Morphodynamics of the south Baltic seabed in the remote foreshore in the light of field measurements

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Abstract

The paper presents results of bathymetric surveys in the remote foreshore of the south Baltic (c.a. 1 – 2 Nm off the shoreline at depths of around 16 – 20 m). Measurements were collected twice in the vicinity of the Coastal Research Station (CRS) in Lubiatowo (Poland), first on November 2017 and then on December 2018. The study site is an area with hydrodynamics and lithodynamics typical of the south Baltic coast built of fine sands. The analysis is based on a differential map calculated from the bathymetric data obtained. The results show changes in the sea bottom ranging from a few to 70 centimeters. Sonar measurements were also made in 2017. The images revealed bottom ripples with an approximate height of 5 – 20 cm and length of 100 – 200 cm. The uniqueness of this research lies in the fact that at such depths there should theoretically be no significant changes at the sea bottom.

Keywords: bottom ripples; bathymetric and sonar survey; seabed level changes; differential map

Plain language summary

The field campaign was conducted in the south Baltic sea in the vicinity of the Coastal Research Station (CRS) in Lubiatowo (Poland). Data collected during measurements allowed to observe the differences in seabed at depth ranging from 16 to 20 m over one year. The results of this research show seabed level changes of magnitude from a few to 70 centimeters. The investigations also revealed the existence of big seabed forms or ripples at the study site with an approximate height of 5 – 20 cm and length of 100 – 200 cm. The detected bed forms migrate. These findings are an evidence of the movement of bottom sediments at depths where theoretically motion of water does not influence the nearbed layer significantly and the sea bottom sediments should not move.

1. Introduction

The intensity of changes in the seabed level is dependent on hydrodynamic impacts. In a region of shallow water near the shore, highly dynamic bathymetry changes are obvious because of wave-induced orbital velocities interacting with the forces of wave-driven

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currents. As the distance from the shore increases, however, the influence of these factors becomes weaker. In the remote foreshore of the south Baltic Sea, namely at depths of a dozen or so metres, sediment transport should theoretically be so slight as to cause no noticeable changes in the bottom level. In coastal research and engineering, the boundary where sediment transport is very small or non-existent is called the “depth of closure” (see Hallermeier, 1978, 1981; Kraus et al., 1998). However, the analysis of bathymetric data shows that significant changes may occur in the seabed at depths greater than 16 m. In addition, at the bottom of the southern Baltic, sand waves with heights of approx. 2 m, known as "sandbanks" or "sand waves," were observed. These features have been observed since 1995 in some sections of the Polish coast at depths of 15 to 30 m (Rudowski et al., 2008, Szefler et al., 2013). This kind of bed forms is typical of shallow tidal seas, and their development is due to intense tidal currents with velocities of 0.5 – 2.5 m/s (Carbajal and Montano, 2001). The causes of the appearance of these forms at the bottom of a non-tidal sea, such as the Baltic Sea, are not well known. The formation of sand waves is explained by a specific combination of hydrodynamic conditions prevailing in the remote foreshore (Rudowski et al., 2008). Another phenomenon observed in the vicinity of Władysławowo is the silting up of dredging pits at depths of approx. 14 – 17 m (Uścinowicz et al., 2014). It is worth noting that also in other non-tidal or micro-tidal basins (with similar hydrodynamic conditions) significant seabed changes may occur beyond the depth of closure. For example, unexpected enormous bottom changes occurred at Hujeong Beach, South Korea. During 2-3 days of storm conditions, when strong waves and currents occurred simultaneously, the seabed eroded by around 0.7 m (Do, J. D, et al., 2019).

Ostrowski et al. 2018 and Stella et al. 2019 explained possible causes of sediment movement in the remote foreshore. The results of their research on currents characteristic of a non-tidal shelf sea, such as the Baltic, suggest that the interaction of deepwater waves with a wind-driven current, mainly during storms, creates conditions causing an intensive movement of sediment. Their results prove that the synergy of a wind-driven current with storm waving favours a more intensive transport of sediments, which results in the formation of new bed forms and the shallowing of dredge pits in the remote foreshore. The present study was aimed at a precise quantitative determination of seabed level changes over one year. This major objective was achieved through extensive *in situ* measurements.

2. Study site

The research was carried out in the southern part of the Baltic Sea in the vicinity of the Coastal Research Station (CRS) in Lubiatowo. This area is characteristic of Polish open sea shores. Hydrodynamic, lithodynamic and morphodynamic processes in the region of Lubiatowo are typical of the south Baltic sandy coast (Cerkowniak et al., 2017; Ostrowski et al., 2015). An area located 1.5 Nm off the shoreline was selected as the study site, where the average water depth amounts to 18 m.

The coastal zone in Lubiatowo is a natural beach with an average bottom slope of about 1 - 2%. The cross-shore profile is characterized by 3 - 4 stable bars and an additional, ephemeral one occurring near the shoreline. Such a multi-bar system in the coastal zone is favourable to gradual wave energy dissipation through multiple wave braking (Pruszak et al., 2008).

Research conducted in the area of CRS Lubiatowo indicates that the seabed is composed of quartz sand with a median grain diameter of 0.1 - 0.4 mm, and the size of predominant sediments is 0.15 - 0.25 mm. The density of the ground skeleton of the bottom amounts to ρ_s = 2650 kg m^{-3} (Pruszak et al., 2008).

Data and information on the dynamics of the south Baltic seabed in the remote foreshore is rather scarce. The results of surveys presented here shed more light on the lithodynamics of the remote foreshore in a non-tidal sea, specifically the south Baltic Sea.

