SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Porthmeor Beach Report

Topographic and LiDAR Data Analysis

SWCM TBR15 22/05/2024

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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 Porthmeor. The aim is to highlight coastal change at Porthmeor using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed Porthmeor, a NNW facing sandy beach with a length of ~590 m and a cross-shore width of ~200 m. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change of the intertidal beach area over time. LiDAR data is compared from each available flight to show difference models of the intertidal area, to compare volumetric data over time and to show change in Mean Seal Level and Dune Toe contours over time.

Since 2007, 37 topographic surveys were conducted at Porthmeor, including 4 baselines and 32 interim surveys and 1 post-storm survey. Topographic analysis shows the lowest recorded combined area was during the 2021 spring interim (2,023 m^2), however the beach recovered to 2019 volume levels by 2023. The highest recorded combined area was during the spring interim of 2011 (2,440 m^2). Overall, the unit has seen a steady decline in CSA since the baseline survey in 2007.

Surface volume was extracted from the Beach and Mobile Zone for 9 LiDAR flights between 2008 and 2023. The data shows the Mobile Zone has experienced gradual erosion, with the most erosive period between the 2012 and 2014 surveys, which saw a 31% loss in volume. Despite a slight recovery by 2017, the Mobile Zone has shown gradual signs of continual erosion. Similarly, to the Mobile Zone, volume extracted from the Beach Zone has also indicated a decline in volume between 2008 and 2023, losing 7% in volume between 2011 and 2023.

Overall Porthmeor beach has a gradual decline in volume and area from the upper and lower beach areas.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Porthmeor Beach using data collected as part of the South West Coastal Monitoring (SWCM) Programme since 2007. Four zones have been identified to define the beach/dune area and are defined as:

- **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

Porthmeor is a NNW facing sandy beach, protected from the prevailing south-westerly swell by a rocky headland. The beach has an alongshore length of ~590 m and a cross-shore width of ~200 m and an average tidal range of 5.8 m. Porthmeor is backed by a sea wall on the western end of the beach and residential buildings to the east. Rocky headlands provide protection on either side. It is important to note that all data captured will be impacted by reprofiling that occurs most years, depending on how much sediment builds up along the residential housing. Porthmeor has no active dune system with the three beach and dune zones represented in Figure 1.



Figure 1 - Location Map of Porthmeor 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 2024. 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).

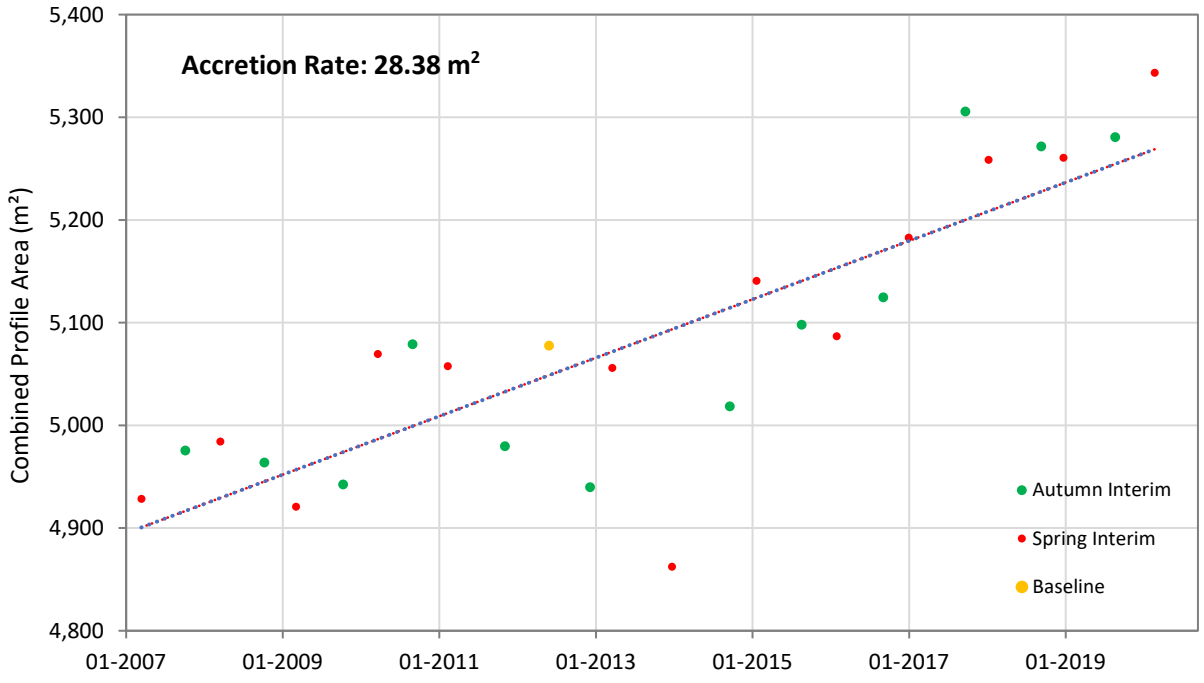


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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 (2006-2024) 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.

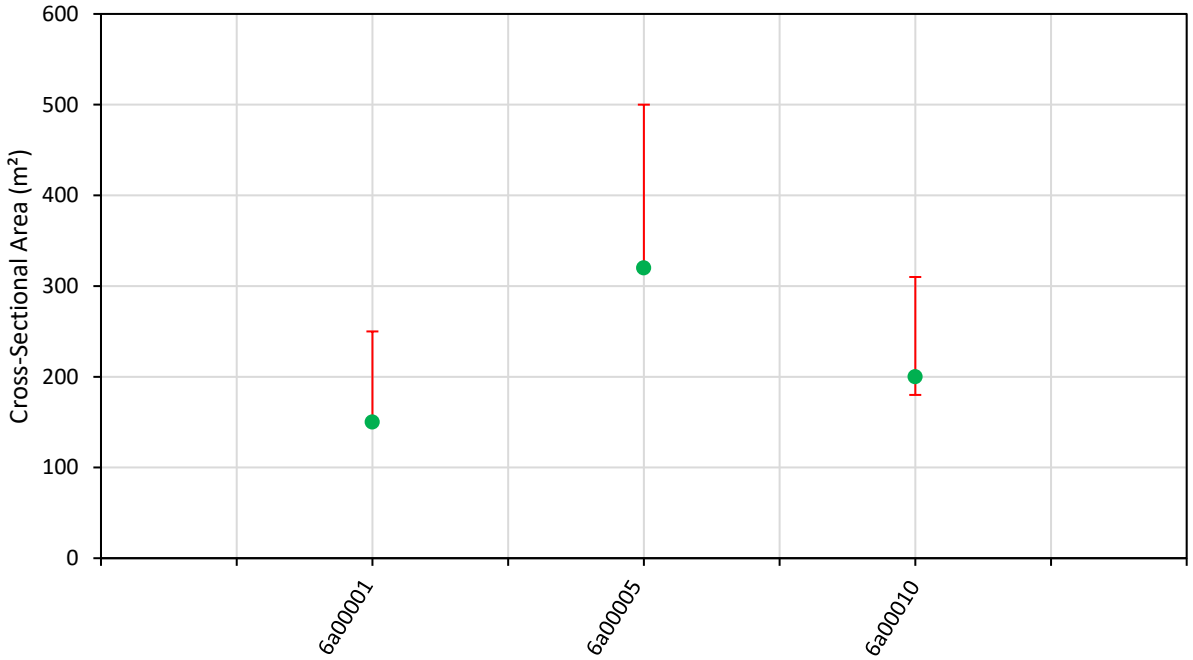


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

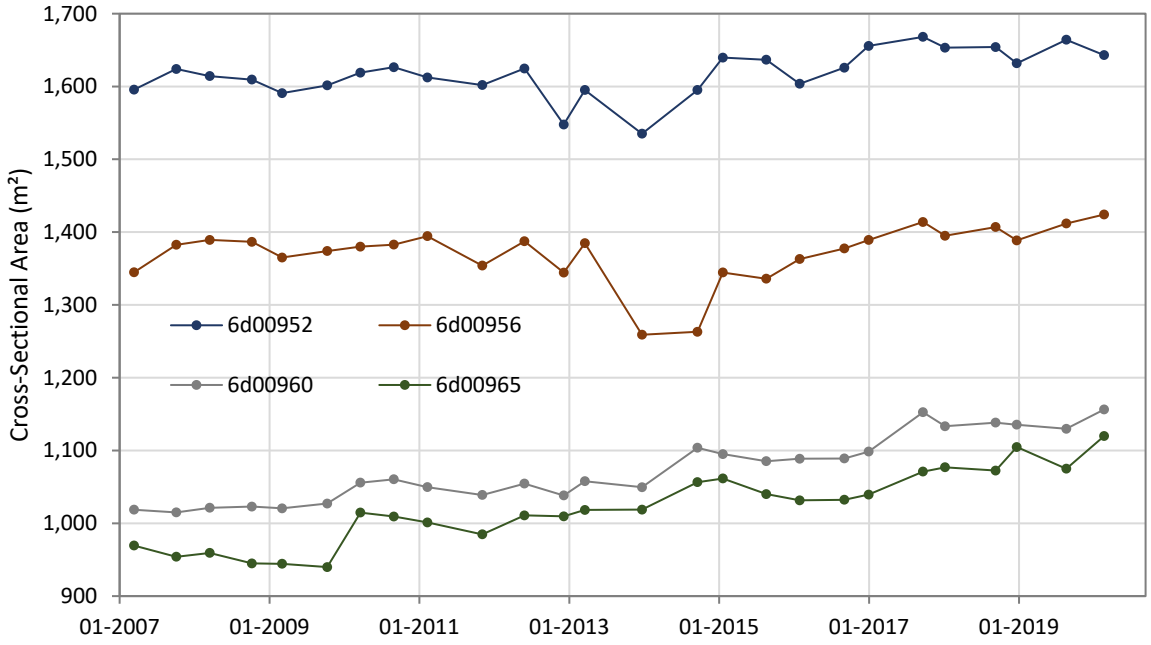


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 37 topographic surveys at Porthmeor since 2007, 4 of which are baseline surveys, 32 are interim surveys and 1 post-storm survey. Exact dates of each survey for Porthmeor are available to view on our survey record. Analysis of the CPA indicates the survey unit has been eroding at 5.5 m^2 y^{-1} equating to 0.25% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2021 spring interim (2,023 m^2), however the beach recovered to 2019 volume levels by 2023. The highest recorded combined area was during the spring interim of 2011 (2,440 m^2). Overall, the unit has seen a steady decline in CSA since the baseline survey in 2007.

