SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Porthcothan Beach Report

Topographic and LiDAR Data Analysis

SWCM	TBR28	02/04/2024

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	**I Kelly**
Checked By	**J Kirby**

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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 Porthcothan. The aim is to highlight coastal change at Porthcothan using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Porthcothan Beach, is a north-west facing cove beach. It is a particularly narrow beach, only 150 m wide and almost 500 m in cross-shore length. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate changes to 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, 35 topographic surveys have been collected at Porthcothan, 4 of which are baseline surveys, 30 are interim surveys and 1 are a post-storm survey. The analysis of topographic data indicates Porthcothan to be eroding. A significant impact was observed after the 2014 storms, with the beach yet to recover to pre-2013 storm beach levels. The lowest combined profile area was recorded during the 2020 spring interim, following a highly energetic winter, but the beach had recovered by the following year. The highest recorded combined area was during the autumn interim of 2012.

Beach volume extracted from 5 LiDAR flights between 2008 and 2022 suggests both the Mobile and Beach Zone have remained stable despite relatively large fluctuations in volume between surveys. The Mobile Zone saw a 31% loss in volume between the 2010 and 2014 survey following the impact of the highly energetic 2013/14 winter.

Overall Porthcothan beach was heavily impacted by the 2013/2014 storms and has yet to recover to pre-2013 beach levels.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Porthcothan 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

Porthcothan is a north-west facing cove beach (Fig.1). It is a particularly narrow beach, only 150 m wide and almost 500 m in cross-shore length, opening out to various small coves at the seaward end. Due to its narrow shape, the beach is often protected from large swell. It has a semi-diurnal tide type and an average spring tidal range of 6.4 m. The beach is backed by a relatively small dune system, with a river flowing down to the north of the dunes. A small settlement is located behind the dune system, as well as properties situated along the cliff to the south.

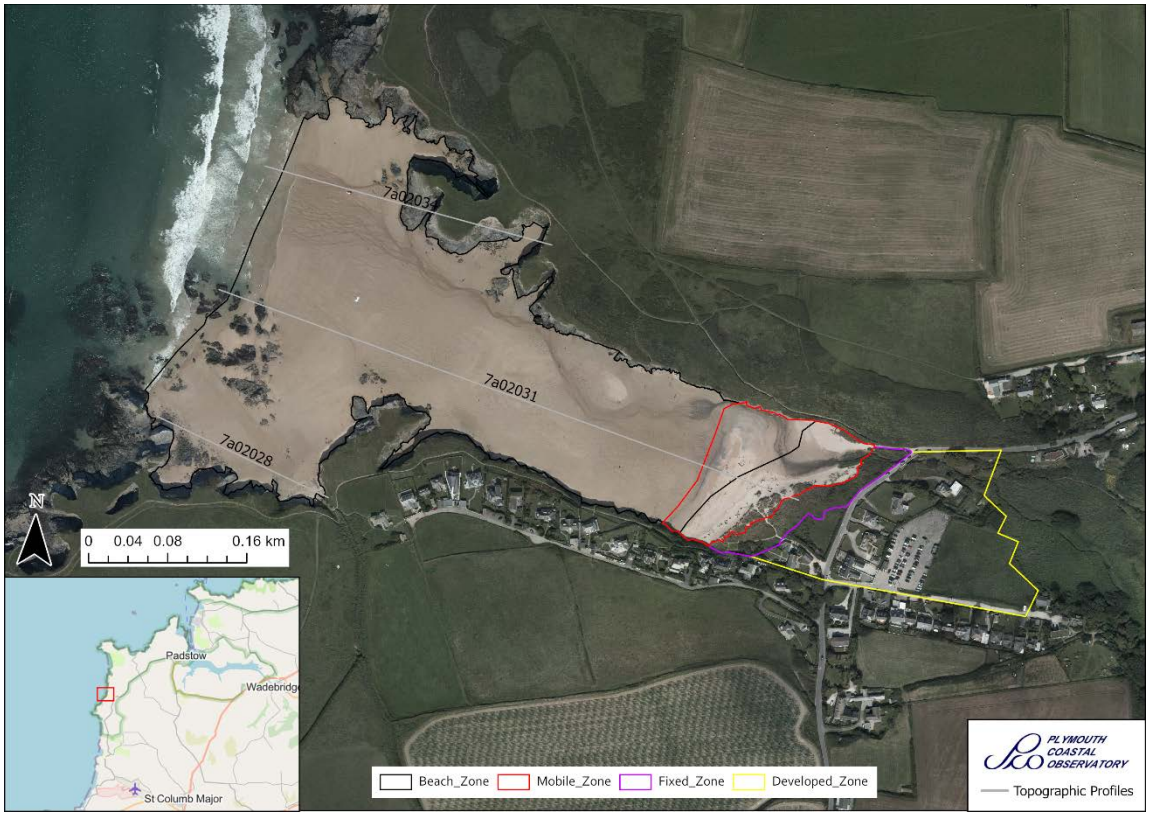


Figure 1 - Location Map of Porthcothan Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

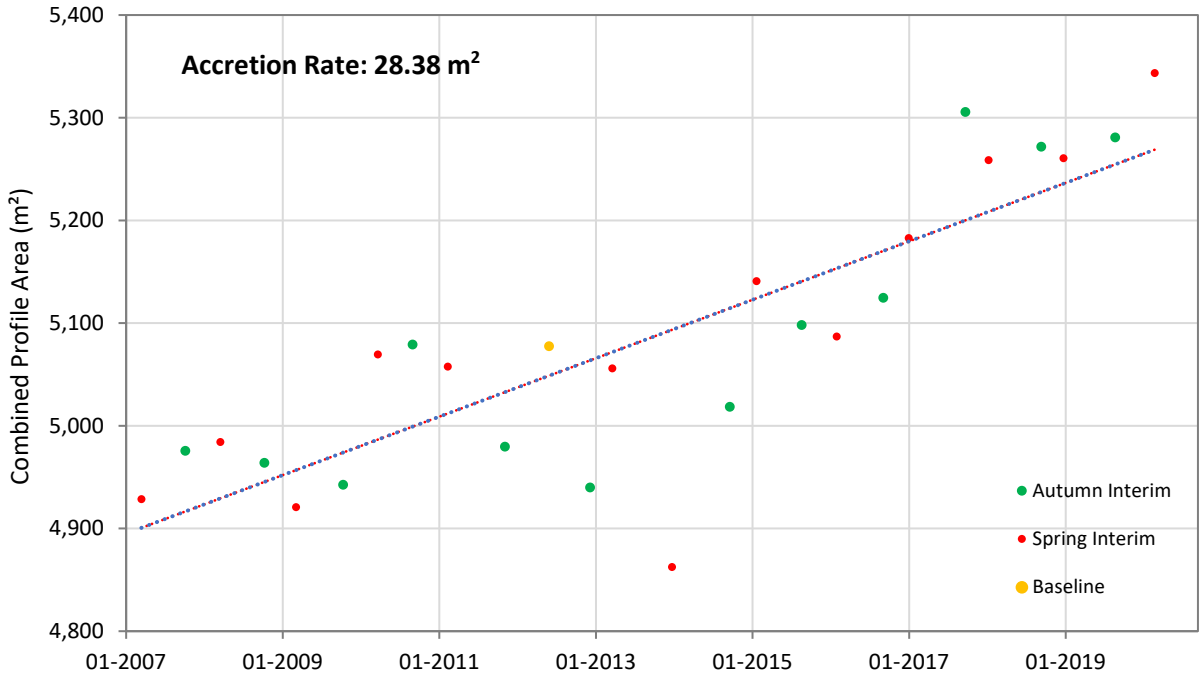


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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.

