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Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2020, 2021)

MULTI-HAZARDS & RESILIENCE PROGRAMME

Commercial Report CR/21/049

BRITISH GEOLOGICAL SURVEY

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Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2020, 2021)

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RGB coloured point cloud for section of 2019 survey.

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Foreword

This report is a published product of the British Geological Survey (BGS) and describes the results of a baseline survey of the cliffs at Hunstanton, Norfolk, for the Borough Council of King's Lynn and West Norfolk.

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Summary

This report is the published product of the **B**ritish **G**eological **S**urvey (**BGS**) and describes the results of the Annual 2020 and 2021 surveys of the cliffs at Hunstanton, Norfolk, for the **B**orough **C**ouncil of **K**ing's **L**ynn & **W**est **N**orfolk (**BCKLWN**).

This report describes the background to the work and discusses the state of the four **LiDAR** (**Li**ght **D**etection **A**nd **R**anging) scans provided by the client, and collected by the **A**nglian **C**oastal **M**onitoring Programme (**ACM**), covering the years 2020 and 2021.

This is an 'annual' report, the objective of which is to derive a series of surfaces for the latest two LiDAR scans and to compare them against the earliest (2010) scan, to the previous (2019) scan and to each other. A table detailing the amount of erosion, the volume loss and the metres lost over the section surveyed is also included.

The report provides a brief discussion, with images, of the results of the changes identified, including the year-on-year comparisons.

1 Introduction

The Borough Council of King's Lynn & West Norfolk is currently looking to implement both annual and post storm LiDAR surveys of the Hunstanton Cliffs over a 4-year monitoring period (likely to be extended), which will potentially be coordinated with the Environment Agency's ACM topographic contractor. The purpose of this would be to monitor erosion rates occurring on the cliff line, with long term monitoring helping to inform when cliff top assets become at risk, in order that planned rock armour can be implemented (likely in 50-60 years' time). The reports would also be made available to residents in the local area, helping to raise awareness of the processes occurring at the cliffs.

In an e-mail, dated November 21, 2019, the Borough Council of King's Lynn & West Norfolk set out the following:

> *A key aspect of the monitoring would be for the data to be placed into an annual report which can present / analyse the terrestrial LiDAR data collected. We would also be looking for some analysis of the terrestrial LiDAR scans conducted by the ACM in 2012, 2017 and 2019 to be analysed and placed into a similar styled report. In particular we would like the report to present any models produced from the data and analysis to focus on the amount of erosional retreat occurring each year, changes in talus at the base of the cliff, major changes on the cliff face and estimations of when cliff top assets are likely to become at risk due to erosion.*

In an e-mail dated May 11, 2021, the Council asked the BGS to supply them with an annual report, based on data acquired from 2020 & 2021 surveys, to include the following (Project Code NEE7028R):

- *Change models identifying areas of loss and/or accretion from 'base' year (2010) to 'current' year (2020, 2021)*
- *Tables detailing the amount of erosion of the section, the volume loss across the section and the metres per year loss of the section*
- *Discussion and images of the areas where the most significant amount of erosion has occurred and the identification of key changes from 'previous' years (fall events, talus removal etc.)*
- *Analysis of the comparisons*

2 Data and Extents

The Borough Council of King's Lynn & West Norfolk supplied the BGS with georeferenced point cloud data (in .las format) from 2020 and 2021. The area under review is shown in Figure 1 and the data are summarised in Table 1, which shows the date of the survey, the instrument used, including the estimated accuracy, and any additional information stored (Intensity and/or RGB colour). It also shows the number of points attributed to each survey, both initially and after filtering of the cloud. Filtering is necessary in order to facilitate the surface modelling of the point cloud which is required for change analyses.

