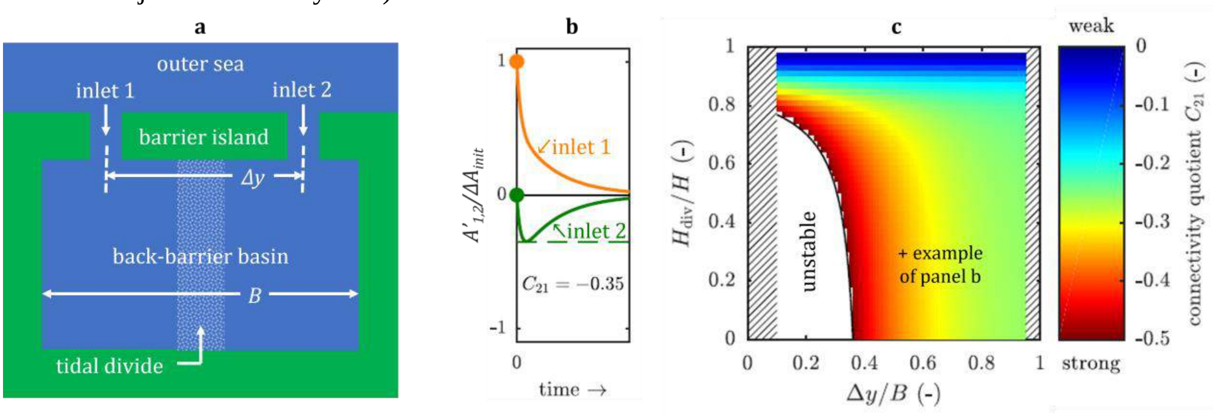

Figure 1: (a) Top view of model geometry showing double inlet system with tidal divide. (b) Example of system's return to equilibrium after perturbing inlet 1, corresponding to a connectivity quotient of C_{21}=-0.35. The plot shows the time evolution of the perturbations to inlet 1 (A'_1 in orange) and 2 (A'_2 in green), scaled with inlet 1's initial perturbation ΔA_{init}. (c) Sensitivity of connectivity quotient to inlet spacing Δy and tidal divide height H_{div} (scaled with basin width B and depth H, resp.). The example shown in panel b is denoted with +. Red (blue) shades indicate strong (weak) connectivity.

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Long-term forecasting of dredging volumes in the Borndiep tidal basin

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Introduction

The primary connection between the Wadden island Ameland and the mainland is the ferry which sails between Nes and Holwerd. It follows several tidal channels within the Borndiep (Figure 1), a tidal basin within the Wadden Sea. The annual dredging volumes to maintain the fairway minimum dimensions f have increased more than tenfold since 1990, to approximately 1.9 M m^3 in 2021. The increased sedimentation causes bottlenecks for the ferry service. Also, the almost continuous dredging is an environmental burden as it disturbs the seabed and locally enhances the turbidity. Currently, a study is being conducted assessing if there are sustainable alternatives for the current ferry route and deployment. To select the optimal alternative, a reliable estimate of the long-term dredging volumes is essential to compare operational effects of the current practices to the potential benefit of alternative infrastructure in the Wadden Sea.

Methods

Most of the sediment is dredged from the southern part of the fairway. To obtain an estimate of future maintenance volumes in the fairway, a relationship is derived between the tidal volume of the sub-basin fed by the channel and historical dredging volumes. Forecasts of this tidal volume are based upon different scenarios for the evolution of the tidal divide, for the observed growth rates of salt marshes, for different sea level rise scenarios, accounting for the response of the basin's hypsometry as a function of sea level rise. The latter is based on both observed sedimentation rates and sensitivity tests using an ASMITA model, which was calibrated for the Borndiep basin (Huismans, Y., et al. (2022)).

Results

It was found that the major contribution (approx. 60%) of the increase in dredging volumes in the southern part of the shipping route is to be attributed to the migration of the tidal divide in the east of the basin. The contribution by a continuous expansion of salt marshes and growth of tidal flats are estimated at 20% each. Further growth of dredging volumes to maintain the current fairway is likely to be limited by a limitation in the migration of the tidal divide. Yet, total dredging volumes may increase with up to 40% in coming decades. Depending on the efficiency of human's joint climate actions, acceleration of sea level rise may cause dredging volumes to decrease in the second half of this century.

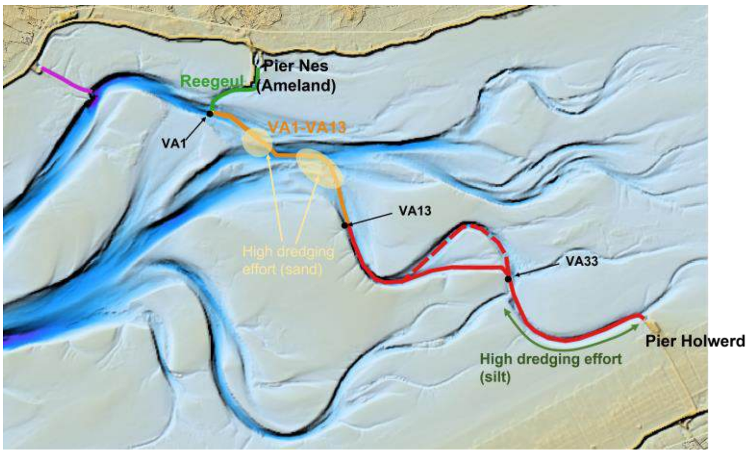

Figure 1: Coloured line shows the ferry route between Nes and Holwerd. The red (silt), yellow (sand) and green (sand and silt) lines indicate the type of sediment that is primarily dredged from that area.

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What are the causes for the unexpected high dredging volumes in the navigation channel Boontjes in the Wadden Sea?

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Introduction

In 2012, the sill in the navigation channel Boontjes in the Dutch Wadden Sea was lowered to allow for bigger ships between the sluice of Kornwerderzand and the port of Harlingen (Figure 1). Nowadays, the dredging volumes are much larger than anticipated in 2012. Deltares and Rijkswaterstaat have investigated the driving factors for the high dredging volumes and estimated the (trend in) dredging volumes for the future (i.e. until 2050).

Methods

First, we analysed the large-scale morphological trends in the wider area of the Boontjes channel using bathymetric surveys. We studied dredging data and depth soundings in order to get a better impression of the sediment composition of the dredged material, the exact location of dredging and disposal and the magnitude of dredging volumes over the year. We used a numerical model (i.e. online coupling from D-Flow FM to D-Water Quality) to study tidal discharges, flow velocities, sediment fluxes and dredging volumes for historic and future scenarios. The future dredging volumes were estimated using empirical relations between tidal volumes, channel cross-section and dredging volumes (Witteveen+Bos, 2022).

Results

The western Dutch Wadden Sea experiences large sedimentation along the coast of Friesland as a response to the closure of the Zuiderzee. This sedimentation is expected to continue in the future (e.g. Grasmeijer et al. 2022). As more and more flat area will evolve from subtidal to intertidal area, the discharge through the Boontjes channel will be further reduced causing the dredging volume to increase. Model simulations show that deepening the Boontjes channel attracts flow to the channel, causing the flow velocities to increase. Nevertheless, the dredging volumes have increased after sill removal. This was likely caused by wave-driven resuspension, with higher resuspension on the flats and lower resuspension from the channel. Also, the effect of gravitational circulation intensifies at larger channel depths, transporting sediment from the disposal locations towards the freshwater source in the South.
The dredging volumes computed with the fine sediment transport model are very similar for several channel dimensions. This result is not trusted and is probably due to shortcomings in the wave model (fetch approach) and too little sediment exchange between the water column and the bed. Measurements from the field (e.g. SSC over the vertical) are needed to improve the sediment transport model.

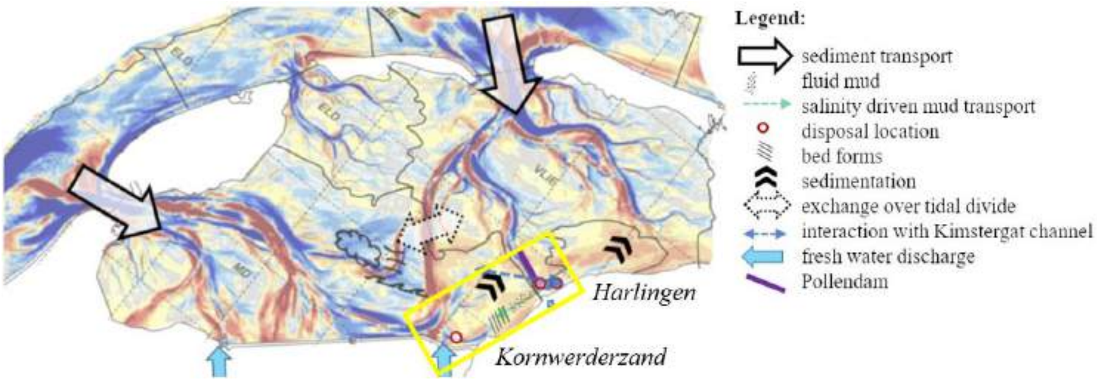

Figure 1: Sedimentation (red) and erosion (blue) map of the study area (yellow box).

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Tidal plume fronts and recirculation in the near field Rhine River Plume during typical and extremely low river discharge conditions

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Introduction

The Rhine River Plume forms one of the largest Regions of Freshwater Influence (ROFI) in Europe. In 2013 and 2014 the STRAINS (STRAtification Impacts Near-shore Sediment) field campaigns were carried out off the Dutch coast during typical river discharge conditions. Tidal plume fronts were foundon every ebb tide as freshwater discharges into a strong tidal cross flow at the mouth of the Rotterdam Waterway, Rijnsburger et al. (2021). However, little is known about the impact of low river discharge conditions on the evolution of tidal plume fronts in Rhine River Plume and their downstream evolution.Here we use both data and numerical models to investigate low river discharge conditions and comparethem to normal conditions.

Methods

During the summer drought of 2022 an extensive field campaign was carried out offshore of the mouthof the Rotterdam Waterway and within the estuary. The field campaign was part of the SALTISolutions research program, and was carried out together with Rijkswaterstaat. Here we focus on the data collected around the river mouth. We use the Dutch Continental Shelf model to simulate the flow and stratificationin the downstream river plume, coupled with the RMM3D model to simulate the flow in the delta duringthe drought. We compare data collected during the drought with data collected during typical discharge conditions. We explore the role of tidal plume fronts on the near to mid field river plume on mixing and recirculation in the Rhine River Plume. Then we compare this data, with some of the data collected during the drought of 2022. We explore how extreme, low discharge conditions impact the Rhine RiverPlume.

Results and discussion

Under typical river discharge conditions tidal plume fronts are shown to play an important role in the mixing, downstream transport of freshwater and re-circulation in the mid to near field river plume. In contrast low river discharge conditions reduce the size and strength of the tidal plume fronts and the recirculation in the downstream river plume. We discuss the consequences for along and cross-shelf transport.

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Spatio-temporal Variability of the Lagrangian Transport in the Dutch Wadden Sea

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Introduction

The spatio-temporal variability of transport in coastal ecosystems is of primary importance for many biological processes. This is particularly critical in highly heterogeneous regions, like in systems of intertidal basins, where transport can exhibit a strong anisotropic response to different forcing mechanisms like winds. To understand the local and temporal variability of transport and exchange of water and freshwater content within a system and with its surroundings, Lagrangian transport time scales (LTTS), such as the residence and exposure times, are commonly employed. Additional information about the preferential pathways in multiple-inlet systems can be obtained by determining the capture areas of the inlets. Tracers deployed in a capture area have the largest probability of exiting the system through the associated inlet. Here, we study the spatio-temporal variations of the LTTS and the capture areas of inlets in the Dutch Wadden Sea (DWS) and their relation to the dominant forcing mechanisms.

Methods and Results

We employed a 36-year (1980-2015) simulation based on an offline coupling of the General Estuarine Transport Model (GETM) and the Lagrangian model "Parcels". For the analysis, around 300 million trajectories of particles (~ 13 000 particles every 12.42 h for 36 years) initially released inside the DWS were employed. We found that most of the spatio-temporal variability of the LTTS is explained by winds from the most dominant and energetic sectors (the southwesterly quadrant), which are aligned with the topographical orientation of the system (Figure 1). The LTTS are strongly anti-correlated with these wind directions in most of the domain, except near the inlets (Figure 1). Periods with easterly winds trigger a dipole-like response on the spatial structure of the LTTS with a decrease of their values in the western DWS and an increase in the eastern DWS. This is explained by easterly winds favouring the export from the western DWS towards the North Sea trough the closest inlets. On the eastern side, particles travel towards the western DWS (and hence longer distances before leaving the system), which increases the LTTS. Northerly and northwesterly winds trigger a more complex spatial structure in the system, but in comparison to the other wind directions they only explain little variability. We found a strong influence of the wind seasonality, which is characterized by stronger wind conditions during autumn-winter than spring-summer, on the size of the capture areas of inlets. The monthly variability of these capture areas can be predicted by the wind energy, especially during the stormy season (autumn-winter). During this season, winds from the southwesterly quadrant push particles towards the eastern part of the DWS, thereby reducing the capture areas of the western inlets and triggering an expansion of the areas on the eastern ones. Other wind directions seem to play a negligible role in this variability.

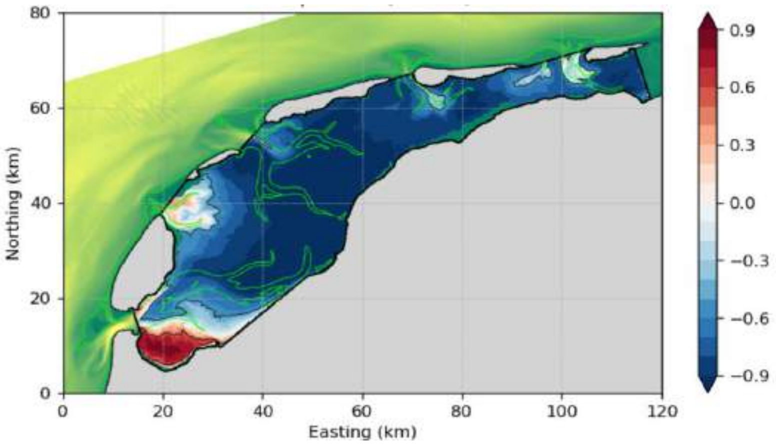

Figure 1: First Empirical Orthogonal Function of the residence time. It is expressed as the correlation between its first Principal Component and the time series of the residence time at each spatial point. This mode explains 64% of the variance, and it is strongly correlated (R=0.9) with the wind energy of the southwesterly quadrant.

Influence of SFCR on Longshore Sediment Transport at the Belgian coast

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Introduction

Along the Belgian coast, multiple shoreface-connected ridges (SFCR) are present. Numerical models are developed to capture the hydrodynamics and morpho-dynamics of the nearshore region (Röbke & van der Werf, 2022). These models suggest that the SFCR interfere with the longshore sediment transport (LST) and predict a strong tidal contribution to LST. This modelling study aims to calculate LST along the Belgian coast using a one-dimensional sediment transport model and to understand these processes by an independent and simplified calculation.

Methods

A 1D LST model is developed in UNIBEST-CL+ using 183 cross-shore depth profiles. This new model provides an independent and faster computation of LST rates. Input for this model is derived from a Delft3D-FM model (Röbke & van der Werf, 2022). A parameter sensitivity analysis on model outcomes and a convergence study on the cross-shore step size are performed.

Results

Large LST rates are mostly associated with large flow velocities in shallow areas. LST gradients indicate a net sedimentation west of Zeebrugge and more erosion east of Zeebrugge, see Figure 1. Four different regions in the tidal contribution are identified, a separation attributable to harbour groynes blocking the tidal flow, with an average contribution of 45% along the whole coastline. SFCR likely cause a supply of sediment at the extension of the shoreface connection, at the lee side of the dominant flood current (northeast of the SFCR). Erosion southwest of the SFCR likely occurs due to flow contraction of the dominant flood current through the channel. The sensitivity analysis shows a large influence of D50 and friction height. However, these results are not uniform along the coast but profile-specific, indicating the need for accurate parametrisations alongshore. Lastly, the convergence study shows the need for accurate cross-shore depth profiles in future models developed in UNIBEST-CL+.

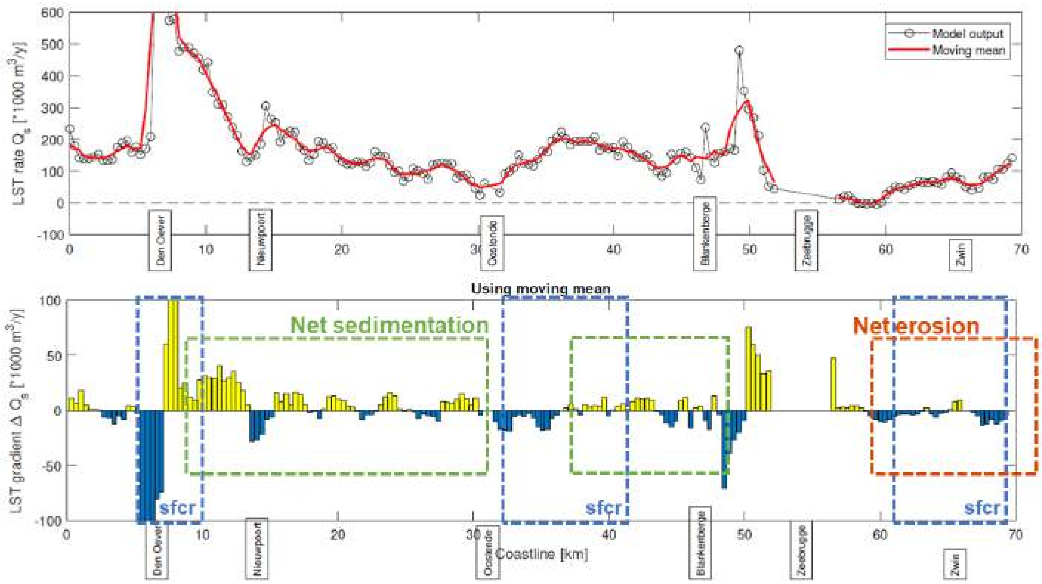

Figure 1: Calculated LST rates (top) and LST gradients (bottom) that can erosion- and deposition locations. The presence of SFCR is shown by blue boxes.

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Nearshore bathymetry estimation at Puerto Rico from Sentinel-2 and hyperspectral PRISMA imagery using machine learning

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Introduction

Accurate measurements of coastal water depths (i.e. near-shore bathymetry) are of fundamental importance for studying coastal hazards, changes in benthic habitats and sea level rise. Despite its importance, a lack of bathymetric information exists for most coastal regions in the world. The conventional method of mapping bathymetry, ship-sounding, is costly and inefficient. Satellite imagery provides a potential alternative for estimating bathymetry at large spatial and temporal scales, especially with recent advances in temporal, spatial and spectral image resolution. Such methods are limited to clear waters, through which the seabed is directly visible. Here, we apply machine learning to multispectral and hyperspectral satellite imagery, and present approaches to estimate near-shore bathymetry from the continental shelf of Puerto Rico.

Methods

This research employed 296 atmospherically corrected Sentinel-2 reflectance images, and three hyperspectral PRISMA images. Three methods were used to derive near-shore bathymetry: an empirical method with the green and blue spectral bands from Stumpf et al. (2003), an XGBoost machine learning model using all spectral bands, and an empirical method using hyperspectral imagery from Ma et al. (2013) using 16 spectral bands in the blue and green spectrum. The variance of each depth prediction was calculated to assess its certainty.

Results

The XGBoost model showed an error of up to 1.05 m for depths up to 20 m (Figure 1). The empirical method with hyperspectral imagery had a mean absolute error of 1.23 m in the same area. Over the entire study area, the XGBoost model had a mean absolute error of 1.64 m, which was 34% better than the empirical model from Stumpf (2003). Areas with high variances were found to be influenced by periodic sediment flows in the water, which reduced the model's performance. Further results are expected from the use of artificial neural networks applied to the images, which we will show at the conference.

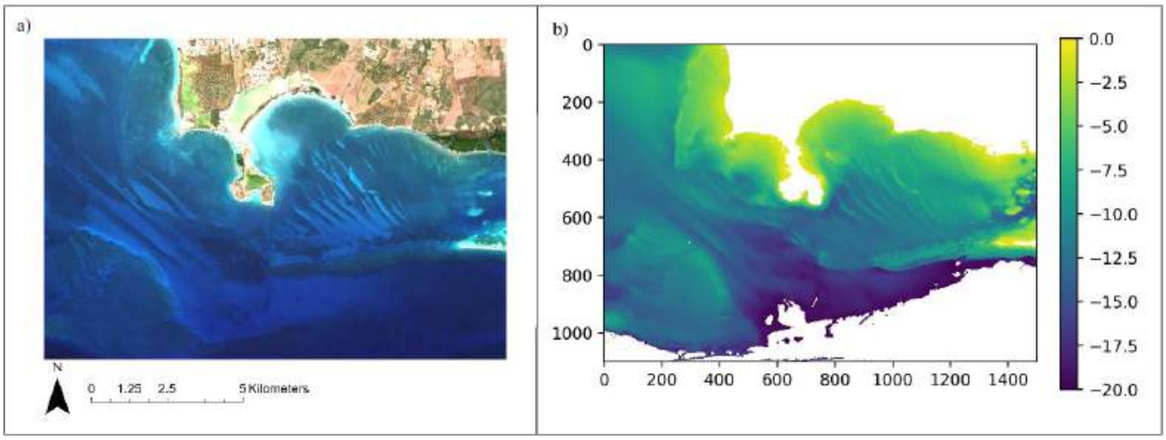

Figure 1: Plots of the median RGB image (a) and predicted depth in meters by XGBoost model (b) of the study area.

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What happened to the sandpit?

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Introduction

Coastal maintenance requires lots of sand. Where does the sand come from and what happens to the sandpits from an ecological perspective? In the Netherlands, the sand is extracted from designated offshore sites. In response to an increasing demand for sand, sandpits seem to be excavated deeper and deeper. More depth means less surface area disturbed. So, not an overall bad development for the benthic community, you would think. After the initial disturbance, benthic organisms can recolonize the bare seafloor of a shallow pit, making a full recovery within a few years. Except, as a pit becomes deeper, it seems more likely to alter the local environmental conditions. Different conditions favour different organisms; so how will the benthic community develop and will it recover fully?

Methods

Four sandpits and adjacent reference areas were selected. The time since last sand extraction differed for each pit (2011, 2014, 2018, 2020) and all were up to 6 meters deep. In early spring 2022, 71 samples were collected using the NIOZ Triple-D sledge; at least 8 samples for each pit and reference (tracklength = 50 m, ca. $10m^2$/track). The benthos, benthic fish and sediment was analysed.

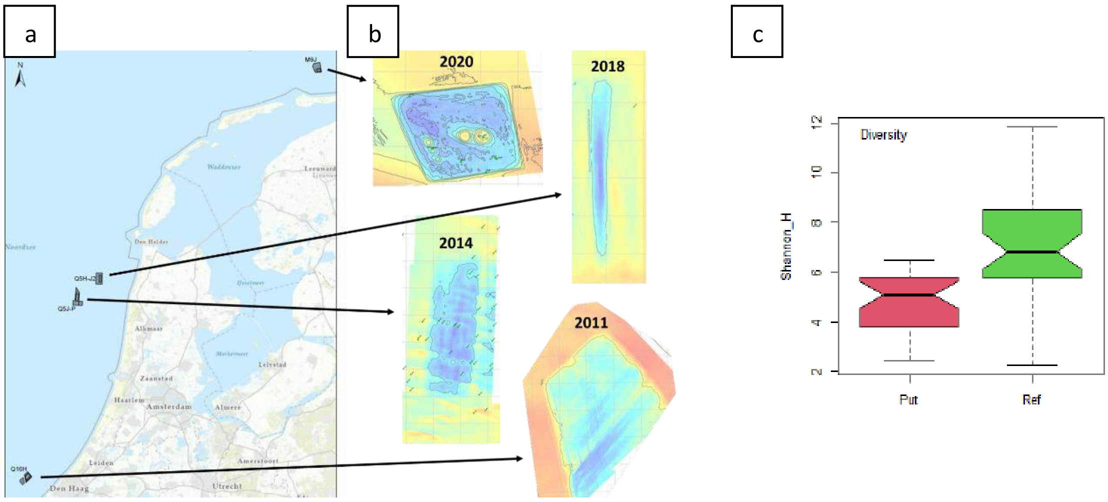

Figure 1: (a) Sandpit location, (b) year of excavation and bathymetry (blue is deep) and (c) biodiversity.

Results

The results are startling. All pits contained a higher percentage of fine sediment and organic matter, though the amount varied greatly. All pits differed in benthic community composition from the reference areas. The pits harbour less diversity and in some cases a higher biomass and abundance of macrozoöbenthos, caused by a few dominant species. The youngest pit was recolonized quickly (within 2 years) by opportunistic benthic species, but lacked characteristic species like the sand eels that were very abundant in the reference area. The pits from 2014 and 2018 both showed much more similarity to the reference areas. Benthic species composition still differed, likely in response to the influx of fines. The oldest pit (2011) contained extremely high percentages of fines (30% average). Effects on the species composition were very apparent, favouring (sub-) surface deposit-feeders and excluding suspension feeders. This pit is likely never to recover to its original condition. The disappearance of clams and sand eels may also have a strong effect on the foodweb.

The study clearly highlights the necessity of studying the effects of sand extraction in the Netherlands and serves as a basis for future policymaking. The research report and other ongoing and planned research projects can be found online at *www.zanduitzee.nl*.

Efficient Modelling of Sand Wave Field Dynamics for Offshore Engineering Activities

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The pressure on the offshore area is increasing at an unprecedented pace due to (a.o.) ambitious green energy goals. To facilitate the construction and maintenance of offshore developments, such as wind farms, detailed bed level predictions are required. The presence of tidal sand waves, which can be found on sandy seabeds throughout the world, increases the uncertainty in these predictions significantly. Sand waves can grow up to 25% of the water depth, have wavelengths of hundreds of meters and migrate with several meters per year. Migration and deformation of these dynamic bed forms may pose a threat to all kinds of offshore constructions. To predict future sand wave dynamics, currently data-driven methods are used. Application of process-based numerical models could increase the accuracy of these predictions and give insight into the related uncertainties. Furthermore, these types of models provide a solution for data-scarce areas and can show the effect of extreme events on sand waves.

Applying numerical models to sand wave cases has proven to be difficult. Challenges include the need for small horizontal and vertical grids sizes and related long computation times. To tackle this problem, sand wave models have been applied in simplified set-up. These models, such as the one by Campmans et al. (2018), have a 2DV set-up, excluding the along crest direction. However, in measurements we observe significant changes in the sand wave bathymetry along the crest, e.g. changes in orientation and height and bifurcations (see Figure 1A). Moreover, the influence of sand banks on sand waves (see Leenders et al., 2021) cannot be included in these types of models, due to the difference in orientation between these bedforms (see Figure 1B). Finally, engineering interventions can often not be simplified to a 2DV problem. Including this third dimension is thus vital for qualitative predictions of future sand wave field bathymetries. The aim of this study is to increase our understanding of the dynamics of real-life sand wave fields and to develop efficient ways to predict their dynamics for engineering applications. By applying the newly developed Delft3D Flexible Mesh (FM) software, the efficiency of our models increases significantly. 3D sand wave field models with realistic hydrodynamic forcing are now within reach. By studying multiple sand wave sites with varying amounts of 3D sand wave features, insight is gained into the interaction between the 3D morphology and local tidal currents. The resulting bed levels indicate the ability of the model to predict sand wave field dynamics on decadal timescales. We conclude that including the along-crest direction in sand wave models is vital to accurately predict future bed level evolution. The 3D sand wave field model offers us the opportunity to gain insight into highly 3D cases. Moreover, using this model we are able to simulate the development and impact of engineering interventions, such as the fill-up of a cable trench.

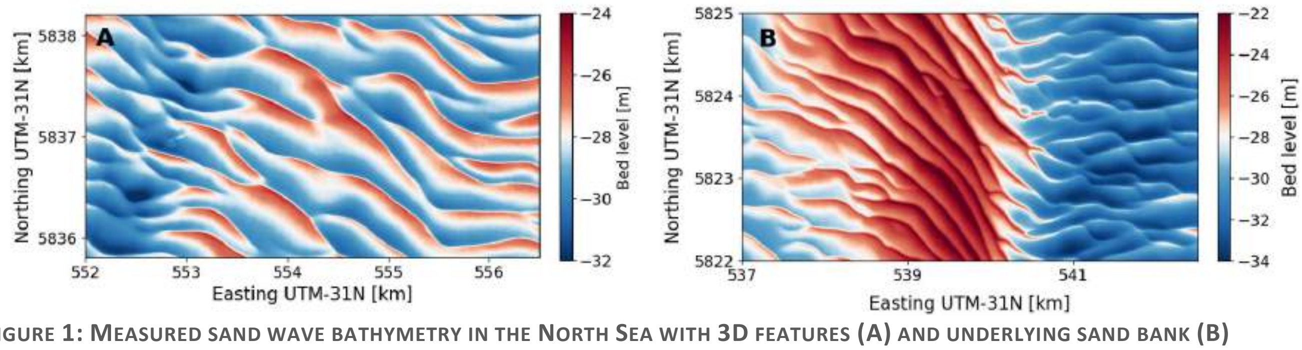

FIGURE 1: MEASURED SAND WAVE BATHYMETRY IN THE NORTH SEA WITH 3D FEATURES (A) AND UNDERLYING SAND BANK (B)

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Response of dune-building grasses to summer precipitation

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Introduction

Dune-building grasses are important for coastal protection. They promote topographic stability and development due to their traits that facilitate dune formation: Perennial grass species such as marram grass (*Ammophila arenaria*) and sand couch (*Elytrigia juncea*) respond to burial by sediment with enhanced growth while also trapping sediments effectively. In this context, species like marram grass have been used as ecosystem engineer in both past and recent dune restoration projects. Whether this solution will be applicable in future depends on climate change. While past research already established a link between precipitation and dune development (Hesp et al., 2021), the direct response of dune building grasses to precipitation has not been quantified to this date.

Methods

We explored the response of dune building grasses to summer precipitation in a two-step approach. We first used a pot-experiment to derive species growth relationships with water availability for marram grass and sand couch. To this end, we treated pots with different levels of water as derived from past summer precipitation records while monitoring the plant response. In a second step we used statistical models to predict the impact of changes in summer precipitation on the growth of these species. We explored three scenarios of changes to long-term average precipitation: climate change (+ 4.7%), a recent extremely dry year (-23 %) and a recent extremely wet year (+ 33%).

Results

We found that both marram grass and sand couch were sensitive to changes in water availability and responded positively to an increase in it. Comparing pot soil moisture measurements to field measurements showed that field moisture tended be on the lower end of ranges in pots. This suggests that dune grasses in the field are susceptible to drought effects. In the precipitation scenarios, plant growth was most affected for the extremely dry year (up to -14.8%), followed by the extremely wet year (up to +8.5%) and least affected in the climate change scenario (up to +1.4 %) (Figure 1).

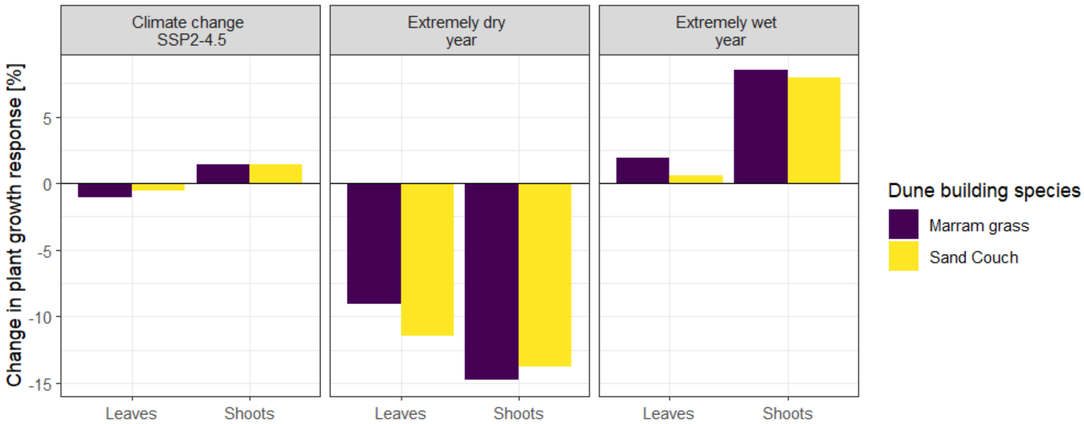

Figure 1: Change in dune building species growth response for different precipitation scenarios.

A bigger change in plant growth during extreme climate events implies a higher impact on dune development and stability. Including relationships between plant growth and climate in coastal models are thus needed to improve the predictions of climate change impacts on topography development.

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The effect of vegetation, sediment properties and inundation duration on the build-up of soil stability in salt marshes

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Introduction

Salt marshes have proven themselves as valuable for coastal protection, due to i) wave attenuation by the vegetated elevated marsh surface and due to ii) building such strong soils that they reduce the depth of a dike breach. To be able to create marshes with highly stable soils for flood safety (either in front of dikes, at managed realignment sites, or in transitional polders located between double dikes) requires a deeper understanding of the development of marsh soil stability under the influence of vegetation. We hence study soil stabilization of marsh soils with *field studies* and *controlled experiments*.

Methods

Field studies: We measured soil stability in pioneer salt marshes in the Westerschelde along age gradients to quantify the rate with which soil stability builds up over time. *Spartina anglica* was dominant in the pioneer zone at three salt marshes, while *Scirpus maritimus* was dominant at three brackish marshes. This enabled us to quantify the species-dependent effect on soil stability.

Controlled experiments: We set up a controlled experiment with pots filled with sandy or muddy sediment and which were left bare or were planted with *Spartina anglica* or *Scirpus maritimus*. All treatments (2 sediment types x 3 plant treatments) were subjected to four different tidal regimes. By studying the development of soil stability over time under different vegetation species, sediment type and tidal regime treatments, we quantified the effect of these variables on the build-up of soil stability.

A Spartina anglica *pioneer salt marsh at Hoofdplaat in the Westerschelde*

Results

Field studies: Our results show that *Spartina anglica* significantly increased soil strength compared to the bare mudflat within the first six years of vegetation coverage. *Scirpus maritimus* did not increase soil strength. We ascribe this difference to the different clonal expansion strategies of both species. Furthermore, we observed that soil stability typically decreased with longer inundation duration and higher soil water content.

Controlled experiments: In the controlled pot experiment, soil stability was higher in pots with vegetation than without vegetation, and higher in pots with sandy mud than with soft mud. Most build-up of soil stability over time resulted from the growth of the root systems.

Overall, we can conclude that vegetation, sediment properties and inundation duration are strongly affecting the build-up of soil stability in salt marshes. If we want to create salt marshes for coastal protection, we should consider these effects when assessing if a location is suitable to facilitate the formation of an erosion-resistant salt marsh soil that contributes to coastal protection, or if certain conditions need to be adjusted or managed or if a different location needs to be chosen.

Optimal wave reflection as a mechanism for seagrass self-organization

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Abstract

Spatial patterning, a universal feature of ecosystems worldwide, has recently been recognized as a driver of ecosystem resilience under environmental stress. Understanding pattern formation mechanisms is therefore crucial. Seagrass meadows exhibit a richness of spatial patterns. Spatial self-organization was recently suggested as an explanation for striped and hexagonal patterns in wave-exposed seagrass ecosystems, yet the responsible biogeomorphic interactions have not been clearly identified yet. Here, we show that regular patterning in seagrass meadows can be explained from self-reinforcing feedbacks between wave reflection, bed shear stress and seagrass-induced bedform growth. Field measurements show that seagrass pattern wavelength is approximately half the wavelength of the most energetic forcing waves. We therefore hypothesize that seagrass patterning is driven by Bragg resonance, i.e. maximal reflection of waves travelling over bed undulations with half their wavelength. We derive a full set of coupled equations for wave propagation and the interactions of bed shear stress with seagrass and bedform growth. We then linearize these equations, to study the development of perturbations around the uniform equilibrium state. Numerical simulations of the development of these perturbations show that a uniform seagrass meadow exists for weak wave forcing, but that a modulation instability exists for moderate forcing strength. Beyond this critical threshold, the seagrass meadow develops a pattern with wavelength half that of the incoming wave. Furthermore, the modelled bedforms cause maximal reflection of the forcing wave field. These findings confirm our hypothesis that Bragg reflection can explain meadow self-organization. Future field campaigns should confirm whether seagrass patterning hence provides natural protection of the ecosystem against wave impact. Our findings might apply to other patterned coastal ecosystems as well, and may inspire building-with-nature efforts worldwide in sustainably protecting densely populated coastlines against increasing flood risks.

