Multi-scale analysis of sandbank features optimising geomorphological mapping of sandy shelf environments: Belgian part of the North Sea

Lars Kint *Royal Belgian Institute of Natural Sciences, Belgium – lkint@naturalsciences.be*
Nathan Terseleer *Royal Belgian Institute of Natural Sciences, Belgium – nterseleerlillo@naturalsciences.be*
Vera Van Lancker *Royal Belgian Institute of Natural Sciences, Belgium – vvanlancker@naturalsciences.be*

ABSTRACT: Low- and high-resolution digital bathymetry models are freely available as interoperable gridded data layers and data products. The higher resolution data, together with increasing data analyses tools, give new impetus to a more uniform geomorphological mapping of wider marine areas. To test approaches in sandy shelf areas, a multi-scale analysis is performed on data from the Belgian part of the North Sea using the Bathymetric Position Index (BPI). A comparative study of the calculated surface area and the perimeter (or contour) of sandbank features is illustrated using measures of accuracy, complexity or detailedness.

KEYWORDS: Bathymetric Position Index (BPI), marine geomorphology, resolution, sandbank features, scale factor.

1 INTRODUCTION

Rapid access to reliable and accurate data is vital in addressing threats to the marine environment (e.g., in relation to policy and legislation-oriented measures, understanding trends and rare events, forecasting future changes). European marine data projects such as Geo-Seas (FP7), EMODnet (DG MARE), SeaDataNet (FP7, Horizon 2020) are influential in standardizing and harmonizing marine datasets allowing subsequent use by scientific institutes, organisations and services, authorities, industry, universities and schools.

An abundance of bathymetric charts has been released in the last decade, comprising single beam and/or multibeam datasets at low to high resolution and combined over several sea basins. This evolution triggers the re-awakening and renewal of geomorphological mapping over wider areas, but also at higher resolution for dedicated applications (e.g., Marine Spatial Planning, Habitat Directive; or supporting industrial design). Still ‘no one size fits all approach’ exists and testing of most suitable parameterization is needed.

Determining geomorphological seabed features from bathymetric datasets is strongly dependent on the resolution and the scale factor of the bathymetry, as well as its data quality. A case study on sandbank features on the Belgian part of the North Sea (BPNS) has been worked out in a GIS environment using the Benthic Terrain Modeler (Lundblad et al., 2006).

1.1 A tidal wave of bathymetric data and charts

Under the impetus of Europe’s Integrated Maritime Policy, the European Marine Observation and Data Network (EMODnet) collects fragmented and scattered marine data. Harmonization and standardization allow use of the data by a wider community, creating new opportunities for research and innovation in ‘blue growth’. Data archives are managed by regional and national organisations, whilst the data products, interoperable and quality-controlled, are managed centrally (e.g., www.emodnet.eu).

The gateway to bathymetry data is EMODnet Bathymetry (http://www.emodnet-bathymetry.eu), bringing together hydrographic surveys and other professionals in bathymetric data collection, processing and management. The main data product, the Digital Terrain Model (DTM) or Digital Elevation Model (DEM), is based on three types of bathymetric data sources: 1. High-resolution bathymetric data from single and multibeam echo sounding, combined with historic leadline soundings where needed; 2. Gridded bathymetry datasets, provided by Hydrographic Offices producing and maintaining nautical charts following international procedures; 3. GEBCO Digital Bathymetry as the minimum resolution (1/2 arc minutes interval grid), where data gaps still exist.

In October 2016 EMODnet Bathymetry released a major update of the European digital bathymetry model. The grid resolution of the DTM was increased from the 1/4 x 1/4 arc minutes of the February 2015 version to a grid with 1/8 x 1/8 arc minutes (± 230 by 230 meters) covering all European seas (e.g., Adriatic Sea, Aegean Sea, Baltic Sea, Barents Sea, Black Sea, Celtic Sea, Ionian Sea, Icelandic Sea, Levantine Sea, Mediterranean Sea, North Sea, Norwegian Sea). A new version is available for download since mid-September 2018, upgrading the grid resolution to 1/16 x 1/16 arc minutes (± 115 by 115 meters). Both digital bathymetry models are available via the viewing and downloading service of the EMODnet Bathymetry data portal (http://portal.emodnet-bathymetry.eu).

