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MANABAS COAST – Living Lab Raversijde – Monitoring Soft Coastal Defences

Factual data report 2021-2023

11-12-2023

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MANABAS COAST
– Living Lab Raversijde –
Monitoring Soft Coastal Defences

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Flanders Hydraulics
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Abstract

In the framework of the MANABAS COAST and Living Lab Raversijde project, an intensive topo-bathymetric monitoring campaign of the soft coastal defences has started from the beginning of 2021. The aim of this report is to provide an overview of all the acquired topo-bathymetric surveys, including UAV, hand RTK-GPS and multibeam surveys for the period from 2021 to 2023, as well as to document the processing on the raw data. Also, a comparison of the bathy-topographic methods from the beach to the offshore area is presented. Finally, a description of the grain size, based on sediment samples in the nearshore area is reported. This report presents the monitoring of the soft coastal defences at Raversijde in the period from 2021 until September 2023.

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1 Introduction

An intensive survey monitoring has already started from 03/2021 in the framework of the Raversijde Living Lab. In 2022 the study area has been included as a pilot case in the Interreg project MAinstreaming NAture BAsed Solutions through COASTal systens (MANABAS COAST). MANABAS COAST (https://www.interregnorthsea.eu/manabas-coast) is an INTERREG North Sea Programme project running from 2022 to 2027. It is a cooperation of partners from Sweden, Denmark, The Netherlands, Belgium and France. The project intends to set the stage for widescale application and implementation (mainstreaming) of Nature based Solutions (NbS) in the North Sea Region by developing a proven and accessible framework, tools, guidelines based on pilot examples. A number of eight pilot sites, both sandy and muddy coasts, across the entire area were setup and the application of NbS will be developed and extended during the project using these sites as reference.

Bathymetric surveys consisting of single and multibeam methods have been carried out in the shoreface zone and the offshore neighbouring sea bottom. Also topographic surveys covering the area from the dyke to the low water line have been acquired by UAV system and field hand Real Time Kinematic-GPS (RTK-GPS) profiles have been obtained mainly by walking or setup on a quad. Table 1 presents a timeline of the bathymetric and topographic campaigns. Typically, the offshore, nearshore and UAV surveys take 3 days, 2 days and a few hours to be carried out respectively. Figure 1 displays the dune for dyke pilot area (section 100-102).

The aim of this report is to provide an overview of all the acquired surveys monitoring the soft coastal defences, to document the processing on the raw data and to present the results. In this report, a comparison of the bathy-topographic processing methods is included. Finally, an overview of the grain size, based on sediment samples, is also presented. Results about the dune morphological behaviour and evolution of the dune for dyke pilot area are reported in more detail in Montreuil et al. (2023).

Table 1 – Timeline of the bathymetric and topographic surveys.

T0	31/03/2021	UAV & hand RTK-GPS profile
T1	28/04/2021	UAV & hand RTK-GPS profile
L1	28/04/2021	LiDAR
T2	27/05/2021	UAV & hand RTK-GPS profile
B0	09/06/2021	Bathy single-beam
T3	25/06/2021	UAV & hand RTK-GPS profile
B1	24/06/2021	Bathy multibeam
T4	08/09/2021	UAV & hand RTK-GPS profile
B2	19/10/2021	Bathy single-beam
B3	09/11/2021	Bathy single-beam
BO1	10/11/2021	Offshore Bathy multibeam
T5P	08/12/2021	hand RTK-GPS & Quad profile
T5	24/11/2021	UAV & hand RTK-GPS profile
T6	07/12/2021	UAV
B4	07/12/2021	Bathy single-beam
T7	18/01/2022	UAV & Quad profile
B5	26/01/2022	Bathy single-beam

T8P	03/02/2022	Hand RTK-GPS
T8	11/02/2022	UAV
T9	23/02/2022	UAV
L2	23/02/2022	LiDAR
B6	23/02/2022	Bathy single-beam
T10P	04/03/2022	Quad profile
T10	21/03/2022	UAV
B7	21/03/2022	Bathy single-beam
L3	17/04/2022	LiDAR
T11	19/04/2022	UAV
B8	19/04/2022	Bathy single-beam
T12	02/05/2022	UAV
B9	02/05/2022	Bathy single-beam
B10	30/05/2022	Bathy single-beam
T13	01/06/2022	UAV
T14	12/09/2022	UAV and hand RTK-GPS
B11*	12/09/2022	Bathy multibeam
B02*	13/09/2022	Offshore Bathy multibeam
B12*	10/10/2022	Bathy multibeam
T15	12/10/2022	UAV
B13*	12/12/2022	Bathy multibeam
T16	24/01/2023	UAV and hand RTK-GPS
B14*	24/01/2023	Bathy multibeam
L4	08/02/2023	LiDAR
T17	09/02/2023	UAV and hand RTK-GPS
B15*	09/02/2023	Bathy multibeam
T18	09/03/2023	UAV and hand RTK-GPS
T19	29/03/2023	UAV and hand RTK-GPS
B16*	05/04/2023	Bathy multibeam
T20	08/05/2023	UAV and hand RTK-GPS
L5	17/06/2023	LiDAR
B17*	19/06/2023	Bathy multibeam
T21	21/06/2023	UAV and hand RTK-GPS
T22	14/09/2023	UAV and hand RTK-GPS
B03*	14/09/2023	Offshore Bathy multibeam
B18*	26/09/2023	Bathy multibeam

* Bathymetric data is based on an averaged-depth processing. Previous data was based on minimum-depth processing for nautical purposes.

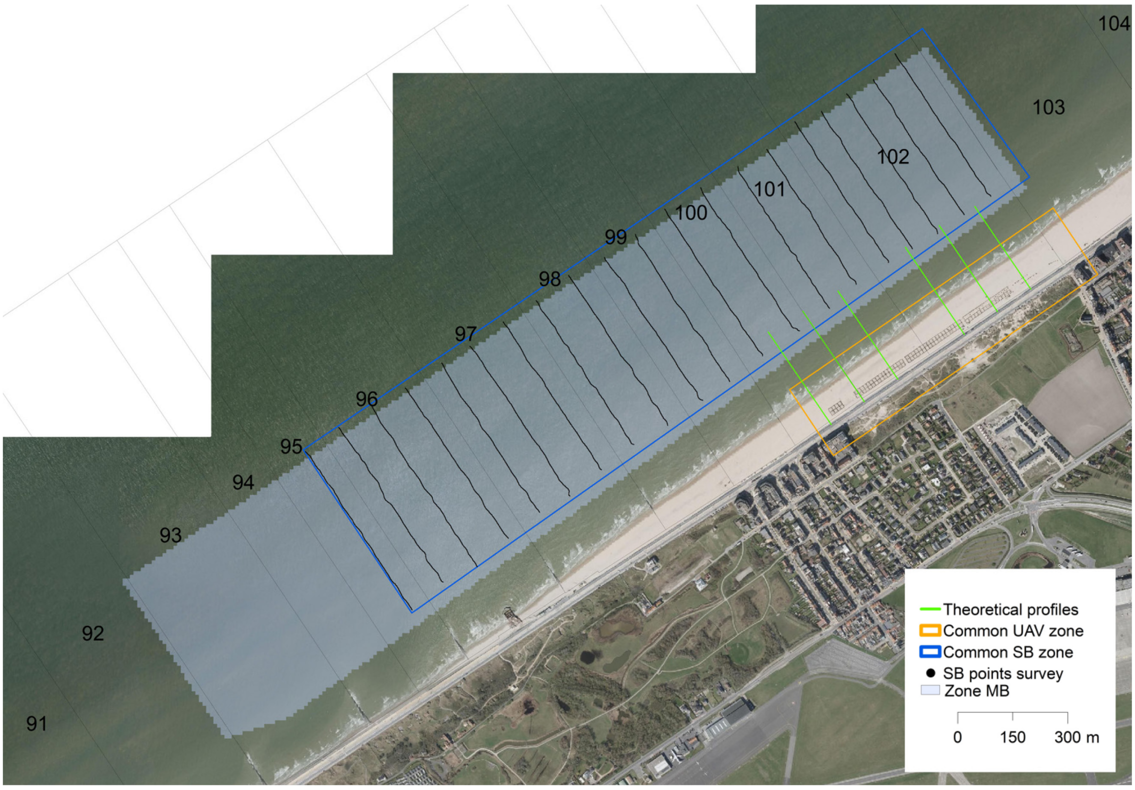


Figure 1 – Map of the monitoring coverage at Raversijde from section 93 to 102.

2 Bathymetric monitoring

2.1 Data Surveys

Multibeam surveys for this project are organised by Flemish Hydrography which is the survey and charting authority for the Belgian part of the North Sea. It is part of the Coastal Division from the Flemish Government's Agency for Maritime and Coastal Services. Surveys are executed by an external survey company, Enviros Survey BV.

Multibeam surveys in the Living Lab Raversijde area can be divided into 3 types: a reduced shoreface area, a large one and the offshore zone. The reduced shoreface area is measured monthly and can be covered during one high water (Figure 2). Especially in winter time, the hydro-meteo circumstances can be too rough to allow for safe survey circumstances that deliver good quality data. Planning of the multibeam surveys is synchronised as much as possible with the UAV measurements on the part of the beach that is adjacent to the multibeam area, but out of reach for bathymetric survey vessels.

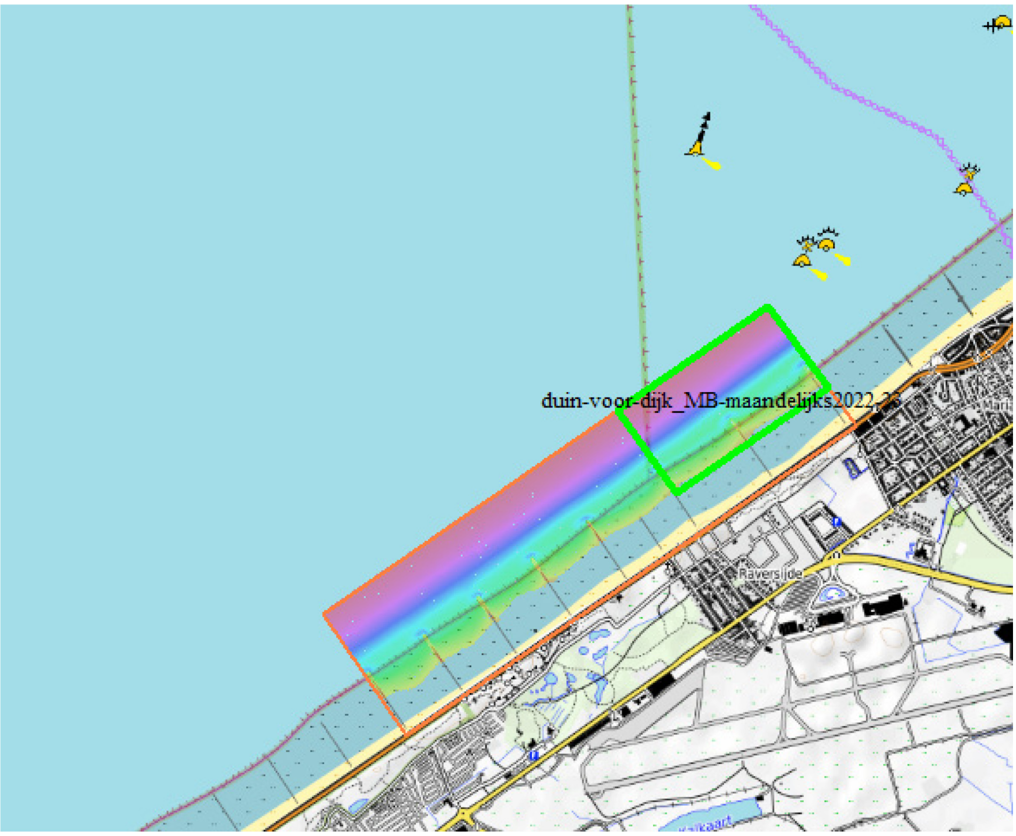


Figure 2 – Typical coverage of the large (red rectangle) and reduced (green rectangle) multi-beam shoreface surveys

The entire Living Lab Area is covered with multibeam surveys once per year. The annual multibeam survey of the larger area is done by the survey company for the shoreface and by the Agency's own survey vessels for the areas further offshore (Figure 2, Figure 3).

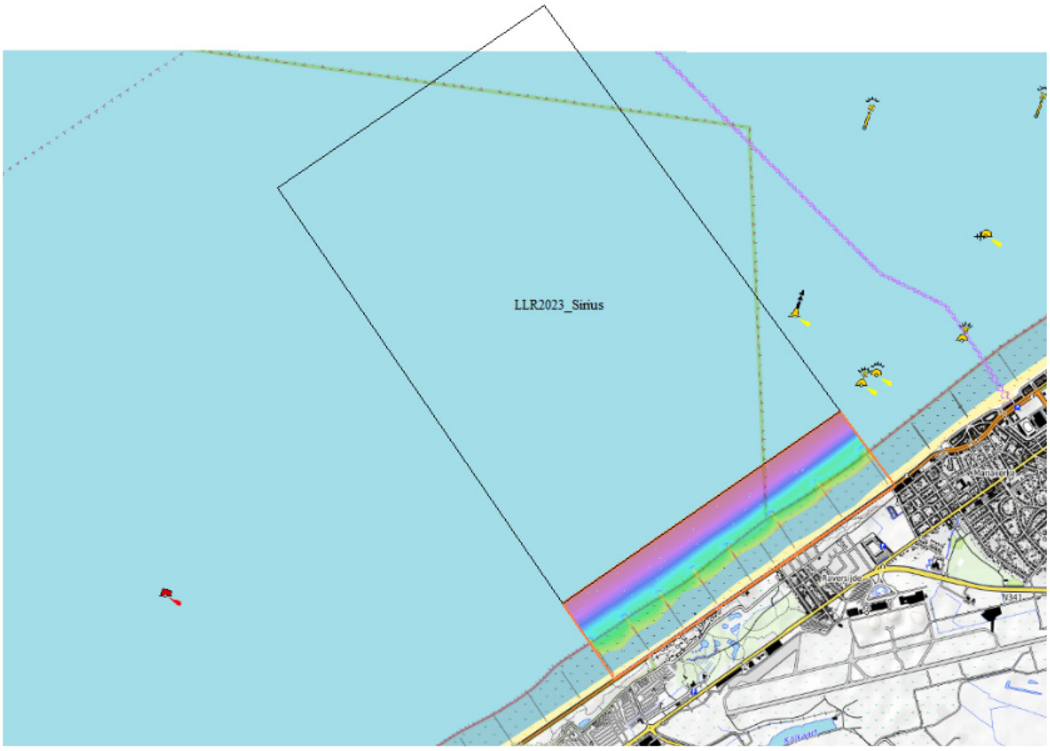


Figure 3 – Typical coverage of the multi-beam offshore (black rectangle) surveys.

The processed survey data includes all the data points which are validated and rejected. In some areas, the evaluation of the rejected data provides the necessary insight to understand the challenges during the survey. Areas with groynes are known to create very noisy data. The rejected data (pink colour) is concentrated in these areas (Figure 4).

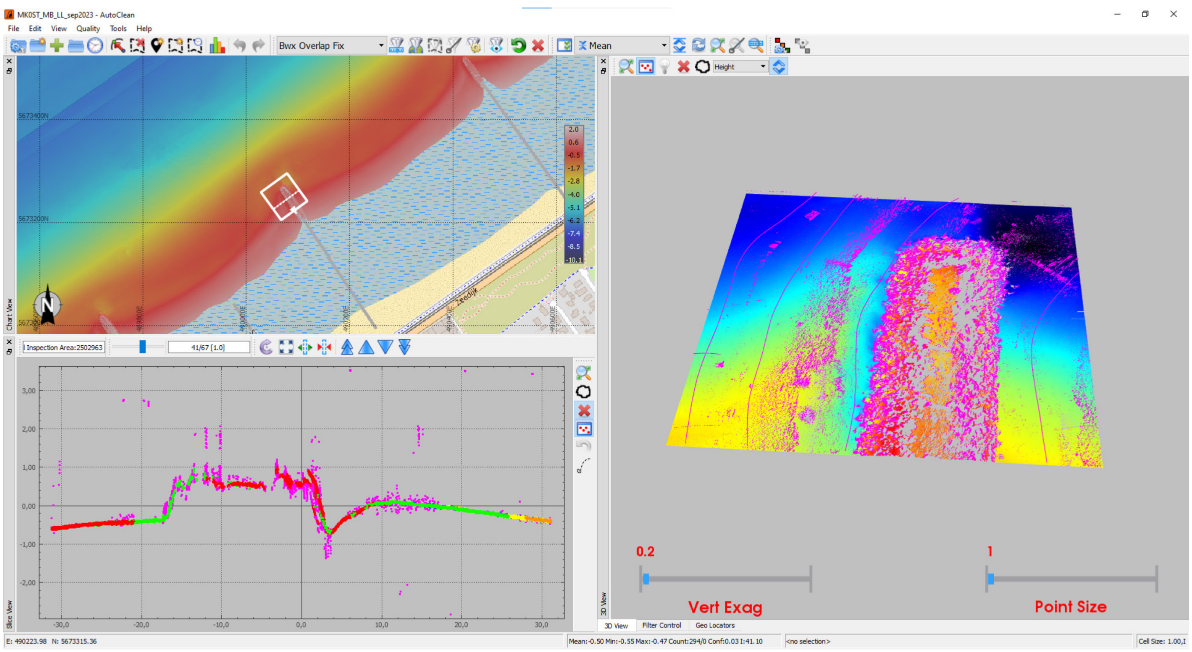


Figure 4 – Example of processing near a groyne. The noisy data measured points (pink colour) are rejected.

