SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Constantine Bay Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR30 | 21/03/2024

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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 Constantine Bay. The aim is to highlight coastal change at Constantine Bay using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Constantine Bay is a west facing sandy beach backed by a large dune system followed by a golf course. Rock platforms are present at either end of the beach, with a large rock island protruding out to the north. A small stream flows from the back of the dune, meandering around the dune system, out to the sea. Topographic data collected bi-annually along fixed cross-shore profile lines and 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.

There has been a total of 35 topographic surveys at Constantine Bay since 2007; 4 full coverage surveys, 30 interim surveys and 1 post-storm survey. Analysis of topographic data suggests the survey unit to be eroding, after being significantly impacted by the 2013/2014 and 2020 winter period. The highest record was measured during the 2012 autumn interim. Since the 2007 baseline survey, material has built-up along the dune toe and the majority 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; the beach being heavily impacted after the 2013/14 winter period, but subsequently showing signs of recovery to pre-2013 beach levels. Dune toe contours have advanced across the length of the beach, with the exception of the section of dune that protrudes out in the middle of the unit, which has seen a significant loss of material.

Overall Constantine Bay has been significantly impacted by the 2013/2014 and 2020 winter period; however, the beach has shown signs of recovery in subsequent years.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Constantine Bay 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 32021 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

Constantine Bay is a west facing sandy beach backed by a large dune system followed by a golf course. Rock platforms are present at either end of the beach, with a large rock island protruding out in the north. A small stream flows from the back of the dune, meandering around the dune system, out to the sea. Constantine is over 600 m in width, and experiences an average tidal range of 6.4 m. The four beach and dune zones are represented in Figure 1.

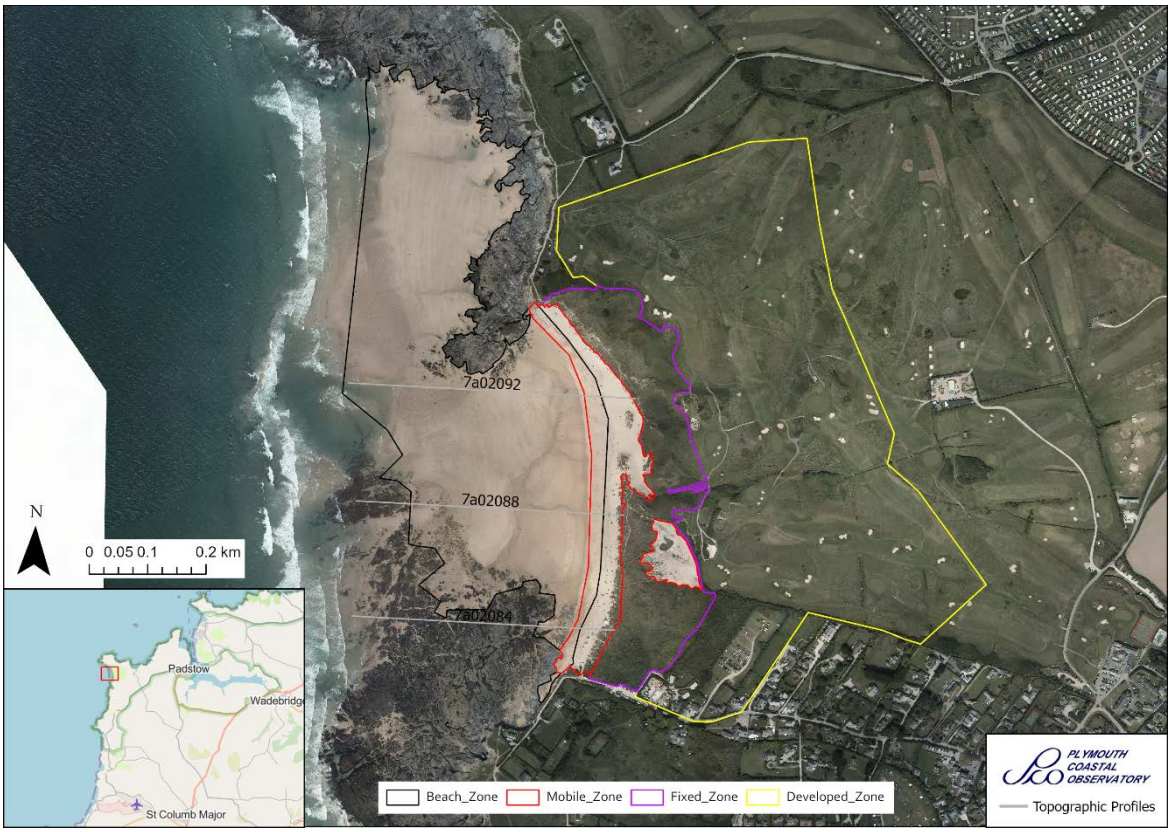


Figure 1 - Location Map of Constantine Bay and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

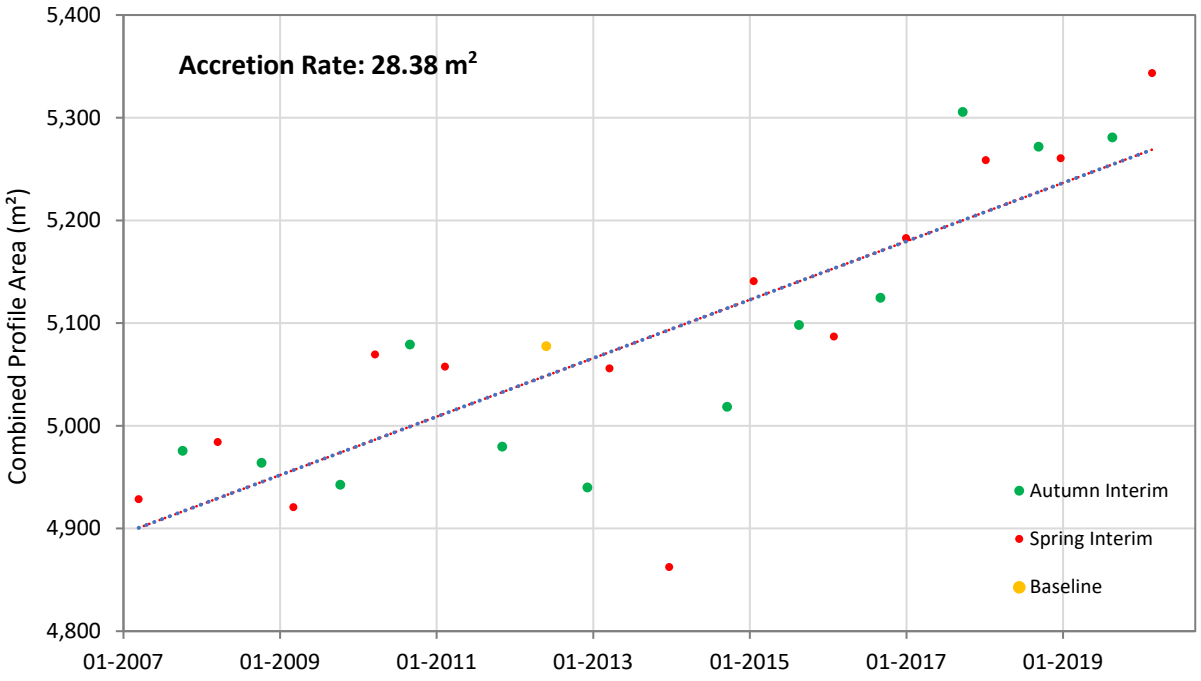


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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.

