SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand - Caerhays Beach Report

Topographic and LiDAR Data Analysis

SWCM TBR05 19/12/2023

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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 Caerhays. The aim is to highlight coastal change at Caerhays using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Caerhays is a south facing pocket beach backed by a small dune system which has primarily been repurposed as a car park; the beach is approximately 280 m long and 340 m wide. 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 32 topographic surveys at Caerhays since 2007. Analysis of topographic data suggests the survey unit has been gradually accreting by 0.5% of the combined profile area every year, despite being heavily impacted by the 2013/14 winter, with the highest recorded combined profile area during the 2022 autumn survey.

Beach volume extracted from 8 LiDAR flights since 2007 within the Mobile Zone suggests a different story to the topographic data, with gradual erosion observed between 2007 and 2022, with the dune area losing material from the foredune. Volume extracted from each LiDAR flight in the beach zone agrees with the topographic data indicating a gradually accreting beach, despite recording the highest value on record during the 2014 survey.

Overall Caerhays has seen an accreting beach with a gradually eroding upper beach face and fore dune.

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1.0 Introduction

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

Caerhays is a south facing pocket beach backed by a small dune system (which has mostly been repurposed as a car park) and fresh water pond, confined by rocky cliffs to the east and west (Fig.1). The beach has a cross-shore distance of ~280 m and longshore distance of ~340 m with a spring tidal range of 4.5 m. The beach has a south westerly wave climate. The four beach and dune zones are represented in Figure 1.

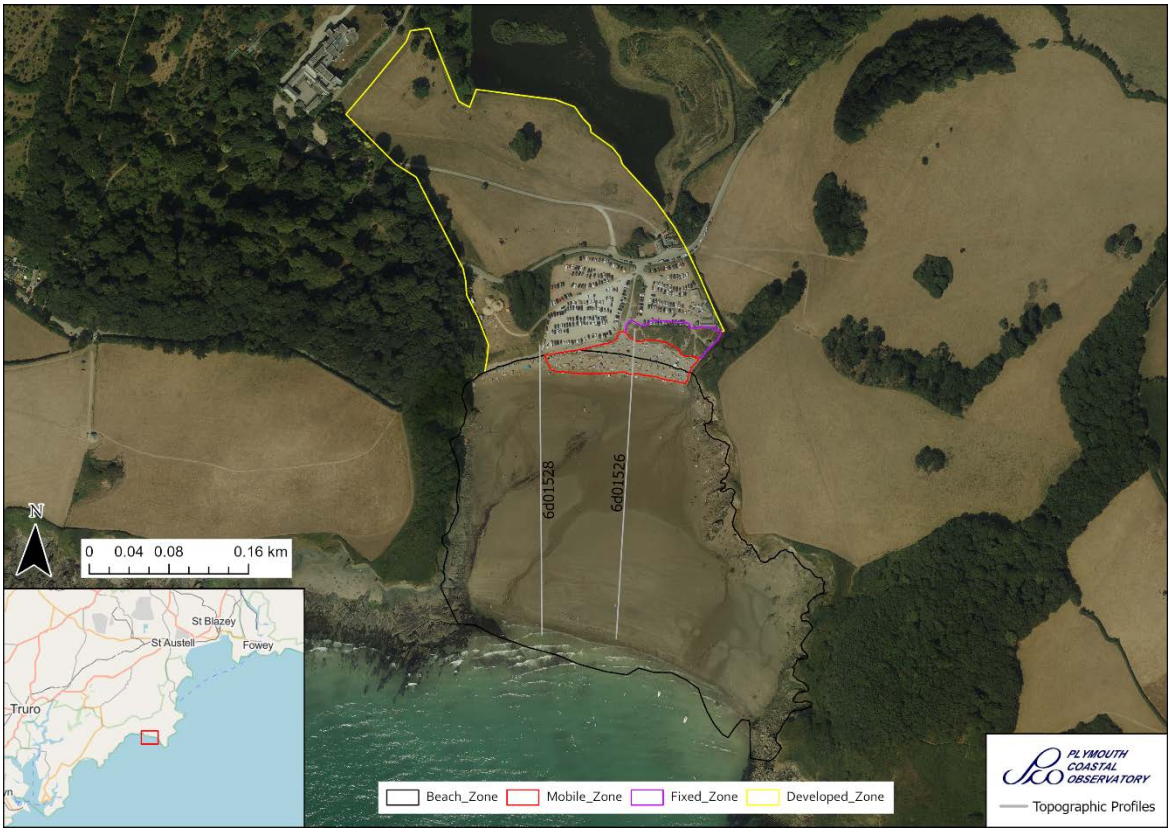


Figure 1 - Location Map of Caerhays Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

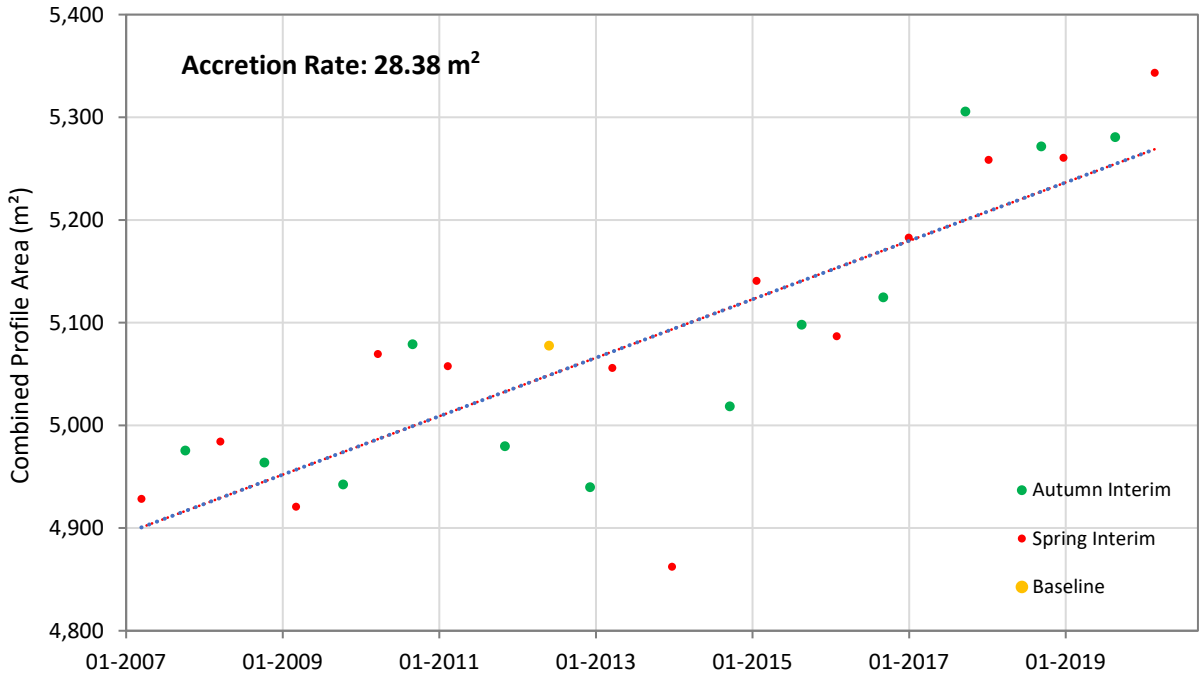


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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 (2006-2022) 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.