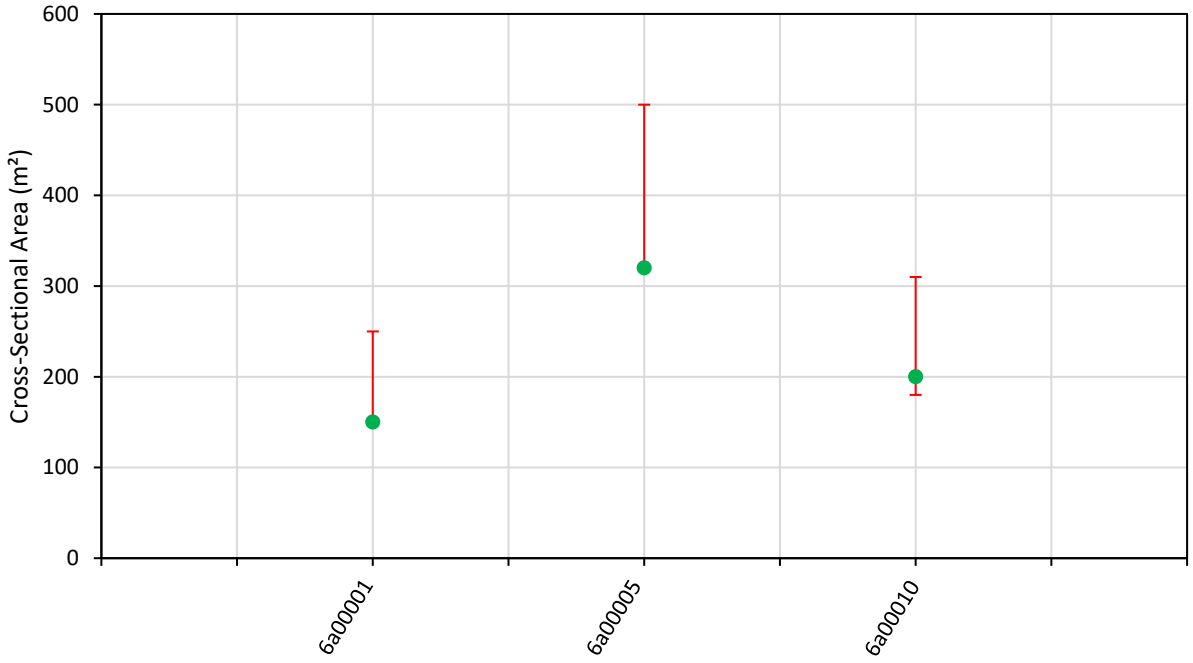


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

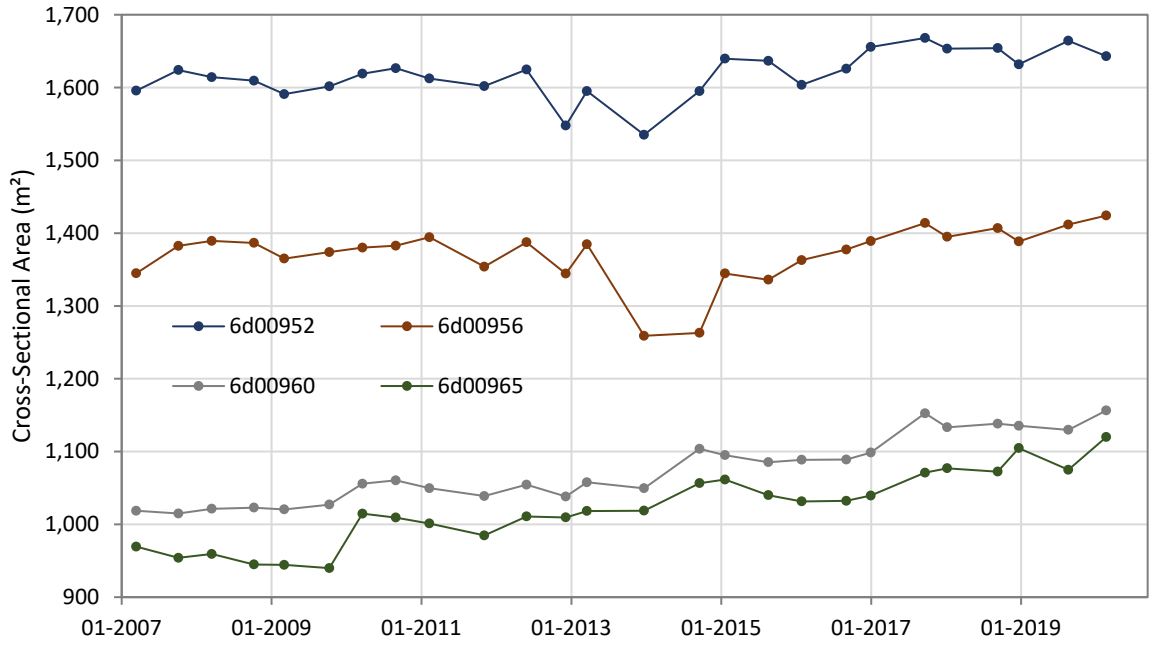


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 35 topographic surveys at Porthcothan since 2007, 4 of which are baseline surveys, 30 are interim surveys and 1 are post-storm surveys. Exact dates of each survey for Porthcothan are available to view on our survey record. Analysis of the CPA indicates the survey unit has been eroding at 12.7 m^2 y^{-1} equating to 0.43% of the average beach area per year (Fig.5). A distinct impact was measured after the 2014 storms losing ~250 m^2. The lowest recorded combined profile area was during the 2020 spring interim, following the highly energetic winter period, however the beach had recovered by the following year. The highest recorded combined area was during the autumn interim of 2012 (3,162 m^2).