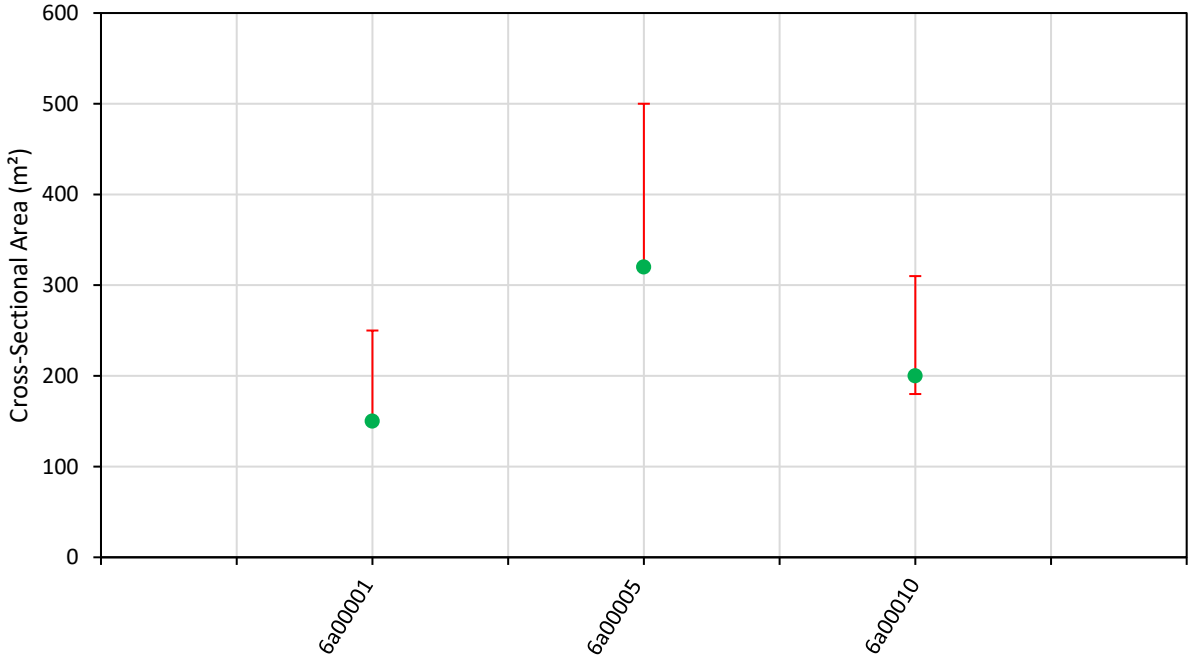


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

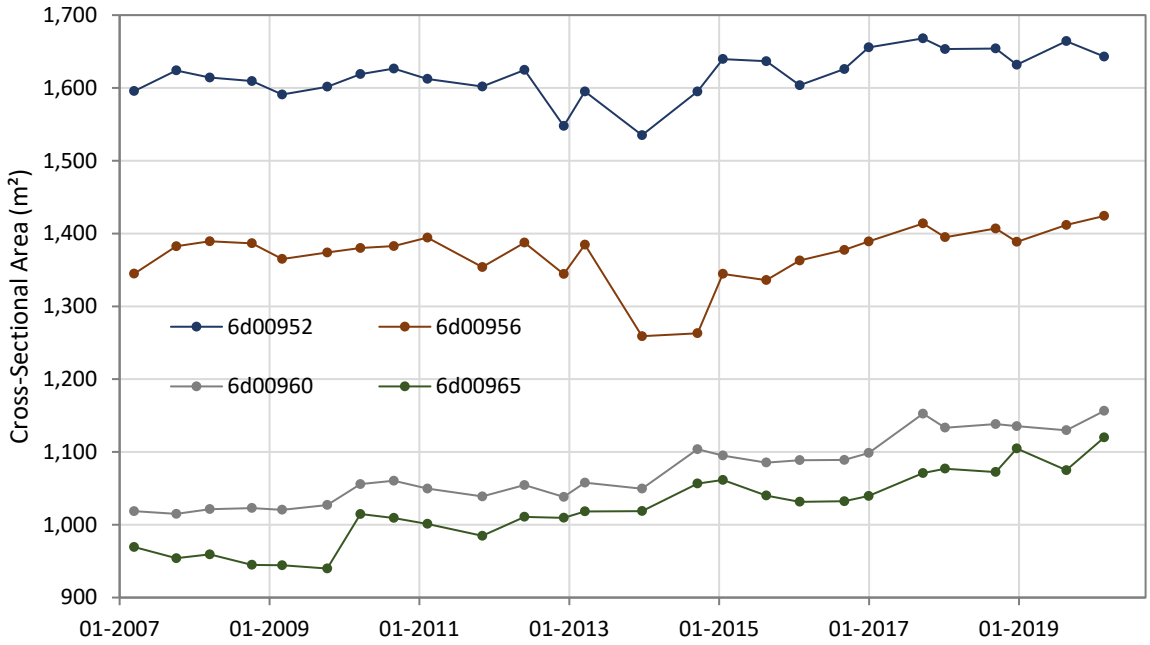


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 Baseline (red). Profiles are displayed against the master profile (dotted red line) and are presented in the Appendices.

The 2013/2014 Storms – The winter period between September 2013 and April 2014 was, for many beaches in Cornwall, the most destructive period since SWCM records began in 2007. An abnormal number of significant storms, occurring in quick succession, heavily impacted many beaches, causing the loss of sediment from the intertidal area and dune face. This period is extensively discussed throughout this report and will hereinafter be referred to as the 2013/2014 winter period.

2.2 LiDAR Data

Airborne Light Detection and Ranging (LiDAR) data have been captured as part of the SWCM since 2007. Products include a point clouds, from which filtered and unfiltered 1 m^2 gridded surface models are derived:

- Unfiltered (Digital Elevation Model) representing the earth's surface including natural and artificial features such as trees and buildings.
- Filtered (Digital Terrain Model) representing the bare earth surface, with trees, buildings, cars etc. removed.

LiDAR is captured between September and March to minimise vegetation capture. Data is captured between MLWS and up to approximately 500 m inland. This report utilises "filtered" LiDAR data.

2.2.1 LiDAR Data Analysis

LiDAR data analysis is presented as the following:

Difference Modelling – Separate LiDAR surfaces are compared to produce a difference model of change based on gridded spot height elevations. The raw spot height data is processed into a gridded digital terrain model (DTM) and successive models are subtracted from one another to produce a difference model for the survey unit. Change in elevation is shown for values +/- 0.25 m and is represented by a colour scale bar.

Volume Extraction - Net sediment volume (m^3) is extracted for each LiDAR surface from the Beach Zone above MLWS and Mobile Zone above MHWS for trend comparison over time.

Contour Analysis – Contours are mapped from four LiDAR epochs spanning from 2007 to 2023, representing Mean Sea Level (MSL) and dune toe (calculated using the Stockdon equation by UoP, 2023[2]).

2.3 Accuracy Statement

Topographic Data – All survey points recorded along profiles have a measurement accuracy of +/- 0.03 m RMSE[3] in the horizontal and +/-0.03 m RMSE in the vertical.

LiDAR Data – Each LiDAR point cloud dataset has an average point density of 1.5 points per square metre. The digital terrain surfaces provide a minimum accuracy in elevation data of +/- 0.10 m RMSE with a minimum horizontal standard deviation as < 0.05 m. Please note that while every endeavour has been made to capture LiDAR as far seaward as MLWS, tidal and weather restrictions may in some instances have precluded this and coverage may be slightly reduced.

[2] Please refer to the following for Dune Toe elevation calculation: UoP, 2023. MS4S: Contemporary Dune Evolution and Future Predictions, Report, University of Plymouth, 33 pp.

[3] RMSE – Root-Mean-Square Error

3.0 Results

3.1 Topographic Data Analysis

There has been a total of 35 topographic surveys at Constantine Bay since 2007, 4 of which are full coverage surveys, 30 are interim surveys and 1 is a post-storm survey. Exact dates of each survey for Constantine Bay are available to view on our survey record. Analysis of the CPA indicates the survey unit has been eroding at 7.5 m^2 y^{-1} equating to 0.1% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2014 autumn interim, following the highly energetic winter period, however the beach had begun to recover in the following years. Another energetic winter period was seen in 2020, resulting in beach volume dropping again by 502 m^2. The highest recorded combined area was during the 2012 autumn interim (7,734 m^2).