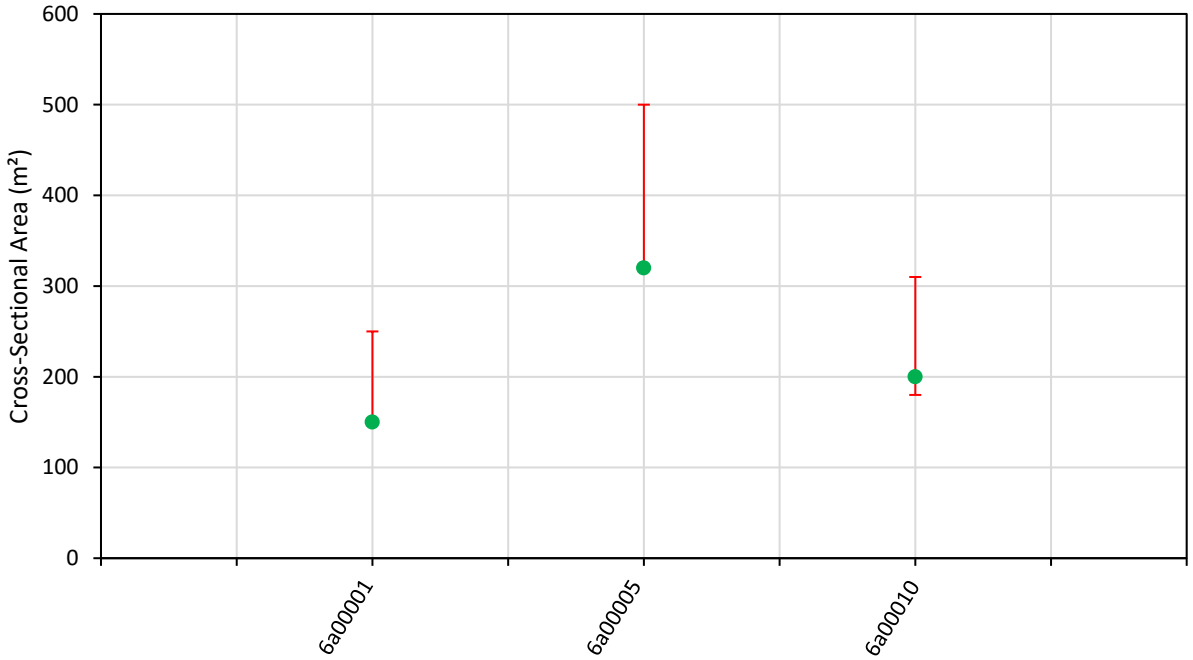


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

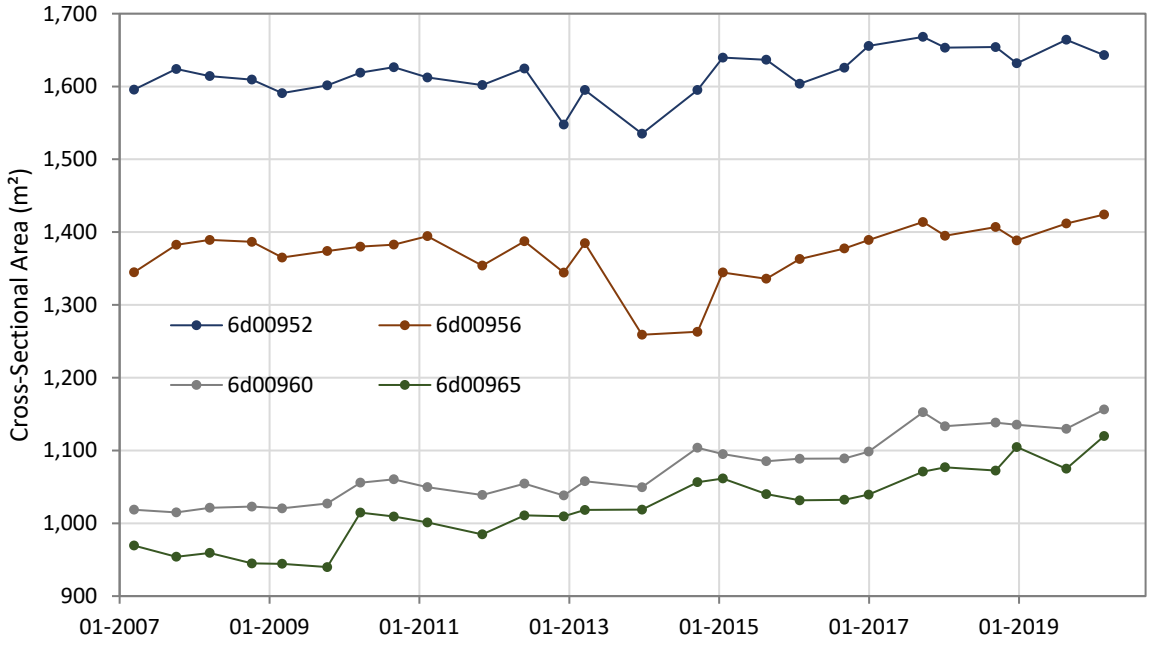


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 32 topographic surveys at Caerhays since 2007; 4 full coverage surveys and 28 interim surveys. Exact dates of each survey for Caerhays are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting at 4.6 m^2 y^{-1} equating to 0.5% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2014 spring interim (830 m^2) during the highly energetic winter period; however, the beach had recovered to pre storm levels by 2017 (Fig.5). The highest recorded combined area was during the 2012 (1,070 m^2) and 2022 (1069 m^2) autumn interims (Fig.5).

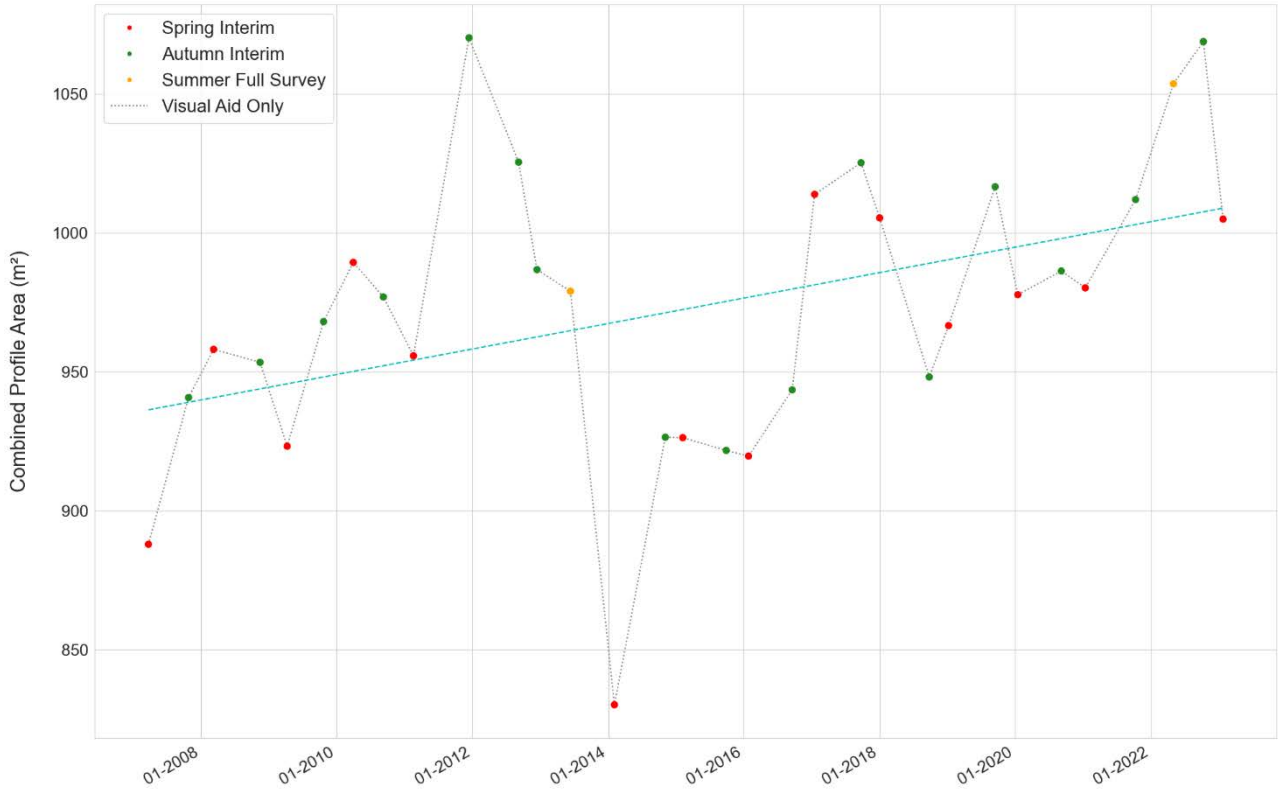


Figure 5 - The Combined Profile Area (CPA) for Caerhays, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing the 2023 autumn interim survey to the entire dataset (Fig.6), both Caerhays profiles were healthy, displaying relatively high cross-sectional areas but also indicating a large range throughout the survey record.

When comparing profile cross-sectional areas to the entire time series (Fig.7), both profiles suggest a gradual accretion through the time series, with both also recording their lowest values during the 2014 spring interim (Fig.7) following a period of general accretion.

Profile Charts for Caerhays 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.

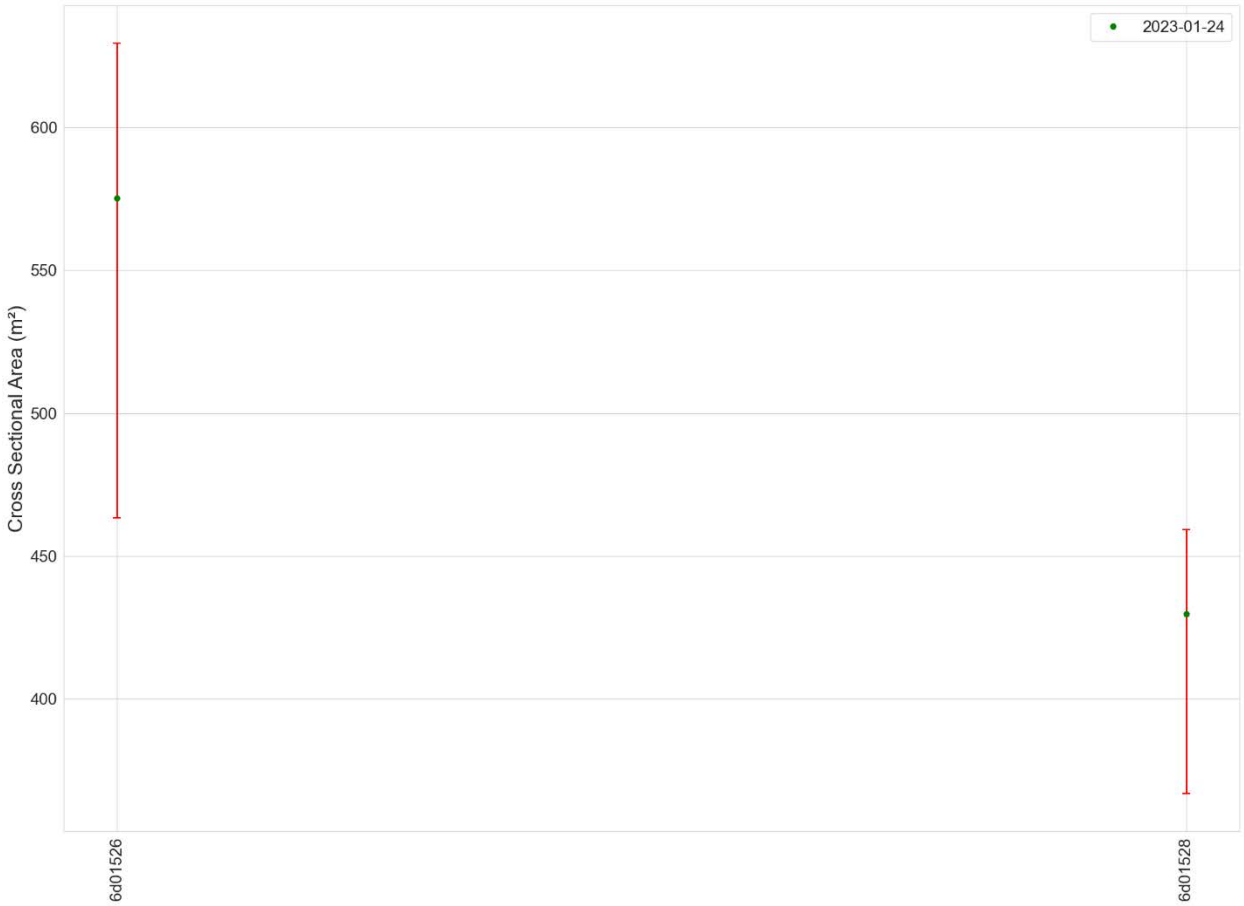


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2023.

