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MANABAS COAST – Living Lab Raversijde – Monitoring Soft Coastal Defences

Factual data report 2024

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MANABAS COAST
NATURE-BASED SOLUTIONS

MANABAS COAST – Living Lab Raversijde – Monitoring Soft Coastal Defences

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Abstract

In the framework of Living Lab Raversijde and the MANABAS COAST project, an intensive topo-bathymetric monitoring campaign of the Nature based Solution (NbS) soft coastal defences in the Living Lab Raversijde has started from the beginning of 2021. This factual data report provides an update of the acquired topo-bathymetric surveys, including drone photogrammetry (UAV), handheld RTK-GPS profiles and multibeam echo sounder surveys, for the period from 2021 to 2024. In addition, human intervention affecting the beach morphology are reported and a beach monitoring campaign before and after a storm in November 2023 is presented. Finally, the effect of vegetation on the generated UAV DEM as well as the vegetation image processing are documented.

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1 Introduction

The intensive monitoring of the soft coastal defences in the framework of the Raversijde Living Lab has started in 03/2021, right after the beach nourishment and the installation of brushwood and marram grass.

In 2022 the area has been included as a pilot case in the Interreg project MANABAS COAST (MAinstreaming NAture BAsed Solutions through COASTal systems; https://www.interregnorthsea.eu/manabas-coast). MANABAS COAST is an INTERREG North Sea Program project, it is a cooperation of partners from Sweden, Denmark, Germany, The Netherlands, Belgium and France, running from 2022 to 2027. 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.

Table 1 and Figure 1 present a timeline of the bathymetric and topographic campaigns that were executed in Raversijde. Topographic surveys covering the area from the dyke to the low water line have been acquired by drone photogrammetry (UAV) and field hand Real Time Kinematic-GPS (RTK-GPS) obtained mainly by walking or setup on a quad. Bathymetric surveys consist of single and multibeam echo sounder methods, carried out in the shoreface zone and the offshore neighbouring sea bottom. Additionally LiDAR surveys are available for the entire Belgian coastline. In 2024, the frequency of UAV and nearshore bathymetric surveys was decreased as the system is stabilizing and because of budgetary reasons. Also in 2024, the additional handheld RTK-GPS profiles during the UAV-flights were suspended because the validation was completed.

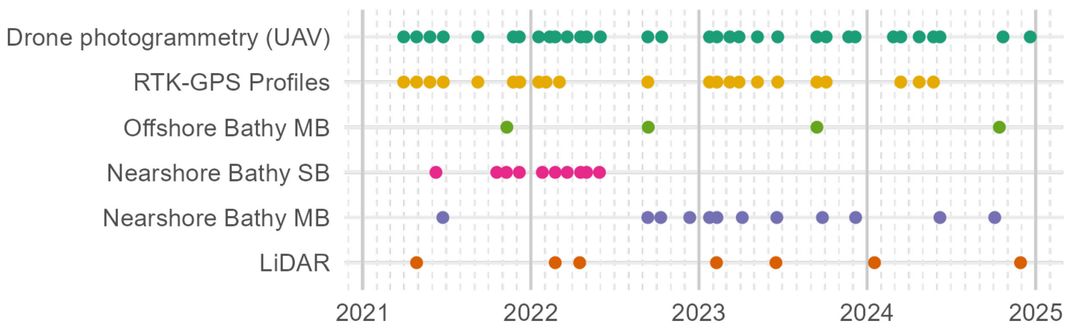


Figure 1 – Timeline of the bathymetric and topographic surveys 2021-2024

Figure 2 displays the dune in front of dyke pilot area (section 100-102). Typically, the offshore, nearshore and UAV surveys take 3 days, 2 days and a few hours to be carried out respectively. The planning of the multibeam and UAV surveys is generally synchronized as much as possible.

The aim of this 3rd factual report is to provide an overview of the acquired surveys monitoring the soft coastal defences, to document the processing on the raw data and to present the results. The factual reports for the first two years of the monitoring are reported in Montreuil et al., 2022a, 2023a.

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 presented. Results about the dune morphological behaviour and evolution of the dune for dyke pilot in Raversijde from 2021-2024 are reported in more detail in Montreuil et al. (2024).

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
BO2	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
BO3	14/09/2023	Offshore Bathy multibeam
B18*	26/09/2023	Bathy multibeam
T23	04/10/2023	UAV and hand RTK-GPS
T24	22/11/2023	UAV
T25	06/12/2023	UAV
B19*	07/12/2023	Bathy multibeam
L6	17/01/2024	LiDAR
T26	27/02/2024	UAV
T27	14/03/2024	UAV and hand RTK-GPS
T28	23/04/2024	UAV and hand RTK-GPS
T29	24/05/2024	UAV and hand RTK-GPS
T30	07/06/2024	UAV
B20*	07/06/2024	Bathy multibeam
(B21*)	04/10/2024	Bathy multibeam
(T31)	22/10/2024	UAV
(B04)	14/10/2024	Offshore Bathy multibeam
(L7)	29/11/2024	LiDAR
(T32)	20/12/2024	UAV

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

() The surveys between brackets are not yet processed in this report

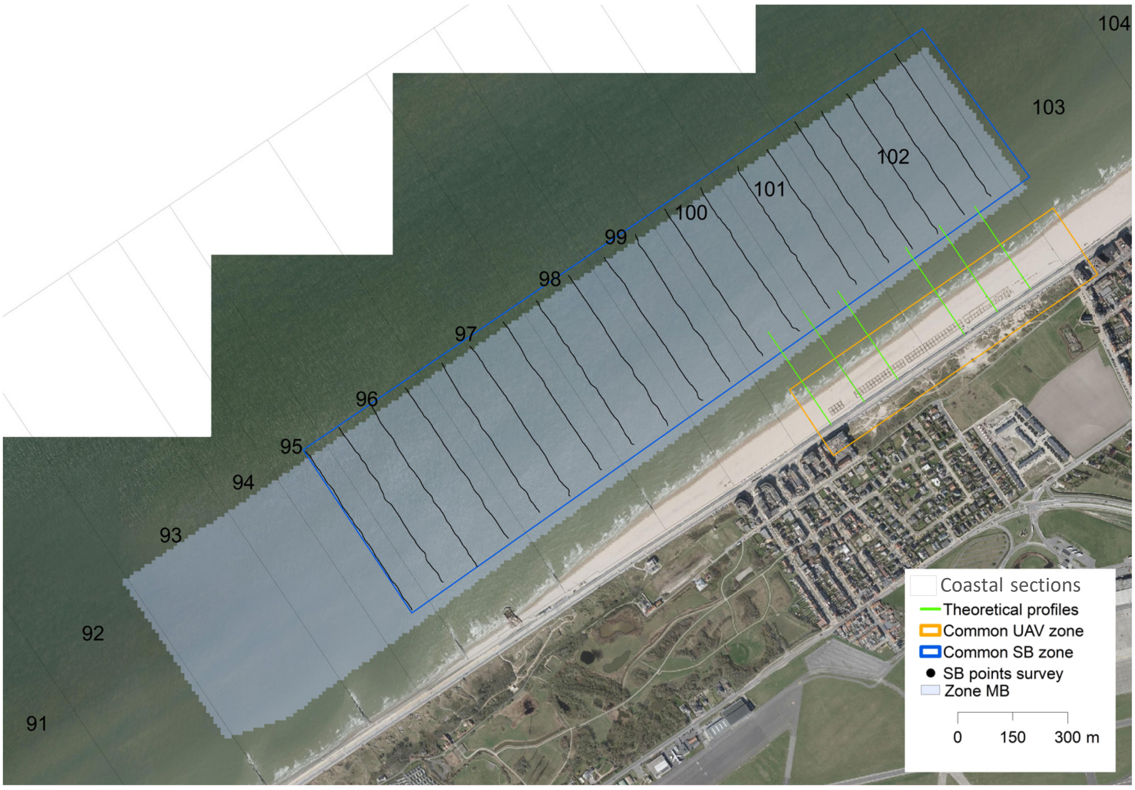


Figure 2 – Map of the monitoring coverage at Raversijde. The dune vegetated boxes are located in section 100 to 102.

2 Bathymetric monitoring

2.1 Data Surveys

Multibeam surveys for this project are carried out by the Flemish Hydrography, 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: (i) a reduced shoreface area, (ii) a large one and (iii) the offshore zone. The reduced shoreface area is measured monthly and can be covered during one high water (Figure 3). The entire site is covered with multibeam surveys once per year, which is carried out by a private survey company for the shoreface and by the Flemish Government's Agency with the own survey vessels for the areas further offshore. For the processing of the multibeam survey data, refer to Montreuil et al., 2023. The cell size of the final generalized DEM is 1 m.

Regarding the annual single beam bathymetry, the survey is composed of 20 profiles (except on 19/10/2021 with only 12 profiles). The coverage of the total zone is of 2 km alongshore and 500 m cross-shore. The distance between profiles is about 100 m and extend from 0 m to nearly -7 m TAW (Figure 4). 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.

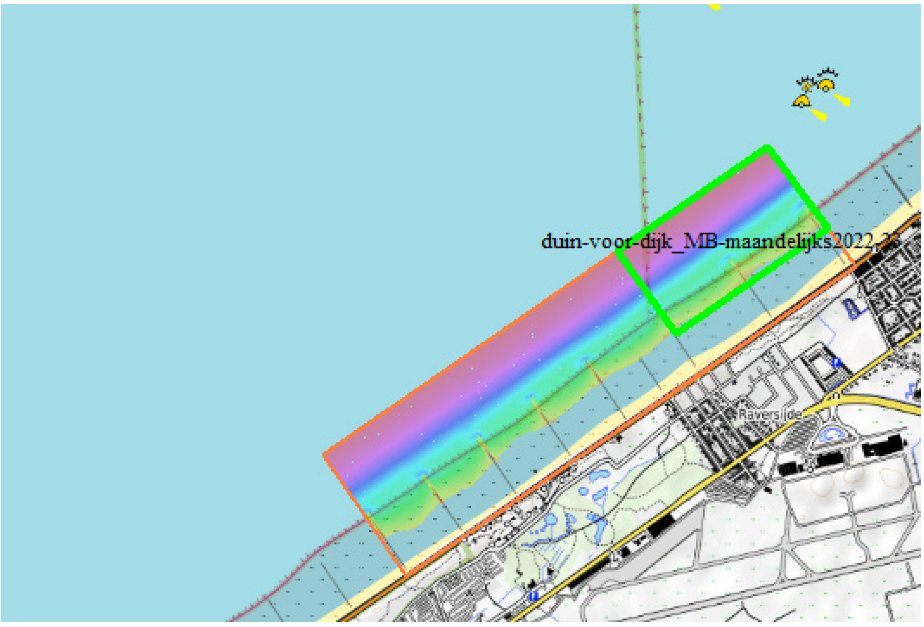
Additionally, three offshore multibeam bathymetric surveys were carried out on 11/2021, 09/2022 and 09/2023 (Table 1, Figure 5). They cover part of the Stroombank and Kleine Rede bank-gully system, and extend up to 4.7 km from the dyke and are about 2.6 km wide.

All the raw and processed data can be found in this folder:

E:\RaversijdeLivingLab_21_012\Data\TritonBathyData

P:\21_012-LLabRaversyde\3_Uitvoering\1_Data\TritonBathyData

A)



B)

Figure 3 – A) Typical coverage of the large (orange rectangle) and reduced (green rectangle) multi-beam shoreface surveys, B) Typical coverage of the multi-beam offshore (black rectangle) surveys.

