SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand - Maenporth Beach Report

Topographic and LiDAR Data Analysis

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Taken by: Miranda Soskin

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 Maenporth. The aim is to highlight coastal change at Maenporth using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Maenporth is an east facing pocket beach with a cross shore distance of 290 m and longshore distance of 200 m. There is no active dune system at Maenporth, however there is an extinct system which has been replaced with a car park, road, and other developments. 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 33 topographic surveys at Maenporth since 2007. Analysis of topographic data suggests the survey unit has remained stable with very minor accretion occurring between 2007 and 2023. Maenporth beach displays a strong seasonal signal, with erosion occurring over the summer and autumn months, replaced by accretion in the winter and spring months, the opposite to what is usually expected on beaches in Cornwall, likely due to the sheltered nature of the beach.

Beach volume extracted from 6 LiDAR flights since 2007 have seen the Mobile Zone and Beach Zone to show similar trends to the topographic surveys; with the former showing gradual accretion despite significant fluctuation of volume between surveys (up to 68%). The Beach Zone has also remained stable between 2007 and 2022 and has followed a coupled response to the Mobile Zone despite significantly less fluctuation in volume.

Overall, Maenporth has been remained stable between 2007 and 2023, showing limited impact from the 2013/14 winter storms.

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1.0 Introduction

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

Maenporth is an east facing, dissipative pocket beach backed by a through road and river floodplain and confined by two rocky headlands (Fig.1). The beach has a cross-shore distance of 290 m and longshore distance of 200 m with an average spring tidal range of 4.6 m. Presently, there is no active dune system at Maenporth, however historic maps suggest there was previously, situated along the car park and road which have now replace it. The theoretical dune zones are presented in figure 1.

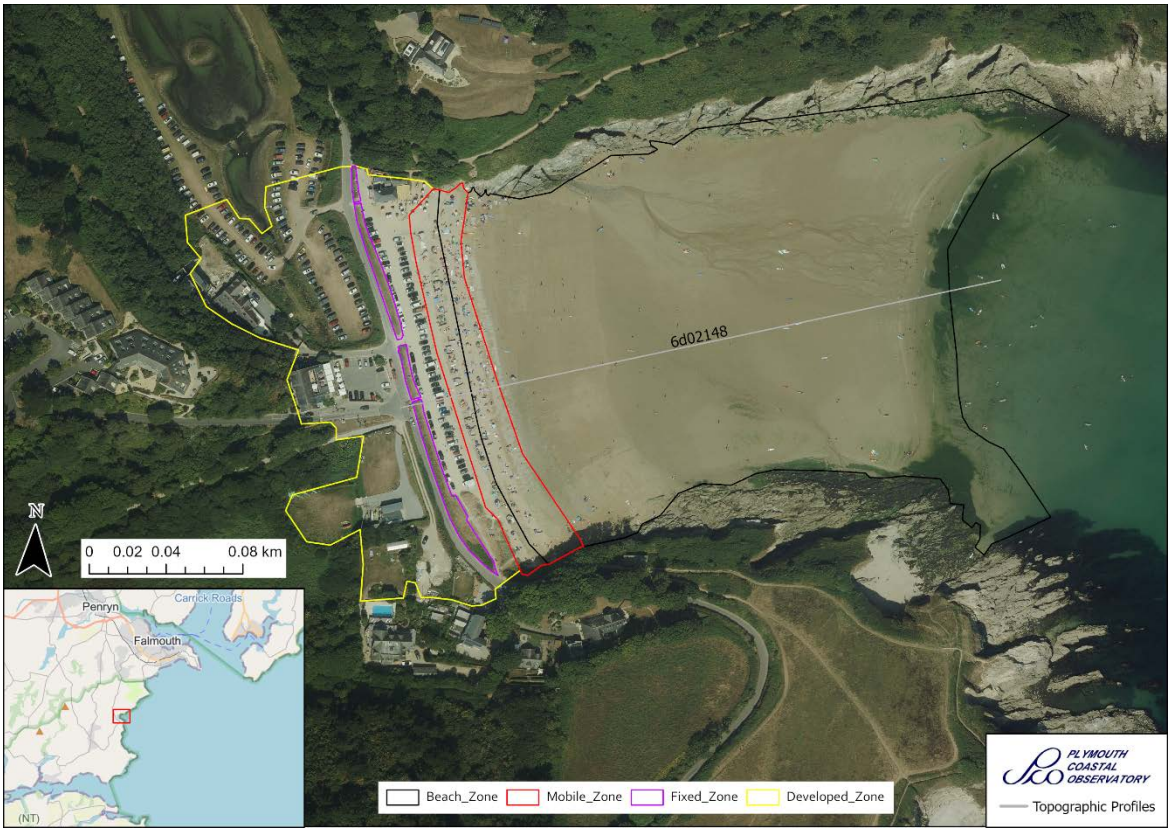


Figure 1 - Location Map of Maenporth Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

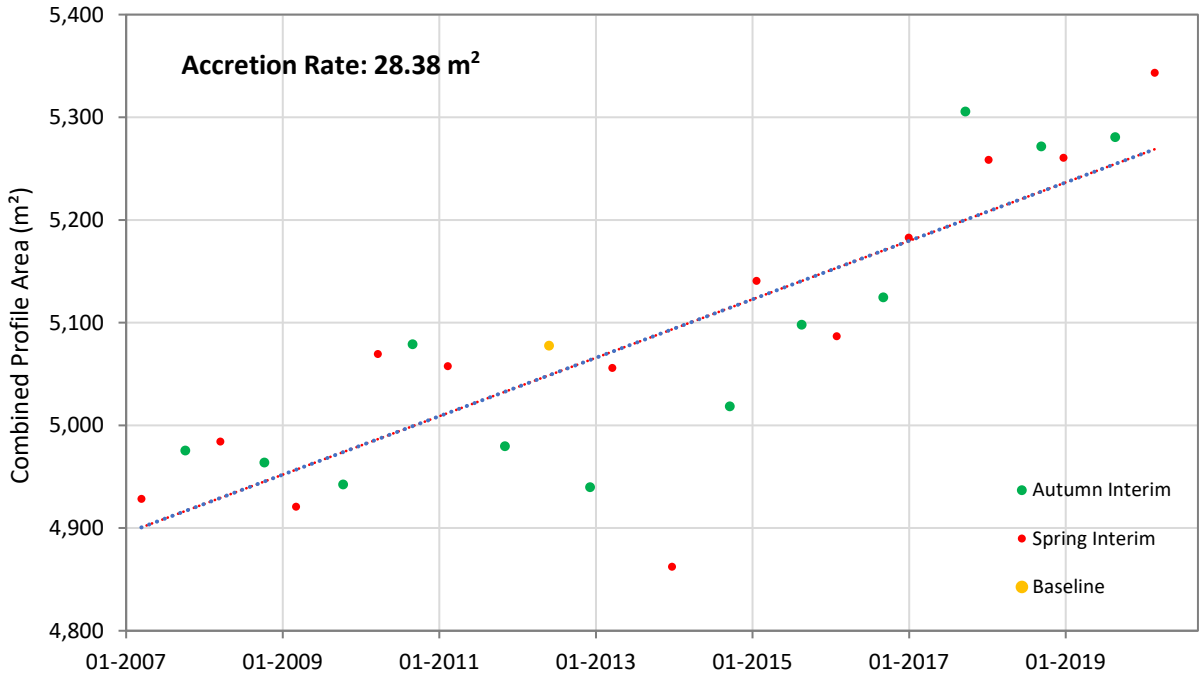


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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.