3. Methods of field measurements

The overall aim of this study was to identify seabed changes in the remote foreshore of the south Baltic Sea, where depths amount to 16 – 20 m. A particular purpose of our investigations was to examine whether it is possible to notice any migration of seabed structures over one year and to determine the magnitude of this migration. To achieve the above, two bathymetric and sonar measurements were made near the CRS Lubiatowo. The measuring works were carried out on November 07-08, 2017, and December 17-18, 2018. The study polygon was a rectangular area parallel to the shoreline, with dimensions of about 2.6 x 0.53 km, the basis of which was located at a distance of 1.5 Nm (ca. 2.5 km) from the shore. The coordinates of the vertices of the polygon were 54°50'14" N 17°48'37" E, 54°49'57" N 17°48'45" E, 54°50'22 "N 17°51'03 "E, and 54°50'38" N 17°50'54" E (Figure 1). Water depth in the polygon amounted to 16.4 – 20.6 m. The Polish height coordinate system Kronsztad 86 and the horizontal coordinate system UTM 33 were used. Conditions during the measurements:

- 07-08.11.2017: waves direction: N-E, wave height: 0.2 - 0.4 m, wind direction: N-W, wind velocity: 3 – 4 m/s. There was a small swell wave from the east.
- 17-18.12.2018: waves direction: W, wave height: 0.2 - 0.4 m, wind direction: N-W, wind velocity: 3 – 4 m/s.

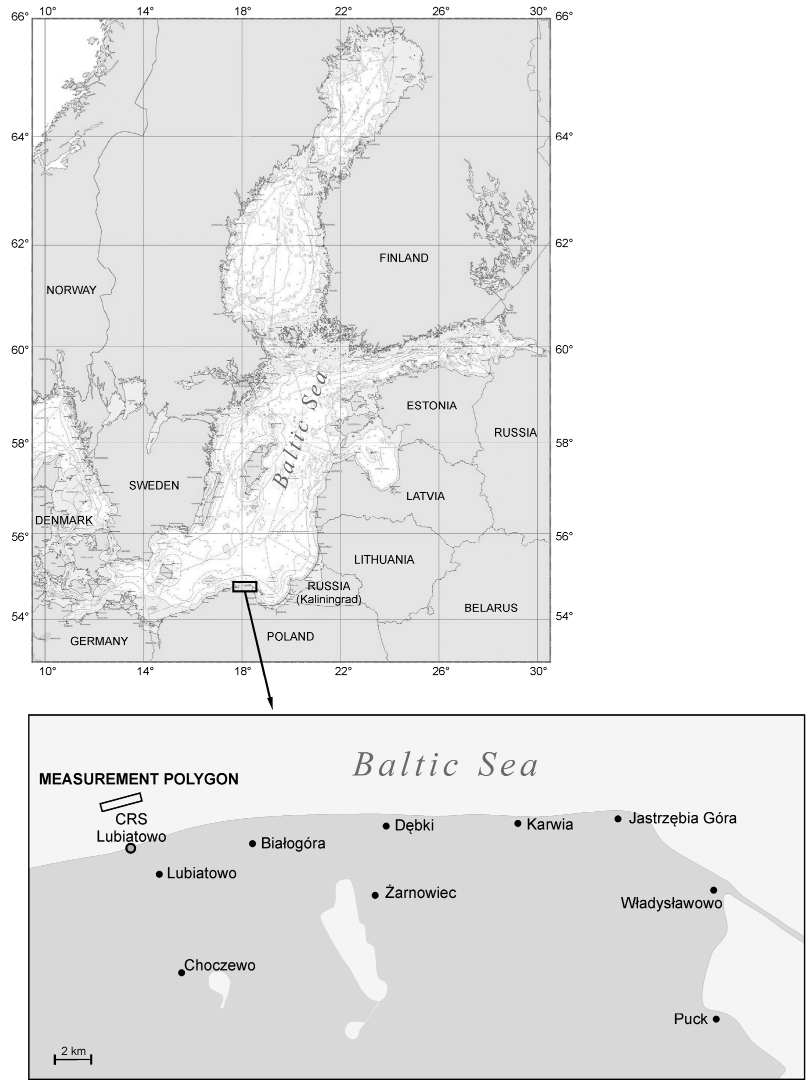

Figure 1. Study site with the measurement polygon

Bathymetry measurements

Studies of bottom morphology outside the surf zone in 2017 were carried out with a multibeam sonar MultibeamResonSeaBat 8101 at a frequency of 240 kHz. In 2018, the study was performed with a multibeam sonar MultibeamResonSeaBat 7125 at a frequency of 400 kHz. Both sonars were mounted centrally on the bow of the boat.

During bathymetric measurements in 2017 (Figure 2), 25 profile passes were made, each 2500 m long, every 20 m, whereas in 2018 (Figure 2) 22 profile passes were made, each 2500 m long, every 25 m.

Before measurements, the sonar was calibrated on the Margaret wreck. Prior to calibration and measurements, the sound velocity was measured in a water column at intervals of 0.5 m. RTK corrections were downloaded from Leica SmartNet, which resulted in a position accuracy of up to 2 - 5 cm. A positioning compensator IXBlueOctans 1000 was also used to support positioning.