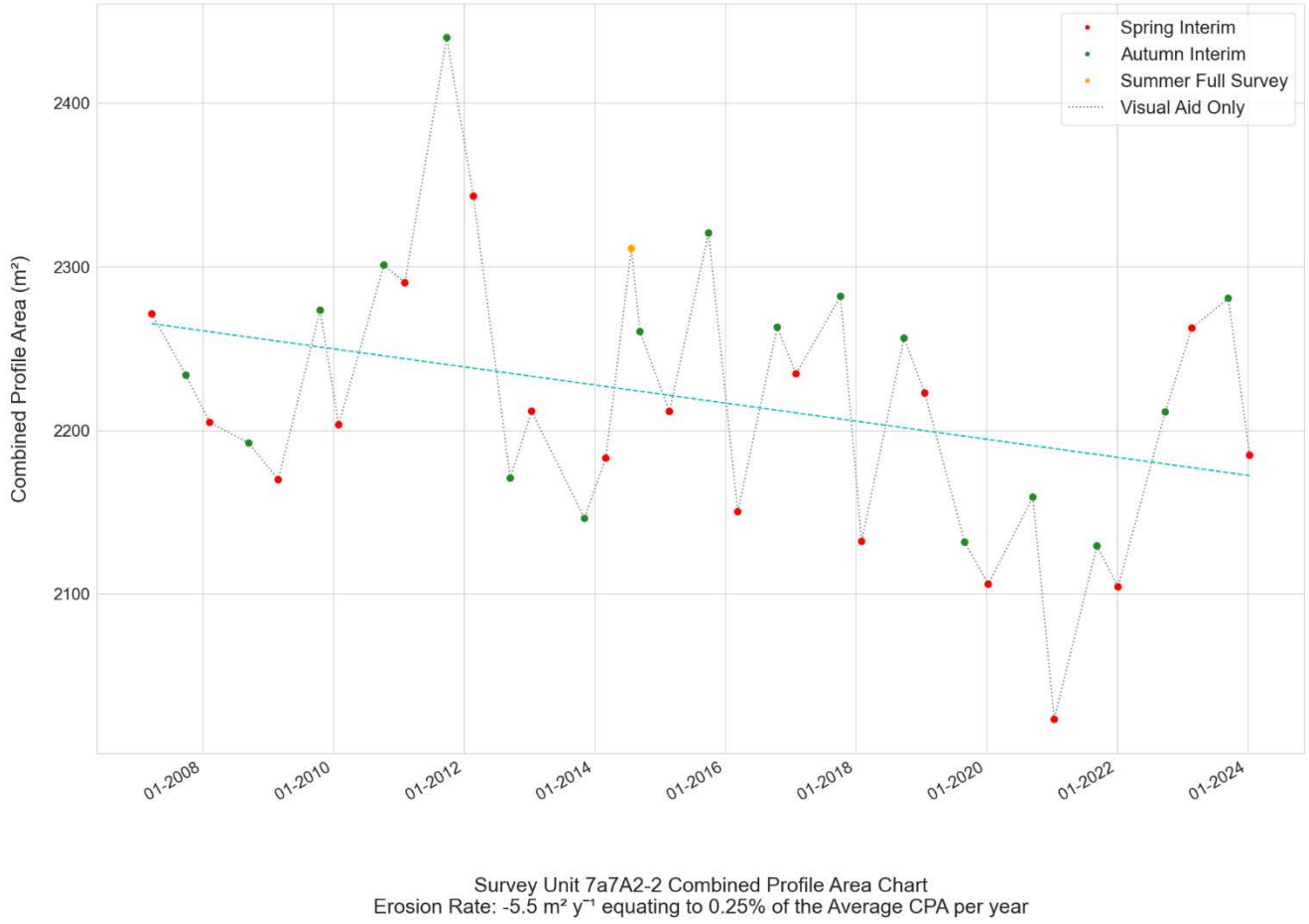


Figure 5 - The Combined Profile Area (CPA) for Porthmeor, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When comparing to the entire dataset (Fig.6), during the 2024 spring interim profiles 7a00681 to 7a00689 displayed below average cross-sectional area to date, whilst profile 7a00679 has seen an above average trend.

When comparing profile cross-sectional areas to the entire time series (Fig.7), profiles 7a00685 and 7a00689 were impacted in 2013/2014, whereas profiles 7a00679 and 7a00681 see a decline 2012/2013. A distinct drop is also noted in the latest 2024 survey, except for profile 7a00679. Overall, Porthmeor profiles display seasonal variation across the epoch.

Profile Charts for Porthmeor 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. Profiles 7a00679, 7a00685 and 7a00689 have observed an increase in beach elevation on the upper beach of up to ~0.75 m since the 2007 baseline. Whereas profile 7a00681 has seen the opposite effect, with a loss of up to almost a meter of sediment at the top of the beach.

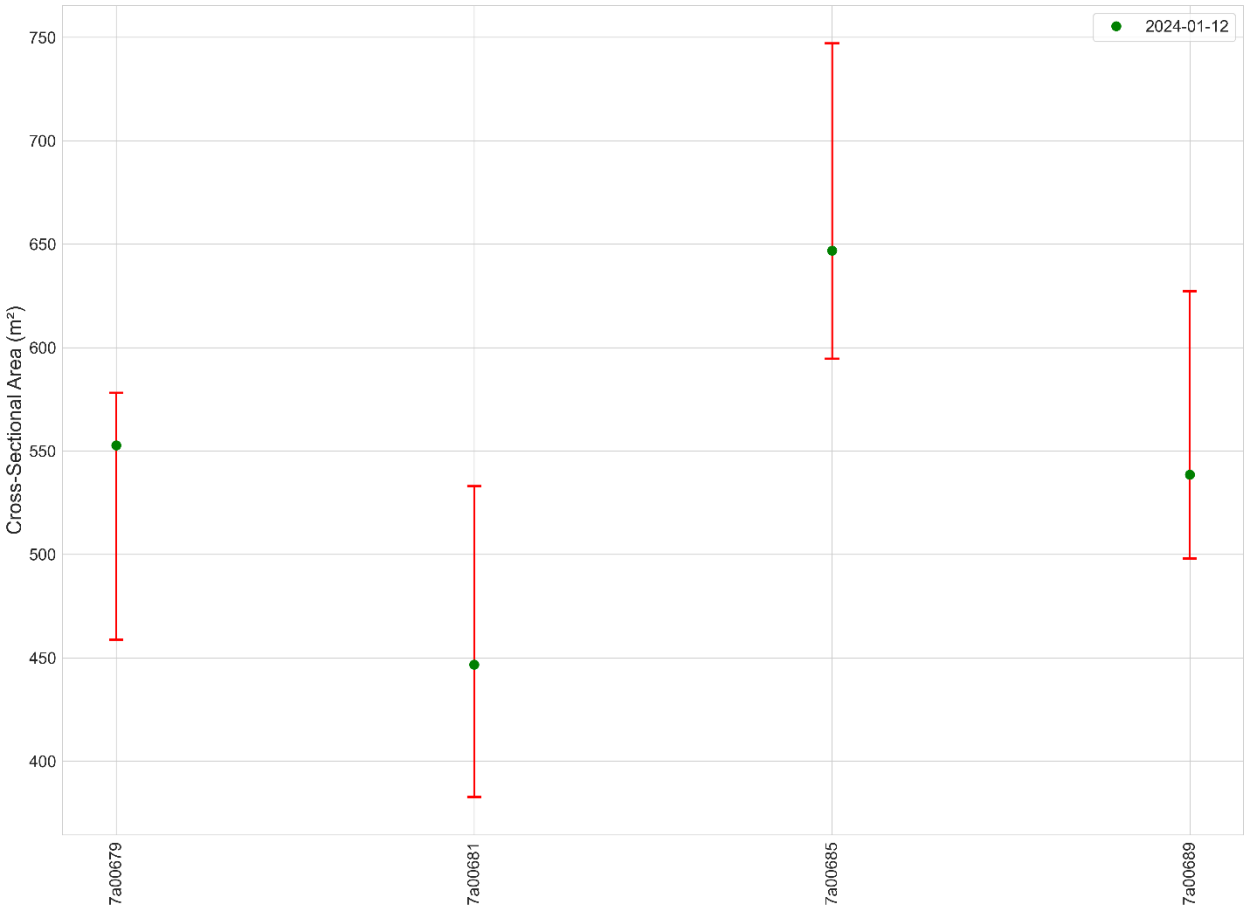


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2024.



Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

There has been a total of 9 LiDAR flights captured at Porthmeor since 2007, by the SWCM Programme.

3.2.1 Difference Models

Difference models between each epoch of LiDAR data 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 March 2008 compared to the most recent, captured in January 2023. A band of ~1 m of erosion is suggested to be present above the MSL mark, which continues along the beach face forming cusp type features. Low-level change can be seen along the seaward end of the beach, whilst the intertidal zone remained stable. A small area of acute accretion is suggested on the upper beach under the hard cliff to the west.

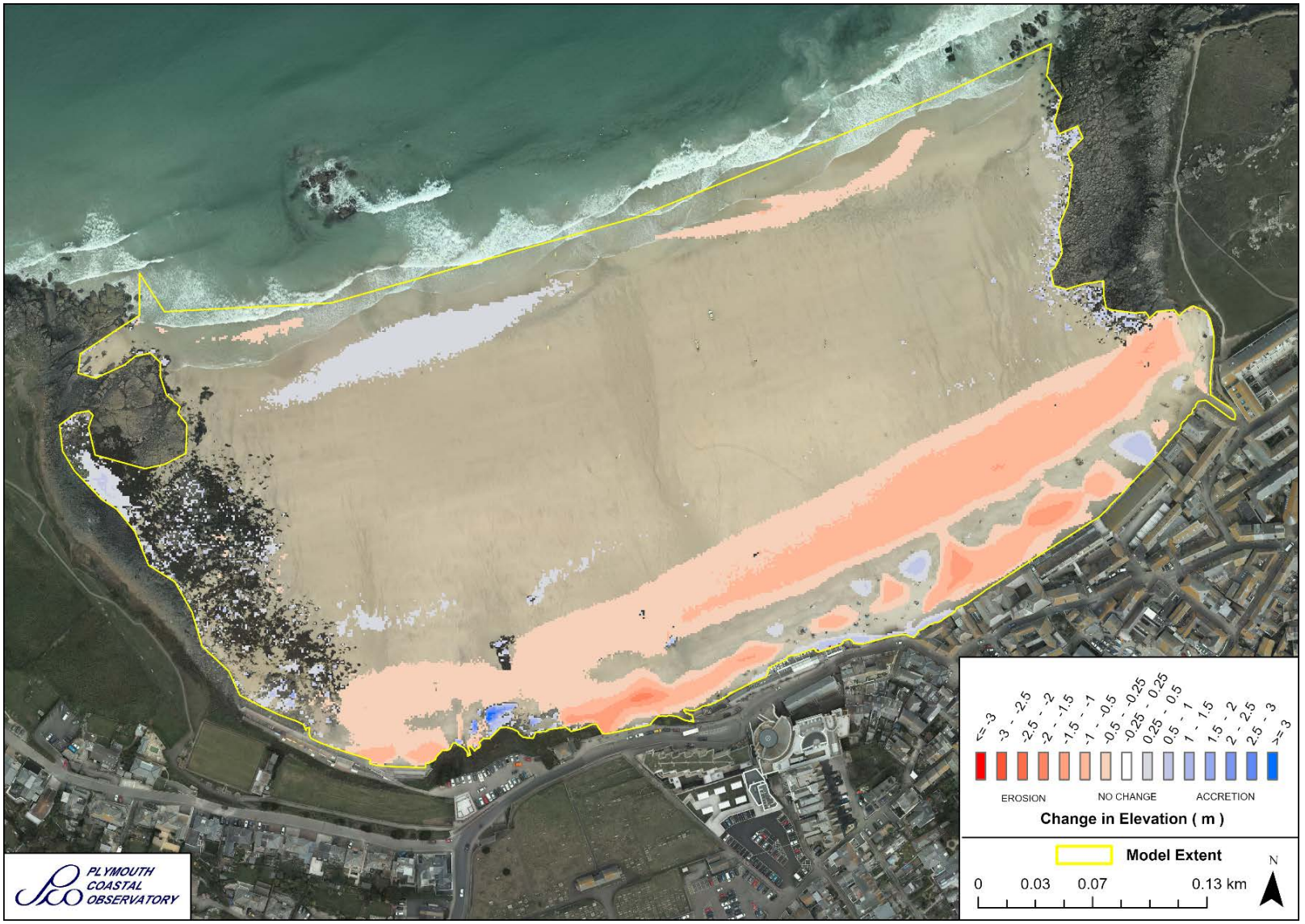


Figure 8 – Difference model indicating the changes in elevation observed between March 2008 and January 2023 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows the difference in elevation between the first filtered LiDAR data from March 2008 compared to March 2011. There is considerable accretion observed along the upper beach face to the west, seeing up to a 2 m increase in elevation, whilst the eastern half saw a dominant trend for erosion. The beach face, again, is beginning to form cusp like features to the east. Large areas of the intertidal zone have experienced low-level erosion, mostly to the outer edges of the unit, whilst a lot of the area has also remained stable.