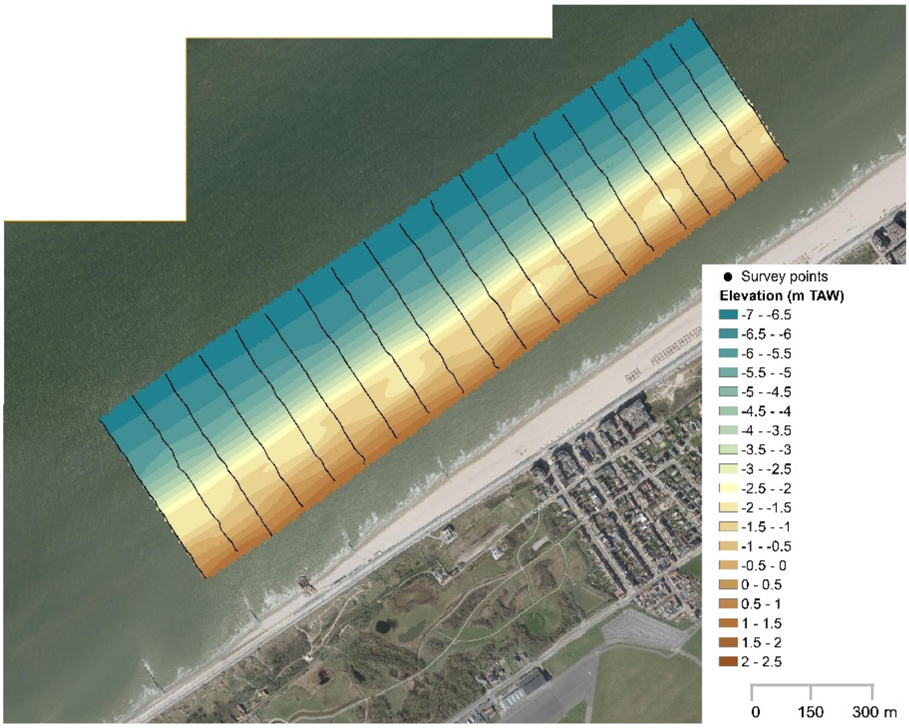
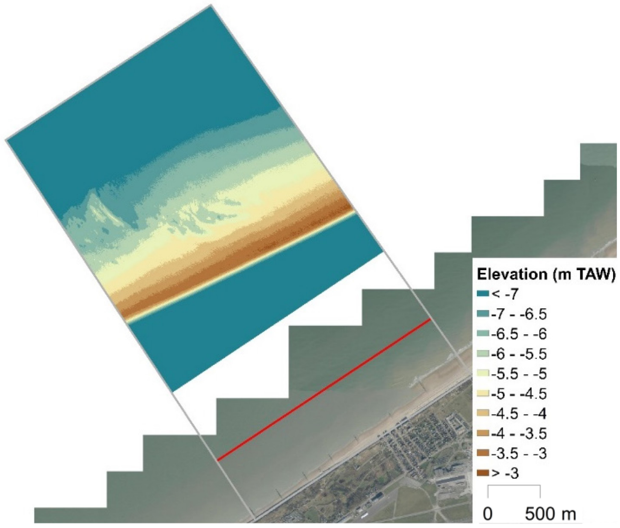
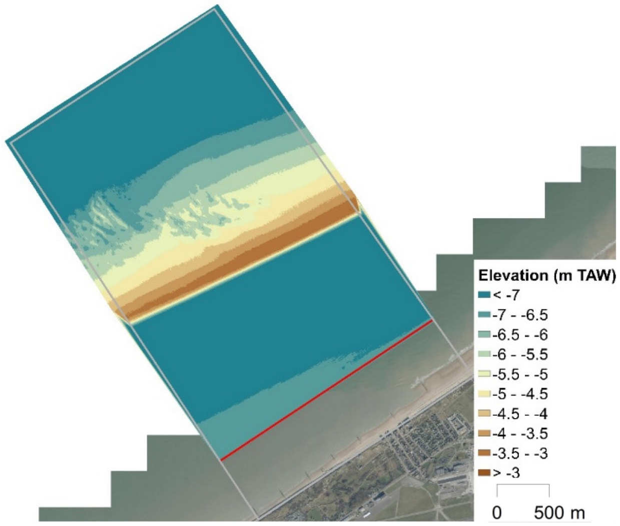


Figure 4 – Example of profile points of the single beam bathymetric survey and generated DEM of the survey.

A) 11/2021



B) 09/2022



C) 09/2023

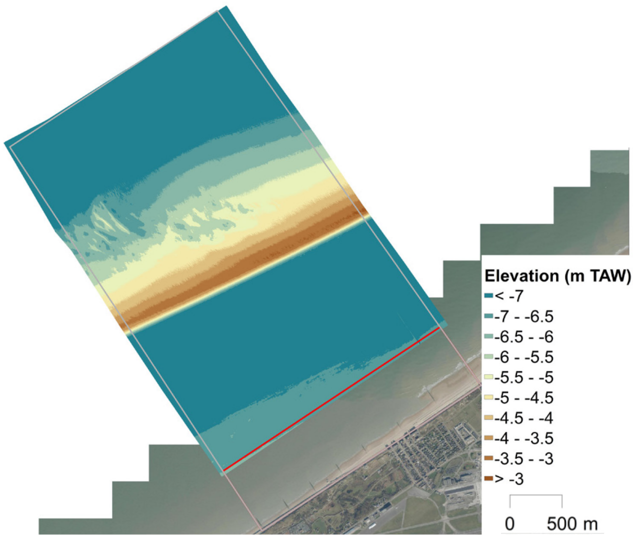


Figure 5 – Offshore DEMs of the multibeam bathymetric in: A) 11/2021, B) 09/2022, C) 09/2023.
Grey and red lines correspond to the entire study site of Living Lab Raversijde and the landward boundary of the survey respectively.

3 Topographic monitoring

3.1 UAV Surveys

From 03/2021, monthly UAV surveys have been carried out by ATO (Afdeling Algemene Technische Ondersteuning, DMOW). The error of the surveys ranges from 0.8 to 1.4 cm (Verwaest et al., 2022). For more details about acquisition and pre-processing, refer to Montreuil et al., 2023.

The final delivered products are orthophotographs of 2.5 cm resolution, DEMs of 5 cm cell size, low confidence raster provided together with the quality report per survey. Figure 6 displays an example of a produced data set from a UAV survey. From the DEMs, consecutive DEMs of difference (DoD) are generated as well as DoDs starting from the first survey (T0) as reference. DEMs and DoDs from 31/3/2021 (T0) to 23/04/2024 (T28) are reported in Montreuil et al. (2024).

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. 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

All survey data can be found:
E:\Duin voor dijk pilots_21_014\raversijde_mariakerke

G:\Nieuwe data voor Masterarchief\dhm\KST_top_2021-20xx_ATO_lam72_TAW_R°\raversijde_mariakerke (temporary location)

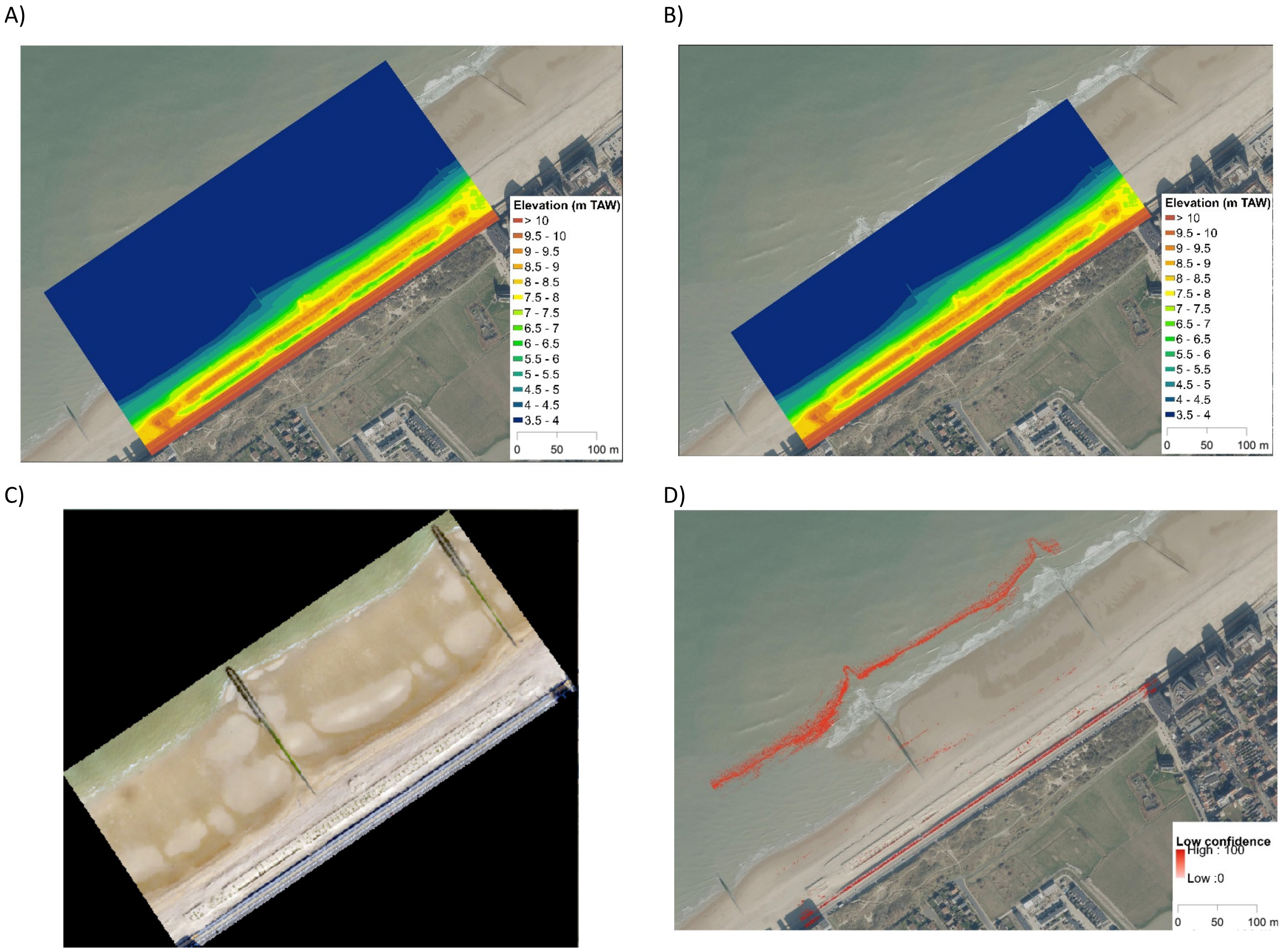


Figure 6 – Typical delivered UAV products A) DEM of the entire survey coverage covering the beach and intertidal zone, B) orthophoto, C) low confidence raster.

