netherlands centre for coastal research

Book of Abstracts

NCK Days 2018

Geo-logic in coastal and shelf research: a matter of multi-disciplinarity

March 21-23

Teylers Museum – Haarlem

Sponsored by:

Netherlands Organisation for Scientific Research

Organized by:

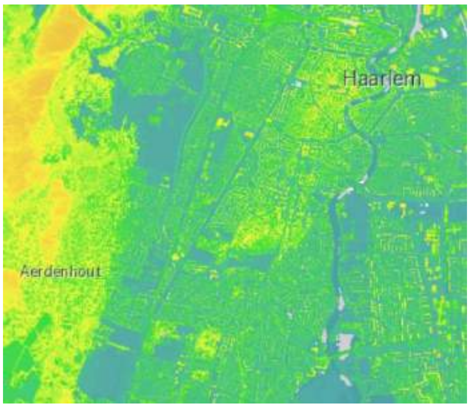
TNO innovation for life

Contents

Preface

Welcome to the 26th NCK Days!

This year's NCK Days are organized by TNO - Geological Survey of the Netherlands as part of its 100-year mapping anniversary. In his budget for 1918, Minister of Water Management *Cornelis Lely* made a reservation for systematic geological mapping, noting that this important task could no longer be postponed. His decision would be instrumental for the exploration of mineral resources, and serve other sectors of society equally well: ensuring the sustainable supply of drinking water, supporting the construction of large infrastructural works, optimizing agriculture, and bolstering science.



It is not accidental that we chose Teylers Museum in Haarlem as the conference venue. In 1918, the newly minted 'Geological Survey' and its first director, *Pieter Tesch*, moved to a building right across the river: Spaarne 17. About 7 km away from the present coastline, Haarlem is unmistakably a coastal city. Its center lies on a beach ridge flanked by beach plains. The Spaarne River marks a former tidal channel draining a once mighty tidal basin. The Museum itself has been open to the public since 1784. It is a treasure trove for those interested in arts and sciences, paying homage to heroes like physicist *Hendrik Lorentz*.

To highlight the relevance and beauty of coastal and marine geological research, we invited Gerd Masselink, Carol Cotterill and Cees Laban. These keynote speakers anchor a program around '***geo-logic in coastal and shelf research: a matter of multi-disciplinarity***'. To get some fresh air, we will go out to explore the city, looking at building stone as well as cityscape. We will also tour the best-preserved 18th-century public-knowledge institution for the arts and sciences in the world. We hope that your visit to Teylers Museum will be an unforgettable experience!

We thank NWO for sponsoring and wish you inspiring and enjoyable NCK days 2018!

The organizing committee,

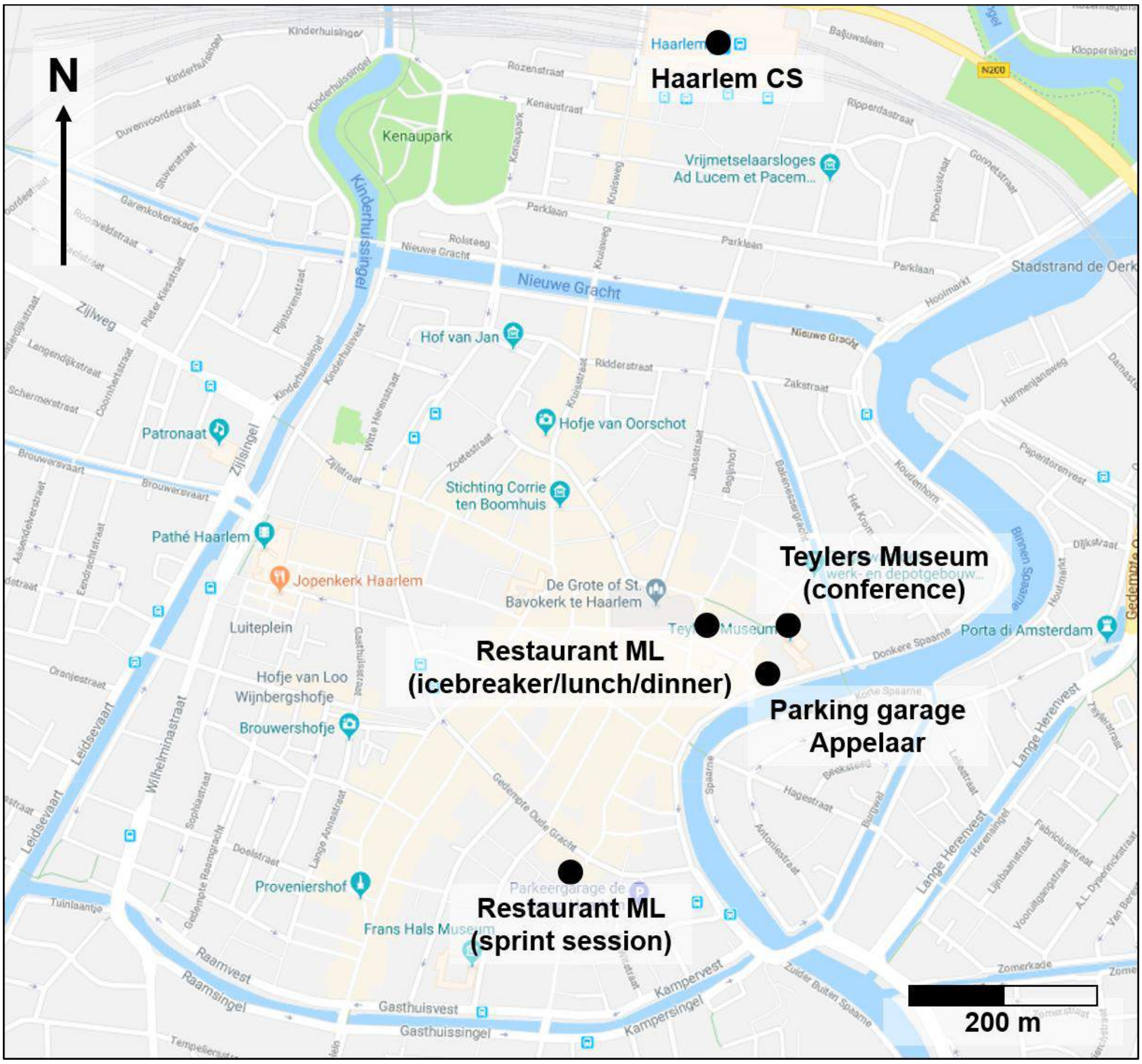
Sytze van Heteren and Ina Vissinga-Schalkwijk

Conference locations

Important locations for this conference are shown on the map below.

The plenary sessions with oral presentations and posters are at Teylers Museum, which is also the starting point of the city walk on Thursday afternoon. From Haarlem Central Station, it is an 11-minute walk. Parking garage Appelaar is directly adjacent to the Museum.

On Wednesday afternoon (prior to the plenary meeting) a sprint session on DINO*loket*, EMODnet and OpenEarth will be hosted by Jelte Stam, Denise Maljers and Gerben de Boer at Restaurant ML, *location Kleine Houtstraat 70*. The icebreaker reception on Wednesday evening, lunches on Thursday and Friday, and Thursday night's conference dinner will be at Restaurant ML, *location Klokhuisplein 9*, a 2-minute walk from Teylers.



Geological city walk and Museum tour

During the Thursday afternoon social event, from 14:00 to 16:30 h, we will break into 6 groups of ca. 20 people (as indicated on your badge). The 1-hour city walk is guided by Wim Dubelaar, Timo Nijland or Sytze van Heteren. It will feature building stone and remnants of the coastal landscape. The 1-hour Museum tour is organized by Teylers. In between, you will have 30 minutes for coffee and posters.

The Netherlands Centre for Coastal Research (NCK)

“Our network stimulates the cooperation and exchange of wisdom between coastal researchers from various research themes and institutes, making us all better.”

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 center 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 sufficiently 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 25 years, the NCK collaboration has stimulated the interaction between coastal research groups. It facilitates a strong embedding of coastal research in the academic programs and courses, attracting young and enthusiastic scientists. Several times a year, the NCK organizes workshops and/or seminars, aimed at promoting cooperation and mutual exchange of knowledge.

NCK is open to researchers from abroad and encourages exchanges of young researchers. Among the active participants are people from a lot of different institutes and companies.

Organization NCK

Netherlands Centre for Coastal Research

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The Board of Directors of NCK consists of:

- *prof. J. Kwadijk PhD. (Deltares, Chairman)*
- *J. Vroom MSc. (Program Secretary NCK, c/o Deltares)*
- *K. van der Werff MSc. (Rijkswaterstaat)*
- *prof. S.G.J. Aarninkhof PhD. (Delft University of Technology)*
- *prof. P. Hoekstra PhD. (Utrecht University - IMAU)*
- *prof. S.J.M.H. Hulscher PhD. (University of Twente)*
- *prof. H. Brinkhuis PhD. (Royal Netherlands Institute of Sea Research NIOZ)*
- *prof. J.A. van Dijk PhD. (IHE Delft Institute for Water Education)*
- *J. Asjes MSc. (Wageningen Marine Research)*
- *M. van der Meulen PhD. (TNO - Geological Survey of the Netherlands)*

The NCK Program Committee consists of:

- *A.J.F. van der Spek PhD. (Deltares, Chairman)*
- *J. Vroom MSc. (Program Secretary NCK, c/o Deltares)*
- *G. Ramaekers MSc. (Rijkswaterstaat)*
- *B.C. van Prooijen PhD. (Delft University of Technology)*
- *K.M. Wijnberg PhD. (University of Twente)*
- *D.S. van Maren PhD. (Deltares)*
- *T. Gerkema PhD. (Royal Netherlands Institute for Sea Research, NIOZ)*
- *prof. T.J. Bouma PhD. (Royal Netherlands Institute for Sea Research, NIOZ)*
- *prof. J.A. Roelvink PhD. (IHE Delft Institute for Water Education)*
- *M.J. Baptist PhD. (Wageningen Marine Research)*
- *M. van der Vegt PhD. (Utrecht University – IMAU)*
- *S. van Heteren PhD. (TNO - Geological Survey of the Netherlands)*

Historical context

Coastal research in The Netherlands has a long history. For many centuries, experience gained from the country's successes and failures in the struggle against the sea has been the major source of innovative knowledge. A more formal and systematic approach has developed over the last hundred years:

1920
An important step in the development of formalized knowledge was taken in the 1920s by the Nobel-prize laureate *Hendrik Lorentz*, who designed a computational scheme for assessing the tidal effects of the closure of the Zuiderzee. At the same time, with the founding of Delft Hydraulics, physical scale models became the favorite instrument for designing coastal engineering works. They remained so for a long time.

1953
The storm-surge disaster of 1953 provided a strong incentive for coastal research in support of the Delta Project, which entailed a drastic shortening of the Dutch coastline. The Delta Project profoundly affected the morphodynamics of the Rhine-Meuse-Scheldt delta; large parts of the system were transformed into what one might call a life-size hydraulic laboratory.

1965
In the 1960s, a monitoring program (JARKUS) was established to assess the evolution of the nearshore zone along the entire Dutch coast on a yearly basis. The resulting data base has revealed not only short-term fluctuations of the shoreline, but also large-scale structural trends. The JARKUS data set represents a key source of coastal information, particularly in combination with historical observations of Dutch coastline evolution that date back to 1840-1850. With no equivalent data set available worldwide, the unique JARKUS data base has inspired a wealth of coastal research programs throughout the years.

1985
The growing need for integrated coastal management during the second half of the 1980s triggered the development of a national coastal defense policy of 'Dynamic Preservation' (1990). It involved sustainable maintenance of the coast through 'soft' interventions (commonly nourishment of the beach and shoreface with sand taken from offshore), allowing for natural fluctuations. The basic principles were derived from a major research project for the systematic study of persistent trends in the evolution of the coastal system. This Coastal Genesis project - carried out by a multidisciplinary team of coastal engineers, physical and historical geographers and geologists - laid the ground for NCK.

1991
The successful multidisciplinary collaboration initiated during the Coastal Genesis project was institutionalized by means of the founding of the Netherlands Centre for Coastal Research (NCK). The NCK was initiated by the coastal research groups of Delft University of Technology, Utrecht University, WL | Delft Hydraulics and Rijkswaterstaat RIKZ. Early 1996, the University of Twente and TNO - Geological Survey of the Netherlands joined NCK (Deltares ‘inherited’ the Geological Survey Membership in 2008), followed by the Netherlands Institute for Sea Research (NIOZ, 1999), the Netherlands Institute for Ecology - Centre for Estuarine and Marine Ecology (NIOO-CEME, 2001), UNESCO-IHE Institute for Water Education (now IHE Delft Institute for Water Education, 2004) and Wageningen IMARES (now Wageningen University and Research, 2008). In 2017, the Geological Survey of the Netherlands rejoined NCK.

The NCK partners

TNO
Geological Survey of the Netherlands

The Netherlands Organisation for Applied Scientific Research (TNO) is a nonprofit company in the Netherlands that focuses on applied science. Established by law in 1932, TNO is a knowledge organization supporting companies, government bodies and public organizations with innovative, practicable knowledge. With 2,800 employees, it is the largest research institute in the Netherlands. The government has assigned various tasks to TNO in respect of information on the Dutch subsurface. TNO acts (internationally) as the Geological Survey of the Netherlands, which manages and models publicly available geological data and information. Its core expertise is the construction of voxel-based subsurface models that are highly suitable as input for decision-support systems. In addition, TNO has the legal task of making information on the Dutch subsurface available to Dutch society so as to enable the sustainable use and management of the subsurface and the mineral resources it contains. This information is needed to organizate the space above and below ground in a sustainable way.

More information
https://www.tno.nl/en/

Representatives
NCK Board of Supervisors: M. van der Meulen PhD
NCK Program Committee: S. van Heteren PhD

Delft University of Technology
Faculty of Civil Engineering and Geosciences

The Faculty of Civil Engineering and Geosciences is recognized as one of the best in Europe, with a particularly important role for the Department of Hydraulic Engineering. This department encompasses the Sections Fluid Mechanics and Hydraulic Engineering. Over the years, both have gained an internationally established reputation, in fluid dynamics in general; in coastal dynamics; in the fields of coastal sediment transport, morphology, wind waves, coastal currents. Mathematical, numerical modelling and experimental validation of these processes is at the forefront internationally. Recently, the development of field expertise has been an important focal point.

More information
http://www.citg.tudelft.nl/over-faculteit/afdelingen/hydraulic-engineering/

Representatives
NCK Directory Board: prof. S.G.J. Aarninkhof PhD.
NCK Program Committee: B.C. van Prooijen PhD.

Deltares
Applied research in water, subsurface and infrastructure

WL | Delft Hydraulics, GeoDelft, the Subsurface and Groundwater unit of TNO and parts of Rijkswaterstaat joined forces in January 2008 to form a new independent institute for delta technology, Deltares. Deltares conducts applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Our main focus is on deltas, coastal regions and river basins. Managing these densely populated and vulnerable areas is complex, which is why we work closely with governments, businesses, other research institutes and universities at home and abroad.

Enabling Delta Life
Our motto is Enabling Delta Life. As an applied research institute, the success of Deltares can be measured in the extent to which our expert knowledge can be used in and for society. For Deltares the quality of our expertise and advice is foremost. Knowledge is our core business. All contracts and projects, whether financed privately or from strategic research budgets, contribute to the consolidation of our knowledge base. Furthermore, we believe in openness and transparency, as is evident from the free availability of our software and models. Open source works, is our firm conviction. Deltares employs more than 800 people and is based in Delft and Utrecht.

More information
http://www.deltares.nl/en

Representatives
NCK Board of Supervisors: prof. J. Kwadijk PhD
NCK Program Committee: A.J.F. van der Spek PhD, D.S. van Maren PhD

IHE Delft Institute for Water Education

IHE Delft Institute for Water Education is the largest international graduate water-education facility in the world and is based in Delft, the Netherlands. The Institute confers fully accredited MSc degrees, and PhD degrees in collaboration with partner universities. Based in Delft, it comprises a total of 140 staff members, 70 of whom are responsible for the education, training, research and capacity building programs both in Delft and abroad. It is hosting a student population of approximately 300 MSc students and some 60 PhD candidates. UNESCO-IHE is offering a host of postgraduate courses and tailor-made training programs in the fields of water science and engineering, environmental resources management, water management and institutions and municipal water supply and urban infrastructure. UNESCO-IHE, together with the International Hydrological Programme, is the main UNESCO vehicle for applied research, institutional capacity building and human resources development in the water sector world-wide.

After having been in existence for more than 50 years, IHE was officially established as a UNESCO institute on 5 November 2001 during UNESCO's 31st General Conference. Recently, IHE Delft signed a partnership agreement with UNESCO for the transition period from 2017 to mid-2018 when a decision on its category 2 status is expected. As from 1st January 2017, IHE Delft Institute for Water Education (formerly UNESCO-IHE) operates as a Foundation under Dutch law, working in in partnership with UNESCO. Throughout this period and once the new status is obtained, the Institute will continue to cooperate closely with the UNESCO Secretariat, the Science Sector and the International Hydrological Programme (IHP), and the Institute will remain a flagship institute in the UNESCO Water Family.

More information
https://www.unesco-ihe.org/

Representatives
NCK Board of Supervisors: J.A. van Dijk PhD
NCK Programme Committee: prof. D. Roelvink PhD

NIOZ
Royal Netherlands Institute for Sea Research

NWO-NIOZ Royal Netherlands Institute for Sea Research is the national oceanographic institute and principally performs academically excellent multidisciplinary fundamental and frontier applied marine research addressing important scientific and societal questions pertinent to the functioning of oceans and seas. Second, NIOZ serves as national marine research facilitator for the Dutch scientific community. Third, NIOZ stimulates and supports multidisciplinary fundamental and frontier applied marine research, education and marine policy development in the national and international context. The Netherlands Institute for Sea Research (NIOZ) aspires to perform top level curiosity-driven and society-inspired research of marine systems that integrates the natural sciences of relevance to oceanology. NIOZ supports high-quality marine research and education at universities by initiating and facilitating multidisciplinary and sea-going research embedded in national and international programs. We aim to generate the expertise and fundamental knowledge needed to underpin and improve longer-term sustainable and responsible marine management.

More information
www.nioz.nl/home_en.html

Representatives
NCK Board of Supervisors: prof. H. Brinkhuis PhD
NCK Program Committee: T. Gerkema PhD, T.J. Bouma PhD

Rijkswaterstaat
Water, Traffic and Environment

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

As the executive body of the Ministry of Infrastructure and Water Management, Rijkswaterstaat manages the Netherlands' main highway and waterway network. Rijkswaterstaat takes care of the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. Its employees are responsible not only for the technical condition of the infrastructure, but also for its user-friendliness. Smooth and safe traffic flows, a safe, clean and user-friendly national waterway system and protection from flooding: that is what Rijkswaterstaat is about.

Participation in NCK

The participation of Rijkswaterstaat in NCK is covered by the service Water, Traffic and Environment (WVL). WVL develops the vision of Rijkswaterstaat on the main highway and waterway network, as well as the interaction with our living environment. WVL is also responsible for the scientific knowledge that Rijkswaterstaat requires to perform its tasks, now and in the future. As such, Rijkswaterstaat - WVL works closely with knowledge institutes. By participating in joint ventures and forming strategic alliances with partners from the scientific world, WVL stimulates the development of knowledge and innovation with and for commercial parties.

More information

http://www.rijkswaterstaat.nl/en/

Representatives

NCK Board of Supervisors: K. van der Werff MSc
NCK Program Committee: G. Ramaekers MSc

University of Twente
Civil Engineering & Management

Since 1992, the University of Twente has had an educational and research program in Civil Engineering, which aims at embedding (geo)physical and technical knowledge related to infrastructural systems into its societal and environmental context. The combination of engineering and societal faculties makes the university particularly well equipped to run this program. Research of the section Water Engineering and Management (WEM) focuses on i) physics of large, natural, surface-water systems such as rivers, estuaries and seas; and ii) analysis of the management of these systems. Within the first research line WEM aims to improve the understanding of physical processes and to model their behavior appropriately, which means as simple as possible but accurate enough for the water-management problems that are considered. Dealing with uncertainty plays an important role here. An integrated approach is central to the water-management analysis, in which we consider not only (bio)physical aspects of water systems, but also the variety of functions these systems have for the users, the way in which decisions on their management are taken, and the translation of these decisions into practical applications. Various national and international research projects related to coastal zone management, sediment transport processes, offshore morphology, biogeomorphology and ecomorphodynamics have been awarded to this section.

More information
http://www.utwente.nl/ctw/wem/

Representatives
NCK Board of Supervisors: prof. S.J.M.H. Hulscher PhD
NCK Program Committee: K.M. Wijnberg PhD

Utrecht University
Institute for Marine and Atmospheric Research Utrecht IMAU

The Institute for Marine and Atmospheric research Utrecht (IMAU) is hosted partly at the Faculty of Science and partly at the Faculty of Geosciences. The Institute's main objective is to offer an optimal, stimulating and internationally oriented environment for top quality fundamental research in Climate Dynamics and Physical Geography and Oceanography of the coastal zone, by integrating theoretical studies and extensive field studies. IMAU focuses on the hydrodynamics and morphodynamics of beaches and surf zones, shoreface and shelf, as well as on the dynamics of river deltas, estuarine systems and barrier islands. Research in coastal and shelf sea dynamics focuses on the interactions between the water motion, sediment transport and bottom changes in coastal seas and estuaries. Both sandy and mud-dominated coastal systems are investigated. The following approaches are used to gain more understanding of hydrodynamic and morphodynamic processes: collection and analysis of field observations, simulations with complex numerical models and interpretation of these results, development and analysis of idealized mathematical models. The Faculty of Geosciences studies the Earth: from the Earth's core to its surface, including man's spatial and material utilization of the Earth – always with a focus on sustainability and innovation.

More information
http://www.uu.nl/faculty/geosciences/EN/Pages/default.aspx
http://imau.nl/

Representatives
Board of Supervisors: prof. P. Hoekstra PhD
NCK Program Committee: M. van der Vegt PhD

Wageningen Marine Research

Wageningen Marine Research (WMR) explores the potential of marine nature to improve the quality of life. It is the Netherlands research institute established to provide the scientific support that is essential for developing policies and innovation in respect of the marine environment, fishery activities, aquaculture and the maritime sector. We conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas. WMR is an independent, leading scientific research institute. We carry out scientific support to policies (50%), strategic RTD programmes (30%) and contract research for private, public and NGO partners (20%). Our key focal research areas cover marine ecology, environmental conservation and protection, fisheries, aquaculture, ecosystem-based economy, coastal zone management and marine governance. WMR primarily focuses on the North Sea, the Wadden Sea and the Dutch Delta region. It is also involved in research in coastal zones, polar regions and marine tropical areas throughout the world and in specific freshwater research. WMR has some 200 people active in field surveys, experimental studies, from laboratory to mesocosm scale, modelling and assessment, scientific advice and consultancy. Our work is supported by state-of-the-art in-house facilities that include specialist marine analysis and quality labs, outdoor mesocosms, specific field-sampling devices, databases and models. The Wageningen Marine Research quality system is ISO 9001 certified.

More information
http://www.wur.nl/en/Expertise-Services/Research-Institutes/marine-research/about-us.htm

Representatives
NCK Board of Supervisors: J. Asjes MSc
NCK Program Committee: M. Baptist PhD

Final program NCK Days 2018

Wednesday March 21

16.00-20.00 Sprint session DINO*loket*, EMODnet and OpenEarth by Jelte Stam, Denise Maljers and Gerben de Boer, at Restaurant ML, Kleine Houtstraat 70
20.00-22.30 Icebreaker at Restaurant ML, Klokhuisplein 9 (formerly Café Stempels)

Thursday March 22

09.00-09.29 Registration
09.30-09.44 Opening Tirza van Daalen and Michiel van der Meulen
Session 1 - BEACH AND BARRIER BEHAVIOR
09.45-10.25 Keynote 1 - **Gerd Masselink** (University of Plymouth): *Variability in the North-East Atlantic wave climate and its influence on annual-to-decadal beach dynamics*
10.26-10.33 **Koen Reef**: *Long-term morphological behavior of barrier coasts: Influence of storm-induced breaches using stochastic modelling*
10.34-10.41 **Max Radermacher**: *Long-term evolution of subtidal sandbars at the Delfland coast under the influence of repeated nourishments*
10.42-10.49 **Daan Wesselman**: *The morphological development of Rottumeroog during a stormy winter*
10.50-10.56 Questions
10.57-11.09 Poster pitches
11.10-11.39 Coffee break and poster session

Session 2 - VEGETATION AS A DRIVER AND RECORDER OF COASTAL PROCESSES
11.40-11.50 **Valérie Reijers**: *The dance of Ammophila: On how individual movement patterns control the formation of coastal dunes*
11.51-11.58 **Marinka van Puijenbroek**: *Raising the (subtidal) bar for embryonic dune growth and survival*
11.59-12.06 **Stephanie IJff**: *How seabed sediments are transformed into a new dune slack: The case of Spanjaards Duin, Delfland coast*
12.07-12.14 **Muriel Brückner**: *Effects of biological traits on salt-marsh-species distribution and estuarine bar morphology*
12.15-12.22 **Sanja Selakovic**: *Sediment-stabilising and -destabilising ecoengineering species from river to estuary: The case of the Scheldt system*
12.23-12.30 **Stephanie Janssen**: *Implementation of vegetated foreshores for flood-risk reduction: Dealing with social dilemmas*
12.31-12.38 **Patrick Kiden**: *Reconstructing long-term sea-level rise for the northern Netherlands*
12.39-12.53 Questions

12.54-13.59 Lunch
14.00-16.30 **Geological city walk and Teylers Museum Visit** / Coffee break and poster session

Session 3 - THE MARINE SUBSURFACE

16.31-17.01 Keynote 2 - **Carol Cotterill** (British Geological Survey): *Evolution of the Dogger Bank, North Sea: A complex history of terrestrial and marine environmental change*
17.02-17.09 **Bart Meijninger**: *Geology of the Borssele Offshore Wind Farm Zone*
17.10-17.17 **Harm Jan Pierik**: *Effects of inherited resistant layers on shape and long-term evolution of the Eems-Dollard estuary*
17.18-17.25 **Marc Hijma**: *Subsidence along the Dutch coast*
17.26-17.33 **Freek Busschers**: *The stuff a harbor is made of: Ancient and recent sand from the Maasvlakte 2 pit*
17.34-17.44 **Lars Kint**: *Incorporating data uncertainty in 3D voxel modelling and the importance in decision making*
17.45-17.55 Questions
19.00-21.30 **Conference dinner**

Friday March 23

Session 4 - MONITORING THE COASTAL ZONE

09.00-09.30 Keynote 3 - **Cees Laban** (Marine Geological Advice, former Head of Marine and Coastal Research at the Geological Survey of the Netherlands): *Fifty years of marine geological mapping in the Dutch part of the North Sea*
09.31-09.38 **Stefan Aarninkhof**: *Coastline observatory to examine coastal dynamics in response to natural forcing and human interventions*
09.39-09.46 **Bram van Prooijen**: *Kustgenese 2.0/SEAWAD - Ameland Inlet field campaign*
09.47-09.54 **Roeland de Zeeuw**: *Quick reaction force Ameland Noordwest: First results*
09.55-10.02 **Matthijs Gawehn**: *Real-time estimation of ebb-tidal-delta bathymetry using navigational X-band radar*
10.03-10.10 **Yvonne Smit**: *Spatiotemporal surface moisture dynamics on a coastal beach*
10.11-10.18 **Cas van Bemmelen**: *Beach scarp morphodynamics*
10.19-10.26 **David Barmentloo**: *Analysing large-scale differences in long-term morphologic behaviour along the North Sea coast*
10.27-10.41 Questions
10.42-10.55 Poster pitches
10.56-11.20 Coffee break and poster session

Session 5 - COASTAL SEDIMENT TRANSPORT

11.21-11.31 **Stuart Pearson**: *Sediment transport patterns on Ameland ebb-tidal delta determined by dual-signature sediment tracers*
11.32-11.39 **Glenn Strypsteen**: *Aeolian sediment transport processes in a managed beach-dike system*
11.40-11.47 **Evelien Brand**: *Measuring suspended sediment transport in the intertidal zone of a macro-tidal beach (Mariakerke, Belgium)*
11.48-11.55 **Erik van Onselen**: *Promoting beach-dune interaction in the presence of man-made obstacles*
11.56-12.03 **Kirstin Schultz**: *Unraveling the decisive factors for the transport of sediment as a supply for salt-marsh growth*
12.04-12.14 Questions

Session 6 - SAND-WAVE FIELDS

12.15-12.22 **Janneke Krabbendam**: *Modeling the evolution of observed tidal sand waves in the North Sea*
12.23-12.30 **Chiu Cheng**: *Small-scale variations in sediment characteristics over the different morphological units of tidal sand waves offshore of Texel*
12.31-12.38 **Rick de Koning**: *A classification method for the presence of tidal sand waves and maintenance dredging design*
12.39-12.46 **Jane Zhou**: *Modelling sand-wave fields on the Taiwan Banks, northern South China Sea: The formation of two-scale sand waves in different periods*
12.47-12.55 Questions
12.56-13.59 Lunch

Session 7 - COASTAL MORPHODYNAMICS AND ESTUARINE HYDRODYNAMICS

14.00-14.10 **Anna Kroon**: *The importance of uncertainty assessment in morphology predictions*
14.11-14.18 **Ahmed Elghandour**: *Efficient modelling of coastal evolution: Development, verification and validation of ShorelineS*
14.19-14.26 **Bart Roest**: *The influence of the Sand Engine on the Delfland coastal cell*
14.27-14.34 **Merel Verbeek**: *Measuring two-scale flow response to resistance at tidal turbines in the Eastern Scheldt*
14.35-14.42 **Long Jiang**: *Modeling residence time of the Eastern Scheldt*
14.43-14.50 **Yorick Broekema**: *Positive feedback through three-dimensionality of the flow: Enhancement of scour potential at the Eastern Scheldt storm-surge barrier*
14.51-15.03 Questions
15.04-15.30 Coffee break and poster session

Session 8 -ESTUARINE MORPHODYNAMICS

15.31-15.41 **Cynthia Maan**: *Morphodynamic feedback loops control stable fringing flats*
15.42-15.49 **Steye Verhoeve**: *Rapid morphology assessment for estuaries*
15.50-15.57 **Abdel Nnafie**: *Morphodynamic impact of sea-level rise on the Western Scheldt estuary and its mouth region: Insights from an idealized modeling study*
15.58-16.05 **Ana Colina Alonso**: *Unravelling the mechanisms behind the morphodynamic evolution of the Haringvliet ebb-tidal delta*
16.06-16.13 **Jana Cox**: *Effects of dredging and dumping in laboratory scale experiments of estuaries*
16.14-16.24 Questions
16.25-16.45 Awards and closure

List of posters

Thursday March 22

Name	Title
Laura Brakenhoff	*Characteristics of saw-tooth bars on the ebb-tidal deltas of the Wadden Sea*
Wout van Dijk	*Perturbation effect of shoal-margin collapses on the channel-shoal morphodynamics in the Western Scheldt*
Sytze van Heteren	*A new generation of marine geological maps for the North Sea*
Gijsbert van Holland	*Study and measures to reduce Marina Inlet sedimentation in Blankenberge and beach erosion in Wenduine, Belgium*
Harriëtte Holzhauer	*The ebb-tidal delta: Bare or rare?*
Sjoerd Leenders	*Numerical modelling of the migration direction of offshore sand waves using Delft3D*
Timothy Price	*Shoreward-propagating accretionary waves (SPAWs): Observations from a multiple sandbar system (Egmond aan Zee)*
Anne Ton	*Sandy foreshores as dike reinforcement in lake systems: A nature-based solution at the Houtribdijk*
Tommer Vermaas	*Geology and morphology at Ameland Southwest*
Roeland van de Vijsel	*Algal mats boost present-day biogeomorphology using Precambrian self-organisation strategies*
Pim Willemsen	*Seasonal wind and biota drive tidal mudflat dynamics*
Floris de Wit	*Measuring the spatial and temporal variability of currents on Ameland ebb-tidal delta*

Friday March 23

Name	Title
Vera van Bergeijk	*Modelling of the effect of transitions on wave overtopping flow and erosion for flood-defence reliability*
Lisanne Braat	*Preservation of mud layers in tidal bars: shoal of Walsoorden*
Marcio Boechat Albernaz	*Parameterization of wave orbital motion and its effect on long-term morphological development in the nearshore*
Marco Gatto	*Large-scale effects of tidal energy extraction in the Eastern Scheldt*
Pam Hage	*Using Argus video monitoring to determine limiting factors of aeolian transport on a narrow beach*
Julia Hopkins	*Morphological diffusivity experiment*
Klaas Lenstra	*Cyclic behavior of ebb-tidal deltas from model simulations*
Quirijn Lodder	*Coastal research at Ministry of Infrastructure and Water: Coherence and overall perspective*
Jan-Willem Mol	*What it takes: Planning and risk management field campaign Kustgenese 2.0*
Max Radermacher	*Evaluating the impact of the Sand Motor on swimmer safety*
Willeke van de Wardt	*Improving formulations for the cross-shore transport of graded sediment in Delft3D*
Chen Weiqiu	*Experimental study on the influence of transitions on wave overtopping*
Winnie de Winter	*The influence of beach-foredune morphology on local wind characteristics*

Abstracts of oral presentations
in order of oral presentations at the conference program

VARIABILITY IN THE NORTH-EAST ATLANTIC WAVE CLIMATE AND ITS INFLUENCE ON ANNUAL-TO-DECADAL BEACH DYNAMICS

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Using southwest England as a natural laboratory, this presentation will discuss the coastal morphodynamics along exposed, macrotidal and embayed shorelines. Using recorded and modelled wave data, the key drivers for the Atlantic wave climate are discussed, highlighting the importance of climatic indices such as NAO and WEPA in controlling especially the storm wave conditions. The variability in wave conditions is what drives beach morphodynamics on the annual to decadal time scales, and a detailed analysis of storm response and recovery is presented for two key sites with unprecedented data sets: monthly survey data for 10 years from a fully exposed sandy beach (Figure 1) and a partially exposed gravel beach. A key concept associated with embayed coastlines is the notion of whether an embayment is closed or open, and whether the sediment budget is balanced or not. This will be addressed using the 'total sediment budget' approach, which entails quantifying all sediment present within the coastal system, including the dune, upper beach, intertidal zone, and the subtidal zone up to the depth of closure. Determining the total sediment budget is far from trivial and requires a multi-method survey programme as well as robust error propagation to yield reliable results. Nevertheless, to attain quantitative understanding of the long-term coastal morphodynamics requires full insight into the cross-shore and longshore sediment fluxes and a total sediment approach is an essential tool to achieve this.

