SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Porthtowan Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR20 | 18/04/2024

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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 Porthtowan. The aim is to highlight coastal change at Porthtowan using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Porthtowan Beach, a small west north-westerly facing sandy beach over 200 m in width and 450 m in length, is detailed as the study site. 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 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.

Since 2007, 34 topographic surveys were conducted at Porthtowan, including 4 full coverage and 30 interim surveys. Analysis of topographic data suggests the survey unit has remained relatively stable between 2007 and 2024. Notable fluctuations were observed in survey results, with the lowest combined area recorded in 2016 and the highest in 2012. In 2024, both profiles showed below-average cross-sectional area values. Despite seasonal variation, profiles generally remained stable, with a loss in cross-sectional area after the 2016 winter period. This unit was not affected by the 2013/2014 storms.

Beach volume was extracted from the Beach and Mobile Zones from 5 LiDAR flights between 2008 and 2023. Volume extracted from the Mobile Zone has seen gradual erosion, losing 7% of material between 2008 and 2013, with the lowest volume recorded during the latest 2023 survey. Similarly, the Beach Zone has also shown gradual erosion, seeing a 3% loss in volume between 2008 and 2023 with the latter recording the lowest volume on record. Both the Beach and Mobile Zone saw limited impact from the 2013/14 winter.

Overall, Porthtowan beach has remained relatively stable with more recent observations of gradual erosion between 2007 and 2023.

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1.0 Introduction

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

Porthtowan is a small west north-westerly facing sandy beach over 200 m in width and 450 m in length (Fig.1). It is an Area of Outstanding Natural Beauty (AONB) backed by a small dune system and high hard rock cliffs to the north and south. There is also a stream running through the centre of the village along-side the car park in the middle of the dune system. In recent years the community has planted marram grass along the dune face as well as constructing a fence around the dune face to allow the dune to re-establish itself.



Figure 1 - Location Map of Porthtowan 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).

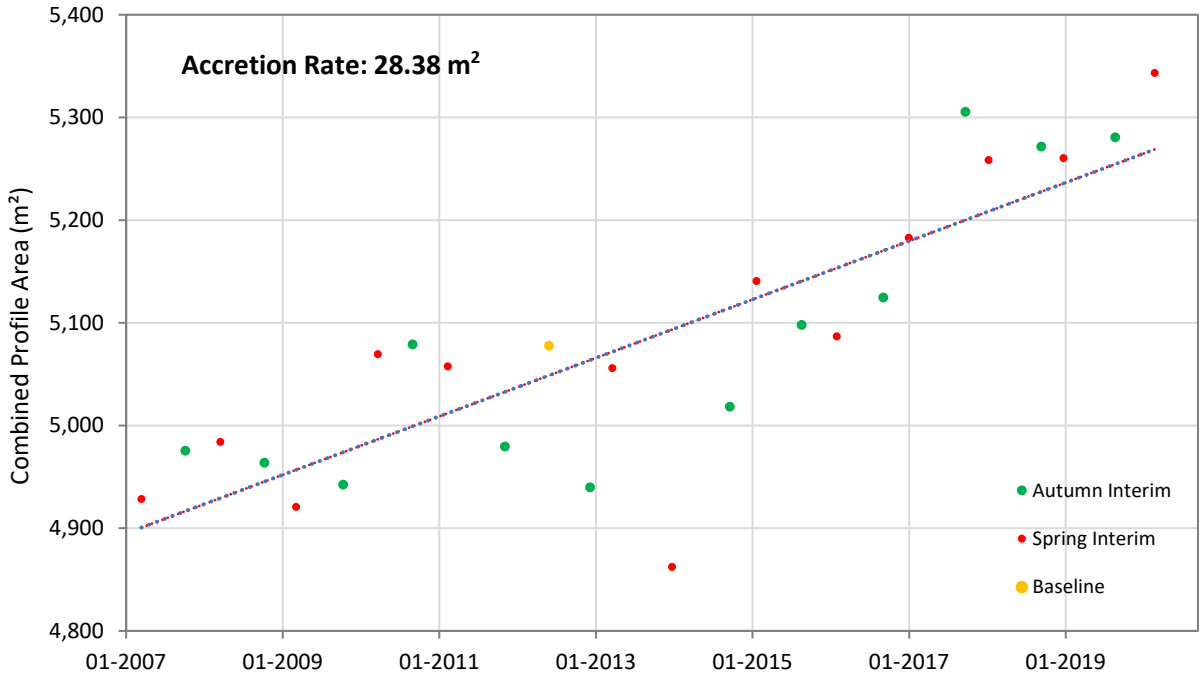


Figure 2 - Example of trend analysis for CPA for each interim and baseline survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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.

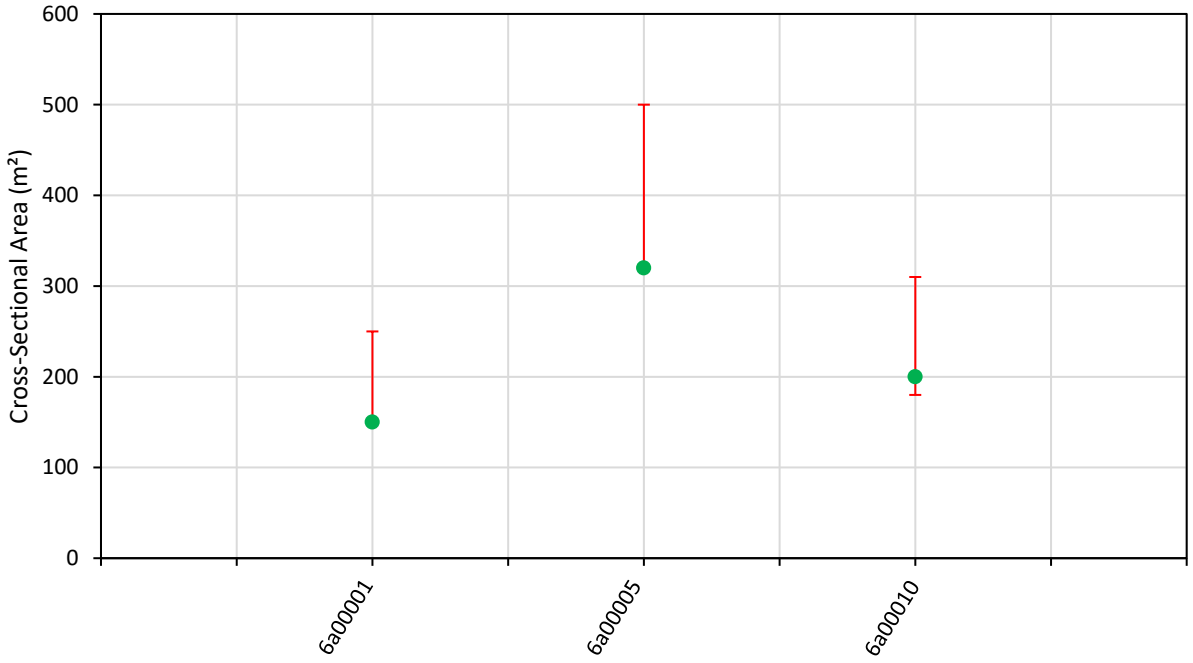


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

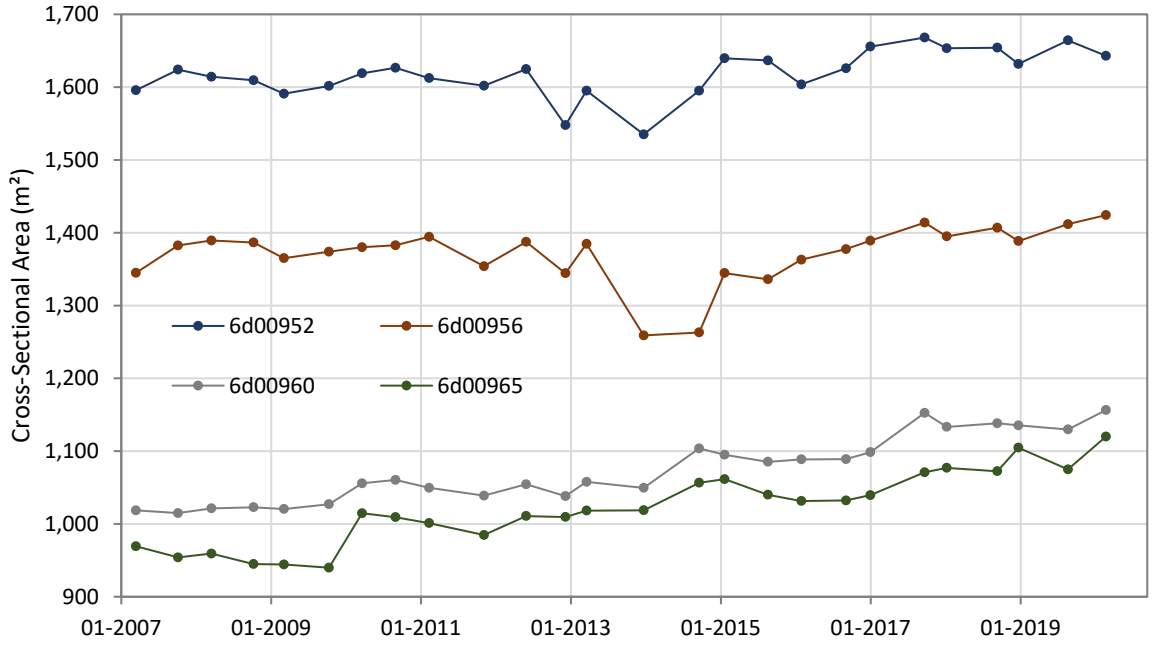


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 34 topographic surveys at Porthtowan since 2007; 4 full coverage surveys and 30 interim surveys. Exact dates of each survey for Porthtowan are available to view on our survey record. Analysis of the CPA indicates the survey unit has been eroding at 2.7 m^2 y^{-1} equating to 0.09% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2016 spring interim (2,509 m^2) however the beach had recovered by the following year. The highest recorded combined area was during the autumn interim of 2012 (3,107 m^2).

