SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Poldhu Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR10 | 11/04/2024

South West Coastal Monitoring
University of Plymouth
Drake Circus
Plymouth
PL4 8AA
+44 (0)1752 586 155
coastal.observatory@plymouth.ac.uk
www.southwest.coastalmonitoring.org

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Author	**J Saunders**
Checked By	**J Kirby**

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Taken by: Joseff Saunders

Summary

This report utilises Light Detection and Ranging (LiDAR), topography and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Poldhu. The aim is to highlight coastal change at Poldhu using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Poldhu is a west facing, sandy pocket beach bound by rocky cliffs to the north and south and backed by a small dune system and through road. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change to the intertidal beach area over time. LiDAR data from each available flight is compared to create difference models of the intertidal area, compare volumetric data over time and to show change in Mean Seal Level (MSL) and dune toe contours over time.

There has been a total of 34 topographic surveys at Poldhu since 2007. Analysis of topographic data suggests the survey unit to be gradually accreting between 2007 and 2024 despite being heavily impacted from both the 2013/2014 and 2020 winter period. Seasonal variation in beach morphology is also evident, with erosion occurring in the winter and spring months and accretion recorded during the summer and autumn months.

Beach volumes extracted from 5 LiDAR flights since 2007 show the Mobile Zone accreting gradually between 2007 and 2023 and Beach Zone remaining stable despite large volume fluctuations. The Beach Zone saw a decrease in volume detected during the 2014 LiDAR survey following the 2013/14 storm season, however this loss in volume had recovered by the following survey in 2019. The Mean Sea Level contour had advanced seawards by nearly 350 m between 2007 and 2023.

Overall Poldhu has remained stable between 2007 and 2023 despite being impacted by the 2013/14 and 2020 winter storms and has since recovered to pre-2013 beach levels.

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1.0 Introduction

The aim of this report is to highlight beach change at Poldhu using data collected as part of the SWRCMP since 2007, focusing on the beach area and the mobile dune area. Four zones have been developed to define the beach/dune area; they are defined here:

- **Beach Zone** – The wet beach area has been defined using Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS) contours extracted from all LiDAR data captured by SWCM. The Beach Zone will therefore encompass the area between the MHWS and MLWS contours, with volumes for this area extracted from each LiDAR surface.
- **Mobile Zone** – This area is defined as the active dune face and embryo dune[1] from MHWS +1 m to the back of the mobile area, often distinguished by vegetation depth or urban development. The Mobile Zone has been defined using aerial imagery from 2007 to 2021 and historic OS maps and has been verified through site visits.
- **Fixed Zone** – This area is defined by permanent dune vegetation that may also include scrub or invasive species, effectively denoting vegetation atop sandy soil.
- **Developed Zone** – This is defined as urban development areas (i.e., car parks, unnatural grassy areas, roads, houses etc.) which have been built atop previously present dune systems.

1.1 Study Site

Poldhu is a west facing pocket beach comprised of sand and backed by a small dune system and through road with a small stream exiting through the dune (Fig 1). The beach is confined to the north and south by rocky cliffs and has a cross-shore length of ~330 m and longshore length of ~150 m with an average tidal range of 4.7 m.

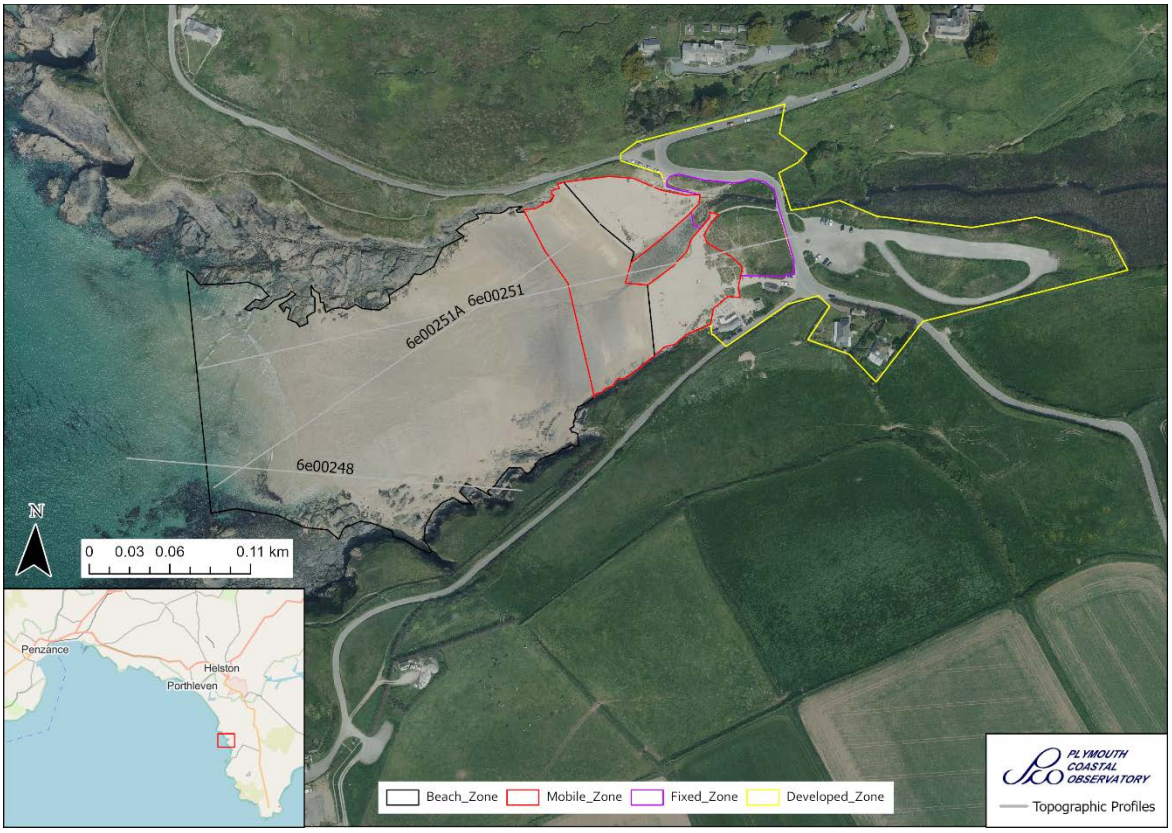


Figure 1 - Location Map of Poldhu Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1.

[1] An embryo dune, or yellow dune, is the earliest stage of dune growth, usually found along the seaward extent of a dune system or newly formed dune.

2.0 Methods

Data utilised in this report was collected by SWCM between 2007 and 2023. Information on topographic and LiDAR data collection and specifications can be found on the Website for the National Network of Coastal Monitoring Programmes.

2.1 Topographic Data

SWCM have undertaken routine topographic beach surveys at 34 of the 40 MS4S sites since 2006. All surveys are conducted from the MLWS contour to the backshore. On average, each surveyed beach receives two interim surveys a year and one full coverage survey every 5 years:

- Interim - Conducted twice a year in the spring (conducted between January and April), and autumn (conducted between September and December). An interim survey consists of collecting data points at 5m intervals along pre-defined profiles; these are outlined in Figure 1.
- Full coverage – Conducted once per phase (6 years), or annually at more vulnerable sites (conducted between May and September). Full coverage surveys include a full profile survey at 50 m intervals and continuous spot height data collected across a 5 m grid covering the whole beach.

Analysis of the Cross-Sectional Area (CSA) change is conducted for each individual profile between each separate survey. Changes in CSA are measured relative to the fixed master profile which is defined by a pre-determined stable landward position and the MLWS level in reference to Ordnance Datum.

2.1.1 Topographic Data Analysis

Topographic data is presented as the following, where applicable:

Trend Analysis Plot - The combined profile trend in CSA is presented for each survey unit (example shown in Fig.2). The sum of all interim profile CSA is combined for each survey conducted to date to provide a survey unit with a single 'beach area' value, known hence-forth as the Combined Profile Area (CPA). CPA is compared using linear trend analysis over a temporal scale (Fig.2).

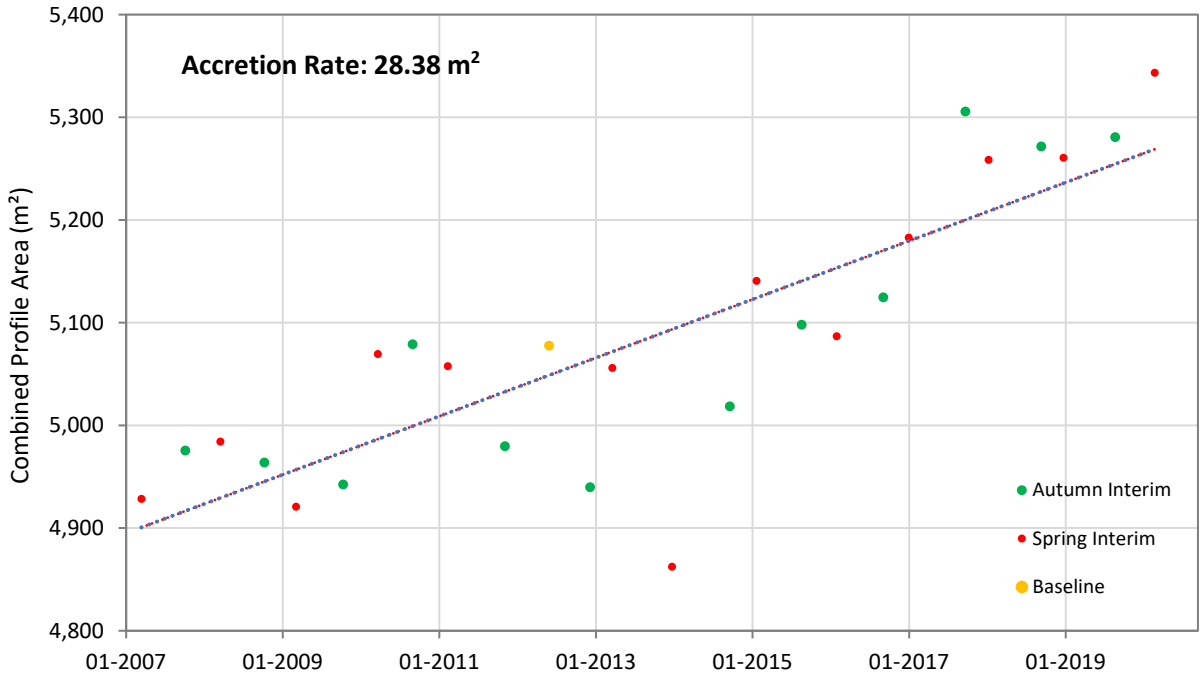


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

If a profile has been omitted from a particular survey, for reasons of obstruction or similar, the average CSA of that profile from all available surveys is taken to ensure a consistent 'beach area'; if fewer than 75% of surveys have been conducted for a particular profile, the profile is omitted.