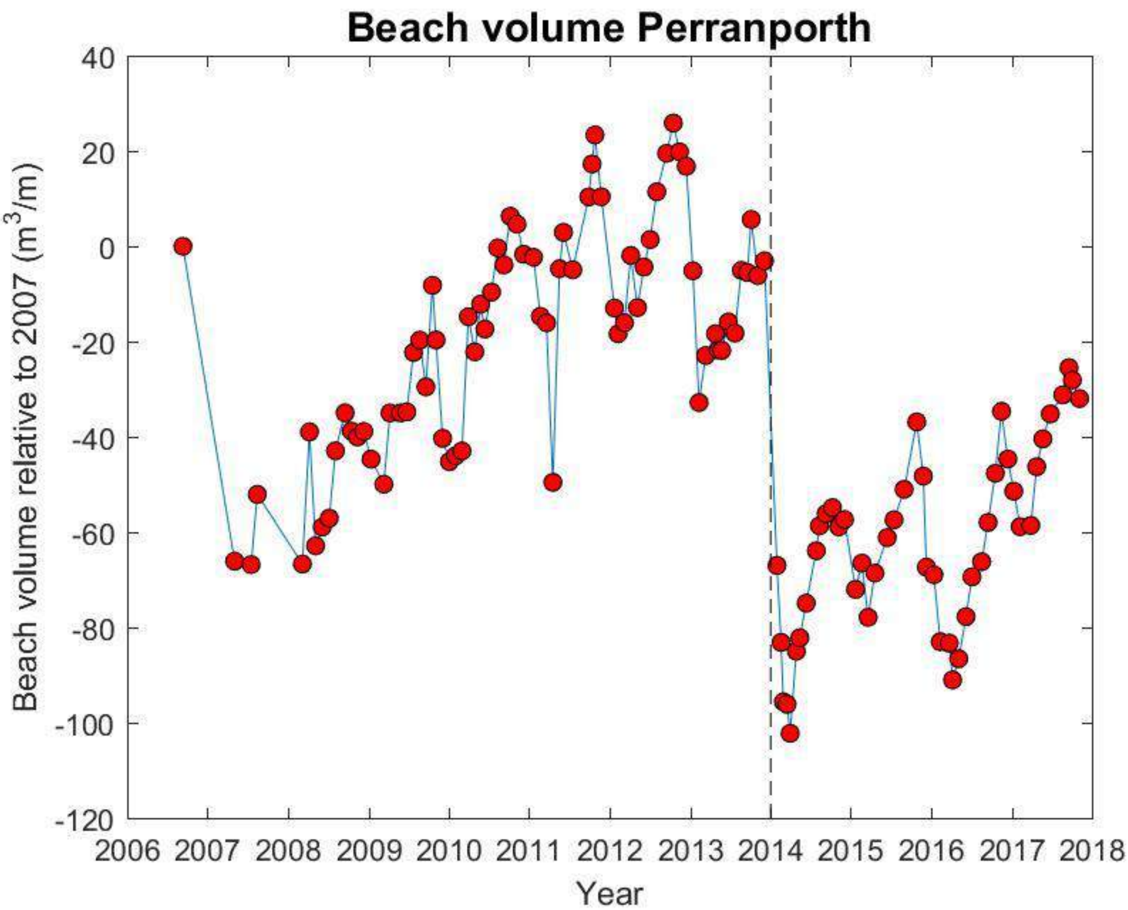

Figure 1. Monthly time series of intertidal beach volume for Perranporth, north Cornwall.

LONG-TERM MORPHOLOGICAL BEHAVIOR OF BARRIER COASTS: INFLUENCE OF STORM-INDUCED BREACHES USING STOCHASTIC MODELLING

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* K.R.G.Reef@utwente.nl

Many barrier coasts are characterized by an interrupted coastline with a chain of barrier islands that are separated by tidal inlets, through which water and sediment flow between the open sea and the tidal basin. They are found around the world (e.g. the Long Island coast, USA and the Wadden Sea, the Netherlands, Germany, Denmark) and they are important for coastal safety, ecology, and economy.

Previous work on the long-term (decades to centuries) behavior of barrier coasts has focused on the evolution of single (Escoffier 1940), double (e.g. van de Kreeke 1990; Brouwer et al. 2012), and multiple inlet systems (Roos *et al.* 2013). This earlier research revealed the existence of equilibria and interaction among adjacent inlets. However, how randomly appearing storm-induced breaches influence these dynamics is unclear.

The effect of storms on barrier coasts can be significant, ranging from increased sediment transport to the creation of new tidal inlets through storm-induced breaches (e.g. as happened during Hurricane Sandy at Long Island near New York in 2012).

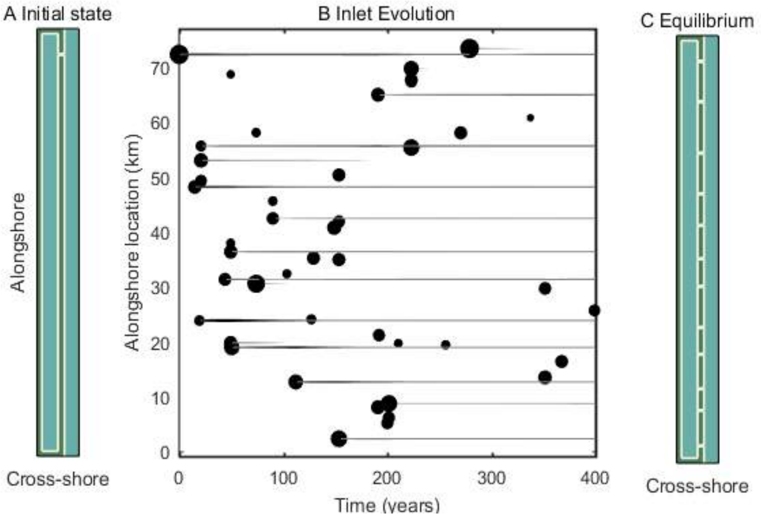

Figure 1. Example of a model run showing:

A, initial configuration with a single inlet.
B, evolution of the barrier coast with storm-induced breaches as black dots (dot size is proportional to initial breach size, line thickness proportional to inlet width over time).
C, the final configuration in which the inlets are in equilibrium.

Here we present our work on how storm-induced breaches influence the long-term behavior of barrier coasts, using a morphodynamic model based on Escoffier's (1940) concept for inlet evolution (whilst neglecting inlet migration), combined with an idealized hydrodynamic model. Herein, storm-induced breaches are included as a stochastic forcing. As part of the WADSnext! Project, aimed at understanding the long-term behavior of barrier coasts to support sustainable management, we conducted Monte-Carlo simulations (n = 10,000) with duration of 400 years for each simulation to investigate the effect of randomly appearing storm-induced breaches on the long-term behavior of barrier coasts.

Results, as depicted in Figure 1, show that breach evolution (closing or staying open), is governed by the breach characteristics (i.e. initial width and distance to the nearest inlet) in combination with the state of the full system (proximity to contemporary equilibrium, which, in our model, is related to the total inlet area and number of inlets). Furthermore, we found that when a breach remains open, the nearby pre-existing inlets decrease in size, confirming field observations.

Brouwer, R.L., van de Kreeke, J., Schuttelaars, H.M. (2012). Entrance/exit losses and cross-sectional stability of double inlet systems. *Estuarine, Coastal and Shelf Science*, 107, 69-80.

Escoffier E.F. (1940) The stability of tidal inlets. *Shore and Beach*, 8, 114–115.

Roos, P.C., Schuttelaars, H.M., Brouwer, R.L. (2013). Observations of barrier island length explained using an exploratory morphodynamic model. *Geophysical Research Letters*, 40(16), 4338-4343.

Van de Kreeke, J. (1990). Can multiple tidal inlets be stable?. *Estuarine, Coastal and Shelf Science*, 30(3), 261-273.

LONG-TERM EVOLUTION OF SUBTIDAL SANDBARS AT THE DELFLAND COAST UNDER THE INFLUENCE OF REPEATED NOURISHMENTS

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Introduction

Subtidal sandbars play an important role in nearshore hydrodynamics and morphodynamics. The presence and evolution of subtidal sandbars are influenced by the introduction of sand nourishments in the coastal system. While the impact of individual nourishments on individual sandbars has been studied before, the long-term impact of enduring nourishment activities on sandbars is largely unknown. In this study, 52 years of subtidal sandbar evolution at the Delfland coast is analysed, a time span that includes more than 20 nourishments of various types.

Results

The presence and behaviour of subtidal sandbars at the Delfland coast is strongly influenced by the applied nourishment strategies. Three notable transitions in sandbar dynamics occurred during the study period. (1) Following the first beach nourishments at the central part of the Delfland coast in 1987, a subtidal sandbar emerged in this previously unbarred section of the coastal cell (see Figure 1). (2) After the introduction of shoreface nourishments from 1997 onwards, the migration direction of subtidal sandbars switched from offshore to onshore. (3) Following an extensive nourishment operation in 2009-2011 (including construction of the Sand Motor), a new, shallow sandbar with relatively high alongshore variability formed along the entire Delfland coast. These results imply that individual nourishments can influence the formation and migration of individual sandbars, whereas series of consecutive nourishments can fundamentally change long-term sandbar dynamics along an entire coastal cell.

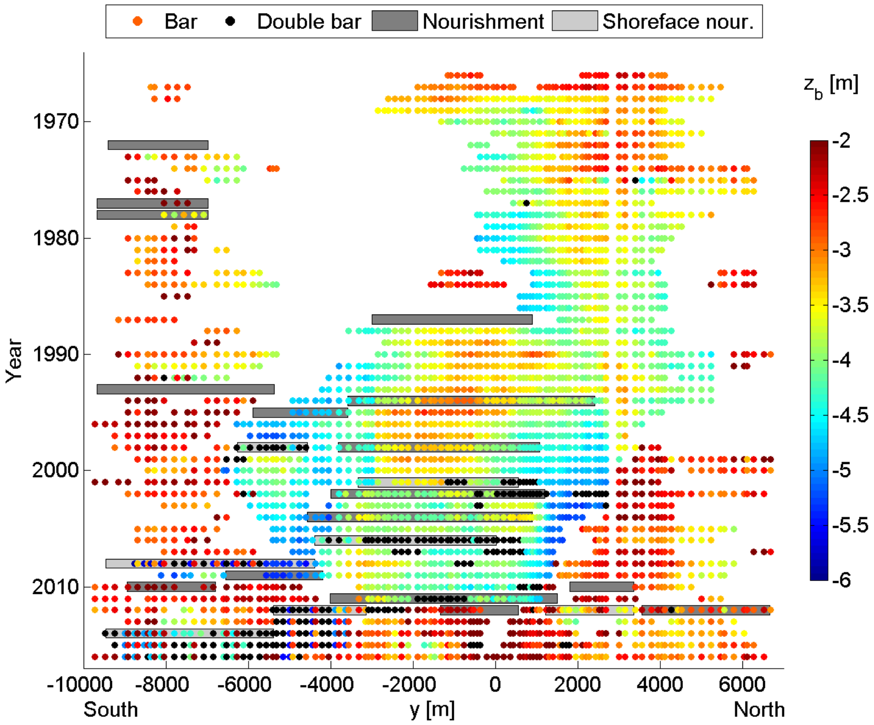

Figure 1. Presence and crest level relative to NAP (mean sea level) of subtidal sandbars at the Delfland coast between 1965 and 2016 as derived from JARKUS data. Grey bars indicate year of construction and spatial extent of sand nourishments.

The morphological development of Rottumeroog during a stormy winter

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Introduction

In order to keep up with long-term sea-level rise, Wadden Islands need input of sand for the area behind the dunes. Storm-induced inundation and the related sand transport across the island is a potential source; however, many islands are partly or completely closed off from the North Sea by elevated or artificial dunes. Rottumeroog, an uninhabited Wadden Island in the Netherlands, still contains a washover opening of approximately 600 m wide. Furthermore, the coastline is no longer maintained, so this island can be described as relatively natural and dynamic. Therefore, Rottumeroog is an ideal location to investigate morphology change during storms and how that is caused by the hydrodynamic processes.

Methods

In the winter of 2016/2017, we gathered a unique data set with measurements of 6 major inundation events. We installed 6 pressure sensors in a cross-shore array through the washover opening to measure water levels and waves, from North Sea to Wadden Sea. Furthermore, we measured the bed level before and after those inundation events.

In addition, we conducted an XBeach model study, trying to validate the model for the hydrodynamic processes and bed level change, with the focus on the washover opening. XBeach is a process-based model created to simulate the impact of storm events on beaches and dunes.

Results

The 6 inundation events resulted in significant bed level change (Figure 1). The beach eroded up to 80 cm, while the washover opening became approximately 70 cm higher. The island tail shows similar results. Our measurements show that the areas behind dunes can grow in height during storm-related inundation in a situation without artificial dunes, which implies that re-opening the washover openings by removing sand-drift dikes at other islands should be considered.

XBeach was capable of reproducing the water levels and waves; however, it significantly underestimated the bed level change. This suggests that other processes that are not included in XBeach also played a role in the substantial morphodynamical change during the inundation events.

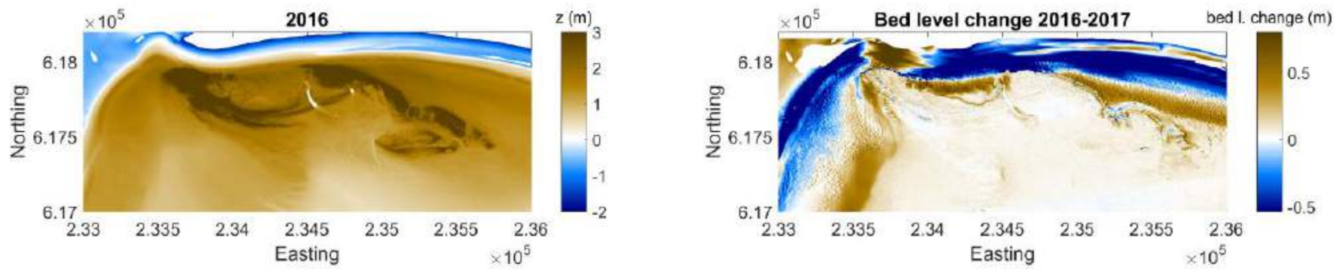

Figure 1. Left: Lidar image (from RWS) of Rottumeroog, 2016. Right: Bed level change at Rottumeroog between 2016 and 2017. Positive means sedimentation and negative means erosion.

THE DANCE OF *AMMOPHILA*: ON HOW INDIVIDUAL MOVEMENT PATTERNS CONTROL THE FORMATION OF COASTAL DUNES

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Protecting about one-third of the world's shorelines, coastal dunes arise from a biophysical feedback in which dune-building plants increasingly trap and accumulate aeolian sand particles as their density and patch size grows, in turn stimulating growth by alleviating salt stress. However, the size and shape of these dunes and thus their capacity to defend the hinterland, has been found to differ greatly depending on the dune-building species involved, even under the same environmental conditions (Hacker *et al.* 2012). For instance, dunes formed by European marram grass, *Ammophila arenaria*, are typically tall and steep, whereas dunes formed by its North American congener, *A. breviligulata*, are much lower and wider (Hacker *et al.* 2012; Zarnetske *et al.* 2012). However, to what extent these species can influence the availability and spatial distribution of sand particles themselves by spatially organizing their shoots, remains to be elucidated.

Here, we used a series of field observations, model simulations and a large-scale field experiment to demonstrate that the differences in dune-building capacity of the two species can be traced back to their inherent clonal expansion strategy (Figure 1). We found that the superior dune builder of the *Ammophila* genus, *A. arenaria*, exhibits a clonal expansion strategy best described by a power-law distribution of step sizes. Furthermore, we found this strategy to optimize sand-trapping efficiency by generating a complex pattern of multiple dense patches interspaced with larger steps in between. Our research demonstrates how the formation of coastal dunes is controlled at the shoot placement level and highlights the importance of power-law movement patterns in the emergence of complex self-organized environments

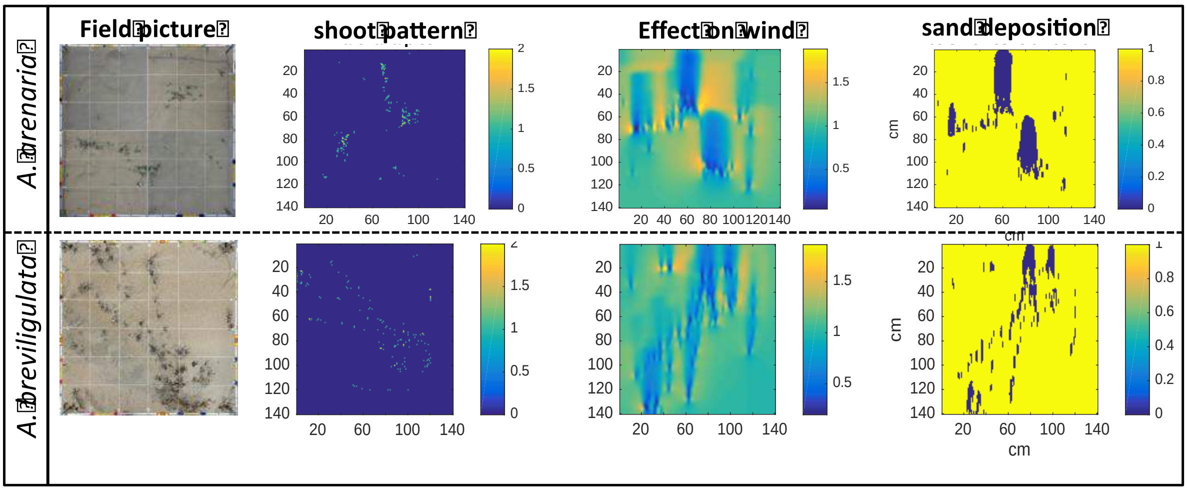

Figure 1. Translation from photographs in the field to the quantification of the resulting feedback for both Ammophila arenaria (top) and Ammophila breviligulata (bottom).

Hacker, S.D., Zarnetske, P., Seabloom, E., Ruggiero, P., Mull, J., Gerrity, S., Jones, C. (2012). Subtle differences in two non-native congeneric beach grasses significantly affect their colonization, spread, and impact. *Oikos*, 121(1), 138-148.

Zarnetske, P.L., Hacker, S.D., Seabloom, E.W., Ruggiero, P., Killian, J.R., Maddux, T.B., Cox, D. (2012). Biophysical feedback mediates effects of invasive grasses on coastal dune shape. *Ecology*, 93(6), 1439-1450.

RAISING THE (SUBTIDAL) BAR FOR EMBRYONIC DUNE GROWTH AND SURVIVAL

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Motivation

Along sandy coasts, the development of new dunes depends on the ecological and geomorphological processes. The development of new dunes starts above the high-water line with the establishment of vegetation, which facilitates sand deposition and forms an embryo dune. During severe storms, wave-induced processes can dramatically erode embryo dunes and therefore the plants' tolerance to hydrodynamic disturbances, which is vital for the development of new dunes. Recent observations have shown that alongshore variations in subtidal sandbar morphology may also lead to variations in wave attenuation and foredune erosion. It remains unclear, however, whether subtidal bar characteristics play a role in long-term embryo dune development. We hypothesize that beaches with shallow sandbars, located closer to shore, experience less embryo dune erosion during storms than beaches with deeper bars located farther offshore.

Methodology

To test this hypothesis, we analyzed the presence of embryo dunes from aerial photographs, together with annual bathymetric, topographic and meteorological measurements, spanning 50 km along the Dutch coast, for the period 2010 to 2016. Embryo dune area and the distance of the vegetation to the sea were calculated by supervised classification of vegetation pixels on the beach. We examined the area of embryo dunes and the distance of the vegetation to the sea in relation to beach width and sandbar volume, and compared changes in embryo dune area and the distance of the vegetation to the sea to changes in sandbar volume and meteorological conditions.

Findings

We found that the area of embryo dunes depended on beach width and that an increase in area was related to high precipitation in the growing season. The distance of the vegetation from the sea decreased when the sandbar volume increased (Figure 1). We conclude that embryo dune area depends on beach width, but vegetation can occur closer to the sea at beaches with shallow sandbars that attenuate more waves.

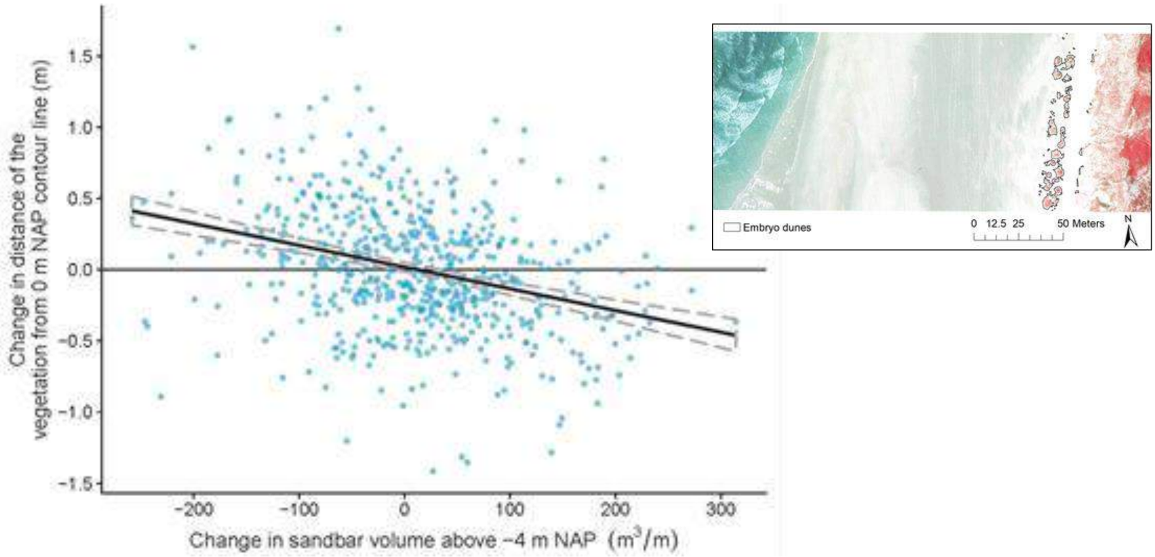

Figure 1. Relationship between the change in sandbar volume above -4 m NAP and the change in distance of the vegetation to the 0 m NAP contour line. Aerial photograph of the Dutch coast, with the black polygons indicating the embryo dunes.

Funded by seed money from the Future Deltas research focus area of Utrecht University.

HOW SEABED SEDIMENTS ARE TRANSFORMED INTO A NEW DUNE SLACK, THE CASE OF SPANJAARDS DUIN, DELFLAND COAST

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* stephanie.ijff@deltares.nl

Description of research

In 2008, a new dune section was created in the Natura 2000 area 'Voornes Duin en Solleveld & Kapittelduinen', near 's-Gravenzande (NL) (Figure 1.). Using seabed material, the objective of these constructed dunes was to compensate for the expected negative impacts from the Maasvlakte2 harbour extension. The compensation targets are that by 2033, 6.1 ha of dune slack (H2190B) and 9.8 ha of grey dune habitat (H2130) are present, including one population of *Liparis loeselli* (Fen Orchid). It is only in 2016, some 9 years after construction, that the first dune slack pioneer species start to grow in the valley.

Results

The sediments down to 1 m depth were found to be of highly different grain size: between 150 and 700 µm. Shells and shell hash occur in each location and at every depth. Fine-grained material (< 2 µm) is not present. Levels of organic material and nitrogen and phosphate values are very low. Thus, in principle, the soil is suitable for target vegetation types. Surface samples were checked for the presence of specific dune slack species. *Sagina nodosa* (Knotted Pearlwort) was found both flowering and in the macroremains collected for botanical analysis.

Discussion

Geomorphological, grain-size, geochemical and ecological data that have become available indicate that lowering the surface over some parts of the area is a viable management option. On the other hand, the data also indicate that it is sensible to preserve already developed parts of the dune slack vegetation. In our presentation we will show the results from the analyses described above, discussing how to optimally use natural dynamic factors as water level and wind force to steer nature towards the compensation targets (Van der Meulen *et al.* 2017).

Figure 1. Left: Location of Spanjaards Duin along the Dutch coast (photo: adapted from Google). Right: Lowest part of the dune valley, a potential habitat for dune slack vegetation (photo: F. van der Meulen).

Van der Meulen, F., Van der Valk, B., IJff, S. (2017). Building with Nature in Coastal Dune Management; learning by doing. In: E. Özhan (ed.) *Proceedings MEDCOAST 13*, Mellieha, Malta, 215-222.

EFFECTS OF BIOLOGICAL TRAITS ON SALT-MARSH-SPECIES DISTRIBUTION AND ESTUARINE BAR MORPHOLOGY

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The ability of vegetation to modify local conditions in fluvial and coastal environments has been extensively studied and widely acknowledged. However, bio-geomorphological modelling studies only incorporated simplified spatio-temporal vegetation dynamics, limiting their applicability to real ecosystems especially when long-term morphodynamic changes are of interest. By including species-specific strategies for establishment, growth and resilience against physical pressures in our numerical model, we underline the necessity for a more detailed description of vegetation dynamics to reproduce more realistic patterns than before, and thereby quantify the bio-geomorphological effects.

We coupled our new vegetation model to a two-dimensional hydro-morphodynamic model in Delft3D. To validate the vegetation zonation produced by the model, we analysed the 2-km-long tidal bar "Plaat van Walsoorden" in the Western Scheldt estuary, the Netherlands, where vegetation establishment has been mapped at 0.25 m spatial resolution since the mid-1990s and large parts are now covered by various salt-marsh species.

We show that mortality due to desiccation and inundation period determines the density of salt-marsh growth and hence reproduces zonation (Figure 1). Resilience against fast flow determines die-off not only at the bar margins but also on the tidal flat itself. The first model runs also suggest that seasonal variation in biomass modifies the morphological development of the flat as it directly affects sedimentation in winter. Ongoing runs for decadal development include mud and sensitivity to species traits.

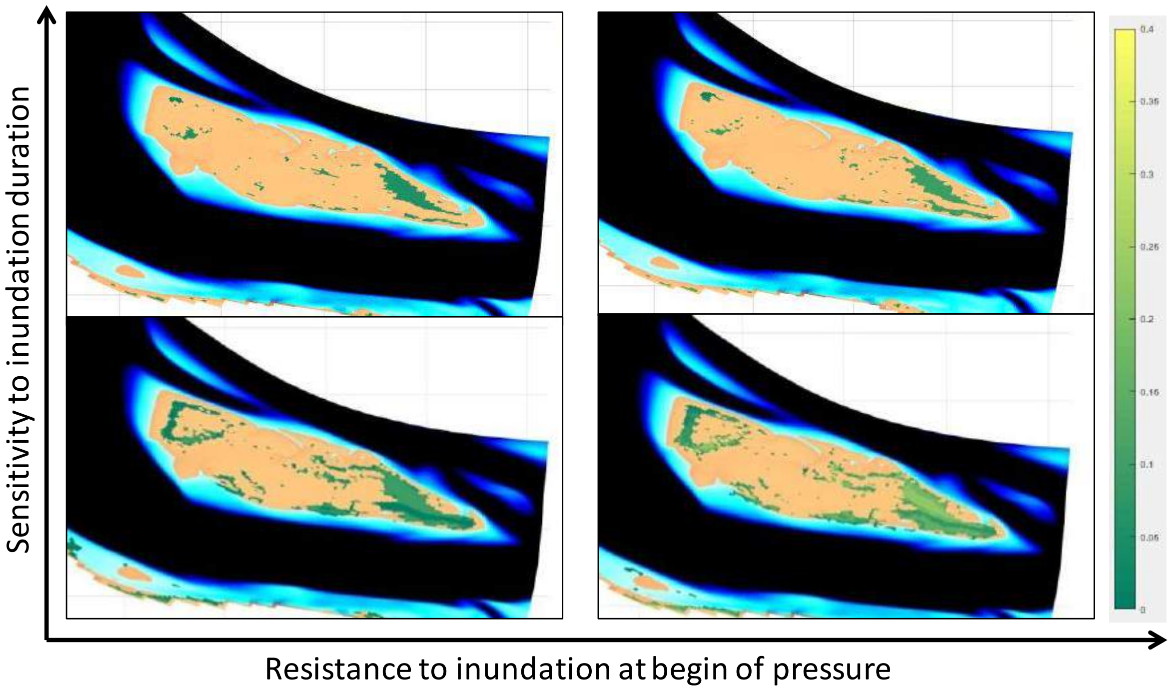

Figure 1. Salt-marsh vegetation cover after 5 years as a cover fraction of the cell depending on the degree of resilience against mortality caused by desiccation and inundation duration. The x-axis represents resistance against the start of mortality with regard to duration of the pressure, the y-axis the speed of mortality after the start of dying. The brown color is bare soil, black-blue the water depth.

SEDIMENT-STABILISING AND -DESTABILISING ECOENGINEERING SPECIES FROM RIVER TO ESTUARY: THE CASE OF THE SCHELDT SYSTEM

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[4] Netherlands Institute for Sea Research (NIOZ)
* S.Selakovic@uu.nl

Interactions between organisms and landscape-forming processes play an important role in evolution of coastal landscapes. In particular, biota has a strong potential to interact with important geomorphological processes such as sediment dynamics. Although many studies worked towards quantifying the impact of different species groups on sediment dynamics, information has been gathered on *ad hoc* base. Depending on species' traits and distribution, functional groups of ecoengineering species may have differential effect on sediment deposition and erosion. We hypothesize that the spatial distribution of sediment-stabilising and -destabilising species across the channel and along the whole salinity gradient of an estuary partly determines the planform shape and channel-shoal morphology of estuaries.

To test this hypothesis, we analyse vegetation and macrobenthic data taking the Scheldt river-estuarine continuum as model ecosystem. We identify species traits with important effects on sediment dynamics and use them to form functional groups. We are able to accurately describe the distributions of the different functional groups along the estuarine gradient and observe a clear distinction of dominant ecosystem-engineering functional groups and their potential effects on the sediment in the river-estuarine continuum.

The first results for the longitudinal cross section show the highest effects of stabilising plant species in riverine and sediment bioturbators in the weak polyhaline part of the river-estuarine continuum. Analysis of the distribution of functional groups in transverse cross sections shows dominant stabilizing effects in the supratidal zone compared to dominant destabilizing effects in the lower intertidal zone (Figure 1).

This analysis offers a new and more general conceptualisation of the distribution of sediment-stabilizing and -destabilizing functional groups of ecoengineering species and their potential impacts on sediment dynamics, shoal patterns and planform shapes in the river-estuarine continuum. We will test this concept in future modelling and experiments.

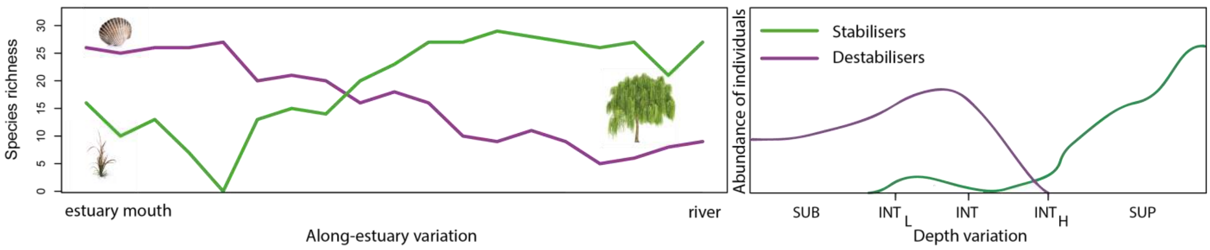

Figure 1. Distribution of sediment-stabilising and -destabilising ecoengineering species in Scheldt system.

IMPLEMENTATION OF VEGETATED FORESHORES FOR FLOOD-RISK REDUCTION: DEALING WITH SOCIAL DILEMMAS

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Vegetated foreshores, such as salt marshes and reed swamps in the Netherlands or mangroves in tropical climate zones, can function as nature-based flood defences (NBFD). Both the shape and the vegetation on the foreshore contribute to wave mitigation. In addition, foreshores may - under favourable conditions - grow naturally with rising sea levels. While different studies demonstrate that salt marshes contribute to flood protection, implementation of vegetated foreshores for flood-risk reduction is not yet common practice. By including nature areas, the flood-protection barrier becomes multifunctional and with this, new actors enter the decision-making arena. In our research project we look into the implementation dilemmas of vegetated foreshores for flood-risk reduction in the Netherlands.

Multifunctional projects are characterized by social dilemmas. In a social dilemma the preferred 'selfish' strategy of individual parties does not align with the best strategy for the larger coalition: "everyone is tempted to take one action but all will be better off if all (or most of them) take another action" (Ostrom 2005). A NBFD solution may maximise neither nature value nor flood-protection value, but rather it is often the very best combined solution for both. We use game theory to model and then address NBFD social dilemmas. Game theory is concerned with "the actions of decision-makers who are conscious that their actions affect each other" (Rasmusen 2007) and describes and provides solutions by means of "logical analysis of situations of conflict and cooperation" (Straffin 1993).

We present a case study on implementation of vegetated foreshores for flood-risk reduction along the Frisian Wadden Sea coast and model the present social dilemma using game theory (Figure 1). Second, we present a game-theory-based workshop tool that helps decision-makers to assess the added value of cooperation among stakeholders in multifunctional projects. Our research shows that implementation of vegetated foreshores for flood-risk reduction is not self-evident. Well-designed process support is required to move beyond essential social dilemmas.

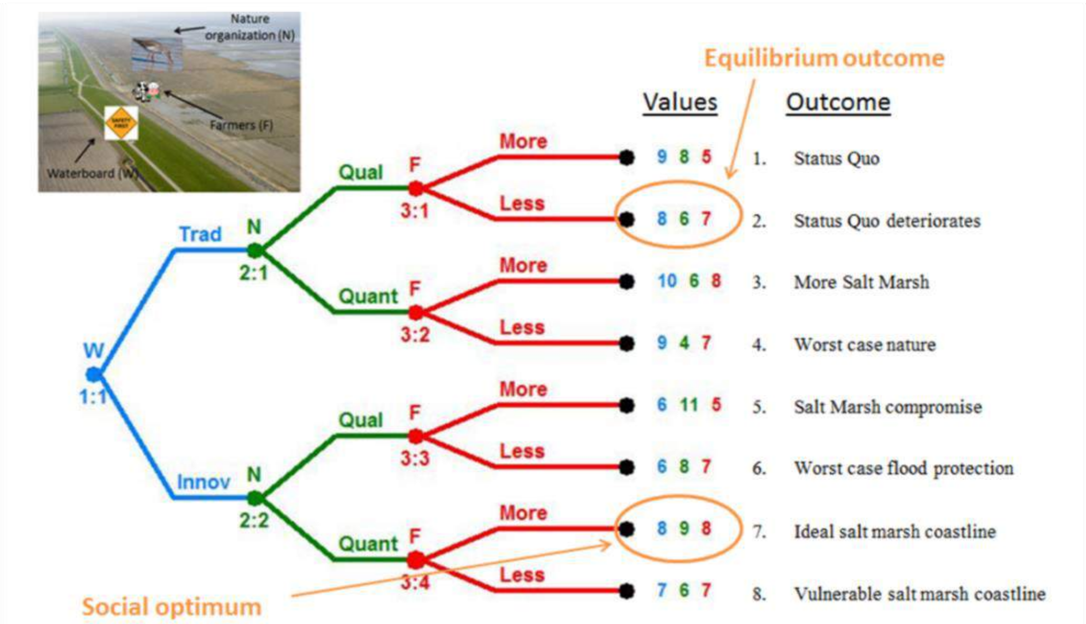

Figure 1. Game tree demonstrating the social dilemma of using vegetated foreshores for flood-risk reduction along the Frisian Wadden Sea coast: without cooperation the Water board (W), Nature organisation (N) and Farmers (F) will reach outcome '2', while outcome '7' is the social optimum.

Ostrom, E. (2005). *Understanding Institutional Diversity*. Princeton University Press, 376 p.
Rasmusen E (2007). *Games and information: an introduction to game theory*. 4th edition. Blackwell, Malden, MA.
Straffin, P.D. (1993). *Game Theory and Strategy*. New Mathematical Library 36, 244 p.

HOLOCENE RELATIVE SEA-LEVEL CHANGE IN THE WADDEN SEA, NORTHERN NETHERLANDS

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[1] TNO – Geological Survey of the Netherlands, [2] Faculty of Spatial Sciences and Centre for Landscape Studies, University of Groningen, [3] Centre for Isotope Research, University of Groningen, [4] Deltares, [5] Environment Department, University of York, [6] Department of Earth & Planetary Sciences and Institute of Earth, Ocean & Atmospheric Sciences, Rutgers University
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Although the Netherlands has a long tradition of sea-level research, no Holocene relative sea-level curve is available for the Wadden Sea area. On the basis of limited available data from the northern Netherlands, previous studies hypothesised that the well-established relative sea-level curve for the western Netherlands is also valid for the northern part of the country. However, glacial isostatic adjustment (GIA) models predict a lower and steeper relative sea-level curve because of greater postglacial isostatic subsidence. Long-term data of relative sea-level change in this region are important to understand postglacial vertical land motion related to the rebound of Fennoscandia and neotectonic activity, to improve GIA models, and to better predict future sea-level rise.