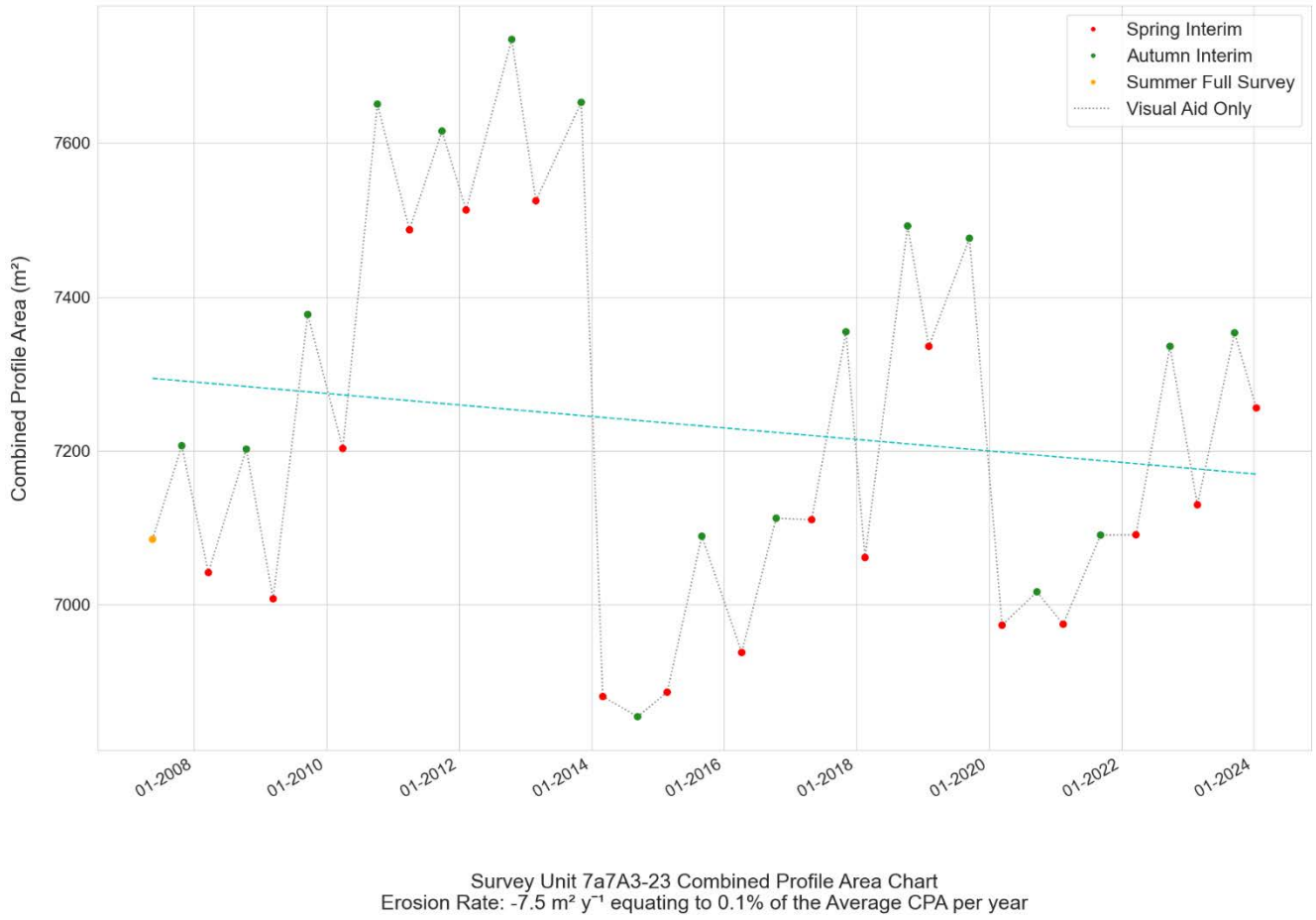


Figure 5 - The Combined Profile Area (CPA) for Constantine Bay, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When comparing to the entire dataset (Fig.6) the 2024 spring interim profiles 7a02084 and 7a02092 were relatively healthy, displaying an above average cross-sectional area, whereas profile 7a02088 was below average.

When comparing profile cross-sectional areas of the entire time series (Fig.7) profiles 7a02088 and 7a02092 both display a seasonal cycle, but were impacted by the 2013/2014 winter storms; profile 7a02084 has remained stable.

Profile charts for Constantine Bay can be found in Appendix 1; these display the cross-sections of each profile for the initial full coverage survey conducted in 2007 along with the two most recent interim surveys. All three profiles have shown accretion since the 2007 baseline survey, with material building up along the dune toe as well as the majority 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.

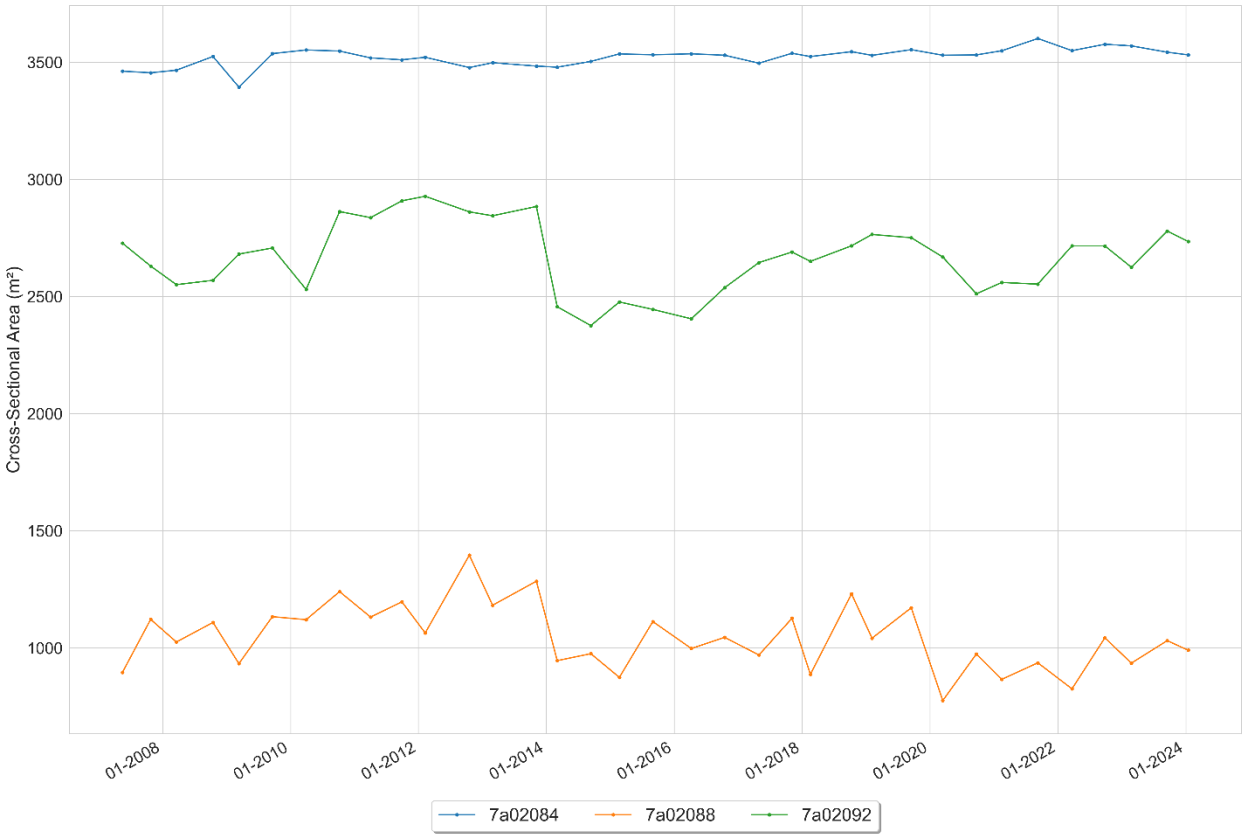


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

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

3.2.1 Difference Models

Difference models between each epoch of LiDAR data are presented here. Accretion and erosion values observed behind the dune system can be attributable to noise in the filtered LiDAR data or man-made changes in elevation and should be dismissed as such.

Figure 8 shows the difference in elevation between the first filtered LiDAR data from March 2008 compared to the most recent, captured in October 2022. There is considerable erosion to the dune system in the middle of the beach. This is also where the river flows out, meandering around the dune system. Up to 3 m of accretion can be seen at the dune face along the majority of the unit, whilst the dune crest has seen low level erosion. Widespread accretion can be seen across most of the northern beach.

