SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand - Par Sands Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR03 | 19/12/2023

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Taken by: Joseff Saunders

Summary

This report utilises Light Detection and Ranging (LiDAR), topography and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Par Sands. The aim is to highlight coastal change at Par Sands using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Par Sands is a large, south facing sandy beach, backed by an accreting dune system approximately 800 m long and >600 m wide. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change to the intertidal beach area over time. LiDAR data from each available flight is compared to create difference models of the intertidal area, compare volumetric data over time and to show change in Mean Seal Level (MSL) and dune toe contours over time.

There has been a total of 30 topographic surveys at Par Sands since 2007. Analysis of topographic data suggests the combined profile area has been accreting continuously since 2007 (0.7% increase per year) despite recording the lowest combined profile area following the 2013/14 storms.

Beach volume extracted from 10 LiDAR flights since 2007 have seen the Mobile Zone and Beach Zone to show similar trends to the topographic surveys; with both accreting. The Mobile Zone in particular has seen a considerable and uninterrupted accretion since 2007, with considerable growth of the dune system observed in difference models and aerial imagery.

Overall Par Sands has significantly accreted since 2007, with both topographic and LiDAR data indicating significant gain of material from the upper beach and foredune.

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1.0 Introduction

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

Par Sands is a large south facing sandy beach backed by an accreting dune system and confined by a small stream and Par docks to the west and Gribbin Head to the east (Fig.1). The beach has a cross-shore distance of ~800 m and longshore distance of ~650 m with an average spring tidal range of 4.5 m. Par Sands has a large and active Dune system. The four beach and dune zones are represented in Figure 1.

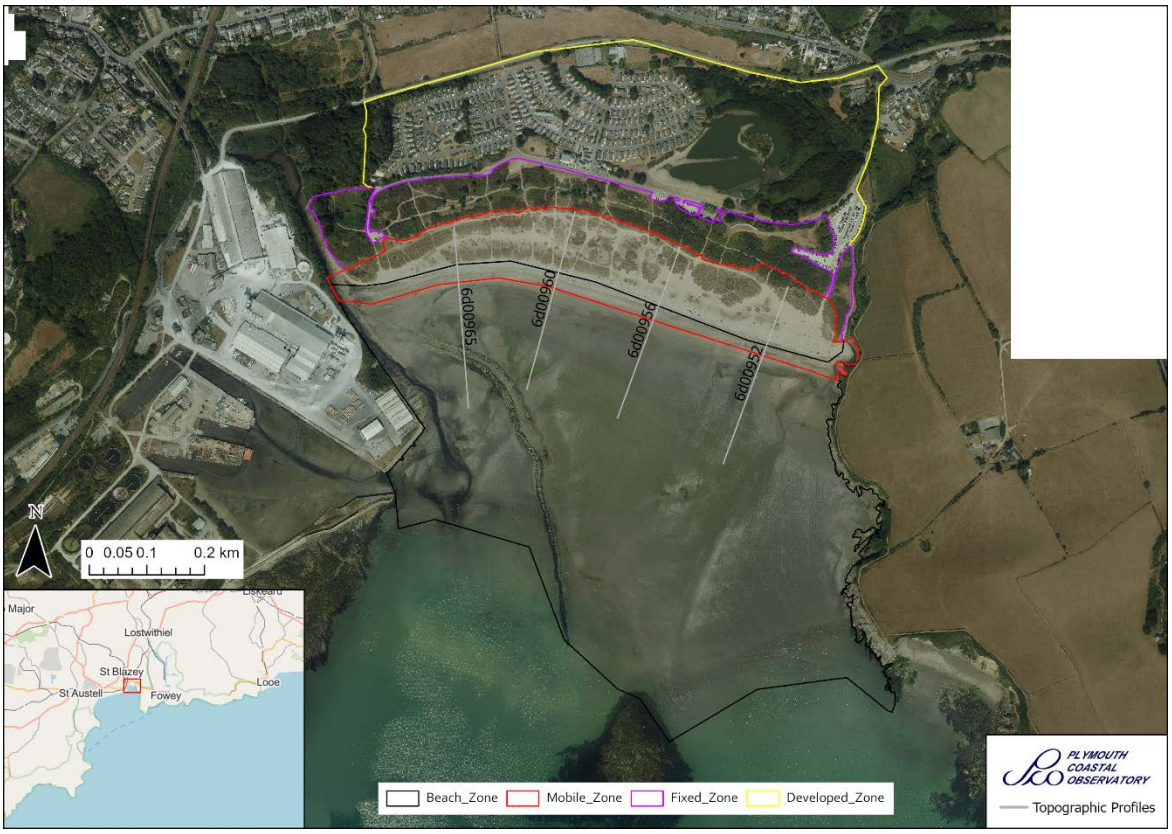


Figure 1 - Location Map of Par Sands Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[1] An embryo dune, or yellow dune, is the earliest stage of dune growth, usually found along the seaward extent of a dune system or newly formed dune.

2.0 Methods

Data utilised in this report was collected by SWCM between 2007 and 2024. Information on topographic and LiDAR data collection and specifications can be found on the Website for the National Network of Coastal Monitoring Programmes.

2.1 Topographic Data

SWCM have undertaken routine topographic beach surveys at 34 of the 40 MS4S sites since 2006. All surveys are conducted from the MLWS contour to the backshore. On average, each surveyed beach receives two interim surveys a year and one full coverage survey every 5 years:

- Interim - Conducted twice a year in the spring (conducted between January and April), and autumn (conducted between September and December). An interim survey consists of collecting data points at 5m intervals along pre-defined profiles; these are outlined in Figure 1.
- Full coverage – Conducted once per phase (6 years), or annually at more vulnerable sites (conducted between May and September). Full coverage surveys include a full profile survey at 50 m intervals and continuous spot height data collected across a 5 m grid covering the whole beach.

Analysis of the Cross-Sectional Area (CSA) change is conducted for each individual profile between each separate survey. Changes in CSA are measured relative to the fixed master profile which is defined by a pre-determined stable landward position and the MLWS level in reference to Ordnance Datum.

2.1.1 Topographic Data Analysis

Topographic data is presented as the following, where applicable:

Trend Analysis Plot - The combined profile trend in CSA is presented for each survey unit (example shown in Fig.2). The sum of all interim profile CSA is combined for each survey conducted to date to provide a survey unit with a single 'beach area' value, known hence-forth as the Combined Profile Area (CPA). CPA is compared using linear trend analysis over a temporal scale (Fig.2).

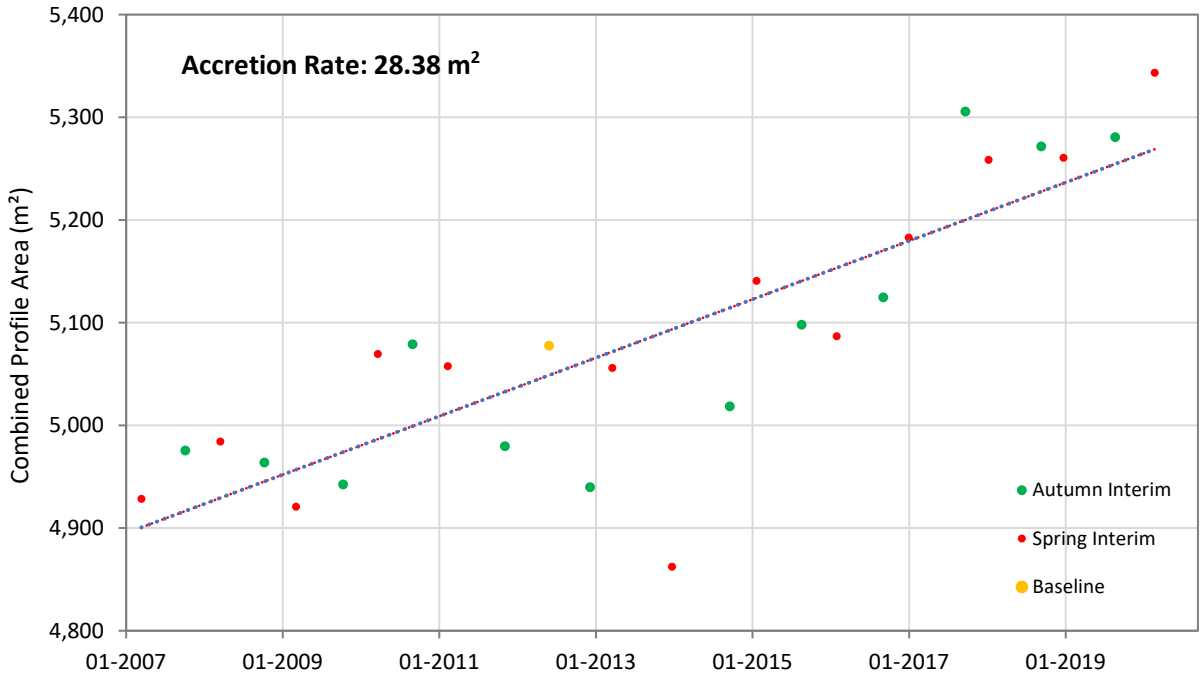


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

If a profile has been omitted from a particular survey, for reasons of obstruction or similar, the average CSA of that profile from all available surveys is taken to ensure a consistent 'beach area'; if fewer than 75% of surveys have been conducted for a particular profile, the profile is omitted.

Profile Extremes Analysis - This plot displays the range of CSA values recorded throughout the duration of data collection (2006-2022) for each individual interim profile; the most recent survey is represented as a green dot. An example is given in figure 3. This plot provides the reader with information on how the CSA for each interim profile from the most recent survey corresponds to the entire dataset range.

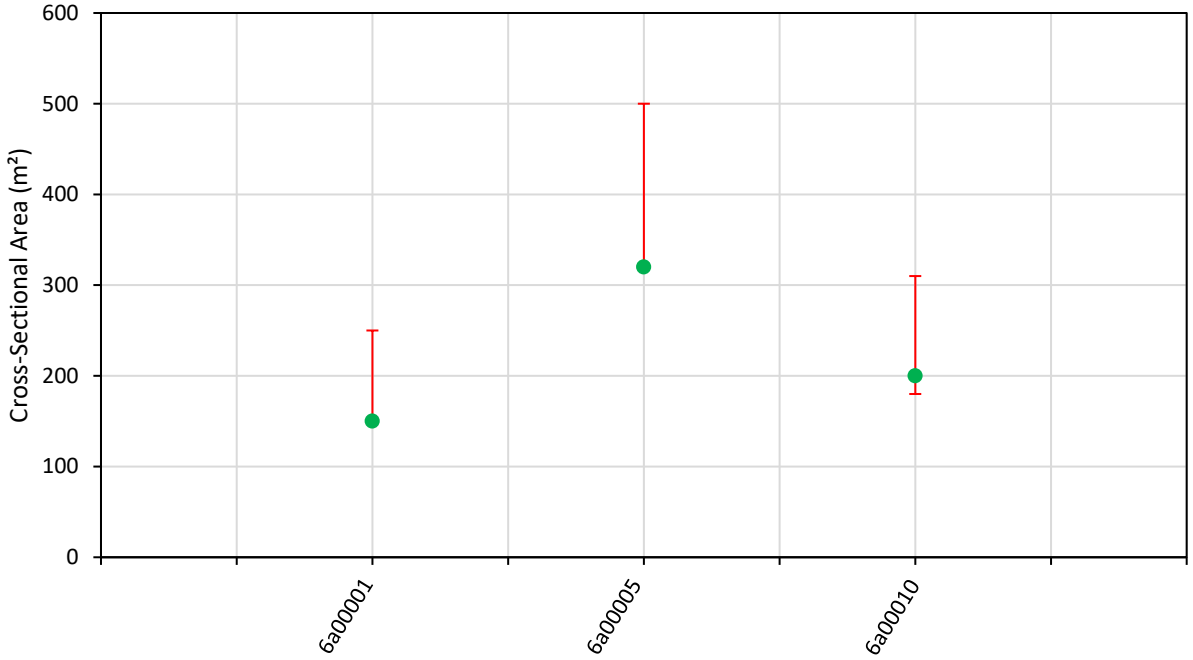


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

CSA Time Series Plot - CSA measurements for each interim profile are displayed on a separate plot representing values from each interim and full coverage survey conducted to date (example shown in Fig.4). This provides the reader with information on each interim profile's CSA evolution through time.