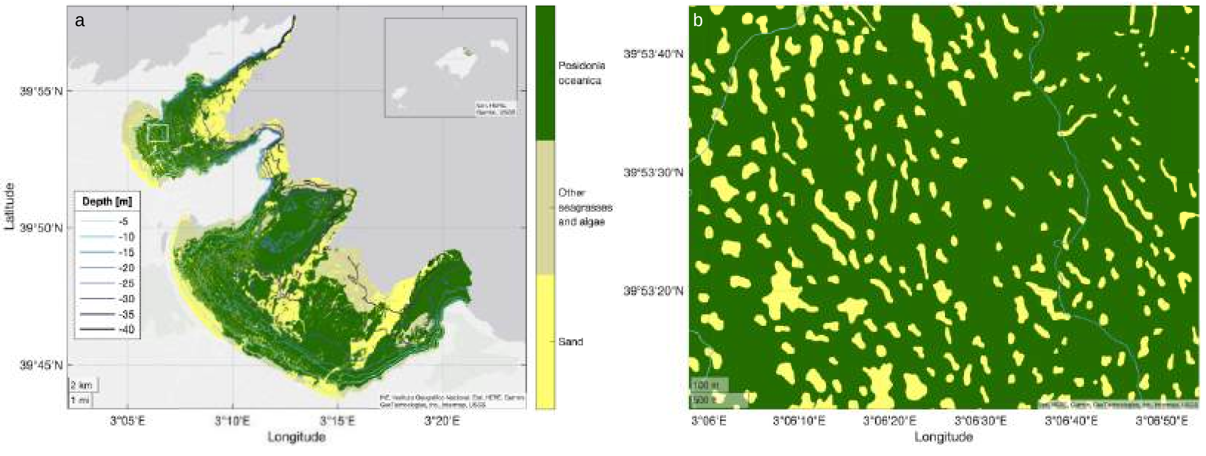

Figure 1: Seagrass patterns in the Bays of Pollença and Alcúdia (Mallorca, Spain). (a) Overview of the study area. Color shadings indicate different substrate types. Blue lines are isobaths. Inset shows the area's location within the Balearic Islands. White rectangle indicates the location of map b. (b) Detail of map a, showing spatially regular gap patterns in the seagrass meadow. Bathymetric and substrate data derived from the Life Posidonia project (https://lifeposidonia.caib.es).

Biocompacting livestock accelerate drowning of tidal salt marshes with sea level rise

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Introduction

A global concern for coastal ecosystems is the predicted rise in sea-level for which salt marshes must keep pace by increasing in surface elevation sufficiently. Variables that control the marsh accretion rates need to be identified to predict the adaptability of marshes to future sea-level rise. Many European marshes are grazed by livestock to maintain plant diversity. These heavy grazers can biocompact the marsh soil, a process often underestimated in studies assessing the long-term survival of salt marshes.

Methods

We measured marsh accretion rates and vegetation composition for thirteen years in the field in neighbouring grazed and non-grazed marshes at Holwerd, the Netherlands. The most important factors controlling current marsh accretion rates were identified using a statistical model and provided the input for mathematical model to study future accretion rates of grazed and non-grazed salt marshes up to 2100 under three sea level rise and sediment supply scenario's.

Results

We found that trampling by grazing cattle significantly reduced marsh accretion rates from 11.9 mm yr^{-1} in the non-grazed marsh to 3.6 mm yr^{-1} in the grazed marsh. Next to biocompaction by livestock, precipitation deficit and a period of extreme drought resulted in extra compaction of the marsh. Our model results showed that cattle presence had a negative impact on the future adaptability of salt marshes to grow vertically for rising sea levels. Biocompaction reduced the total accretion of the marsh by 42% if the current linear SLR does not accelerate. For an accelerating and high SLR to 109 cm +NAP in 2100, biocompaction reduced total accretion by 12% and the grazed marsh can no longer outcompete the rise in sea level from around 2050 onwards, compared to the non-grazed marsh. The grazed marsh will slowly drown but this will not lead to a significant change in vegetation composition yet. For an extreme SLR to 195 cm +NAP in 2100 the accretion rate in both the grazed and non-grazed marshes cannot keep pace with the rise in sea level and the marsh vegetation is expected to show regression to plants typical for a low marsh. A reduction in sediment supply will aggravate the effects of SLR and may result in highly increasing inundation frequencies and subsequent disappearance of the marsh vegetation.

Figure 1: Grazing can reduce salt marsh accretion and thereby accelerate drowning with sea level rise. (image courtesy: M. van Puijenbroek).

Preserving estuarine foraging habitats for shorebirds through sand nourishments

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Introduction

Estuaries are world-wide under pressure due to anthropogenic activities and climate change. Many face system-wide erosion resulting in loss of intertidal areas, leading to negative ecological consequences. Intertidal areas provide important foraging grounds for shorebirds along flyways. Loss in one estuary can affect populations on a global scale. It is therefore important to mitigate locally. The Eastern Scheldt estuary is a drowning estuary in the southwest of the Netherlands. In 2019, 1.13 million m^3 of sediment was nourished on the Roggenplaat (1440 ha), covering 15% (211 ha) of the tidal shoal with a 30-80cm thick layer of sediment, to preserve foraging habitat for the coming 25 years.

The nourishment buried locally most of bird's prey (benthic macrofauna). Through recolonization prey abundance recovers over time. However, it is unknow how much time this takes. The Roggenplaat nourishment consist of seven elements (Figure 1), each element is unique regarding their location, elevation and thickness of the sediment layer. Differences between these elements enables us to study how nourishment design affects recolonization speed of the benthic macrofauna. These insights could steer optimisation of future nourishment designs and inform coastal managers about the potential of this mitigation measure to other estuaries worldwide.

Figure 1: Areal pictures before (left) and after (right) nourishment placement (image courtesy: satelietdataportal.nl).

Methods

Since 2015 an extensive long-term eco-morphological monitoring programme is executed on the Roggenplaat. Benthic macrofauna was sampled before and after the nourishment to study changes at tidal shoal scale (113 sampling stations) and nourishment scale (120 sampling stations). Total bird numbers foraging on the tidal shoal where counted 8 times a year. During bird counts, spatial and temporal data were collected enabling us to analyse spatial heatmaps of the birds.

Results

Recolonization of benthic macrofauna differed per nourishment element and showed a trend with thickness of the sediment layer. Two years after nourishment placement, worm biomass was restored to the pre-nourishment situation on the thinnest nourishments. Shellfish biomass increased significantly between the first and second year after nourishment placement. Total bird numbers foraging on the tidal flat did not change before and after the nourishment. An increase in habitat use occurred in areas which were not nourished, whereas nourished areas were avoided even two years after construction, despite the increased biomass of prey species. These result indicates that the carrying capacity of the Roggenplaat seems to be sufficient to buffer for a temporal decline in foraging area. This short-term decline is necessary to mitigate future recession. In the long run, nourished areas are expected to be fully recolonized and become valuable again due to their increased emersion time. From this we learned that, in order to compensate for the temporary loss of carrying capacity due to nourishment, undisturbed areas needs to be of sufficient quality and quantity to support birds visiting the tidal shoal.

Benthic macrofauna under extreme weather events: unraveling the response strategies from individual behavior to community structure in tidal flats

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Introduction

Extreme weather events are increasing in intensity, duration, and frequency and threatening tidal flat ecosystems due to global climate change. Benthic macrofauna take essential roles in biogeomorphic feedback as ecosystem engineers, while they are prone to extreme environmental fluctuations in alternating flooding and drying tidal regimes. Moreover, modern globalization has accelerated the invasion of introduced species, which compete with native species for natural resources. Therefore, studying how benthic macrofauna respond to extreme weather events may convey an essential message on short-term erosion-deposition equilibrium and the long-term development of tidal flat ecosystems.

Methods

A mesocosm system was customized in the lab to mimic the heatwaves with contrasting magnitudes and durations on tidal flats. Simulated heatwaves were imposed on the model bioturbator species *Cerastoderma edule* living in different micro-topographies and sediment types, to study the response of bioturbation activities under thermal stress. Moreover, the effects of compound extreme weather events on species shift were studied by imposing different salinity settings and heatwave profiles on the native *C. edule* and an introduced bivalve *Ruditapes philippinarum*. Besides individual-level response, an *in-situ* experiment was applied to study the effects of repeated storm events on benthic community structure, using a raking treatment to mimic storm-induced sediment disturbance.

Results

Macrobenthos' response on the individual level is categorized into the "fight, flight, or freeze" framework. Bioturbators increase metabolic rates to "fight" against the thermal stress and maintain optimal physiological conditions; they burrowed deeper during low tide to escape from ("flight") the thermal stress, thereby causing more sediment mixings; they reduce activity and metabolism ("freeze") to maintain basic physiological functions under acute extreme stress or long-term intermediate stress. On the community level, internal environmental stress can select species with specific biological traits, while species with unfitting traits decrease in abundance. Moreover, compound extreme weather events may create "disturbance-driven invasion windows" that benefit the introduced species to overtake native species.

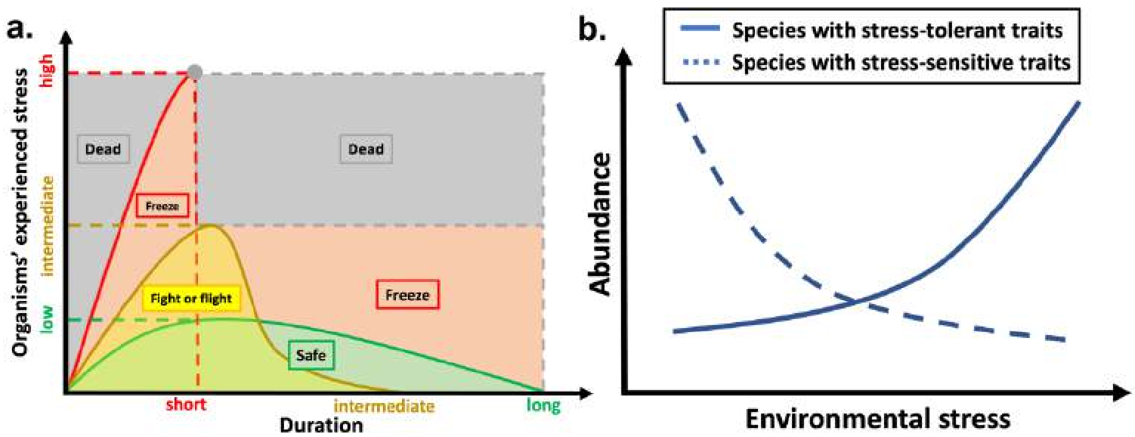

Figure 1: An illusion of the fight, flight, or freeze response (a) and the filtering effects of internal environmental stress on species' biological traits

Potential ecosystem effects of large upscaling of offshore wind in the North Sea

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Introduction

Upscaling wind-energy capacity in the North Sea is considered an important step in the energy transition. The aim of the Dutch government is to speed up the development of offshore wind and to realise 21GW offshore wind capacity by 2030. These developments come also with known direct adverse effects such as collision risk for birds, habitat loss of seabirds and effects of noise on marine mammals and effects of electromagnetic fields from cables on benthos and fish. However, indirect effects, via physical and ecological processes, have been underexposed. Within the WOZEP programme knowledge gaps regarding ecosystem effects of large-scale offshore wind farms in the North Sea are assessed.

Methods

To assess potential ecosystem effects, the 3D Dutch Continental Shelf Model in Flexible Mesh (3D DCSM-FM; Zijl et al., 2021) has been extended with a wave, fine sediment and ecological module. This validated integrated online coupled flexible mesh model allows to assess large-scale domains.

Results

Large-scale extraction of wind energy from the atmosphere affects local wind patterns, wave generation, tidal amplitudes, stratification and consequently fine sediment dynamics. Such physical changes have consequences for the ecological functioning of the North Sea. Changes in the vertical stratification of suspended sediment concentration (SSC), for example, affect both the nutrient and light availability. On a North Sea scale, the numerical model results show that the enhancing and reducing effects of offshore wind farms on SSC partially cancel out. However, our results also suggest that persistent changes may occur at regional scales, such as a significant decrease in SSC flux in the Dutch coastal zone. These effects become more pronounced for hypothetical upscale scenarios up to 70GW capacity in 2050. Wind farming in the North Sea has effects at a scale beyond that of single wind farms. These effects on the physical environment and ecosystem functioning should be considered and if needed mitigated to prevent large-scale side effects.

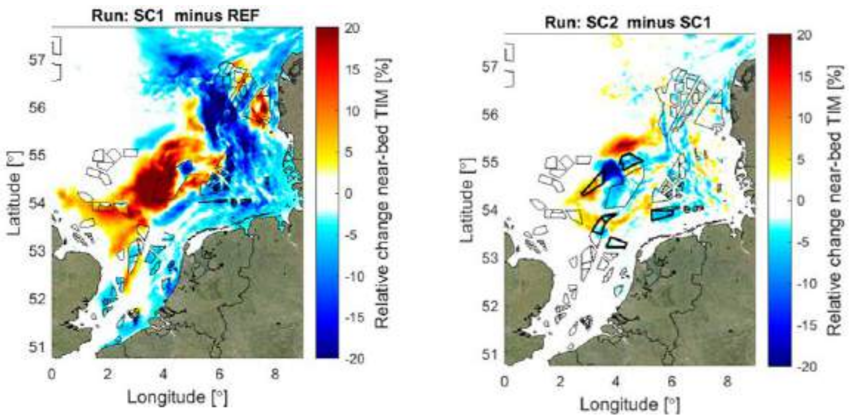

Figure 1: Changes in year-average, near-bed total inorganic matter (TIM) for future wind park scenarios 1(left) and 2 (right) in 2050.

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High-resolution grain size analysis using photos

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Introduction

The traditional approach for grain size analysis, mechanical sieving, is a time-consuming process that limits its spatial and temporal resolution. Here, we used a method that determines the grain size distribution from just images of the sediment surface (i.e., optical granulometry), called pyDGS (Buscombe, 2013). We developed a new method to convert the area-by-size measure of pyDGS to the volume-by-weight measure obtained by sieving, enabling their direct comparison. The Prins Hendrikzanddijk, a poorly sorted sandy beach, was used as a case study to test the performance of this novel (adapted) method, and its applicability for mapping grain-size distribution at an entire beach.

Methods

A photo of sediment captures a certain area and pyDGS computes the percentage of each grain size class within this frame by fitting translated and scaled wavelets. To convert this information into useful statistics, the following steps are taken for all grain size categories in an image: 1) calculate the total number of grains in the photo frame, 2) estimate the volume of each grain class, and 3) compute the mass of each grain size category by multiplying the number of grains by their volume and density. In this study, the grain shape was estimated and calibration was done with sediment samples that were photographed and sieved.

Results

Figure 1 shows the potential of this new method by displaying the results of high-resolution spatial sampling. Despite the relatively large standard deviations, the relative patterns are apparent. As such, the results are promising for detailed and time-efficient mapping of spatiotemporal trends in volume-by-weight measures of grain sizes .

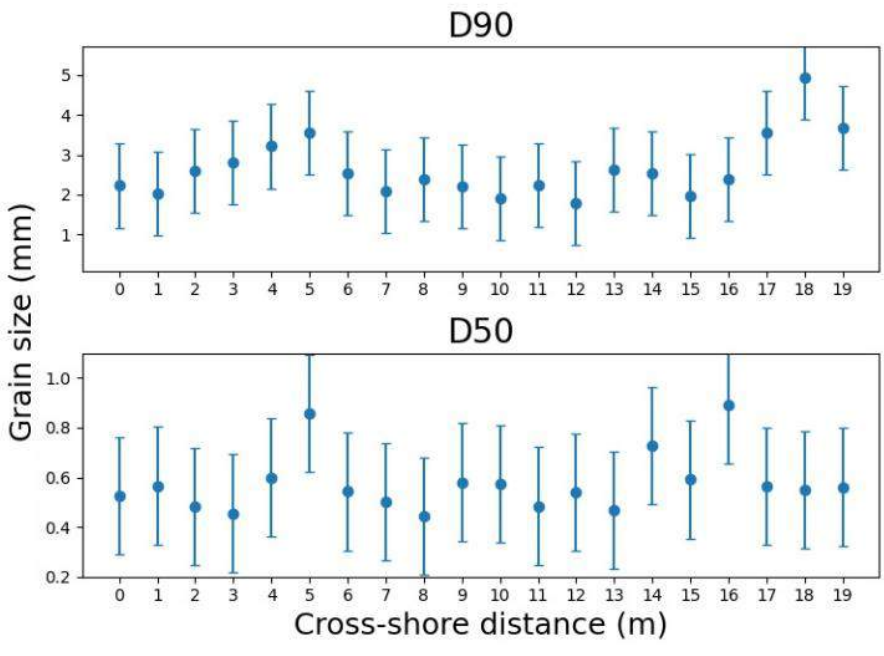

Figure 1: Cross-shore distribution of grain sizes acquired with the new method (note: 0 and 19 m correspond to the high and low waterline, respectively).

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The effect of brushwood fences and marram grass on initial dune development

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Introduction

During strong wind conditions, wind-blown sand accumulates on hard engineered coastal infrastructures (e.g., dikes, roads, railways), leading to increasing costs in infrastructure management and destructive fails (e.g. train derailment) [1]. Every year, a lot of effort goes into cleaning these infrastructures especially in Raversijde, Belgium. Jersey blocks already present on the dike are able to stop a part of this wind-blown sand but are insufficient during high windspeeds. To mitigate this sand nuisance, a dune-in-front-of-a-dike pilot site was implemented on the upper beach in front of the seawall. In this study, volume changes and changes in dune parameters will be related to forcing factors (e.g., windspeed and -direction) and parameters of vegetation and brushwood fences (e.g., cover and density). In this way, the effect of brushwood fences and marram grass on initial dune development will be studied.

Methods

In the spring of 2021, a new engineered dune area of 750 x 20 m² was constructed 10 m in front of the traditional sea dike (Figure 1). A split-plot design of 10 x 10 m² blocks was used to plant vegetation in different spatial distributions (regular, random and clustered) with low and high densities. Occasionally, vegetation was surrounded by brushwood fences (low and high densities) at an original height of 1m. Monthly drone surveys are used to monitor topographical changes along 12 cross-shore profiles and 8 divided zones, simultaneously with wind conditions.

Results

Results show a clear difference in cross-shore development during the first year of monitoring. The influence of vegetation combined with brushwood fences is much more prominent than vegetation on itself. The combined zones had a dune growth of 18-26 m³/m while the vegetation zones captured 12-14 m³/m. These brushwood fences are able to capture a larger amount of sand but have a decrease in trapping efficiency over time as several combined zones became completely saturated at the end of the first year (March 2022). New planting will be necessary as these fences are, compared to vegetation, unable to grow and consequently trap sand in the future.

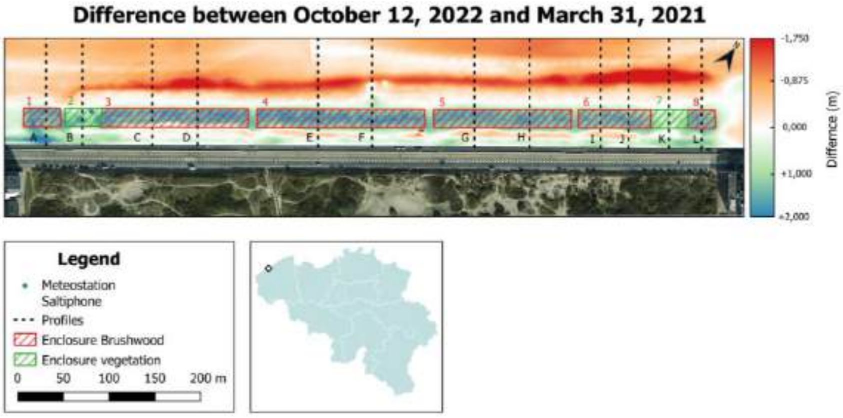

Figure 1: Dune-in-front-of-a-dike pilot site at Raversijde, Belgium divided in 8 zones and 12 cross-shore monitoring profiles.

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Acknowledgments

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Parameter uncertainty in ShorelineS predictions of the Hondsbossche Dunes

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Introduction

Parameter uncertainty can be an important contribution to uncertainty in the predictions of morphological models on an engineering time scale (~2-20y). This uncertainty is rarely assessed in practical model applications in the coastal zone because existing morphological models are computationally demanding. However, a single deterministic prediction does not provide an uncertainty range originating from parameter uncertainty. The one-line model ShorelineS is now being upgraded to the level of a verified engineering software tool as part of a joint industry TKI project led by Deltares and IHE-Delft. The efficiency of this model creates the opportunity to assess the parameter uncertainty in coastal zone applications by doing many computations.

Methods

To assess the parameter uncertainty, the development of the Hondsbossche Dunes nourishment is modelled for the first five years after placement. Over 7000 simulations with different parameter settings have been analysed using the probabilistic GLUE method. Within this method, an uncertainty bandwidth conditioned on observations is established. A total of five model parameters have been varied within reasonable ranges: (1) the median grain size, D50; (2) the breaker index, γ; (3) the scaling factor in the longshore sediment transport formulae, q_{scale}; (4) the offshore depth of the applied wave boundary conditions, d_{deep}, and (5) the active profile height, d. Moreover, four different longshore sediment transport (LST) formulae are used in the model simulations.

Results

Results show that the model can be calibrated to accurately predict (the temporal variation in) the volume change over the central part of the nourishment (Figure 1a). Two parameters are identified that influence the model predictions significantly: the sediment transport scaling factor, q_{scale}, and the active profile height, d, with especially q_{scale} strongly dependent on the LST formula. In addition, the model skill increases when the wave boundary is applied at a larger depth (d_{deep}), enabling the foreshore to rotate with the shoreline change. The observed variation in the shoreline position is well enclosed by the predicted uncertainty bandwidth (Figure 1b). In more detail, the model is not able to reproduce the strong alongshore variations in the observed shoreline retreat.

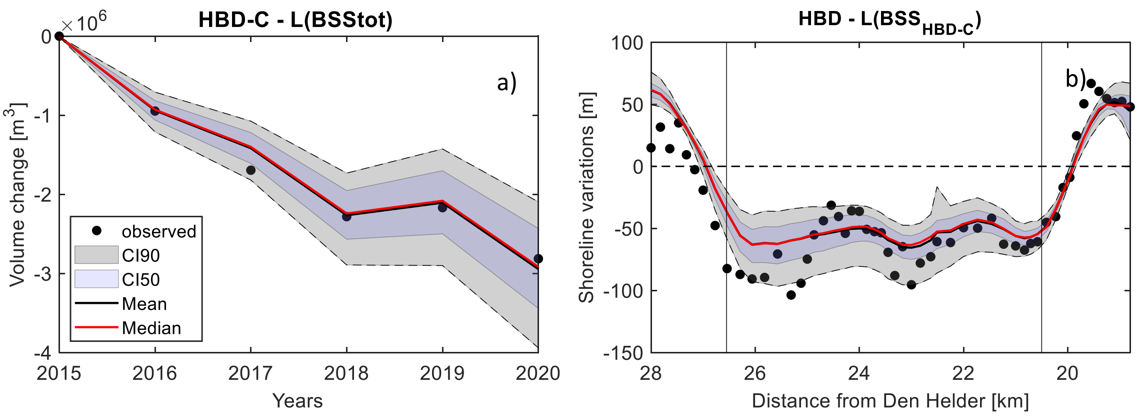

Figure 1: Temporal volume changes over the central sector of the HBD since construction (a), and shoreline position change in the alongshore direction after 5 years (b). Central sector indicated by black vertical lines in panel b.

The results reveal the uncertainty in ShorelineS model applications and their origin. Parameter uncertainty can result in large variations in the forecasted values, with parameters and LST formulations showing a co dependence. The results show that a reasonable estimate of uncertainty can be obtained with only 200-500 simulations.

Particle motion in the nearshore zone of sandy beaches- quantifying the role of horizontal and vertical processes

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Introduction

In this study, the motion of particles in the nearshore zone of single-barred beaches is investigated. Spreading and accumulation of particles in the coastal areas are very relevant to study, e.g. in the context of waste management and maintaining clean beaches. Particularly important drivers of particle motion include rip currents, the Stokes drift, wind-driven currents, currents driven by wave rollers, the undertow, and turbulence (van Sebille et al., 2020). Here, the motion of both passive buoyant and non-buoyant particles under different environmental conditions is analysed. Focus is on whether, and under what conditions do the particles beach, get trapped close to the shore, or escape into the open ocean.

Methods

As a case study, the motion of plastics in a single-barred beach system in Duck, North Carolina, is analysed. To track the particles both on the surface of the water, but also within the water column, a 3D wave-averaged model was developed. The Lagrangian velocity field used for the computations was derived from the output of a nonlinear morphodynamic nearshore model (Garnier et al., 2008). Several simulations with varying wave conditions and wind patterns were performed to quantify the relative importance of the drivers on the motion of both floating and sinking plastics released at different locations of the model domain. Moreover, the probability distribution of the particles' fate, i.e. whether they beach, get trapped or escape, and the associated time scales were computed.

Results

The relative importance of different drivers depends on the initial environmental conditions. For floating particles (Fig. 1 left), weak rip circulation favours onshore movement of the particles due to combined effects of the Stokes drift and wave rollers. However, if the particles sink (Fig. 2 right), the undertow moves them away from the coastline where they can get trapped in the rip cells. The turbulence affects the trajectories of the particles widening the probability distribution of their final position.

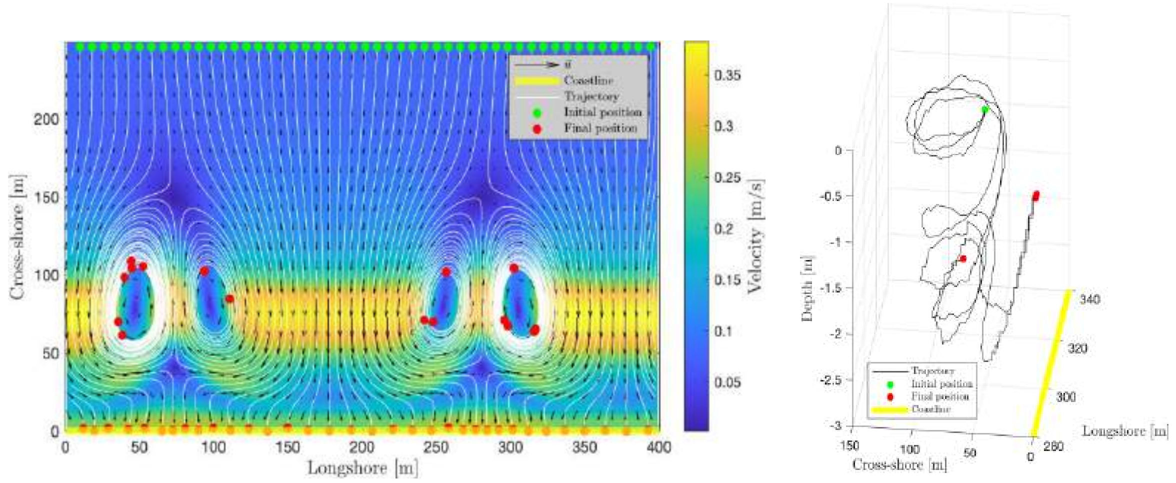

Figure 1: Left: Lagrangian flow field in the nearshore zone of Duck and the resulting trajectories of floating particles released at the offshore boundary without the effect of turbulence. Right: Trajectories of 3 sinking particles released close to a rip cell with added turbulence.

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Longshore transport by tides and waves

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Introduction

The effect of tides on the total, tide-averaged longshore transport can be profound but is not easy to represent in existing bulk transport formulas. The formula by van Rijn (2014) allows for the inclusion of a tidal velocity, but this leaves open the question of how this is varying in space, across the profile and through the tidal cycle. In the framework of the ShorelineS TKI project, a collaboration between 15 companies and institutes to operationalize the ShorelineS model (Roelvink et al, 2020) for coastal engineering applications, including the effects of tides featured prominently. Here we outline a method, inspired by that by Southgate (1989), to accurately deal with the combination of vertical and horizontal tides and obliquely incident waves to predict longshore transport rates.

Methods

The longshore velocity due to tidal water level gradients can be solved analytically using linearized bottom friction. The solution includes the effect of inertia and describes the amplitude and phase of the longshore velocity as a function of the amplitude and phase of the water level and the mean water depth. We can apply this, e.g., to the M2 and M4 components, and obtain estimates of the tidal velocity signal; a residual component can be resolved as well. Wave-driven currents through the tidal cycle can be computed by solving the wave direction and cross-shore wave energy balance for each tidal water level, and solving the longshore velocity from the balance between longshore forcing and bed friction. The resulting tidal velocity and wave-driven current, both functions of cross-shore distance and tidal phase, can be fed into a transport formulation such as Soulsby-van Rijn, integrated over the nearshore zone and averaged over the tidal cycle. This principle was implemented in a highly efficient Matlab function that can be called from within the ShorelineS model just like other bulk transport formulas. The tidal coefficients needed can be easily extracted from a series of observations along a depth contour in a 2D tidal model.

Results

The method of reproducing tidal velocity time series was tested using data from a Delft3D model of the coast of Flanders and the Netherlands. A typical time series 14km east of Zeebrugge and the longshore distribution of the tidal velocity skewness, a proxy for tidal transport, is shown in Figure 1; the analytical model accurately reproduces the tidal features. More comparisons and an application in ShorelineS will be presented at the NCK days.

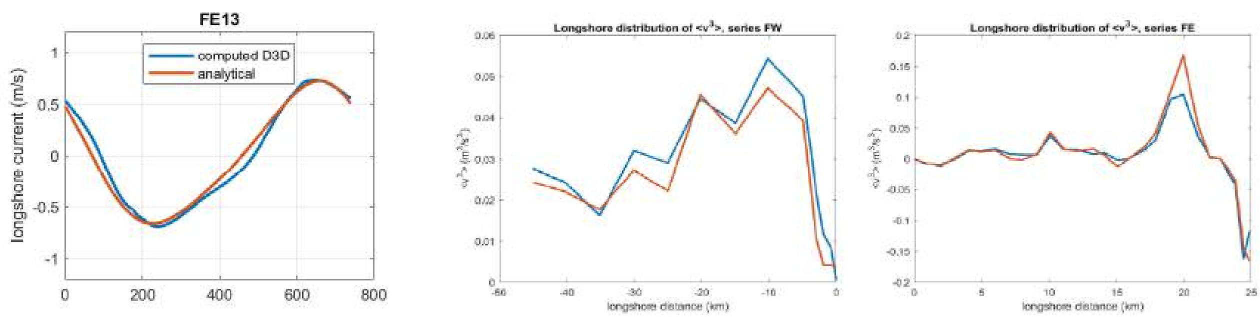

Figure 1: Example time series of tidal velocity (left panel); longshore distribution of tidal velocity skewness, West (middle) and East (right panel) of Zeebrugge

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Sandy beaches in low-energy, non-tidal environments: Beaches of the Markermeer and IJsselmeer

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Introduction

Low-energy or sheltered beaches are expected to have similar, but less pronounced, morphodynamics compared to high-energy or exposed beaches. Therefore, only few studies have focused on low-energy coasts and thus, knowledge of morphodynamics in this field lags behind that of high-energy beaches (Vila-Concejo et al., 2020). The lack of morphodynamic knowledge became especially apparent in the dike reinforcement project of the Houtribdijk, the Netherlands. The aim of this research is to gain fundamental understanding of the hydrodynamic processes driving the morphology of low-energy, non-tidal, sandy beaches and develop methods to predict these morphodynamics. The Houtribdijk and Marker Wadden beaches in the IJsselmeer region are used to reach this aim.

Results and Conclusion

The hydrodynamic processes steering the morphology of low-energy, non-tidal, sandy beaches in the IJsselmeer region were determined. Cross-shore beach face erosion is linked to the yearly 95th percentile wave height, implying the importance of higher energy conditions. However, the morphodynamics of individual events is difficult to ascertain, due to the design of the monitoring campaign, but also due to the similarity in morphodynamics caused by mid energy and higher energy conditions.

Below the beach face, the platform and offshore section of the profile evolve through cross-shore and longshore processes. Combined wave heights and water levels steer the platform depth, while wave-driven and circulation-driven longshore flows determine whether the platform extends offshore (Ton et al., 2023, 2021). Longshore sediment transport is quantified through the adjusted and recalibrated Van Rijn (2014) bulk equation. By combining cross-shore beach face erosion, platform height and longshore sediment distribution at the platform and offshore, beach development can be predicted.

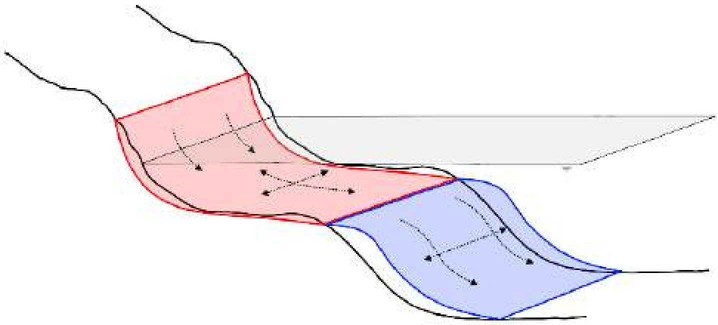

Figure 1: Conceptual model of sediment transport at low-energy, non-tidal, sandy beaches during storm

Acknowledgements

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Flume modelling to investigate the erosion of sand-mud mixtures under currents and waves in the laboratory and in Delft3D

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Introduction

Bed sediments in estuaries and tidal basins often consist of mixtures of sand and mud. But although much is known about the erosion behaviour of the individual sediment fractions, our quantitative understanding of the erosion of sand-mud mixtures remains limited, especially under the combined effects of waves and currents. In order to advance our knowledge on sand-mud interaction processes, an international consortium of research institutes, consultants and dredging contractors is jointly investigating sand-mud dynamics by means of physical experiments, field measurements and numerical modelling. The expected outcome of this project is a better suite of complex numerical models (such as Delft3D and Mike) and simple analytical tools to better predict, for instance, the navigability of channels and effects of accelerated sea level rise on the sediment budget of coastal systems.

Earlier research has suggested that (1) the erosion fluxes of sand and mud are proportionally coupled, and (2) the amount of clay in the bed determines whether the sand and mud interact as a cohesive or non-cohesive mixture. We further investigate this, with additional focus on the combined effect of currents and waves.

Methods

Wave-current flume experiments were carried out in a 13 m long and 0.4 m wide flume. Sediment samples of varying composition were placed over a 3 m long stretch in the middle of the flume, after which the wave height and current speed were progressively increased. Next to visual observations of the erosive behaviour, OBS measurements were performed and water samples were taken at different heights to determine sediment concentrations. A digital wave-current flume was developed (in Delft3D) to hindcast the analogue flume results, in order to quantitatively understand the observations and improved formulations describing erosion processes.

Results

The laboratory experiments show that sediment cohesion affects the critical bed shear stress of the sand-mud mixture for mud fractions larger than 15%. The formation of ripples and near-bed sand transport was already suppressed for smaller mud fractions. The continuous OBS signal was used to estimate the erosion rate of sand and mud. Using the Delft3D model, we were able to further quantify the erosion rate, and show the sensitivity of results to different sediment transport formulations.

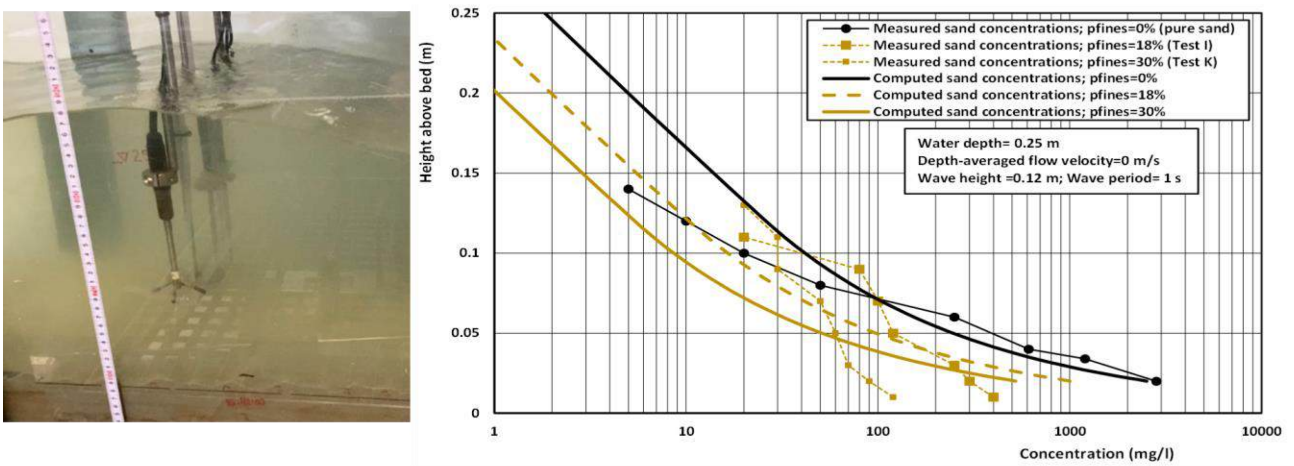

Figure 1: Picture of the experimental set-up in the wave-current flume (left) and comparison between measured and computed sediment concentrations in the flume (right).