Areas with natural marine features are less sensitive to noise and contain significantly less data that is rejected (Figure 5). Next to the data sets, survey charts with an overview of the survey data and difference charts to compare the current survey with the previous survey, are provided (Appendix A).

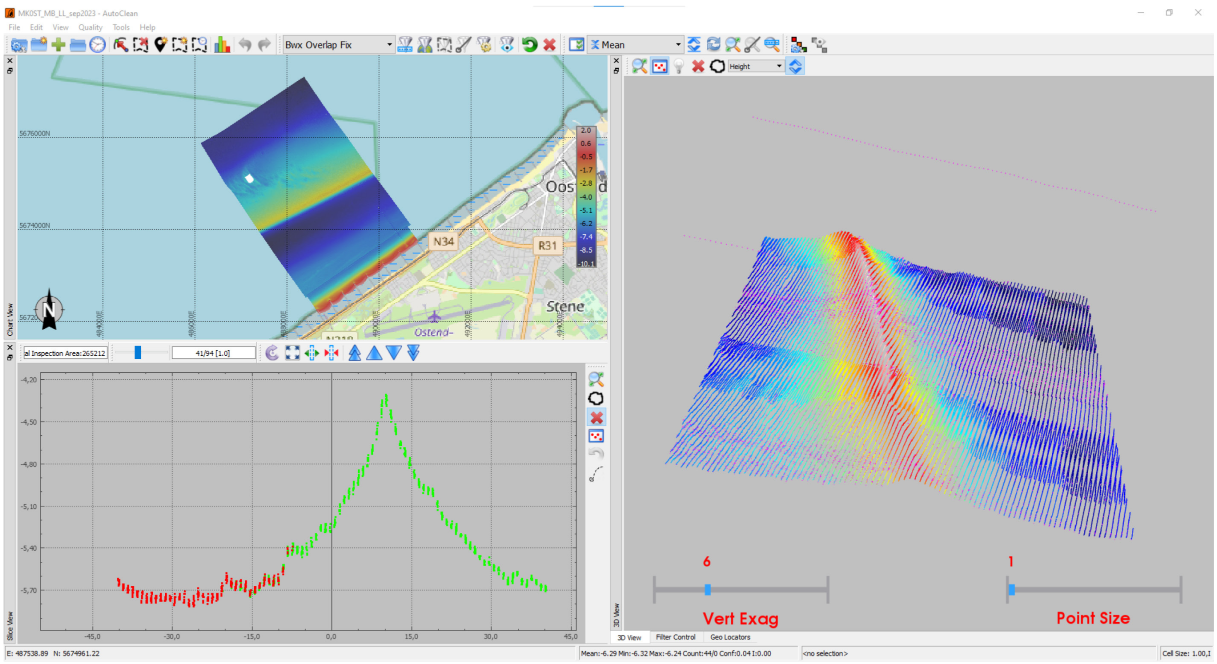


Figure 5 – Example of processing for an area with natural features.

Normally, a **single beam** bathymetric survey is composed of 20 profiles (except on 19/10/2021 when only 12 profiles were surveyed, Table 1). The coverage of the total zone is of 2 km alongshore and 500 m cross-shore. The distance between profiles is about 100 m (Figure 1 and Figure 6). They extend from 0 m to nearly -7 m TAW. Data acquired with an echo sounder of 200 kHz and 38 kHz are available and processed by Flemish Hydrography. Data correspond to minimum depth (depth points selected for nautical purposes). For this study, the survey data at 200 kHz are processed to generate DEMs of 10 m cell size after creating a TIN.

In total, 10 multibeam shoreface surveys with an echo sounder of 400 kHz took place over the monitoring period. It covers an area of at least 750 m alongshore and 560 m cross-shore (Figure 7). Both the processed data points and a derived DEM were obtained. The cell size of the DEM is 1 m. The data correspond to the averaged-depth (except B1 and BO1 carried out in 2021, Table 1).

A comparison of generated DEM between a multibeam and a single beam survey was presented in Montreuil et al. (2022). The groynes and the surrounding areas are clearly visible on the multibeam bathymetry, while they are not displayed on the single-beam bathymetry. The sea bottom in front of the tip of the groynes is overestimated up to 1.5 m by the single beam surveys. This is caused by the interpolation carried out between neighbouring survey lines.

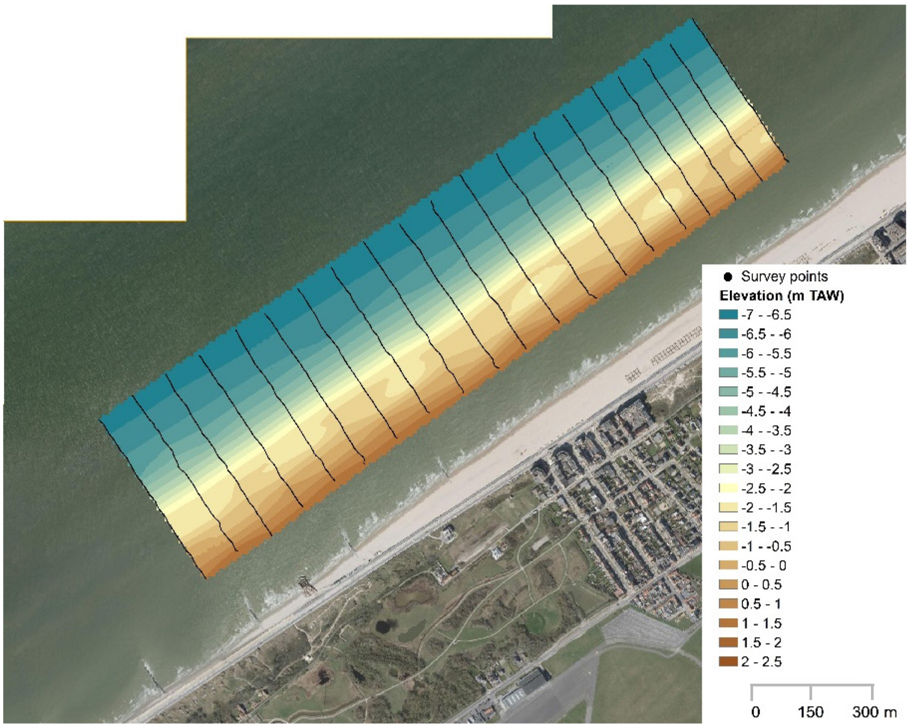


Figure 6 – Example of profile points of the single beam bathymetric surveys and generated DEM of the survey on 23/02/2022.

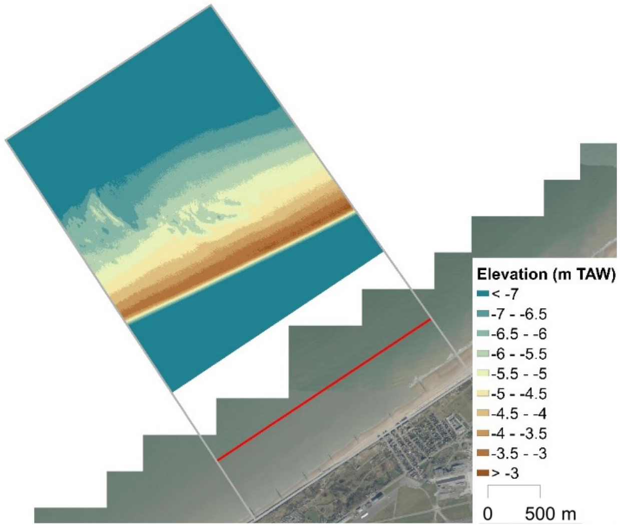
Figure 7 – Example of points of the multibeam bathymetric surveys of the survey on 24/06/2021.

Additionally, three offshore multibeam bathymetric surveys were carried out on 11/2021, 09/2022 and 09/2023 (Table 1, Figure 8). They cover part of the Stroombank and Kleine Rede bank-gully system, and extend up to 4.7 km from the dyke and are about 2.6 km wide.

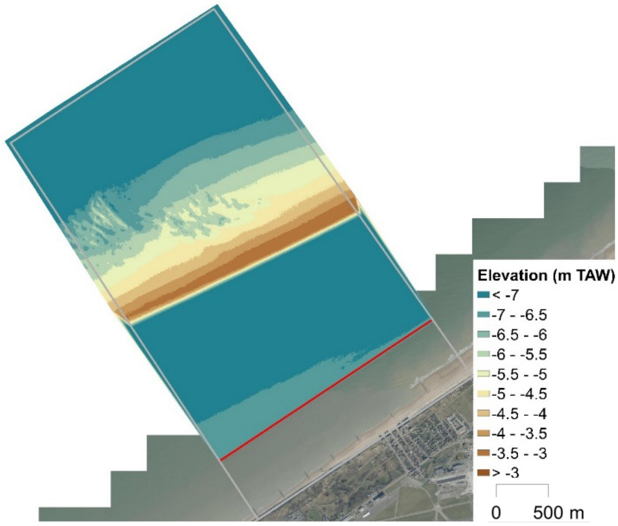
All the raw and processed data can be found:

E:\RaversijdeLivingLab_21_012\Data\TritonBathyData

A) 11/2021



B) 09/2022



C) 09/2023

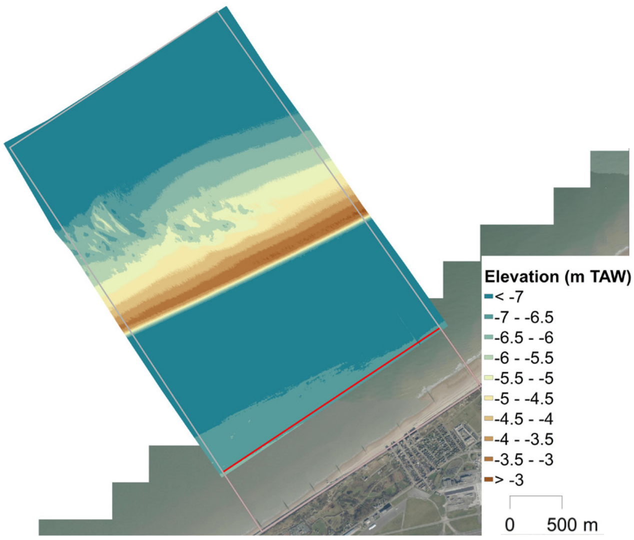


Figure 8 – Offshore DEMs of the multibeam bathymetric in: A) 11/2021, B) 09/2022, C) 09/2023.
Grey and red lines correspond to the entire study site of Living Lab Raversijde
and the landward boundary of the survey respectively.

3 Topographic monitoring

3.1 UAV Surveys

From 03/2021, monthly UAV surveys have been carried out by ATO (Afdeling Algemene Technische Ondersteuning). For more details, refer to Montreuil et al., 2023.

The first UAV processing step is the image optimalisation. It consists of adjusting the highlights and the shadows of the surveyed area in order to offer optimal image quality. Then, the following images are imported in Agisoft, a photogrammetry software, to be are aligned together. The software is looking for common points in the overlapping photos to get a sparse cloud of tie points. After the image alignment, ground control points (GCP) and check points (CP) are added to the project. These are used to get a quality control of the UAV mapping. After adding GCP and CP, a bundle block adjustment is preformed to get a more accurate and robust coherence of the images. The next step is the dense cloud generation. The software generates a dense point cloud (2x ground sample distance) and depth maps of the images by using these to get a better understanding of the point confidence. Similar to the photo alignment, the software uses common points from overlapping photo's to create a dense point cloud. Once the dense point cloud is generated, we can filter points with lower confidence values and exclude them to generate a Digital Elevation Model (DEM). Where holes appear due to confidence filtering (excluding points with lower confidence values), an interpolation of the points is preformed to generate a complete DEM. This DEM is used to orthorectify all the images in the project before ortho-mosaicking is done. Regarding the vegetation, no extra filtering is applied. Nevertheless, vegetation tends to move on windy days which might affect the point confidence filtering. The software might find these points less reliable and then fall in the defined threshold.

Orthophotographs of 2.5 cm resolution and DEMs of 5 cm resolution are usually provided together with the quality report. The error of the surveys ranges from 0.8 to 1.4 cm (Verwaest et al., 2022). Figure 8 displays an example of produced data from the survey on 01/06/2022 (T13). From the DEMs, consecutive DEMs of difference (DoD) were generated as well as DoDs starting from the first survey (T0) as reference. DEMs and DoDs from 31/3/2021 to 09/03/2023 are reported in Montreuil et al. (2023).

A)

B)

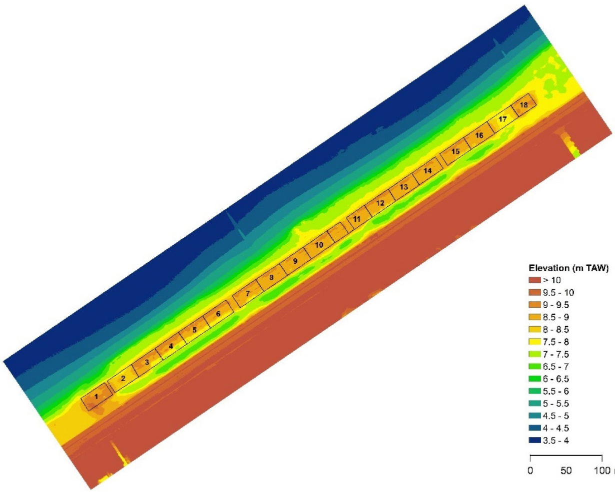


Figure 9 – Example of A) orthophotograph and B) DEM (T13 survey).

Since the UAV survey in 09/2022 (T14), the cross-shore distance of the UAV survey was extended up to 1 m TAW which is more than 250 m from the dyke (Figure 10). For every dataset, the most seaward area of the DEM around 300 - 400 m is removed due to the presence of water based on a visual observation from the orthophoto. The delimitation between the saturated beach and the water is usually related to the omnipresence of points with low confidence flagged by the photogrammetric processing procedure Figure 10, subplot C). This is caused by the presence of the water and saturated sand in this area characterized by less or none beach structures.

All the raw and processed data can be found:
E:\Duin voor dijk pilots_21_014\raversijde_mariakerke

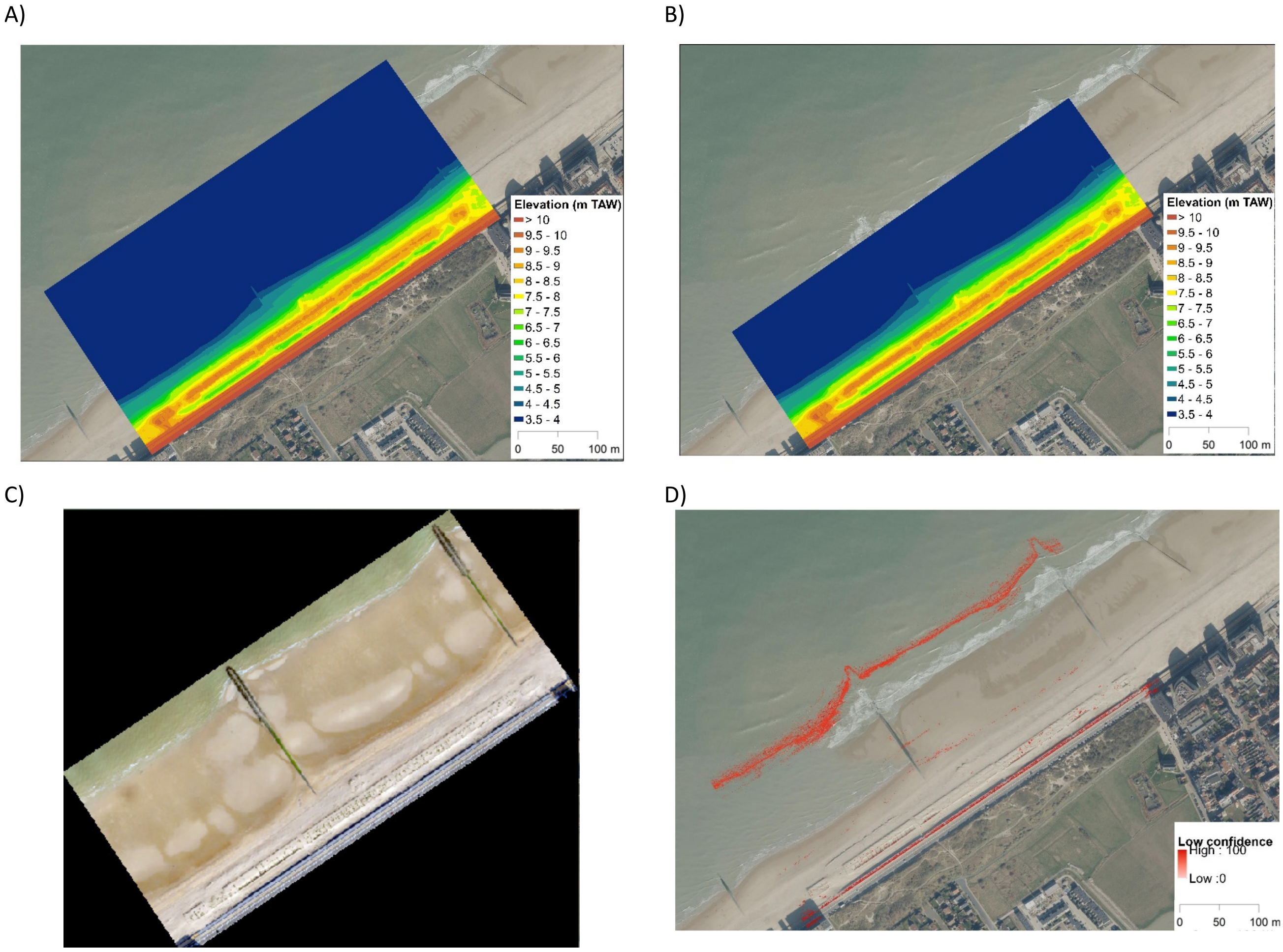


Figure 10 – A) DEM of the entire survey coverage for T14 (12/09/2022), B) DEM representative of the beach and intertidal zone (i.e. removed water area), C) orthophoto, D) low confidence raster.

