SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Holywell Beach Report

LiDAR Data Analysis

SWCM | TBR23 | 16/04/2024

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Summary

This report utilises Light Detection and Ranging (LiDAR) and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Holywell. The aim is to highlight coastal change at Holywell using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Holywell is a west north-westerly facing, large sandy beach, backed by a large dune system. LiDAR data is compared from each available flight to show difference models of the intertidal area, to compare volumetric data over time and to show change in Mean Seal Level and Dune Toe contours over time.

Beach volume was extracted from the Beach and Mobile Zones from 10 LiDAR flights between 2008 and 2023. The Mobile Zone remained stable between 2008 and 2023 despite a 15% loss in volume between the 2012 and 2014 surveys, mostly likely as a result of the 2013/14 winter period. The Mobile Zone has since recovered, recording the highest volume to date during the 2020 LIDAR survey. The Beach Zone followed a similar trend to that of the Mobile Zone, remaining stable between 2008 and 2023 despite a 15% loss in volume between the 2012 and 2014 survey.

Overall Holywell beach has remained stable between 2008 and 2023 despite being highly impacted by the 2013/2014 storms.

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1.0 Introduction

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

Holywell is a west north-westerly facing, large sandy beach, backed by a large dune system (Fig.1). A river flows along the southern extent of the cliff and out across the beach. Holywell consists of a ~650 m long dune system, followed by hard rock cliffs bounding the beach to the north and south. The beach has a cross-shore distance of ~1,000 m and longshore distance of ~350 m with an average spring tidal range of 6.3 m.

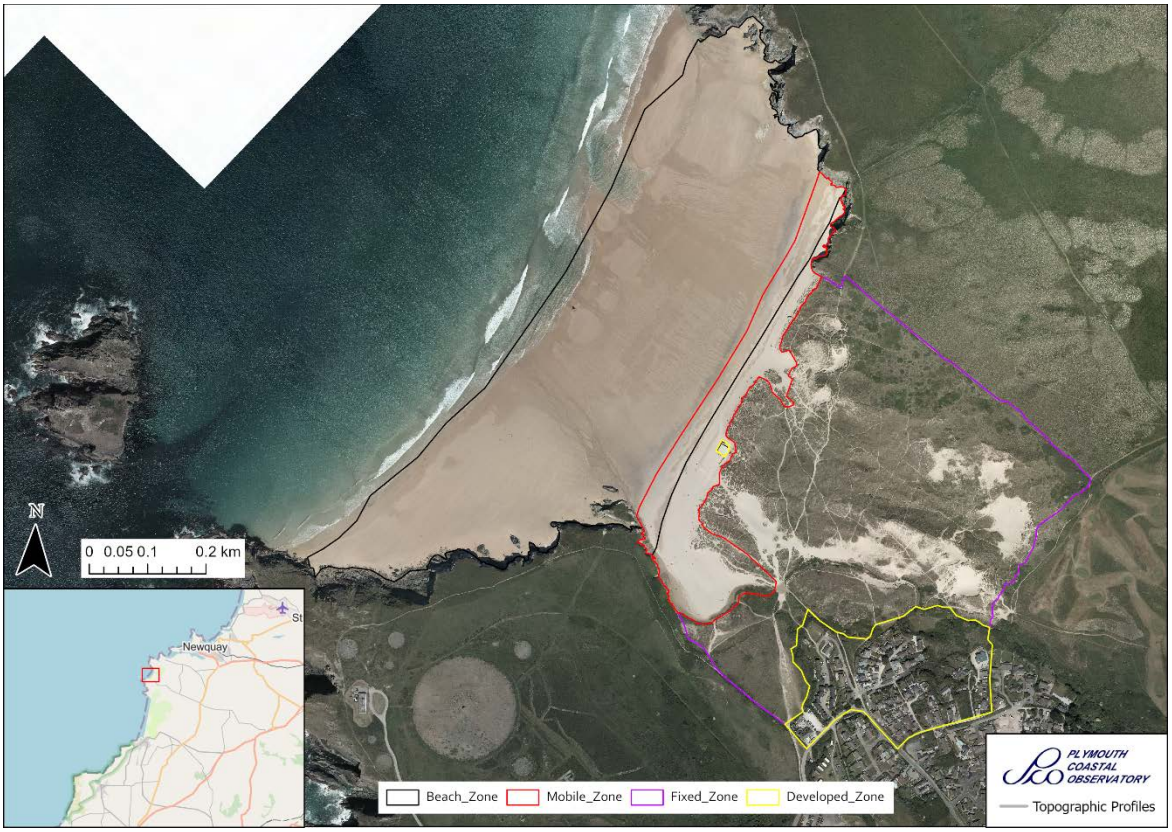


Figure 1 - Location Map of Holywell Beach and Dune System, indicating the four defined zones outlined in section 1.0.

[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 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.

2.1.1 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]).

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 Accuracy Statement

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.

3.0 Results

3.1 LiDAR Data Analysis

There has been a total of 10 LiDAR flights captured at Holywell since 2007 through the SWCM Programme.

3.1.1 Difference Models

Difference models between each epoch of LiDAR data are presented here (Figs. 2-11). 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 2 shows the difference in elevation between the first filtered LiDAR data from March 2008 compared to the most recent, captured in January 2023. There is considerable accretion observed along the upper beach face and mobile dune face, with the latter accreting and eroding by >3 m. The northern half of the dune system has experienced acute erosion, whilst the southern half has seen acute accretion. The very southern end of the dune system has also seen a large section of erosion, eroding the corner of the dune. The rest of the beach has seen large patches of low-level erosion and accretion.

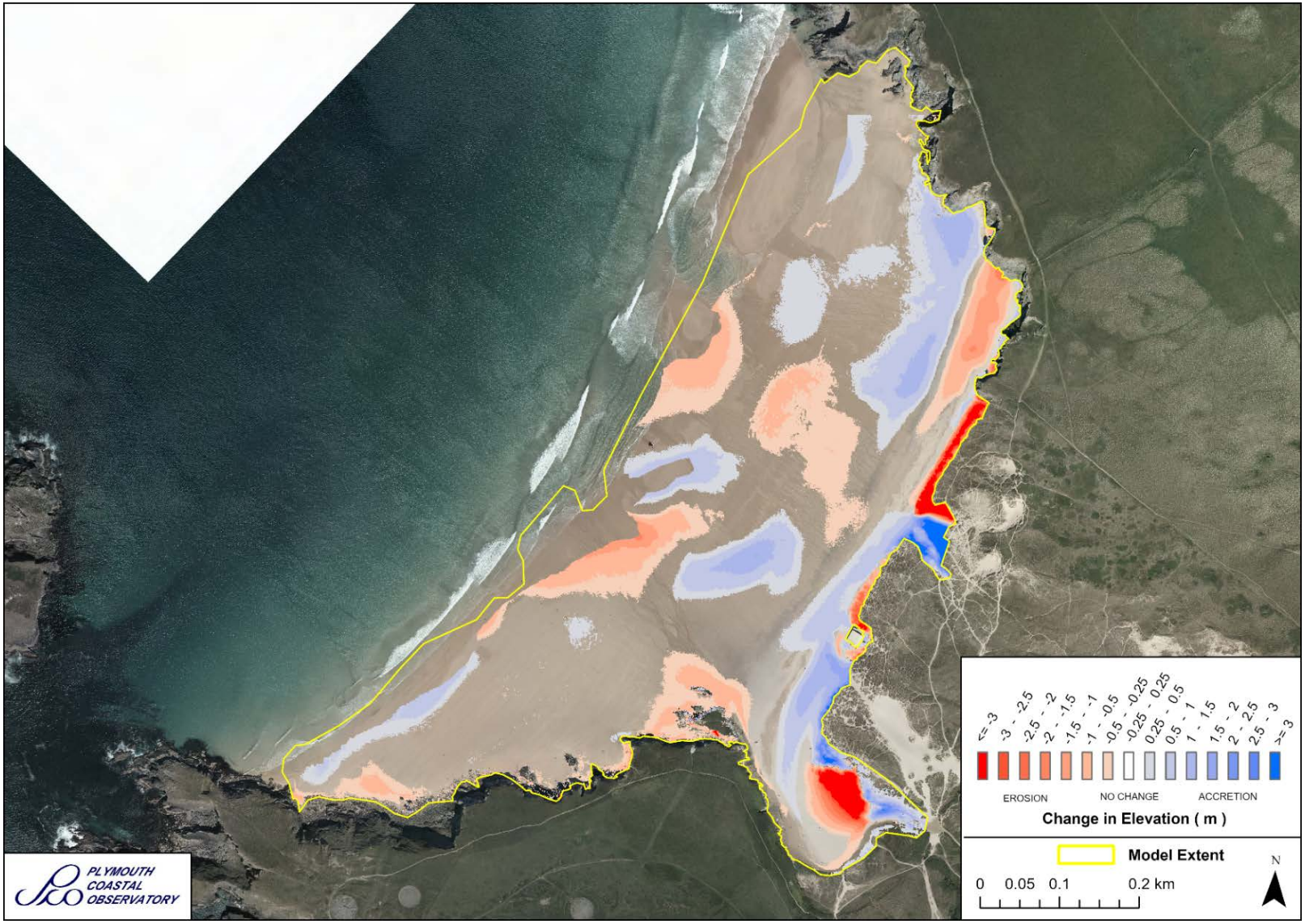


Figure 2 – Difference model indicating the changes in elevation observed between the March 2008 and January 2023 filtered LiDAR datasets within the yellow model extent.