The development of a three-dimensional idealised model for estuarine hydrodynamics: iFlow3D

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Introduction

The water motion in tidally-dominated estuaries is greatly influenced by the geometry and bathymetry. To study this interaction, a 3D model is required, where both the longitudinal and lateral processes are resolved. Two types of process-based models are typically employed to get insight into these dynamics. High complexity 3D numerical models, such as TELEMAC and Delft3D, and idealised 3D models, such as the model of Kumar (2018). The latter models are explicitly developed to gain insight in the dominant physical processes and to systematically analyse the influence of parameters by performing parameter sensitivity studies. Up till now, 3D idealised models were restricted to idealised geometries and simple bathymetries. To systematically analyse the influence of complex geometries and bathymetries on the water motion, we developed a new idealised model, iFlow3D.

Methods

The iFlow3D model solves the three-dimensional shallow water equations using a perturbative approach. The resulting equations are solved in the frequency domain, allowing for the direct computation and identification of prescribed tidal constituents, e.g., M0, M2, M4 etc. The governing equations can be decoupled in the vertical dimension and the resulting 1DV problem can be solved analytically. Thus the 3D problem is reduced to a 2DH problem. To obtain fast and numerically accurate solutions, the 2DH problem is solved using a high-order finite element method (spectral element method with modal basis functions) with curved elements, which is essential to obtain accurate first- and second-order numerical derivatives in curved geometries. The bathymetry can be prescribed in terms of along- and across-channel coordinates, allowing for a systematic approach to study the influence of the bathymetry and geometry on the water motion.

Results

To illustrate the strength and versatility of the iFlow3D model, a sensitivity study is performed in which the bathymetry is slowly varied. An idealised estuary inspired by the characteristics of the Scheldt estuary is considered. In the converging geometry, a two channel bathymetry is morphed into a single channel bathymetry. The effects of this transition on the water motion is illustrated in Fig. 1. In the presentation, I will systematically study the generation mechanisms of the residual and tidal flows under changing geometry and bathymetry.

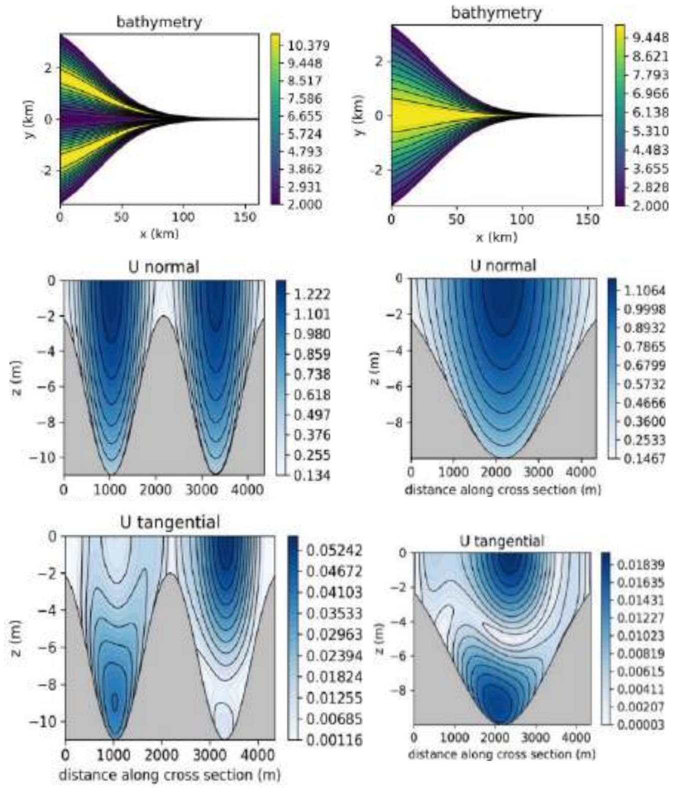

Figure 1: Example of an idealised estuary with a two channel and one channel bathymetry. At km 25, a cross section is taken. The amplitude of the M2 velocity along channel (normal) and across channel (tangential) are shown.

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Shoreline evolution on decadal time scales: role of tides

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Introduction

A substantial portion of the world's shorelines are being threatened by erosion, a situation that might accelerate by rising sea levels and changes in storm and wave climate. In order to mitigate risks of shoreline erosion, it is crucial to increase our knowledge of the processes that affect shoreline evolution on yearly and decadal time scales. Many studies [1,2] have focused on the evolution of shorelines on decadal time scales, but little is known about the role of tides in this evolution. As tides affect sediment transport in the nearshore, they might significantly impact the evolution of shorelines in macro-tidal coastal environments, such as the Belgium coast (Fig. 1a). This study, which is part of a new research project of the Flemish government (called MOZES), aims to quantify the relative effects of tides on the decadal evolution of shorelines.

Methods

Simulations are carried out with an existing idealized 2DH shoreline evolution model (called Q2D-morfo, [3]), but extended such that tides are included. The macro-tidal Belgium coastal zone (Fig. 1a) is selected as a study area, which features the presence of large-scale ridges on the shelf. The model is forced with waves and tides. Different scenarios of tidal amplitudes are explored.

Results

Results indicate that the inclusion of tides suppresses the growth of shoreline undulations (Fig.1b). Results for different tidal scenarios will be presented during the conference.

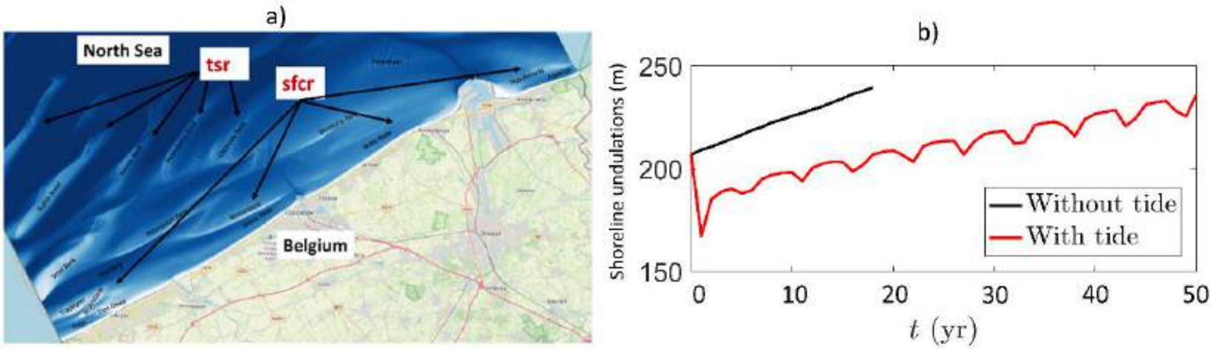

Figure 1: a) Bathymetric map of the Belgian shelf, which shows a field of the so-called shoreface-connected sand ridges (sfcr) and tidal sand ridges (tsr). b) Rms amplitude of shoreline undulations (with respect to the initially straight shoreline profile) versus time.

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Observations of directional characteristics of infragravity waves in the North Sea

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Introduction

Infragravity waves (IG) are long period (25s-250s) waves that contribute importantly to extreme runup and hence are a driver for dune erosion. The description of IG waves at the offshore boundary is important to predict accurately the coastal impact and safety. However, uncertainties exist. Generally, bound IG waves (*BIG*), proportional to sea-swell (SS) wave energy, are included but free IG waves (*FIG*) are not. In semi-enclosed basins, such as the North Sea, *FIG* energy can be substantial (e.g., Reniers et al., 2021; Rijnsdorp et al., 2021). Numerical modelling (Rijnsdorp et al., 2021) demonstrated that *FIG* waves may bounce off the distant coasts of the UK and Denmark, cross the North Sea basin, and become a source of incoming IG energy at the Dutch coast. To further improve the understanding and quantify the importance of incoming *FIG* waves in semi-enclosed basins, observations of the directional field of *BIG* and *FIG* waves are essential. In this contribution, we aim to determine the directional characteristics of bound and free IG waves from detailed measurements of an entire storm season (2021/2022).

Methods

A 5-month dataset (Nov 2021-Apr 2022) of continuous 4 Hz measurements of velocity, pressure and sea surface elevation was collected as part of the Realdune/REFLEX campaign. Data was obtained by ADCPs and an ADV deployed in a cross-shore array with bottom frames at 14.5m, 8.9m and 6.5 m depth. *BIG* waveheight (H_{BIG}) was estimated from the pressure head time series using bispectral analysis, whereas *FIG* waveheight (H_{FIG}) followed from the total IG waveheight (H_{TIG}) and H_{BIG}. Directional spectra of *BIG* and *FIG* waves were estimated using the spectra reconstruction method of Matsuba et al. (2022).

Results

Ten energetic events were identified in the data set with substantial H_{TIG} (> 0.12m at the most offshore frame). Figure 1 shows how *BIG* and *FIG* evolve during the most energetic event. The directional distribution of FIG changes from isotropic to anisotropic during the peaks of the storm (red boxes). At the conference we will discuss in detail how the direction of *FIG* waves changes from predominantly outgoing to incoming depending on the direction of *SS* waves. Potentially, the observed energetic incoming FIG waves are important to accurately assess coastal safety.

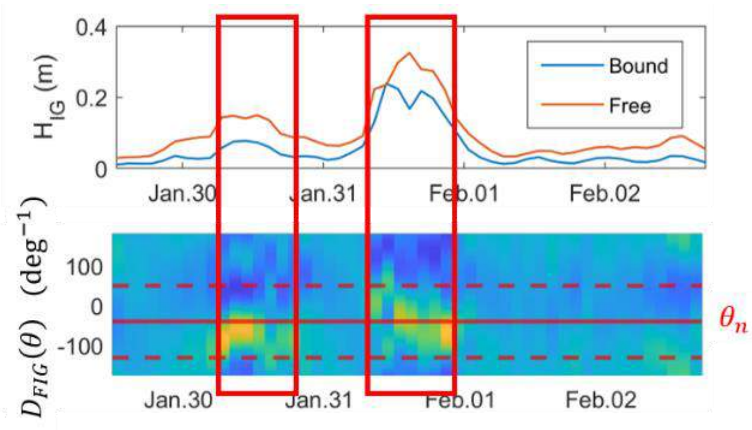

Figure 1: Evolution of bound and free infragravity waveheight (top) and the free infragravity directional distribution (bottom) during storm Corrie (2022). The horizontal line on the bottom panel represents the shorenormal θ_n, and the dashed lines θ_n +/- 90degrees.

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Abstracts of Poster presentations

Using Agent-Based modelling to explore human impact on sandy beaches in the Netherlands

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Introduction

A combination of natural processes (wind, waves, and tides) and human activities (management and uses), gradually shape the landscapes of sandy beaches (Lazarus, Ellis et al. 2016). Worldwide, studieshave mainly focused on analysing the impact of nature on the vegetation cover and morphology of sandybeaches. Human effects on sandy beach landscapes have rarely been discussed. The beach visitors' footprint is the permanent impact recreation has on the beach landscape. In this research, we aim to analyse the pattern of beach visitors' footprints to explore the impact of human activities on vegetation cover and morphology and quantify their combined lasting effects in space and time. We aim to achievethis goal by developing an agent-based model (ABM).

Methods

Our ABM contains two sub models, a natural processes sub model and a user impact sub model, to estimate the impact of beach visitors on the geomorphology. Data on the number of visitors was collected by installing sensors at three different entrances of the Sand Motor. Sensor data were combined with meteorological data (average daily temperature, average daily rainfall, and wind speed), types of the day (weekend, working day, and holiday), types and number of recreational facilities around each entrance, and the entrance accessibility (access to the car parking and public transport) to find rules to predict the number of visitors per entrance. We conducted surveys of beach visitors on several days in summer, spring and autumn to derive information about visitor activities, the entrances and exits used, the walking paths and the duration of the visit. This information was used to design and implement visitor behaviour in our model. The impact of the visits was simulated by combining the two sub modelsto evaluate the visitors' footprint in space and time. We tested the model on a sandy beach in the Netherlands, the Sand Motor, by running the model for one year and comparing the impact with satelliteimages.

Results

Figure1 shows the accumulated area and severity of human impact in the Sand Motor for one year, without taking the natural impacts into account. Integration of the natural processes sub model and the human influence to calculate the total human footprint still has to be conducted. In the next step, we willadd the vegetation cover and the impact of the human footprint on the vegetation. We will also implement for a second study area (Hondsbossche Dunes). Experiments will be conducted running the model for a longer period to assess long-term impacts, evaluating the changes in beach width and the impact of the human footprint on embryo dune development.

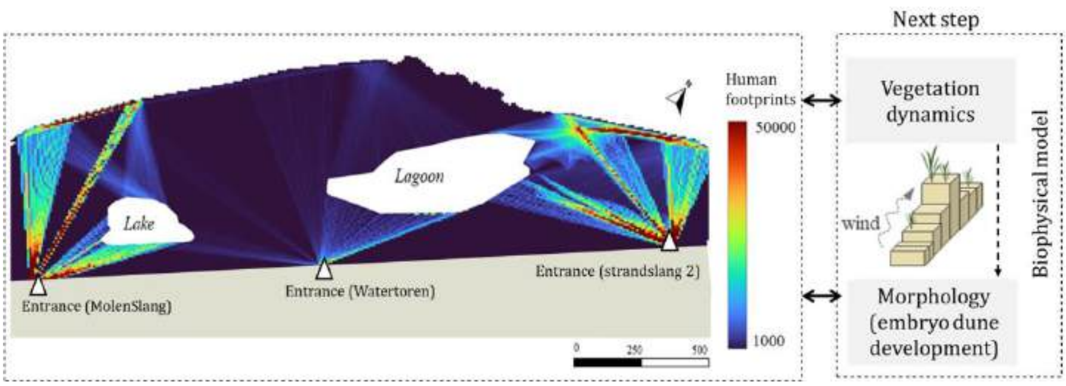

Figure 1: The number of human footprints per 50 m^2 in Sand Motor for one year

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The social response to coastal realignment: results from three project locations in the Southwest delta, the Netherlands

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Coastal realignment is a coastal management approach that involves the relocation of the primary flood defense. Nowadays, nature compensation projects and climate adaptation of the coastal zone are resulting in landward realignment, leading to a re-establishment of tidal flooding and restoration of intertidal ecosystems in a formerly reclaimed area from the sea. Intertidal ecosystems contribute to human well-being and society at large by providing important ecosystem services such as coastal protection against flooding, opportunities for recreation and habitat for a variety of plants and animals.

While the benefits of restoring intertidal ecosystems through coastal realignment are widely accepted in policy and academic circles, the implementation of concrete projects often faces opposition from the local community. Public opposition to coastal realignment may result in the delay or complete cancellation of planned projects and disturbs relationships between authorities and the local population. In consequence, to facilitate design and implementation processes, it is important to understand to what extent and under what circumstances coastal realignment interventions are supported by the local population and what factors contribute to social support or opposition.

Accordingly, in this study we examine the social response to coastal realignment. We hereby focus on one ongoing (Hedwigepolder) and two fully established (Rammegors and Perkpolder) project locations in the Southwest delta, the Netherlands. A comprehensive questionnaire instrument was elaborated and administered in neighboring towns, resulting in about 100 filled-out questionnaires per project location. We computed correlations and constructed regression models using SPSS and R to analyze the questionnaire data.

The results show that inhabitants in the surroundings of the Rammegors and Hedwigepolder project locations have little sympathy for coastal realignment. Negative sentiments revolve around governance-related aspects (e.g. lack of trust in authorities and planning procedures) and socio-psychological factors (e.g. disruption of place-related bonds and feelings of disconnection with the social and physical surroundings). In addition, inhabitants associate the landscape transformation with the loss of ecosystem services. This is a noticeable outcome, given that it is a key policy objective of coastal realignment to increase the availability of ecosystem services.

When it comes to the transformation of Perkpolder, the local population is critical toward planning authorities and concerned about the possibility of salt intrusion and environmental pollution (due to the presence of PFAS in the Western Scheldt and heavy metals in the newly established sea dike). Meanwhile, in contrast to Rammegors and Hedwigepolder, the transformation of Perkpolder is generally considered to have increased the availability of ecosystem services. Local inhabitants recognize the contribution of coastal realignment to erosion control and flood risk protection, but the new landscape is particularly valued for its cultural ecosystem services, including landscape aesthetics and opportunities for recreation and tourism. We found that this translates into an overall positive attitude to the coastal realignment intervention and the landscape transformation more broadly. Hence, to achieve socially acceptable and sustainable outcomes, it will be important to minimize the loss of cultural ecosystem services, or better yet, look for possibilities to increase the availability of cultural ecosystem services through coastal realignment.

The role of vegetated intertidal areas for salt intrusion mitigation

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Introduction

Intertidal areas in estuaries are often inhabited by vegetation, which plays a crucial role in shaping these ecosystems and providing valuable ecosystem services. It is essential to understand how intertidal vegetation responds to changes in sea level, river discharge and salinity induced by climate change or anthropogenic influence, to determine the effect on its ecosystem services. Furthermore, while nature-based solutions are receiving attention for the sake of coastal safety, these solutions are understudied for the mitigation of salt intrusion.

Approach

A combination of available data from field surveys, remote sensing, and modelling techniques will be applied to identify the potential of vegetated intertidal areas, both fringing as mid-channel flats, as nature-based solutions to mitigate salt intrusion. Vegetated intertidal areas located in salt, brackish and freshwater regions in the Scheldt estuary, from the mouth near Vlissingen, the Netherlands, till Gent, Belgium are used as study areas in this project. In the first phase, the distribution of estuarine intertidal vegetation over the past 30 years will be studied using remote sensing techniques and available data from field surveys. In phase two, the vegetation distribution will be linked to a level of salinity to obtain response curves. An expected vegetation distribution can then be obtained by coupling these curves with future scenarios for salt intrusion. Shifts in vegetation distribution will alter hydrodynamics, sediment dynamics and therefore bed level dynamics, ultimately influencing the ecosystem services by vegetated intertidal areas. Therefore, the third phase comprises a full biogeomorphological analysis of the development of vegetated intertidal areas, forced by changes in salinity, sea level and river discharges. By combining insights from the first three phases, the final phase investigates the potential of vegetated intertidal areas as nature-based solution to mitigate salt intrusion.

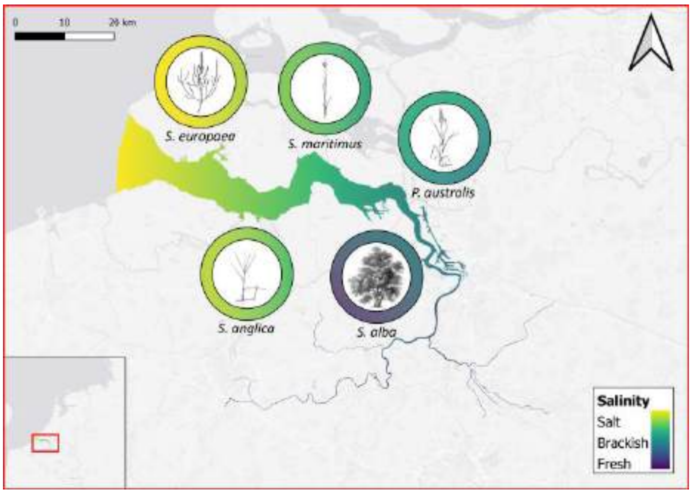

Figure 1: A schematic representation of the Scheldt estuary, showing its salinity distribution and the presence of the five vegetation species at their typical salinity. The illustrations of the vegetation species are not to scale. Salinity data from (Breine et al., 2008). Vegetation illustration courtesy of Lizzie Harper and Botanical-online.

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Cross-shore Distribution of Alongshore Sediment Transport in a Macro-tidal Environment

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Introduction

Alongshore sediment transport is one of the key parameters in the design of coastal infrastructure. It determines the life-time of nourishments and the intensity of maintenance dredging.
However, sediment transport in the alongshore direction is not uniformly distributed over the cross-shore profile as demonstrated by e.g. Kamphuis (1991) and Bayram et al. (2001). Wave-driven transport is bound between the run-up limit and the depth of closure. As the alongshore transport is governed by wave energy dissipation, peaks in transport rate are expected over bars and in the swash zone. Furthermore, aeolian transport only takes place on the sub-aerial and sufficiently dry intertidal beach. Especially in macro-tidal environments the boundaries for sediment transport are highly modulated with the tide and wave run-up. The question is how that modulation averages out and where in the beach profile the highest transport rates are found.

Methods

In the harbour of Blankenberge, Belgium, over 100 multi-beam surveys were performed for maintenance dredging operations, covering 2015 to 2021. The harbour access channel functions as a sand trap, due to the smooth low-crested breakwaters, nearly level with the adjacent beach. Between surveys sediment is deposited in the channel. Volumes and patterns can be correlated to the theoretical transport, based on nearshore hydrodynamics. A tide-gauge and meteorological station are present in Blankenberge harbour, a directional wave-buoy is located nearby at 8 m depth.

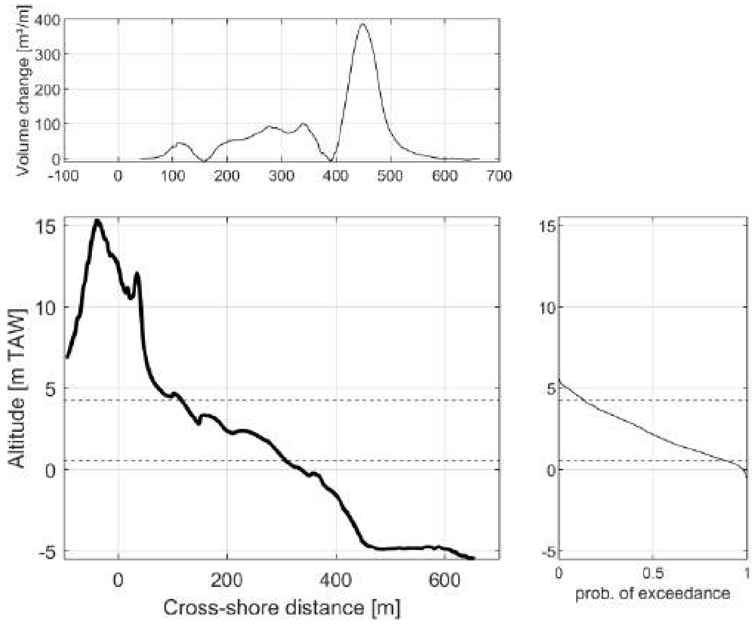

Figure 1: Deposition in relation to the coastal profile during the February 2020 storm. Upper panel: deposited volume in the channel (m³/m). Lower panel: coastal profile (May 2020) and mean high and low water levels (dashed). Right panel: probability of exceedance of the still water level.

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Footprint: first results of a three-vessel offshore windfarm sampling campaign

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Introduction

In sandy coastal seas, such as the North Sea, tidal forces cause the formation of sand waves. These bedforms can grow up to 10 meters in height and hundreds of meters long, and migrate several meters per year. Variations in physical parameters and food availability along these sand waves lead to a high heterogeneity of habitats on a small spatial scale, where particularly the troughs house a surprisingly high amount of benthic organisms (Damveld et al, 2018). The increasing number of offshore windfarms (OWFs) will lead to cascading effects both during the construction phase (immediate impact) and the operational phase through alterations of local currents, sediment transport and, consequently, morphological patterns (chronic impact) (Rivier et al., 2016). Within Footprint we aim to investigate this interplay between dynamic bedforms and hard structures.

Sampling campaign

During the summer of 2022 we carried out a field sampling campaign around the Dutch-Belgian OWF (Figure 1). In this campaign three research vessels collaborated to study the hydrodynamic patterns, water column suspended matter characteristics (SPM), and sediment oxygen consumption, in and around the OWFs, and on the sand wave fields present in this area. During the conference we will present the first results from this sampling campaign, with a focus on the hydrodynamic and SPM results from the Dutch side of the windfarm area.

Figure 1: NIOZ research vessel Pelagia close to the Borssele OWF area near the Dutch-Belgian border, location of the 2022 summer sampling campaign in the Footprint project.

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The effect of sediment grain size on dune erosion: a field experiment

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INTRODUCTION

Along a substantial stretch of the Dutch coastline, coastal dunes act as the primary sea defence to protect the low-lying areas behind it from flooding. To ensure that these dunes are strong enough to meet national safety standards, models are used to assess their strength. Even though our modelling capabilities have significantly improved over the years, model uncertainties remain because specific processes are not yet fully understood.

One of these uncertainties is the effect of sediment grain size on dune erosion, causing the relative importance and effect of this parameter to differ significantly among dune erosion models (van Wiechen et al. 2022).

APPROACH

Field experiments to study the effect of sediment grain size on dune erosion were conducted from September 24 until September 27 2022. Two open shipping containers were placed in the intertidal zone and acted as coastal wave flumes. Inside both containers, artificial dunes consisting of different types of sediment were built and exposed to wave attack during high water. In total six experiments were conducted in which 4 different grain sizes were tested. Dune profile development and erosion volumes were monitored using GoPro images and GPS transects. Hydrodynamic conditions were measured using pressure sensors (RBR) and velocimeters (ADV).

ANALYSIS AND RESULTS

Wave impact theory (Fisher et al. 1984; Larson et al. 2004) was used to (1) compare the incident hydrodynamic conditions to measured erosion volumes and profile development in time, and (2) isolate the relative importance of sediment grain size on dune erosion. Preliminary results imply that larger grain sizes result in smaller erosion volumes. These findings will be presented at the NCK days.

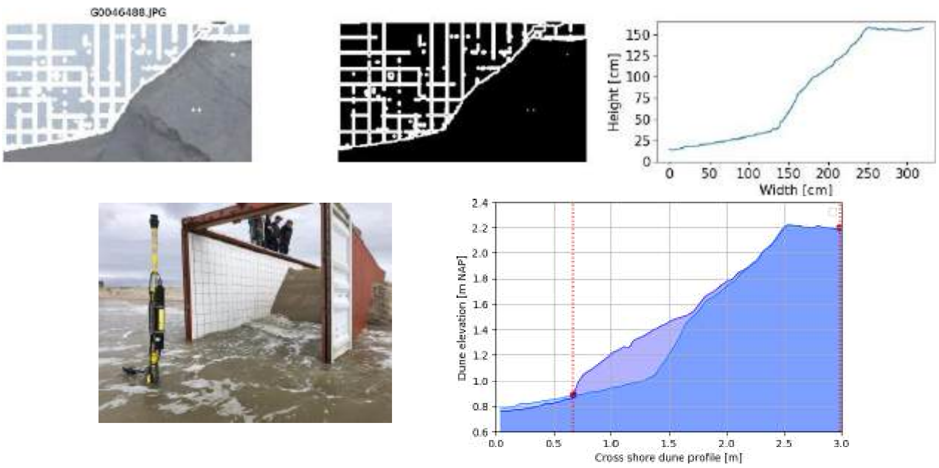

Figure 1: a) Extraction dune profile contour from GoPro image. b) Artificial dune inside container, exposed to run up. c) Definition of the erosion volume.

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Geen Zee Te Hoog: Anticipating for accelerating sea level rise in the spatial design of land-water transitions via a participative design process

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Introduction

Sea level rise (SLR) threatens low-lying coastal areas. After 2050 SLR may potentially accelerate, but how strong the acceleration will be is unknown. Extreme scenarios call for extreme measures to ensure water safety, and the uncertainty in SLR rates calls for flexibility in spatial planning. However, today's professionals want to leave room for future generations to make decisions. This leads to a dilemma. Large decisions are postponed, putting their feasibility under pressure when circumstances call for them. Therefore, there is a need for a joint learning process to obtain insight in the feasibility and durability of possible coastal defence strategies, and their societal support.

Approach

With Geen Zee Te Hoog, we aim to develop a participative and iterative process to develop spatial designs of land-water transitions and apply this to the Western Scheldt via living labs. In this context we will also investigate opportunities for nature-based solutions and the physical and ecological boundaries thereof.

Firstly, promising nature-based solutions will be selected based on present and potential future developments for each living lab (of e.g., SLR, sedimentation/erosion patterns, waves, suspended sediment concentrations, etc), which we will determine from existing data and literature. The selected solutions will be assessed on wave attenuation and shear stress reduction using a 1D wave model. Land level growth potential under SLR will be estimated from SSC and inundation duration.

Secondly, results of step 1 will be used to design potential future bathymetries in each living lab. Flow and wave patterns will be modelled in 2D as part of assessing landscape quality. This will serve as input for the development of spatial strategies and design guidelines which will be developed in a co-creative manner with all stakeholders involved.

Example of a dyke landscape in the Western Scheldt (Knuitershoek, photo by Edwin Paree).

Connectivity of sand mining regions in San Francisco Bay estimated using SedTRAILS

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Introduction

San Francisco Bay (SF Bay) is one of the largest estuaries along the U.S. West Coast, connected to the Pacific Ocean through the Golden Gate. The estuary has been subject to anthropogenic activities, such as channel dredging and sand mining. Replenishment potential of these mining locations and their impact on the neighbouring bathymetry is mostly not known. This research assesses how sediment dynamics connect the mining areas to their surrounding environment. This shows, on a regional scale, which areas may morphologically be affected by the respective mining activities. The SedTRAILS methodology and its visualisation of sediment dynamics shows to be a promising tool to analyse the impact of dredging activities.

Methods

The sediment transport will be calculated using a morphostatic depth averaged Delft3D 4 model, set-up and validated by Elias and Hansen (2013). As postprocessing step, SedTRAILS (**Sed**iment **TRA**nsport v**I**sualization & **L**agrangian **S**imulator) was applied to visualize and analyse both the net and gross sediment pathways to determine the connectivity within SF Bay (Pearson et al., 2021).

Results

In an environment like SF Bay, influenced by tidal forcing, waves, river discharge and complex geometry, the SedTRAILS results give a clear indication of sediment transport directions. SedTRAILS results show that the influence of waves and river discharge on the sediment transport is limited when compared with the tidal forcing. SedTRAILS results clearly reveal sub-area connections and local relocation of sediment. Figure 1 illustrates, as an example, that on the short-term sediment is mainly coming from the North and deposited at the shoal south of Angel Island. On the longer term, sediment is also coming from South Bay and mainly ending up beyond the Golden Gate, at the ebb tidal delta.

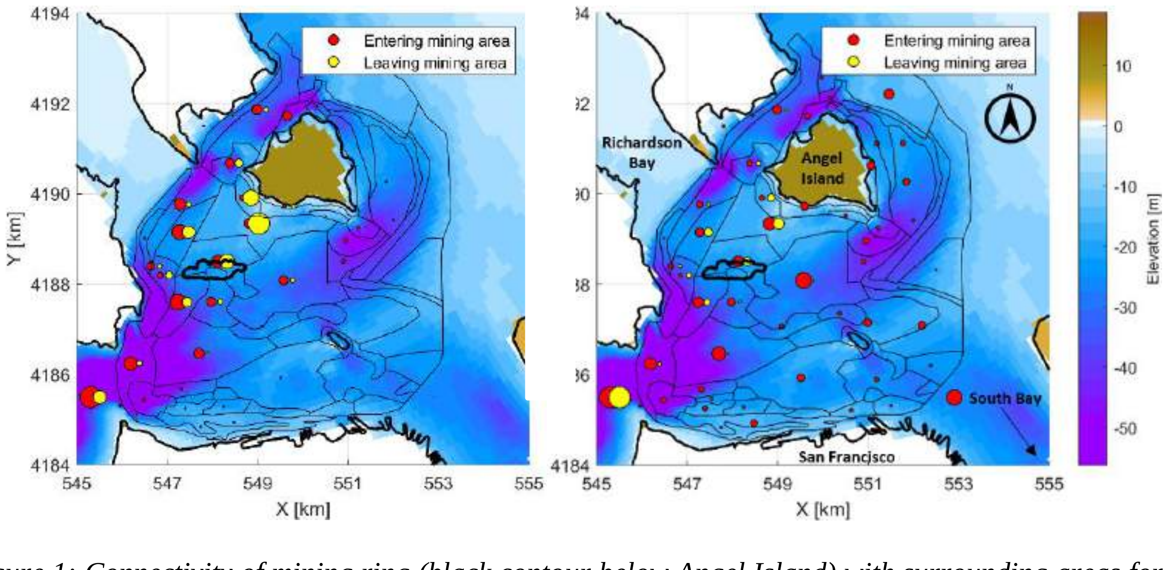

Figure 1: Connectivity of mining ring (black contour below Angel Island) with surrounding areas for (a) 5 tidal cycles and (b) 50 tidal cycles, the size of the dot indicates the strength of the connectivity.

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Stochastic results from deterministic wave-resolving models

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Introduction

Studies involving detailed wave-resolving models gained substantial popularity over the past decade. The main advantage of such models is that more physical processes, such as nonlinear wave dynamics and wave breaking, are intrinsically resolved by the model equations. They are for instance applied to determine wave runup on beaches, wave overtopping over coastal structures (e.g., using SWASH) and to assess storm-induced dune erosion (e.g., using XBeach). Despite the more accurate representation of the physics, a downside of such models is the deterministic nature of the models. As the phases of each wave component are randomly picked by the offshore wavemaker, the spatial model results are a single realisation of this specific random phasing. Consequently, different random phases result in a spatially different outcome, thereby introducing a range of uncertainty. Recently, Rutten et al. (2021) showed that the uncertainty associated with the random phasing for the specific case of extreme wave runup is up to 31%. So, the results of a single model simulation can be either an under- or overestimation, which is undesirable for engineering purposes. Therefore, this study quantifies the uncertainty for a broad range of hydrodynamic and morphodynamic model results and proposes a future solution to reduce this.

Method and results

Three different 1D cases are simulated: 1) wave dynamics over a coastal profile with SWASH; 2) wave reflection and overtopping against a seawall with SWASH; and 3) dune erosion during a storm using XBeach Surfbeat. Stochastic model results are obtained by ensemble-averaging the outcome of 100 simulations with different random phasing.

The uncertainty in hydrodynamic (e.g., infragravity wave height, overtopping, wave shape, max crest height) and morphodynamic results (e.g., beach profile, bar height and dune erosion) is quantified by comparing the individual model simulation results to the ensemble-averaged results. As an example, Figure 1 shows the uncertainty of the maximum wave crest height along a coastal profile.

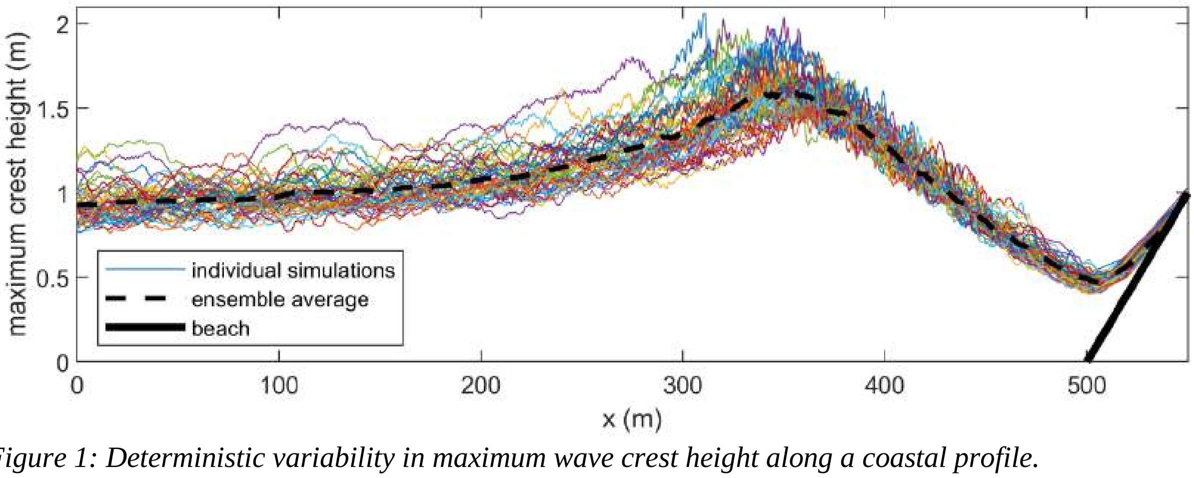

Figure 1: Deterministic variability in maximum wave crest height along a coastal profile.

Discussion and outlook

The design of for instance a seawall crest height, scour protection stability or wind farm foundation can be supported using SWASH results. Additionally, in The Netherlands dune safety is assessed using the XBeach Surfbeat model. Hence, obtaining reliable stochastic results from these deterministic models is of high importance. Therefore, a new development will be proposed to adapt the random phasing of the wavemaker to reduce future model uncertainty.

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Biogeomorphological Evolution of Salt Marshes under Natural Conditions and the Influence of Artificial Structures on Marsh Resilience

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Introduction

Salt marshes are valuable ecosystems that provide a variety of services worldwide. Their potential for coastal protection by attenuating waves is increasingly being demonstrated. However, salt marshes are temporally and spatially variable systems. Therefore, it is important to understand and predict the dynamics of salt marshes to assess their resilience to future stresses and to underpin the design of nature-based solutions such as living dikes. Resilient marshes are stable or expanding over time under varying pressures. However, tipping points can be reached for example under conditions of high wave energy and low sediment availability, leading to cliff formation at the transition from the salt marsh to the mudflat and salt marsh retreat. The physical factors that determine lateral salt marsh dynamics, and the interaction between salt marshes and tidal flat dynamics, are poorly understood and rarely parameterized in numerical models. Therefore, this study aims to (i) provide insights into the natural dynamics of salt marshes and tidal flats, (ii) predict future changes in biogeomorphological processes under different scenarios of sea level rise, storms, and suspended sediment availability, and (iii) determine the influences that artificial structures (i.e. brushwood dams) can have on the resilience of salt marshes.