3.2 Hand RTK-GPS profiles

Hand RTK-GPS surveys were carried out along 6 profiles, aiming to survey from the beach to the intertidal zone (Table 1 and Figure 1). Each profile extends from the seaward vegetation boxes to the low water line over a length of ca. 250 m. The distance from the first survey points to the dyke is ca. 40 m. The interval between profiles is 110 a 215 m. Since the measurements are not always located along a straight line, they have been re-projected on planned profiles in ArcGIS using the linear reference tool (Figure 11). Then, they were linearly interpolated at a distance of 1 m. This allows easier comparison of the profiles over time. Figure 12 is an example of re-projected points for profile 1 for all the hand RTK-GPS surveys.

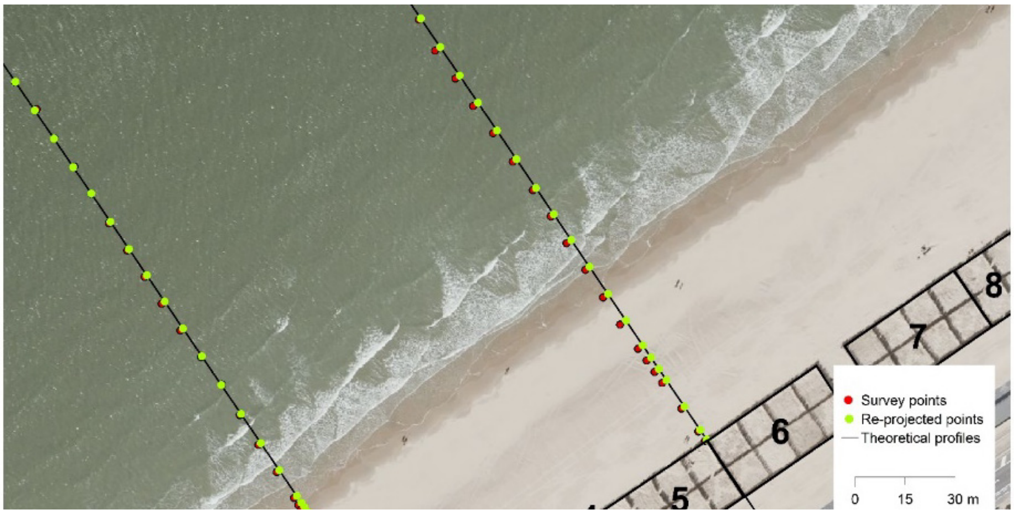


Figure 11 – Example of measured and reprojected hand RTK-GPS profile surveys

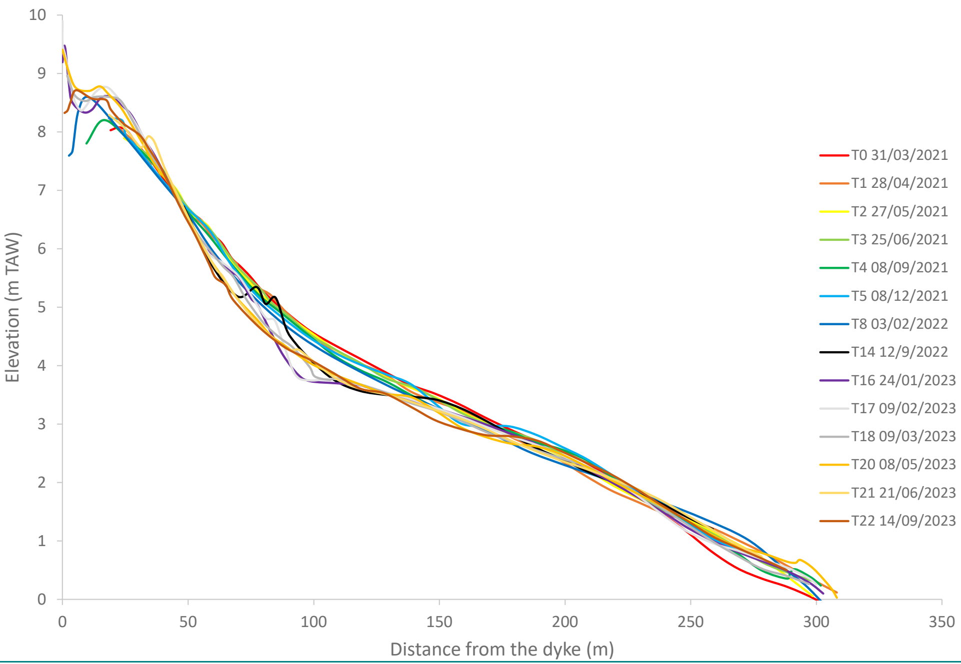


Figure 12 – Example of re-projected profile 1 for all the hand RTK-GPS.

All the raw and re-projected profiles can be found:

E:\Duin voor dijk pilots_21_014\Analyses\raversijde_mariakerke\Profiles

3.3 Comparison between UAV and hand RTK-GPS

To assess the reliability of UAV derived DEM's, a comparison analysis was carried out between UAV and hand RTK-GPS for 3 common survey periods in 12/09/2022 (T14), 09/02/2023 (T17), 21/06/2023 (T21). It is assumed that RTK-GPS measures the true topography, thus UAV DEM values were extracted at the measured RTK-GPS points (i.e. not re-projected and not interpolated). Table 2 presents a summary of the measured error between techniques. Based on 3 surveys, it suggests that the UAV DEMs overestimate the height of the true terrain with an average error ranging from 0.02 to 0.05 mt. In general, the distribution of the standard deviation error (SD) is low which leads to a limited total error of the technique (including systematic and random error) below 0.06 m.

Table 2 – Summary statistics of the comparison between UAV and hand RTK-GPS.

Time	12/09/2022	09/02/2023	21/06/2023
Avg (m)	0.05	0.02	0.02
Max (m)	0.29	0.10	0.07
Min (m)	-0.02	-0.11	-0.04
SD (m)	0.03	0.02	0.01
Count	167	232	197
Total error (m)	0.06	0.03	0.02

3.4 Merging UAV and hand RTK-GPS-profiles

Since the hand RTK-GPS profiles do not cover the area landward of the vegetation boxes, the topography along the theoretical profiles from the UAV DEMs is extracted to obtain the complete beach profiles. RTK-GPS and UAV surveys are usually carried out on the same day (Table 1). Then, all the profiles were interpolated to 1 m in order to allow easier comparison over time. Figure 13 presents a typical time series of profiles merged from UAV (dyke – upper-beach part) and hand RTK-GPS (upper-beach to low water line part). The observed peaks at a distance from 20 to 40 m from the dyke correspond to the vegetation boxes area.

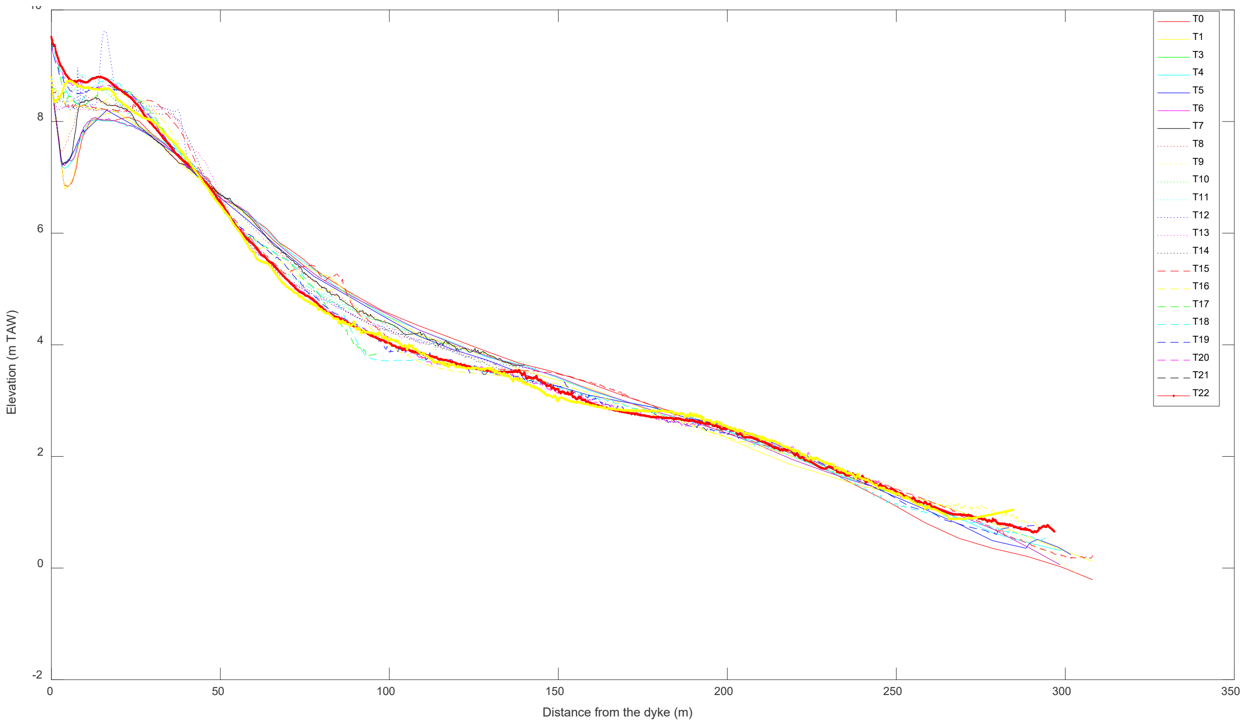


Figure 13 – Profile 1 merging UAV and hand GPS from the dyke to the low water line combining UAV and hand GPS surveys.

In general, the error between UAV and RTK-GPS is higher for the upper-beach (from top to 4.39 m TAW) where the complexity of the beach topography is greater. For the lowest part of the beach (< 1.39 m TAW), the average error is smallest (systematic error around 0.01 m). For more details referred to Montreuil et al. (2022).

All the data and analyses can be found:

E:\Duin voor dijk pilots_21_014\Analyses\raversijde_mariakerke\Profiles

3.5 Effect of the vegetation on the topographic survey techniques

3.5.1 Comparison of the topography in the vegetated boxes between UAV and LiDAR

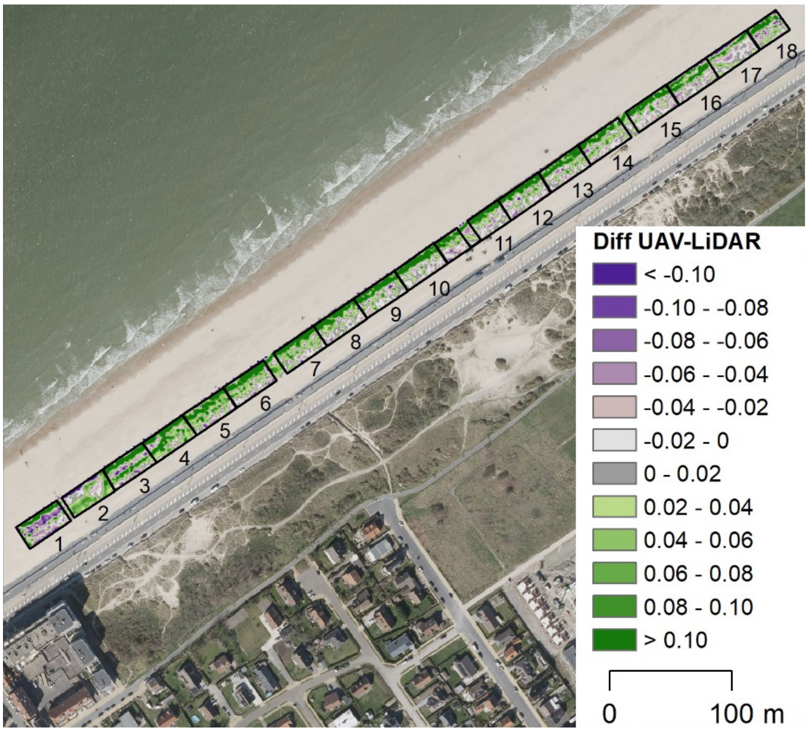
The difference of the measured topography in the vegetated boxes between UAV and LiDAR was investigated for 4 surveys when the day of the surveys was close to each other (Table 3 and Figure 14).

The average difference between the UAV and LiDAR ranges from 0.04 m in 4/2021 and 2/2023 to 0.08 m in 6/2023. This means that the height of the terrain from the UAV DEM is a few cm higher compared to LiDAR DEMs. In general in the beginning of the project (4/2021), the difference is the greatest in the seaward side of the vegetated boxes, while it is lower in the landward side. This was probably due the low planted marram grass. With the time, no clear pattern of difference can be observed.

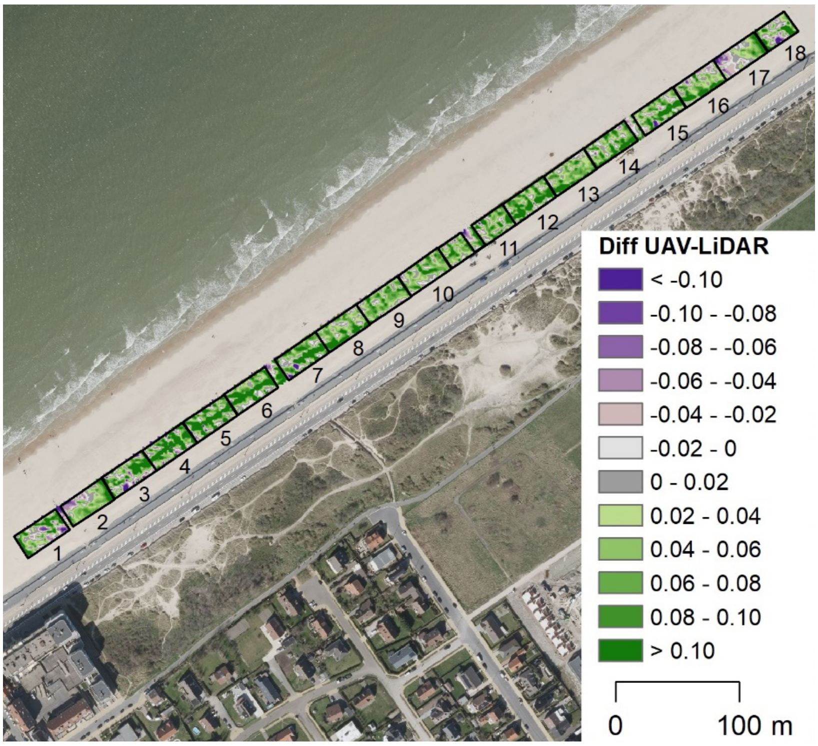
Table 3 – Topographic comparison in the vegetated boxes between UAV and LiDAR.