Profile Extremes Analysis - This plot displays the range of CSA values recorded throughout the duration of data collection (2006-2023) for each individual interim profile; the most recent survey is represented as a green dot. An example is given in figure 3. This plot provides the reader with information on how the CSA for each interim profile from the most recent survey corresponds to the entire dataset range.

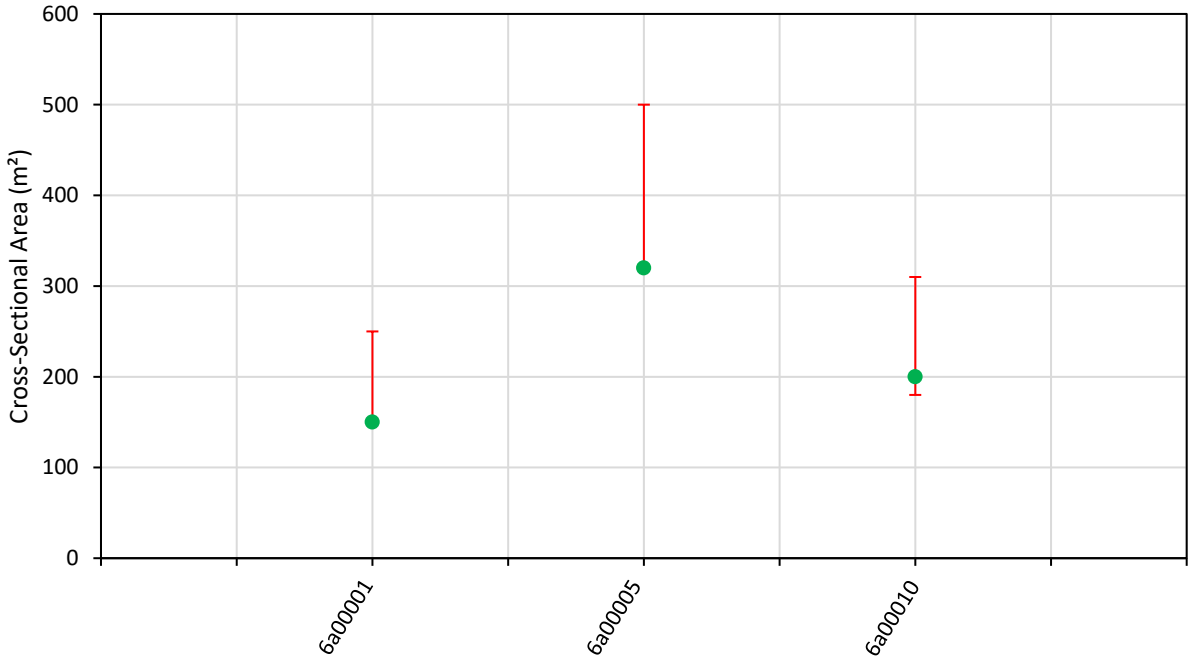


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

CSA Time Series Plot - CSA measurements for each interim profile are displayed on a separate plot representing values from each interim and full coverage survey conducted to date (example shown in Fig.4). This provides the reader with information on each interim profile's CSA evolution through time.

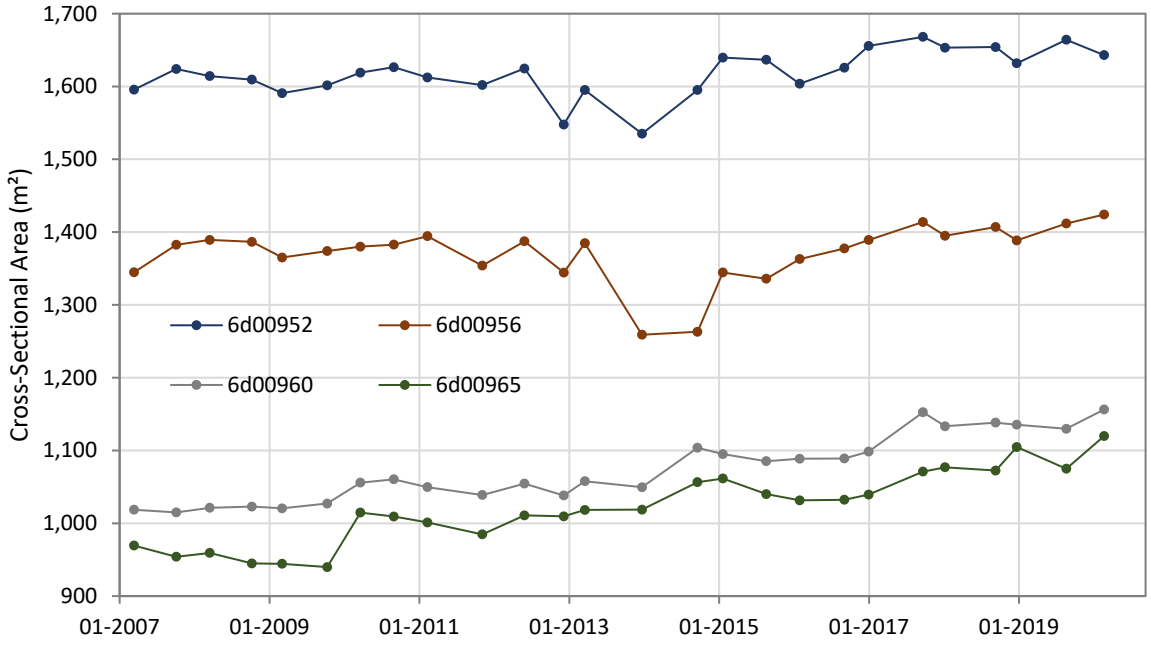


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

Individual Profile Charts - Each interim profile is portrayed as a cross-sectional profile comparing the most recent spring interim (blue), the previous spring interim (green) and the original full coverage survey (red). Profiles are displayed against the master profile (dotted red line) and are presented in the Appendices.

The 2013/2014 Storms – The winter period between September 2013 and April 2014 was, for many beaches in Cornwall, the most destructive period since SWCM records began in 2007. An abnormal number of significant storms, occurring in quick succession, heavily impacted many beaches, causing the loss of sediment from the intertidal area and dune face. This period is extensively discussed throughout this report and will hereinafter be referred to as the 2013/2014 winter period.

2.2 LiDAR Data

Airborne Light Detection and Ranging (LiDAR) data have been captured as part of the SWCM since 2007. Products include a point clouds, from which filtered and unfiltered 1 m^2 gridded surface models are derived:

- Unfiltered (Digital Elevation Model) representing the earth's surface including natural and artificial features such as trees and buildings.
- Filtered (Digital Terrain Model) representing the bare earth surface, with trees, buildings, cars etc. removed.

LiDAR is captured between September and March to minimise vegetation capture. Data is captured between MLWS and up to approximately 500 m inland. This report utilises "filtered" LiDAR data.

2.2.1 LiDAR Data Analysis

LiDAR data analysis is presented as the following:

Difference Modelling – Separate LiDAR surfaces are compared to produce a difference model of change based on gridded spot height elevations. The raw spot height data is processed into a gridded digital terrain model (DTM) and successive models are subtracted from one another to produce a difference model for the survey unit. Change in elevation is shown for values +/- 0.25 m and is represented by a colour scale bar.

Volume Extraction - Net sediment volume (m^3) is extracted for each LiDAR surface from the Beach Zone above MLWS and Mobile Zone above MHWS for trend comparison over time.

Contour Analysis – Contours are mapped from four LiDAR epochs spanning from 2007 to 2023, representing Mean Sea Level (MSL) and dune toe (calculated using the Stockdon equation by UoP, 2023[2]).

2.3 Accuracy Statement

Topographic Data – All survey points recorded along profiles have a measurement accuracy of +/- 0.03 m RMSE[3] in the horizontal and +/-0.03 m RMSE in the vertical.

LiDAR Data – Each LiDAR point cloud dataset has an average point density of 1.5 points per square metre. The digital terrain surfaces provide a minimum accuracy in elevation data of +/- 0.10 m RMSE with a minimum horizontal standard deviation as < 0.05 m. Please note that while every endeavour has been made to capture LiDAR as far seaward as MLWS, tidal and weather restrictions may in some instances have precluded this and coverage may be slightly reduced.

[2] Please refer to the following for Dune Toe elevation calculation: UoP, 2023. MS4S: Contemporary Dune Evolution and Future Predictions, Report, University of Plymouth, 33 pp.

[3] RMSE – Root-Mean-Square Error

3.0 Results

3.1 Topographic Data Analysis

There has been a total of 34 topographic surveys at Poldhu since 2007, 4 of which are full coverage surveys and 29 are interim surveys. Exact dates of each survey for Poldhu are available to view on our survey record. Analysis of the CPA indicates the beach has been accreting slowly at 5 m^2 y^{-1} equating to 0.24% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2014 spring interim, following the highly energetic winter period which saw a 21% loss of material from the 2013 full coverage survey (Fig.5). The beach has since recovered to pre-2014 levels, with the highest recorded combined area during the 2022 autumn interim (2,198 m^2) (Fig.5). A weak seasonal trend is visible at Poldhu, whereby the autumn interim data is more accreted than the spring interim (Fig.5).

