

Seabed morphology and dynamic in the Hollandse Kust Zuid and Borselle windfarm zone

The Hollandse Kust Zuid (HKZ) and Borselle windfarm zone possess a diverse seabed morphology (Figure 1) and a significant seabed dynamic. Different bedforms exist in both areas (Table 1). The seabed morphology can be described by the length, height, steepness and asymmetry of the bedforms and the seabed dynamic by the growth and migration of the bedforms. This documents describes the seabed morphology and dynamics of the HKZ in detail while for the Borselle windfarm zone only the figures are presented and crucial bedform parameters are listed in Table 1.

Seabed morphology

Megaripples with a wavelength between 6 and 12 m are superimposed on sand waves with wavelengths varying from 200 to 1050 m (Figure 3). The orientation of the sand waves and megaripples is relatively equal, with a general orientation perpendicular to the shore and a migration towards the north-northeast. Megaripples reach heights of up to 50 cm. Sand wave heights vary between 1.5 and 5 m in the western part and 1 to 3 m in the eastern part of the study area.

While the shape of the sand waves is relatively consistent over the entire study area, the shape of the megaripples varies. In the western part of the study the megaripples are straight crested with a slope of up to 11 degrees, whereas towards the east the megaripples are more curved and with a more gentle slope of maximum 5 degrees. This observation can be seen in Figure 1, where the slope map indicates steeper slopes (yellow colours) between the sand waves in the western compared to the eastern part. The slope of the sand waves reaches values of up to 20 degrees. An example of the morphology representative for the western part of the HKZ is given in Figure 2 and Figure 3 .

Seabed dynamic

Overlapping areas between adjacent multibeam echosounder lines with a time difference up to 10 days indicated significant bedform migration of megaripples within the HKZ (see Appendix for a detailed explanation of a multibeam echosounder). Due to the lack of a proper time series of MBES measurements, an accurate estimation of the migration rate of the megaripples was not feasible. However, scientific studies have indicated that the migration rate increases with decreasing bedform height (Wever, 2014). Existing literature indicates a migration rate for megaripples in the decimetre scale per day; with up to 50cm/day for megaripples with a height of 50 cm (Wever, 2014). Sand waves are consequently more temporally stable. Still, modelling studies have indicated sand wave migration between 0 and 10 m/year for the North Sea (Nemeth et al., 2002). Paulsen et al. (2016) have classified the HKZ as dynamic based on the sand wave migration. They estimated the average migration speed between 0.7 and 3.0 m/year. In general, the migration speed is higher in the southern part where for some areas migration rates reach up to 5.2 m/year. While megaripple and sand wave migration result in a dynamic seabed, the general sand wave shape remains unaltered in the HKZ. This was demonstrated for the southern part of the HKZ by Paulsen et al. (2016), in which they compared a historical bathymetry chart with the recent MBES measurements taken 16 years later. Although the long-term shape remains unaltered, it should be noted that short-term variation can occur (e.g., Van Santen et al., 2011).

Migration direction and rate are controlled by the residual current but can also change with varying wave action (van Dijk et al., 2005; Sterlini et al., 2012). Storm events can alter the morphology and dynamic of the seabed on a short term and might play a role in the HKZ as well (Paulsen et al., 2016).

Studies in the North Sea indicate that storm events yield to a smoothing of the morphology with a reduction of sand wave heights up to a disappearing of megaripples (e.g., Houthuys et al., 1994). However, other studies also indicate that storms may create bedforms, such as hummocks (e.g., Passchier et al., 2005). Therefore, the exact acquisition of the MBES data relatively to the storm event is important.

Table 1 Bedform characteristics in Hollandse Kust Zuid and Borssele windfarm zone. Migration rates and directions of sand waves are calculated by Paulsen et al. (2016) and migration rates of megaripples are rough approximations taken from Wever (2004).

Bedform	Characteristic	Hollands Kust Zuid	Borssele
Megaripples	Wave length	6 to 12 m	8 to 15 m
	Wave height	up to 50 cm	up to 50 cm
	Migration rate	Up to 50cm/day	Up to 50cm/day
Sand waves	Wave length	200 to 1050 m	120 to 430 m
	Wave height	1 to 5 m	1.6 to 7 m
	Migration rate and direction	0.7 to 5.2 m/year; NE direction	1.6 to 1.8 m/year; NE and SW direction
Sandbank	Wave length	-	varies
	Wave height	-	up to 20 m
	Migration rate	-	stable