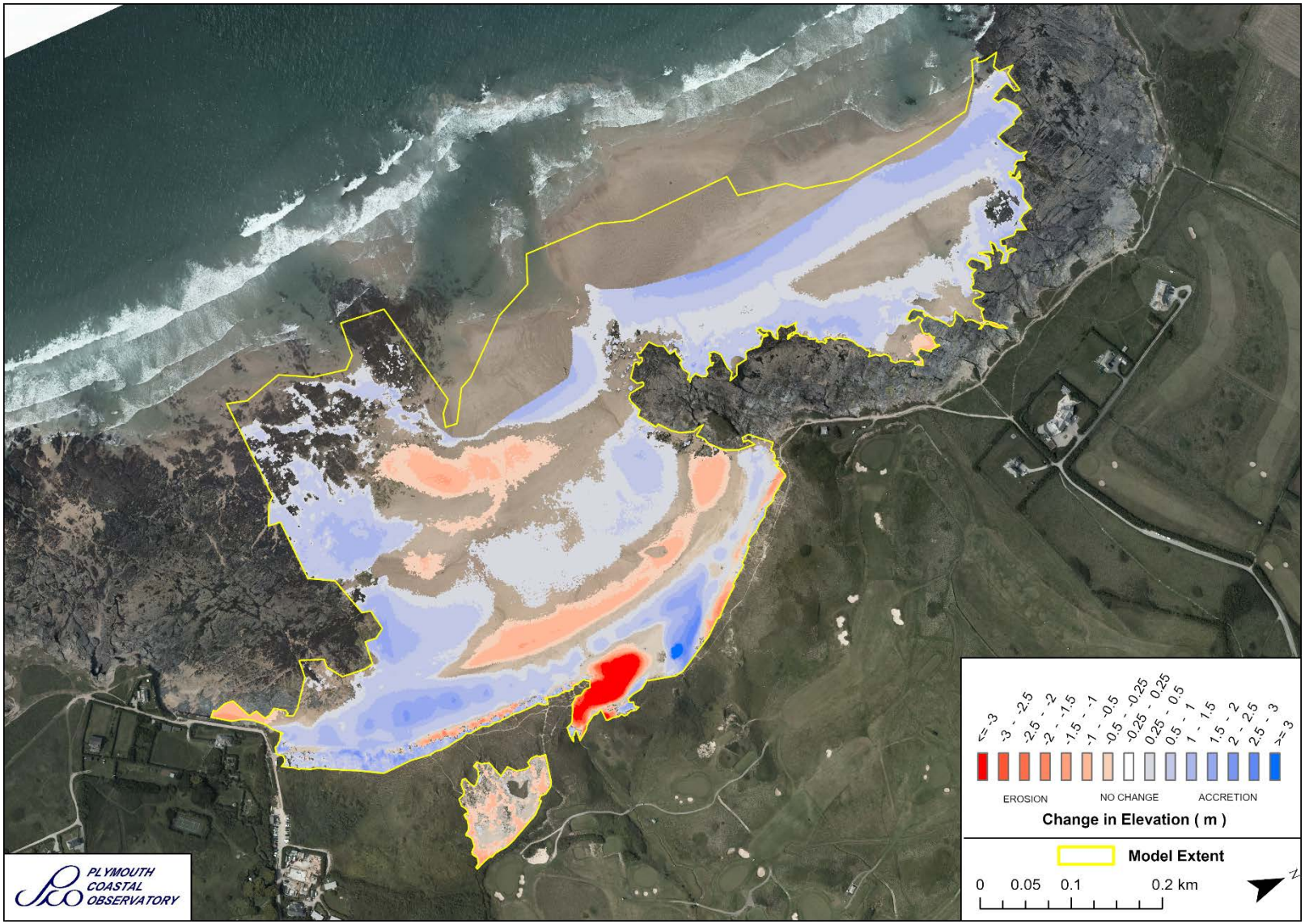


Figure 8 – Difference model indicating the changes in elevation observed between the March 2008 and October 2022 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from March 2008 compared to 2010. Widespread accretion can be seen across both bays, seeing an increase in elevation of up to 2m. Some erosion is observed on the dune crest along the southern bay, which has experienced a loss of up to 3 m.

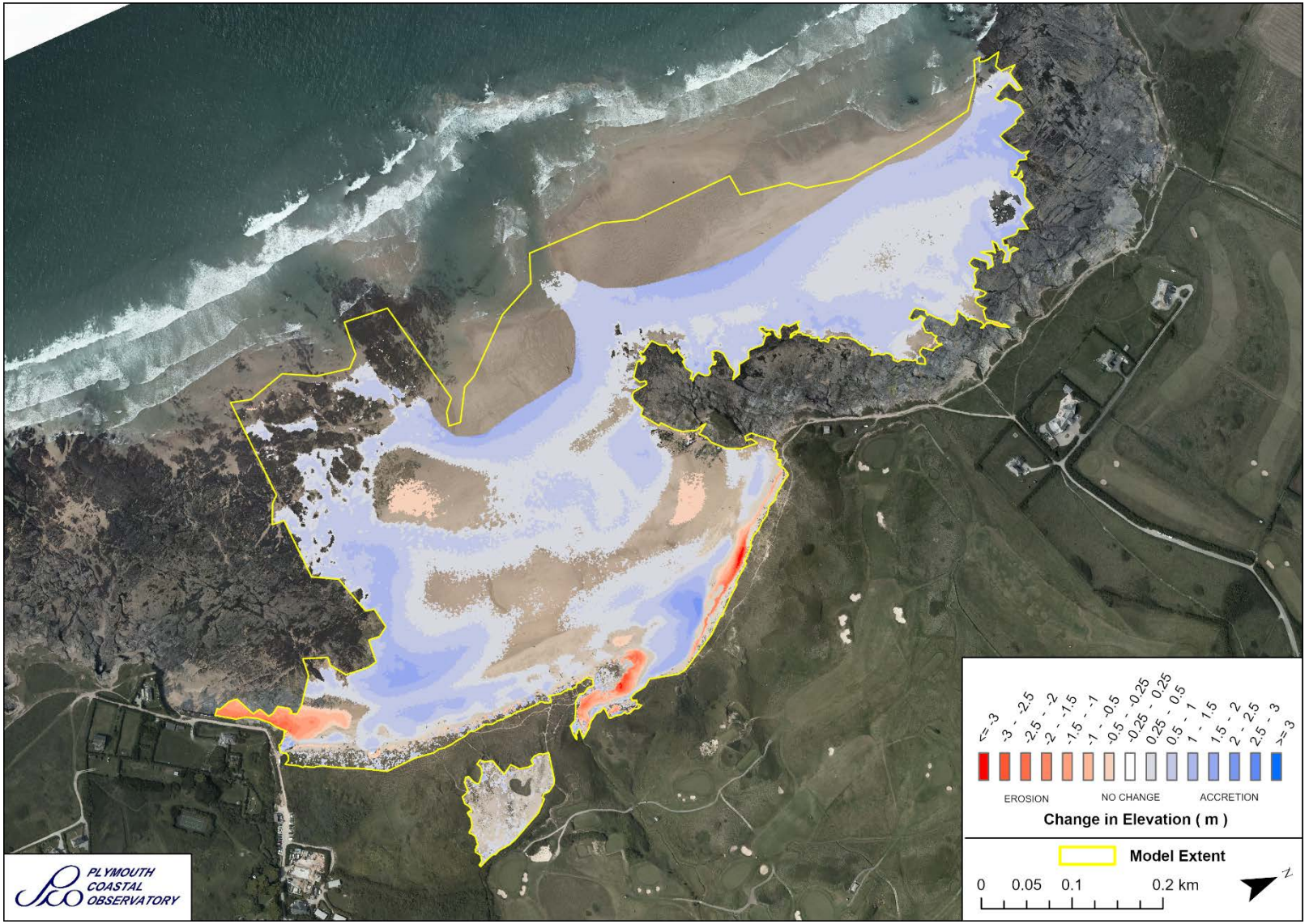


Figure 9 - Difference model indicating the changes in elevation observed between the March 2008 and 2010 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from 2010 compared to 2014. Contrary to changes observed in figure 9, there is widespread erosion across both bays, eroding by up to 3 m in places. A mixture of erosion and accretion can be seen along the dunes; to the north of the southern bay the dunes experienced a loss along the crest, but a gain in material along the dune face, suggesting a redistribution of material.

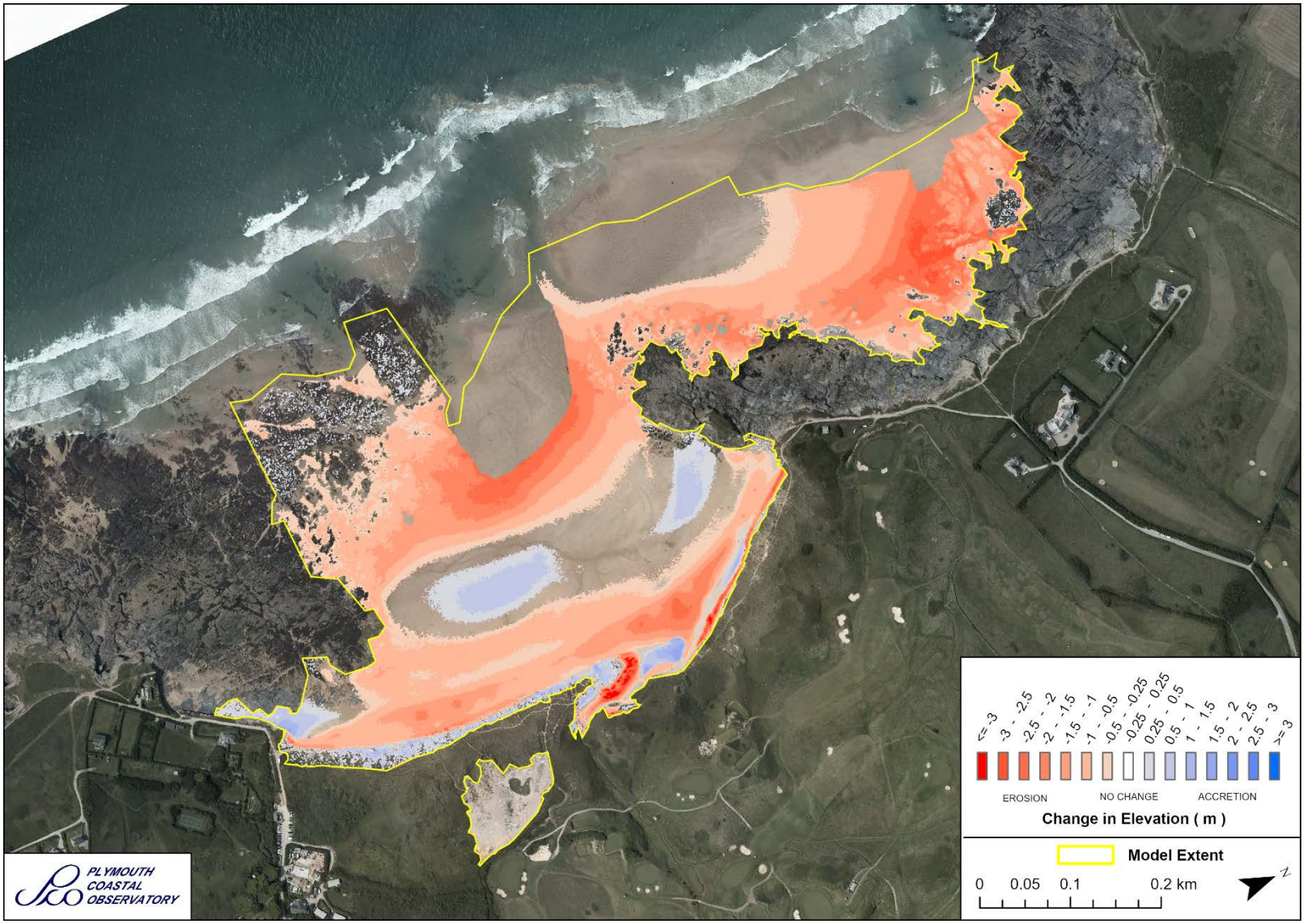


Figure 10 – Difference model indicating the changes in elevation observed between the 2010 and 2014 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from 2014 compared to 2019. This epoch indicates large areas of change, with accretion observed along the dune face countered by erosion observed along the dune crest. Acute erosion can be seen along the middle of the dune system, losing up to 3 m in elevation. The seaward extent of the unit suggests an intertidal bar is forming.

