SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand - Millendreath Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR02 | 18/12/2023

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Taken by: Isabel Kelly

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 change at Millendreath. The aim is to highlight coastal change using SWCM data collected since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Millendreath is a south facing sandy beach backed by a sea wall with a cross-shore distance of ~80 m and longshore distance of ~160 m. 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 Millendreath since 2007. Analysis of topographic data indicates the survey unit is gradually accreting despite a 20% loss in combined profile area following the 2013/14 winter. Despite this, the beach recovered quickly, with the highest area recorded during the most recent survey in spring 2023.

Volume extracted from 9 LiDAR flights since 2008 have seen the Mobile Zone and Beach Zone to show similar trends to the topographic surveys; with both gradually accreting between 2008 and 2022. Only the Beach Zone saw a decrease in volume during the 2014 LiDAR survey followed by a swift recovery of material.

Overall Millendreath beach has seen a gradual increase in material since 2007, with a sharp erosive period following the 2013/14 storms followed by the swift recovery of beach material.

Contents

Summary ii
1.0 Introduction 1
2.0 Methods 2
2.1 Topographic Data 2
2.2 LiDAR Data 4
2.3 Accuracy Statement 4
3.0 Results 5
3.1 Topographic Data Analysis 5
3.2 LiDAR Data Analysis 6
3.2.1 Difference Models 6
3.2.2 Beach and Dune Volume Extraction 18
3.2.3 Contour Comparison 19
3.3 Historic Aerial Maps 19
Glossary 28
Appendices 28

1.0 Introduction

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

Millendreath is a south facing sandy beach backed by a sea wall protecting several buildings and a holiday camp, it is confined by a rocky shore platform to either side (Fig.1). The beach is oriented to the south and has a cross-shore distance of ~80 m and longshore distance of ~160 m with an average spring tidal range of 4.5 m. Millendreath Beach currently has no active dune system in place, the mobile and fixed zones are therefore defined using theory of previous dune coverage at the site. The four beach and dune zones are represented in Figure 1.

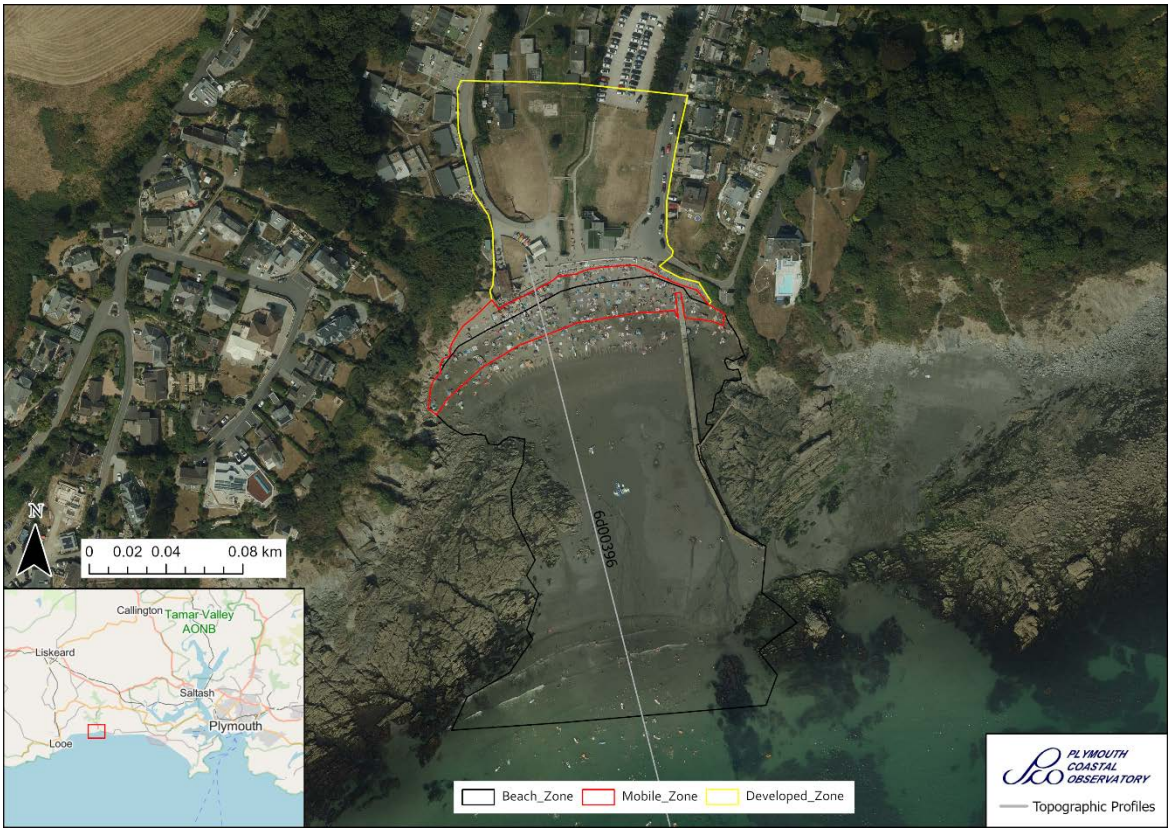


Figure 1 - Location Map of Millendreath Beach, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

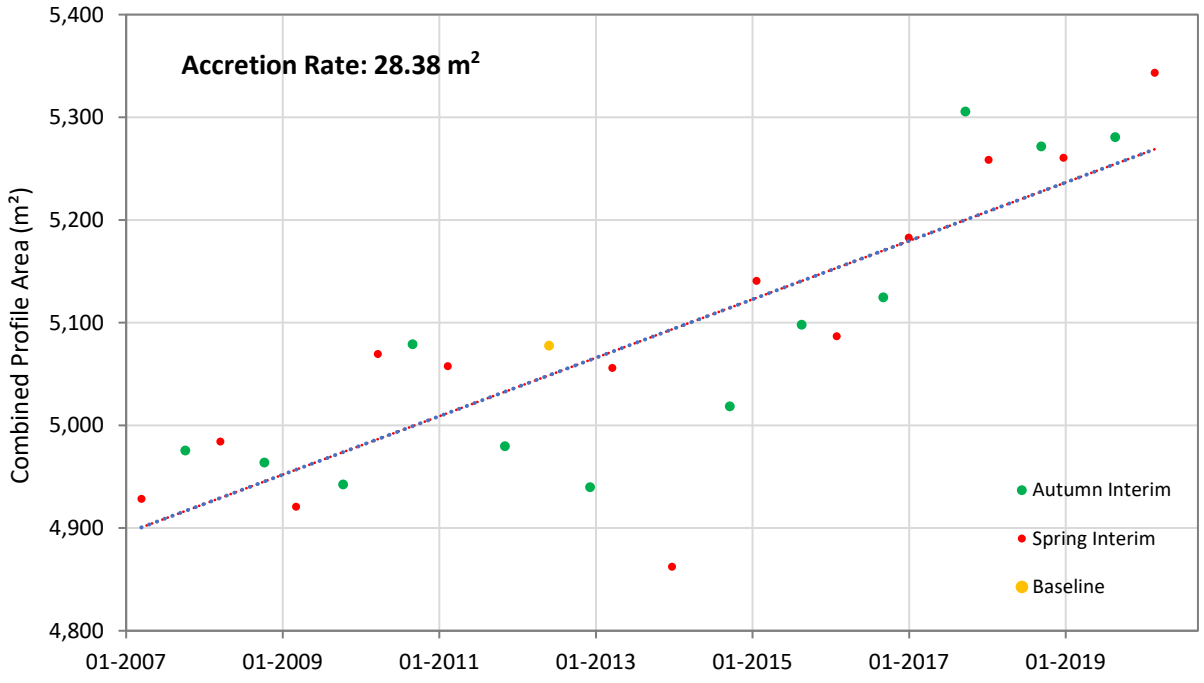


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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.