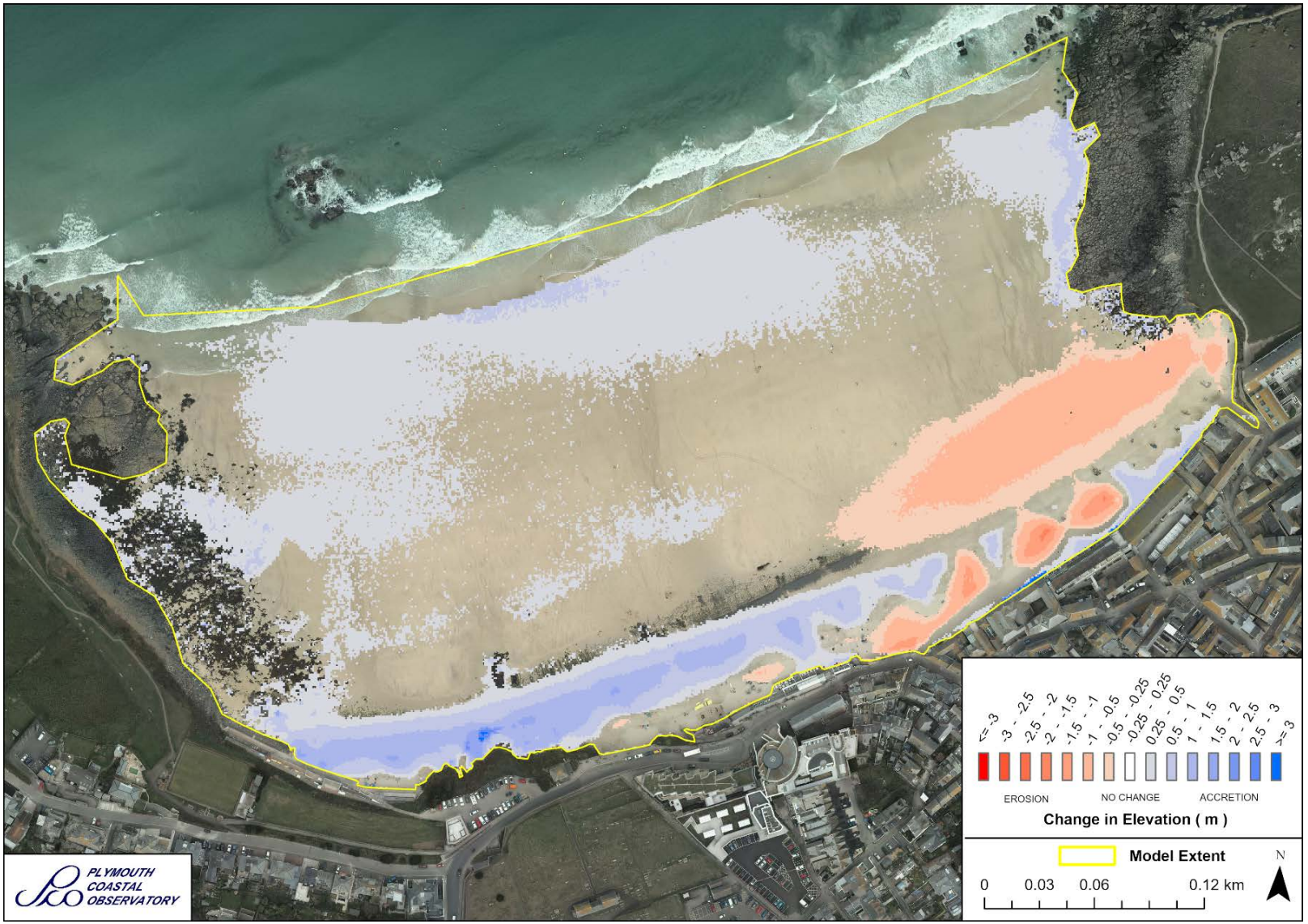


Figure 9 - Difference model indicating the changes in elevation observed between March 2008 and March 2011 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from March 2011 compared to April 2012. The very top of the beach along the residential housing, to the east, has observed a band of erosion including some small patches of acute sediment loss. The western half of the unit has seen a dominant trend for erosion (up to 1.5 m loss), along the beach face and most of the seaward extent. Whereas the eastern side has seen accretion, indicating the formation of beach-cusps along the beach face. Further accretion can be seen continuing in the east within the intertidal zone.

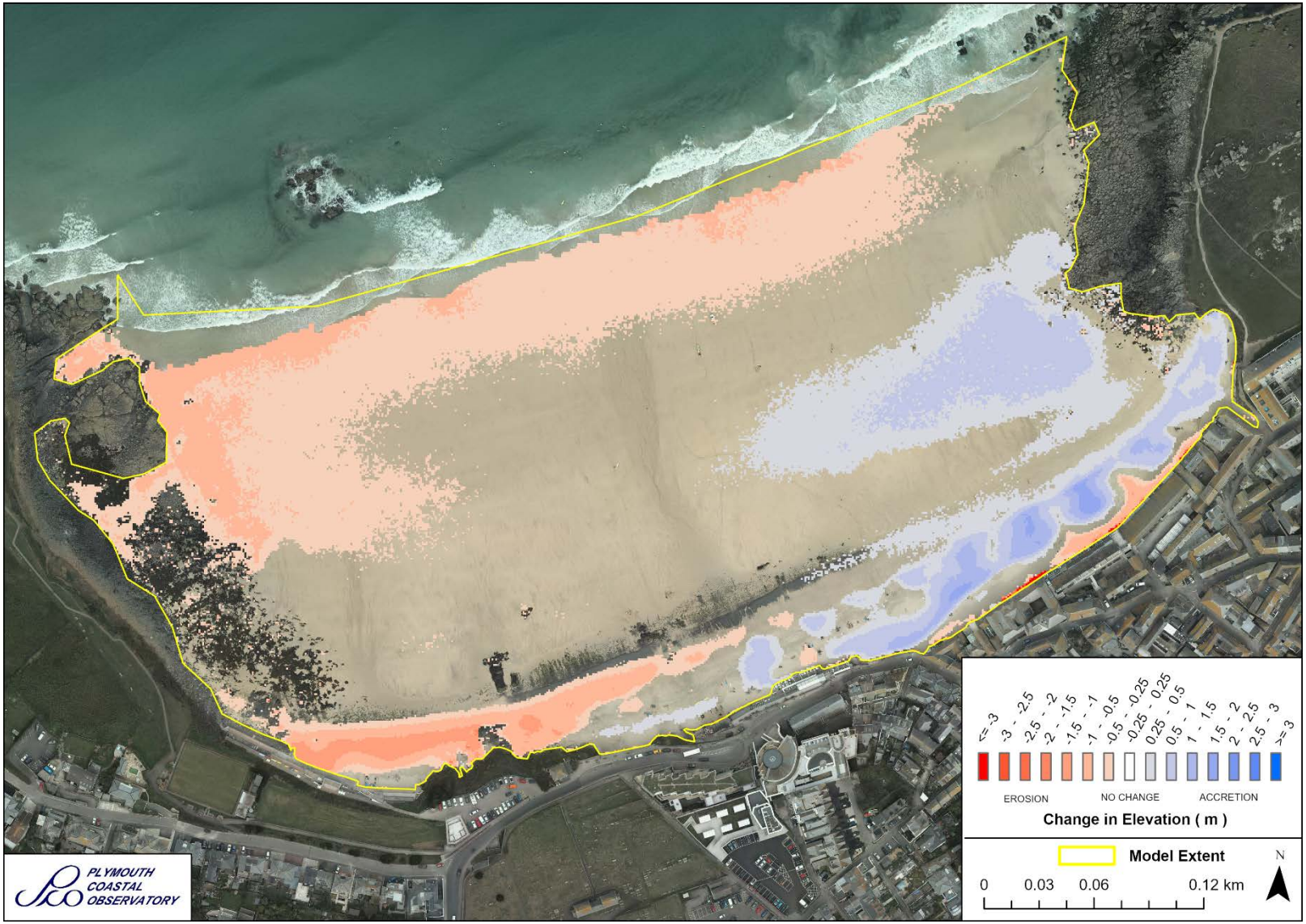


Figure 10 - Difference model indicating the changes in elevation observed between March 2011 and April 2012 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from April 2012 compared to April 2014. A band of widespread erosion can be seen across the entire beach face, losing up to 2.5 m in some places. Patches of low-level erosion can be seen across the intertidal zone, predominantly along the seaward and western extent.

