Spatial variations in sand waves superimposed on sand banks: an automated analysis method

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ABSTRACT: Sand waves superimposed on sand banks may vary in morphology due to variations in local conditions. Apart from scientific reasons to understand the processes controlling sand wave shapes, these variations are also relevant to safe navigation and offshore engineering projects. Previous research reported variations in sand wave shape and migration over sand banks based on local observations. However, quantification of shape variations for all individual sand waves in a sand wave field remains to be investigated. In this study we present a 2D approach to analyse sand wave height and asymmetry. It is applied to two study sites in the North Sea where sand waves are superimposed on sand banks. The results show that the sand wave heights only vary over sand banks at one of the locations and that asymmetry varies in magnitude and direction at these sites.

1 INTRODUCTION

Sand wave shapes are determined by various processes, such as the tidal flow (Hulscher, 1993) and storms (Le Bot, 2000). Sand banks, larger-scale topographic features, cause local variations in these processes which may lead to varying shapes of sand waves superimposed on sand banks (Houthuys, 1994; Lanckneus and De Moor, 1995; Deleu, 2004). A commonly applied method to determine sand wave shape characteristics uses an analysis of representative transects perpendicular to the sand wave crests (e.g. Van Dijk et al., 2008; Van Santen et al., 2011; Franzetti et al., 2013). This method is highly dependent on the chosen transect location and orientation. The sand wave shape characteristics of an individual transect are determined based on the positions of the crests and troughs, which has previously been done both manually (Franzetti et al., 2013) and using an automated approach (Van Dijk et al., 2008; Duffy, 2012).

Duffy (2012) presented a method that was able to analyse 2D data of sand waves by scanning all transects of the data in the direction of the largest bed level variation.

When using the direction of largest variation, other bed features (e.g. megaripples, sand banks and dredged areas) may hinder an accurate estimate of the sand wave direction. For a large quantified account of the North Sea sand waves, the analysis methods should be applicable in areas with other bed features.

For this study we propose a Fourier-based analysis to separate sand waves from other bed forms in order to determine sand wave orientation.

We aim to describe the variation in sand wave morphology over sand banks. To this end, we improved existing methods from Van Dijk et al. (2008) and Duffy (2012) for the automated determination of sand wave shape characteristics. Our improved method is applied to two study areas with sand waves superimposed on sand banks (figure 1). The first area is located near the Brown Bank; here sand waves have typical wavelengths between 200 and 1000 m. The second study area is located at the Hinder banks and contains sand waves with wavelengths between 200 and 400 m.

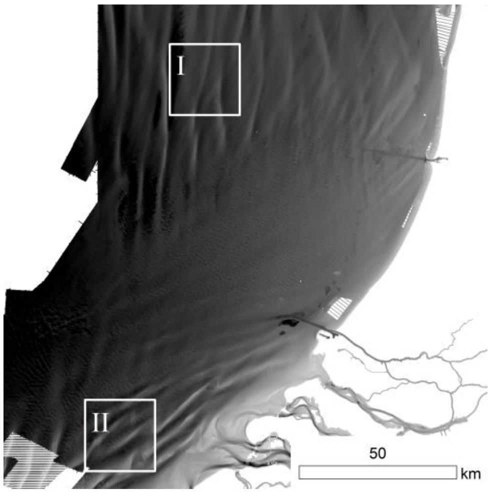

Figure 1: Study locations in the Southern Bight that contain sand waves superimposed on sand banks. Study area I is located in the northern part of the Southern Bight and study area II is located at the Hinder banks.

2 METHODS

2.1 Sand wave orientation analysis

A 2D Fourier analysis is applied to the bathymetry data to determine the orientation of the sand waves. The Fourier analysis of bed forms results in point clusters, separating the different types of bed forms depending on orientation and wavelength (Knaapen et al., 2001; Van Dijk et al., 2008). A line is fitted through the wave numbers that fall within the definition of sand waves (wavelength between 100 and 1000 m) by minimizing the residual sum of squares

$$RSS = \sum \epsilon_i^2 = \sum_{i=1}^{M} \sum_{j=1}^{N} \left(D_{i,j} * A_{i,j} \right), \quad (1)$$

where $D_{i,j}$ is the distance of a point in the Fourier space to the trend line and $A_{i,j}$ is the amplitude of an individual wave in Fourier space. The orientation of the trend line is derived as the direction perpendicular to the sand wave crests.