In this study we compiled and evaluated a (partly unpublished) set of basal peat radiocarbon dates to reconstruct an upper limit of relative mean sea-level rise in the Dutch Wadden Sea area (Figure 1). From ca. 8200 to 6400 cal a BP, this reconstruction plots distinctively lower than the western Netherlands curve. After 6400 cal a BP however, the curve for the Wadden Sea is statistically indistinguishable from that for the western Netherlands, a result that conflicts with GIA model results. It remains to be investigated whether the problem lies with the GIA model predictions or with the quality of the currently available data. Additional samples of basal peat should be collected from suitable sites. Dating these samples will further solve this problem.

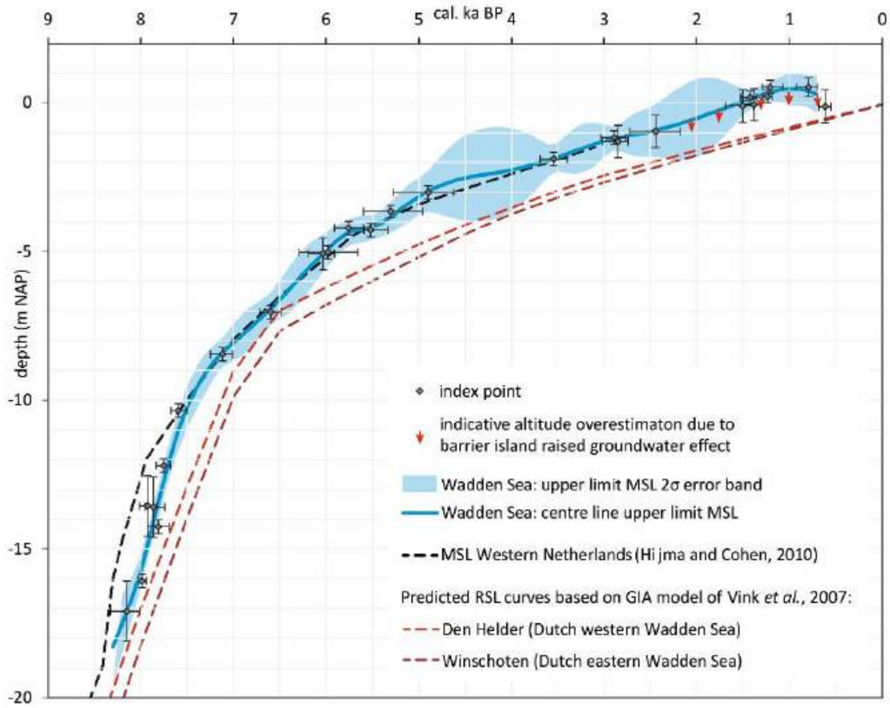

Figure 1. Reconstructed upper limit of mean sea level (MSL) for the Wadden Sea region compared to the MSL curve for the western Netherlands and to relative sea-level predictions from the GIA model of Vink et al. (2007).

Hijma, M.P., Cohen, K.M. (2010). Timing and magnitude of the sea-level jump preluding the 8200 yr event. *Geology*, 38(3), 275-278.

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THE EVOLUTION OF THE DOGGER BANK, NORTH SEA: A COMPLEX HISTORY OF TERRESTRIAL AND MARINE ENVIRONMENTAL CHANGE

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This paper presents a summary of the results of a detailed multidisciplinary study of the near surface geology of the Dogger Bank in the southern central North Sea, forming part of a site investigation for a major windfarm development undertaken by the Forewind consortium. It has revealed that the Dogger Bank is internally complex rather than comprising a simple "layer cake" of the Quaternary sediments as previously thought. Regional and high-resolution seismic surveys have enabled a revised stratigraphic framework to be established for the upper part of this sequence which comprises the Eem (oldest), Dogger Bank, Bolders Bank formations and Botney Cut Formation (youngest), overlain by a typically thin Holocene sequence. Detailed mapping of key horizons identified on the high-resolution seismic profiles has led to the recognition of a series of buried palaeo-landsystems which are characterised by a range of features including; glacial, glacifluvial and fluvial channels, a large-scale glacitectonic thrust-moraine complex with intervening ice-marginal basins, a lacustrine basin and marine ravinement surfaces (Figure 1). Interpretation of these buried landscapes has enabled the development of an environmental change model to explain the evolution of the Dogger Bank. This evolution was driven by the complex interplay between climate change, ice sheet dynamics and sea level change associated with the growth and subsequent demise of the British and Irish and Fennoscandian ice sheets during the Weichselian glaciation. Following the decay of these ice sheets the Dogger Bank entered a period of significant climatic and environmental flux which saw a terrestrial landscape being progressively inundated as sea levels rose during the Holocene.

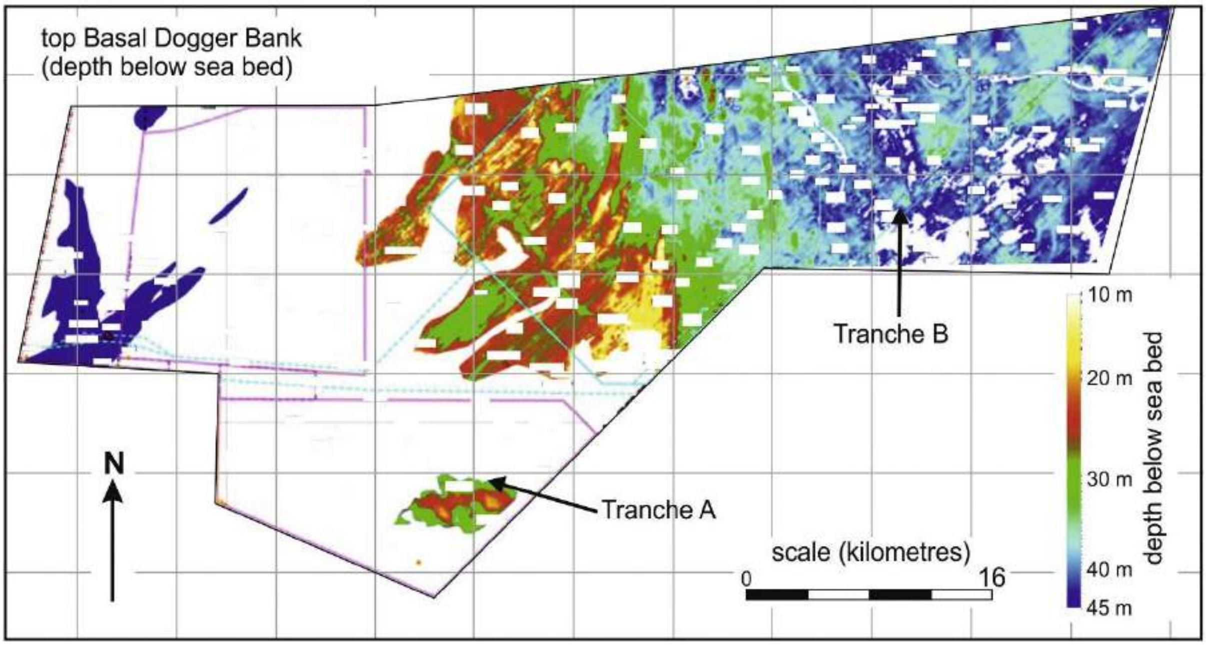

Figure 1. Upper surface of the Basal Dogger Bank showing the presence of a series of arcuate moraines, most visible in yellow and red above Tranche A (horizon courtesy of RPS Energy Ltd).

GEOLOGY OF THE BORSSELE OFFSHORE WIND FARM ZONE

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Between 2015 and 2016 an extensive site investigation was performed offshore the Netherlands for the development of the Borssele Offshore Wind Farm Zone (WFZ) approximately 25 km from the coast of Zeeland. The site investigation was commissioned by the Netherlands Enterprise Agency (RVO) to provide information for Front-End Engineering Development (FEED) studies and to make competitive bids in the grant and permit tenders possible.

The Borssele Offshore WFZ comprises an area of 344 km^2, which was fully covered by the site investigation. The site investigation included geophysical and geotechnical surveys as well as morphodynamic and geological desk studies and a metocean campaign. Detailed bathymetric data and high-resolution geophysical data from seafloor to 100 m below the seafloor were acquired as well as geotechnical data and samples from the seafloor surface up to 80 m depth. Samples were analyzed and dated by means of palynology to assess the geological age and depositional environment.

This large and high-quality dataset is unique. It is available to the public. The dataset provides a detailed insight into the seafloor dynamics and unravels the Quaternary, Neogene and Paleogene stratigraphy of the Southern Bight of the North Sea. In summary, bedforms of different scales are present on the seafloor (Holocene Southern Bight Formation), underlain by Pleistocene river sediments deposited during the last Ice Age (Kreftenheye Formation). This Quaternary sequence unconformably overlies northerly dipping Neogene and Paleogene strata (Westkapelle Ground to Dongen Formations). Locally, Pleistocene erosion features have incised deeply into the underlying strata (Figure 1).

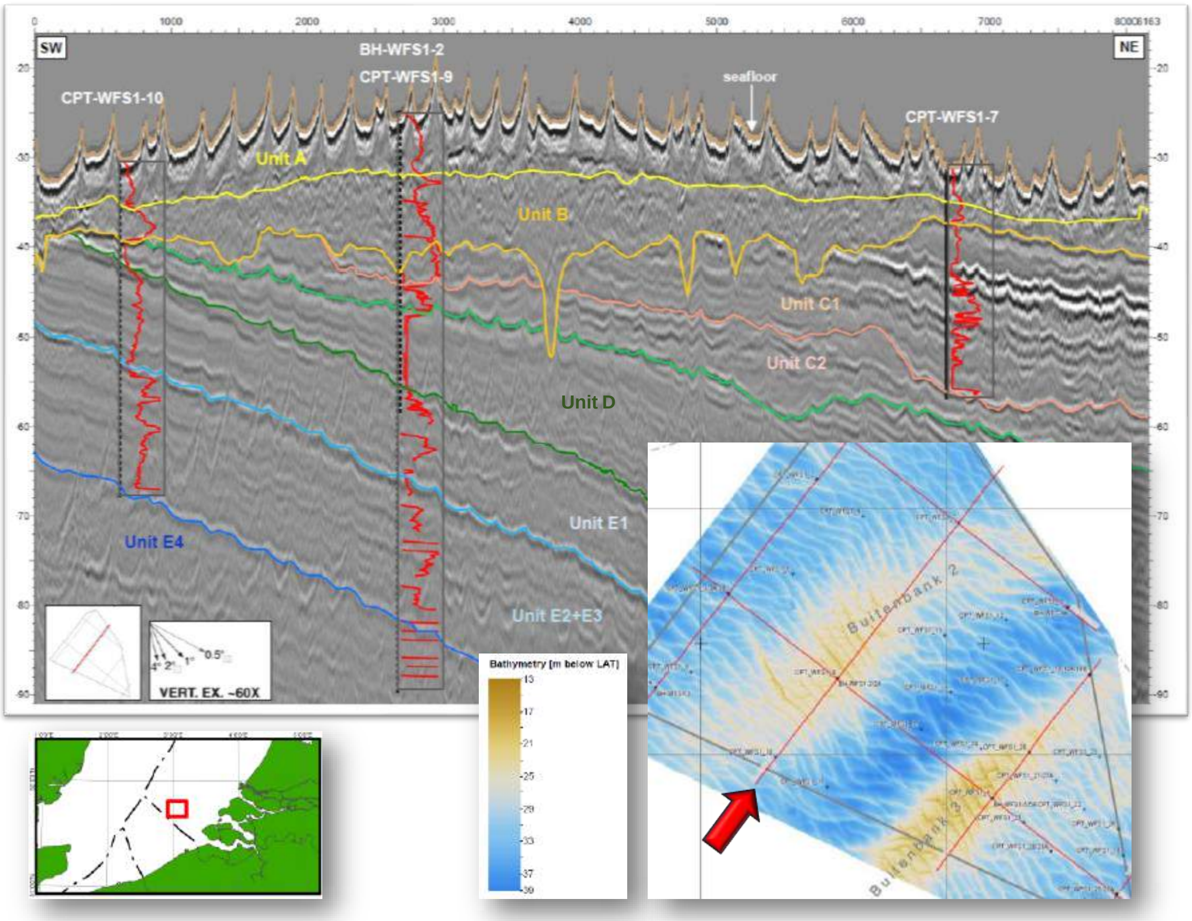

Figure 1. Example of a multi-channel seismic line. A red arrow marks its location on the bathymetric map. The red graphs are CPT cone resistance data. Key map denotes the wind farm location (figures from Fugro Report).

EFFECTS OF INHERITED RESISTANT LAYERS ON SHAPE AND LONG-TERM EVOLUTION OF THE EEMS-DOLLARD ESTUARY (THE NETHERLANDS/GERMANY)

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Estuaries increasingly face pressures from sea-level rise, urbanization, and damming, leading to disturbed sediment balances, changes in biogeomorphological areas, and hence loss of biodiversity. To mitigate these effects, understanding the long-term functioning of these systems is crucial. Although widely acknowledged as an important driver, little is known on the effects of constraining agents, such as the presence of erosion-resistant layers, on the long-term evolution of estuaries. Here we show how resistant layers affected channel-bar patterns along the Eems-Dollard estuary, located on the Dutch-German border. We reconstructed the channel-bar pattern evolution of the last two centuries in high detail using historical bathymetry maps. These spatial patterns were subsequently compared to the position of newly mapped resistant layers covering the entire estuary. Results show that resistant layers at moderate depths (ca. 10-15 below sea level or two-thirds of the maximum channel depth) cause channels to widen locally. This channel widening increases the estuary width, which has led to mid-channel bar formation. Bend curvature causes the effect to propagate at least a meander wavelength in the flood direction. Thus the presence of resistant layers strongly determines the position of confluences and bars along the entire estuary. As the channels have generally imported sediment over the last 200 years, hydrodynamical conditions became more important in the more fully alluviated system. However, resistant layers form important constraints (Figure 1), especially where human impact has changed the state of the estuary, for example where dredging increased channel volume again in the second half of the 20th century. Because resistant layers are expected to majorly affect channel-bar patterns after possible future measures, new insights into the effects of inherited geology on channel-bar patterns will help to better manage estuaries in a sustainable way. These results also raise the question to what degree other bar-filled estuaries are the result of self-organization or of geological constraints.

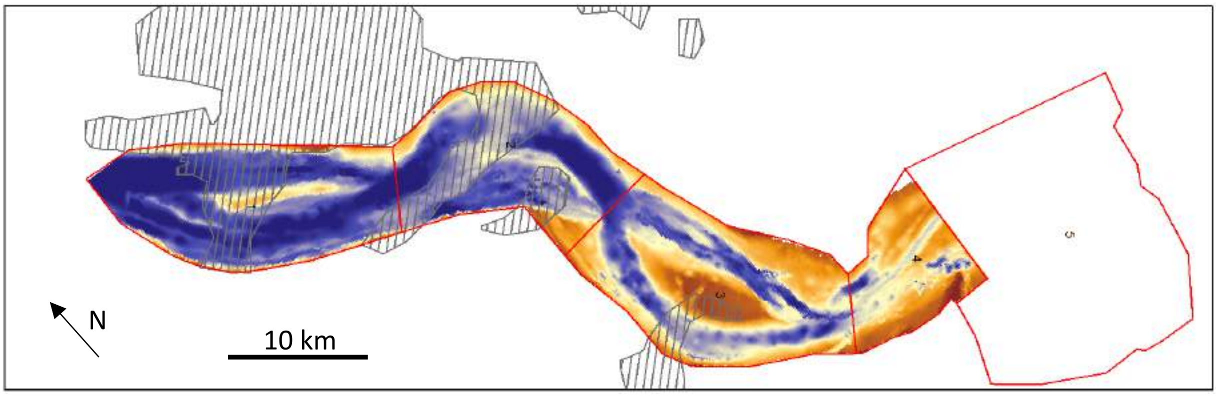

Figure 1. Maximum depth of the Eems-Dollard estuary between 1812 and 2014 (range from dark blue (20 m below sea level) to brown (intertidal). Hatching indicates the position of shallow resistant Pleistocene clays that have strongly influenced the channel-bar pattern of the estuary.

SUBSIDENCE ALONG THE DUTCH COAST

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The entire coastal zone of the Netherlands is subsiding and this contributes to relative sea-level rise (the sum of absolute sea-level rise and vertical land movements). At present this rise has a nation-wide averaged rate of nearly 20 cm/century. The rate of subsidence, however, varies strongly in space and time as a consequence of variations in geological processes and human activity. To give an example: in Vlissingen subsidence was 2-3 cm over the last century, while near Delfzijl subsidence was close to 30 cm (Figure 1). 'Geological' subsidence in the Netherlands is caused by tectonic and isostatic movements and by autocompaction; the subsidence due to human activities is related to the extraction of gas, oil, salt and water and to the loading effect of large infrastructural works such as Maasvlakte 2 near Rotterdam.

We analysed the contribution to and spatial variation of subsidence for each of the mentioned processes. This knowledge has strong practical relevance, because the rate of relative sea-level rise is used to calculate the annual volume of sand nourishment to maintain the elevation of 'the coastal foundation' relative to sea level. For the future the national water authority (Rijkswaterstaat, within the Kustgenese 2.0 programme) wants to better substantiate the nourishment volume by accounting for the spatial variation in subsidence and hence for spatial variation in relative sea-level rise, using the formula:

$$Volume_{nourishment} = (Area_{coastalfoundation} * Rel.Sea\text{-}LevelRise) + Volume_{import\_basins} + Volume_{subsidence}*.$$

In regions of the coastal zone where human-induced subsidence is limited, the main driver of subsidence is glacio-isostatic adjustment (GIA) that is an aftereffect of the last ice age. During the ice age the kilometre-thick ice sheets north of The Netherlands pushed the land down, while The Netherlands were elevated. After the disappearance of the ice sheets the land rebounded where the ice was present and sank where it was elevated. In The Netherlands the current rate of GIA-related subsidence is 1-4 cm/century in the southwestern Netherlands and 4-9 cm/century in the northern Netherlands. Human-induced subsidence is largest in regions where a lot of gas is extracted: locally this has resulted in more than 30 cm of subsidence in the last decades (Figure 1).

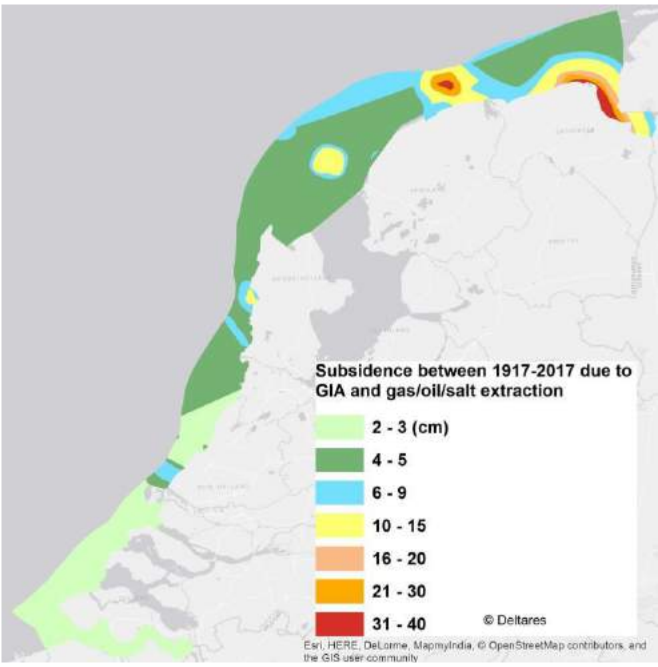

Figure 1. GIA and gas/oil/salt extraction are the main drivers of subsidence in the coastal foundation.

THE STUFF A HARBOR IS MADE OF: ANCIENT AND RECENT SAND FROM THE MAASVLAKTE 2 PIT (NORTH SEA, THE NETHERLANDS)

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A set of vibrocores from an offshore sand-extraction pit located west of Maasvlakte 2 sheds light on the sedimentology and origin of the primary offshore sand resource in the Netherlands. The boreholes are (partly) positioned on the dipping flank of the pit, providing a high-resolution, vertically continuous insight into the sediment record of this area between ~24 and ~46m below mean sea level (MSL). As part of a sedimentological study, the cores were described, photographed and subsequently sampled for biostratigraphical (pollen, malacology, macro- and microfossils), provenance (mineralogy, gravel) and chronological (quartz-feldspar OSL) analysis.

We identified seven stacked sedimentary units of fluvial and possibly estuarine origin, forming a sequence marked by substantial vertical and more moderate lateral variability (Figure 1). Below -31m MSL, the stratigraphy consists of Middle Pleistocene gravelly sand of Rhine-Meuse origin (units MV2-6&7). A provisional age model based on OSL and biostratigraphy shows that unit MV2-6 was deposited during the penultimate glaciation (Saalian, Marine Isotope Stage (MIS) 6) and that unit M2-7 is much older. Late Pleistocene sediments are present between -31m and -27m MSL. They consist of an alternation of coarse-grained gravelly sand (units MV2-3&5) and finer-grained sediments (unit MV2-4). Most of these intervals represent fluvial depositional environments marked by substantial reworking of marine beds of MIS5 age, as evident from the taphonomic signature of the faunas. We identified a small interval with *in situ* boreal molluscs that may be attributed to the later part of MIS5 or even the MIS4/3 transition (Weichselian glaciation). The top section of the pit consists of Holocene sediments (unit MV2-2) and of sediment deposited during and directly after the extraction process (unit MV2-1).

The sediment comprising Maasvlakte 2, source of numerous archaeological and palaeontological finds, comes from all seven units described above. Even where units have not become mixed during extraction and dumping, the original, natural reworking of fossils and artefacts make it difficult to link specific beach finds to the record presented here. Regional stratigraphic studies from neighbouring areas, partly on land, provide additional large-scale paleogeographic context needed to place beach finds originating from the extraction pit in their proper palaeoenvironmental and chronological framework.

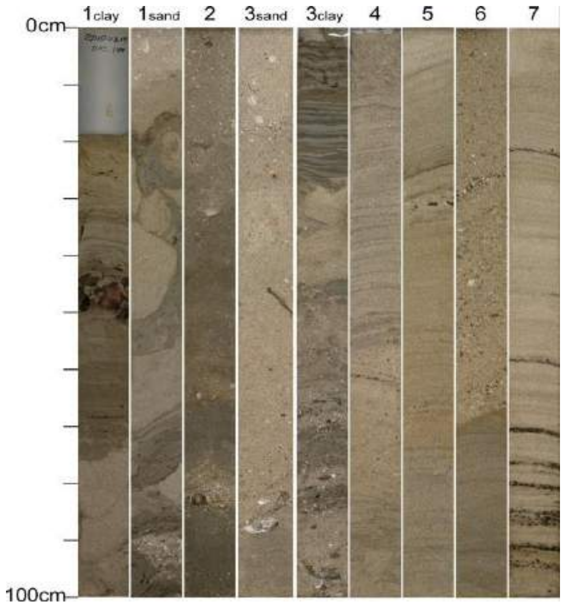

Figure 1. Core samples showing the variability of sand (and some clay) extracted from the Maasvlakte 2 pit. Numbers refer to units MV2-1 to 7, with multiple cores highlighting the different sediment types in units MV2-1 and MV2-3.

INCORPORATING DATA UNCERTAINTY IN 3D VOXEL MODELLING AND THE IMPORTANCE IN DECISION MAKING

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Geological databases resulting from the merging of various data sources and time periods jeopardize harmonization of data products. Data standardization is already common practice and a first step in avoiding semantic overlap. European marine data-management infrastructures provide such standards, e.g., Geo-Seas *(http://www.geo-seas.eu/)* for geological data and SeaDataNet *(https://www.seadatanet.org/)* for marine metadata in general. In addition, metadata quality control is important, though data uncertainty is seldom quantified and yet to be used in modeling.

Preliminary uncertainty analyses were worked out to provide an extra dimension to the cross-border 3D voxel models of the geological subsurface of the Belgian and southern Netherlands part of the North Sea *(http://odnature.naturalsciences.be/tiles/)*. Starting from simple quality flagging in geological databases and model-uncertainty calculations (probability and entropy) in the 3D modelling, data uncertainty (e.g., related to qualities in positioning, sampling and vintage) is now quantified. Combining all uncertainties remains a challenge, as is communicating their importance in decision making.

A demonstration will be given on the status of the uncertainty analyses and on the way these are incorporated into a newly developed decision support tool allowing interactive querying of the 3D voxel model, now comprising geological parameters as well as entropy, probability and data-uncertainty attributes (Figure 1).

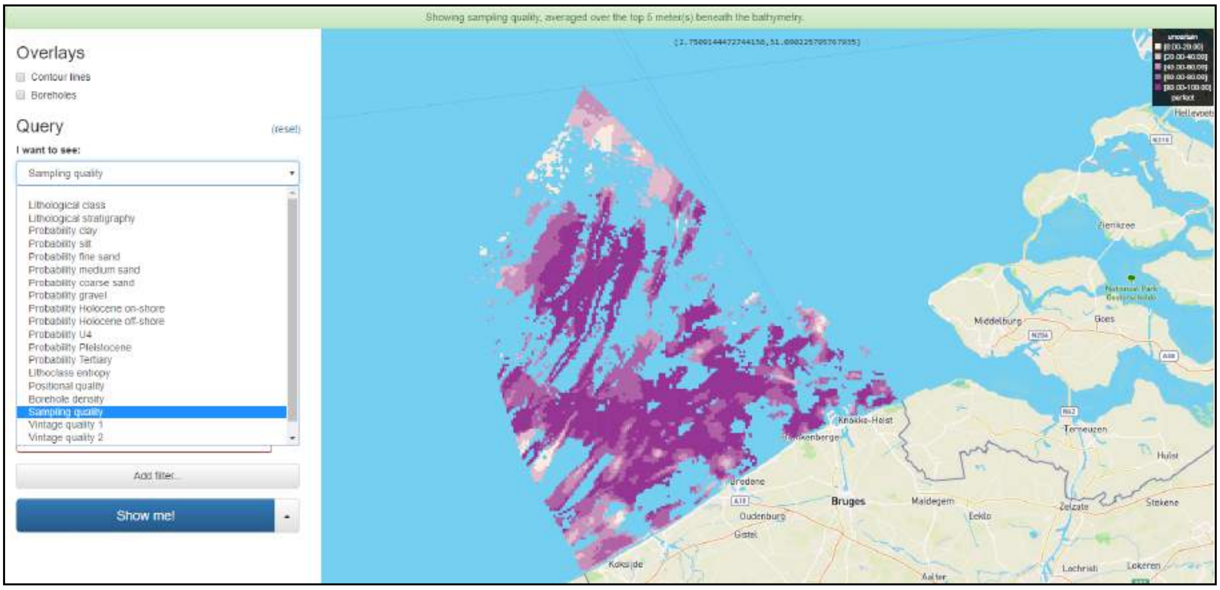

Figure 1. Interactive querying of the 3D geological voxel model in the newly developed 2D Decision Support System (DSS).

FIFTY YEARS OF MARINE GEOLOGICAL MAPPING IN THE DUTCH PART OF THE NORTH SEA

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Since the end of the 19th century, scientists from several countries have published seabed-sediment maps of the southern North Sea. Well-known early examples are the maps of the French investigator M. Delesse (1872), the Norwegian/British investigator O.T. Olsen (1883), and the Dutch biologist J.J. Tesch (1911). Highlights from the last 100 years include the thesis on heavy minerals of J.A. Baak (1936) and the seabed-sediment map of the German geologist J. Jarke (1955).

During the early sixties of the last century the Dutch Geological Foundation started investigations in the North Sea in co-operation with the ministry of Public Works and the Hydrographic Office of the Royal Netherlands Navy, mainly for the search of sand and gravel resources and for monitoring shipping routes. Upon the delimitation of the North Sea in sectors in 1968 and the start of the exploration for oil and gas in the Dutch offshore sector, the Geological Foundation became Geological Survey of the Netherlands (RGD), governed by the Ministry of Economic Affairs. One of its tasks was systematically investigating the geology of the Dutch part of the North Sea. About 57,000 km2 in size, it is 50% larger than the Dutch land area. For decades, marine geological mapping was carried out in a close co-operation with the North Sea Directorate of the Ministry of Public Works.

To get information of the upper ca. 10 meters of the seabed, several sampling devices were developed by public/private co-operation (Figure 1), and sub-bottom profilers for acoustic investigations were acquired from private companies. The first map showing the geology of the upper meters of the subsurface of the northern part of the Dutch sector was published as early as 1969 by E. A map for the southern part of the Dutch sector, also by Oele, followed two years later. In 1984, a reconnaissance mapping program started along the median line with the UK in close co-operation with the British Geological Survey. The maps produced give information about the seabed sediments and the litho-stratigraphy of the Holocene, Pleistocene and top of the Pre-Quaternary formations.

Data management was initially analog carried out by the North Sea Directorate and later, owing to EU-financed projects, digitally in an international frame work. At present, the Geological Survey of the Netherlands is producing digital custom-made maps based on existing information. All non-confidential borehole data and information are made available on the web.

Over the years, marine mapping has provided numerous challenges. Tackling these challenges has required maximum inventiveness, co-operation and R&D. As new data become available, the maps and models produced will get better and better.

Figure 1. Sampling with a "Zenkovitch" vibrocorer in the late sixties.

ICON.NL

COASTLINE OBSERVATORY TO EXAMINE COASTAL DYNAMICS IN RESPONSE TO NATURAL FORCING AND HUMAN INTERVENTIONS

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Climate change and rising population pressure are driving increasing risk for coastal domains worldwide, and especially for low-lying deltas. Yet, our knowledge base to manage or mitigate these challenges lags behind. Modern-day sustainable coastal design concepts (e.g. 'Building with Nature') demand fundamental insight into the complex interplay of hydrodynamic, morphological and ecological processes. In the past, improved understanding was mostly based on laboratory experiments or dedicated theoretical research on isolated processes. However, field observations have revealed that the coastal system behaves as a nonlinear dynamic system with emergent behaviour of unknown predictability for many processes. To cater for these new paradigms, Dutch coastal scientists are in urgent need of a world-class, natural coastline observatory to ensure continuous, long-term and high-resolution monitoring of coastal processes.

We therefore propose the establishment of a facility named ICON.NL, the first node in an envisioned International Coastline Observatories Network (ICON). The objective of ICON.NL is to establish a truly multidisciplinary data corpus, which will inspire and enable internationally outstanding coastal research, fundamental as well as applied, by the entire Dutch coastal science community and their international partners. To that end, we envision an innovative, interconnected data-collection scheme that fuses together, for the first time ever, i) remote-sensing instruments (including optical and infrared cameras, X-band radar, drones, and laser altimetry); ii) *in situ* instrumentation (to measure offshore wave forcing, to yield ground-truth bathymetry/topography estimates and to map the marine and terrestrial ecosystems); and iii) a mature modelling system (to produce time-varying, dynamically consistent maps of the important coastal bio-geophysical variables).

ICON.NL will be based at the Delfland Coast with core observations focused on the internationally well-known Sand Engine experiment. As part of this initiative, a man-made sandy peninsula was built to ensure long-term coastal safety and to promote nature development, science and recreation. The combination of the unique site and ambitious facility design enables a new avenue in coastal science and a leap in interdisciplinary research. ICON.NL will allow field experimentation to advance our understanding in fundamental science topics such as unsteady currents and circulation, sediment transport near the beach, emergent morphological patterns, wave breaking/turbulence and storm/recovery cycles. It will also serve as home to interdisciplinary work that crosses the sea-land interface, which has always been difficult or impossible to perform in traditional labs. The open-source data corpus from ICON.NL will form a growing resource that can be the research spearhead for Dutch coastal scientists and will focus the eyes of the world on the Dutch coast.

The proposed facility is supported by the full Dutch coastal science community (united in the Netherlands Centre for Coastal Research, NCK), aligns with the strategic agendas of industry and government and is well embedded in international research frameworks. In all, ICON.NL and the research that it facilitates will be a crucial step toward sustainable Coastal Engineering and Management to meet societal challenges in a changing climate.

KUSTGENESE 2.0/SEAWAD - AMELAND INLET FIELD CAMPAIGN

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Climate change challenges us to come up with effective and efficient solutions to protect the Dutch coast. Sand nourishments are part of these solutions. How much, where, and when sediment should be nourished may seem like trivial questions but are not that simple to answer. The fate of the nourished sediment under the action of waves and tidal currents is still hard to predict. This is especially the case for ebb-tidal deltas, where the highly varied bathymetry introduces complex interactions among the different forcings.

As part of projects Kustgenese 2.0 and SEAWAD, a large-scale field campaign was carried out in September 2017 at the ebb-tidal delta of the Ameland Inlet (Figure 1). Five frames were emplaced for a month, equipped with instruments to measure flow velocities, pressure, sediment concentration, sediment composition, bed-level variations, and bedform dynamics. Additionally, the flow through the inlet was measured during 13-hr cross-sectional measurements; boxcores were taken for benthos, sediment composition, and stratigraphy; sediment tracers were released (and partly retrieved); current drifters were employed; and flow meters were installed at the watersheds.

Although not all instruments were retrieved in their original shape and condition, a large and rich data set is now available for further study. Inclusion of the storm Sebastian on the 13th of September means that interactions among wind, waves, tides, and sediment transport can be studied for fair-weather as well as storm conditions. The new dataset will help us to test our numerical models and to better understand the sediment transport pathways in this complex environment. For example, our measurements show that wind-driven flow dominated over tidal flow on the tidal divides and on the shallow lobes of the ebb-tidal delta during the peak of the recorded storm. These and some other initial results are highlights in an overview of the total campaign, including its preparatory phase. In addition, we offer a glimpse of the further steps planned to test existing numerical models and to substantiate future management decisions.

Figure 1. Installation of a main frame on the ebb-tidal delta (left). Installation of flow meters on a tidal divide (right).

QUICK REACTION FORCE AMELAND NOORDWEST: FIRST RESULTS

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The Quick Reaction Force (QRF) is a new organizational structure established by Rijkswaterstaat in collaboration with governmental and research partners, aiming to increase the knowledge on water safety as a result of better acquisition, disclosure and use of field data around storm situations. This type of knowledge is very useful in the analysis of the condition of (soft) sea defenses shortly after large storm events and can also be used to obtain insight into the (real-life) behavior of the morphodynamic system during extreme conditions. The latter is valuable to the validation of existing knowledge as most of the current validation data have been obtained with laboratory experiments.

The research presented in this paper is based on observations of the Ameland Noordwest QRF location, which entails the beach and dune area at the northwestern side of Ameland as well as the outer delta of the Amelander Zeegat. The Ameland Noordwest location is used to investigate 1) the behavior of the coastal foundation and plate-channel interactions and 2) the dynamics of the beach, dunes, salt marshes and overwash areas. During the 2017/2018 winter season, focus lies on the effect of storms on: the penetration of offshore waves through the outer delta, wave run-up on the beach and the impact on the sedimentation and erosion of the beach/ dunes.

A wide range of measurements is being executed for the winter season of 2017/2018. The wave field is monitored from offshore to the dune foot with, consecutively, an X-band Radar on the Ameland lighthouse, wave buoys and pressure sensors (Figure 1, left) on the beach. Topography was measured using RTK-GPS and UAV LiDAR prior to the season in September 2017. Fortunately, several particularly strong high-energy events impacted the area during the winter of 2017/2018, such as storms 'Eleanor' on January 3rd and 'Friederike' on January 18th 2018. Measurements were executed rapidly following these events to capture the short-term impact on the Ameland coast.

The morphodynamic changes in the beach and dune area are quantified with the UAV-LiDAR. Results from this monitoring show very large responses to the storms, especially at locations marked by narrow beaches (Figure 1, right). The first results of the QRF (topography) measurements will be discussed during the presentation.