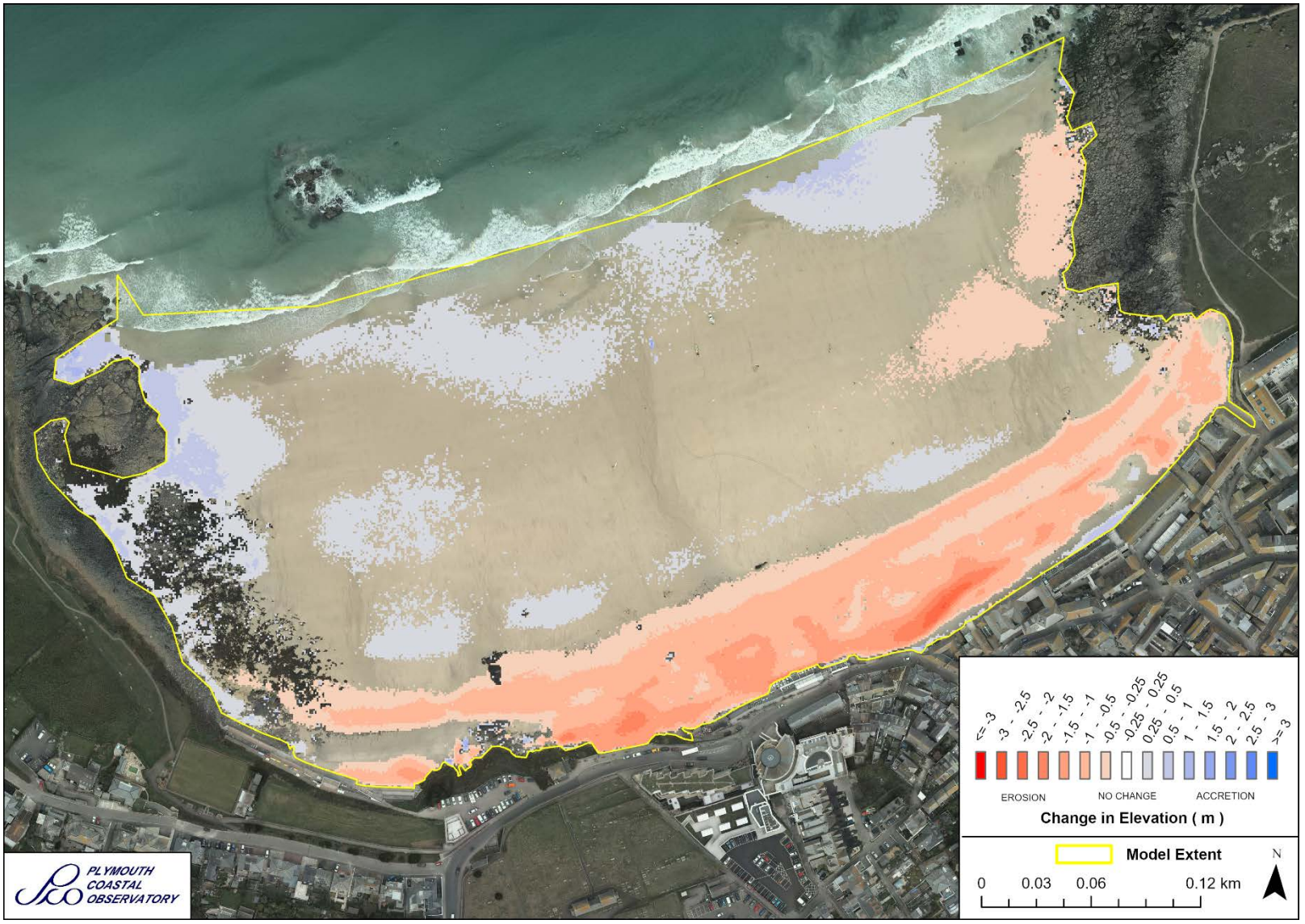


Figure 11 – Difference model indicating the changes in elevation observed between the April 2012 and April 2014 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from April 2014 compared to March 2016. The top of the beach has seen a trend for accretion, observing up to 2 m elevation gain towards the centre of the upper beach. This follows into a band of erosion, along the high-water mark, stretching across the width of the beach, losing up to 1.5 m in elevation.

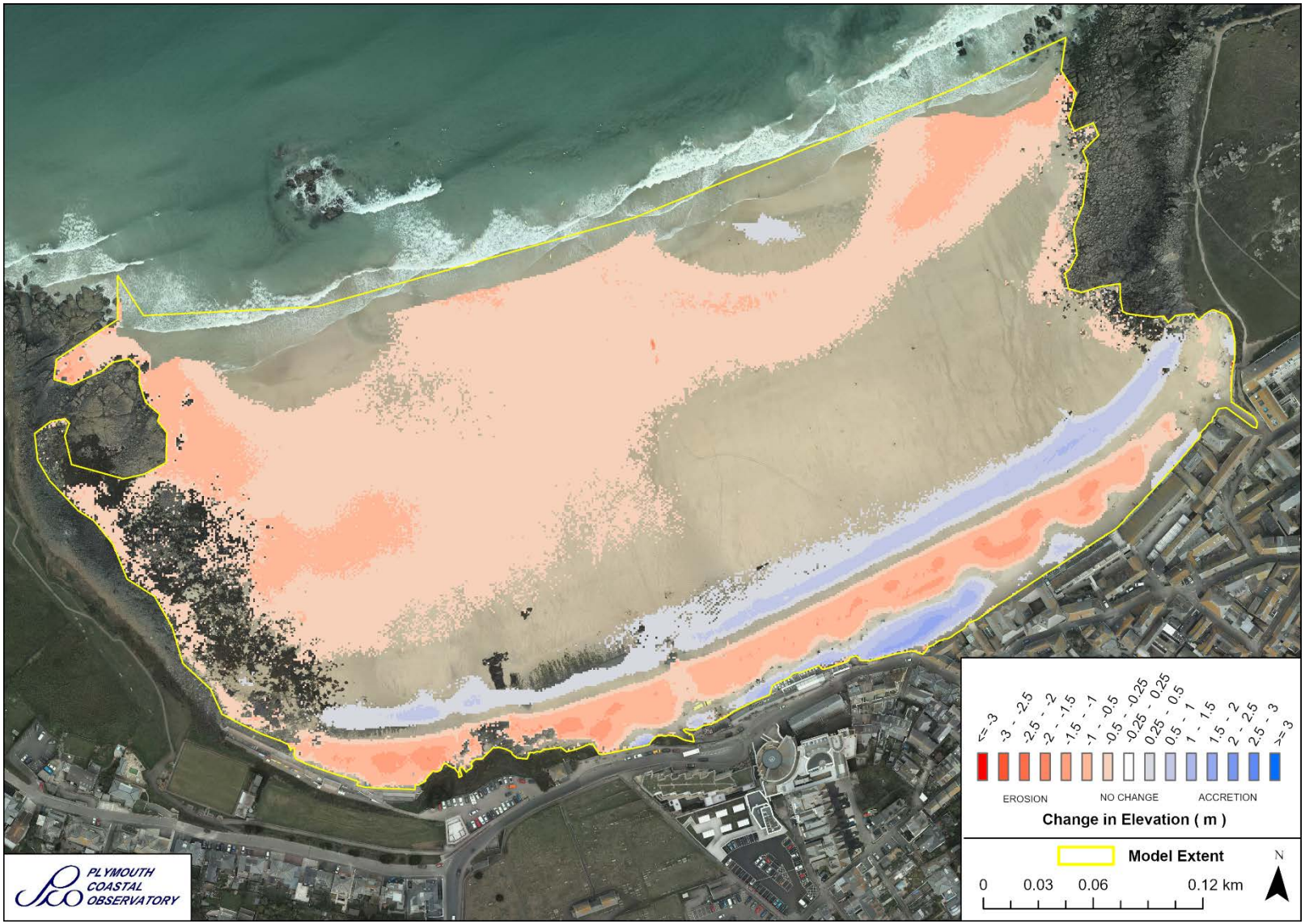


Figure 12 - Difference model indicating the changes in elevation observed between the April 2014 and March 2016 filtered LiDAR datasets within the yellow model extent.

Figure 13 shows differences in elevation between filtered LiDAR data from March 2016 compared to April 2017. Accretion can be observed in a band along the MHWS mark across the width of the beach, indicating beach cusps, followed by a band of erosion below the MHWS mark. A bar of low-level accretion is observed, stretching across the width of the beach.

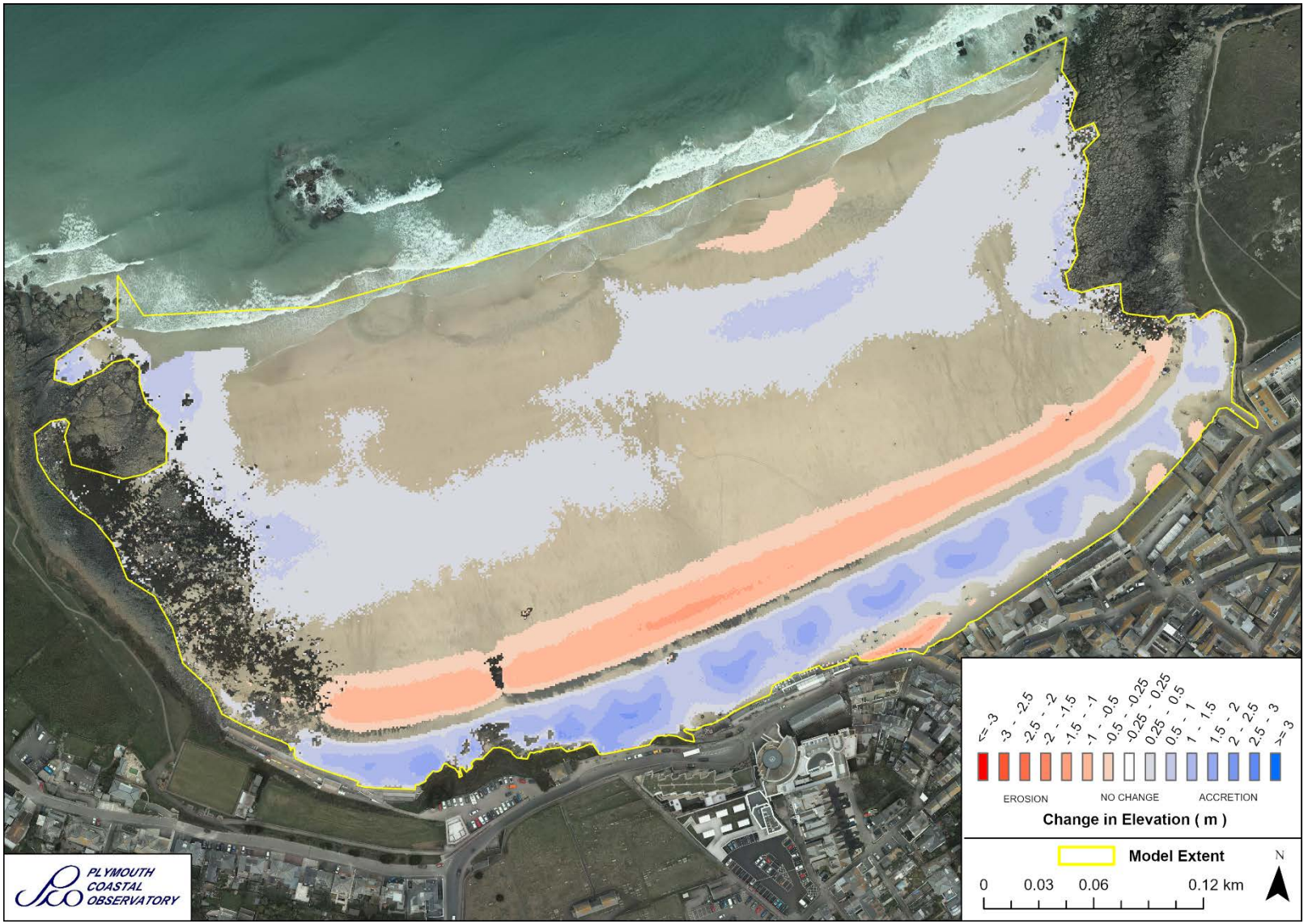


Figure 13 - Difference model indicating the changes in elevation observed between the March 2016 and April 2017 filtered LiDAR datasets within the yellow model extent.

Figure 14 shows differences in elevation between filtered LiDAR data from April 2017 compared to April 2019. Again, beach cusps are suggested along the beach face with dominant channel features. Towards the west, small patches of high erosion are present under the cliff, whereas the majority of the intertidal zone has remained stable. A band of accretion is observed spanning the width of the beach just below the high-water mark.