2.2 Sand wave shape analysis

Sand wave height h is defined as the vertical distance from the crest to the baseline that connects the two adjacent troughs (see figure 2). Sand wave asymmetry A is defined as follows:

$$A = \ln\left(\frac{L_1}{L_2}\right), \quad (2)$$

where L_1 is the distance from a trough to the next crest and L_2 the distance from that crest to the following trough. A purely symmetric sand wave is characterised by $A = 0$, whereas the sign of A reveals the direction of the asymmetry.

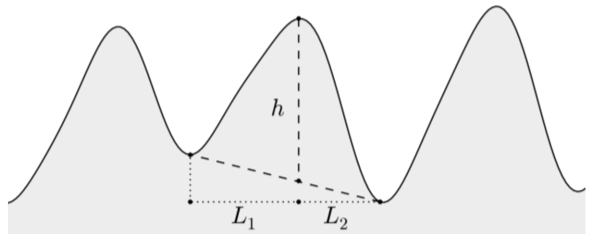

Figure 2: Definition of sand wave height h and lengths L_1 and L_2 used in the definition of the asymmetry A.

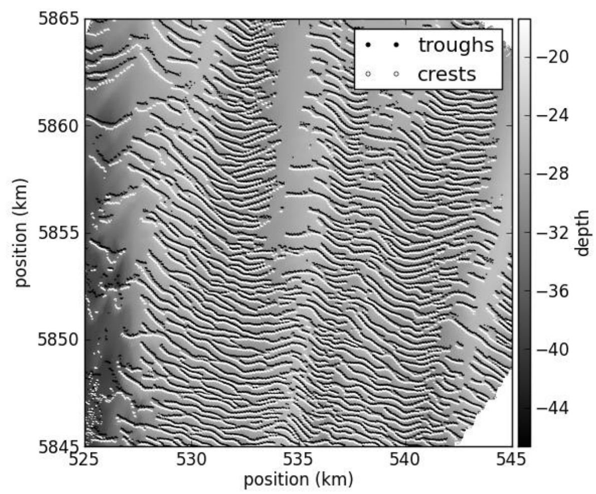

Figure 3: Sand wave bathymetry with crest and trough positions detected for a part of study area I using the method described in section 2.2.

For each transect perpendicular to the orientation of the crest lines, as derived in section 2.1, the peaks and troughs are detected (see also Duffy, 2012). To exclude bed forms smaller than sand waves, a moving average is applied to the transect data with a window size just below the minimum wavelength (100 m). Based on the slope of the smoothed bed elevation the positions of the crests and troughs are determined (see Van Dijk et al., 2008). The smoothing process leads to a reduced sand wave height (Van Dijk et al., 2008). To correct for this undesired effect, the buffering

technique suggested by Duffy (2012) is applied. The sand wave crests and troughs detected for area I are shown in figure 3.
A threshold for sand wave height of 0.5 m is used to remove remaining small-scale bed patterns from the results. This was done by iteratively removing the smallest bed form below the threshold.
Sand waves will be compared in terms of their position on a sand bank, differentiating between the sand bank trough, the lee flank, the crest and the stoss flank. This classification is based on the slope of the smoothed bathymetry data.

3 RESULTS

The high-resolution analyses of all sand waves in the study areas result in spatial distributions (maps) of sand wave height and asymmetry (for example, the asymmetry at site I in figure 4) and scatter plots (figures 5 to 8). These scatter plots show that sand waves at the Hinder Banks are higher and less asymmetrical (area II) than those at the Brown Bank (figures 5 - 6 and 7 - 8, respectively) and that the shape characteristics of sand waves vary over sand banks. Preliminary results for location I reveal that sand waves are both higher (figure 5) and more asymmetrical (figure 7) at the sand bank crest. This effect is not evident at location II. However, at location II, the asymmetry direction of the sand waves varies systematically over the banks (not shown here), with the steep sides of sand waves to the NE ($A = 0.5$) on the eastern flanks and to the SW ($A = -0.4$) on the bank crests and western flanks (this corresponds to earlier findings by Jones et al., 1965 and Lanckneus et al., 1995). The zonation and comparison based on sand bank position should provide more insight into these differences.
The horizontal line pattern visible in the asymmetry plots (figures 7 and 8) is the effect of a discrete mapping of crests and troughs to the data cells. Some ratios are therefore more common than others. This effect becomes smaller when sand waves have longer wavelengths or when the data resolution is higher.