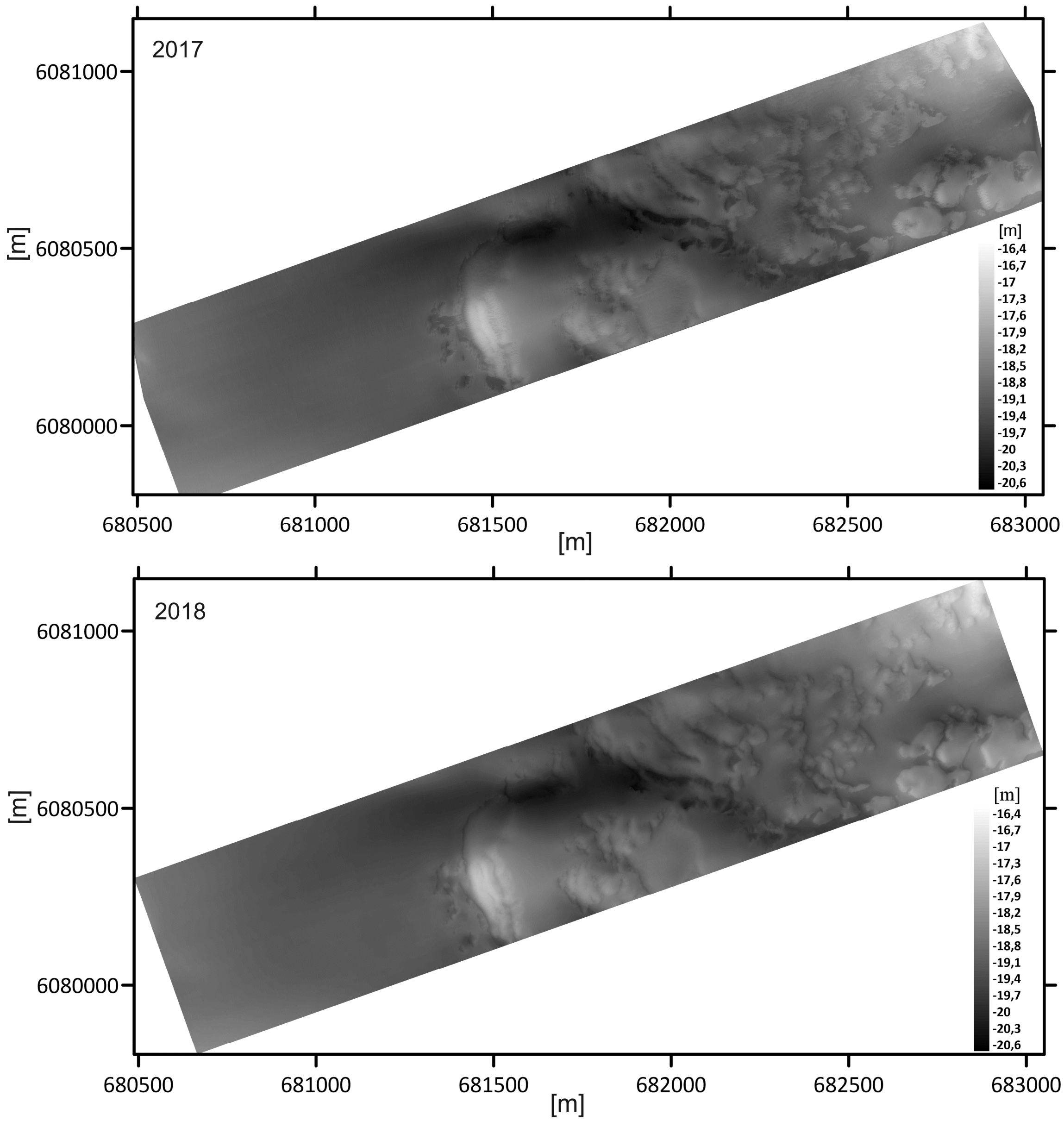

Figure 2. Bathymetry of November, 07–08, 2017 and December 17–18, 2018

Side scan sonar measurements

During the sonar measurements, 15 profile passes were made at a spacing of 40 m. For the tests, a Sidescan Sonar Klein 3900 sonar was used, towed on a cable line, approx. 6 - 9 m above the bottom. The sonar frequencies were 445 kHz and 900 kHz, the horizontal beam width was 0.21°, and the vertical beam width was 40°.

Exemplary images of the seabed showing bottom ripples are presented in Figure 3a. Larger forms were observed (see Figure 3b), whose shape can be compared to the previously mentioned sand waves. Those forms were located at approximately equal distances from each other. Their height exceeded 20 cm, and the ridge line was usually laid at an angle of about 45° relative to the sea shoreline.