Figure 1 – Hunstanton cliffs survey area. *Figure provided by BCKLWN*

Table 1 – Summary of survey data

Survey Year	Instrument Used	*Estimated Accuracy (mm)	Scan Colour	Number of Points Initial	North	Middle	South
2010	Leica Scan Station	+/- 6	None	18184620	454765	535525	181922
2012	Leica Scan Station	+/- 6	None	445526	-	-	102303
2017	Faro Laser Scanner	+/- 3.5	Intensity	180308350	466837	628424	243039
2019	Faro Laser Scanner	+/- 3.5	RGB	59152684	456427	517044	140064
2020	Faro Laser Scanner	+/- 3.5	RGB	10381057	539679	222476	124645
2021	Faro Laser Scanner	+/- 3.5	RGB	34403524	679524	581698	128023

Note:*Estimated accuracy is that of the scanner and does not take into account the spatial accuracy of the **G**lobal **N**avigation **S**atellite **S**ystem (**GNSS**) position, so is not absolute positional accuracy.

The surveys of 2020 and 2021 were the same size as the previous (2019) survey, and were again divided into three smaller sections in order to provide a better accuracy for the volume calculations, and to take into account that the 2012 survey covered a smaller southern section of the cliff-line. The sections were split where the 2012 data was situated (south) and at a gap in the data on the 2010 survey. These splits are shown in Figure 2 on a 3D illustration and in Figure 3 on a plan. The section extents are given in Table 2.

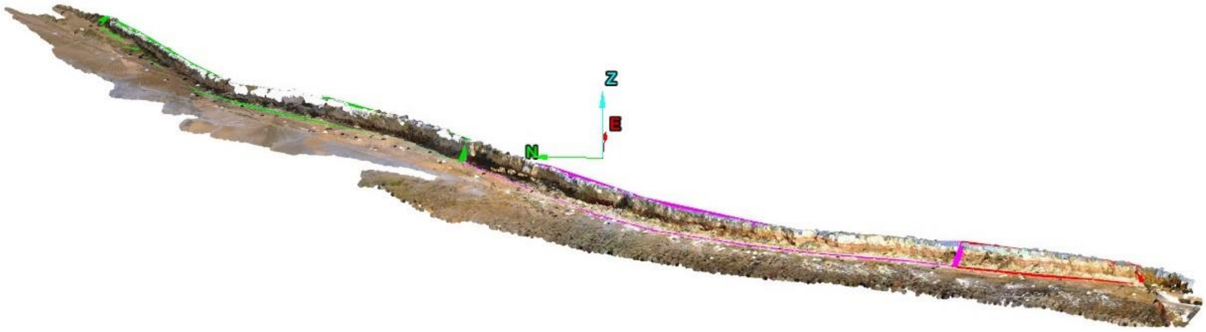


Figure 2 – RGB coloured point cloud of 2021 survey showing sections: Green = North, Magenta = Middle, Red = South (Extents: E 567954 m, N 342450 m to E 567268 m, N 341332 m. Height range = 6.3 m to 18.8 m)

Note: Figure 2 is a 3D illustration of the data and therefore it is difficult to show a representative scale of the Z-value as it varies from ~6 m to ~19 m across the section. This applies to all figures in this report. Therefore, XY extents and Z ranges have been appended to all figures.

Table 2 **– Section extents**

Section	Start		End		Length	Average
	Easting	Northing	Easting	Northing	(m)	Height (m)
North	567578	342050	567934	342430	515	14.75
Middle	567314	341539	567584	342052	575	17.84
South	567267	341356	567333	341548	185	16.14

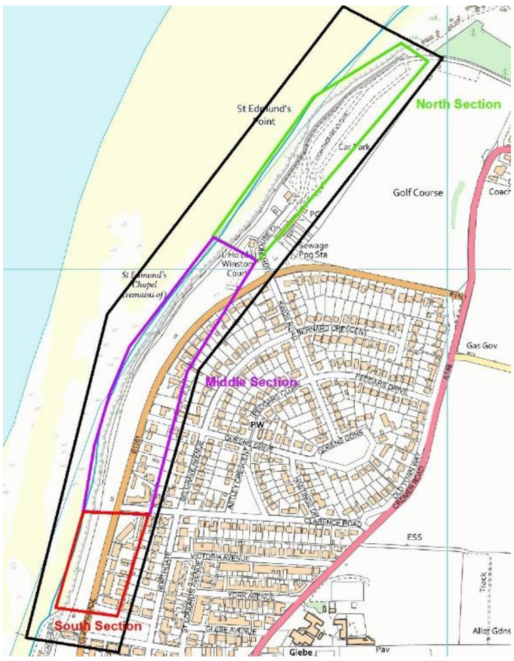


Figure 3 – Plan view of scan area sections: Green = North, Magenta = Middle, Red = South

Figures 4 and 5 show the coverage and extents of the scans from the two surveys. They are displayed as RGB colour values for both 2020 and 2021 (Figure 7).