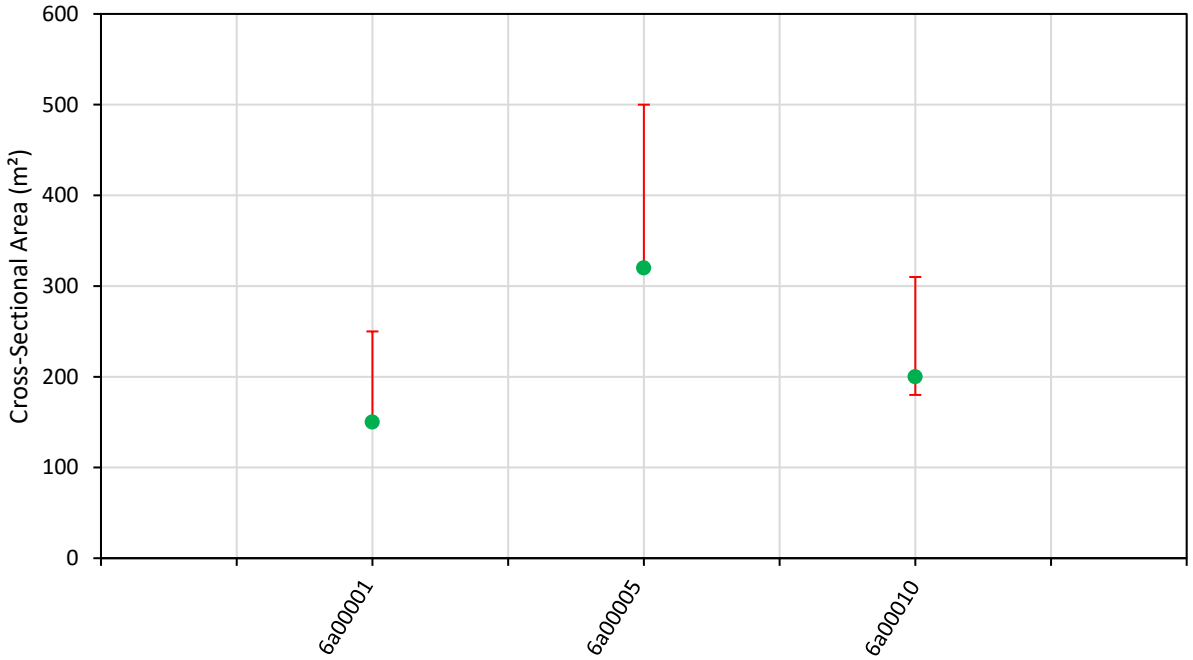


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

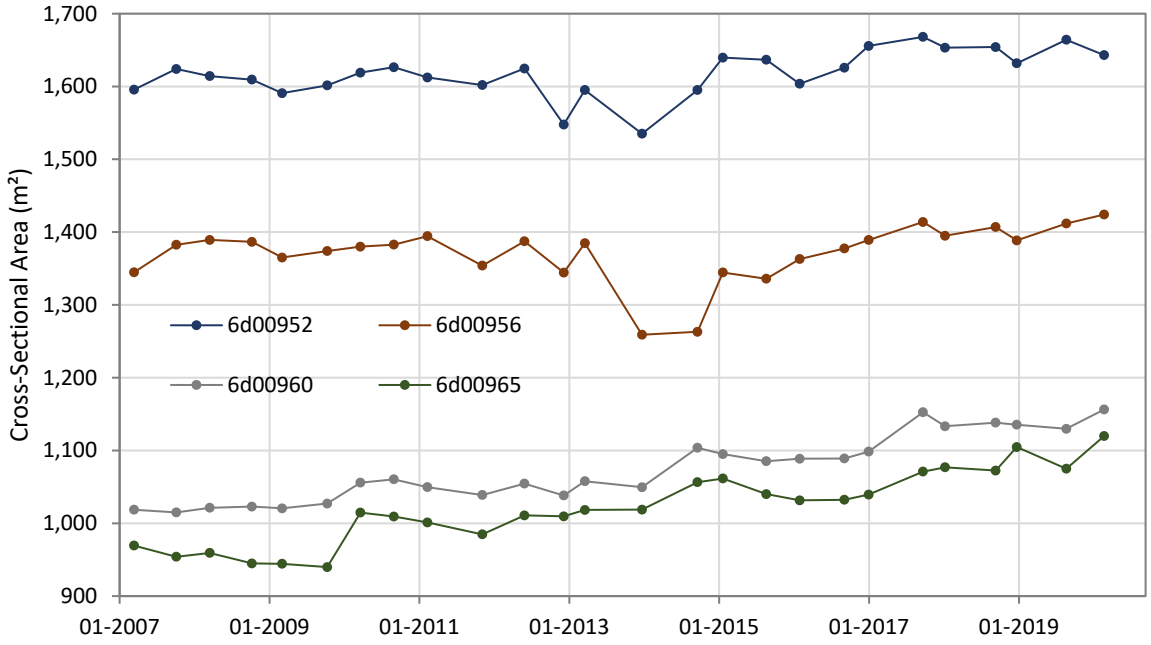


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 33 topographic surveys at Millendreath since 2007, 4 of which are baseline surveys and 29 are interim surveys. Exact dates of each survey for Millendreath are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting at 1.8 m^2 y^{-1} equating to 0.5% of the average beach area per year (Fig.5). The lowest recorded CPA was recorded during the 2014 spring interim (309 m^2) following the highly energetic winter season which saw a 78.6 m^2 loss in material from the previous survey, equating to a 20% reduction in CPA. Since 2014, the beach has recovered to previous levels, showing a minor trend of accretion, with the highest recorded CPA during the 2023 spring interim (397.1 m^2).

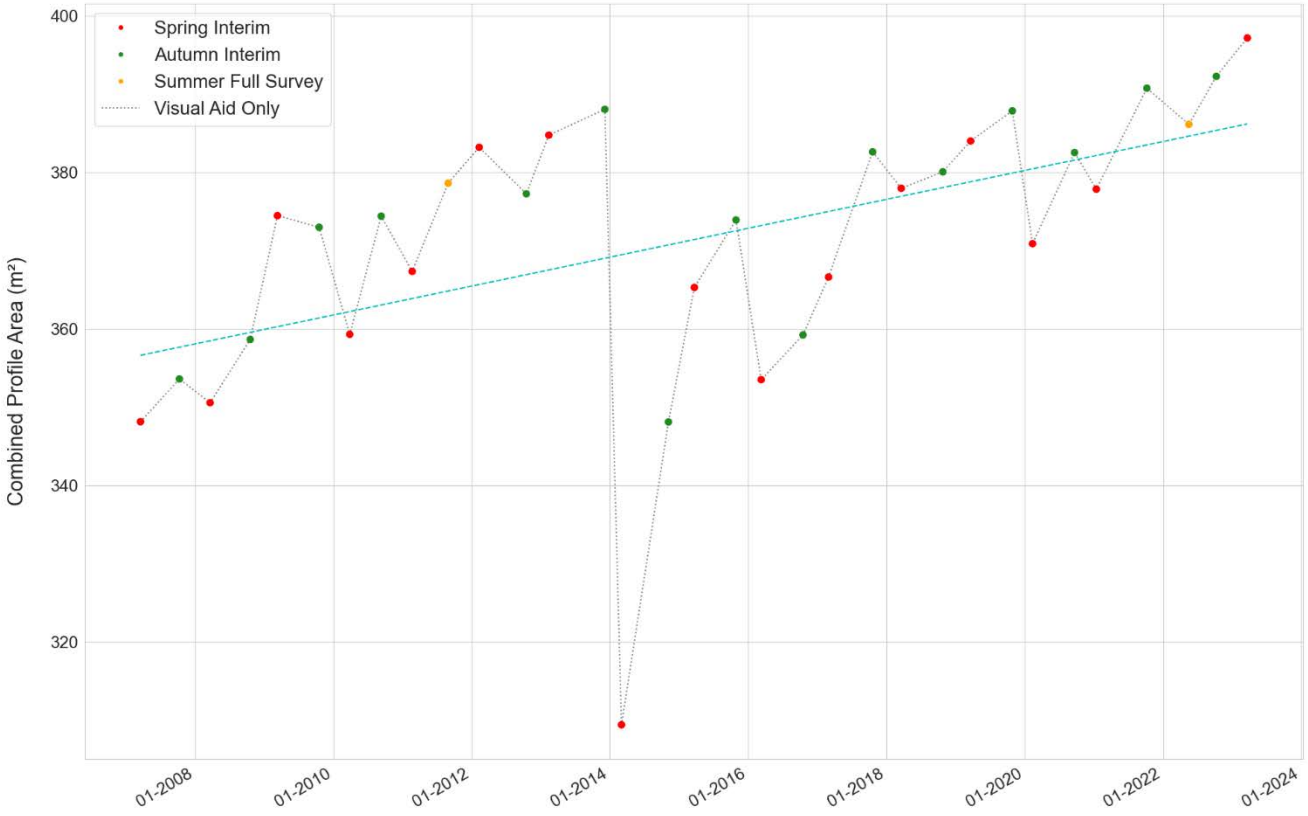


Figure 5 - The Combined Profile Area (CPA) for Millendreath, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing the 2023 spring interim survey to the entire dataset (Fig.6), the one interim profile at Millendreath (6d00396) showed the highest CSA on record.

The Profile Chart for Millendreath can be found in Appendix 1, this chart display the cross-sections of profile 6d00396 for the initial baseline survey conducted in 2007 along with the two most recent interim surveys. The profile chart shows considerable increase in material of the upper beach area and low tide terrace when comparing 2023 surveys to 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 2023.

3.2 LiDAR Data Analysis

There has been a total of 9 LiDAR flights captured at Millendreath since 2007 through the SWCM.

3.2.1 Difference Models

Difference models between each epoch of LiDAR data are presented below. 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 7 shows the difference in elevation between the first filtered LIDAR data from 2008 compared to the most recent, captured in 2022. The difference model is primarily dominated by accretion along the upper beach within the Mobile Zone, with a smaller band of erosion below the cliff to the east of the beach (Fig.7). Also evident is the construction of a outfall pipe between the two datasets, as indicated by the dark blue band running down the length of the beach (Fig.7).

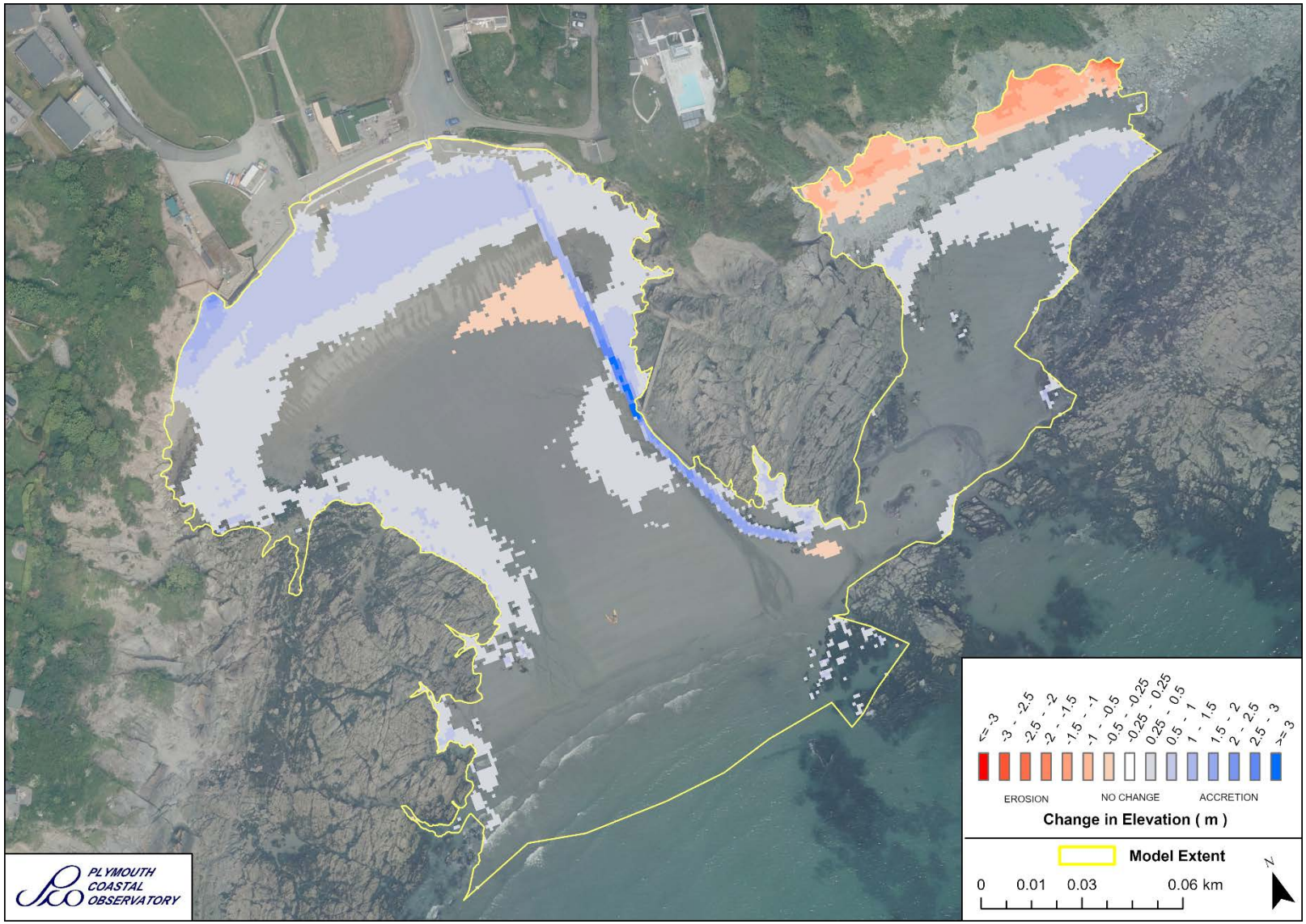


Figure 7 – Difference model indicating the changes in elevation observed between the February 2008 and March 2022 filtered LiDAR datasets within the yellow model extent.