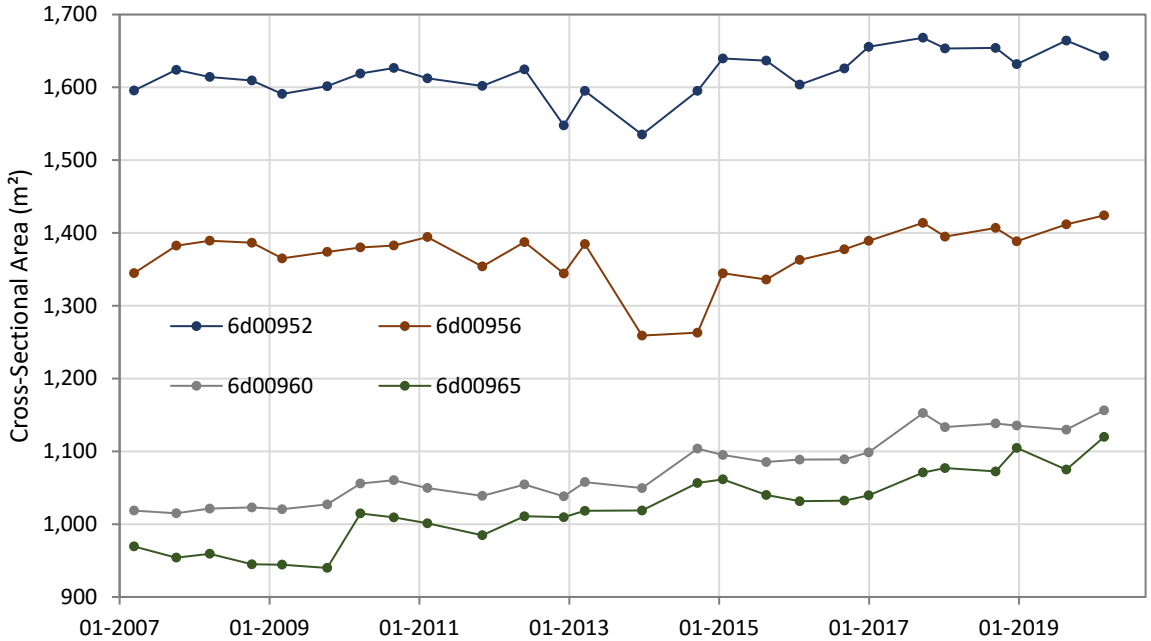


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

Individual Profile Charts - Each interim profile is portrayed as a cross-sectional profile comparing the most recent spring interim (blue), the previous spring interim (green) and the original full coverage survey (red). Profiles are displayed against the master profile (dotted red line) and are presented in the Appendices.

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

2.2 LiDAR Data

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

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

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

2.2.1 LiDAR Data Analysis

LiDAR data analysis is presented as the following:

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

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

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

2.3 Accuracy Statement

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

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

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

[3] RMSE – Root-Mean-Square Error

3.0 Results

3.1 Topographic Data Analysis

There has been a total of 30 topographic surveys at Par Sands since 2007; 4 of which are full coverage surveys and 26 are interim surveys. Exact dates of each survey for Par Sands are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting at 36.4 m^2 y^{-1} , equating to 0.7% 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 autumn interim of 2022 (5,519 m^2).

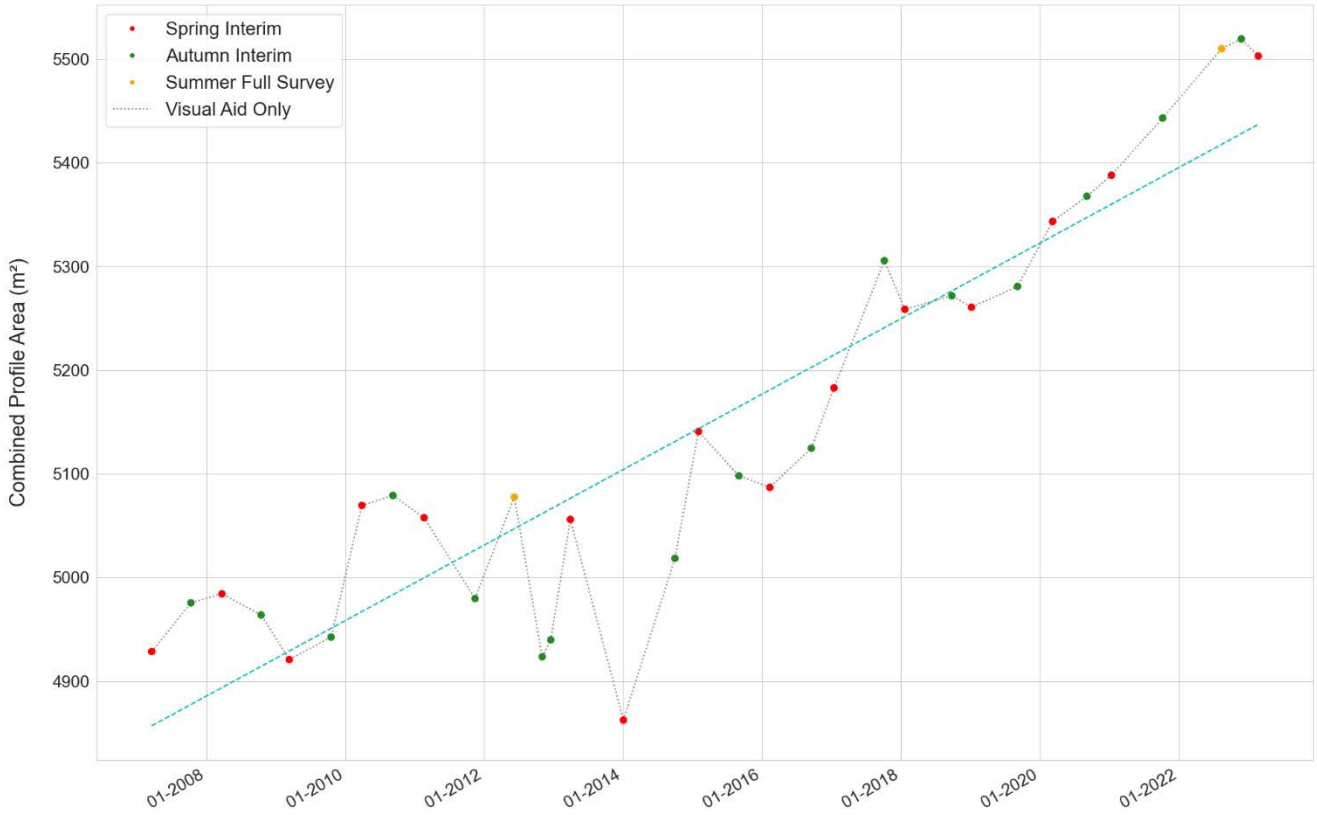


Figure 5 - The Combined Profile Area (CPA) for Par Sands, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing the 2023 autumn interim survey to the entire dataset (Fig.6), all Par Sands profiles were very healthy with 6d00960 and 6d00965 displaying the highest cross-sectional area to date.

When comparing profile cross-sectional areas to the entire time series (Fig.7), all profiles again have displayed continual accretion since 2007 with minimal seasonal variation apparent in any profile. Profile 6d00956 was the only one to indicate a real erosive impact from the 2013/14 winter season (Fig.7).

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. All four profiles have shown accretion since the 2007 baseline survey, with up to 1 m gain in elevation of the embryo dunes in all four scenarios.



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

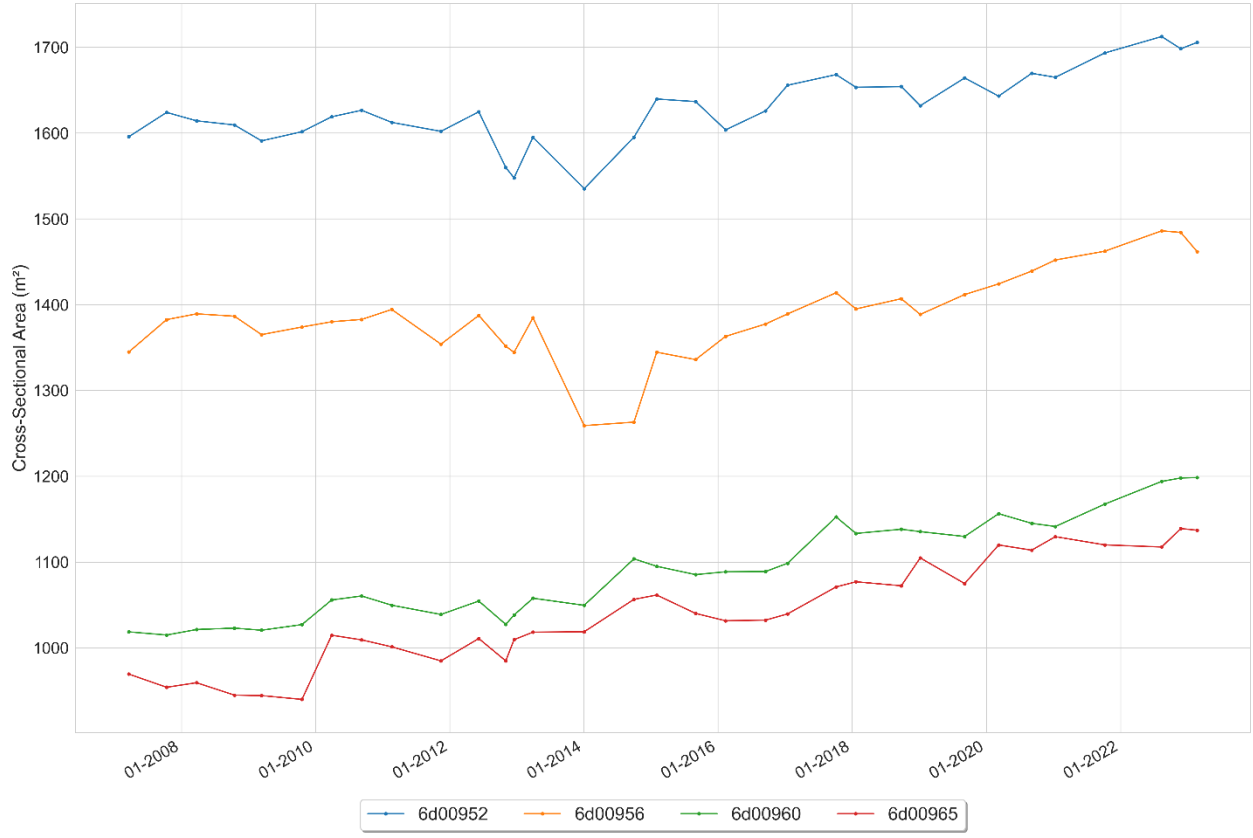


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

3.2 LiDAR Data Analysis

There has been a total of 10 LiDAR flights captured at Par Sands 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.