Time	UAV	LiDAR	Avg diff UAV - LiDAR (m)
4/2021	28/4/2021	28/4/2021	0.04
2/2022	23/2/2022	23/2/2022	0.06
2/2023	8/2/2023	9/2/2023	0.04
6/2023	17/6/2023	21/6/2023	0.08

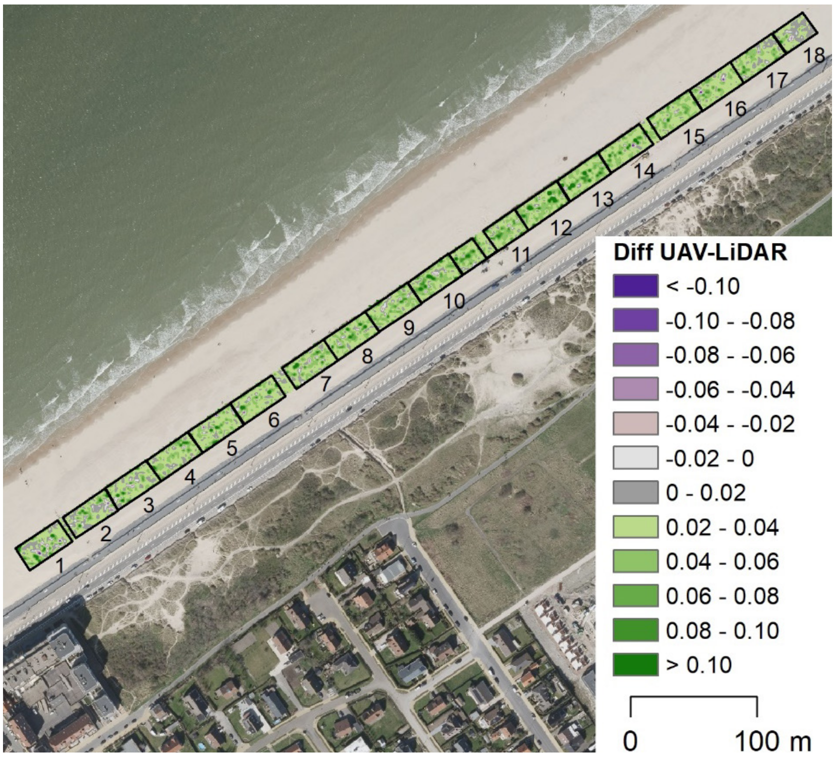
A) 4/2021



B) 2/2022



C) 2/2023



D) 6/2023

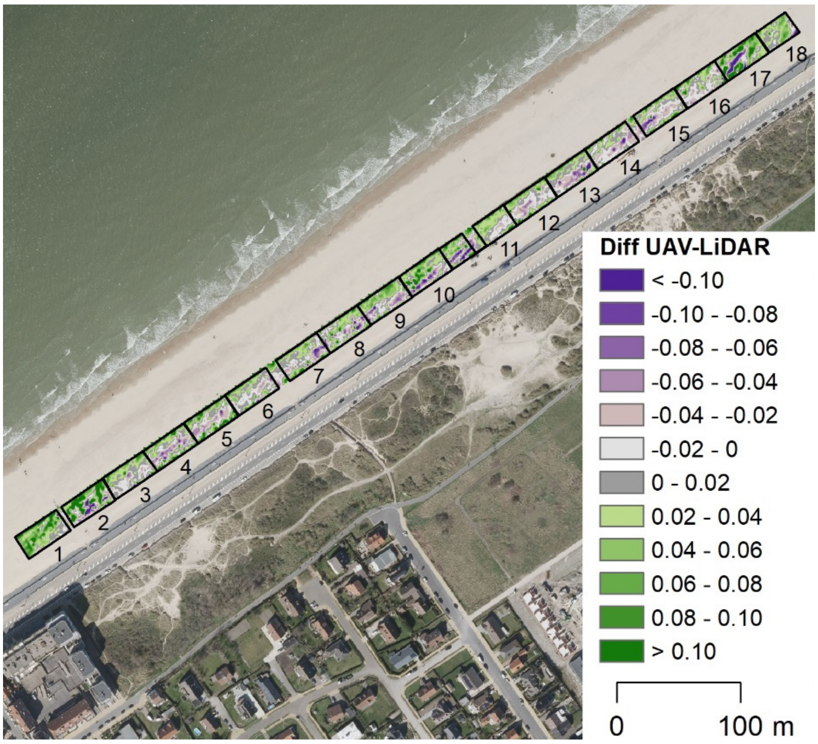


Figure 14 – Topographic comparison in the vegetated boxes between UAV and LiDAR: A) 4/2021, B) 2/2022, C) 2/2023, D) 6/2023.

3.5.2 Comparison of the topography in the vegetated boxes between UAV and hand RTK-GPS

Hand RTK-GPS is the most reliable survey technique measuring the true ground elevation since UAV and LIDAR can either measure the top vegetation or ground elevation. Thus, an investigation of the topographic measurement was carried out by comparing in total 40 measured points in the vegetated boxes along Profile 2 and 3 during the survey T16 (24/01/2023), T17 (09/02/2023) and T22 (14/09/2023) (Figure 15). The average difference per survey between the UAV and hand RTK-GPS ranges from to 0.01 to 0.03 m (slight overestimation by the UAV DEMs). Also, a very good relationship is found (R^2: 0.987). Therefore, UAV technique in the vegetated boxes estimates well the true ground elevation when the vegetation is relatively low and sparse (see orthophotos in Appendix B).

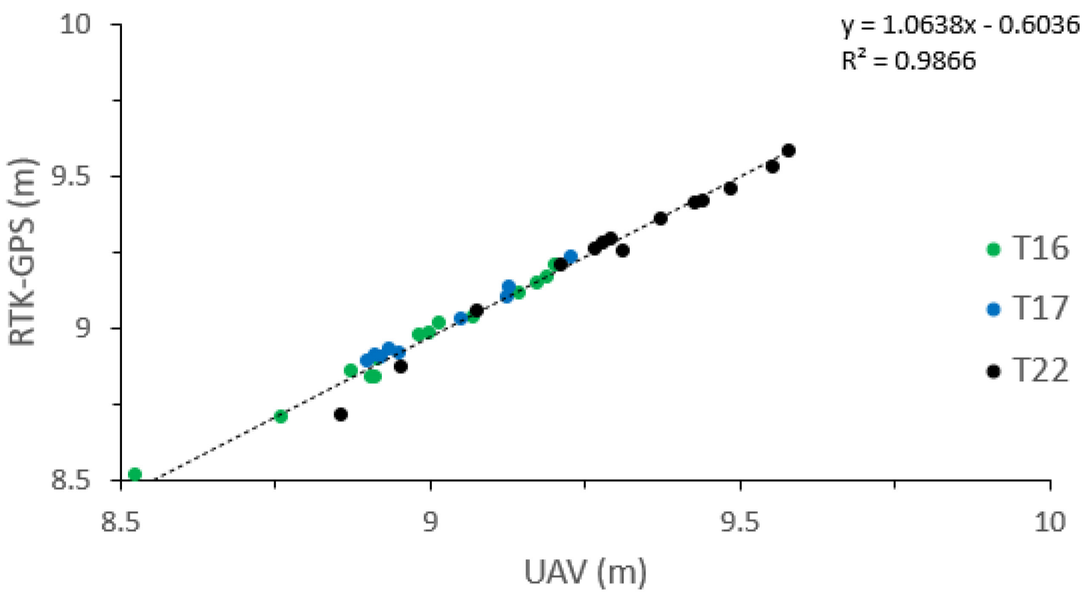


Figure 15 – Comparison of the measured topography between UAV and hand RTK-GPS.

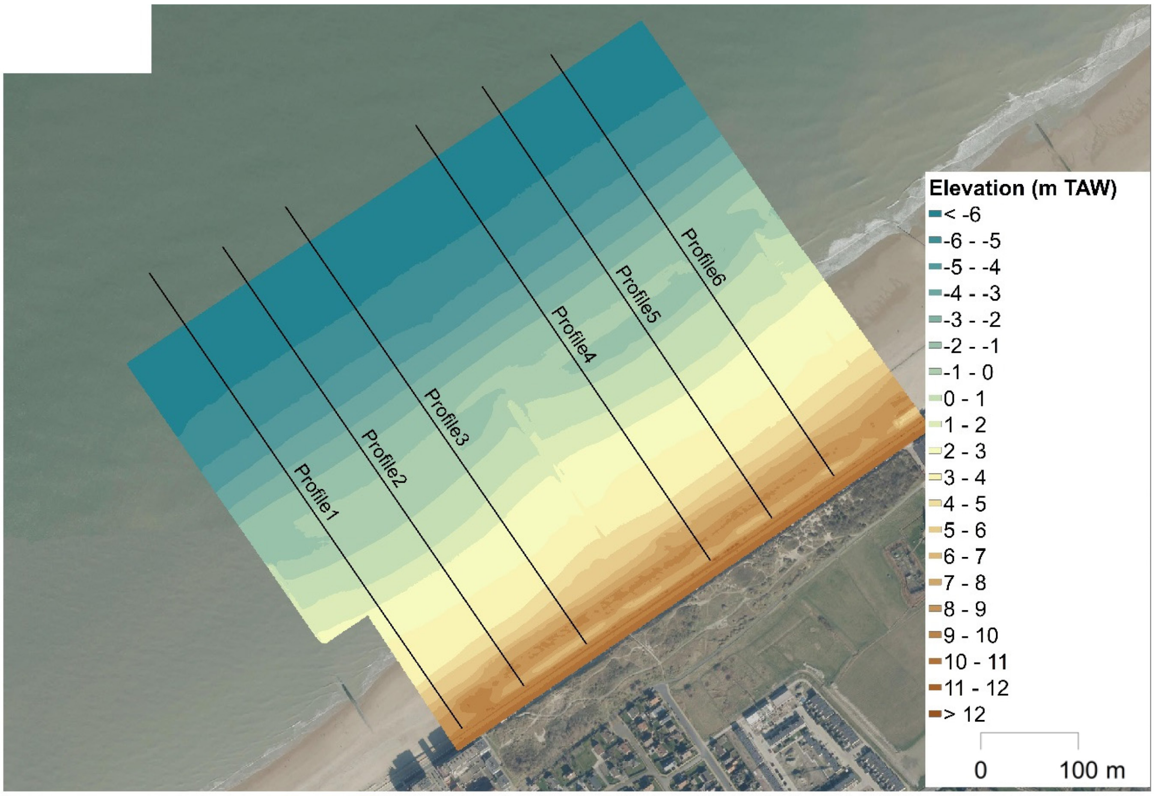
4 Bathy-topographic monitoring

4.1 Merging Beach and Shoreface Surveys

UAV and multibeam bathymetric surveys carried out around the same period were merged to produce DEMs of 1 m covering from the beach to the shoreface. Table 5 and Figure 16A present the combination of the survey dates and an example of DEM. Following this, consecutive DoDs and extracted profiles were produced to investigate the morphological changes (Figure 16B, Figure 17).

Table 4 – Merging beach from LiDAR topographic survey and shoreface from bathymetric survey.

Name	Beach	Shoreface (Multi-beam bathymetric survey)
202104_06	28/04/2021 (LiDAR survey)	24/06/2021
202209	12/09/2022 (UAV survey)	13/09/2022
202210	12/10/2022 (UAV survey)	10/10/2022
202301	24/01/2023 (UAV survey)	24/01/2023
202302	09/02/2023 (UAV survey)	09/02/2023
202303_04	29/03/2023 (UAV survey)	05/04/2023
202306	21/06/2023 (UAV survey)	16/06/2023
202309	14/09/2023 (UAV survey)	23/09/2023



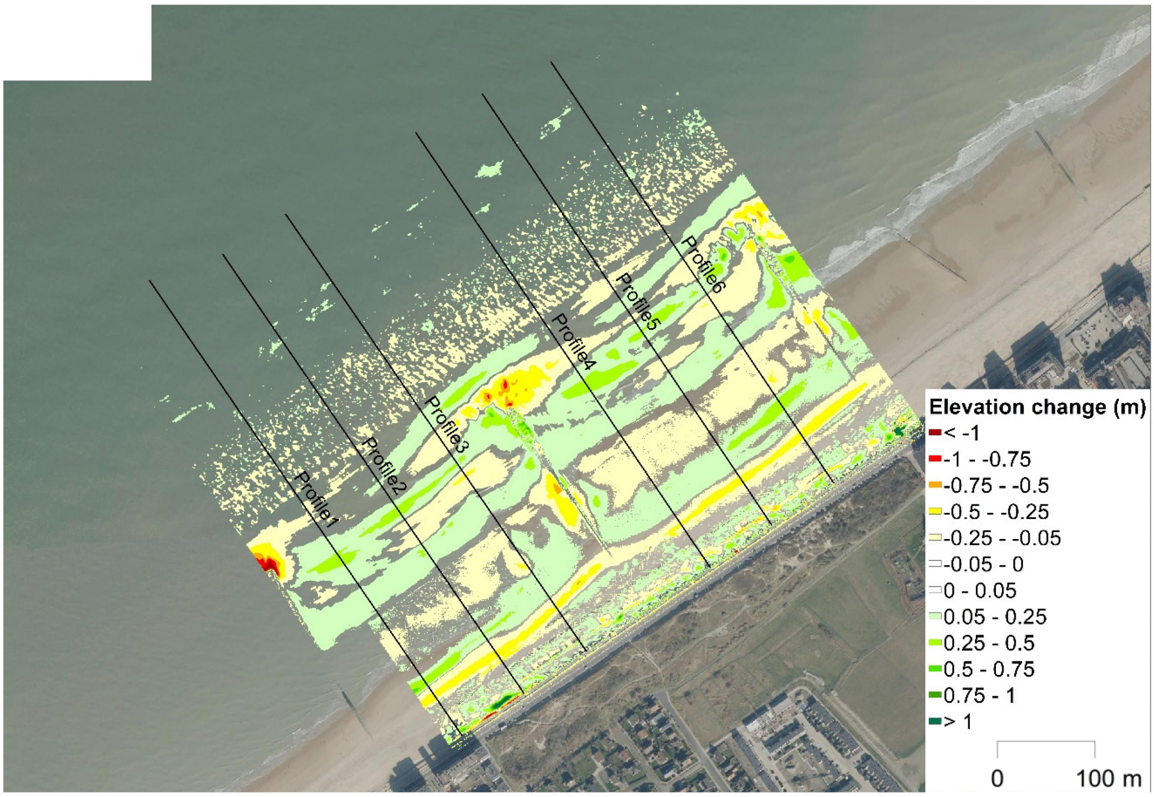


Figure 16 – Example of merged beach (UAV survey) and shoreface (MB survey) DoD between 02 and 03/2023.

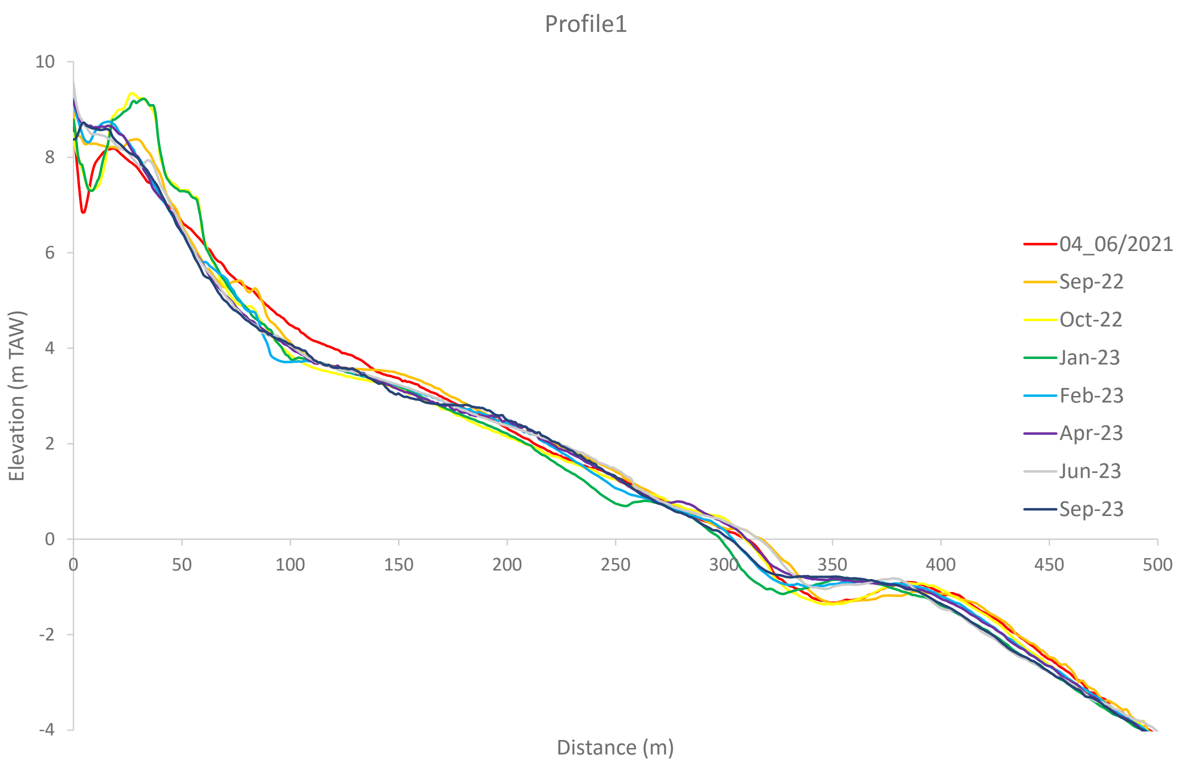


Figure 17 – Example of extracted profile 1 from the merged beach and shoreface DEMs.

All the data and analyses can be found:

E:\RaversijdeLivingLab_21_012\Data\Topography\MergedBeachShoreface

4.2 Comparing Survey Techniques for the Region around the Low Water Line

The study site was surveyed on 12-13/09/2022, 09/02/2023 and 06/2023 with UAV, hand RTK-GPS and multibeam techniques. These give the opportunity to compare techniques for the region around the low water line (Figure 18). In addition, Appendix C compares with 2 days apart the UAV and multibeam surveys in 09/2022 when no RTK-GPS measurement was carried out. No comparison of the UAV, multibeam and RTK-GPS surveys in 09/2023 was carried out due to the long period of 9 days between the measurement acquisitions when energetic marine conditions occurred which could have caused morphological changes around the low water line .

In general, the width of the overlapping area ranges from 36 to 74 m between UAV (i.e. cut DEM excluded water area) and multibeam in 10/22, from 58 to 79 m in 02/2023 and from 10 to 21 m in 06/2023. Regarding the overlapping between RTK-GPS and multibeam, the average width was about 17 m, 70 m and 16 m in 10/2022, 02/2023 and 06/2023 respectively.