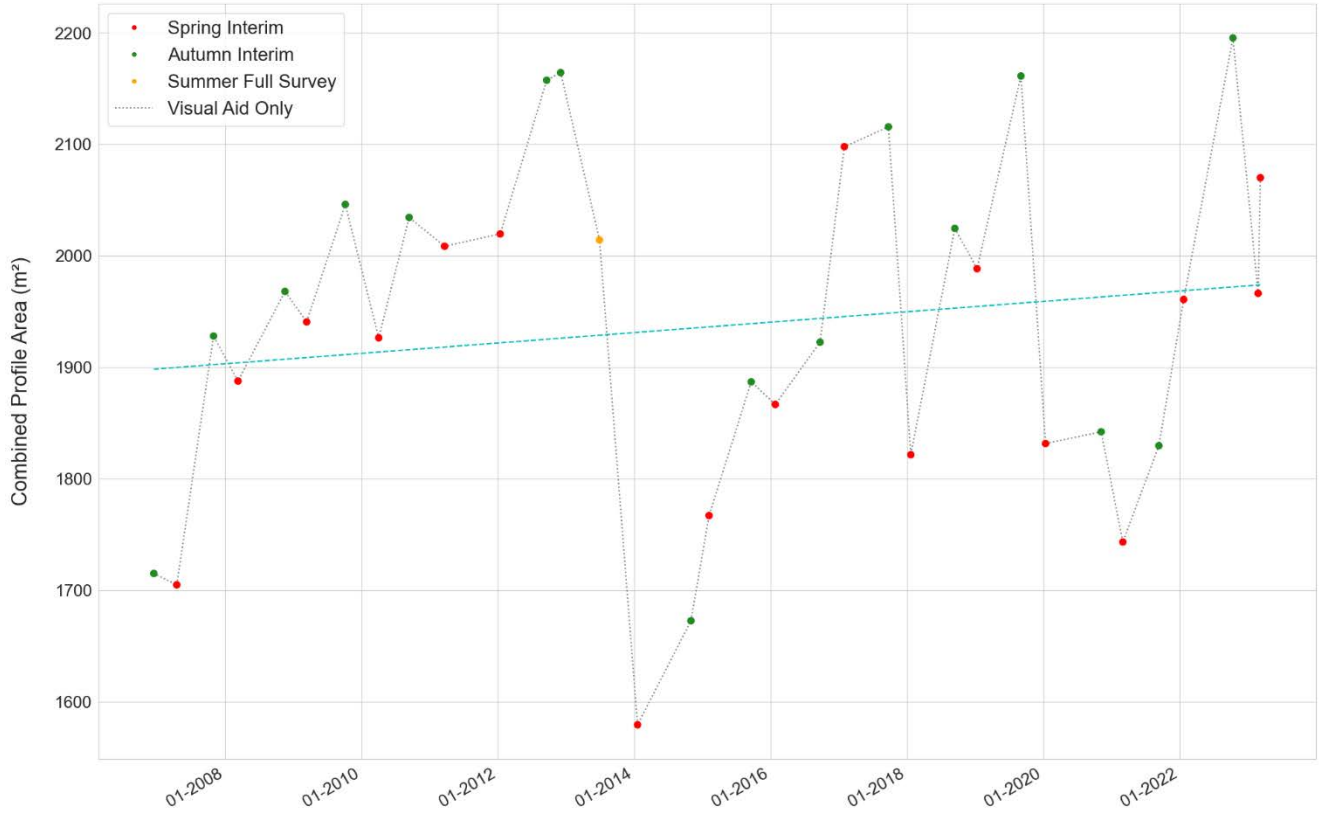


Figure 5 - The Combined Profile Area (CPA) for Poldhu, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing to the entire dataset (Fig.6), during the 2023 spring interim all Poldhu profiles were very healthy, indicating above average cross-sectional areas.

When comparing profile cross-sectional areas to the entire time series (Fig.7), as expected from a small pocket beach, the two profiles encompassing the beach and dune envelope (6e00251 and 6e00251A) have followed the same trend of erosion and accretion with both showing loss of material in 2014, 2018 and 2020 (Fig.7).

Profile Charts for Par Sands can be found in Appendix 1, these display the cross-sections of each profile for the initial baseline survey conducted in 2007 along with the two most recent interim surveys. All profiles have seen considerable gain of material across the entire beach face when comparing the most recent survey to the 2007 baseline with little or no change observed along the dune toe.

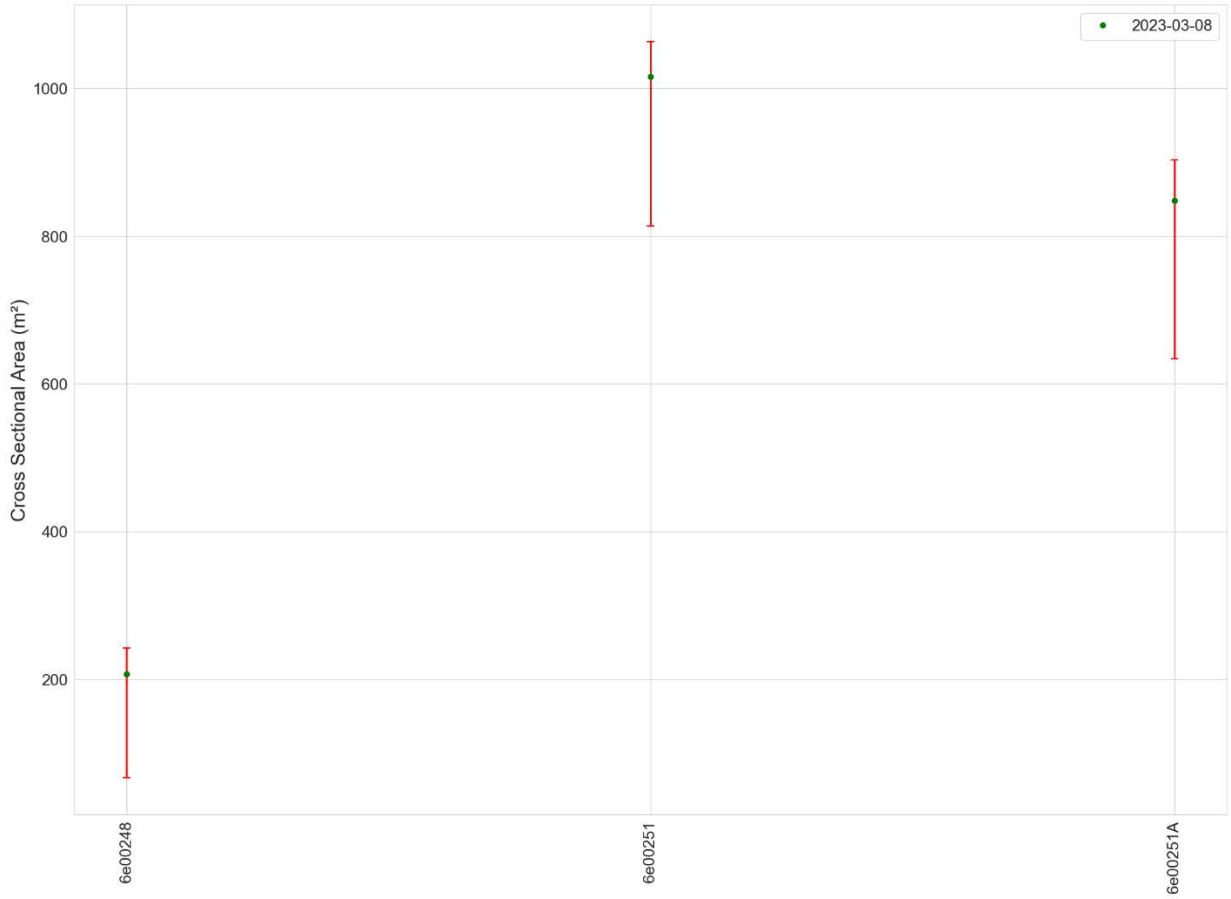


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2023.

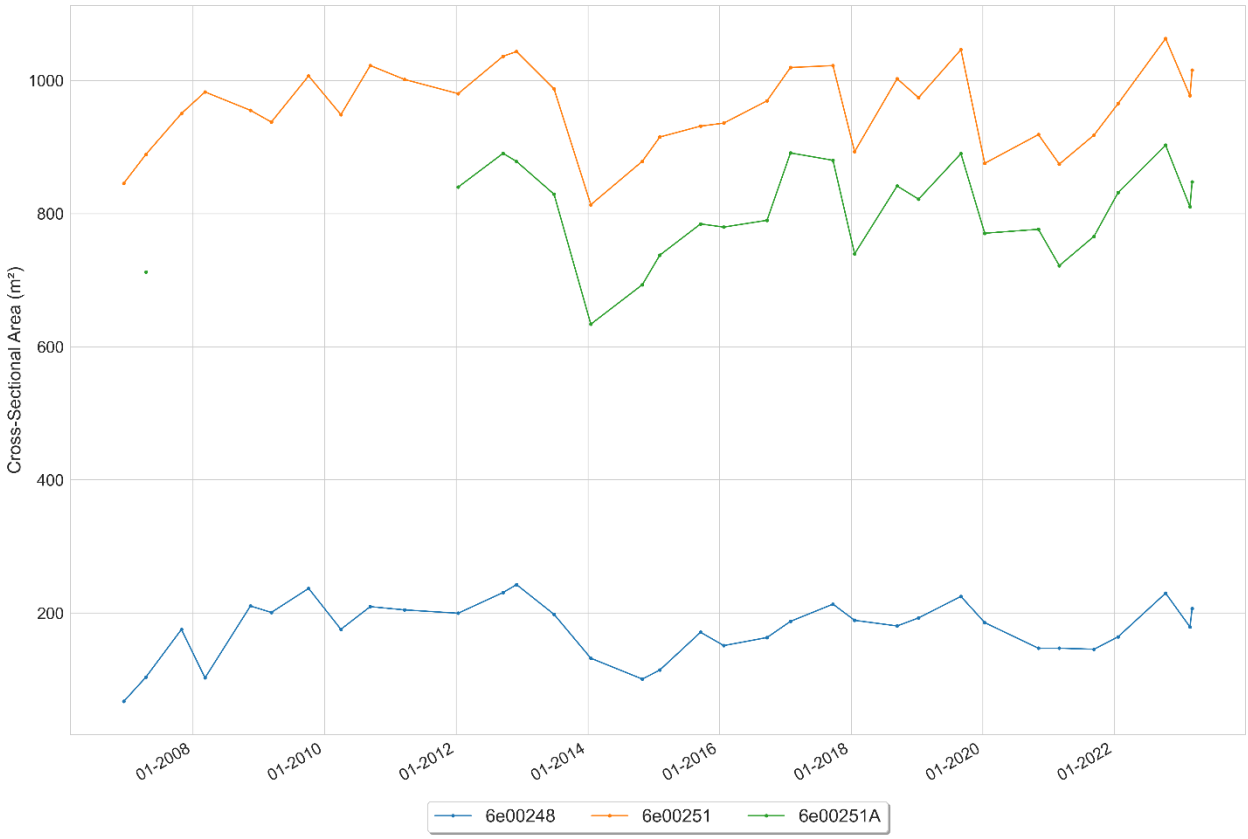


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

3.2 LiDAR Data Analysis

There has been a total of 5 LiDAR flights captured at Poldhu since 2007.