Figure 8 shows the difference in elevation between filtered LIDAR data from February 2008 and January 2009. There is minimal change detected, however there is minor accretion observed along the low tide terrace of the beach (Fig.8).

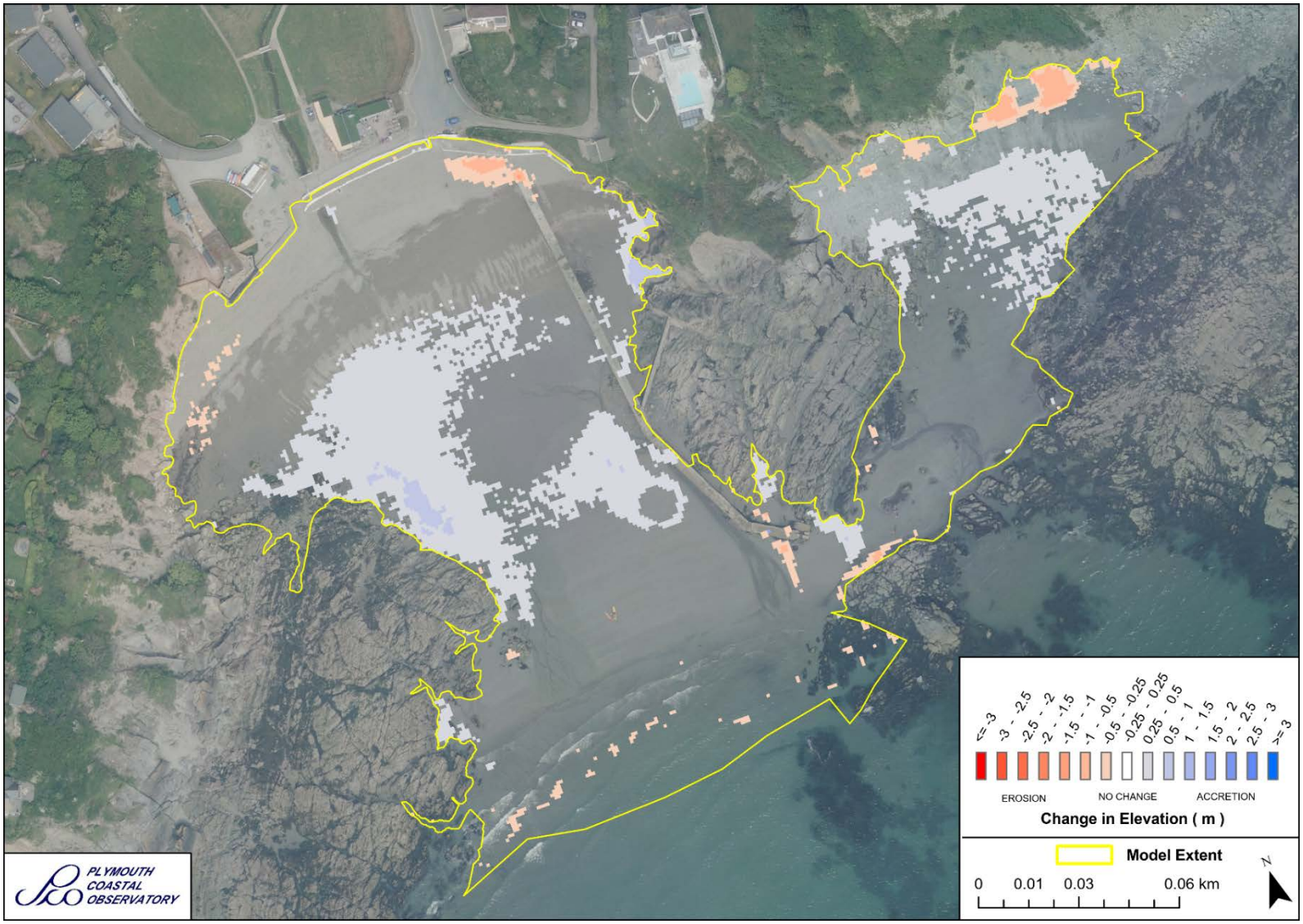


Figure 8 - Difference model indicating the changes in elevation observed between the February 2008 and January 2009 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows the difference in elevation between filtered LIDAR data from January 2009 and January 2010. Considerable accretion of material is observed along the upper beach face, with subsequent loss and erosion observed along the low tide terrace across the entire beach with elevation loss of up to 2 m in places (Fig.9). There is also considerable accretion in the place of the outfall, indicating it was built between the two epochs, accretion values should therefore be ignored.

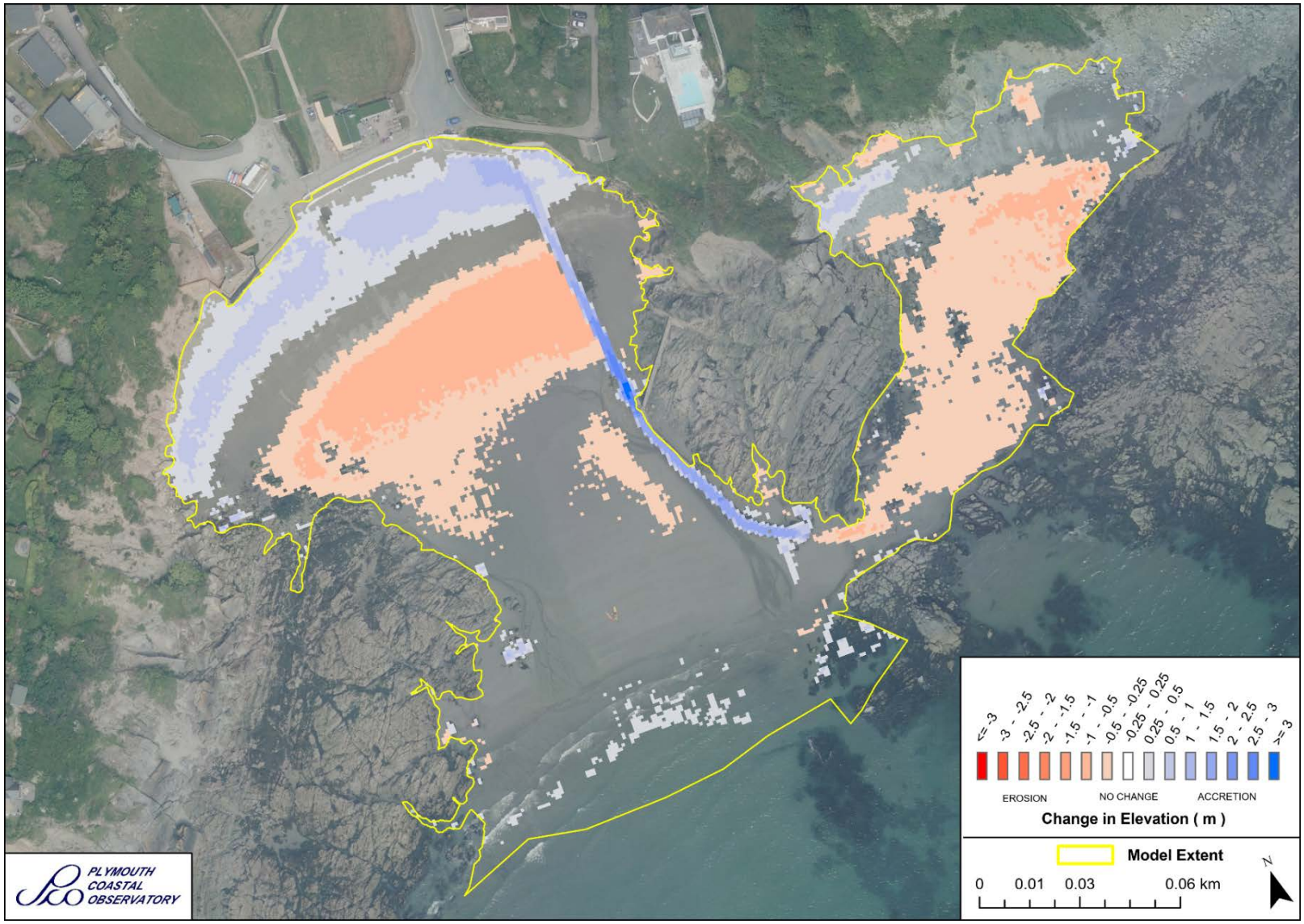


Figure 9 – Difference model indicating the changes in elevation observed between the January 2009 and January 2010 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows the difference in elevation between filtered LIDAR data from January 2010 and January 2011. Minimal change is observed between these two datasets, however there is minor erosion observed along the upper beach within the Mobile Zone, and subsequent accretion observed along the low tide terrace within the Beach Zone (Fig.10), the exact opposite of the comparison between 2009 and 2010.