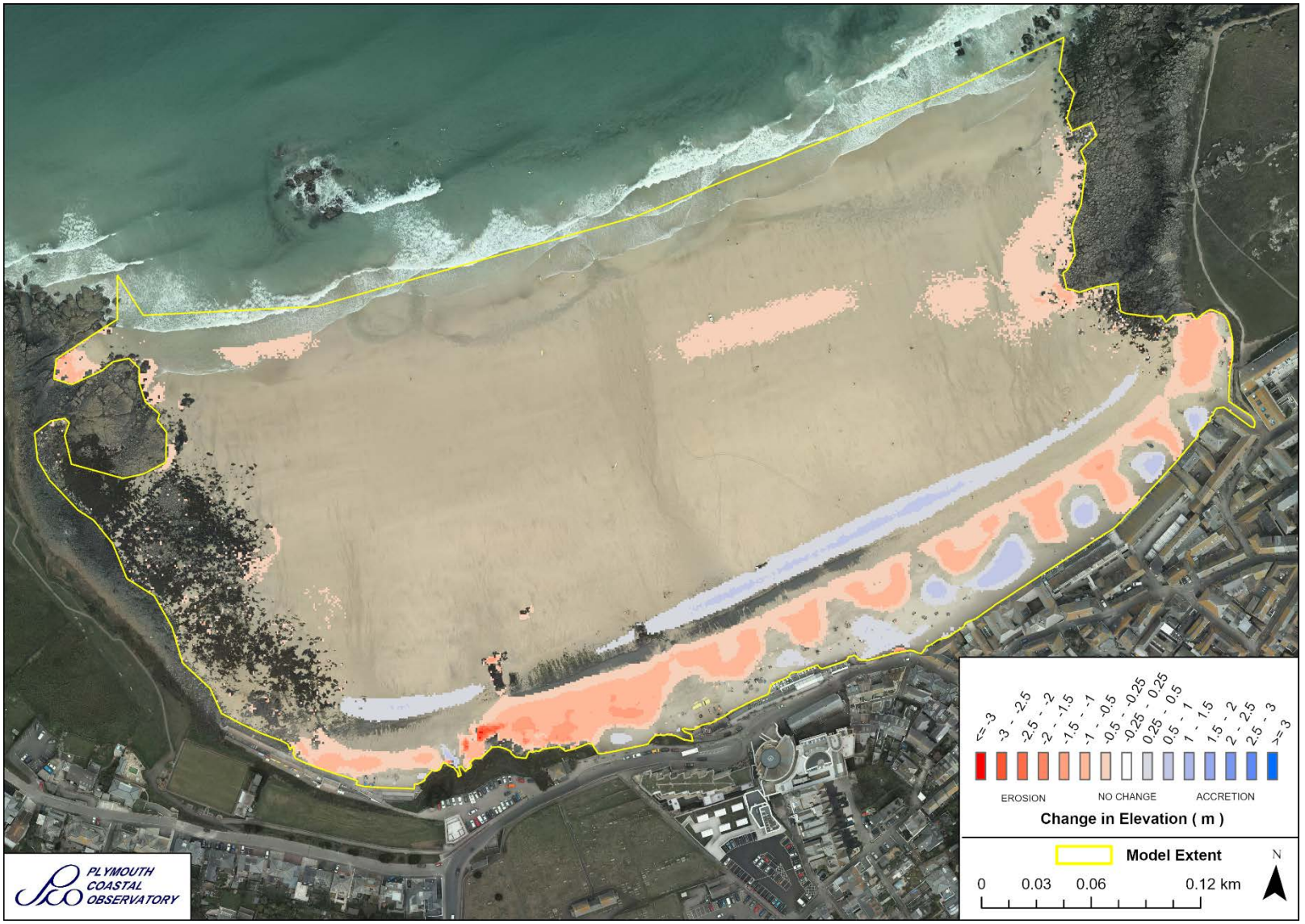


Figure 14 - Difference model indicating the changes in elevation observed between the April 2017 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 15 shows differences in elevation between filtered LiDAR data from April 2019 compared to September 2020. The western half of the beach face has seen a loss of up to 1.5 m in elevation, continuing along the width of the beach just below the high-water mark. Some erosion can be seen to the east, located on the very top of the beach, experiencing ~1 m drop in beach levels. This is followed by an area of accretion, gaining up to 1.5 m in elevation on the beach face.

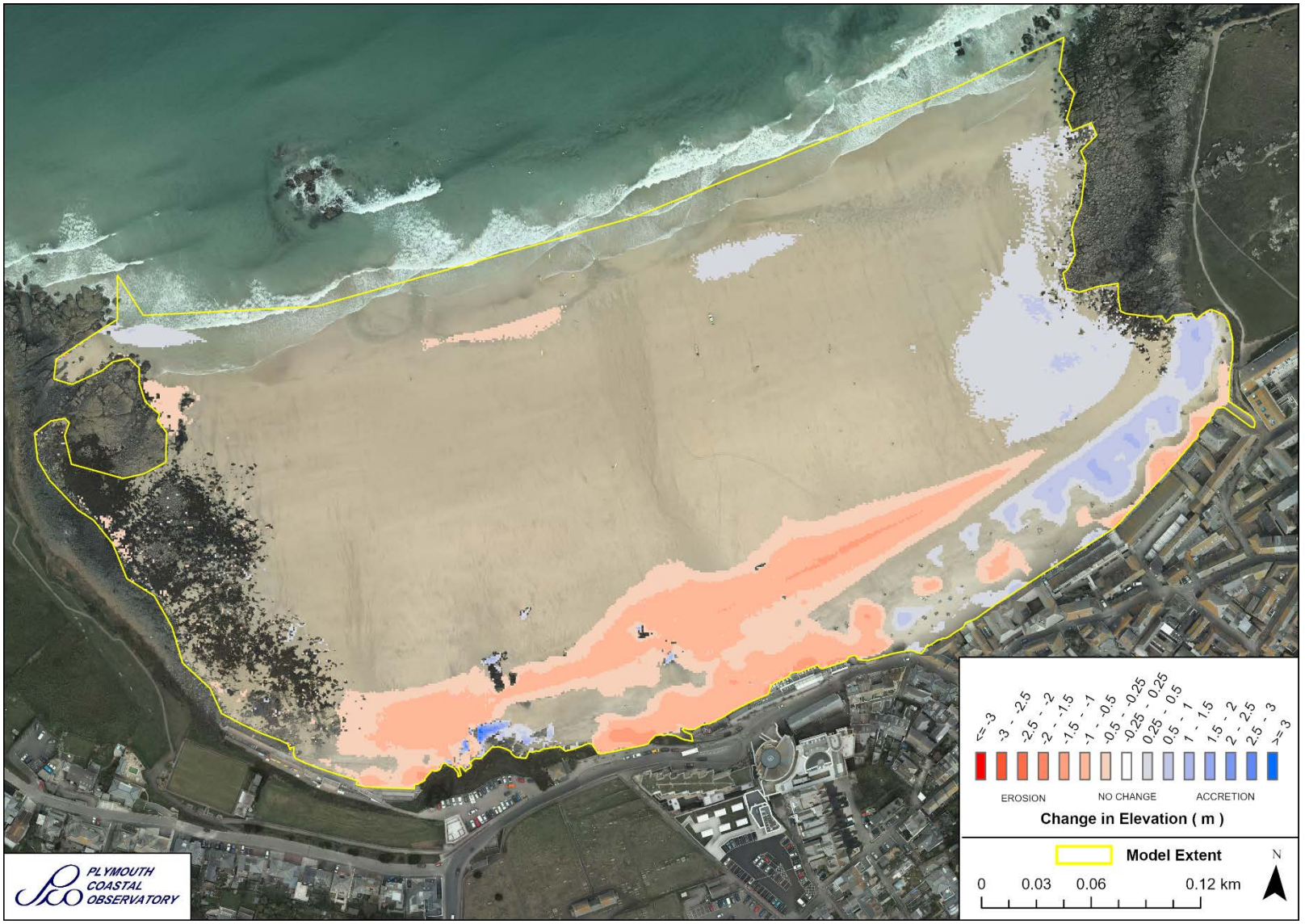


Figure 15 - Difference model indicating the changes in elevation observed between the April 2019 and September 2020 filtered LiDAR datasets within the yellow model extent.

Figure 16 shows differences in elevation between filtered LiDAR data from September 2020 compared to January 2023. Considerable change can be observed across the entire upper beach area, with low-level accretion (1 m) dominating the beach face to the west, whilst erosion (1.5 m) dominates to the east. Beach cusps are indicating to form along the beach face, whilst a band of accretion is observed below the high-water mark. Areas of erosion are present towards the east, within the intertidal zone, whereas a strip of accretion can be seen along the western seaward extent.

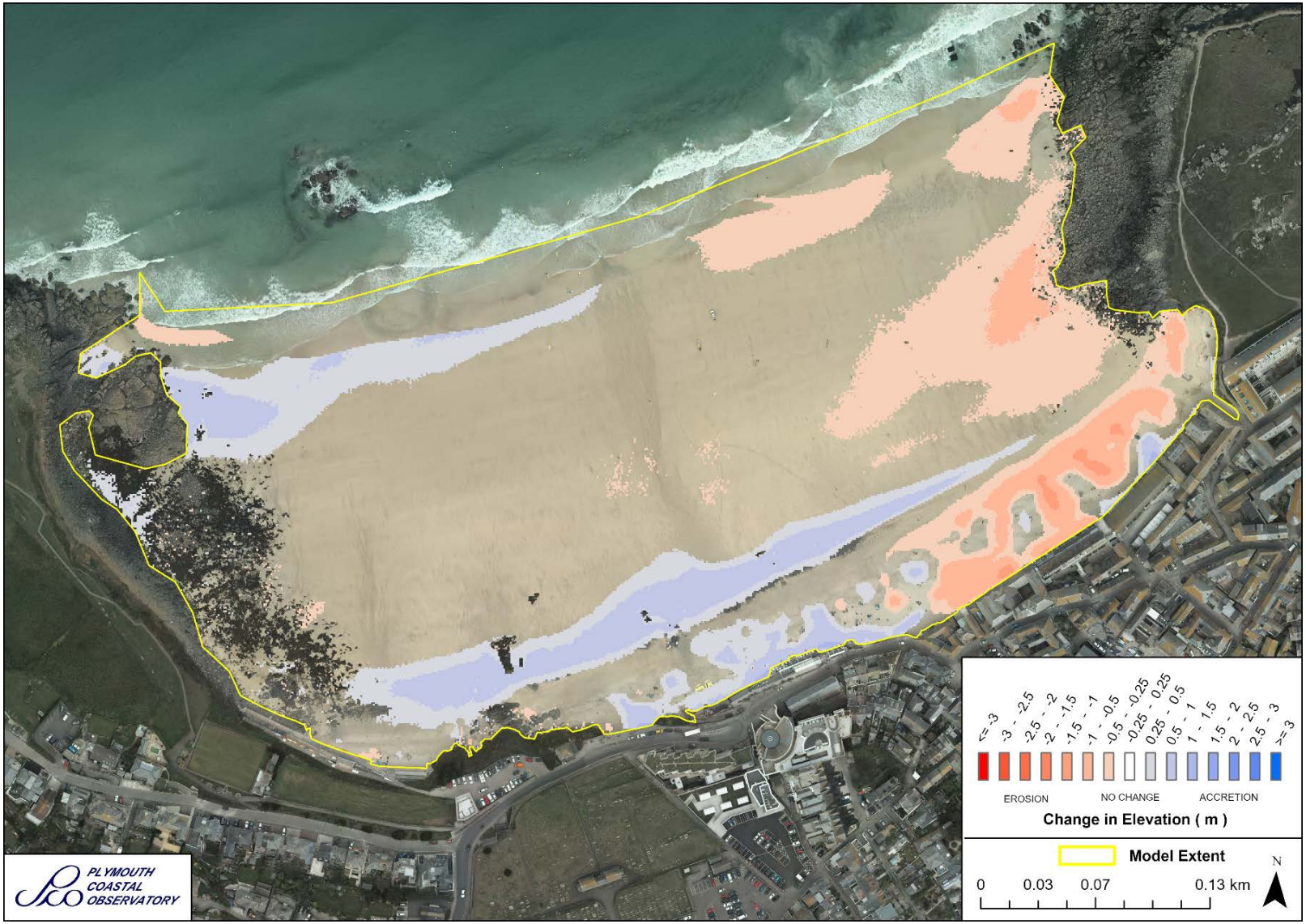


Figure 16 - Difference model indicating the changes in elevation observed between September 2020 and January 2023 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.20 m OD) are shown in Table 1 and Figure 17. The data shows the Mobile Zone to have a negative trend and was largely impacted after the 2013/14 storm season, losing ~31% in volume between the 2012 and 2014 surveys (Fig. 17). The mobile Zone continues to lose volume until the 2016 survey but does indicate signs of recovery in 2017, gaining 56% in volume from the previous survey. The remaining 3 surveys between 2019 and 2023 have seen the Mobile Zone remain relatively stable.