Methods

The research will be conducted in three phases. First, the natural dynamics of salt marshes and tidal flats will be studied using high-resolution, UAV-derived DEMs and orthomosaics of five different salt marshes in the Dutch Wadden Sea over a three-year period. Secondly, the resilience of salt marshes to different influences (e.g. wave height, availability of suspended sediment, rise in sea level) will be tested by extending a recently developed numerical model (Willemsen et al., 2022) and including cliff erosion processes. The model will be calibrated and validated using the field data gathered in phase 1. Thirdly, the effect of artificial structures on salt marsh dynamics will be investigated using the previously validated model.

Results

This research is part of the project Living on the Edge and runs from 2022 to 2026. The results will provide insights into the resilience of salt marshes, potential future tipping points leading to salt marsh retreat, and the use of artificial structures to help ensure the resilience of salt marshes under future pressures.

Figure 1: Wierum salt marsh cliff (image courtesy: S. Dzimballa).

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The origin of patterns on tidal flats and their role in marsh expansion

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Introduction

Predicting where intertidal vegetation will occur in the future is important for the management of nature in our estuaries. Currently we rely mainly on measurements of elevation and local hydrodynamic forces to predict the occurrence of vegetation. However, small-scale morphological features on the tidal flat known as 'ridge-runnel patterns' have been found to create uniquely suitable habitat for the establishment of pioneer vegetation. If these patterns are to play an important role in the transition between tidal flats and marshes, it is important that we understand (1) how and why they form, and (2) where we are most likely to find them.

Figure 1: Photos of the same tidal flat near the marsh of Zuidgors in the Western Scheldt, NL, in 2021 and 2022, where ~20 ha of marsh expansion occurred in a single year. Note the pattern of ridges and pools on the tidal flat in 2021. The red ovals highlight a reference pole featured in both photos.

Methods

We investigated these questions using a combination of geospatial surveys, field measurements, and laboratory flume experiments.

Results

We found that ridge-runnel patterns generally form in very silty sediment, high in the tidal frame (above neap high water), on tidal flats of very shallow slope (< 3 degrees). The ridges of the patterns are protected by no more than a 2 mm thick layer highly cohesive erosion-resistant sediment that does not form beneath pooling water. This layer forms on extremely short time scales and can form significant erodibility gradients across the landscape within 24 hours, as long as the sediment remains undisturbed. We think that the build-up of this erosion-resistant dry layer is the key mechanism driving pattern formation, and later facilitating seedling establishment. In this regard, ridge-runnel patterns could be considered a transitional stage between a tidal flat and a marsh. Thus, when the patterns become a consistent feature of a tidal flat, it strongly indicates future marsh expansion into area. By monitoring the formation, longevity, and growing intensity of these patterns with aerial photography, we can receive prior warning of vegetation expansion potentially years in advance of the actual appearance of new vegetation.

Lower shoreface sand transport: offshore or onshore?

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Introduction

The Dutch lower shoreface is a sandy and gently sloping (1:200 to 1:1000) environment that separates the upper shoreface and the continental shelf, situated between the depths of -8m and -20m. Sand transport rates in the lower shoreface are relatively small, complex and determined by nonlinear processes. It is assumed that waves and storm events play a large role in the morphological evolution of the lower shoreface (van der Spek et al., 2022, and references therein), though the effects of storm events on lower shoreface sand transport have not been studied in depth. Most knowledge on lower shoreface sand transport stems from modelling efforts, where calculated cross-shore sand transport rates are unreliable, to the extent where it is unknown if the transport is directed offshore or onshore. This transport might impact the long term evolution of the coastal foundation and consequently may be important for coastal protection, which becomes increasingly relevant with the continuous threat of increased sea level rise.

Aim & Approach

This PhD research aims to identify and quantify dominant sand transport processes (e.g., waves, winds, density-driven currents) in the lower shoreface, with a specific interest in the effects of storm events. We will investigate the importance of these processes on shorter timescales and their influence on net sediment transport over longer (morphological) timescales. This will be done with a combination of 2DV and 3D hydrodynamic simulations of the Dutch Coast in Delft3D-FM, coupled with sediment transport equations. The research is part of the recently started MELODY (**M**od**E**ling **LO**wer Shoreface Seabed **DY**namics for a Climate-Proof Coast) project, that has the goal to improve the understanding of lower shoreface seabed dynamics and is funded by the NWO.

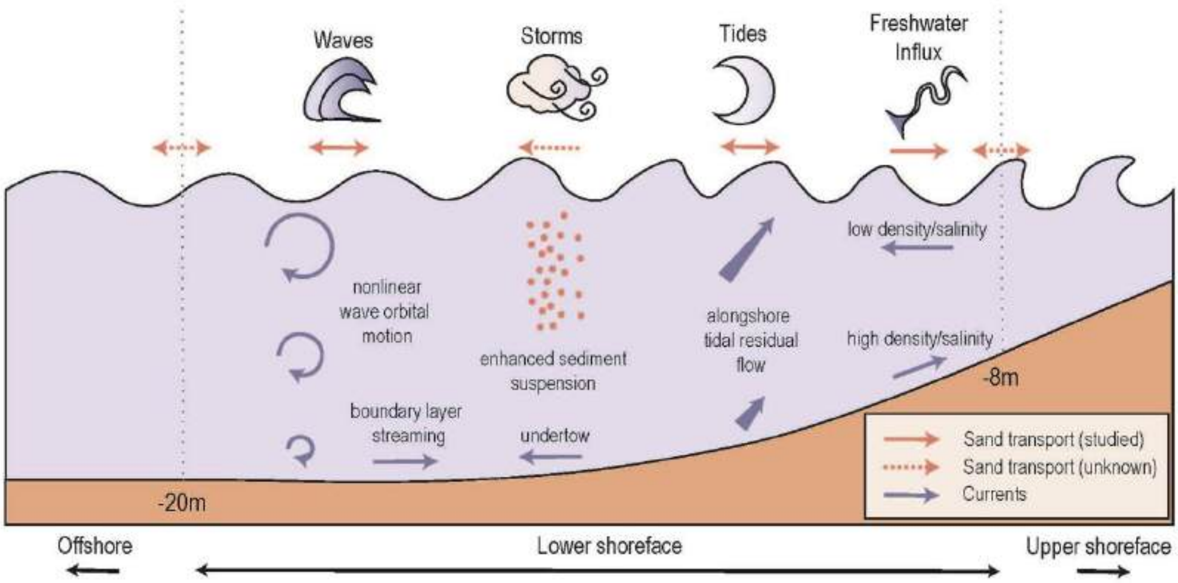

Figure 1: Schematic cross-shore overview of the lower shoreface showing different physical processes with associated net sediment transport direction. In general, these processes are stronger closer onshore.

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A framework to unify academic and applied approaches in coastal research and engineering

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Introduction

Sediment transport processes in coastal systems are extremely dynamic and complex. For example, bed properties vary spatially and temporally as forcing conditions like waves and wind change over time. Simultaneously, sediment transport both depends on the bed properties and alters the bed properties. It is nearly impossible to study or simulate the full variability and interaction between different coastal processes. However, we believe that a systematic strategy to unifying the knowledge exchange between different academic and applied research approaches can generate new insights into coastal dynamics.

Connecting academic and applied approaches through the adapted Burland Triangle

Guidance on the application of newly gained insights and the role of modeling are provided by the Burland Triangle (Burland, 1987). We have adapted the Burland Triangle that is commonly used in geotechnical engineering into a framework that fits the coastal context (ABT; Figure 1). We use the ABT to create effective interaction between different academic and applied approaches based on (a) measurements of physical properties, (b) numerical modeling and (c) coastal evolution observations. As an example, we show how field measurements of grain size variability on a beach (a) can inform generic model scenarios that can be used to evaluate the effect of grain size on aeolian sediment transport simulations (b). These simulations show that the effect of grain size variability on aeolian sediment transport may be limited under certain conditions. This finding helps to interpret and predict (c) coastal dune development. For future work, the ABT can be used as a guide to ensure that diverse approaches are integrated and that they contribute to building experience within coastal research and engineering.

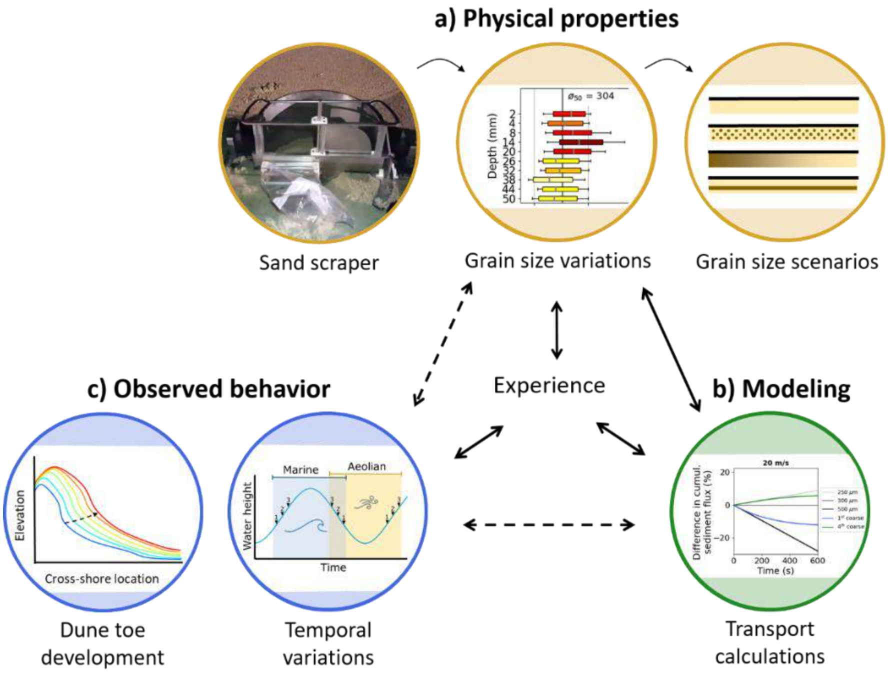

Figure 1: The implementation of recent work within the adapted Burland Triangle (ABT) which was modified from Burland (1987) to fit the coastal research and engineering context. Dashed arrows indicate potential connections between components.

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The influence of bivalve shells on sediment transport: an experimental flume study

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Introduction

Sand nourishments have become larger in scale and more complex over the last 70 years. In the coming decades, the demands for nourishment are expected to further increase due to the rising sea levels. Therefore, it becomes increasingly important to have more-reliable sediment transport predictions to help manage the placement of sand. However, in addition to sand, large quantities of mollusc shells can also be found on the ocean floor. With increasing shell content, sand ripple dimensions are reduced and ripple migration rates slow down (Cheng et al., 2021). In essence, this limits the rate of bed-load transport. Nevertheless, there is still a need to better quantify the bed-load transport of a bed composition consisting of a sediment-shell mixture. Moreover, the shape of the shells is expected to also play a role. This study aims to gain insight into current-driven bed-load transport of a sediment-shell mixture using bivalve shells of different shapes and sizes.

Methods

Flume experiments were carried out in the racetrack flume facility at the NIOZ Royal Netherlands Institute for Sea Research (Figure 1a). The flume is equipped with a conveyer belt to generate unidirectional flow. A set of two separate experiments were conducted: (i) a slowly accelerating flow experiment to measure the influence of bivalve shells on the threshold of motion of sand particles, and (ii) a constant flow experiment to measure their influence current-driven bed-load transport (Figure 1b). In the constant flow experiment, flow velocities ranging from just below (0.25 m/s) to well-above (0.45 m/s) the threshold of motion were tested. The sediment-shell bed composition was altered in both experiments by changing the volumetric percentage of shell content. The bed compositions consisted of two different bivalve shell species: *Ensis leei* (elongated) and *Spisula subtruncata* (rounded)(Figure 1c).

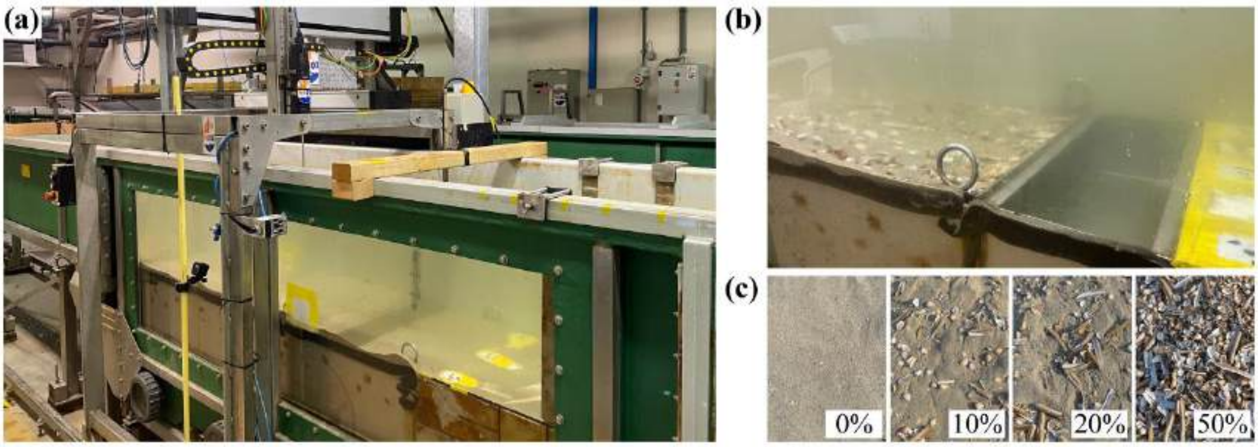

Figure 1: (a) The racetrack flume. (b) Bed-load trap used during the constant flow experiments. (c) Bed composition with changing percentages of shells.

Results

Here we show preliminary results of the influence of shells on the threshold of motion of sand particles under varying bed compositions. Additionally, we quantify the bed-load transport over time for the different flow velocities. Finally, we relate this to characteristics such as particle size and shell cover. Preliminary results show that the dry-weight of the transported material reduces with the presence of shells. Moreover, we have observed an increase in shell cover over time.

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Longer-term morphological evolution of the Belgian coast in relation with the nearshore shelf

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Introduction

A coastal morphological analysis (Houthuys *et al.*, 2022) has been conducted on high-resolution surveys of the Belgian coastal zone, spanning the dune front or seawall area down to the nearshore channels and sandbanks up to 1500 m offshore. In the MOZES project (Dujardin *et al.*, 2023), bathymetric charts of a mid-1980s survey covering the nearshore and inner shelf zone (up to ca. 12.000 m offshore) have been digitized and compared to a recent survey of the same area (Figure 1).

Methods

LIDAR data of the area above low water are available at a (semi-)annual interval since 1999. Below low water mainly single-beam echo soundings are used; multi-beam data becomes more frequent since 2007. Time series of sand volumes have been computed per coastal stretch. They have been corrected for artificial removal by dredging or sand borrowing and supply by nourishments. Volume changes have been studied in their spatial context.

Results

Flow channels flank much of the Belgian beaches. It is observed that they have deepened over time. It is hypothesized that the tidal flow in the channels is subject to squeeze: the shallow sandbanks at the seaward side are under the presently slowly rising sea levels migrating shorewards, while the coast is kept at its location, and even expanded seaward, by nourishment. As a result, these channels can only maintain their flow section by eroding their bed. The nearshore sandbanks do migrate, with rates of a few m/yr in the landward and a few tens of m/yr in the eastward direction. These conclusions will be further substantiated within the MOZES project, using more inner shelf zone surveys.

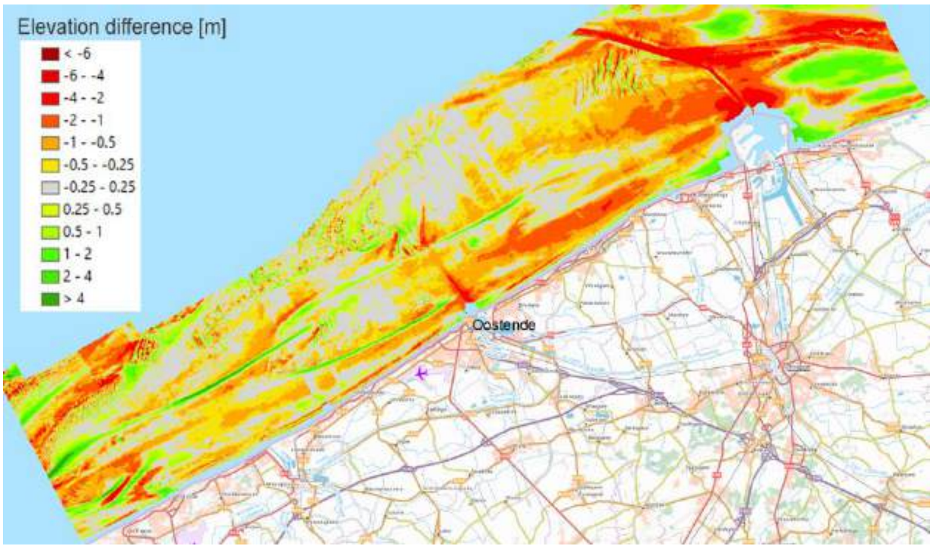

Figure 1: Elevation difference map of the overlap area between the 1984/7 and the 2022 bathymetric maps.

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The impact of sea level rise and a changing discharge on salt intrusion in the Rhine Meuse Estuary

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Abstract
Climate change is expected to cause sea level rise and both higher and lower river discharge extremes. The resulting increase in water depth and lower discharges will both enhance the surface water salt intrusion and reduce freshwater availability. To infer the impact of a changing discharge regime, ideally long timeseries of current and future discharge conditions are modelled (Mens et al., 2021). But in stratified systems, like the Rhine Meuse Estuary, computationally intensive 3D models are needed for a correct representation of the governing physical processes.

In this study, we developed a method to derive the combined impact of sea level rise and a changing discharge regime on salt intrusion based on a limited set of 3D simulations, with and without sea level rise. By combining this with the low-flow event probability (from a 100-year timeseries), the frequency and duration of the problematic salt intrusion events can be retrieved for both current climate and future projections.

Our results indicate that the impact of sea level rise and a changing discharge regime will lead to strong changes in return period of problematic salt intrusion events in the Rhine Meuse Estuary (high-end KNMI'14 projection for 2085), see figure 1. The probability of a problematic salt intrusion event is expected to increase from rare (once in 50-100 years) to frequent (once in a few years). The impact of the changing discharge regime is thereby larger than the impact of sea level rise. With the same method, we investigated the impact of a changing bed level and showed that the climate change impact is much larger than the impact of a bed level change of 1.0 m applied to the seaward 30 km section of the estuary. This implies that mitigation of salt-water intrusion by shallowing the entrance channel will require large bed level changes.

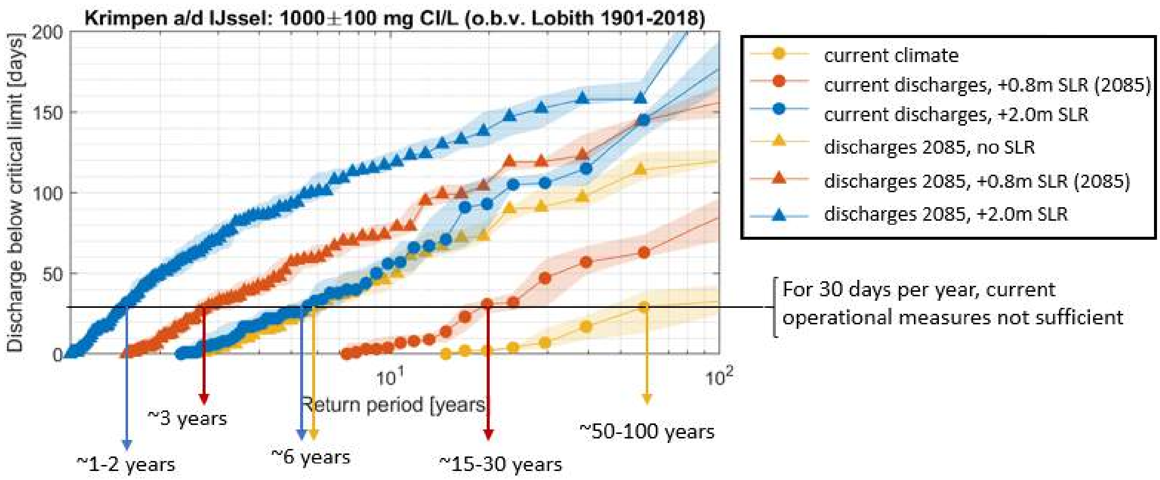

Figure 1: The impact of sea level rise and a changing discharge regime on the return times of salt intrusion events at one of the critical locations for fresh water in the Rhine Meuse Estuary. For sea level rise 0.8 m (high end KNMI'14 projection for 2085) and 2.0 m were taken. The discharge regime projection is based on high-end KNMI'14 projection for 2085 (Sperna Weiland et al., 2015).

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How SANDsitive are seafloor animals in the Wadden Sea?
Quantifying sandification sensitivity of Wadden Sea benthic communities

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Introduction

The composition of benthic communities is strongly associated with the particle size of the sediment they are found in. Particle size depends on the environmental forcing that the sediment is exposed to. As such, sea level rise, increased occurrence of storms, and changes in sediment supply could drive coarsening of currently muddy coastal sediments. Benthic fauna are thus expected to be affected by this 'sandification'. Species-sediment relationships allow the prediction of how these changes may be manifested. We explore quantile-regression models to obtain detailed species-sediment relations for a Wadden Sea tidal basin, with the purpose to identify sensitivity of benthic communities to changes in sediment composition. Such detailed knowledge of area-specific sensitivity is needed if we want to inform coastal management decisions, for instance on the consequences of sediment nourishments.

Methods

Quantile regression models give a complete view of a species' distribution over an environmental variable range and take into account different response rates for the lower and the higher ends of the distribution. The top quantiles reflect the optimum habitat for the species, where limitations from other environmental constraints are minimized. Non-linear quantile regression models are fitted to benthos biomass and abundance data collected from the Ameland Inlet and ebb-tidal delta. Within this dataset, environmental gradients from inter- to subtidal and from muddy to sandy sediments are covered. Species-specific sediment relations are classified from generalists to specialists, and from mud- to sand-loving. These parameters are summarised per community and per area.

Results

Here we present our first results on sandification sensitivity per species, community and sub-area. The modelled predictions for species abundance and biomass over sediment gradients are used to determine changes in abundance, biomass and community composition at different levels of coarsening over the study area. Eventually, these results will be implemented in an online tool to illustrate benthos responses to changes in sediment composition.

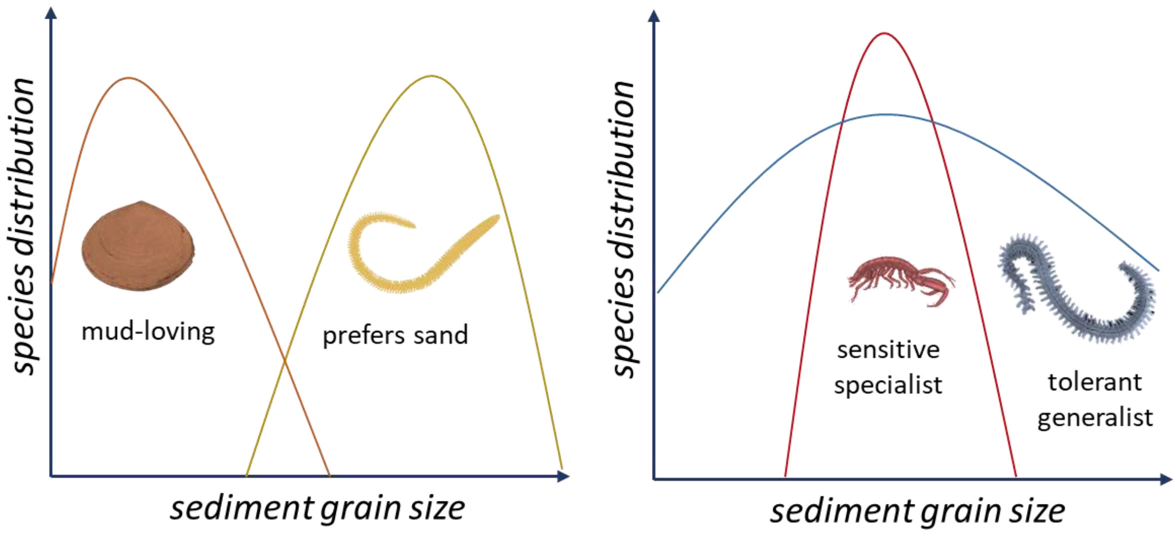

Figure 1: Conceptual figure of benthic species' sediment preferences and tolerance to coarsening. Left: the clam Scrobicularia plana *(brown) is an a mud-loving species, while catworm* Nephtys cirrosa *(yellow) is found in coarse sediments. Right: while ragworm* Hediste diversicolor *(blue) occurs over a wide range of sediment textures, the mud shrimp* Corophium voluntator *(red) has a very narrow distribution.*

How vegetated foreshores can contribute to limiting dike dimensions of sea dikes: a case study into the assessment and design procedure of including the quantitative effect of the foreshore in the flood defence system

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Introduction

Due to the inevitable effects of climate change, more frequent and more extreme storms will take place. In addition, Sea Level Rise (SLR) will be present such that the pressure on coastal flood protection increases. Moreover, since the magnitude of the effects of climate change is still uncertain, there is a great need for primary flood defences to be adaptive. Due to the self-organising behaviour of ecosystems, there is more often looked for solutions that work together with nature resulting in Nature-based flood defences. In this research, the Wide Green Dike (WGD) pilot study in the Ems-Dollard estuary in the Netherlands is used as an example of a Nature-based flood defence. For the WGD pilot study, 1 km of dike is being reinforced with a thick clay layer on the seaward side while also decreasing the outer dike slope to fulfil the safety standards against erosion. Besides the adaptive capacity of this reinforcement, a wide vegetated foreshore is present in front of the dike. Due to the self-sustaining behaviour of this foreshore, caused by the enhancement of sedimentation by the presence of vegetation, the foreshore should be able to grow along with SLR. Moreover, due to the capacity of the vegetation to mitigate wave conditions by increased bottom friction, especially effective during daily conditions, the vegetated foreshore lowers the hydraulic boundary conditions. As a result, the vegetated foreshore could limit the required dike dimensions under extreme storm conditions but could also strongly influence the needed dike maintenance if dike erosion is prone to arise for example. Doing so, a more sustainable dike reinforcement arises. The above-described processes are visualised in Figure 1.

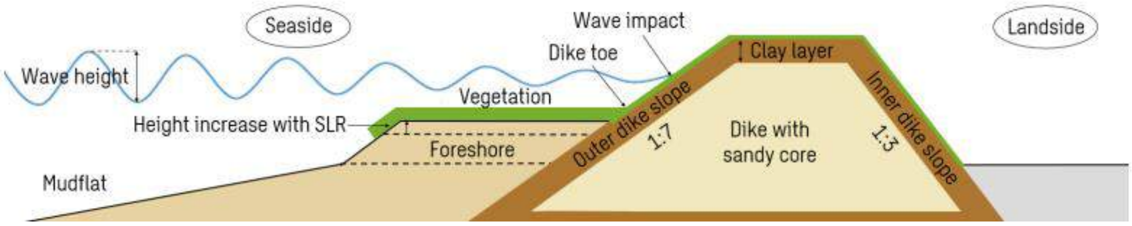

Figure 1: Visualisation WGD pilot study

Methods

With the use of a Simulating Waves Nearshore (SWAN) model, a sensitivity as well as scenario analysis was conducted. For the sensitivity analysis, there was looked into the model input parameters as well as the foreshore dimensions and the method of the SWAN model to implement the effect of vegetation. Within the scenario analysis, changes to foreshore dimensions were combined with an indirect method to include vegetation. Finally, the potential influence of the foreshore was linked to their influence on the required dike design.

Results

The sensitivity analysis showed that the water depth on the foreshore has a greater influence on the significant wave height than the width of the foreshore (for the WGD transect). Moreover, by including vegetation in the method of the model, the significant wave height showed a significant decrease. Together with the conducted scenarios analysis it could be concluded that the foreshore potential depends on the ability of the foreshore to pace with SLR and the presence of vegetation which causes increased bottom friction.

When comparing the required dike dimensions if foreshore height increase (with SLR) and the influence of vegetation are not taken into account (current approach) with using an approach where those influences are taken into account, a required height decrease of 22 cm and clay layer thickness decrease of 31 cm arises. This concludes that the (changing) foreshore dimensions and vegetation are of great importance to lower the hydraulic boundary conditions and thus required dike dimensions of the WGD.

Tracing Sand Nourishment Dispersal by Modelling Light Exposure History

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Introduction

To mitigate the threat of coastal flooding and erosion, sand nourishments are commonly employed to preserve coastal sediment buffers. However, keeping track of where these nourished sand grains go and distinguishing them from natural local sediment is still challenging, especially in locations with complex flow and transport patterns (e.g., tidal inlets). Here we propose a new tool for our coastal management toolbox: numerically simulating the exposure of sand grains to sunlight as they travel along the coast. This approach is a first step towards using an intrinsic light-sensitive property called luminescence to track nourished sand.

Methods

We use field measurements from the Dutch Wadden Sea to estimate the relationships between suspended sediment concentration, sand versus mud content, chlorophyll content, and light attenuation as a function of water depth. Our measurements reveal strong differences in suspended sediment concentration and consequent light penetration depending on seasonally varying storminess. These relationships are then introduced into a numerical sediment particle tracking model (SedTRAILS) of Ameland Inlet.

Results

SedTRAILS can then predict the cumulative exposure history of a given sand particle to light. We show that light exposure of sand grains on intertidal flats and shallow shoals is up to three orders of magnitude greater than in deeper areas (e.g., lower shoreface where nourishment sand originates). This model will be complemented by ongoing field experiments to quantify how subaqueous light exposure determines luminescence signal resetting rate of feldspar mineral grains. Together, these components will enable us to better predict luminescence signal resetting rates and hence fate of nourished sand, making a useful tool for more strategic coastal protection.

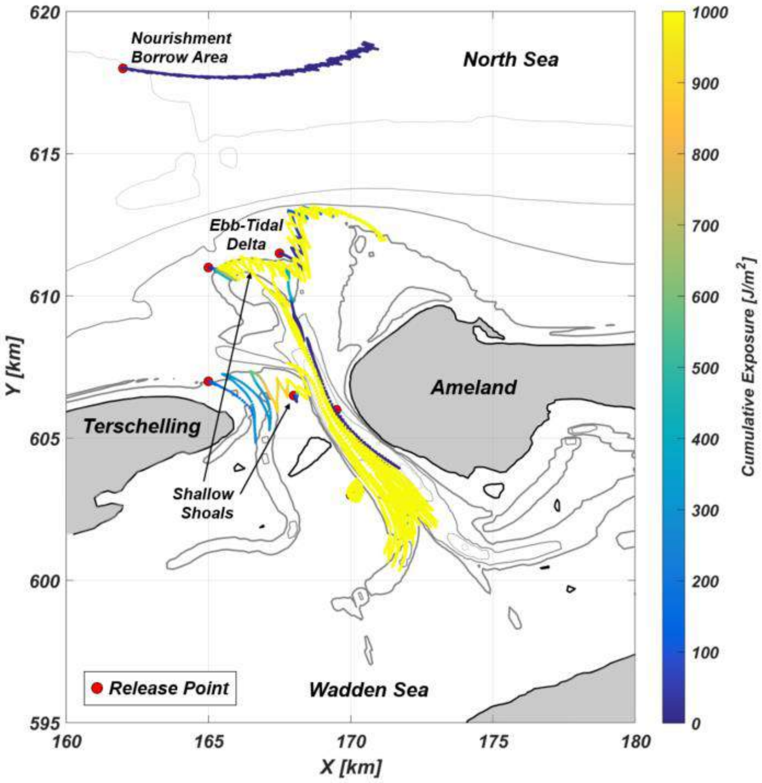

Figure 1: Example showing modelled cumulative light exposure of sand particles released for 30 days at Ameland Inlet, the Netherlands. Brighter colours indicate greater light exposure but do not yet reflect actual luminescence signal resetting, which will be resolved by ongoing field experiments.

Unravelling the drivers of salt marsh cliff initiation

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Introduction

Coastal vegetated wetlands are increasingly recognised for their wave attenuating role in nature-based flood defences (NBFD), which depends on the marsh retaining a sufficient cross-shore width. Consequently, processes at the saltmarsh-mudflat interface which determine saltmarsh growth or retreat are highly relevant for coastal defence. Given that lateral marsh erosion (retreat) is usually triggered by the formation of a cliff at the marsh edge, unravelling cliff initiation represents a major knowledge gap for the implementation of NBFD. Several studies have suggested that wind-waves may drive height differences between the mudflat and marsh edge, thereby causing the initiation of a marsh cliff (Callaghan et al., 2010, Bouma et al., 2016). We hypothesize that height differences between the unvegetated mudflat and vegetated marsh result from an offset in erodibility under increased hydrodynamic conditions, driven by differences in biogeomorphic sediment characteristics.

Methods

Field measurements were taken along a marsh edge gradient (cliff to no-cliff) to compare sediment stability and properties. Novel *fast flow flumes* were used to test field cores for an offset in erosion rates between the vegetated cliff top and cross-shore neighbouring unvegetated mudflat, while *wave mesocosms* were used to quantify the contribution of sediment characteristics to driving offsets in erodibility. Preliminary results and further measurements plans will be presented.

Results

Field measurements showed a greater contrast in sediment characteristics across the cliff edge compared to a 'no-cliff' edge. A clear offset in erodibility was evident across a cliff edge, with novel *fast-flow flume* tests revealing vertical erosion of samples being 54 ± 12 % in the mudflat compared to 3.4 ± 3.8 % in the vegetated cliff top. Finally, coarser, less cohesive sediment eroded more rapidly in a *wave mesocosm*, highlighting the role of sediment characteristics in driving an erodibility offset. Preliminary results imply that an offset in sediment parameters under homogeneous hydrodynamic forcing is a key driver of cliff initiation.

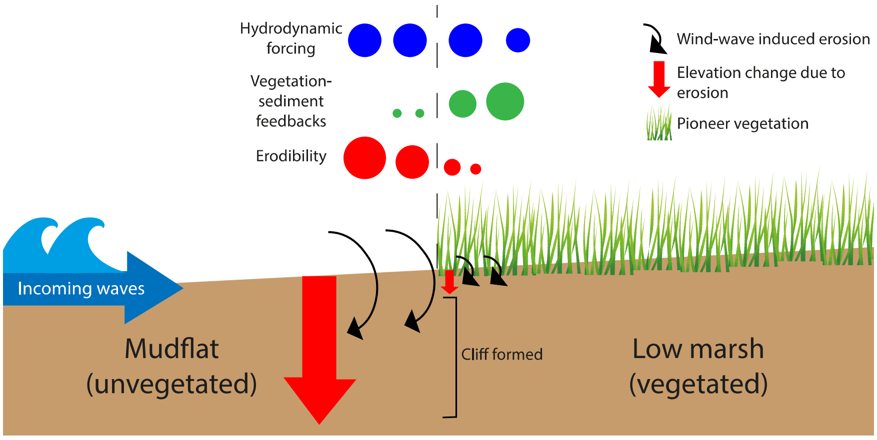

Figure 1: Conceptual figure showing differences in erodibility across a saltmarsh edge, leading to cliff formation due to wind-wave induced erosion.

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Key research required for the safety assessment of the Dutch sandy coast

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Introduction

Sandy coasts (e.g., beaches and dunes) protect large stretches of the Dutch coast against flooding. To maintain an adequate level of flood protection, primary flood defences are regularly evaluated as prescribed by the Dutch Water Law. The safety assessment methodology for sandy coasts was recently updated within the framework of the program BOI (Assessment and Design of Flood Defences). This process contributed to the identification of key research gaps in the source-pathway-receptor-consequence chain of the current coastal flood risk assessment in the Netherlands.

Knowledge agenda

In Q4 of 2022, Deltares, Arcadis and Rijkswaterstaat organised workshops with experts on sandy coasts and flood risk in the Netherlands to identify key areas of future research. The results of these workshops were used to develop a knowledge agenda for research within the Rijkswaterstaat "Kennis voor Keringen" program, focussing on the need to improve flood risk assessments for purely sandy coasts (i.e., dune coasts), as well as hybrid (e.g., dike-in-dune) coastal defences.

At the NCK days 2023, we would like to share these key research gaps with interested parties and discuss upcoming or potential research that can contribute to an improved safety assessment of the Dutch coast.