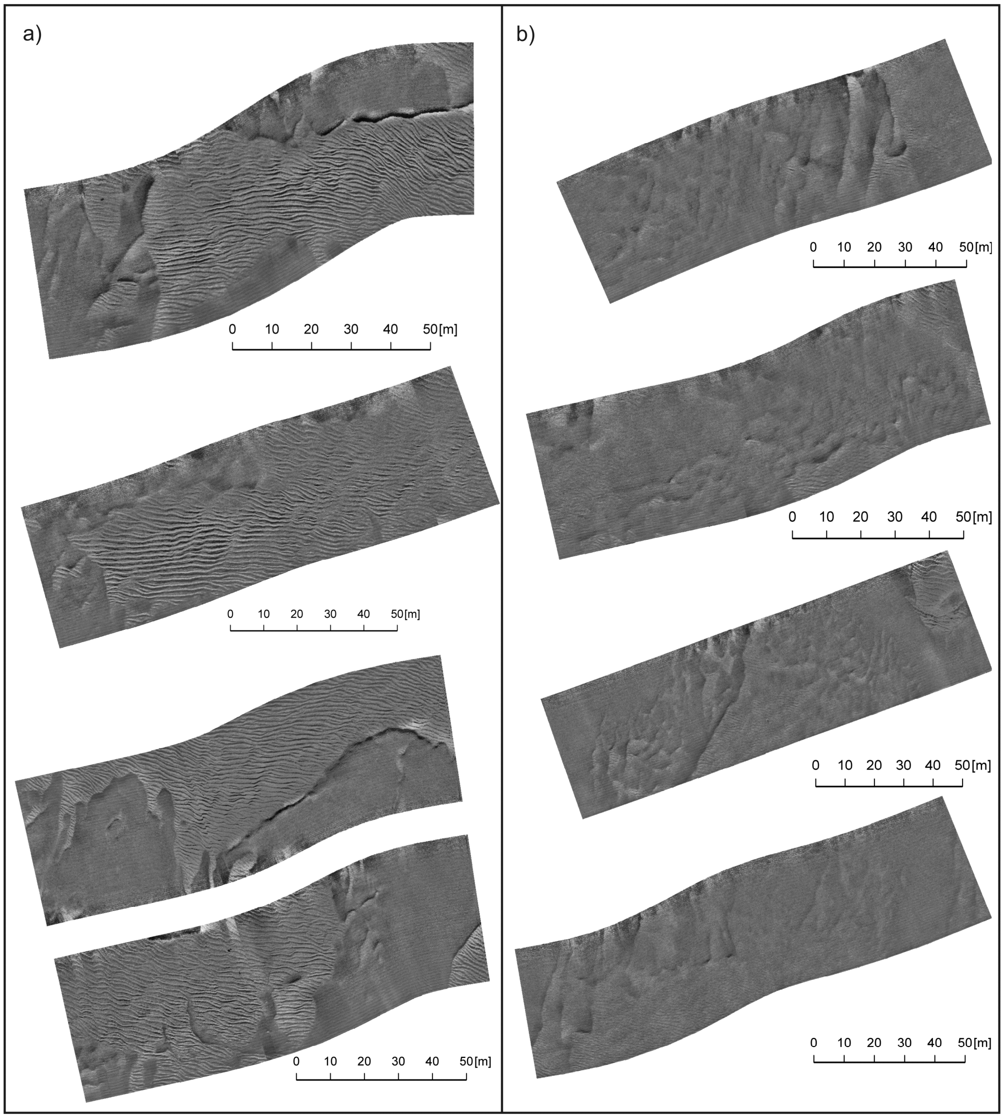

Figure 3. Sonar images with: a) bottom ripples in the vicinity of CRS Lubiatowo, height around 5–20 cm, length around 100–200 cm; b) Bigger seabed forms

4. Results and discussion

The distribution of all bottom forms detected by sonar measurements is shown in Figure 4. Ripples with a height of around 5 - 20 cm and the above-mentioned larger bottom forms occupy, respectively, about 20% and 6% of the area. In the rest of the area, no bottom forms were detected, or the image was too blurry to identify them clearly.

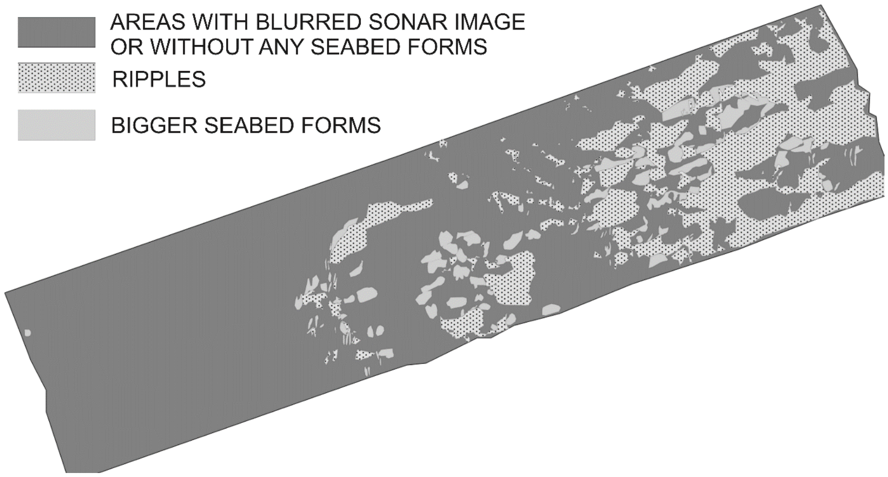

Figure 4. Map of seabed features within the study site

A differential map calculated from the bathymetric data obtained in 2017 and 2018 is presented in Figure 5. For better visualization, two areas from this map are zoomed. The seabed level changed by up to 0.7 m. The analysis revealed that the seabed forms shifted around 20 m to the east, which is more visible in cross-sections (Figure 6) along profiles indicated on the map.

Figure 5. Differential map based on bathymetric measurements from November 07 – 08, 2017, and December 17 – 18, 2018 with zoomed areas