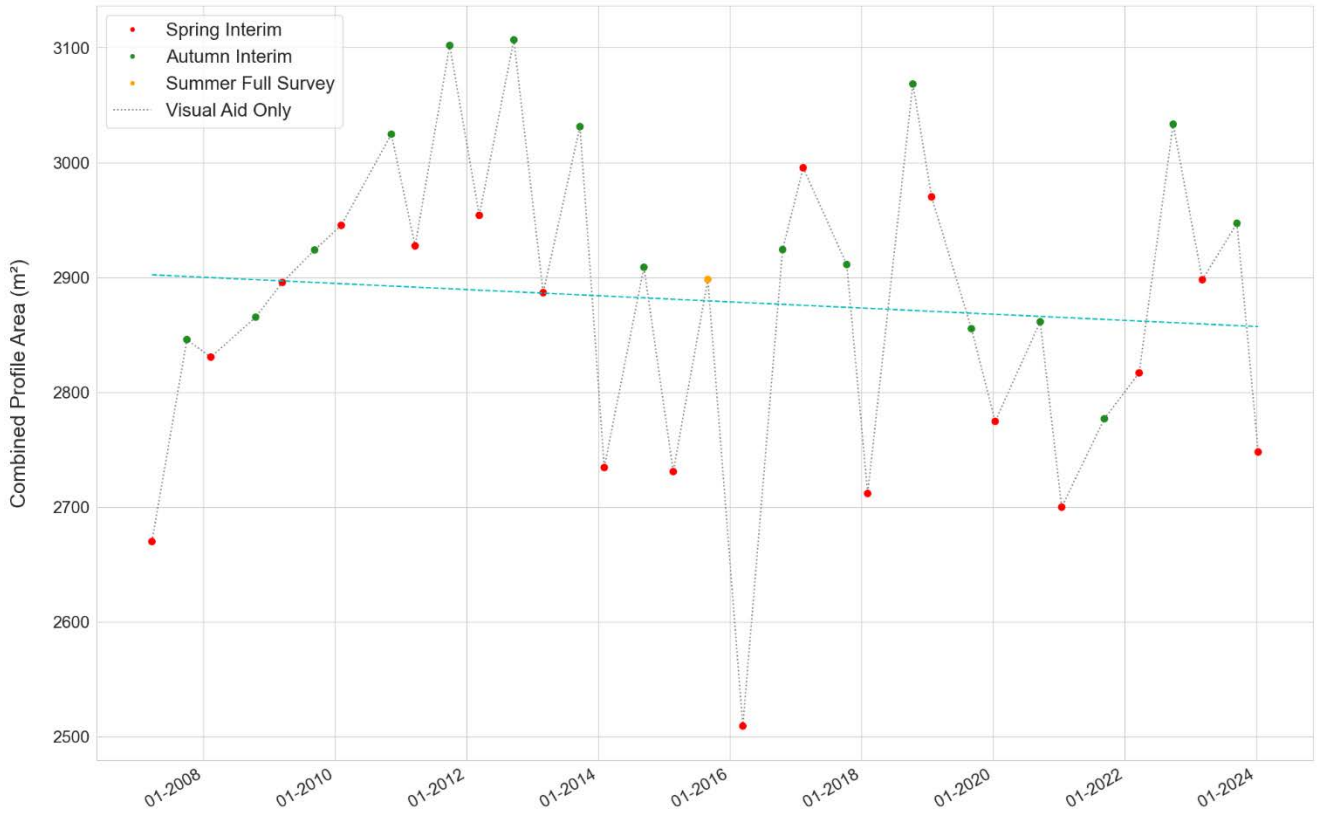


Figure 5 - The Combined Profile Area (CPA) for Porthtowan, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When comparing to the entire dataset (Fig.6), during the 2024 spring interim both profiles at Porthtowan profiles were displaying below average cross-sectional area.

When comparing profile cross-sectional areas to the entire time series (Fig.7), all profiles again have displayed seasonal variation, with a noticeable impact seen in both profiles in the 2016 spring interim.

Profile Charts for Porthtowan 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. Both profiles have seen accretion along the top of the beach, as well as ~0.5 m of elevation along the lower half of the beach.

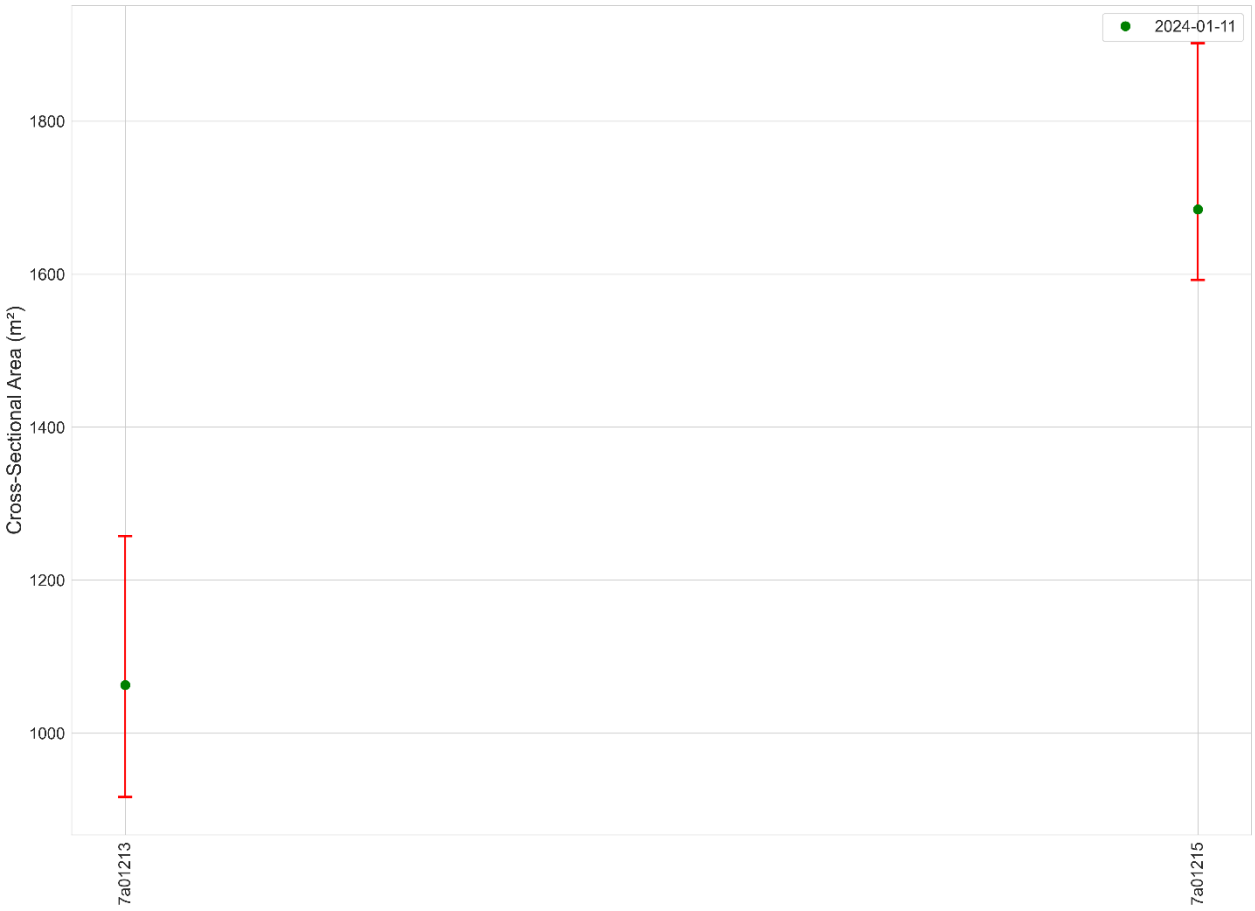


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2024.