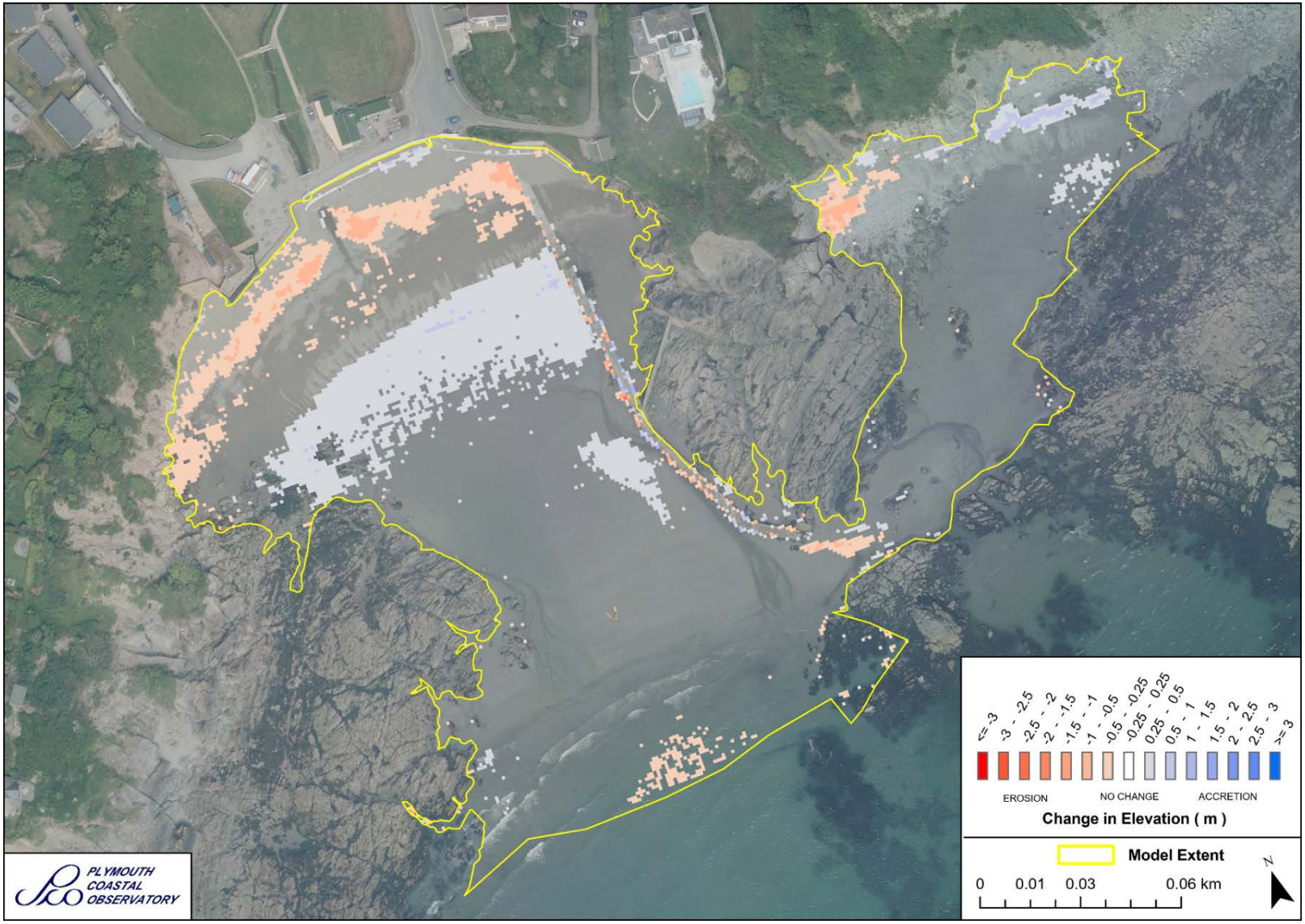


Figure 10 - Difference model indicating the changes in elevation observed between the January 2010 and January 2011 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows the difference in elevation between filtered LIDAR data from January 2011 and March 2012. Again, minimal change is observed between these two epochs, with minor accretion observed along the low-tide terrace (Fig.11).

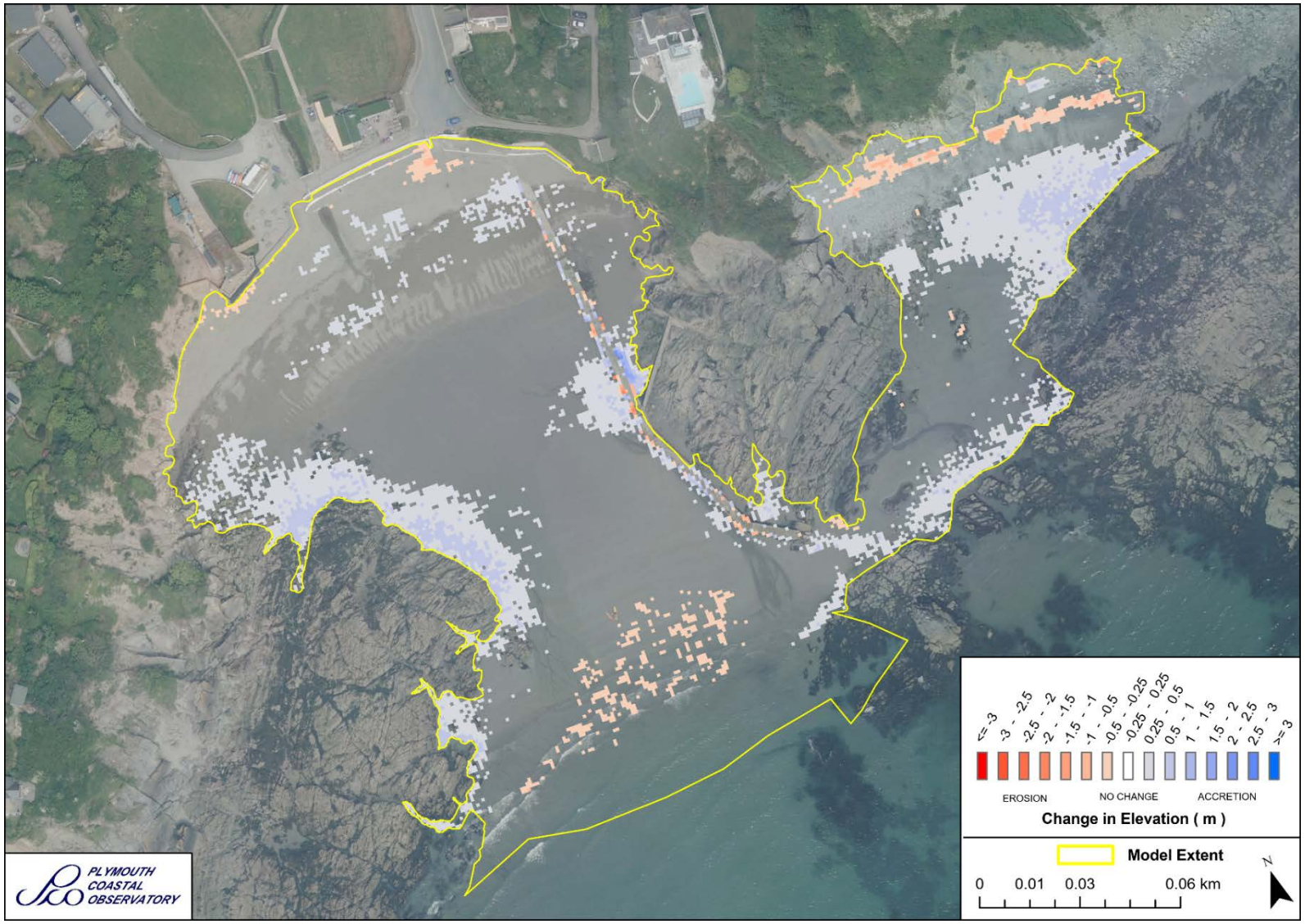


Figure 11 - Difference model indicating the changes in elevation observed between the January 2011 and March 2012 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows the difference in elevation between filtered LIDAR data from March 2012 and May 2014. The most substantial change observed in beach elevation to date has been between these two epochs, with considerable erosion observed across the entire low-tide terrace with up to 2.5 m loss in elevation across the centre of the beach (Fig.12). Subsequent accretion is observed along the upper beach face, particularly to the west of the survey unit (Fig.12).

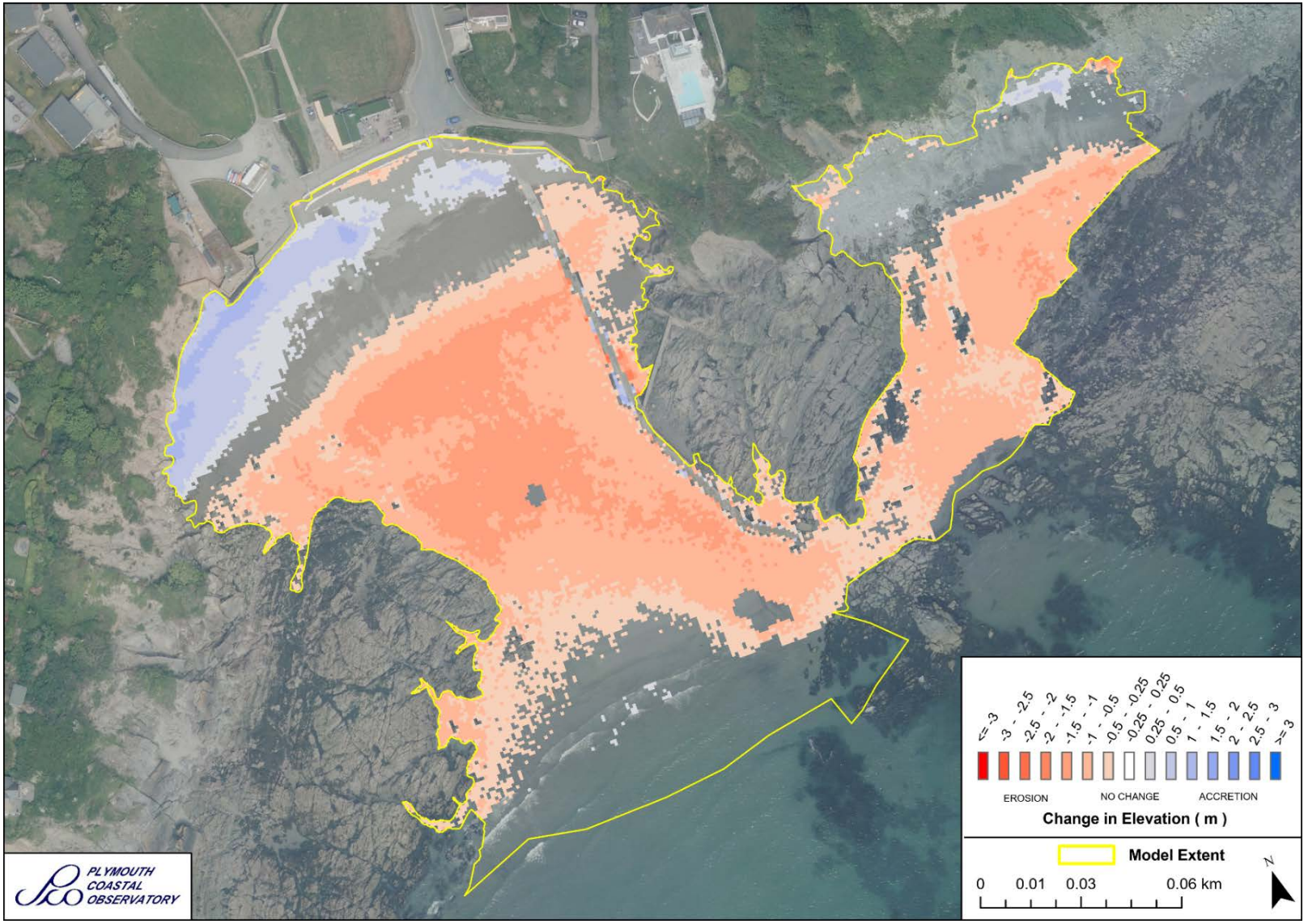


Figure 12 - Difference model indicating the changes in elevation observed between the March 2012 and May 2014 filtered LiDAR datasets within the yellow model extent.

Figure 13 shows the difference in elevation between filtered LIDAR data from May 2014 and February 2016. The difference between the two datasets represent the relatively rapid recovery of the survey area following the highly energetic 2013/14 winter, with substantial accretion observed across the entire beach with elevational gains of up to 2 m in places (Fig.13).