01/2008 to 03/2022 – Figure 8 shows the difference in elevation between the first filtered LiDAR data from 2008 compared to the most recent, captured in 2022. The plot shows considerable accretion observed along the upper beach face and mobile dune face, with the latter accreting by up to 2 m. The only small areas of comparative erosion present along the Polmear stream to the west and centre of the beach (Fig.8).

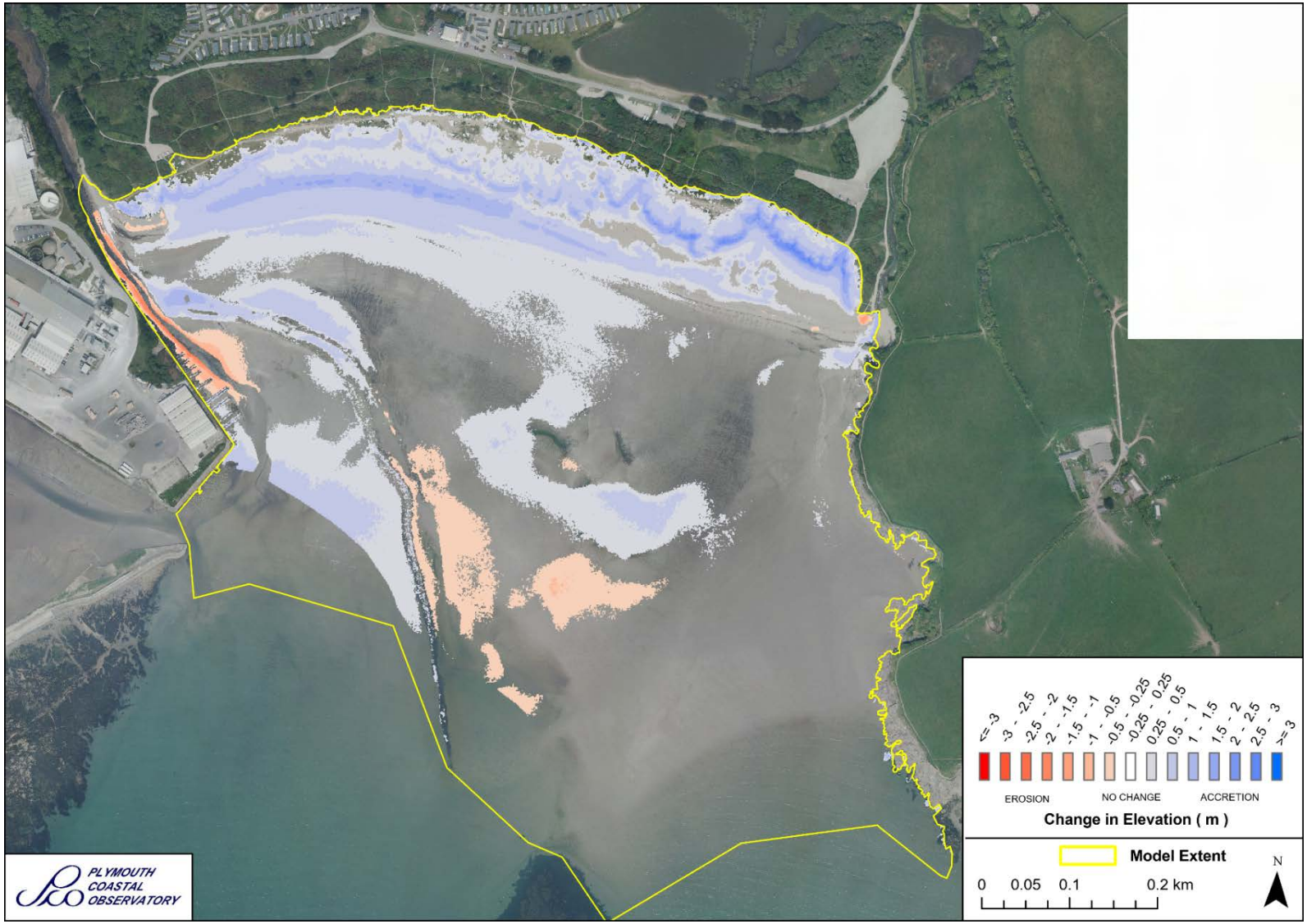


Figure 6 – Difference model indicating the changes in elevation observed between the January 2008 and March 2022 filtered LiDAR datasets within the yellow model extent.

01/2008 to 02/2009 – Figure 9 shows differences in elevation between filtered LiDAR data from 2008 compared to 2009. There is minimal change observed at the upper beach and dune system, with most of the observed erosion/accretion attributable to the changing course of the Polmear stream, representing a calm period for the survey area.

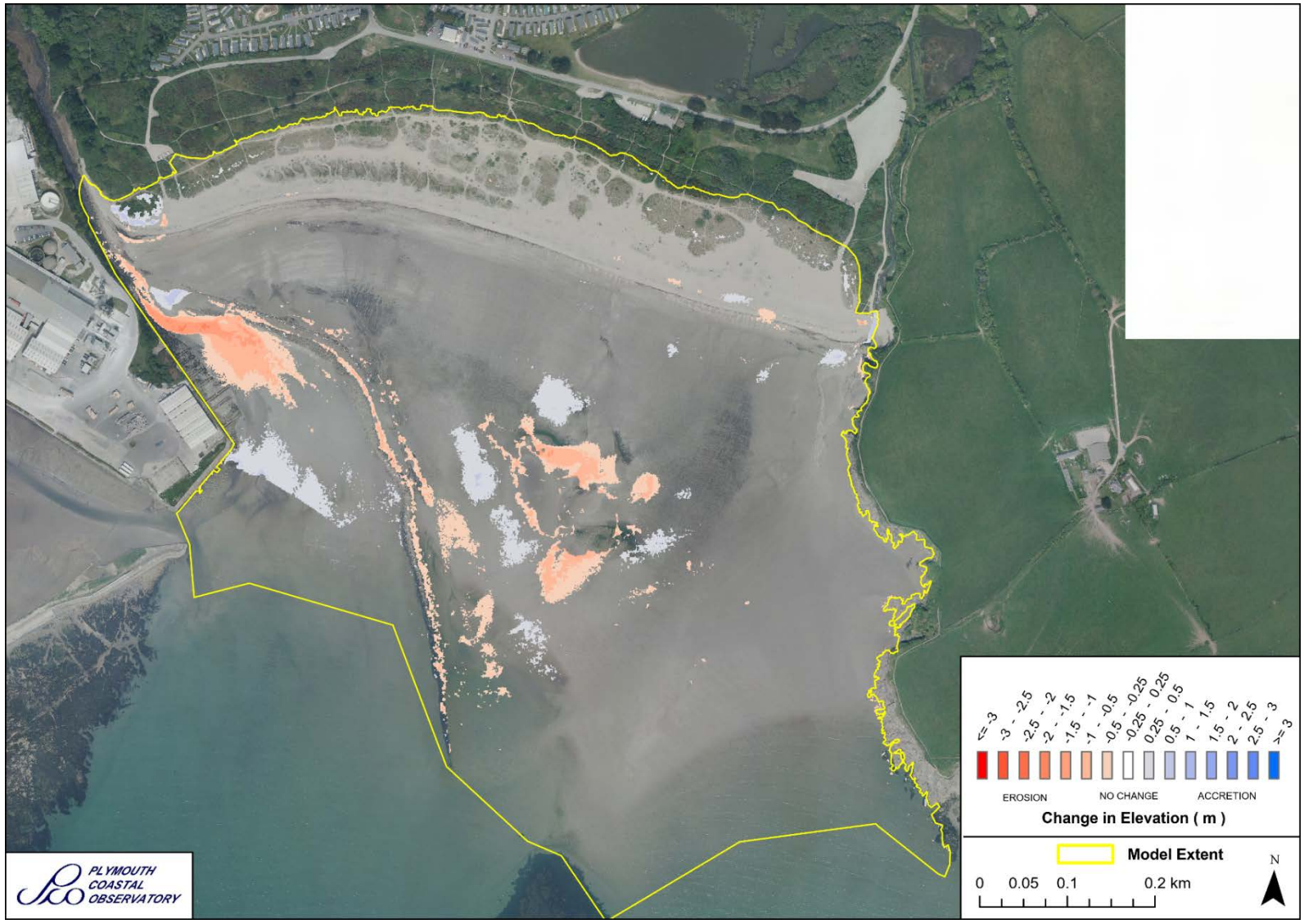


Figure 7 - Difference model indicating the changes in elevation observed between the January 2008 and February 2009 filtered LiDAR datasets within the yellow model extent.

02/2009 to 10/2009 – Figure 10 shows differences in elevation between filtered LiDAR data from February 2009 compared to October 2009. Again accretion/erosion can be observed along the course of the Polmear stream, however a band of accretion can be seen along the upper beach near to the MHWS mark, particularly to the east of the beach.



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

10/2009 to 03/2012 – Figure 11 shows differences in elevation between filtered LiDAR data from October 2009 compared to March 2012. Between the two epochs there has been widespread accretion along the MHWS mark for the entire beach, accreting by up to 1 m in places. A relatively large area of erosion can also be observed to the east of the Polmear stream along the low tide terrace.