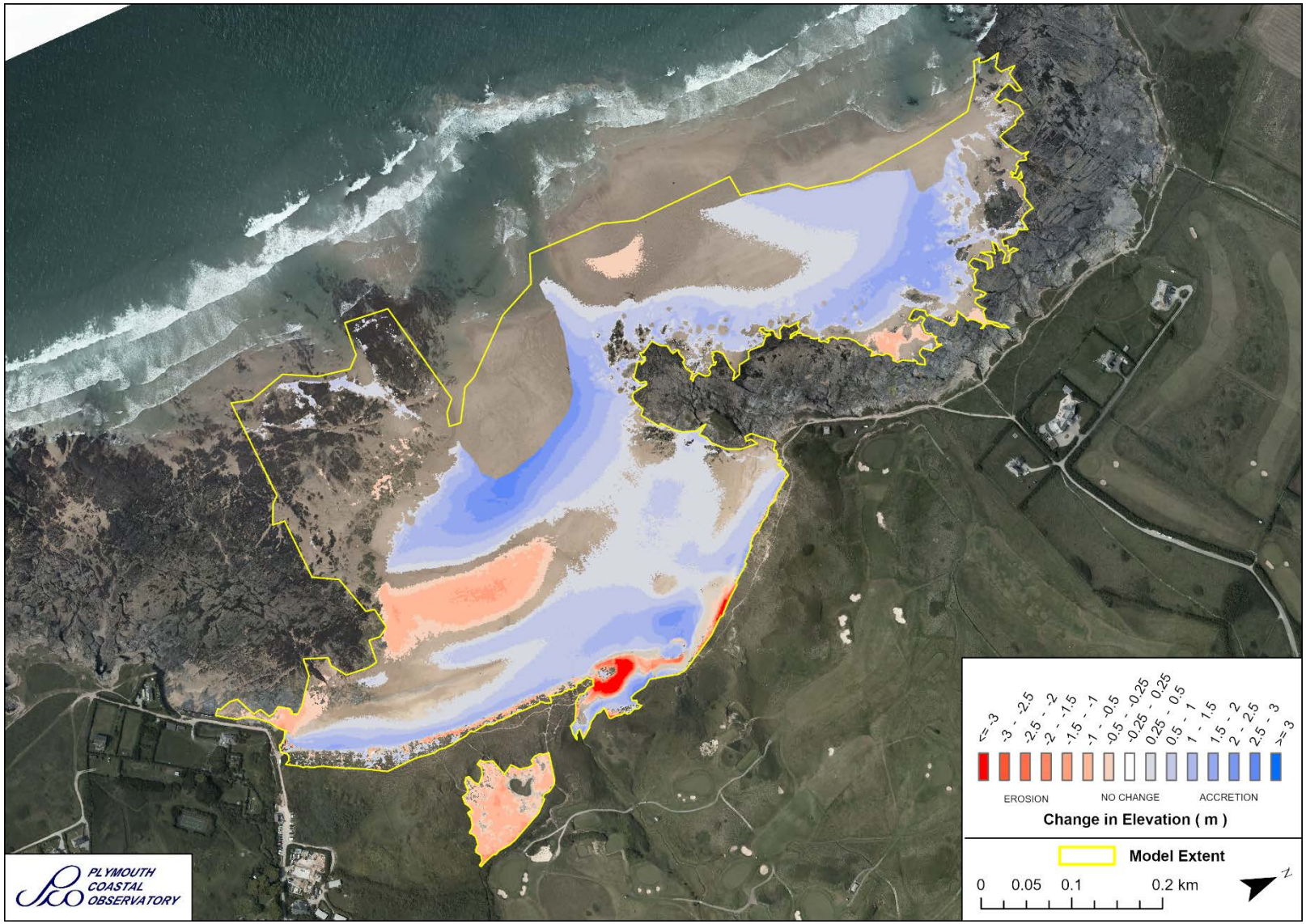


Figure 11 - Difference model indicating the changes in elevation observed between the 2014 and 2019 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from 2019 compared to 2022. The northern bay has seen low-level accretion, whilst the southern bay has seen both erosion and accretion. Again, acute erosion can be seen to the middle of the dune system, whilst the northern and southern ends have experienced accretion along both the dune and beach face. Erosion can be seen along the MSL mark and towards the seaward extend of the unit.

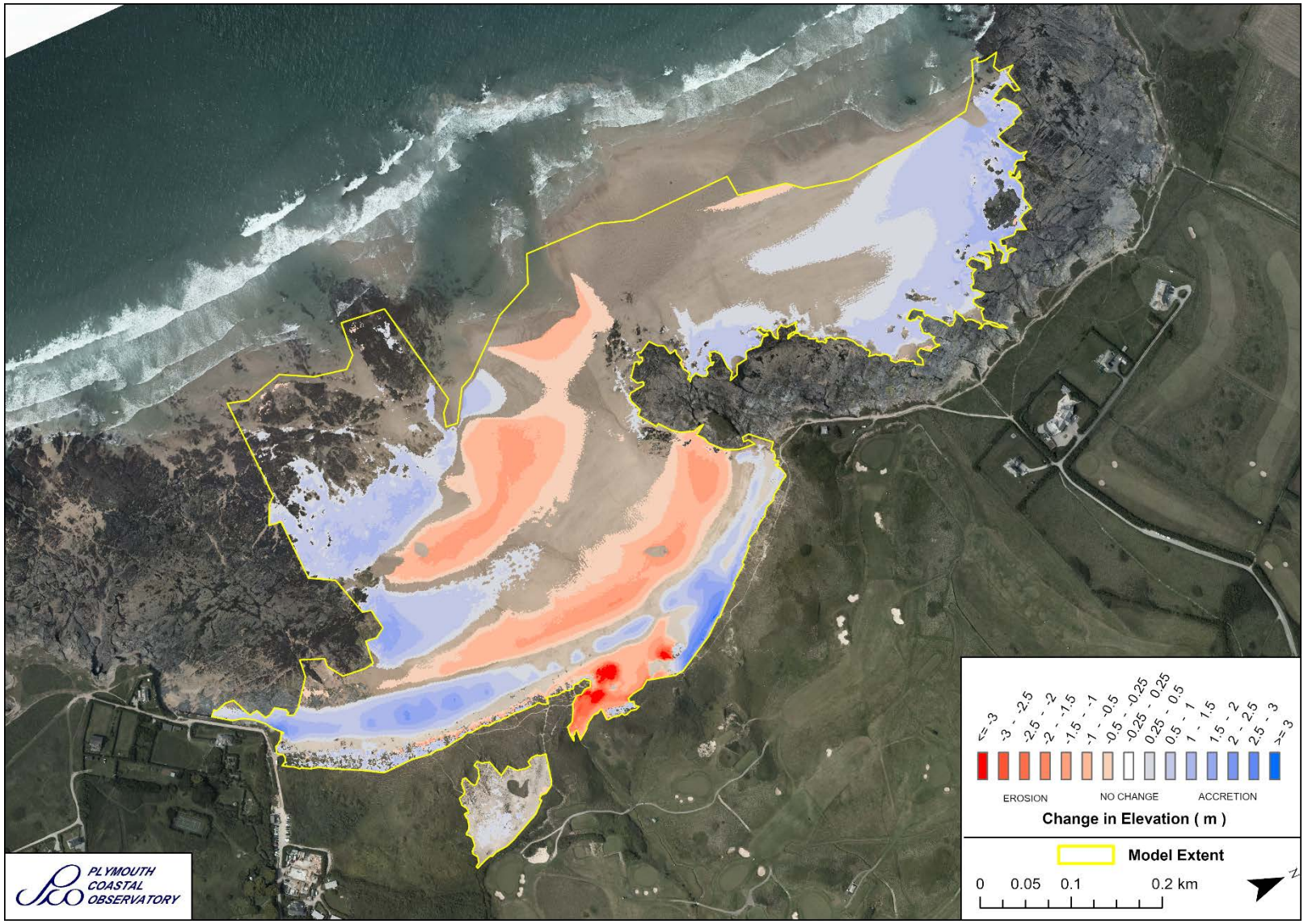


Figure 12 - Difference model indicating the changes in elevation observed between the 2019 and 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.45 m OD) is shown in Table 1. The Mobile Zone has varied in volume between 2008 and 2022 but has remained relatively stable (Fig.13). The largest change was observed between the 2010 and 2014 LiDAR surveys, where an 8% loss in volume was recorded. The Mobile Zone has since recovered to pre 2013/14 storm levels (Fig.13).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-3.00 m OD) are also shown in Table 1. Beach Zone volume has followed a similar trend to the Mobile Zone, with a 24% loss in volume between the 2010 and 2014 LiDAR surveys (Fig.14). Since 2014, the Beach Zone has fully recovered to pre-2013/14 levels (Fig.14).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.45 m OD) and for the Beach Zone above MLWS (-3.00 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
03/2008	254,165	524,488
10/2010	261,777	643,529
04/2014	240,585	488,398
04/2019	249,930	597,215
10/2022	261,212	613,230