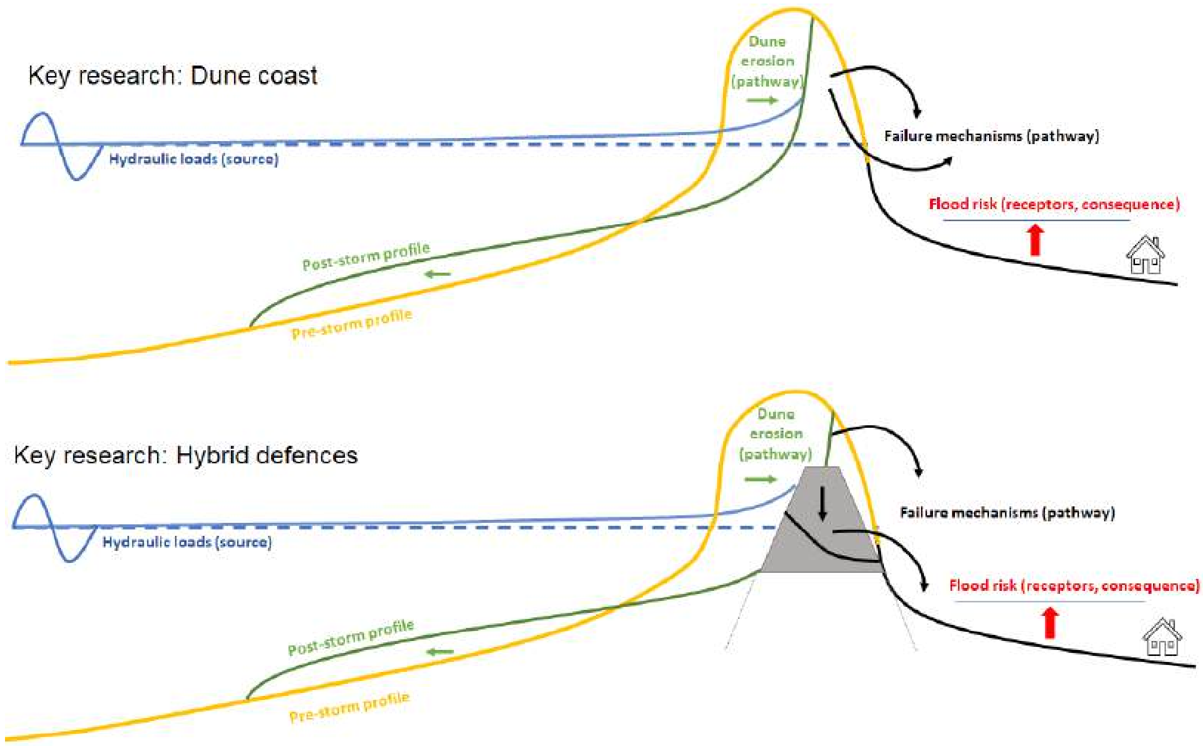

Figure 1: Categorization of research questions in the knowledge agenda in sources (hydraulic loads; blue), pathways (dune erosion, green; further failure mechanisms, black), and receptors and consequences (flood risk, red) for dune coasts and hybrid defences.

Large scale coastline modelling in Belgium for design and quick assessment of coastline adaptation

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Introduction

Climate change and anthropological interventions are changing the landscape of coastal zones. Coastline evolution models are key to design adaptations for coastal zone management. Several process-based models exist to predict coastline evolution with varying accuracy and computational needs. One of these is ShorelineS (Roelvink et al. 2020), used in this study, which adopts a vector-based approach and is able to deal with complicated coastline features such as spits and shoals and is relatively fast.

Study area

The present analysis focusses on the entire Belgian coastline (67 km long), along which multiple harbours are located, for which a few different coastline adaptation alternatives are being developed. The hydrodynamic conditions are characterized by; mean spring tidal range of 5 m, significant wave height of 1 m and peak period of 6 s. Waves from the southwest and the north-northeast are dominant wave conditions in longshore sediment transport along the Belgian coastline.

Model setup & calibration

To set up and calibrate the ShorelineS model, an initial coastline (LiDAR data from 2009), a wave climate (wave timeseries 30 km offshore, Westhinder) and the position of the harbours (satellite imagery), were extracted. The model is calibrated by varying several model parameters, for a 9-year period (2009-2018), such as; the active profile height, the sediment transport efficiency and the nearshore refraction depth. The calibrated model includes the nourishments during this period as well.

Application of the model in designing adaptation alternatives

The calibrated model is used to simulate a 5 year simulation using the current coastline and harbour locations and hydrodynamic conditions (named ‘reference case’). After that period it is observed that the location of the shoreline hardly varies, and thus a ‘stable’ shoreline is obtained (Figure 1) . The orientation of this ‘stable’ coastline is then used as baseline to build up potential adapted coastlines (named ‘alternatives’), aiming at reducing the alongshore sediment transport gradient and consequently reduce erosion and need for maintenance (nourishments). The model is then used to evaluate these alternatives on the basis of required nourishment.

Conclusion

In this study it is shown how a quick and useful tool can help design and evaluate coastal adaptations, by providing the opportunity to evaluate different alternatives in reasonable time and reduce the number of viable alternatives.

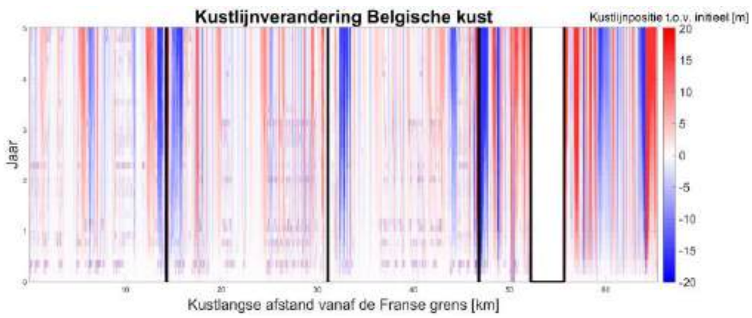

Figure 1: Cumulative evolution of the Belgian coastline, red shows sedimentation and blue erosion.

Acknowledgement

The authors want to acknowledge “Vlaamse Overheid, MOW – Afdeling Maritieme Toegang” for the financing of this study as part of the project of Kustvisie (Vlaamse Regering, 2017).”

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The impact of tidal creeks on the morphology of a tidal flat

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Introduction

Tidal flats are heterogeneous landscapes with a variety of topographic features (bed forms). These bed forms influence the biotic and abiotic conditions of the tidal flat. Creeks are a specific bed form that cut through a tidal flat and are oriented perpendicular to the main channel (Figure 1). Previous measurements show that flow velocities in such a creek can be significant compared to the flow over the tidal flat. It is not known how creeks affect the hydrodynamic conditions and sediment transport of a flat and what the zone of influence is.

Methods

We measured the flow velocity, water levels, sediment concentration, bed composition and bed level in a creek and on the adjacent tidal flat in the Loire (France), during a one month field campaign. We placed 10 frames with instruments in, close to and at distance from the creek to cover the spatial variation.

Results

The measurements showed a clear distinction of the function of the creek between ebb and flood conditions. When the flat starts falling dry, the creek starts playing a more dominant role. The creek keeps discharging water even when the surrounding flats are virtually dry. Remaining water cannot flow over the tidal flat itself, but can only be discharged via the creek and connected smaller creeks. The creek discharges water with a flow velocity in the order of centimeters per second. Consequently, the duration of ebb flow in the creek is significantly longer than the duration of the flood flow. With this drainage function the creek affects the net sediment transport on the tidal flat (depending on the sediment concentration) and the dewatering of the bed material and its resulting strength.
The bed samples show that the grainsize becomes smaller towards the creek. This refining is more pronounced for a larger creek depth. This indicates that a creek can affect the bed composition in the adjacent region, depending on its depth.

Based on the measurements of this fieldwork, we can quantify the effect of a creek on the hydrodynamic conditions, sediment fluxes and bed composition of a tidal flat, which is crucial to understand the flat morphology and biotic conditions. This knowledge makes it possible to use creeks as an indicator for the morphological and ecological state of a tidal flat in estuarine management.

Figure 1: Frames with instruments placed in a creek and on the adjacent tidal flat in the Loire estuary.

Effect of sea level rise and artificial deepening on peak water levels in deep tidal channels

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Sea level rise (SLR) is predicted to accelerate in the coming decades. With globally decreasing sediment supplies, sedimentation cannot keep pace with SLR and many estuaries and deltas are at the risk of becoming deeper. At the same time, many estuarine channels are artificially deepened for navigation purposes. These factors potentially favour amplification of the tides through reduced friction. As a result, the increase of peak water levels may exceed mean sea level rise in deepened channels, leading to a higher flood risk in these areas. The extent of this effect however is largely unknown, and other mechanisms affecting tidal amplification may be relevant. Here, we investigate the tidal response to increasing channel depths by both SLR and artificial deepening in the Rhine-Meuse Estuary (RME).

The RME is an example of a deepened multi-branch delta that has undergone many human interventions. We introduce and use a validated model for the multi-branch RME to systematically model the effect of increasing channel depth. The response of the tidal range and peak water levels is analysed for different scenarios in terms of river discharge and wind setup, aiming for a mechanistic understanding of non-linear SLR-effects on peak water levels.

Results show that, when the current bed level will be maintained, sea level rise reduces the inland tidal range (Figure 1). The expected tidal amplification caused by the increasing water depth is compensated by the decreasing channel depth convergence after SLR. Thus, peak water levels increases less than the mean sea level. Our mechanistic explanation shows that this effect is relevant for deep channels, which are typically engineered shipping channels as present in urbanized deltas worldwide. Contrary to the effect of SLR, local channel deepening has an amplifying effect on the tides on the short term due to increased depth convergence. Nevertheless, the effect of 1 m SLR extends far beyond the range of present-day seasonal variations and tidal damping. This implies that only a minor part of the SLR-effects can be mitigated if channels are allowed to shallow in the coming decades.

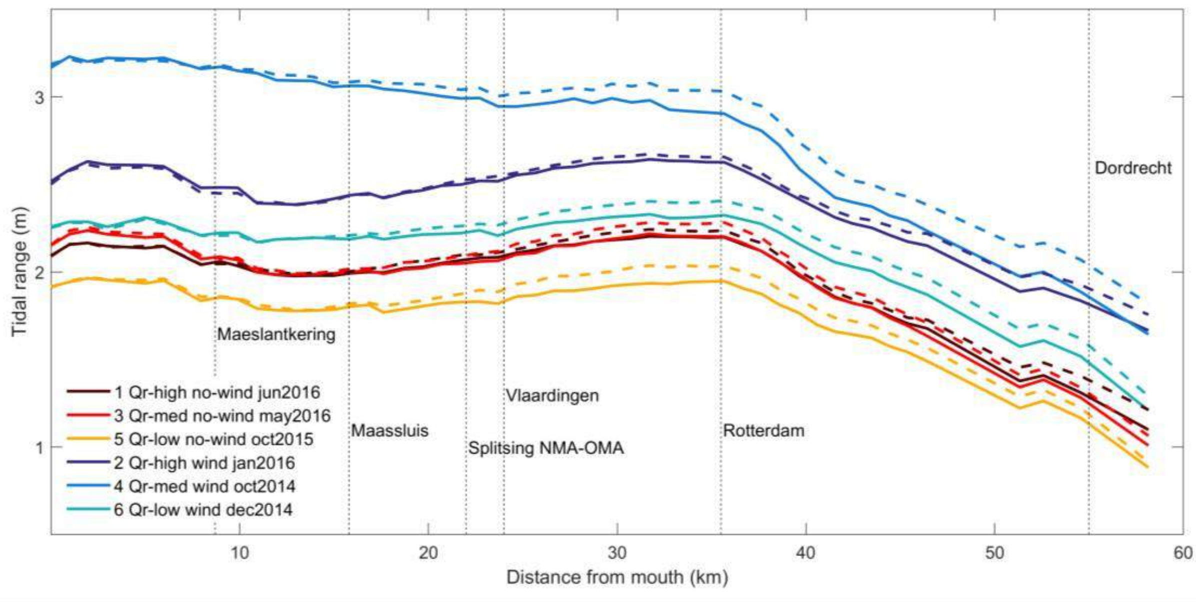

Figure 1: Tidal range along the northern branch of the Rhine-Meuse estuary for different scenarios before (dotted lines) and after (solid lines) 1 m sea level rise, for different forcing conditions.

Millimeter-scale beach topography measured with structure-from motion photogrammetry

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Introduction

Structure-from-motion (SfM) photogrammetry computationally combines photos from different points of view into a 3D model of an object or area. This technique can be used at the beach to make high-resolution DEMs (digital elevation models), point clouds and orthophotos (distortion-free top views). During my PhD on the morphological effects of beach buildings, I used SfM photogrammetry to take millimeter-scale measurements of beach topography around scale models of buildings. This contribution will focus on showcasing the power of SfM photogrammetry for high resolution topography measurements and possible spin-off opportunities this dataset may offer.

Methods

During the experiments, boxes were placed on the beach as scale models of buildings, at Terschelling, the Sand Motor and Noordwijk. Beach topography around the scale models was measured, for areas of up to 60×60 m. For these measurements, 1000 to 2000 photos were taken from a height of approximately 5 m, using a drone or a camera on a telescopic stick. Using SfM photogrammetry, this resulted in orthophotos and digital elevation models with a resolution of approximately 2 mm (Figure 1).

Data availability and use cases

The topographic datasets are publicly available online (Poppema et al., 2021; 2022) and can be used to further study morphological effects of beach buildings. Moreover, because of the extremely high spatial resolution, the data could also be used to explore or study completely different topics, e.g. bed roughness or the size and shape of aeolian ripples.

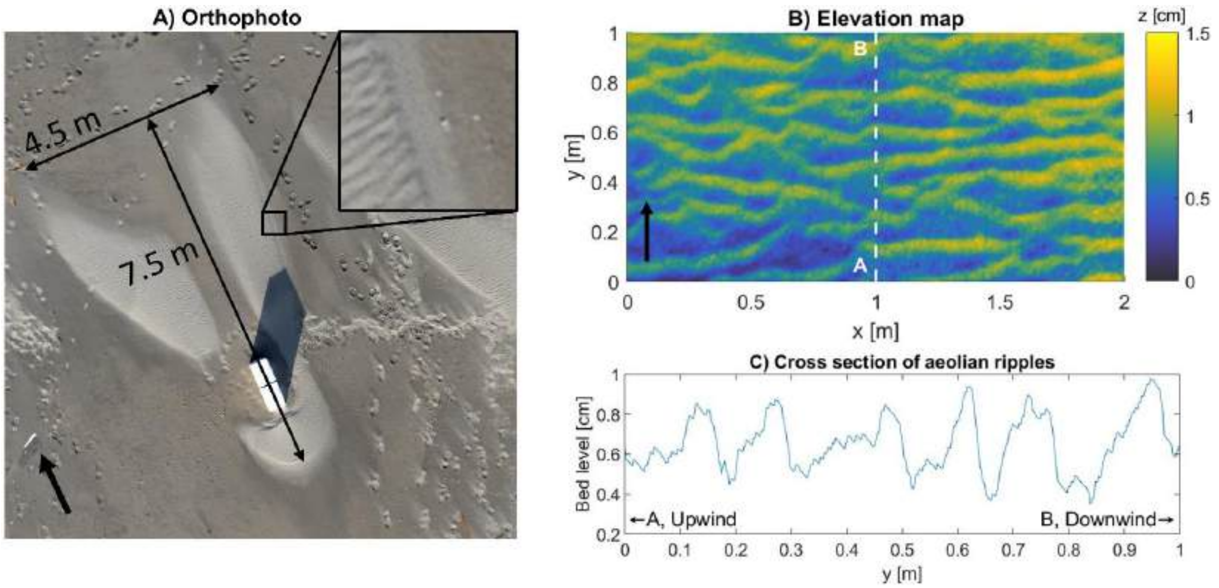

Figure 1: SfM results. A) Orthophoto of deposition (lighter colored sand) around scale models. B) DEM of beach area with aeolian ripples, unaffected by scale models. C) Cross section of the dashed line in B).

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Quantifying the effects of bedforms on basin-scale hydrodynamics

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Introduction

The effects of bedforms (tidal sand waves as well as sand banks) are usually not considered in hydrodynamic basin-scale modeling studies (see Brakenhoff et al., 2020, and references therein). Instead, the friction coefficient is taken as a calibration parameter, moreover it is taken constant in the entire domain. We derive a physics-based mathematical formulation to parametrize the bed shear stress experienced by the flow over a bedform field in a basin-scale domain (such as the North Sea).

Methods

The depth-averaged, shallow water equations on the *f*-plane are spatially averaged over bedform field scales. For convenience, as a first step, we consider the local bed shear stress (τ_b) to depend on the linear friction coefficient r, $\tau_{b,x} = ru$, $\tau_{b,y} = rv$, where u and v are the depth-averaged components of the flow. The resulting parametrizations include information on the local bedform characteristics, such as shape, height and orientation. Thus, a basin-scale model using such parametrizations could solve the hydrodynamics without resolving each bedform, but still account for their effects.

Results

We have computed the *effective* friction (that containing the effects of bedforms) for two different bedform profiles (one purely sinusoidal, and the other more sharply crested, see Figure 1). Results show that the friction coefficient increases with increasing bedform height. Furthermore, the friction depends on the bedform shape, as well as on the orientation with respect to the flow (the latter not being shown here).

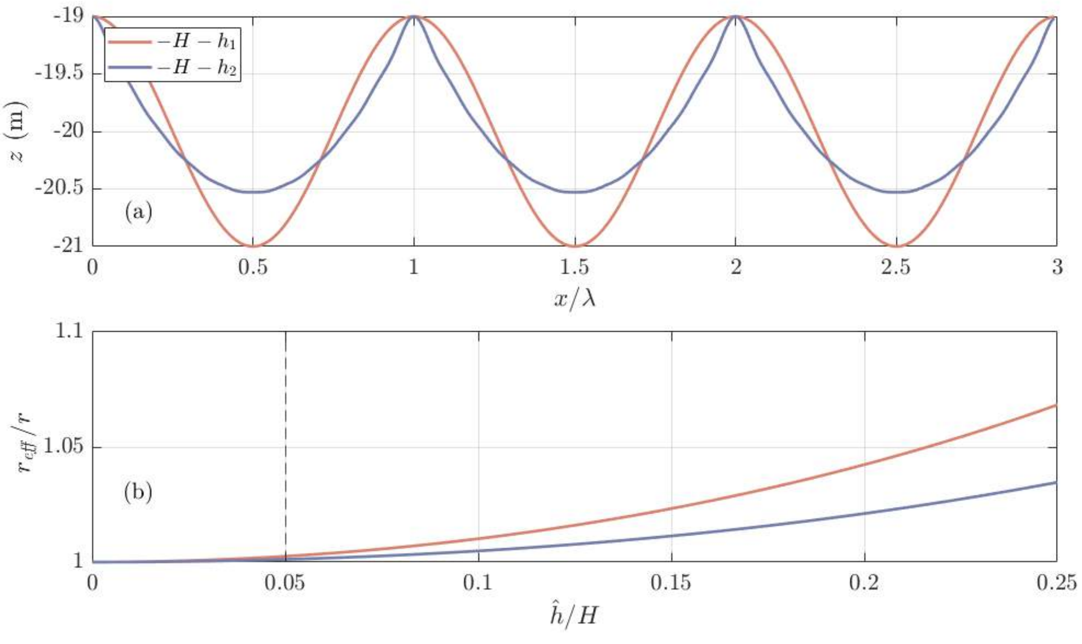

Figure 1: (a) Different sand wave profiles used in the present study, and (b) resulting effective friction coefficient r_{eff} relative to the reference friction r for different sand wave field amplitudes ($\hat{h}$) to mean water depth (H) ratio. The vertical dashed line in panel (b) corresponds to the situation depicted in panel (a), where the sand wave field amplitude is 1 m, and mean water depth H = 20 m. We have taken the Coriolis parameter representative of the North Sea ($f = 1.15 \cdot 10^{-4}$ s^{-1}), and a linear friction coefficient $r = 2.5 \cdot 10^{-3}$ m/s.

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Duration of saltwater intrusion shapes freshwater trees' response to salt stress

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Introduction

In many estuaries worldwide, saltwater is intruding further and further inland. As it progresses inland, it can reach freshwater wetlands previously inaccessible to saltwater. This reduces vegetation growth, increases mortality, and promotes colonization by new salt-tolerant species. Ecosystem services, like flood defence and carbon sequestration, decline. However, the duration and intensity of saltwater intrusion varies significantly among estuaries. Even minor differences between environmental factors or their interactions may lead to considerable differences in plant response. Yet, their specific influence on plants is still uncertain.

Methods

In this study, we exposed 3 common freshwater trees (willow *Salix alba*¸ alder *Alnus glutinosa*, and elderberry *Sambucus nigra*) to a combination of 2 tidal regimes (tidal and non-tidal), 3 different salt concentrations (freshwater, 2 PSU, and 5 PSU), and 2 durations of salt stress (continuously exposed to saltwater or only one week each month).

Results

Contrary to common belief, our results suggest that alders can live in tidal conditions and tolerate saltwater better than willows. Moreover, occasional saltwater intrusion causes lower damage to plants, even when repeated over time. As most Dutch riverine wetlands are now dominated by willow trees (mostly planted for human use), they might be more vulnerable than alder wetlands. As an alternative to current efforts to completely exclude saltwater from wetlands, increasing species composition (e.g., by planting alder) and reducing the time plants are exposed to saltwater might provide a cost-effective method to maintain ecosystem health.

Figure 1: Carnisse grienden: a willow-dominated wetland in the Netherlands (image courtesy: E. Saccon).

Estuarine salt-intrusion affected by changing channel depth and intertidal width

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Introduction

Estuarine regions are unique regions where fresh- and saltwater meet. Freshwater discharge drive export of saltwater while density driven gravitational flow imports salinity, driving estuarine circulation. During low river flow, saltwater intrudes farther into the estuary, limiting freshwater availability.

Worldwide, estuaries are undergoing constant human interventions to utilise the regions natural resources optimally. To allow large ships to enter the ports, channels are deepened and subsequently are constantly dredged to maintain channel depth. In addition, intertidal wetlands are claimed for human use and subsequently embanked for flood-safety. However, a trend is developing to restore intertidal area, as a nature-based solution for flood protection and sediment trapping. A consensus exists that salinity intrusion increases with channel depth, while the impact of channel deepening on estuarine circulation and stratification may vary. However, the impact of intertidal restoration or reclamation on salinity intrusion is not well known. This study aims to explore the impact of two human interventions on fresh-salt water dynamics: 1) Changing of the channel depth and 2) changing intertidal area.

Methods

An 3D-hydrodynamic model is developed in Delft3D-FM, representing a part of the Rhine-Meuse Delta (RMD). A schematised bathymetry is developed, simplifying the model while keeping the essentials. This way, computation times are reduced while making results more generically applicable. The model is validated by hindcasting two 10-day periods, during a low and average-high discharge period. Simulated water levels and salinity at 3 depths are validated at one point in the channel.

Channel deepening is implemented (but also undeepening of the channel) by a uniform change in channel depth. Changing intertidal area is performed by varying the depth of the intertidal over a 15km stretch along the channel. Beach barriers separate the intertidal from the coast, representing the system of the past, such that the width of the estuarine mouth remains constant.

Results

The model shows relatively good performance in predicting salinity values over the stratified estuary. Channel deepening increases both stratification and saltwater intrusion length (Figure 1). Intertidal restoration increased ebb & flow velocities within the channel, but not uniformly over the water depth. This in turn reduced stratification within the channel. Less stratification reduces the estuarine exchange flow, the dominant driver for increasing saltwater intrusion length (Lerczak et al; 2006). Consequently, intertidal area was able to limited salt intrusion lengths (Figure 1).

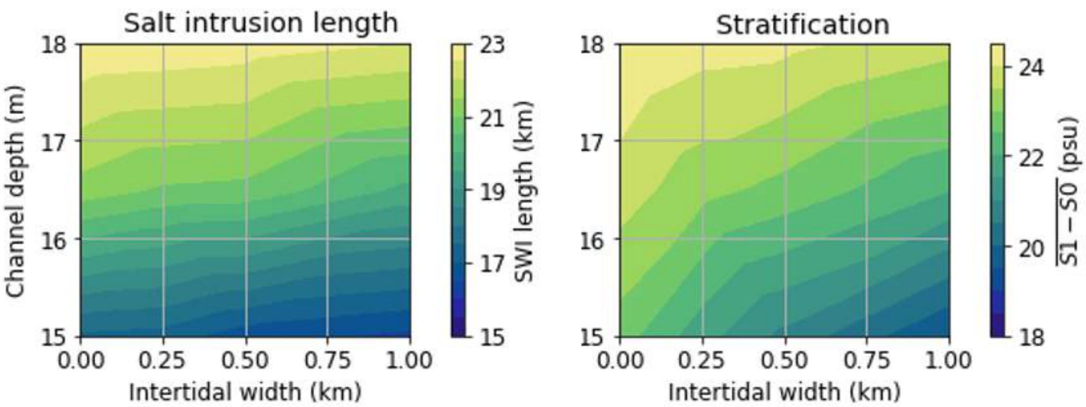

Figure 1: Saltwater intrusion and stratification affected by channel depth and intertidal width

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Conceptualizing aeolian sediment transport modes in a bio-geomorphological cellular automata model of the beach-dune system

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Introduction

Aeolian sediment transport plays a crucial role in the growth of foredunes. The cellular automata model DuBeVeg (Keijsers et al., 2016) provides a powerful tool for simulating bio-geomorphological evolution of sandy beach-dune systems, as it captures the key elements and interactions of aeolian, hydrodynamic and vegetation dynamics in a simple and efficient manner. The model has successfully been applied to beach-dune systems along the Dutch coast, providing useful predictions of beach-dune evolution over decadal time scales, generally focussing on final states rather than the transient path towards that state. Currently, sand transport in DuBeVeg is predominantly represented as bedload transport, or ripple migration. When we consider shorter time spans and very wide beaches, this representation seems to misrepresent the timing of embryo-dune and foredune development as well as the rate at which sand is transported over longer distances. This study explores a different representation of the aeolian transport in DuBeVeg to reflect transport by saltation rather than ripple migration.

Methods

DuBeVeg simulates sediment transport through the stochastic movement of slabs of sand, which are picked up by the wind and moved across the domain in the downwind direction over a fixed distance, the jumping length L. This allows for the self-organization of the slabs resulting in the emergence of new dunes. At the same time the movement of slabs represents, in an aggregated manner, the transport of grains of sand. Consequently, the slab size and the jumping length must agree with the actual volume and mode of the sand transport. Previous modelling studies applied a unit jumping length of $L = 1$ m which can be interpreted as the migration of bed ripples. An increased jumping length of $L = 5$ m is more representative of saltation transport (Werner, 1995). In this study, we implement different jumping lengths in DuBeVeg and compare the resulting dune development predicted for two idealized beach profiles (narrow and wide) and for a real-case scenario (the southern part of the Sand Motor).

Preliminary Results

An increase in the jumping length results in striking differences in the predicted 50-year morphological development of a beach-dune system as well as its intermediate states (e.g. at 10 years), producing fewer but taller dune ridges, especially for wide beaches (Figure 1) similar to the central part of the Sand Motor.

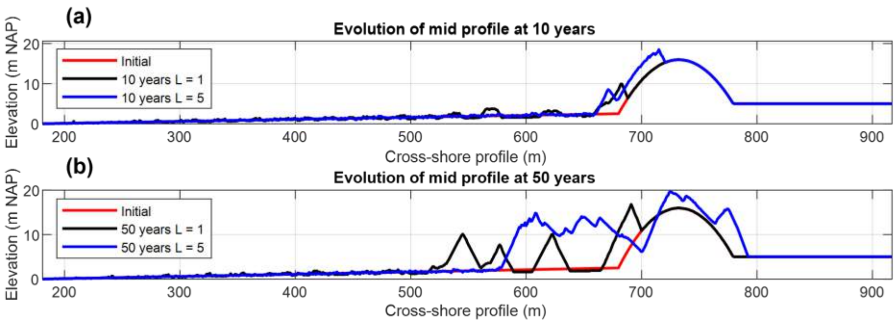

Figure 1: Comparison of the cross-shore profile development obtained when running DuBeVeg with different jumping lengths (L) for an idealized wide beach after (a) 10 years and (b) 50 years.

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Probabilistic design of green sea dike revetments: required thickness for revetment of local clay

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Introduction

The demonstration project Brede Groene Dijk (Wide Green Dike) focusses on the question whether sea dike revetments could be constructed with clay, made from locally dredged silt. Furthermore, the goal is to design and build a sea dike with a clay and grass revetment on the entire outer slope to demonstrate the possibilities of building sea dikes with local and natural material. At present, this demonstration dike has been built in Groningen close to Finsterwolde.

To be able to design such a dike, research has been done on, among others, the aging properties, erodibility, erosion process and erosion resistance of the clay. The erodibility and erosion process have been assessed by means of 1:1 scale physical model testing in the Delta Flume of Deltares. Based on the results of these tests, formulae to describe the erosion rate have been developed as well as a description of the development of the erosion profile over time.

Using these erosion formulae and the development of the erosion profile, a model has been developed to perform probabilistic calculations on the expected return period of erosion depths. This model has been used to determine the minimum required thickness of the clay revetment of the demonstration dike Brede Groene Dijk.

Methods

The model developed for the probabilistic calculations consists of a module which determines the strength of the clay revetment and a module which determines the hydraulic loads. The strength module is based on the descriptions of the erodibility and the erosion process based on physical model testing in the Delta Flume. The hydraulic loads module makes use of the HydraRing software to determine the hydraulic loads for a specific location in the Netherlands. HydraRing is used to generate millions of hydraulic load events to perform probabilistic calculations based on the Crude Monte Carlo method, which is a robust method for complicated Z-functions (Z=strength-load) such as the failure of a clay revetment due to erosion.

Results

The probabilistic calculations for the clay revetment of the demonstration dike Brede Groene Dijk resulted in a return period of erosion depths for this specific location and dike geometry, see Figure 1. The minimum required clay layer thickness regarding erosion can be read from the figure at the return period corresponding to the maximum acceptable failure probability. Additional thickness is incorporated in the design to mitigate, for example, animal activity.

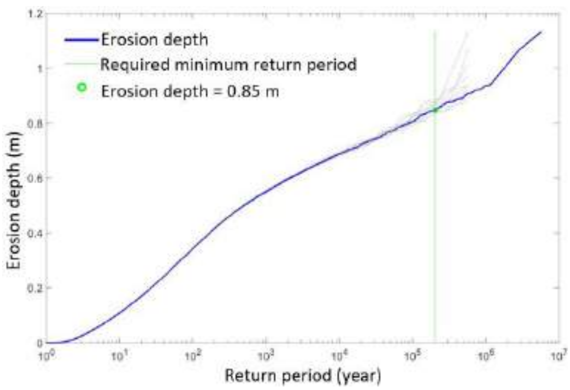

Figure 1: Return period of the erosion depth calculated with the probabilistic model.

Acknowledgement

The probabilistic calculations have been performed in cooperation with the Waterboard Hunze en Aa’s and Sweco. Especially the contributions of Henk van Norel, Marco Veendorp and Jos van Zuylen are acknowledged.

Seabed sediment: from hand-drawn map to AI-generated model

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Introduction

The bed of the North Sea plays an important role as a habitat for animals and plants, and many human interventions take place on and in it. It is important to visualize this dynamic environment as accurately as possible. The old hand-drawn map, in use for more than 20 years, has been replaced by a grid model, calculated with machine learning.

Methods

The random forest algorithm, a machine-learning technique that makes regular updates of the maps feasible and affordable, was used to automate the interpolation of point data from sample locations to full-coverage maps. On the basis of visual sediment descriptions, grain-size analyses and bathymetry-derived positional attributes, the most likely sediment type and associated uncertainty were predicted for 100 by 100 meter grid cells. Statistical analysis has been used to quantify the best combination of input variables and interpolation settings.

Results

The new seabed-sediment maps show which sediment class typifies the top half meter of the seabed. The user can choose between three classification systems based on the ratio of mud (< 63 µm), sand (63-2000 µm) and gravel (> 2000 µm): the international Folk standard, a simplified version of this standard for a single-image overview of the entire Dutch North Sea bed, and a further simplification consistent with the European Union Nature Information System (EUNIS). For each map, the probability of the predicted class is visualized as well. This attribute is important when a map view is used to make decisions. Users will need some time getting used to the new views. The simple, flowing pattern of the old, hand-drawn map has been replaced by a higher-resolution but speckly representation in which areas with a particular sediment type can be very small. Once users are accustomed to this visual change, a brand-new generation of seabed-sediment maps can be applied to its full capability. The grid format makes integration of seabed-sediment data into decision-support systems easier than before. Public data provided by users and other stakeholders will be incorporated into these maps once a year.

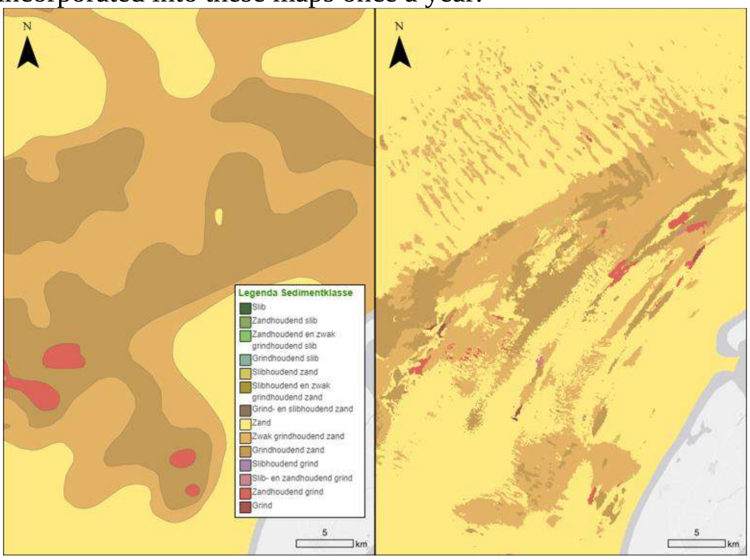

Figure 1: Old and new map views for an area northwest of Texel island.

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Multi-annual research program Management and Maintenance of the Dutch Coast

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Introduction

In 1990, the Dutch government introduced the Dynamic Preservation policy. This included that coastal erosion should be compensated with sand nourishments where possible, and hard coastal protection structures where necessary (Ministry of Infrastructure and Water Management, 1990). Since 1991 Rijkswaterstaat is maintaining the Dutch coast with sandy nourishments on a national level. To continuously optimize and adjust the Dutch Coastal policy and practice, Rijkswaterstaat, as part of the Ministry of Infrastructure and Water Management, coordinates the research program Management and Maintenance of the Dutch Coast (*Beheer en Onderhoud Kust*, *in Dutch*). Deltares and Rijkswaterstaat collaborate in this research program.

Scope program

The main goal of the research program Management and Maintenance of the Dutch Coast is efficient and effective coastal maintenance. This is done within four main goals:

- Consistent and up to date knowledge of the state of the Dutch coast;
- Ability to evaluate and predict the effects of the current coastal policy;
- Support local authorities of Rijkswaterstaat in managing and the coastal area;
- Use insights in the long term effects of the current coastal management policy (including sand availability, sea level rise and spatial planning) for advising policy makers;

The research program is multi-annual and will be continued in the coming years. The focus area is on the Dutch Coast, between -20m NAP up to and including the inner dune row. The tidal inlets such as the Marsdiep are included within the program as well. Sediment sharing systems such as the Wadden Sea, Eems estuary and Western Scheldt are included within adjacent research programs at Rijkswaterstaat.

Featured research programs

The research program Management and Maintenance of the Dutch Coast contains among others the subjects depicted in Figure 1. We will give a coherent overview of these subject within the Dutch Dynamic Preservation policy in our intended poster.

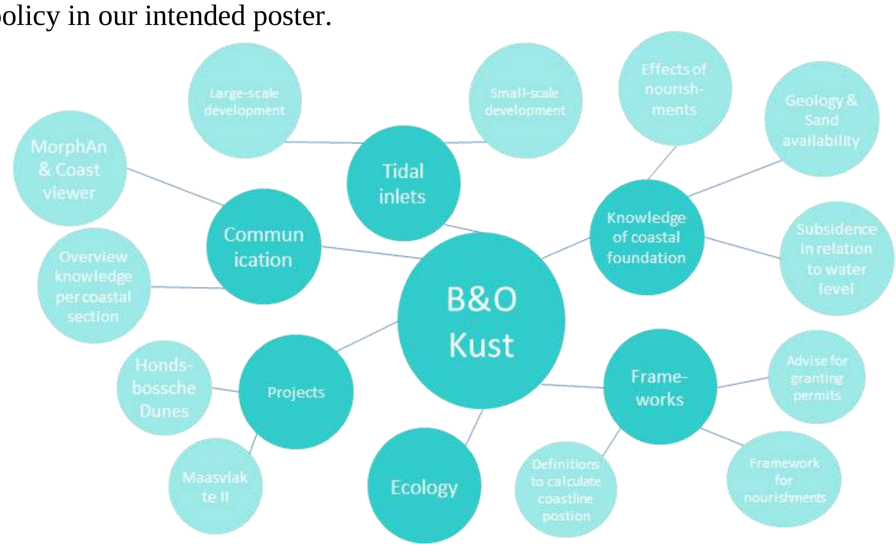

Figure 1: Overview of the featured subjects within the research program Management and Maintenance of the Dutch Coast (B&O Kust).