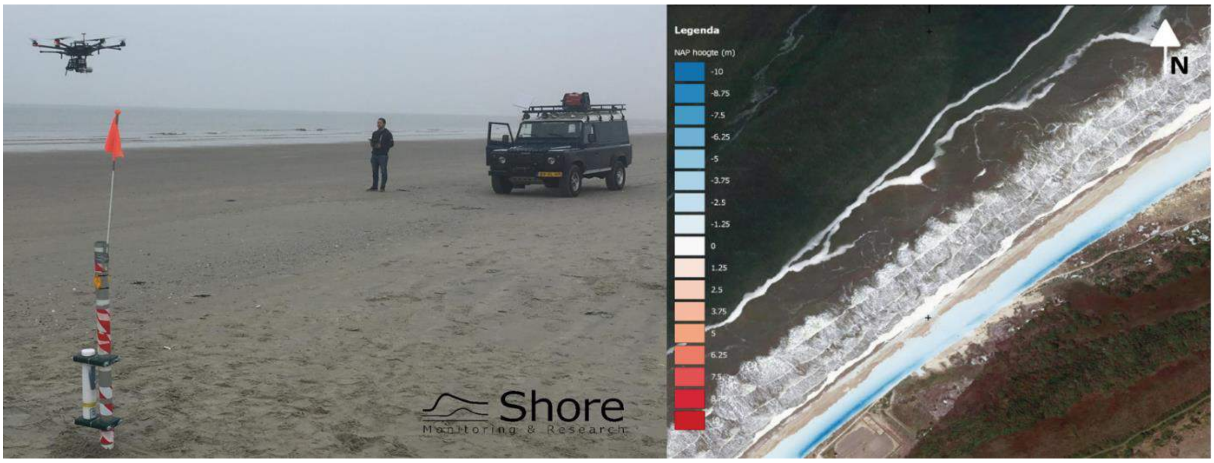

Figure 1. Left: Pressure sensor and UAV-LiDAR survey after installation in September 2017. Right: Bed-level changes derived from the survey of January 2018, following the two storm events.

REAL-TIME ESTIMATION OF EBB TIDAL DELTA BATHYMETRY USING NAVIGATIONAL X-BAND RADAR

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The Dutch ebb-tidal deltas are important nearshore morphological features on the Wadden Sea coast. They cause dissipation of North Sea waves in storm and other extreme conditions, thus reducing the wave loads on the sea defenses on the main land. Furthermore, ebb-tidal deltas are thought to be conduits through which sediment is passed from one island to the next.

However, still much is unknown about the mechanisms and time scales of bathymetric change of tidal inlets, in large part because high-resolution data in time and space are commonly lacking, owing to their high cost. In the Netherlands, ebb-tidal deltas are presently monitored *in situ* once every 3 years. This means significant changes at event, seasonal or annual time scales are not observed.

This lack of data can be overcome by using remote-sensing equipment, such as X-Band radar. Since 2015 we have used data from the already operational navigational radar on top of the lighthouse at the Amelander Inlet to estimate bathymetries. Recently, an automated system was set up to process 5-minute bursts of radar images every 40 minutes for 24 hours a day using the XM-Fit method. This method applies a 3D (x,y,t; k_x, k_y, ω) Fast Fourier Transformation, as well as a linear dispersion relation including currents to estimate bed levels and surface-current magnitudes and directions in an area with a radius of 7 km and at a horizontal resolution of 100 m.

This new method allows us to closely monitor the entire ebb-tidal delta and its surroundings in real time (Figure 1). Thus, it can follow the effects of storms on the local geomorphology of the ebb-tidal delta. In the paper, we will present some validation results of this method against recently obtained *in situ* data. We will also discuss the observed morphological change in terms of sedimentation and erosion patterns.

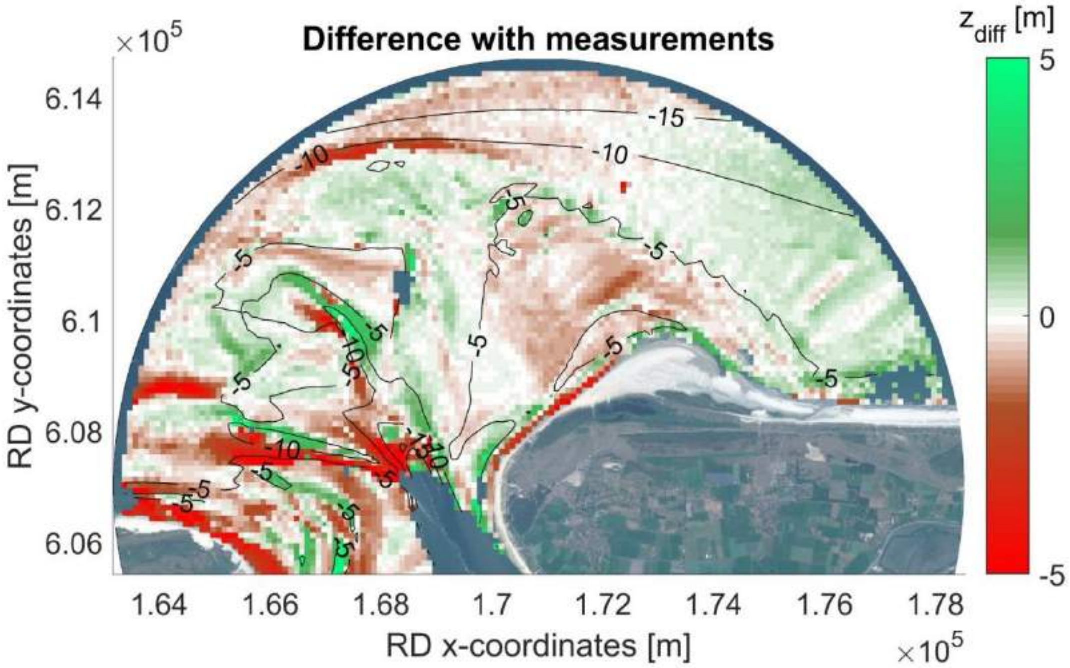

Figure 1. Difference between measurements and XMFit estimates of the Ameland ebb-tidal delta bathymetry in 2017. The time difference between measurements and XMFit estimates is 8 months.

SPATIOTEMPORAL SURFACE MOISTURE DYNAMICS ON A COASTAL BEACH

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Surface moisture is a major limiting factor for aeolian sand transport on coastal beaches and, accordingly, understanding its spatiotemporal variability will aid in developing a predictive model for the input of wind-blown beach sand into the foredune. In our earlier work (Smit *et al*. 2017) we illustrated that the reflectance signal of a near-infrared Terrestrial Laser Scanner (TLS) corresponds well to gravimetric surface moisture content (in %) over its full range. Here, we analyze TLS-derived surface moisture maps with a 1x1 m spatial and a 15-min temporal resolution (Figure 1) and concurrent groundwater measurements collected during a falling and rising tide at Egmond beach, the Netherlands. The maps show that the beach can be conceptualized into three surface moisture zones. First, the swash zone, where the moisture content is always high (18% - 25%). Secondly, the intertidal zone, where the moisture content can vary between 5% and 25%. And thirdly, the back beach, which is always dry (3% - 7%). Temporal and spatial variations in surface moisture were linked strongly to the groundwater depth. Their relationship can be described well by a 'Van Genuchten-type' soil-water retention curve. This opens up new opportunities to calculate surface moisture from groundwater measurements (or model predictions thereof) but also *vice versa*: to calculate groundwater depth with surface moisture measurements. Preliminary results already show corresponding patterns between measured and calculated surface moisture maps and groundwater depth maps. Concluding, the TLS-derived moisture maps and groundwater measurements clearly show that groundwater depth is a key control on spatiotemporal surface moisture variations.

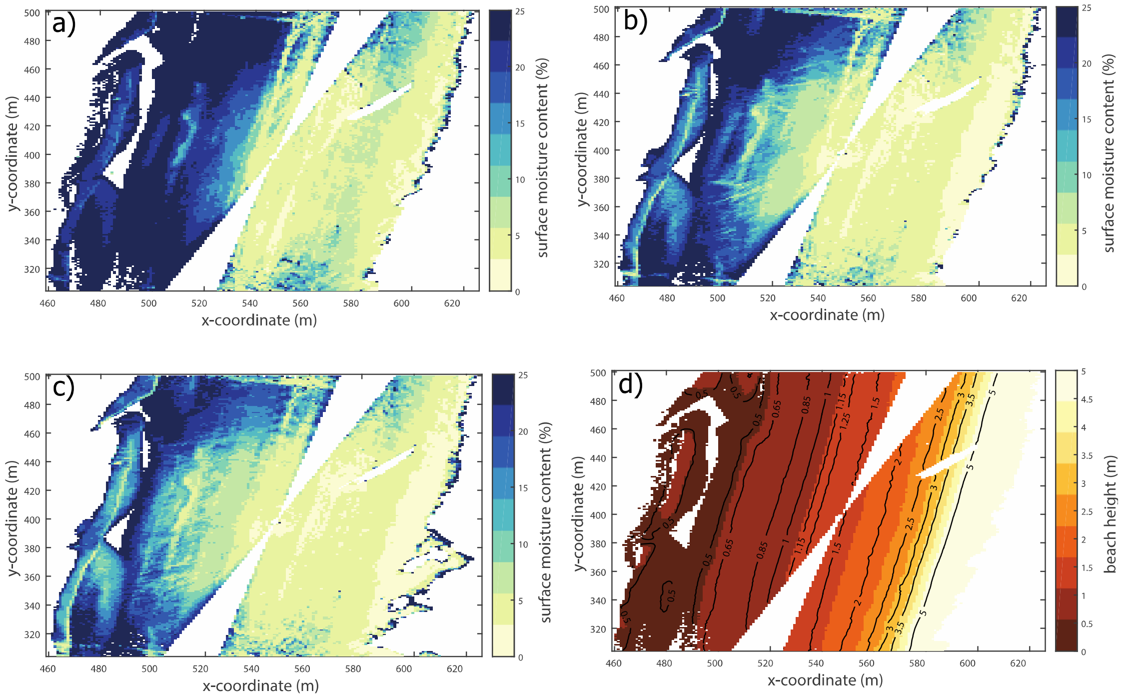

Figure 1. Three surface moisture maps that show the surface moisture variations during falling tide on September 29, 2016 at the beach of Egmond aan Zee, with a corresponding beach height. On the right side the dunes are situated and on the left side the sea. A clear trough at approximately 480 m in the x-coordinate is visible, which dries out during the day. Also, the yellow color spreads out towards the sea, which means the sand dries up during the day. Graph (a) was taken at 10:30 h, (b) at 14:00 h, (c) at 16:00 h. (d) Shows the beach height above mean sea level on September 29, 2016. (Smit et al. 2017).

Smit, Y., Ruessink, G., Brakenhoff, L.B., Donker, J.J. (2017). Measuring spatial and temporal variation in surface moisture on a coastal beach with a near-infrared terrestrial laser scanner. *Aeolian Research*.

BEACH SCARP MORPHODYNAMICS

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Introduction

Beach scarps are nearly vertical seaward-facing walls within the cross-shore beach profile. These features are often associated with eroding (nourished) coastlines and can reach heights of 2-3 m, leading to serious hazards to beach users and negatively impacting local ecosystems. New insights into beach scarp morphodynamics (formation, migration, destruction) related to geometrical, geotechnical and hydrodynamic parameters are presented in this study.

Results long term data analysis

Beach scarp presence at the Sand Engine nourishment between 2011 and 2017 has shown that the formation is linked to mildly erosive (summer storm) conditions, whereas destruction is related to both extremely erosive (winter storm) conditions (overwash or inundation) and non-hydrodynamic controls (drying collapse or aeolian transport). Additional high-detail GPS-measurements of the beach scarps at the Sand Engine in the summer of 2017 indicate that the toe elevation is 'fixed' around the maximum runup elevation ($R'_{2\%}$) in the latest storm event.

Field experiments

Using a front-loader, five artificial mounts with varying platform heights and initial slopes were constructed at the Sand Engine in the summer of 2017 (Figure 1). Monitoring these mounts showed that the formation of beach scarps was related to the platform height, whereas the rate of formation was determined by the initial steepness. Next to the topographical measurements, video recordings have shown that the formation of beach scarps occurs between $R'_{15\%}$ and the maximum wave-runup elevation.

Conclusion and outlook

The collected data and analysis provide a guideline to predict beach scarp formation with a height (S_h) based on the nourishment platform height ($h_{n,p}$) and hydrodynamic conditions; ($S_h = h_{n,p} - R'_{2\%}$). Moreover, using the geotechnical aspects of beach scarps, an estimate of the maximum scarp height and slope can be obtained. These findings provide a better understanding of beach scarp morphodynamics and their relation to various geometrical, geotechnical and hydrodynamic parameters. By taking these concepts into account, the future design of beach nourishments could be adjusted to limit the formation of beach scarps and to increase the natural destruction of these unwanted beach features.

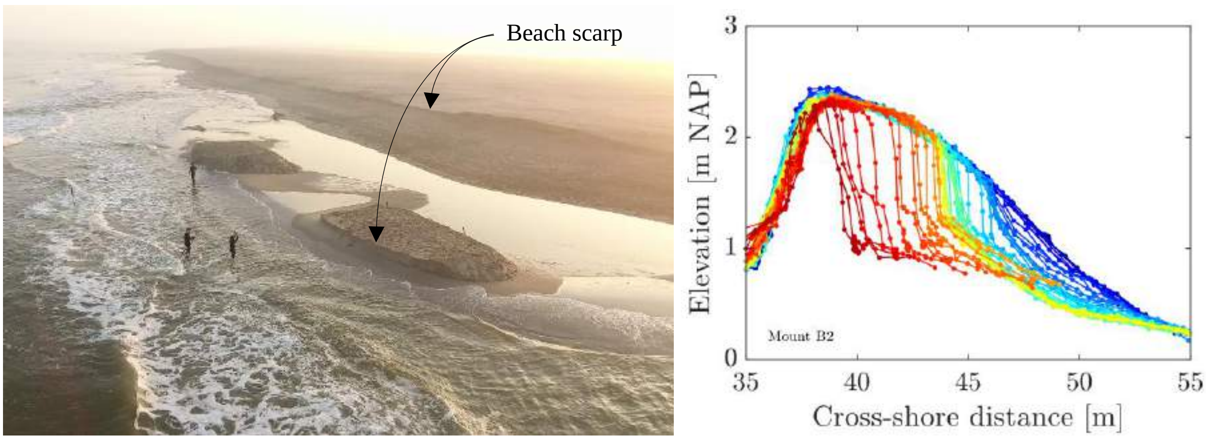

Figure 1. Drone snapshot of a beach scarp creation experiment performed at the Sand Engine (left). Measured cross-shore profile development (right) of one of the mounts between the first (in blue) and last day (in red).

ANALYSING LARGE-SCALE DIFFERENCES IN LONG-TERM MORPHOLOGIC BEHAVIOUR ALONG THE NORTH SEA COAST

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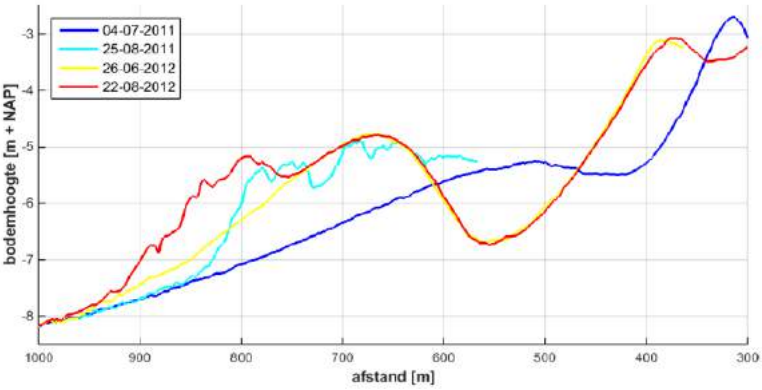
Introduction

At many locations along the North Sea region (NSR), erosion of the coast is counteracted by supplying sand to the coastal system (nourishments). Nourishments on the shoreface have increasingly been applied in the NSR over the last decades. The implementation and observed behaviour (migration direction, effect on bar-trough system) of these shoreface nourishments are spatially different along the Dutch-Danish NSR (Lodder and Sørensen 2015). To improve the effectiveness of these nourishments, coastal zone managers seek better understanding of the regional morphologic response in relation to hydrodynamic forcing and geophysical characteristics, such as sediment distribution (Wilmink *et al.* 2017).

Figure 1. Location of cross-shore profiles in dataset.

Methods

The regional morphological differences can be studied through a recently developed trans-national database, containing more than 135,000 mostly yearly cross-shore bed profiles from 5840 locations, comprising the NSR from Belgium to Denmark (Figure 1) and covering typical time spans of 20-50 years. By applying data-analysis techniques, e.g. empirical orthogonal functions (EOF), the existence of regional differences in morphologic behaviour can be examined. There will be a specific focus on the pre- and post-nourishment behaviour of nourished regions (Figure 2), in order to assess the impact of nourishments on the regional-scale morphologic evolution of the coast. The results of this research are expected to contribute to the understanding of the effectiveness of nourishments in the NSR.



Interreg
North Sea Region
Building with Nature

Figure 2. Cross-shore redistribution of nourishment near Heemskerk (Deltares 2017).

Deltares (2017), Ontwikkeling Suppletie Heemskerk 2011-2016, Delft: Deltares. Report number: 1230043-001

Lodder, Q.J., Sørensen, P. (2015). Comparing the morphological behaviour of Dutch-Danish shoreface nourishments. In: A. Baptiste (ed.): *Coastal Management: Changing coast, changing climate, changing mind*. DOI:10.1680/cm.61149.397.

Wilmink R.J.A., Lodder Q.J., Sørensen, P. (2017). Assessment of the design and behavior of nourishments in the North Sea Region. *Proceedings of Coastal Dynamics*, Helsingør, Denmark, No. 043, 801-809.

SEDIMENT TRANSPORT PATTERNS ON AMELAND EBB-TIDAL DELTA DETERMINED BY DUAL-SIGNATURE SEDIMENT TRACERS

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Introduction

The long-term erosional/accretionary trends of the Dutch Wadden Islands depend, in part, on the fate of the ebb-tidal deltas between them. In order to understand how these ebb-tidal deltas will respond to future conditions (e.g. sea level rise) or interventions (e.g. nourishments), it is necessary to identify the main pathways for sediment transport through the system.

Methodology

To assess sediment transport pathways across the ebb-tidal delta, 2000 kg of specially-designed tracer material with both a fluorescent and ferrimagnetic signature. was utilized. The physical and hydraulic properties of the tracer closely matched the native sediment on the seabed at the site (d_{50}= 285 μm, ρ= 2628 kg/m^3). The tracer was deposited on the ebb-tidal shoal from a ship at -6.5 m NAP, and then allowed to disperse naturally. After deployment, an extensive sampling campaign was conducted to monitor the spatiotemporal distribution of the tracer material (Figure 1). In total, 300+ surficial sediment samples were collected across the ebb-tidal delta and Ameland Inlet. To capture tracer material transported in suspension, high-field bar magnets were secured to mooring lines at intervals 1, 2, and 5 m above the bed, and strategically positioned around the tracer deployment site. Tracer particles were later magnetically separated from the native sediment load and counted under UV illumination.

Preliminary Findings

Tracer material was recovered from the grab samples taken in the first few days after deployment, up to 900 m away from the source. Furthermore, tracer material was recovered on all of the suspended magnets, indicating that some of the tracer travelled in suspension, for part of the time. Qualitative inspections also revealed that tracer was recovered three weeks after deployment, during a period that included at least one significant storm. The next steps are to perform a grain size analysis on the recovered tracer to determine the influence of grain size on sediment transport and contextualize the study findings from *in situ* wave and current measurements recorded during the study period.

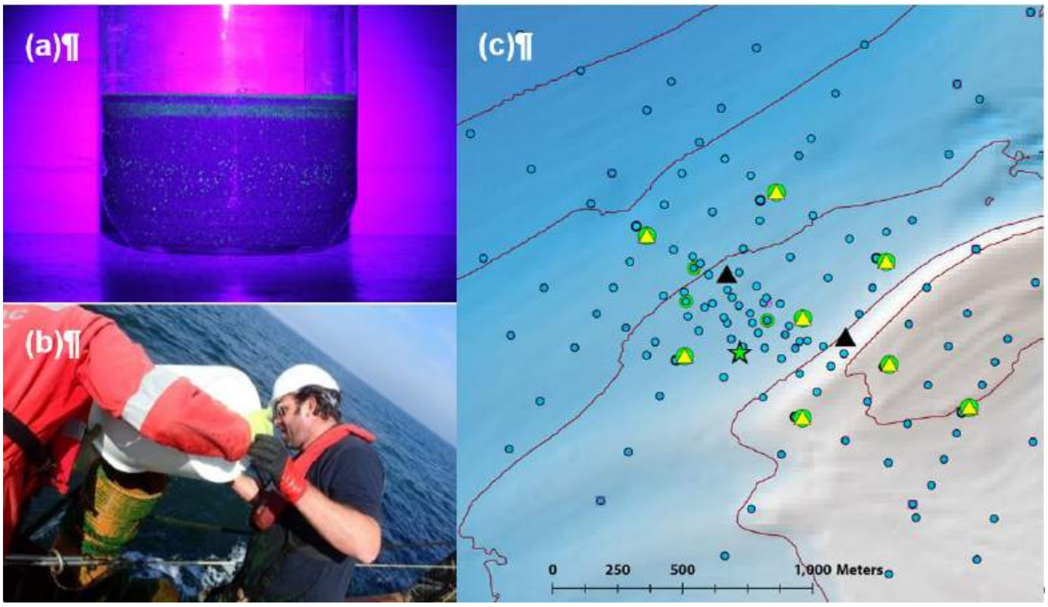

Figure1. (a) Fluorescent and magnetic tracer particles retrieved from the seabed of Ameland ebb-tidal delta several days after initial deployment. (b) Deployment of the tracer from a ship. (c) Map of grab sample locations (blue dots) on Ameland ebb-tidal delta with preliminary confirmed tracer recovery locations (green dots). Suspended magnets were placed at each of the yellow triangles. All samples are yet to be analyzed.

AEOLIAN SEDIMENT TRANSPORT PROCESSES IN A MANAGED BEACH-DIKE SYSTEM

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Although we have a good understanding of the mechanics of aeolian sediment transport, quantifying and predicting aeolian sediment transport in coastal environments remains a major challenge. The interaction between topography, wind flow and supply-limiting factors such as beach width, surface-moisture content and armoring effects makes it hard to predict sediment transport. Moreover, humans modify beaches and dunes and aeolian transport potential by: building structures, walking or driving, extracting resources, accommodating recreation, increasing levels of protection, removing storm deposits, or restoring landforms and habitats.

A two-week monitoring campaign was carried out to measure detailed aeolian transport, topographical changes and wind on the upper beach of a managed beach-dike system at Mariakerke-Bad, located in Belgium at the southern edge of the North Sea basin, in November 2017 (Figure 1). Preparing this beach against winter storms, the coastal town orders bulldozers to create an artificial plateau (upper beach), thereby removing an excess of sand from the higher beach seawards, making an artificial bluff at a distance 50-60m from the dike. Moreover, a trench is dug at the toe of the dike to limit aeolian transport towards the hinterland. A two-hour transport event revealed a rapid change in topography during onshore moderate wind conditions (9 m/s). An increase in sediment transport was measured over the seaward half of the upper beach (positive gradient, erosion), followed by a decrease in sediment transport towards the dike (negative gradient, deposition). The artificial bluff and upper beach, introduced and managed by the coastal town, changes into a beach with a more natural slope. Surprisingly, when calculating the total transport rate by the exponential decay function, $q(z) = q_0.exp(-B.z)$, the exponential parameter, B, increases downwind as one moves away from the bluff, meaning that the vertical spreading of sediment transport changes over distance. Variations in vertical flux profiles between traps were larger near the dike region than elsewhere. This increase can be attributed to the wind-field perturbation at the bluff. Furthermore, we measured a drop in shear velocity in the downwind direction, which is confirmed by the observed deposition of sand in the region 30 m in front of the dike. On the basis of our results, we are able to understand the dynamics of aeolian sand transport at a managed beach and to quantify the time scales at which sand-transport events take place.

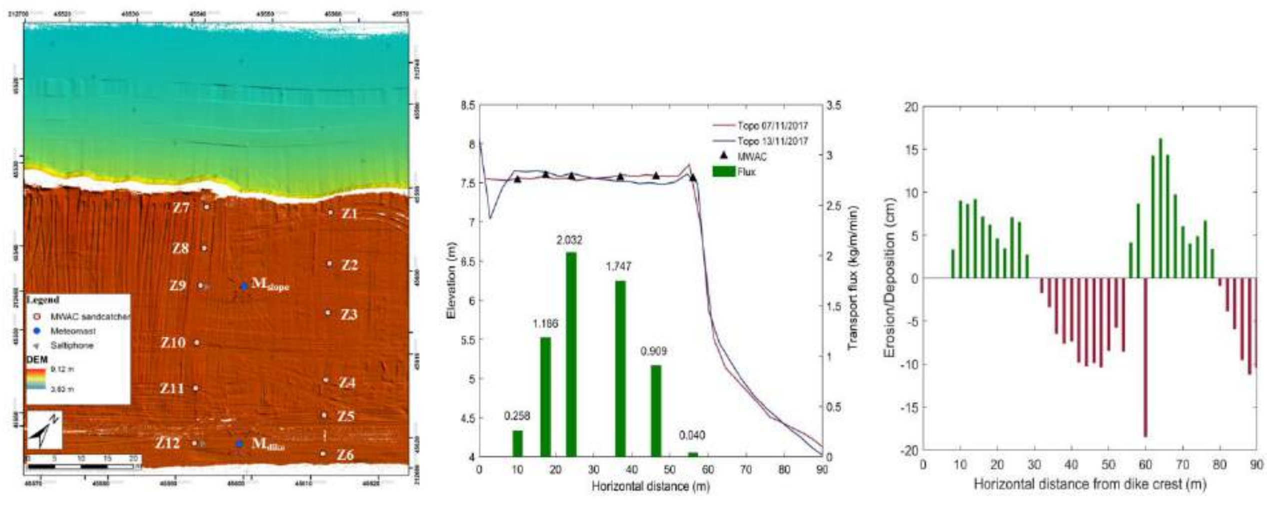

Figure 1. Left panel shows the measurement area with the positions of the MWAC sand traps, meteorological stations and saltiphones. Middle panel shows the topography before and after a two-hour transport event combined with the spatial variation in sediment transport. Right panel shows the difference in topography caused by the transport event. Significant erosion and deposition is measured towards the dike during onshore winds.

Measuring suspended-sediment transport in the intertidal zone of a macro-tidal beach (Mariakerke, Belgium)

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Introduction

The intertidal beach, the part of the beach between the low- and high-water line, is very dynamic. It receives most of the wave energy and is affected by currents and wind. However, the effect of hydrodynamic forcing on the intertidal beach morphology is not yet fully understood. This is mainly due to a shortage of field studies relating hydrodynamic forcing, sediment transport, and morphological response in the intertidal area. Therefore, two measuring campaigns were carried out in the intertidal zone of Mariakerke (Belgium). A frame (Figure 1) was deployed near the low-water line to measure wave height and period, profiles of flow velocity, and suspended-sediment concentration. The topography of a 300 x 300 m stretch of the beach was measured with a mobile laser scanner three times during the campaigns. In addition, the topography of five cross-shore profiles was measured daily with an RTK-GPS.

Results

The results show that the suspended-sediment concentration is weakly related to local bed shear stress. The largest part of the suspended sediment is thus supplied by incoming currents. Under calm conditions the suspended sediment is transported in the same direction as the observed topographic changes suggest. However, under more energetic conditions there are large differences between measured sediment transport and sediment transport derived from topographic changes.

The beach at Mariakerke is macro-tidal, with a tidal range of 5 m during spring and 3.5 m during neap tide. As a result, topographic changes are related to both waves and tidal currents. During spring tide the currents are generally directed alongshore and erosion is observed. During neap tide wave effects become dominant, especially when the wave height is large (> 1 m). The currents then become cross-shore directed and accretion is observed. However, large waves (height > 2 m) lead to erosion.

Figure 1. Intertidal measuring frame with 3 optical backscatter sensors, 3 acoustic current profilers, 1 electromagnetic current meter, and 1 pressure sensor (not on photograph).

PROMOTING BEACH-DUNE INTERACTION IN THE PRESENCE OF MAN-MADE OBSTACLES

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Introduction

The exchange of sediment between the beach and dunes is of paramount importance for maintaining a healthy and dynamic dune system. At various places along the Dutch coast, this exchange of sediment is hindered by man-made structures such as beach houses and pavilions. Their presence leads to a loss in dune dynamics and dune growth potential. The goal of this project is to find ways to promote sediment transport around, between and below these structures, such that dune dynamics at these locations are (at least partly) restored. This is in line with present-day coastal dune management in the Netherlands that focuses on restoring dune dynamics rather than on continuous maintenance.

Methods

For the first time, this problem was approached by using computational flow dynamics (CFD), rather than field observations or satellite imagery. This different method allowed us to test and compare potential measures that reduce the negative impact of beach structures. Two measures were tested: 1) increasing the distance between structures to allow sediment transport between structures; and 2) placing structures above the ground on poles to allow unhindered sediment transport. Numerical modelling of airflow was done using the simpleFoam steady-state solver in openFOAM, a free open-source CFD toolbox. A simplified coastal profile based on AHN3 measurements serves as a basic mesh, on top of which building objects were placed. In addition to the variable associated with the investigated measure, all situations were tested for six incoming wind directions ranging from 0° (shore-normal) to 75°.

Results and Discussion

Preliminary results for ten 7 x 4 m beach houses show that placing the houses above the ground on poles is the most effective way to promote unhindered flow and sediment transport. The effectiveness of poles expressed in terms of sediment mobility (based on Bagnold's mobility criterion for wind-blown sediments) increases rapidly up to a pole height of 1.5 - 2 m. At heights > 2 m the extra benefit is negligible (Figure 1). Increasing the space between houses to more than 3 m leads to some flow acceleration, allowing sediment to be transported between houses. However, duneward flow and sediment mobility is much lower than in the case of placing structures 1.5 - 2 m above the ground. In addition, much of the sediment is expected to be trapped in tail bars that form behind the houses. Further efforts will focus on the inclusion of a sediment transport predictor, different building types, different wind conditions and a third measure of placing objects farther away from the dune foot.

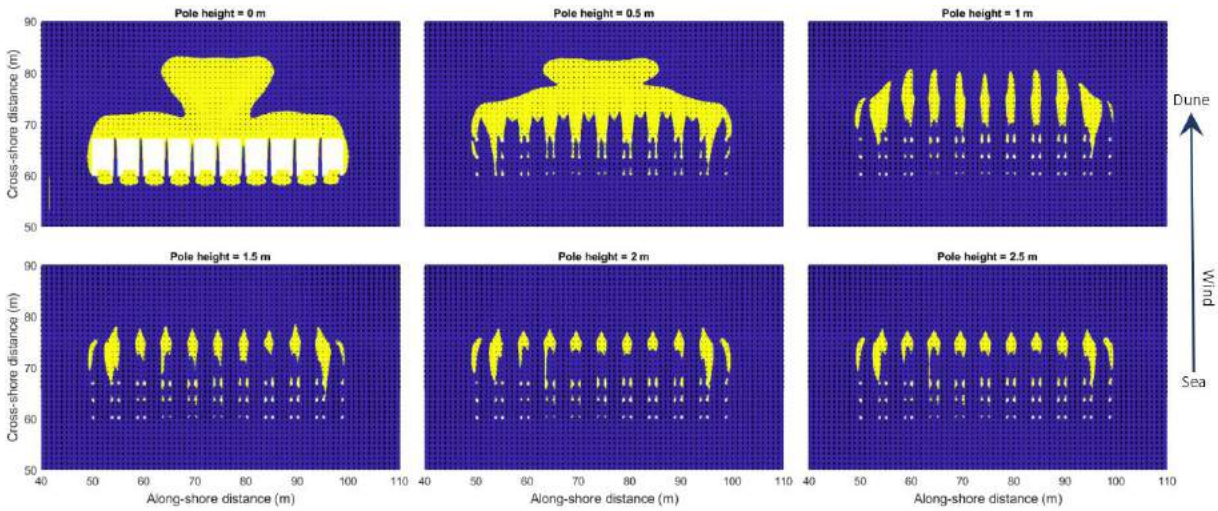

Figure 1. The effect of different pole heights on sediment mobility in the case of shore-normal incoming winds with a reference speed of 10 m/s. Space between houses is 1 m. The yellow area shows where sediment is immobile.

UNRAVELING THE DECISIVE FACTORS FOR THE TRANSPORT OF SEDIMENT AS A SUPPLY FOR SALT-MARSH GROWTH

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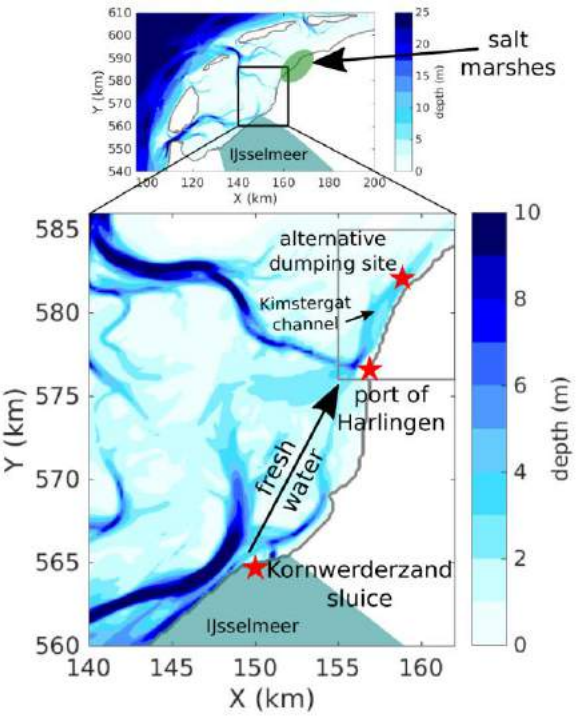
* kirstin.schulz@nioz.nl

The MudMotor project

Sediment accumulation in the harbor of Harlingen (Figure 1) necessitates frequent maintenance dredging. In the MudMotor project, this sediment is now partly deposited farther into the Kimstergat channel (gray rectangle) to establish a semi-continuous source to nourish the adjacent salt marshes and reduce recirculation of sediment into the harbor.



Measurements in the Kimstergat

Ship-based measurements of suspended particulate matter (SPM) transport close to the Harlingen harbor and in the channel revealed three features: 1) Sediment is generally transported towards the salt marshes and away from the harbor, supporting the idea of the MudMotor. 2) The tide in the channel is asymmetric: The flood phase is shorter than the ebb phase, but maximal current velocities are higher during flood than during ebb. 3) Freshwater originating from the large sluice in Kornwerderzand enters the channel with the flood current and causes a periodically occurring stratification (stratified during flood, well-mixed during ebb) that is inverse to what is expected in a classical estuary (well-mixed during flood, stratified during ebb).

Modeling the dynamics in the Kimstergat

1D model: To investigate whether the asymmetric tidal current or the freshwater source at the mouth governs the SPM transport in the Kimstergat, a 1D water-column model (GOTM) was used, in which salinity stratification and tidal asymmetry could separately be switched on and off. The observations could be nicely reproduced, and it was furthermore found that: 1) The freshwater source at the mouth of the channel counteracts sediment transport towards the salt marshes. Without the periodic stratification, transport rates in the channel would be ~60% higher. 2) In the absence of tidal asymmetries (in the presence of a perfectly sinusoidal tidal current), the freshwater influence would even reverse the direction of SPM transport and lead to a transport towards the harbor (Schulz and Gerkema 2018).

3D model: It is known that wind conditions can have a high impact on sediment transport in the Wadden Sea, but wind effects were neglected in the 1D model described above. To examine those effects, a 3D hydrodynamic model (GETM) was set up to investigate the effect of different wind speeds and directions on SPM transport in the Kimstergat, to examine the influence of the exact dumping position, and to provide a more detailed understanding of the influence of freshwater discharged through Kornwerderzand on the sediment dynamics.

Schulz, K., Gerkema, T. (2018). An inversion of the estuarine circulation by sluice water discharge and its impact on suspended sediment transport. *Estuarine, Coastal and Shelf Science*, 200, 31-40.