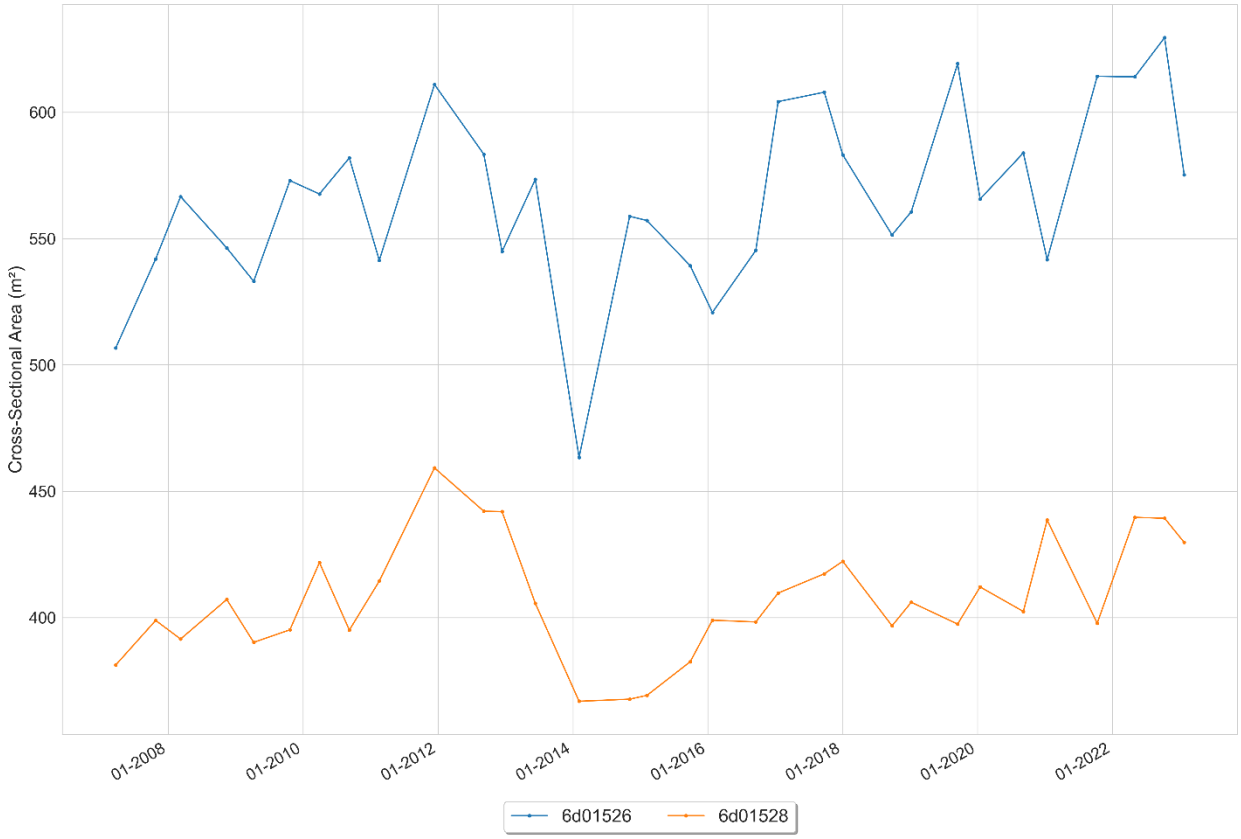


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

3.2 LiDAR Data Analysis

There has been a total of 8 LiDAR flights captured at Caerhays 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.

04/2007 to 03/2022 – Figure 8 shows the difference in elevation between the first filtered LiDAR data from 2007 compared to the most recent, captured in 2022. The plot shows a large band of erosion across the entire upper beach face up to the foot of the sea defence as well as considerable loss of the dune front to the east of the beach (Fig.8) ; the lower beach is dominated by low level accretion.

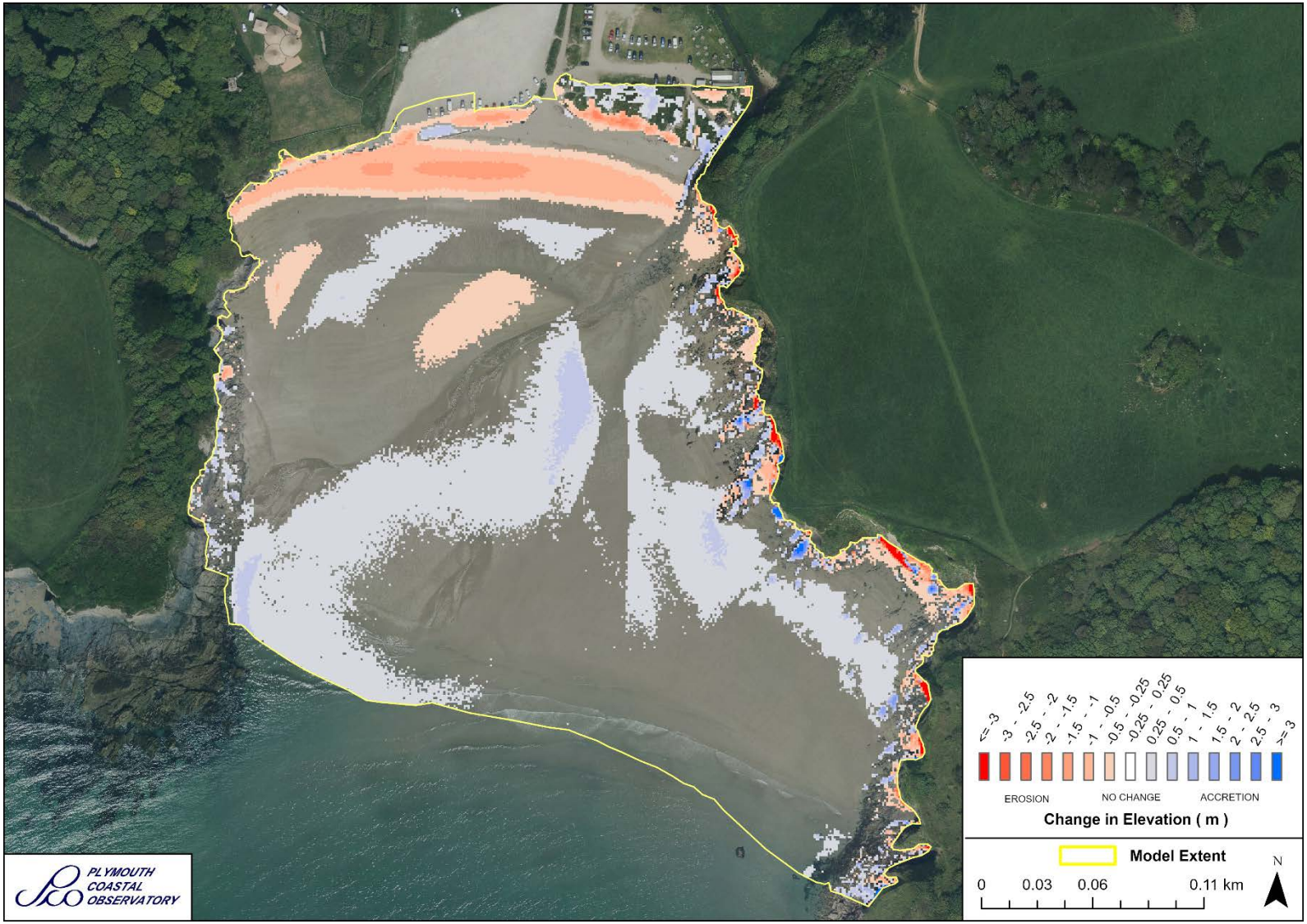


Figure 8 – Difference model indicating the changes in elevation observed between the April 2007 and March 2022 filtered LiDAR datasets within the yellow model extent.

04/2007 to 11/2007 – Figure 9 shows differences in elevation between filtered LiDAR data from spring 2007 compared to winter 2007. There is minimal change observed along the upper beach face, with a mixture of accretion and erosion across the beach (Fig.9)