3.2 Hand RTK-GPS profiles

RTK-GPS profiles surveys were acquired from 31/03/2021 (T0) to 14/09/2023 (T22) by foot or quad vehicle in order to cover the intertidal zone. However, this zone is covered by the UAV from 12/09/2022 (T14). Montreuil et al. (2023) compared RKT-GPS profiles with the extracted values from UAV DEM profiles and found minor differences: the UAV DEMs overestimate the height of the true terrain with an average error ranging from 0.02 to 0.05 m. Also, the distribution of the standard deviation error (SD) is low, leading to a limited total error of the technique including systematic and random error below 0.06 m. After Montreuil et al. (2023), the systematic execution of hand RTK-GPS profiles in addition to UAV was suspended. The saved time and resources were used to do additional profiling in the vegetated boxes instead.

3.3 Effect of the vegetation on the topographic survey techniques

Hand RTK-GPS is the most reliable survey technique measuring the true ground elevation since UAV can either measure the top vegetation or ground elevation. Thus, an investigation of the topographic measurement was carried out by comparing in total 376 measured points in the vegetated boxes during the survey T16 (24/01/2023), T17 (09/02/2023), T22 (14/09/2023), T27 (14/03/2024), T28 (23/04/2024), T29 (24/05/2024) (Figure 7). By considering different seasonal surveys, the impact of the vegetation and its growth on the topography depicted from the UAV DEM can be investigated.

The average difference per survey between the UAV and hand RTK-GPS ranges from 0.015 in T17 to 0.1 m in T29 (Table 2). As expected, there is a slight overestimation by the UAV DEMs and in particular with higher and more dense vegetation like in T29. Also, a very good relationship is found (R^2: 0.991). Therefore, UAV technique in the vegetated boxes estimates well the true ground elevation when the vegetation is low and sparse as well as for high and dense (see orthophotos in Appendix A).

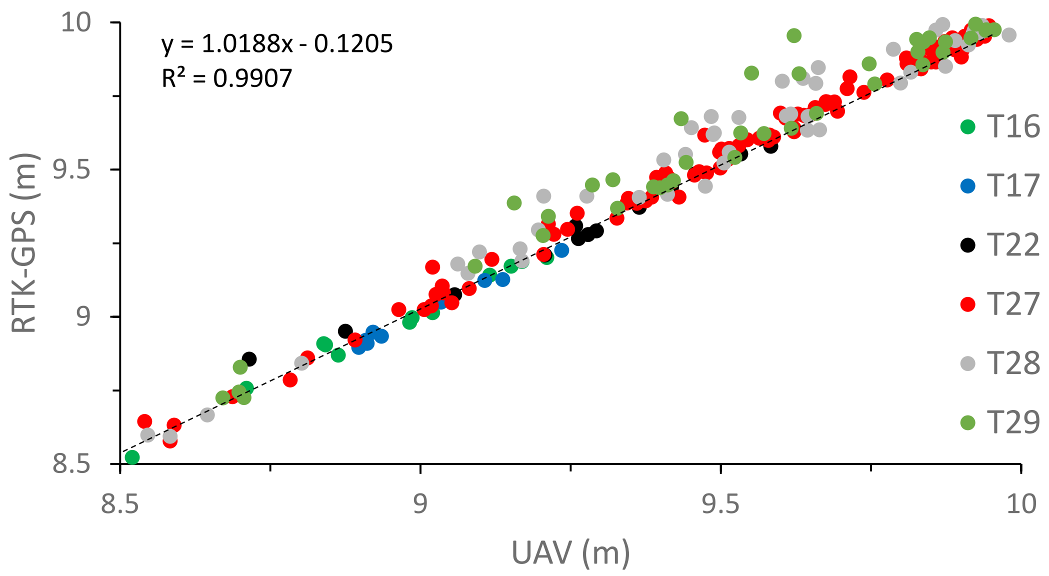


Figure 7 – Comparison of the measured topography between UAV and hand RTK-GPS.

Table 2 – Summary of absolute difference between UAV and hand RTK-GPS per season

	T16	T17	T22	T27	T28	T29
	24/01/2023	09/02/2023	14/09/20023	14/03/2024	23/04/2024	24/05/2024
Avg	0.031	0.015	0.032	0.041	0.070	0.104
Max	0.141	0.056	0.140	0.148	0.205	0.372
Min	0.001	0.001	0.000	0.003	0.001	0.012
SD	0.036	0.016	0.041	0.026	0.053	0.080
Nb	15	10	15	150	99	87

All the raw and processed data can be found:

E:\Duin voor dijk pilots_21_014\Analyses\raversijde_mariakerke

4 Topo-bathymetric monitoring

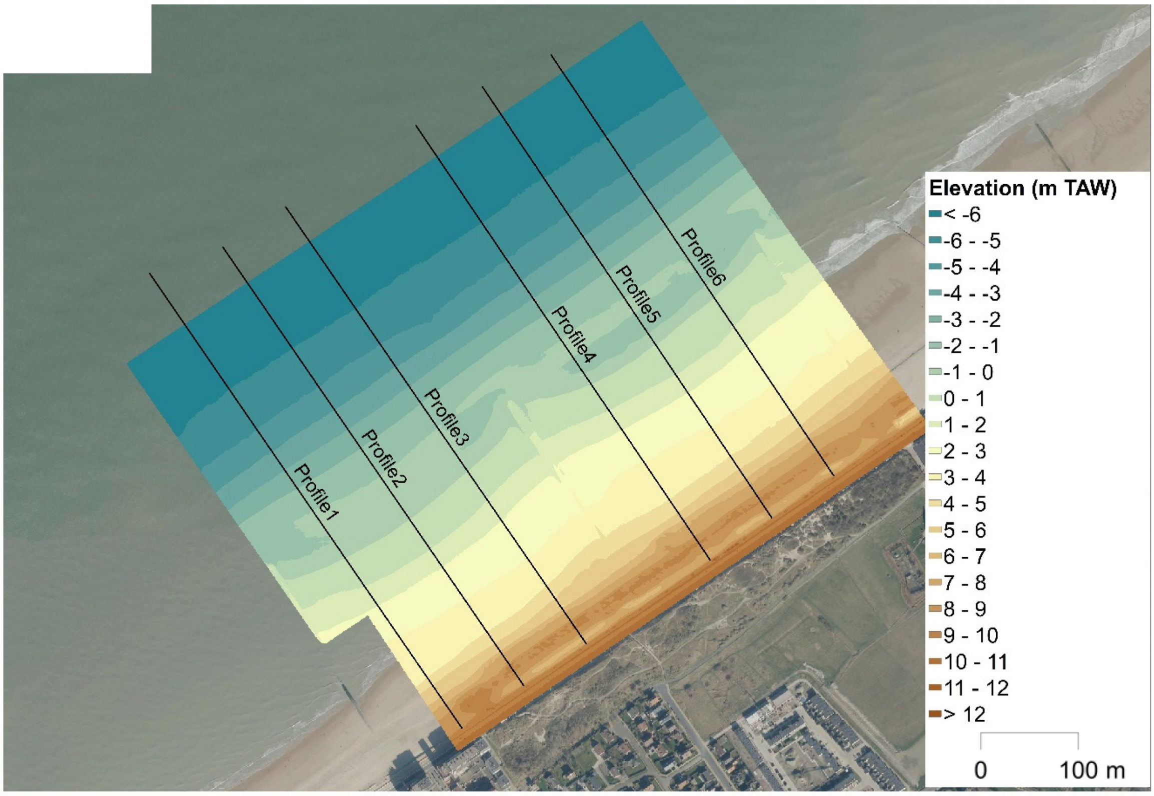
4.1 Merging Beach and Shoreface Surveys

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 3 and Figure 8 present the combination of the survey dates and an example of DEM. Following this, consecutive DoDs and extracted profiles (Figure 9) were produced to investigate the morphological changes.

Table 3 – 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
202312	22/11/2023 (UAV survey)	07/12/2023

Montreuil et al. (2023) compares UAV, hand RTK-GPS and multibeam techniques for the region around the low water line. In general, the UAV is capable to depict correctly the low part of the beach near the low water line. The average error referenced to the hand RTK-GPS technique ranges from 0.02 to 0.03 m with a slight overestimation by the UAV DEMs. Regarding the multibeam DEMs, DEMs it tend to overestimate the height of the sea bottom with 0.05 to 0.10 m. Therefore, it was concluded that UAV and multibeam DEMs 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).



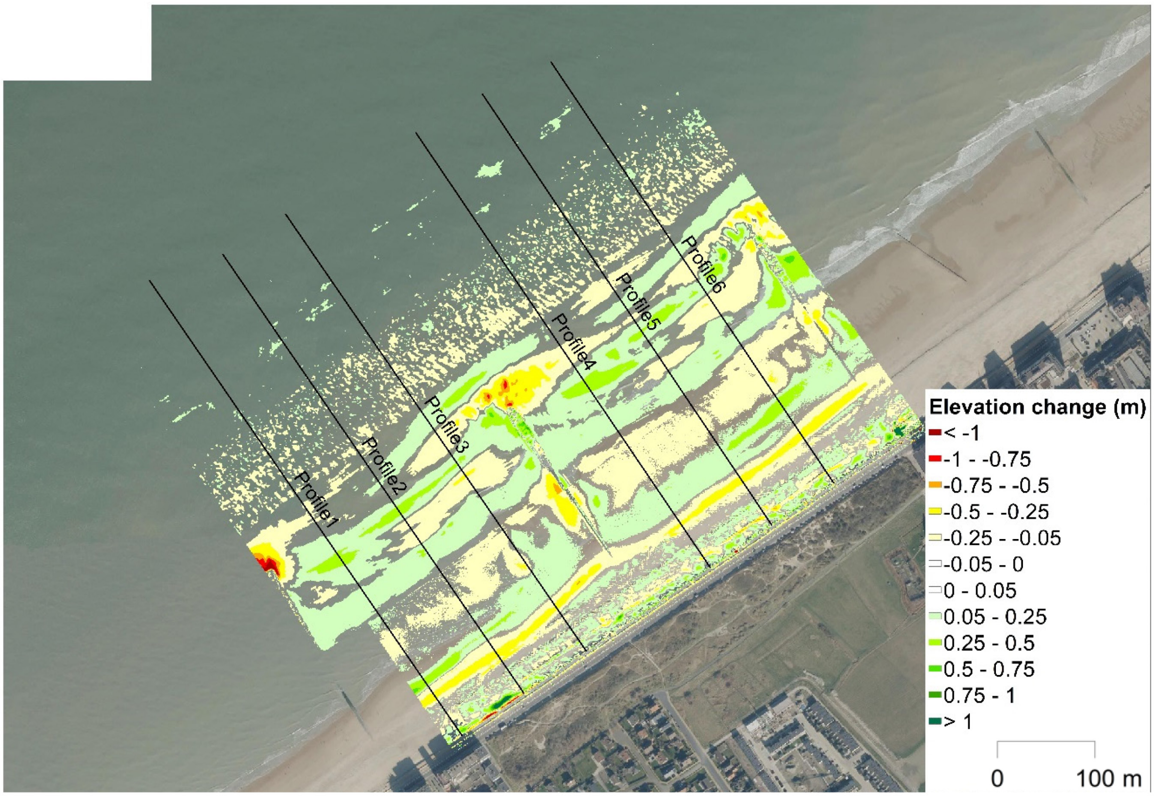


Figure 8 – Example of merged beach (UAV survey) and shoreface (MB survey) DoD between 02 and 03/2023.