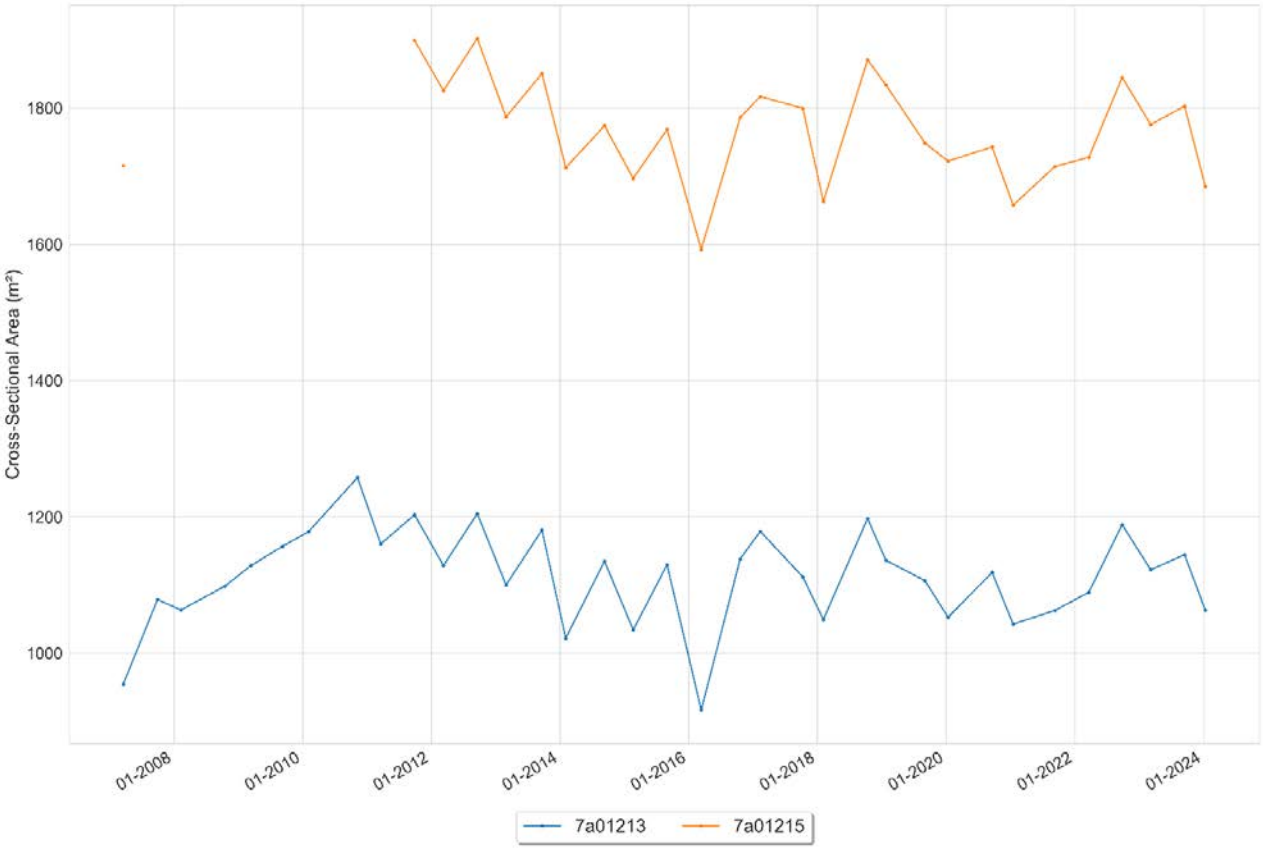


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

There has been a total of 5 LiDAR flights captured at Porthtowan 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 January 2023. The majority of the beach has experienced low-level erosion, as well as the northern end of the upper beach. Considerable accretion is suggested to the south, along the dune and beach face, followed by erosion in the foredune.

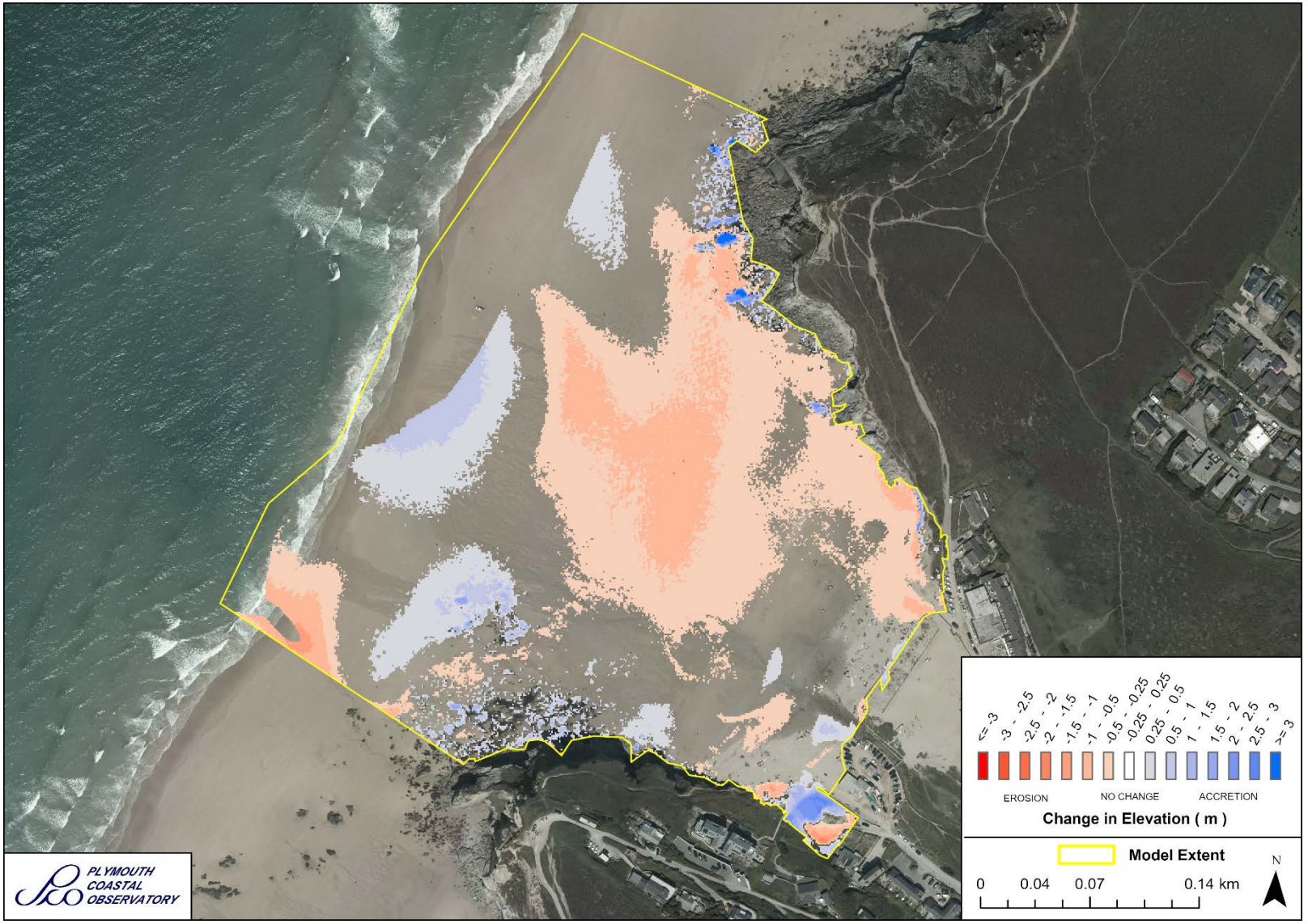


Figure 8 – Difference model indicating the changes in elevation observed between the March 2008 and January 2023 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from March 2008 compared to March 2011. Low-level erosion can be observed along the upper beach/embryo dune. Medium-level erosion is indicated on the southern dune system, followed by accretion on the exposed edge. The lower half of the beach has seen widespread accretion, gaining up to 1.5 m in elevation.