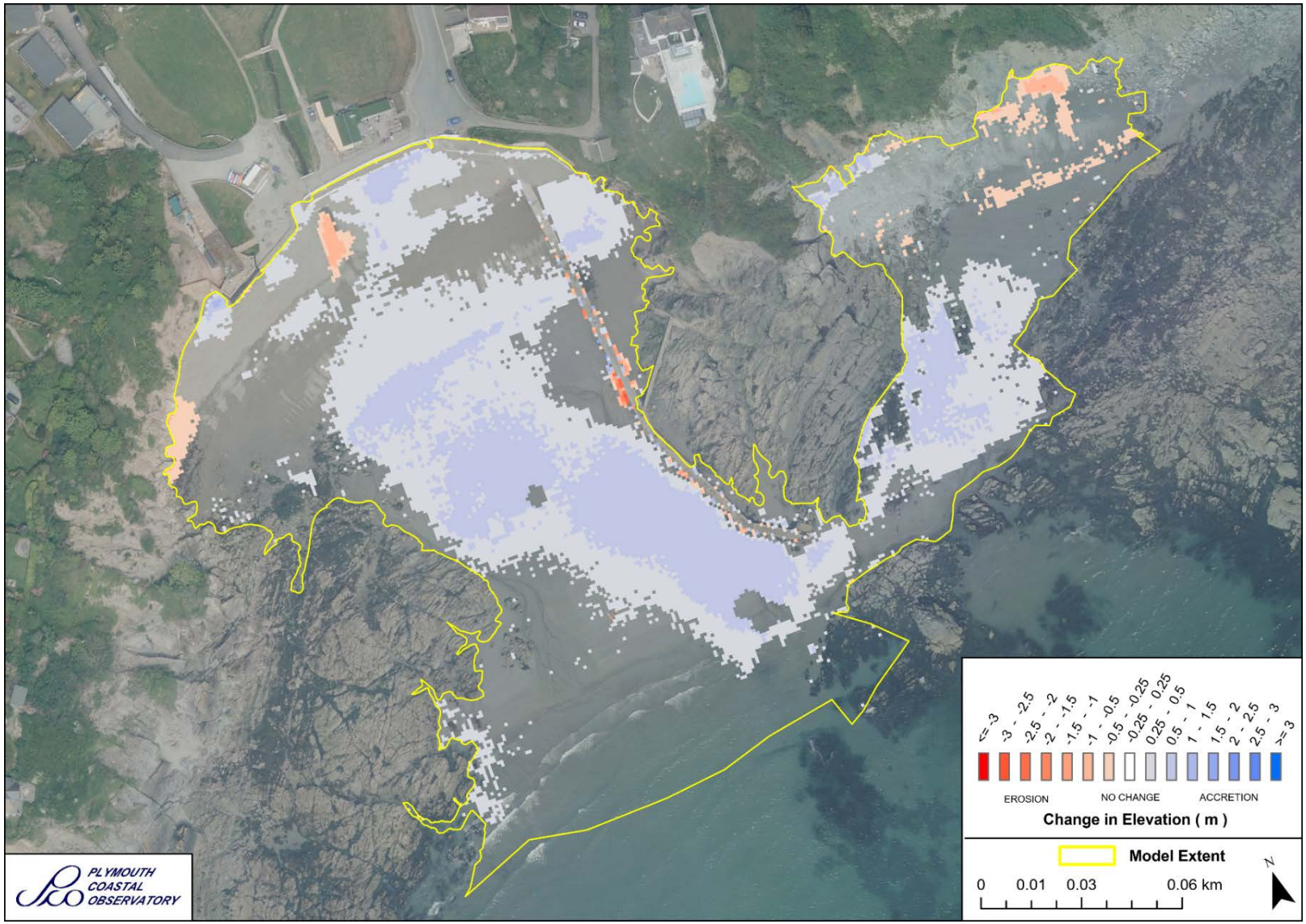


Figure 13 - Difference model indicating the changes in elevation observed between the May 2014 and February 2016 filtered LiDAR datasets within the yellow model extent.

Figure 14 shows the difference in elevation between filtered LIDAR data from February 2016 and March 2017. The difference between the two surveys represents minimal change, with minor pockets of erosion and accretion throughout (Fig.14).

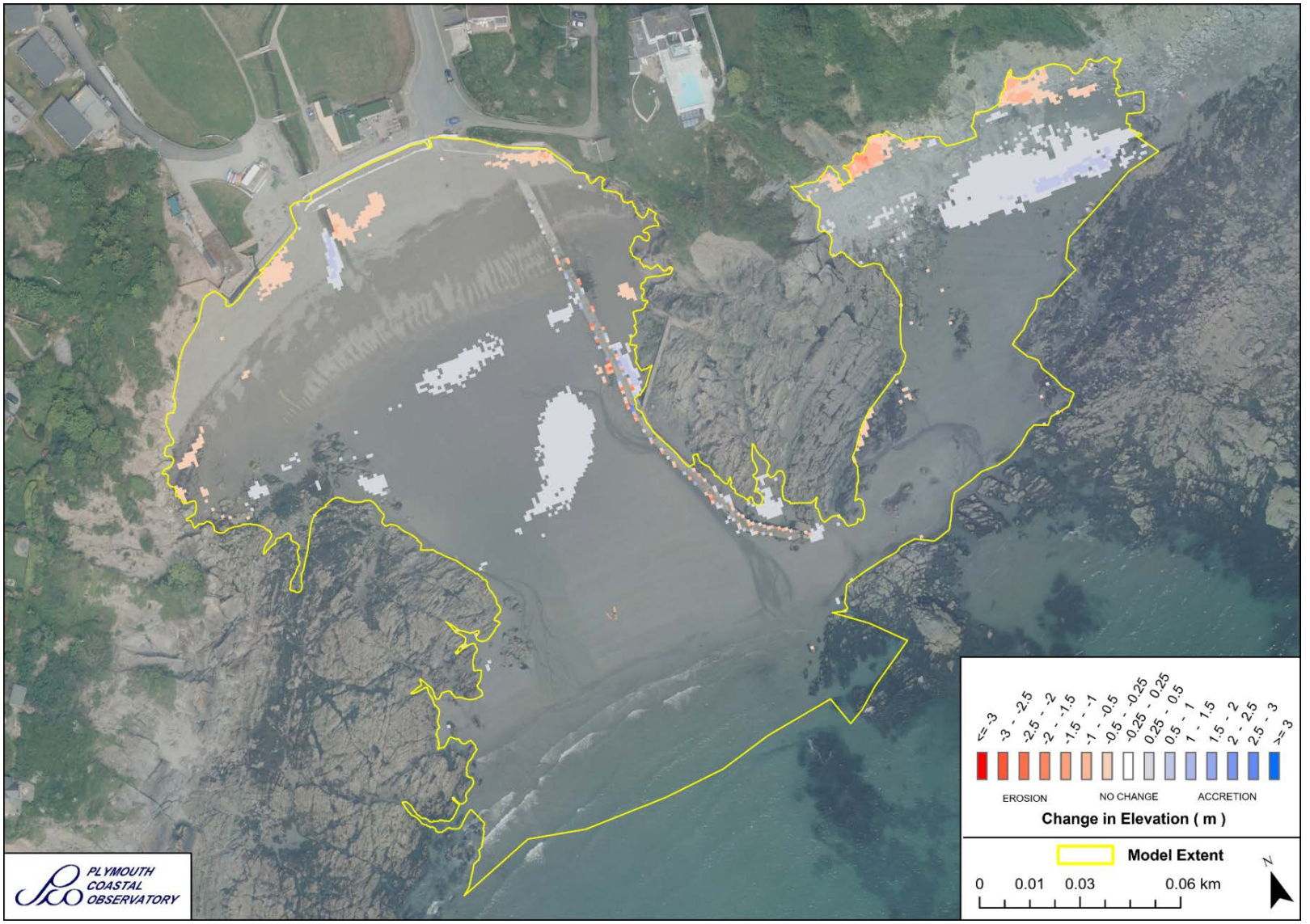


Figure 14 - Difference model indicating the changes in elevation observed between the February 2016 and March 2017 filtered LiDAR datasets within the yellow model extent.

Figure 15 shows the difference in elevation between filtered LIDAR data from March 2017 and April 2019. The difference between the two datasets shows minor accretion with elevation gains up to 1.5 m in places along the low-tide terrace (Fig.15).

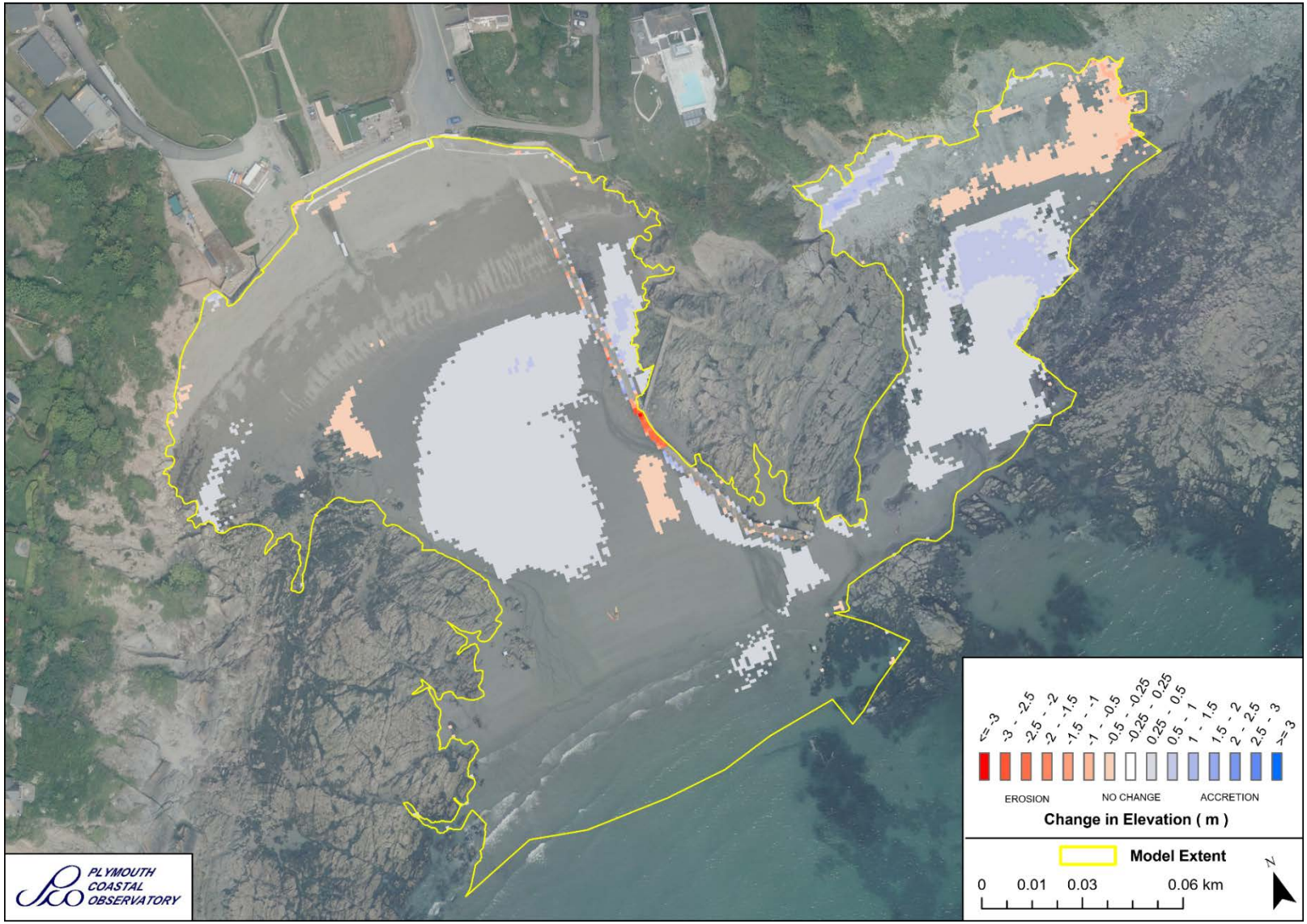


Figure 15 - Difference model indicating the changes in elevation observed between the March 2017 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 16 shows the difference in elevation between filtered LIDAR data from April 2019 and September 2020. The difference between the two datasets shows minimal change with small pockets of erosion and accretion dotted across the survey area (Fig.16).