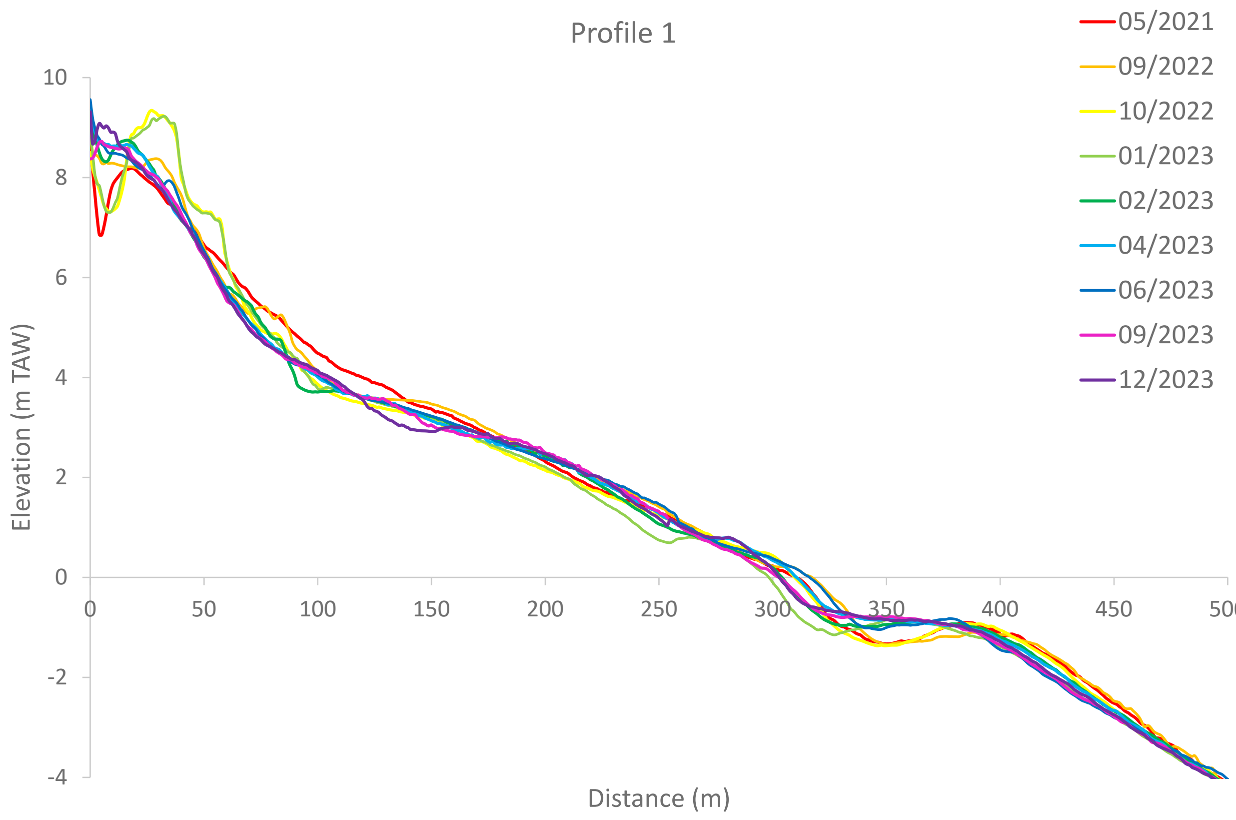


Figure 9 – Example of extracted profile 1 from the merged beach and shoreface DEMs.

All the data and analyses can be found:

P:\RaversijdeLivingLab_21_012\Data\Topography\MergedBeachShoreface

4.2 Combining Beach, Shoreface and Offshore Area Surveys

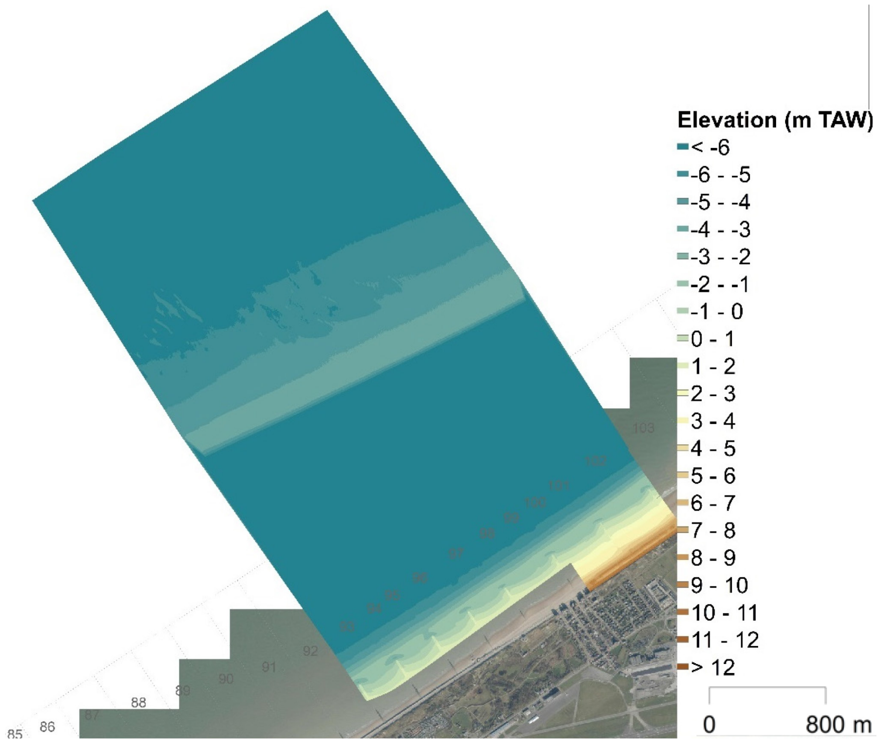
The beach surveyed by UAV, shoreface and offshore area by multi beam bathymetry in 09/2022, 09/2023 were merged to DEM of 1 m cell size. The total cover area is up to 4.7 km long from the sea dyke (Table 4 and Figure 10).

Table 4 – 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)

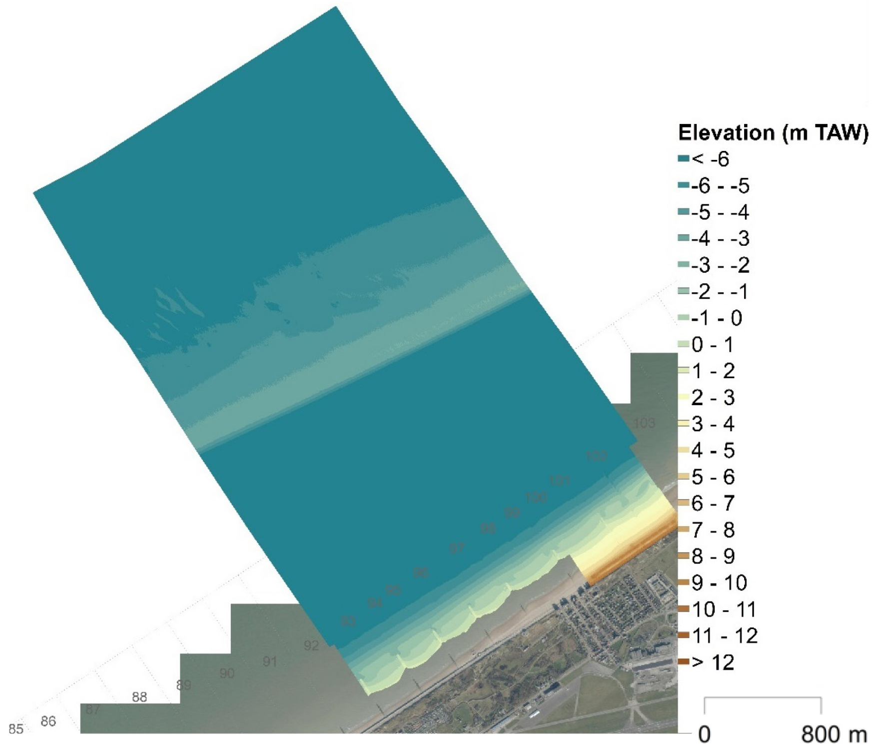


Figure 10 – Combined DEM of the beach, shoreface and offshore area in A) 09/2022, B) 09/2023.

All the data and analyses can be found:

E:\RaversijdeLivingLab_21_012\Data\Topography\MergedBeachShorefaceOffshore

5 Human interventions

5.1 Excavation works between dune and dyke

From 15/01/2024 to 16/02/2024, the city of Ostend has created a large trench (approximately 2,5 m depth), in between the planted dune and the seawall in Raversijde. This measure creates a sand trap to limit the aeolian sand transport towards the seawall and further inland (Table 5, Figure 12). The sand from the excavation was brought back to the high waterline in front of the dune, by trucks.

Along the seawall, the city regularly had to level or remove sand in order to keep the drain outlets free and to create a barrier for aeolian sand on the dyke. According to Table 5, this was done every week. The drain outlets, which are located in the seawall approximately 50 cm below the dyke surface, are illustrated in Figure 11.

Furthermore, when needed, sand accumulation is removed from the adjacent promenade and tram line. This sand is assumed to be brought back to the beach in an area close to the high water mark. Unfortunately the volumes and locations of these interventions are not reported in detail.

Table 5 – Description of the human interventions (Ostend city)

	Clearing of the seawall			
	NbS Raversijde	Zone west of NbS	Zone East of NbS	Trench in front of the seawall
4/12/2023- 08/12/2023	x	x	x	
03/01/2024- 05/01/2024	x	x	x	
15/01/2024- 19/01/2024	x	x	x	x
22/01/2024- 26/01/2024	x	x	x	x
29/01/2024- 02/02/2024	x	x	x	x
05/02/2024- 09/02/2024	x	x	x	x
12/02/2024- 16/02/2024	x	x	x	x

Figure 11 – The seawall in Raversijde, after the excavation works. Notice the drain outlet

A)

B)

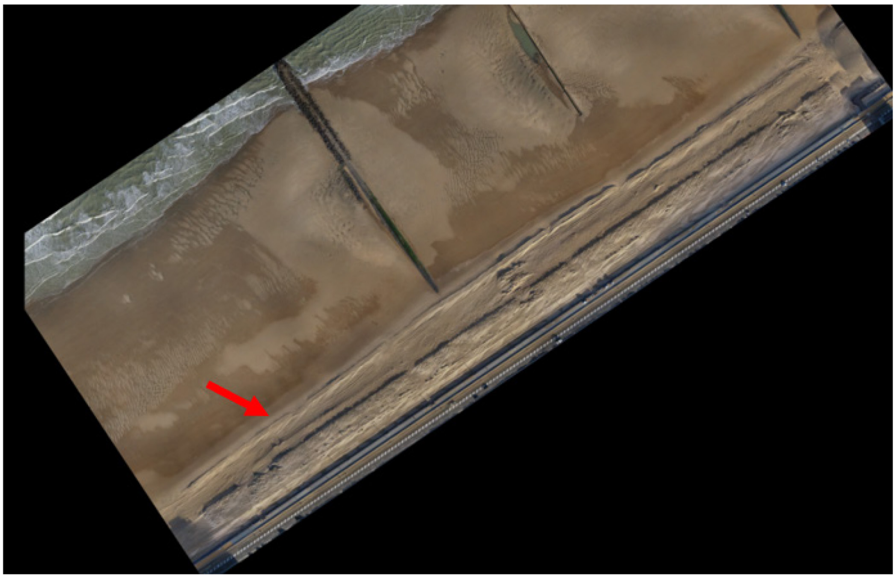


Figure 12 – A) work excavation along the seawall, B) presence of an artifical plateau in Raversijde

Volume calculations were done based on the elevation difference between T25 and T26 (Figure 13). Based on both the volume calculation of the trench and the bar, the volume of displaced sand can be estimated in the order of 5000 m³.