Funded by the TTW project "Sediment for the salt marshes".

MODELING THE EVOLUTION OF OBSERVED TIDAL SAND WAVES IN THE NORTH SEA

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Sand waves on the outer shelf are rhythmic bedforms with wavelengths of 100-1000 m, wave heights up to 10 m. They have migration speeds of up to 10 m/year. Because of their dynamic nature they may expose previously buried cables and pipelines. Since the burial of cables and pipelines is a costly procedure, there is a need to determine the optimum burial depth for cables and pipelines. So far, this has been done empirically by extrapolating trends from historical bathymetry data over periods of order 50 years, which is the typical lifetime of the structures. This empirical method may lead to uncertain results and is limited by the lack of high-quality bathymetry data. Therefore, there is a demand to study the long-term evolution of sand waves with the use of models.

In this research the Delft3D sand-wave model by Van Gerwen *et al.* (2018) is used to study the evolution of observed sand waves in the North Sea on decadal timescales. Rijkswaterstaat measurements made in 1999 of the sand-wave field in windpark Hollandse Kust Zuid are taken as the initial bathymetry. The model is run for a 17-year period and the output is compared with measurements done by Fugro (2016) at the same location. The results are shown in Figure 1, with the red lines representing the observations and the blue line showing the model output. The interest is in the migration speed, shape and maximum crest height and trough depth. The depth and migration of the troughs is predicted well by the model, but this is not the case for the crests. The reasons for this difference will be discussed during the presentation.

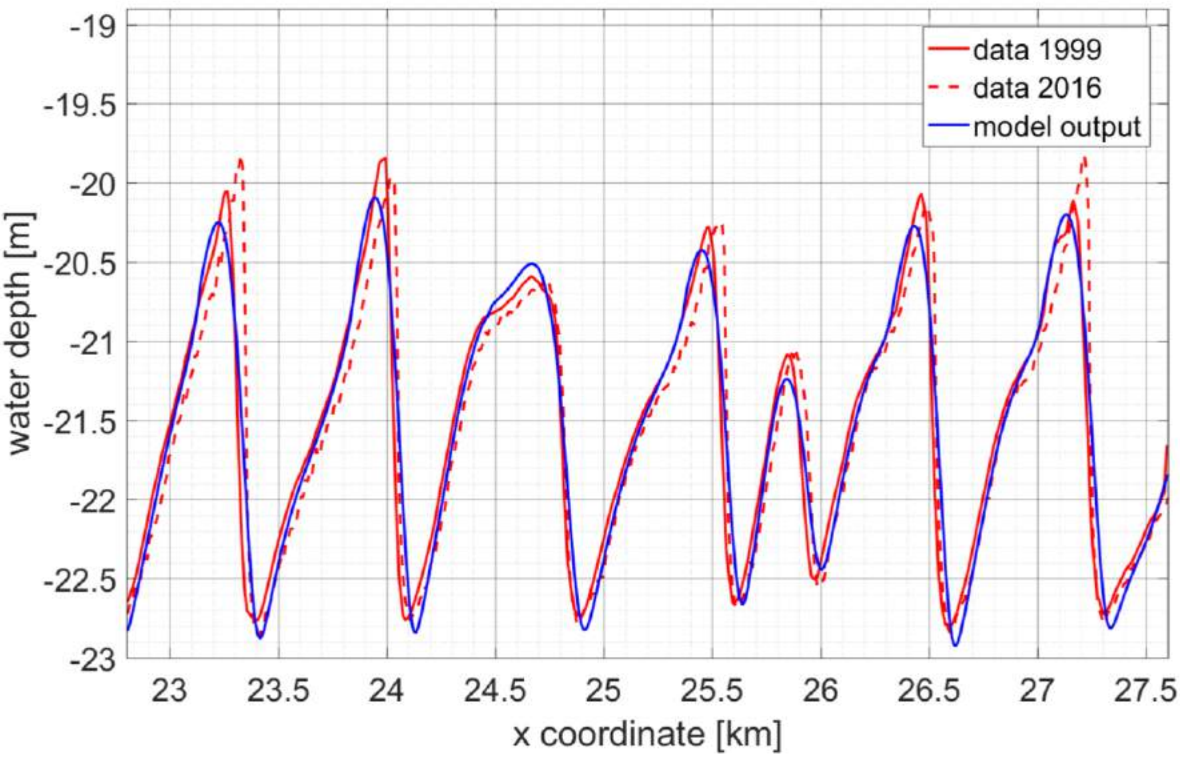

Figure 1. Comparison between data and model output for Hollandse Kust Zuid. Solid red line = measurements by Rijkswaterstaat 1999, dashed red line = measurements by Fugro 2016, blue line = model output.

van Gerwen, W., Borsje, B.W., Damveld, J.H., Hulscher, S.J.M.H. (2018). Modelling the effect of suspended load transport and tidal asymmetry on the equilibrium tidal sand wave height. *Coastal Engineering*, 136, 56-64.

SMALL-SCALE VARIATIONS IN SEDIMENT CHARACTERISTICS OVER THE DIFFERENT MORPHOLOGICAL UNITS OF TIDAL SAND WAVES OFFSHORE OF TEXEL

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Beds of sandy coastal seas are dominated by large rhythmic bedforms. Tidal sand waves are highly challenging bedforms to understand given their migration rates (several meters per year) and dimensions (several meters height and several hundreds of meters in wavelength). Almost all experimental investigations addressing the formation and behavior of these sand waves neglect the non-uniformity of bed material. Moreover, scarcely any information is available on the seabed-sediment composition along a sand-wave field, especially when focusing specifically on the different morphological units (trough, slopes and crest) over multiple seasons. To help fill this knowledge gap, a sand-wave field located in the North Sea was investigated in June and October 2017. Sediment samples were collected to measure grain-size characteristics and sediment permeability over a transect spanning 16-18 sampling stations covering 4 sand waves (Figure 1). Results show significant variations in both parameters between the different areas of the sand wave (crest, trough, lee and stoss slopes), indicating a distinct sediment-sorting process that corresponds to increasing permeability and also coarsening of bed material towards the crests. The range in the median grain size (D50) was much greater than found in previous studies. We discuss the potential implications of this finding on the benthic distribution, biochemistry and morphodynamics of tidal sand waves.

Figure 1. Sediment collected from the North Sea using a 30-cm-diameter boxcore, with subsamples taken for sediment analyses (photo: C. Cheng).

A CLASSIFICATION METHOD FOR THE PRESENCE OF TIDAL SAND WAVES AND MAINTENANCE DREDGING DESIGN

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Tidal sand waves and Port of Melbourne maintenance dredging

Tidal sand waves are bedforms that grow under the influence of residual tidal currents driving sediment particles to the crest of the sand wave. Generally, tidal sand waves are several meters high, hundreds of meters long, and migrate up to tens of meters per year. Tidal sand waves can cause failure of offshore structures when migrating waves expose buried pipelines or structure foundations. Sand waves can also cause hindrance to vessel navigability. After dredging, monitoring of the Melbourne port shipping channel (South Channel) bathymetry revealed fields of bedforms with high growth rates. These bedforms threaten to hinder marine traffic and the matter requires an adequate maintenance strategy. The dimensions and growth rate of the local bedforms are remarkable and, therefore, classical sand wave theory does not automatically apply.

Research questions and methodology

The central research questions are: 1) whether bedforms can be classified as tidal sand waves on the basis of low-detail hydrodynamic data and 2) how dredging affects the suppression of tidal sand waves. To study the research questions, bathymetry and (numerical) flow data are analyzed alongside established sand-wave literature to investigate if the bedforms can be classified as tidal sand waves. New maintenance strategy concepts are designed with the prevention and delay of sand-wave growth in mind. A 2DV Delft3D numerical model is used to evaluate the different dredging strategies.

Main findings

To determine if bedforms in South Channel can be classified as tidal sand waves, both the physical dimensions and the hydraulic environment of the bedforms are studied. Hulscher (1996) defined a spectrum of hydrodynamics in which tidal sand waves are able to grow. Borsje *et al.* (2014) revealed how an upper boundary to this spectrum is added, based on the transition from bedload to suspended load sediment transport. Subsequently, a 74% agreement was found between the predicted and actual bedform presence in the channel (Figure 1). The results also indicate local generation of sand waves, which defines the focal point of the maintenance strategy design. A probabilistic approach shows similar regrowth time for the simulated and measured sand waves. Furthermore, smoothing the bed may increase the maintenance interval by 3 years while removing more sand from the system increases that period substantially.

Outlook

The project provides the knowledge, methods and tools required for the classification of bedforms as tidal sand waves using only low-detail hydrodynamic data. Our approach also shows the potential as a predictive tool for sand-wave presence. Additionally, the numerical study enables the design of dredging strategies that require less volume of material moved and are less intrusive on the environment. Including sand-wave migration in the method will provide additional design-optimization potential.

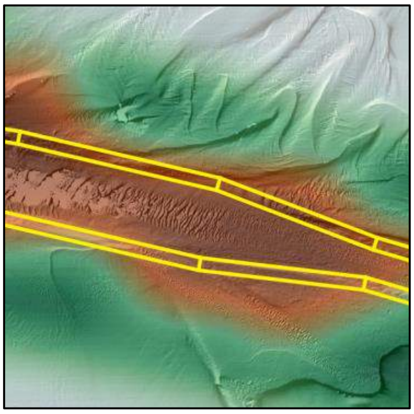

Figure 1. Result of predicted presence of tidal sand waves in South Channel. Red indicates presence, green indicates absence.

Hulscher, S.J.M.H. (1996). Tidal-induced large-scale regular bed form patterns in a three-dimensional shallow water model. *Journal of Geophysical Research: Oceans*, 101 (C9), 20727-20744.

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MODELLING SAND WAVE FIELDS ON THE TAIWAN BANKS, NORTHERN SOUTH CHINA SEA: THE FORMATION OF TWO-SCALE SAND WAVES IN DIFFERENT PERIODS

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Tidal sand waves create a widespread seabed pattern on tide-dominated continental shelves around the world. The growth and migration of sand waves are of both scientific and practical relevance, as they can hamper navigation and cause exposure of cables. Field data acquired over the Taiwan Banks reveal co-existing sand waves on two distinct spatial scales: immobile large-scale sand waves (~15 m height, ~750 m wavelength) and small-scale sand waves (~1.5 m height, <100 m wavelength) with migration rates of 2-5m/yr (Zhou *et al.* 2018, see Figure 1).

These two-scale sand waves have not yet been linked to hydrodynamic conditions using a process-based sand-wave model. Considering borehole data and sea-level variation, we apply linear stability analysis (Campmans *et al.* 2017) to model the formation of the two-scale sand waves, attempting to link with appropriate hydrodynamic conditions under geological background, and investigating the sedimentary environment of the study area since the Last Glacial Maximum.

Model results produce ranges of wavelengths likely resulting from the prevailing hydrodynamic conditions. In particular, we find that the large-scale sand waves are not able to develop under present hydrodynamic conditions. Greater water depth by sea-level rise due to the large transgression in Holocene times provides the most likely hydrodynamic conditions for the formation of large-scale sand waves. Moreover, the small-scale sand waves have likely developed under shallower water depth and weaker tidal current amplitude.

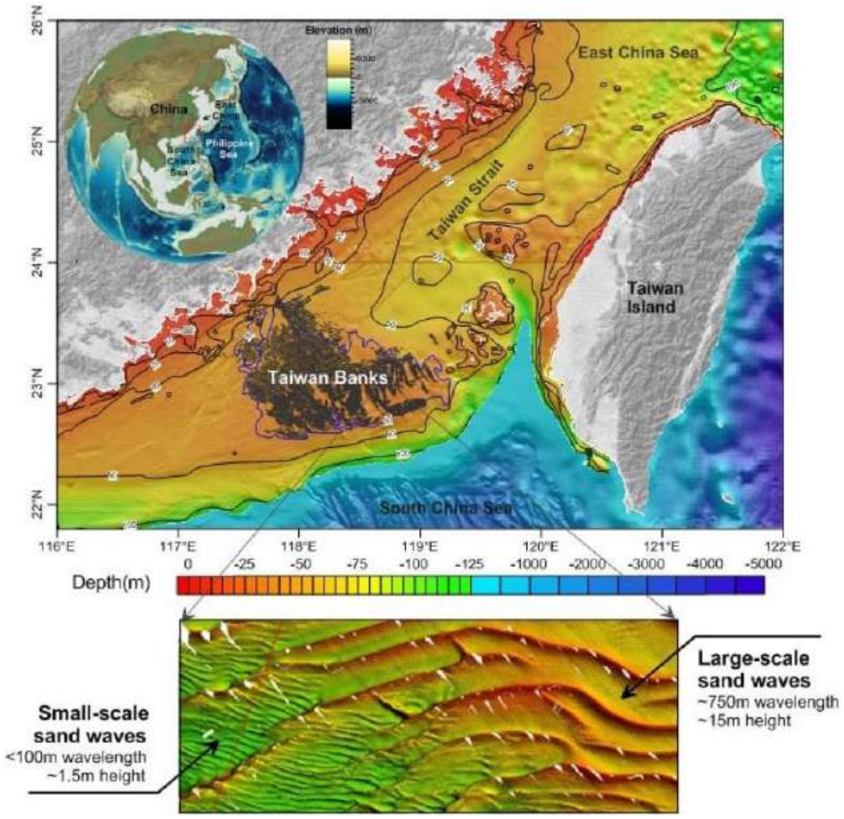

Figure 1. Location and geomorphology of the sand-wave fields on the Taiwan Banks, northern South China Sea.

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THE IMPORTANCE OF UNCERTAINTY ASSESSMENT IN MORPHOLOGY PREDICTIONS

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Introduction

Society increasingly calls for sustainable, nature-based solutions for coastal engineering and management. These are inherently associated with uncertainties on their evolution over time. Yet, the use of stochastic methods to estimate these uncertainties is not very common in coastal engineering because stochastic methods are computationally expensive and difficult to validate. In addition, improvement of model description is more urgent to many. This research investigates the hypothesis that accounting for uncertainty via a stochastic approach results in a 50% exceedance value and a mean that are different from the deterministic predictions. This difference would imply that treating a deterministic forecast as being a mean value or having 50% chance of exceedance would create a false sense of accuracy.

Method

The development of a sinusoidal coastline perturbation or idealized large-scale nourishment with an offshore extent of 500 m and a length of 10 km is modelled with a simple line model, using the Kamphuis formula (Kamphuis 1991). A deterministic computation with a 5-year time series of observed waves is compared to several stochastic simulations. For the stochastic simulations a time series of 20 years of nearshore wave observations is split up into a 15-year calibration period and a 5-year forecast period. The uncertainty distribution of the wave forcing is based on 15 years of wave statistics from the calibration period, and the calibration uncertainty is established with a calibration method called GLUE.

Results

The stochastic simulations are based on a Monte Carlo technique in which the calibration factor and various realistic wave conditions are drawn from different types of probability density distributions. A 5-year forecast is made with the established probability density distributions (Figure 1, left). These stochastic computations are used to calculate the spread in volume losses in the nourished area; results are compared to synthetically observed development for the 5-year forecast period (Figure 1, right). The results show that neither the mean nor the 50% exceedance value of the stochastic computation aligns with the deterministic computation. Our simple methodology is able to translate uncertainty from different sources into a representative bandwidth; the interpretation of the deterministic prediction being a mean value or having 50% of exceedance can often be wrong.

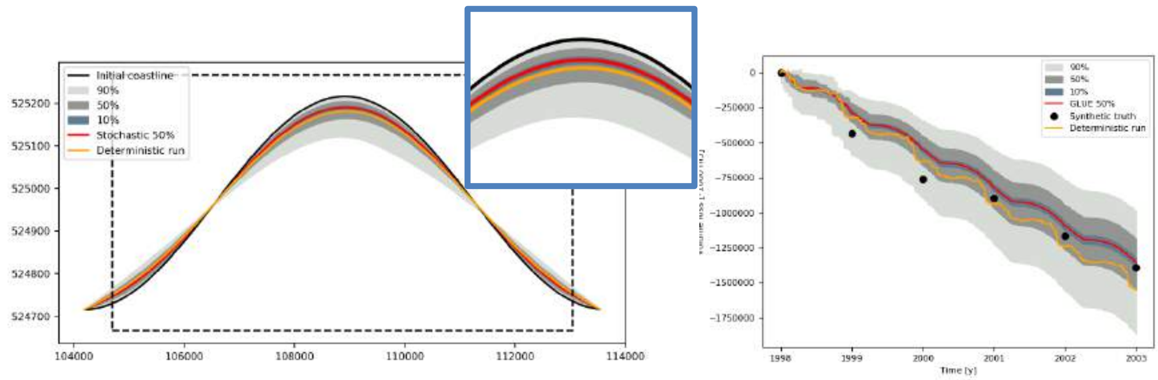

Figure 1. Left panel: Five year coastline development of an idealized large scale nourishment with a 50% bandwidth. The control area for volume losses is indicated by the dashed rectangle. Red line is the 50% value. Grey lines indicate the 90%, 50% and 10% envelope. Right panel: Volume losses in the control area. Red line is the 50% value. Grey shades indicate the 90%, 50% and 10% envelope.

Kamphuis, J.W. (1991). Alongshore sediment transport rate. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 117, 624-640.

EFFICIENT MODELLING OF COASTAL EVOLUTION: DEVELOPMENT, VERIFICATION AND VALIDATION OF SHORELINES

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Many coasts around the world experience erosion as a result of a lack in sediment supply, local interventions or sea-level rise. Mitigation of this erosion requires thorough insight into the processes that drive these changes as well as means to evaluate potentially viable interventions (e.g. sand nourishments or coastal structures). The evaluation over the full lifetime (i.e. decades) of these interventions, however, has a high computational cost with a need for 2D/3D models. The current one-line models have some limitations in simulating all coastal features. A new model with reasonable computational cost and an ability to simulate any sandy beach worldwide on the long term, was made by extending the ShorelineS model (Roelvink 2017).

The ShorelineS model represents the coast with a flexibly generated one-dimensional grid that can move freely in both directions (2D). Multiple separate coastal sections can be included, which are automatically merged or split depending on physical conditions. Even complex high-angle wave conditions (i.e. generating spits or undulations) are represented. It has performed well for a range of preliminary validation cases.

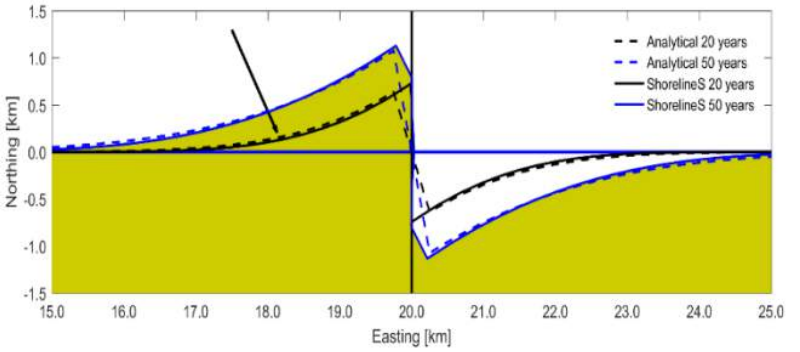

Figure 1. Comparing between ShorelineS results and analytical solution of the single groin case (wave diffraction excluded).

The current work focused on increasing the model robustness, efficiency, and accuracy. First an adaptive time step was introduced to ensure the stability of the explicit numerical scheme as well as different types of boundary conditions (e.g. Neumann and Dirichlet). Second, we included the local wave-diffraction effect behind structures or headlands as well as the subsequent effect on the beach morphology. The wave diffraction was represented using the simplification introduced by Dabees (2000) and Hurst *et al.* (2015). Local climate conditions were then used to compute transport gradients at the shoreline.

Evaluation of the model performance after these developments showed good agreement with analytical solutions. It also showed acceptable behaviour under a specific situation such as high-angle wave incidence.(Figures 1 and 2). The work is now ongoing to evaluate the performance for real-world case studies.

Figure 2. Island is merging with the coastline.

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Hurst, M.D., Barkwith, A., Ellis, M.A., Thomas, C.W., Murray, A.B. (2015). Exploring the sensitivities of crenulate bay shorelines to wave climates using a new vector-based one-line model. *Journal of Geophysical Research: Earth Surface*, 120(12), 2586-2608.
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THE INFLUENCE OF THE SAND ENGINE ON THE DELFLAND COASTAL CELL

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The Sand Engine is an example of a feeder nourishment that is intended to nourish coastal systems. This strategy is based on placing sediments highly concentrated at one location, from which they are expected to spread alongshore over large distances on decadal timescales. Here the morphological development of the Sand Engine mega-feeder nourishment and the adjacent coastal sections is presented. This study is based on 37 high-resolution topographical surveys, spanning a coastal cell of 17 km alongshore. These data are explored to examine the alongshore sand dispersion in the first five years after construction in 2011, as well as the response at different depth contours in the coastal profile.

The analysis shows that the highly concentrated nourishment supplies sediment to a stretch of coast that is several times the initial length of the nourishment, as the size of the Sand Engine peninsula increased from 2.2 to 5.8 km alongshore (Figure 1). The plan-form shape of the peninsula is found to gradually extend alongshore, while reducing in cross-shore extent. This behaviour is found to vary strongly with depth contours. The strongest response was found around the mean sea level isobath in contrast to the deeper nearshore and supratidal aeolian parts of the Sand Engine. The observed variability in response over depth results in different profile-slope development in accretionary and erosional areas. In coastal sections that are eroding the sub-tidal slope decreases. Accretionary profiles experience a profile-slope increment over time. The cross-shore extent of the morphologic response shows limited morphodynamic activity below the -8m NAP depth contour and confirms earlier assessments of closure depth at this coast.

The current findings at the Sand Engine imply that mega-feeder nourishments can be beneficial to the sediment budget of a larger coastal cell. However, volumes that are deposited around or below the depth of closure (around 15% for the Sand Engine) may react on much longer time scales than intended. Therefore, the feeding characteristics of mega-feeder nourishments on time scales of years should be assessed using the nourished volumes above the depth of closure rather than the total volume.

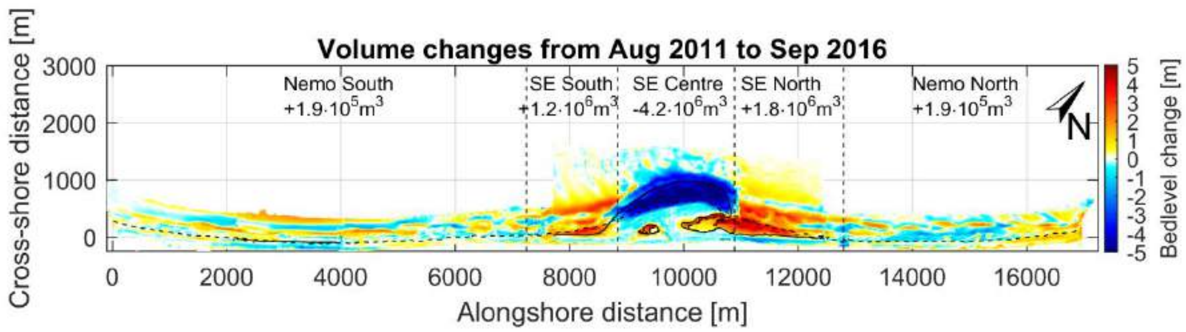

Figure 1. Volume changes in the different sub-sections of the Delfland coastal cell since 2011, Hoek van Holland to the left, Scheveningen to the right. Cold colours indicate erosion, warm colours accretion.

MEASURING TWO-SCALE FLOW RESPONSE TO RESISTANCE AT TIDAL TURBINES IN THE EASTERN SCHELDT

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Measuring flow response

Energy generation from marine currents shows the potential to cater for a significant part of the world's energy need. To optimally harvest from the geographically distributed tidal resource, turbines could be deployed in fences across tidal channels. However, large-scale deployment requires an assessment of the impact on the environment using field surveys. As one of the first of its kind, this study investigates the flow past full-scale free-stream turbines with a total installed capacity of 1.2 MW deployed in a gate of the Dutch Eastern Scheldt (ES) storm-surge barrier (Figure 1). The high occupation ratio of the turbines in the gate leads to great turbine performance, two-scale flow response and fast wake-flow recovery.

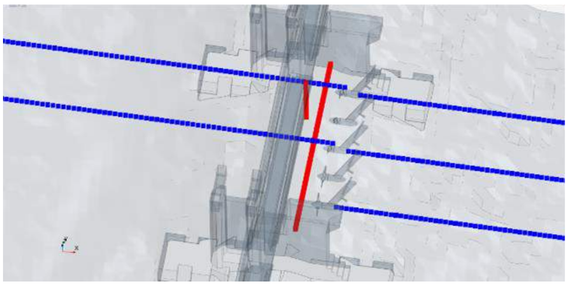

Figure 1. The gate in the ES barrier where five Tocardo International BV turbines are deployed. The red and blue lines are the measurement locations of 16-Hz five-beam Acoustic Doppler Current Profiler (ADCP) transducers that measure the flow velocity. Courtesy of Deltares.

Flow scales communicate

When tidal currents flow past a fence of turbines, resistance is encountered not only at the turbine scale, but also at the fence scale (Nishino and Willden 2013). Field observations obtained at the tidal fence in the ES storm-surge barrier (the Netherlands) show this two-scale flow response to turbine operation. The flow passing through both the turbines and the gate decelerates, while the flow bypassing the gate and turbines slightly gains velocity (Figure 2). Also, owing to the strong ambient turbulence in the gate, the greater part of the wake downstream the turbine appears to recover within a few rotor diameters.

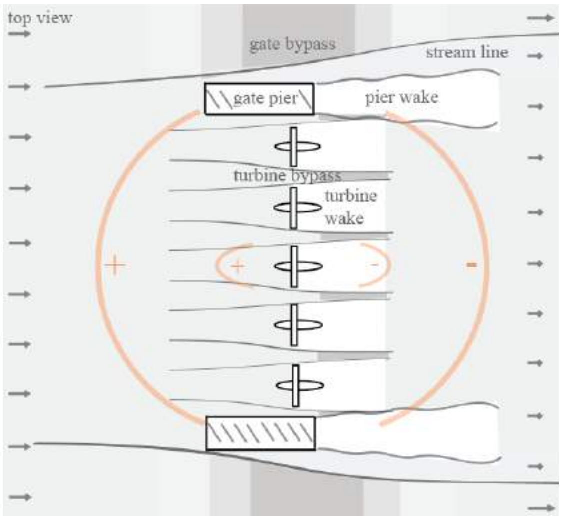

Figure 2. Artist impression of the interaction between turbine-scale and gate-scale hydrodynamics by wake-wake interaction (in white) and an along-stream pressure build-up (in orange); the figure is a depth-mean top view based on an intepretation of the field measurements at the ES tidal fence; flow decelerates in the wakes (white), and accelerates in the bypass area (grey).

Outlook: Coupling with regional flow

In this project, field data, physical model tests and analytical methods will be combined to assess the influence of different configurations of turbine fences on the resistance experienced by passing flow as well as the evolution of the turbine wakes. The results are beneficial to ecological and morphological studies ongoing in the basin, which evaluate the turbine impact in the OP Zuid Monitoring Programme.

Nishino, T., Willden, R.H. (2013). Two-scale dynamics of flow past a partial cross-stream array of tidal turbines. *Journal of Fluid Mechanics*, 730, 220-244.

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MODELING RESIDENCE TIME OF THE EASTERN SCHELDT

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The Eastern Scheldt (Figure 1) is an estuary with extensive anthropogenic activities. The storm-surge barrier implemented at the mouth of the estuary has greatly reduced the tidal prism and areas of tidal flat. In addition, it has modified the tidal currents, sediment transport, and hence biogeochemical cycling in the basin. Owing to the limited freshwater input, the system is more a semi-enclosed tidal bay than an estuary. However, as an important nearshore habitat, many hydrodynamic characteristics including the general circulation, the residence time, and the wind-driven sediment transport have been far from well understood. We developed a hydrodynamic model for the Eastern Scheldt and its adjacent coastal ocean using the General Estuarine Transport Model (GETM). The model was run for the period 2009-2010 and validated with observed water elevation, temperature, salinity, and current velocity. Seasonal mean flow of the Eastern Scheldt was computed from the model average. Residence time of the Eastern Scheldt was calculated with a modified method using passive tracers. Preliminary modeling results will be shown in the presentation.

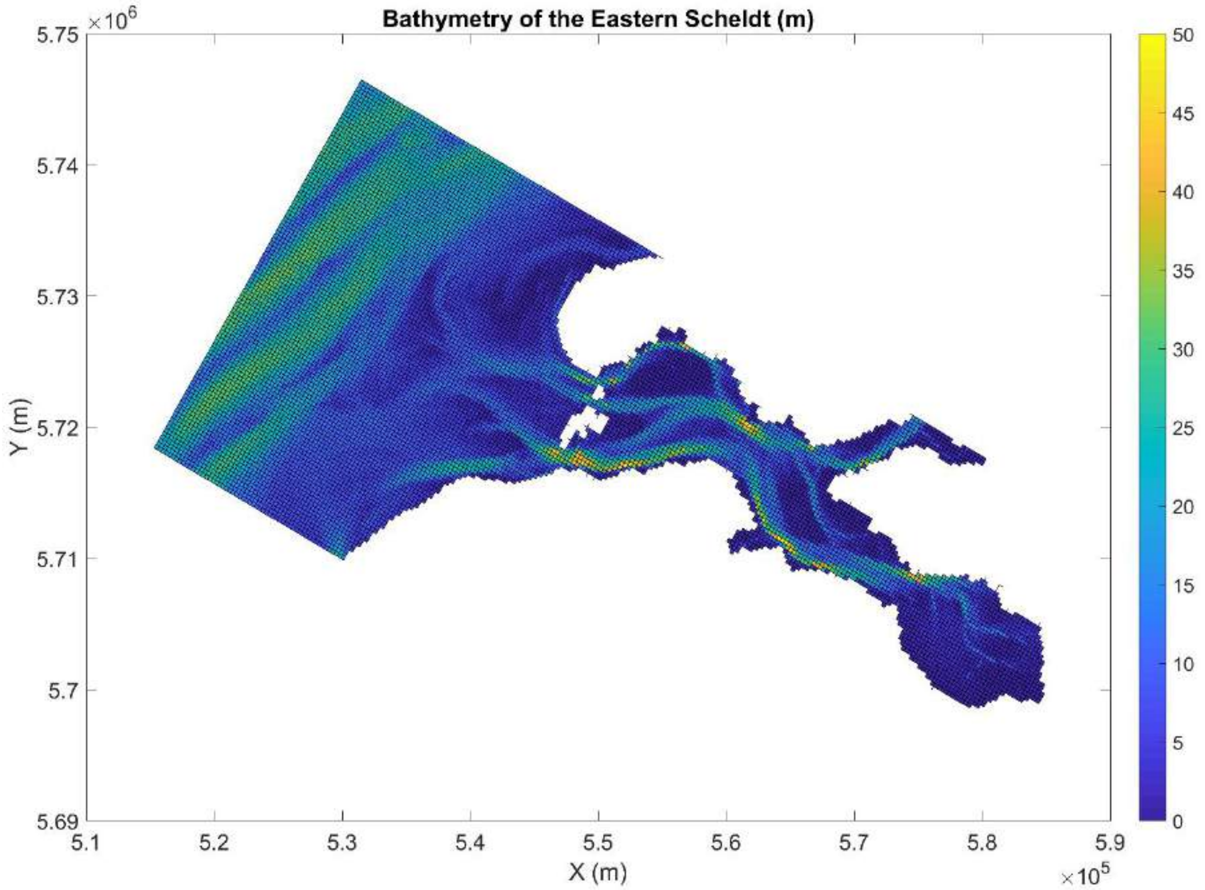

Figure 1. Model grid and bathymetry of the Eastern Scheldt.

POSITIVE FEEDBACK THROUGH THREE-DIMENSIONALITY OF THE FLOW: ENHANCEMENT OF SCOUR POTENTIAL AT THE EASTERN SCHELDT STORM-SURGE BARRIER

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The Eastern Scheldt, a tidal basin in the southwestern part of the Netherlands, was partly closed by a semi-open barrier in response to catastrophic flooding in 1953. Continuous monitoring of the seabed by Rijkswaterstaat has shown that on both sides of the barrier, downstream of the applied bed protection, large scour holes have developed. Bathymetry data show that local water depths of up to 60 meters occur, associated with roughly 40 meters of scour. The scouring process is not fully understood, making future development of scour (and mitigation strategies) hard to predict. In this study, we show the existence of a feedback mechanism that potentially enhances the formation of scour holes at the Eastern Scheldt storm-surge barrier.

Although much fundamental research has gone into scour processes at the edge of bed-protection elements, most of the studies are done in a 2D-vertical framework, while in reality lateral velocity differences are commonly present in the flow. For 2D-vertical laterally uniform flows, equilibrium scour depth is reached because streamwise velocity decreases proportionally to increasing flow depth as the scour progresses, until the flow loses capacity to entrain sediment (often in combination with detachment of the boundary layer from the bed). However, when lateral velocity differences are present, the road to equilibrium may be quite different.

Laboratory experiments performed at Delft University of Technology investigated the development of flow with lateral velocity gradients over a sloping bed. It was shown that if the lateral gradient of the flow velocity upstream of the scour hole is sufficiently large, the flow can stay attached to the bed for relatively steep slopes of up to 1 in 2 (Figure 1a). For such flows (boundary layer stays attached to the bed) the lateral velocity differences are sustained, leading to a flow structure with concentrated high velocities. This structure is explained using conservation of potential vorticity; vorticity (which, by approximation, equals the lateral gradient of the streamwise velocity) increases proportionally to the relative depth increase, leading to squeezing of the flow. A positive feedback mechanism is thus revealed: lateral gradients lead to relatively high near-bed velocities in the scour hole, potentially enhancing erosion (causing an even stronger horizontal contraction). Conversely, for smaller lateral gradients of the streamwise velocity upstream of the scour hole, the boundary layer was shown to detach from the bed, leading to a horizontal divergence of streamlines (Figure 1b). This situation resembles the 2D-vertical case, for which the scour depth will then tend to reach equilibrium in response to a reduction in near-bed flow velocity.

Field observations of the flow at the scour holes fronting the Eastern Scheldt show similar patterns, suggesting that this mechanism indeed plays a role at this location.

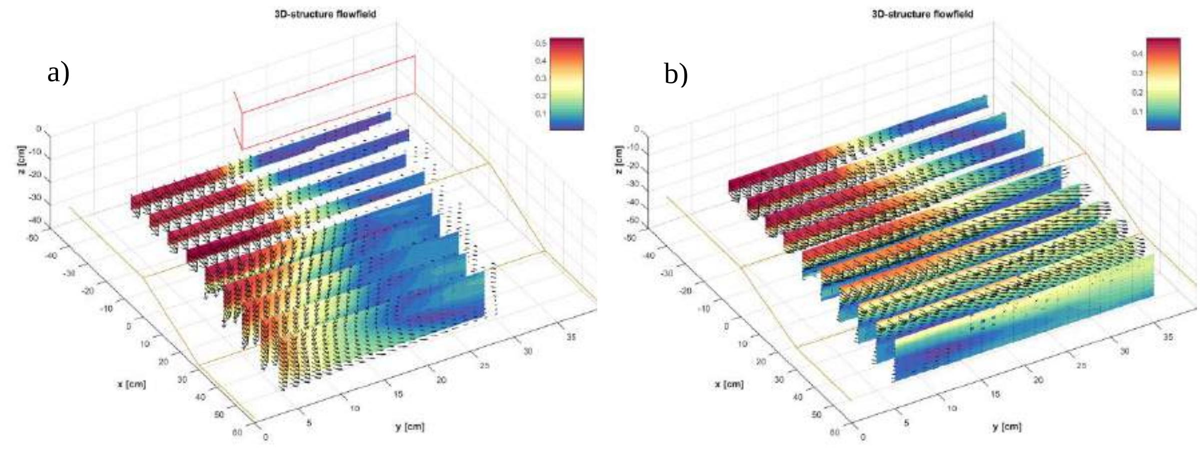

Figure 1. Experimentally observed flow field (structure) for a mixing layer type of flow in which the boundary layer either stays attached to the bed (a, left) or detaches from the bed (b, right).

