Environmental controls on the spatial variation in sand wave morphology and dynamics on the Netherlands Continental Shelf

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ABSTRACT: The morphology and dynamics of sand waves on continental shelves may interfere with navigation and offshore constructions. Understanding the controlling parameters of the spatial variation in sand wave morphology and dynamics will allow for better predictions of bed dynamics and thereby helps the optimisation of monitoring and maintenance strategies. Previous investigations are mostly local studies. However, for the explanation of spatial variation on continental shelves, large-scaled investigations are required. Quantified sand wave morphologies on the Netherlands Continental Shelf (NCS) and correlated environmental parameters reveal that sediment grain size and transport mode seem the controlling parameter/process. These also reveal that sand waves on the NCS are relatively high compared to the empirical relationship of Allen (1968). For sand wave dynamics, these relationships still have to be investigated. Preliminary results of migration rates on the Netherlands Continental Shelf are between 0 and 20 m/yr.

1 INTRODUCTION

Sand waves are a common feature on sandy continental shelves. The increase in sand wave heights may interfere with navigation. Certainly with increasing draughts of offshore vessels in shallow seas, such as the Southern Bight of the North Sea, calling on major harbours such as Rotterdam, water depths become increasingly critical. The migration of sand waves is important in the design and maintenance of offshore wind farms, cables and pipelines.

North Sea bathymetry shows that the occurrence and morphology of sand waves is spatially variable, and the analyses of time series show that also dynamics are spatially variable. A large-scaled study of vertical nodal seabed dynamics at the Netherlands Continental Shelf (NCS) revealed that sand waves are the most dynamic feature offshore, due to sand wave migration (Van Dijk et al., 2012a). By understanding the processes that control these spatial variations, we can improve risk-based monitoring policies of continental shelves and the maintenance of fairways (Fig. 1).

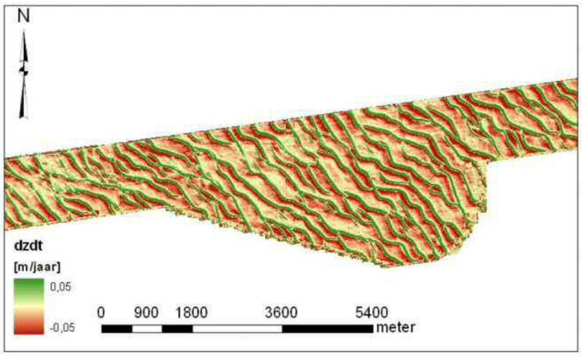

Figure 1. Vertical bed dynamics (m/yr) revealing sand wave migration in the Eurogeul, the approach channel to Rotterdam harbour (from Van Dijk et al., 2012b).

In this paper, quantified sand wave morphology of all sand waves on the NCS at 25-m resolution and correlations to the spatial variation in environmental parameters and processes (Damen et al., 2018a) are presented. In addition, preliminary results of morphodynamics of sand waves may be investigated in a similar way.

2 METHODS AND RESULTS

2.1 Morphology

Using a scanning technique in the direction perpendicular to sand wave crests along transects 25 m apart, the quantification of all sand waves results in morphologic maps of sand wave lengths, heights and asymmetries (Damen et al., 2018a; heights are displayed in Fig. 2).

These maps show that the longest and lowest sand waves occur along the Holland coast, where also asymmetries are the largest. Distribution plots reveal the limits of sand wave morphologies for all sand waves on the NCS (Fig. 3).

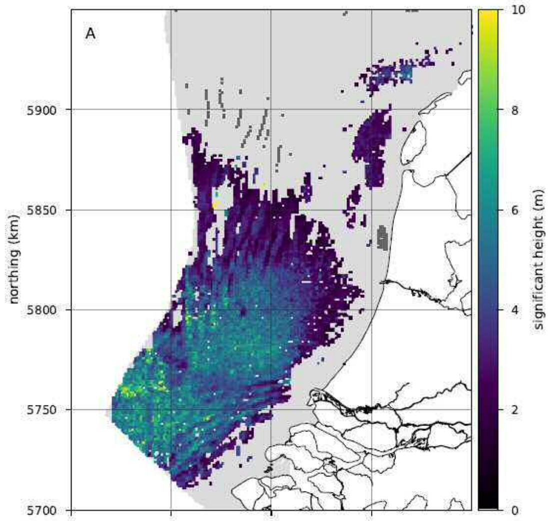

Figure 2. Quantified sand wave heights per km^2 on the Netherlands Continental Shelf (after Damen et al., 2018a). Results of all individual sand waves are available in a repository (Damen et al., 2018b).