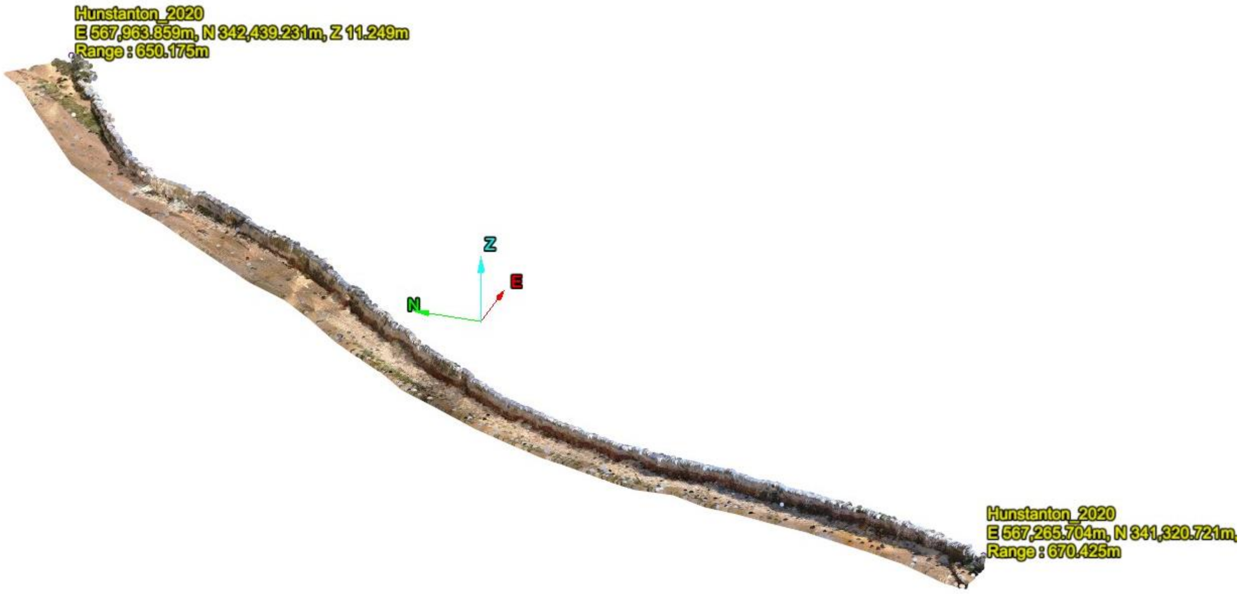


Figure 4 – 2020 point cloud data displayed using the RGB colour values (Extents: E 567964 m, N 342439 m to E 567266 m, N 341320 m. Height range = 6.3 m to 18.8 m)