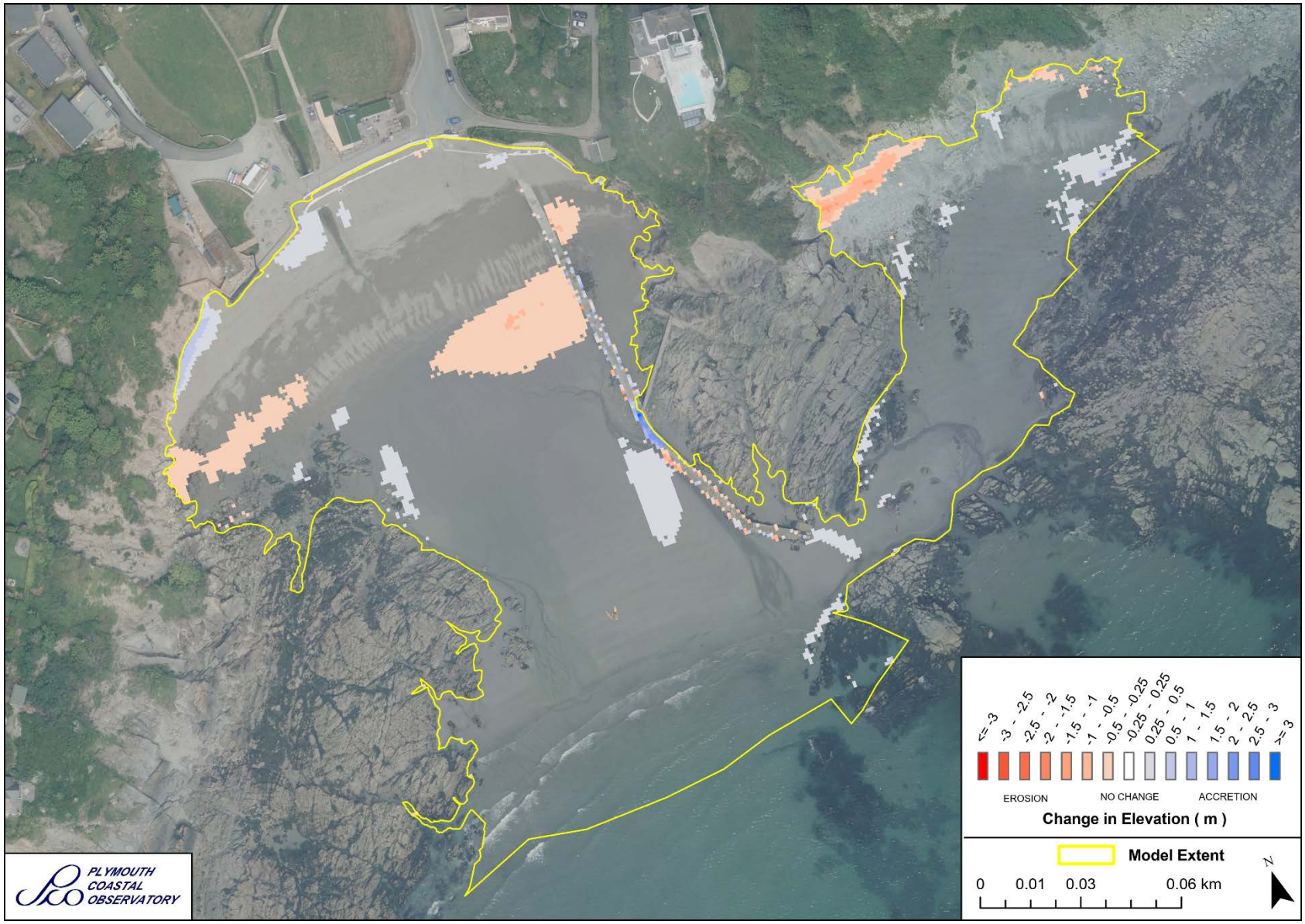


Figure 16 - Difference model indicating the changes in elevation observed between the April 2019 and September 2020 filtered LiDAR datasets within the yellow model extent.

Figure 17 shows the difference in elevation between filtered LIDAR data from September 2020 and March 2022. The difference between the most recent epochs highlights a band of erosion along the upper beach face and subsequent accretion at the beach toe (Fig.17).

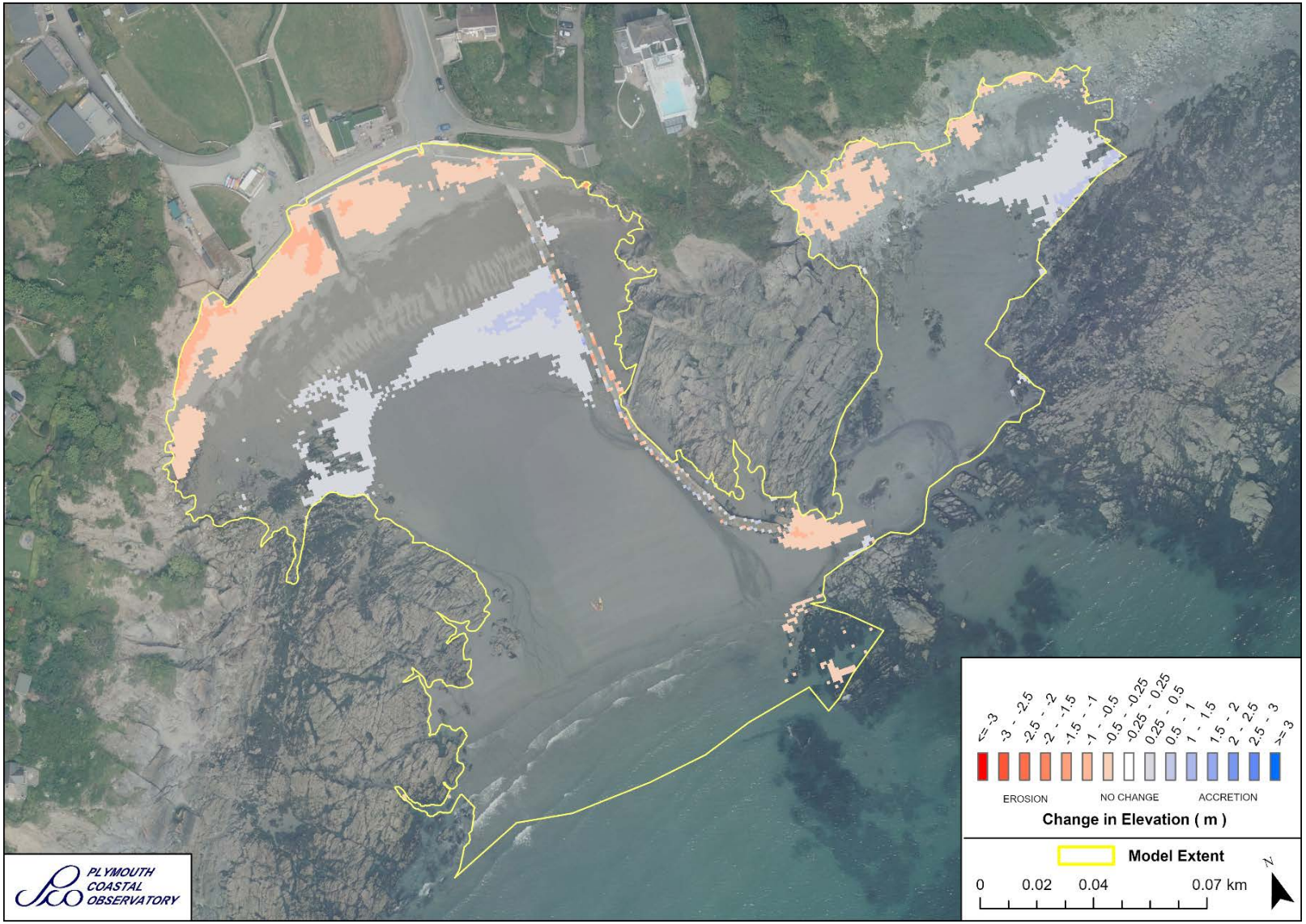


Figure 17 - Difference model indicating the changes in elevation observed between the September 2020 and March 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.35 m OD) are shown in Table 1 and figure 18. Volumetric data extracted from the Mobile Zone suggests a progressive accretion rate of 70 m^3 y^{-1} between 2008 and 2022 (Fig.18). There was significant accretion of the Mobile Zone following the 2013/14 winter, with a gain of 1,024 m^3 between the 2012 and 2014 data, representing a 128% increase in material above the MHWS contour (Fig.18).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.45 m OD) are also shown in Table 1 and figure 19. The volumetric data suggests a similar pattern to that observed in the topographic data, with progressive accretion of the Beach Zone since the first flight in 2008, accreting at a rate of 270 m^3 y^{-1} to the survey in 2022 (Fig.19). Similarly to the topographic data, there was a large decrease in material from the Beach Zone following the 2013/14 winter storms, whereby the 2014 flight recorded a volume of 38,076 m^3, losing 8,356 m^3 from the previous survey in 2012, equating to a 17% loss in material (Fig.19).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (2.35 m OD) and for the Beach Zone above MLWS (-2.45).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
02/2008	395	41,651
01/2009	322	43,473
01/2010	1,127	43,846
01/2011	694	44,633
03/2012	799	46,432
05/2014	1,823	38,076
02/2016	2,135	43,352
03/2017	1,906	44,480
04/2019	1,804	46,699
09/2020	1,948	46,016
03/2022	1,355	45,446