3.2.1 Difference Models

Difference models depicting each epoch of LiDAR are presented here. Accretion and erosion values observed behind the dune system can be attributable to noise in the filtered LiDAR data or man-made changes in elevation and should be dismissed as such.

Figure 8 shows the difference in elevation between the first filtered LiDAR data from September 2007 compared to the most recent, captured in February 2023. There has been considerable accretion observed across the lower beach as well as along the dune face and dune toe which is supplemented by a band of erosion representing up to 2.5 m loss in material elevation spanning the width of the beach face.

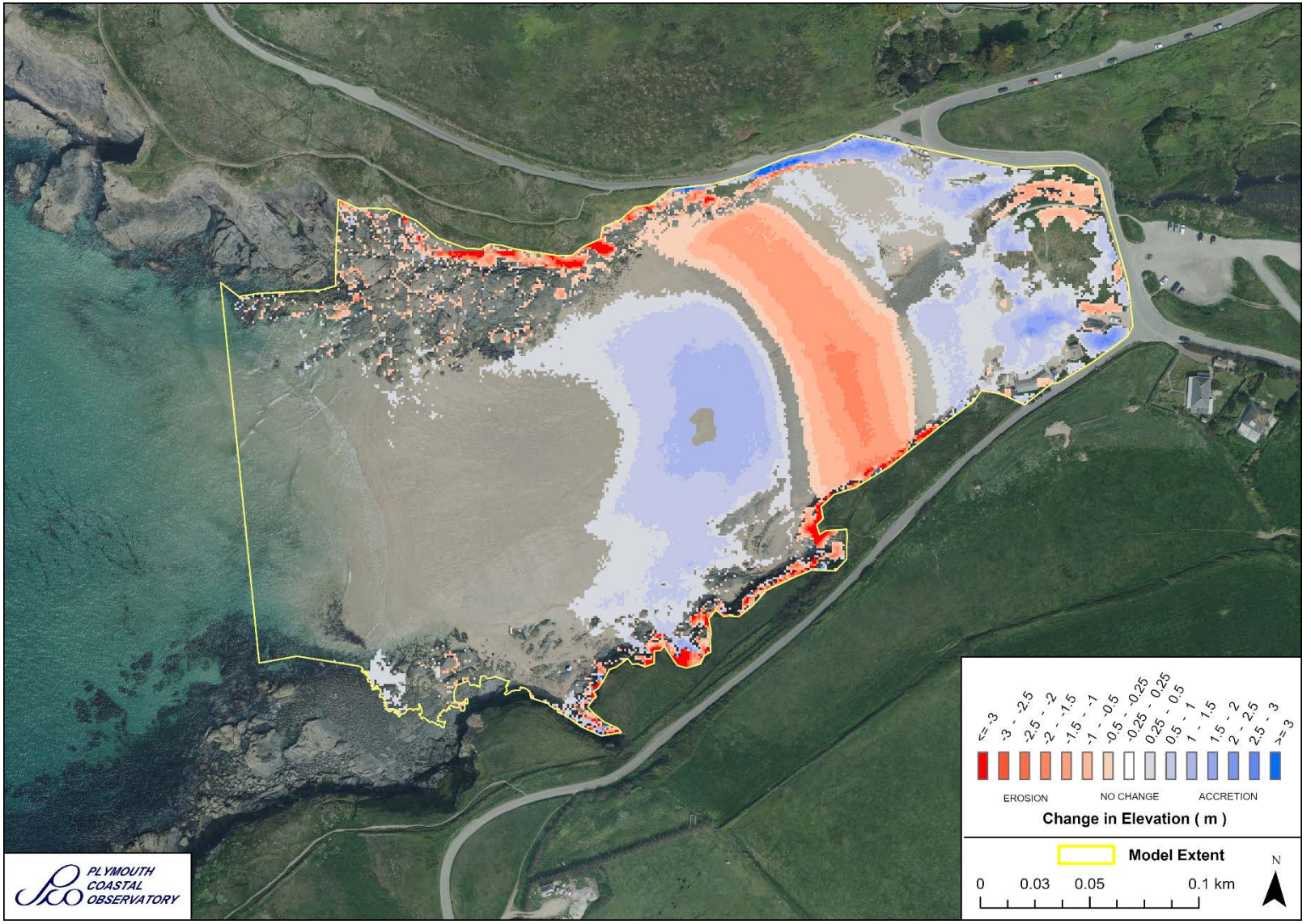


Figure 8 - Difference model indicating the changes in elevation observed between the September 2007 and February 2023 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from September 2007 compared to October 2010. Widespread accretion can be observed across most of the lower beach, with gains in material also observed along the upper beach face and dune toe. Similarly to figure 8, a band of erosion can be seen across the width of the beach at the MSL region and also along the course of the Poldhu stream.

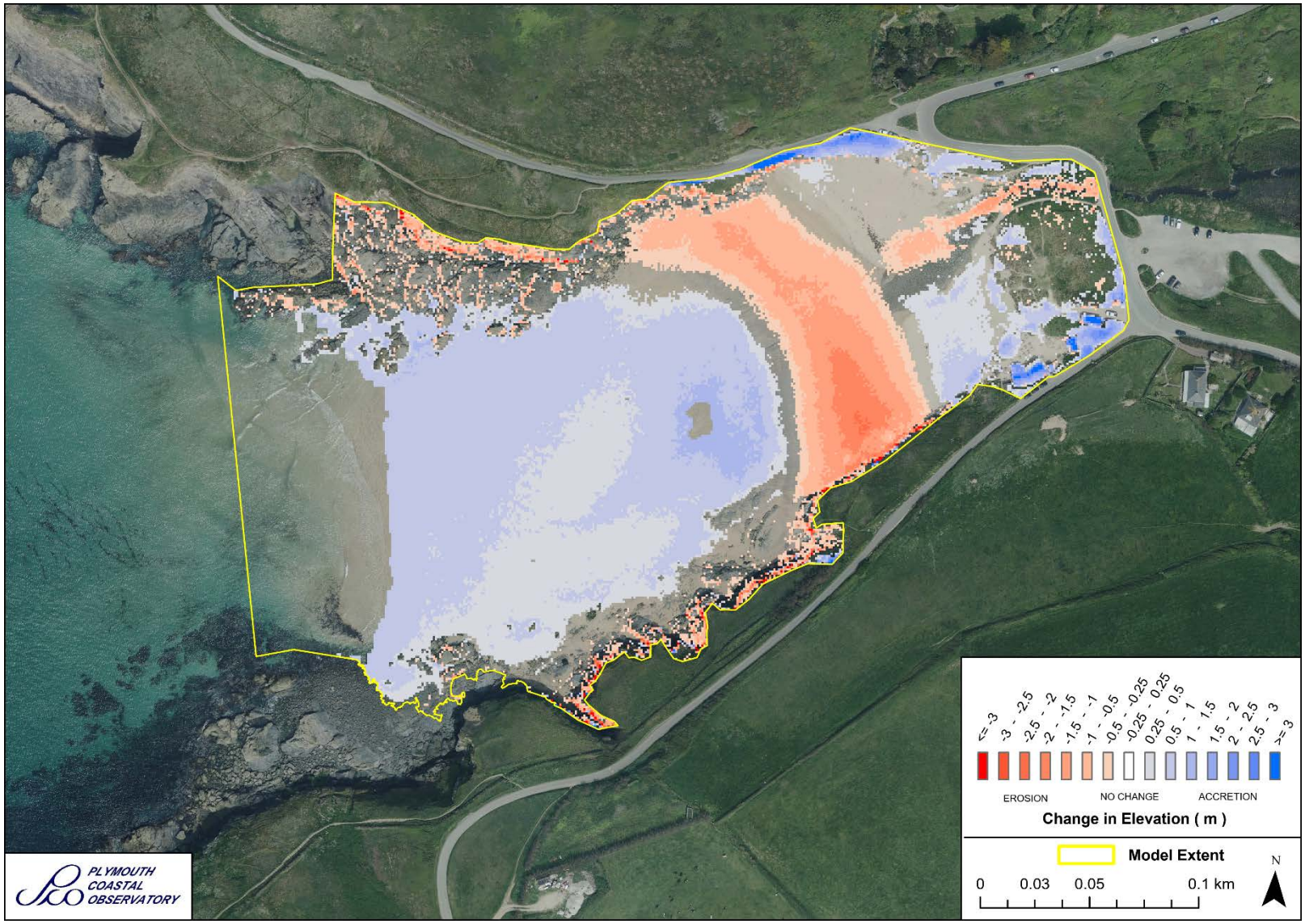


Figure 9 - Difference model indicating the changes in elevation observed between the September 2007 and October 2010 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from October 2010 compared to May 2014. Following the 2013/14 winter storms, the comparison between datasets is dominated by erosion across the entire lower beach with up to 2 m of elevation loss towards the MLWS mark, there is also some minor accretion along the beach toe and within the fore dune area.