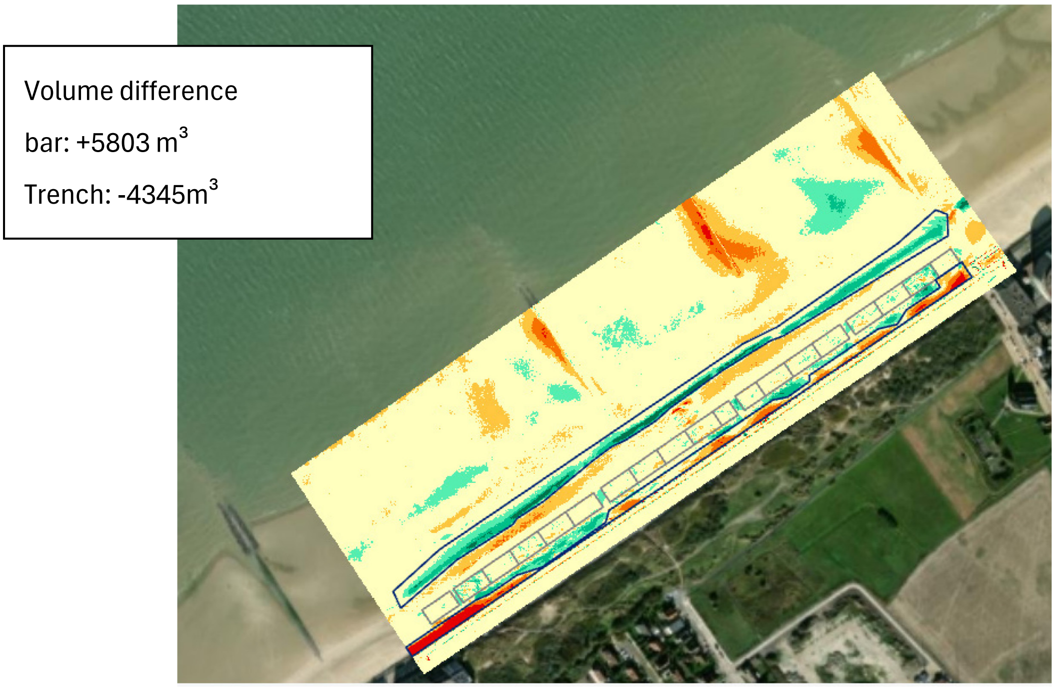


Figure 13 –Volume calculations for the areas affected by the sandworks, difference between surveys T25 and T26

5.2 Pipeline

There is a presence of a large pipeline on the intertidal beach perpendicular to the shoreline (Figure 14). The pipeline appears for the first time on the survey of 8 May 2023, and has been there on every survey since. Although we have not verified the origin of the pipeline, it could be an unused dredging pipeline that is stored there temporarily.

The pipeline affects the water and sand dynamics in its direct surroundings, so it is important to keep the presence of it in mind when analysing topobathymetric changes.

Figure 14 – A pipeline parallel to the groynes in front of the dune (Orthophoto from UAV survey 8 May 2023)

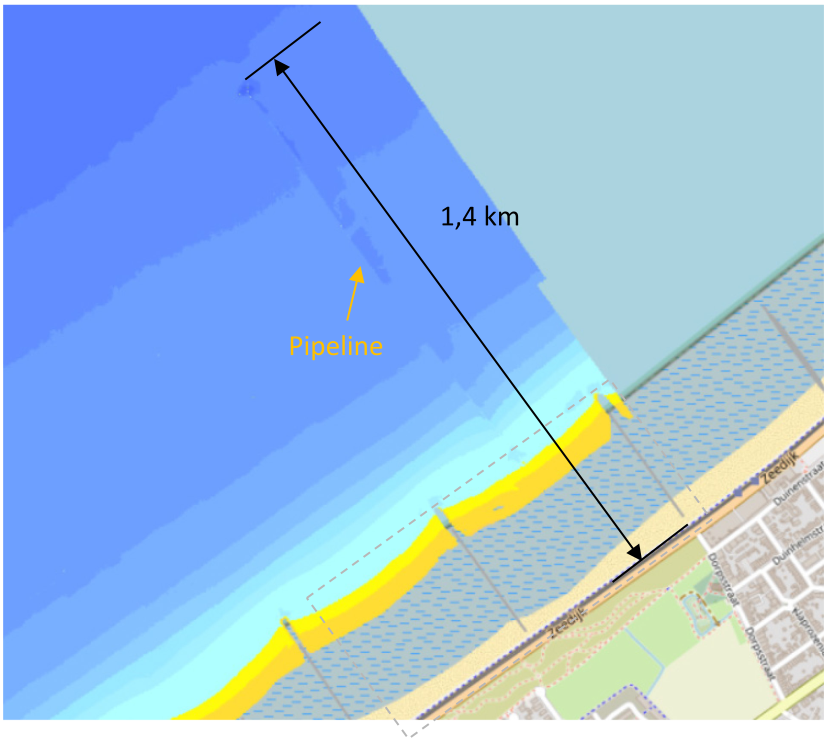


Figure 15 – The pipeline has provoked a small gully on its eastern side. It extends to 1,4 km seaward from the dyke (merged bathymetry October 2024)

6 Storm Impact Monitoring

On the night of Friday, November 24, 2023, to Saturday, November 25, 2023 a storm with a return period of approximately one year, hit the Belgian coast. The relatively high storm surge of 5.60 meters TAW was predicted well beforehand. Thus, an e-mail alert from Meetnet Vlaamse Banken was received and the team mobilized for measuring dune erosion in Raversijde.

Figure 16 shows in the top pane, the astronomical tide (yellow), measured water levels in the harbor of Ostend (blue) and build up (turquoise), during the storm. Notice how water levels were elevated during several tides before and after the storm peak on November 24. The middle pane shows the waveheight measured at the wavebuoys Raversijde 1 and Raversijde 2 and the bottom pane shows the windspeed and wind direction measured at Ostend Meteopark.

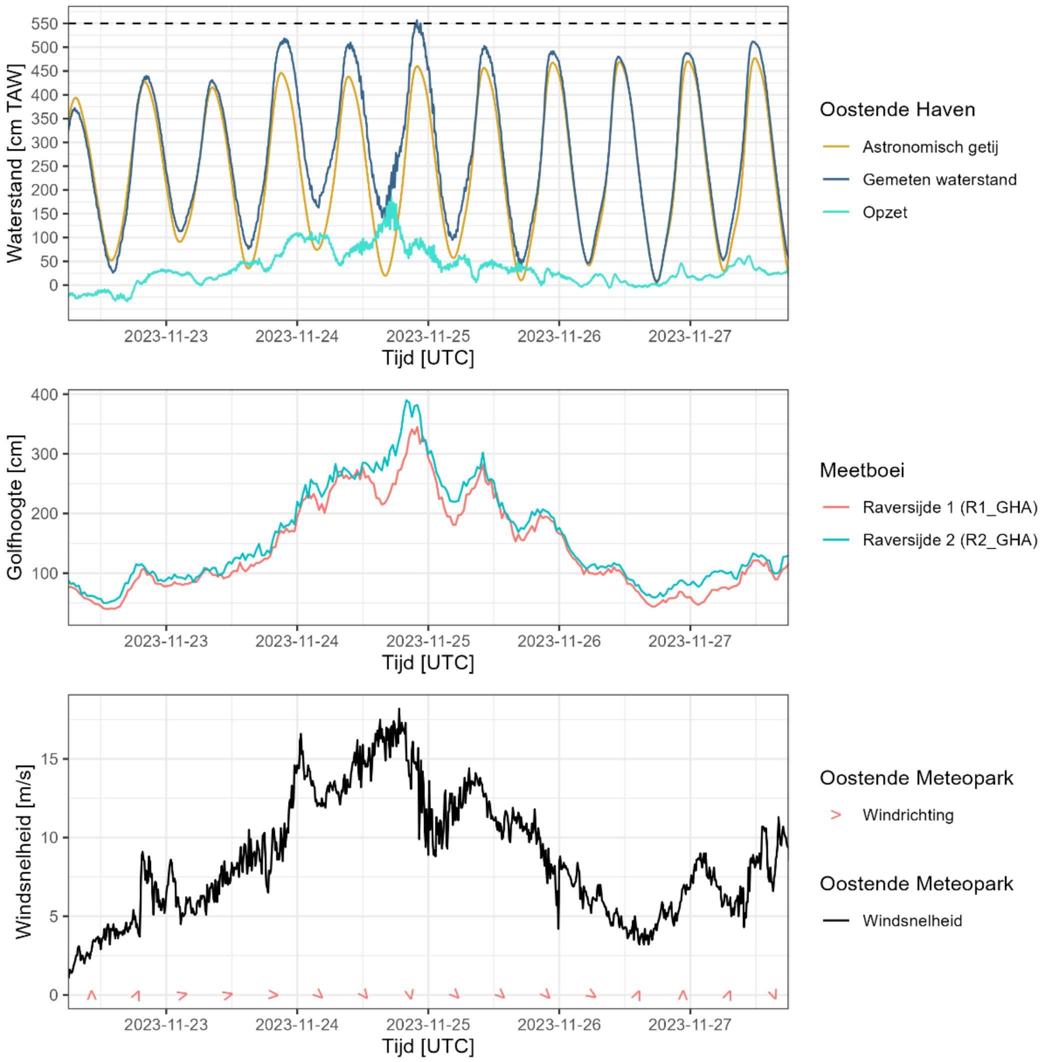


Figure 16 – Astronomical tide (yellow), measured water levels (blue) and build up (turquoise) during the storm, the highest tide was on 24/11 around 11 pm.

6.1 Sediment samples and RTK-GPS profiles

On Friday afternoon, at low tide before the storm peak, the first set of measurement was done. We measured profiles with the RTK-GPS and collected sediment samples (Figure 17, profiles 1, 2, 4, and 6). Due to the difficult conditions (strong wind), only four of the six predetermined profiles were sampled and measured.

On Saturday morning, after the highest storm surge, the profiling and sampling were repeated on the same transects and sampling spots.