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.60 m OD) are shown in Table 1 and Figure 18. Similarly, to the Mobile Zone, the Beach Zone has also shown a decline in volume from a high stand in 2011 to the second lowest recorded volume on record in 2023, seeing a 7% loss in volume (Fig.18). The fluctuations in volume are relatively minor, and the Beach Zone has remained stable between 2008 and 2023.

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.20 m OD) and for the Beach Zone above MLWS (-2.60 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
03/2008	29,121	331,700
03/2011	34,330	368,410
04/2012	36,335	361,561
04/2014	24,924	364,986
02/2016	20,375	342,249
04/2017	31,766	359,305
04/2019	27,956	347,132
09/2020	26,341	346,155
01/2023	25,252	341,132

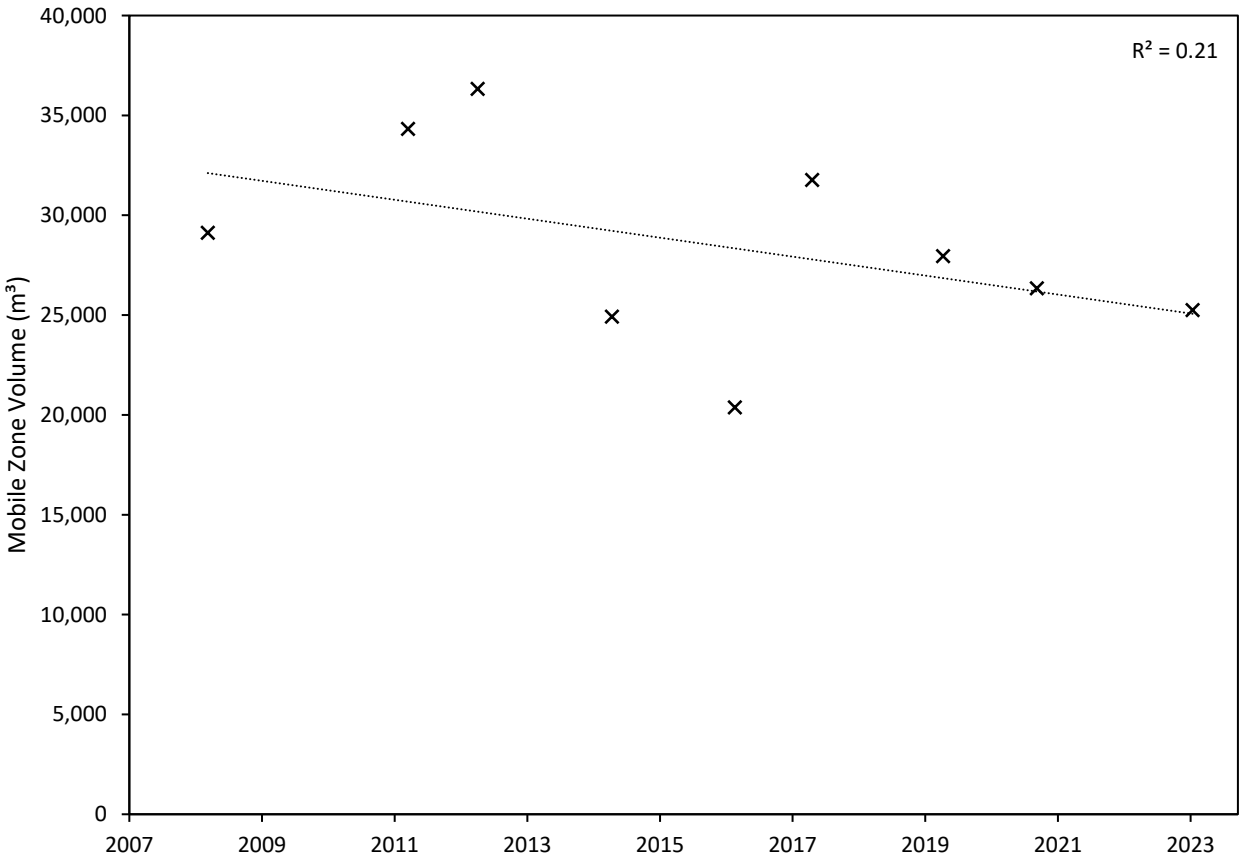


Figure 17 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.20 m OD) for each filtered LiDAR datasets between 2008 and 2023.

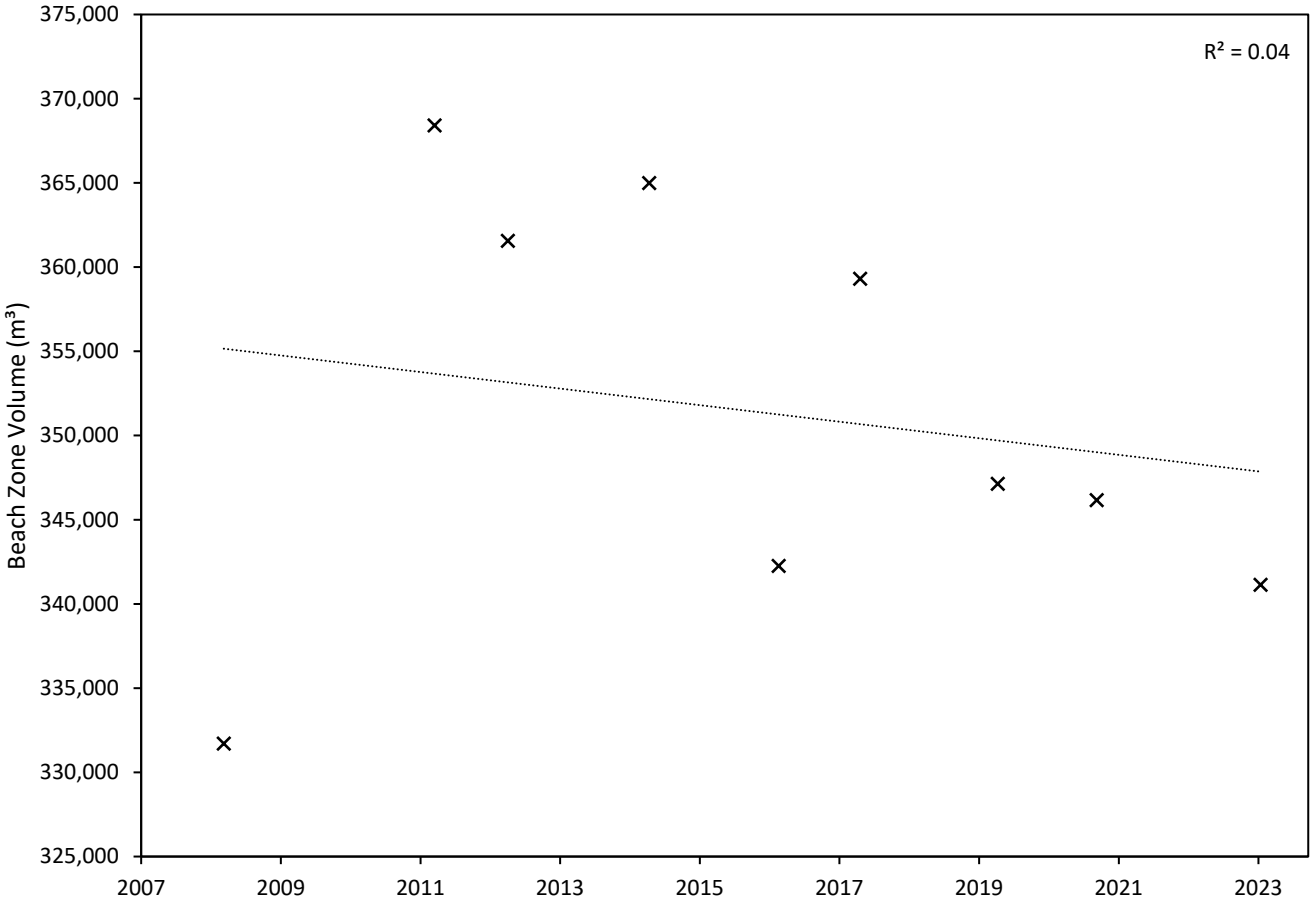


Figure 18 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.60 m OD) for each filtered LiDAR datasets between 2008 and 2023.

3.2.3 Contour Comparison

Figure 19 indicates the Mean Sea Level (MSL) and Dune Toe contours from the 2008, 2014, 2019 and 2023 LiDAR datasets. From 2008 to 2023 the MSL contours indicate a widening of the beach towards the western half, but a narrowing of the beach towards the east by up to 12 m, suggesting the beach is rotating clockwise. Interestingly, the beach widened, especially the western half, after the 2014 winter storms. Dunes are not present on this beach; therefore, the Dune Toe contours do not show any significant change on the upper beach.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency (Figs.20 and 21) and from 2006 onwards by the SWCM (Figs. 22 – 25) are presented here.