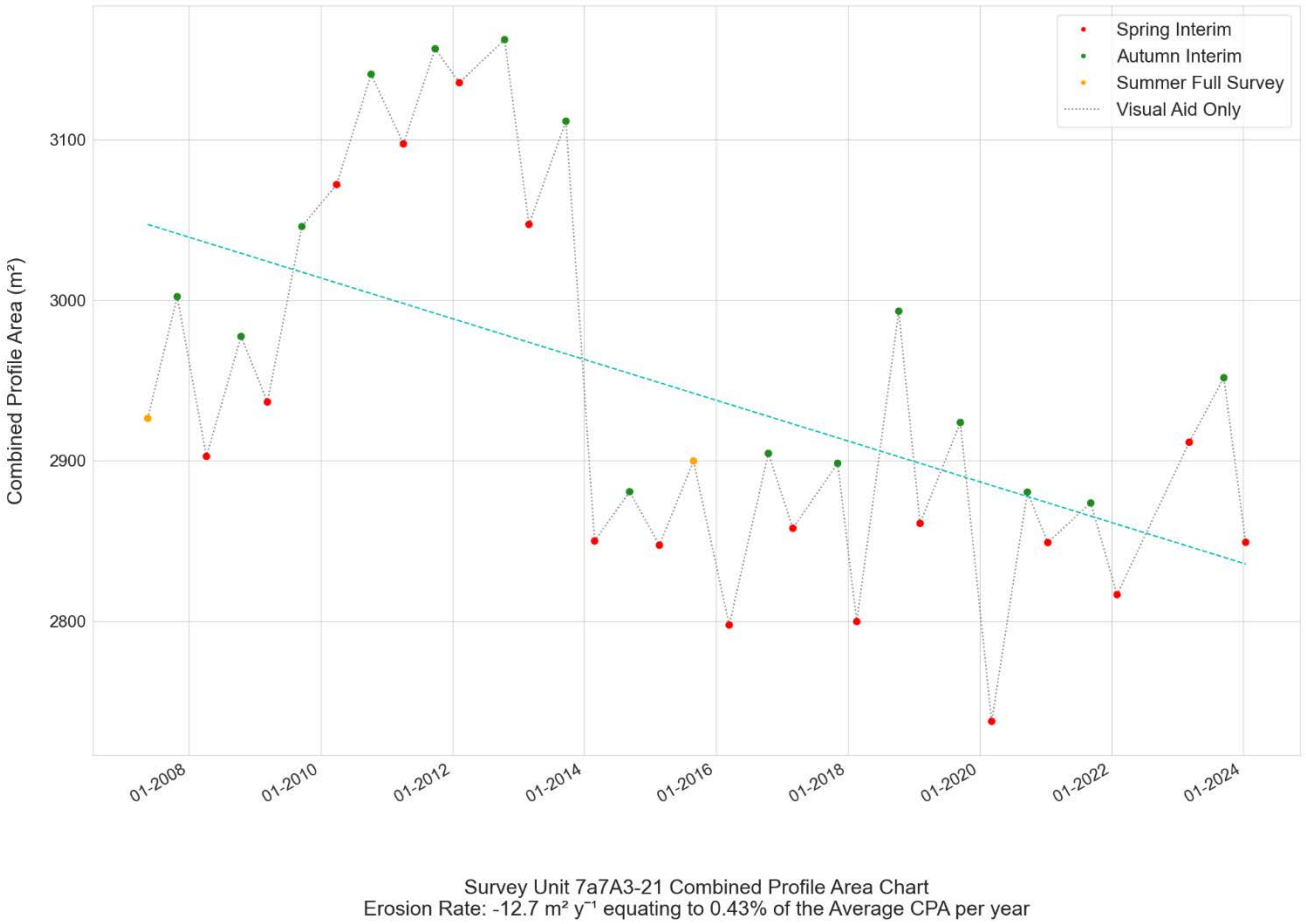


Figure 5 - The Combined Profile Area (CPA) for Porthcothan, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When analysing the entire dataset (Fig.6), the 2024 spring interim survey shows two of the profiles, 7a02028 and 7a02034, displaying just above average cross-sectional area, whereas 7a02031 shows a below average area.

When comparing profile cross-sectional areas to the entire time series (Fig.7), profiles 7a02028 and 7a02034 have remained relatively stable, showing some seasonal variance, whereas profile 7a02031 shows more variability, peaking in around 2012, being impacted from the 2014 storms, and now displaying a new lower 'norm' since 2014.

Profile Charts for Porthcothan 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. Profile 7a02031 shows a retreating dune system of ~16 m, since the 2007 baseline. Profile 7a02028 has seen some build-up at the top of the beach whilst profile 7a02034 has seen beach elevation of up to 0.5 m across the whole profile, since the 2007 baseline.



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.

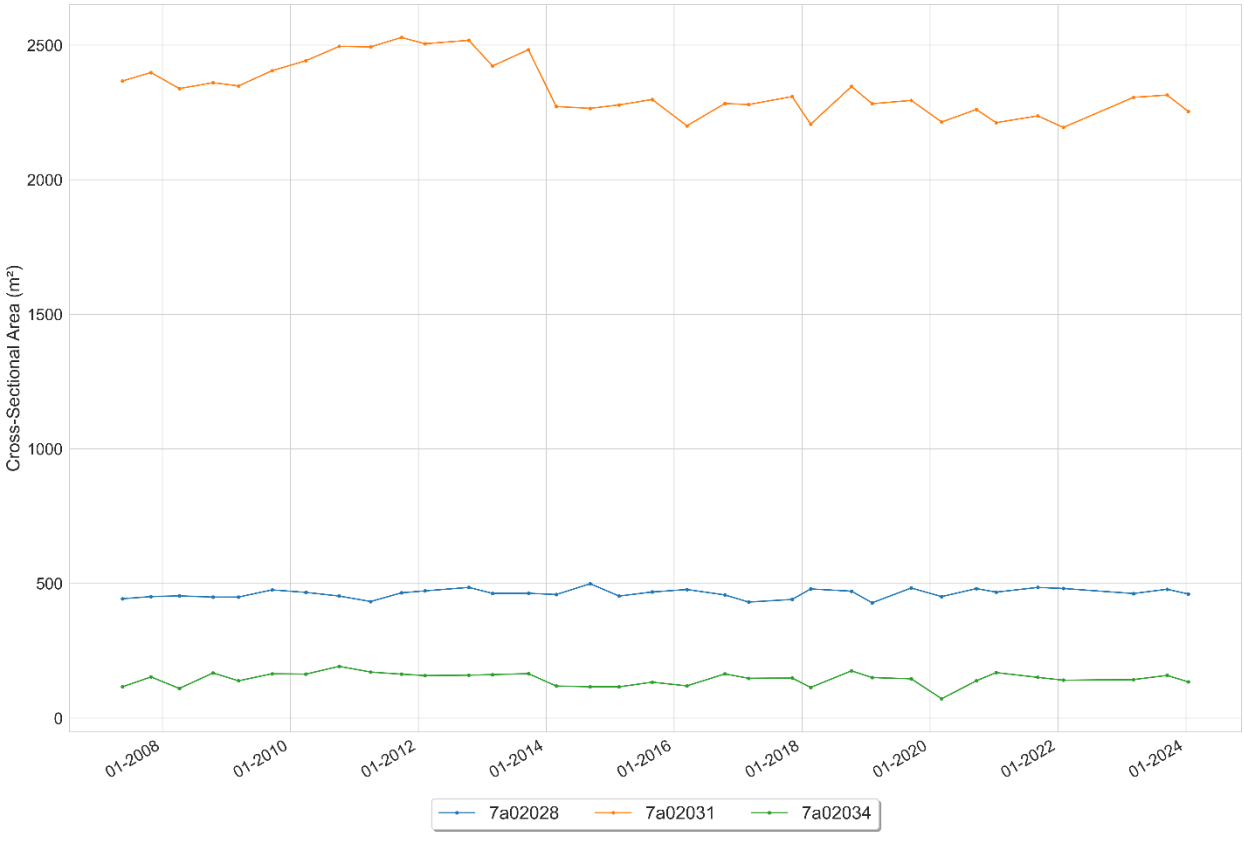


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

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

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 October 2022. There has been a mixture of erosion and accretion across the unit. A build-up of material can be seen on the lower half of the unit, mostly on the northern side, whilst the upper half of the unit has seen up to 2.5 m loss of beach elevation. The beach face has experienced high levels of erosion, whilst the dune crest has seen up to 1.5 m of accretion.