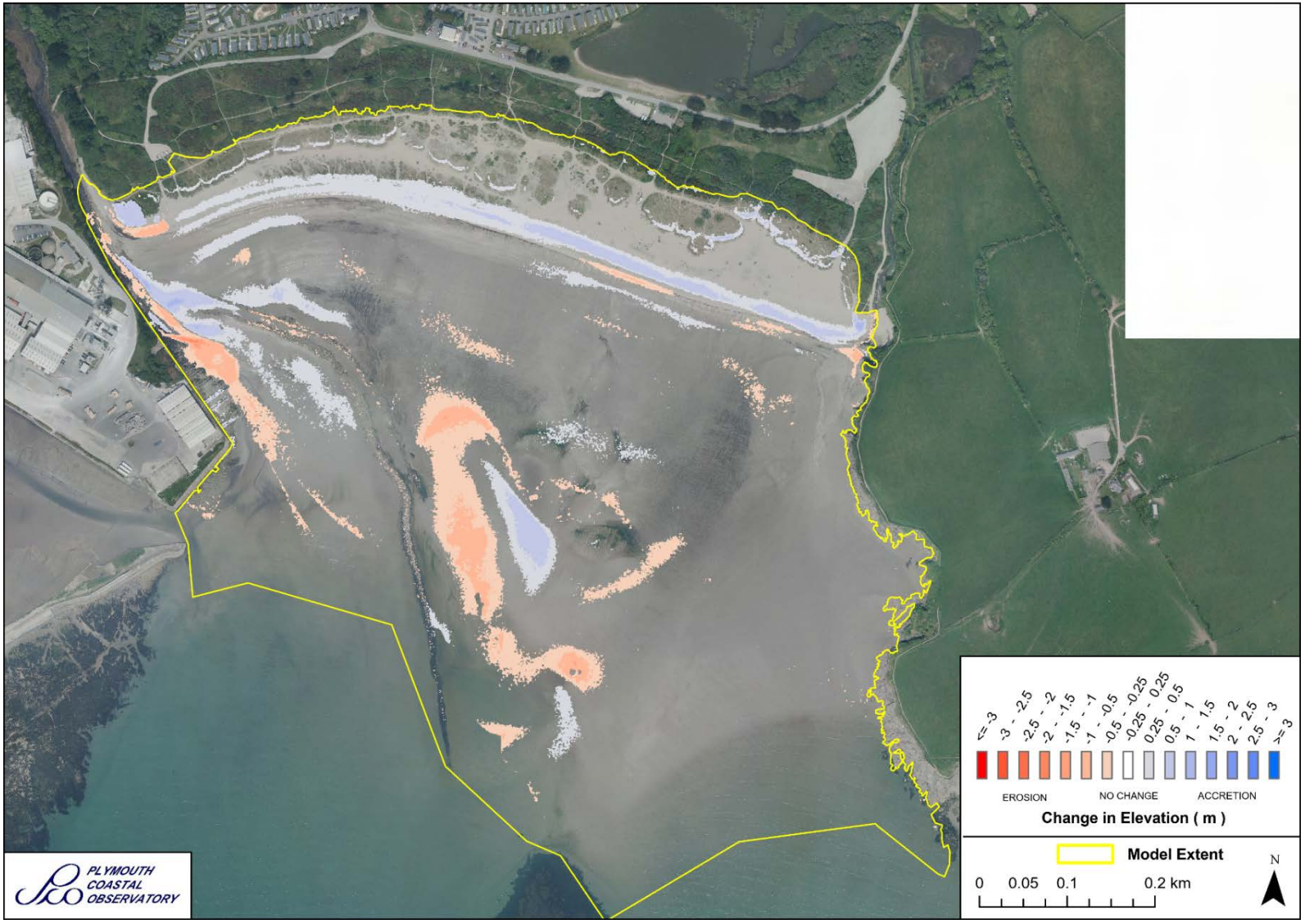


Figure 9 – Difference model indicating the changes in elevation observed between the October 2009 and March 2012 filtered LiDAR datasets within the yellow model extent.

03/2012 to 04/2013 – Figure 12 shows differences in elevation between filtered LiDAR data from March 2012 compared to April 2013. This epoch indicates large areas of change, with accretion observed within the embryo dune and dune face countered by erosion observed along the MHWS mark to the east and extreme west of the beach. General accretion can be observed across the low tide terrace of the beach, with several smaller pockets of erosion.

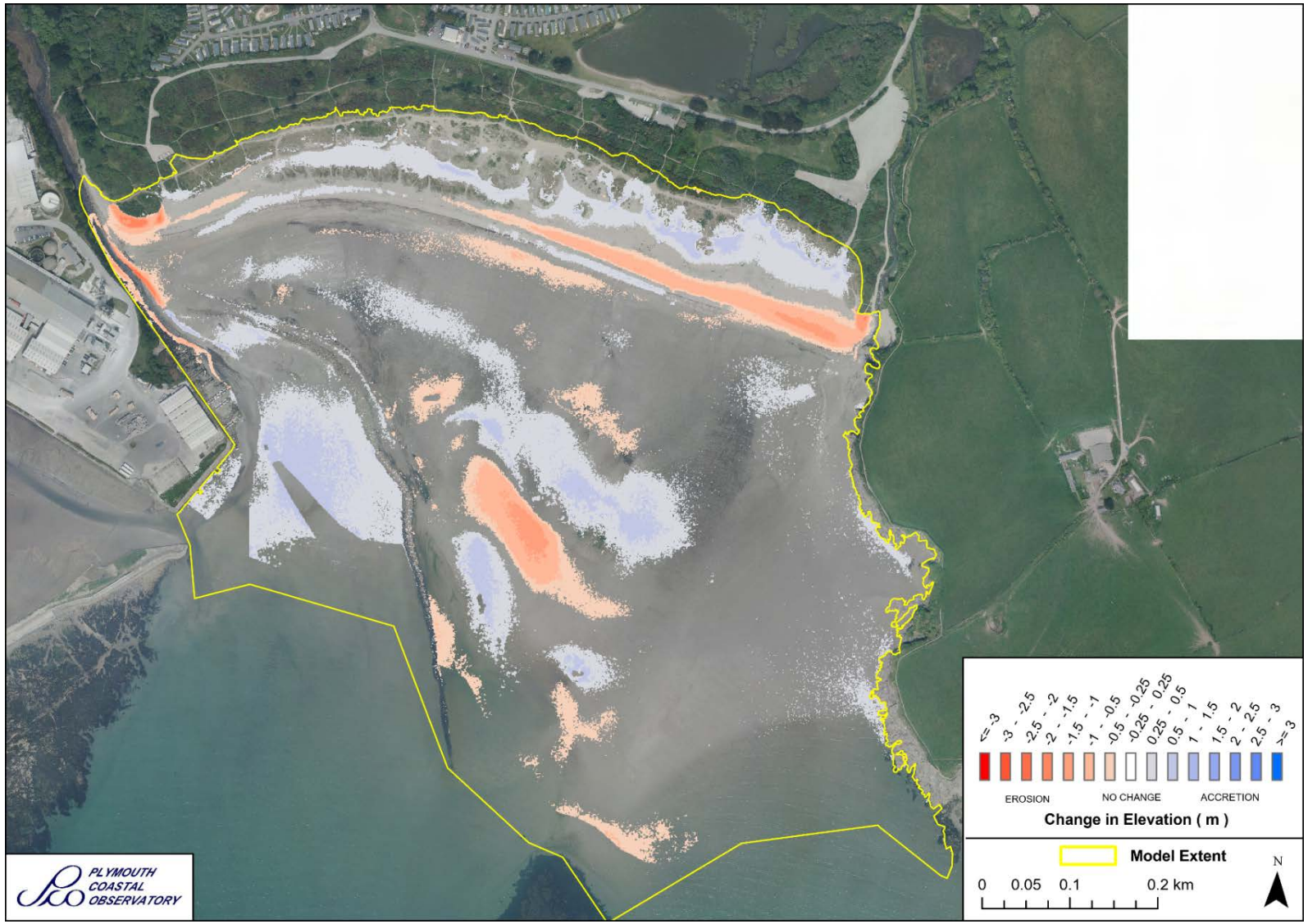


Figure 10 - Difference model indicating the changes in elevation observed between the March 2012 and April 2013 filtered LiDAR datasets within the yellow model extent.

04/2013 to 02/2016 – Figure 13 shows differences in elevation between filtered LiDAR data from April 2013 compared to February 2016. Despite the impact of the 2013/14 winter storms, the majority of the change shows accretion, with up to 1.5 m gains observed along the MHWS mark across the entire width of the beach.



Figure 11 - Difference model indicating the changes in elevation observed between the April 2013 and February 2016 filtered LiDAR datasets within the yellow model extent.

02/2016 to 03/2017 – Figure 14 shows differences in elevation between filtered LiDAR data from February 2016 compared to March 2017. There are relatively minimal changes observed between the two epochs, with minor accretion to the eastern extent of the upper beach face coupled with erosion/accretion areas around the Polmear Stream route.



Figure 12 - Difference model indicating the changes in elevation observed between the February 2016 and March 2017 filtered LiDAR datasets within the yellow model extent.

03/2017 to 04/2019 – Figure 15 shows differences in elevation between filtered LiDAR data from March 2017 compared to April 2019. Accretion can be observed in a band above the MHWS mark across the width of the beach, followed by a minor band of erosion below the MHWS mark at the centre of the beach.

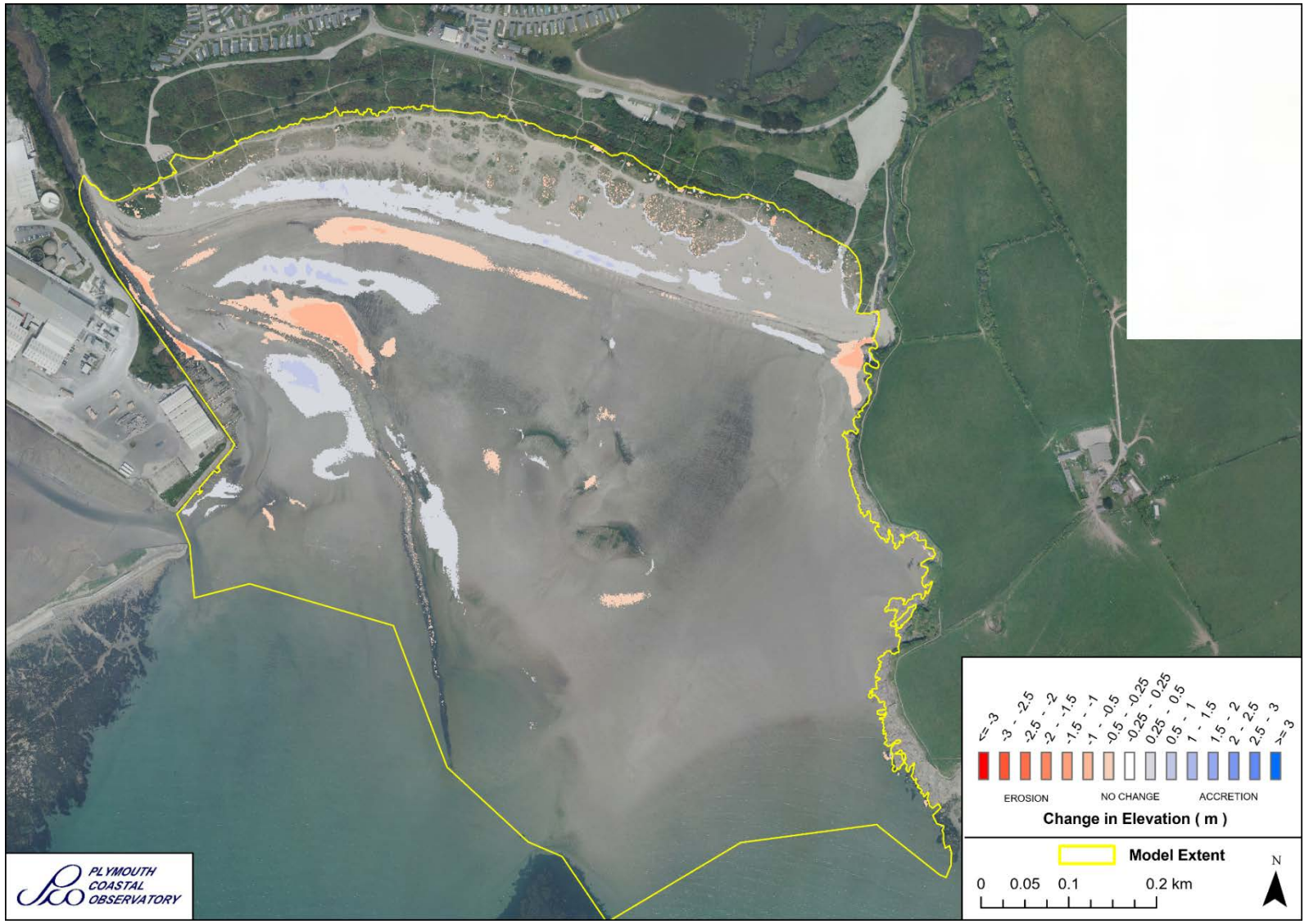


Figure 13 - Difference model indicating the changes in elevation observed between the March 2017 and April 2019 filtered LiDAR datasets within the yellow model extent.