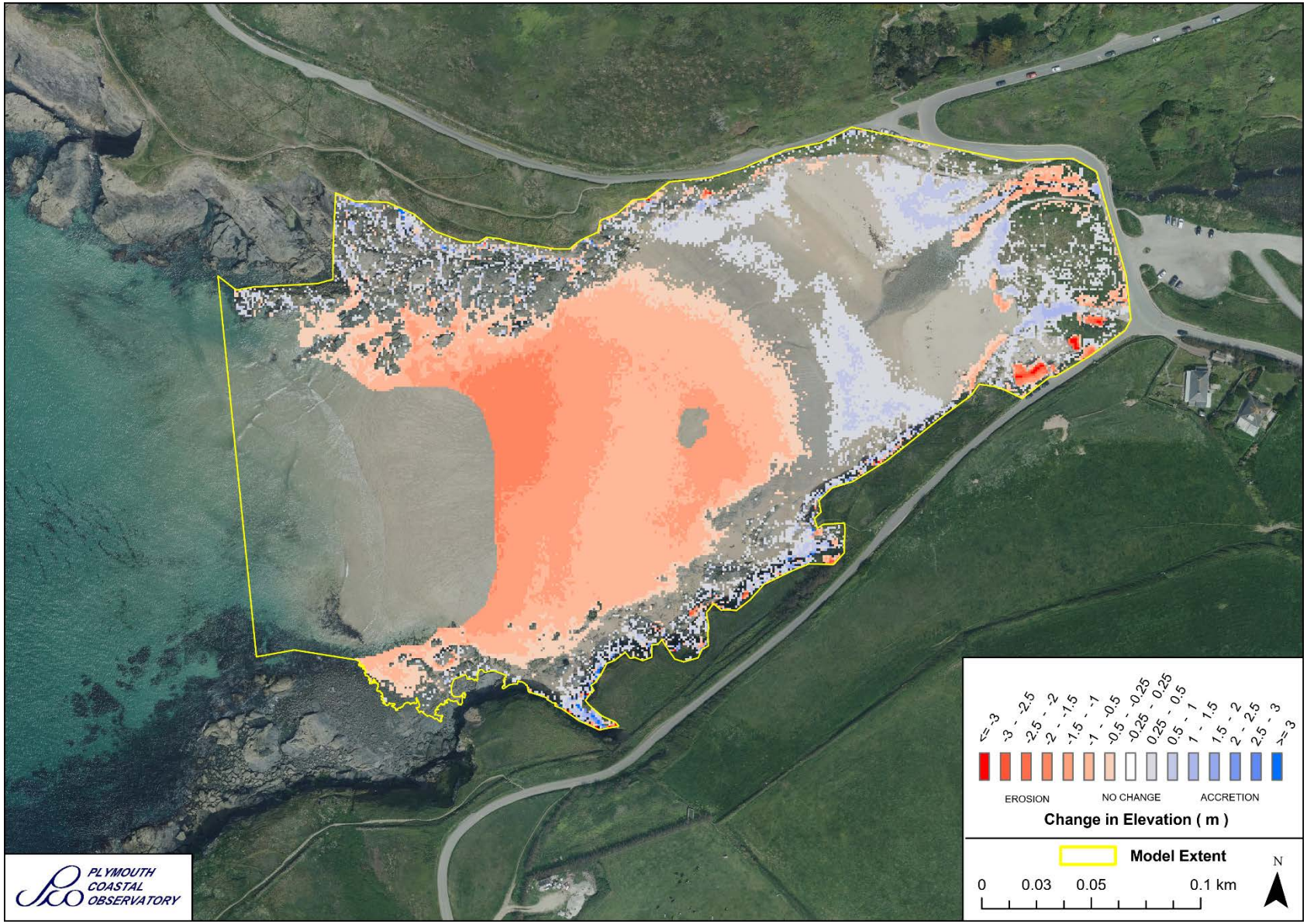


Figure 10 – Difference model indicating the changes in elevation observed between the October 2010 and May 2014 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from May 2014 compared to February 2019. Widespread accretion can be observed across most of the beach, with up to 2.5 m gain in elevation along the beach toe area indicating the recovery of the beach following the 2013/14 winter storms. Some accretion can also be seen around the dune toe area.

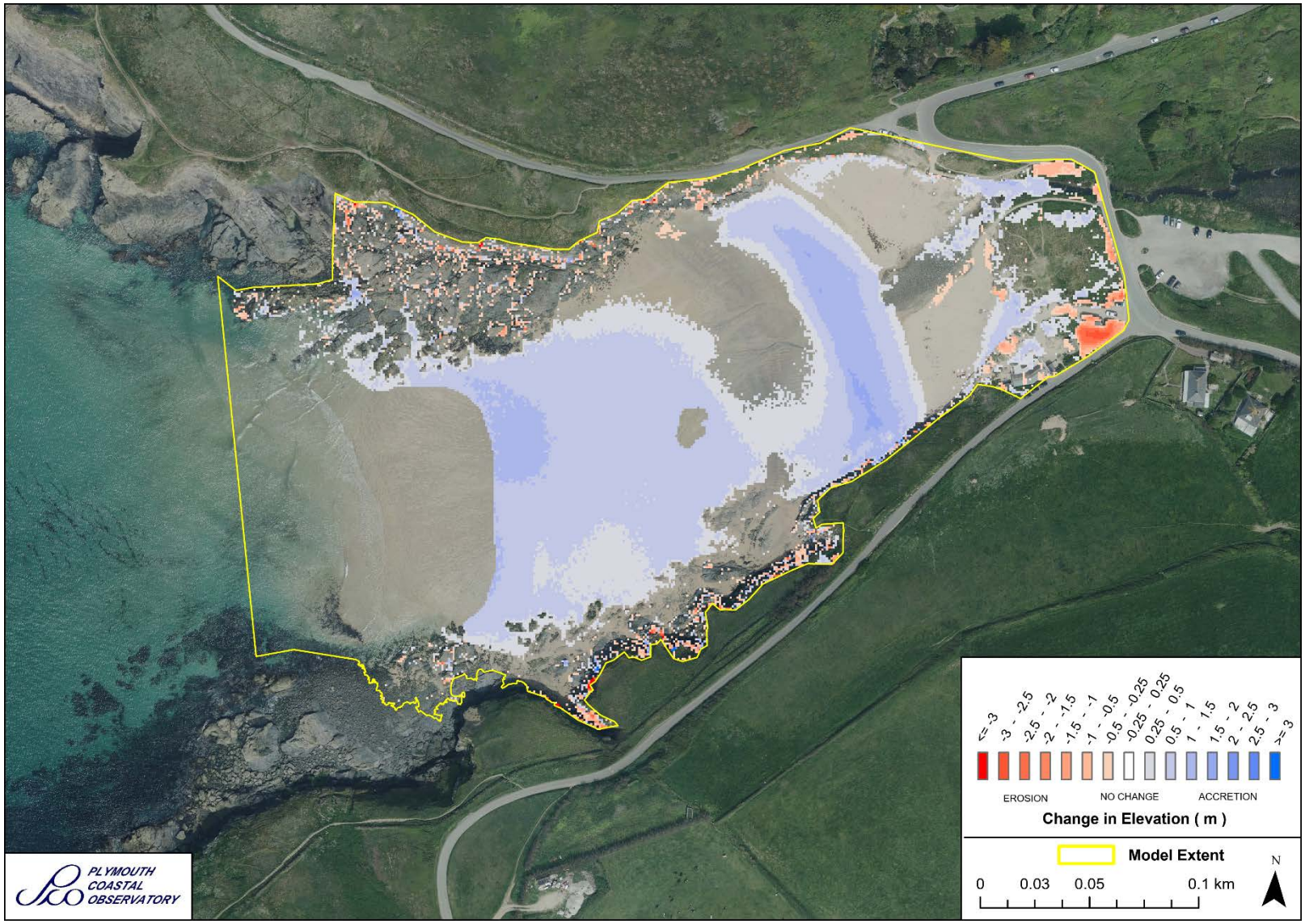


Figure 11 - Difference model indicating the changes in elevation observed between the May 2014 and February 2019 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from February 2019 compared to February 2023. The large berm which had built up in 2019 as depicted in figure 11 along the beach toe has been eroded, with respective accretion occurring along the low tide terrace. There is some visible loss of material along the dune toe.