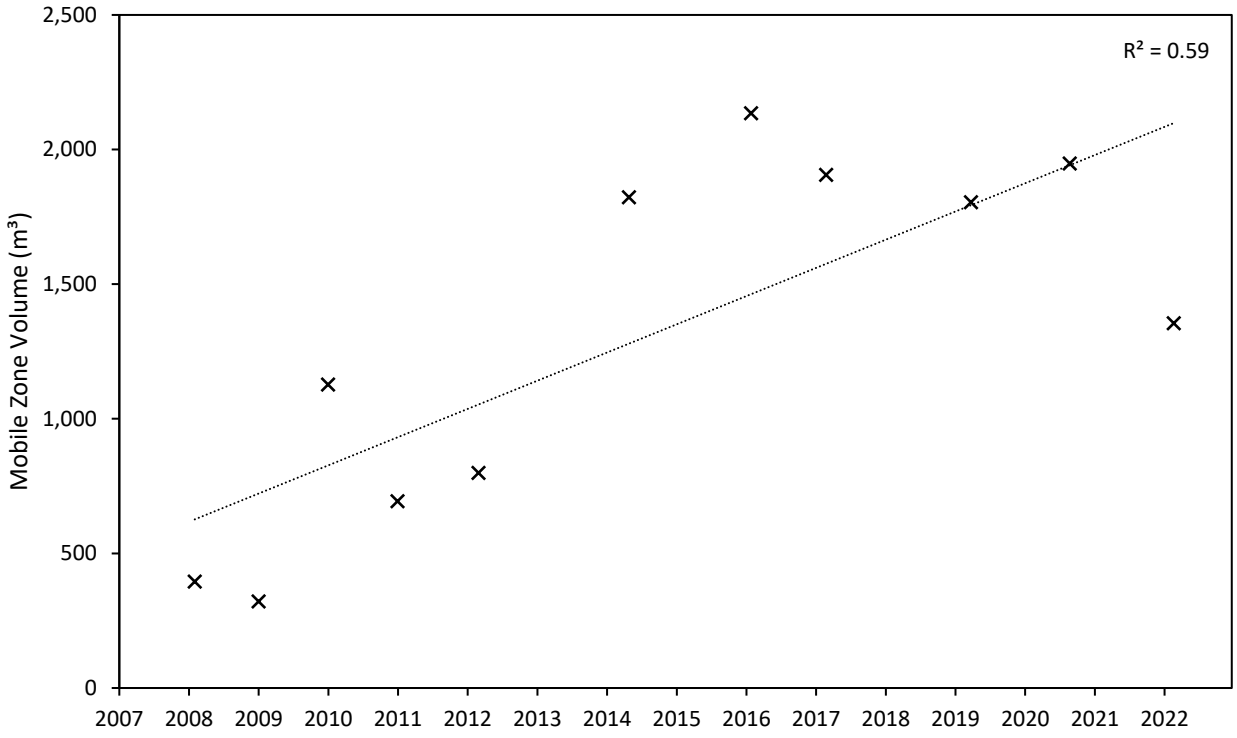


Figure 18 - Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.35 m OD) for each filtered LiDAR datasets between 2008 and 2022.

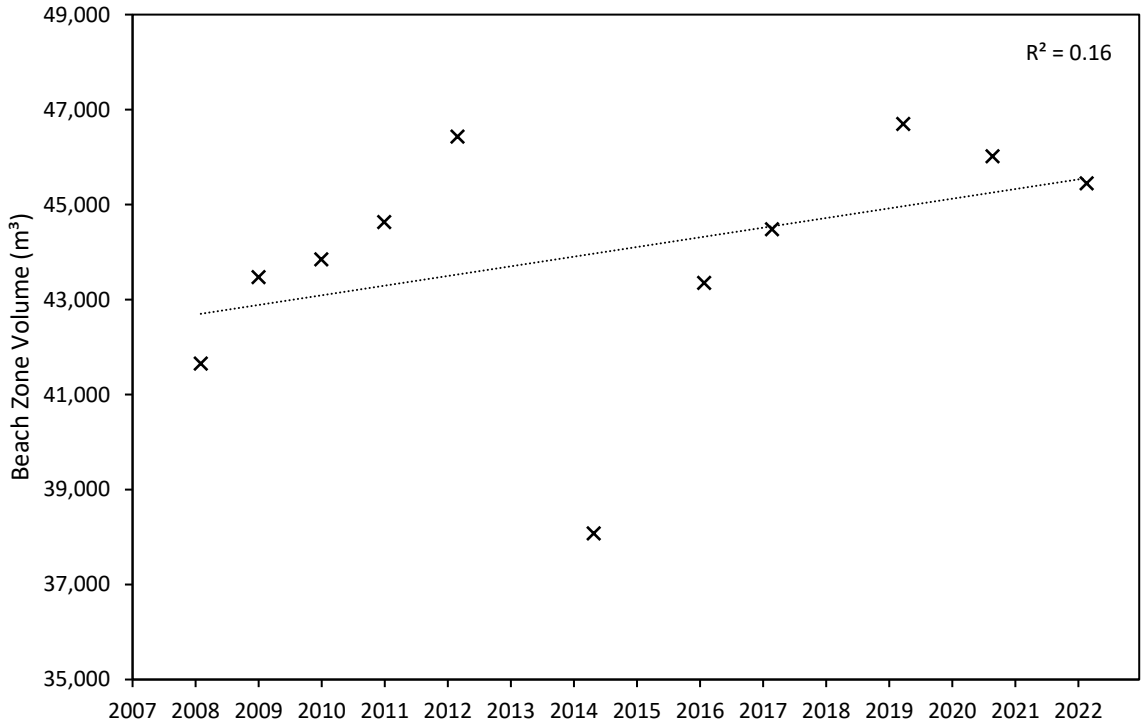


Figure 19 – Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.45 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.2.3 Contour Comparison

Figure 20 indicates the Mean Sea Level (MSL) and Dune Toe contours from 2008, 2014, 2019 and 2022 LiDAR datasets, projected onto aerial imagery captured in 2022. The MSL contour fluctuates between each presented epoch with the 2008 dataset appearing to show the widest beach with the 2014 contour suggesting the narrowest beach (Fig.20). This is contradicted by the Dune Toe contour, whereby the 2008 contour is the narrowest and the 2014 contour suggesting the widest (Fig.20).

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.

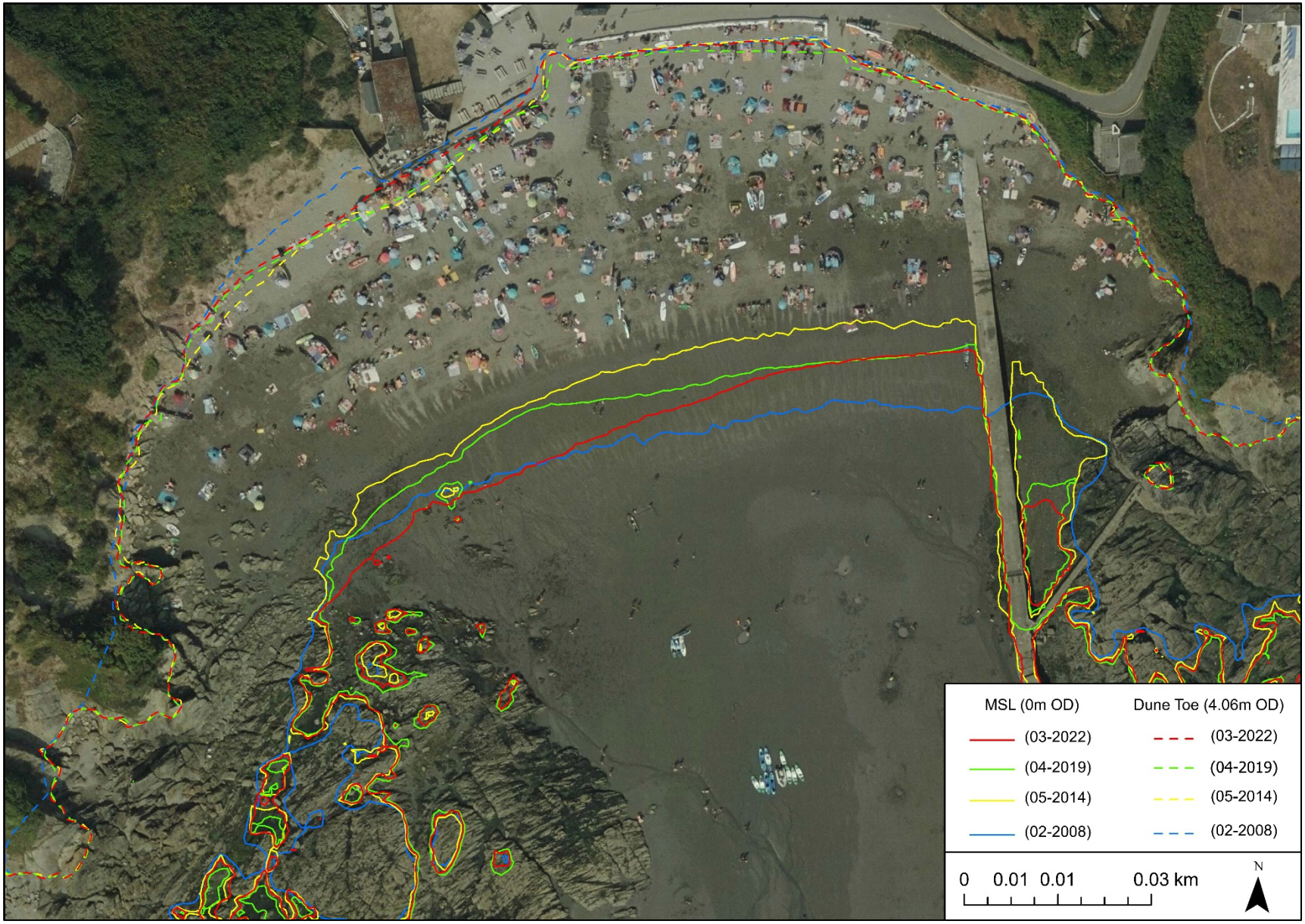


Figure 20 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022 LiDAR datasets.