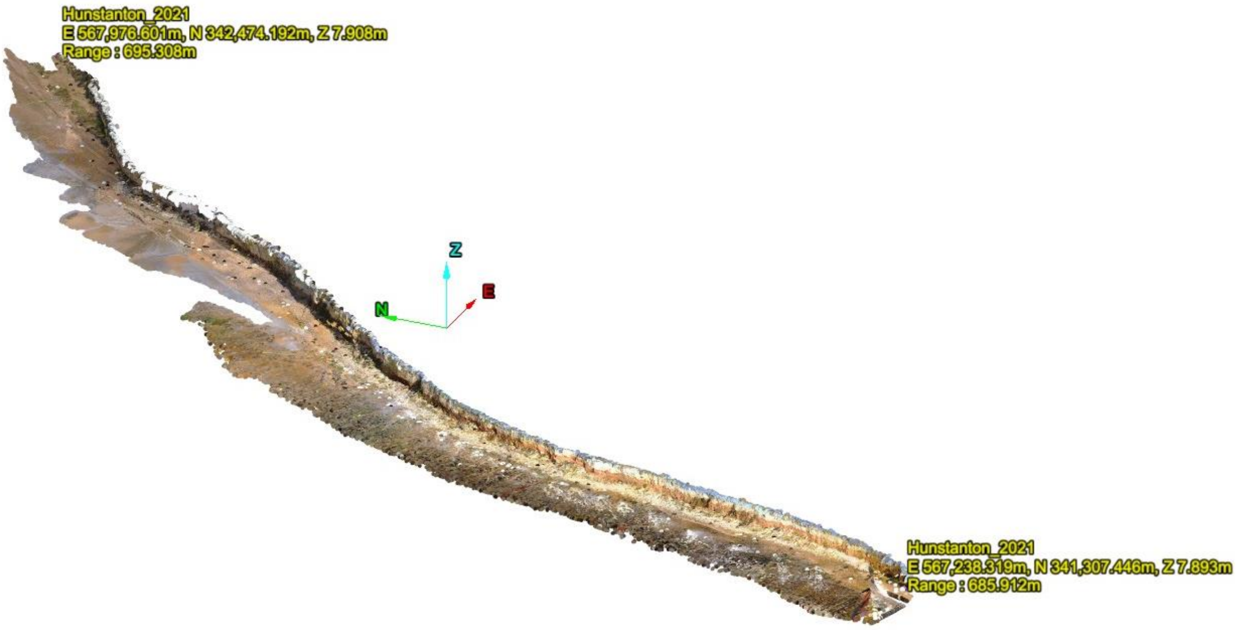


Figure 5 – 2021 point cloud data displayed using the RGB colour values (Extents: E 567976 m, N 34247474 m to E 567238 m, N 341307 m. Height range = 6.3 m to 18.8 m)

The point cloud data provided, in .las format, for both surveys, was imported by BGS into Maptek I-Site Studio where it was cleaned, removing any artefacts in the data (e.g. bird strikes, anomalous points etc.), and trimmed to equivalent extents, where possible. These data were then trimmed to the cliff-line, leaving a small section of beach, and cut to the section extents shown in Figure 2 and described in Table 2 above.

3 Model Creation

In order to create a 3D surface model of each section, for each survey year, the point clouds needed to be filtered. This is done to reduce the amount of points and to further clean the data. Initially, an *Isolated Points filter* was carried out to remove points that were a large distance from any other points in the scan, helping to remove dust particles and insects which may not have been removed from the earlier cleaning. A *Topography filter* was then carried out to remove unwanted features such as equipment and trees etc. from the scan, retaining only the single lowest point in a defined horizontal grid cell. This has the effect of reducing the data to a more even point distribution. The amount of points retained for each section is shown in Table 1.

3.1 FUSION SURFACE MODELS

In order to best represent the topography of the point clouds a Fusion Surface model was created from a Topographical Triangulation and a Spherical Triangulation. The Topographical Triangulation works in the XY plane, that is, it triangulates straight down, meaning that areas of undercutting will not be modelled correctly. In order to make allowance for this, a Spherical Triangulation, which creates a surface on a sphere, was carried out. As the triangulation grid is spherical from the defined origin point, it allows for overhanging surfaces to be created. The Fusion Surface creates a new surface of evenly sized triangles by following the original surfaces of the two triangulations. Where the surfaces overlap, the Fusion Surface will follow the most detailed triangulation, giving a better combined 3D result. Following the creation of the Fusion Surface de-spiking was carried out, to remove spikes caused by any remaining dust or vegetation, and any small holes (~1 m) in the surface were filled; larger holes, where there were no points, were not.