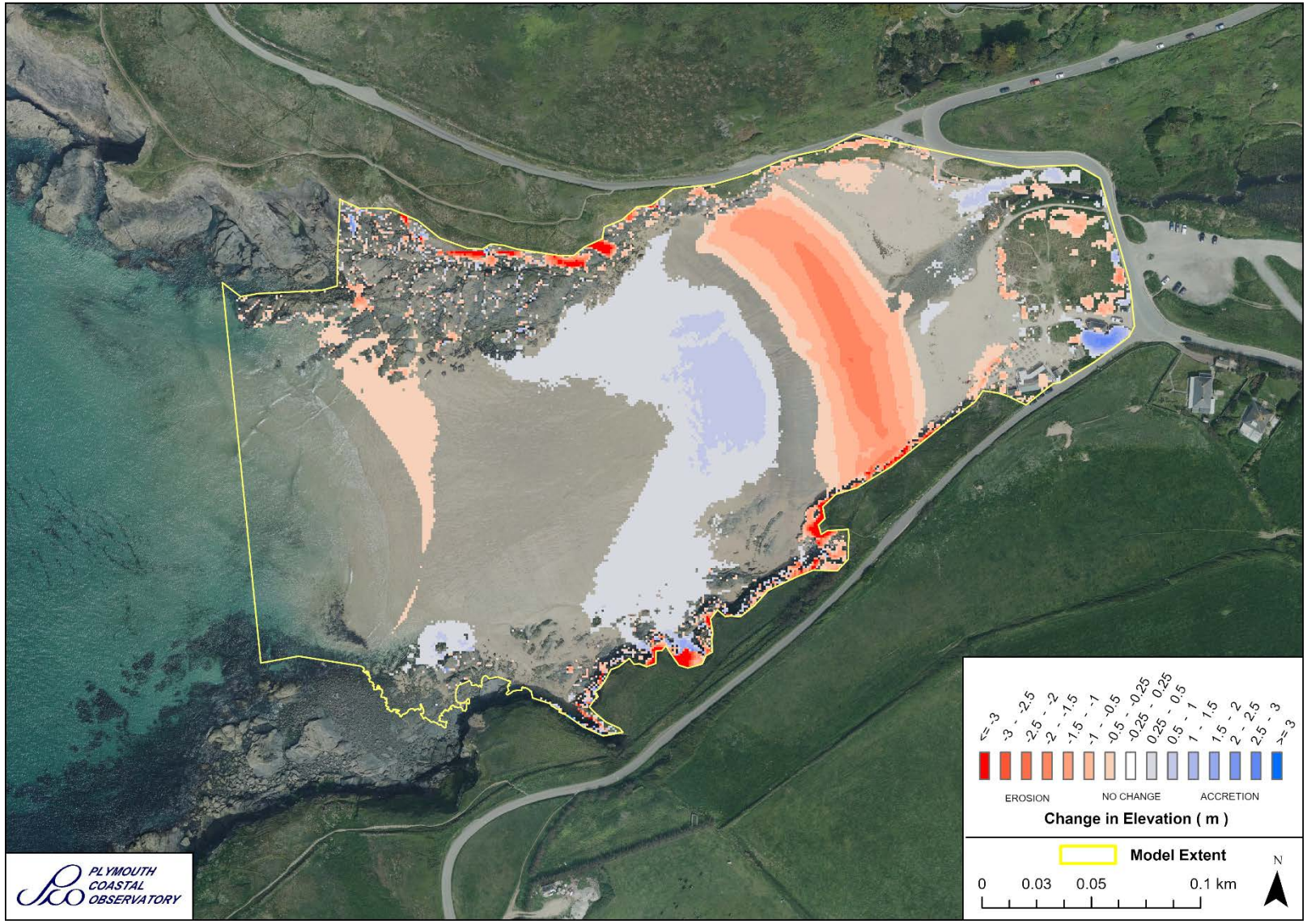


Figure 12 - Difference model indicating the changes in elevation observed between the February 2019 and February 2023 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.40 m OD) are shown in Table 1 and figure 13. LiDAR data from the Mobile Zone shows gradual accretion between 2007 and 2023, the highest recorded volume was during the 2019 survey which saw a 26% increase since the 2014 survey (Fig.13).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.30 m OD) are shown in Table 1 and figure 14. The Beach Zone has also remained stable (with gradual gain) between 2007 and 2023 despite a large fluctuation of volume in 2014 following the 2013/14 storm season, where a 20% loss in material was seen following the 2010 survey.

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (2.40 m OD) and for the Beach Zone above MLWS (-2.30 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
09/2007	12,290	82,518
01/2010	10,022	91,241
05/2014	11,295	68,934
02/2019	15,693	87,228
02/2023	11,581	85,381

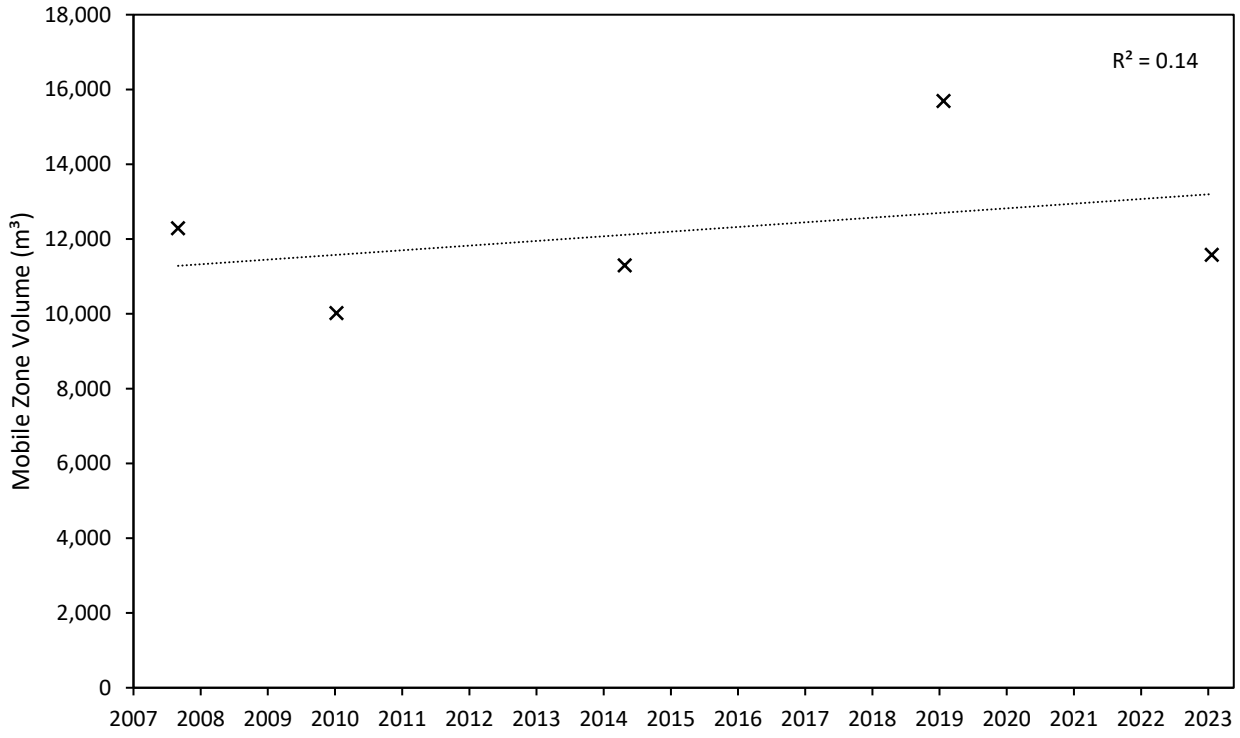


Figure 13 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.40 m OD) for each filtered LiDAR datasets between 2007 and 2023.

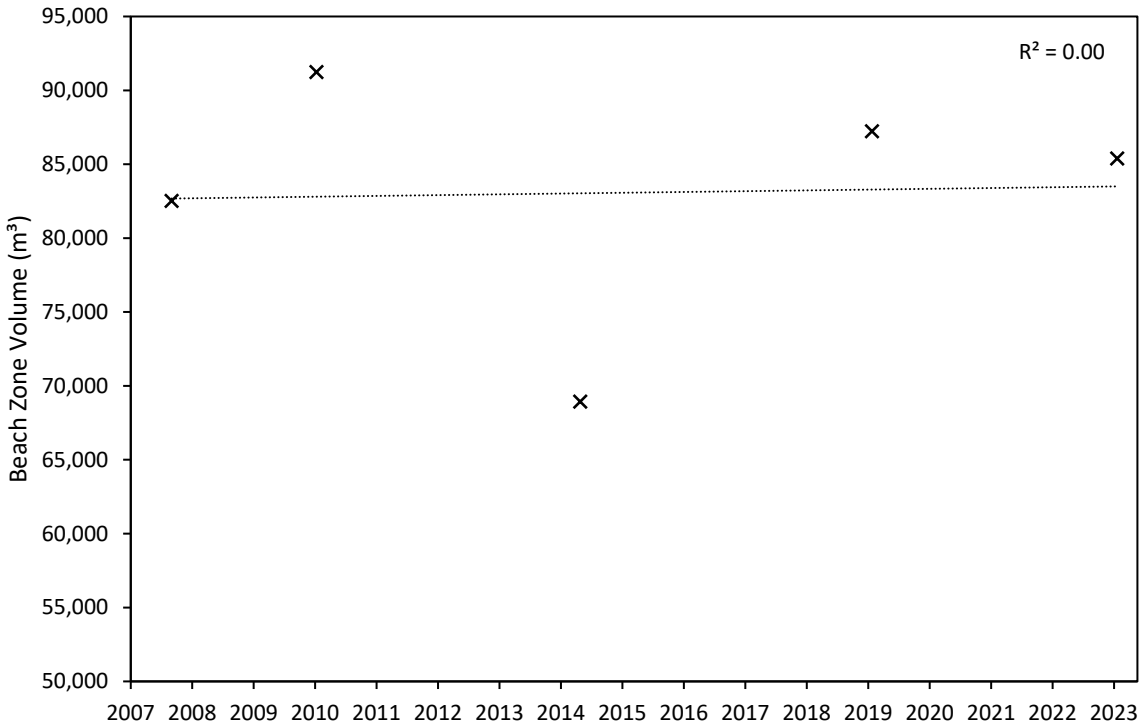


Figure 14 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2007 and 2023.

3.2.3 Contour Comparison

Figure 15 shows the Mean Sea Level (MSL) and dune toe contours from the 2007, 2014, 2019 and 2023 LiDAR datasets. MSL contours indicate a gradual widening of the beach, with widened of up to 350 m between 2007 and 2023 (Fig.15). The dune toe has moved seaward since 2007 and 2022, with fluctuations in movement seaward and landward, the most seaward position of the dune toes was recorded by the 2019 LiDAR.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency (Figs. 16 and 17) and from 2007 onwards by the SWCM (Figs. 18-22).