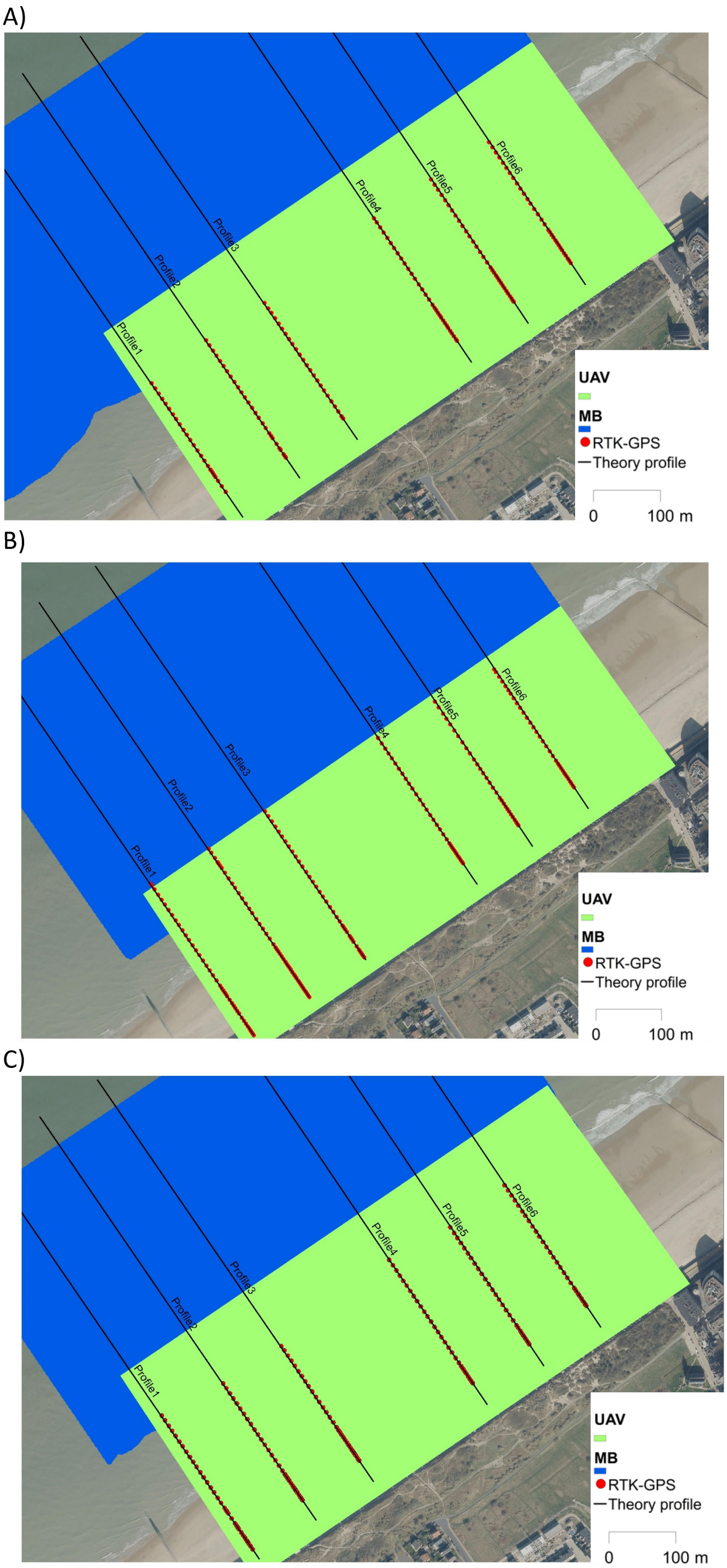


Figure 18 – Areas of the different survey techniques in A) 09/2022, B) 02/2023 and C) 06/2023.

Figure 19 presents the DoDs between UAV and multibeam for the three surveys.

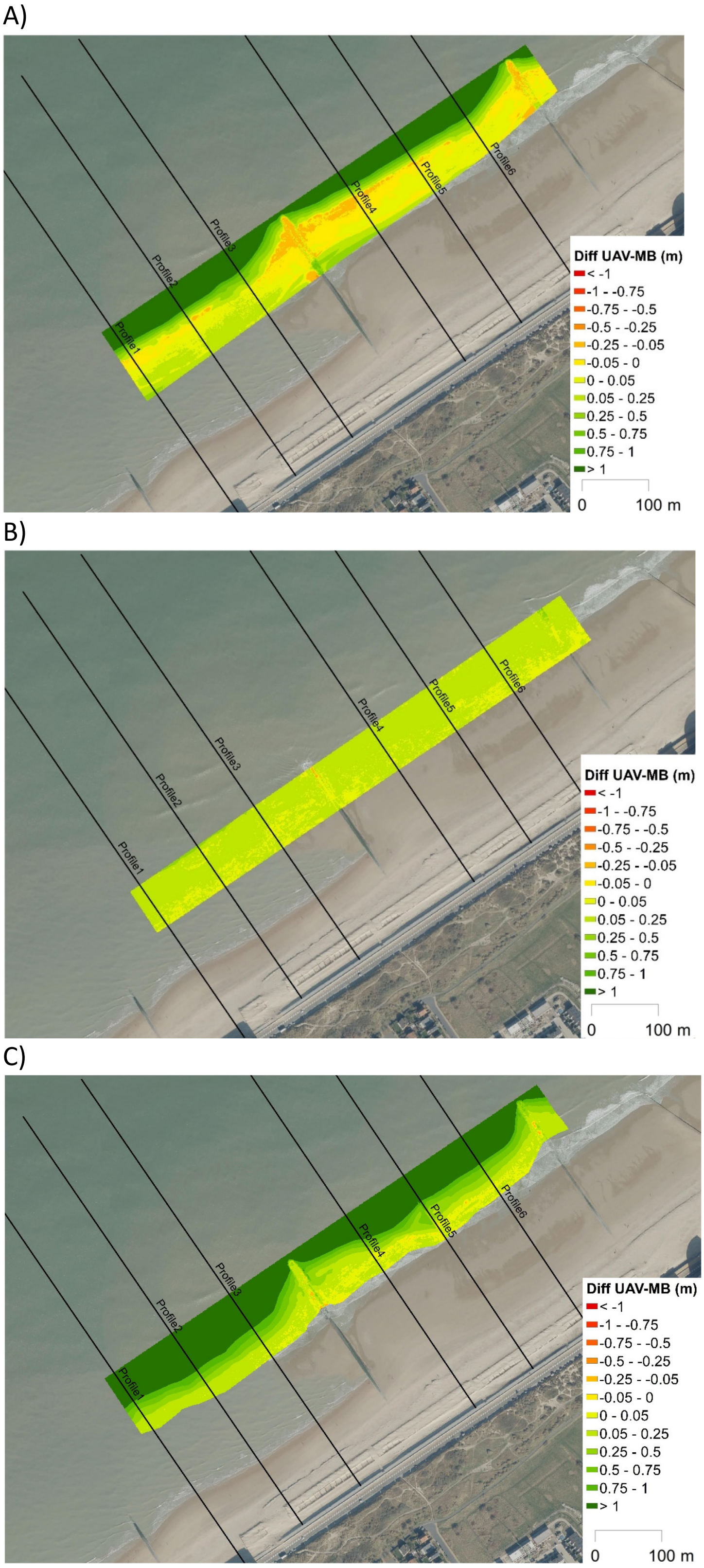


Figure 19 – DoDs between UAV and multibeam survey A: 09/2022, B) 02/2023 and 06/2023.

To investigate the error of the different techniques, a comparison analysis was carried out on the raw data for the 3 survey periods. UAV and MB DEMs were compared to the measured RTK-GPS points (i.e. not re-projected and not interpolated).

Table 6 presents the average differences between the survey techniques based on the common locations ranging from 17 to 33 points for UAV and from 17 to 60 points for multibeam (MB). As previously observed, UAV estimates well the beach topography. For the low water zone, the average error referenced to the hand RTK-GPS technique ranges from 0.02 to 0.03 m (slight overestimation by the UAV DEMs). The distribution of the error is low leading to a total error not exceeding 0.04 m (avg 0.03 m). Therefore, the UAV is capable to depict correctly the low part of the beach near the low water line. Regarding the difference between MB and hand RTK-GPS, it is of 0.11 m in 09/2022 and then decreases to 0.05 m for the following surveys. Since the distribution of the error is limited, the total error does not exceed 0.11 m (average of total error is 0.08 m for MB). So MB DEMs tend to overestimate the height of the sea bottom with 5 to 10 cm. From this, the average difference between UAV and MB is around 0.08 m to 0.13 m. Therefore, both techniques can be merged to cover the area from the dyke to the shoreface to study morphological changes on decimetre scale (i.e. not centimetre scale).

Table 5 – Summary statistics of the difference between survey techniques on the point locations for the low water area.

Time	09/2022			02/2023			06/2023		
Comp	UAV-RTKGPS	MB-RTKGPS	UAV-MB	UAV-RTKGPS	MB-RTKGPS	UAV-MB	UAV-RTKGPS	MB-RTKGPS	UAV-MB
Avg (m)	0.02	0.07	0.10	0.03	0.05	0.07	0.02	0.08	0.08
Max (m)	0.06	-0.01	0.32	0.07	0.00	0.14	0.06	-0.05	0.16
Min (m)	0.00	-0.32	0.02	-0.01	-0.09	0.00	-0.02	-0.12	0.03
SD (m)	0.02	0.08	0.09	0.02	0.02	0.03	0.01	0.02	0.03
Count	13	18	13	33	60	53	17	17	17
Total Error (m)	0.02	0.11	0.13	0.04	0.05	0.08	0.02	0.08	0.09

All the data can be found here:

E:\RaversijdeLivingLab_21_012\Analysis\RawData

4.3 Combining Beach, Shoreface and Offshore Area Surveys

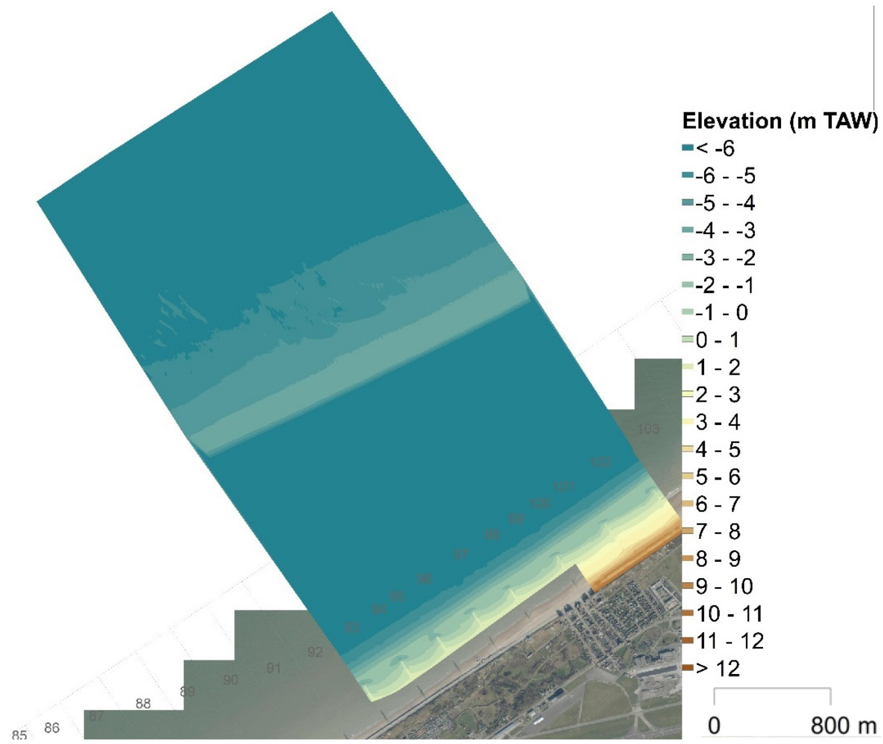
The beach surveyed by UAV, shoreface and offshore area by multi beam bathymetry in 09/2022, 09/2023 were merged to DEM of 1 m cell size. The total cover area is up to 4.7 km long from the sea dyke (Table 7 and Figure 20).

Table 6 – Description of the combined beach, shoreface and offshore data sets.

Name	Beach (UAV survey)	Shoreface (Multi-beam bathymetric survey)	Offshore area (Multi-beam bathymetric survey)
mergbso202209	12/09/2022	12/09/2022 (3 days*)	13/09/2022-11/10/2022 (6 days*)
mergbso202309	14/9/2023	26/09/2023 (2 days*)	14/09/2023 (3 days*)

Note *: survey duration

A)



B)

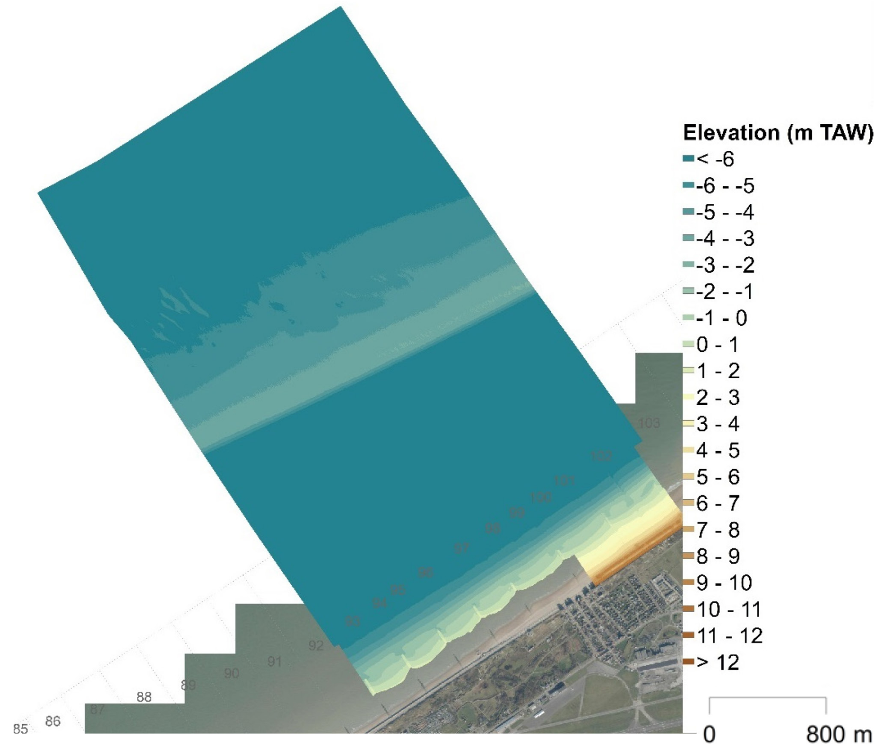


Figure 20 – Combined DEM of the beach, shoreface and offshore area in A) 09/2022, B) 09/2023.

All the data and analyses can be found:

E:\RaversijdeLivingLab_21_012\Data\Topography\MergedBeachShorefaceOffshore

5 Grain Size Monitoring

5.1 Beach Zone

Sediment samples were collected on the beach along 6 beach profiles from the dyke to the low water line on 09/03/2022 when the lowest water level was of 4.12 m TAW (Figure 21). In total, 48 samples were collected (i.e. 8 samples per profile). Then they were analysed by a laser particle size analyser in the sediment lab at WL. In general, the sediment grain size decreases from the beach to the dyke with a D50 ranging from 400 to 268 µm . Appendix D displays the results of D10 and D90 of the sediment samples.

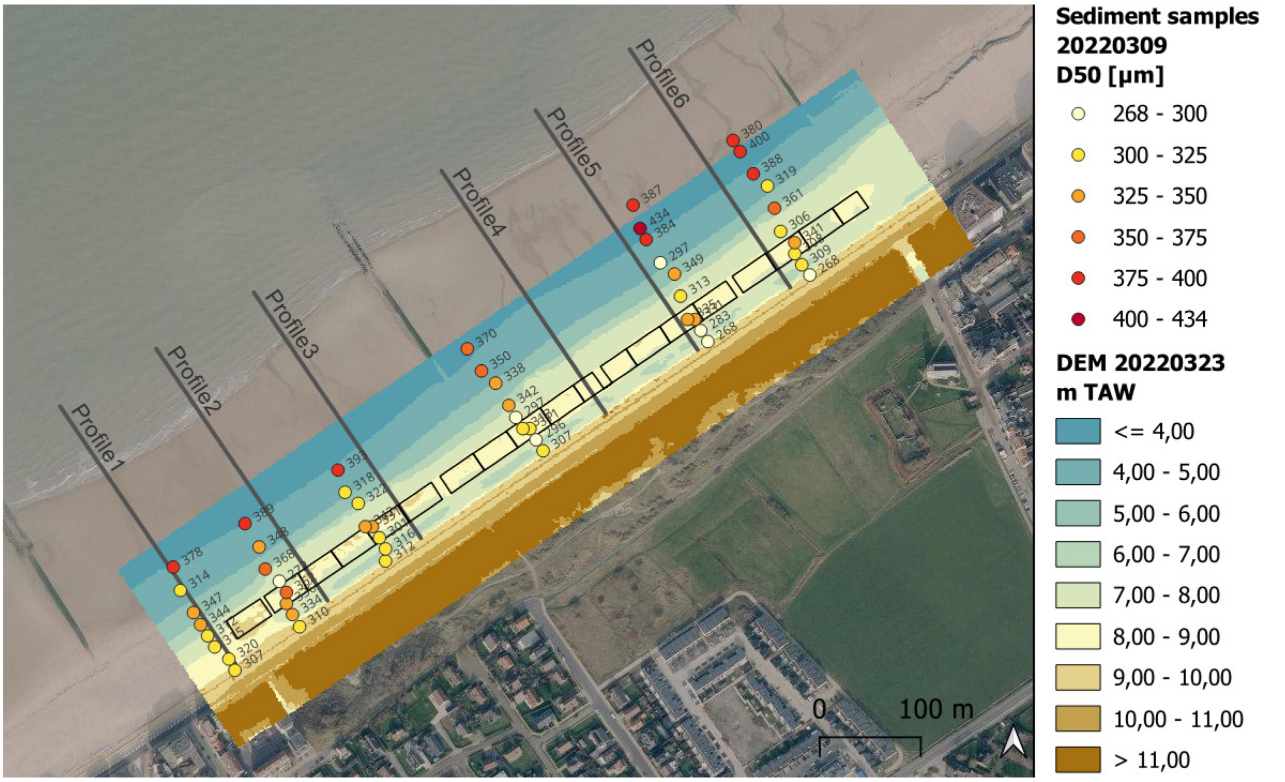


Figure 21 – Result map of the sediment samples of D50 collected on the beach on 09/03/2022.