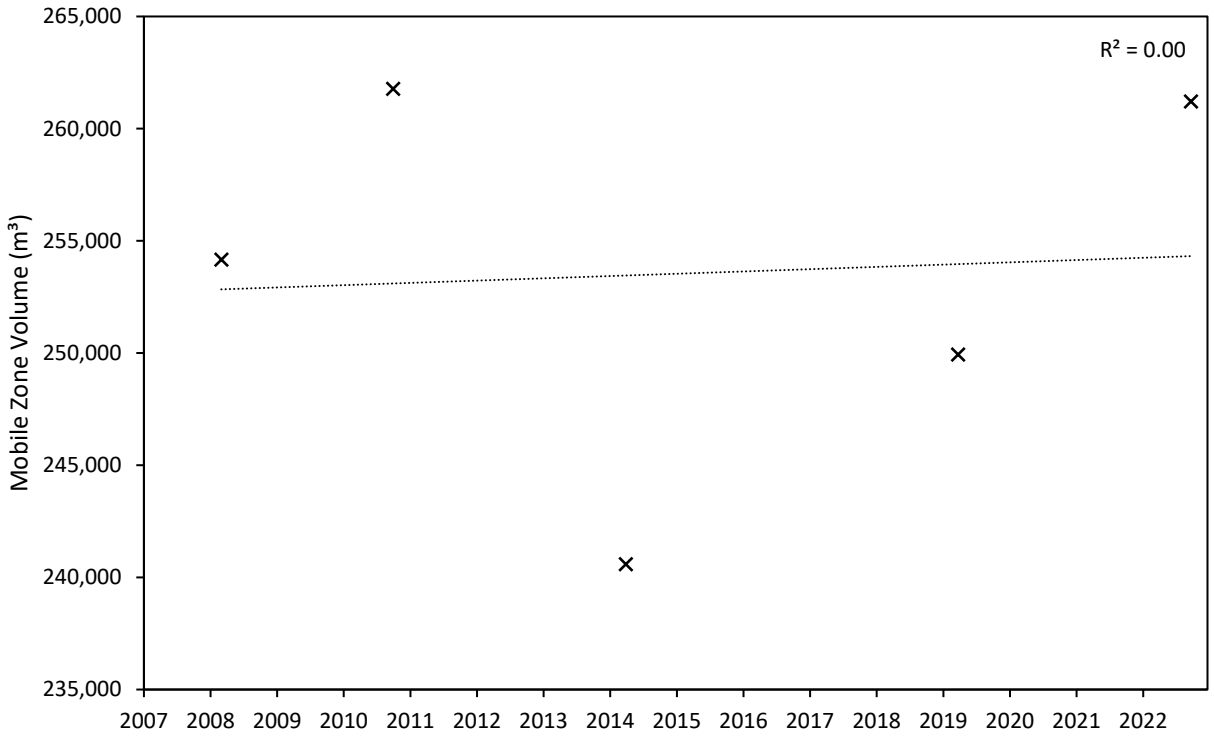


Figure 13 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.45 m OD) for each filtered LiDAR datasets between 2008 and 2022.

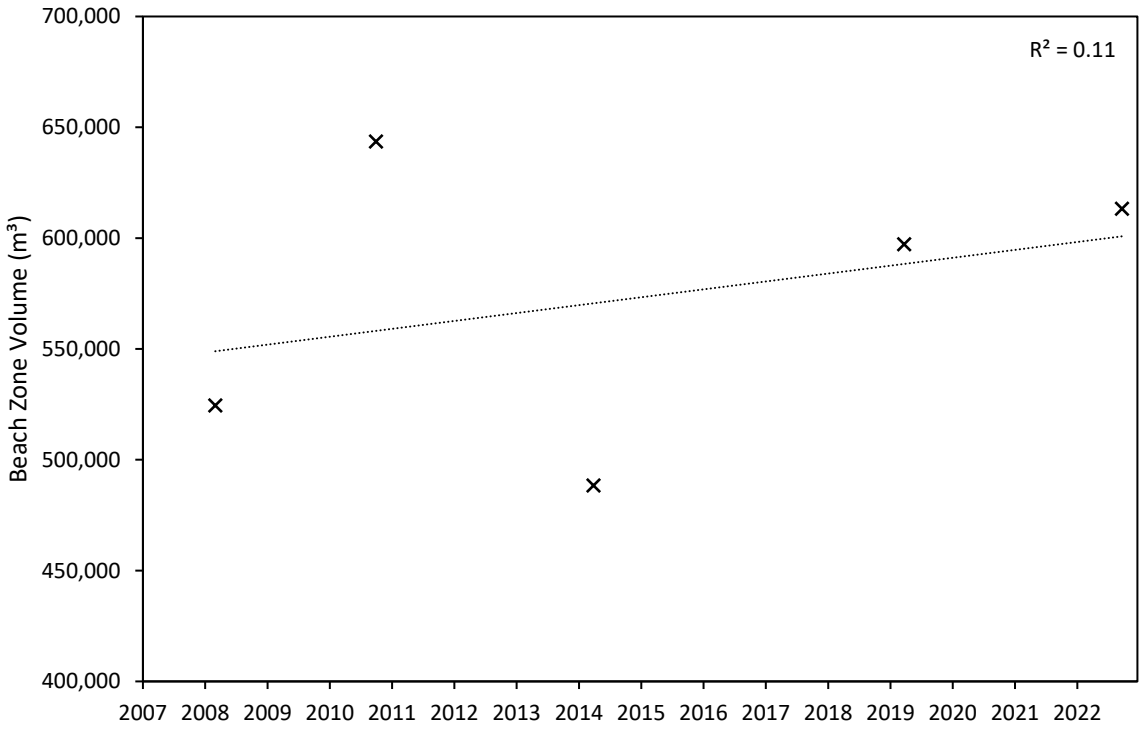


Figure 14 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.2.3 Contour Comparison

Figure 15 indicates the Mean Sea Level (MSL) and dune toe contours from the 2008, 2014, 2019 and 2022 LiDAR datasets. MSL contours indicate a widening of the beach from 2008 to 2022 by approximately 10-32 m. The same is true of the dune toe contours, which have advanced by 7-16 m across the length of the beach, with the exception of the middle section of section of the dunes, which has lost up to 27 m of material.

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.