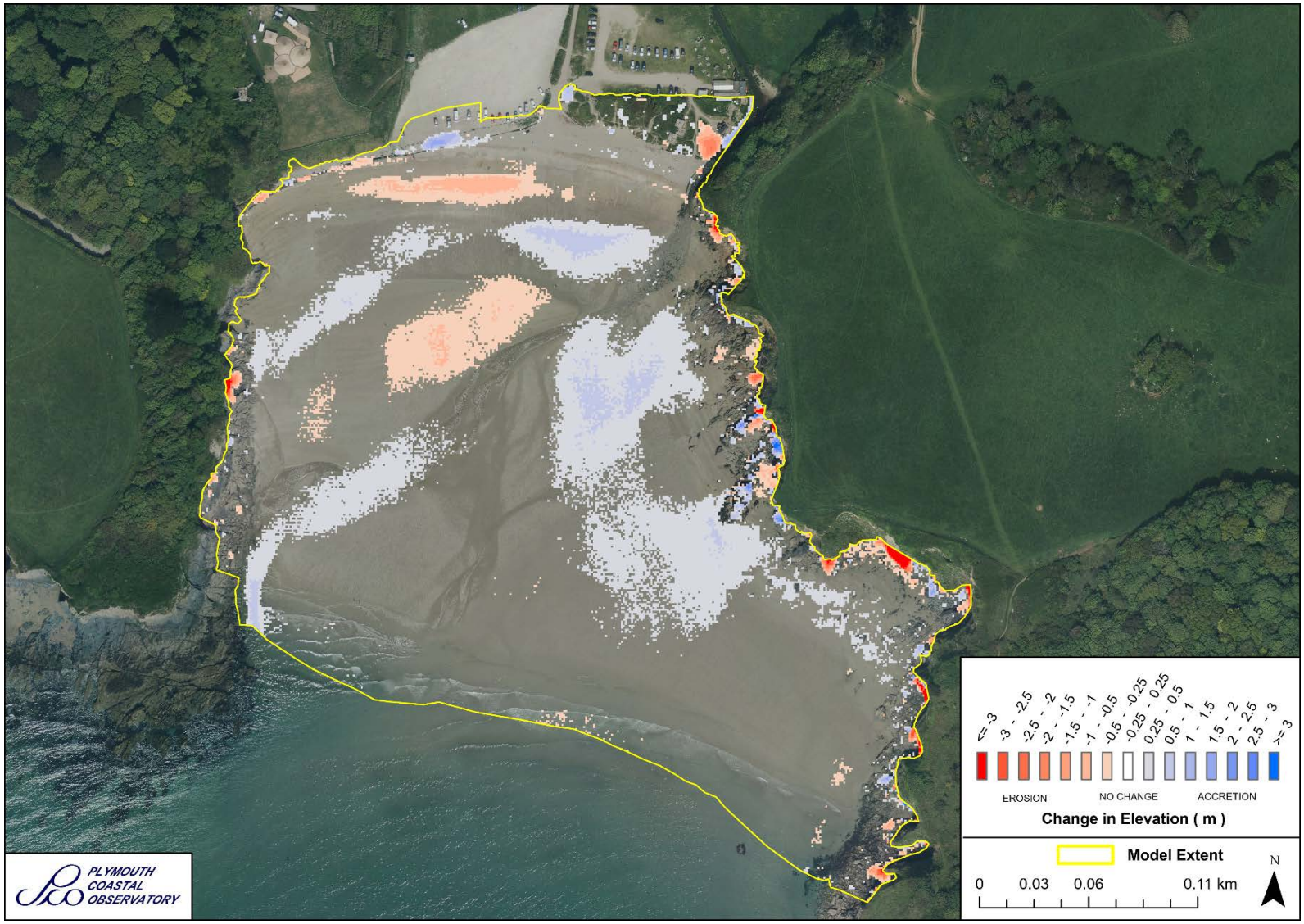


Figure 9 - Difference model indicating the changes in elevation observed between the April 2007 and November 2007 filtered LiDAR datasets within the yellow model extent.

11/2007 to 01/2009 – Figure 10 shows differences in elevation between filtered LiDAR data from 2007 compared to 2010. There is considerable erosion observed across the entire upper beach face, with some loss also noticeable along the foot of the dune to the east; minimal, if any, accretion is observed (Fig.10).

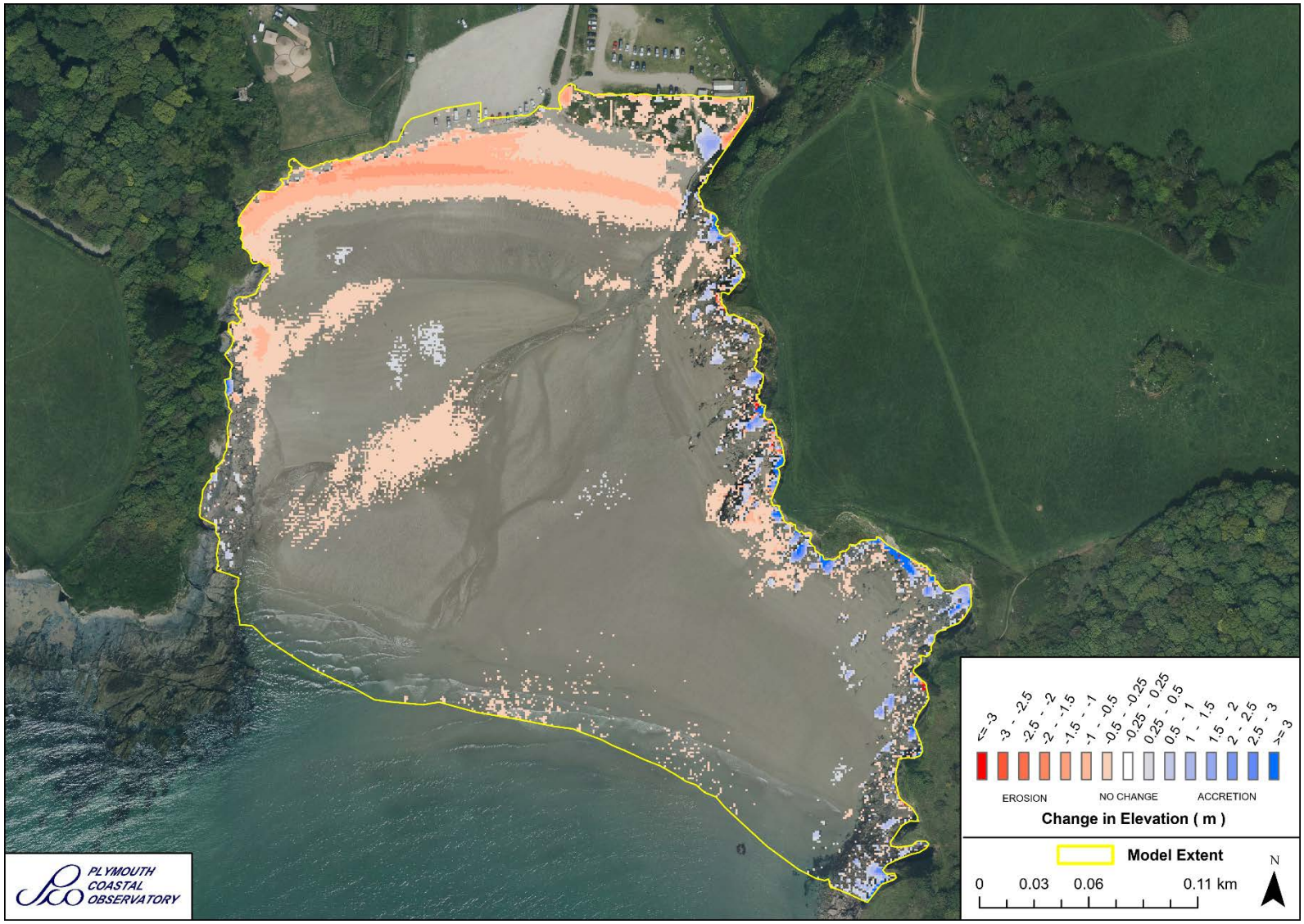


Figure 10 - Difference model indicating the changes in elevation observed between the November 2007 and January 2009 filtered LiDAR datasets within the yellow model extent.

01/2009 and 10/2009 – Figure 11 shows differences in elevation between filtered LiDAR data from early 2009 compared to autumn 2009. As expected when comparing winter to autumn months, there has been a recovery of material across the majority of the beach, with accretion observed along the upper beach face, with only a small band of erosion across the centre of the beach (Fig.11).

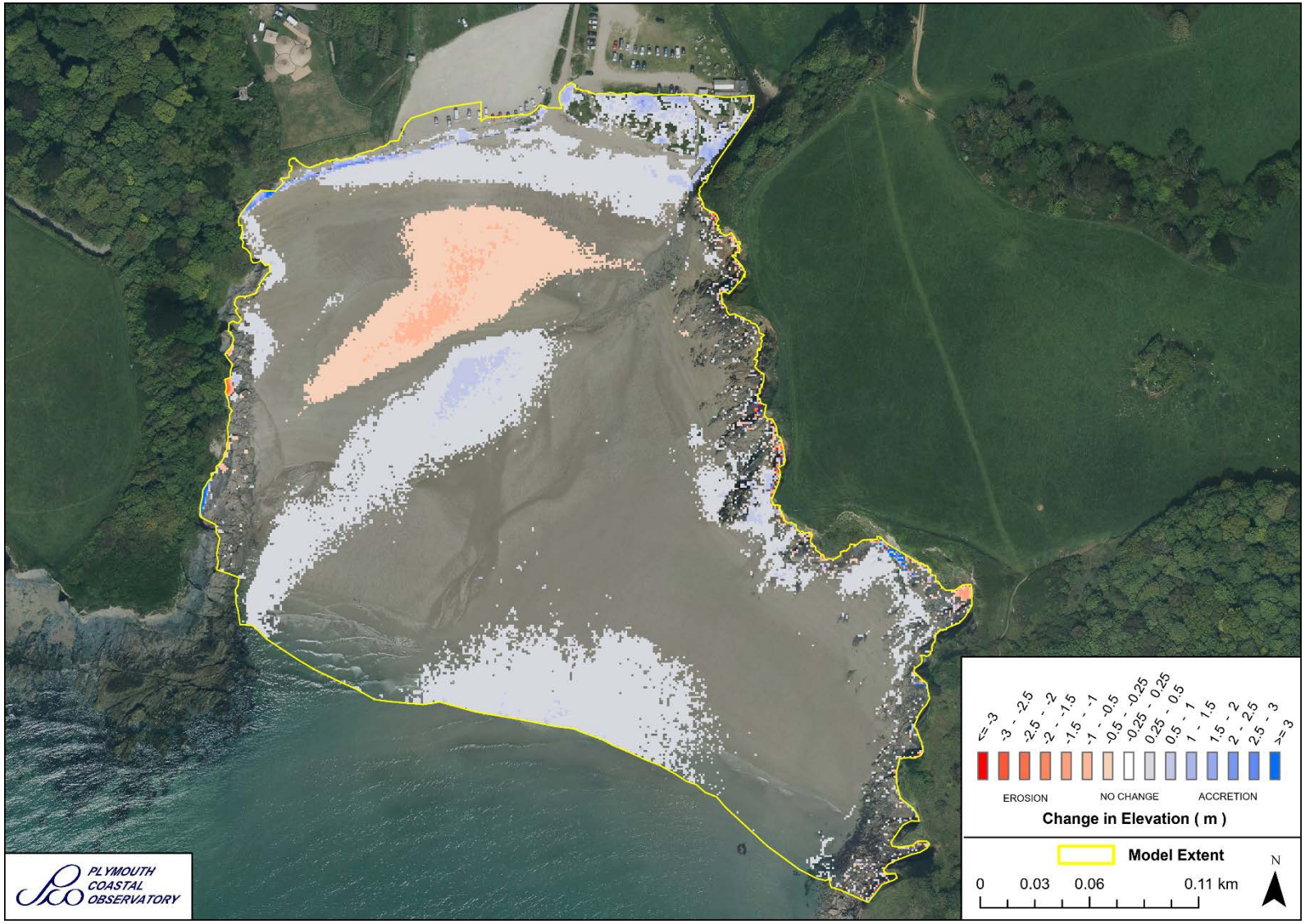


Figure 11 – Difference model indicating the changes in elevation observed between the January 2009 and October 2009 filtered LiDAR datasets within the yellow model extent.