i. 2.1.1 Correlation to primary parameters

For the correlation of morphology to primary environmental parameters (depth,

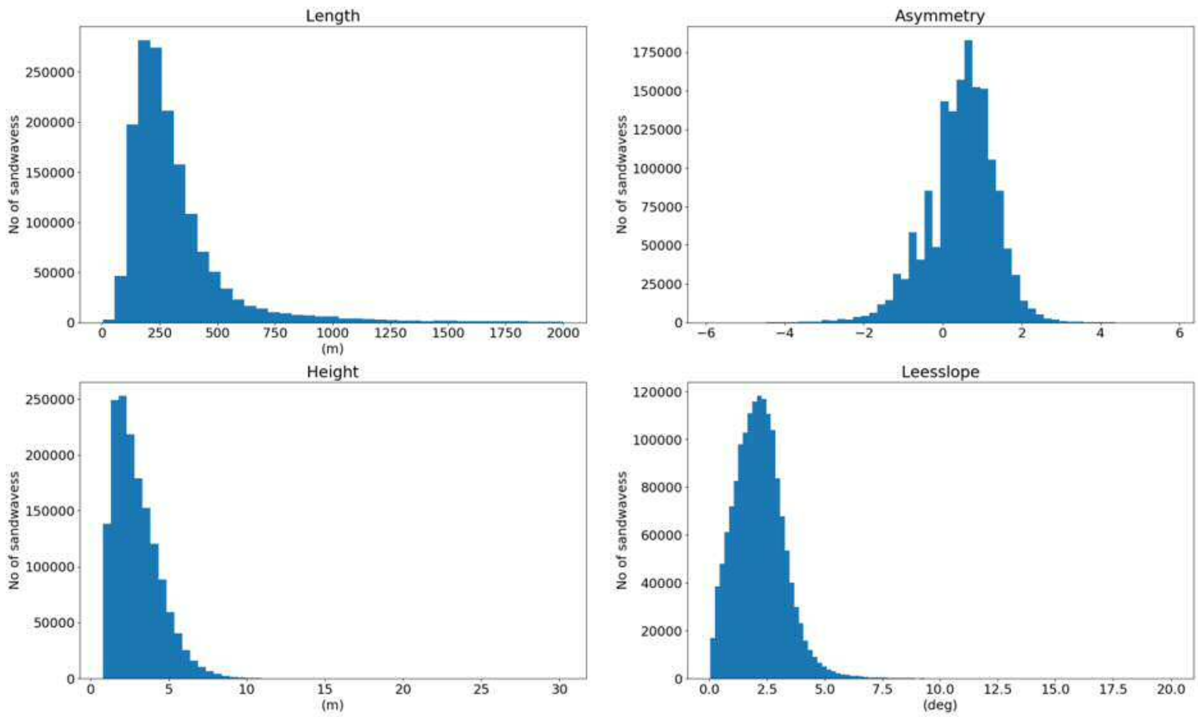

Figure 3. Distribution plots of lengths, asymmetries, heights and lee-slope angles of all sand waves on the NCS (n = ~1.5 million observations, after data repository Damen et al., 2018b). Most common lengths are 150-250 m, most common heights are 1-2 m, most sand waves are asymmetric, and lee-side slopes are mostly between 0.5 and 5 degrees, although slopes up to more than 11 degrees occur.

tidal current velocity, residual current, significant surface wave height and median grain size), sand waves were binned, in order to separate areas where four out of five parameters are more or less ‘constant’ and where merely one parameter varies. Most correlation results of the primary parameters with morphology were weak, thereby falsifying the hypotheses, except for median grain size and sand wave height (Fig. 4), and for the tidal (M2) current velocity and sand wave length.