04/2019 to 09/2020 – Figure 16 shows differences in elevation between filtered LiDAR data from April 2019 compared to September 2020. Considerable change can be observed across the entire upper beach area, with low level accretion (+0.5 m) dominating the dune face and low tide terrace with pockets of erosion observed to the eastern extent of the MHWS area.

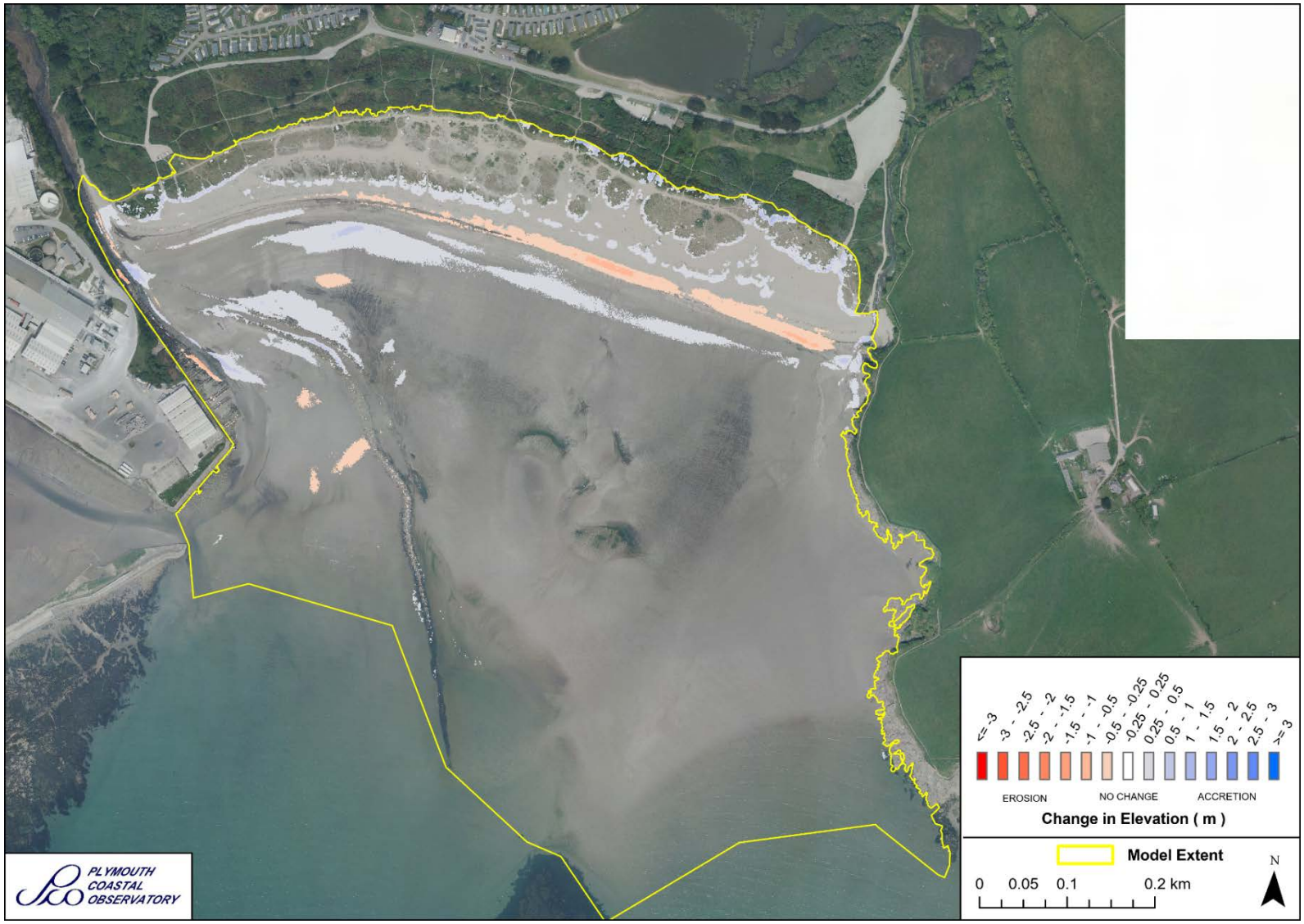


Figure 14 - Difference model indicating the changes in elevation observed between the April 2019 and September 2020 filtered LiDAR datasets within the yellow model extent.

09/2020 to 03/2022 – Figure 17 shows differences in elevation between filtered LiDAR data from September 2020 to March 2022. There has been minimal change between the two datasets, with minor areas of erosion and accretion along the MHWS area below the embryo dunes and an area of erosion around the low tide terrace next to the Polmear Stream.

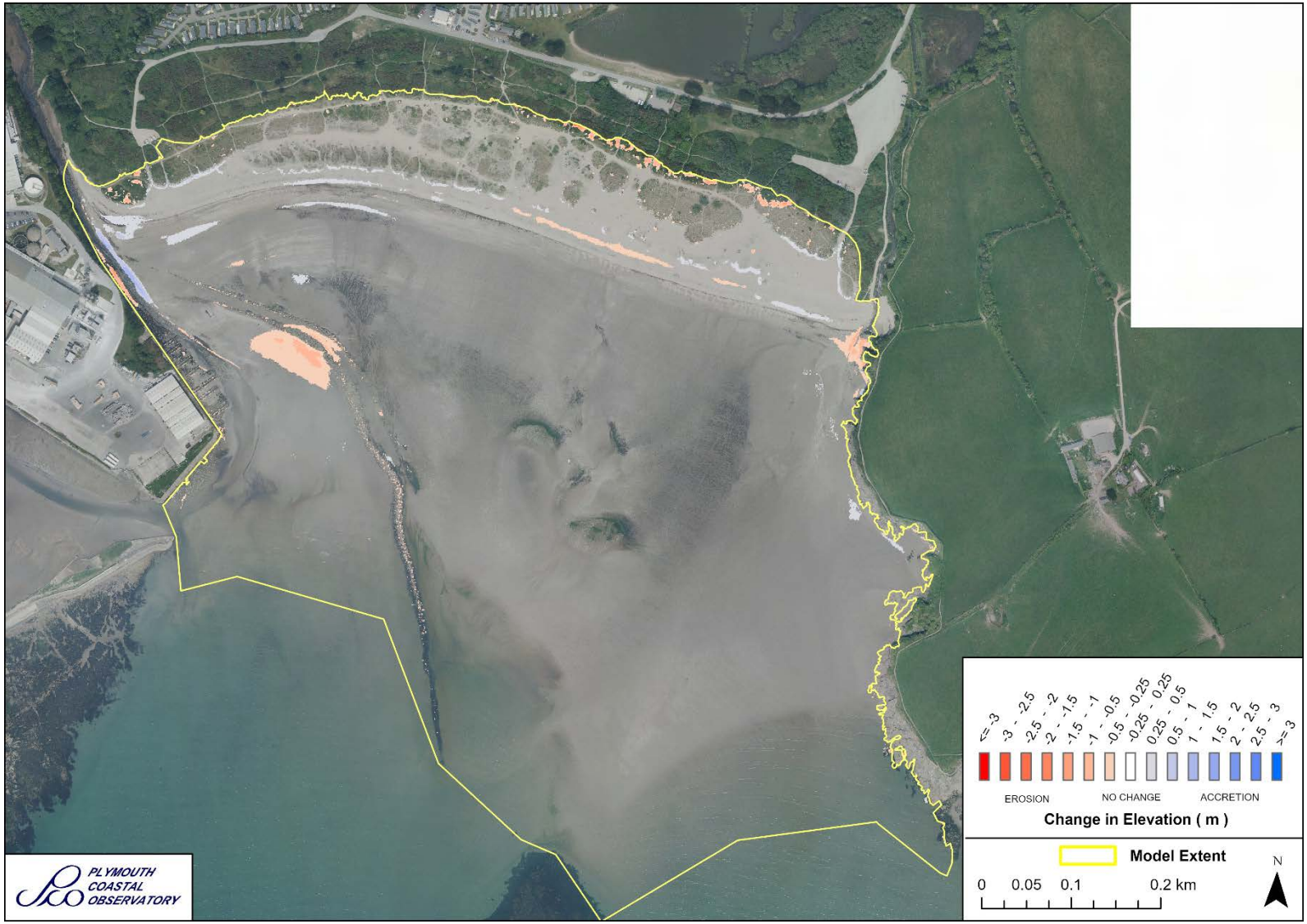


Figure 15 - Difference model indicating the changes in elevation observed between the September 2020 and March 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.05 m OD) are shown in Table 1. The volumetric data in the Mobile Zone is comparable to that recorded in the topographic dataset, showing progressive and relatively even accretion since the first flight in 2008, accreting at a rate of 4,289 m^3 y^{-1} to the most recent survey in 2022 (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. The volumetric data in the Beach Zone suggests a similar story of accretion throughout 2008 to 2022, with an accretion rate of 5,113 m^3 y^{-1} (Fig.19); considerably less as a total percentage change when compared to the Mobile Zone accretion. As expected from the more fluctuating Beach Zone, accretion is not as linear as that of the Mobile Zone, with erosive periods observed in the 2012, 2016 and 2019 data.