Apart from international initiatives, Hydrographic Services may still release higher resolution data and/or gridded datasets. For the BPNS, a first DTM, at a resolution of 80 m, was produced in 2006 based on data from the Maritime Services and Coast Agency, Flemish Hydrography, completed with data from the Hydrographic Office of the Netherlands and the United Kingdom. This grid was used for the mapping of sandbank features (Verfaillie et al., 2007; Verfaillie, 2008), as well as marine landscapes (Verfaillie et al., 2009). Recently, Flemish Hydrography made available a DTM at a grid resolution of 20 by 20 meters, combining single beam (2004-2010) and more recent multibeam (post 2010) echo sounding data (table 1), a high-resolution patchwork quilt.

Table 1. Resolution of available digital bathymetry models.

Name	Year	Resolution [m]
EMODnet bathymetry	2016	230x230
	2018	115x115
Flemish Hydrography	2006	80x80
	2016	20x20

1.2 Sandbank features off the Belgian part of the North Sea

The BPNS, with a coastline of approximate 65 km and an area covering 3454 km², is situated in the southern bight of the North Sea and is geomorphologically characterized by the presence of four sandbank systems, several swales and many sand waves and (mega)ripples formed by the interaction between water movement, i.e. local tidal and wind-driven currents, sediment transport and seabed nature. The overall water depth reaches from 0 to 40 meters LAT (Lowest Astronomical Tide).

A series of NE-SW trending linear sandbanks are developed in the BPNS, commonly asymmetric in cross-section and kinked in their plan view, but rather stable in position (Van Cauwenberghe, 1971). With a height up to 20 meters and display angles of 0 to 20 degrees relative to the main axis (Kenyon et al. 1981), these long ridges of tens of kilometres in length are often overlain by superimposed NW-SE trending sand waves and (mega)ripples with spatially-variable asymmetric patterns. Their height and wavelengths are typically 4 to 8 meters, and 200 meters respectively. Their migration changes over relatively short time intervals (Trentesaux, 1993; Houthuys et al., 1994; Lanckneus et al., 1994; Terseleer et al., this volume), but is typically in the order of 20 meters (Lanckneus et al. 2001).

Four systems with elongated sandbanks are distinguished: the Coastal Banks nearshore, the Flemish Banks located in the southwest, the Zeeland Banks in the northeast and the Hinder Banks offshore (figure 1). The Coastal and Zeeland Banks are quasi parallel to the coastline, while the Flemish and Hinder Banks have a rather oblique position.

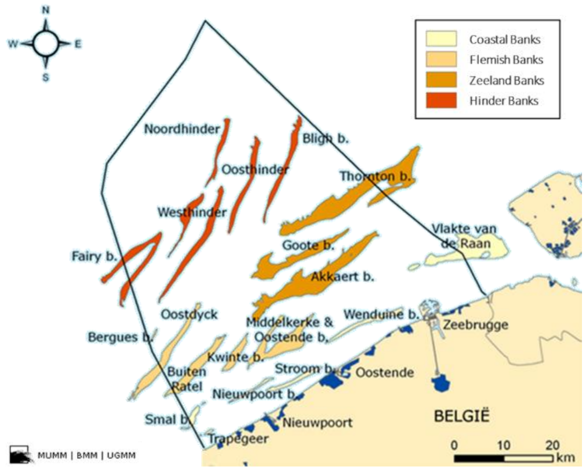

Figure 1. Simplified representation of the sandbanks on the Belgian part of the North Sea, based on the main contour lines. Small-scale sandbanks are missing.