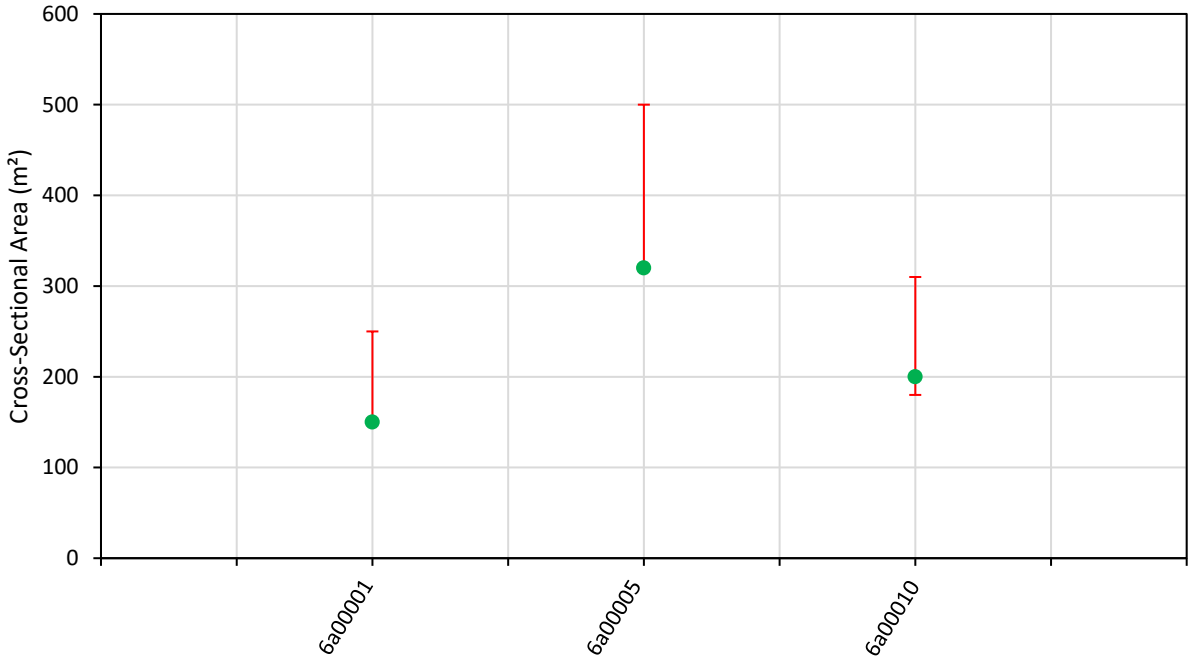


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

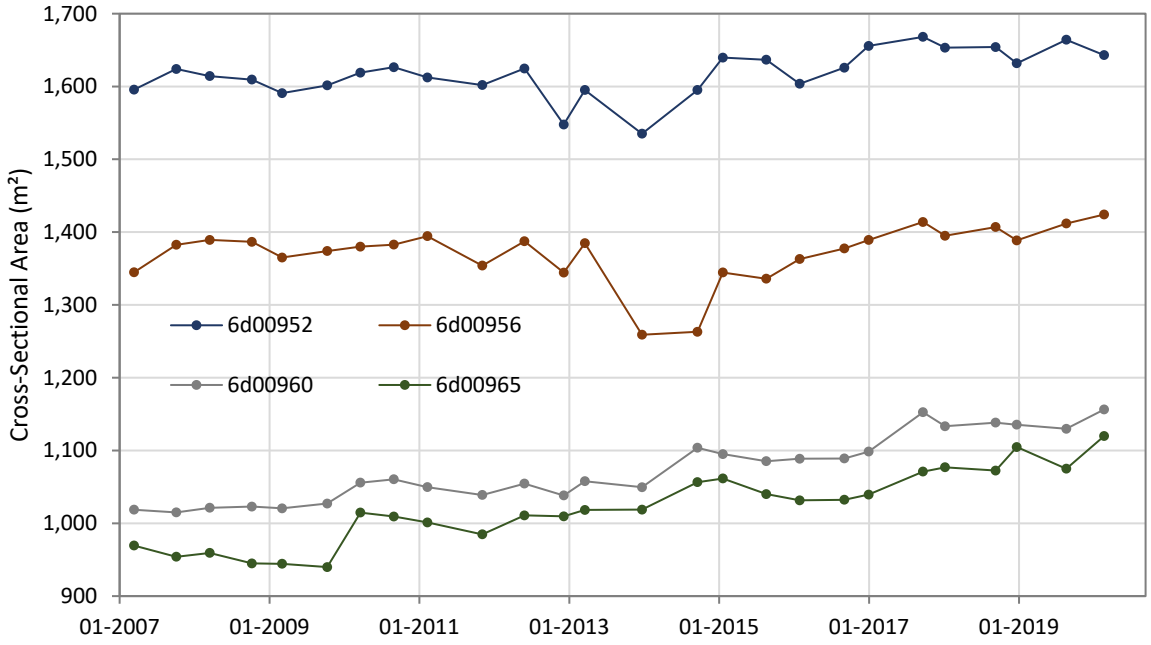


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 33 topographic surveys at Maenporth since 2007; 4 full coverage surveys and 29 interim surveys. Exact dates of each survey for Maenporth are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting very gradually at 1 m^2 y^{-1} equating to 0.2% 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, however the beach had recovered by the following year. The highest recorded combined area was during the 2017 baseline at 486 m^2 (Fig.5). It is clear from the CPA data that Maenporth displays a strong seasonal signal, however it is the opposite to what is usually expected, with spring interim surveys (red dots) indicating a more accreted beach and autumn interim surveys (green dots) showing a relatively eroded beach for each year (Fig.5).

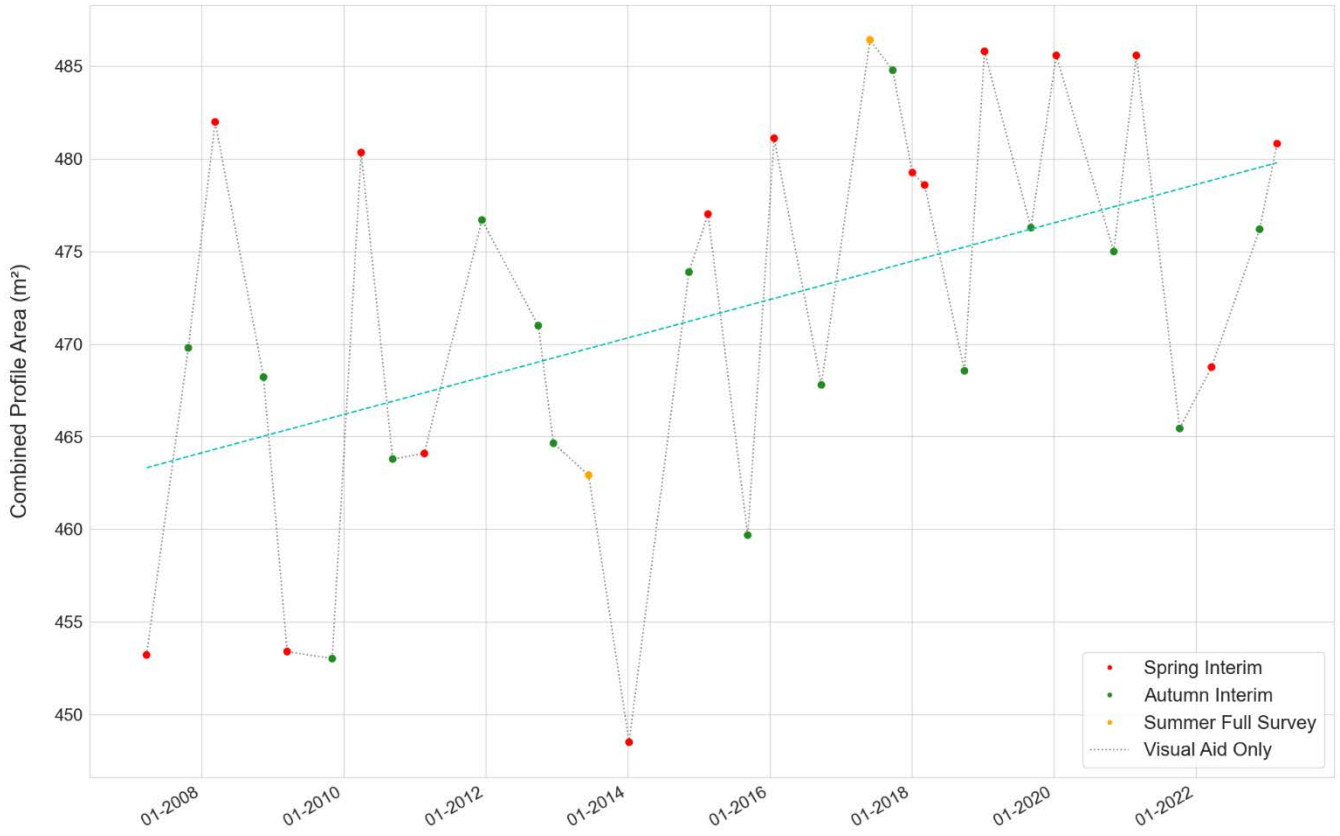


Figure 5 - The Combined Profile Area (CPA) for Maenporth, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing to the entire dataset (Fig.6), during the 2023 spring interim profile 6d02148 displayed an above average cross-sectional area when compared to the entire dataset.

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. Profile 6d02148 has seen an increase in beach material across the low-tide terrace when comparing the more recent surveys from 2023 to the initial 2007 survey.



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.

3.2 LiDAR Data Analysis

There has been a total of 6 LiDAR flights captured at Maenporth 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.

04/2007 to 03/2022 – Figure 7 shows the difference in elevation between the first filtered LiDAR data from 2007 compared to the most recent, captured in 2022. A large band of erosion can be seen across the upper beach to the south, with smaller areas of accretion found along the low tide mark and to the north of the upper beach face (Fig.7). Any change detected behind the car park can be presumed to be human impact.