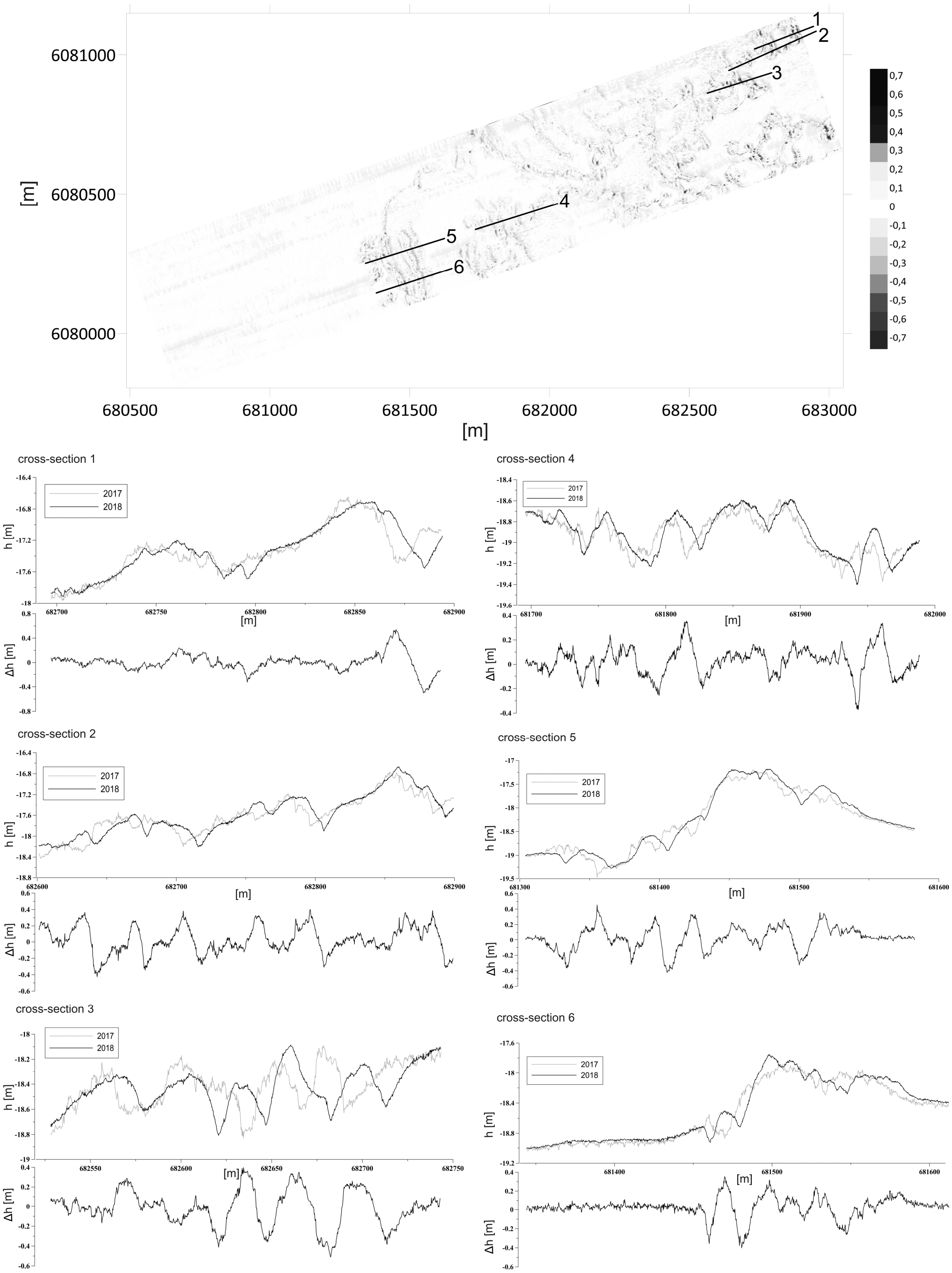

Figure 6. Differential map with cross-sections 1-6

The values of maximum erosion and accumulation Δh observed in the selected cross-sections are shown in Table 1.

Table 1. Extreme values of changes in the seabed in cross-sections 1-6.

Cross-section	**Maximum Δh [m]**	**Minimum Δh [m]**
1	0.54	- 0.50
2	0.48	- 0.53
3	0.39	- 0.51
4	0.35	- 0.37
5	0.45	- 0.42
6	0.35	- 0.40

5. Final remarks and conclusions

Changes in seabed elevation were observed during a field experiment conducted in the remote foreshore of the south Baltic sea along the coast of Poland in November 2017 and December 2018.

The surveys provided detailed quantitative data. Analysis of the measurements revealed that at least 26% of the study area was covered by seabed forms. It appears that seabed level changes can reach up to 0.7 m, but this was rather rare (2 or 3 locations within the polygon). The changes usually varied between 0.3 and 0.5 m.

The results of the present investigations prove the existence of bigger seabed forms or ripples which also migrate in the remote foreshore at depths of around 16 – 20 m. Significant seabed dynamics were detected in the remote foreshore of a non-tidal sea, beyond the depth of closure, which is conventionally assumed to be the offshore limit of noticeable bottom evolution. These findings, together with quantitative data obtained in the study, can be useful in coastal engineering projects planned in such areas. Further studies, both experimental and theoretical, will be aimed at a joint analysis of seabed level changes and nearbed hydrodynamic impacts occurring in the area of interest.

Acknowledgements

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Datasets for this research are available in this data citation reference: Stella, Magdalena (2020), “Bathymetry of the southern part of the Baltic Sea in the vicinity of the Coastal Research Station (CRS) in Lubiatowo - year 2017 and 2018”, Mendeley Data, v1 http://dx.doi.org/10.17632/cfss48v9gx.1