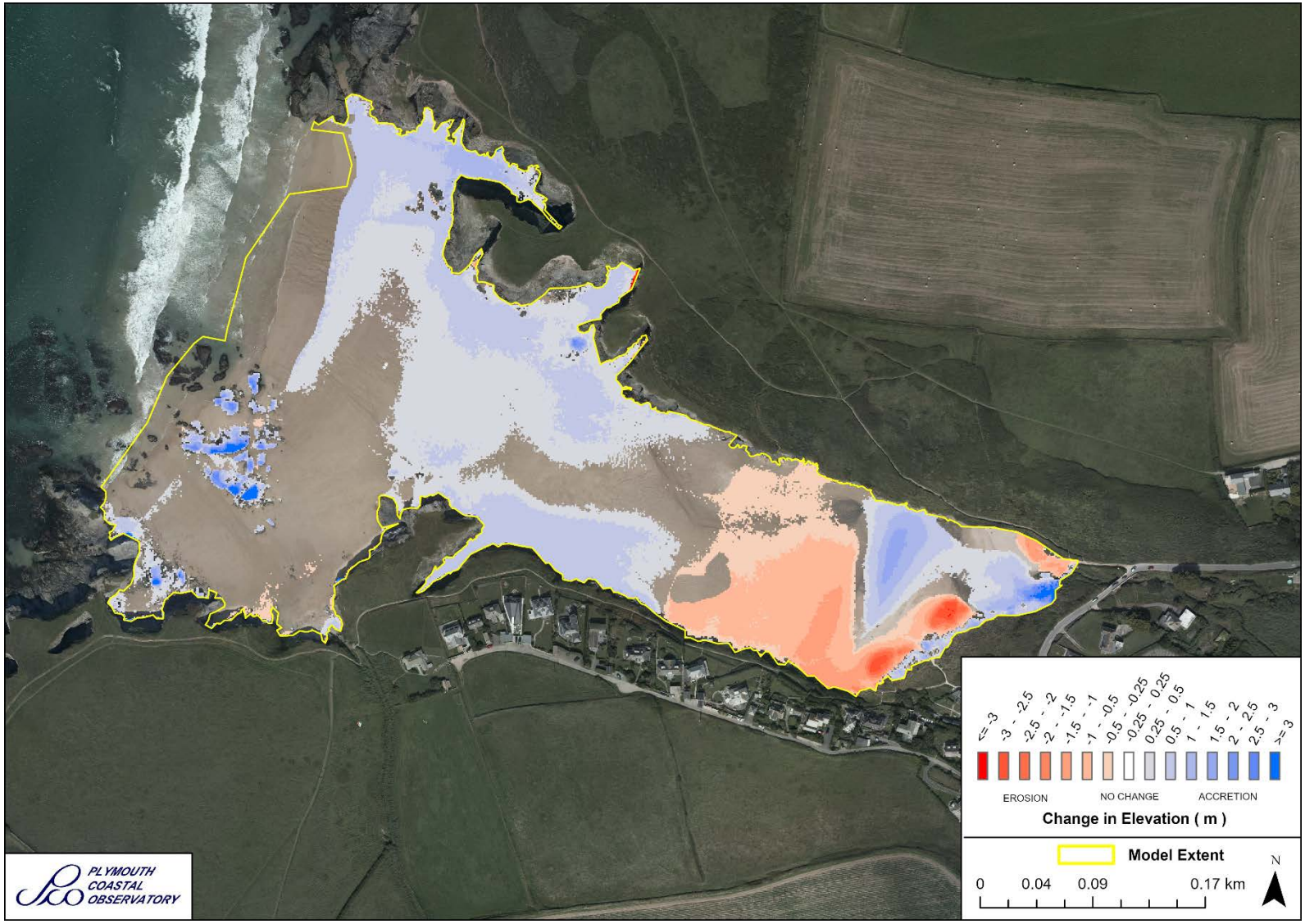


Figure 8 – Difference model indicating the changes in elevation observed between the March 2008 and October 2022 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from March 2008 compared to October 2010. Widespread accretion can be seen across the unit, mostly on the northern half of the bay. A berm-like structure can be seen on the upper beach, gaining up to 2 m in elevation on the northern half of the beach. Some scattered low-level erosion can be observed along the dune system.

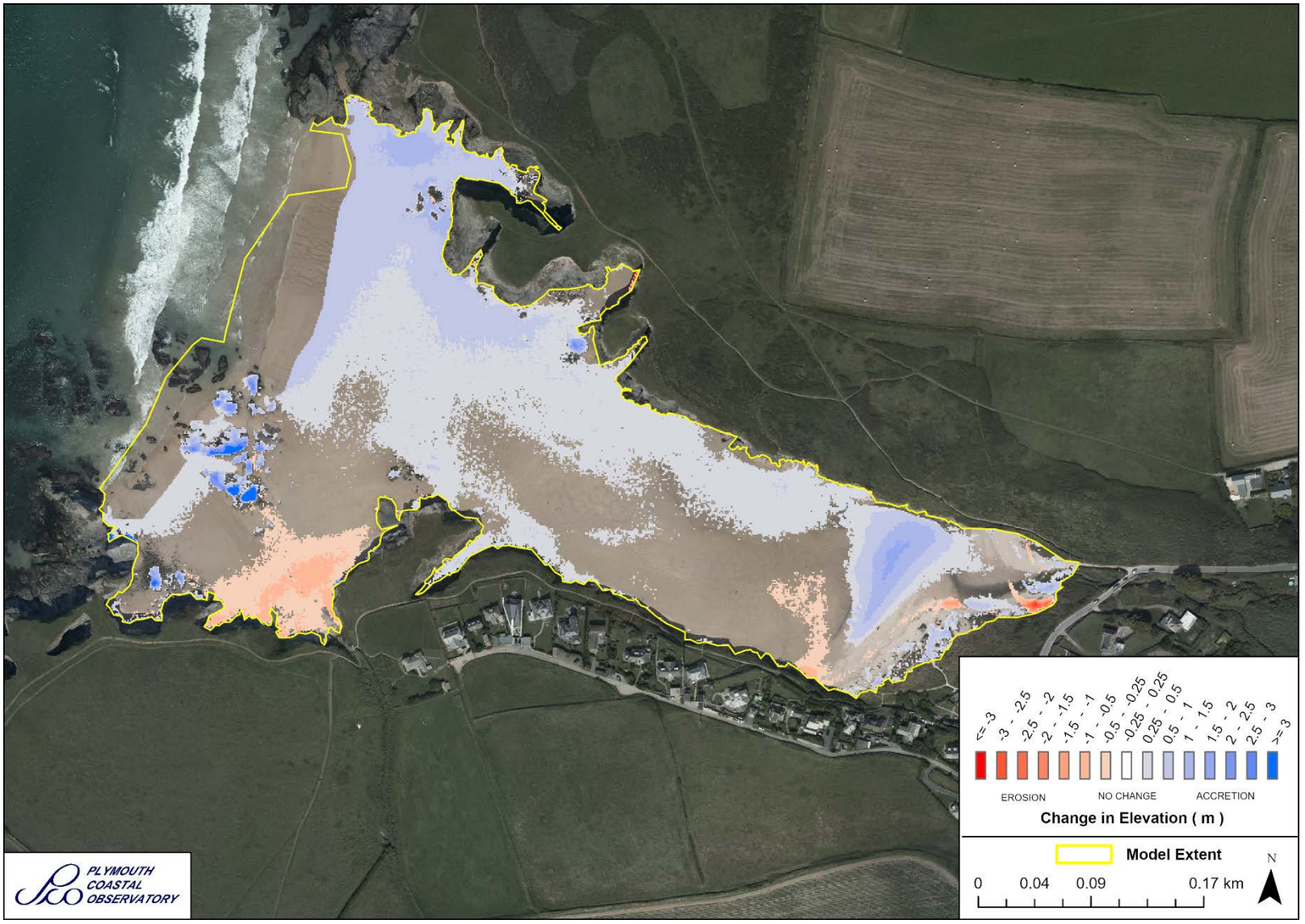


Figure 9 - Difference model indicating the changes in elevation observed between the March 2008 and October 2010 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from October 2010 compared to March 2014. In contrast to the accretion observed in figure 9, there is widespread erosion along the high-water mark for the entire beach, eroding by up to 2.5 m in places. This significant change is likely to be the result of the 2013/2014 winter storms. Some low-level accretion is measured along the dune system.