2 BENTHIC TERRAIN MODELER

The Bathymetric Position Index (BPI) (Lundblad et al., 2006), part of the Benthic Terrain Modeler (BTM) toolbox in ArcGIS, is a marine modification of the Topographic Position Index (TPI) algorithm developed by Weiss (2001), and was initially used to classify the terrain on land. It allows metric calculations where a georeferenced location with a defined elevation is relative to the overall surrounding landscape, the second order derivative of the surface from an input single or multibeam bathymetric dataset. The algorithm compares each cell’s elevation to the mean elevation of the surrounding cells within a user defined inner and outer radius of a rectangle, annulus (donut shape) or circle. Using negative bathymetry data, a cell lower than its neighbouring cells gets a negative BPI (valleys), a cell higher than its neighbouring cells a positive BPI (ridges). This results in a map with geomorphological features like crests (+BPI), depressions (-BPI), constant slopes and flat areas (zero BPI). Distinction between flats and slopes, the first order derivatives, is based on a user-defined threshold. For the BPNS this is 0.65 degrees, a value equal to the mean slope value of the slope map multiplied by 0.6 standard deviation (Burrough & McDonnell, 1998; slope classification from Burrough & McDonnell, 1999). A broad-scale BPI (B-BPI) is used to determine the large geomorphology structures, a fine-scale BPI (F-BPI) for the smaller features (figure 2). For the standardization of the raw BPI, both B-BPI and F-BPI are needed. The bathymetric data tend to be spatially autocorrelated (i.e. locations that are closer together are more related than locations that are farther apart), allowing classifications against a defined dictionary of fine- and broad-scale BPI values, slopes and depths on almost any scale (Weiss, 2001).

Verfaillie et al. (2007) applied the BPI on datasets of the Belgian and Netherlands part of the North Sea (NPNS). A scale factor of ± 1600, an outer radius of 20 meters multiplied by the grid resolution of 80 meters, for the B-BPI and a scale factor of ± 240 for the F-BPI, outer radius of 3 meters, was found most appropriate for the sandbank features on the BPNS and NPNS (Verfaillie et al., 2007). Comparative scale factors are now used for the EMODnet bathymetry datasets with a resolution of 230 by 230 meters and 115 by 115 meters, as well as for the Flemish Hydrography data grid with a resolution 20 by 20 meters. Also, other scale factors (table 2) were tested for the latter high-resolution bathymetry. Results were filtered with a minimum surface of 1 km² (1 000 000 m²) to distinguish the sandbank crests from the smaller remaining features (e.g., sand waves

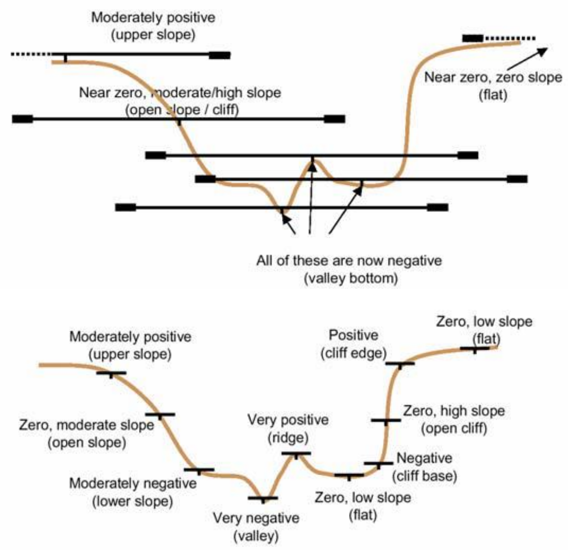

Figure 2. Top: a broad-scale BPI (B-BPI) is used to determine the large-scale geomorphological structures. Bottom: a fine-scale BPI (F-BPI) represents the smaller features.

and other small crests). Depressions, slopes and flats have not yet been charged. On the 80 by 80 meters resolution map of Verfaillie et al. (2007), based on only single beam echo sounding data, a threshold of 300 000 m² was used.

3 RESULTS

Analysis of the 230 by 230 meters resolution dataset of the BCS, resulted in extra ridges in front of the Bergues Bank, Fairy Bank, Leopold Bank, Smal Bank, the northernmost bank and the bank north of the Fairy Bank, creating an extension of the sandbanks. The surface area in km² and perimeter (contour) in km, without those low-resolution additions, are listed in table 3. Even though the resolution gets a dozen times better in the 20 by 20 meters resolution, several sandbanks remain having a constant surface area (+/- 15 %). This is the case for the Bergues Bank, Bligh Bank, Buiten Ratel, Fairy Bank, Hinder Banks (Noord-, Oost- and Westhinder) and Oostdyck. A 15 to 60 % increase of the perimeter was instead calculated. For all other sandbanks, the surface area decreased drastically with better resolution. High contours are representative in the highest resolution for the Broers Bank (+98.4 %), Kwinte Bank (+65.2 %), Leopold Bank (+89.6 %), Middelkerke Bank (+36.9 %), Smal Bank (+69.6 %) Stroom Bank (+10.4 %), Thornton Bank (+135.8 %), the intermediate bank between the Buiten Ratel and Oostdyck (+34.2 %), the northernmost bank (+136.0 %) and the bank north of the Fairy Bank (+262.9 %), while lower contours are consistent for the nearshore banks, Nieuwpoort Bank (-9.8 %) and the intermediate sandbank between the Nieuwpoort and Wenduine Bank (-28.8 %). The coastal banks, Oostende Bank and Wenduine Bank, only occur from the analysis on the lowest resolution (230 by 230 meters), similar to the appearance of the extensional ridges as described above. The Akkaert Bank and Goote Bank are topographically expressed as sandbanks. However, they disappear or shred in two or three with higher resolutions (115 by 115 meters and 20 by 20 meters).