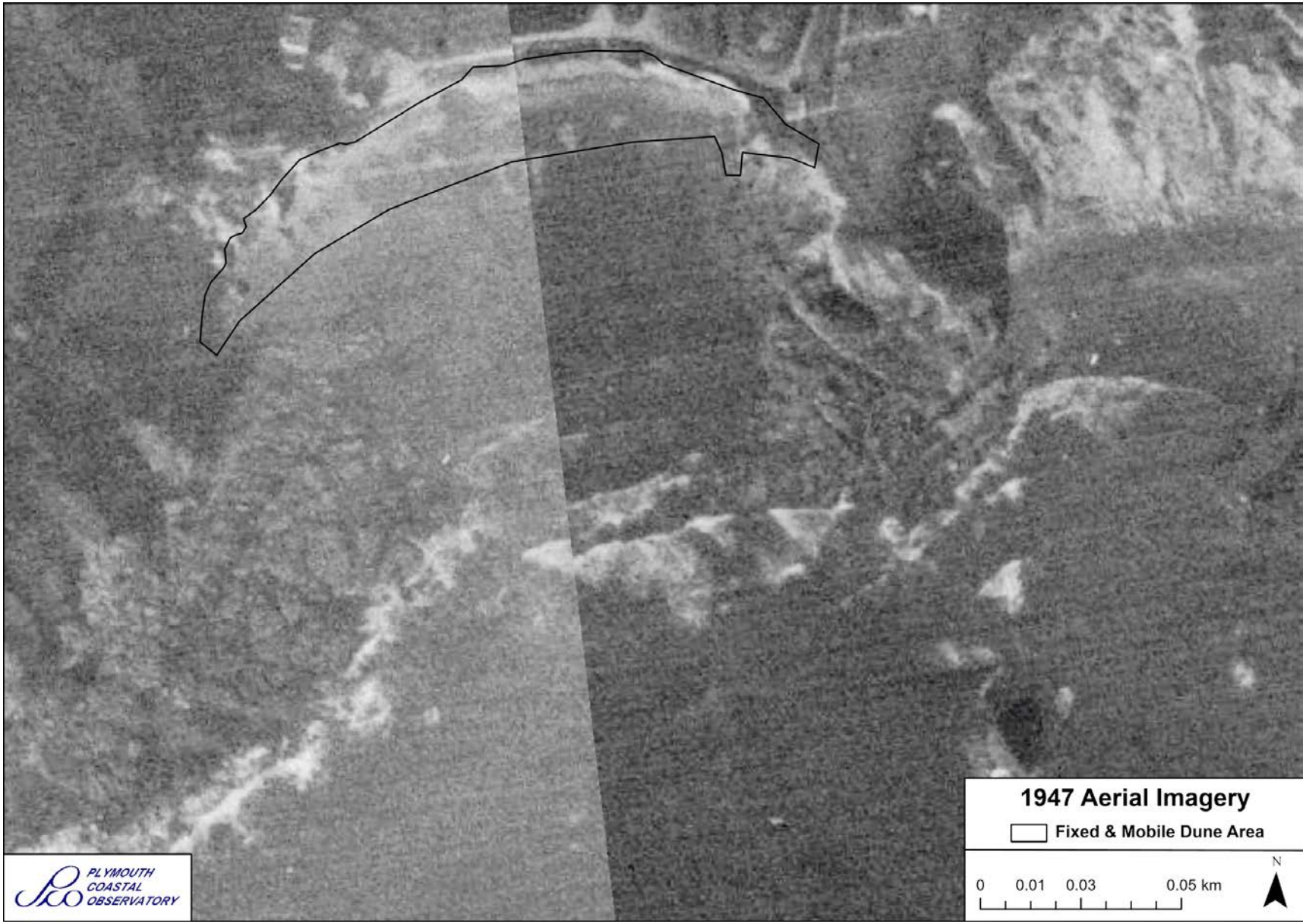


Figure 21 – Aerial imagery from 1947.



Figure 22 – Aerial imagery from 2001.

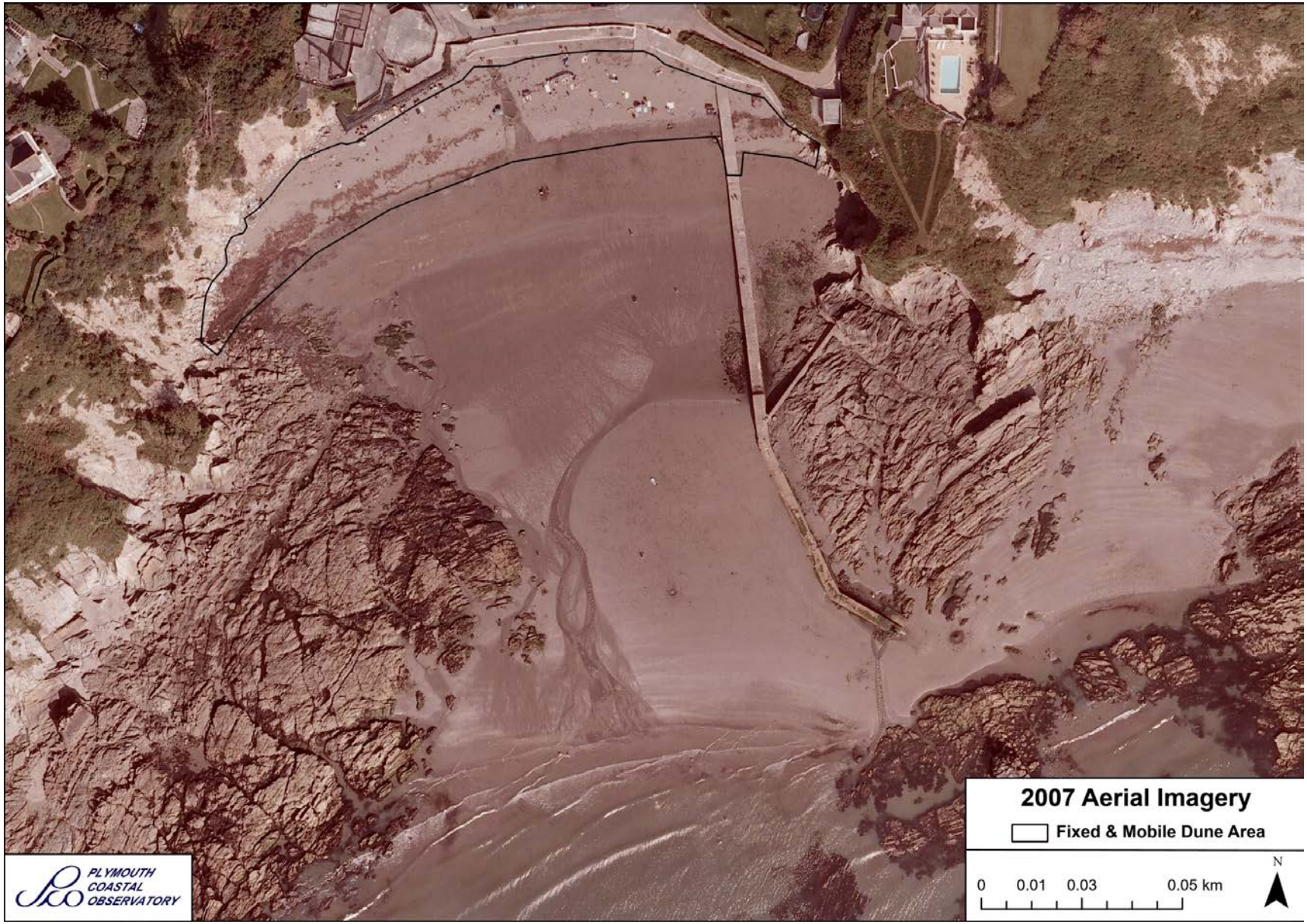


Figure 23 – Aerial imagery from 2007.



Figure 24 – Aerial imagery from 2009.



Figure 25 – Aerial imagery from 2014.



Figure 26 – Aerial imagery from 2018.



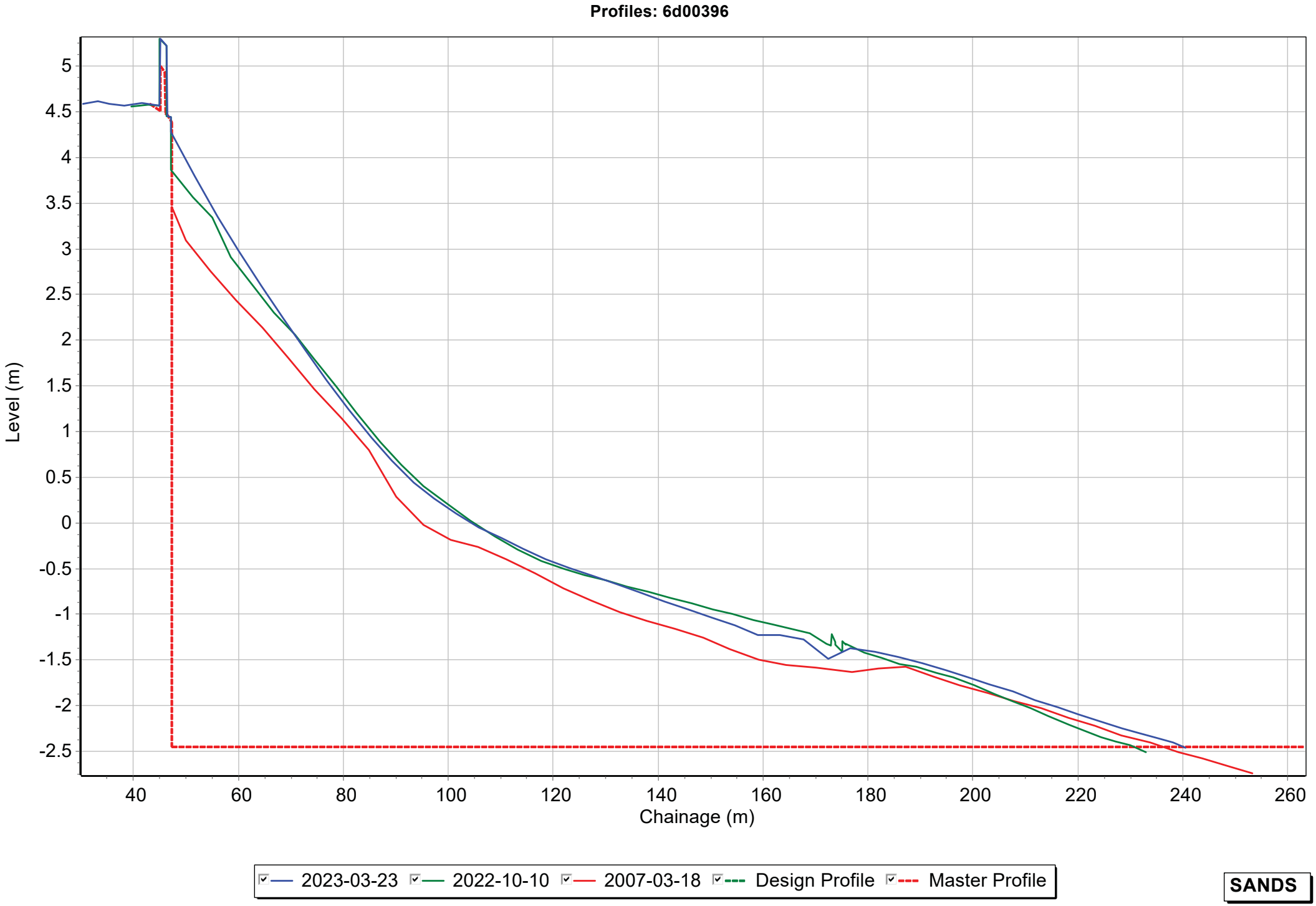
Figure 27 – Aerial imagery from 2022.

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 Millendreath are presented below.


Profiles: 6d00396
Level (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
40
60
80
100
120
140
160
180
200
220
240
260
Chainage (m)
2023-03-23
2022-10-10
2007-03-18
Design Profile
Master Profile
SANDS