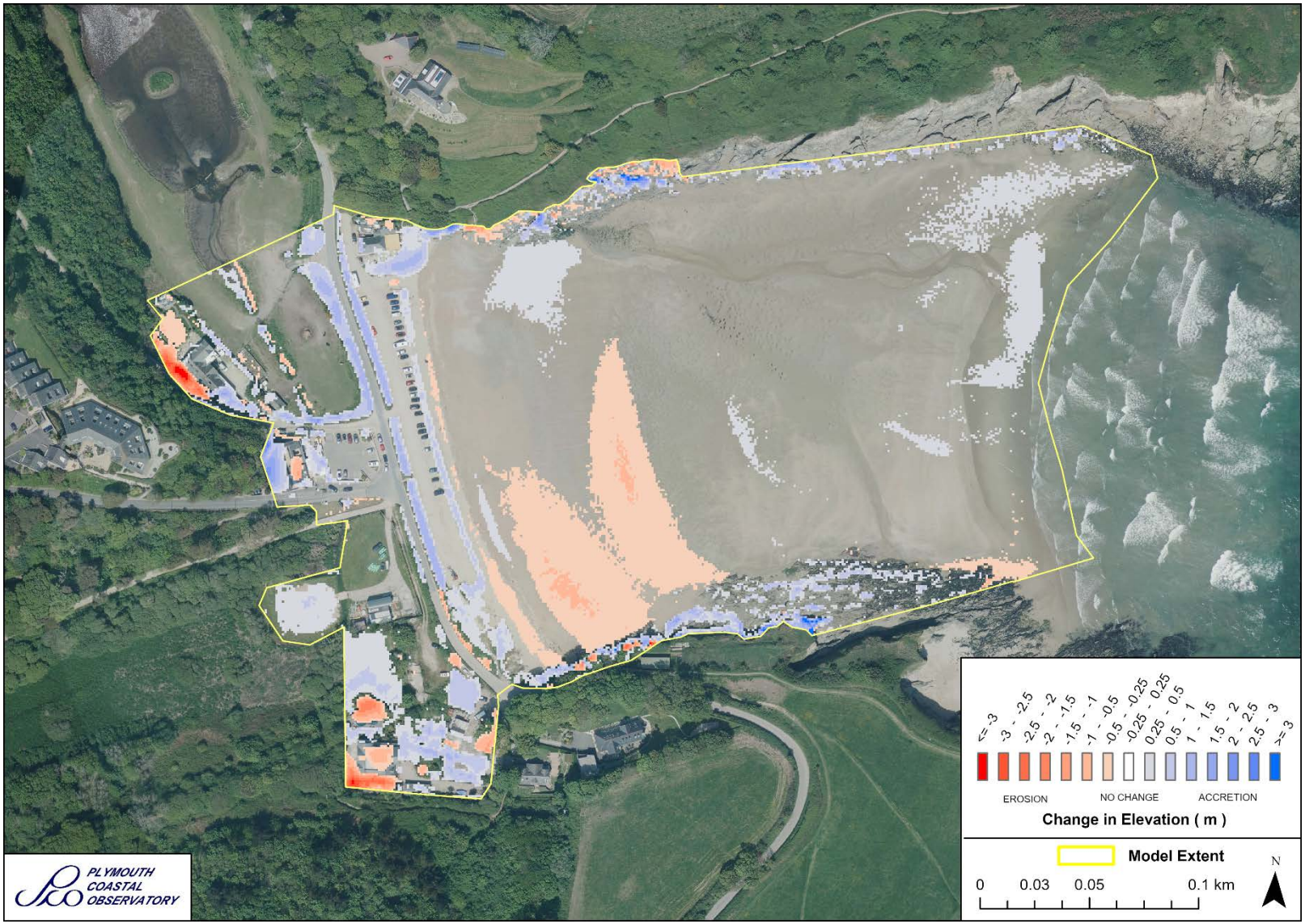


Figure 7 – Difference model indicating the changes in elevation observed between the April 2007 and March 2022 filtered LiDAR datasets within the yellow model extent.

04/2007 to 11/2009 – Figure 8 shows the difference in elevation between the first filtered LiDAR data from 2007 compared to November 2009. Again, a large band of erosion can be seen across the upper beach, predominantly to the south, with smaller areas of accretion found along the beach foot and across the low tide terrace (Fig.8).

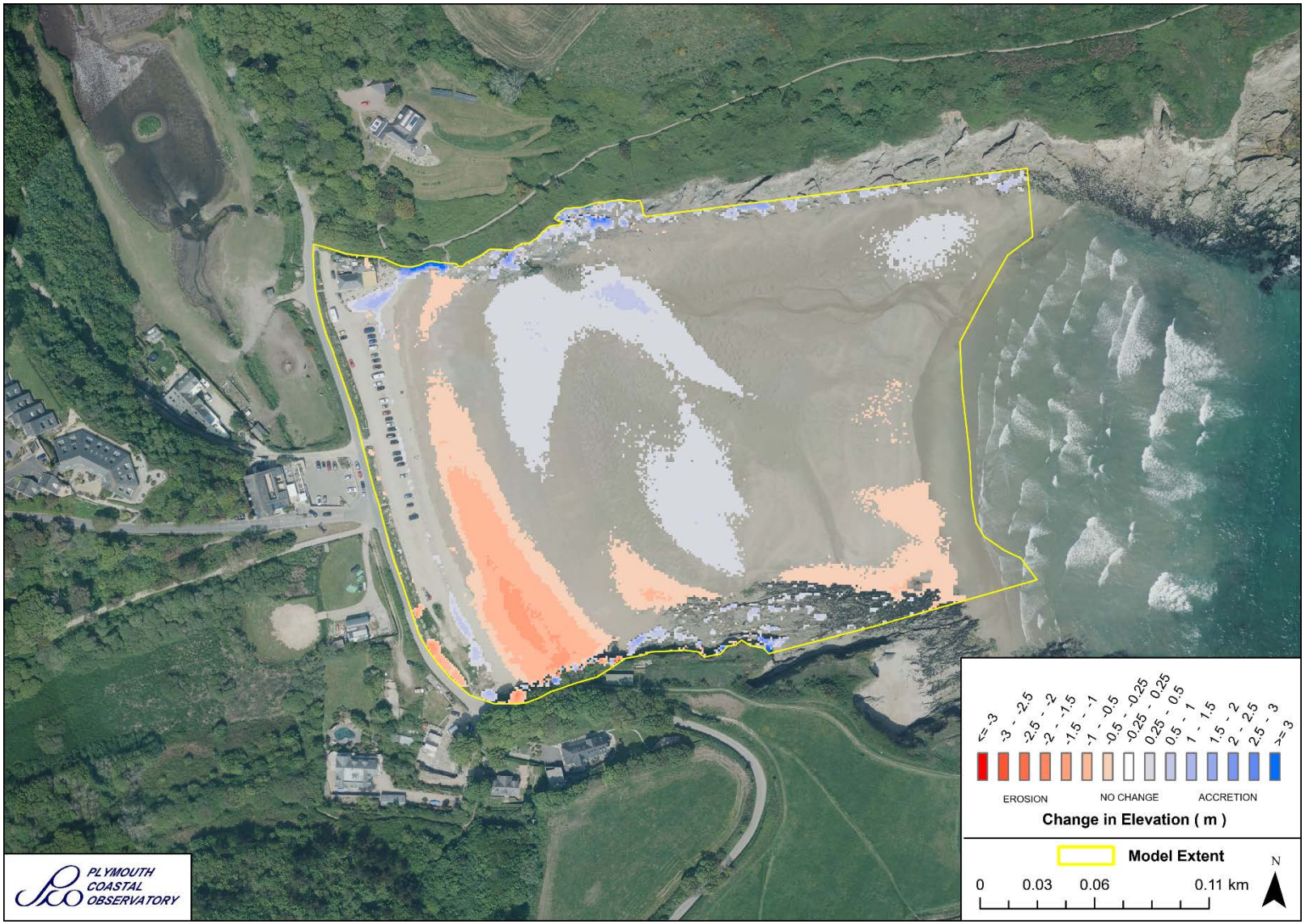


Figure 8 - Difference model indicating the changes in elevation observed between the April 2007 and November 2009 filtered LiDAR datasets within the yellow model extent.

11/2009 to 01/2011 – Figure 9 shows the difference in elevation between filtered LiDAR data from November 2009 and January 2011. A band of erosion showing a loss of between 0.25 - 0.5 m in elevation is visible along the beach toe and across the low tide terrace with minor accretion to the south of the upper beach face (Fig.9).