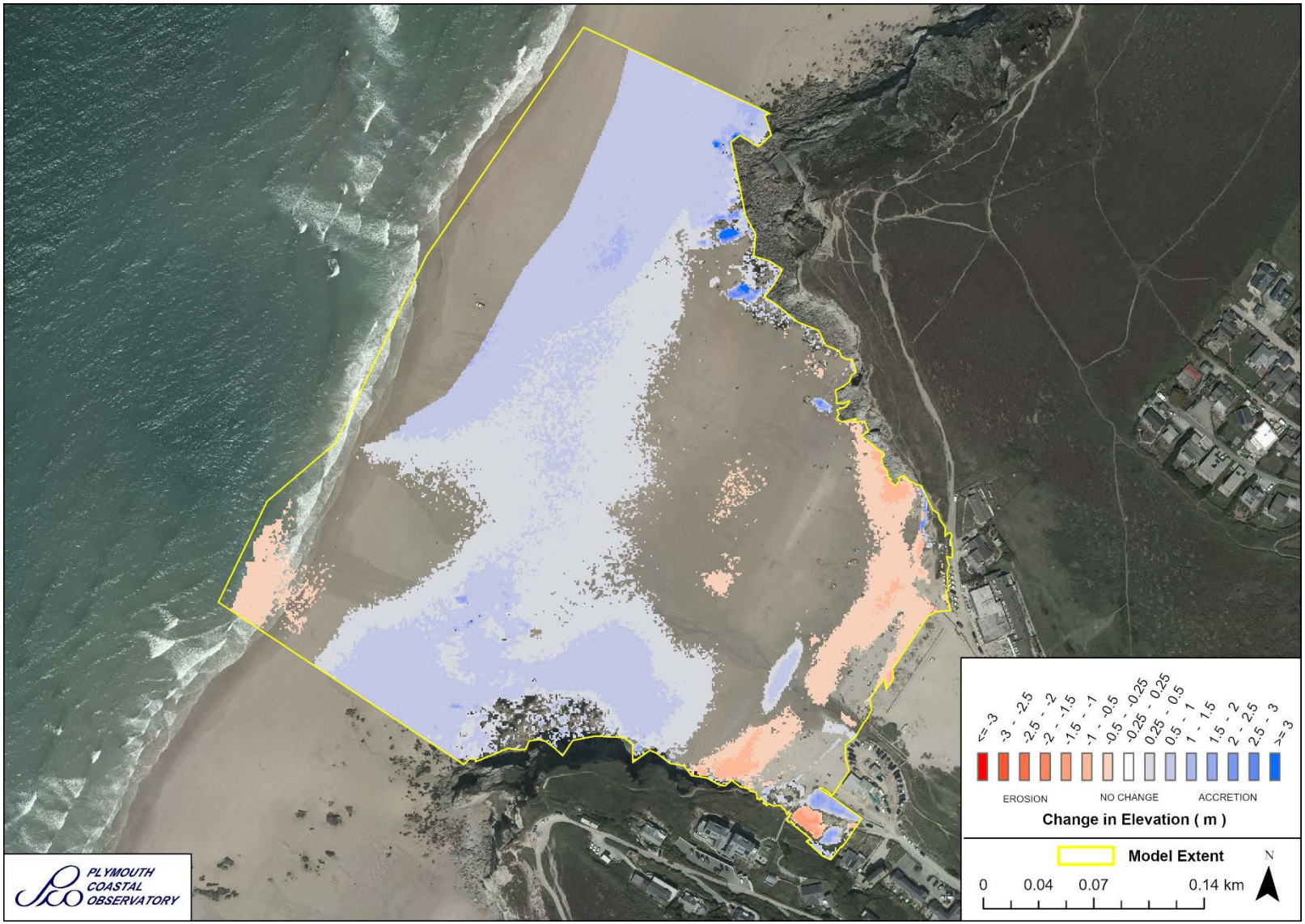


Figure 9 - Difference model indicating the changes in elevation observed between the March 2008 and March 2011 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from March 2011 compared to April 2014. Widespread erosion is seen on the lower half of the beach, losing up 1.5 m in some areas, whereas the upper beach has seen a sand bar form, increasing beach elevation by up to 2.5 m. A strip of low-level erosion is present on the embryo dune, as well as on the dunes to the south. Some accretion can be observed on the foredunes to the south.

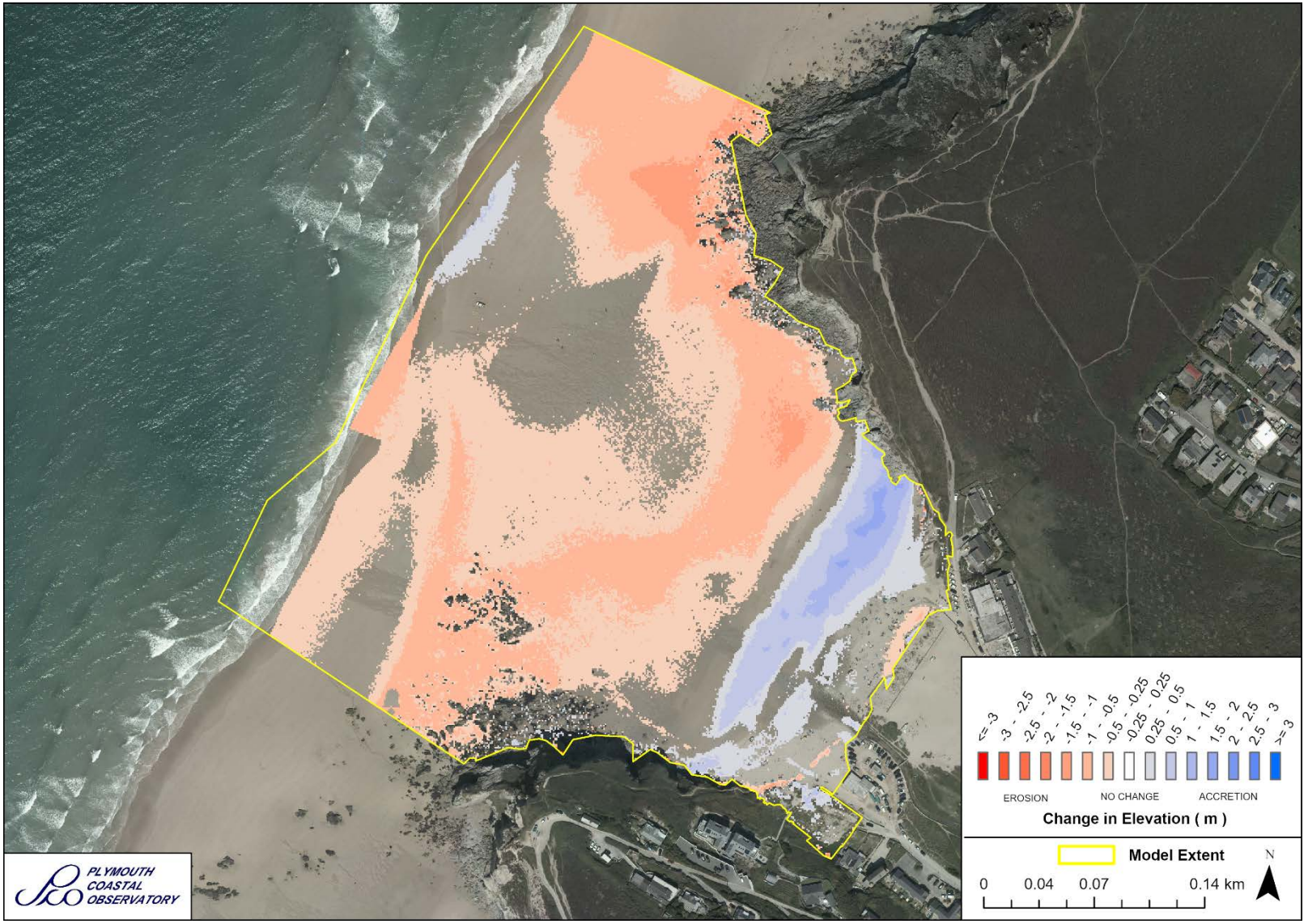


Figure 10 - Difference model indicating the changes in elevation observed between the March 2011 and April 2014 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from April 2014 compared to April 2019. In contrast to that observed in Figure 10, there is widespread accretion along the MSL mark for most of the beach, accreting by up to 1.5 m in places. A relatively large area of erosion can also be observed just below the high-water mark, losing up to 1.5 m. On the upper beach low-level accretion can be seen along the embryo dune, whilst the dune to the south has seen low-level erosion on the dune face. Acute erosion and accretion can be seen in the south, due to construction.