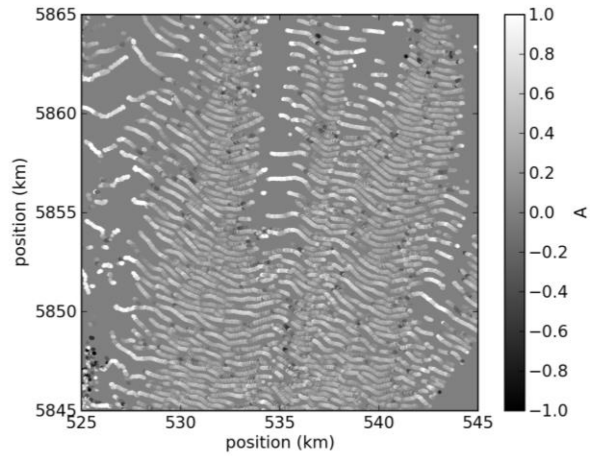

Figure 4: Sand wave asymmetry for study area I denoted at the sand wave crests.

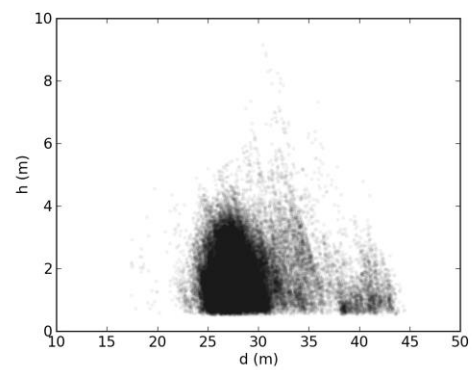

Figure 5: Scatter plot of sand wave height versus water depth above the crests. Each dot represents a single sand wave crest point detected in study area I.

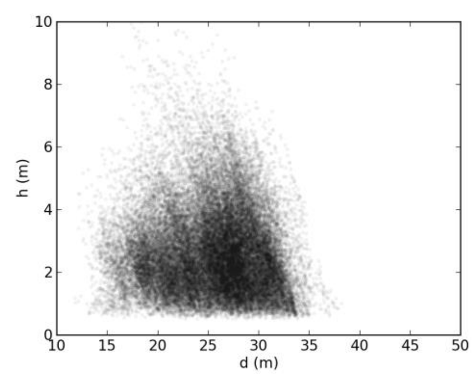

Figure 6: Scatter plot of sand wave height versus water depth above the crests. Each dot represents a single sand wave crest point detected in study area II.

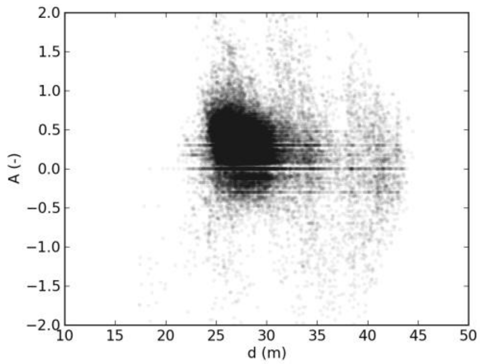

Figure 7: Scatter plot of sand wave asymmetry versus water depth. Each dot represents a single sand wave crest point detected in study area I.

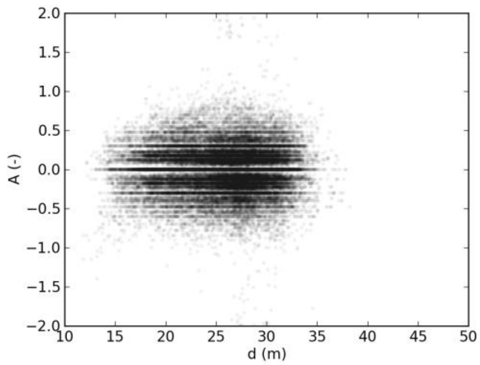

Figure 8: Scatter plot of sand wave asymmetry versus water depth. Each dot represents a single sand wave crest point detected in study area II.

4 CONCLUSION

Sand wave height and asymmetry vary depending on their position on the sand banks. For the study area near the Brown Bank both sand wave height and asymmetry are larger at the sand bank crest. At the Hinder Banks, the direction of the asymmetry varies over the bank.

Further research in the “SMARTSEA”-PhD project is aimed at unravelling the controlling processes of the variations of sand wave morphology and dynamics over sand banks.

5 ACKNOWLEDGEMENTS

This research is supported by the Dutch Technology Foundation STW, which is part of the Netherlands Organisation for Scientific Research (NWO), and which is partly funded by the Ministry of Economic Affairs.

The data used in this study were made available by the Netherlands Hydrographic Office of the Royal Netherlands Navy.

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