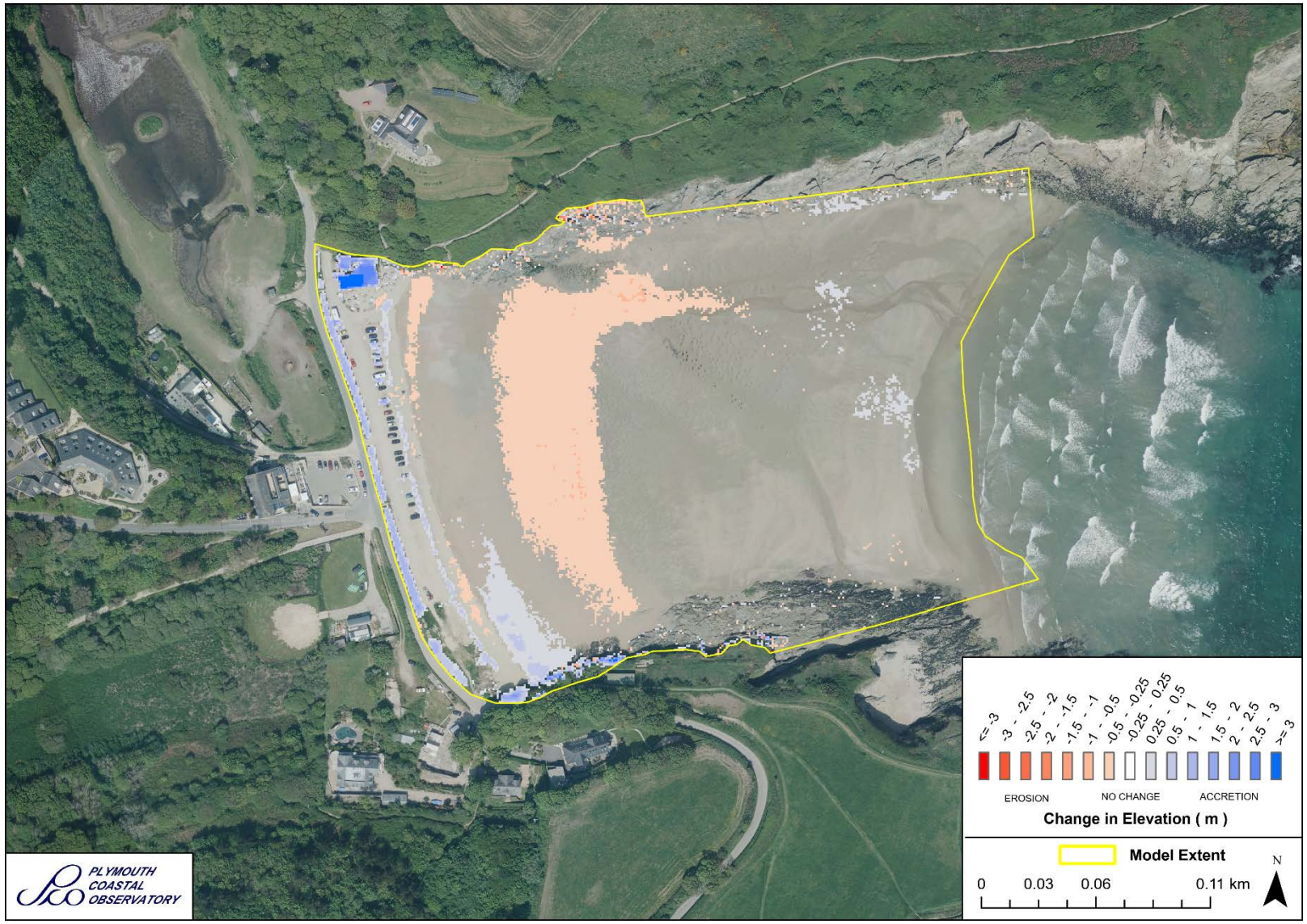


Figure 9 - Difference model indicating the changes in elevation observed between the November 2009 and January 2011 filtered LiDAR datasets within the yellow model extent.

11/2009 to 04/2013 – Figure 10 shows the difference in elevation between filtered LiDAR data from 2011 compared to 2013. In contrast to earlier year comparisons, there is a band of accretion observed across the upper beach face and along the low tide mark (in the range of 0.25 to 1.5 m elevation gain) with a relatively minor area of erosion along the centre of the beach (Fig.10).

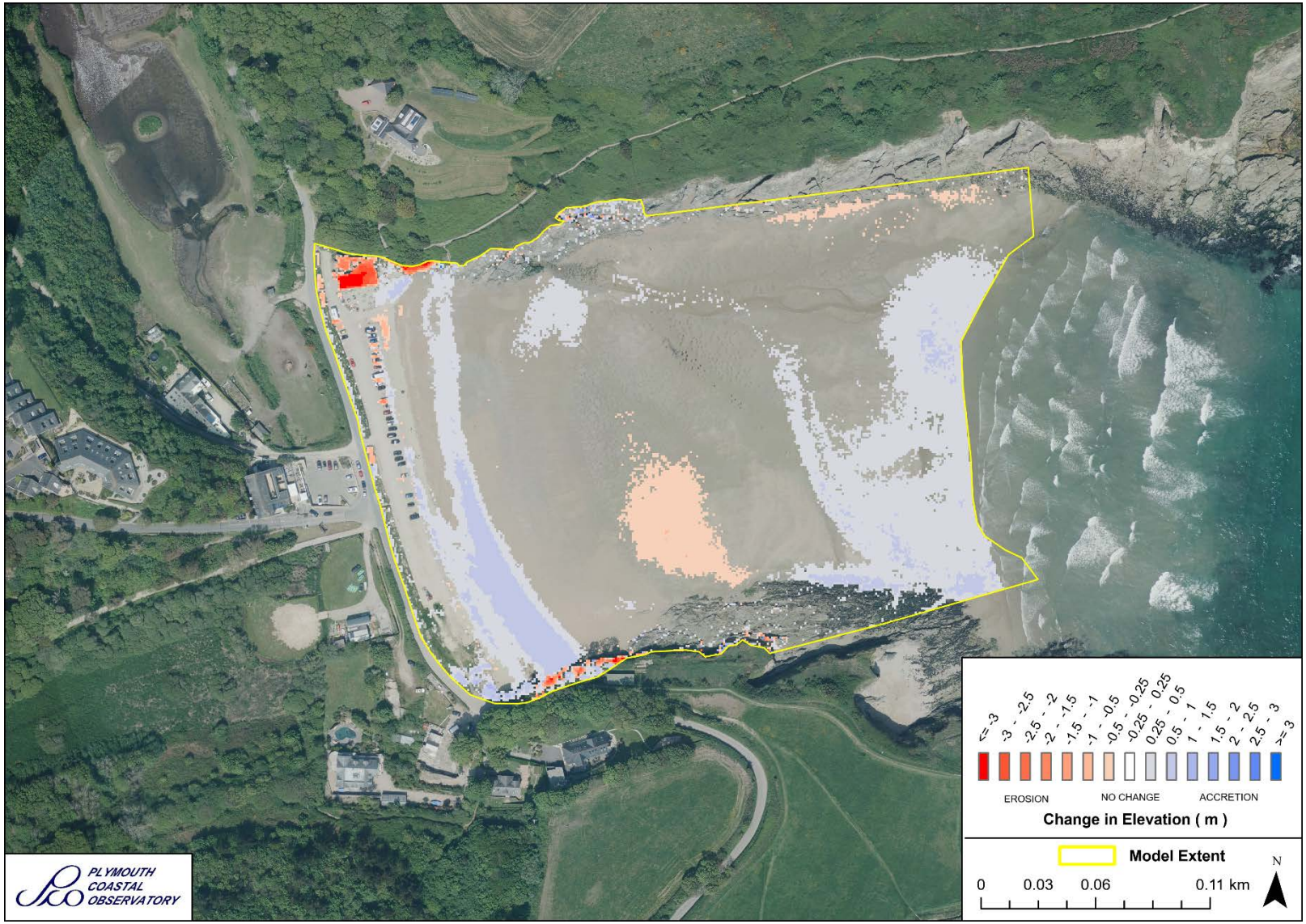


Figure 10 – Difference model indicating the changes in elevation observed between the November 2009 and April 2013 filtered LiDAR datasets within the yellow model extent.

04/2013 to 04/2019 – Figure 11 shows the difference in elevation between filtered LiDAR data from 2013 compared to 2019. Unfortunately, there is a large gap between these two datasets, however, the beach is dominated by erosion with the upper beach face and low tide mark indicating a loss of between 0.5 and 2 m in vertical elevation for much of the beach width (Fig.11). There is also a visible loss of material from the theorised dune toe area, with up to 2 m lost in vertical elevation directly in front of the car park and café areas (Fig.11), likely as a result of the 2013/14 winter storms.