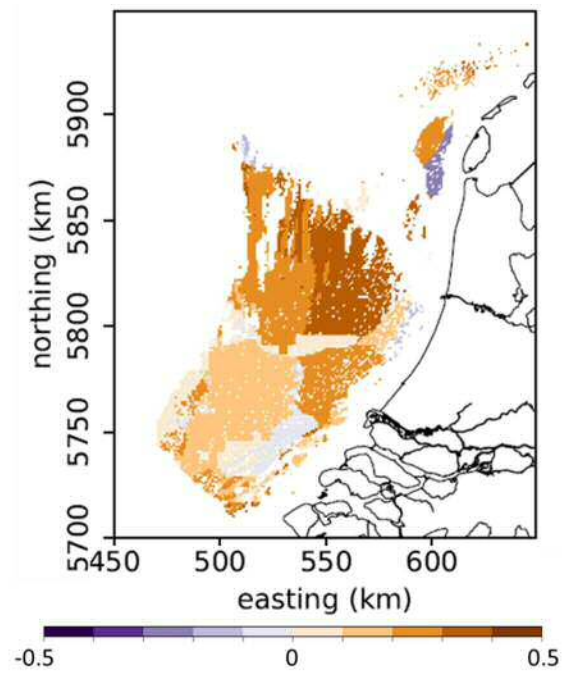

Figure 4. Correlation values (colour scale) of median grain size (D50) and sand wave height in bins of ‘constant’ water depth, tidal current and wave regimes (after Damen et al, 2018a).

Bi-variate plots were used to visualise the strengths of the correlations and to reveal limits of local conditions for sand wave occurrence and morphology.

The correlations, however, do not explain the variation in morphology in full. An inverse approach, of identifying areas of contrasting sand wave morphology and finding out the ranges and limits of local environmental parameters may provide additional insight.

ii. 2.1.2 Correlation to processes of sediment transport

Since the primary parameters were not conclusive, sand wave morphology was correlated to marine processes, such as the Rouse number of the mode of transport, Shields parameters of incipient motion for both the tide and waves, and the residual bed load transport (Damen et al,. 2018a). Out of these, the Rouse number seems the dominant factor for sand wave lengths, and heights, as well as asymmetries.

2.2 Sand wave dynamics

Sand wave migration rates were determined from single- and or multibeam time series at a number of sites distributed on the NCS and were found to be between 0 m/yr (stable) offshore Rotterdam and 20 m/yr near the Wadden island Texel. Migration directions were found to be to the south-west and to the north-east both on the larger shelf scale and more locally, the latter related to larger-scaled morphology, such as sand banks (e.g., Fig. 5). Although, to date not as quantitative as the morphologic results, the spatial variation in sand wave migration may be correlated to environmental parameters in a similar way as was done for morphology.

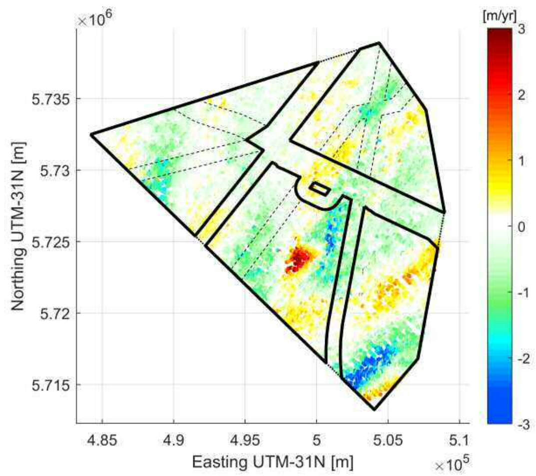

Figure 5. Example of opposite sand wave migration directions for the offshore wind farm site Borssele, over the period 2000 to 2015, based on 29522 transects (updated from Deltares, 2015). Colour scale is sand wave migration rates (m/year) with negative values (blue) indicating sand wave migration towards southwest and positive values (red) indicating sand wave migration towards northeast.

3 DISCUSSION

When the morphologies of sand waves on the NCS are compared to sand waves on other continental shelves, sand waves on the NCS are relatively high, exceeding the empirical relationship of Allen (1968) for heights as function of water depth, $H = 0.086d^{1.19}$. However, giant sand waves reported in the literature (e.g. Franzetti et al., 2013) exceed these heights even more. The new data reveal a new empirical relationship on steepness (Damen et al., 2018; see also Flemming, 2000).

4 CONCLUSIONS

The quantification of all sand waves on the Netherlands Continental Shelf reveals the distributions of sand wave lengths, heights, asymmetries and lee-slope angles. Correlating the primary parameters depth, tidal current velocity, residual current, significant surface wave height and median grain size to the morphology and dynamics of sand waves, most parameters were weak, except for median grain size (D50), which seems to control the occurrence and heights of sand waves, and the tidal current velocity seems to control the wavelength. Of the sedimentary processes, the Rouse number of sediment transport mode seems to control lengths, heights and asymmetries.

Sand wave migration rates vary between 0 m/yr near Rotterdam and 20 m/yr near Texel. Where the morphology seems to be controlled by D50, Shields parameter for tides, and the residual bed load transport, migration rates may be explained in a similar manner.

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