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Unravelling sediment deposition in pioneer salt marshes through flume experiments

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Introduction

If we are to rely on salt marshes for nature-based coastal protection, we must understand how they expand and retreat. Salt marshes are vegetated intertidal wetlands, which are commonly found in estuaries and on sheltered coastlines. The area at the seaward edge is known as the pioneer zone. This region is characterised by patchy vegetation, fine sediment, and frequent tidal inundation. Critically, it is also the region in which salt marsh expansion and retreat are first observed. Sediment accretion is a key process for expansion in this complex setting alongside other morphological and biological drivers.

The presence of vegetation in wave-current conditions modifies the sediment transport dynamics compared to a bare bed (e.g. a mudflat). Vegetation changes flow patterns, dampens waves, and drives turbulent eddies. These affect the flow velocities, shear stresses, and diffusivity that control sediment transport (Lou et al, 2022) and deposition (Xu et al, 2022). In this study, we will unravel how pioneer vegetation affects spatial and temporal sediment deposition patterns under wave-current conditions using flume experiments. Our aim is to understand how deposition rates depend on wave, current, vegetation and sediment conditions.

Figure 1: Pioneer salt marsh in the Taf Estuary, Wales, UK (own photo).

Methods

The experiments will be conducted in the Nepf Environmental Fluid Mechanics Lab at the Massa-chusetts Institute for Technology, USA. The artificial vegetation is inspired by pioneer specie *Spartina anglica*. We will feature a realistic range of current (0-0.2 m/s), wave (height: 0-0.15 m), vegetation, and sediment (grain size: 40-100 µm) conditions based on field data in northwestern Europe (e.g. Hu et al., 2021). Our results will enable new modelling tools and can in the future be applied to the understand deposition patterns as observed in the field after taking relevant scale differences into account.

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The method that despises the little is not worthy of the great: Dealing with the patchiness of vegetational effects on large scale flow

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Introduction

Coastal areas around the world can be characterised based on the occurring vegetation. Vegetation varies strongly at small scale (O(1m)), but it has an effect on the currents and the waves at a much larger scale (O(500m)). These areas are not only characterised by strong vegetation variations, but also by strong bathymetry variations. However, to take these small-scale features into account in hydrodynamical models covering an estuary can be computationally costly. We propose a method that can take these small-scale effects into account, while keeping the computational times short.

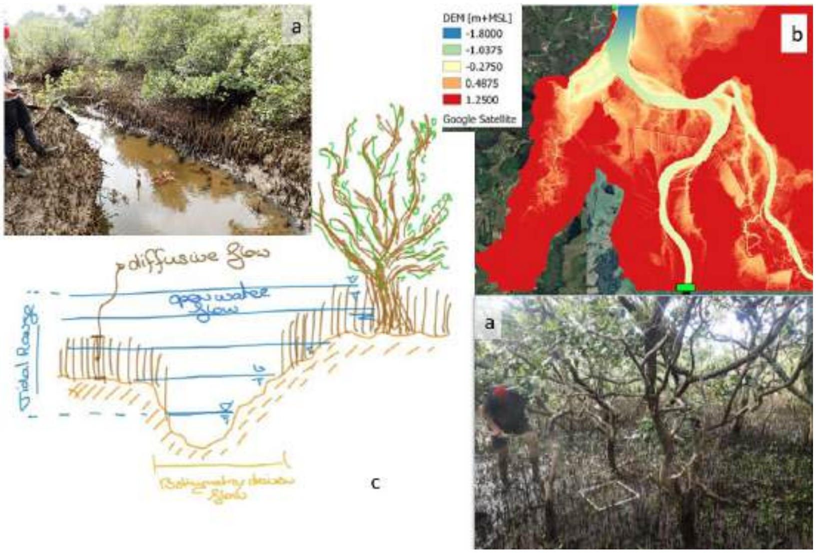

FIGURE 1: A) IMPRESSIONS OF THE MANGROVE FOREST AREA OF THE WHITIANGA ESTUARY (HORSTMAN ET AL. (2021)) B. THE BATHYMETRY OF THE STUDY AREAS (O. BALTUS, 2022) C) SKETCH FOR MODELLING THE TYPES OF FLOW IN DIFFERENT LAYERS.

Methods & Results

Vegetation affects the vertical flow structure. The presence of vegetation alters the familiar logarithmic flow profile, known from flow over a rough bottom. Especially, in case of dense vegetation, the flow through the vegetation is uniform. For larger water depths and less dense vegetation, the flow structure re-establishes the familiar flow profile, although affected by a vertical drag. In areas where the vegetation is dense, the bathymetry height is difficult to measure, and is known to have large uncertainties. However, in areas with a more open coverage, the bathymetric variations become very important for the flow behaviour. We propose a depth-averaged, two-layer approach for modelling densely vegetated areas in large scale models. The bottom layer describes the diffuse flow through the dense layer of vegetation. The upper layer accounts for the bathymetric, roughness and a newly derived method for vegetation variations at high resolution, using a so-called subgrid-method (Volp et al. 2013). We will introduce the method and test it based on an application of a mangrove forest in the Whitianga Estuary.

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Field observations of turbulent flow patterns and salinity variations in a stratified scour hole

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Introduction

The presence of scour holes (bathymetric depressions) in estuaries adds complexity to the salt intrusion phenomenon. Denser saltwater accumulates in the deeper parts of the scour holes in each flood tide andit may not be flushed back to the sea by the subsequent ebb tide. Understanding the flushing mechanismof saltwater from scour holes is of particular interest in semi-closed estuaries, such as the Haringvliet inthe Netherlands, where the trapped saltwater in scour holes may pose a threat to the freshwater supply. Forcings such as high river discharge and strong wind can initiate the mixing process by providing enough shear and turbulence at the pycnocline of the highly stratified scour holes. In this study, we investigate the flow velocity and salinity dynamics in a scour hole in the Haringvliet, at times when the floodgates are either closed or partially open.

Methods

The measurement instruments were deployed in a scour hole in the Haringvliet for 73 days from November 2022 to January 2023 to capture saltwater trapping and flushing events. The flow velocity data were collected using bed-mounted acoustic Doppler current profilers (ADCPs) with a vertical resolution of 30 cm and a sampling frequency of 4 Hz. In order to be able to track the pycnocline, we used high-resolution echosounder data along the center-beam of the ADCP with a resolution of 5 cm. In addition, salinity data at three different heights through the water column were recorded by CTD instruments.

Results

The flow patterns in the water column over a stratified scour hole will be analyzed by relating mean velocities and turbulence intensities to salinity concentrations and echosounder data. Such an example is shown in Figure 1.

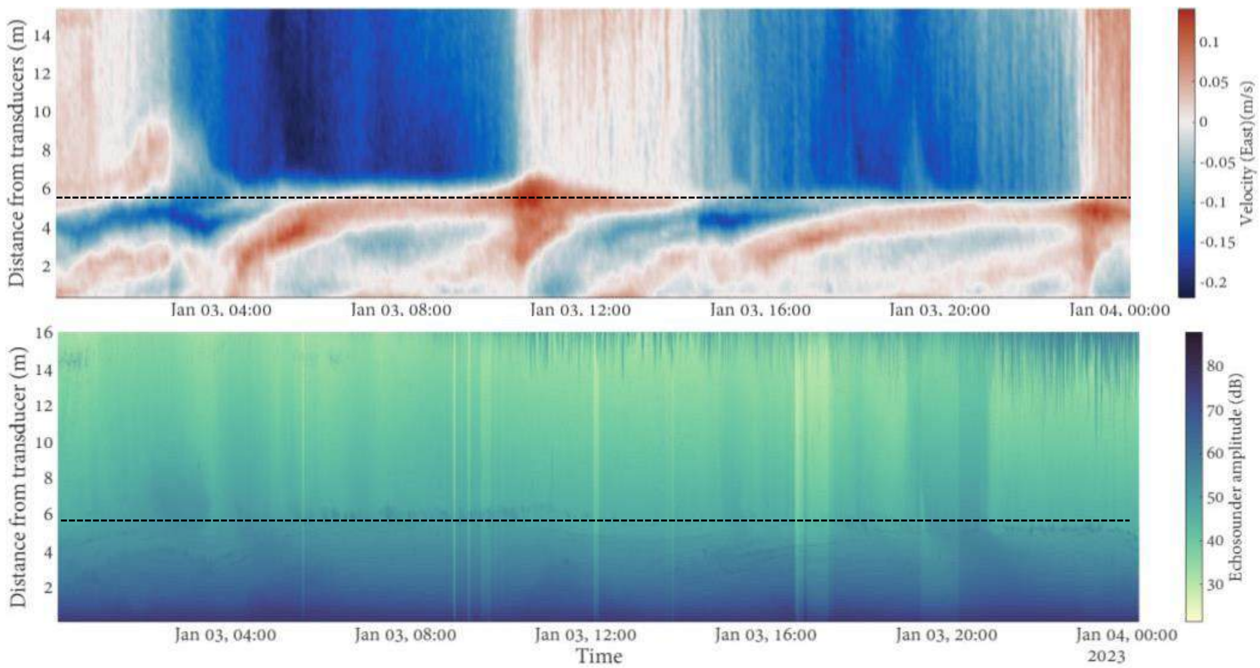

Figure 1: Flow velocity in east-west direction and echosounder amplitudes in a stratified scour hole in the Haringvliet Estuary over one day. The dashed horizontal line indicates the upper part of the scour hole.

The importance of 2D effects on dune erosion during the 2022 winter storms at Maasvlakte II

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Introduction

Many of our coastlines are curved and therefore storm erosion likely originates from both alongshore and cross-shore processes. In the national program BOI (Assessment and Design Instrument for flood defences) a new instrument for dune safety assessments is being developed based on the XBeach modelling software. The methodology within this instrument includes a 1D XBeach approach at present. However, a 2D approach is more suitable for complex coastal sections. At this moment the instrument for the 1D XBeach approach is being rolled out, while the 2D approach still needs to be developed. In anticipation of these developments, this study investigates the importance of a 2D approach compared to a 1D approach with an eminently suitable dune erosion case study at the strongly curved sandy sea defence of Maasvlakte II. In this case study XBeach is utilized to reproduce the measured dune erosion up to 80 m^3/m at Maasvlakte II due to the winter storms at the start of 2022.

Methods

Firstly, the detailed topographical measurements taken in Q4 of 2021 before the storms and in Q1 after the storms of 2022 are analysed and quantified to learn more about the dune erosion patterns along the Maasvlakte II. Subsequently, to investigate the importance of a 1D or 2D approach the dune erosion measurements are compared with the 1D and 2D XBeach BOI model results. The XBeach model of Maasvlakte II is setup to simulate the dune erosion over a period of 130 days between the measurements. The XBeach model is applied in 1D and 2D surfbeat mode. For the 2D model, a curvilinear grid is used with cells measuring 2.5x25 m (cross- x longshore) in the area of interest, whereas the 1D model is based on specific transects of this 2D model. Both models have been set-up with wave climate reduction techniques and a morphological acceleration factor to speed up the simulations.

Results

The results show that significant differences in the amount of dune erosion occur between a 1D and 2D XBeach model approach at strongly curved coastal sections such as transect a), see top panel in figure 1. The results at straight coastal sections are more similar between the two approaches, see transects b) and c). Furthermore, it was found that the default settings from the XBeach BOI version are able to accurately model the dune erosion, see bottom panel in figure 1. It should be noted that after the winter storms of 2022 a nourishment has been placed on the beach, therefore significant difference are observed below 3 m+NAP, nonetheless the erosion above 3 m+NAP is represented accurately.

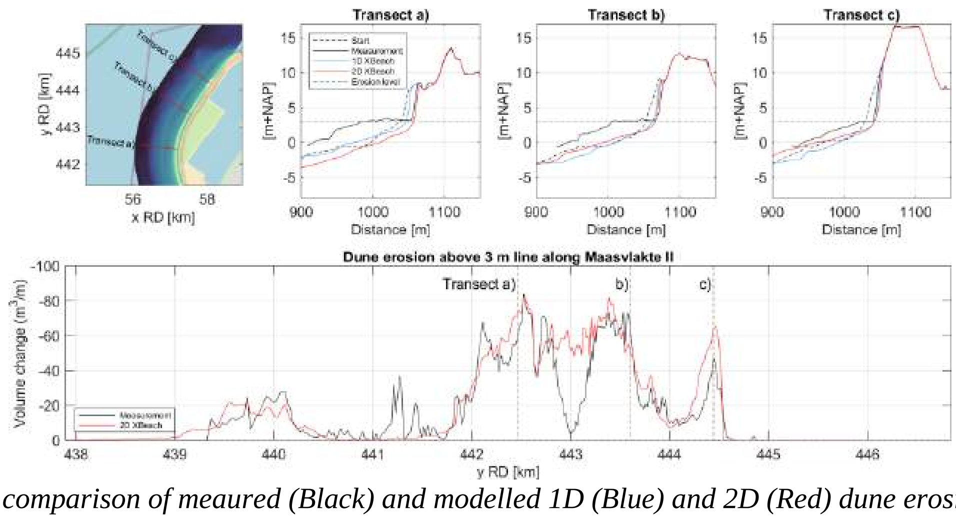

Figure 1. A comparison of meaured (Black) and modelled 1D (Blue) and 2D (Red) dune erosion.

These results suggest that 2D effects on the dune erosion are important at strongly curved coastlines and that the 2D XBeach model with BOI settings is able to accurately model dune erosion at Maasvlakte II.

Investigating Hydrogeological Feedback Mechanisms During Artificial Dune Development

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Introduction

Freshwater lenses beneath the Belgian dunes play a crucial role in protecting the hinterland from saltwater intrusion. However, urbanization and other human activities have led to a decline in their formation and preservation, putting freshwater storage and the economy at risk. To address this issue, gaining a deeper understanding of the hydrogeological feedback mechanisms during dune development is crucial, especially in the case of nature-based solutions such as artificial dunes. The project aims to fill a knowledge gap in existing research by investigating the hydrogeological feedback mechanisms involved in dune development and designing a hydrogeological model to predict freshwater lens growth in dynamic artificial dune environments.

Methods

To better understand and model freshwater lens development, an artificial dune area of 750 x 20 m² has been constructed in Raversijde, Belgium. Vegetation has been planted with varying spatial distributions and planting densities, some surrounded by brushwood fences with different densities. The project will use a combination of field measurements, data analysis, and numerical modelling. Regular ERT measurements will be conducted to visualize subsurface resistivity (salinity) and monitor the development of the freshwater lens. The water table, tidal response, salt levels, and topographical changes will be monitored. Drone surveys will be conducted to monitor topographical changes, and RTK measurements will be taken before and after storm conditions to understand the effects of storm surges on groundwater variations and salinity. The dataset generated from the analysis of these measurements, combined with information from nearby monitoring wells, a weather station, and an artificial dike, will be used to create and validate a hydrogeological SEAWAT model simulating the development of the freshwater lens, mixing process of saline and freshwater recharge, and maximum storage of fresh groundwater.

Results

The results of this study will have a significant impact on coastal management and the preservation of freshwater resources. By validating the hydrogeological model through case studies along the Belgian coast, the impact of sea level rise and different scenarios of coastal management on freshwater lens development will be evaluated. This will provide valuable insights and recommendations for creating climate-resilient coastal areas. The research will also explore the potential of artificially replenishing the dune with waste or runoff water to improve freshwater lens growth. Ultimately, the results of this study will offer a valuable toolkit for effectively understanding and managing freshwater lenses in artificial dune systems.

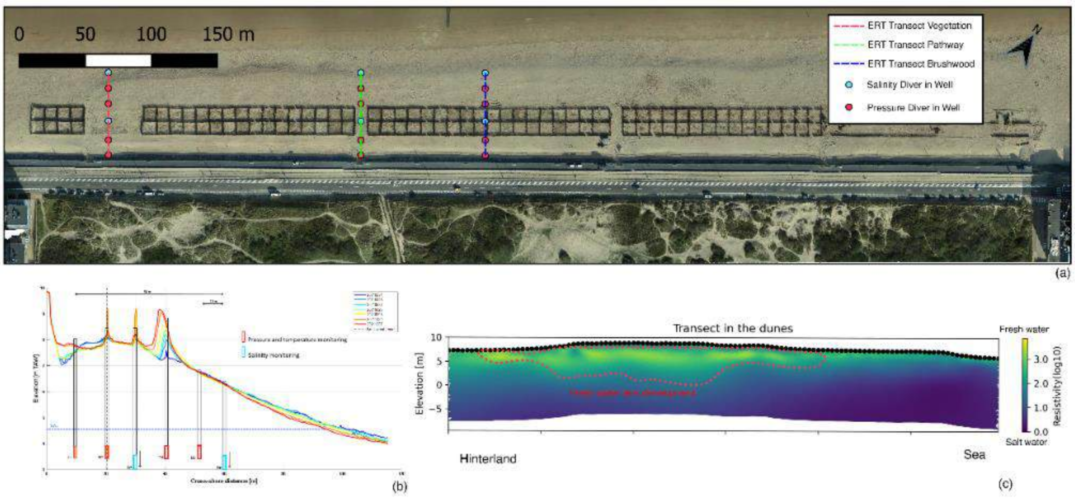

Figure 1: (a) Experimental setup at the artificial dune site [Raversijde, Ostend] (b) Cross-section dune with placement monitoring wells (c) Inverted ERT Survey in transect dune

Shoreface-connected sand ridges strongly affect decadal coastline evolution in a coupled shelf-shoreline system forced by waves and tides

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Introduction

Coastal evolution, in particular erosion, is a major concern for many communities around the world, as it can lead to the loss of valuable property and infrastructure, as well as to the degradation of natural habitats. In order to mitigate and adapt to this threat, it is important to understand the complex processes that contribute to erosion. One factor that can have a significant impact on the evolution of coastlines is the presence of shoreface-connected sand ridges (SFCR), which are bedforms with a scale of several kilometres and with crests that are obliquely oriented with respect to the coastline. This is exemplified at the Belgian coast, where the onshore propagation of SFCR destabilizes the coastline, thereby requiring the need for nourishment of growing size and costs. SFCR have been recognized to cause undulations of the adjacent coastline of Fire Island (USA). The ridges at this location are rather oblique, are present at a considerable distance to the coast and local hydrodynamic conditions are microtidal and a unidirectional wave climate (Safak et al., 2017). This research specifically expands our understanding of such coastline dynamics in the presence of 1) significant tides, 2) a bi-directional wave climate and 3) almost shore-parallel, onshore located and onshore migrating sand ridges, as found along the Belgian shore.

Methods

In this project an idealized numerical modelling approach is used, following the method of Nnafie et al., (2021). The decadal shoreline evolution of the Belgian coast is simulated by forcing a morphodynamic, non-linear shoreline model (Q2Dmorfo) with waves that are obtained from a morphostatic shelf model (Delft3D + SWAN). The latter computes wave propagation on an idealized shelf bathymetry in the presence of tides.

Results

The model is applied to quantify the decadal shoreline evolution of the Belgian coast for different locations and orientations of SFCR and for different wave climate scenarios (see figure below for a typical result). In particular, potential erosion hotspots will be identified and explained.

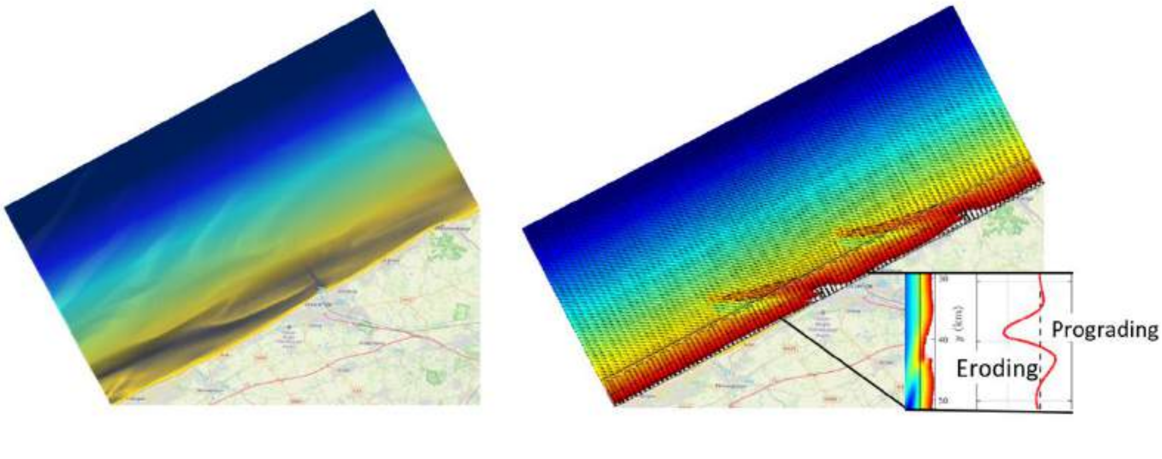

Figure 1: Shoreface-connected sand ridges (SFCR) at the Belgian coast (left) and a typical result of the simulated shoreline evolution in presence of SFCR (right)

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Long-Term Morphological Modelling of Tidal Inlet Systems:Implementing Salt Marshes in ASMITA

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A rise in the global mean temperature induced by climate change is expected to have a large impact on ecosystems in all regions of the world. One of the threats is the accelerated sea level rise (SLR). This may induce partial loss of intertidal areas, which are important feeding ground birds (Huismans et al., 2022). The long-term morphological response of tidal inlet systems can be modelled using the reduced complexity model ASMITA (Aggregated Scale Morphological Interaction between Tidal inlets and the Adjacent coast) (Stive et al., 1998). The ASMITA model simulates morphological development on an aggregated spatial and temporal scale by imposing a morphological equilibrium condition. As such the model is fast, allowing for multiple long-term simulations. The model parameters represent real world processes and can be related to field values.

Currently, salt marshes are not implemented in ASMITA. However, salt marshes may be of vital importance to the morphological development in tidal basins and estuaries. This research aims to investigate how salt marshes can be implemented in ASMITA and to what extent salt marsh development can be simulated by ASMITA.

The governing processes for salt marsh development in ASMITA are sedimentation and relative sea level rise (rSLR), which includes deep subsidence and SLR. A data analysis for the Dutch barrier islands Ameland and Schiermonnikoog indicates that salt marshes experience sedimentation rates between ~ 0.10 – 1.0 [cm/year], depending on the location where measurements were taken. In the first implementation of salt marshes in ASMITA, the sedimentation is related to the amount of water that flows onto the salt marsh and the Suspended Sediment Concentration (SSC). The amount of sedimentation is computed by an aggregated version of the advection-diffusion equation. The first results indicate that ASMITA is able to simulate the morphological development of salt marshes. In a follow-up step, we are carrying out further research into the parameter setting and an additional model extension.

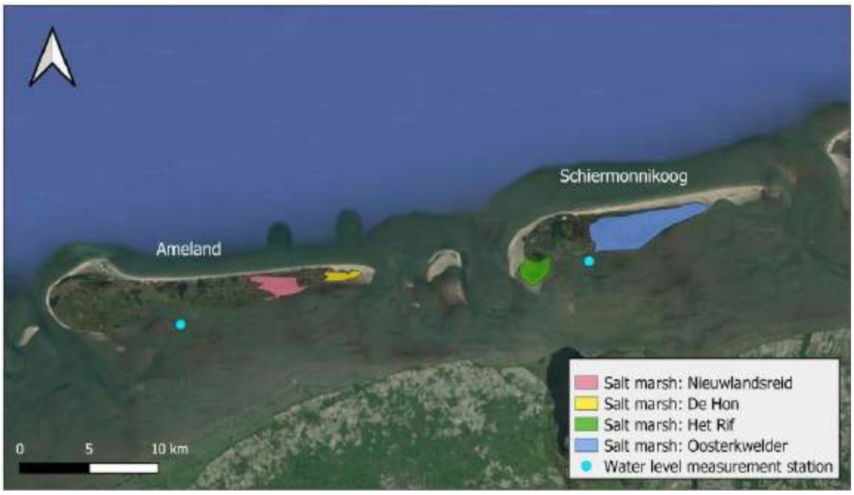

Figure 1: An overview of the salt marshes on Ameland and Schiermonnikoog that were studied for model validation.

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Initial development of a poorly sorted back-barrier beach nourishment

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Introduction

Sand nourishments have become an increasingly popular alternative to the traditional rigid (or 'grey') flood defences made of concrete, asphalt and stones. Our predictive understanding of how coastal nourishments evolve stems from wave-dominated coasts, such as the exposed Holland coast (Huisman et al., 2019). In recent years, however, also existing flood defences in (semi-)enclosed regions have been upgraded with sandy foreshores (Perk et al., 2019). Here, the hydrodynamic boundary conditions are considerably different from the open coast, and coarser sand is often used to minimise erosion and account for the lack of natural supply. Accordingly, this work aims to characterise the morphologic development of such an artificial beach in a semi-enclosed system by linking it to the interplay between grain-size sorting and hydrodynamics.

Study site and methods

We focus on the Prins Hendrikzanddijk, an artificial sandy foreshore on the mainland (or Wadden Sea) side of the barrier island of Texel (Perk et al., 2019; Fig. 1), completed in 2019 and featuring a man-made spit. The nourished sediment is very mixed and in general much coarser than the native sediment (700 µm v. 200 µm). Long-term monitoring (2-3 month return period) of bed levels and grain sizes, and measurements of waves and currents during a dedicated field campaign (5 weeks) have resulted in an extensive dataset (which continues to grow).

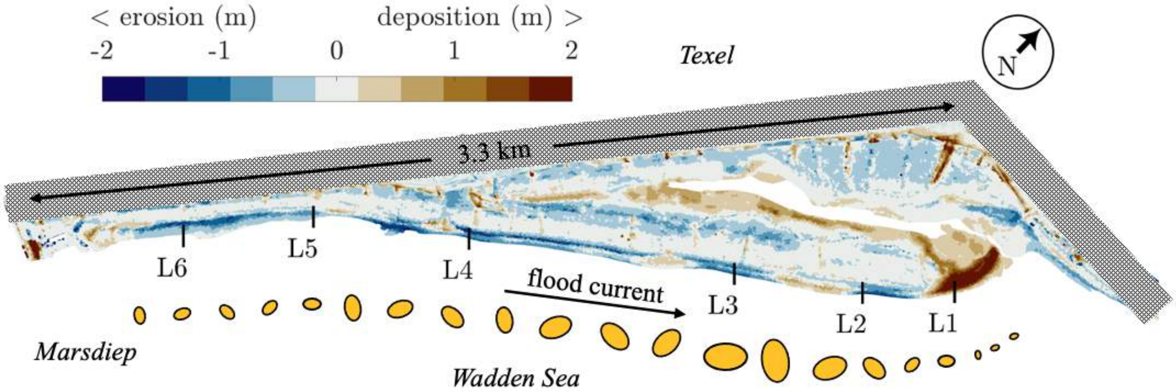

Figure 1: Bed-level change at the Prins Hendrikzanddijk in the first 3 years after construction and a schematic representation of the longshore distribution of cross-shore mean intertidal grain size (D_{50} = 500-900 µm). The black hatched area indicates the location of the old Prins Hendrikdijk.

Results

In the first four years after completion, net erosion of the upstream intertidal areas (dark blue strokes, Fig. 1) acted as the sediment source for the extension of the spit (by tens of metres per year; NE of L1) due to continuous accretion of relatively fine sediment (< 600 µm), resulting from persistent preferential entrainment by the dominant flood current. During storms, poorly sorted nourishment sand is stirred up from deeper layers and eroded from the upper beach to be delivered to the lower parts of the beach, refining the bed and suppressing the formation of clear large-scale sorting patterns. These developments are a consequence of design choices regarding profile shape and sediment type.

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Sand Wing: Feasibility study towards sustainable sandbank maintenance

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Introduction

The Sand Wing development is part of Rijkswaterstaat's innovation program for coastline maintenance. The project studies the feasibility of a near bed fixed structure, i.e. the Sand Wing, in contributing to sand transport and the maintenance of sandbanks. The structure should extend the lifetime of sediment nourishments or reducing the need for them.

Methods

We tested the Sand Wing ogive configuration by means of physical experiments. The physical experiments were performed in a flume (13 x 0.45 x 0.25m) and in a basin (race track basin with 4 x 2 x 0.35m). The experiments enclosed flow-only conditions over a fixed bed and experiments with a mobile sand bed covering different mobility scenarios. Measurements of flow, turbulence and sediment concentrations were carried out for conditions without the wing (reference case) and with different Sand Wing angles wrt to the main flow.

Results

The Sand Wing in its current configuration is able to enhance sand suspension and to deflect the sand transport laterally. Both effects are highly desirable for the sandbank application. The physical experiments were able to unravel the conceptual working principle of the structure and also to quantify the turbulence and the resulting sand transport and deposition. The sand transport and deposition with the Sand Wing are a factor of 2-3 higher than the reference. The next phases of the project contemplate the assessment of the structure in numerical models and possibly a pilot project.

Figure 1: Flume experiments of the Sand Wing with mobile sand bed. Left: Sand Wing with 30º orientation; Right: no Sand Wing. Both experiments were performed with 0.3 m/s flow velocity.

Context and framework of the recent and future coastal management toolbox

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Introduction: the past and present

Starting in 1990, the main goals of Dutch coastal management are to sustainably maintain the flood protection and to sustainably preserve other functions of the dune areas (Ministry of Infrastructure and Water Management (MinI&W), 1990). In 2000, a third goal was added; to keep the sediment budget of the coast in equilibrium with sea level rise (MinI&W, 2000). In practice, these goals are achieved through sandy nourishments. Preferably, these nourishments are placed on the shoreface, but in practice (30-40% of the total nourished volume) beach nourishments are needed as well.

In the National Water Plan (MinI&W, 2009), new ways of adding sand to the system were encouraged. Since then, channel wall nourishments, ebb-tidal delta nourishments (i.e. at the Ameland Inlet) and mega nourishments (i.e. the Sand Motor) have been executed (Brand et al., 2022). These nourishments act at increasingly large spatial and temporal scales (Figure 1).

Methods: the future

Under accelerated sea level rise, it is the question whether the already expanded toolbox has all the tools needed to achieve the above mentioned policy goals. Also, questions arise on the implementation of these new techniques in legislation, and on their effect on functions like ecology. To answer these questions, the Knowledge Programme Sea Level Rise (KP SLR) was set up.

In the Sandy Coast theme of the KP SLR, Rijkswaterstaat studies (1) the physical impact of 0.5, 1, 2, 3 and 5 m of sea level rise on the sediment and nourishment demand of the coastal system, as well as (2) to what amount of sea level rise we can use our current nourishment toolbox and strategy, and by what measures we can 'stretch' them.

Results

Results will be combined in one or more nourishment strategies per sea level rise scenario. The effects will be determined of each strategy on several aspects, like costs, ecology, CO_2 emissions etc. The results of this assessment will provide a first insight into the adaptation pathways we should take as a country with regards to sea level rise.

Figure 1: Spatial and temporal scales on which the various types of nourishments act.

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Hydraulic load model for the Dutch coast

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Introduction

In recent years, research into hydraulic loads along the Dutch coast such as water levels and waves, has been boosted by the availability of long time series of meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF), for which the Royal Dutch Meteorological Institute (KNMI) calculated the resulting water levels on the North Sea. As a result, a period of 8,000 years of simulated meteorological data of the current weather climate have become available for a large number of Dutch coastal stations. Compared to the limited availability of measurements from coastal stations (up to 50 or 100 years for a limited number of stations) these long time series are a great source of additional information. It provides the opportunity to study in greater detail how wind, water levels and waves evolve in time during extreme storm surges.

For the Dutch coastal regions, the safety standards of the primary flood defences range from 1/1,000 per year to 1/30,000 per year. In the currently applied approach, erosion of dunes and coastal dikes is computed for fixed assumptions with respect to the load evolution in time. With the insights of this study, the variability of storms can be included in safety assessments of dunes and dikes, by means of a time-dependent load model.

Methods

An hydraulic load model has been developed, yielding time series of water levels, wind and waves for Dutch coastal stations, with corresponding probabilities. The model is based on the 8,000 years of simulated data, from which storm evolutions are selected based on maximum wind speed. The developed load model is used to gain insight into relevant aspects for (time dependent) failure of dunes and coastal dikes, by linking the model to XBeach and to dike failure models. Another purpose of the model is to provide more consistency in the hydraulic loads that are used for the safety assessments of dunes and dikes, which currently utilizes different methods. Moreover, the impact of applying such a time-dependent load model on the failure probabilities along the Dutch shore can be investigated and compared to the currently applied approach with a single representative storm.

Results

Based on the analysis, one of the conclusions is that wind durations and wind speed are strongly related, which is not included in the current load models. High wind speeds are often related to short wind durations. This plays an important role in the statistics of the wind, and it is recommended to add this correlation in future load models. Besides, a proof-of-concept was created in Python, to calculate exceedance frequencies of water levels, wave heights, and required dike heights. Currently, an extension is made to calculate time-dependent dune erosion by connecting XBeach to the hydraulic load model.

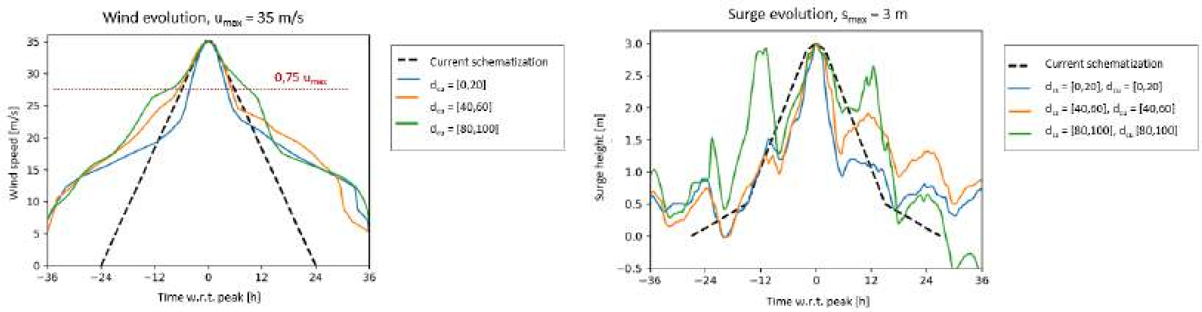

Figure 1: Comparison of the current implementation of the wind and surge evolution in load models for flood defence assessments (dashed lines) and the schematized wind and surge evolutions based on the ECMWF data analyses (coloured lines for different duration classes of wind and surge).

The Power and Limit of Building with Nature for the Venice Community

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Introduction

Co-management is a participatory and inclusive approach to building adaptation capacity and promoting well-being in delta communities, facing the complex challenges of mass tourism and migrant pressure due to climate change and social transformations. Here we comment on some recent attempts of addressing the unique challenges and opportunities of the Venice highly polycentric coastal community. Starting from the need to increase the socio-ecological and cultural adaptation capacity of people of the Venice Lagoon we are performing bottom-up activities that we want to scale-up: direct stakeholder Engagement; comprehensive assessment of the community needs, assets, visions related to climate, sanitary, and social transformations; integration of local culture, expertise, and traditional practice opinion leaders (food, cooking, art, artisan, fishing, hunting, horticulture, foraging, wild and social explorations) into the planning and practice; sustainable education, exploration and practice for active tourists and visitors; totally inclusive practise from the needs and perspectives of visitors, migrants, and residents for empowering and involving the most active members of the community.
To ensure that our strategies can survive and have a rapid development improving adaptation capacities we are taking advantage on valuing and incorporating local community culture and experience, but it is not enough: the main limit to that is the lack of a profit management in non-profit organizations, limiting our action in time and space with the main consequences of not delivering job creations and economic development. Only with an **external control** and result related funding, it will be possible to behave as a profit organization, **monitoring and evaluating results** of the implementation process and ensure that the desired outcomes are being achieved. At the moment we are trying to bridge with the governmental and private companies, in charge of the top-down Venice Safeguard solutions: the coastal protection, the Mose storm surge barriers, urban restoration and environmental restoration with naturally based solutions, by means of: -Participating to EU funded, University driven, co-productions: Contratto di area umida della laguna Nord, and other EU projects, such as Rest-Coast. - Working together with non-profit org, such as Venice Calls, Wigwam Circuits, Veras, Associazione Risorse Vitali, for orchestrating generative networks of bottom-up activities surfing the mass tourism for promoting local cultural, food, energy in the highly visible Venice arena. Human networking and well-being will be part of the next Local Exotic project of the Venice Biennial Design called **Acclimatation gardens:** lagoon explorations for residents, students, pensioners, tourists, visitors, and migrants.

Results

The new transition and integrations of traditional coastal engineering with nature-based solutions can bring successful results specially in Venice, "the oldest city of the future" if we increase community engagement and empowerment**.** In this regard Sea level rise scenarios, and sensiblecommunication can help in triggering unexpected opportunities (Fig.1 affordable houses, job opportunities, sustainable transports, fresh water, energy, local food, better living with water and nature).