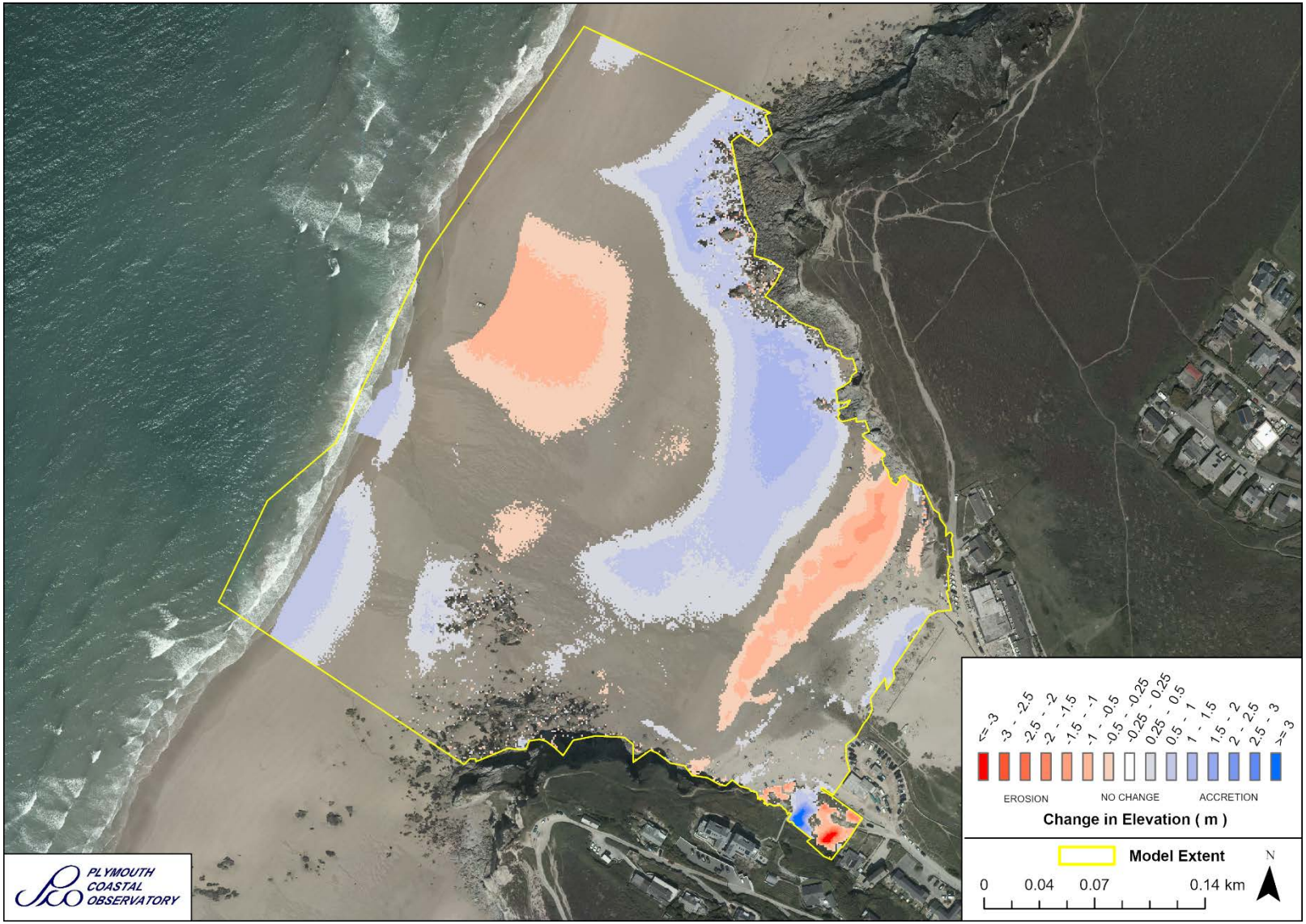


Figure 11 – Difference model indicating the changes in elevation observed between the March 2014 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from April 2019 compared to January 2023. Widespread erosion can be observed across the unit, with the exception of some low-level accretion to the seaward extent. The embryo dune has remained stable, whilst the dune to the south has seen some erosion.

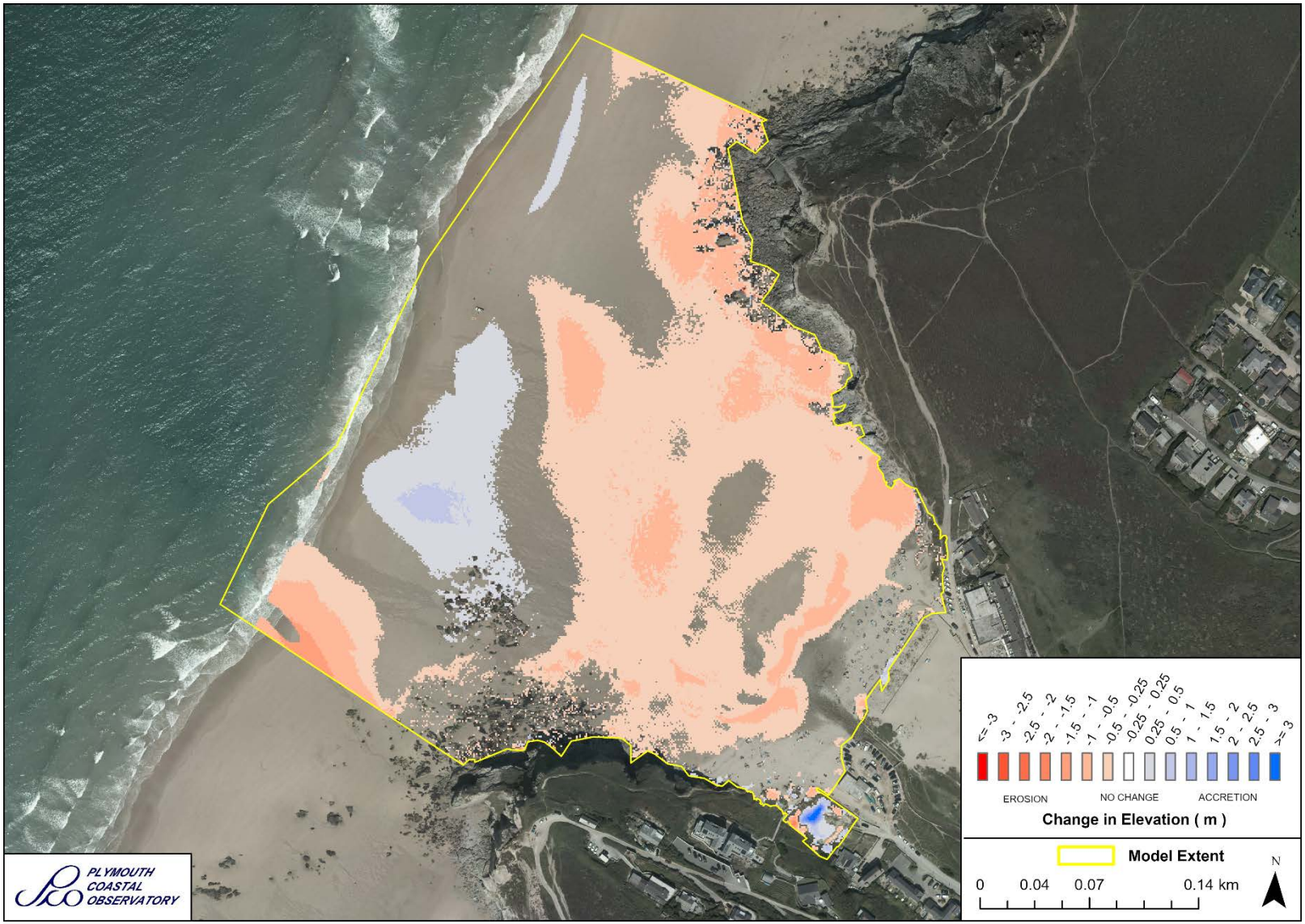


Figure 12 - Difference model indicating the changes in elevation observed between the April 2019 and January 2023 filtered LiDAR datasets within the yellow model extent.

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 13. Similarly to that observed from the topographic data, Porthtowan Mobile Zone has gradually eroded between 2008 and 2023, with the highest volume recorded during the April 2014 survey, in agreement with figure 10. The lowest volume recorded was during the January 2023 survey at 91,286 m^3 (Table 1), which compared to the March 2008 survey has seen a 7% loss in volume (Fig.13).

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 14. The Beach Zone volume was highest in the March 2011 survey (262,970 m^3, Table 1), an increase of 18% from the previous March 2008 survey (Fig.14). Similarly to the Mobile Zone, the lowest volume was recorded in the Beach Zone during the latest survey from January 2023 (215,290 m^3), representing a 3% loss of volume from the initial 2008 survey (Fig.14).