10/2009 and 01/2011 – Figure 12 shows differences in elevation between filtered LiDAR data from 2009 compared to 2011. A mixture of erosion and accretion is observed across the entire beach, with some loss of material from the upper beach face, particularly to the west (Fig.12)

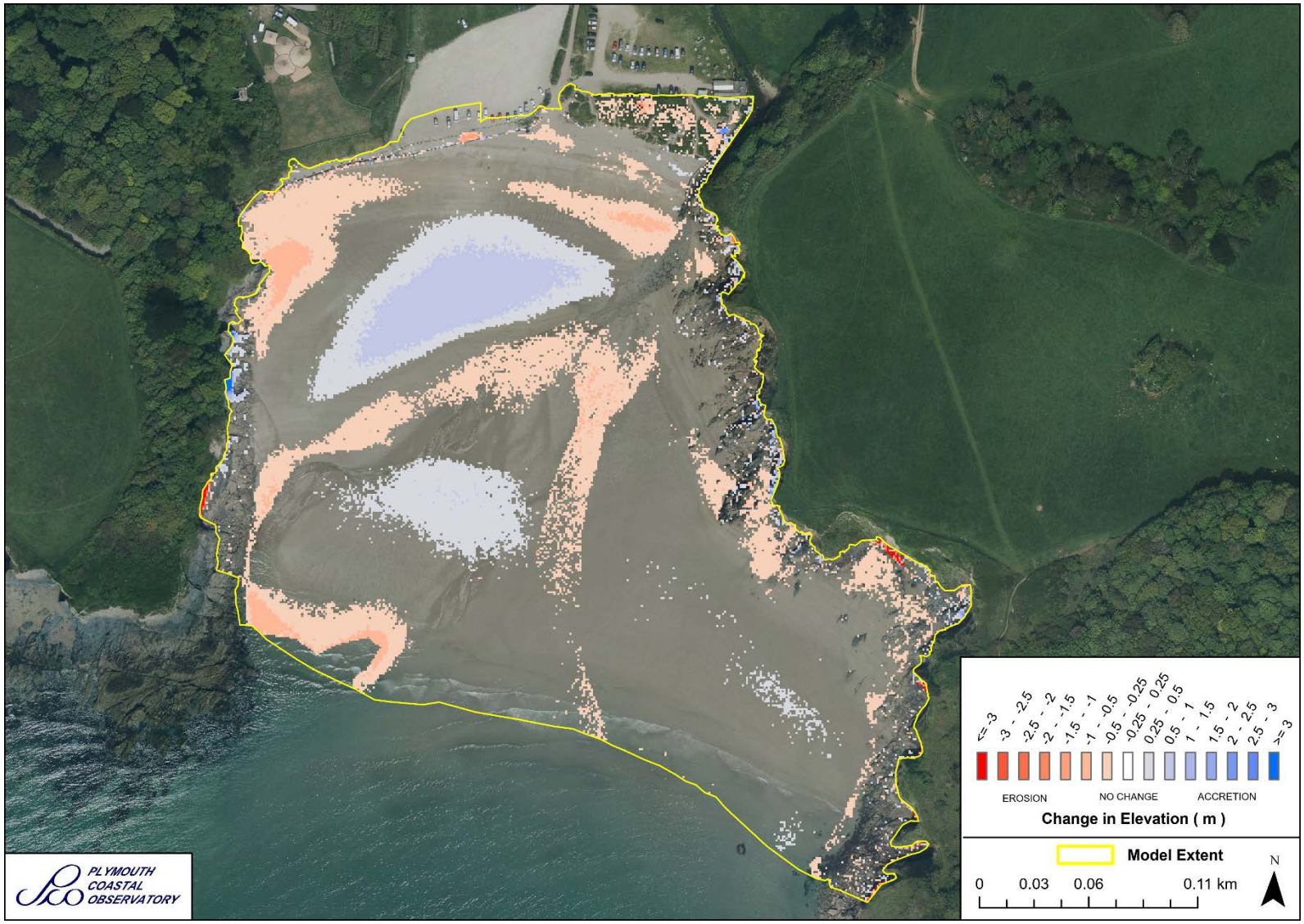


Figure 12 - Difference model indicating the changes in elevation observed between the October 2009 and January 2011 filtered LiDAR datasets within the yellow model extent.

01/2011 and 05/2014 – Figure 13 shows differences in elevation between filtered LiDAR data from 2011 compared to 2014. The beach is predominated by accretion, with the lower beach seeing gains in material across the entire beach width as well as directly in front of the dune system. There is a small band of erosion on the upper beach face to the west, directly beneath the car park (Fig.13). Unlike many beaches in the surrounding area, Caerhays seemed to have gained material following the 2013/14 winter period.

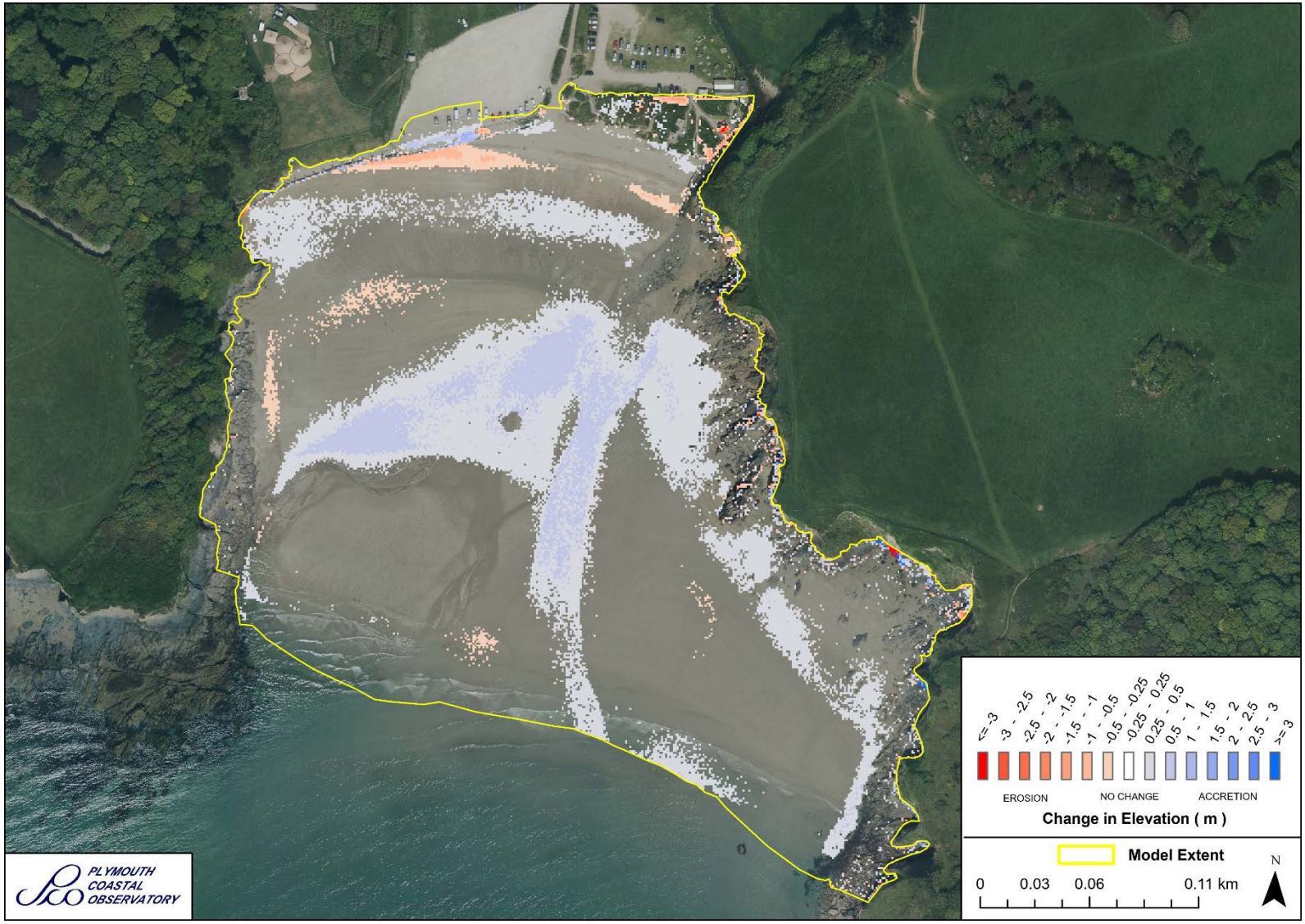


Figure 13 - Difference model indicating the changes in elevation observed between the January 2011 and May 2014 filtered LiDAR datasets within the yellow model extent.

05/2014 and 04/2019 – Figure 14 shows differences in elevation between filtered LiDAR data from 2014 compared to 2019. There is relatively high loss of material observed across the lower beach as well as from the face of the dune system and beneath the car park (Fig.14), this is accompanied by much less accretion observed along the upper beach face.