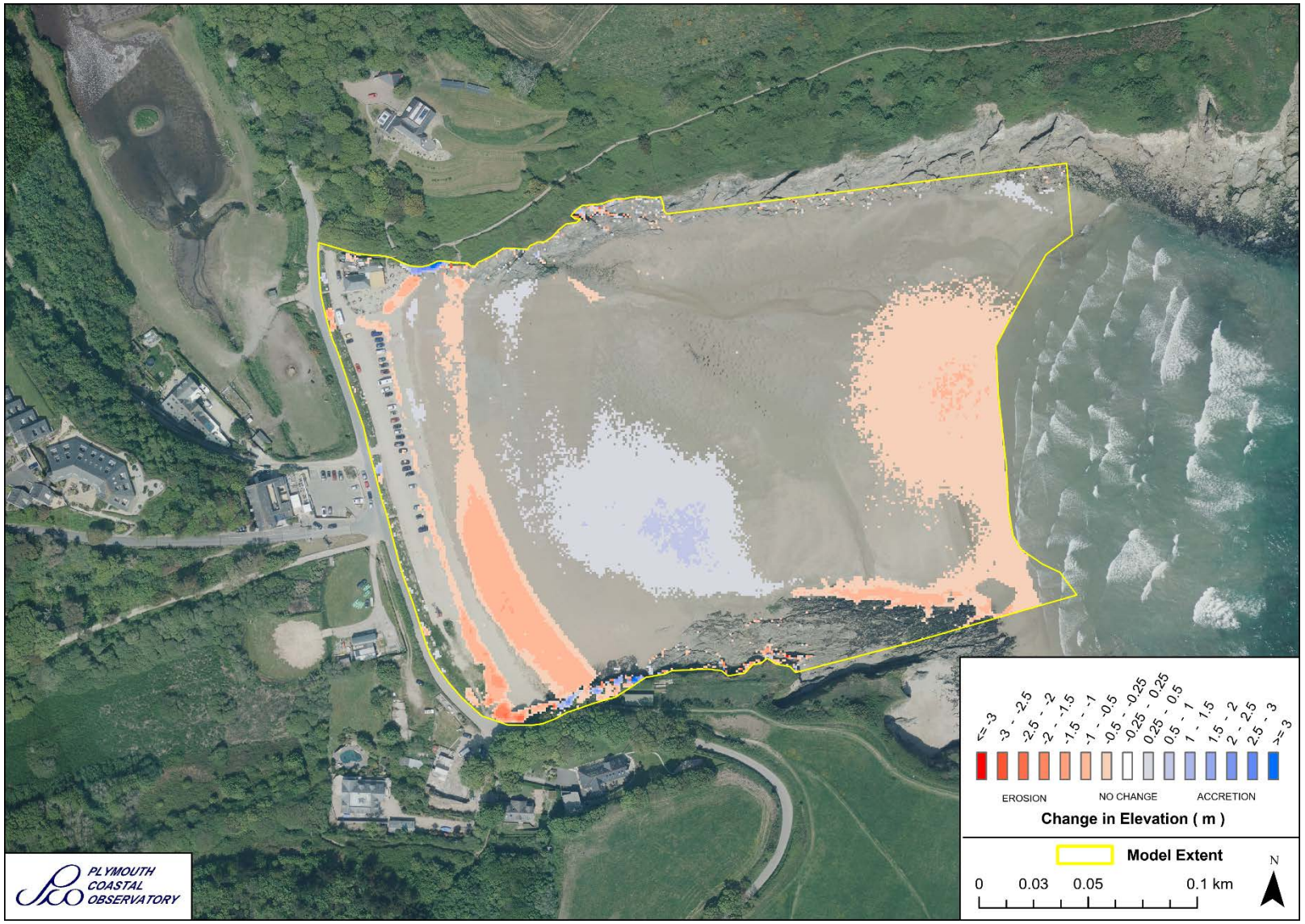


Figure 11 - Difference model indicating the changes in elevation observed between the April 2013 and April 2019 filtered LiDAR datasets within the yellow model extent.

04/2019 to 03/2022 – Figure 12 shows the difference in elevation between filtered LiDAR data from 2019 compared to 2022. There is minimal change from the previous difference model, with a near equal level of erosion and accretion distributed across the beach (Fig,12).

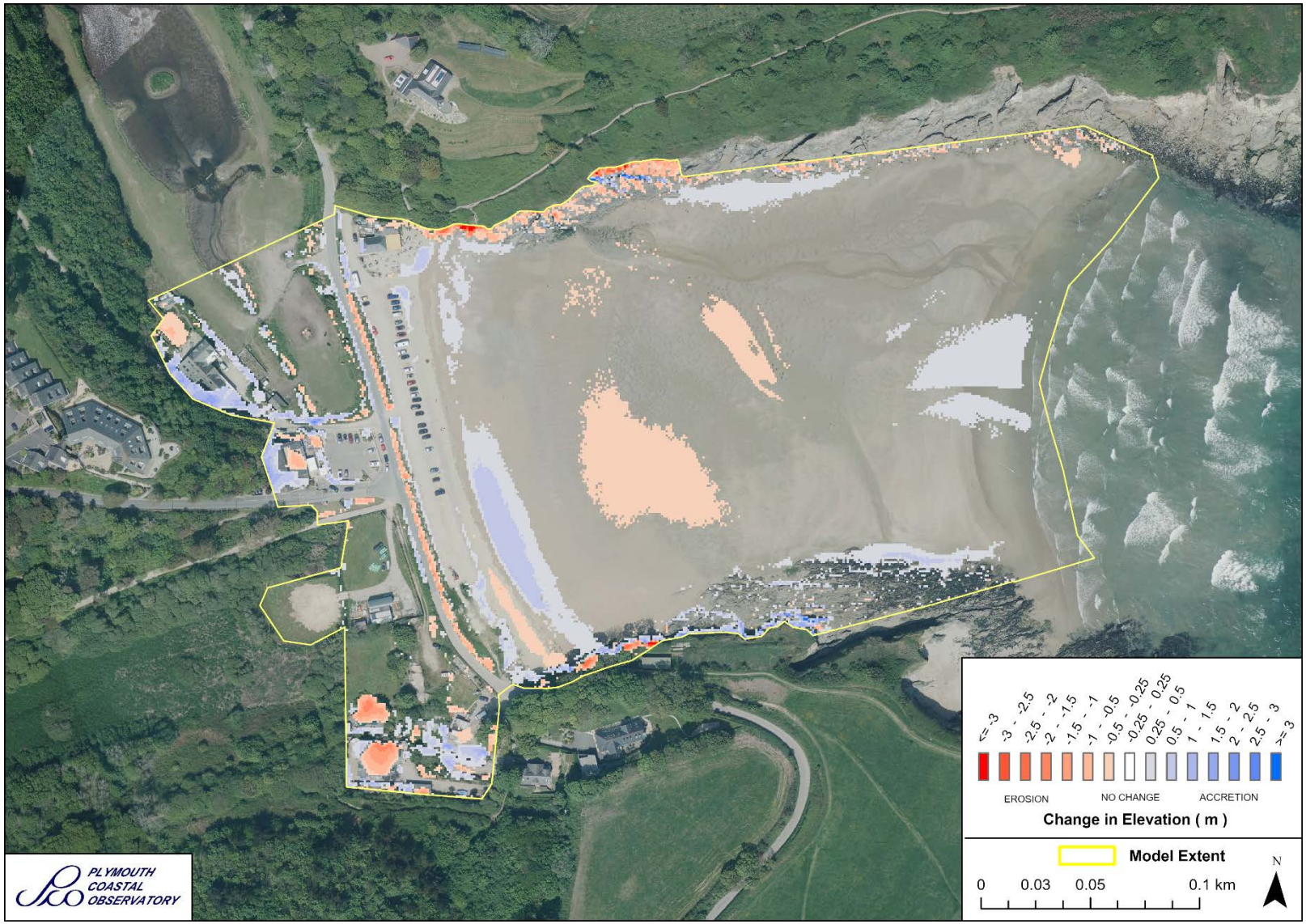


Figure 12 - Difference model indicating the changes in elevation observed between the April 2019 and March 2022 filtered LiDAR datasets within the yellow model extent.

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 and figure 13. Similar to the topographic data analysis, LiDAR data from the Mobile Zone has remained stable with a very gradual accretion between 2007 and 2022, with the highest volume recorded during the 2013 survey at 2,263 m^3 (Fig.13). The Mobile Zone has fluctuated significantly between surveys, with the largest change between the 2011 and 2013 surveys, seeing a 68% increase in volume (Fig.13).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.11 m OD) are shown in Table 1 and figure 14. The Beach Zone has also remained stable between 2007 and 2022. Similarly to the Mobile Zone trend, the lowest recorded volume was during the 2011 survey, and highest volume during the 2013 survey (Fig.14). Despite fluctuations in volume between LiDAR datasets, there is minimal percentage change, with the largest difference being a <1% loss of material between the 2011 and 2013 surveys (Fig.14).