Table 2. Broad- and fine-scale BPI applied to the digital bathymetry models.

	Inner [m]	Outer [m]	Resolution [m]	Scale factor
B-BPI				
20x20	1	80	20	1600
20x20	1	60	20	1200
20x20	1	40	20	800
20x20	1	20	20	400
80x80	1	20	80	1600
115x115	1	14	115	1610
115x115	1	7	115	805
230x230	1	7	230	1610
F-BPI				
20x20	1	12	20	240
20x20	1	9	20	180
20x20	1	6	20	120
20x20	1	3	20	60
80x80	1	3	80	240
115x115	1	2	115	230
115x115	1	1	115	115
230x230	1	1	230	230

4 DISCUSSION

A fitted scale factor of 1600 for the B-BPI and 240 for the F-BPI, as proposed by Verfaillie et al. (2007) for the BPNS, was adopted. With decreasing scale factors on the same resolution of 20 by 20 meters (B-BPI: 1600-1200-800-120; F-BPI: 240-180-120-60), the surface area and perimeter of the sandbank features minimized, until some of them disappeared by the BPI algorithm. Sandbanks were thinning out, fell apart in multiple parts and faded or disappeared when using lower scale factors.

The sandbank features created by Verfaillie et al. (2007), based only on single beam bathymetry data at the time, proved to be not usable for comparing the surface area and perimeter in the multi-scale analysis. Although, the 80 meters resolution is much higher than the 230 by 230 meters or 115 by 115 meters bathymetry available via EMODnet, the fact that the latter also comprises multibeam overrules the importance of the resolution.

The sandbank extensions of Bergues Bank, Fairy Bank, Leopold Bank, Smal

Bank, the northernmost bank and the bank north of the Fairy Bank created in the lowest resolution analysis (230 by 230 meters), needed to be removed to make a correct comparison with the sandbanks at other resolutions (115 by 115 and 20 by 20 meters).

The results confirm that the surface area of the sandbank crests decrease with higher resolutions (or lower scale factors). The complexity or detailedness is reflected in the contours. With constant surface area, the higher the perimeter, the more complex the sandbank will be delineated. As such sandbank protrusion (large sand waves and small crests) will become more visible, being indicative for the varying tide-topography interaction (e.g., Bligh Bank, Buiten Ratel, Hinder Banks (Noord-, Oost- and Westhinder) and Oostdyck). And vice versa, the lower the perimeter, the less detailed and complex the sandbank will appear. (e.g., Nieuwpoort Bank and the intermediate sandbank between the Nieuwpoort and Wenduine Bank).

Some other coastal sandbanks, the Oostende Bank and Wenduine Bank, degraded with higher resolution from sandbanks to smaller and scattered sand crests, resulting in their disappearance on the 115 by 115 meters and 20 by 20 meters resolution map. The same applies for the reduction of the Akkaert Bank and Goote Bank, and the additional ridges of some sandbanks. This highlights the importance of resolving sandbanks on low-resolution datasets (e.g., 230 by 230 meters), and combine the results with a higher resolution analysis of small sand crests (e.g., 20 by 20 meters).

5 CONCLUSION

- Sandbank features off the BPNS are delineated with a fitted scale factor of 1600 B-BPI and 240 F-BPI.
- Multi-scale analyses are still needed, since the resolution will determine how a sandbank is delineated: continuous or as a grouping of multiple consecutive smaller crests.
- The perimeter (contour) can be a measure of accuracy, complexity or detailedness giving insight into varying tide-topography interactions.
- Since the delineations are dependent on the resolution and data quality upfront (e.g., single beam, multi-beam), BPI outcomes may become obsolete with future improvements of available datasets.
- The revisited BPI analysis assists in the creation of a new geomorphological map for the southern bight of the North Sea. It is envisioned to further incorporate the two-part classification system for seabed geomorphology of Dove et al. (2016).
- For the BPNS, smaller-scale bedforms and their dimensions will be included as well. Other topographical highs or lows will be incorporated, together with their origin, where possible.