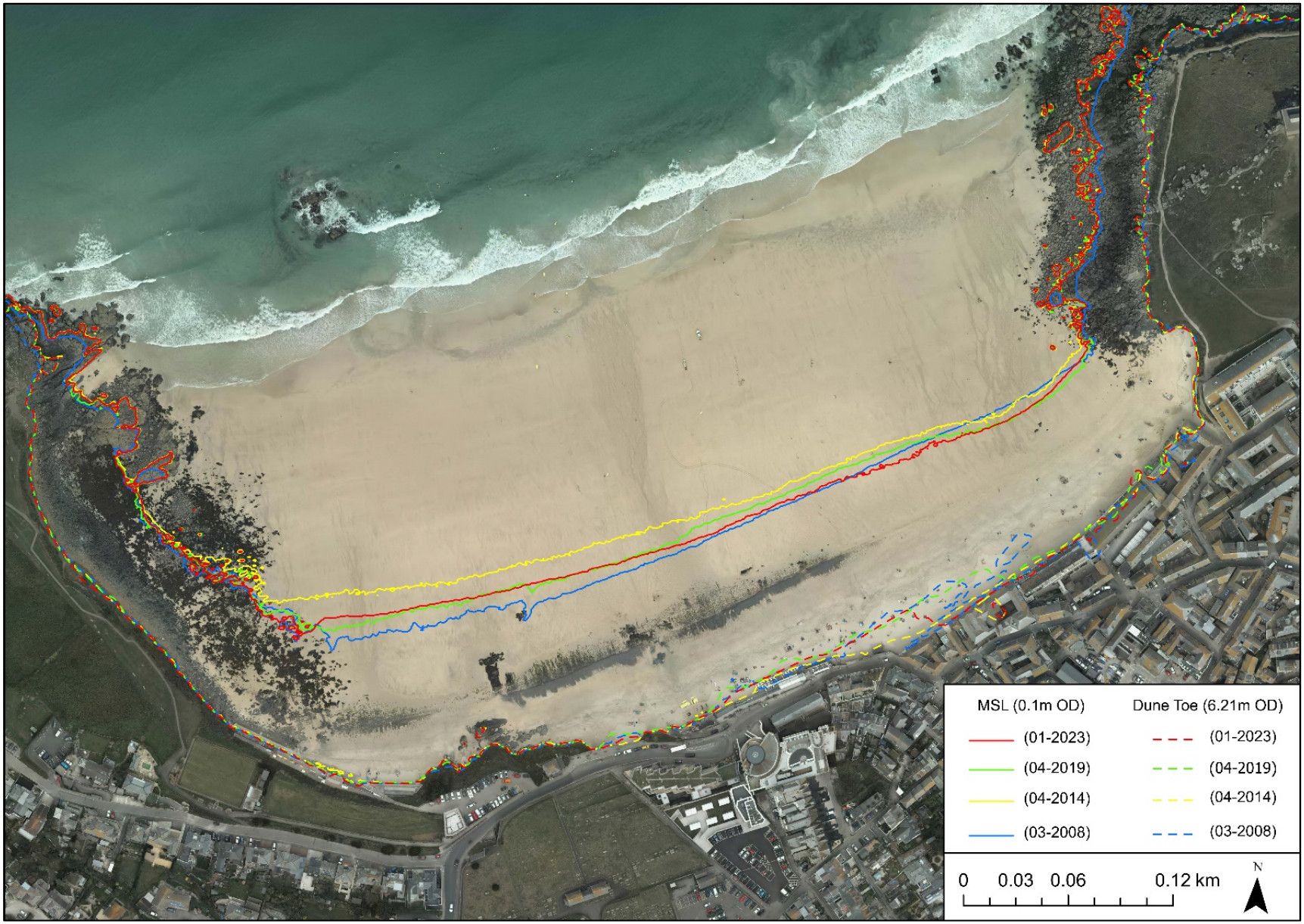


Figure 19 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2023 LiDAR datasets.



Figure 20 – Aerial imagery from 1947.



Figure 21 – Aerial imagery from 2001.



Figure 22 – Aerial imagery from 2008.



Figure 23 – Aerial imagery from 2010.

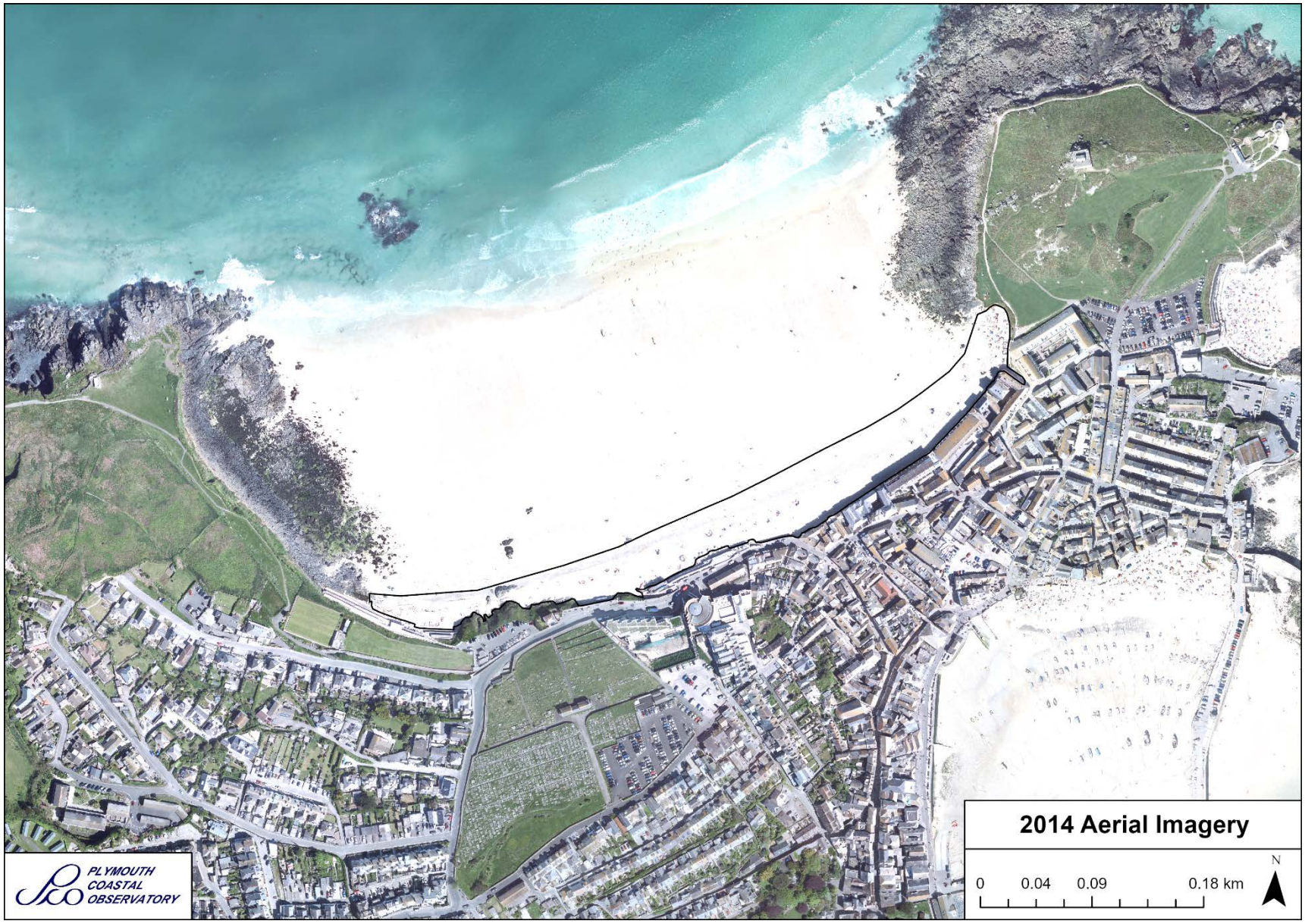


Figure 24 – Aerial imagery from 2014.



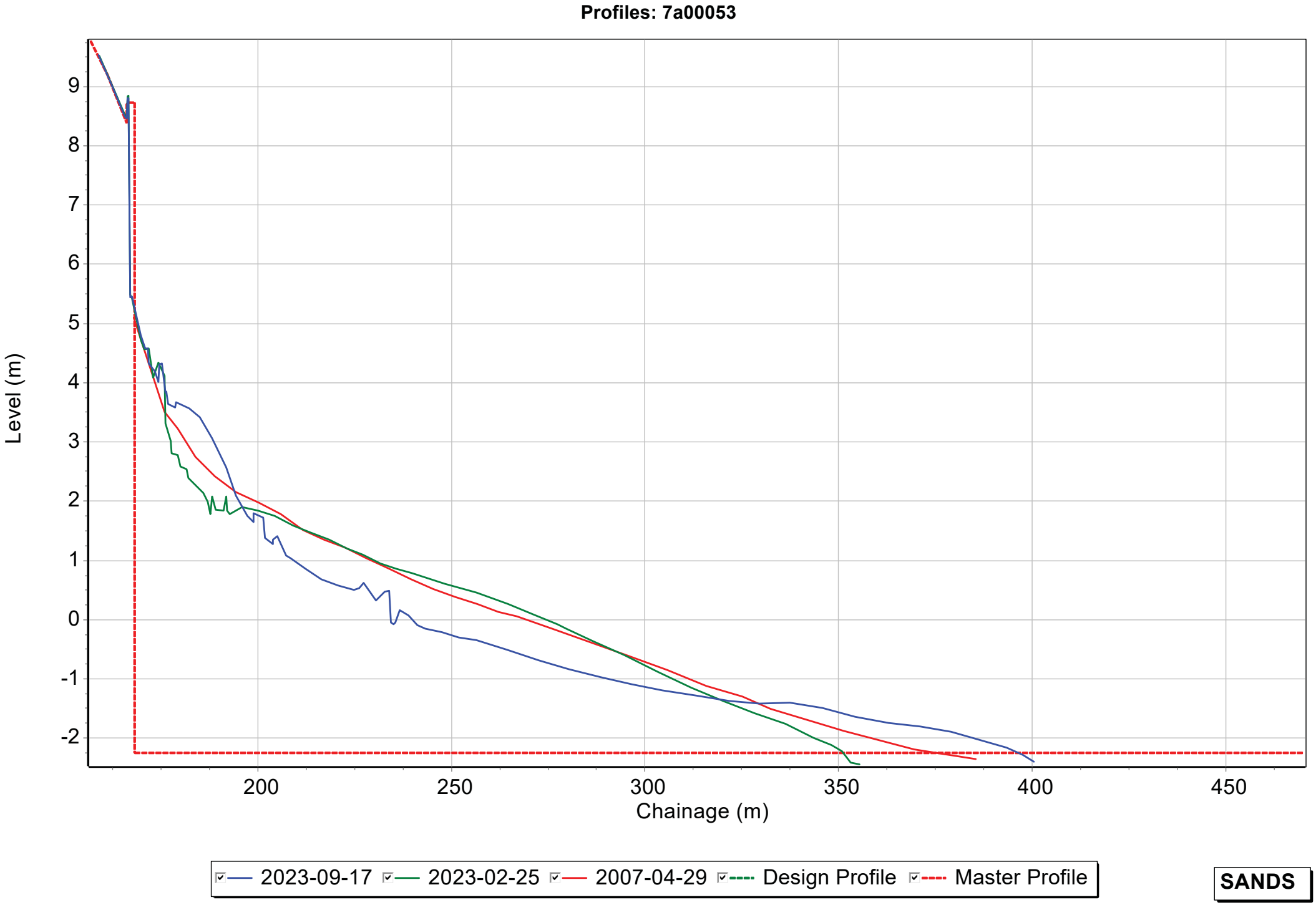
Figure 25 – Aerial imagery from 2018.