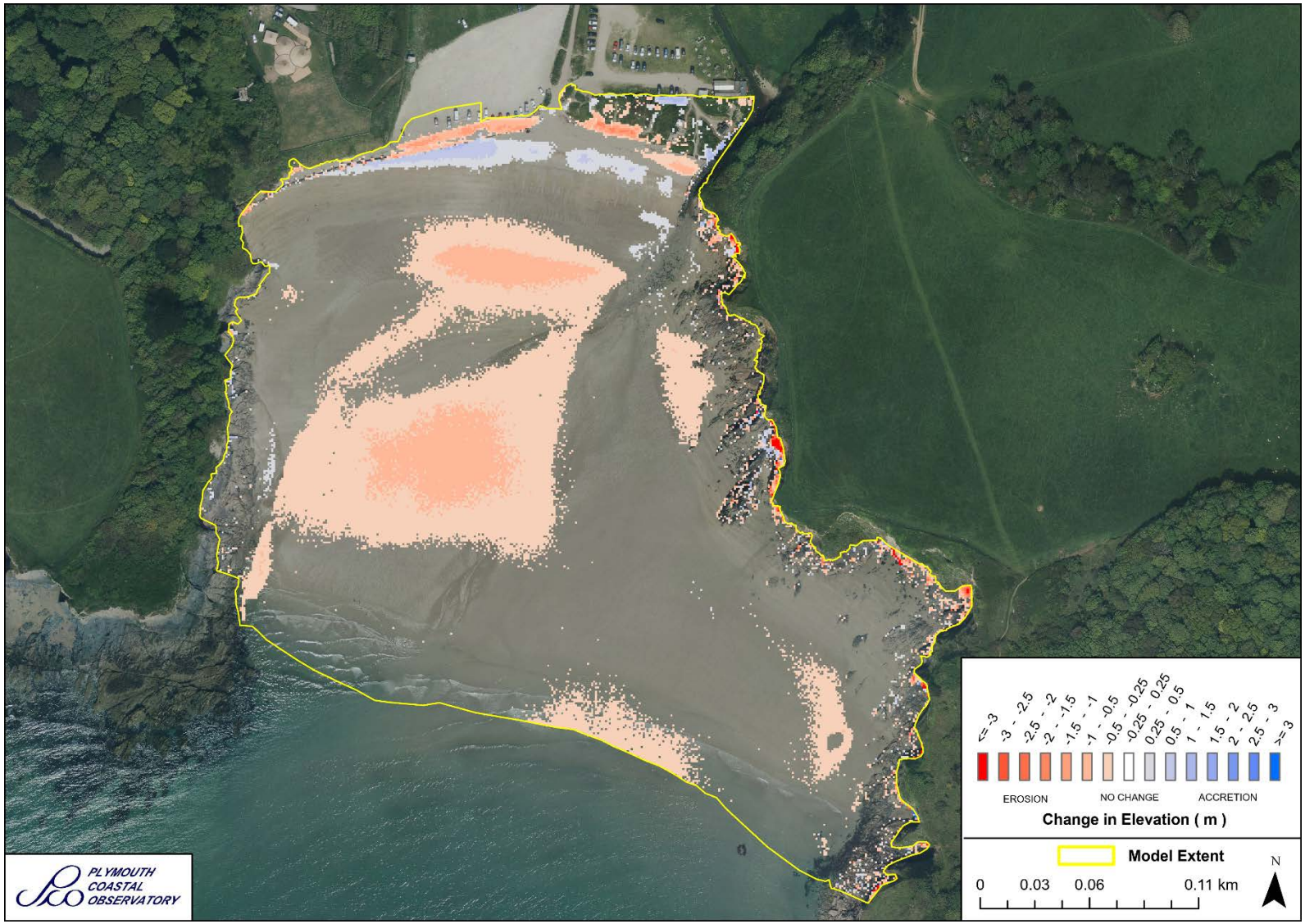


Figure 14 - Difference model indicating the changes in elevation observed between the May 2014 and April 2019 filtered LiDAR datasets within the yellow model extent.

04/2019 to 03/2022 – Figure 15 shows differences in elevation between filtered LiDAR data from 2019 compared to 2022. There is a mixture of accretion and erosion observed across the beach area, however there is a band of erosion observed beneath the car park and sea defence to the east, as well as a loss of material from the dune toe (Fig.15).

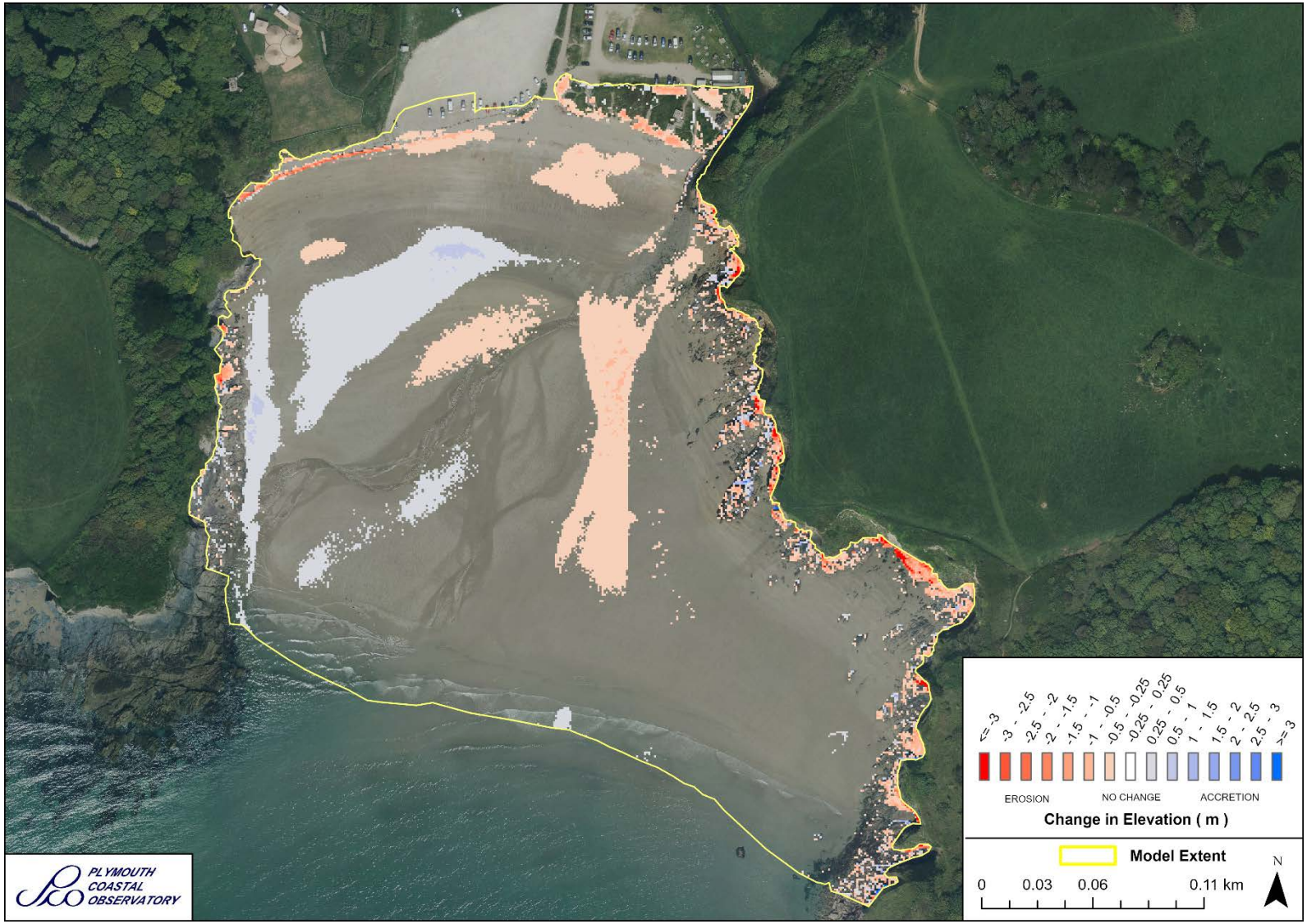


Figure 15 - Difference model indicating the changes in elevation observed between the April 2019 and March 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.49 m OD) are shown in Table 1. In agreement with the difference model comparing 2007 to 2022 surveys (Fig.8), there appears to be an erosive trend for the Mobile Zone volume throughout the time series (Fig.16), suggesting an eroding upper beach face and dune toe.

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.11 m OD) are also shown in Table 1. Similarly, to that observed in the topographic CPA plot (Fig.5), the Beach Zone has undergone accretion since the original 2007 survey (Fig.17). However, the LiDAR data disagrees with the topographic in that the 2014 survey suggested the highest measurement on record at 163,629 m^3 (Fig.17), potentially suggesting a rapid recovery of the beach volume immediately after the 2014 spring.

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (2.49 m OD) and for the Beach Zone above MLWS (-2.11).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
04/2007	2,903	145,286
11/2007	2,890	149,903
01/2009	1,815	143,572
10/2009	2,473	152,222
01/2011	2,254	152,983
05/2014	2,342	163,629
04/2019	2,421	152,282
03/2022	1,934	152,234

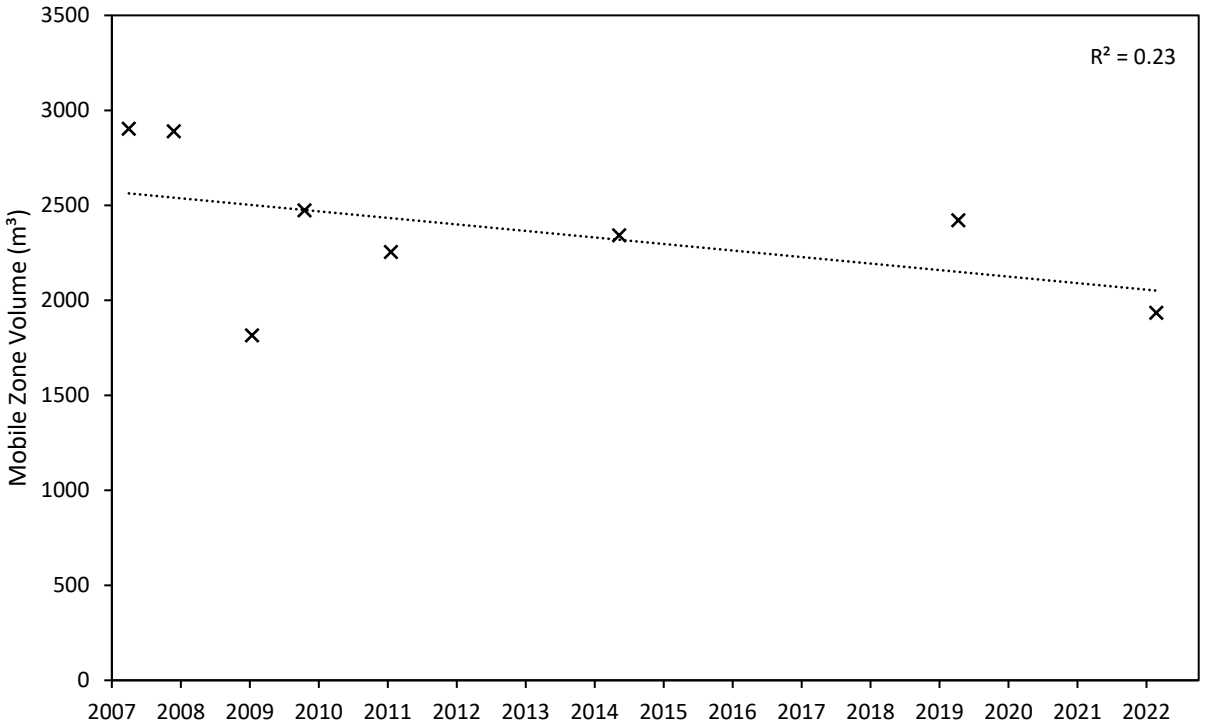


Figure 16 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.49 m OD) for each filtered LiDAR datasets between 2007 and 2022.