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 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
04/2007	2,192	60,955
09/2009	1,480	61,240
01/2011	1,346	58,931
04/2013	2,263	62,021
04/2019	1,666	61,838
03/2022	2,073	59,999

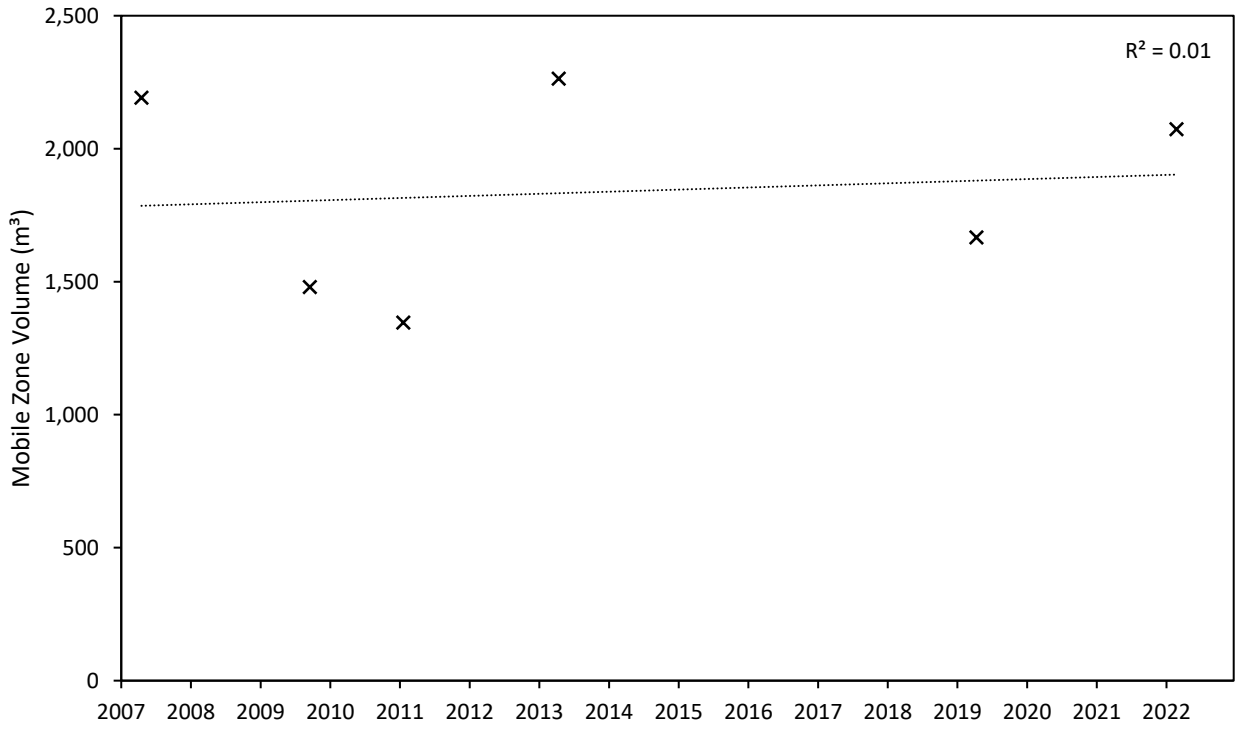


Figure 13 – Plot indicating beach volume (m3) recorded in the Mobile Zone above MHWS (2.49 m OD) for each filtered LiDAR datasets between 2007 and 2022.

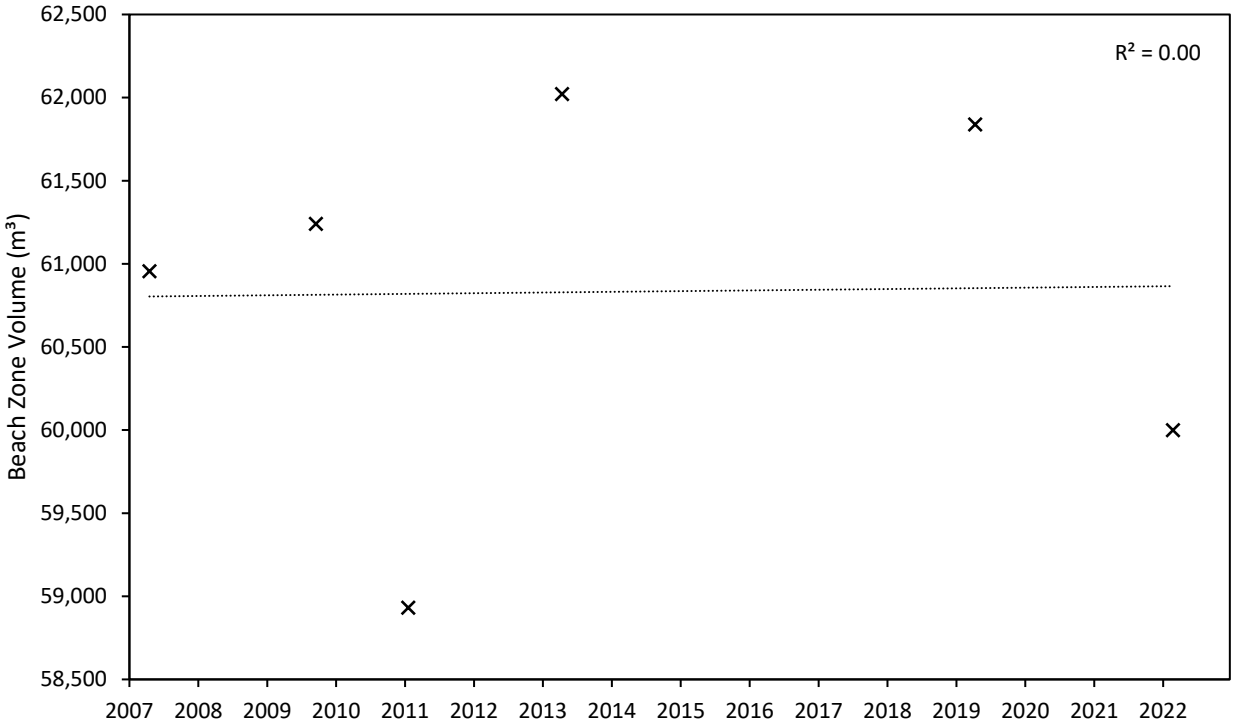


Figure 15 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.11 m OD) for each filtered LiDAR datasets between 2007 and 2022.

3.2.3 Contour Comparison

Figure 16 indicates the Mean Sea Level (MSL) and dune toe contours from the 2007, 2014, 2019 and 2022 LiDAR datasets. MSL contours indicate a slight rotation of the beach from 2007 to 2022, with the 2022 contour advancing to the north and retreating to the south (Fig.16). The dune toe contours indicate an advancing Mobile Zone by up to 5 m along the northern extent of the beach between 2007 and 2022 (Fig.16).

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.