Figure 3 shows differences in elevation between filtered LiDAR data from March 2008 compared to March 2009. The majority of the dune face has remained stable, with the exception of a dune blowout located in the middle of the dune system; acute erosion has occurred, causing the blowout to widen. Similarly, a blowout has begun in the south, round the corner, experiencing up to 2 m of erosion on the dune face. Accretion has occurred, however, to the north of the beach, building up to 1.5 m in elevation. The rest of the beach has seen scattered patches of both erosion and accretion across the unit.

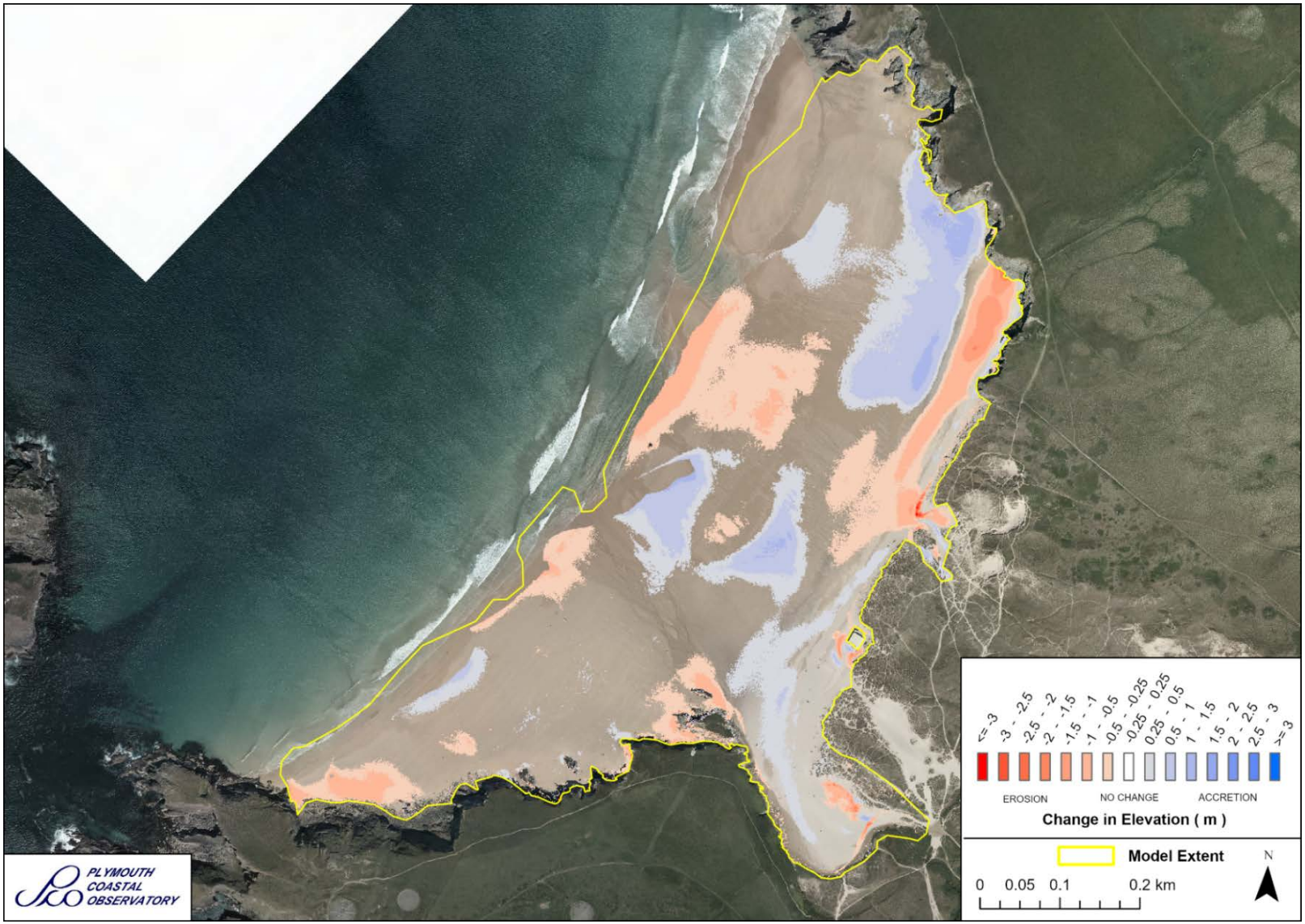


Figure 3 - Difference model indicating the changes in elevation observed between the March 2008 and March 2009 filtered LiDAR datasets within the yellow model extent.

Figure 4 shows differences in elevation between filtered LiDAR data from March 2009 compared to October 2010. Widespread accretion is observed across the beach seeing between 0.25 to 1.5 m gain in beach elevation. The dune face has seen low-level accretion along the entire beach, with the exception of the dune to the south, losing up 2 m in elevation. Again, the dune blowout in the middle of the dune system has seen an area of erosion, widening the blowout. A band of erosion can be seen along the high-water mark on the northern half of the unit, whereas the southern half has seen a trend for accretion. A patch of low-level erosion can be seen to the south of the unit.

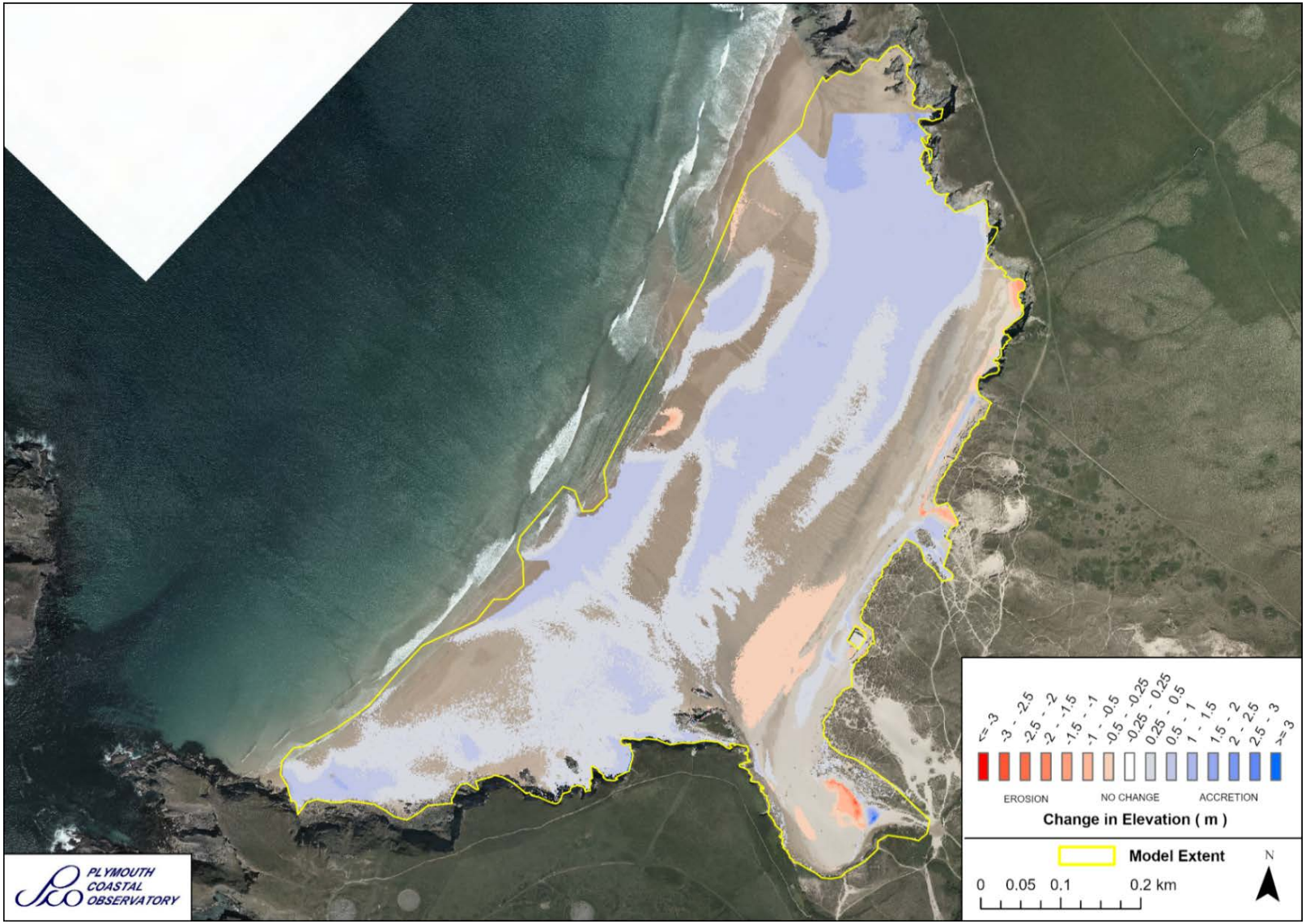


Figure 4 – Difference model indicating the changes in elevation observed between the March 2009 and October 2010 filtered LiDAR datasets within the yellow model extent.

Figure 5 shows differences in elevation between filtered LiDAR data from October 2010 compared to March 2012. This epoch indicates large areas of erosion across the intertidal zone and along the high-water mark, whilst the dune face appears to remain stable. The centre dune blowout has seen erosion to the north, and accretion to the south, and the dune blowout to the south of the beach has experienced a large patch of erosion (up to 2 m).