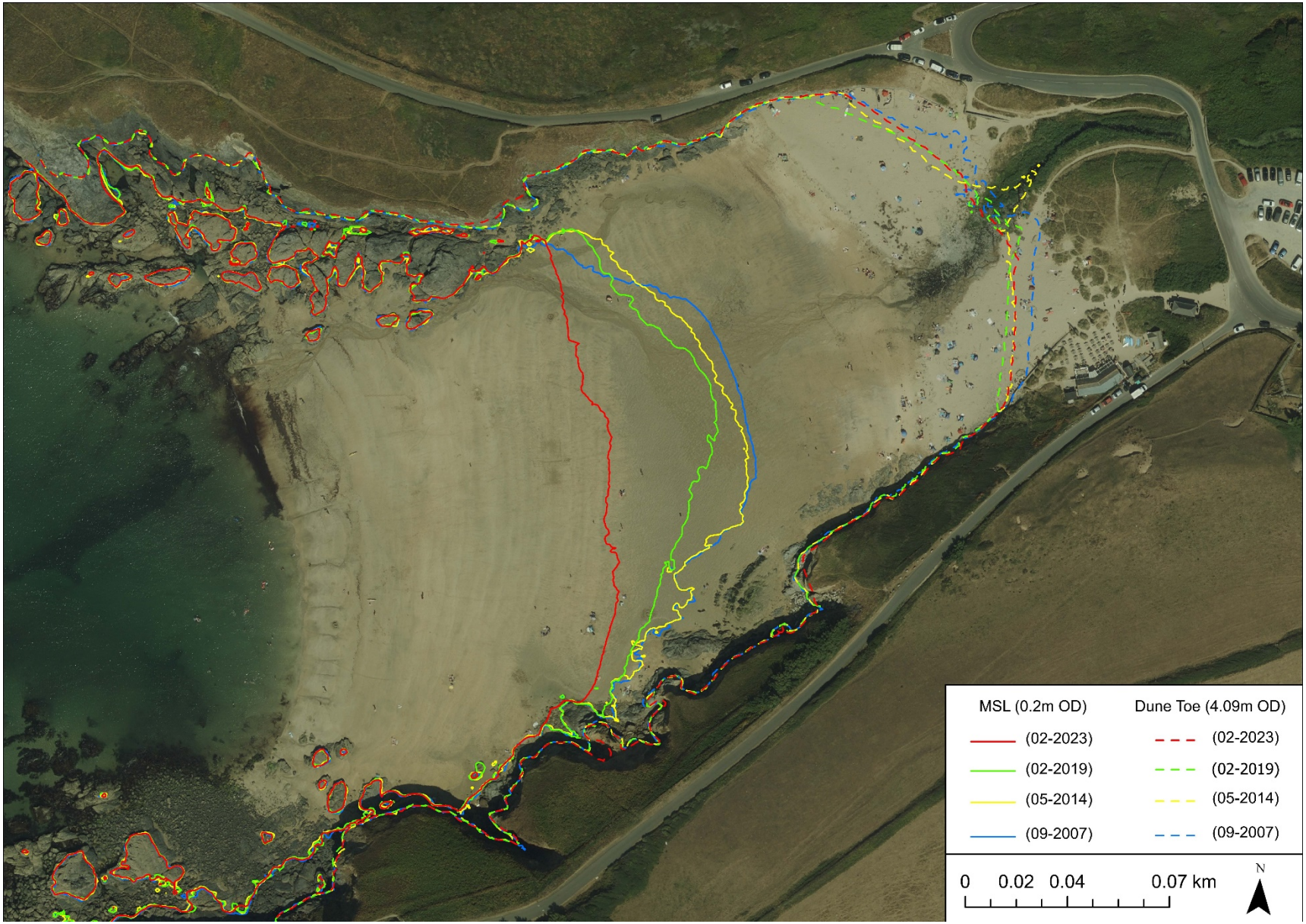


Figure 15 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2007, 2014, 2019 and 2022 LiDAR datasets.



Figure 16 – Aerial imagery from 1947.



Figure 17 – Aerial imagery from 2001.



Figure 18 – Aerial imagery from 2007.



Figure 19 – Aerial imagery from 2009.

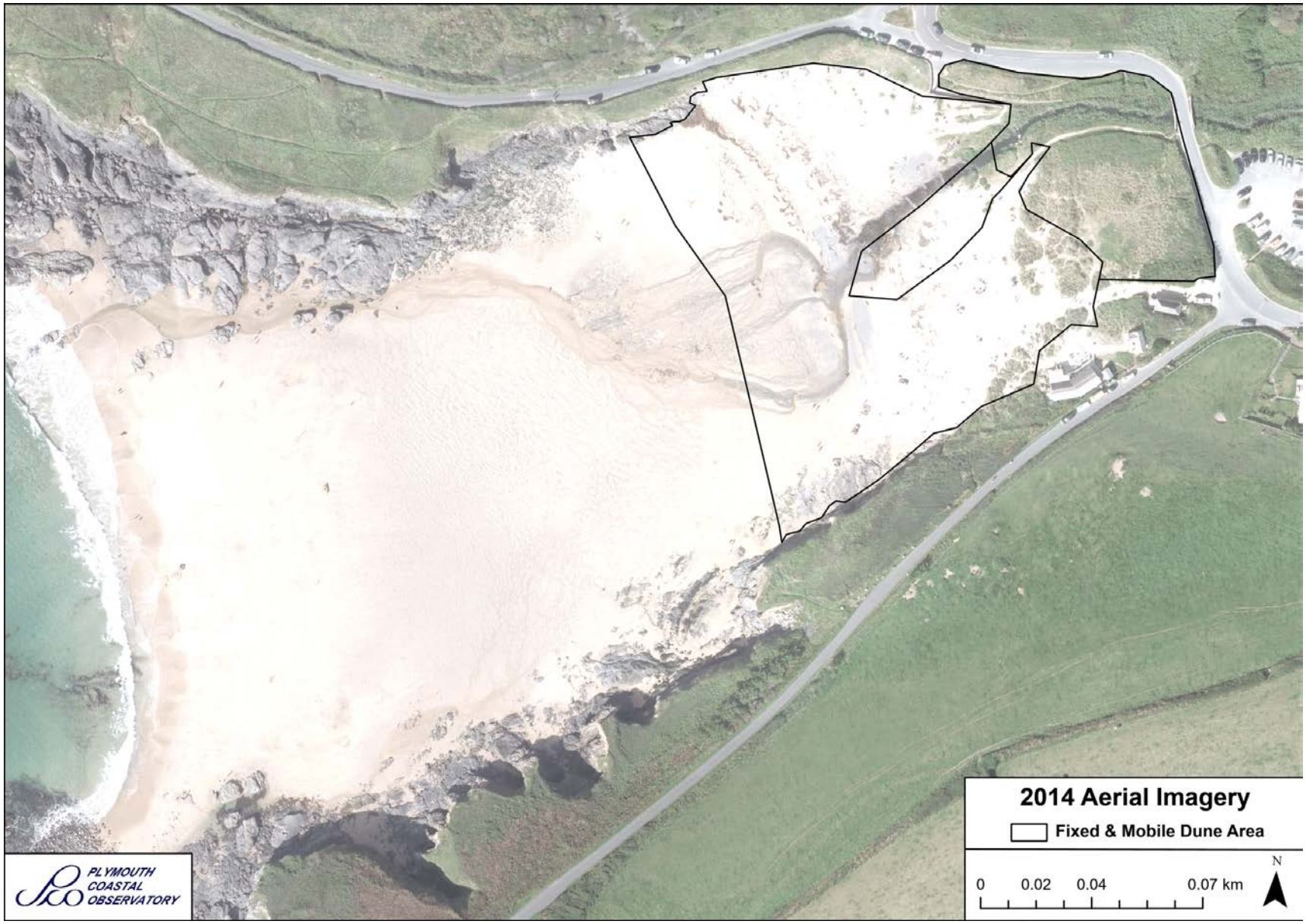


Figure 20 – Aerial imagery from 2014.



Figure 21 – Aerial imagery from 2018.



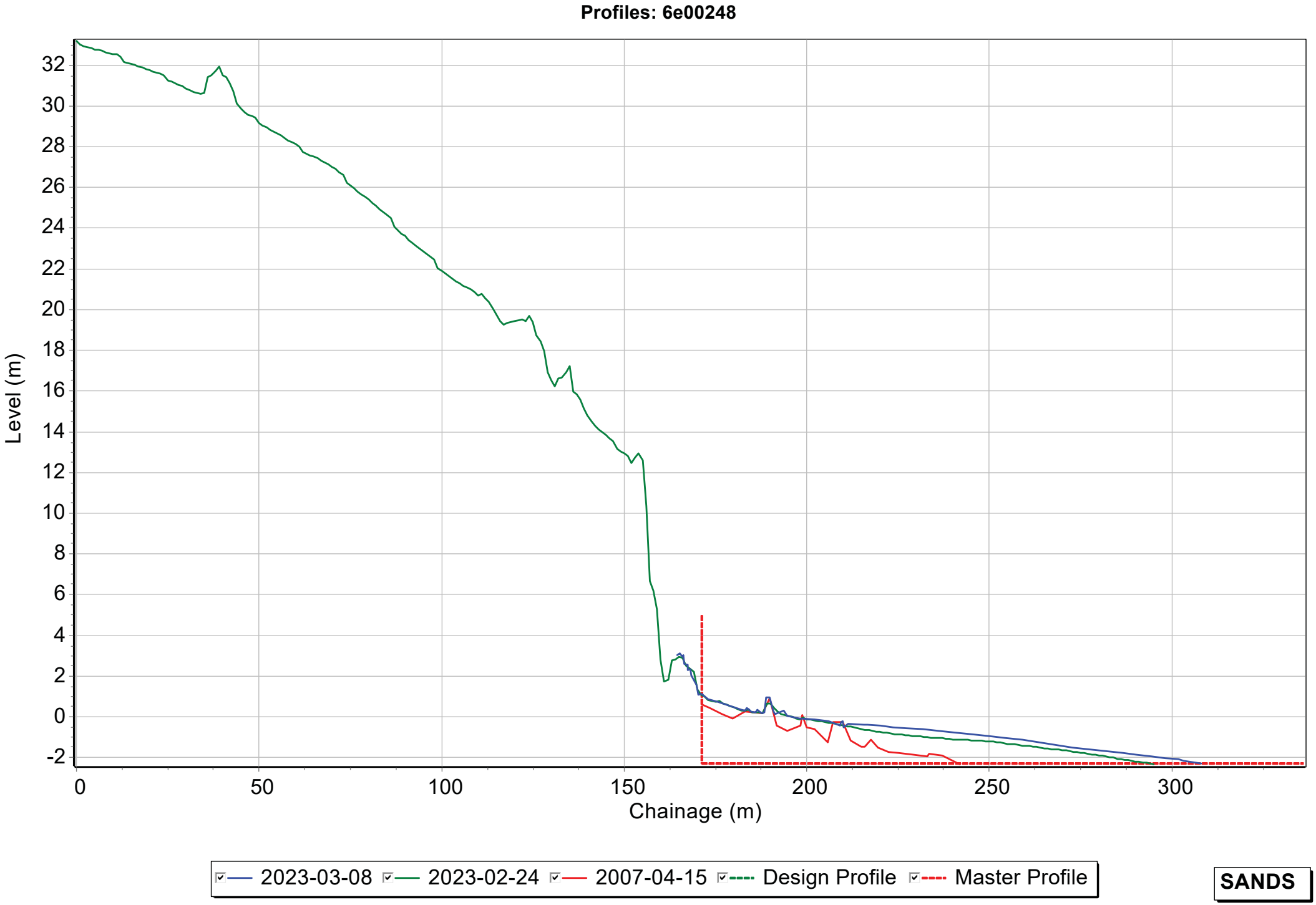
Figure 22 – Aerial imagery from 2022.