MORPHODYNAMIC FEEDBACK LOOPS CONTROL STABLE FRINGING FLATS

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Introduction

The difficulty in 'managing' long-term morphodynamics lies in the interdependencies of the underlying processes; the morphology is shaped by hydrodynamic forces, while it influences these forces at the same time. The resulting internal feedback loops make the long-term morphodynamics difficult to model and to predict. Following a top-down approach, in which we learn from the observed steady states, is a useful strategy to get towards an understanding of complex dynamical systems. It starts with realizing that an equilibrium state is not self-evident. Hence, the observation of conserved properties should naturally lead to the important question: 'why are they conserved?' The answer to this question can reveal the system dynamics.

Methods

We apply a 2D Delft3D model to study the feedback mechanisms that control the long-term dynamics of a fringing intertidal flat in the Western Scheldt estuary. The hydrodynamic model is validated by a comparison with measurements on the intertidal flat and the sediment transport module is calibrated against long-term morphology data. Long-term simulations are performed, and the dependency of the sediment fluxes on the tidal flat bathymetry as well as the corresponding morphodynamic feedback mechanisms are explained.

Results and conclusions

In the long run, a relatively stable state can be approached. Two wave-related processes are found to play an important stabilizing role:

1. With rising and falling tide, maximum wave-induced bed shear stresses occur in shallow waters. These result in a strong stabilizing morphodynamic feedback loop in the subtidal domain, where the minimum water depth strongly increases (decreases) with a decreasing (increasing) bed level.
2. After stabilization of the subtidal region, an additional stabilizing feedback loop gets important on the intertidal flat. Landward of the stable section, an increase (decrease) in the local bed level leads to an increase (decrease) in the cross-sectional slope (in the offshore direction) and thus to an increase (decrease) in the relative importance of wave shoaling versus wave dissipation (see Figure 1). In other words: the equilibrium state extends landwards.

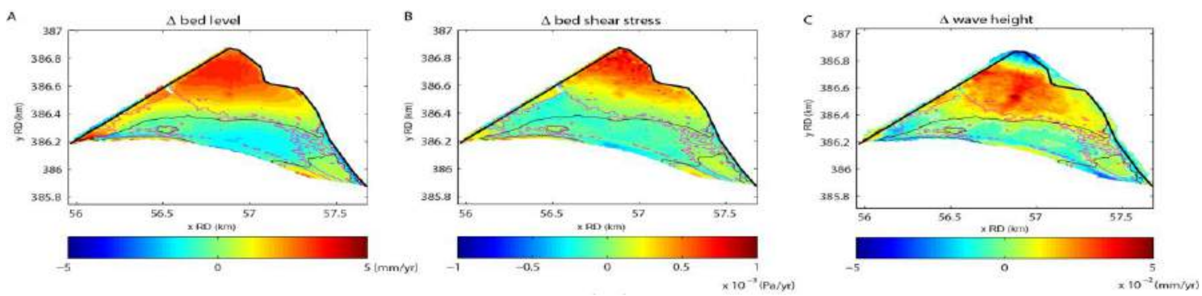

Figure 1. (A) Bed-level changes during the modelled evolution, normalized to mm/yr. (B) Corresponding changes in the tidally averaged bed shear stress (in Pa/yr). The positive correlation between the bed level and the erosion rates suggest a stabilizing feedback loop. (C) Corresponding changes in averaged wave height in shallow waters, implying the importance of wave shoaling.

RAPID MORPHOLOGY ASSESSMENT FOR ESTUARIES

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Introduction and research question

A basic estimate of estuarine morphology is relevant for the management of channels, bars or shoals, because they provide valuable habitat, shipping fairways and flood-safety areas. However, this information is only available for a few estuaries (e.g. Western Scheldt). Here we present and test a rapid morphological assessment tool that requires minimal information, the Estuarine space And Morphology Estimator (EAME).

Methodology

The tool predicts bed-level distributions, inundation duration and typical flow conditions along the estuary on the basis of the estuary outline**,** tidal amplitude and calibrated predictors. To this end, we developed a comprehensive set of empirical, hypsometry-type relations that accurately predict the channel and bar patterns as well as typical flow conditions (Leuven *et al.* 2017, 2016; Savenije 2005). We calculated flow velocities using the local tidal prism and depth of the estuary. The model is validated with data of the Western Scheldt.

Results, discussion and conclusion

The depth distribution along the estuary is modelled well (R^2=0.95) as is its derivative, the tidal prism (Figure 1). Flow velocity is predicted less well; underestimated within a factor 2. The required input data can be collected and processed in the tool within minutes for any estuary. The tool and code will be made available with the publication.

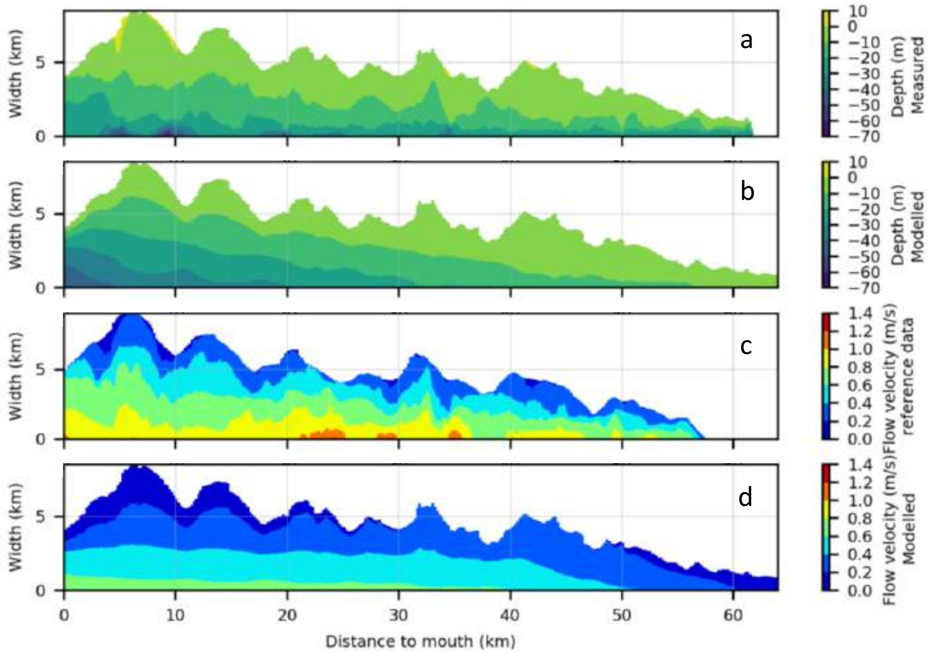

Figure 1: Depth and mean flow velocity in the Western Scheldt estuary during low tide. (a) Measured bathymetry of the Western Scheldt, (b) modelled bathymetry of the Western Scheldt (c) mean flow velocity from the available dataset, and (d) flow velocity calculated from the local tidal prism.

Leuven, J.R.F.W., de Haas, T., Braat, L., Kleinhans, M.G. (2017). Topographic forcing of tidal sandbar patterns for irregular estuary planforms. *Earth Surface Processes and Landforms*. doi:10.1002/esp.4166.

Leuven, J.R.F.W., Kleinhans, M.G., Weisscher, S.A.H., van der Vegt, M. (2016). Tidal sand bar dimensions and shapes in estuaries. *Earth-Science Reviews*, 161, 204–223. doi:10.1016/j.earscirev.2016.08.004.

Savenije, H.H.G. (2005). *Salinity and Tides in Alluvial Estuaries*. Elsevier. doi:https://doi.org/10.1016/B978-044452107-1/50002-2.

MORPHODYNAMIC IMPACT OF SEA-LEVEL RISE ON THE WESTERN SCHELDT ESTUARY AND ITS MOUTH REGION: INSIGHTS FROM AN IDEALIZED MODELING STUDY

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[3] Flanders Hydraulics Research, Antwerp
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Estuaries lie at the interface of land and sea, and are particularly vulnerable to sea-level rise (SLR). Understanding the impact of SLR on the long-term (order decades to centuries) morphodynamic evolution of estuaries is of great importance to successfully manage these areas, such as maintaining shipping routes and preserving ecosystems.

An analysis of historical water-level data for Vlissingen (Figure 1) between 1900 and present revealed that mean sea level has been rising at about 2 mm/yr. Moreover, these data show that the amplitude of the dominant tidal constituent (M_2) has been rising as well during this period (Figure 2), most likely in response to the rising mean sea level (Pickering *et al.* 2012, Idier *et al.* 2017).

The specific aims of this study are 1) to investigate the impact of SLR (2 mm/yr) on long-term evolution of the Western Scheldt and its mouth region, 2) to systematically explore sensitivity of model results to different rates of SLR (0-10 mm/yr), and 3) to address the combined effect of SLR and changes in tidal characteristics on the evolution of the estuary. To this end, the coupled SWAN-Delft3D numerical model is used, which accounts for both flow and waves. A curvilinear grid is created, which extends from Ghent to 30 km seaward. Concerning wave climate, a highly simplified wave forcing (constant wave height, wave periods and wave direction) is considered. The methodology employed is to first spin up the model until a bathymetry is obtained that is comparable to observations. Subsequently, the latter bathymetry is used to address the objectives.

An important model result is that stronger tidal currents are crucial to prevent sedimentation in channels caused by SLR. This result and other findings will be discussed during the presentation.

Figure 1. Study area.

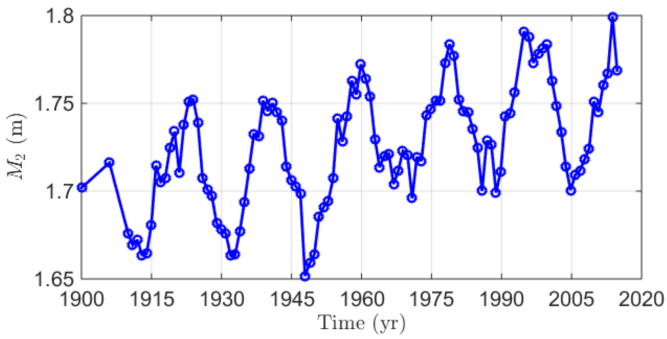

Figure 2. Evolution of amplitude M_2 between 1900 and present.

Pickering, M.D., Wells, N.C., Horsburgh, K.J., Green, J.A.M. (2012). The impact of future sea-level rise on the European Shelf tides. *Continental Shelf Research*, 35, 1-15.

Idier, D., Paris, F., Le Cozannet, G., Boulahya, F., and Dumas, F. (2017). Sea-level rise impacts on the tides of the European Shelf, *Continental Shelf Research*, 137, 56–71.

UNRAVELLING THE MECHANISMS BEHIND THE MORPHODYNAMIC EVOLUTION OF THE HARINGVLIET EBB-TIDAL DELTA

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The morphology of ebb-tidal deltas (ETDs) evolves constantly under the influence of natural processes as well as anthropogenic activities. The Haringvliet ETD in the southwestern Netherlands is an extreme example of the latter: closing off the estuary in 1970 triggered a regime shift, completely altering the evolution of the ETD. Initially, the shore-normal sandy shoals evolved towards a narrow coast-parallel intertidal spit (the Hinderplaat). Subsequently, this tidal flat breached around 1995. Since then continuous erosion has been taking place, with ongoing sediment transport from the flat towards the coast.

Previous research aiming to understand the morphological development of the Haringvliet ETD has provided insights into the processes causing the large morphological changes directly after construction of the Haringvliet Barrier. The processes driving the observed ongoing erosion and flattening of the Hinderplaat are, however, still poorly studied and understood. In this research, we therefore investigate the underlying mechanisms and link these with former anthropogenic interferences and meteorological events.

A combination of data analysis and numerical simulations is applied. In our analysis of the *Vaklodingen* dataset, we separated the development of the subtidal shoreface and the intertidal area of the Hinderplaat. A clear correlation is found, showing that erosion of the intertidal part of the Hinderplaat started when the shoreface stopped eroding. A 2DH Delft3D model is used to reveal the relative importance of the tidal-, wind-, surge- and wave-forcing driving the flow and sediment transport in the outer delta. Various simulations with a range of different forcings are performed. Tide-only simulations show hardly any transport on the Hinderplaat. Modelling results reveal that waves are essential to mobilize the sediment, yet the effects of waves are significantly enhanced by the wind-driven flow (Figure 1).

Obtained knowledge on the importance of the hydrodynamic processes is crucial to understand the complex system of the Haringvliet ETD. Such insight is necessary not only to explain the past evolution, but also to enable well thought-out decision making on future maintenance strategies. Moreover, the outcomes of this study on the development of the Hinderplaat are also a valuable benchmark for model concepts that are to be applied on other ETDs in the Netherlands and abroad.

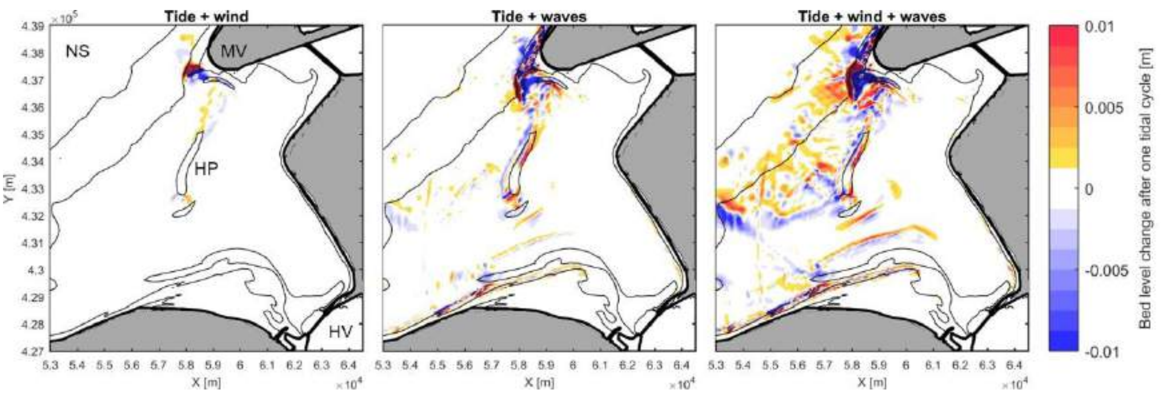

Figure 1.: Initial bed-level changes after one tidal cycle for 3 simulations, showing sedimentation (red) and erosion (blue) patterns. The left panel also indicates the locations of the North Sea (NS), Maasvlakte (MV), Hinderplaat (HP) and Haringvliet (HV).

EFFECTS OF DREDGING AND DUMPING IN LABORATORY SCALE EXPERIMENTS OF ESTUARIES

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Description of research and research question

Shipping fairways are continuously dredged to maintain and increase access of large ships to major ports located in estuaries, for example the port of Antwerp in the Western Scheldt. However, it has been shown in various estuaries worldwide that there are several adverse side effects of these actions including loss of ecologically valuable intertidal area, increased muddiness and turbidity. The Western Scheldt estuary is one such estuary having undergone both channel-enlargement events (capital dredging) and maintenance dredging, which takes place on a continuous basis to maintain a minimum depth required for shipping. Here we study the effect of dredging and dumping in a scale experiment by creating a Scheldt-type estuary to answer the question: what is the effect of dredging and dumping on the morphology of the side channels, shoals and main channel? The results are compared with data from and observations in the Western Scheldt.

Description of the experiment and methodology

A scale experiment was designed using a periodically tilting tidal flume: the Metronome. The periodic tilt mimics reversing tidal flow in tidal periods of 40 seconds on an initially converging channel in a straight sand-bed. For this experiment a shipping fairway was dug with dimensions scaled on measures taken in the Western Scheldt. The dimensions of this channel were maintained during the experiment, with removed material being dumped back into the estuary. Dumping locations were also based on current practices in the Western Scheldt. Results from the experiment are compared with a control experiment without dredging or dumping.

Results, discussion and conclusion

The implications of dredging and dumping were seen on both an estuary-wide scale and for individual morphological features. The overall estuary width decreased due to dredging and dumping. Moreover, the estuary displayed increased stability: for several thousand tidal cycles after the dredging was stopped, the pattern of channels and shoals remained the same and channels were non-migrating (Figure 1). On a smaller scale, dredging and dumping resulted in a main channel that filled in more quickly than in the non-dredged experiment. The main channel and associated side channels all saw increased tidal range in response to dredging and dumping. Shoals became higher and narrower with steeper shoal margins in the dredged experiment, which led to an increase in supratidal area and a corresponding decrease in intertidal area. These findings match with observations in the Western Scheldt, implying that experiments like these can be useful in testing future dredging and dumping strategies.

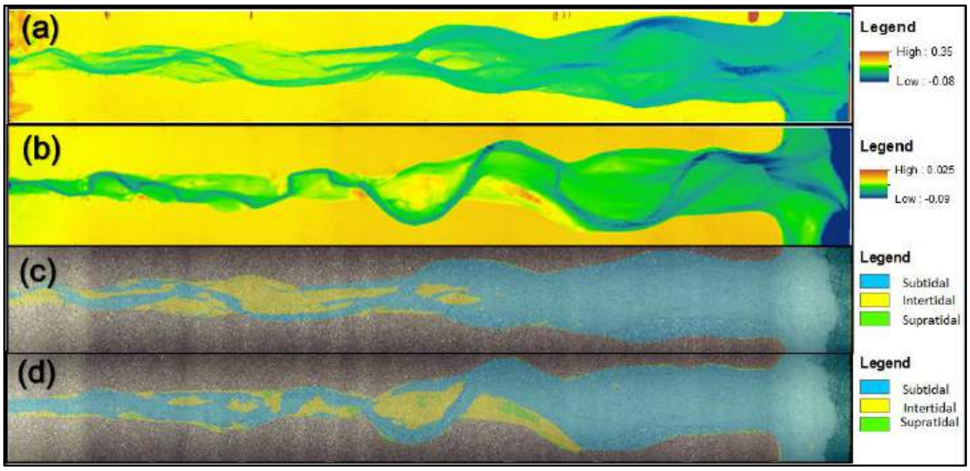

Figure 1. The state of the estuary at tidal cycle 4900 (out of a total of 13,000 cycles). (a) DEM of non-dredged estuary, (b) DEM of dredged estuary (c) Map of subtidal, intertidal and supratidal areas based on water level data for the non-dredged estuary, (d) Map of subtidal, intertidal and supratidal areas based on water level data for the dredged estuary.

Abstracts of poster presentations

in alphabetical order by last name

CHARACTERISTICS OF SAW-TOOTH BARS ON THE EBB-TIDAL DELTAS OF THE WADDEN SEA

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Introduction

In the southwestern part of the Wadden Sea, shore-oblique sand bars known as saw-tooth bars are found on most ebb-tidal deltas and along the shores of the barrier islands (Figure 1). Previous studies have been focusing on single occurrences of these bars, so their general characteristics are not well known. Previously, they were interpreted as transverse bars (Antia 1994), but their spatial scale seems to be much larger. Also, large-scale bedforms like saw-tooth bars are important in sediment transport, both directly by migration (Aberle *et al.* 2012) and indirectly by altering the flow structure (Kwoll *et al.* 2014). It is essential to know the characteristics and behaviour of the saw-tooth bars in order to improve our understanding of the associated sediment transport pathways. The main aim of this study is to describe their wave and crest length, orientation, migration rate and depth of occurrence.

Methods

Bathymetries from the West and East Frisian Wadden Islands (the Netherlands and Germany) were analysed for the period between 1970 and 2015. The shore-normal crest length and bar height were determined from the variance around the mean depth (Figure 1). A Fast Fourier transform of the bar area gives wave length and bar orientation. Migration speed was calculated using spatial correlation.

Results

Bar heights were found to range between 0.5 and 2m, wave lengths are approximately 700m and the angle between the bar crests and the shoreline is about 50°. The crests are between 800 and 2200m long. Saw-tooth bars occur in water depths from 3 to 12m, depending on the slope of the area. Migration speeds of 100-200m/y were found for Ameland Inlet. At Ameland Inlet the peaks in bar height and migration speed occur simultaneously. With these derived characteristics, saw-tooth bars can be defined as a new member of the nearshore-bar family.

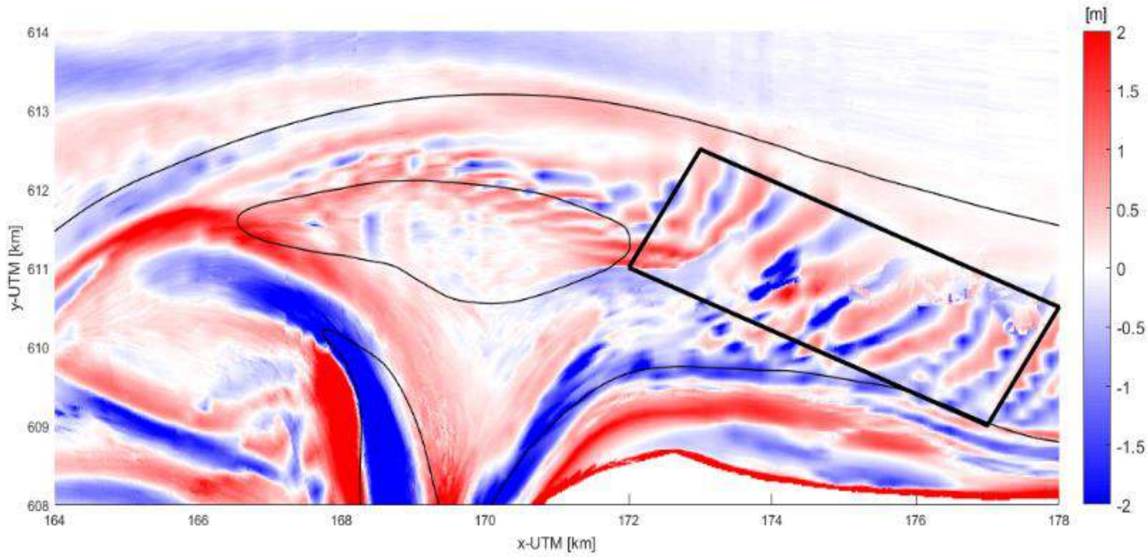

Figure 1. Variance around the mean depth of the ebb-tidal delta of the Ameland Inlet, 2005. The thin black lines indicate the 4 and 10-m depth contours, the black rectangle delineates the saw-tooth bars.

Aberle, J., Coleman, S.E., Nikora, V.I. (2012). Bed load transport by bed form migration. *Acta Geophysica*, 60 (6), 1720-1743.

Antia, E.E. (1994). Long-term and post-storm dynamic patterns of the subtidal rhythmic morphology along the East Frisian island coast, Germany. Geologie en Mijnbouw, 73, 1-12.

Kwoll, E., Becker, M., and Winter, C. (2014). With or against the tide: The influence of bed form asymmetry on the formation of macroturbulence and suspended sediment patterns. *Water Resources Research*, 50, 7800–7815.

PERTURBATION EFFECT OF SHOAL-MARGIN COLLAPSES ON THE CHANNEL-SHOAL MORPHODYNAMICS IN THE WESTERN SCHELDT

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Aim

Shoal-margin collapses of 0.05- 1 Mm^3 have occurred in the Western Scheldt more than five times per year for the past 50 years. In the past such collapses caused dike- and bank-protection failures. The present effects of these collapses on the morphodynamics are unknown. One potential effect, increased dynamics of channel-shoal interactions, could impact habitats and navigability. The processes of shoal-margin collapses are not included in numerical morphodynamic models while other events as well as human interference, such as dredging and dumping, cloud the observed morphodynamic effects in the field. The objective of this study is to investigate how locations, probability, type and volume of channel/shoal-margin collapse affect the morphodynamics at the channel-shoal scale.

Method

We implemented an empirically validated parameterization for shoal-margin collapses and tested their effects on morphodynamics in a Delft3D schematization of the Western Scheldt estuary (Netherlands). Near-field and far-field effects on flow pattern and channel-shoal morphodynamics were analyzed for a control run without collapses against three sets of scenarios with collapse events over 40 years of morphological development: 1) run including the observed shoal-margin collapse of 2014, 2) run with initial collapses on various locations deemed to be susceptible to collapses, and 3) our novel probabilistic model producing collapses over a time span of decades.

Results

Results (Figure 1) show that single shoal-margin collapses only affect the local morphodynamics in longitudinal flow direction and dampen out within a year for typical volumes of 0.1 Mm^3. When larger disturbances reach the seaward or landward sill at tidal channel junctions over a longer time span, the bed elevation at the sill increases while the wetted cross-section of the channel junctions decreases. The extent of far-field effects is sensitive to the grain size of the deposit, with finer sediments being transported farther away. The location of the deposit, resulting from the collapse, across the channel matters for subsequent redistribution of the sediments along the channel. The rate of redistribution is highest for the strongest tidally averaged flow. New model results also imply that disturbances caused by dredging and dumping may likewise affect the dynamics of channel junctions, a phenomenon that we are currently testing.

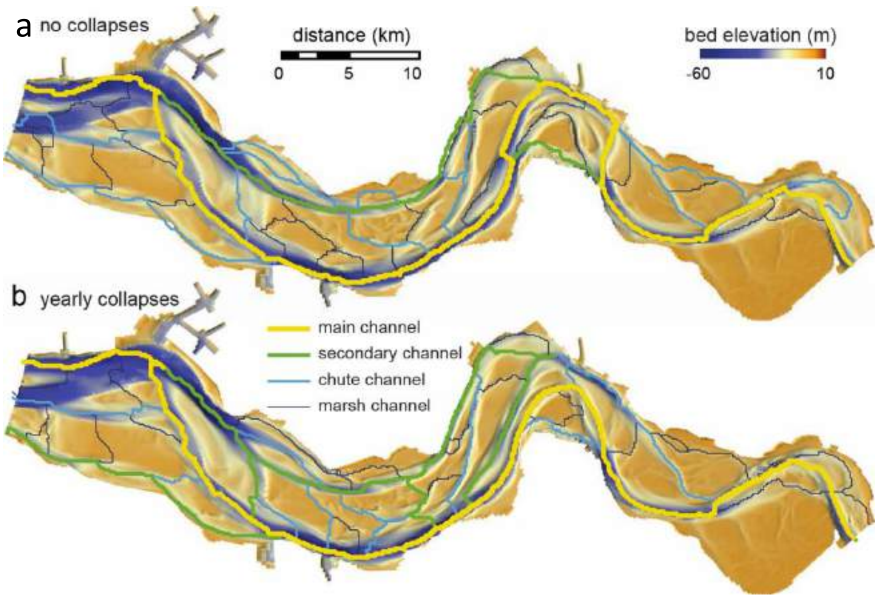

Figure 1. Various network scales for a) the control run without collapses and b) yearly collapses show that channels shift between scales and change their location after 40 years of morphological development.

A NEW GENERATION OF MARINE GEOLOGICAL MAPS FOR THE DUTCH NORTH SEA

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The last new marine geological maps for the Dutch North Sea date from the previous millennium. Even though much work has been done, primarily to quantify sand resources between the 20-m depth contour and the 12-mile zone, dedicated 2D mapping was terminated in the transition to 3D geomodelling as developed and optimized for our terrestrial territory. To celebrate its 100-year mapping anniversary, the Geological Survey of the Netherlands is currently producing a new 1:600,000 surficial geological map characterizing the upper 10 m of land as well as seabed, including our Caribbean territories.

As with any map, a coarse 2D rendition of the subsurface means that concessions need to be made, both in terms of resolution and when it comes to legend units. The key requirement is a map that tells a geological story of ice, saline water, freshwater and air creating, modifying and redistributing sediment, and of organisms ending up in organic layers. This map will be presented in its final form at a dedicated celebratory meeting after the summer of 2018.

Aside from this main map, the Survey is also working on an update of the geomorphological map of the North Sea, refining Van Alphen and Damoiseaux' 1989 map and extending it to cover the entire Dutch part of the North Sea. As part of our responsibilities in EMODnet, the European Marine Observation and Data network, we will use geostatistics to create a digital, updatable map of seabed sediment, using descriptive as well as quantitative grain-size data and joining forces with NIOZ. Finally, existing geochemical data and rough charts will be turned into high-quality data products.

Once this new series of maps is available, coastal scientists and other users can bridge the gap with the next generation of marine geological data products: layer and voxel models like the ones available for our land surface in DINO*loket* (www.dinoloket.nl) (Figure 1). Making these models relies less on boreholes and more on seismic data than on land. The first voxel models, not yet including seismic data, are available for the sand-extraction zone along the Dutch coast. These too are getting an update. Later this year, a full-coverage model will be available for the southernmost part of the Dutch North Sea, as part of transnational project TILES: Transnational and Integrated Long-term Marine Exploitation Strategies. Such models are much easier to incorporate into hydrodynamic models than traditional 2D products.

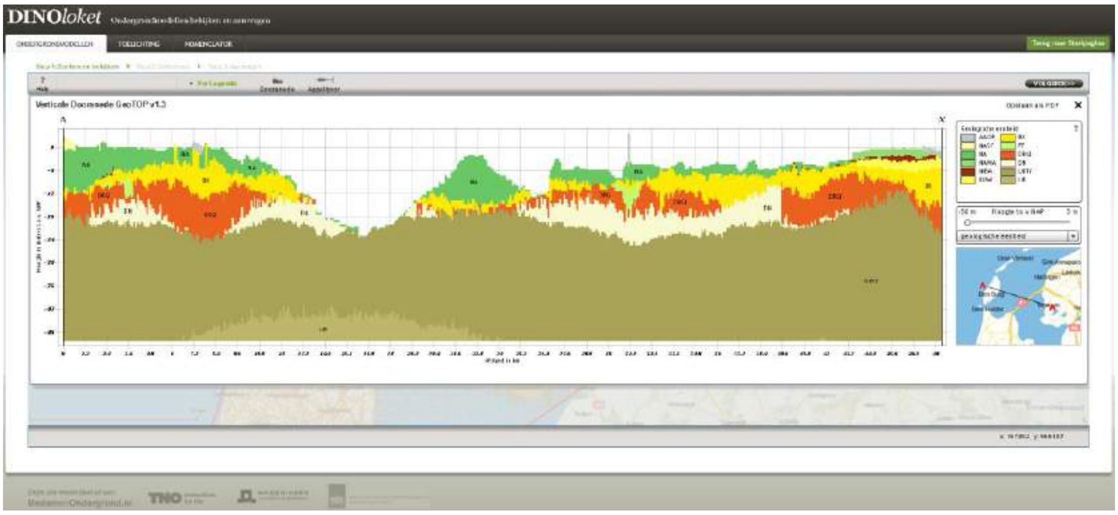

Figure 1. GeoTOP voxel-based cross section through the western Wadden Sea, showing a stacking of 100x100x0.5 m blocks forming a high-quality subsurface sequence. It includes uncertainty.

Van Alphen, J.S.L.J., Damoiseaux, M.A. (1989). A geomorphological map of the Dutch shoreface and adjacent part of the continental shelf. *Geologie en Mijnbouw*, 68, 433-443.

STUDY AND MEASURES TO REDUCE MARINA INLET SEDIMENTATION IN BLANKENBERGE AND BEACH EROSION IN WENDUINE, BELGIUM

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During last year's NCK edition we outlined a project and discussed textbook solutions and innovative alternatives to tackle the marina inlet sedimentation in Blankenberge and the coastal erosion at Wenduine. Now, one year of extensive modelling research later, we can present the results of our study and the selection of promising measures.

Problem statement

Blankenberge and Wenduine are two neighbouring Belgian coastal towns that are each experiencing specific morphological issues. The access channel to the Blankenberge marina is constrained by two low jetties and experiences sedimentation due to littoral drift. Authorities aim to restrict dredging activities in the access channel to winter months only, and avoid dredging works during the summer tourist season. However, channel sedimentation rates are currently too high and summer dredging is sometimes needed after storm events. Less than three kilometres to the west, Wenduine is located at a breakpoint in coastline orientation and experiences structural erosion. Beach nourishments are regularly performed to mitigate the erosion but typically have a short lifespan.

Description of research

The poster will present a synthesis of the results of the numerical modelling (using XBeach and Mike21-BW) of morphology, waves and currents for a range of design alternatives (Figure 1). Emphasis will be on the results and on a comparison of the various measures. As the proposed measures impact densely populated and intensively used recreational areas, the results have been evaluated from the point of view of coastal evolution as well as swimmer safety. For the Blankenberge marina the various measures affect wave penetration into the harbour basin and aim to reduce entrance-channel sedimentation.

Given the proximity of both problem areas and the complementary nature of the observed phenomena, it was investigated if measures could be identified that would solve both problems simultaneously. It was argued that, given the west-to-east oriented littoral sediment transport, reducing erosion in the West may reduce sedimentation issues in the East, or blocking the littoral drift in the East by reorientation of the coastline may (in time) reduce erosion in the West. However, XBeach simulations showed that interactions between the two zones were limited. Optimal measures will therefore be presented for each location separately.

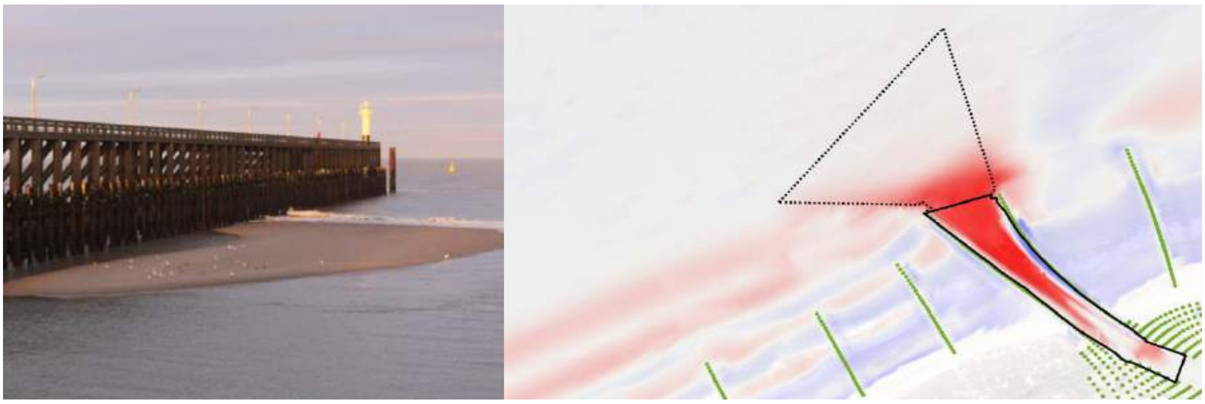

Figure 1. Illustration of the Blankenberge marina inlet sedimentation and XBeach model result of present situation.

THE EBB-TIDAL DELTA: BARE OR RARE?

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The ebb-tidal delta is still an underexplored area in terms of both morphodynamics and benthic species diversity. Ebb-tidal deltas are located at the outflow of tidal inlets and consist of shoals, swash bars and channels with various depths. The position and shape of the morphological features change over time. They are governed by tidal currents and by wind-generated waves, causing frequent erosion and settlement of sediment particles. Ebb-tidal deltas are commonly assumed to be too harsh an environment for benthic species. However, as they are protected in the Netherlands under Natura 2000, knowledge of the state of the benthos and its function in the ecosystem is important for protection and conservation. Furthermore, it gives insight into the abiotic-biotic relations and the environmental conditions these species can endure.

As part of the Kustgenese 2.0 and SEAWAD projects, benthic species were sampled at 166 locations at the ebb-tidal delta of Ameland. Prior to the sampling the ebb tidal delta was divided into eight distinctive habitats on the basis of characteristics of the present bathymetry (bed-level slope, slope direction, and bed-level change). Within each habitat an equal number of randomly placed samples were taken. Cluster analysis of the density per species per location revealed a diverse pattern of 12 significant species assemblages (Figure 1). The number of species per assemblage ranges from 5 to 20. Higher species diversity was found in the clusters at the edge of the ebb-tidal delta; lowest diversity in the cluster at the very dynamic and wave-swept shoals in the western part of the ebb-tidal delta.