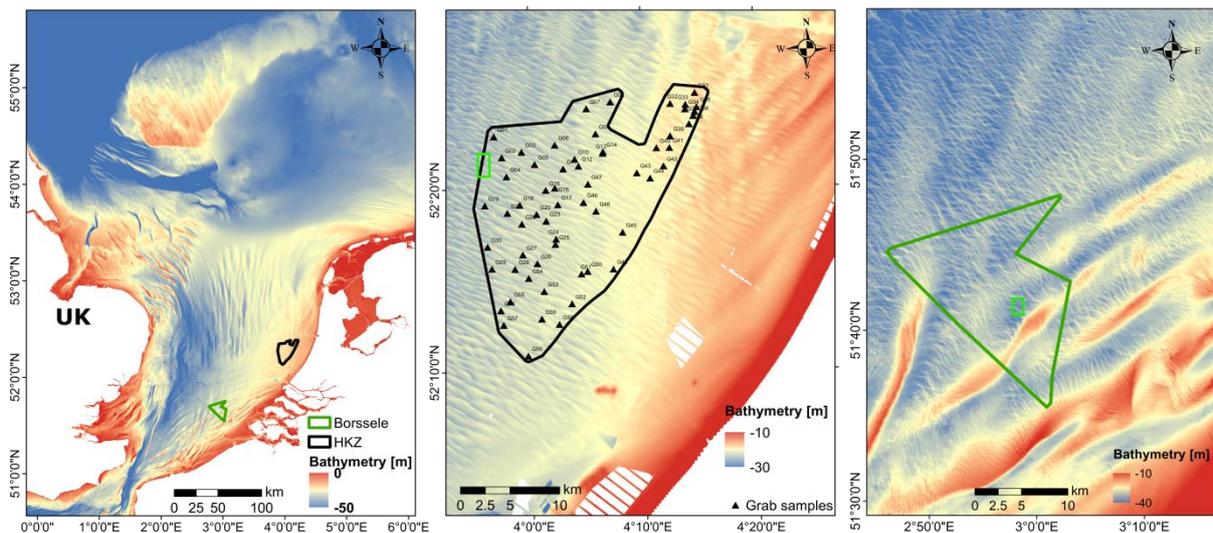


Figure 1 (Left) Bathymetry of the North Sea (EMODnet, 2018) including location of HKZ and Borssele. Grid cell size is 178 m. (Middle) High-resolution bathymetry of HKZ (50 cm). (Right) High-resolution bathymetry of Borssele (50 cm). Green polygon indicate areas presented in Figure 2 and 4.

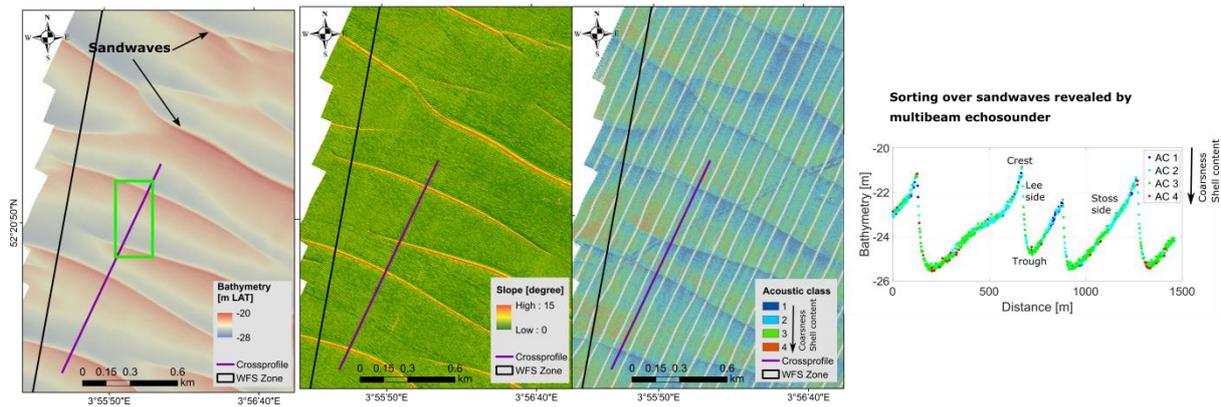


Figure 2 Subset area in the western part of HKZ. (From left to right) Bathymetry, slope, acoustic classification and crossprofile showing sediment sorting along sand waves. The grid cell size is 50 cm for the bathymetry and slope map and 2 m for the acoustic classification map. Green polygon indicates subset area presented in Fig. 3.