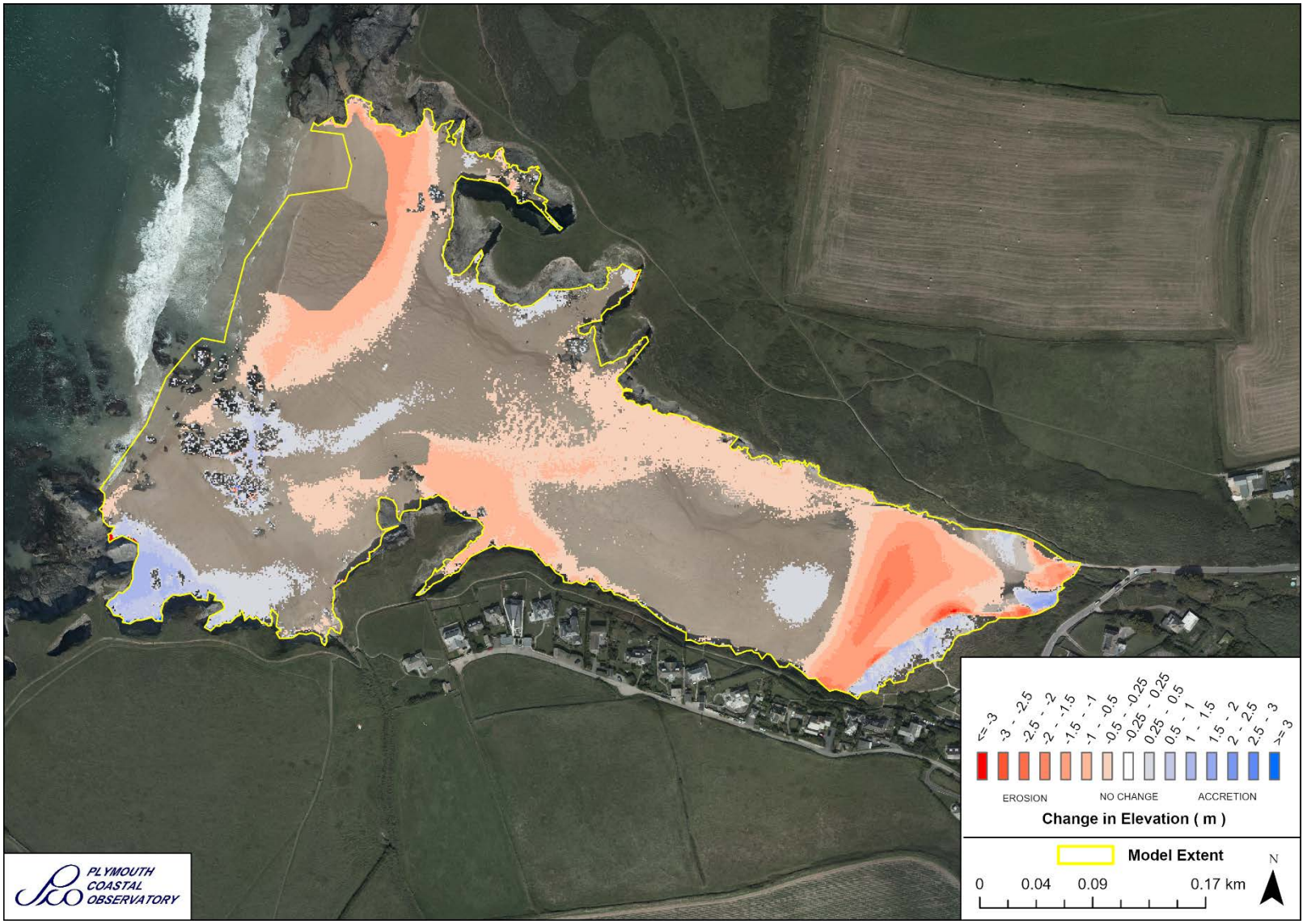


Figure 10 – Difference model indicating the changes in elevation observed between the October 2010 and March 2014 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from March 2014 compared to April 2019. This epoch indicates minimal change across the main body of the beach, but the seaward extent and the upper beach have seen accretion by up to 1m along the whole unit. The berm-like feature is backed by acute erosion of the dune face, of up to 3 m in places.

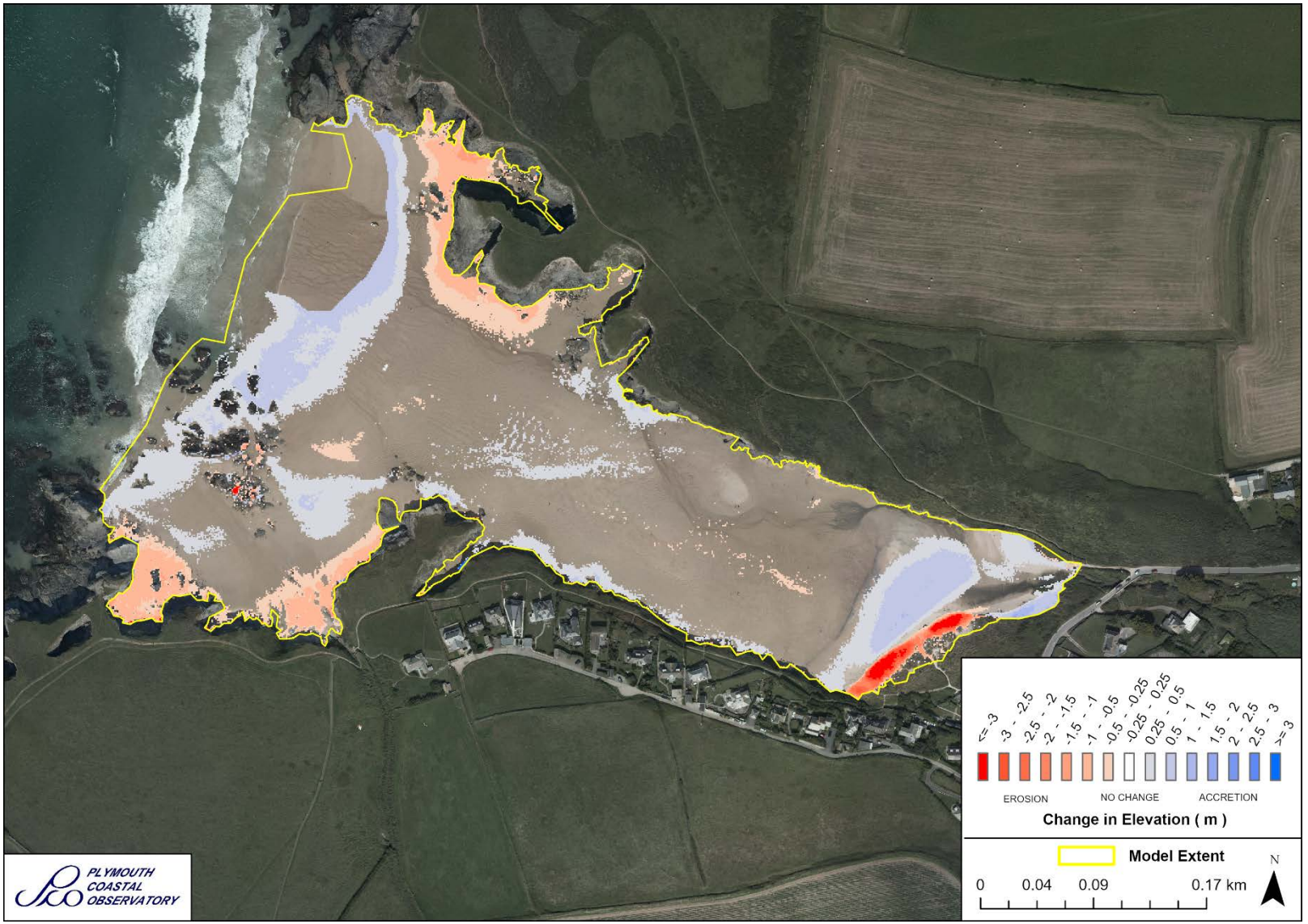


Figure 11 – Difference model indicating the changes in elevation observed between the March 2014 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from April 2019 compared to October 2022. The most recent epoch has seen a mixture of erosion and accretion across the length of the unit. The upper beach has experienced mostly accretion, of up to 2 m, creating a berm at the top of the beach and some low-level accretion along the dune face. The dune crest has seen some patches of erosion, as well as the upper beach and low-tide terrace.