The species assemblages match rather well with the pre-defined habitats, suggesting a strong relationship with the environmental parameters defining the habitat. However, there are exceptions to this pattern, indicating that other factors also play a role. Unravelling these factors is a key objective of further study.

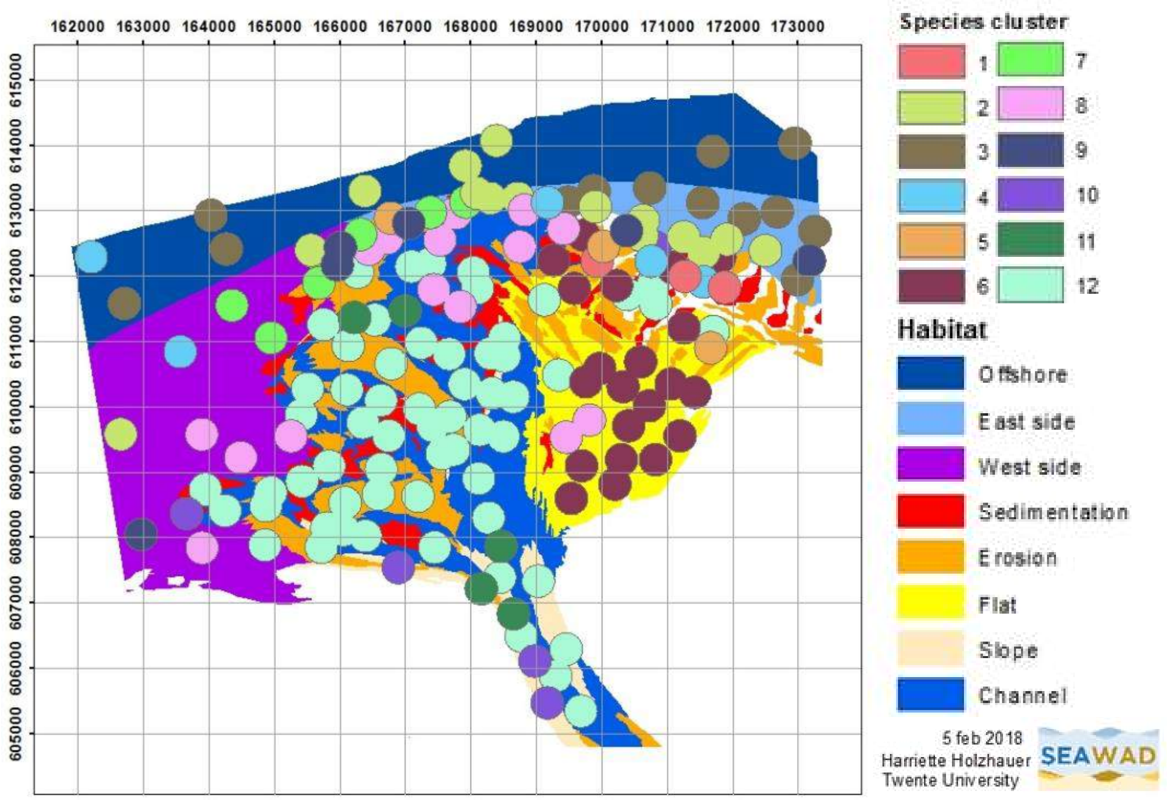

Figure 1: The diversity of the ebb-tidal delta represented in 12 significant species assemblages derived from the density per species per sampled location at the ebb-tidal delta of Ameland.

NUMERICAL MODELLING OF THE MIGRATION DIRECTION OF OFFSHORE SAND WAVES USING DELFT3D

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[1] Delft University of Technology, [2] Deltares, [3] University of Twente
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Rhythmic large-scale bedforms are present in shallow seas with sandy beds (Figure 1). Depending on the length, height, propagation speed and formation timescale a spatial and temporal distinction can be made between these large-scale rhythmic forms (Table 1).

Bed form	Length [m]	Height [m]	Migration speed	Timescale
(Mega) Ripples	(1-10)	(0.01-0.1)	100 m/year	Days
Sand Waves	(100-1000)	(1-10)	10 m/year	Decades
Tidal sand banks	(5000-10.000)	(10-30)	(0-1) m/year	Centuries

Owing to their dynamic behavior, sand waves can interact with human offshore activities. Their large dimensions are relevant for engineering and research purposes. Presently the most commonly used engineering tool to investigate sand waves is data analysis. Data analyses are based on seabed surveys over preferably more than 10 years. Though most reliable at the moment, they are costly. Modelling the dynamics of sand-wave fields has become a relevant alternative for the offshore wind industry, which will grow intensively in the coming decades. However, not all relevant processes regarding sand-wave dynamics are understood well enough to predict sand-wave fields fully over the lifetime of an offshore windfarm. Research so far has focused on the length and height of sand waves. To add a step in determining full development of sand-wave fields, the migration direction of sand wave is essential. Understanding the governing processes of the migration direction of sand waves, the focus of this research, uses the model of Borsje *et al.* (2014) as a starting point.

An idealized (3D) model is set up to investigate the most prominent processes governing the migration of sand waves, being characteristics of tide constituents, sediment transport modes, seabed topography and waves. The model results are compared with bathymetry data analyses over several decades of windfarm areas in the North Sea. To model the presence of larger rhythmic forms under sand-wave fields, a slope is added to the idealized model, representing a sand bank (Figure 2).

Underlying topography in the form of sand banks influences the local hydrodynamics (Figure 3) and thereby sediment transport loads and sand-wave migration. Models indicate the possibility of migration towards opposite directions on a small scale, as also observed in the field.

In this ongoing research, the first results indicate that the topography is an important candidate for deviations in migration direction on small spatial scales. Results of the idealized model are tested regarding the data from the field. The physical mechanisms regarding these small-scale deviations will be further explained.

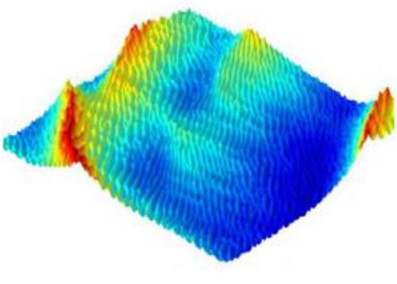

Figure 1. Topography of offshore windfarm Borssele, North Sea.

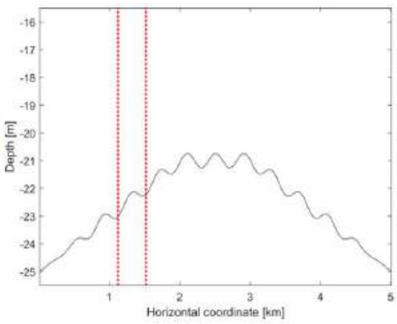

Figure 2. Initial bathymetry sand waves over sand bank; idealized model.

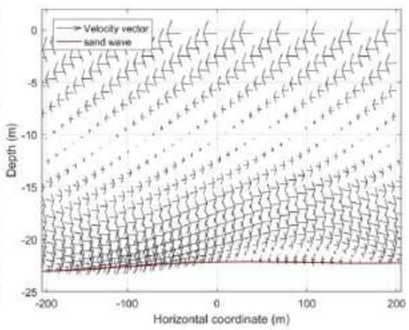

Figure 3. Tide-averaged velocities over sand wave (red lines in Figure 2 indicate sand-wave location).

Borsje, B.W., Kranenburg, W.M., Roos, P.C., Matthieu, J., Hulscher, S. J.M.H. (2014). The role of suspended load transport in the occurrence of tidal sand waves. *Journal of Geophysical Research: Earth Surface*, 119(4), 701-716.

Shoreward Propagating Accretionary Waves (SPAWs): Observations from a multiple sandbar system (Egmond aan Zee)

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Motivation

At straight sandy coasts, wave- and wind-induced processes often lead to intriguing, yet unexplained alongshore-variable morphology on spatial scales from tens of meters to a few kilometers. Recent observations have shown that the shallow parts of subtidal crescentic sandbars may separate from the bar and migrate onshore as spatially coherent features, termed Shoreward Propagating Accretionary Waves (SPAWs). It is thought that the onshore migration of these SPAWs plays a role in the sand exchange within the bar-beach-dune system, by merging with the intertidal beach and resulting in alongshore variations in sand supply for wind-induced transport towards the dunes. With only a handful of observations, however, it remains unclear how much sand is typically brought onshore as SPAWs weld to the shoreline over multiple years. Using a 15-year data set of daily video images from the multiple-barred beach of Egmond aan Zee, the Netherlands, we aim to 1) objectively quantify SPAW occurrence (i.e. frequency, duration, migration rate, size) and 2) characterize the wave conditions and bar morphologies associated with SPAW emergence and onshore migration.

Observations

We observed 93 SPAWs (on average 6.6 per year), with average lifetimes of approximately 40 days, average lengths and widths of 200 m and 30 m, respectively, migrating onshore at an average rate of ~1.3 m/day. Bar patterns were found to determine the alongshore locations of SPAW emergence, emerging either from crescentic bars or from bar splitting, both during more energetic conditions with obliquely incident waves. The interannual net offshore migration of sandbars, in turn, determined from which bar (i.e. the inner or the middle bar) SPAWs emerged. SPAWs typically migrated onshore under moderately energetic conditions (Figure 1), but were found to disappear under more energetic, obliquely incident waves. Using model-data assimilation we estimated the amount of sand within a SPAW to be 15,000 m^3. With 6.6 SPAWs annually this sums up to 100,000 m^3 of sand and, within the 4 km alongshore extent of the field site, an average annual onshore sand transport of 25 m^3/m/year related to SPAWs. This amount is slightly larger than the observed annual aeolian sand transport of 10-15 m^3/m/year from the intertidal beach to the foredune at this site, suggesting that SPAWs play a significant role in the onshore movement of sand within the bar-beach-dune system.

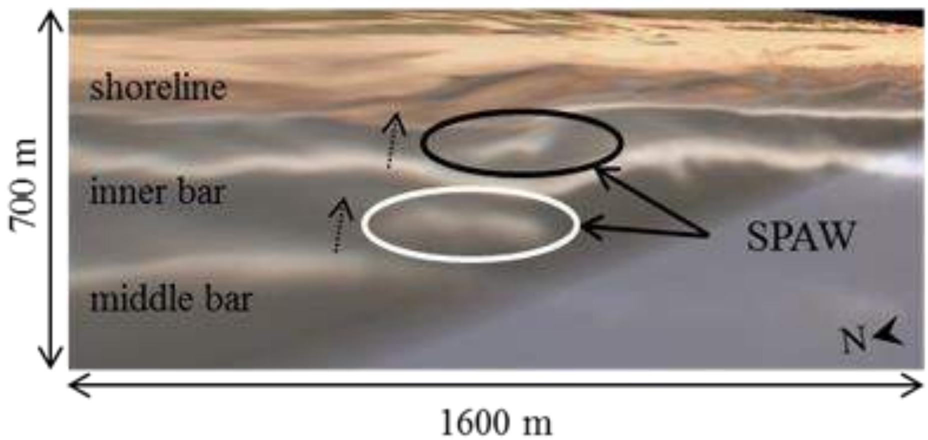

Figure 1. Plan-view time-exposure image, taken on 30 August 2012, showing SPAWs migrating (arrows with dotted lines) from the middle bar to the inner bar (white oval) and from the inner bar to the shoreline (black oval).

Funded by NWO (award to T.D. Price for "Spawning sand from sea to land", contract 016.Veni.171.101).

SANDY FORESHORES AS DIKE REINFORCEMENT IN LAKE SYSTEMS: A NATURE-BASED SOLUTION AT THE HOUTRIBDIJK

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Introduction

The present Houtribdijk reinforcement project (Figure 1) provides an innovative measure to guarantee safety against flooding. For the first time ever, a sandy nourishment is applied to ensure large-scale stability of a dike in a non-tidal, inland lake environment. To gain detailed insight into the key morphological and ecological processes, a dedicated monitoring and research programme will be carried out. It will enable the assessment of the feasibility of nature-based solutions for future dike safety programs.

Previous research

The Houtribdijk sandy foreshore consists of a large quantity of sand that is capable of dissipating the incoming waves, thereby reducing or even eliminating the actual wave load on the existing dike. As a consequence of this alternative reinforcement, no reinforcement on the dike itself is needed. Moreover, this nature-based solution may be more cost-effective in terms of construction as well as maintenance in the long run (Steetzel *et al.* 2017). Aside from ensuring the security of the dike, which is the primary objective, a foreshore solution has various secondary benefits. The natural and societal values of the area are enhanced, especially when considering the effect of vegetation (Steetzel *et al.* 2017).

Since this reinforcement technique is a world-wide first, a pilot study was created in 2014 at the Houtribdijk, in which hydrodynamics, morphology and vegetation development were extensively studied. Although a lot of knowledge has already been developed, it is still uncertain which hydrodynamic and morphological processes are dominant in shaping the foreshore cross-shore profile and additional analysis is needed. Besides, the effectiveness of the vegetation in supplying extra safety to the flood defence has not been proven yet (Penning et al, 2016).

Figure 1. Overview Houtribdijk reinforcement (Rijkswaterstaat,

Plan of approach

As the sandy foreshore at the Houtribdijk will be constructed between 2018 and 2020, a monitoring programme is started in this same period. It will continue up to at least 2022. In this programme, uncertainties about the degree of robustness and the needed maintenance of the sandy reinforcement will be mapped and quantified. While doing so, we will separately address cross-shore and alongshore processes, and investigate the interaction of morphological processes with vegetation. Furthermore, a safety assessment of such sandy foreshore systems is to be developed and the possibilities for upscaling this type of nature-based solution to be explored. We foresee the work carried out in this project will contribute significantly to the future prospect of implementing nature-based solutions for high-water safety and other purposes.

Penning, E., Steetzel, H., van Santen, R., de Lange, M., Ouwerkerk, S.J., Vuik, V., van Thiel de Vries, J.S.M. (2016). Establishing vegetated foreshores to increase dike safety along lake shores. In *Flood Risk 2017 Conference Proceedings*, E3S Web of Conferences (Vol. 7, p. 12008). EDP Sciences.

Rijkswaterstaat (2018). Factsheet: *For a safe IJsselmeer region; Reinforcement of the Houtribdijk.*

Steetzel, H., van der Goot, F., Fiselier, J., de Lange, M., Penning, E., van Santen, R., Vuik, V. (2017). Building With Nature Pilot Sandy Foreshore Houtribdijk: Design and behaviour of a sandy dike defence in a lake system. Coastal Dynamics 2017 Conference Proceedings.

GEOLOGY AND MORPHOLOGY AT AMELAND SOUTHWEST

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At the southwest coast of the Wadden island Ameland the tidal channel Borndiep is located very close to the coast, resulting in a steep slope next to the beach. In order to mitigate the coastward migration of the Borndiep and protect the hinterland, the channel margin was nourished between June 2017 and January 2018. At the same stretch of coast and despite the hard coastal protection at the channel slope, several beach collapses had occurred between March and November 2017 (Figure 1). Although the beach collapses did not form a safety risk for the primary water defense, understanding their cause and the local morphology, geology and state of the hard structures is important for coastal maintenance.

We investigated several aspects of the southwest coast of Ameland: occurrence and cause of beach collapse, presence of erosion-resistant geological layers, presence of hard coastal protection, and morphological development. For this study multiple types of measurements have been used: sidescan sonar (03/2017), sub-bottom profiler (11/2017), multi-beam echo-sounder (MBES) bathymetry (1 to 4 per year, since 2005), MBES backscatter (04/2017 and 10/2017), boxcores to ground-truth the backscatter results (03/2017) and multibeam measurements by the dredging company placing the nourishment (between June 2017 and January 2018). Vibrocores are planned to be taken at locations selected on the basis of seismic interpretation at the beginning of 2018.

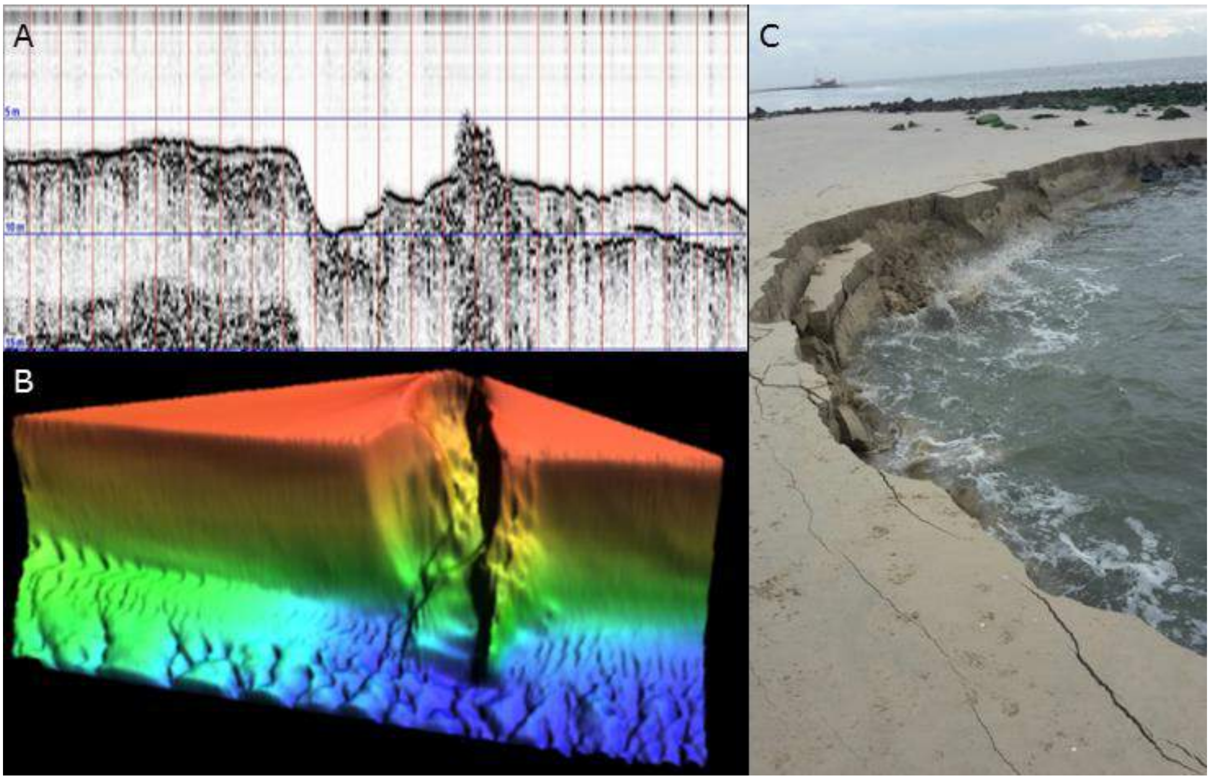

Figure 1. A: detail of seismic line at location of beach collapse, B: 3D image of bathymetry collected on March 14, 2017, after first beach collapse, C: beach collapsing at November 3, 2017 (photo: José Kanger-Wijnberg).

ALGAL MATS BOOST PRESENT-DAY BIOGEOMORPHOLOGY USING PRECAMBRIAN SELF-ORGANISATION STRATEGIES

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Can algae self-organise and sustain intertidal landscapes?

The importance of biology in shaping sedimentary landscapes due to sediment biostabilisation is widely appreciated (Le Hir *et al.* 2007, Grabowski *et al.* 2011). Biostabilisation can be traced back as far as Precambrian stromatolites, laminated sedimentary rocks formed by grain-binding biofilms, ubiquitous in and invaluable for interpreting paleorecords. Recent stromatolite-like structures are more scarce (Bosak *et al.* 2013) and modern algae are mostly found to induce only seasonal, short-lived stabilization (Le Hir *et al.* 2007, Weerman *et al.* 2011). We report on perennially persistent algal stabilisation on intertidal flats, seemingly creating regular bedforms (Figure 1) that resemble self-organised but seasonal microalgal patterns (Weerman *et al.* 2011). We test specific indicators of self-organisation for these perennial bedforms and investigate what might explain the unexpectedly persistent algal influence.

Clues from field and lab

We observe regular bedforms on intertidal flats, with algal-covered ridges and "bare" flat parts and channels (Figure 1). The filamentous algae (*Vaucheria sp.*) composing these algal mats are characterised by strong upward filamentous growth when buried with sediment (Simons, 1975). Our hypothesis of self-organisation due to stress-divergence (Weerman *et al.* 2011) is further motivated by wave flume and field tests of erosion and sediment dynamics, indicating local algal biostabilisation. Remote-sensing data support this self-organisation hypothesis, showing how regular patterns arise without apparent underlying regularity. We quantify the persistence of this self-organised landscape using aerial images and digital elevation models. Finally, sediment cores reveal clear lamination under algal mats and no layering under bare mud, suggesting that these algal bedforms owe their persistence to a stromatolite-like building plan.

Implications: from paleorecords to predictions

Concluding, we report on perennially persistent intertidal drainage landscapes, self-organised by algal mats. This finding emphasises that (micro)algal stabilisation is not necessarily short-lived (Le Hir *et al.* 2007, Weerman *et al.* 2011) and does require our attention when studying geomorphic and ecosystem development. As the laminated deposits found under these algal mats indicate recent analogies to fossil stromatolites, paleorecord interpretations might also benefit from the current study. If ancient stromatolites were self-organising structures as well, drastic changes found in rock lamination should not necessarily be attributed to big (climatic) events, but instead to subtle environmental changes leading to nonlinear, self-organised transitions (Purkis *et al.* 2016).

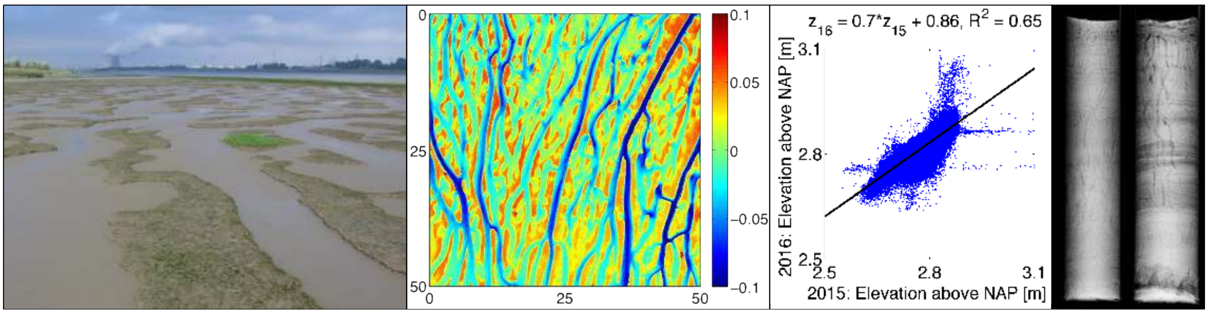

Figure 1. Left: ground view. Middle left: digital elevation model (detrended elevation in m) showing self-organised bedforms with algal-covered ridges in 2015. Middle right: correlation of elevation in 2015 and 2016, indicating pattern persistence. Right: sediment cores (depth 50cm) showing no lamination on bare tidal flat ***(left core)*** *and lamination under algal mat* ***(right core)****. All data from around 51°17'05.7"N, 4°18'43.9"E.*

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SEASONAL WIND AND BIOTA DRIVE TIDAL MUDFLAT DYNAMICS

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Extreme storm events and sea-level rise in the coastal zone emerge as an insurmountable consequence of global climate change. Nature-based flood defences have the potential to satisfy the need for cost-effective and sustainable coastal defence. Although salt marshes are unequivocally proven to be stable under extreme storm conditions (Möller et al. 2014), they can only be implemented in coastal defence schemes if their long-term stability under future climate change is guaranteed. The long-term stability is driven by short-term (i.e. seasonal and shorter changes) bed-level dynamics of the tidal mudflat (Bouma et al. 2016). In this study we want to explore the seasonal bed level dynamics of a tidal mudflat using an established equilibrium model.

The dynamic equilibrium theory-ESTMORF (DET-ESTMORF) was used for obtaining bed-level dynamics over a tidal mudflat. The model explicitly uses spatiotemporal bed shear stress variations to predict tidal flat morphodynamics (Hu et al. 2015). The model was extended with stochastic wind forcing (Weibull) for calculating wind waves, to be able to study climate change scenarios. Moreover the fixed-equilibrium bed shear stress was adapted to be able to change over space and time, for including biological influences. Seasonal bed-level dynamics obtained from model runs with different settings for wind forcing (Weibull distribution per season and a single Weibull distribution) indicate largest differences in winter and summer (Figure 1). Moreover, including biology in spring and summer results in a drastic decrease of the erosion (Figure 1).

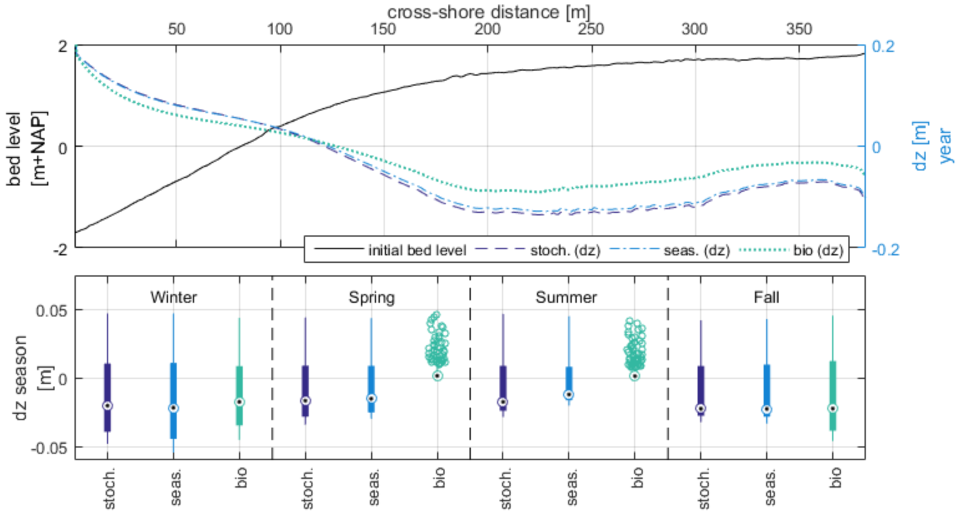

Figure 1. The initial convex profile of a tidal flat (top panel; left axis) and the resulting bed-level differences (top panel; right axis) after 4 seasons (winter, spring, summer and fall), forced by a single Weibull distribution (stoch.; dark blue/dashed) and a Weibull distribution per season without biology (seas.; light blue/dashed-dotted) and with biology (bio; green/dotted). The distribution of the bed-level differences over the entire profile per season per run (bottom panel) indicates the differences per run.

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Funded by NWO (research programme BE SAFE, 850.13.010).

MEASURING THE SPATIAL AND TEMPORAL VARIABILITY OF CURRENTS ON AMELAND EBB-TIDAL DELTA

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Introduction

During the Kustgenese 2.0/SEAWAD field campaign, amongst other measurements, hydrodynamic data were obtained by five frames on the ebb-tidal delta of Ameland Inlet. High-frequency pressure, velocity profile, and sediment-concentration time series are now available for five locations. An important research question within SEAWAD concerns the influence of the tidal current on wave transformation and related sediment transport. In order to answer this question, knowledge of the spatial and temporal variability of the tidal-current field is required. Therefore, Eulerian frame data are supplemented with Lagrangian velocity data obtained from free-floating surface drifters. The aim of this study is to investigate whether low-budget drifters can be used to measure tidal currents.

Methodology

Thirty current-resolving drifters were developed to suit the field campaign (Figure 1). Water-tight containers 6 l in size were partly filled with concrete to reduce buoyancy. A low-budget smartphone is used as a GPS tracker and a flag is attached to increase visibility. The smartphone stores its GPS position every second and sends it to a web application every 30 seconds. This application is developed to track all drifters in order to retrieve them. A Zodiac and a jet ski are used for deployment and retrieval of the drifters. During a two-week period, 54 small-scale (1x1km) and one large-scale (10x10km) deployments were performed.

Preliminary results

The current-resolving drifters have proven to be an accurate and very low-budget solution to map surface-current magnitude and direction. Data obtained from the drifters proved to be useful to observe variability of the currents both in time and space. The temporal variability is caused by the tidal phase, whereas the spatial variability is caused by changes in bathymetry. Interestingly, the tidal current significantly decreases during ebb from the channel towards the North Sea. During this phase, we also expect to observe current-induced changes in the wave field, measured by the frames. Furthermore, the large-scale deployment on the last day (Figure 2) and the fact that all drifters were retrieved by virtue of the real-time, online tracking have shown the potential of this method to be applied in many more studies.

Figure 1. Drifters in front of Ameland lighthouse.

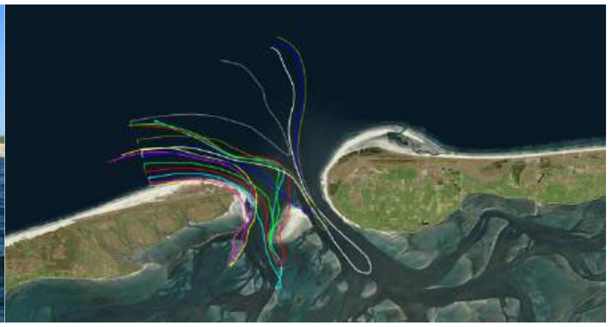

Figure 2. Drifter tracks of large-scale deployment.

Funded by NWO-STW (Dutch Technology Foundation, research programme SEAWAD, project number 14489). The authors want to thank all collaborators from Rijkswaterstaat, Deltares, Delft University of Technology, Utrecht University, and the University of Twente involved in the successful field campaign.

MODELLING OF THE EFFECT OF TRANSITIONS ON WAVE OVERTOPPING FLOW AND EROSION FOR FLOOD DEFENCE RELIABILITY

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Introduction

The major part of the Dutch flood defence consists of dikes. One of the main failure mechanisms of dikes is wave overtopping. Waves that overtop the dike crest run down on the landward slope and cause erosion on landward side of the dike, resulting in weakening of the dike and, in the end, in a dike breach. For this reason, it is important to learn more about the wave-overtopping process and the erosional effects as well as the about the effect of transitions in dike cover and geometry on wave overtopping.

Research plan

The goal of the project is increased understanding of the effects of transitions on the wave overtopping flow and of the erosion due to wave overtopping. In this project, an idealised wave model and a detailed hydrodynamic model will be developed to simulate the overtopping flow over the dike crest and down the landward slope. These models will be coupled to an erosion model for the dike cover to investigate the erosional effects due to wave overtopping. This abstract reports the first results of the idealised wave model.

Idealised wave model

The idealised wave model is built using the theoretically derived formulas of Van Gent (2002) for the maximum flow velocity u_{max} and the maximum layer thickness h_{max} of the overtopping tongue exceeded by 2% of the overtopping waves. Figures 1a and 1b show the decrease in flow velocity and layer thickness over the crest. When the overtopping tongue arrives at the transition towards the landward slope, the flow velocity increases to a constant value while the layer thickness decreases to a constant value. Figures 1c and 1d show the influence of the steepness of the landward slope. The velocity increases with increased steepness, while the opposite holds for the layer thickness, owing to continuity. During this project, the idealised wave model will be extended with other transitions.

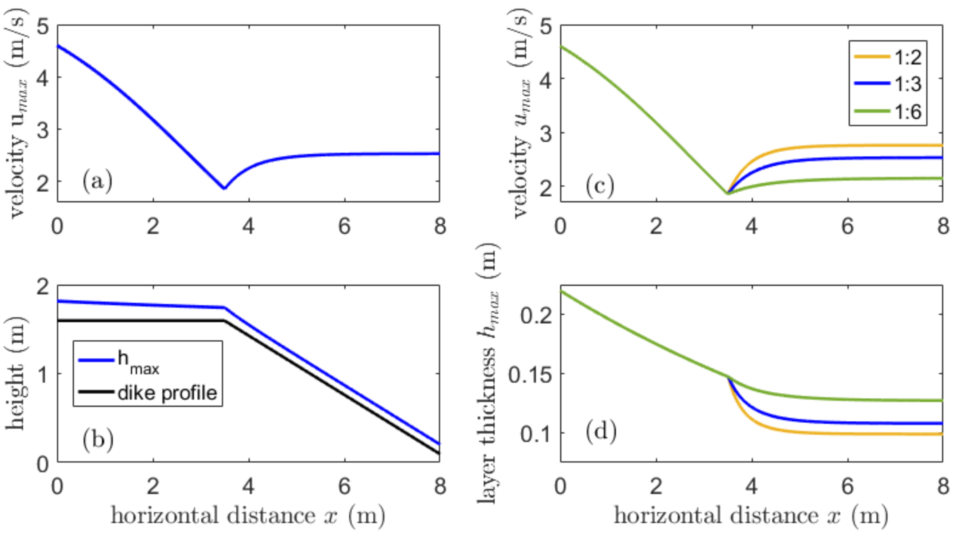

Figure 1. (a) The simulated maximum 2% exceedance velocity u_{max}, (b) the simulated maximum 2% exceedance layer thickness h_{max} and the dike profile with a slope of 1:3, (c) the velocity and (d) the layer thickness for different slope angles.

Van Gent, M.R.A. (2002). Low-exceedance wave overtopping events: Measurements of velocities and the thickness of water-layers on the crest and inner slope of dikes. *Delft Cluster Report* DC030202/H3803. Delft Hydraulics, Delft.

Funded in part by NWO (research programme All-Risk, project number P15-21).

PRESERVATION OF MUD LAYERS IN TIDAL BARS: SHOAL OF WALSOORDEN

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Aim
Mudflats and mud layers can have a large influence on the morphology of estuaries (Braat *et al.* 2017; e.g. confining the estuary width, higher intertidal bars), owing to different erosion and deposition characteristics of mud compared to sandy or silty sediments. Mud typically needs low velocities to settle, but has a high critical shear stress for erosion. On long timescales (decades to centuries) these mud-related effects on the morphology of estuaries are hard to predict. Reasons for this are that it is unclear where these mud layers are and under what conditions they are deposited and preserved. Even very thin mud layers can have large morphological effects and are therefore important to study. In this research we aim to determine when mudflats form and under which conditions they are preserved in the stratigraphy.

Methods
To achieve our aim, we compare numerical modelling results that include stratigraphy (Delft3D) with field data collected from the shoal of Walsoorden in the Western Scheldt. During fieldwork several cores up to 3 m depth were taken over a wide variety of environments on the shoal, including marsh, low- and high-energy tidal-flat environments. Four cores of 45-70 cm long collected near a big flood channel were brought back to the lab. Here, sand and mud layers were described in more detail, relying in part on screens for diatom assemblages and on lacquer peels (Figure 1).

We use a 2DH numerical morphological model to study different scenarios of the shoal of Walsoorden, which setup is based on the calibrated NeVla model. Scenarios that are tested include different concentrations of mud supply at the boundaries and absence versus presence of initial mud in the bed. Results of the modelling study are then compared with the field data to see if the model can accurately reproduce the mud deposits on the shoal. Lastly, the model is used to find if and when mud layers are preserved in the stratigraphy of the shoal.

Results
Preliminary results suggest that exceptional conditions are necessary to preserve mud layers in the stratigraphy. Even though the spatial extent of mudflats is large in the field, only limited mud is found in the stratigraphy. Diatom screening of the mud samples shows that several thin mud layers (2-10 mm) might be related to storm events, because high numbers of marine planktonic species were observed. Other mud layers can be correlated to the occurrence of vegetation, and some deposition angles suggest bedform migration. In line with the field data, it proves difficult to preserve mud layers in the model stratigraphy; even the few thin layers from the cores are not observed in the model. We hypothesise that this omission is due to the simplified conditions, as the model does not capture storm events or large dune or sandbar migration over the shoal.

Figure 1. Lacquer peels of four sediment cores. Darker layers are mud layers.

Braat, L., van Kessel, T., Leuven, J.R.F.W., Kleinhans, M.G. (2017). Effects of mud supply on large-scale estuary morphology and development over centuries to millennia. *Earth Surface Dynamics*, 5 (4), 617-652.