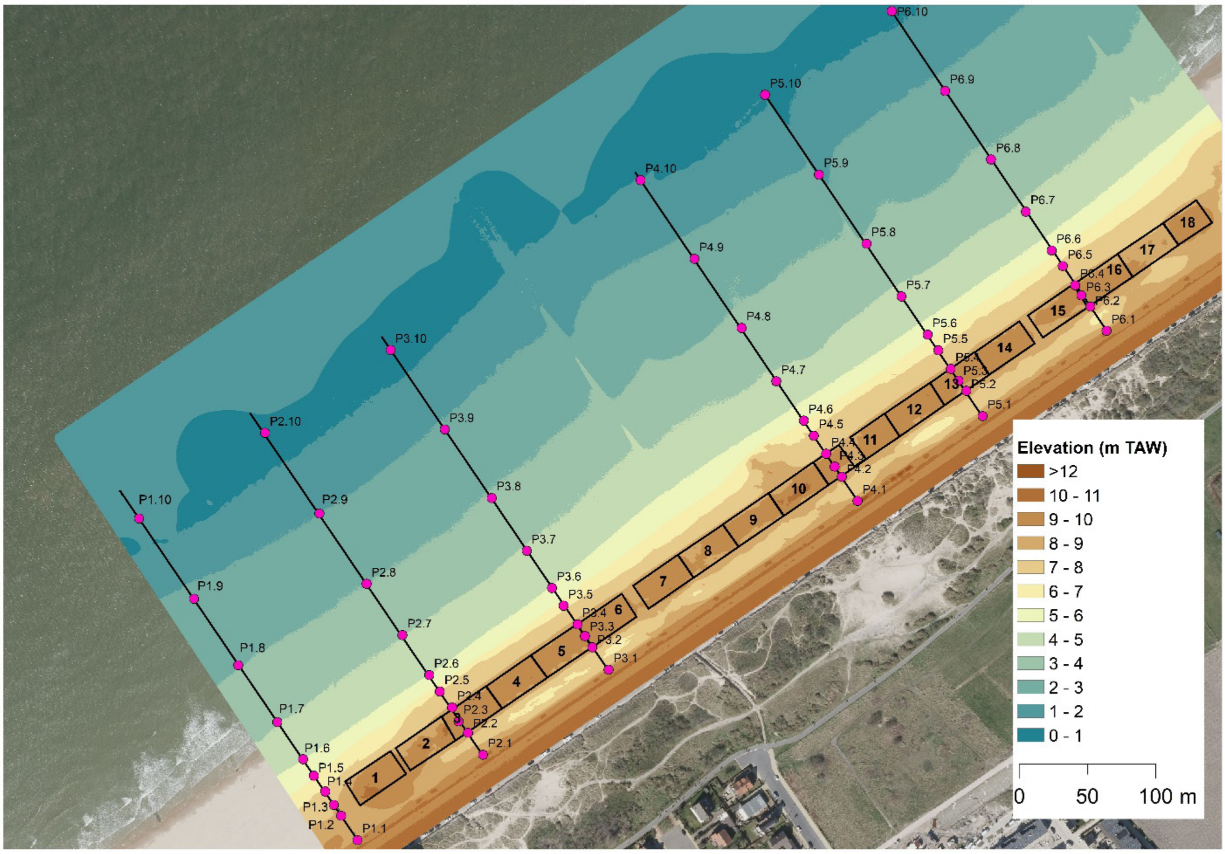


Figure 17 – Six theoretical transects with predetermined locations for sediment samples in Raversijde.

Figure 18 shows the projected RTK-GPS profiles, measured before and after the storm. They reach from the dyke at 10 m TAW to the low water line. Profile 1 does not feature dunes, it is taken before the start of the vegetated box. Profile 2, 3 and 4 show cross-sections of the dune and the beach. In Profile 2 and 3 there is some erosion and cliff formation the higher beach and embryonic dunes. Profile 4 did not have any avalanching, probably because the beach was less steep than in profile 2 and 3. However there is a slight deepening in the lower part of the beach.

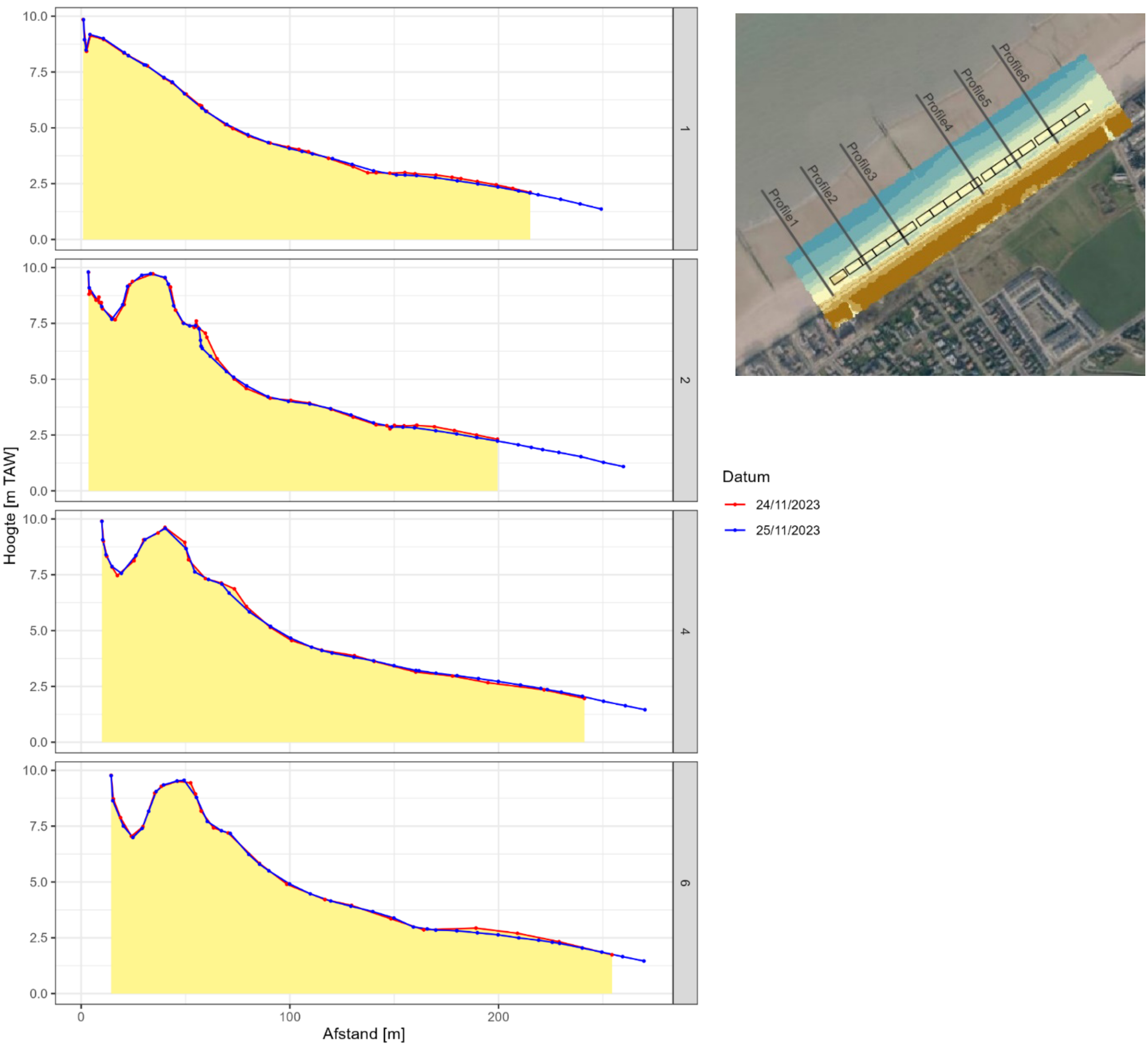


Figure 18 – Projected RTK-GPS elevation measurements for profiles 1, 2, 4, and 6 on November 24, 2023, and November 25, 2023

The sediment samples were analyzed in the sediment lab of Flanders Hydraulics. The resulting grain sizes, are expressed in nm. Figure 19 shows the D50 of the sediment samples before and after the storm. After the storm, the grain size appears more uniformly spread across the site. For most of the samples the D50 has slightly increased.

For the calculation of the sorting coefficient, which refers to the distribution of grain sizes within a sample, the Krumbein phi (ϕ) scale is used. This scale is logarithmic and computed by the equation $\phi = -\log_2(grain\ size\ in\ mm)$.

Thus the sorting coefficient is calculated as:

$$sorting = \frac{(\log_2(D90/1000) - \log_2(D10/1000))}{2}$$

Lower values indicate better sorting. Well-sorted sediments have grains of similar size, while poorly sorted sediments contain a wide range of grain sizes.

Figure 19 – D50 and sorting of the sediment samples. Before (top) and after (bottom) the storm tide

6.2 Time Series from Meetnet Vlaamse Banken

The following time series from the Meetnet Vlaamse Banken are relevant for the beach in Raversijde:

- Raversijde 1 – Buoy: wave data
- Ostend Harbor – Tide: water levels
- Ostend – Meteopark: wind

The data from Meetnet Vlaamse Banken are available online (https://meetnetvlaamsebanken.be/). The data is in UTC.

The timeseries for the period from November 20 to November 30 were downloaded and can be used at a later stage together with the topography data to hindcast the storm in XBeach.

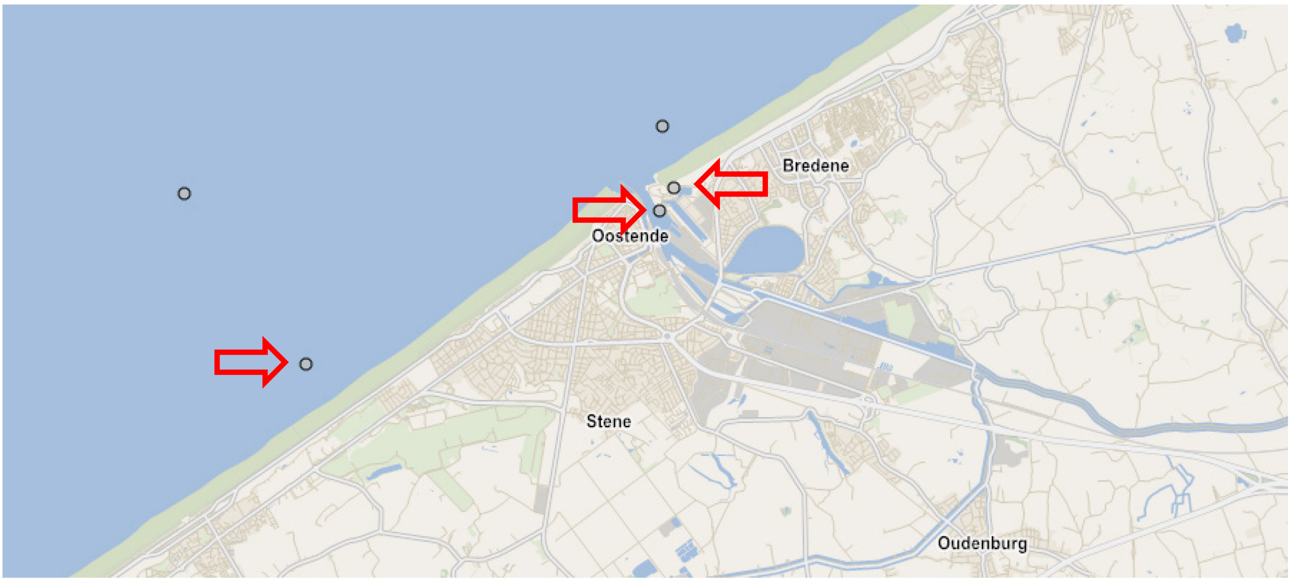


Figure 20 – Meetnet Vlaamse Banken stations in the vicinity of LLR: indication of Raversijde 1 - Buoy, Ostend Harbor - Tide, Ostend – Meteopark.

6.3 Wave data research dike

During the storm, wave data was measured at the research dike. The processed data for this storm can be found here (processing by Vincent Gruwez):

P:\22_006-INTREGMANABAS\3_Uitvoering\1_Data\meetcampagne_november2023\data_meetpalen_onderzoeksdijk

6.4 Topography

There was a drone survey, using photogrammetry, before (22/11/2023) and after the storm event (06/12/2023). Figure 21 shows the difference in elevation between the two surveys.