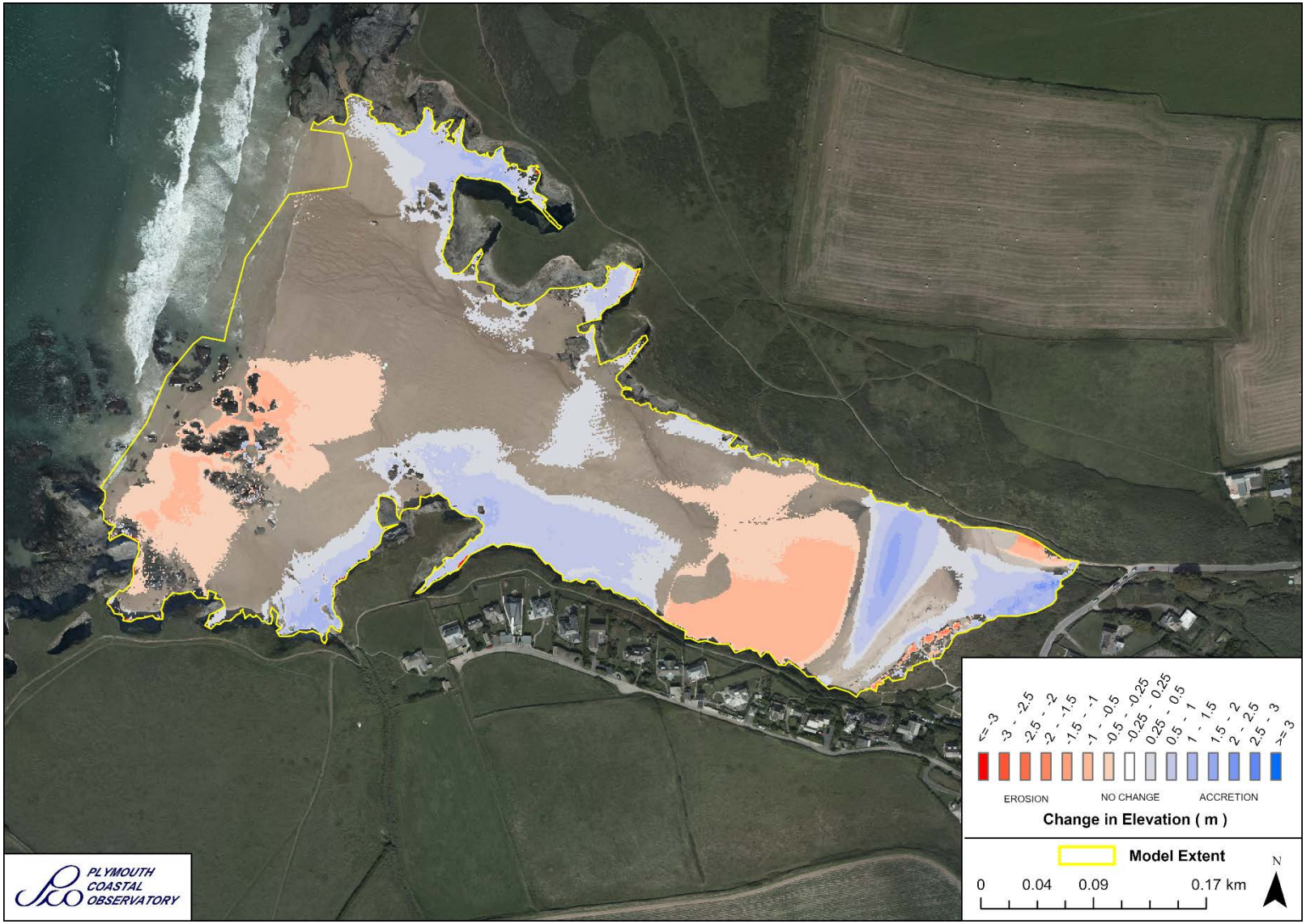


Figure 12 - Difference model indicating the changes in elevation observed between the April 2019 and October 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.40 m OD) are shown in Table 1 and figure 13. The Mobile Zone has remained stable in terms of volume between 2008 and 2022, with the lowest recorded in 2014, following the highly energetic winter period, losing 31% in volume from the previous survey in 2010, which also happened to be the highest on record (Fig.13).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-3.00 m OD) are shown in Table 1 and figure 14. The Beach Zone has remained relatively stable between 2008 and 2022 (Fig.14), despite fluctuation between surveys following a similar pattern to the topographic data. The lowest recorded volume from within the Beach Zone was during the baseline survey in 2008 (Fig.14).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.40 m OD) and for the Beach Zone above MLWS (-3.00 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
03/2008	23,116	352,087
08/2010	26,892	387,883
04/2014	18,421	361,636
04/2019	18,540	374,633
10/2022	23,021	352,351

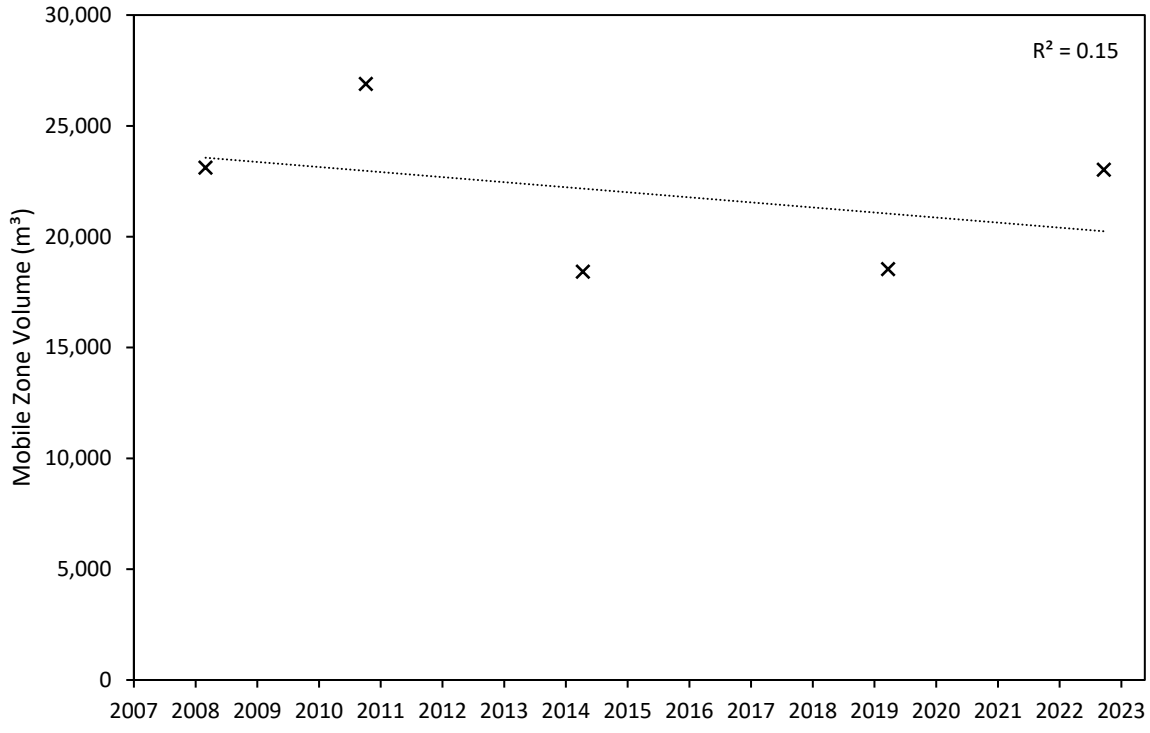


Figure 13 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.50 m OD) for each filtered LiDAR datasets between 2008 and 2022.