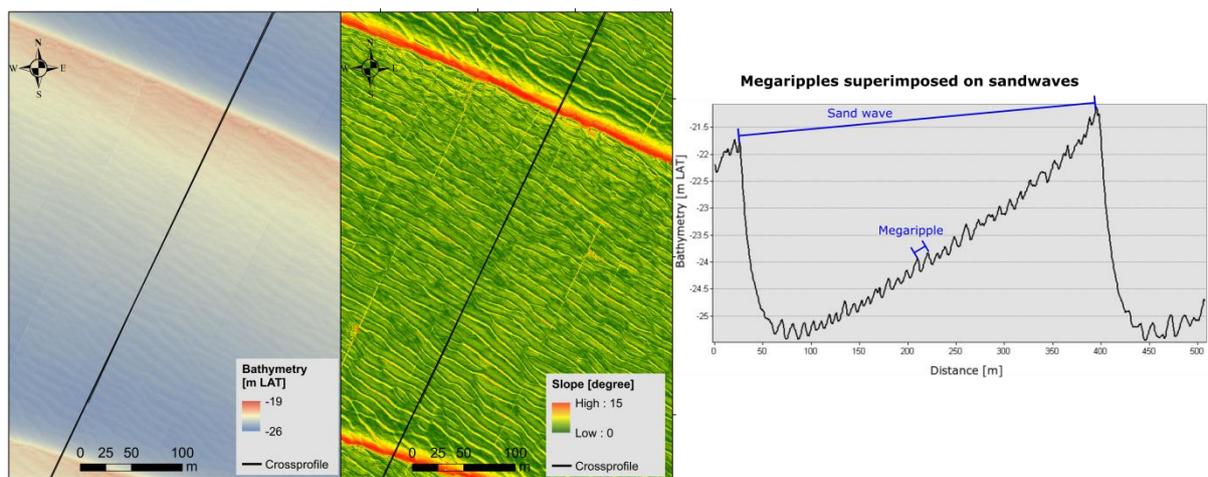


Figure 3 Subset area in the western part of HKZ. (From left to right) Bathymetry, slope and crossprofile showing megaripples superimposed on sandwaves. The grid cell size is 50 cm.

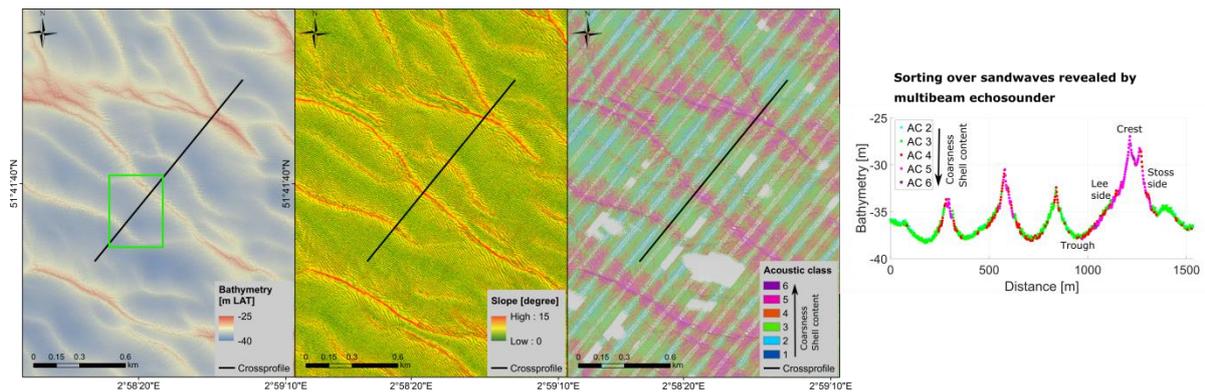


Figure 4 Subset area in the centrum of Borssele windfarm zone. (From left to right) Bathymetry, slope, acoustic classification and crossprofile showing sediment sorting along sand waves. The grid cell size is 50 cm for the bathymetry and slope map and 2 m for the acoustic classification map. Green polygon indicates subset area presented in Fig. 5.

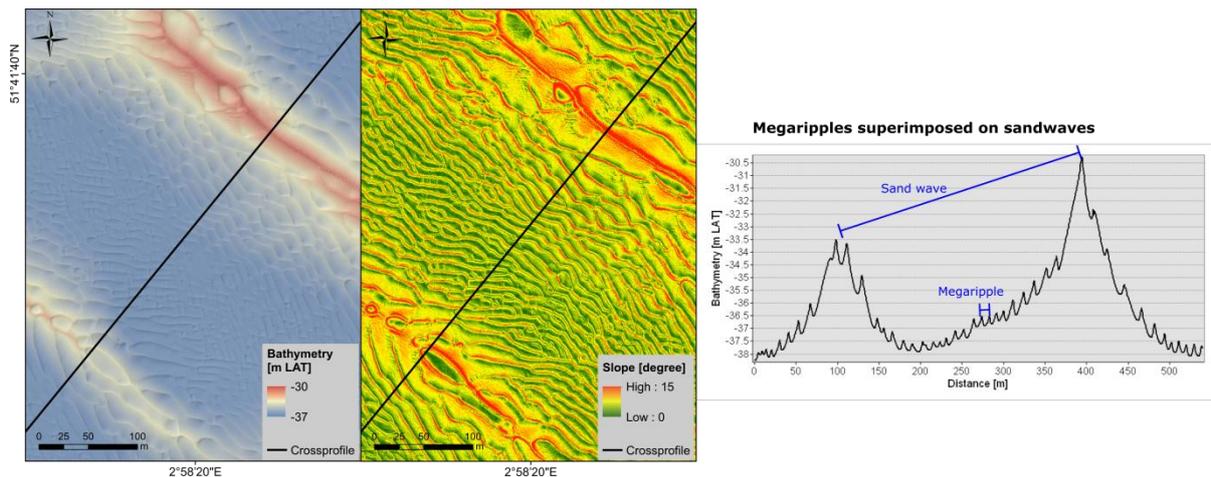


Figure 5 Subset area in the centrum of Borssele windfarm zone. (From left to right) Bathymetry, slope and crossprofile showing megaripples superimposed on sandwaves. The grid cell size is 50 cm.

Literature

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