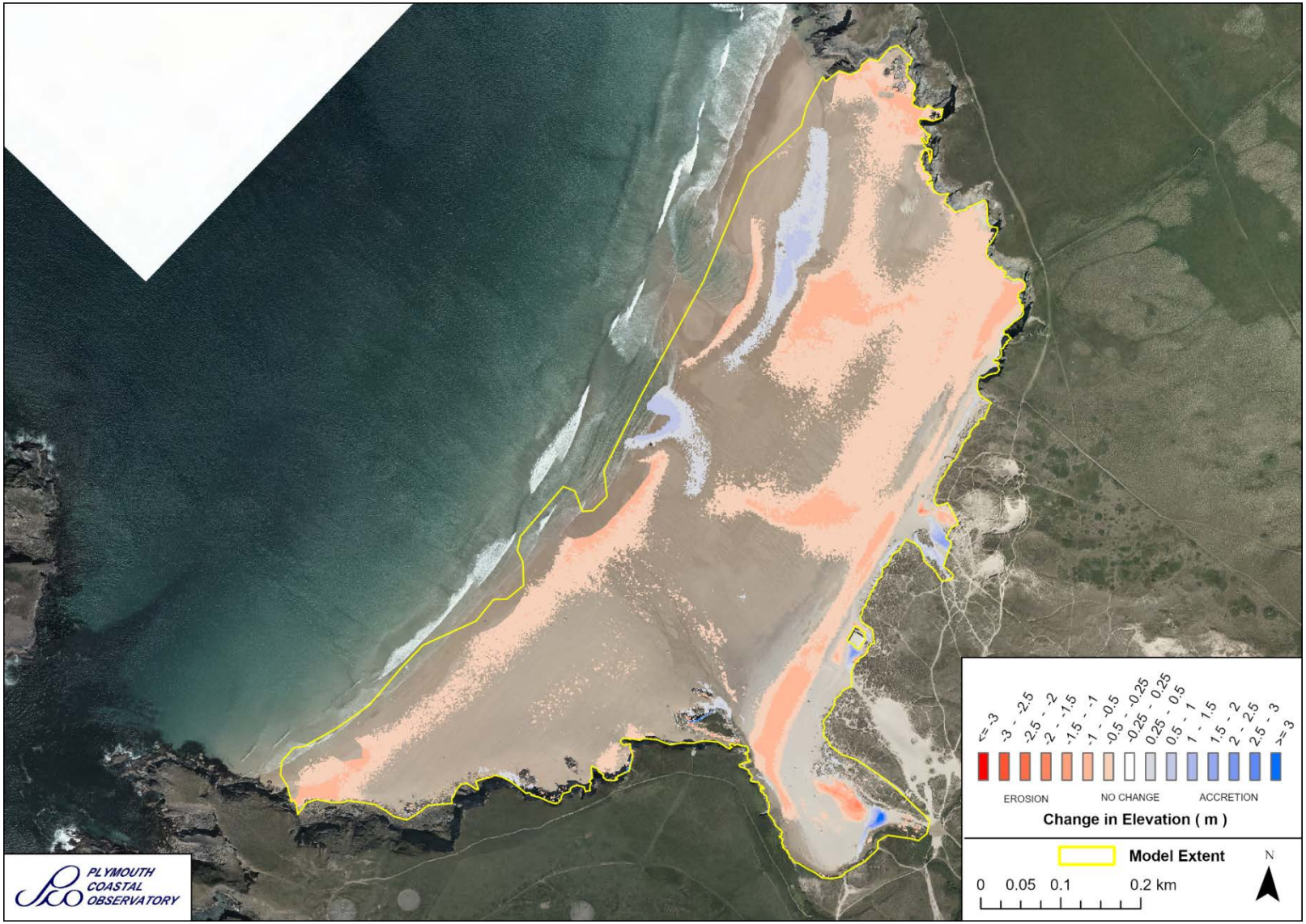


Figure 5 - Difference model indicating the changes in elevation observed between the October 2010 and March 2012 filtered LiDAR datasets within the yellow model extent.

Figure 6 shows differences in elevation between filtered LiDAR data from March 2012 compared to March 2014. After the 2013/2014 storms, acute erosion (>3 m) could be seen along the whole dune system. Some low-level accretion can be measured in the middle dune blowout, as well as along the dune face to the south of the unit. Further erosion can be seen at the very southern end of the dune system, outflanking the dune.

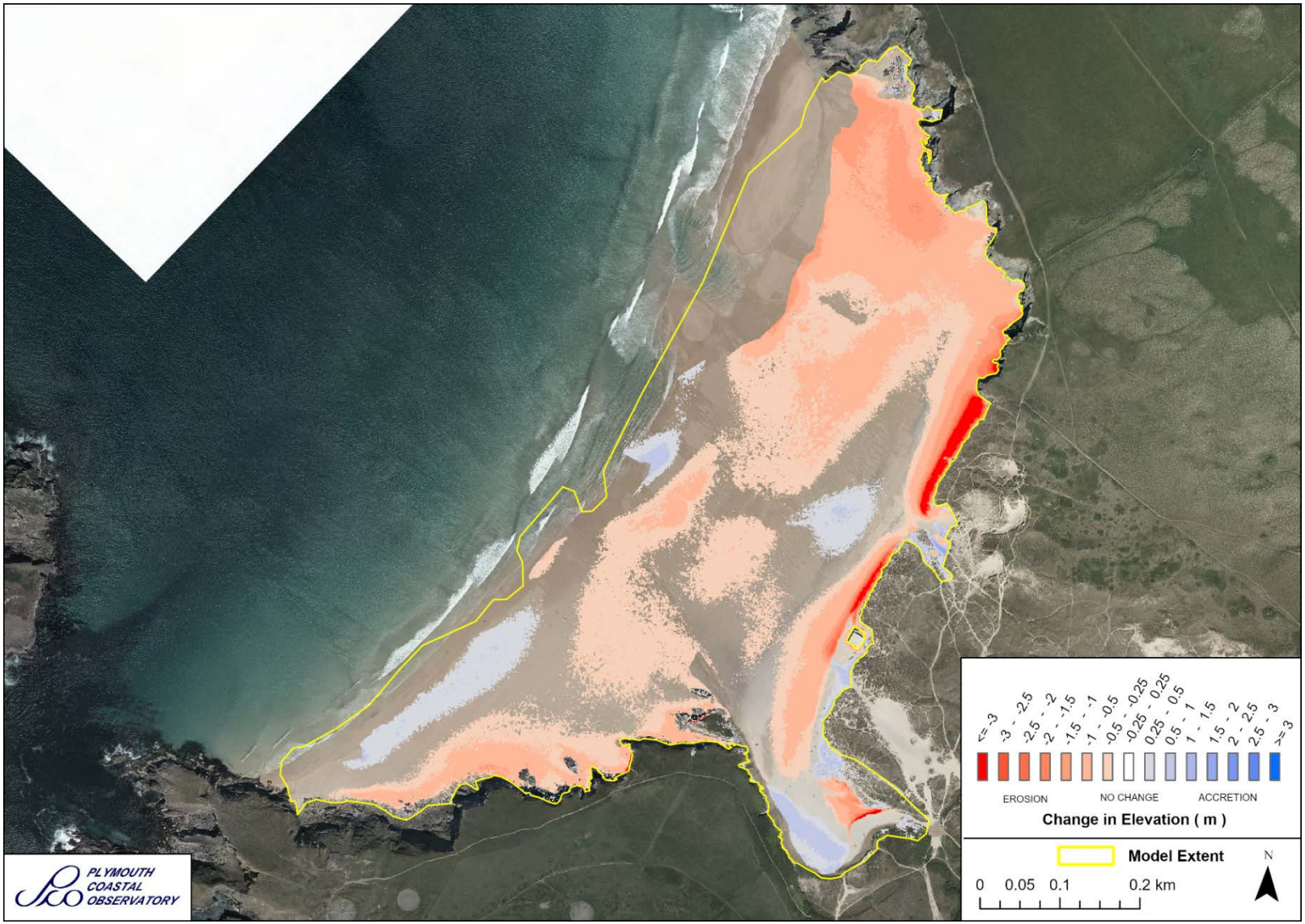


Figure 6 - Difference model indicating the changes in elevation observed between the March 2012 and March 2014 filtered LiDAR datasets within the yellow model extent.

Figure 7 shows differences in elevation between filtered LiDAR data from March 2014 compared to March 2016. In contrast to that seen in Figure 6, widespread accretion can be seen across the beach, with the exception of erosion along the seaward extent of the unit and along most of the dune face. Acute erosion can be seen to the north, of the middle dune blowout, widening it further. Significant beach elevation is also lost to the southern end of the dune system, whilst acute accretion is measured along the beach face and intertidal zone.