Figure 1: Total Inclusive Community Approach to rapid sea level rise in Venice can trigger the anticipation of futures: e.g. A regulated coastal lake around Venice with new opportunities: 30km new littoral with multi-purpose dike: city park, mobility hub, fishing harbours, aquaculture, marinas, local food agriculture, affordable housing, tidal and solar energy, pumps controlingl max-min water level, clear swimmable water in a '700 hundred Venetian landscape as painted by Canaletto.

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SCALDIS COAST: a numerical modelling of 10-year for long-term morphology in the surf zone of the Belgian coast using the Telemac-Mascaret system

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Introduction

The simulation of the long-term evolution of hydrodynamics and morphodynamics by state-of-the-art numerical modelling tools, can have important contribution to the strategic decision-making for the protection of the Belgian Coast from the climate change hazards. The SCALDIS-COAST model, developed in the present study, aspires to become a valuable tool for the assessment of potential coastal protection measures by predicting the morphological behavior of the coast driven by the coupled action of tidal currents and waves.

Methods

The SCALDIS-COAST model consists of three coupled modules, i.e. the hydrodynamic module, the wave module, and the morphology module. The hydrodynamic simulations are performed by means of TELEMAC2D module on an unstructured triangular grid, which solves the shallow water equations (Saint-Venant) on unstructured triangular meshes using the finite element method.

Wave modelling is performed by the TOMAWAC module which solves the non-stationary balance equation of the action density directional spectrum. A special module has been developed to allow for a coupled hydrodynamic and waves model with different resolution and layout in order to reduce computation times (Breugem *et al.*,2019).

Sediment transport and morphology simulations are conducted by means of SISYPHE module. Bed load and suspended sediment transport driven by the combined action of waves and currents are calculated by using a modified formula of Bijker (1992). Then, the bed evolution equation (Exner equation) is solved by use of the finite element formulation. The implementation of cross shore processes is currently under development.

Results

The model is validated both for long term evolution of the sea-bed after the extension of the port of Zeebrugge sea-ward 1986, but also for short term events like the erosion of the beach nourishment in 2014 at Wenduine and the siltation of the navigation channel of the Blankenberge marina during a single storm event.

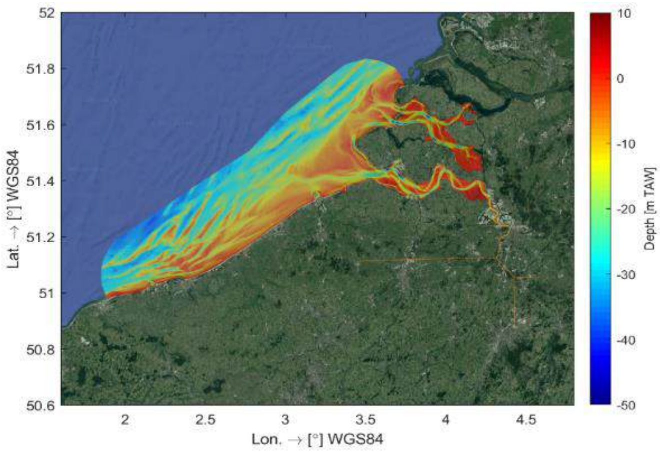

Figure 1: The computational domain and bathymetry of the SCALDIS-COAST model.

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Biophysical Controls on Pollution Flows in Coral Reef MPAs

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Introduction

Coral reef ecosystems along tropical and temperate coastlines provide essential ecosystem services such as coastal protection, fisheries production, blue carbon capture, pollutant removal, and detoxification. Marine Protected Areas (MPAs) are commonly used as management tools to promote the sustainable use of these ecosystems. The increase of tourism in coral reef MPAs is responsible for environmental decline due to the impacts of human activities, such as increased influxes of nutrients and sediments (Kurniawan et al., 2016). Local hydrodynamics determine the transport of pollutants from the coast to the coral reefs. However, there currently is a lack of understanding on the role of local hydrodynamics on such pollution flows, impeding the development of local pollution models to directly estimate the transport and delivery of tourism related pollutants around small islands and surrounding coral reefs. We plan to investigate the local biophysical dynamics at the land-sea interface in coral reef MPAs and their impacts on the transport and dispersion of pollution related to tourism.

Methods

We combine field observations and model simulations of biophysical and pollution flows around small islands with some of the world's most diverse coral reefs in Raja Ampat, Indonesia (Figure 1).

Field data will be collected at 2-3 islands with increasing tourism development (in Dampier Strait and Misool) and during both the dry and wet seasons. The field data will be used to develop a numerical model in Delft3D to simulate pollution flows around the islands, similar to previous models for the transport of marine debris and sediments around small islands (Figure 1; Faizal et al., 2022). The model will help quantifying the impacts of various tourism intensities and activities on pollution flows around the islands and the surrounding coral reefs.

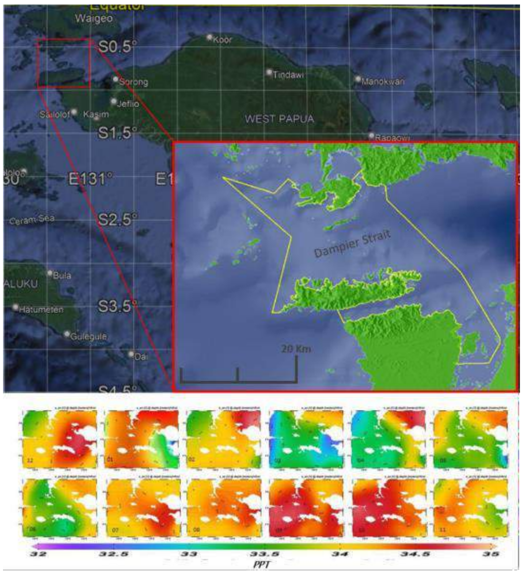

Figure 1: Study site location (top) and illustration of a biophysical model of seawater salinity [PPT] around Raja Ampat(bottom).

Expected Results

By quantifying the biophysical flows around small coralreef islands, this research aims to provide a better understanding of the pollution flows to coral reefs, allowing for the development of mitigation strategies toprevent further ecosystem degradation at tourist destinations in coral reef MPAs.

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The response of dominant vegetation species in saltmarsh to changes of inundation frequency

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Introduction

Saltmarshes are subject to periodic flooding. Inundation frequency may play an important role in the seaward limit of saltmarsh vegetation. This research focuses on the saltmarshes in the Western Scheldt of the Netherlands. Dominant vegetation species in this area include: (1) *Salicornia europaea* and *Salicornia procumbens* (*SalSp*); (2) *Spartina anglica* and *Spartina townsendii* (*SpaSp*); (3) *Bolboschoenus maritimus* (*BolMa*); and (4) *Phragmites australis* (*PhrAu*). We address the following two questions: 1) How does the distribution and abundance of different dominant vegetation species relate to the inundation frequency in saltmarshes? 2) What is the relationship between variations of inundation frequency and the biomass dynamics in saltmarshes?

Methods

Based on surveys of Rijkswaterstaat, time-series (1993, 1998, 2004, 2010, 2016) of vegetation distribution maps, were analyzed in ArcGIS 10.8.2. Google Earth Engine (GEE) was be used to create a time-series of inundation frequency based on aggregating satellite images from Landsat 5/7/8 (U.S. Geological Survey/NASA). Through counting the times each pixel is classified as water, we can calculate the inundation frequency. Pixel-based analysis was used for further investigation.

Preliminary results

First results show changes in the distribution of the selected vegetation species during 1993-2016. For example, a significant increase of SalSp's coverage was observed in the mudflats of both the western and eastern parts of the estuary. SpaSp significantly increased e.g., on the intertidal flat Hooge Platen. As for the total cover area, despite the overall trends of PhrAu, SalSp and SpaSp were increasing and BolMa showed a fluctuant decrease (although it still covers the largest area, in Saeftinghe). For the pioneer species SalSp and SpaSp, the pixels with inundation typically have higher mean vegetation coverage than the ones without inundation, whereas BolMa and PhrAu show the opposite.

Understanding coastal response to sea level rise in Northern Italy: a two-sided approach

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Introduction

Low lying coastal areas all over the world face are challenged by sea level rise. The evolution of these areas is determined by the creation of so-called accommodation space on the one hand and sediment input on the other. It is of vital importance to predict the response of coastal areas to rising sea levels. However, predictive capabilities of morphodynamic models are uncertain because these models need to be calibrated and validated with field data, which often does not exist or only over short periods of time (evolution occurs on centennial to millennial time scale). Combining paleogeographic reconstruction and morphodynamic modelling might fill this gap.
The Tagliamento delta (North-East Italy) provides an interesting opportunity to do this: it is comparable to the Wadden Sea due to the riverine input and presence of coastal lagoons, but is smaller in size, making it easier to model. The Tagliamento river is also one of the most natural rivers in Europe. Extensive research was done to infilling of incised valleys in the area (Ronchi et al., 2020), which were subject to periods of fluvial progradation, rising sea levels and human influence.

Methods

This research aims to provide reliable estimates of infill rates in the Tagliamento lagoonal area via a two-sided approach, using both paleogeographic reconstruction and morphodynamic modelling. Multiple moments in geologic time (8000 BP, 5000 BP, 3000 BP and 1800 AD) are selected, representing a range of conditions with different rates of sea level rise, sediment input and human influence. Paleogeographic maps of these levels, based on lithological core descriptions, C-14 and OSL dating, will serve as input for the initial conditions in the morphodynamic model (see Figure 1). Additionally, pollen analysis of deep cores will help to distinguish the successive vegetation cover and relative human influence in the region. The differences in volume between the paleo-DEM's are used to compute the sediment budget and make a complete paleogeographic reconstruction of the delta, which are then used to calibrate the morphodynamic model and validate the results. In this way, we aim to get a better grasp of the factors determining the rate and location of infill.

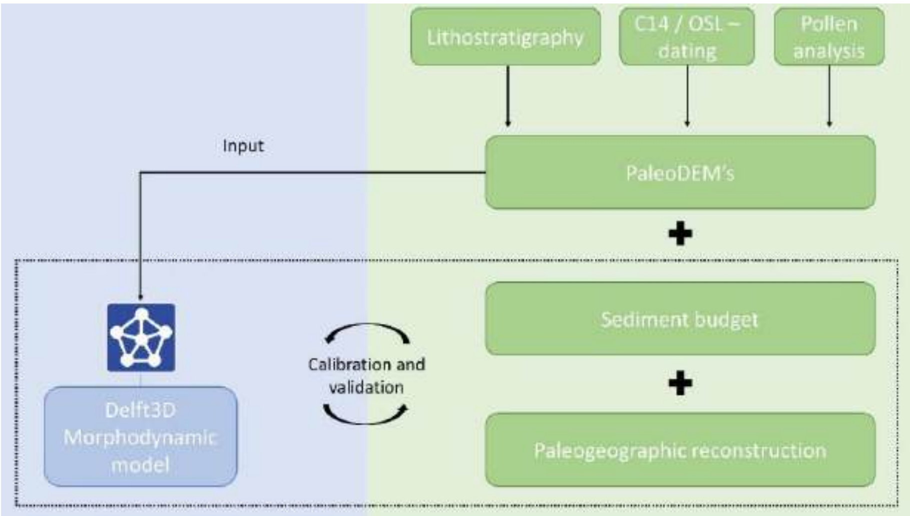

Figure 1: Conceptual framework of the two-sided approach combining paleogeographic reconstruction (right) and morphodynamic models (left).

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Quantifying erosion of saltmarshes under storm conditions in a Living Dike

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Introduction

Nature-based flood defences receive increasing interest as a viable option for improving flood safety worldwide. A contemporary case is using the ability of saltmarshes to attenuate waves during storm conditions for strengthening coastal flood defences (Vuik et al., 2016). This combination of a saltmarsh with a green dike is referred to as a Living Dike. To ensure a long-term reinforcement of flood protection, it is important to understand the erosion mechanisms of saltmarshes during storms. Potential areas for erosion are at the transition between the saltmarsh and the toe of the dike and at the transition between the saltmarsh and the bare mudflat often characterized by a vertical step or cliff (Figure 1). These cliffs vary between 0.2 to 2.0 m in height, depending on soil composition and local hydrodynamics. However, wave-induced hydrodynamics governing saltmarsh erosion and dependency on saltmarsh vegetation are not clearly quantified. Furthermore, the occurrence of erosion mechanisms of a saltmarsh under storm conditions, such as mass failure events at the cliff or scour at the toe of the dike are not fully understood. As a result, existing numerical models are not able to accurately predict erosion of a saltmarsh during storm conditions.

Methods

This research aims at improving the understanding of saltmarsh erosion mechanics through a series of wave flume experiments and expand this by numerical modelling. An overview will be given of the prepared research plan. First step is to identify and quantify hydrodynamic processes governing erosion of a saltmarsh during storm conditions. For this, a 1:10 scaled wave-flume experiments will be performed. Generated waves mimicking storm conditions traverse over a 7 m long saltmarsh transect including a modelled saltmarsh meadow, a varying cliff height to a maximum of 0.2 m and dike section. Particle Image Velocimetry is used to quantify near-cliff velocities patterns in a non-intrusive way. Secondly, erosion mechanics of a real-life saltmarsh transect will be tested under storm conditions in a full-scale flume experiment. Thirdly, the unique datasets on both hydrodynamics and erosion mechanics will be used to update and validate a numerical model specifically for simulating storm event impacts. Finally, several real-life cases will be modelled and recommendations will be drawn on how to design a living dike which will be stable during design conditions.

Figure 1: Retreating saltmarsh near Wierum (north of the Netherlands) with multiple cliffs of approx. 1.2 m in total height (Photo courtesy of P. Willemsen, 2022).

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Exploring multimodal wave conditions relevant to coastal processes on the Dutch shoreface

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Introduction

Simplified parameters are commonly used to describe wave conditions and related coastal processes, such as wave breaking, sediment transport, and wave dissipation. These parameterizations often assume unimodal wave conditions and therefore do not account for coexisting waves that might be related to different meteorological events. The use of generalized wave parameters in multimodal wave conditions in coastal engineering practices leads to uncertainties in wind-wave climate assessments of coastal activities, risk management, and the decision-making of long-term multidecadal coastal strategies that rely on wave climate data (Portilla et al., 2015). This study analyses the importance and application of considering coexisting wave trains.

Methods

The wave trains in the North Sea and the Dutch shoreface are analyzed by spectral wave partitions and wave families (Portilla et al., 2015). In parallel, the spatio-temporal statistics of the wave spectrum are investigated using statistical and machine learning methods to spatially group wave families and to analyze the spatio-temporal variability of the wave climate. Finally, the wave families and characteristic wave conditions are linked with atmospheric patterns, drivers of the wind-generated waves.

Results

On the Dutch shoreface, multimodal wave conditions occur 65% of the time, wherein the angle between wave trains is less than 60 degrees for 39% of the time and greater than 120 degrees 17% of the time. The wave families show the cross-shore development of waves within a specific domain in the frequency-directional spectrum. Relating wave families in a deterministic way is intricate and time-consuming, here we cluster them through machine-learning techniques which is consistent in cases of small spatial domains. Clustering similar wave conditions over time gives additional insight into the temporal-spatial variability of the wave climate, including distinct statistics about wave partitions, families, and sediment transport. The relation with weather conditions shows that waves crossing at an angle of about 90 degrees can be generated with one high- or low-pressure system and are potentially capable of transporting a lot of wave-driven sediment transport, which is hard to accurately predict with state-of-the-art methods.

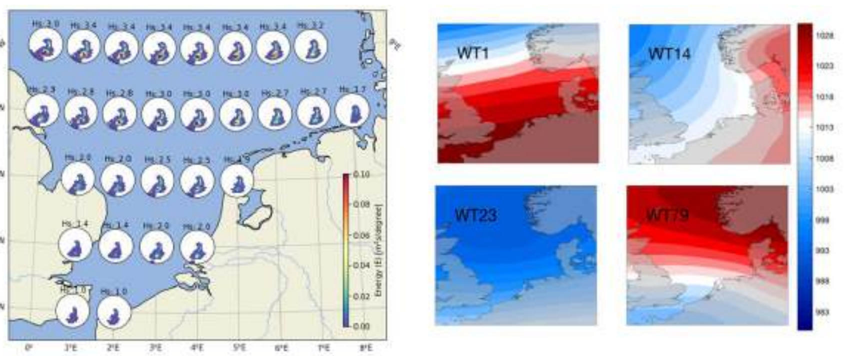

Figure 1: Left: The representative frequency-directional spectra for a specific (grouped) wave condition. The radial axis describes the wave period, with short perioded waves in the center, the angular axis the wave propagation direction, and the Significant wave heights are based on all the wave energy. Right: The sea level pressure for four characteristic weather conditions.

References

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Development of tidal flats under sea level rise

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Introduction

The estuarine intertidal zone provides a habitat for marine ecosystems, coastal protection against floods and behaves as a mechanism to control erosion (Elmilady, *et al.*, 2022). However, climate change and anthropogenic pressure pose a threat to the deterioration of intertidal areas. An understanding of the system is essential to develop coastal management strategies ensuring sustainability of the system under sea level rise. In addition, little is known on the long-term morphodynamic evolution of intertidal area in the presence of both sand and mud (Colina Alonso, *et al.*, 2020). This study aims to assess the morphodynamic development of sand-mud intertidal flats under sea level rise.

Methods

We base our research on published and validated morphodynamic Delft3D area models, to which we add different scenarios of SLR. These include schematized tidal basins comparable to Wadden Sea basins and a Western Scheldt case study. The behaviour and spatial distribution of the tidal flats are investigated under various sediment composition (i.e. sand /mud).

Results

Figure 1 and 2, depicts the cumulative intertidal area and the hypsometric curves with sand-mud interaction, for the schematized model of a tidal inlet, located in between two barrier islands replicating the Ameland inlet. The linear SLR imposed was 0.96m/100years and the modelled morphology starts from T = 100 years until T = 200 years. With sand-mud interaction, less intertidal area is lost as compared without interaction. Model results shows that intertidal area react with inertia to SLR where areas close to the sediment source (i.e. the mouth) adapt faster than areas more landward, so that intertidal areas will become flatter under SLR. Model results also suggest that intertidal flats will become muddier under SLR.

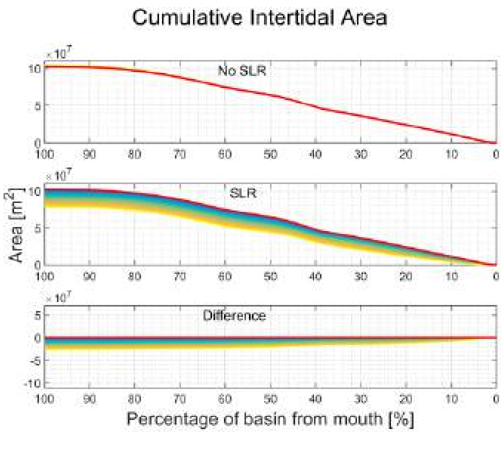

FIGURE 1: CUMULATIVE INTERTIDAL AREA FOR LINEAR SLR = 0.96M/100YEARS. RED LINE INDICATES INITIAL TIME STEP AND YELLOW LINE INDICATES FINAL TIME STEP.

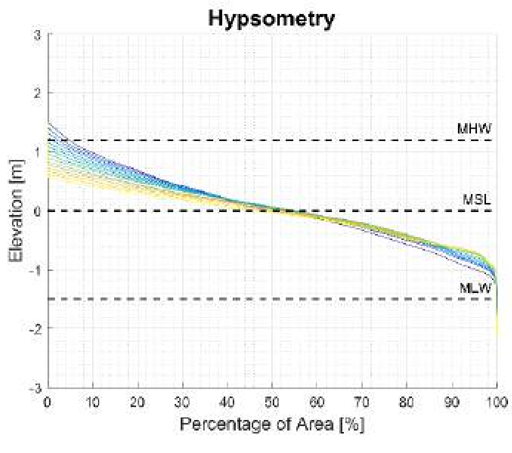

FIGURE 2: HYPSOMETRY FOR LINEAR SLR = 0.96M/100 YEARS. BLUE LINE INDICATES INITIAL TIME STEP AND YELLOW LINE INDICATES FINAL TIME STEP.

References

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Influence of channel bathymetry on subtidal salt transport processes and salt intrusion in single channel systems

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In estuarine networks, channel junctions control the division and dispersion of salt between network branches. Whereas dominant salt transport processes in single channel systems are relatively well understood in a width-averaged sense (Hansen and Rattray, 1965), the bathymetric variations around channel junctions complicate similar idealized analyses. Expanding our knowledge of the complex interactions between lateral and longitudinal salt transport processes induced by the geometric complexity of channel junctions is needed to understand salt distribution in estuarine networks and develop efficient one-dimensional salt intrusion models.

As a first step in resolving salt transport processes around junctions, we construct a three dimensional subtidal idealized model for water motion and salinity in partially stratified estuaries. It provides an extremely fast and numerically accurate way of computing salinity distributions in general geometries and analyzing the dominant salt transport processes. The model extends the width-averaged approach of e.g. MacCready (2004) to general 3D geometries. Following these authors, the vertical dimension is solved analytically. The solution for the horizontal dimensions is formulated using a numerical finite element method with flexible grid size. The resulting coupled system of nonlinear partial differential equations is solved iteratively. The idealized model is limited to well-mixed and partially stratified conditions and will be compared to high-complexity numerical models to test its validity.

As a proof of concept using the newly derived model, we present preliminary results regarding the sensitivity of dominant salt transport processes and salt intrusion with respect to longitudinal and lateral bathymetric variations within a single channel system. Systematic exploration of these sensitivities is expected to lead to improved salt dispersion coefficients and, eventually, nodal point relations between junction branches.

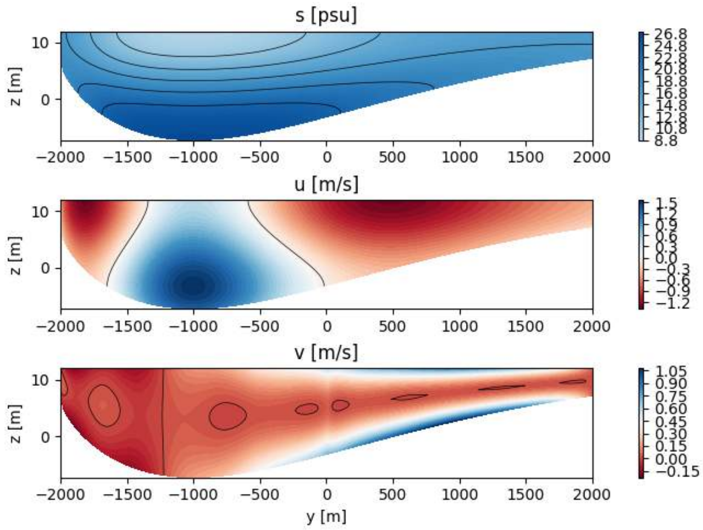

Figure 1: Cross-sectional visualizations of salinity, along-channel flow and cross-channel flow, with salt transport dominated by gravitational circulation inducing lateral circulation through bathymetric variations.

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Predicting morphodynamic long-term changes along the southern Rhode Island, USA,shoreline in the next decades

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Shoreline recession associated to sea level rise (SLR) or other anthropogenically induced factors presents an increasing threat to coastal communities around the world. When the nearshore area is a barrier beach, the threat is particularly insidious, gradually destroying the first line of protection of the landward community. The Southern Rhode Island (RI) shoreline is formed of a sequence of beach barrier systems protecting the landward communities. In the present study, we focus on the long-term dynamics of two beach barrier systems, the Napatree Point, an undeveloped flying spit that has been stable since 1975, and the rapidly recessing Ninigret-Trustom Ponds (NTP) barrier beach, partially urbanized and open to Block Island Sound by a stabilized inlet. The objectives of the study were: (1) simulating the observed shoreline changes at the two study sites using the 1-D shoreline model, ShorelineS (Roelvink et al., 2020); (2) predicting the long-term changes in shoreline position at both sites for the next decades; (3) understanding and explaining the contrasting morphodynamics observedat the two sites. The version of ShorelineS used in the simulations predicted changes in shoreline positions based on the combination of a longshore transport term and a sea level rise term. The cross- shore transport is neglected based on the assumption that this term mostly represents the interannual variability and would balance itself at the decadal scale, resulting in no significant net cross-shore transport. ShorelineS was calibrated and validated at each site based on historical observations from previous studies (Oakley, 2021). The model accurately reproduced the stable planform shape observedin Napatree Point from 1985 to 2014 using local wave climate data and SLR values in input. Based on these results, the model was used to predict the shoreline positions over the next 50 years. Long-term projections of the shoreline at Napatree predicted a slow recession with a shrinking in the width of the barrier. However, when used at the NTP site, the model strongly underestimated the observed shorelinerecession. This site, being more urbanized than Napatree, shows significant portions of the dune stronglydepleted with low-crest and over-washed by the seasonal winter Nor'easters. It was determined that thecross-shore transport and overwash could not be neglected and should be used in future simulations. However, the simulations enlighten the physical processes explaining the divergent behaviours at the two study sites: the stable crescent shape of Napatree Point is controlled by the longshore current shiftingfrom eastward with sediments trapped and conserved in the crescent shape system. Contrastingly, the NTP site is characterized by a dramatic loss of sediments, neither explained by the longshore current orthe SLR, pointing to dynamics predominantly caused by storm-induced cross-shore transport.

Figure 1: Napatree spit, Westerly RI (image courtesy: Ferguson, 2022).

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Understanding the Western Wadden Sea in terms of inlet connectivity: an exploratory modelling approach

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Introduction

Barrier coasts are characterised by a chain of barrier islands, separated by tidal inlets, connecting the outer sea to the basin. This study investigates the cross-sectional morphodynamic stability (i.e., whether the system returns to equilibrium after a temporary perturbation of the inlet cross-sectional area) and connectivity of the tidal inlets (i.e., to what extent perturbations at one inlet induce cross-sectional changes of other inlets) in double and triple inlet systems. This study focuses on the Western Wadden Sea, a triple inlet system with a tidal divide circumventing the middle inlet (see Fig. 1a).

Methods

An idealised process-based model based on Escoffier's (1940) principle is developed. The basin takes a plan view shape of a sector of a circle (Fig. 1a, red line) with a tidal divide (yellow) circumventing the middle. This idealisation allows for a largely analytical solution strategy, as also employed by Roos et al. (2013), to compute the stability and connectivity properties of the system, while preserving the main geometric characteristics of the Western Wadden Sea. The connectivity quotient C_{ij} indicates the response of inlet *i* when perturbing inlet *j* (Roos & Schuttelaars, NCK 2023).

Results

The results indicate that a stable equilibrium exists for a triple inlet system with this configuration, with and without a tidal divide. Additionally, the interaction in a triple inlet system is more complicated than observed in a double inlet system: an increase of the cross-sectional area of one inlet can lead to a temporary increase of another inlet as well ($C_{ij} > 0$). The results also indicate that the connectivity among inlets decreases for increasing tidal divide height. Finally, the results show that asymmetry in the connectivity ($C_{ij} \neq C_{ji}$) is a direct consequence of the asymmetry in the cross-sectional inlet area but depending on the basin area, as shown in Figure 1b. For small basins, perturbing the smaller inlet yields a larger disturbance of the other inlets. Conversely, for large basins, perturbing the larger inlet yields a larger disturbance of the other inlets. This can be explained by the competing effects of the bottom friction in and the pressure gradient over the inlets. Applied to the Western Wadden Sea, the results suggest that the system is stable and that inlets are weakly connected due to the large basin size.

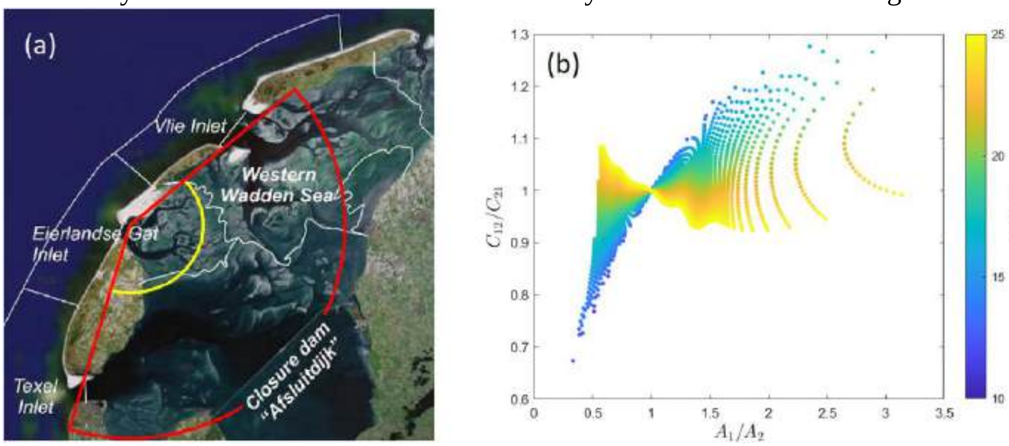

Figure 1: (a) Plan-view of the Western Wadden Sea, including the schematized basin geometry (red) and tidal divide (yellow); (b) Correlation between asymmetry of the inlet connectivities (vertical axis) and asymmetry in inlet areas (horizontal axis) for various basin radii (color).

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A close look at the beach and dune sand for the Vlieland beach nourishment

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The beach of the Dutch Wadden Island Vlieland will be nourished in 2023. Prior to a nourishment, the grain size (D_{50}) of the sand at the extraction site is compared to the beach and dunes as part of the ecological impact assessment. In addition, we propose to look at the sand fractions that are subjected to aeolian transport. This allows for a more accurate assessment of the effects of nourishment grain size on dune development and associated ecological values. The potential aeolian transport sand fraction (PATSF) consists of the main grain size fractions that make up the wind-blown dunes.

The grain size distributions of 66 new samples from the dunes and beach at Vlieland give insight in the distribution of grain size fractions (Arcadis, 2022a). At Vlieland, the PATSF contains the sand fractions in between 125 µm and 355 µm, which make up 96% of the dune sediment. 83% of the current beach sediment falls within the PATSF. The intended sand extraction site at the North Sea is on average coarser than the beach and dune sand at Vlieland. The D_{50} of the extraction site (309 µm) is 30% coarser than the beach sand (238 µm). 66% of the sand in the extraction site falls within the PATSF and could be blown into the dunes, theoretically. Therefore, despite the coarse nature of the beach nourishment, aeolian transport from the planned nourishment towards the dunes is expected to occur, unless the finer particles get trapped beneath the bigger particles (desert pavement).

Among the design aspects of a beach nourishment, the height of the top of the nourishment is crucial for aeolian transport. The higher the top, the more prone it is to develop a desert pavement, which hinders aeolian transport and has little ecological value. This risk increases when using coarse sand. A reduced height promotes frequent reworking of the top layer by waves, preventing the development of a desert pavement. To accommodate natural dune development, the original height of the planned nourishment at Vlieland (NAP + 3.5 m) was therefore reduced by 0.5 - 1.0 m.

To assess the potential ecological impact of beach nourishments we recommend investigating the PATSF of the sand extraction site in addition to the median grain size (Arcadis, 2022b). Despite large differences in the D_{50}, a major amount of the nourished sand can still become subject to aeolian transport. This can be stimulated by careful design of the beach nourishment.

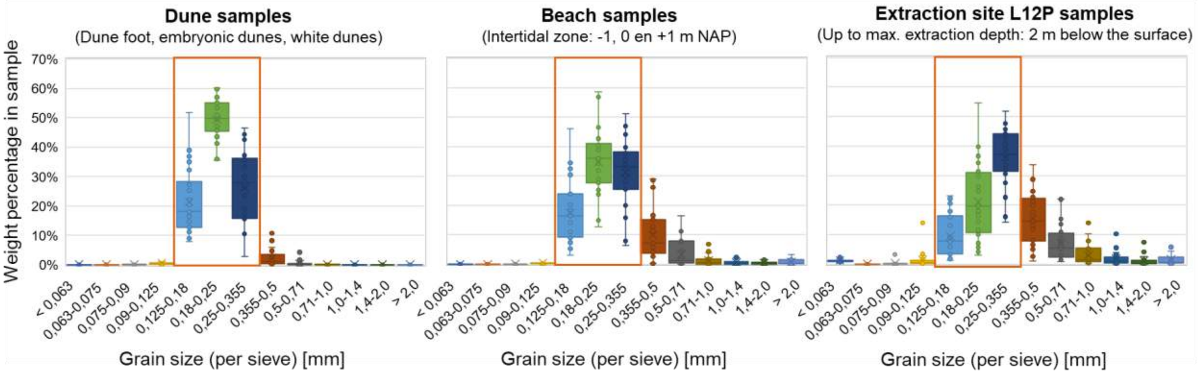

Figure 1: Overview of grain size distribution in the dunes at Vlieland (left), at the beach at Vlieland (middle) and at the sand extraction site for the beach nourishment (right). Orange box indicates the main grain size range in the dunes, which is the potential aeolian transport sand fraction (PATSF).

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Modelling salt marsh dynamics for coastal safety by Living Dikes, a research approach

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Introduction

Effects of climate change, such as sea level rise and increased storminess, require solutions to provide continued safety from flooding. Living Dikes, grass-covered dikes fronted by a salt marsh foreshore, are proposed as a more climate-adaptive and resilient solution for coastal flood protection compared to conventional dike heightening. However, as salt marshes are dynamic ecosystems and thus show natural variation in space and time, these introduce more uncertainty. To realise resilient and climate-proof Living Dikes, knowledge is needed in order to understand, quantify and incorporate these spatial and temporal variations in the flood safety assessment of a Living Dike.

Approach

This research project aims to improve understanding of spatial variations and temporal development of a salt marsh as a result of natural dynamics and disturbances as well as to quantify how these influence flood safety of a Living Dike. The first part of this research project focusses on quantifying the effect of spatial salt marsh variations on the flood safety of Living Dikes. For this, a framework based on models will be developed. The setup developed by Lashley et al. (2022) will be extended to include the effect 2D salt marsh variations on wave overtopping. The second part of this research project focusses on the effect of long and short term temporal salt marsh variations and natural dynamics by developing, improving and using models (e.g. Delft3D-FM) to identify possible development pathways of salt marsh development. Influences of climate change and disturbances, such as storm events or human-induced disturbances, on these development pathways will be studied. By combining the first and second part of the project, this will give insight into both the short term and long-term flood safety of Living Dikes.

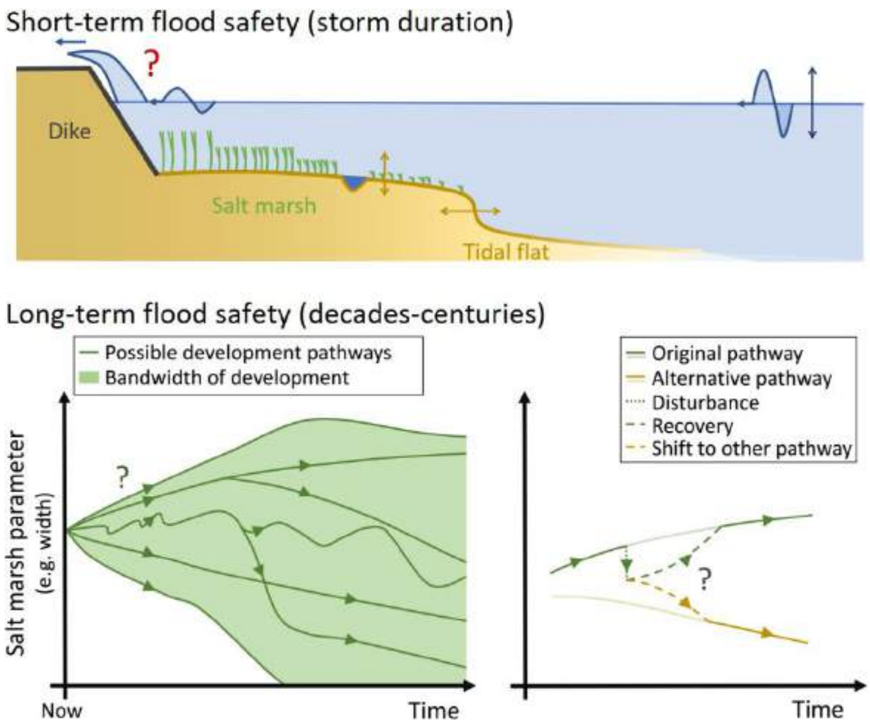

Figure 1: Graphical impression of the two main parts of the project.
Top: Schematic representation of a cross-section of a Living Dike and its effect on flood safety (question mark) based on variations in bathymetry (yellow), vegetation cover (green) and offshore hydraulic conditions (blue).
Bottom left: Schematic impression of possible natural development pathways as a result of parameter values, conditions and climate change scenarios.
Bottom right: Schematic impression of possible responses to a disturbance (e.g. storm/drought event or human intervention).