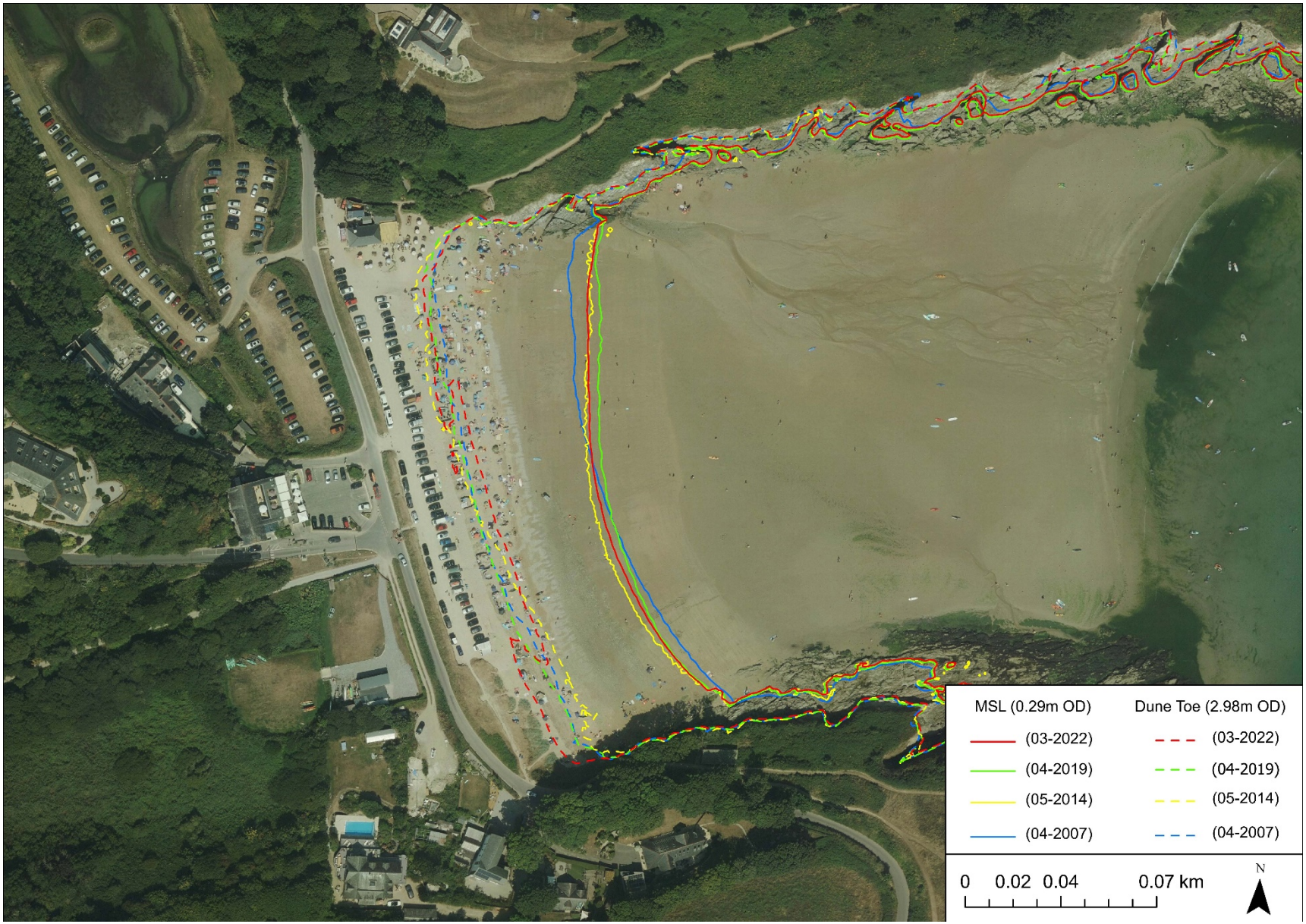


Figure 15 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2007, 2014, 2019 and 2022 LiDAR datasets.



Figure 16 – Aerial imagery from 1947.

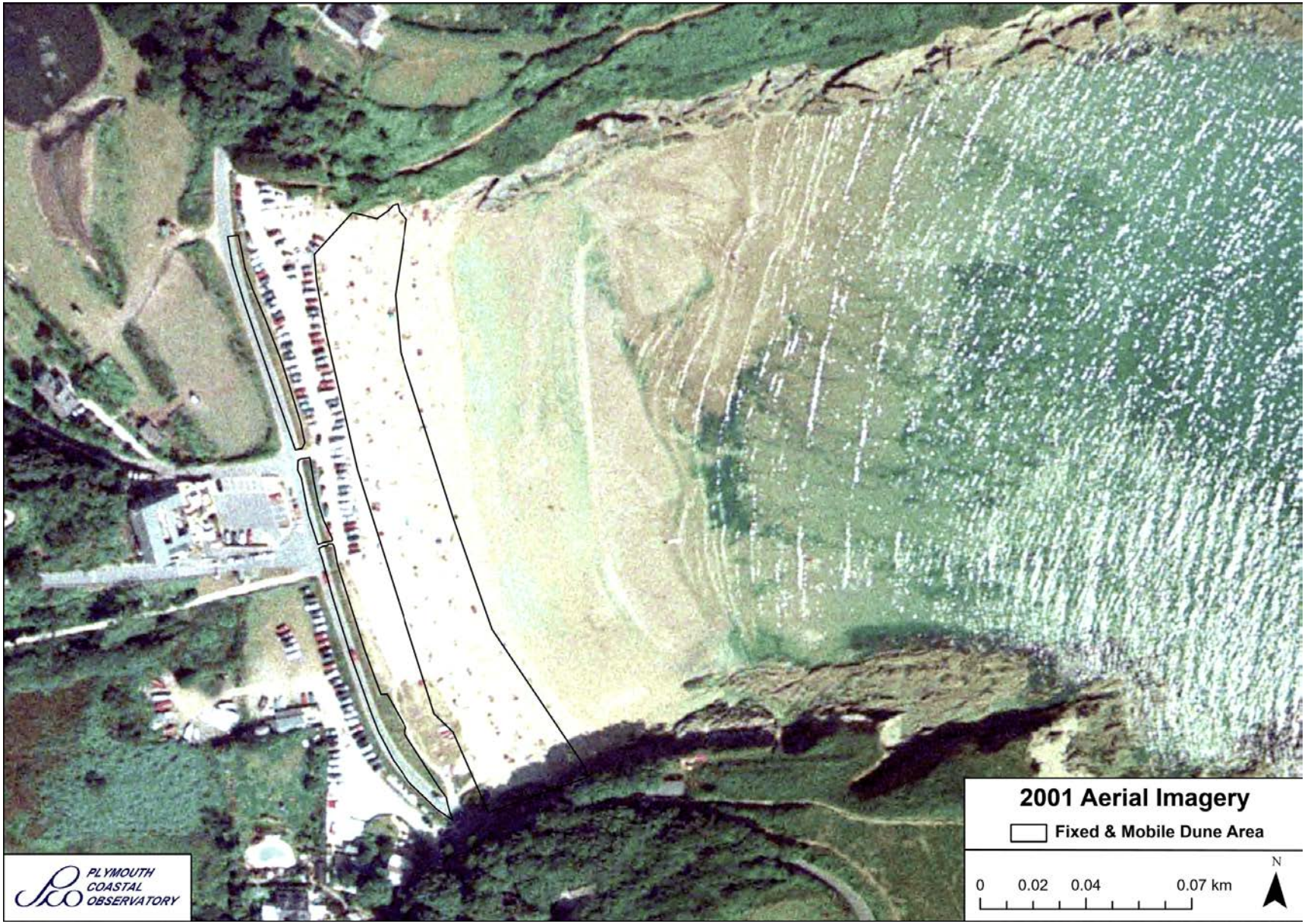


Figure 17 – Aerial imagery from 2001.

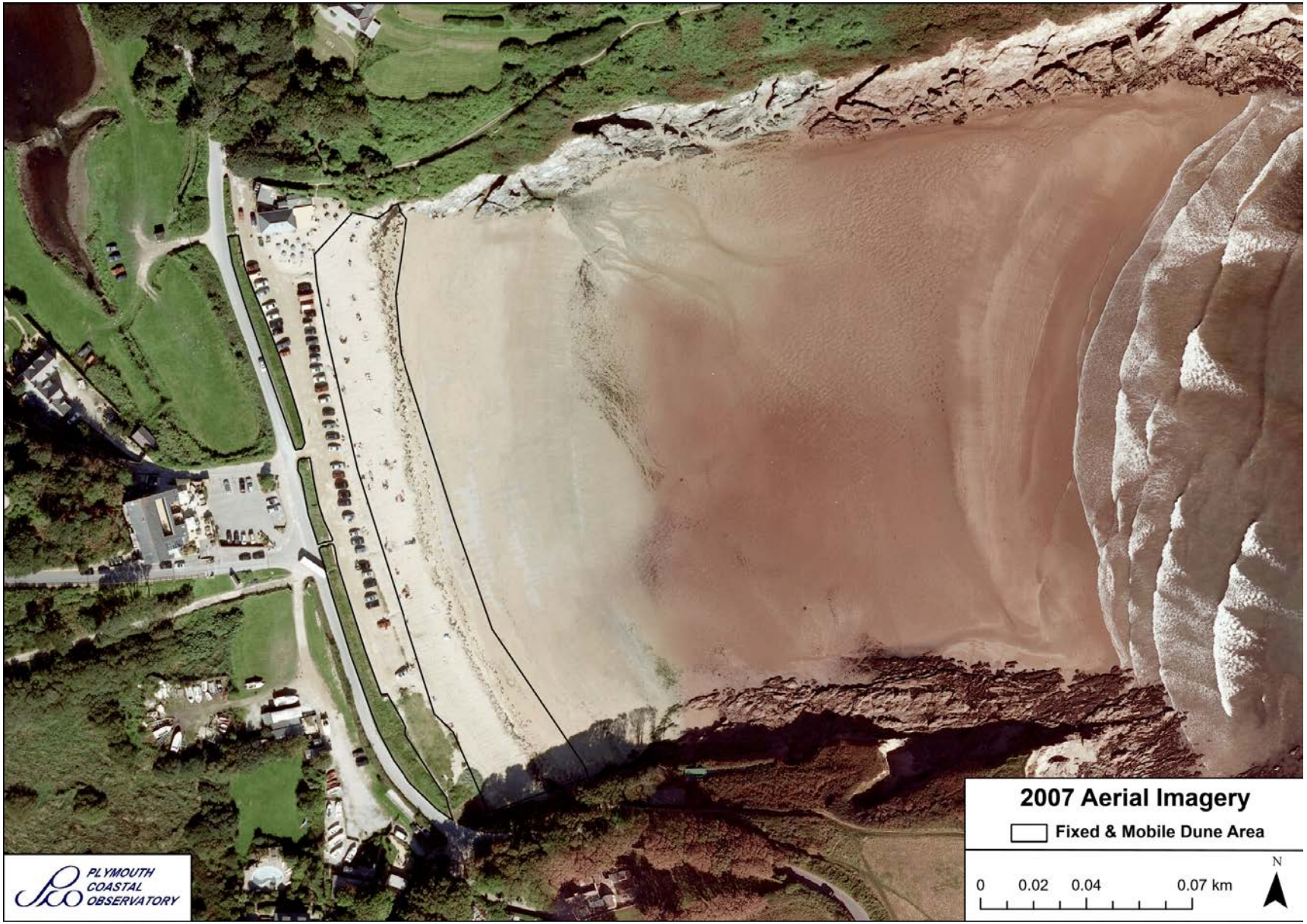


Figure 18 – Aerial imagery from 2007.