T24	22/11/2023	UAV
T25	06/12/2023	UAV

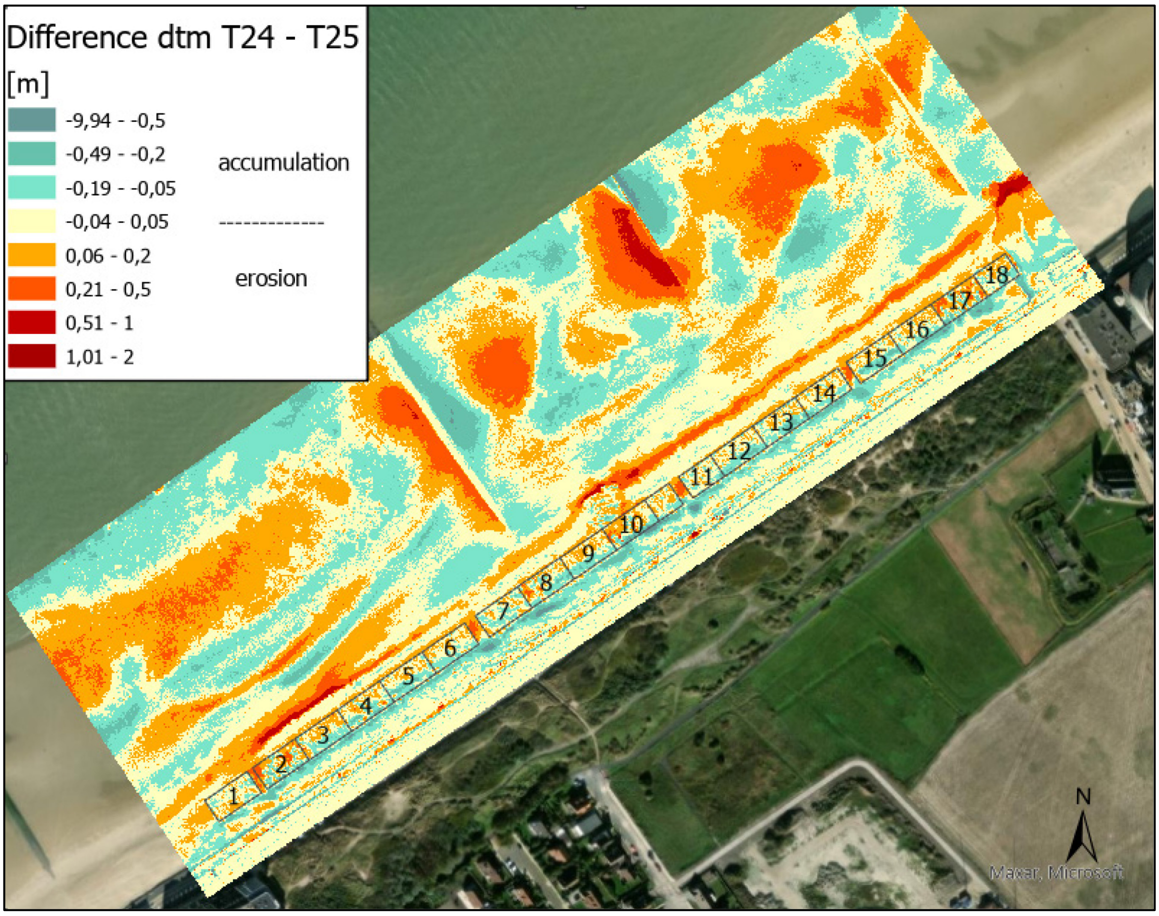


Figure 21 – Elevation difference before (22/11/2023) and after the storm event (06/12/2023)

6.5 Bathymetrie

There was a new survey for the detail zone in front of the dune on 7-8/12/2023 (Plan number: 231207_312_MKOST_MB_DET-TAW).

The previous survey was on 26-27/9/2023 (Plan number: 230926_255_MKOST_MB_DET-TAW).

Although the storm did not have a large impact on the bathymetry, the presence of the pipeline (Chapter 5.2) appears to have caused local deepening (erosion).

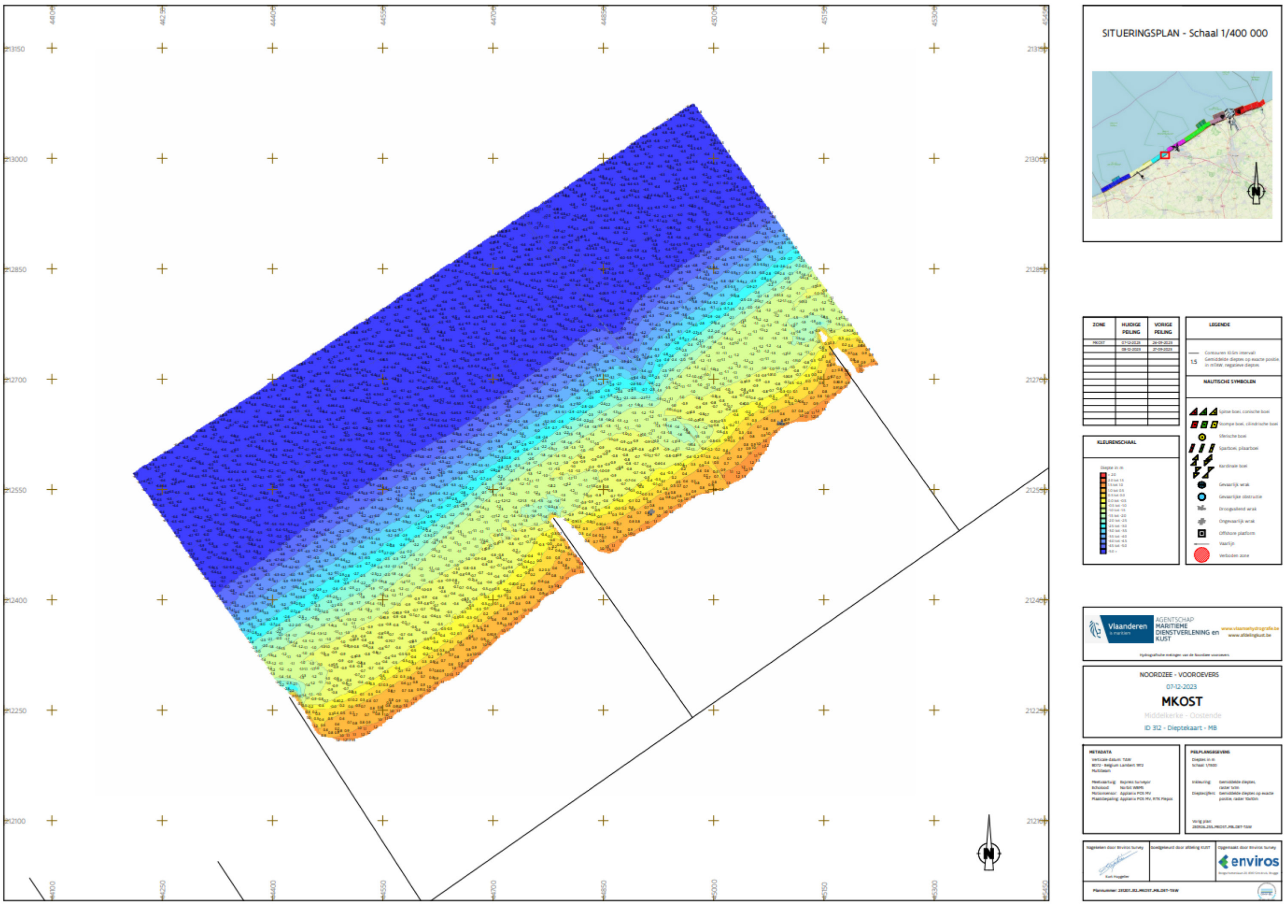


Figure 22 – Bathymetry 7-8/12/2023 (Plan number: 231207_312_MKOST_MB_DET-TAW).

7 Vegetation Monitoring

7.1 Data processing

Figure 23 displays the workflow of the vegetation classification processing which is composed of 3 steps: standardize image, sample image and supervised image classification. The final result is the classified image of vegetation, sand and wet sand per survey. The image classification was applied to Box 2 and Box 7 where only marram grass was planted. The vegetation classification could not be applied to the boxes with brushwoods since they create shadow on the image.

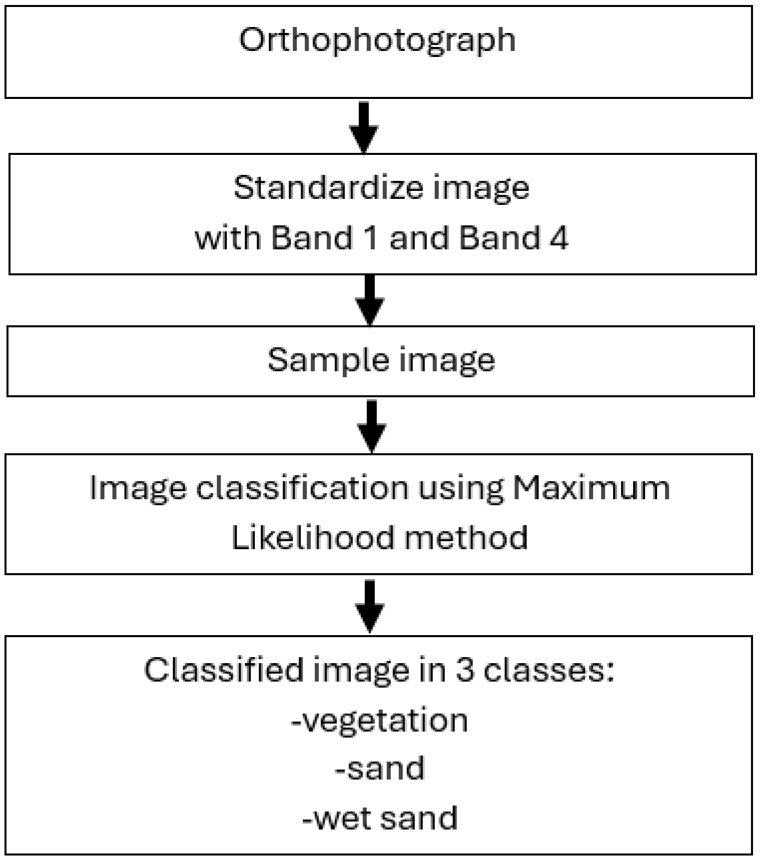
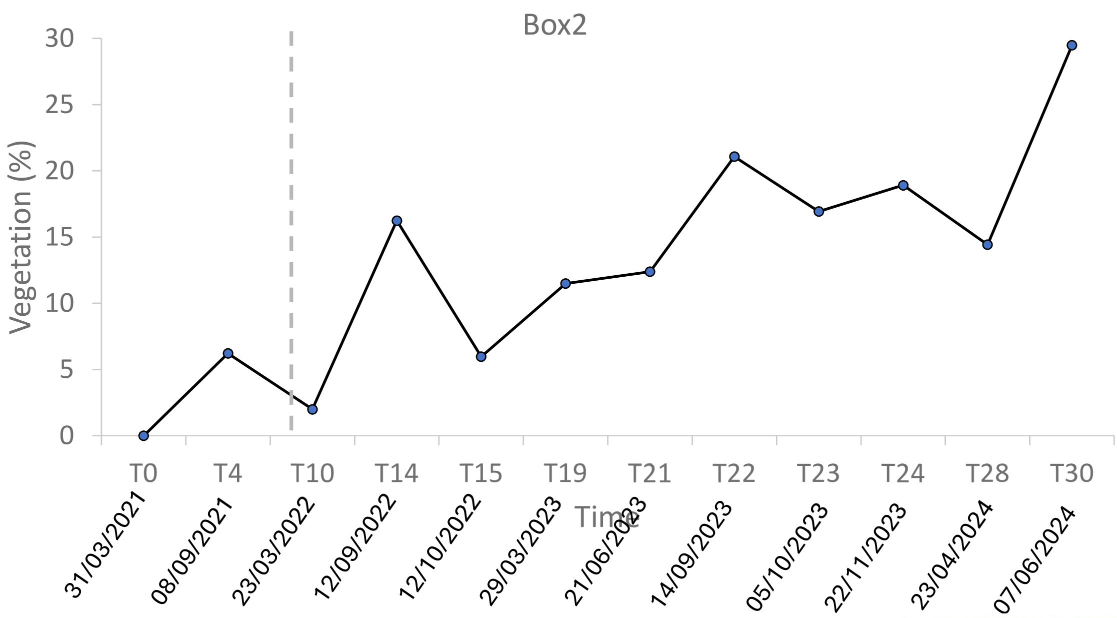