5.2 Offshore Zone

Nine offshore sediment samples were taken on a boat with Van Veen grab samples by MUMM in the framework of the sustainable use of sand in nature-based solutions (SUSANA) campaign with RV Simon Stevin for the Living Lab Raversijde project in 03/2023. The sediments were analysed by a laser particle size analyser at WL. The location of the samples as well as the D50 grain size is shown in Figure 22. The sorting was calculated as half the difference between D10 and D90, both expressed in Krumbein phi. It appears that both the seaward slope and the crest area of the Stroombank contain fine to medium sand. Also, the grain size at the crest of Stroombank is slightly coarser than at its seaward flank. The sand at the crest is much better sorted than at the seaward flank: the average sorting of the three crest samples is 0.56 and of the three seaward slope samples 1.74. These results can be interpreted as net sand transport from the seaward slope to the crest area.

A good sorting at the crest, combined with the overall smooth morphology , also indicates wave reworking process. The three samples from the Kleine Rede flow channel contain muddy sediment. Their poor sorting (averaging at 4.01) indicates a sedimentary area receiving sediment from multiple sources; e.g. suspended sediment (mud) and current driven sand transport. Appendix D presents D10 and D90 of the offshore sediment samples.

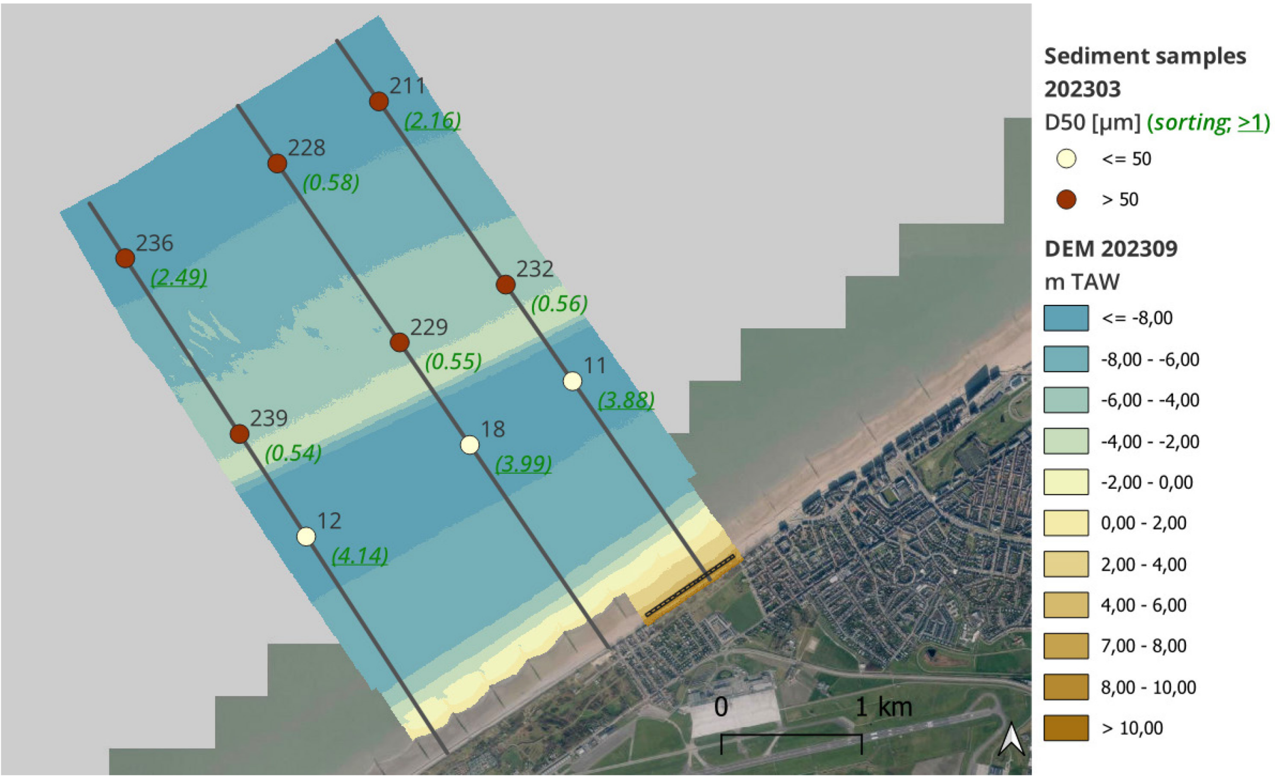


Figure 22 – Result map of the sediment samples of D50 collected on the shoreface on 03/2023.

All the data can be found:

E:\Duin voor dijk pilots_21_014\Analyses\SedimentSamples\20220309

E:\RaversijdeLivingLab_21_012\Data\SedimentSamples

6 Conclusions

- From 09/2022, the UAV survey covers the lower part of the beach. Compared to the measured true ground elevation from the hand RTK-GPS, UAV slightly overestimates the beach topography (total error ranging from 0.02 to 0.06 m). Thus, it could be suggested to survey the lower beach with only UAV and not anymore with hand RTK-GPS.

- The average difference in the vegetated boxes between the UAV and LiDAR techniques is relatively low ranging from 0.04 m to 0.08 m. To estimate the true ground elevation, the comparison between UAV technique and hand RTK-GPS indicates that, up till now, UAV represents well the elevation in the vegetated boxes, it does not measure the canopy when the vegetation is relatively low and not dense. However further follow up is needed as vegetation density might increase and interfere with the UAV DEM. For this reason hand RTK-GPS in the vegetated boxes will have to intensified in the coming years as the vegetation density will increase.

- An analysis of 3 comparing surveys was carried out by assuming that hand RTK-GPS measures the true topography. The average total error is of 0.03 m for UAV and of 0.08 m for MB for the area around the low water line., even though both techniques are pushed to their limit in the area of the low water line.

- An intense monthly UAV survey of the beach, covering from the dyke to the low water line and the multibeam survey of the shoreface from the low water line to -6 m TAW allow to monitor at high-resolution these zones in order to investigate the morphodynamics of the active zone at dm scale.

- Beach sediment grain size decreases from the beach to the dyke. The sediment characteristics in Kleine Rede channel are much different from the sediment characteristics on the Stroombank.

7 References

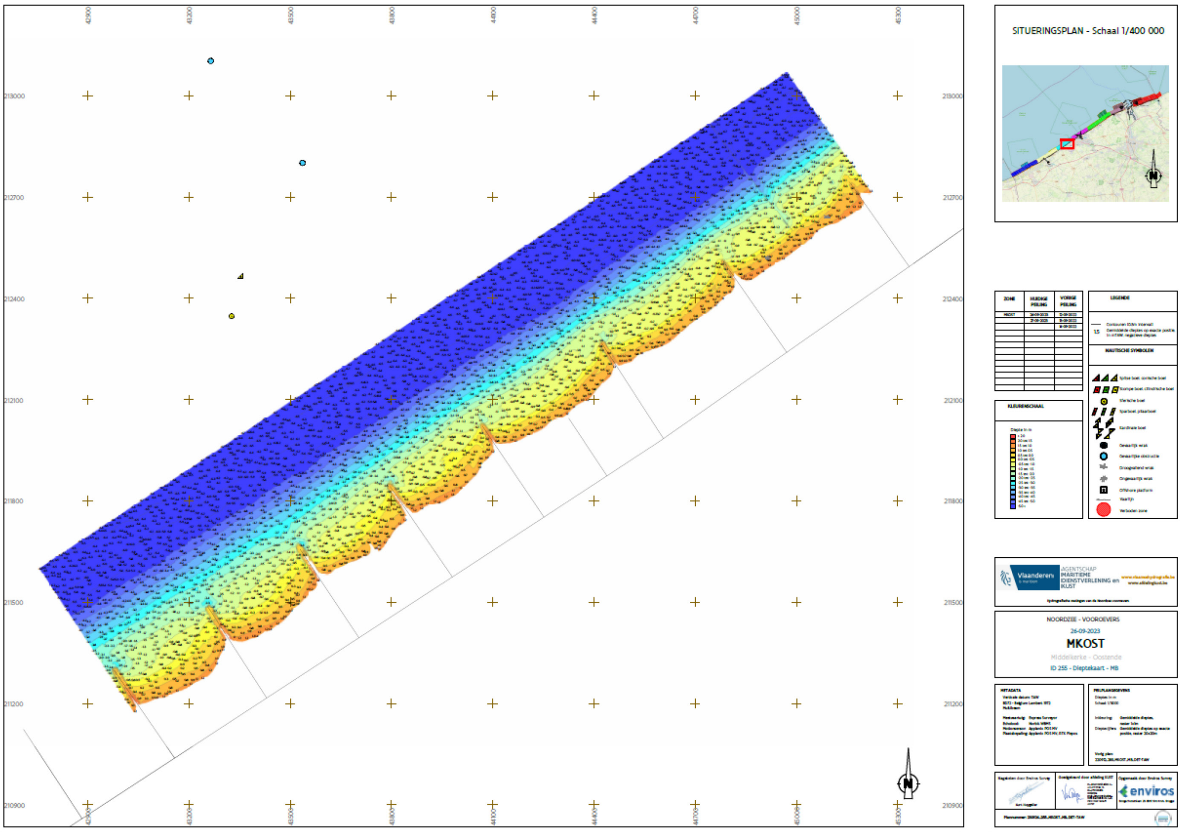
Montreuil, A-L., Verwaest, T., Dan, S. (2022). Living Lab Raversijde – Monitoring Soft Coastal Defences: Factual data report 1st working year 2021-2022. Version 2.0. FHR Reports, 21_012_1. Flanders Hydraulics Research: Antwerp.

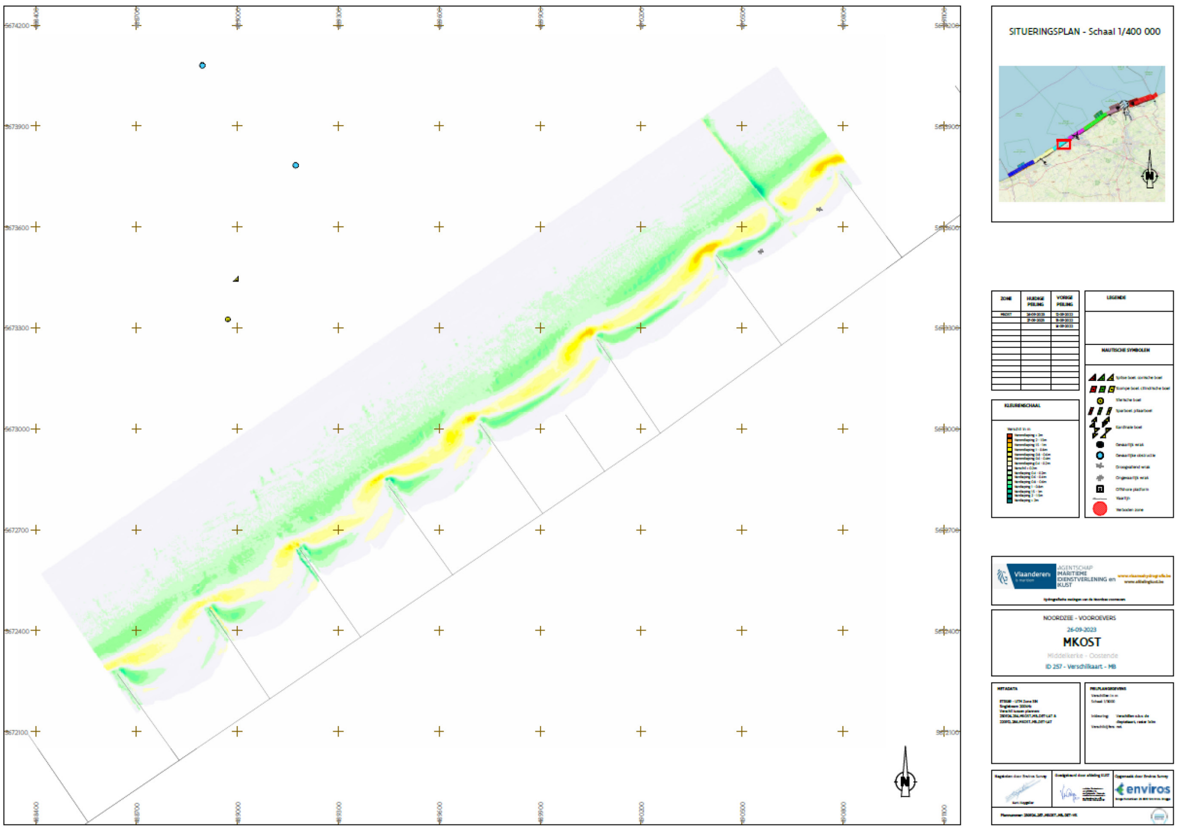
Montreuil, A-L.; Dan, S.; Verwaest, T. (2023). Ostend-Middelkerke, Monitoring of the dune for dyke pilots: Evolution after 2 years. Version 0.1. FH Reports, 21_014_2. Flanders Hydraulics: Antwerp

Verwaest, T.; Montreuil, A.-L.; Dan, S. (2022). Oostende-Middelkerke, Monitoring duin voor dijk pilots: Evolutie gedurende het 1e jaar. Versie 2.0. WL Rapporten, 21_014_1. Waterbouwkundig Laboratorium: Antwerpen.

Appendix A

Example of multibeam products

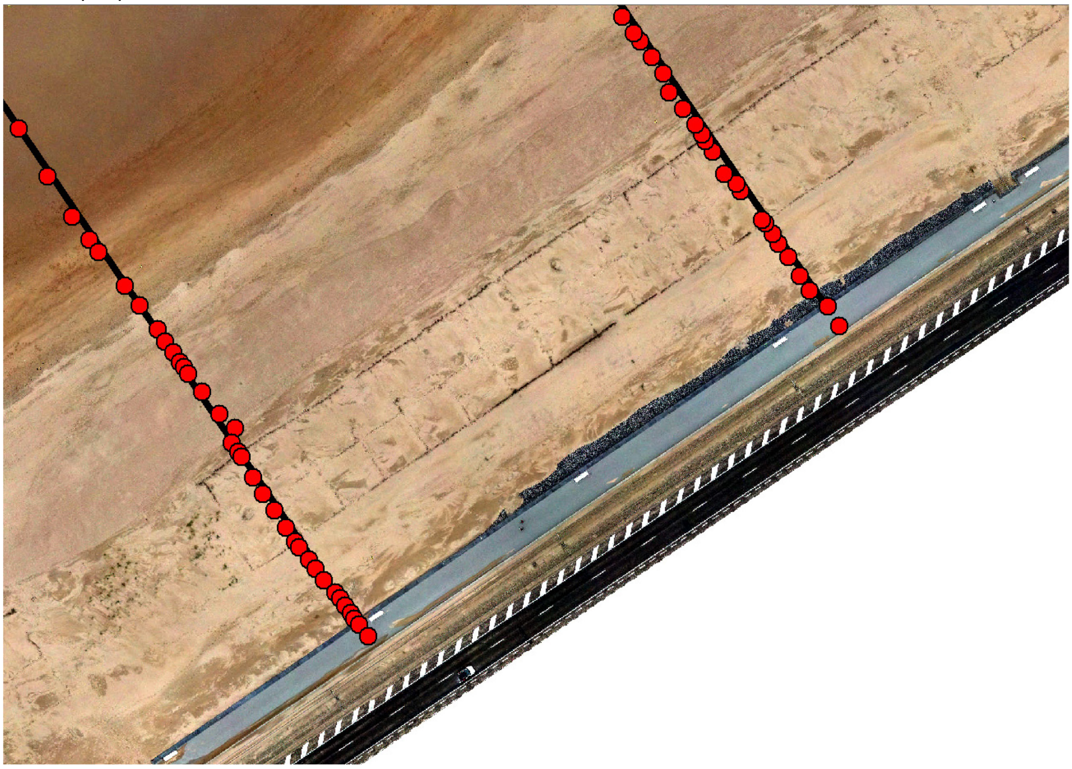




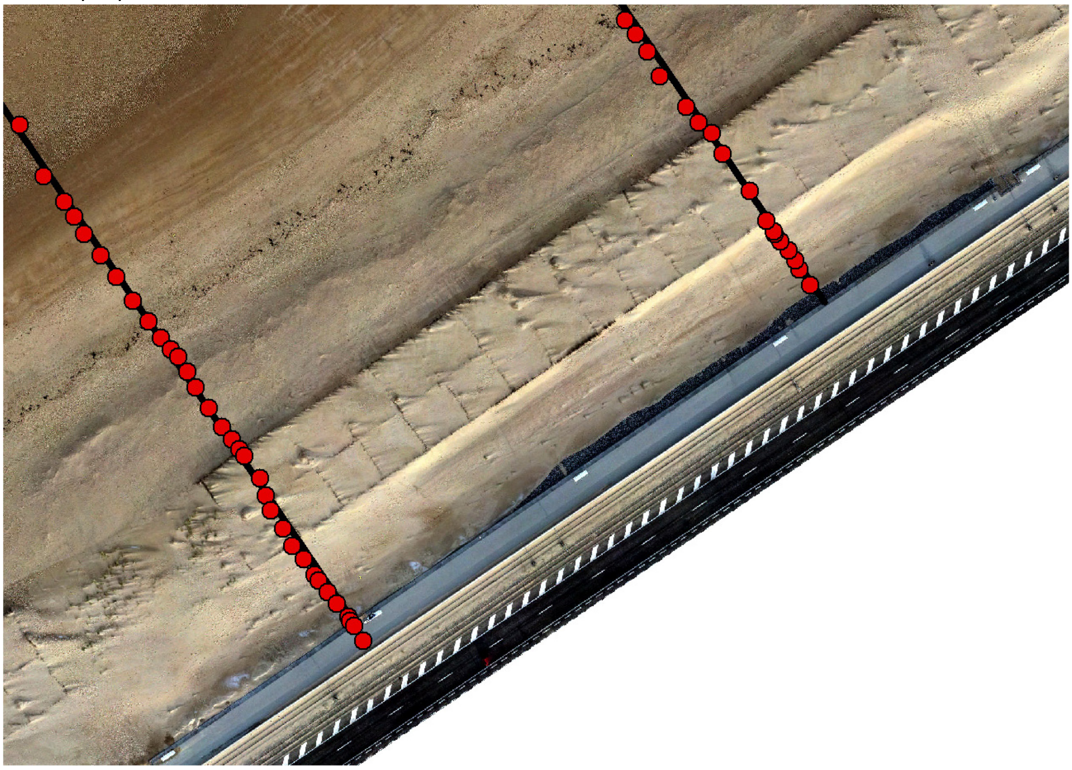
Appendix B

Red points correspond to the location of the measurements where the comparison between UAV and hand RTK-GPS was carried out.