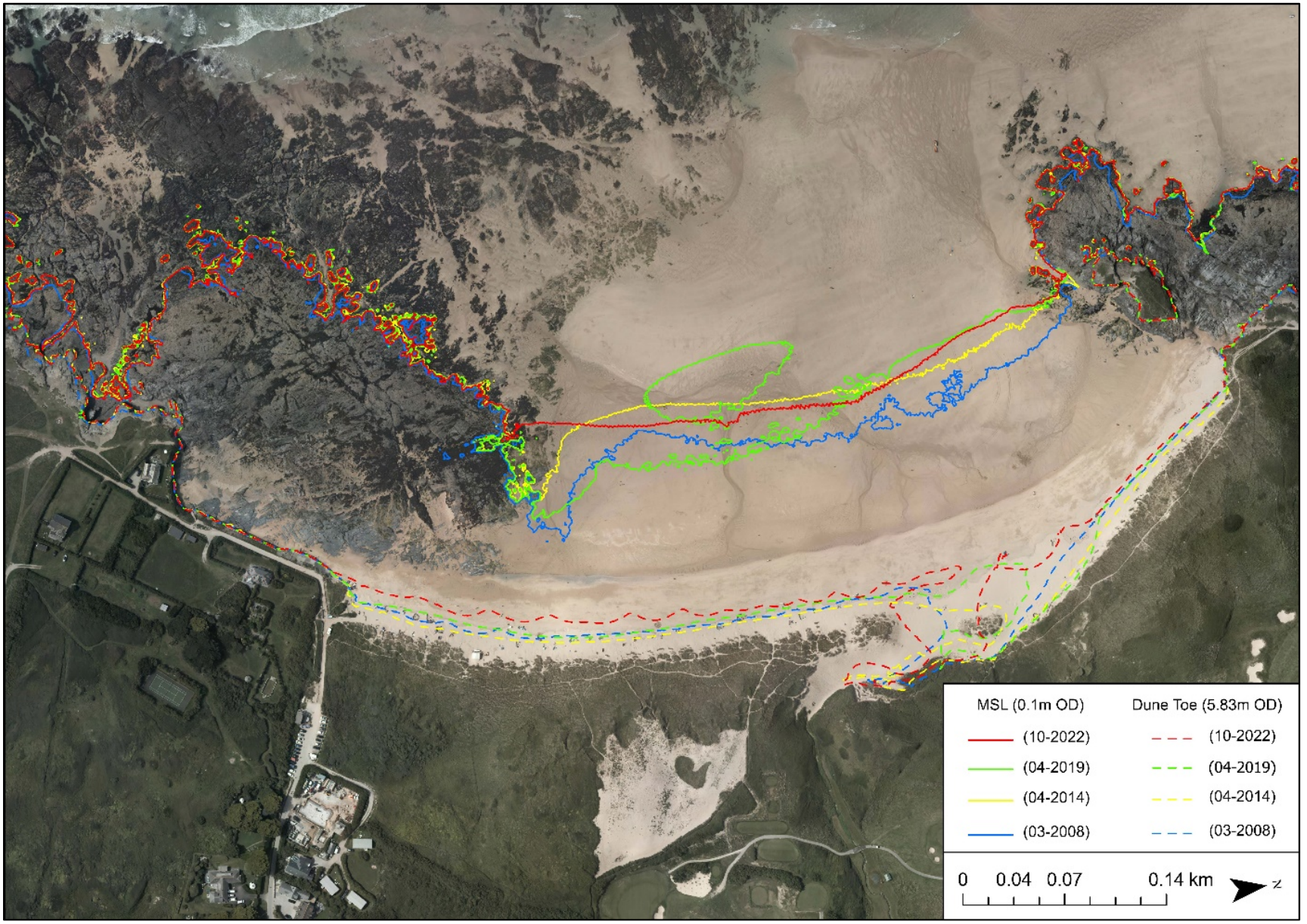


Figure 15 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022.

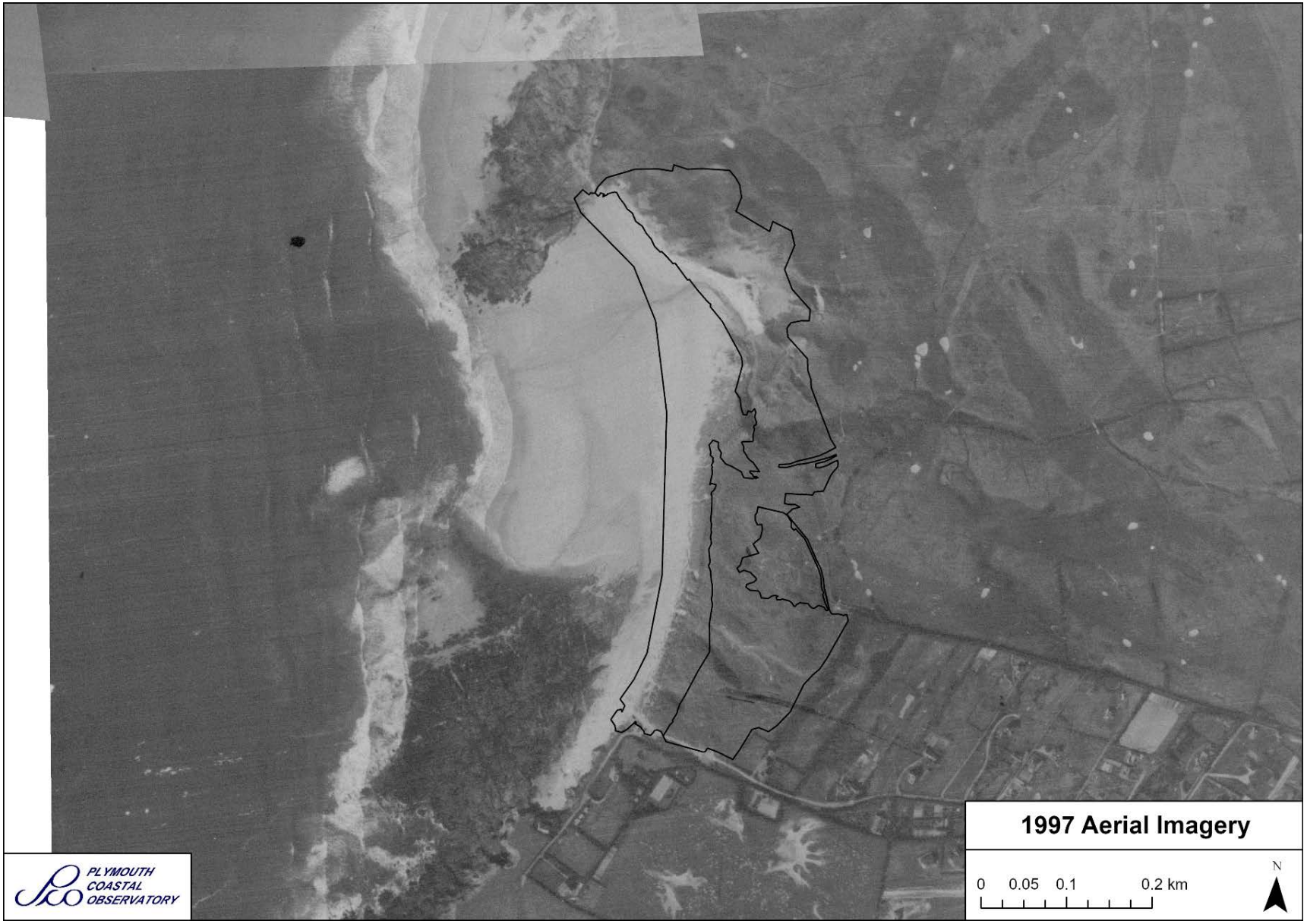


Figure 16 – Aerial imagery from 1947.



Figure 17 – Aerial imagery from 2001.



Figure 18 – Aerial imagery from 2008.



Figure 19 – Aerial imagery from 2010.



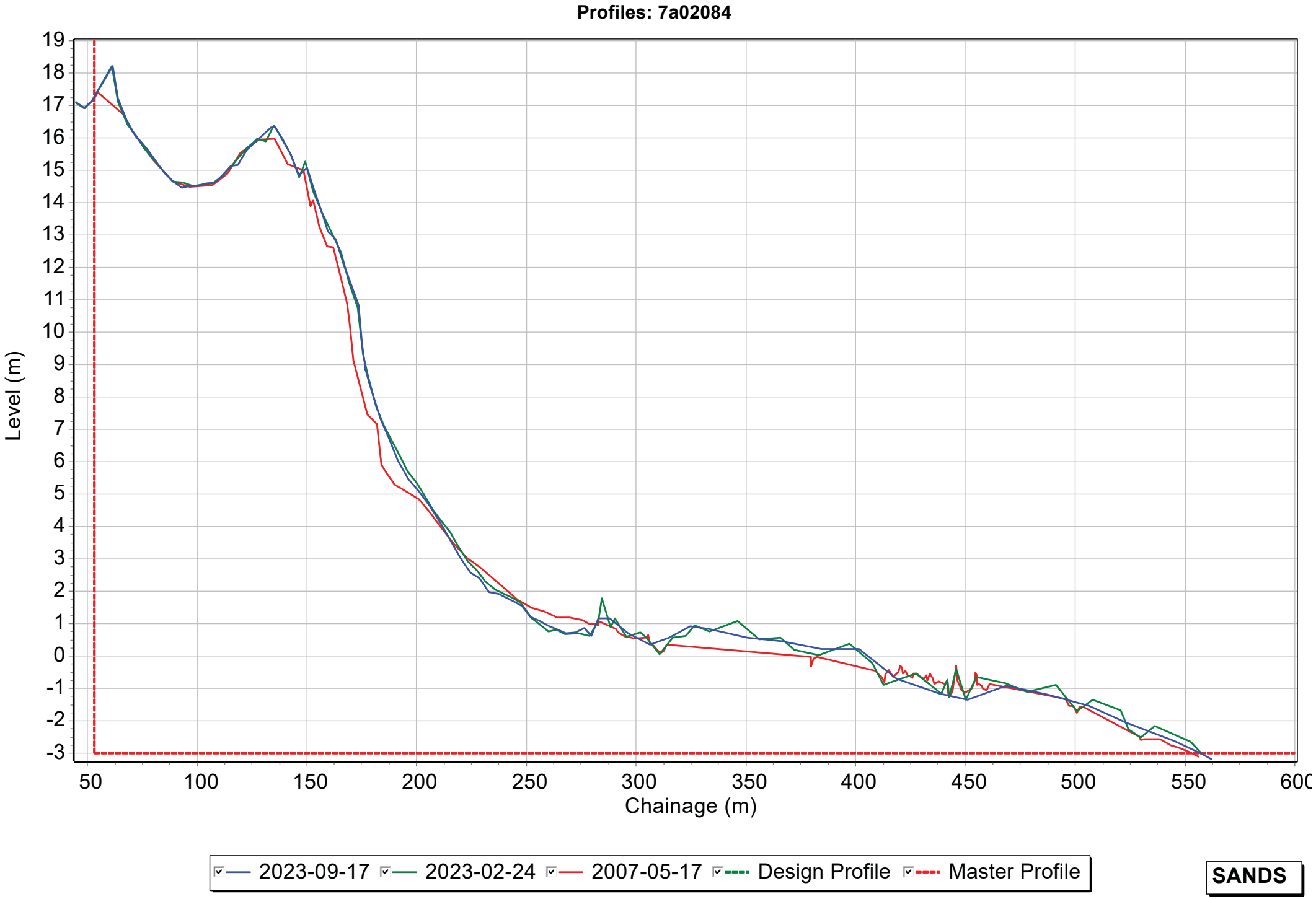
Figure 20 – Aerial imagery from 2017.