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	97,789	223,006
03/2011	96,058	262,970
04/2014	99,231	227,689
04/2019	94,287	239,312
01/2023	91,286	215,290

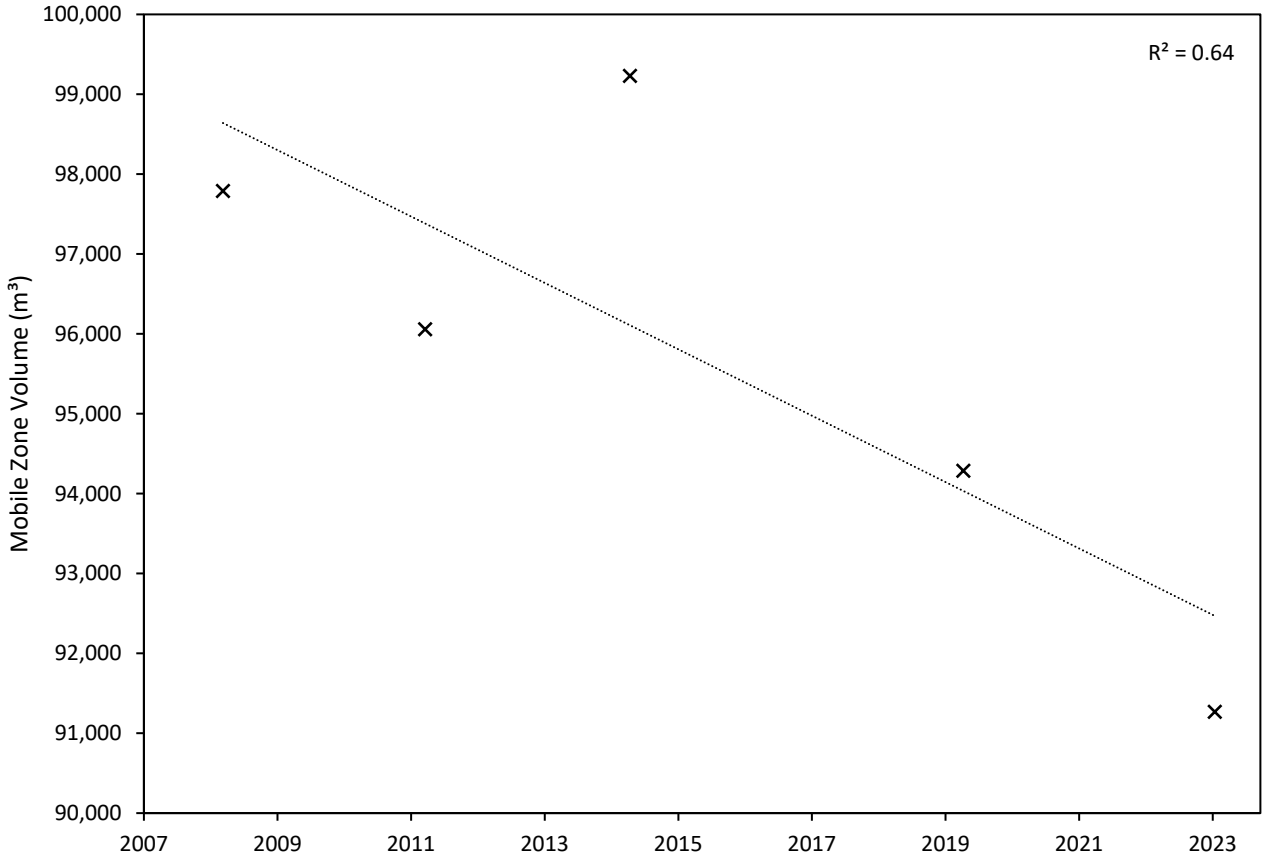


Figure 13 - Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.20 m OD) for each filtered LiDAR datasets between 2008 and 2023.

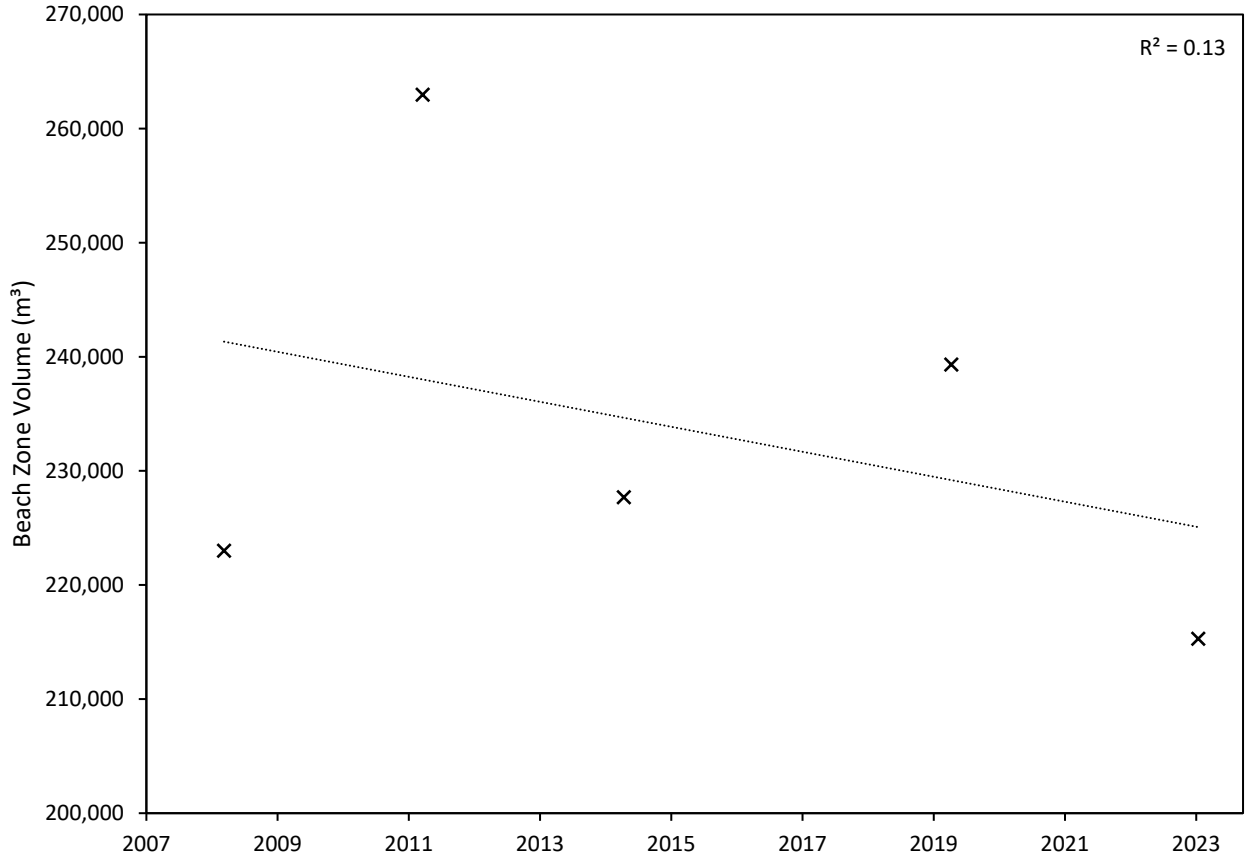


Figure 14 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.60 m OD) for each filtered LiDAR datasets between 2008 and 2023.

3.2.3 Contour Comparison

Figure 15 indicates the Mean Sea Level (MSL) and dune toe contours from the 2008, 2014, 2019 and 2023 LiDAR datasets. MSL contours indicate a narrowing of the beach between 2008 and 2014 of up 50 m. The most recent survey suggests the beach has only narrowed by ~25 m between 2008 and 2023. The same is true of the dune toe contours, which have retreated by up to 6 m to the northern half of the beach.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency and from 2006 onwards by the SWCM are presented here.