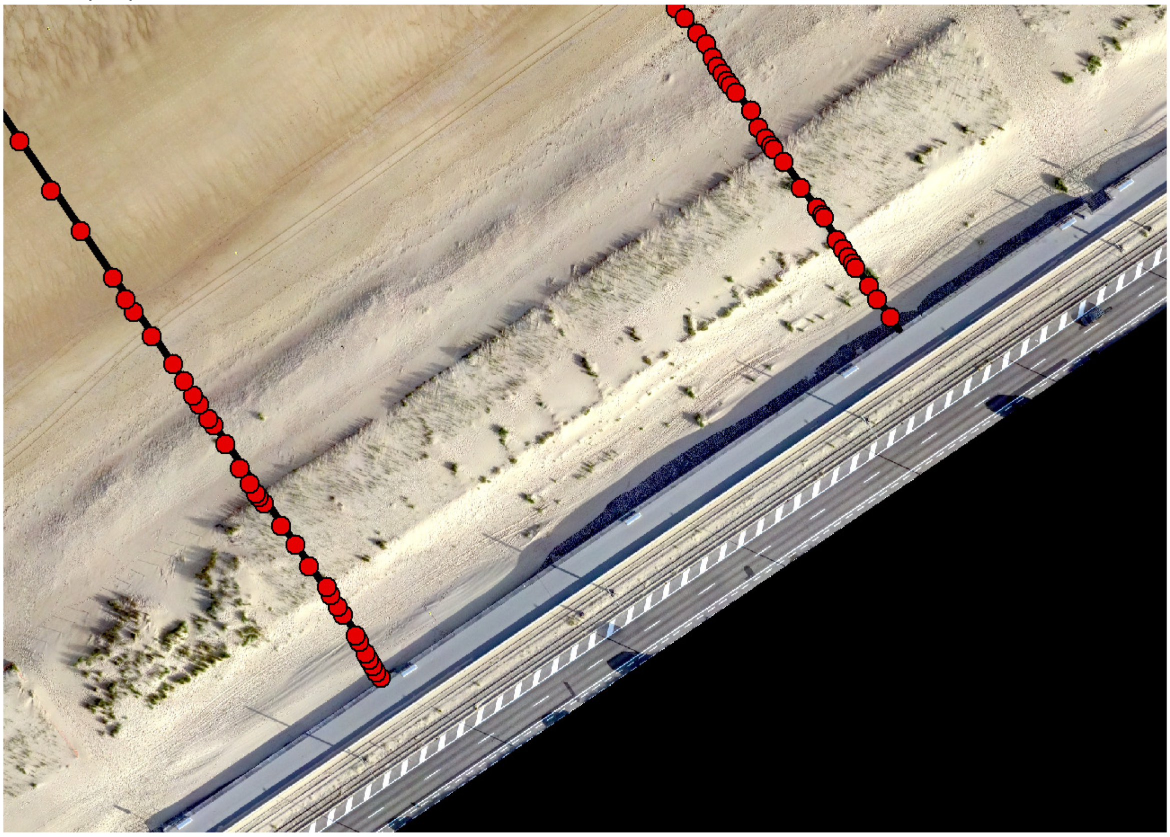
T16: 24/01/2023



T17: 09/02/2023

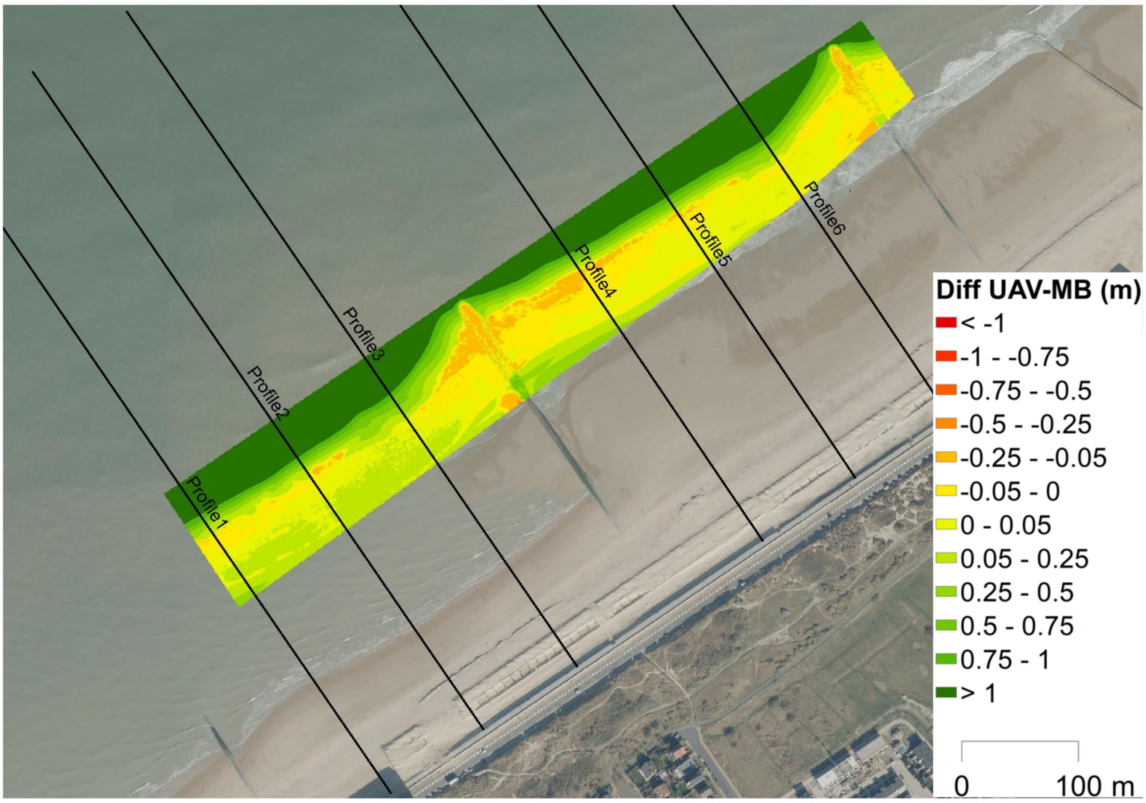


T22: 14/09/2023



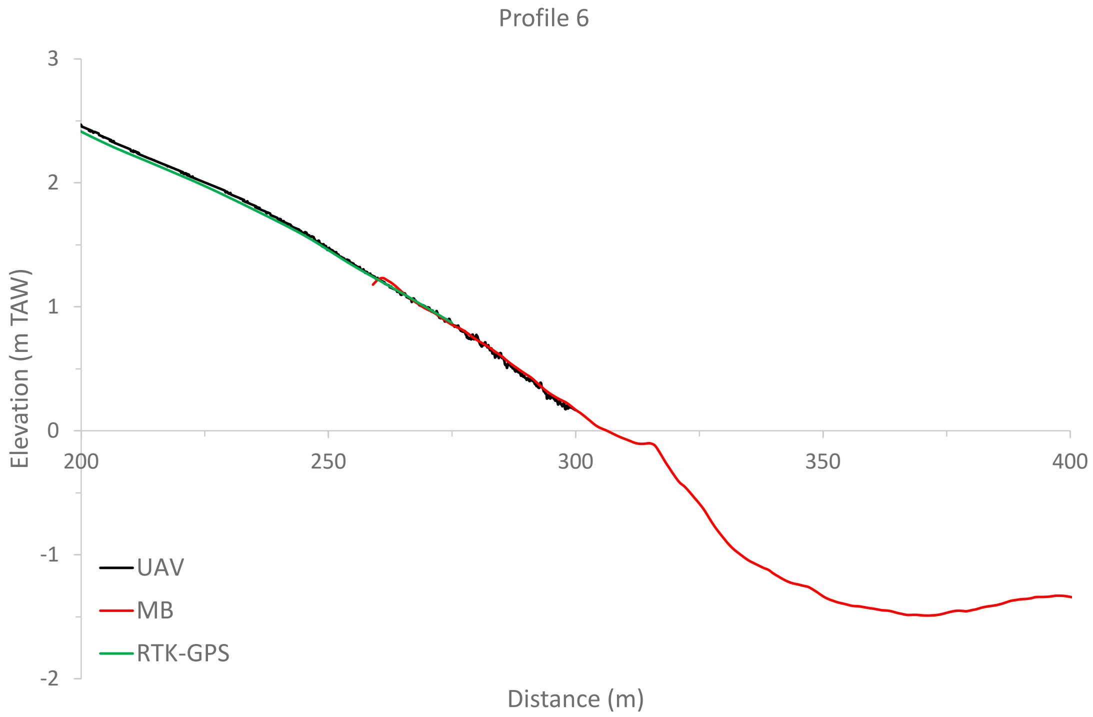
Appendix C

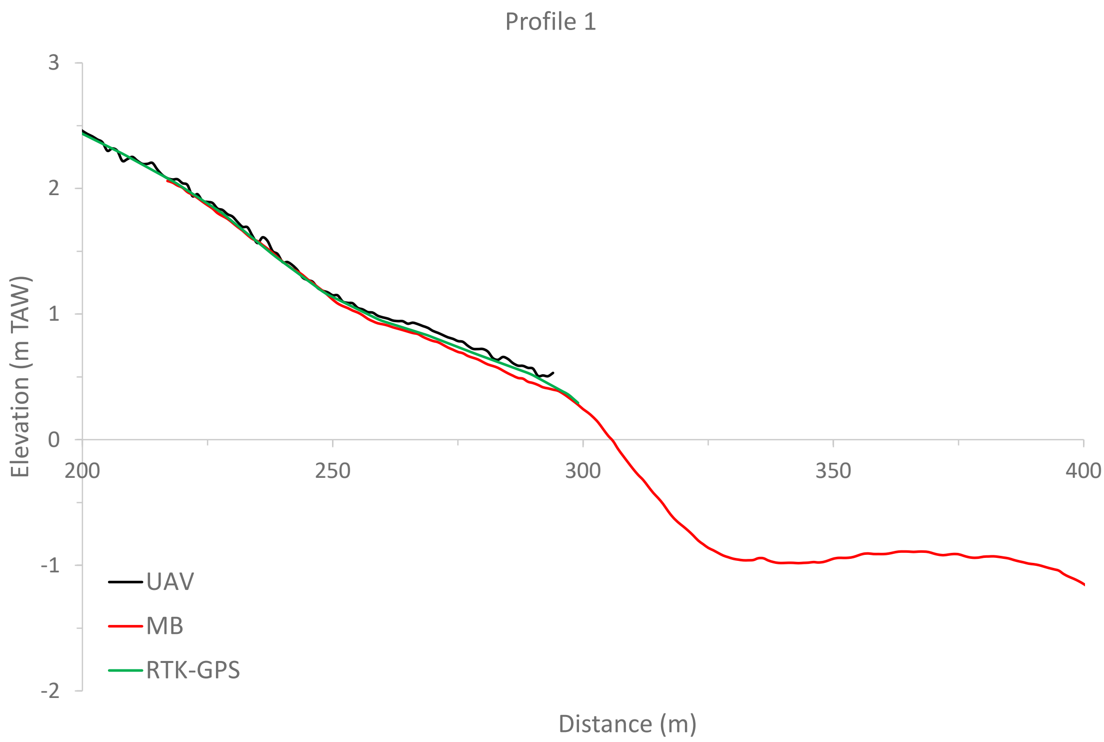
Comparing UAV and multibeam surveys in 09/2022 when no RTK-GPS measurement was carried out. There was 2 days apart between the 2 techniques.

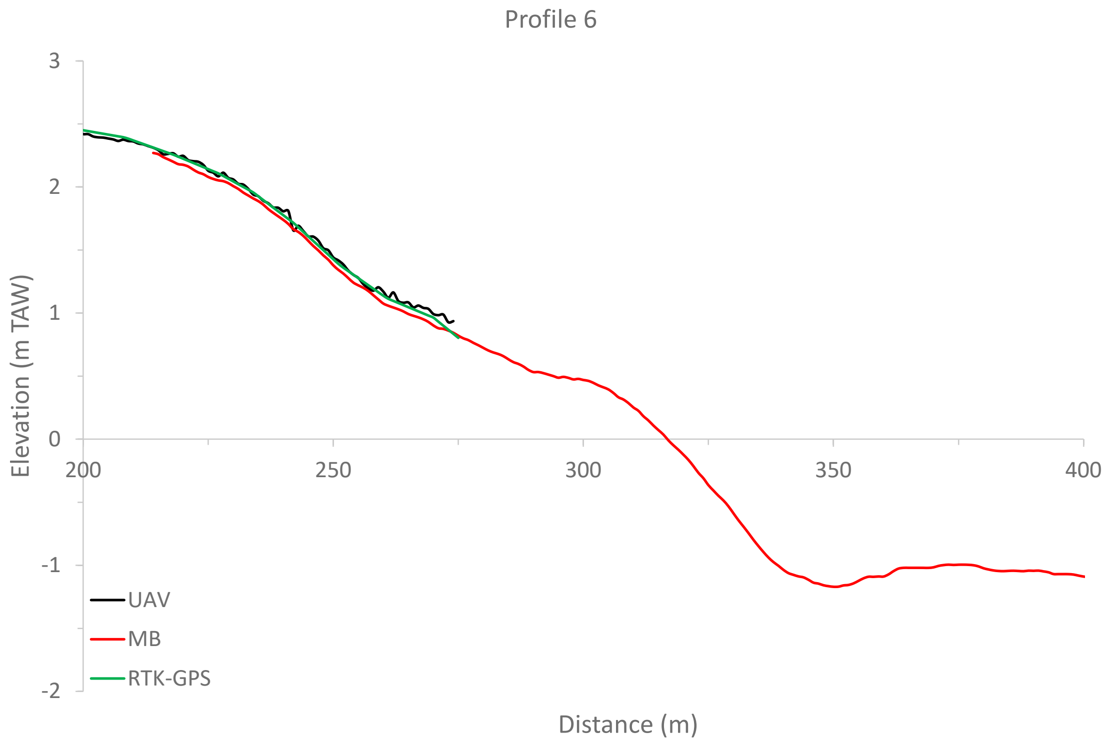


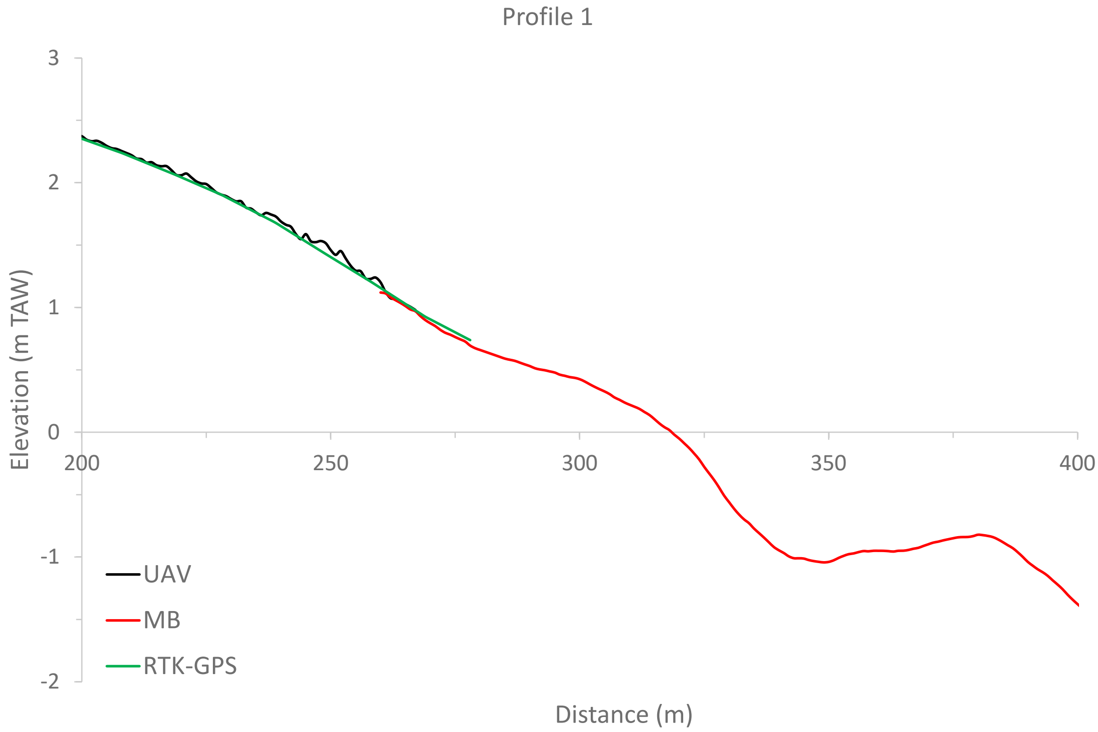
Diff UAV-MB		Profile 1-6
All	Avg	0.07
	Max	0.14
	Min	0.01
	SD	0.04
from 1.2 m TAW to low water	*Avg*	0.04
	Max	0.06
	Min	0.02
	SD	0.01
Diff MB-HandGPS		
All	Avg	0.05
	Max	0.09
	Min	0.17
	SD	0.04
Diff UAV-HandGPS		
All	Avg	0.04
	Max	0.18
	Min	0.36
	SD	0.020