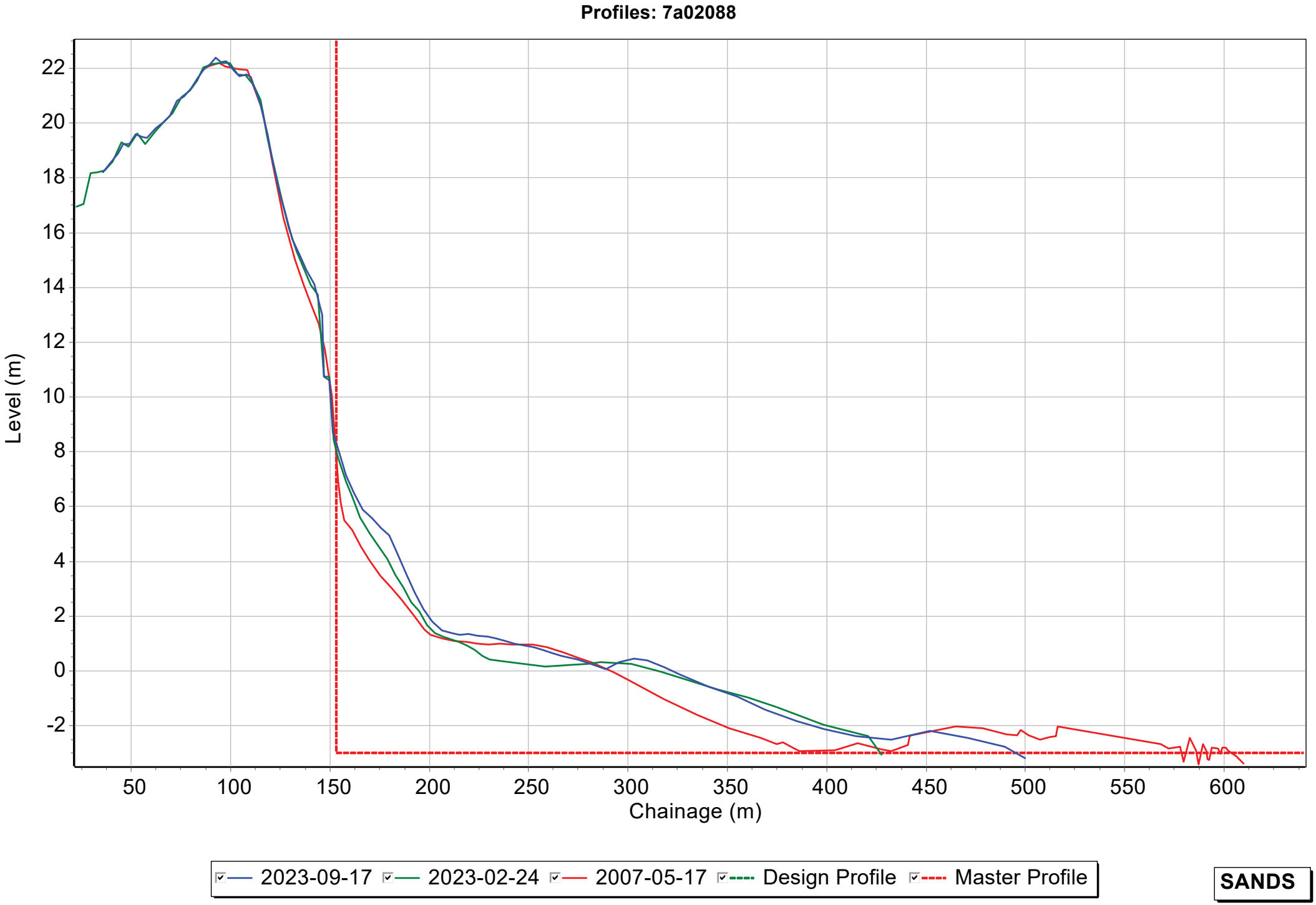
Glossary

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.

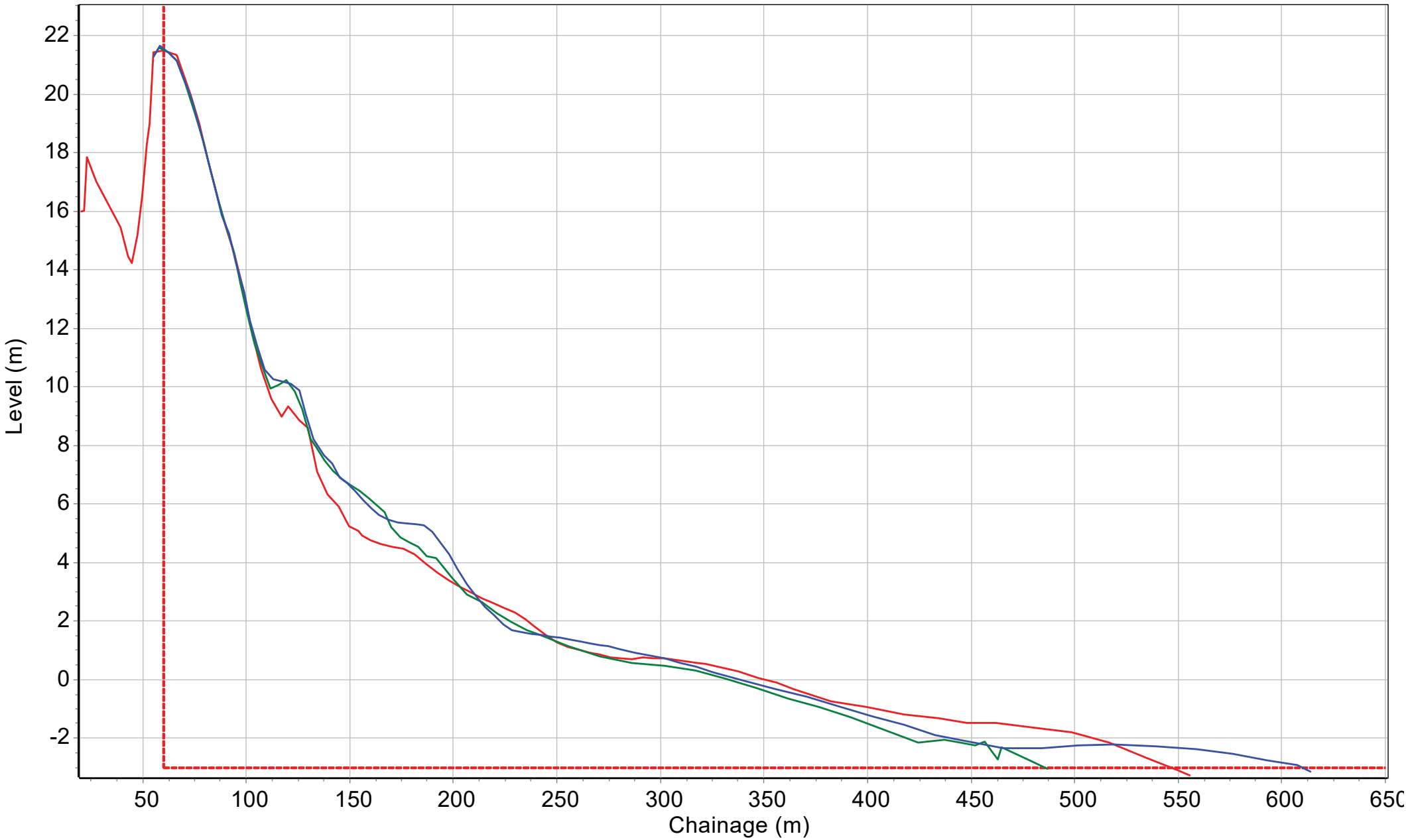
Appendices

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 Constantine Bay are presented below.


Profiles: 7a02084
Level (m)
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
50
100
150
200
250
300
350
400
450
500
550
600
Chainage (m)
2023-09-17
2023-02-24
2007-05-17
Design Profile
Master Profile
SANDS


Profiles: 7a02088
Level (m)
22
20
18
16
14
12
10
8
6
4
2
0
-2
50
100
150
200
250
300
350
400
450
500
550
600
Chainage (m)
2023-09-17
2023-02-24
2007-05-17
Design Profile
Master Profile
SANDS

Profiles: 7a02092



SANDS