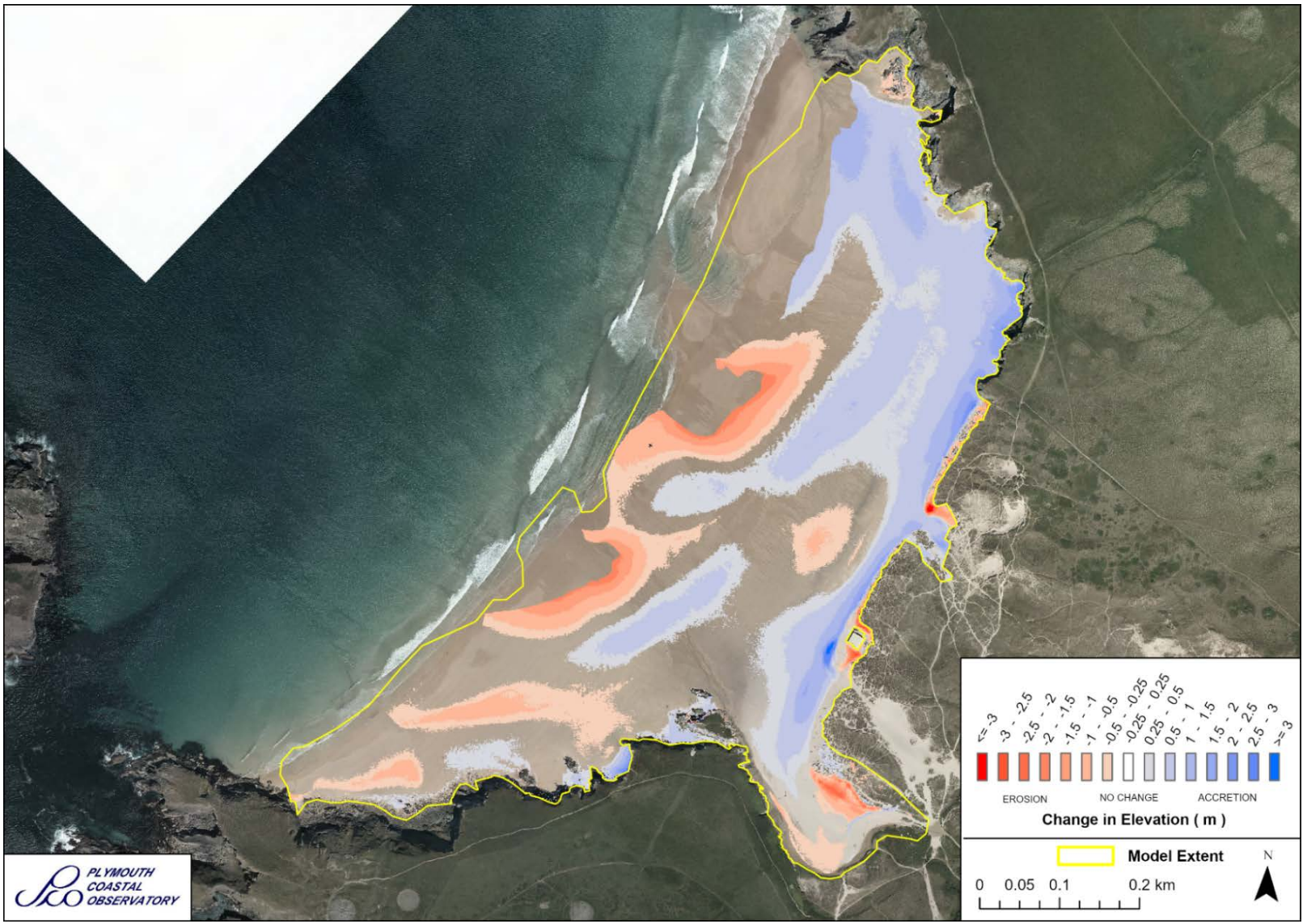


Figure 7 - Difference model indicating the changes in elevation observed between the March 2014 and March 2016 filtered LiDAR datasets within the yellow model extent.

Figure 8 shows differences in elevation between filtered LiDAR data from March 2016 compared to October 2016. A thick band of accretion, up to 2 m, can be seen along the high-water mark, whilst the dune face remains stable. The dune to the south saw a band of erosion, losing up to 2 m in elevation, similar to that of the outflanking seen on the northern section of the middle dune blowout. Large patches of erosion and accretion can be seen across the unit, ranging between +2.5 m and -1.5 m in elevation.

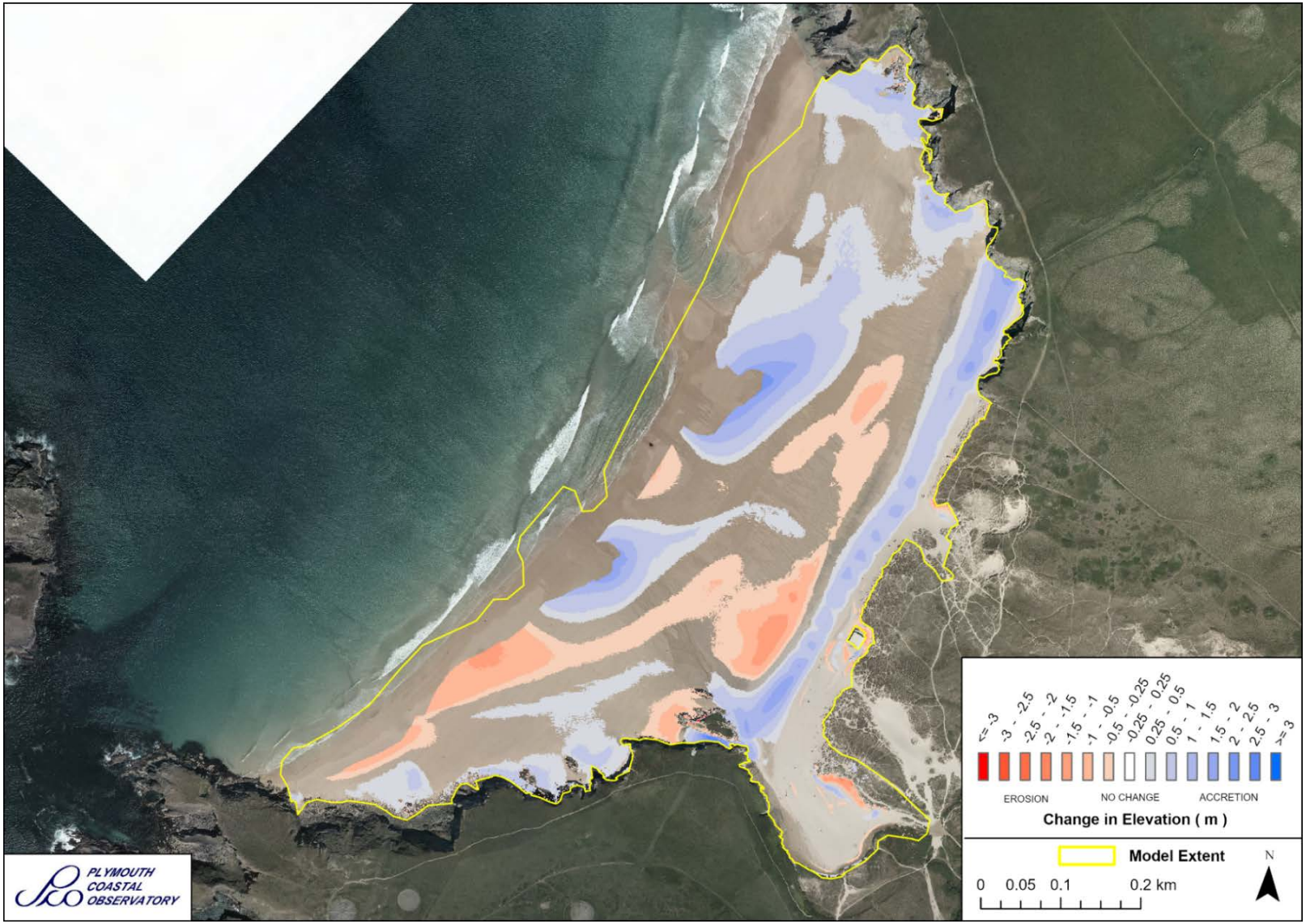


Figure 8 - Difference model indicating the changes in elevation observed between the March 2016 and October 2016 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from October 2016 compared to April 2019. In contrast to that seen in Figure 8, a thick band of erosion be seen along the high-water mark. Again, erosion is measured on the northern side of the middle dune blowout as well as the dune to the south. An intertidal bar has formed, following the erosive band, increasing in elevation by up to 1.5 m.