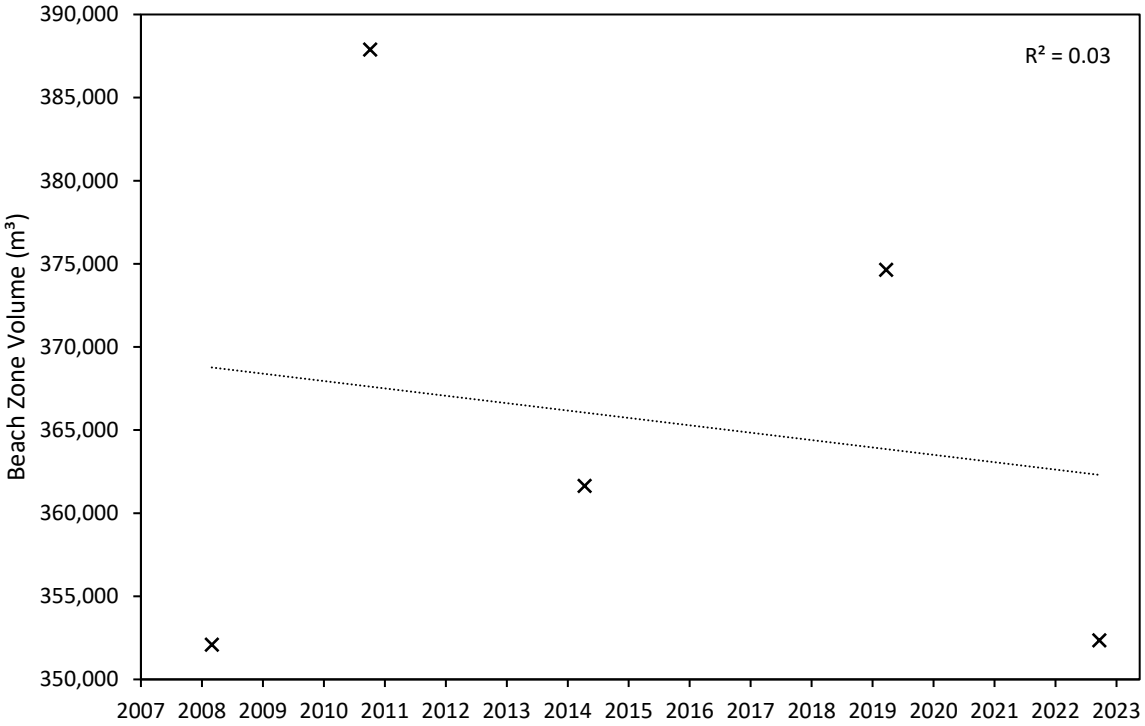


Figure 14 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.2.3 Contour Comparison

Figure 15 shows the Mean Sea Level (MSL) and Dune Toe contours from the 2008, 2014, 2019 and 2022 LiDAR datasets. MSL contours indicate a widening of the beach from 2008 to 2022 by approximately 30 m. Whereas after the 2014 storms, the beach appears to have narrowed by ~25 m in the south. The same is true of the Dune Toe contours, which retreated in 2014 by up to 13 m. The most recent LiDAR suggested the dune toe has begun to protrude out in front of the stream since 2019, changing position but ~45 m since 2008.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency (figures 16 and 17) and from 2007 onwards by the SWCM. These are presented in figures 18 to 21.



Figure 15 - Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022 LiDAR datasets.



Figure 16 – Aerial imagery from 1947.

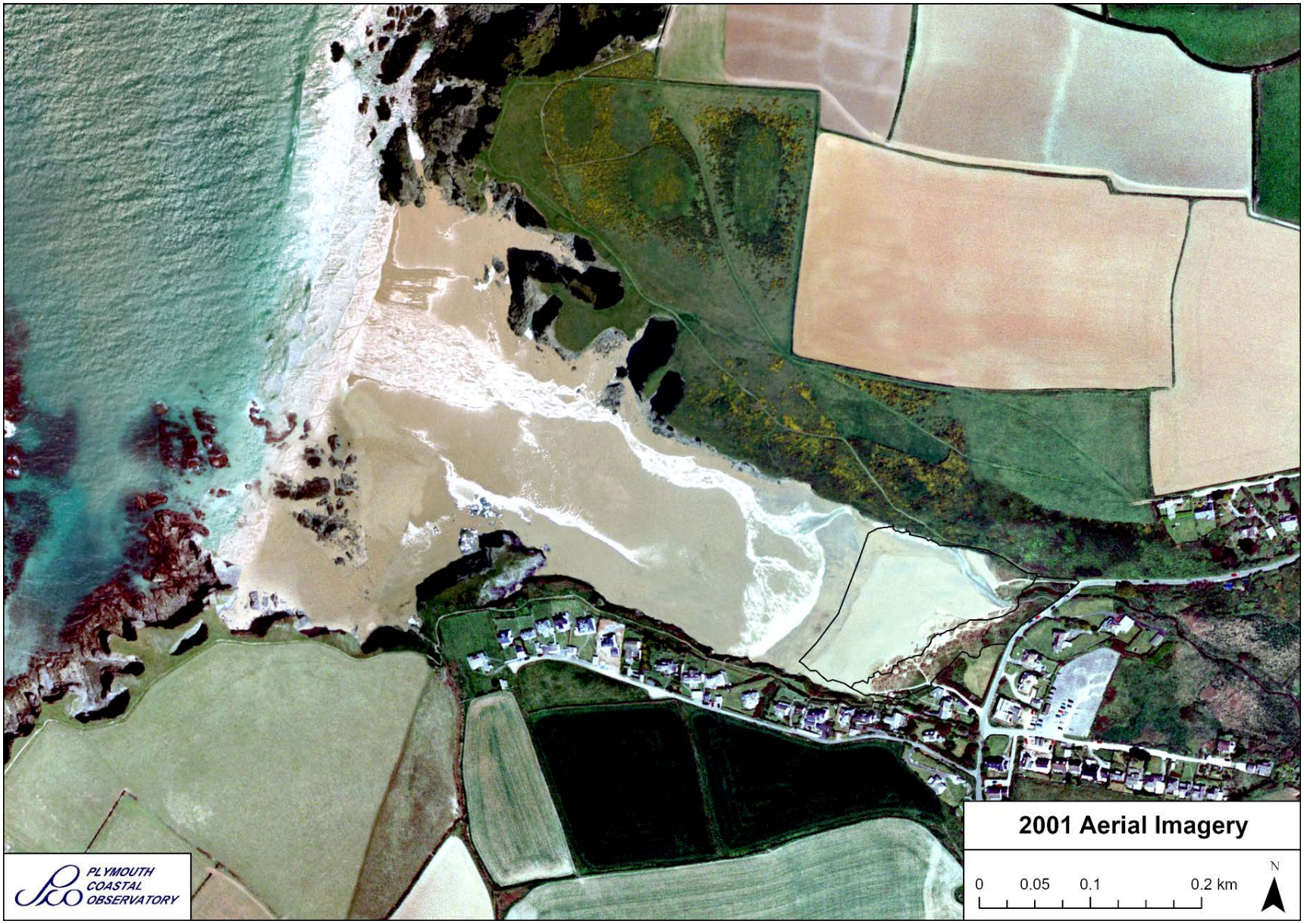


Figure 17 – Aerial imagery from 2001.



Figure 18 – Aerial imagery from 2008.



Figure 19 – Aerial imagery from 2010.



Figure 20 – Aerial imagery from 2014.