Figure 23 – Workflow of image processing for vegetation identification

7.2 Results

Figure 24 presents the evolution of the vegetation growth in the vegetated boxes 2 and 17, where only marram grass was planted. After 3 years, the box was vegetated from 17 % in Box 17 to 29 % in Box 2. Thus, there has been a spatial variability in vegetation growth which is likely related to their location. In addition, a seasonal variability is noticed over the 3 years, June to October was always the more favourable period for vegetation growth.

A)



B)

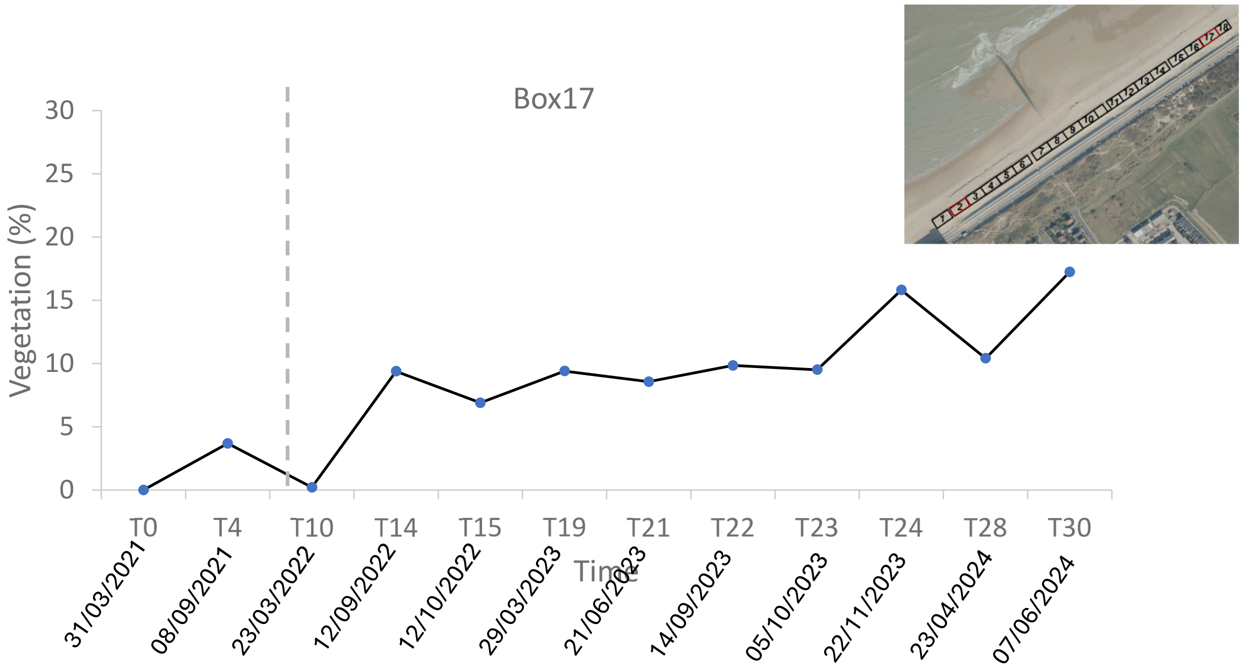


Figure 24 – Time series of vegetation growth in A) Box 2 and B) Box 17 where only marram grass is present.
Inset: location of Box 2 and 17

8 Conclusions

Since 2021, there has been an intensive monitoring in Raversijde in order to investigate the morphodynamics of the active zone. The number of surveys was 30 for the UAV, 6 for the LiDAR to cover the beach, 20 for single and multibeam bathymetric surveys to cover the shoreface and finally 3 multibeam bathymetric surveys to cover the offshore zone during the 3 years.

In the beginning of 2024, a trench was dug in between the dyke and the dune to trap aeolian sand. Reporting on human interventions by the city of Ostend in the LLR area is limited. There is a lack of reporting on e.g. the amount of sand that is cleared from the dyke and supposedly brought back to the beach.

Since May 2023, a piece of pipeline has been resting on the intertidal beach. It has affected the morphology of the beach locally.

The impact of the storm in November 2023 on the beach was closely monitored. The steeper parts of the beach and the protruding embryonic dunes were eroded. The waves did not reach the vegetated boxes. The sediment samples showed less spatial variation after the storm, indicating mixing of the sediment during the storm.

Image processing from the UAV orthophotos for the vegetated boxes where only marram grass was planted (Box 2 and 17) indicate a clear vegetation growth over the 3 years with a seasonal and spatial variability.

The average difference in the vegetated boxes between the UAV DEM and RTK-GPS techniques ranges from 0.015 m (T17, 02/2023) to 0.1 m (T29, 05/2024). Thus, the UAV DEM slightly overestimated the true ground elevation when the vegetation canopy was low and sparse, while the overestimation increased when the vegetation is higher and denser as observed in 05/2024. This should be kept in mind in the interpretation of the morphological analysis.

9 References

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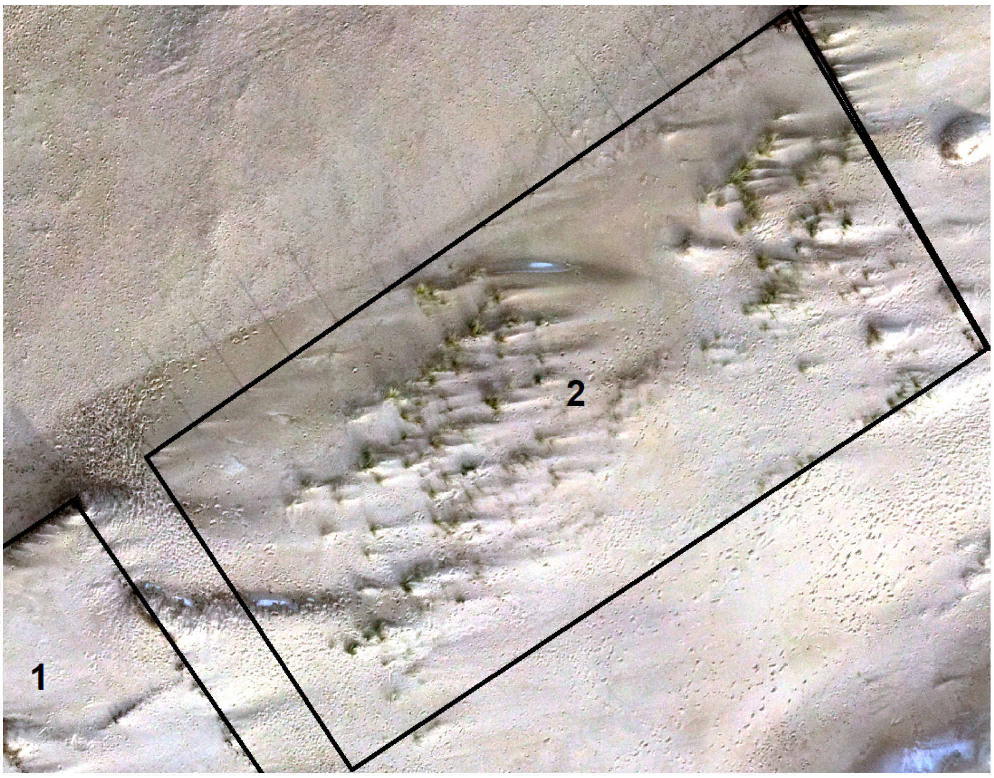
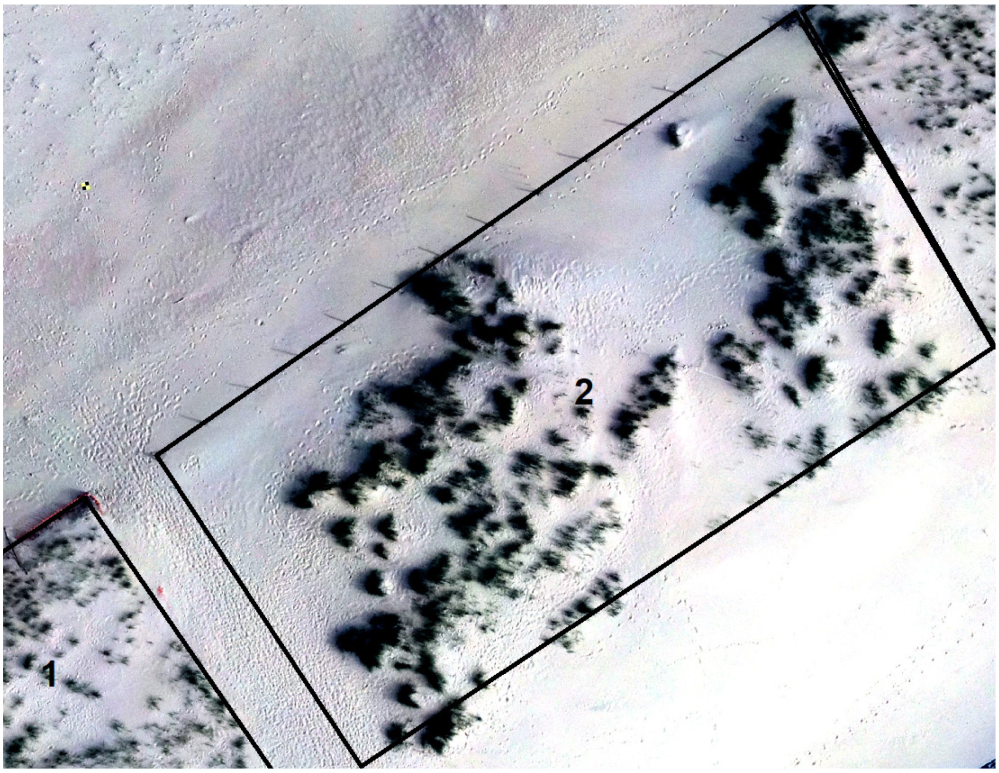
Appendix A

T17: 09/02/2023



T29: 24/05/2024



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