PARAMETERIZATION OF WAVE ORBITAL MOTION AND ITS EFFECT ON LONG TERM MORPHOLOGICAL DEVELOPMENT IN THE NEARSHORE

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For reasons of computational efficiency, the orbital velocities are often parameterized in morphodynamic simulations, e.g. through Isobe and Horikawa (1982). Other methods are summarized in Abreu *et.al.* (2010). The parameterization simplifies the wave shape and velocities by applying higher harmonics, for example. The risk is that this simplifies the nearshore hydrodynamics to such a degree that even a small error in wave-shape prediction leads to large net sediment transport and, in the long term (i.e. months to decades), to unrealistic modelled morphology. To improve the parameterization, Ruessink *et.al.* (2012) compute the intra-wave velocity based on extensive field data.

Our objective is to assess effects on long-term morphodynamics of the differences between the methods described in Ruessink *et.al.* (2012) and Isobe and Horikawa (1982) in a hydrodynamic and morphological model – Delft3D. This comparison is part of a larger project with long-term modelling and large-scale equilibrium-oriented simulations focusing on sediment transport trends and general behaviour from deep water to the beach.

The Isobe-Horikawa parameterization overestimates onshore transport and the depth of closure, causing rapid beach and shoreline accretion. The general steepening of the cross-shore profile is inconsistent with the simulated wave condition. The Ruessink *et al.* parameterization shows more natural development. Morphological changes were limited to water shallower than the depth of closure; a subtidal bar formed and the shoreline and upper beach weakly eroded (Figure 1).

Until now, modellers using IH usually have tuned down the transport factor in order to reduce excessive erosion and coastline accretion, but this affects sediment transport in the entire domain, which inhibits long-term morphological modelling of the coastal system. We believe that a new intra-wave parametrization implemented into Delft3D may improve long-term 2DH and 3D morphological models. We are expanding this analysis to larger model domains and looking into comparisons with field data.

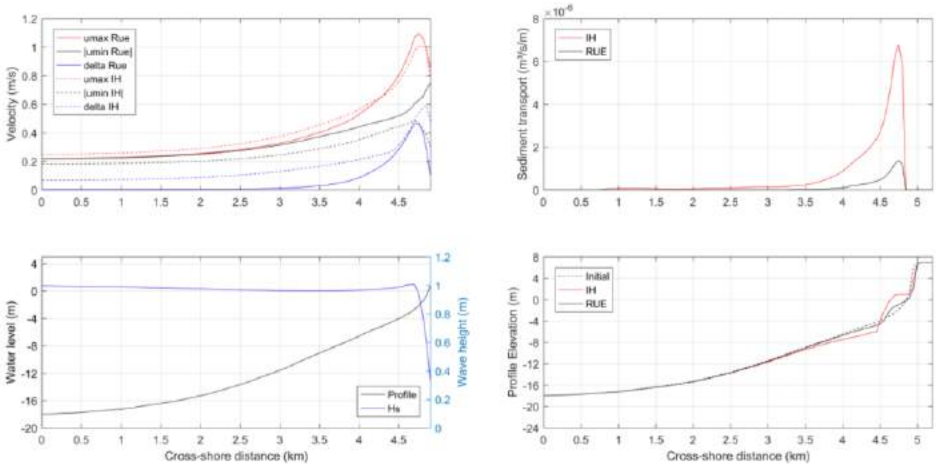

Figure 1: Comparison between IH and Ruessink parameterization along the beach profile for a perpendicular wave condition of 1m, 8s. Top Left: peak intra-orbital velocity; Bottom Left: Bed level and wave height; Top Right: sediment transport along the profile; Bottom Right: resulting topography after 10 morphological years.

Abreu, T., Silva, P.A., Sancho, F., Temperville, A. (2010). Analytical approximate wave form for asymmetric waves. *Coastal Engineering*, 57(7), 656-667.

Isobe, M., Horikawa, K. (1982). Study on water particle velocities of shoaling and breaking waves. *Coastal Engineering in Japan*, 25(1), 109-123.

Ruessink, B.G., Ramaekers, G., van Rijn, L.C. (2012). On the parameterization of the free-stream non-linear wave orbital motion in nearshore morphodynamic models. *Coastal Engineering*, 65, 56-63.

LARGE-SCALE EFFECTS OF TIDAL ENERGY EXTRACTION IN THE EASTERN SCHELDT

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The tidal flats in the basin are eroding and intertidal habitat is progressively lost. Such an *autonomous negative trend* (ANT) is due to the presence of the storm-surge barrier (SBB), which reduces the accreting tidal currents from the North Sea with respect to the eroding wind waves generated inside the basin. Deploying turbines in the gates of the SBB further decreases the tidal energy inside the basin and the ANT might consequently accelerate. A 2DH numerical model of the full basin is built (package *Delft3D*). The configuration of turbines nested inside a SBB represents a unique case study in the literature. Special attention has to be paid to the parameterization of the barrier and the energy extraction (*momentum-sink* approach), whose calibration is performed based on high-resolution 3D simulations of the turbines' near-field (package *Star-CCM+*). The hydrodynamic effects of energy extraction are evaluated at the basin scale. A range of scenarios has been simulated, from the present license held by the concessionaire *Tocardo* (2 gates of the southern section of the SBB, each filled with an array of 5 turbines) to a complete 1-on-3 rollout along all 62 gates. Results confirm our assumption that 2 regions are conceptually distinguished: mid-field and far-field (Figure 1). In the mid-field, hydrodynamics are affected by both position and number of gates filled with turbines. In the far-field, only the total number of turbines matters. Hydrodynamic results are then used to infer possible morphological changes. For the licensed 2-gates scenario, an average 0.1% loss of intertidal acreage is predicted on the basis of the tidal-range reduction. This decrease is roughly equivalent to a few months of the current ANT. Variations in discharges along the main channels are smaller than $\pm 0.8\%$, which are not likely resulting in relevant modifications of the sediment transport patterns. Ongoing developments are concerned with further improvement of the turbines' parameterization and with the analysis of residual sediment fluxes.

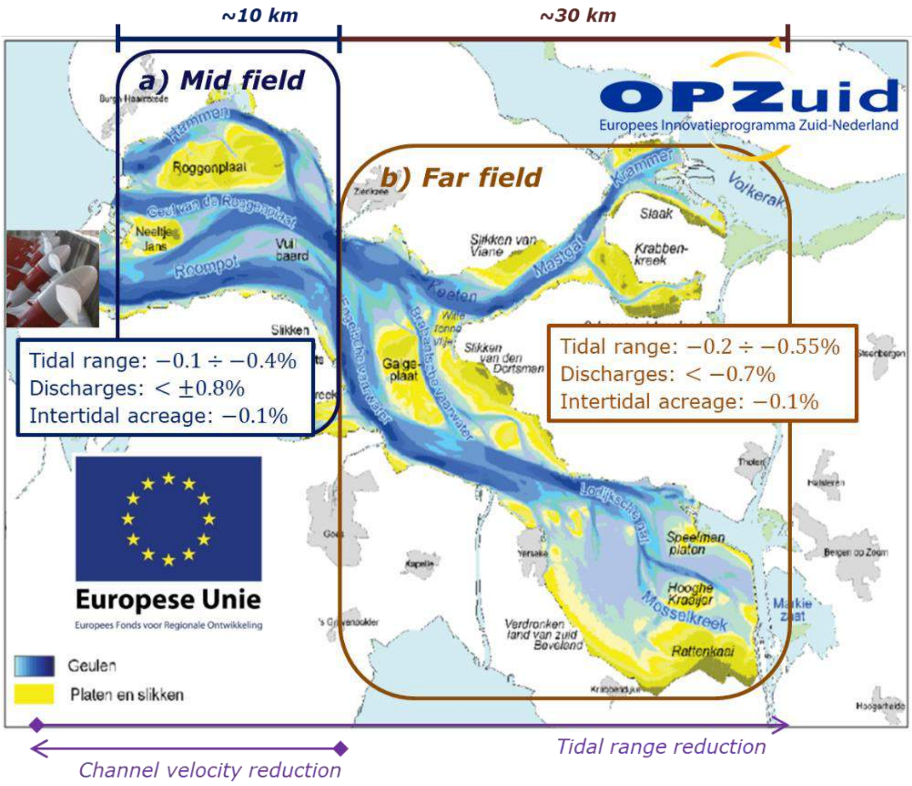

Figure 1. Effect of tidal energy extraction on the Eastern Scheldt's dynamics. (a) In the mid field, the position of the turbines can affect flow asymmetries, and hence net sediment transport patterns. (c) In the far-field, the tidal-range reduction is the only relevant effect. Model results for the near-future scenario (2 gates, total power ~2.4MW) are summarized.

Funded by the European Regional Development Fund (ERDF)OP-Zuid 2014-2020 and the New Delta programmes.

USING ARGUS VIDEO MONITORING TO DETERMINE LIMITING FACTORS OF AEOLIAN TRANSPORT ON A NARROW BEACH

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Introduction

In most aeolian models, sand is predicted to be transported when the wind velocity exceeds a certain threshold (typically, 8 m/s). When these models are applied to narrow (< ≈ 100 m) beaches, they sometimes predict aeolian sand transport while this does not take place in reality. These moments are called limited events. Here, we use signs of aeolian transport visible on camera, together with weather and beach characteristics, to determine what factors, aside from wind velocity, influence aeolian transport on narrow beaches.

Study site

The study site is located between Egmond aan Zee and Castricum, the Netherlands. The beach is approximately north-south oriented, has a gentle slope (~1:30), is relatively narrow (100 m maximum at spring low tide) and consists of quartz sand with a median diameter of about 250 μm. An optical remote-sensing system consisting of 5 RGB-colour cameras, known as Argus (Figure 1), monitored the site from 1998 to 2015. An automatic weather station in De Kooy, 40 km north of the study site, provided the weather data.

Methods

The Argus images taken between 2005 and 2012 were searched for actual aeolian transport events. These images were classified according to their visual signs of transport. An event is considered to be limited if the Argus imagery shows little or no transport, but the mean wind velocity exceeds the threshold velocity substantially. Next, the wind characteristics of limited and unlimited events were compared to each other.

Results

Westerly winds were more common during limited events. These shore-normal winds resulted in a short fetch length, which is unfavourable for aeolian transport. Some of the limited events were unlimited during a different part of the day. The weather conditions during such days tended to remain the same, but signs of aeolian transport were visible at low tide only (wider beach). This observation shows that fetch is important for aeolian sand transport on a narrow beach. Unlimited events were observed both in summer and winter. In summer, events were numerous but mostly took place when the wind speed was just above the threshold. In winter, in contrast, unlimited events were few, but then showed strong signs of transport.

Figure 1. The Argus tower at the study site.

MORPHOLOGICAL DIFFUSIVITY EXPERIMENT

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MODEX (MOrphological Diffusivity EXperiment), planned for May and June 2018, will use flume observations of the evolution of a sand mound to quantify the primary physical drivers of morphological diffusivity in nearshore environments. Morphological diffusivity is linked to the behaviour of sand banks in shallow seas, tidal inlets and estuaries, and to the nearshore response to human interventions like nourishments and dredging.

The prediction of this 3D behaviour is currently impeded by 1) a lack of data and 2) incomplete understanding of the underlying physical processes. As a result, numerical models of sediment transport must parameterize morphodynamic diffusivity. To reduce parameterization and improve the understanding of diffusivity on long-term morphological evolution, this experiment will collect observations of multiple processes thought to affect diffusivity, including bed-slope effects, bottom roughness, sub-harmonic waves, wave-breaking turbulence and high-angled waves.

The flume setting for MODEX (Figure 1) is ideal for testing these competing factors, since it allows both waves and currents to be simulated in an idealized environment and enables the measurement of diffusion rates along with the properties of incident waves and flows at high temporal and spatial resolutions.

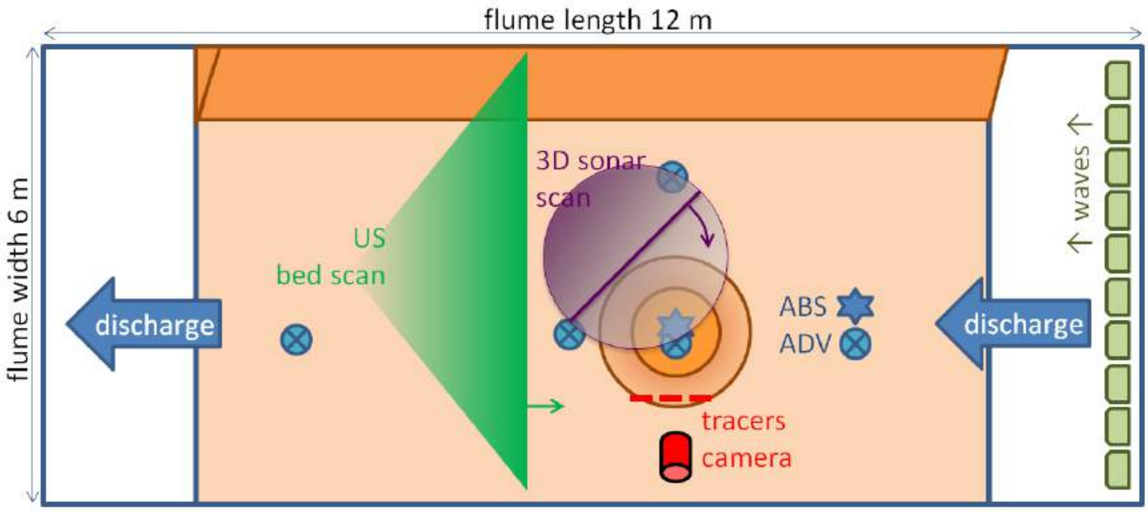

Figure 1. Overview of the initial proposed test layout.

The MODEX Experiment is a Hydralab+ project with a consortium of international partners (B. Castelle (France), N. Senechal (France), F. Ribas (Spain), M. Wengrove (USA)) and hosted by the University of Hull (S. McLelland).

CYCLIC BEHAVIOR OF EBB-TIDAL DELTAS FROM MODEL SIMULATIONS

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Introduction

Ebb-tidal deltas are shallow sandy features located seaward of tidal inlets and are important for coastal safety in barrier systems. They act as a shield for incoming (storm) wave energy and they are a source of sediment for the barrier islands and the back-barrier basin. This 'feeder' function is commonly related to the observed cyclic behavior of shoal formation, migration and attachment to the downdrift island. Yet, our knowledge of the cyclic behavior of channels and shoals on the ebb-tidal delta is insufficient to predict the period between successive shoal attachments and understand the physical processes involved. The main objective of this study is to quantify the effect of waves and tides on the cyclic behavior of an ebb-tidal delta and to understand the underlying mechanisms.

Methods

A numerical morphodynamic model - Delft3D/SWAN - was employed with an idealized geometric set-up, representative for the smallest tidal inlet systems in the German Wadden Sea. Hydrodynamic forcing consisted of a combination of tides and waves and the model computed the resulting sediment transport and subsequent bed-level evolution. Many model runs were conducted to test the relative importance of waves and tidal currents on the morphological evolution of the tidal inlet and ebb-tidal delta.

Results

We modeled cyclic behavior of ebb-tidal deltas that resembles observed patterns in the Wadden Sea. Channels migrated, shoals formed and periodically attached to the downstream coast. Obtained bathymetries (Figure 1) further specify how changes in the inlet - similar to the one-channel/two-channel transformation of the Ameland Inlet in the Dutch Wadden Sea - are inherently linked to periodic shoal dynamics. The results indicate that the cyclic behavior is forced by feedbacks between channel rotation and breaching, shoal migration, wave-related sediment transport and direction of net sediment transport in the inlet. Furthermore, a relation is found between incoming wave height and time scale of cyclic behavior. Larger waves and smaller tidal prism result in faster migration of shoals and shorter time scales.

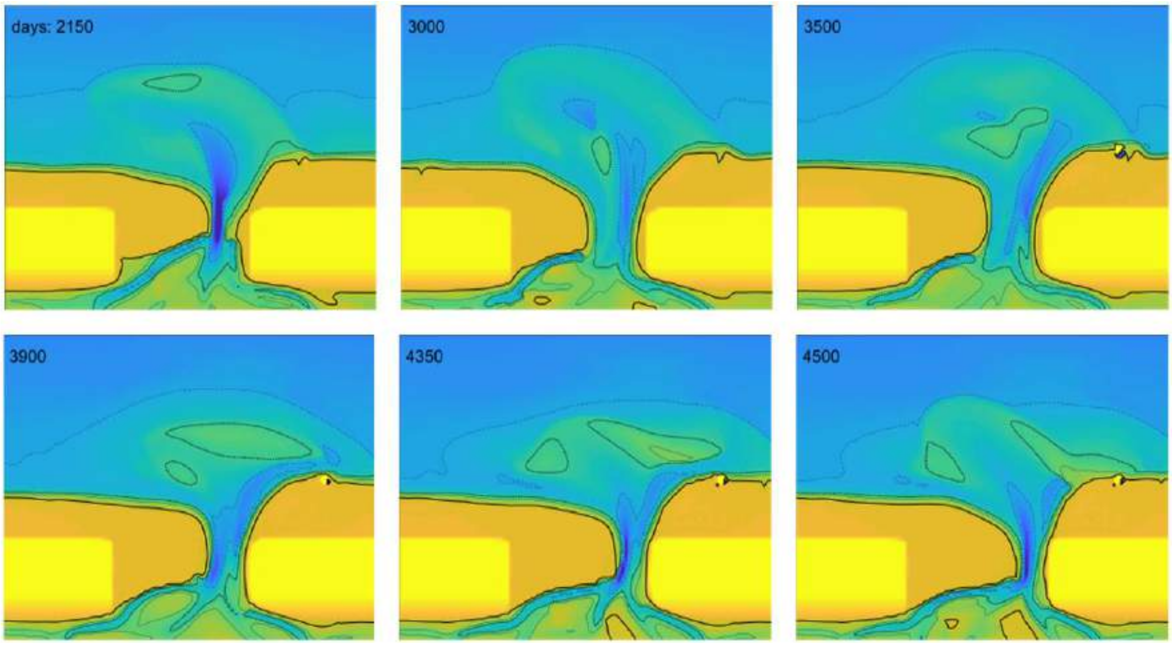

Figure 1. Contour plot of modelled cyclic behavior. Hydrodynamic forcing consists of tides (amplitude M_2 -tide = 1 m) and waves (H_s = 2 m) originating from the north-west.

COASTAL RESEARCH AT MINISTRY OF INFRASTRUCTURE AND WATER: COHERENCE AND OVERALL PERSPECTIVE

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Introduction

The Dutch government decided to put a stop to the prevalent structural coastal erosion in 1990 by introducing the Dynamic Preservation policy. This policy states that coastal erosion should be compensated predominantly with sand nourishments in order to keep flood risks at an acceptable level and to give lasting protection to the functions and features of the coastal dunes. Since 1991 Rijkswaterstaat is maintaining the Dutch coast with three types of nourishments: at the beach, on the shoreface and at channels.

To continually optimize and adjust the Dutch Coastal policy and practice, Rijkswaterstaat, as part of the Ministry of Infrastructure and Water, coordinates multiple research programs (Figure 1). Our poster gives an overview of these projects and shows the coherence between the projects.

Featured research programs

- Kustgenese/Coastal Genesis 2.0
- Beheer en Onderhoud Kust/Operations and Maintenance Coast
- Natuurlijk Veilig/Naturally Safe
- Sand Motor
- Interreg Building with Nature
- USACE Guideline for Natural and Nature-Based Features

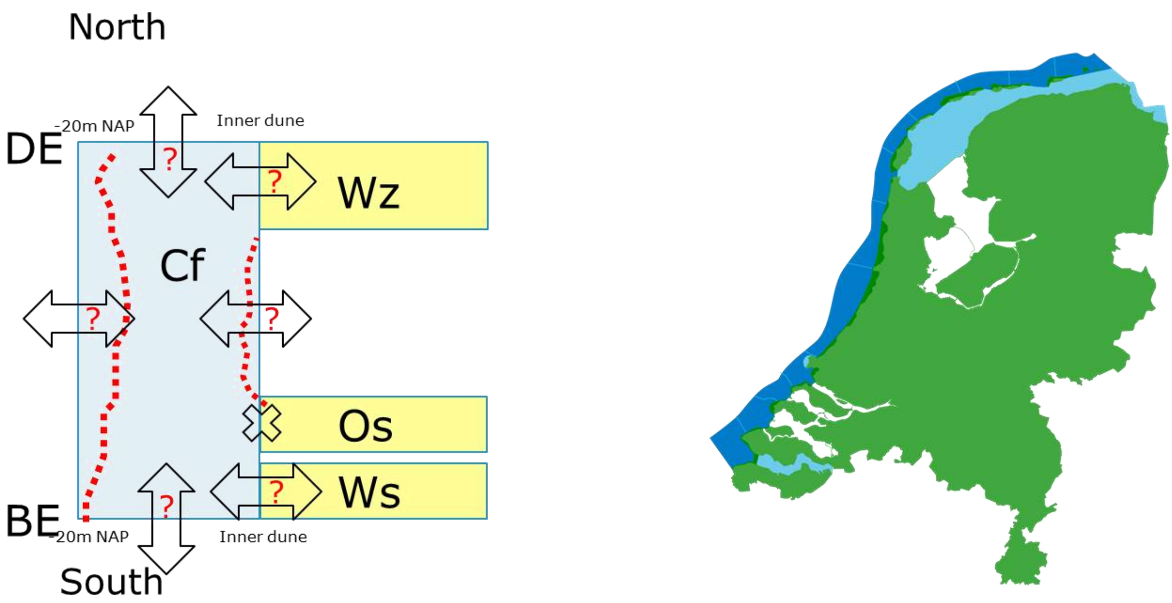

Figure 1. Schematization of long-term sediment exchange and demand in the Dutch coastal system. The question marks indicate sediment exchanges that are still not fully understood and are being assessed in the research programs.

WHAT IT TAKES: PLANNING AND RISK MANAGEMENT FIELD CAMPAIGN KUSTGENESE 2.0

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Rijkswaterstaat has had a long tradition of monitoring and measuring physical, biological and chemical parameters. Th resulting long- and short-term information is used to define policy measures for the integrated water management of Rijkswaterstaat: dry feet, sufficient clean water and reliable and useful information.

The program Kustgenese 2.0 was started to define the policy measures for the protection and maintenance of the Dutch coast after 2020. Extensive field campaigns (Figure 1) are being organized along the coast to acquire hydro-, morpho- and ecological data needed for the development of system knowledge and for fine-tuning prediction models.

The organization of the field campaigns requires a strict planning and risk management for each of their phases. The poster presents potential risks and corresponding measures for the Amelander Zeegat campaign. Process stages are distinguished together with the corresponding activities.

The main outcome is that the organization of a field campaign on such a scale requires a direct iteration between the information requirements of the intended stakeholder groups and the protocols for data acquisition and processing.

Figure 1. Recovery of one of the monitoring frames and cardinal buoy (photo: A.J. Ponger).

EVALUATING THE IMPACT OF THE SAND MOTOR ON SWIMMER SAFETY

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Introduction

The construction of large-scale beach nourishments, such as the Sand Motor, inherently has an effect on nearshore hydrodynamics and morphodynamics. Potentially, this might give rise to physical hazards for swimmers and bathers. Adverse effects of coastal engineering works on recreational safety are generally considered unwanted and unacceptable, all the more since such human interventions often aim to stimulate the recreational value of the coastal zone. Adequate prediction and evaluation of swimmer safety around mega-scale beach nourishments is therefore highly important. This study combines recent insights into the effect of mega-nourishments on hydrodynamics, morphodynamics and governance of the coastal system to evaluate the impact on swimmer safety, using the Sand Motor as a central study object.

Results

Three different hydrodynamic phenomena were included in the analysis. Their combined impact on swimmer safety was determined by evaluating their coincidence in space and time with the presence of beach users. The analysis shows that: (1) Offshore-directed flows related to tidal flow separation occur in an area with very low beach attendance, leading to a low impact of this phenomenon on swimmer safety. (2) Rip-current generation over subtidal sandbars was found to occur mainly during bad weather conditions associated with low beach attendance, again leading to a low impact on swimmer safety. (3) Tidal currents in the entrance channel to the artificial Sand Motor lagoon have a high coincidence with the presence of beach users both in time and space. This phenomenon consequently is the single largest risk for swimmer safety at the Sand Motor, although the strength of tidal currents in the channel has strongly decreased over the years as the morphology of the nourishment has evolved. Altogether, the analysis shows that mega-nourishments can impose additional risks for swimmers and bathers. A combined analysis of nearshore hydrodynamics and beach attendance provides important insights that help predict the impact of mega-nourishments on swimmer safety (Figure 1).

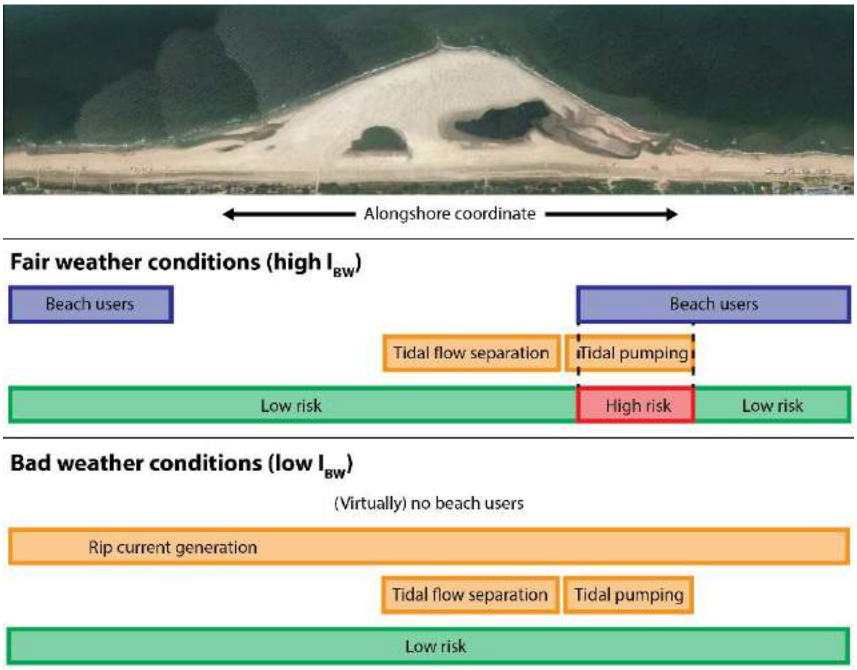

Figure 1: Evaluation of swimmer safety around the Sand Motor, based on the coincidence in space and time of beach attendance and hazardous hydrodynamic phenomena.

Improving formulations for the cross-shore transport of graded sediment in Delft3D

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Introduction

The shoreline is continuously exposed to wave forcing. With sea-level rise and extreme weather events ahead, it is even more important to ensure the safety of coastal regions. A key measure is strengthening beaches by adding sand to the shoreline (nourishments). The effects of these nourishments are estimated and assessed up front, so that engineers can apply these large scale interventions in the most cost-effective way and with optimal results in terms of long-term coastal protection. A widely used morphodynamic model by coastal engineers is Delft3D. The original beach and the nourishments often differ in terms of grain size. The transport of such sand mixtures differs substantially from that of uniform sands. Consequently, Delft3D requires accurate formulations for the transport of mixed sediments as suspended and bedload, in order to determine the long-term morphodynamic evolution of the beach profile. Current formulations for graded sediment transport have been parameterised on the basis of experimental data that were primarily obtained in steady-flow conditions or in oscillatory-flow tunnels. However, recent experiments in the large-scale wave flume in Barcelona (CIEM) now give the opportunity to study the transport of mixed sediment under real full-scale waves (Figure 1).

Methods

As a first step, bedload-transport models will be validated with data from oscillatory-flow tunnels in which vertical wave-related processes are absent and suspended-sediment transport is minor. Subsequently, the wave flume experiment (Cáceres *et al.* 2018) will be simulated in Delft3D, which allows testing and validation of model parameterizations for suspended and bedload transport of graded sediment. The wave flume experiments have been carried out with Coarse (0.54mm) and Medium (0.25mm) sand, involving different mixtures and wave conditions, being I) 100% M, II) 100% C and III) 50% M – 50% C. Model parameters and processes that will be tested and improved are related to a) hiding and exposure, b) unimodal versus multi-fraction approach and c) bed roughness. The output of the model will be analysed in terms of suspended sand concentration profile and total net sediment transport. The findings will contribute to better understanding and modelling of graded sediment transport under waves.

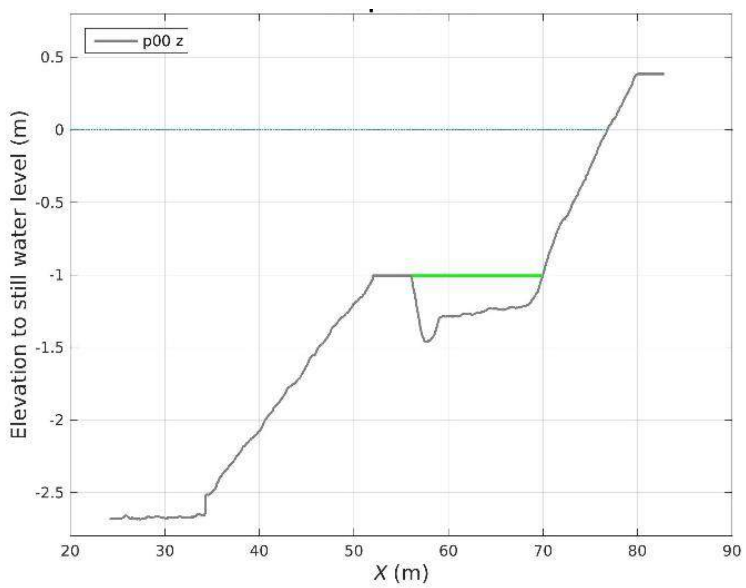

Figure 1. Schematisation of the wave-flume test setting at CIEM. The non-erodible bed is depicted in grey. The green line denotes the location of the mixed sediment bed (Cácares et al. 2018).

Cáceres, I., Cooke, R., Thorne, P., Hurther, D., Sánchez-Arcilla, A. (2018). Ripple Complex Experiments (RIPCOM). *Data report UPC.*

EXPERIMENTAL STUDY ON THE INFLUENCE OF TRANSITIONS ON WAVE OVERTOPPING

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Transitions in the dike cover from grass to roughness element, stairs, or geometric changes are commonly present in the slopes of dikes. Prior research showed that these transitions might pose a threat to slope-cover stability, but they still receive limited attention in design and assessment methods. The objective of this recently started PhD study is to investigate the effect of transitions on the wave overtopping discharge and overtopping flow parameters.

Materials such as concrete blocks, asphalt and grass are often applied as revetments on the seaward slope of dikes. In practical engineering, different elements are often combined as an armor of the slope (Figure 1). Roughness differences and geometrical changes can be regarded as transitions in the seaward slopes and may have an effect on the wave overtopping and revetment stability. Damage may be more likely to occur in the vicinity of the transitions, owing to induced turbulence with the function of wave run-up and wave overtopping. Failure of a dike cover due to wave overtopping may initiate dike breach. Thus, reliable estimation of wave overtopping discharge is necessary for the design and safety assessment of dikes.

Existing overtopping-discharge estimators normally take a single type of revetment into consideration. A roughness-influence coefficient was introduced into the empirical equations to describe the reduction effect of revetment roughness on the wave overtopping. Many researchers have investigated the performance of different armor units on the outer slope. Bruce *et al.* (2009) determined the relative difference in overtopping discharge for different types of armor units and finally presented the roughness factor value of various types of armor. Capel (2015) studied the effect of special roughness patterns in placed-block revetments on wave overtopping and wave run-up. New equations to assess the roughness coefficient, wave run-up, mean overtopping discharge and wave reflection for impermeable structures have been put forward.

It still remains unclear how the combined roughness factor affects the overtopping over the dike with a berm. Prior research has shown that roughness may significantly affect the required crest level of a dike. Optimal use of roughness elements pays off economically by reducing the required crest elevation. It is worth noting that the permeability that is related to porosity and shapes of the pores in the materials can also affect the roughness factor. However, the relationship between roughness factor and permeability is unclear and therefore needs further research. Hence, the separate and combined effect of roughness, permeability and a berm on the wave overtopping will be studied by conducting series of physical model tests at Deltares.

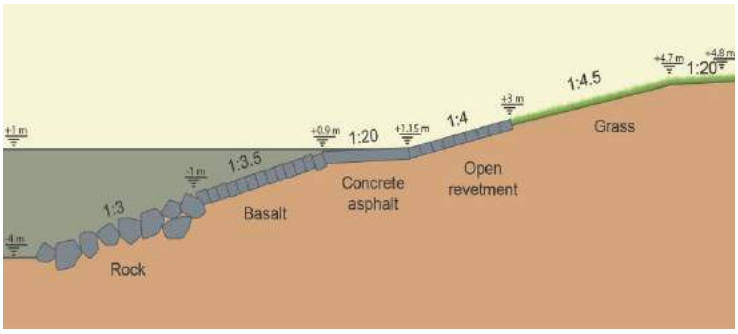

Figure 1: Cross-section of the dike with different roughness elements on the slopes and a berm (Eurotop, 2016).

Bruce, T., van der Meer, J.W., Franco, L., Pearson, J.M. (2009). Overtopping performance of different armour units for rubble mound breakwaters. *Coastal Engineering*, 56(2), 166-179.

Capel, A. (2015). Wave run-up and overtopping reduction by block revetments with enhanced roughness. *Coastal Engineering*, 104, 76-92.

THE INFLUENCE OF BEACH-FOREDUNE MORPHOLOGY ON LOCAL WIND CHARACTERISTICS

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Introduction

Along the Holland coast in the Netherlands high and steep dunes act as a primary defense against flooding of the hinterland. To predict dune erosion by wave action, advanced numerical models can be used in both scientific projects and policy-making. However, coastal foredunes recover in between storms by aeolian sediment transport from the (intertidal) beach. Predictive models for dune recovery are still in their infancy because of, among a number of aspects, the potentially strong spatial variability in wind characteristics on the beach. Mean wind characteristics (speed and direction) are likely to vary across the beach, owing to the presence of the foredune front. Furthermore, because aeolian transport is strongly intermittent, a better understanding of wind turbulence across the beach is needed to improve predictions of sediment transport rate. In our research we examine the spatial variability of mean wind velocity and direction, and of turbulence at the beach of Egmond aan Zee, the Netherlands.

Methods

Three-dimensional wind velocities were measured at a height of 0.9 m and a frequency of 10 Hz. We used 4 to 6 ultrasonic anemometers (Figure 1) in a cross-shore array between the waterline and the dune foot, depending on the beach width. During two 6-week field campaigns in autumn 2015 and 2017 and three additional days with strong winds (winter 2017), measurements were performed nearly every day during daytime. This field work resulted in an extensive dataset with mean wind speeds ranging from no wind up to 15 m/s. The velocity data were processed into a 10-minute mean velocity ($\bar{u}$), mean turbulent kinetic energy (TKE) and wind direction.

Results

Results show that during onshore winds the mean wind velocity is decreasing from the waterline towards the dune foot, while the TKE remains constant over the beach and is slightly higher at the dune foot. As a result, the gustiness (that is, the ratio of TKE to mean wind speed) increases towards the dune foot. The mean wind velocities can be 1.5 times higher at sea than at the dune foot. During times of more alongshore winds, wind speed and TKE are spatially more uniform, but the wind direction is steered substantially in the alongshore direction, especially near the dune foot.

Discussion and outlook

The effect of a coastal foredune on local wind patterns has the potential to substantially reduce the aeolian sand supply to coastal foredunes, because the drop in velocity near the dune foot reduces pick-up rates and promotes deposition. Our findings show that in order to accurately predict aeolian sand supply to coastal foredune systems, at least the effects of local wind patterns should be incorporated. Moreover, a cubic relation between TKE and windspeed, a basic assumption for most sediment transport equations, was not found here. Further research is needed to elucidate the role of turbulent structures and spatial variation herein on sediment pick-up rates.

Figure 1. An ultrasonic anemometer in front of the high and steep foredune at Egmond aan Zee, the Netherlands.