Figure 19 – Aerial imagery from 2009.

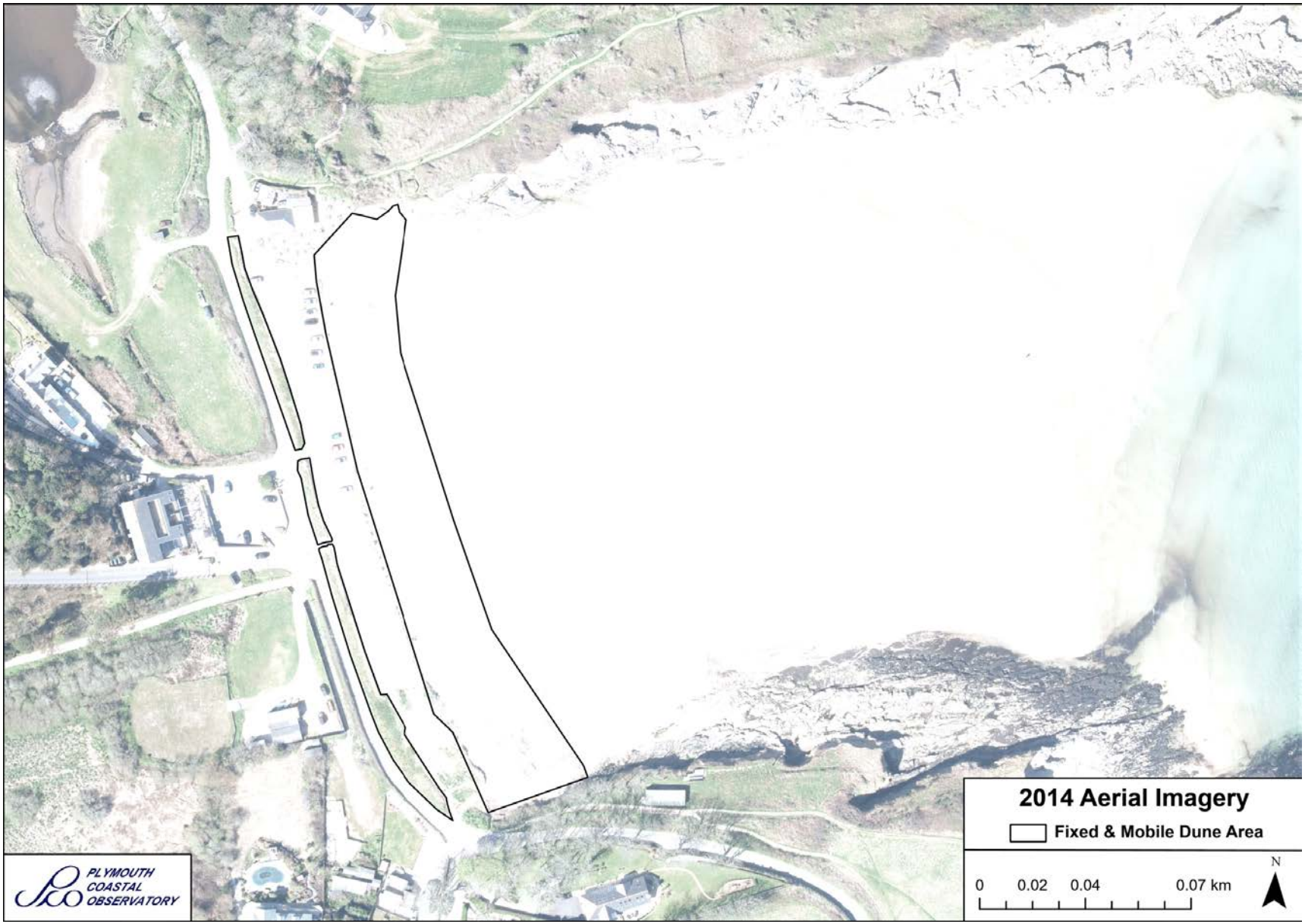


Figure 20 – Aerial imagery from 2014.



Figure 21 – Aerial imagery from 2018.



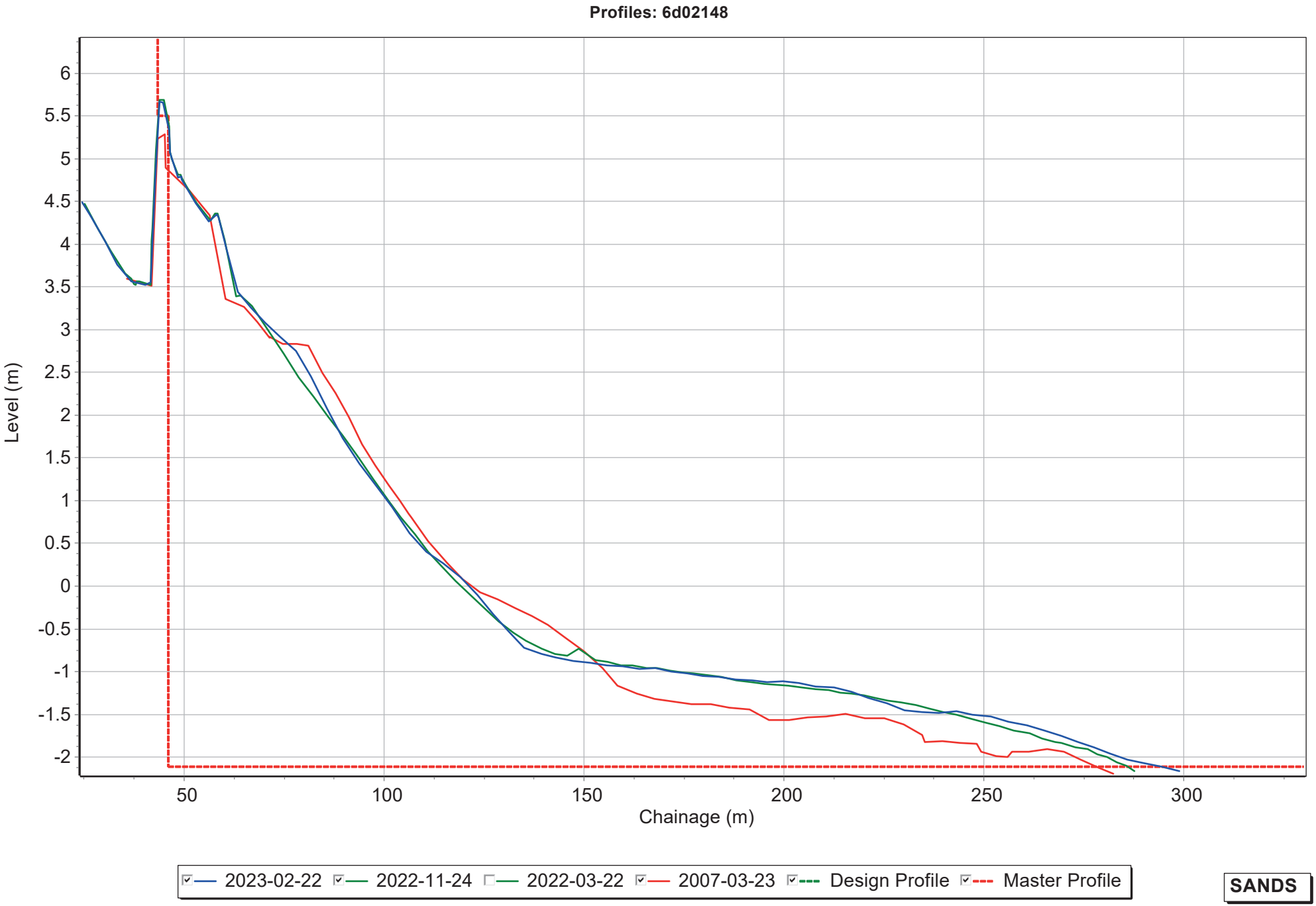
Figure 22 – Aerial imagery from 2022.

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 Maenporth are presented below.


Profiles: 6d02148
Level (m)
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
Chainage (m)
2023-02-22
2022-11-24
2022-03-22
2007-03-23
Design Profile
Master Profile

SANDS