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)
01/2008	116,382	618,030
02/2009	119,932	618,783
10/2009	124,130	613,173
03/2012	137,431	608,172
04/2013	142,018	625,887
02/2016	158,087	654,589
03/2017	160,701	647,805
04/2019	165,797	640,916
09/2020	172,623	662,614
03/2022	172,670	706,806

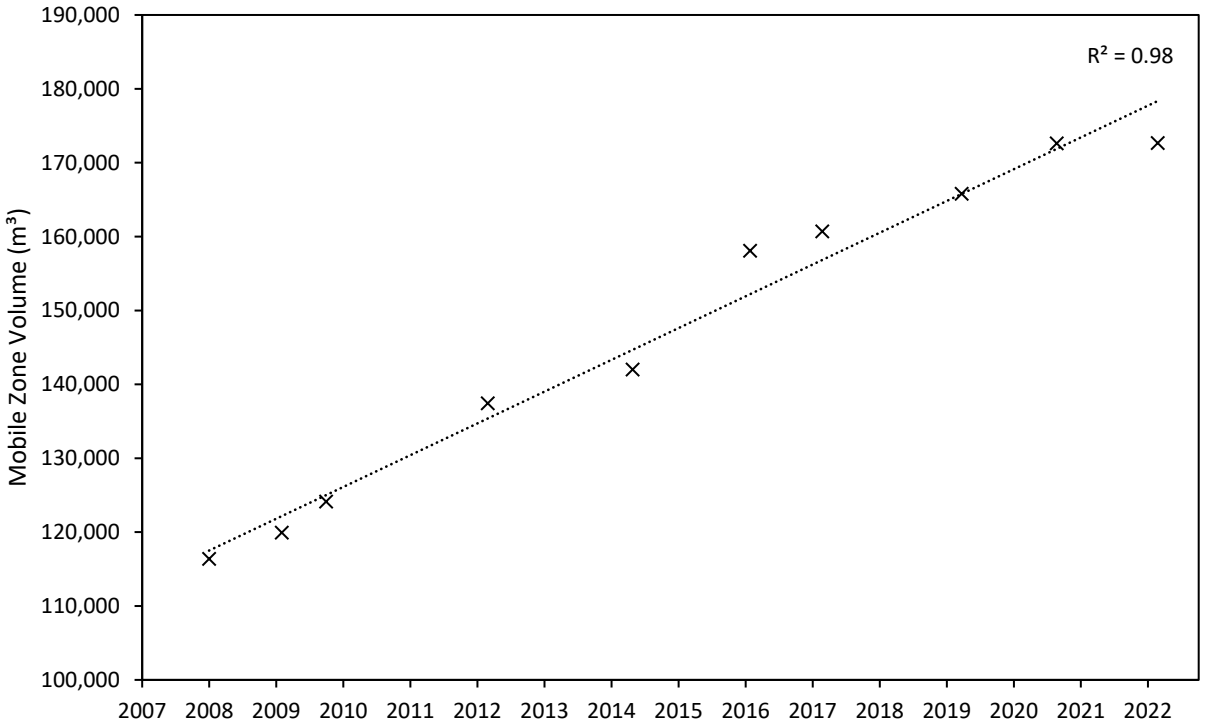


Figure 18 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.05 m OD) for each filtered LiDAR datasets between 2008 and 2022.

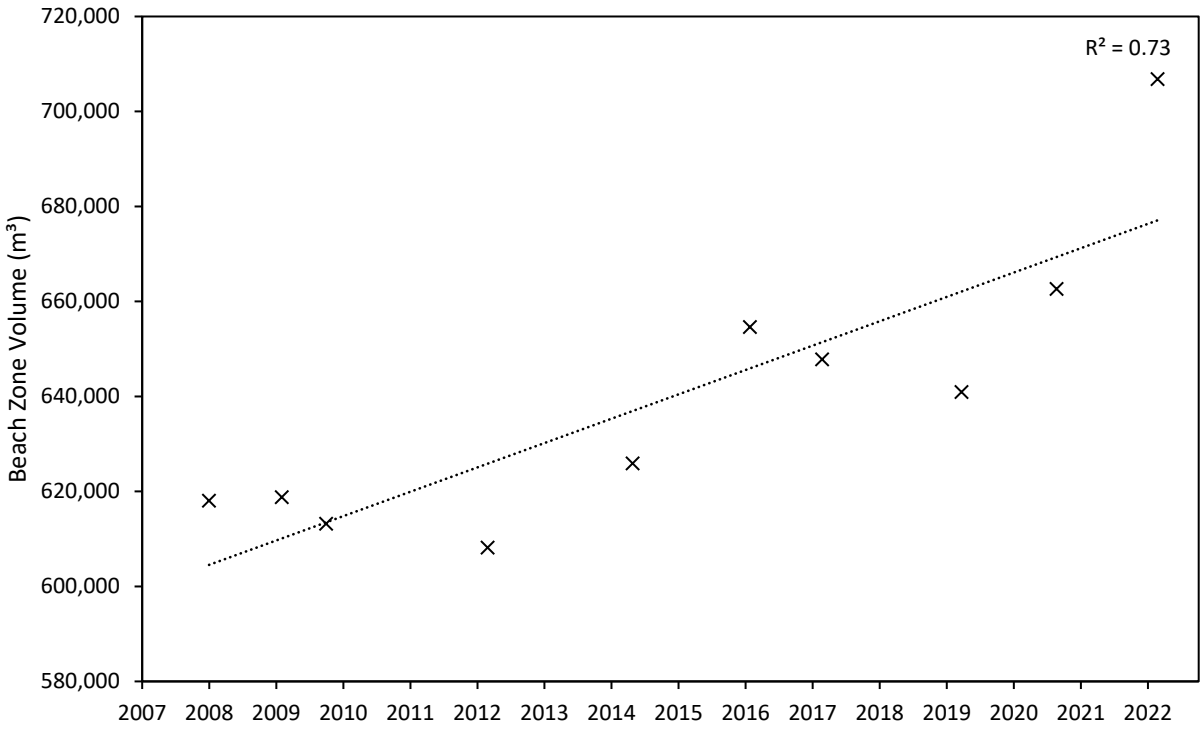


Figure 19 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.45 m OD) for each filtered LiDAR datasets between 2008 and 2022.

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. MSL contours agree with CPA and volumetric data, indicating a widening of the beach from 2008 to 2022 by approximately 20 m. Similar is true for the dune toe contour, however the 2022 survey suggests a retreat of the contour (Fig.20), potentially coinciding with an energetic period pre survey.

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.

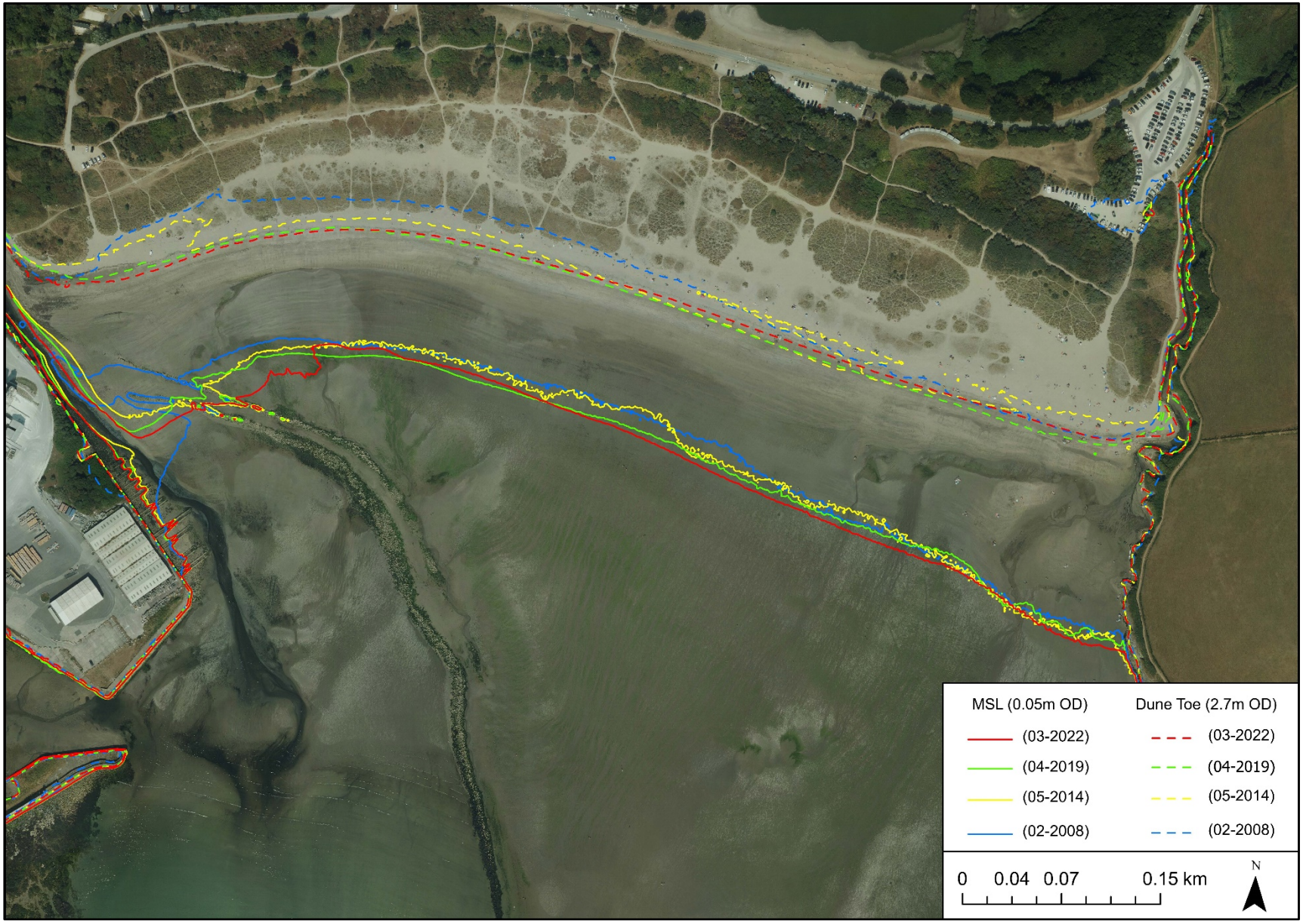


Figure 20 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022 LiDAR datasets.