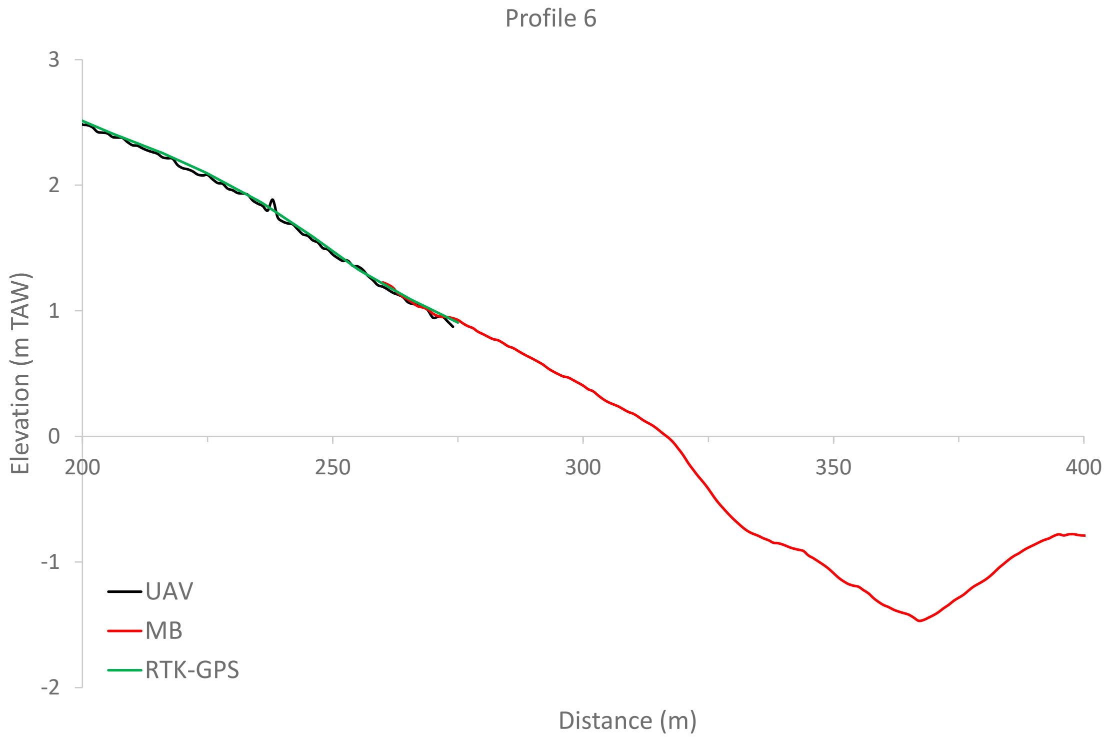
Extracted and interpolated profiles for the 3 comparison surveys




Profile 1
Elevation (m TAW)
3
2
1
0
-1
-2
200
250
300
350
400
UAV
MB
RTK-GPS
Distance (m)


Profile 6
Elevation (m TAW)
3
2
1
0
-1
-2
200
250
300
350
400
UAV
MB
RTK-GPS
Distance (m)

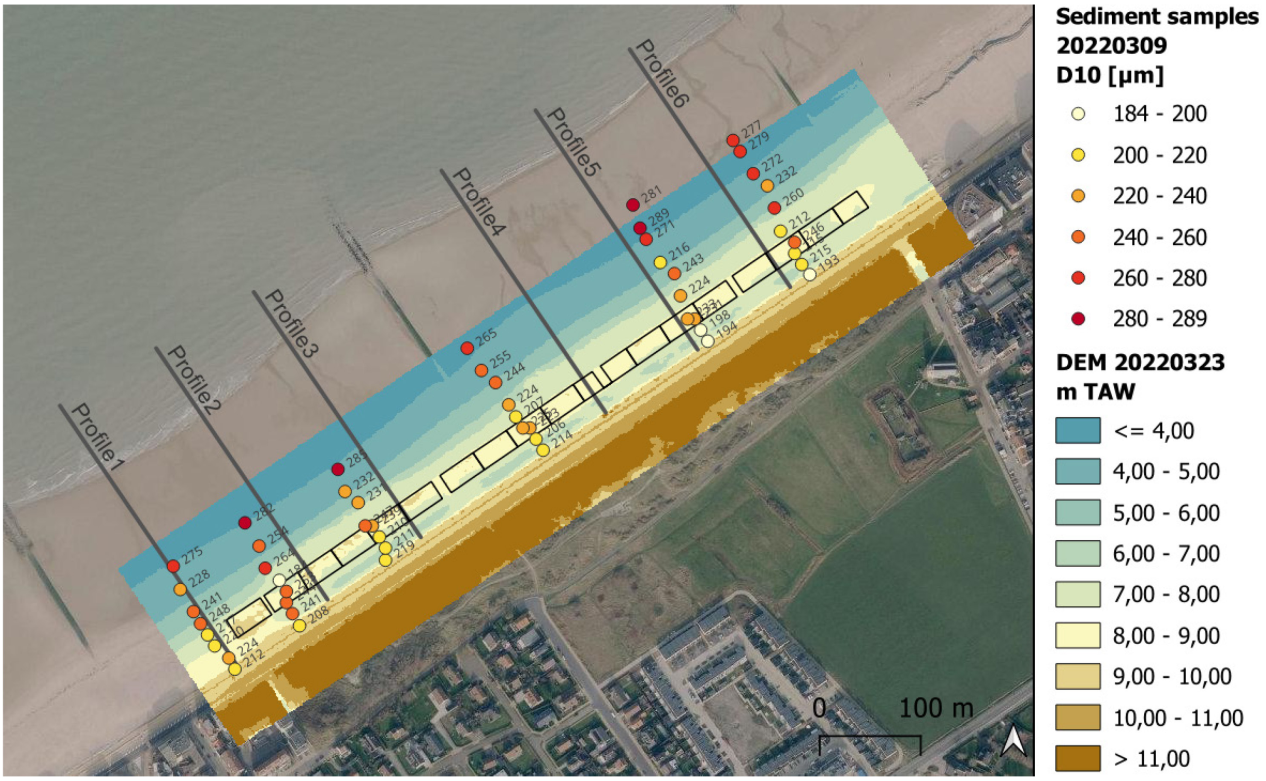

Profile 1
3
2
1
0
-1
-2
200
250
300
350
400
Elevation (m TAW)
Distance (m)
UAV
MB
RTK-GPS


Profile 6
3
2
1
0
-1
-2
200
250
300
350
400
Elevation (m TAW)
Distance (m)
UAV
MB
RTK-GPS

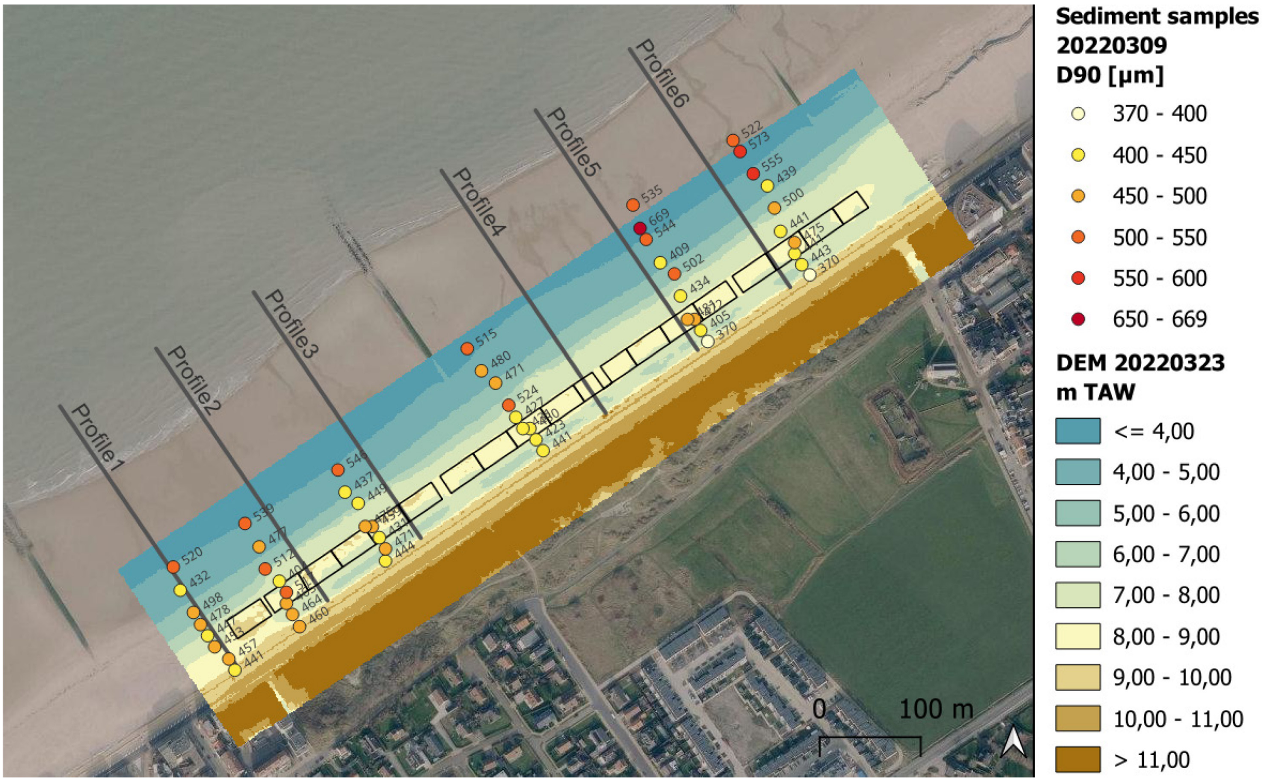
Appendix D

Results of sediment samples on the beach in 03/2022 overlayed on the UAV DEM in 03/2022

D10

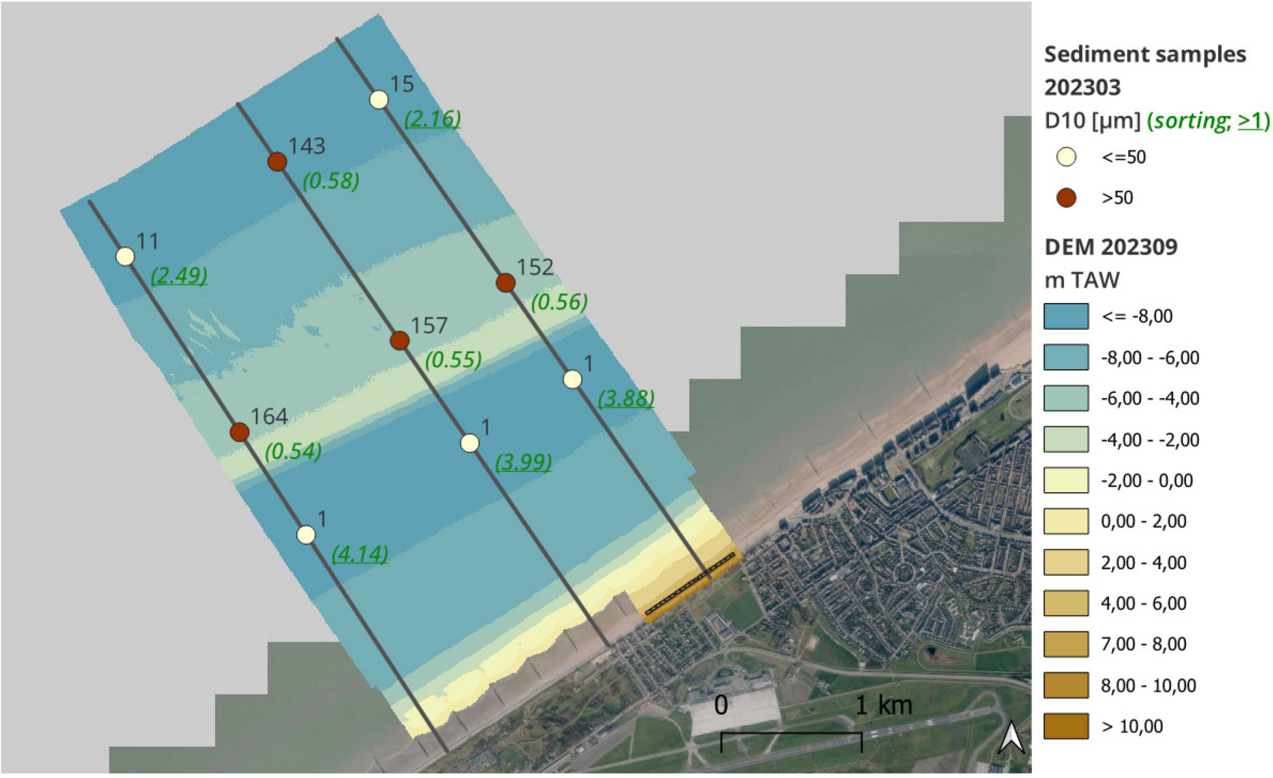


D90

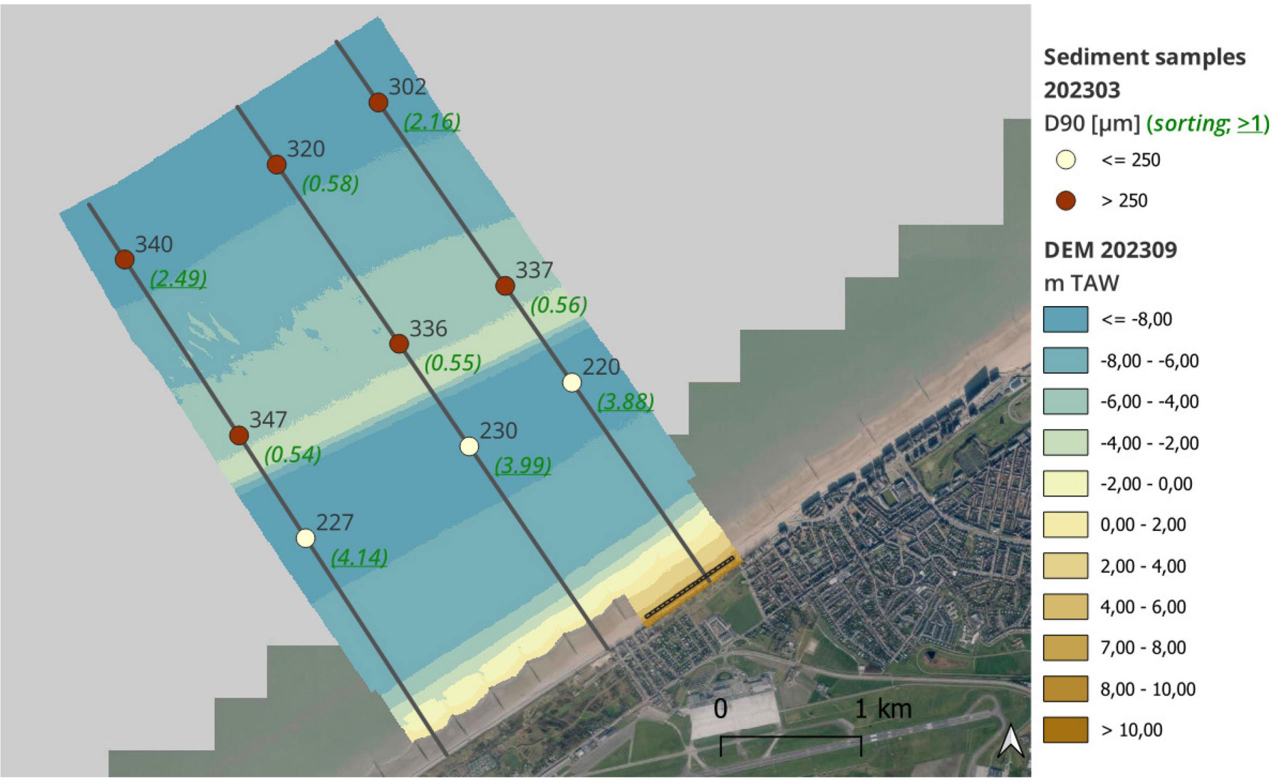


Results of sediment samples on the shoreface in 03/2023 overlayed on the DEM in 09/2022

D10



D90



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