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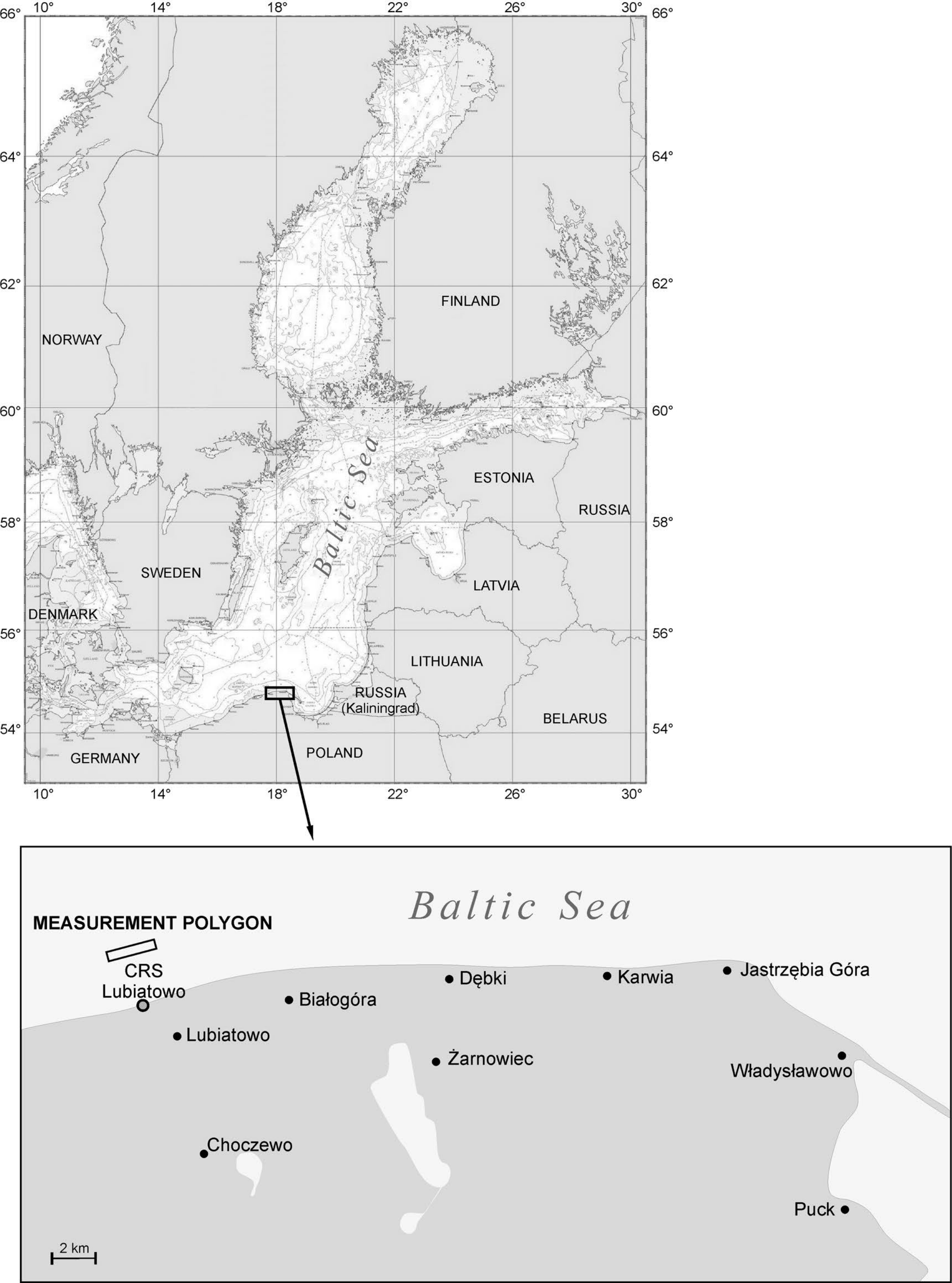
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Figure 2.

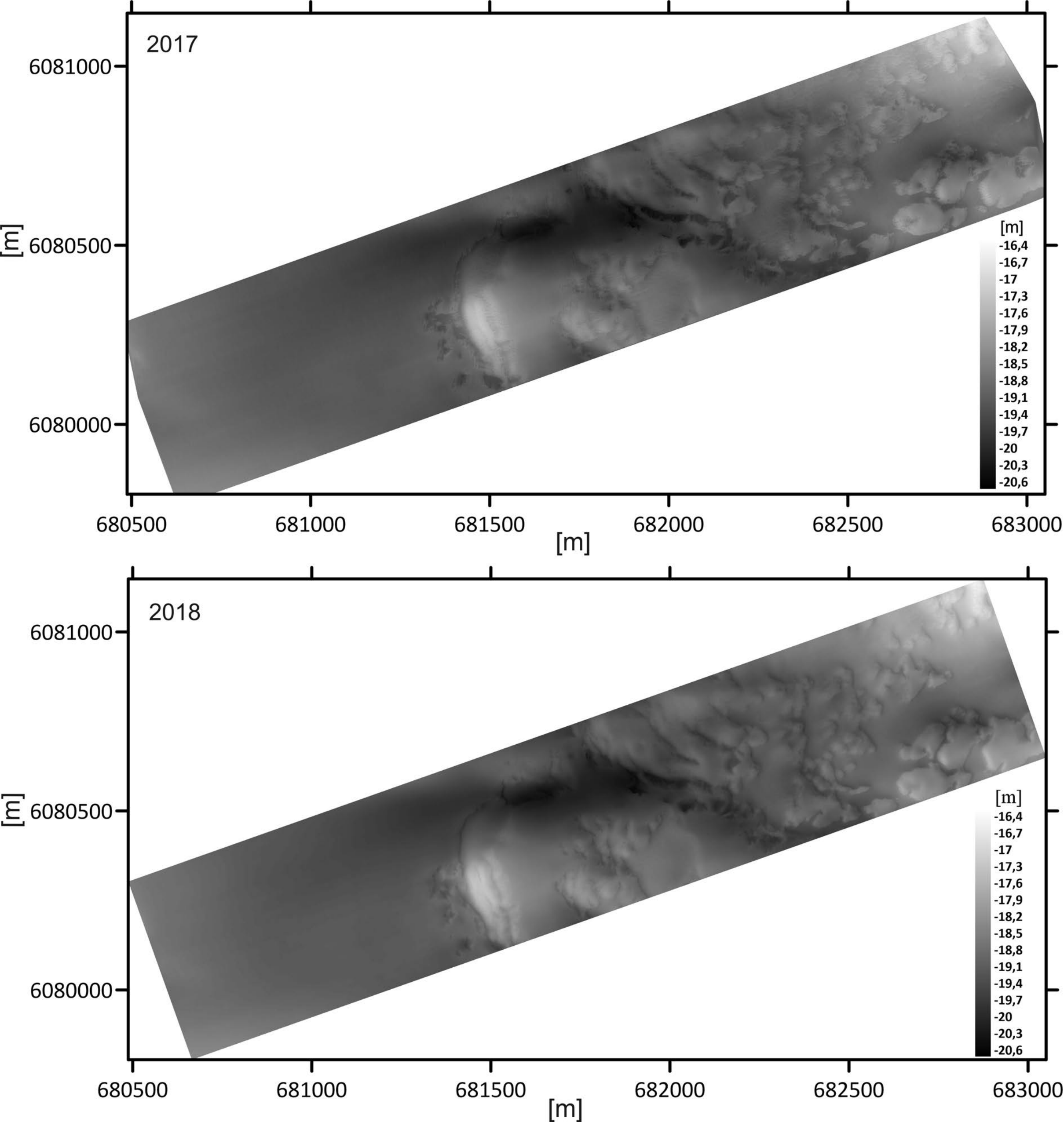
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Figure 3.