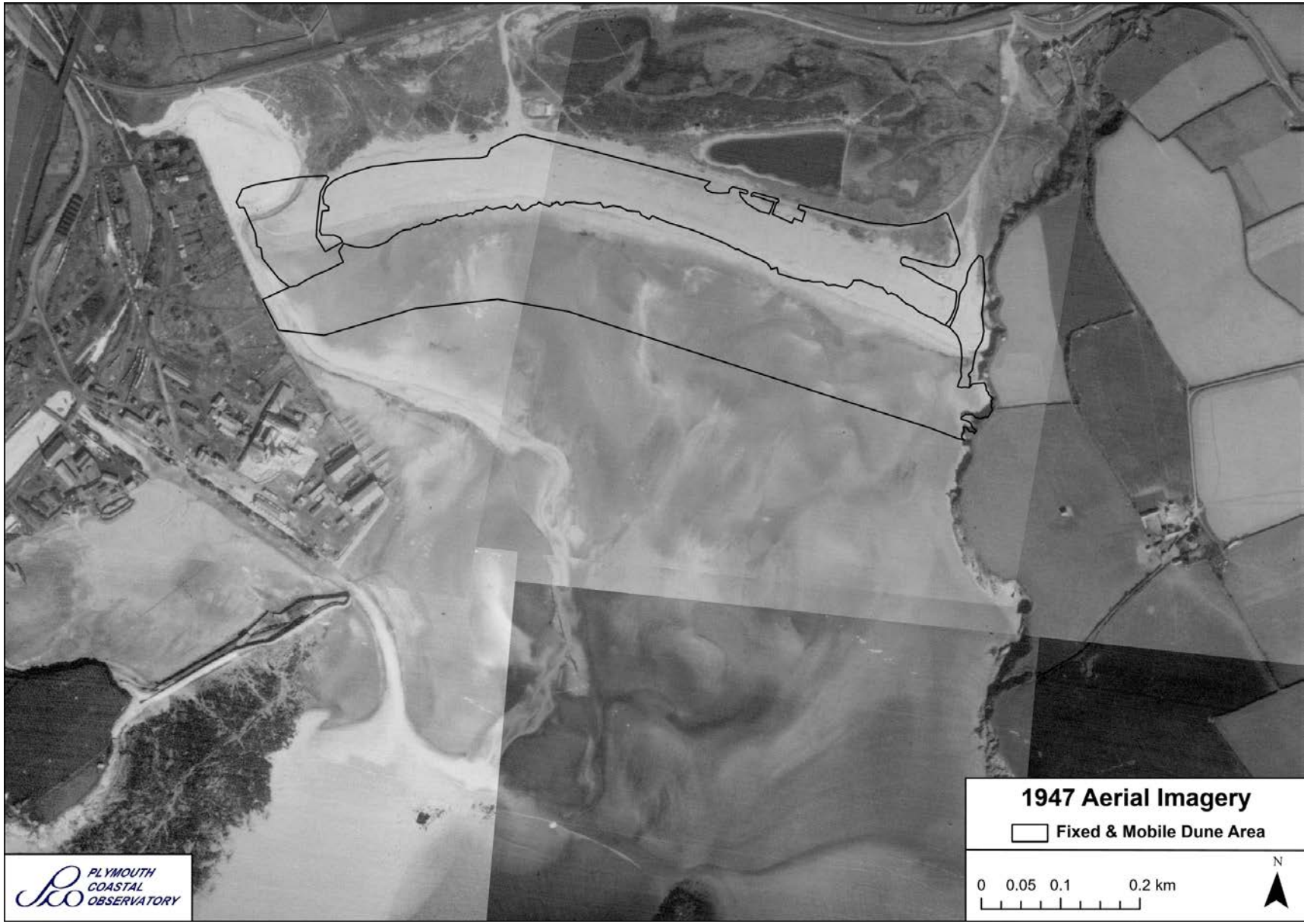


Figure 21 – Aerial imagery from 1947.



Figure 22 – Aerial imagery from 2001.

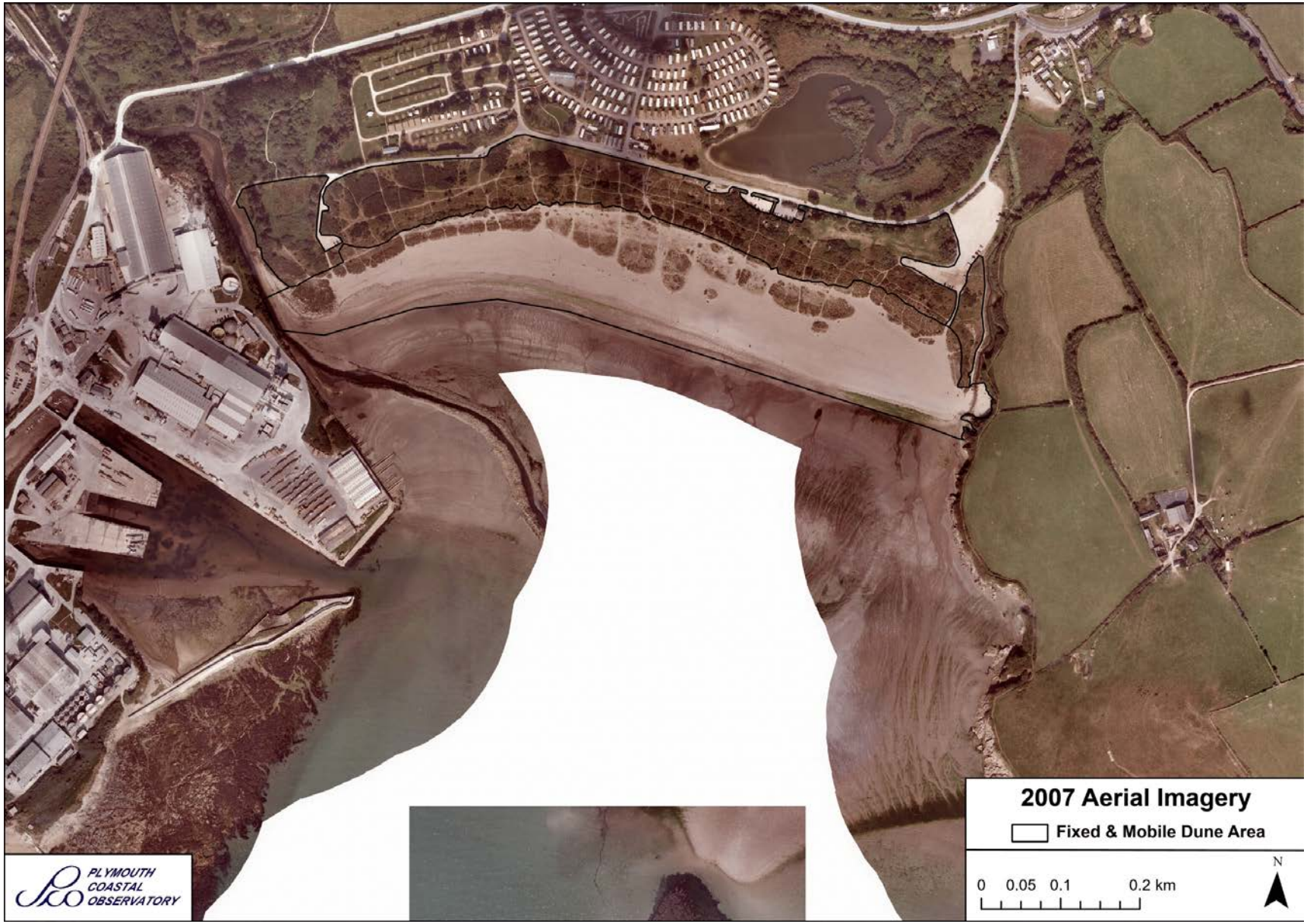


Figure 23 – Aerial imagery from 2007.



Figure 24 – Aerial imagery from 2009.



Figure 25 – Aerial imagery from 2012.



Figure 26 – Aerial imagery from 2018.



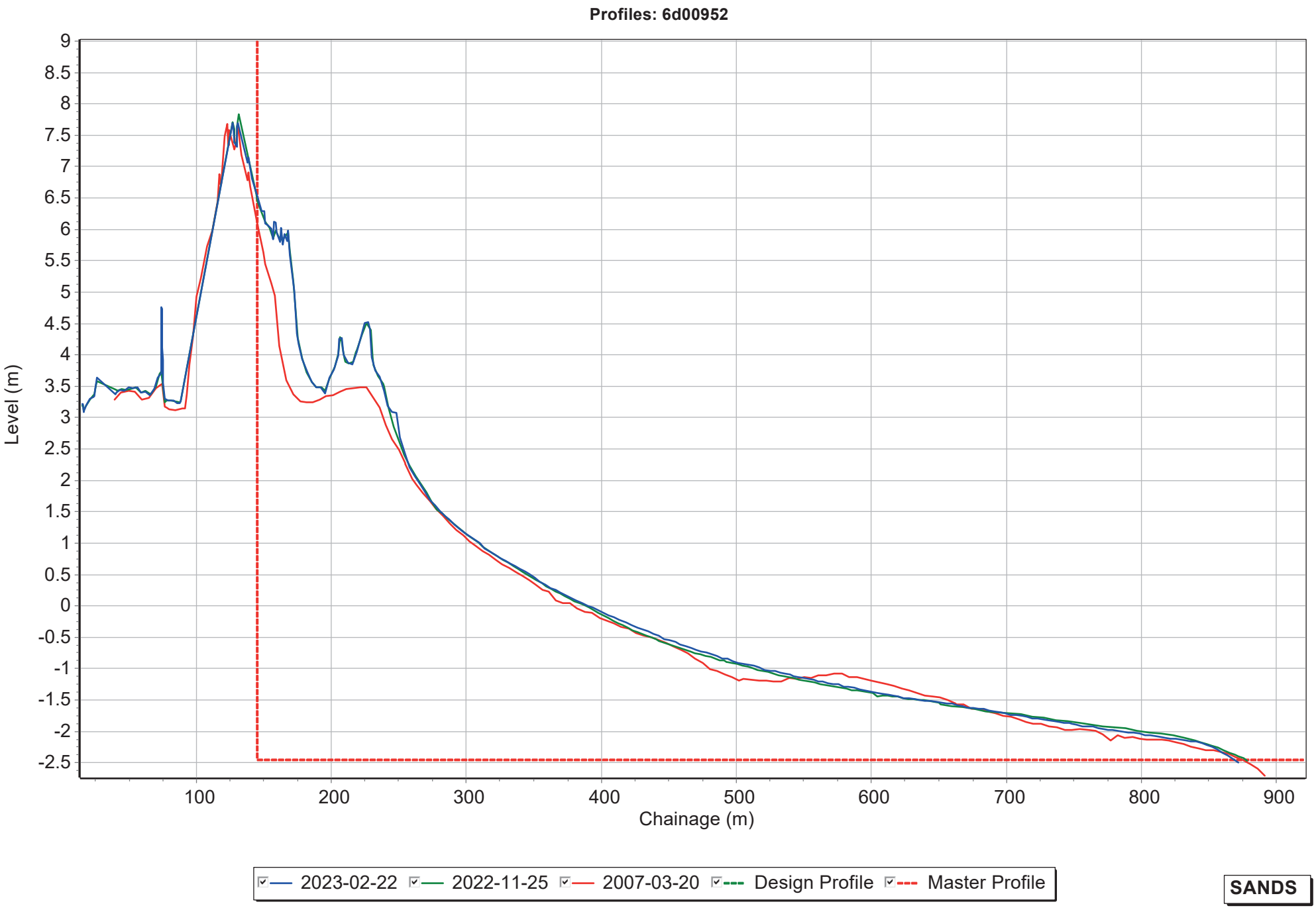
Figure 27 – Aerial imagery from 2022.