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Table 3. Surface area and perimeter (contour) of BPNS sand banks (crest only) delineated on the basis of datasets with a resolution of 230 meters, 115 meters, 20 meters and B-BPI = ± 1600, F-BPI = ± 240.

	230x230		115x115				20x20			
Name	Area [km²]	Contour [km]	Area [km²]		Contour [km]		Area [km²]		Contour [km]	
COASTAL BANKS										
Broers Bank	7.98	17.09	2.25	-71.8%	13.32	-22.1%	2.87	-64.1%	33.90	98.4%
Nieuwpoort Bank	9.12	29.28	5.47	-40.0%	23.22	-20.7%	5.66	-38.0%	26.41	-9.8%
Nieuwpoort-Wenduine Bank	4.20	17.59	1.37	-67.3%	10.14	-42.3%	1.78	-57.6%	12.52	-28.8%
Smal Bank	9.71	24.92	5.09	-47.6%	21.62	-13.2%	6.48	-33.3%	42.26	69.6%
Stroom Bank	8.13	27.88	4.17	-48.7%	26.07	-6.5%	4.16	-48.8%	30.78	10.4%
Wenduine Bank	2.85	16.80	Na	Na	Na	Na	Na	Na	Na	Na
FLEMISH BANKS										
Bergues Bank	5.25	14.81	3.82	-27.4%	12.97	-12.4%	4.59	-12.7%	17.15	15.8%
Buiten Ratel	26.84	42.75	22.37	-16.7%	50.64	18.5%	25.27	-5.9%	58.92	37.8%
Kwinte Bank	23.99	73.00	14.46	-39.7%	56.65	-22.4%	19.79	-17.5%	120.60	65.2%
Middelkerke Bank	10.87	29.96	6.47	-40.5%	26.55	-11.4%	8.20	-24.6%	41.02	36.9%
Oostdyck	31.02	65.57	24.19	-22.0%	71.03	8.3%	27.72	-10.6%	93.35	42.4%
Oostdyck-Buiten Ratel	6.64	18.37	4.18	-37.0%	14.59	-20.5%	5.21	-21.6%	24.65	34.2%
Oostende Bank	8.79	41.33	Na	Na	Na	Na	Na	Na	Na	Na
Smal-Kwinte-Middelkerke Bank	3.74	12.94	2.35	-37.2%	10.24	-20.8%	2.56	-31.6%	12.90	-0.2%
HINDER BANKS										
Bligh Bank	18.80	59.09	12.64	-32.8%	60.33	2.1%	21.25	13.0%	93.43	58.1%
Fairy Bank	20.05	51.06	16.20	-19.2%	54.29	6.3%	17.88	-10.8%	62.15	21.7%
Noordhinder	32.35	94.81	22.78	-29.6%	94.24	-0.6%	31.67	-2.1%	125.85	32.7%
Oosthinder	31.18	89.96	21.31	-31.7%	102.86	14.3%	32.35	3.7%	125.74	39.8%
Westhinder	27.64	62.05	23.66	-14.4%	70.08	12.9%	28.67	3.7%	79.54	28.2%
bank north of the Fairy Bank	7.88	19.23	5.79	-26.5%	26.40	37.3%	6.07	-22.9%	69.79	262.9%
northernmost bank	11.79	31.50	6.87	-41.7%	38.22	21.3%	6.26	-46.9%	74.33	136.0%
ZEELAND BANKS										
Akkaert Bank	19.91	69.37	7.06	-64.6%	51.38	-25.9%	9.47	-52.4%	80.28	15.7%
Goote Bank	10.91	39.31	Na	Na	Na	Na	2.18	-80.0%	24.88	-36.7%
Leopold Bank	10.29	31.75	5.78	-43.8%	30.04	-5.4%	7.92	-23.1%	60.20	89.6%
Thornton Bank	25.13	55.96	17.44	-30.6%	62.40	11.5%	20.25	-19.4%	131.94	135.8%