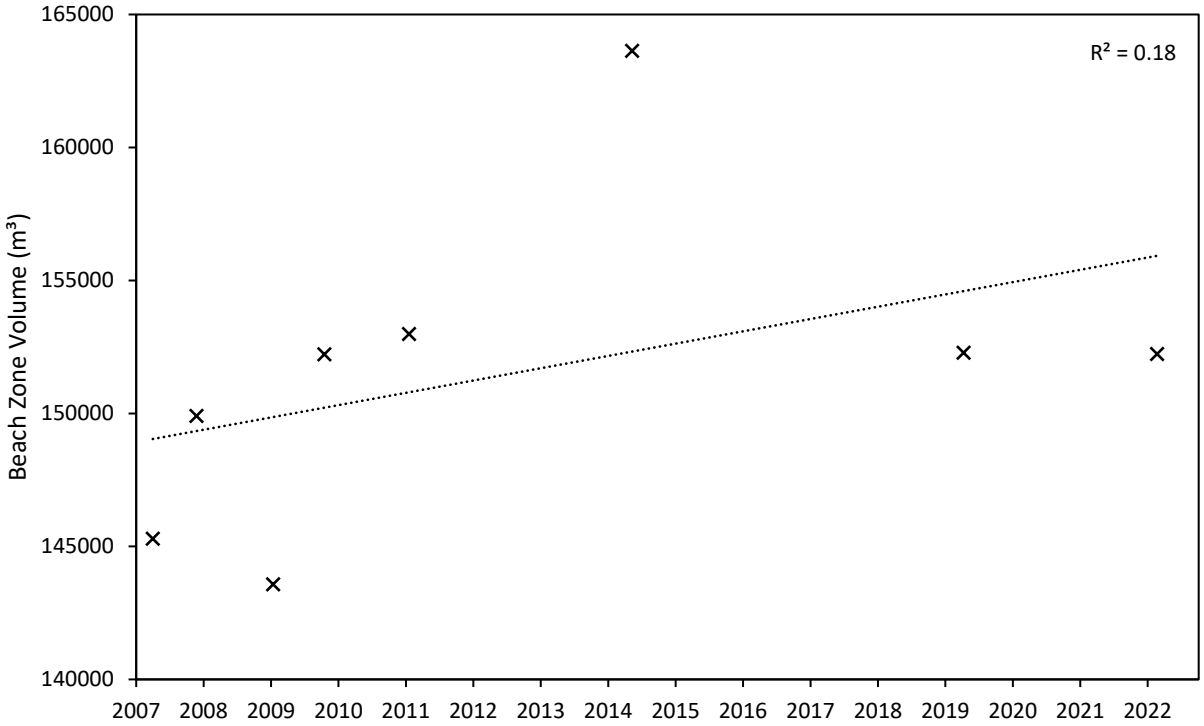


Figure 17 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MLWS (-2.11 m OD) for each filtered LiDAR datasets between 2007 and 2022.

3.2.3 Contour Comparison

Figure 18 indicates the Mean Sea Level (MSL) and Dune Toe contours from 2007, 2014, 2019 and 2022 LiDAR datasets, projected onto aerial imagery captured in 2022. The MSL contour suggests a fluctuating beach width between each of the 4 survey datasets, with 2014 suggesting the most accreted, agreeing with the Beach Zone volume plot (Fig.17). There is minimal change between the Dune Toe contour between each of the datasets, however. The widest dune toe along the actual dune front to the east of the beach was observed during the 2014 survey (Fig.18).

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency and from 2007 onwards by the SWCM are presented here.

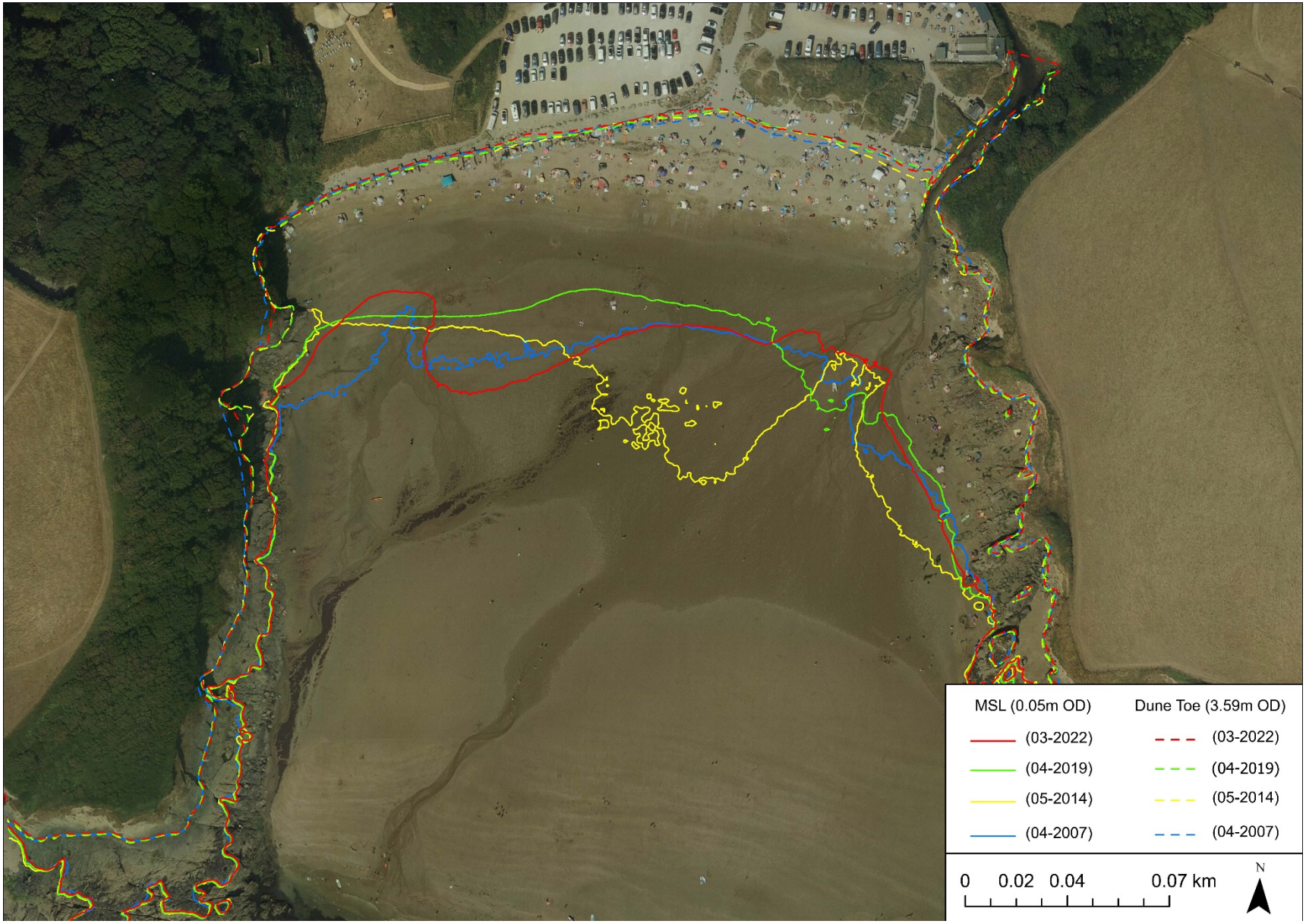


Figure 18 - Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2007, 2014, 2019 and 2022 LiDAR datasets.



Figure 19 - Aerial imagery from 1947.



Figure 20 – Aerial imagery from 2001.



Figure 21 – Aerial imagery from 2007.



Figure 22 – Aerial imagery from 2009.