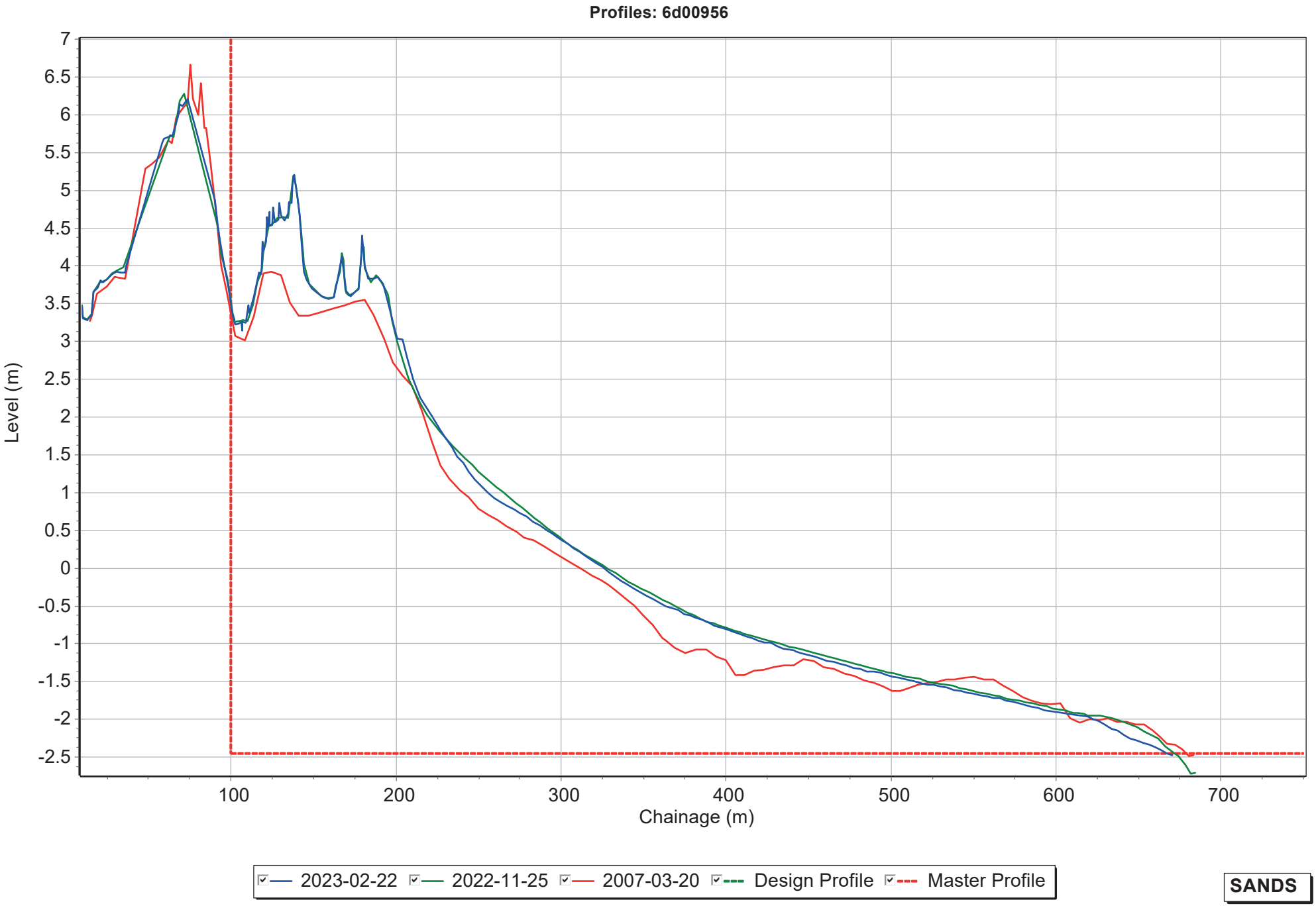
Glossary

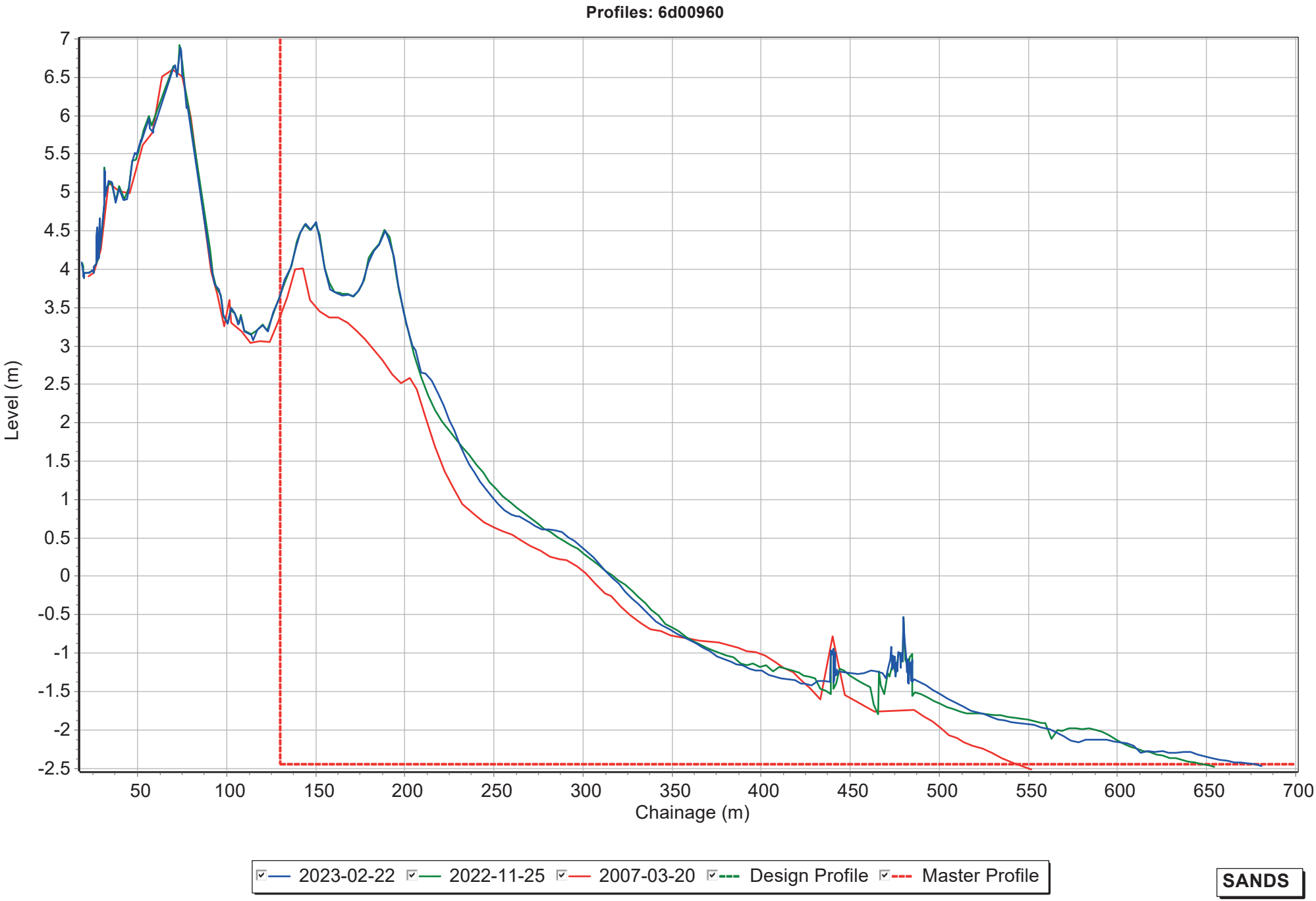
1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
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.

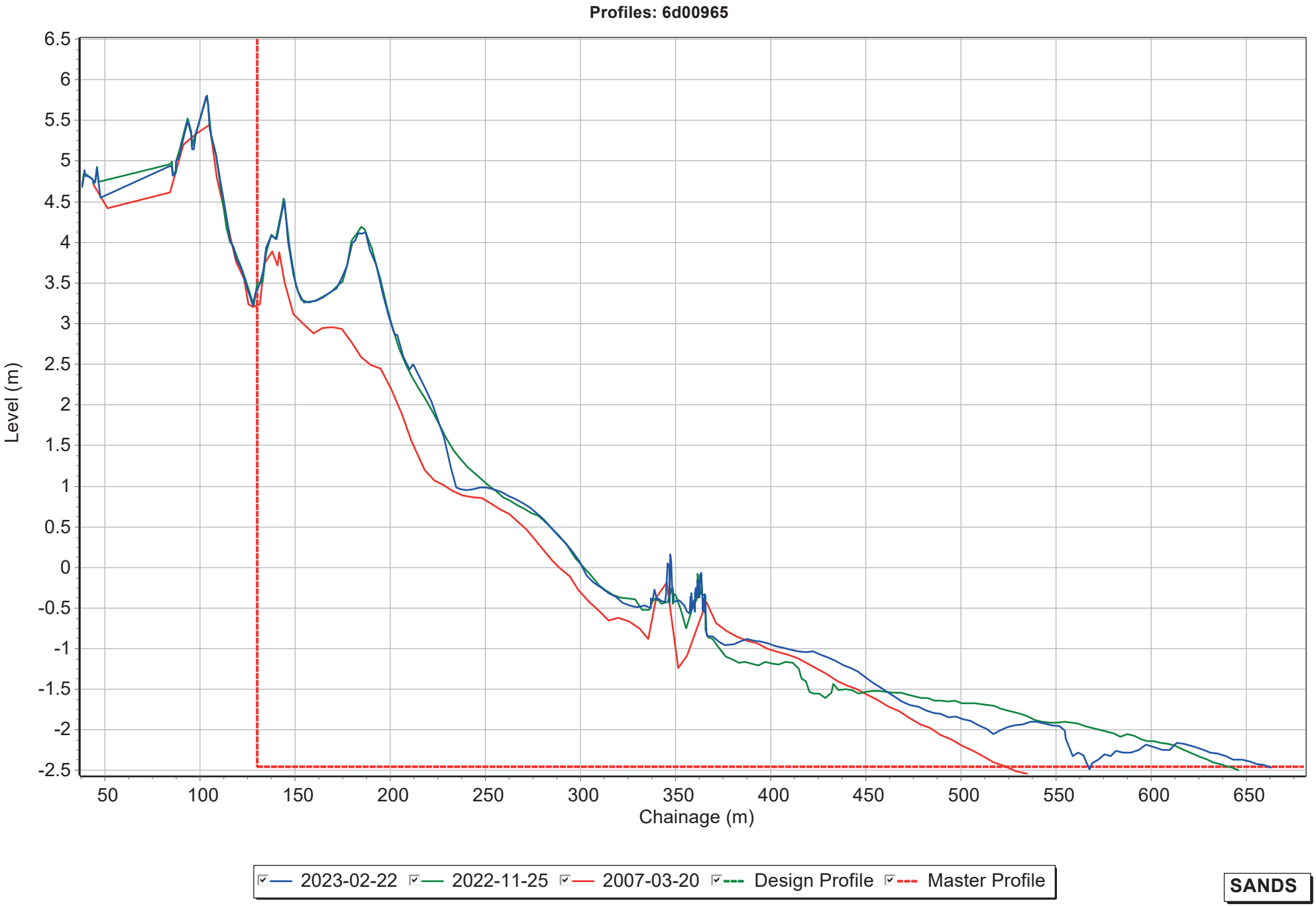
Appendices

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 Par Sands are presented below.


Profiles: 6d00952
Level (m)
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
100
200
300
400
500
600
700
800
900
Chainage (m)
2023-02-22
2022-11-25
2007-03-20
Design Profile
Master Profile
SANDS


Profiles: 6d00956
Level (m)
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
100
200
300
400
500
600
700
Chainage (m)
2023-02-22
2022-11-25
2007-03-20
Design Profile
Master Profile
SANDS


Profiles: 6d00960
Level (m)
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
650
700
Chainage (m)
2023-02-22
2022-11-25
2007-03-20
Design Profile
Master Profile
SANDS


Profiles: 6d00965
Level (m)
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
650
Chainage (m)
2023-02-22
2022-11-25
2007-03-20
Design Profile
Master Profile
SANDS