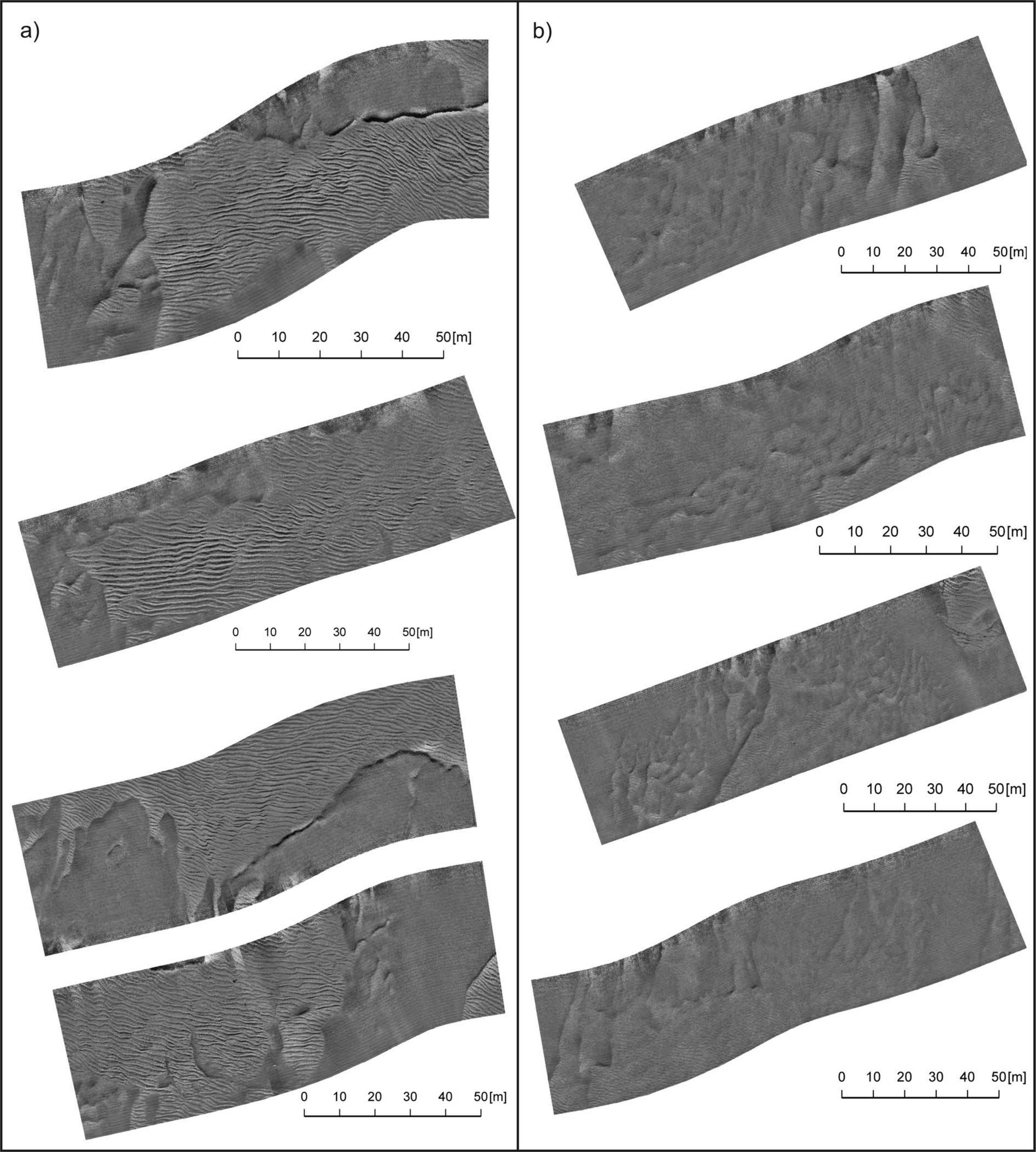
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Figure 4.