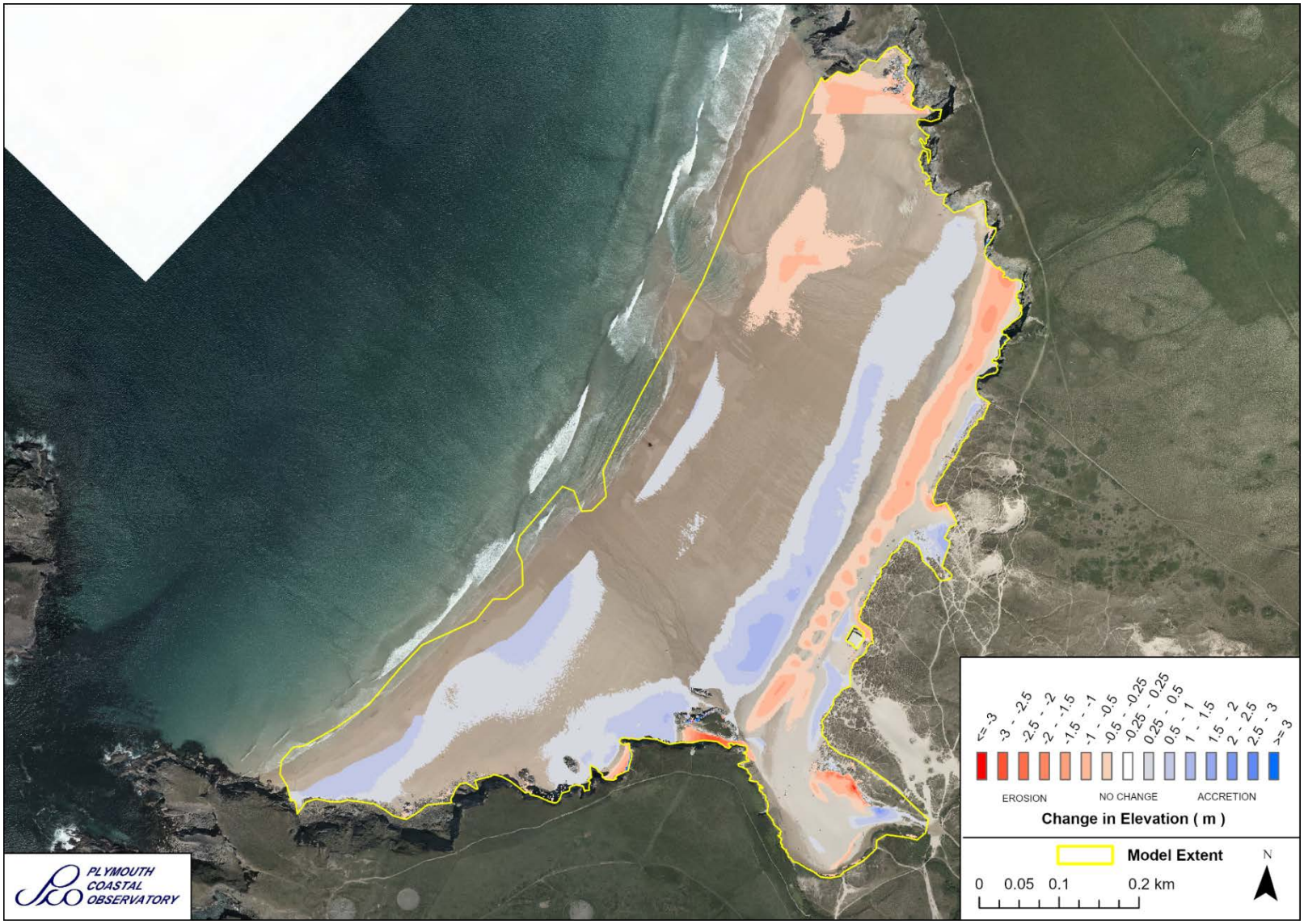


Figure 9 - Difference model indicating the changes in elevation observed between the October 2016 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from April 2019 compared to November 2020. In contrast to that of Figure 9, a band of accretion can be seen along the high-water mark, followed by a thick band of erosion extending out to the MSL contour. Low-level accretion is measured along the dune face, whereas a mixture of erosion and accretion can be seen on the corner of the dune, to the south, ranging between +1.5 m to – 2 m in elevation. Erosion is also present on the northern section of the dune blowout, located in the middle of dune system, whilst the southern half has seen accretion.

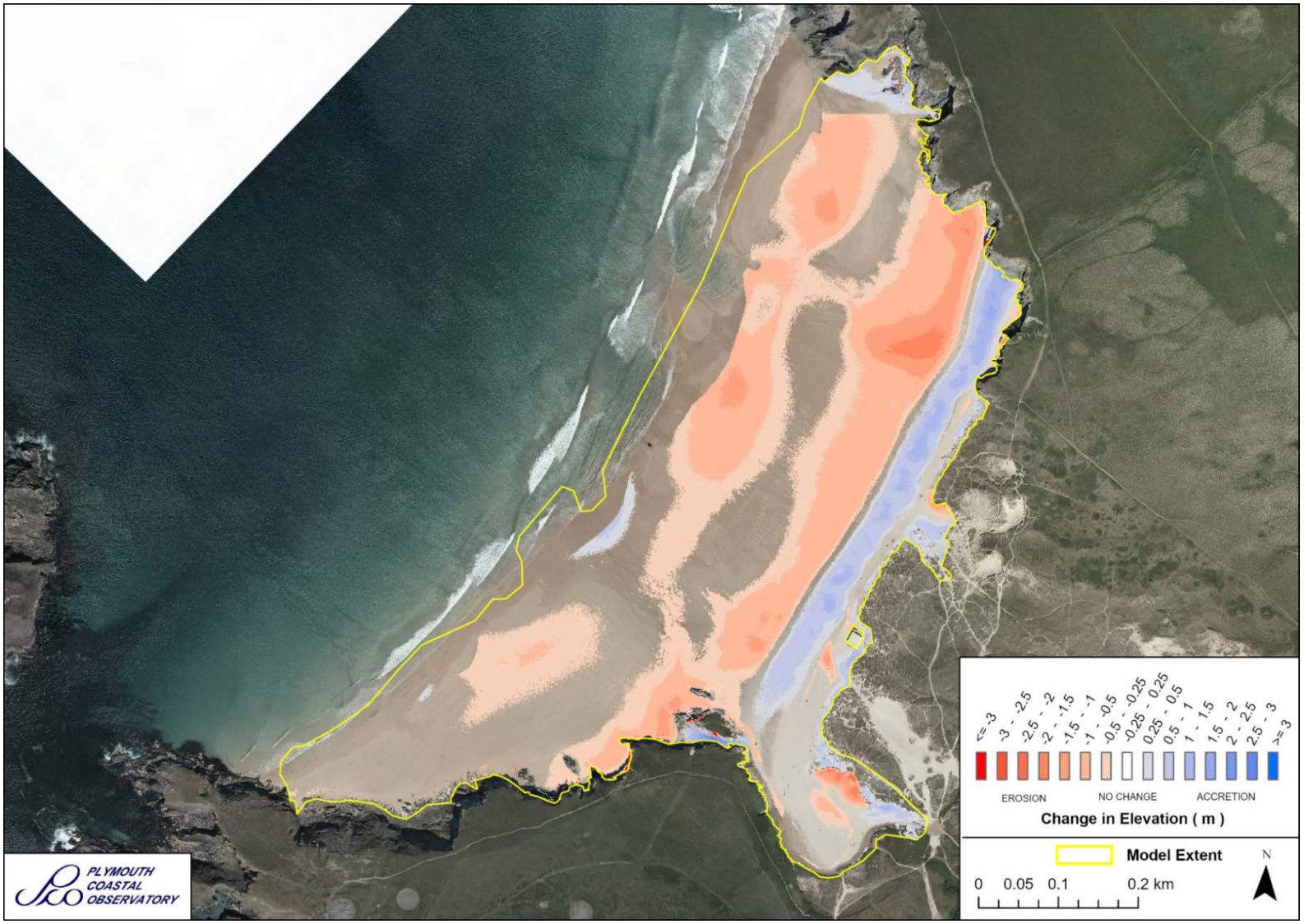


Figure 10 - Difference model indicating the changes in elevation observed between the April 2019 and November 2020 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from November 2020 compared to January 2023. Considerable change can be observed across the entire upper beach area, with two bands of accretion, either side of a band of erosion, along the length of the beach. The dune face has seen low-level accretion, whilst the very southern point of the dune system has experienced some outflanking, eroding by up to 2.5 m. Large patches of erosion and accretion can be seen across the rest of the beach.

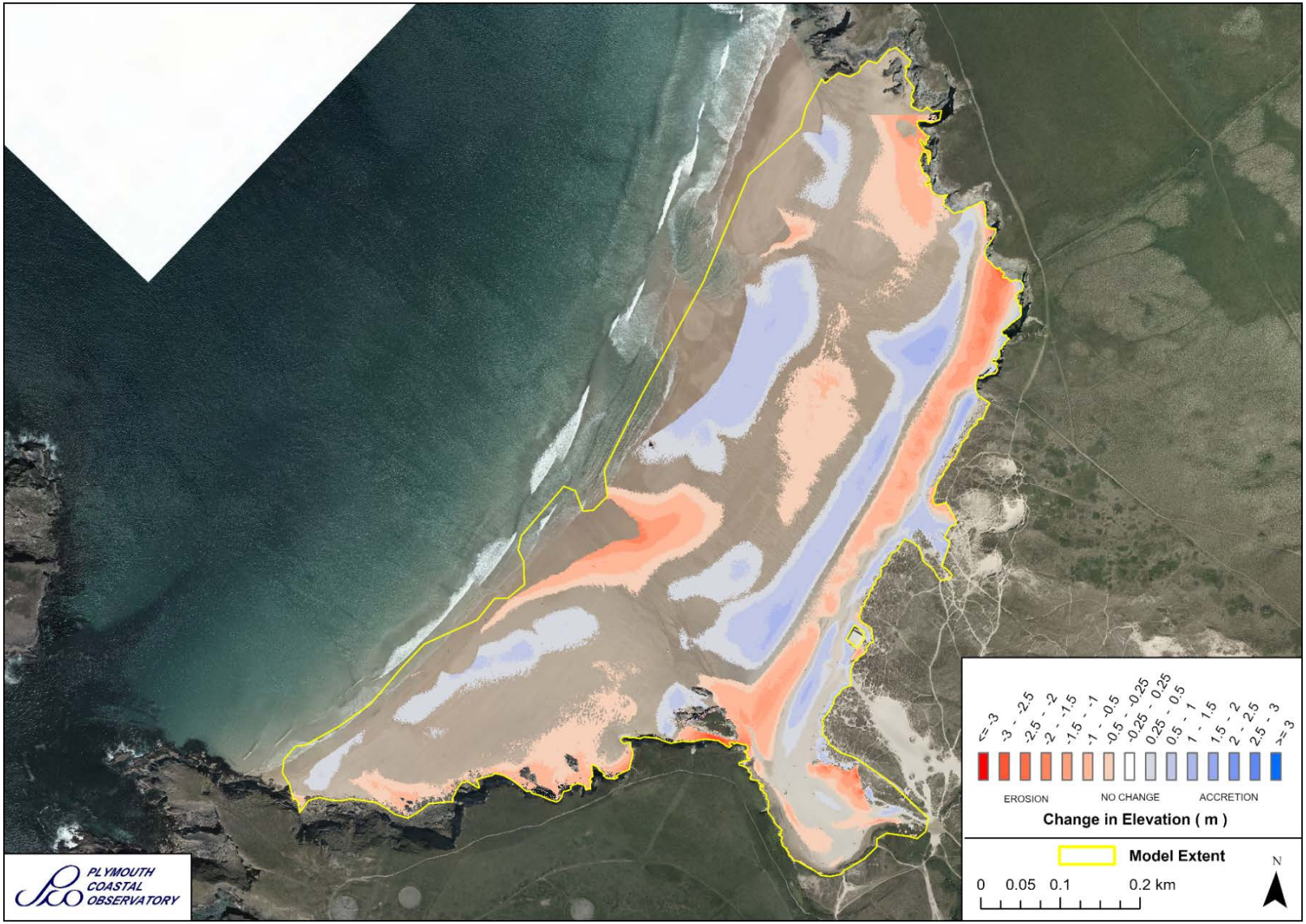


Figure 11 - Difference model indicating the changes in elevation observed between the November 2020 and January 2023 filtered LiDAR datasets within the yellow model extent.