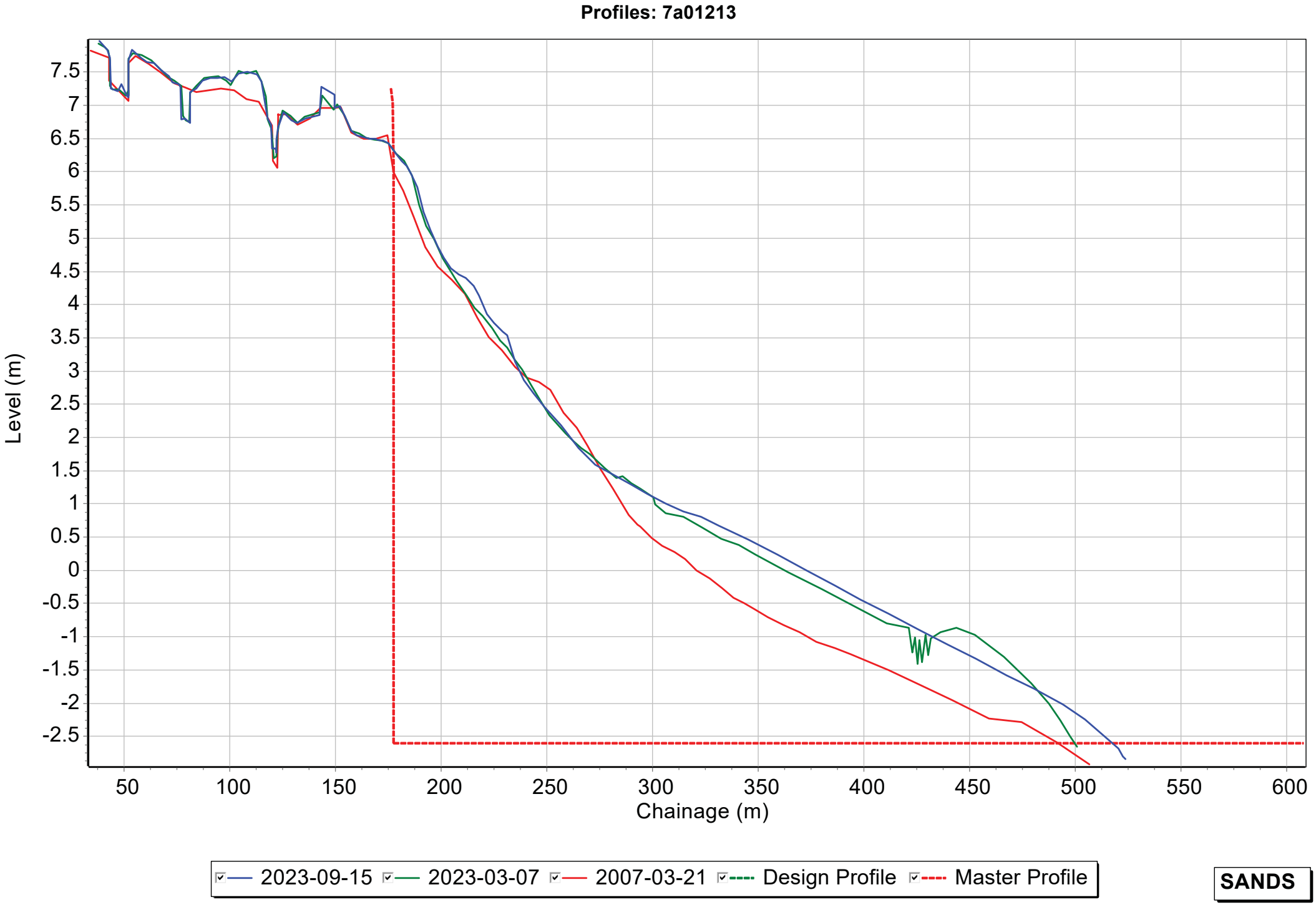
Figure 21 – Aerial imagery from 2017.

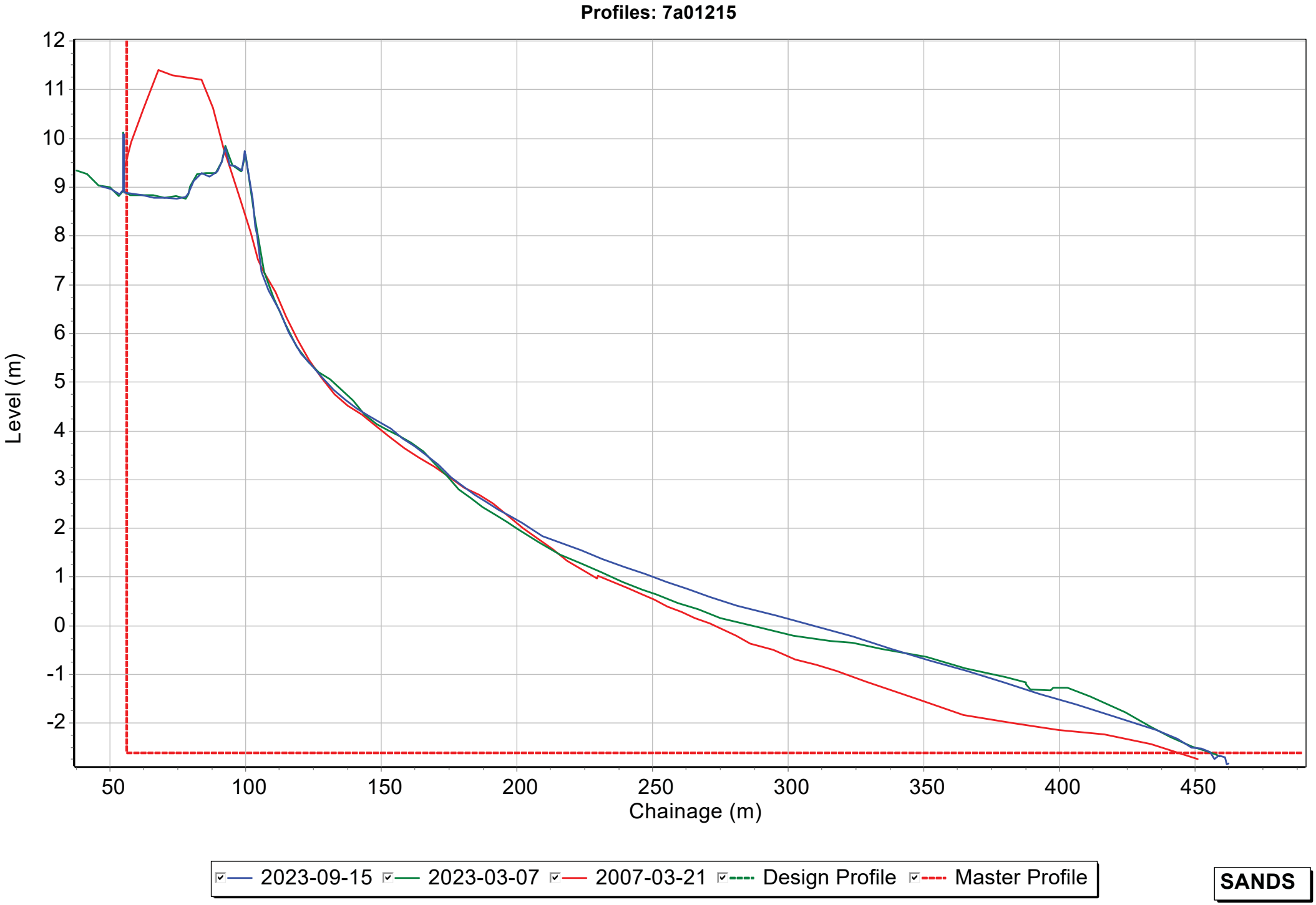
Glossary

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 Porthcothan are presented below.


Profiles: 7a01213
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
-2.5
50
100
150
200
250
300
350
400
450
500
550
600
Chainage (m)
2023-09-15
2023-03-07
2007-03-21
Design Profile
Master Profile
SANDS


Profiles: 7a01215
Level (m)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
50
100
150
200
250
300
350
400
450
Chainage (m)
2023-09-15
2023-03-07
2007-03-21
Design Profile
Master Profile
SANDS