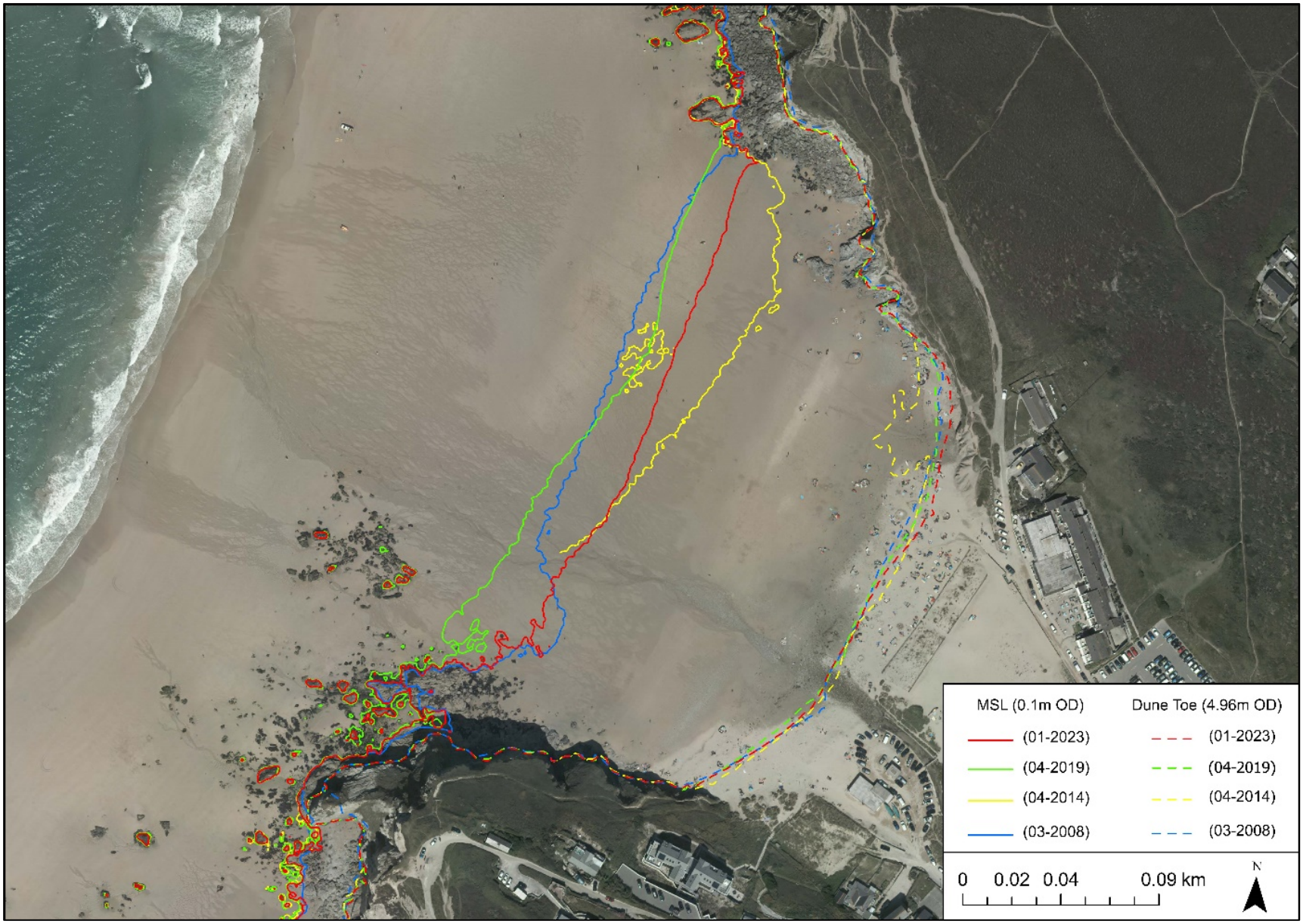


Figure 15 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022 LiDAR datasets.

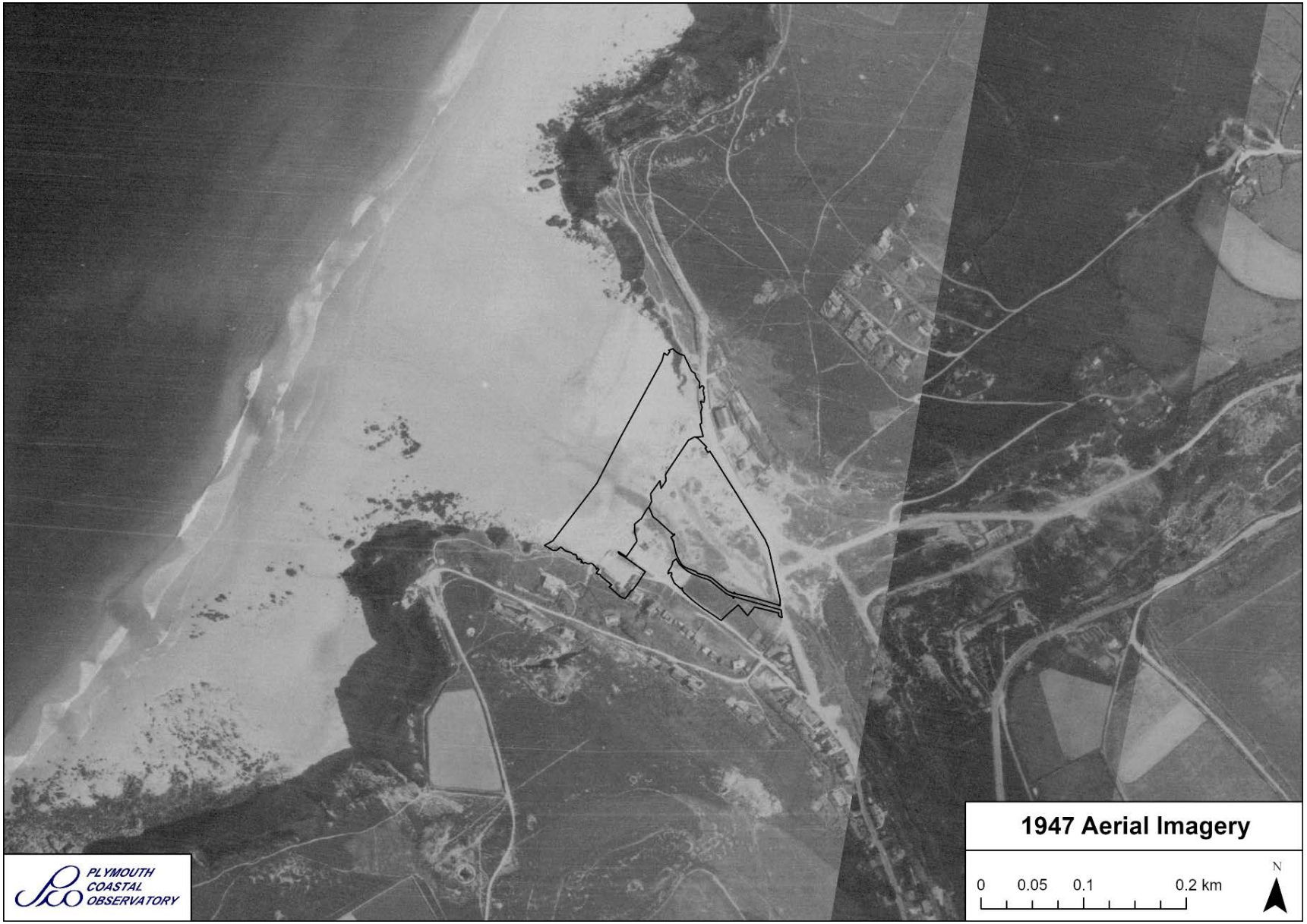


Figure 16 – Aerial imagery from 1947.



Figure 17 – Aerial imagery from 2001.

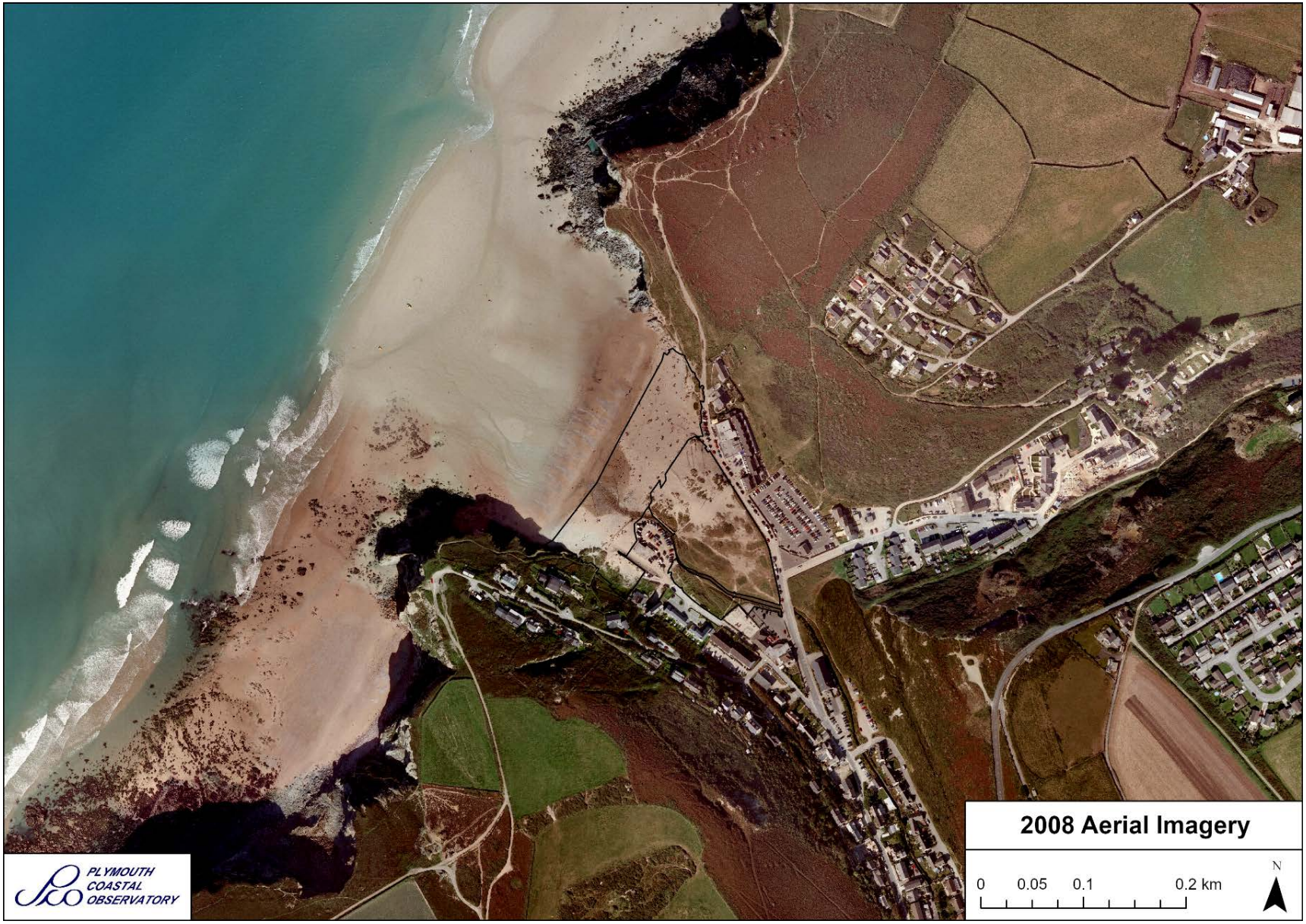


Figure 18 – Aerial imagery from 2008.