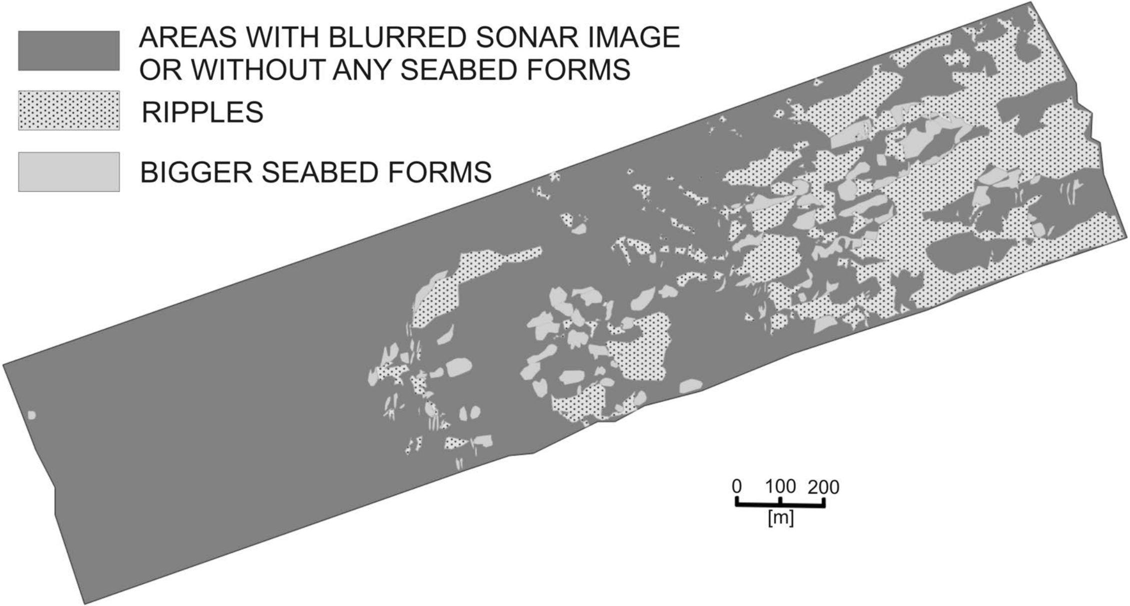
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Figure 5.


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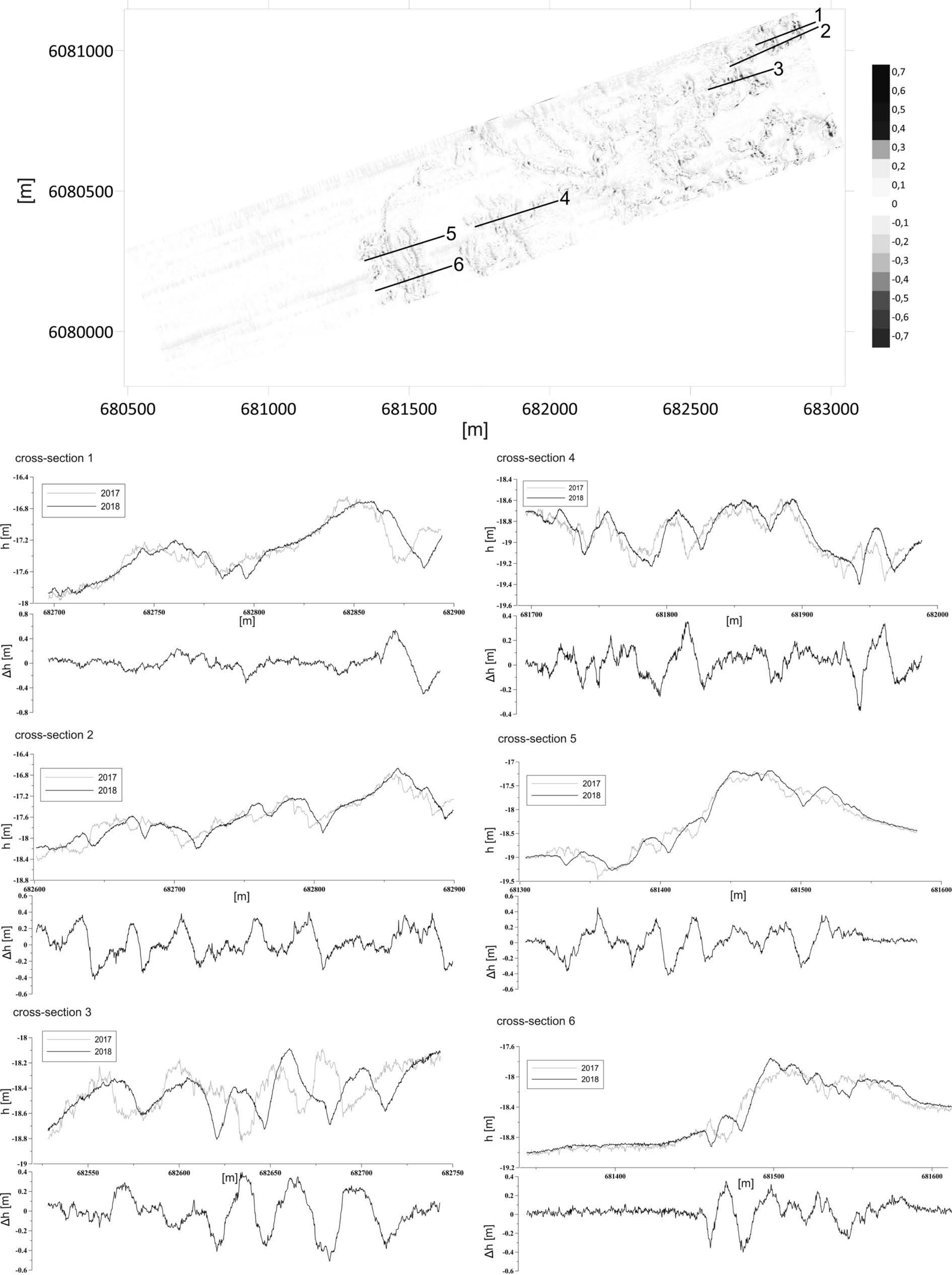
Figure 6.



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Cross-section	**Maximum Δh [m]**	**Minimum Δh [m]**
1	0.54	- 0.50
2	0.48	- 0.53
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