Reference

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Detecting turbid coastal features with satellite Earth Observation

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Introduction

A novel algorithm is presented to detect coastal features such as turbid plumes and turbidity maximum zones (TMZs). While TMZs are zones of highly concentrated particulate matter buffering sediment exchange between land and the coastal sea, coastal plumes are a marker of major exportation of suspended sediments. Satellite Earth Observation (EO) is a valuable tool to explore the characteristics of these coastal turbid features, providing synoptic time-series. We propose to use EO data archives to investigate two contrasting turbid systems (Figure 1).

Methods

First, turbidity maps are derived from EO data for each turbid system. Secondly, a set of reference points are identified from the turbidity maps. For example, for TMZs, the algorithm runs a moving average within each turbidity map, automatically setting the reference point as the region of strongest turbidity (i.e., the core). Thirdly, the turbid coastal feature is determined by applying a measure of similarity of pixels in each satellite scene.

Results

The proposed algorithm shows adaptability to distinguish plumes and TMZs from the ambient background water. Results are shown considering the metrics of the detected turbid features (area of extension, orientation, shape, mean turbidity, core position) extracted from EO data. The observed spatial patterns and metrics of the detected coastal features are compared against state-of-the-art threshold methods. Our approach highlights the importance of re-thinking traditional methods that usually apply fixed thresholds to delimit plumes and TMZs.

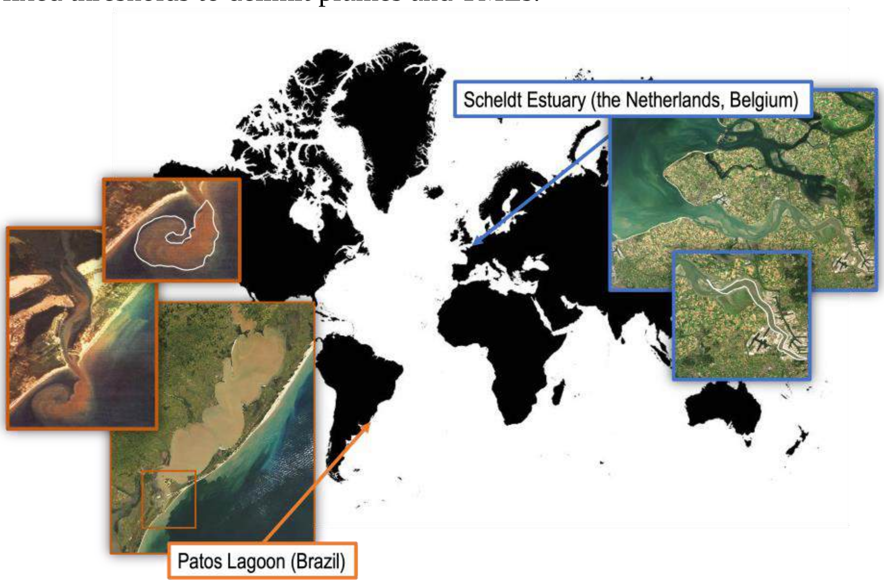

Figure 1: Location of contrasting turbid systems. White contours represent detected coastal features as observed from Landsat (United States Geological Survey – USGS) for Patos Lagoon and Sentinel-2 (European Space Agency – ESA) for the Scheldt Estuary.

Patterned coastal peatland ecosystems facing sea-level rise

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Introduction

Coastal peatlands are dynamic ecosystems subject to complex environmental and anthropogenic controls. Observations from the past (Holocene southwestern Netherlands), where peatlands expanded seaward following sea-level rise, make them relevant to current and possible future conditions and raise the question as how they can adapt and develop under such pressures. Their development scheme includes different spatial and temporal scales, as well as non-random pattern formations along them, determined by biogeomorphic and hydrological controls. The aim is to assess if the formations and processes of the different scales affect the resilience of coastal peatlands, if these patterns can be used as indicators for the ecosystem state, and if there are more than one stable ecosystem states where after a threshold of condition changes there is an ecosystem shift, i.e., peatland-to-saltmarsh.

Methods

First, a large-scale numerical model including revisited concepts of the ridges-pools surface patterns model (Eppinga, M.B. et al., 2009) and the bog-growth model (Clymo, R. S., 1984) will be implemented within an HPC context, to simulate the development of large-scale patterned domes and depressions in time. It's spatial and temporal size requires that the computations will be carried out on graphical processing units (GPUs). We will then study the development of a complex landscape of small-scale patterning embedded within a large-scale fen-bog complex, and its resilience to SLR. Finally, the model results will be compared to real-world ecosystems using remote sensing data and field data acquired from relevant locations.

Results

The expected results of the project will include (i) the numerical model simulations, (ii) field and remote-sensing data to validate them and (iii) visualizations of the numerical model results to enhance communication with the public.

Figure 1: Close-up to the patterned peatlands in Arkhangelsk estuary, Russia [© Google Earth].

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Dissemination of structurally monitored and up-to-date abiotic data in the Wadden Sea through a Digital System Reporting tool

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Introduction: cause and aims

The complex morphodynamics and dynamic nature of the Dutch Wadden Sea have been researched extensively over the last few decades. Despite being an essential part of the management and policy cycle, the related data was often scattered and hard to find. As part of the project *Basismonitoring Wadden* and Rijkswaterstaat research programme Management and Maintenance of the Wadden Sea (*Beheer en Onderhoud Wadden*), the aim of the Digital System Reporting tool (DSR) Wadden is to present up-to-date, transparent and consistent series of abiotic indicators that are easily and publicly accessible. In this way, trends and developments can quickly be detected and analysed. This contributes to a more efficient and effective execution of maintenance tasks, informs long-term policy and aids the calibration and validations of integrative models. Consequently, it is easier to identify knowledge gaps and additional monitoring needs.

Methods

The DSR Wadden is developed in consultation with stakeholders and experts. An iterative method of collecting and processing feedback was used, resulting in high-quality and usable product for stakeholders in the Wadden Sea area. Moreover, the tool makes it possible to easily update the information based on the latest monitoring data and project measurements.

Results

The DSR Wadden currently consists of more than 25 frequently used abiotic indicators and therefore enables an integrated, system-oriented monitoring of the Wadden Sea that provides a coherent insight into the functioning of the Wadden Sea system as a whole. To be prepared for current and future challenges in the area, such as morphological changes as well as the anthropogenic and climate-change-related pressures, the DSR Wadden serves as an important basis for administrators, researchers, policy makers and other stakeholders. We invite researchers to use and combine the information on the DSR and to contribute their own data to the DSR. This will enable the users of the DSR to tackle coastal engineering and science challenges in a diverse yet coherent way.

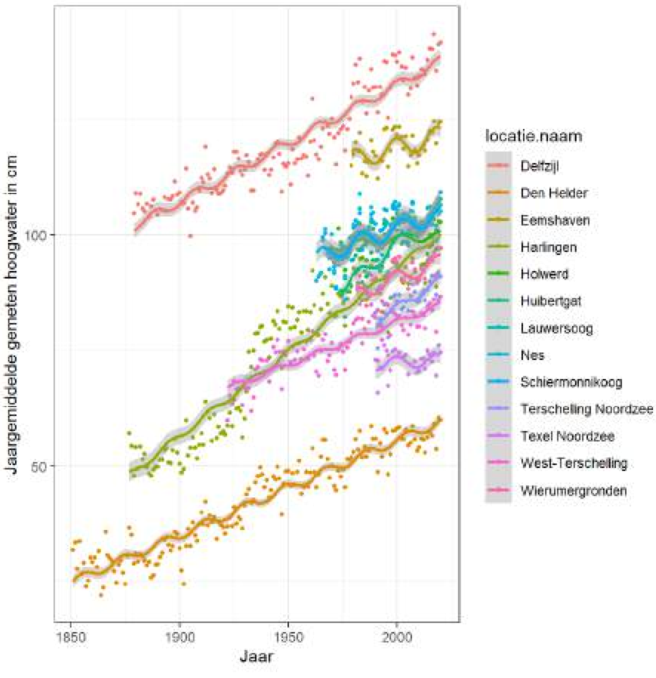

Figure 1: Example of a monitored indicator for water levels on the DSR (source: systeemrapportage.nl).

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Connecting dikes and vegetated foreshores at managed realignments

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Introduction

Managed realignment is the landward relocation of flood infrastructure to reintroduce the tide on former reclaimed land. Managed realignment can be seen as a way towards more diverse approaches in coastal engineering by combining flood protection by the realigned dike (artificial) and restored vegetated foreshores such as saltmarshes (nature-based). Connecting dikes and vegetated foreshores in a hybrid flood defence such as a managed realignment adds to making our coasts ready for upcoming climate change. But, are the realigned dikes ready for a connection with the restored foreshores?

Methods

We performed a literature review to characterize European realigned dikes and to indicate the characteristics that offer opportunities for connecting the dike and restored foreshore. An initial list of realignments at coastal seas and estuaries was composed using the Online Managed Realignment Guide (OMReG). This list was updated by consulting scientific literature in the database Scopus, by consulting experts, and by searching for additional and ongoing realignment projects in Google search engine.

Results

We categorized 90 European coastal managed realignment projects into two main realigned dike groups: 1) Newly built landward dikes and 2) Existing landward dikes of former multiple dike systems (Figure 1). The second group has two subcategories: 2a) Former hinterland dikes and 2b) Realignments within summer polders. From a nature-based flood protection perspective, the presence of an artificial dike is ambiguous. Our results show that targeted and expected saltmarsh restoration at managed realignments does not necessarily result in a greener realigned dike design that suits for combined flood protection with restored saltmarshes. Therefore, in further research we study how the dike revetment can be suited for a connection with the restored foreshores to form a nature-based hybrid flood defence. Pre-liminary results of our real size field experiment show that sod transplantation can provide local resources for the revetment of realigned dikes. We found that the vegetation of transplanted sods continued to grow and started to connect to the dike after one growth season. While very extreme circumstances still eroded part of the transplanted sods, the erosion resistance of the sods revetment is promising.

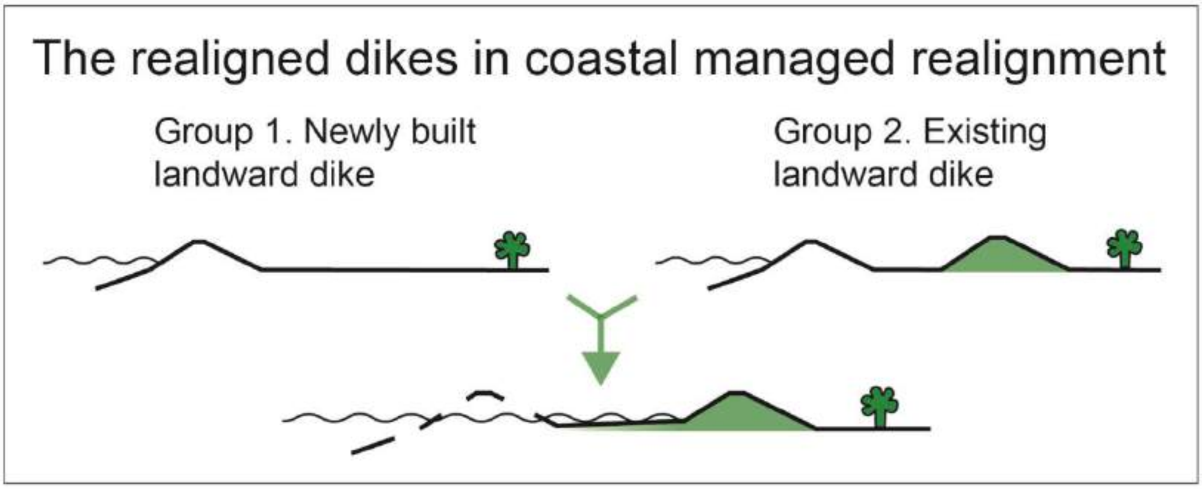

Figure 1: Two main groups of realigned dikes in coastal managed realignment (source: graphical abstract Van den Hoven et al. 2022).

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Coupled evolution of hydrodynamics and morphology in the western Dutch Wadden Sea

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Introduction

The tidal flow in the western Dutch Wadden Sea has strongly been influenced by the closure of the Zuiderzee in 1932. The western Wadden Sea has been subject to net sedimentation since the closure, and is still adapting to this intervention, causing shoal height to accrete more quickly than present sea level rise (e.g. Colina Alonso et al., 2021). Our study focuses on better understanding the coupled evolution of hydrodynamics and morphology on a decadal scale and evaluating the implications for the future morphological evolution of the Western Dutch Wadden Sea.

Methods

We describe the evolution of flow and morphology in the western Dutch Wadden Sea based new model calculations, from the mega-scale (western Wadden Sea), via macro-scale (tidal basin area) to meso-scale (channels and shoals), with specific focus on the evolution of the (navigation) channels. The effects of four different historical bathymetries (1976, 1991, 2003, 2015) on hydrodynamics have been calculated using the 2D hydrodynamic Dutch Continental Shelf Model in Delft3D.

Results

Our model results show clear trends in hydrodynamics. The tidal prism through the Texel inlet has increased between 1970s and nowadays, while the tidal prism of the Vlie inlet decreased. At the same time, we see high net sedimentation at the landward sides of both basins. The low-lying flat area north of the Texelstroom is eroding and channel re-orientation is taking place. The altered tidal propagation and morphological evolution of the Marsdiep basin causes the tidal prism to increase. In the Vlie basin, the continuous sedimentation at the landward side coincides with a reduction in channel volume, which is consistent with a reduction of the tidal prism. Our results help us understand how seemingly similar accreting behaviour in two adjacent tidal basins result in different effects on the hydrodynamics. We expect these trends of strong sedimentation at the landward side of the basin to continue for the next years to decades, further reducing channel dimensions and increasing the channel maintenance efforts.

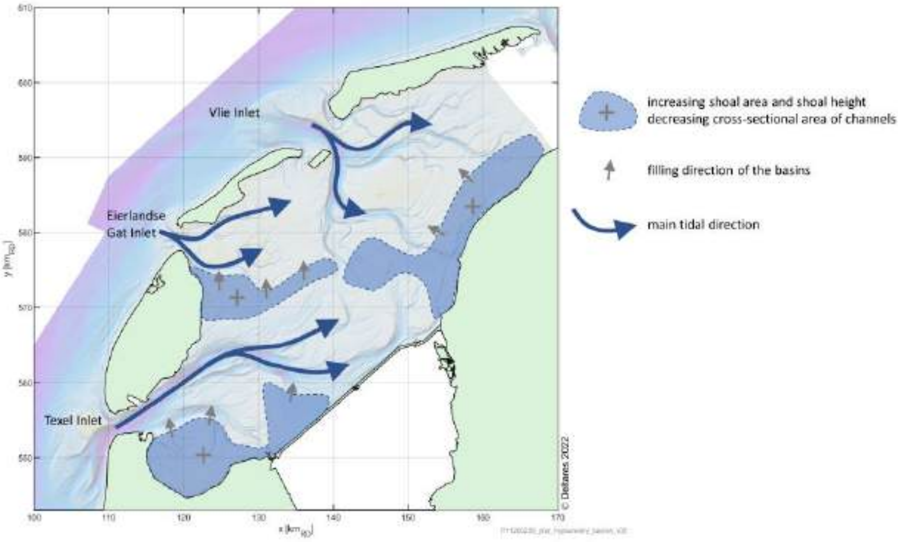

Figure 1: Sketch of the developments of the western Dutch Wadden Sea.

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Quantifying complex relations between spit growth and its hydrodynamic drivers, in non-tidal, wind-dominated lake environments. Application to the Marker Wadden

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Many sand spits are morphodynamically complex cases, that are either analysed with complex and expensive computational models or at a conceptual level. Therefore, most case studies on spits in different types of environments are descriptive. A novel method was devised to analyse morphodynamic data of spits at a quantitative level in a non-tidal, wind-dominated lake environment, at the Marker Wadden islands in lake Markermeer, the Netherlands. Sedimentation was quantified around both spits in the horizontal plane using polar coordinates and in the vertical through morphologically simplified elevation levels. It was found that, sediment transporting currents that pass over the spit-platform into deeper waters, drive spit-platform growth in that direction. The spit-platform growth in turn dictates the growth of the emerged spit. Spit growth quantification enables a detailed understanding of the Marker Wadden spits, which gives insights in spit behaviour in low-energy lake environments. At the Marker Wadden the submerged spit-platform grows during high energy wind conditions (Figure 1) while the emerged spit part grows under significantly lower energy conditions. Spit growth is a build-up of different morphodynamic processes all of which relate back to the loss of transport capacity around the spit. With this method we can quantitatively investigate the role of these morphodynamic processes, not only on a conceptual level, but also for a specific spit.

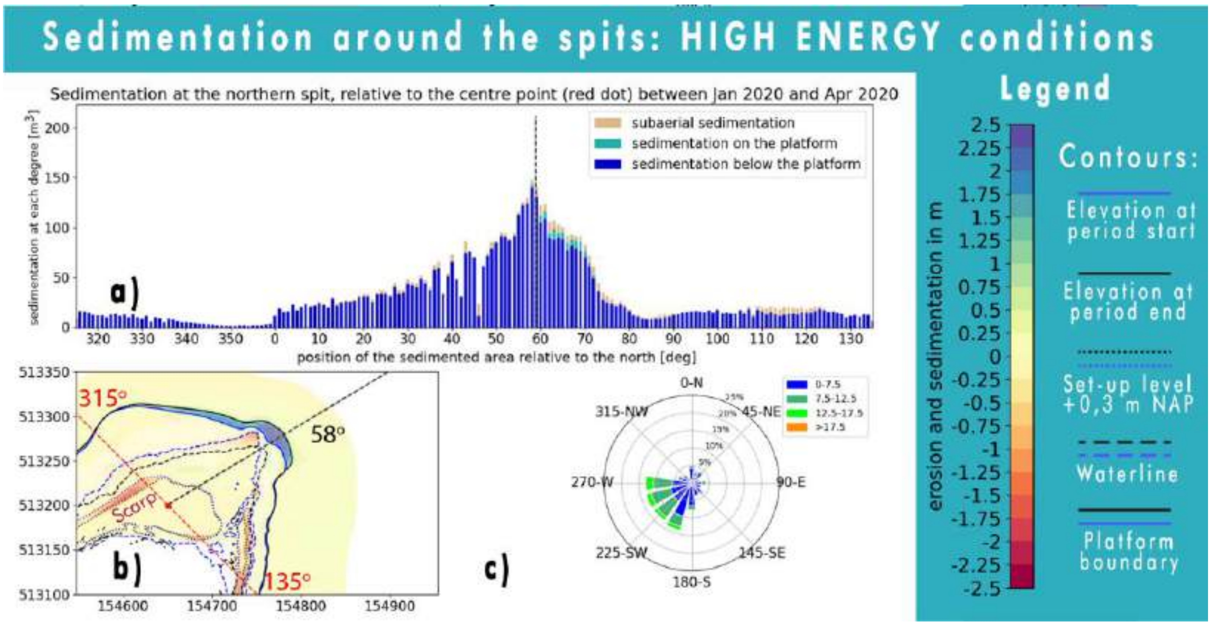

Figure 1: Examples of sedimentation patterns during high-energy periods at the northern spit of the Marker Wadden. a) Each bar gives the sedimentation that occurred in the period on that particular direction. In the bar graphs the grey lines indicate the centre of mass of a distinguishable deposition. The difference in the elevation of sedimentation locations can be seen by the size difference between the sub-platform level (blue) and the platform level (turquoise). b) A visual representation of the location of sedimentation (blue) and erosion (red). c) The wind rose gives the wind conditions during the period.

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Guano-mediated island genesis in the Dutch Waddensea

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Introduction

Bird faeces contains high concentrations of nitrogen, phosphate and potassium. This natural fertilizer fosters vegetation growth at hard-substrate islands (Buelow et al., 2018). Yet, for sandy islands it is unknown if similar links between bird presence and vegetation development exist. Whereas, especially on sandy islands, vegetation acts as an autogenic ecosystem engineer driving island morphodynamics through vegetation-sedimentation feedback processes (Bonte et al., 2021). We therefore hypothesise that birds interact with island morphology through fertilizing the sandy islands they breed on. Insight into relationships between coastal bird presence, vegetation growth dynamics and subsequently landscape development is advantageous in integrated coastal zone management in which policy serves both coastal safety and biodiversity.

Methods

We assessed to what extent the plant community composition and its trait expressions depend on bird presence by conducting a field survey on 11 different sandy islands in the Waddensea. To verify whether plants grew on guano-subsidized soils, we analysed stabile isotopes of nitrogen within- and outside of bird colonies. Subsequently, we elucidated whether bird-meditated reciprocal interactions between plants and sediment can be linked to ecotope shifts on these islands. We classified ecotopes using a supervised classification on satellite imagery and elevation data between 2017 and 2022.

Results

Pre-liminary results show that community composition, dry biomass, rooting depth are a function of distance to bird colony. Stabile isotope $^{15}N/^{14}N$ ratios revealed vegetation was nourished by ^{15}N-rich guano. Moreover, ecotopes classified as bare areas develop faster into vegetated- and elevated landscapes when guano was present compared with bare areas under no guano influence.

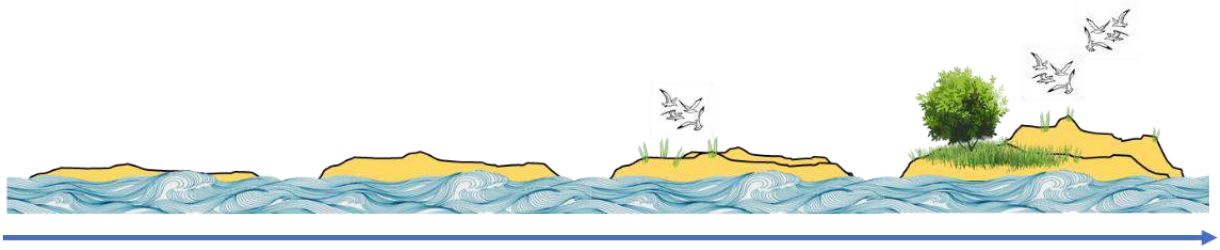

Figure 1: Transition from sandbar to vegetated island under bird influence.

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Recreation impact on the establishment of dune building species

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Introduction

Sandy shores serve a multitude of purposes: they protect the inland from flooding, support a high biodiversity, and are recreation hotspots (Everard, Jones, and Watts 2010). To what extent these functions can coexist or are mutually exclusive is unclear, especially given increasing stressors such as rising sea levels and urbanization. Knowledge about the trade-offs between these functions is important to ensure optimalization of the desired purpose when designing nature-based solutions at sandy shores. One such potential trade-off is between recreation and nature development. Therefore we investigated the effect of recreational pressure on the establishment of the two common dune building species Marram grass (*Ammophila arenaria*) and Sand couch grass (*Elytrigia juncea*).

Methods

We conducted a field introduction experiment with seeds and rhizomes of both species along increasing distance to beach entrances. We used a randomised block design with 4 factorial treatments (species * type diaspore) and 60 replicates for two beaches on the Dutch barrier island of Terschelling. Plant material was collected from the wild, using local genetic material. The plant seeds were left in their husk to mimic natural dispersal. To enable undisturbed recreation, the plots were left unmarked and georeferenced by means of Real Time Kinematic positioning. Recreation pressure was assessed by counting visitations to different beach sections, confirming that anthropogenic pressure decreased with distance from the beach entrance. Establishment success was monitored by counting the number of emerged seeds and sprouted rhizomes per plot across the growing season. To control for other drivers, we also monitored environmental variables, such as the change in beach level.

Results

Preliminary results suggest that environmental factors such as erosion and burial limit the establishment success for both dune building species. Moreover, a positive effect of distance from the entrance on the establishment success of both species can be observed. This is especially clear within the first 100 meters. The strongest effect seems to be for Marram grass. These preliminary results indicate that both sediment dynamics and recreational pressure play a role in the successful establishment of these species on the upper beach. This trade-off between recreation and nature development should be considered when designing sandy coastal areas.

Figure 1: Example of a plot with emerged seedlings.

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Coastal Vision: Assessing a long term coastal protection strategy for the Belgian Coast

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Introduction

In order to keep protecting the entire coast against storms and flooding as a consequence of higher sea levels, it is key to identify appropriate long term adaptive coastal protection strategies. Determining the most appropriate strategy is however a challenging task due to the uncertainties related to the long term aspect and the balance needed between the level of detail required to assess the strategies and the strategic level of the studies. On December 22, 2017, the Flemish government decided to develop such a long-term 'Coastal Vision' (Vlaamse Regering, 2017) to define the space needed for the socially most desirable measures that are necessary to gradually protect our coast and the hinterland against a sea level rise of up to 3 meters in the long term. The assessment approach, focussing on the model tools as used to design solutions and to assess the hydromorphological aspects of the project, are discussed.

Approach

In this study, a wide range of solutions with corresponding space claims were investigated through a participatory approach. An assessment framework based on a framework of ambitions was applied to investigate with increasing detail throughout the project the different solutions. As part of the assessment framework several criteria have been evaluated related to hydromorphological aspects for which a wide range of tools have been applied at different moments during the process of designing, assessing, optimising and selecting alternative strategies (illustrated by Figure 1). As each tool has its own strengths and limitations it was important to determine how this tool can contribute in the process and how the results can be integrated in an overall assessment.

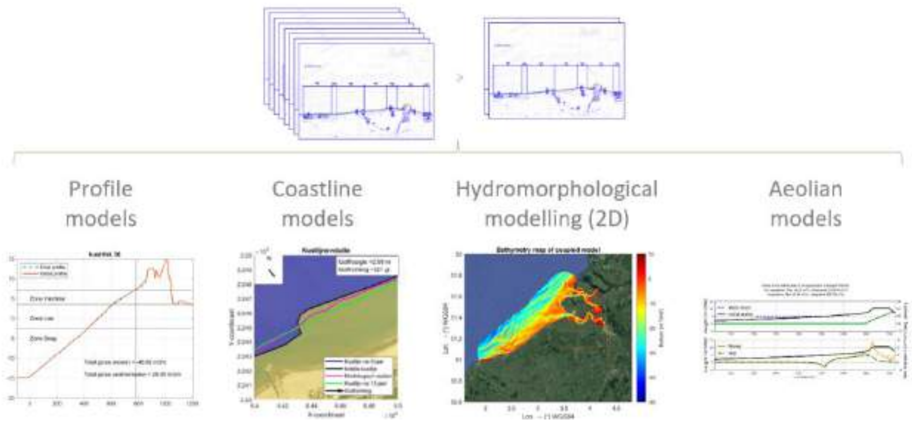

Figure 1: Selection of the model toolbox as used to assess, optimise and select different strategies.

Conclusion

Coastal Vision focused on adaptive coastal protection strategies in the long term for the Belgian coast, against higher and accelerated sea level rise. An approach is presented how to assess and select high-potential alternative strategies illustrated by the hydromorphological research approach and toolset.

Acknowledgement

The study team wishes to acknowledge the Flemish government and the department of public works by making these long term strategic studies possible, allowing in view of the changing environment the basis for good stewardship of our surroundings.

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MOZES: Research on the Morphological Interaction between the Sea Bottom and the Belgian Coastline

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Introduction

Within the framework of a new research project called MOZES, in the coming years 2022-2026 the importance of the seabed for sustainable coastal protection of the Belgian coast will be addressed. It is well known that the dunes are the natural sea defences but less known is that these dunes were formed through a process of natural feeding from the channel-bank system of the shoreface-connected sand ridges. Figure 1 shows the locations of three wider dune areas, which seem to coincide with the landward ends of the three shoreface-connected ridges. This suggests that the ridges have provided sand to shape these dunes, a process that took place on centennial time scales. By order of magnitude, this involves about an intensity of 200,000 m^3/year over a period of 1000 years. Furthermore, there are zones along the coast with encroaching channels that threaten the stability of beaches. Slowly but steadily, these channels are moving inland and/or deepening. These processes are slow but, in the long term (on decadal time scale), the onshore movement of these channels is expected to lead to an increase of nourishment works to maintain coastal protection at these locations.

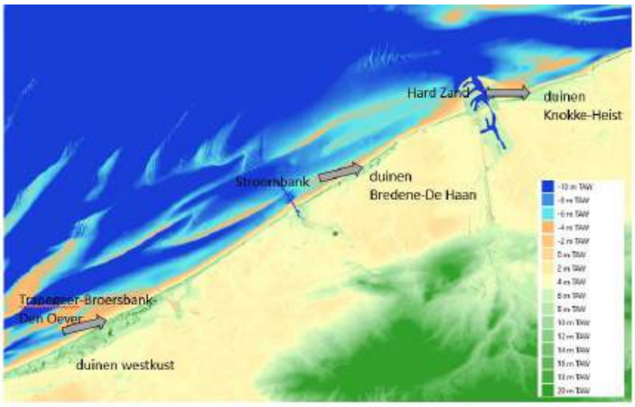

Figure 1: shoreface-connected ridges co-occur with wide dune areas at the Belgian coast

Methods

The 2022-2026 MOZES research project combines data-analysis with numerical model development. Older topobathymetric maps are vectorised in order to map the decadal and centennial morphological evolution. The numerical models will address the slow morphodynamics of the shoreface-connected sand ridges and their interaction with the coastline through cross-shore sand transport (either through a natural feeding related to the presence of a coastal bank, or through erosion due to the presence of a coastal channel).

Results

Results achieved in the first year of the MOZES research will be presented in globo in this contribution. More detailed results will be presented in two additional contributions: 1) on data-analysis results (cf. the abstract submitted by Dujardin *et al.*) and 2) on numerical model development to simulate the morphodynamics on decadal/centennial time scale (cf. the abstract submitted by Nnafie *et al.*).

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Preliminary analysis of salt intrusion observations during the extreme drought of 2022

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Introduction

Climate change and the associated sea level rise and increasing frequency in droughts, are making deltasworldwide more susceptible to salt intrusion. It is very rare to have extensive field datasets during extreme droughts. In 2022 one of the worst droughts occurred in Europe.

Method

Here we present preliminary results from a unique dataset that was collected in the Dutch Rhine-MeuseDelta during a 17 week period in the summer and autumn of 2022. The dataset contains velocity and salinity measurements of instruments which were deployed around the mouth of the Rotterdam Waterway, the data also includes measurements of salinity concentration at many locations within the estuary. In addition to the moored observation points, along-channel velocity and salinity observations were collected during ship borne surveys.

Results

A first analysis of this dataset is presented here, focussing on the estuary response to low river discharge. We present results of the changing stratification around the mouth of the Rotterdam Waterway during thesummer, and preliminary insights into the role of the coupling between the offshore river plume and salt intrusion in the delta. We analysed the ship transects to evaluate how the stratification and salt transport mechanisms alter during the drought. A vertically well-mixed structure is observed in the shallower, upstream estuary. As found in a normal year, a vertically stratified structure is still observed in the downstream estuary. However, the upper layer has a salinity of up to 8 PSU, in contrast to the fresh watertypically found in the surface layer during normal discharge conditions.

Along the thalweg of the estuary we observe an abrupt transition from a salt wedge estuary to a well-mixed estuary, where the salt intrudes significantly farther upstream compared to typical discharge conditions. The discharge reached a minimum of 663 m^3/s compared to the 1500 and 2000 m^3/s observedduring normal summer conditions.

Figure 1: Survey vessel with a freshwater front in the background

Pathway analysis to support long-term coastal management

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Introduction

Functions, such as recreation, drinking water, housing, flood safety and nature all claim space in the Dutch coastal zone, and this is expected to further increase in the future. For example, the tourism sector expects more tourists in the coming decades requiring extra facilities such as restaurants and parking space. Also, with sea level rise more sand is needed to keep the sandy coast stable and safe. Exploring strategies and better insight in cause – effect relations between these functions is essential to discuss the options for long term (up to 2100) coastal management. Here, we describe different pathways, based on a morphological line of reasoning for long-term coastal management. This approach not only demonstrates the existing cause–effect knowledge gaps, but also highlights the need for longer-term adaptive thinking.

Pathways - Morphological line of reasoning

Key in the approach is the morphological response of the coastal zone to sea level rise in the different pathways. A pathway is considered as a set of management strategies / options for different measures in the coastal zone, such as nourishment strategies, nature management strategies and intensity of recreation. Among these, we specifically explored the possibilities to strengthen the sandy coast with variations in dune notches and nourishments.

Start-up notches

Using data from the Dutch coast we provide indications on the ability of (notched) dunes to grow with sea level rise, also reflecting on associated temporal scales. This resulted in generalized recommendations on design and maintenance guidelines for implementing notches. For example, vegetation in the opening of the notch should be removed if large amounts of aeolian transport is required for the growth of dunes. In contrast, if the natural value of the notch is most important then the vegetation should remain. These and more examples are offered to help decision-making for long-term coastal management.

Aeolian transport at notch 'De Kerf' near Schoorl, North Holland

A numerical study of aeolian sediment transport affected by moisture, using discrete element modelling

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Introduction

Worldwide, coastal sandy dunes are bedforms that are essential to protect the land from flooding. They are formed by aeolian processes, in which sediment is transported by wind across the beach. To better understand dune development, it is important to study the dynamic nature of aeolian sediment transport on a small scale. Aeolian sediment transport is not only determined by wind conditions, but also by the properties of the sediment bed. Moisture, as a result of precipitation or tide, is a limiting factor for the erodibility of the sediment bed. This study quantifies the influence of moisture on the two main mechanisms of aeolian sediment transport, i.e., aerodynamic entrainment and the collision process between saltating particles and the bed, on the grain scale.

Methods

Sediment grains and liquid bridges between them are modelled in a discrete element model MercuryDPM (Weinhart et al., 2020). A height-dependent flow profile is applied at the bed boundary to couple the sediment-fluid drag in two directions to force wind-driven sediment transport. In this model, the amount of liquid carried by the particles is determined by the gravimetric moisture content, which allows the modelling of sediment bed with different moisture levels.

Results

In the case of dry sediment transport, the numerical results show a good match with the observations. The existence of moisture increases the threshold for initiating transport, and the bed particles show different behaviours when either initiated by aerodynamics or ejected by saltating particles.

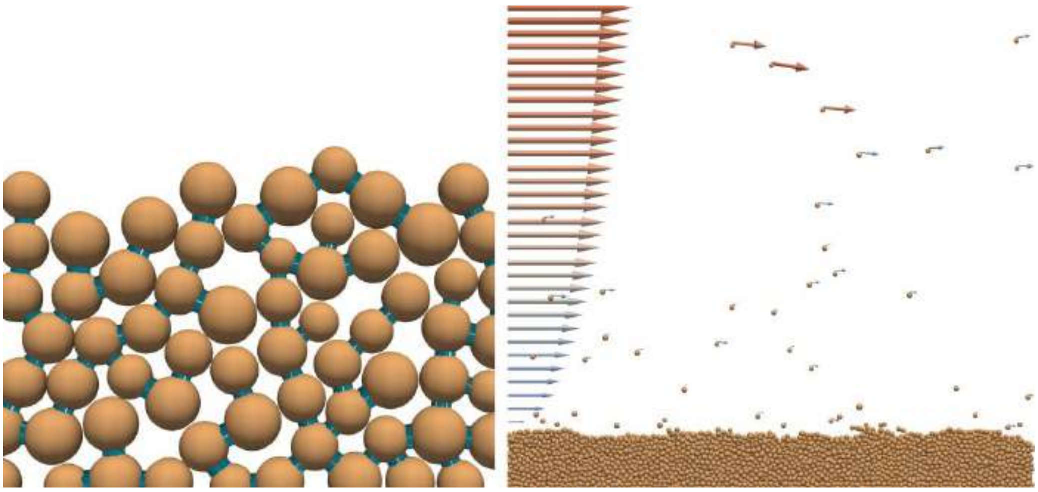

Figure 1: Simulation results in MercuryDPM: left) Sand particles with liquid in between. Right) sand particles being transported by wind (the group of arrows on the left indicates the streamwise wind velocity and the arrows attached to the particles indicate the particle velocities, the larger the size of the arrows, the higher the velocity is).

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Visual modelling of the development of a managed-realignment project.

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Introduction

Managed-realignment, e.g. the de-embankment of polder areas, is an important tool for coastal managers to create climate-resilient coastlines. Managed realignment, however, remains a challenging goal, for two reasons. First, the wetland needs to be designed in such a way that the target ecosystem can efficiently develop. Second, stakeholders and the general public need to be convinced that realignment will lead to a valuable ecosystem.

Methods

Using remote sensing data, we studied managed realignment projects in the Netherlands and in the UK to investigate the success of de-embankments in facilitating ecosystem establishment. From this, we developed and implemented a model to predict wetland development in a future managed realignment project in the Biesbosch, to study the implications of more natural or more controlled designs. Using a pipeline from biogeomoprhological model to a 3D Computer graphics system, we develop a visually tangible representation of how the area will look in 15 years time (Figure 1).

Results

Our survey and model analysis highlighted that restored marshes are less resilient than their natural counterparts: model simulations with and without an imposed initial creek system showed that self-organized creeks had higher sediment transport efficiency than dug-out creeks, especially when the artificial creeks deviated more from a natural creek pattern. Finally, we present depictions of the predicted de-embanked landscape, that will be integrated in an on-site visualization system to explain the project development to a general audience.

Figure 1: A 3D visualization of a modelled future de-embankment in the Biesbosch.