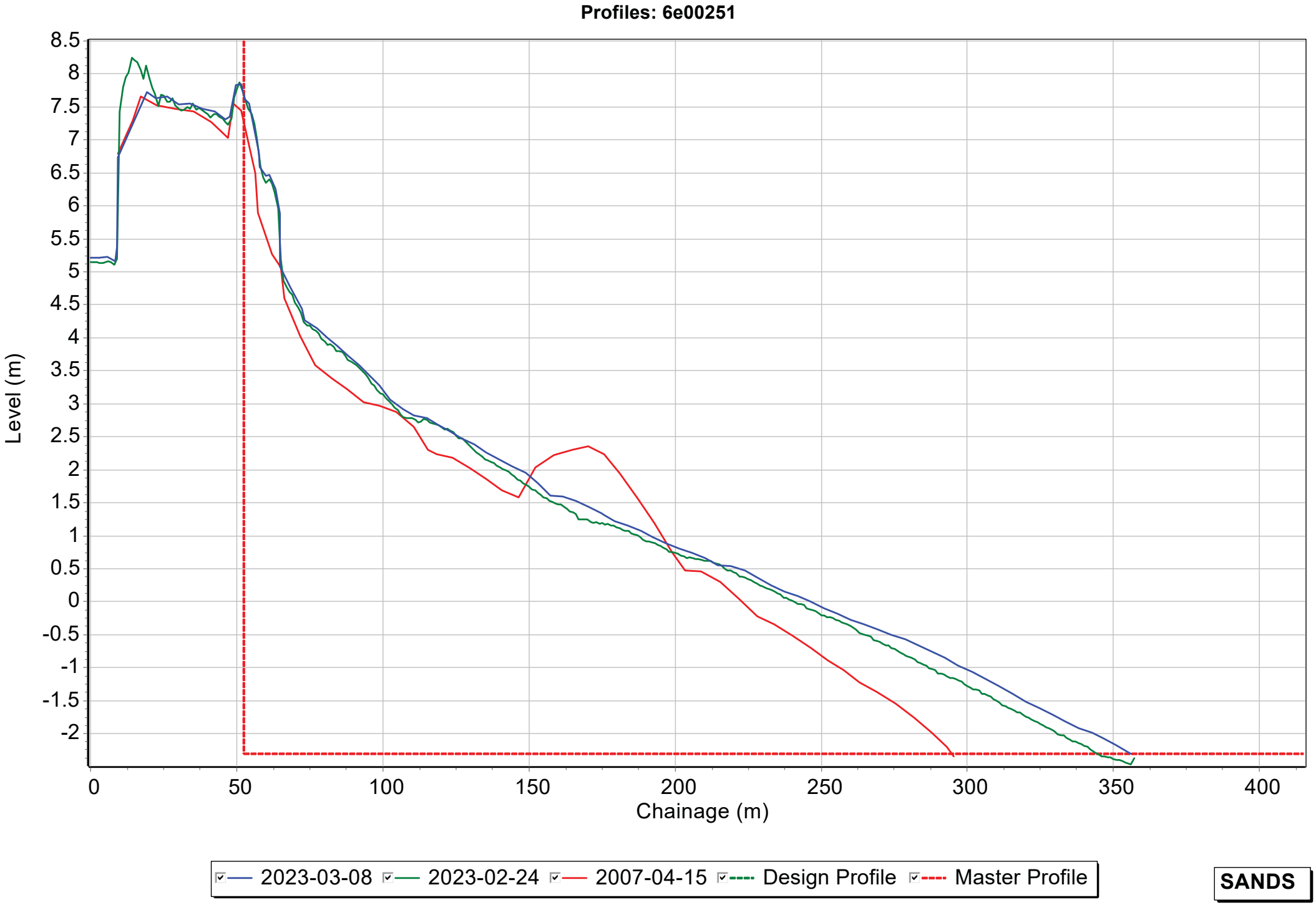
Glossary

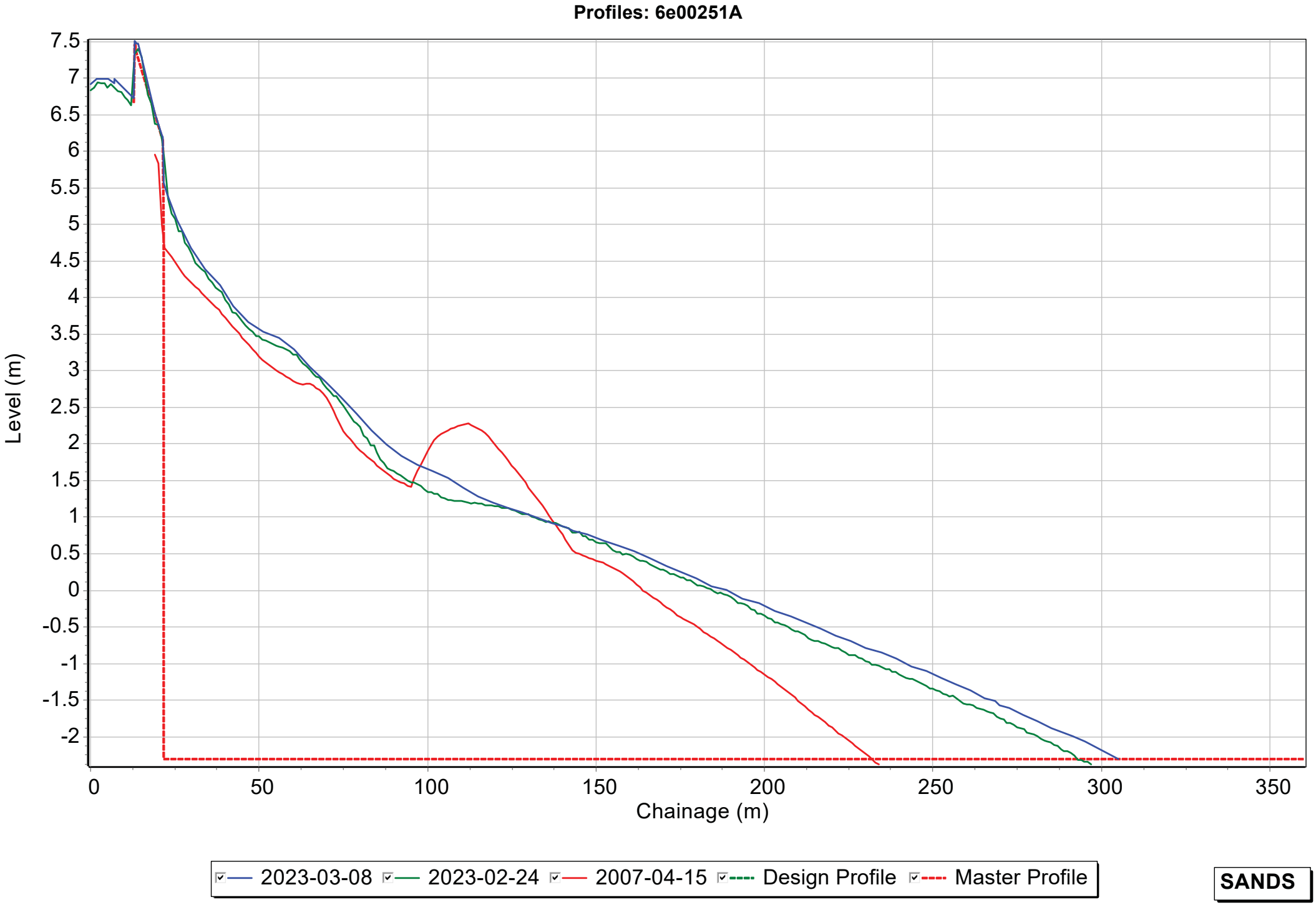
1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
4. Cross-Sectional Area (CSA): The area of a two-dimensional cross-section of a cross-shore beach profile, running between Mean Low Water Spring and the back of the beach.
5. Developed Zone: Areas of urban development built atop previously present dune systems.
6. Difference Modelling: Comparison of separate LiDAR surfaces to produce a difference model of change based on gridded spot height elevations.
7. Digital Elevation Model (DEM) and Digital Terrain Model (DTM): DEM represents the Earth's surface with all features, while DTM represents the bare earth surface, excluding vegetation and structures.
8. Embryo Dune: The earliest stage of dune growth, typically found along the seaward extent of a dune system or newly formed dune.
9. Erosion: The process by which local sea level rise, strong wave action, and coastal flooding wear down or carry away rocks, soils, and sands along the coast.
10. Fixed Zone: Area defined by permanent dune vegetation, including scrub or invasive species, denoting vegetation atop sandy soil.
11. Intertidal Bar: A ridge or mound of sand, gravel, or other sediment deposited in the intertidal zone along a shoreline.
12. LiDAR: Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth.
13. Mean High Water Spring (MHWS): The height of mean high-water springs is the average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.
14. Mean Low Water Spring (MLWS): The height of the mean low-water springs is the average height obtained by the two successive low waters during the same period.
15. Mobile Zone: The area including the active dune face and embryo dune that is in motion due to wind action or other factors.
16. Root-Mean-Square Error (RMSE): A measure of the differences between values predicted by a model and the observed values.
17. Tidal Range: The vertical difference between high tide and low tide during a tidal cycle.

Appendices

Appendix 1 – Profile charts showing the cross-shore area of each interim profile from the most recent survey (blue), the preceding survey (green) and first full coverage survey, also known as the baseline (red) at Poldhu are presented below.


Profiles: 6e00248
Level (m)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
Chainage (m)
2023-03-08
2023-02-24
2007-04-15
Design Profile
Master Profile
SANDS


Profiles: 6e00251
Level (m)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
50
100
150
200
250
300
350
400
Chainage (m)
2023-03-08
2023-02-24
2007-04-15
Design Profile
Master Profile
SANDS


Profiles: 6e00251A
Level (m)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
50
100
150
200
250
300
350
Chainage (m)
2023-03-08
2023-02-24
2007-04-15
Design Profile
Master Profile
SANDS