3.1.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.30 m OD) are shown in Table 1 and Figure 12. The Mobile Zone has remained stable between 2008 and 2023, except for a 15% loss in volume between the 2012 and 2014 surveys as a result of the 2013/14 winter storm period (Fig.12). The Mobile Zone has since recovered, recording the highest volume to date during the 2020 survey at 208,620 m^3 (Table 1).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.80 m OD) are shown in Table 1 and Figure 13. Beach Zone volume follows a similar trend to that of the Mobile Zone, remaining stable between 2008 and 2023 despite a 15% loss in volume between the 2012 and 2014 survey (Fig.13).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.30 m OD) and for the Beach Zone above MLWS (-2.80 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
02/2008	204,584	731,004
02/2009	199,341	738,650
01/2011	201,387	858,896
04/2012	192,695	803,904
04/2014	163,109	689,010
03/2016	185,242	747,880
03/2017	199,687	793,636
04/2019	190,611	831,456
11/2020	208,620	754,360
01/2023	196,692	743,999

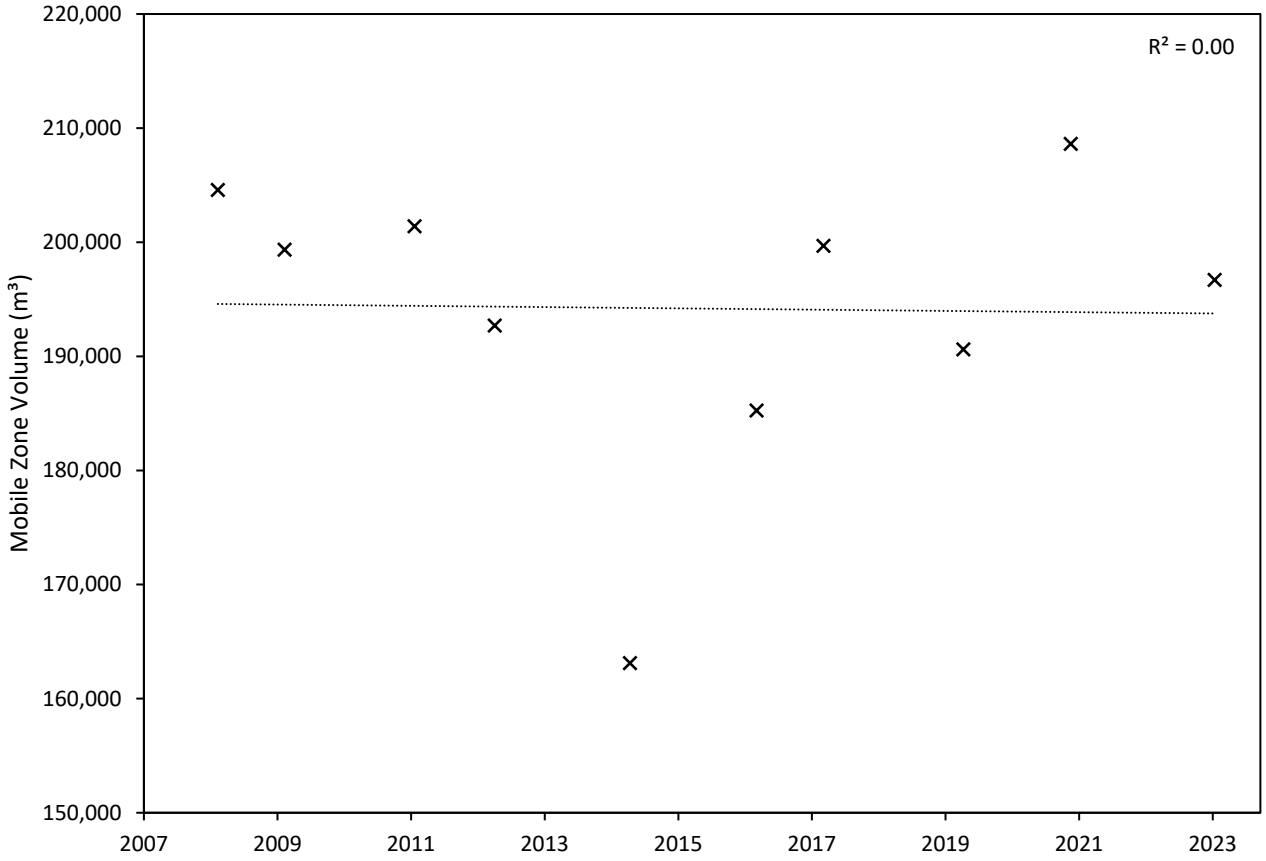


Figure 12 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.30 m OD) for each filtered LiDAR datasets between 2008 and 2023.

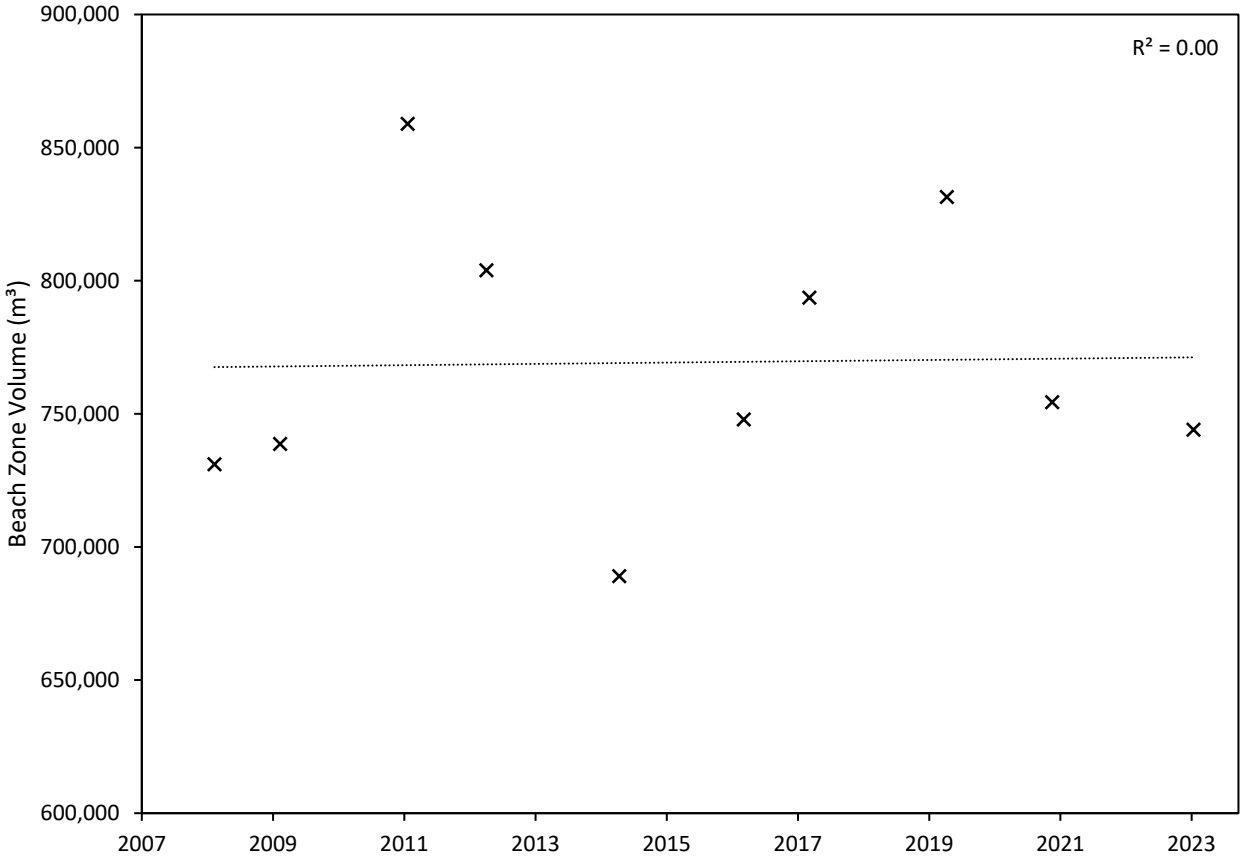


Figure 13 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.80 m OD) for each filtered LiDAR datasets between 2008 and 2023.

3.1.3 Contour Comparison

Figure 14 indicates the Mean Sea Level (MSL) and Dune Toe contours from the 2008, 2014, 2019 and 2023 LiDAR datasets. MSL contours indicate a widening of the beach to the south but a narrowing to the north from 2008 to 2023 by approximately 30-60 m. The Dune Toe contours show a retreat of the dune system in the very south of the beach, losing up to 19 m, whilst the northern half of the Dune Toe remained stable.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency (Figs. 15 and 16) and from 2007 onwards by the SWCM (Figs. 17 – 20) are presented here.