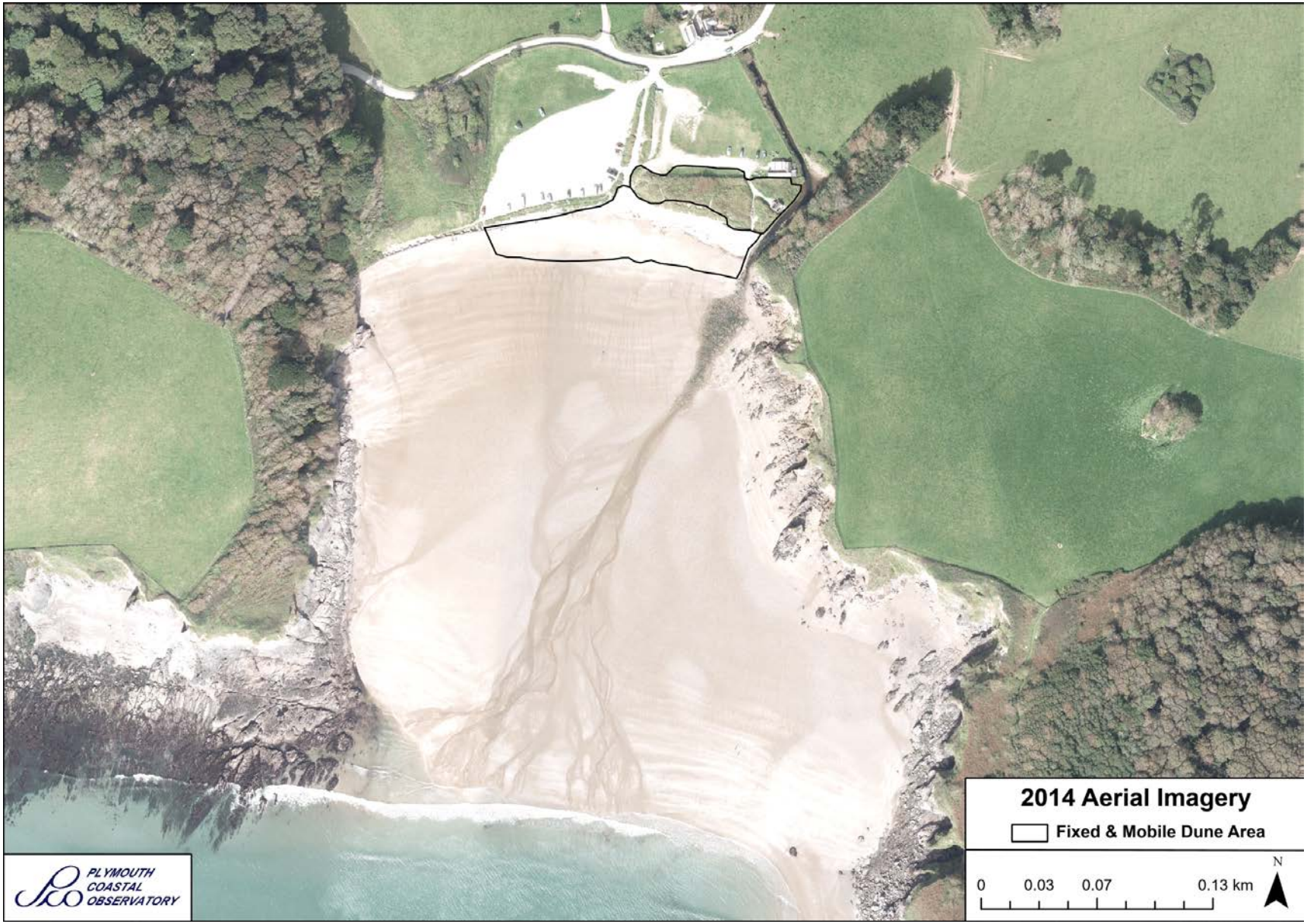


Figure 23 – Aerial imagery from 2014.



Figure 24 – Aerial imagery from 2018.



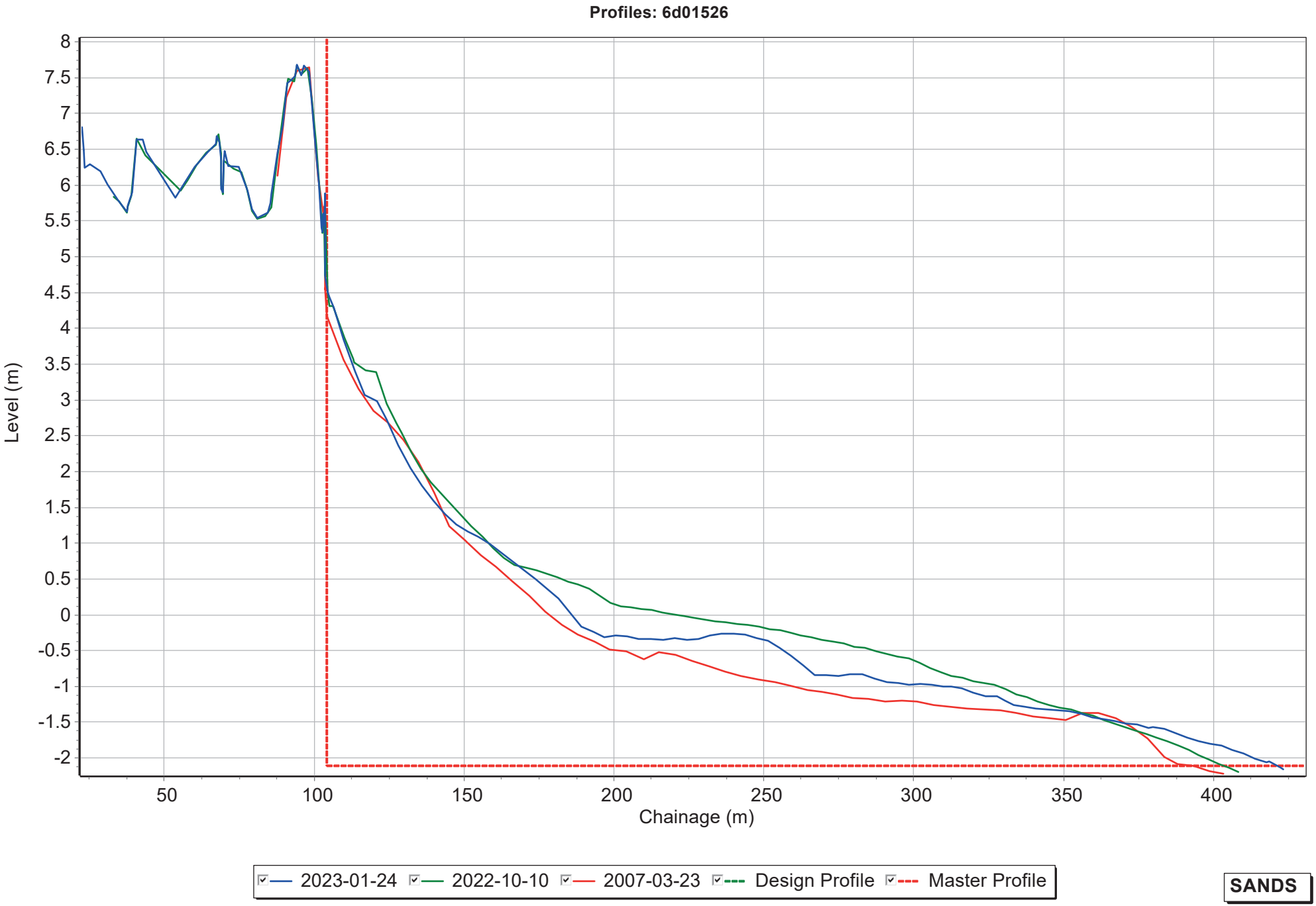
Figure 25 - Aerial imagery from 2022.

Glossary

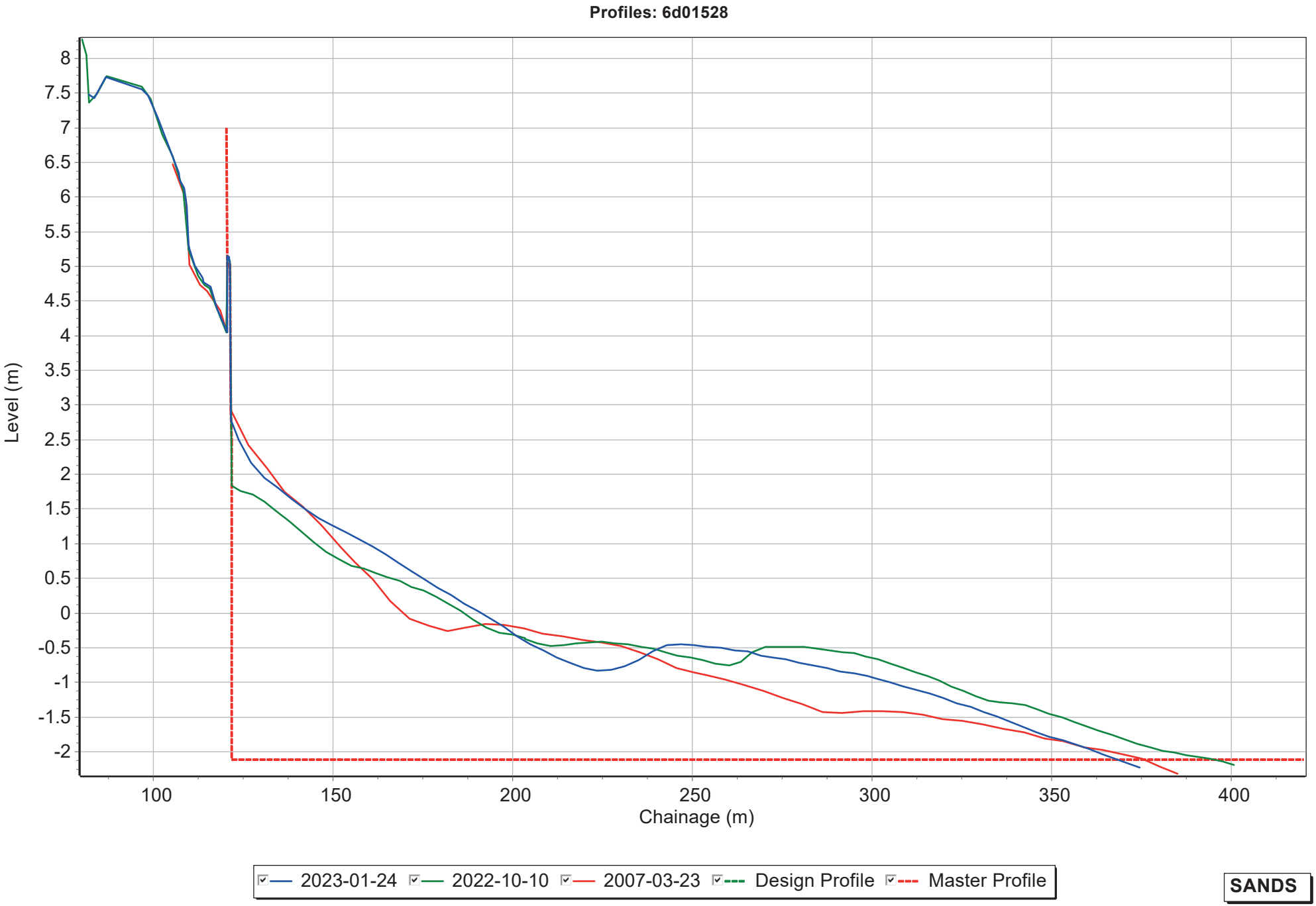
1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
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), second most recent survey (green) and first survey, also known as the baseline (red) at Caerhays are presented below.


Profiles: 6d01526
Level (m)
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
50
100
150
200
250
300
350
400
Chainage (m)
2023-01-24
2022-10-10
2007-03-23
Design Profile
Master Profile

SANDS


Profiles: 6d01528
Level (m)
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
100
150
200
250
300
350
400
Chainage (m)
2023-01-24
2022-10-10
2007-03-23
Design Profile
Master Profile

SANDS