Figure 19 – Aerial imagery from 2010.



Figure 20 – Aerial imagery from 2014.



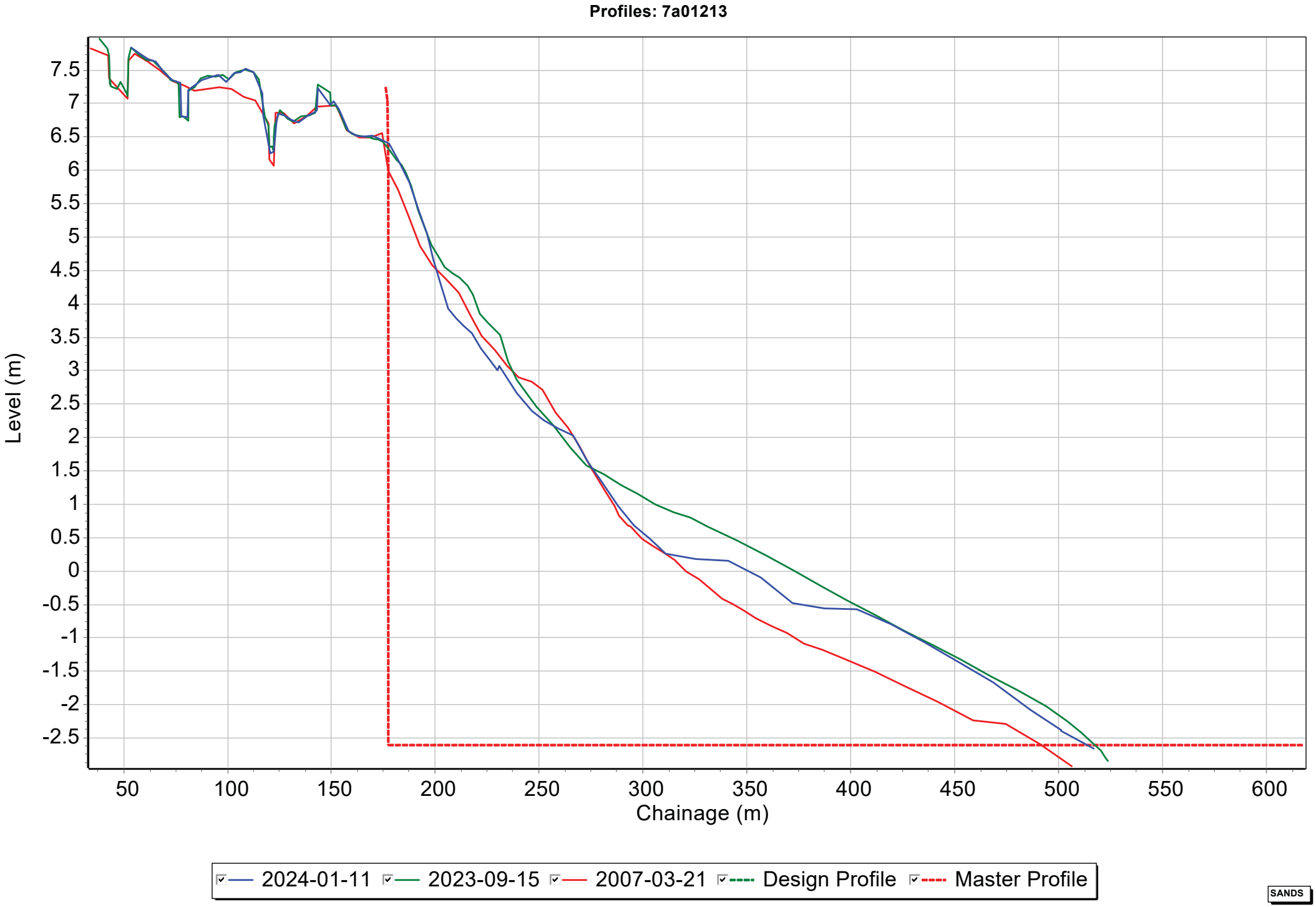
Figure 21 – Aerial imagery from 2017.

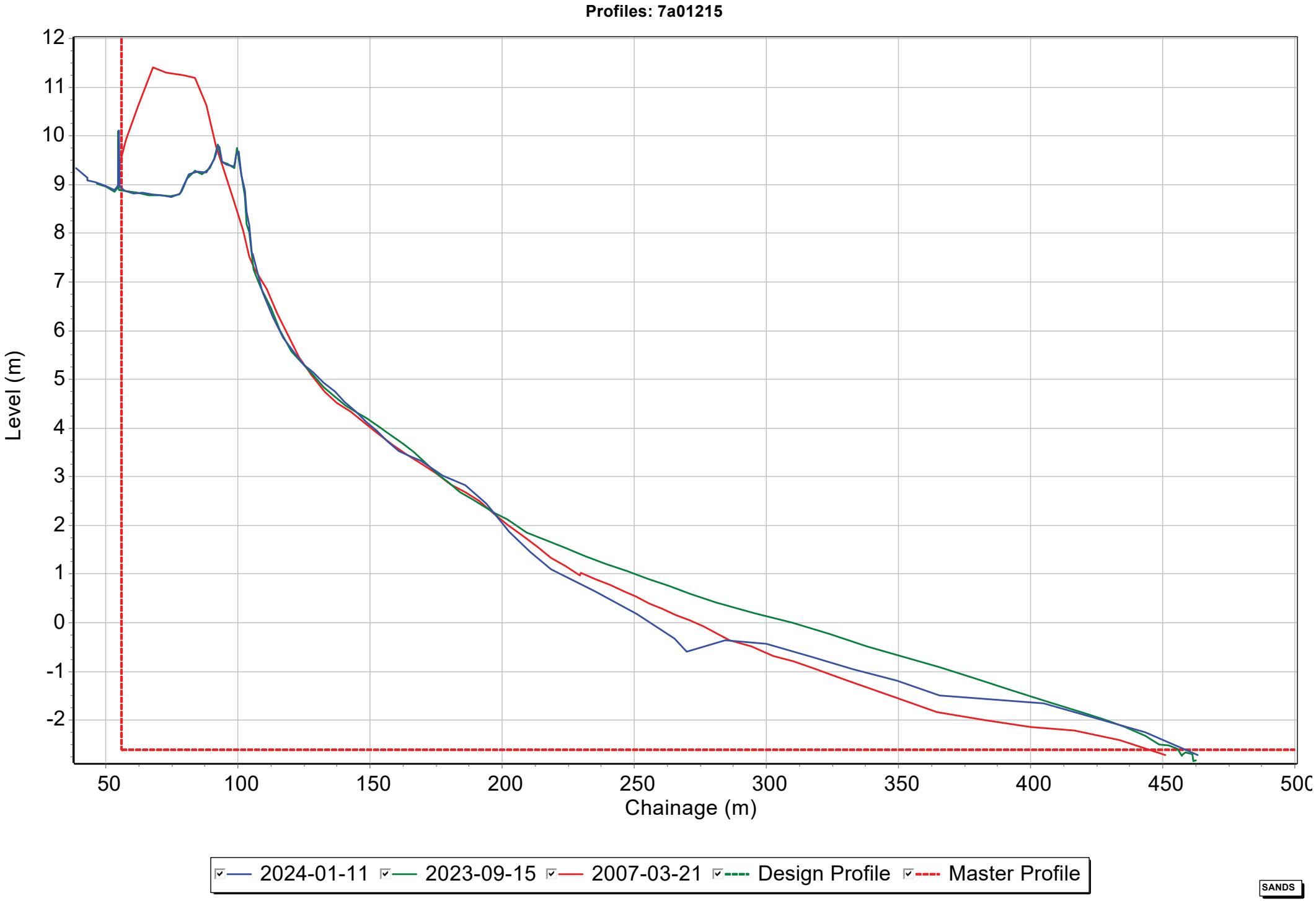
Glossary

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 Porthtowan 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)
2024-01-11
2023-09-15
2007-03-21
Design Profile
Master Profile


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
500
Chainage (m)
2024-01-11
2023-09-15
2007-03-21
Design Profile
Master Profile

SANDS