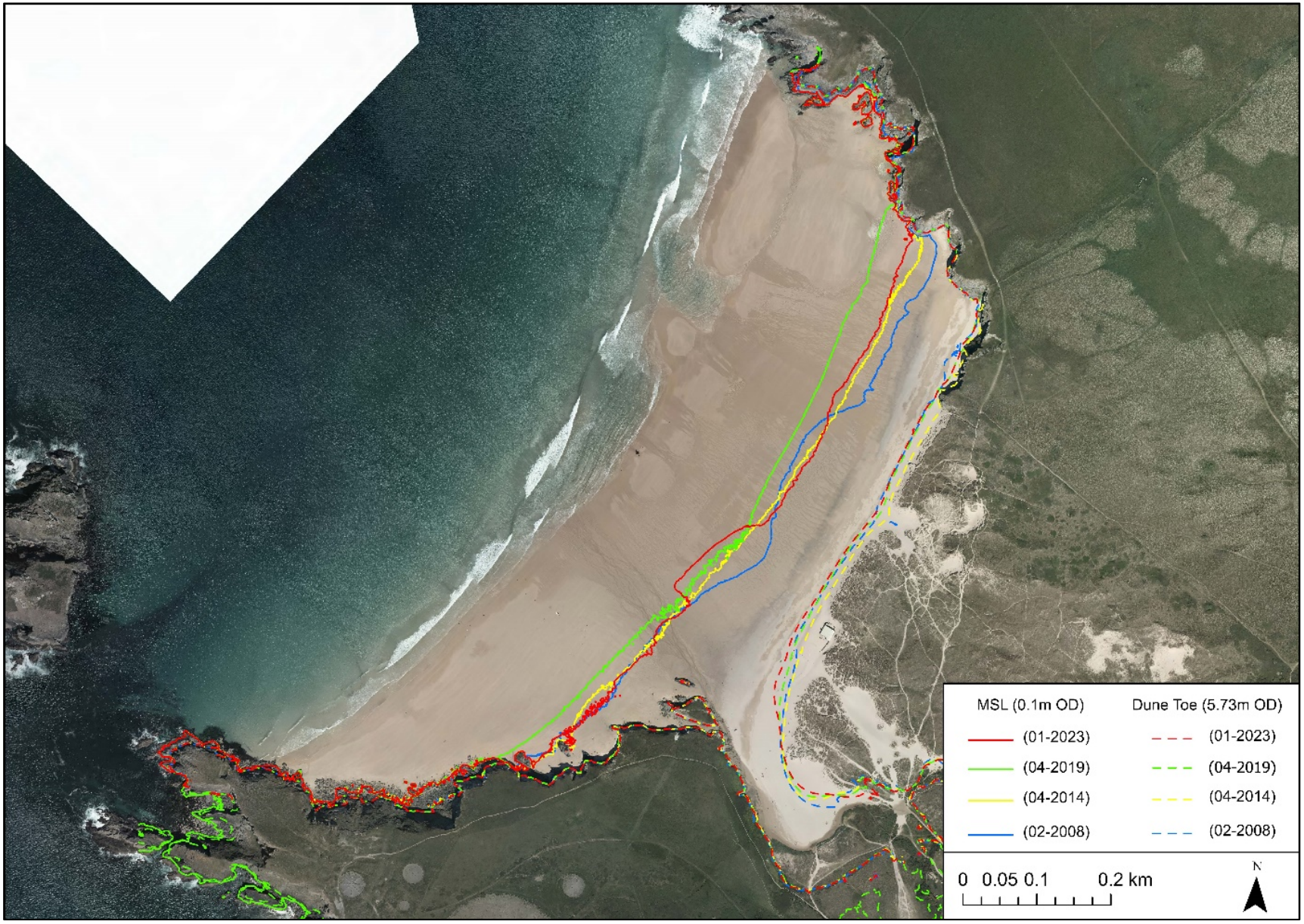


Figure 14 - Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2023 LiDAR datasets.

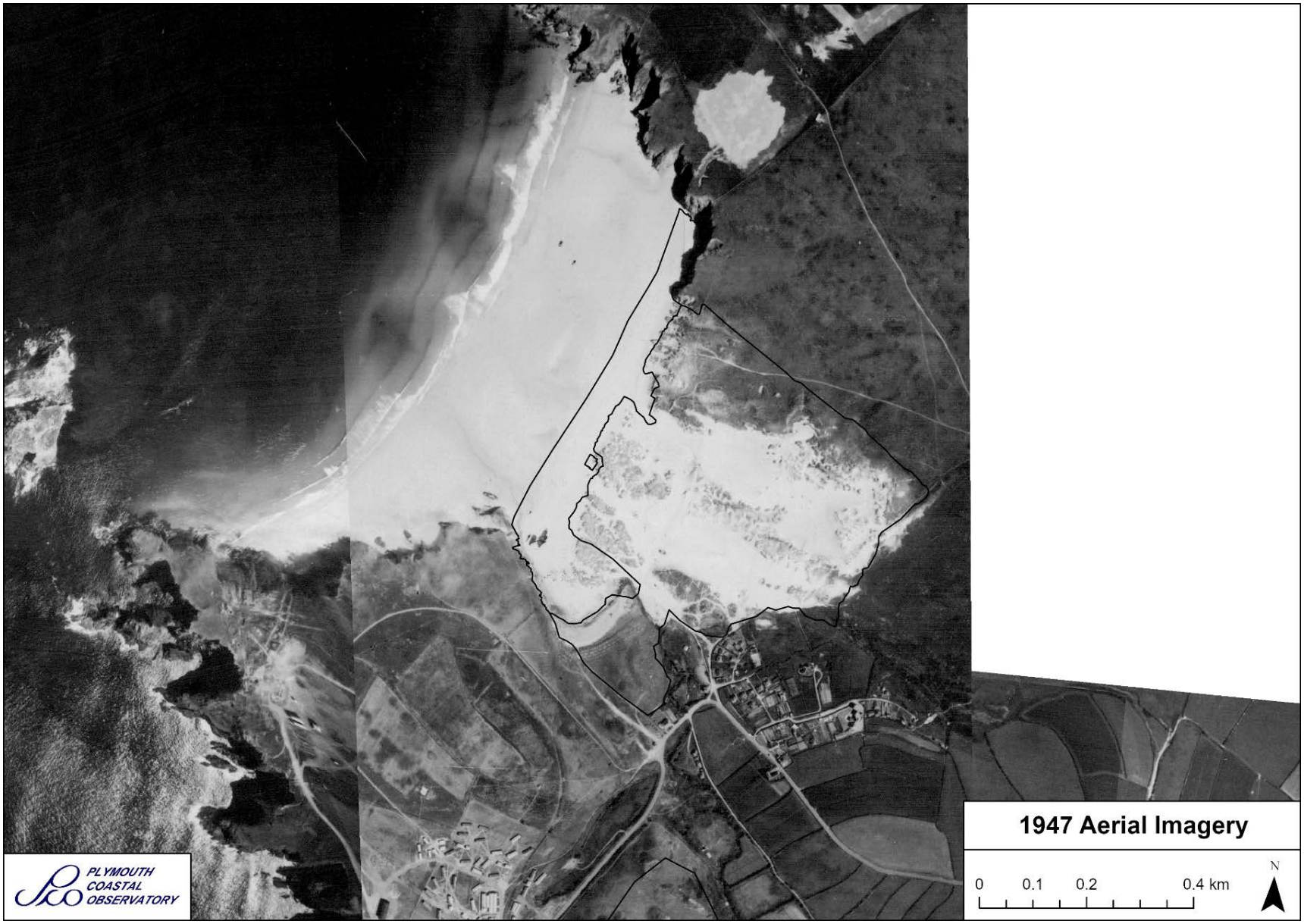


Figure 15 – Aerial imagery from 1947.