Glossary

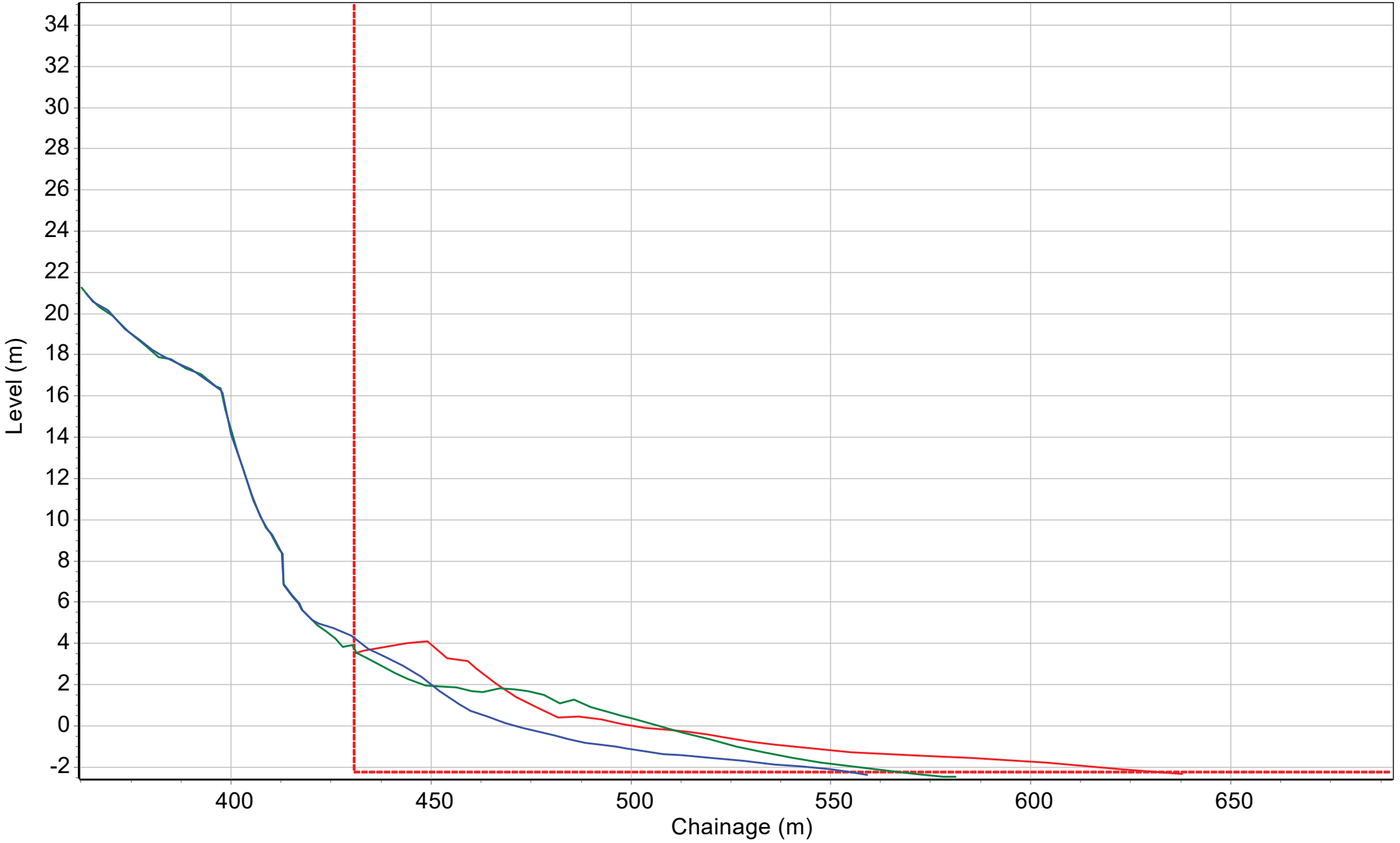
1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
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

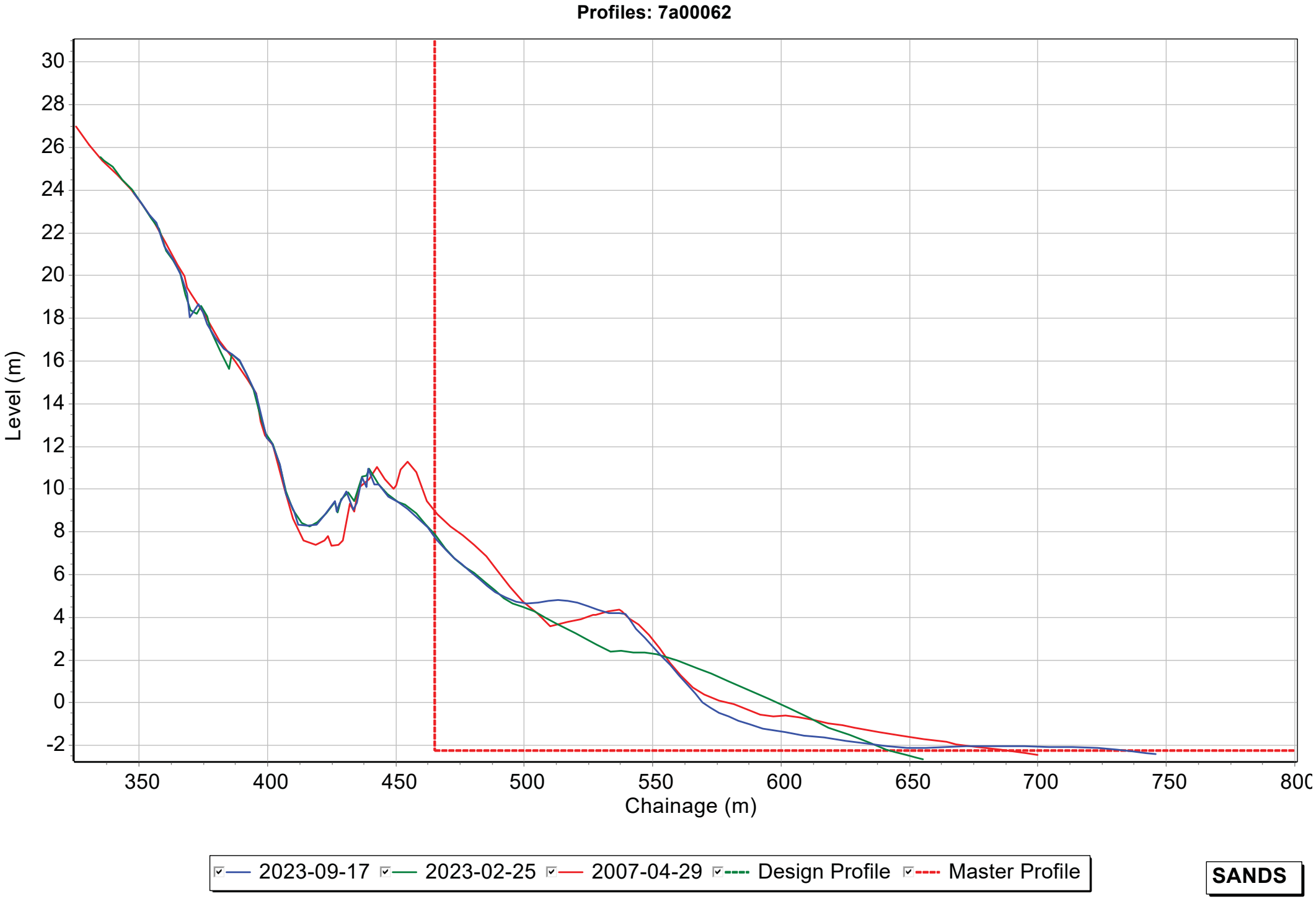
Appendix 1 – Profile charts showing the cross-shore area of each interim profile from the most recent survey (blue), second most recent survey (green) and first survey, also known as the baseline (red) at Porthmeor are presented below.

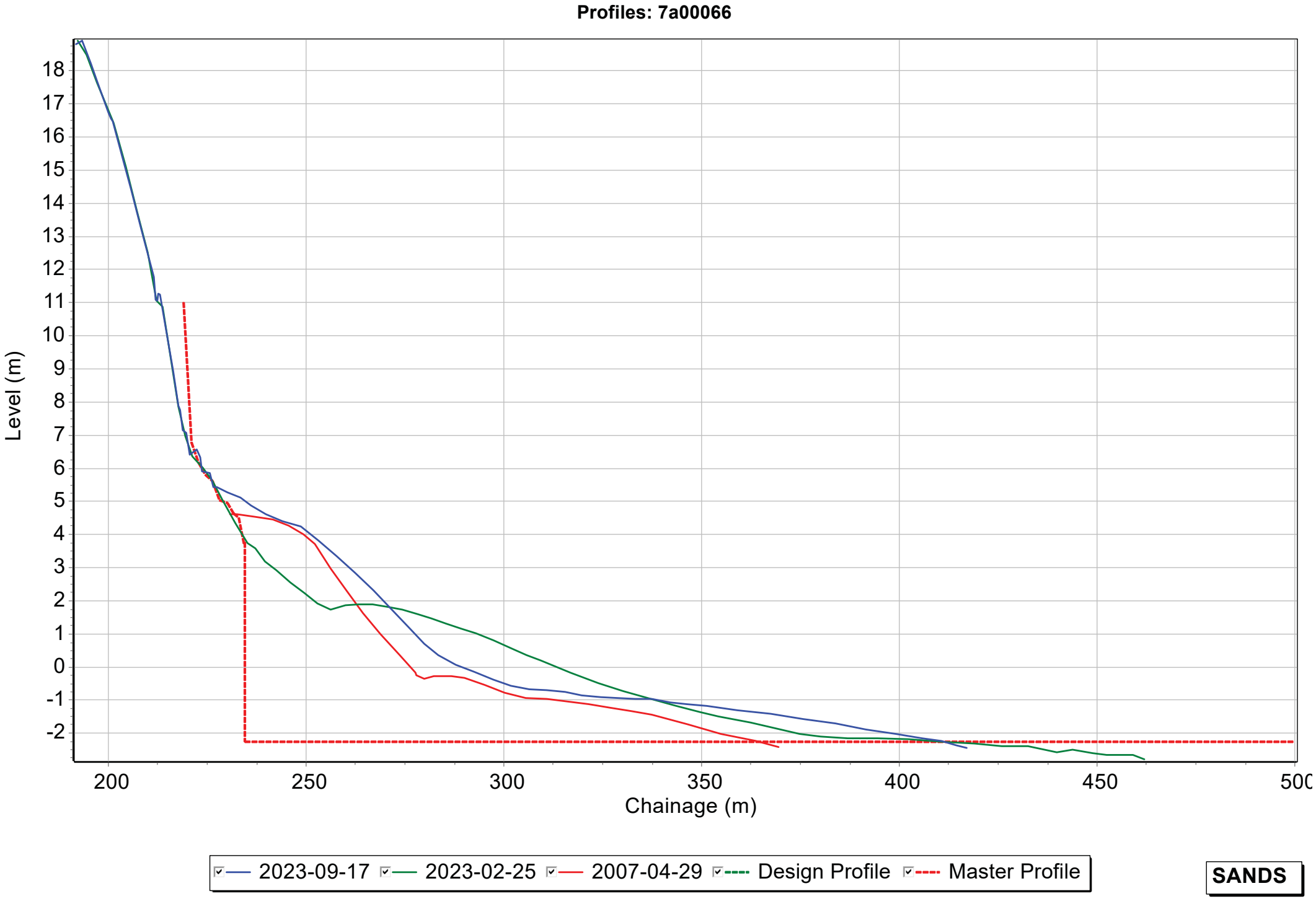

Profiles: 7a00053
Level (m)
9
8
7
6
5
4
3
2
1
0
-1
-2
200
250
300
350
400
450
Chainage (m)
2023-09-17
2023-02-25
2007-04-29
Design Profile
Master Profile
SANDS

Profiles: 7a00058



SANDS


Profiles: 7a00062
Level (m)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
350
400
450
500
550
600
650
700
750
800
Chainage (m)
2023-09-17
2023-02-25
2007-04-29
Design Profile
Master Profile
SANDS


Profiles: 7a00066
Level (m)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
200
250
300
350
400
450
500
Chainage (m)
2023-09-17
2023-02-25
2007-04-29
Design Profile
Master Profile
SANDS