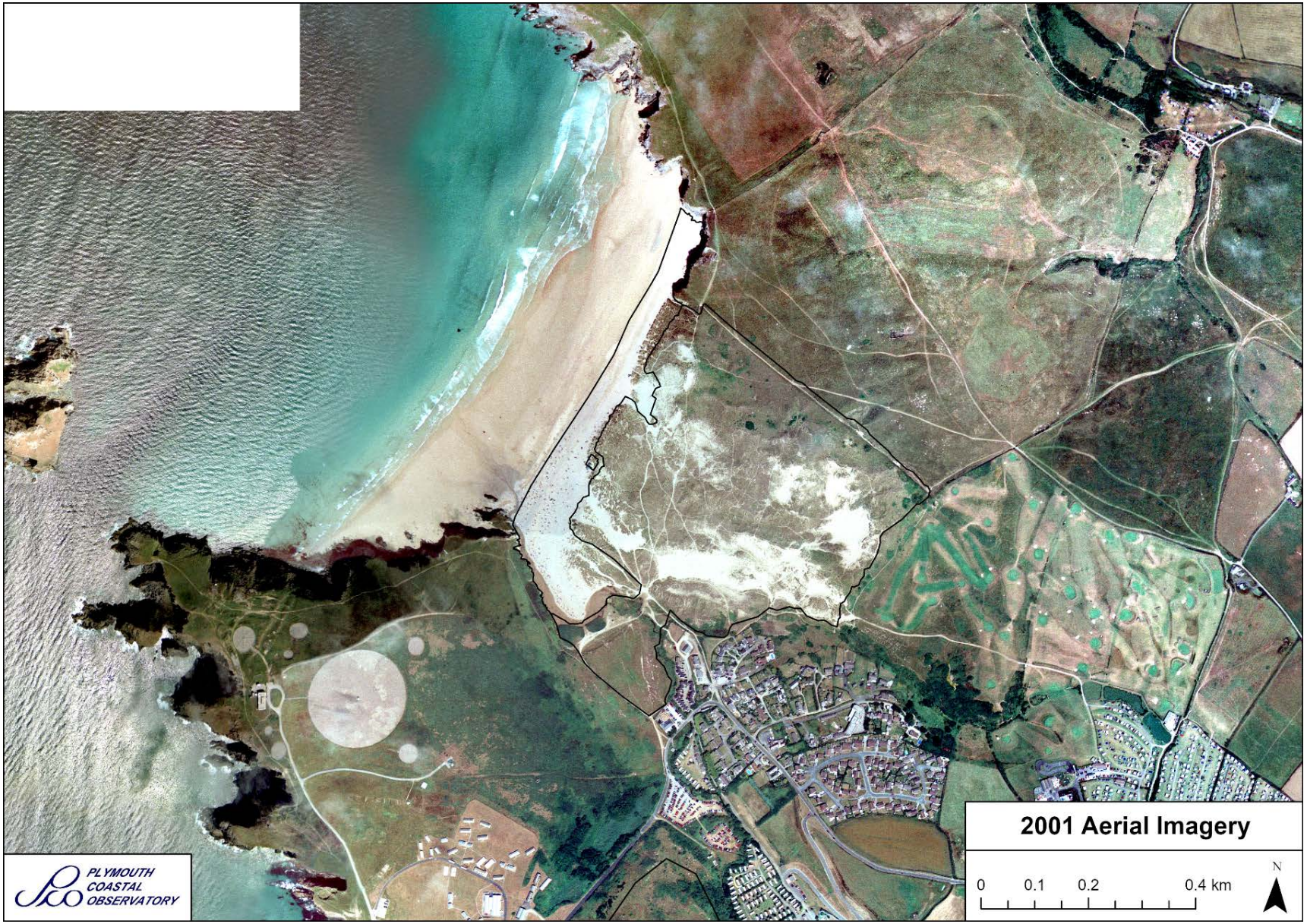


Figure 16 – Aerial imagery from 2001.

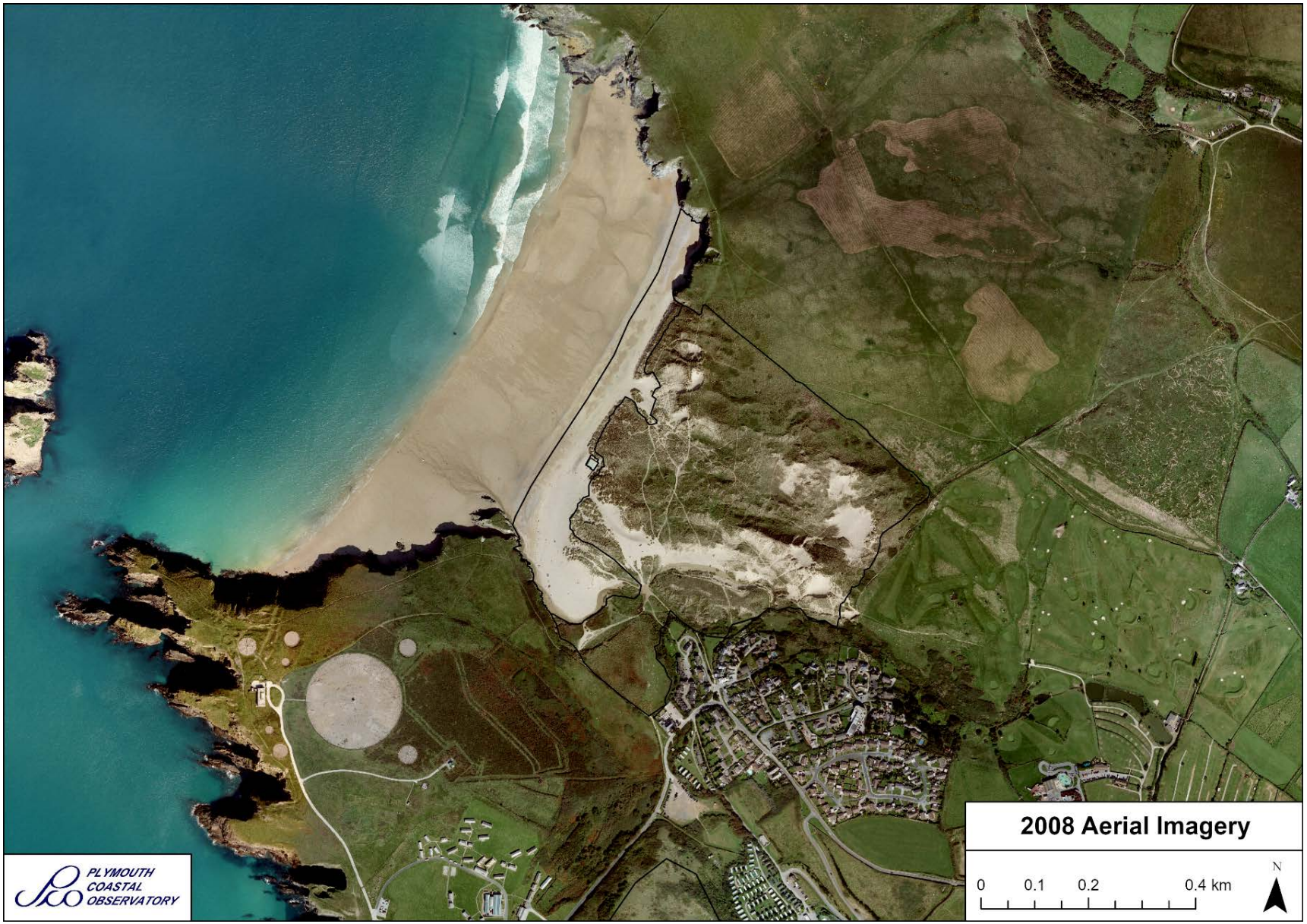


Figure 17 – Aerial imagery from 2008.



Figure 18 – Aerial imagery from 2010.

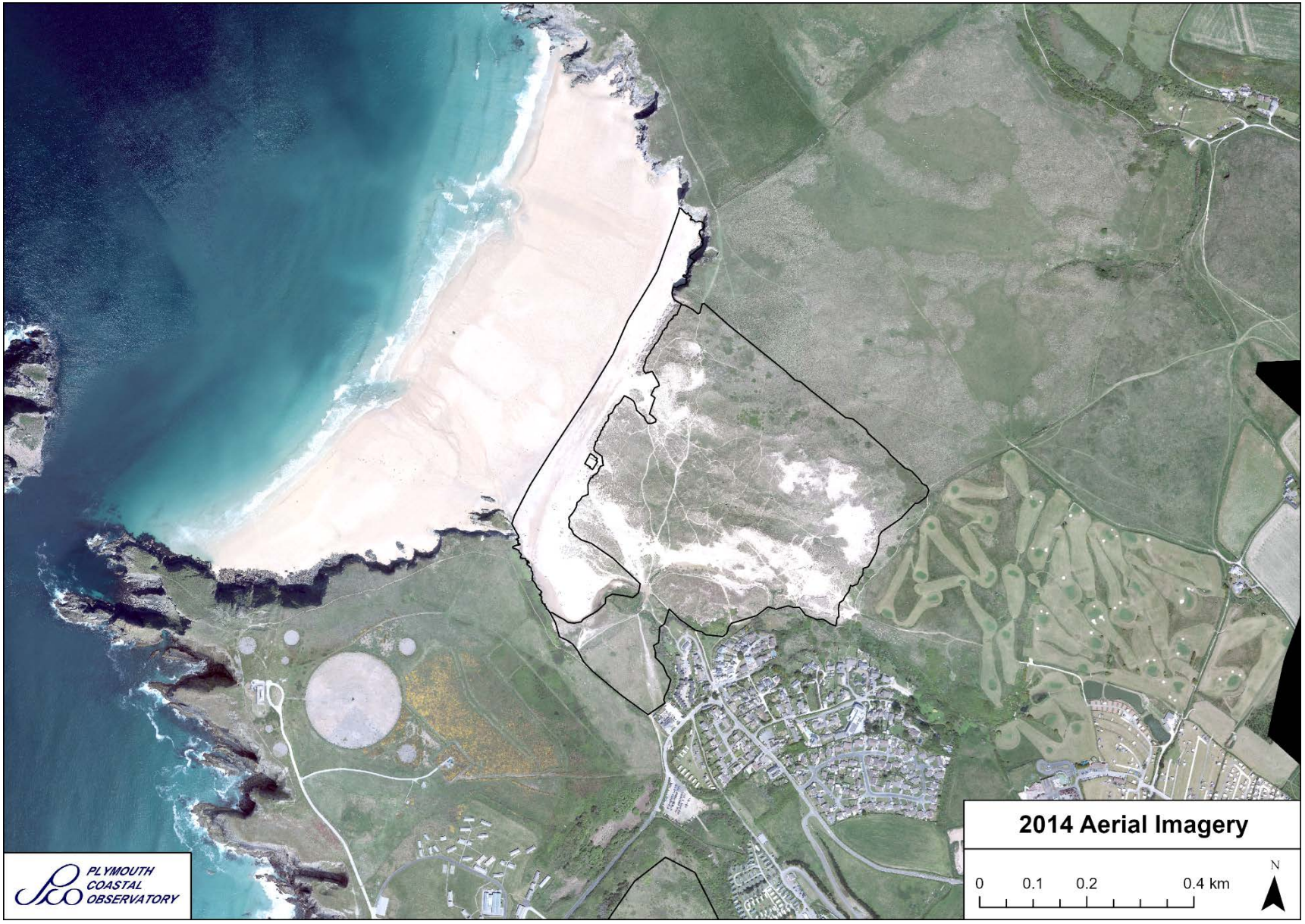


Figure 19 – Aerial imagery from 2014.



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.