Based on the sections shown in Figure 2 and described in Table 2, the following Fusion Surface models were created (Appendix 1):

- North – 2020, 2021
- Middle – 2020, 2021
- South – 2020, 2021

3.2 CHANGE MODELS

Maptek I-Site Studio was used to create change models between the base year (2010) and each subsequent year, and from each intermediate year to the subsequent year, as follows:

- North – 2010 to 2020, 2010 to 2021, 2019 to 2020, 2020 to 2021 (4)
- Middle – 2010 to 2020, 2010 to 2021, 2019 to 2020, 2020 to 2021 (4)
- South – 2010 to 2020, 2010 to 2021, 2019 to 2020, 2020 to 2021 (4)

Change models were created using the *Colour Distance from Objects* tool. The tool is used to visualise areas of change between two triangulated surfaces of the same area. The resulting model is coloured by the distance between the objects according to the colour versus distance relationship specified. This relationship is shown in the legend, which shows a graph displaying the distribution of data in front and behind the surface. Change models for all sections, of all years, can be found in Appendix 2.

4 Volume Calculations

Volumes lost from the cliffs at Hunstanton have been calculated directly from the **T**errestrial **L**iDAR **S**canning (**TLS**) models for the period August 2010 to March 2021 (Table 3). The data shown have been extracted from the three sections previously outlined in Figure 2 and Table 2. In order to estimate the maximum horizontal movement values of the cliff-line, parallel sections were created at 50 m spacing along the entire 3D model, for the North (Figure 6), Middle (Figure 7) and South (Figure 8) sections of the cliff. The section lines appear closer together towards the north; this is because of the angle of the image, in order to make sure all lines are visible.

Table 3 – Cliff recession, derived from TLS

Period		Elaspsed Time	Cumulative Time	North Section			Middle Section			South Section		
Start	End	(days)	(days)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)
Aug-10	Oct-12	785	785							200	200	1
Oct-12	Oct-17	1829	2614	1850	1850	4	5500	5500	10	2000	2200	12
Oct-17	Mar-19	522	3136	1200	3050	6	1250	6750	12	150	2350	13
Mar-19	Aug-20	510	3646	2000	5050	10	3500	10250	18	950	3300	18
Aug-20	Mar-21	239	3885	2700	7750	15	500	10750	19	100	3400	18
Aug-10	Mar-21		*3885*		7750	15		10750	19		3400	18
Loss/Year					729			1011			320	

North Section			Horizontal Movement	Middle Section			Horizontal Movement	South Section			Horizontal Movement
Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	(m)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	(m)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	(m)
								460	460	2	
4255	4255	8		12650	12650	22		4600	5060	27	
2760	7015	14	*1.5*	2875	15525	27	*1.0*	345	5405	29	*2.5*
4600	11615	23		8050	23575	41		2185	7590	41	
6210	17825	35	*2.4*	1150	24725	43	*1.8*	230	7820	42	*3.0*
0											
	17825	35	*2*		24725	43	*2*		7820	42	*3*
	1676				2325				735		

The data show a *new* total loss of 21900 m^3 across the 1.275 km combined sections, relating to an estimated mass of approximately 50370 tonnes* of material. These values work out to 2059 m^3/year (up from the previous value of 1415 m^3/year), which is an estimated 4736 tonnes/year (up from the previous value of 3255 tonnes/year). Graphs showing the cumulative loss of material in cubic metres (Figure 9) and the cumulative loss of material in tonnes (Figure 10) are also presented here. These graphs show a consistently steady increase in the amount of material lost from the Middle section throughout the survey period 2012 to 2021, an increase in the amount of loss from the North section over the period 2020 to 2021, and a very slight rise in the amount of loss from the South section over the period 2012 to 2020.

Cliff height has not been taken into account in the calculations (above) as it varies considerably, from ~6.3 m to ~15.7 m in the north section, from ~16.5 to ~18.8 m in the middle section and from ~14.0 m to ~17.0 m in the south section. Across the whole of the surveyed section the cliffs show an average height of ~16 m. A mean recession rate can be calculated by taking into account the yearly loss (2059 m^3), the cliff length (1275 m) and the cliff height (16 m) giving a total value of 0.10 m/year (up from the previous value of 0.07 m/year).

These results show an increasing rate of recession, albeit a small one, across the time period 2019 to 2021 (mainly from 2019 to 2020) of 0.03 m/year.

Note: *The geology of the cliffs is made up of Carstone (Sandstone) and Chalk. As there is no easy way of differentiating where these layers lie within the scans, the mass calculated is based on the average density value of 2.3 kg/m^3.

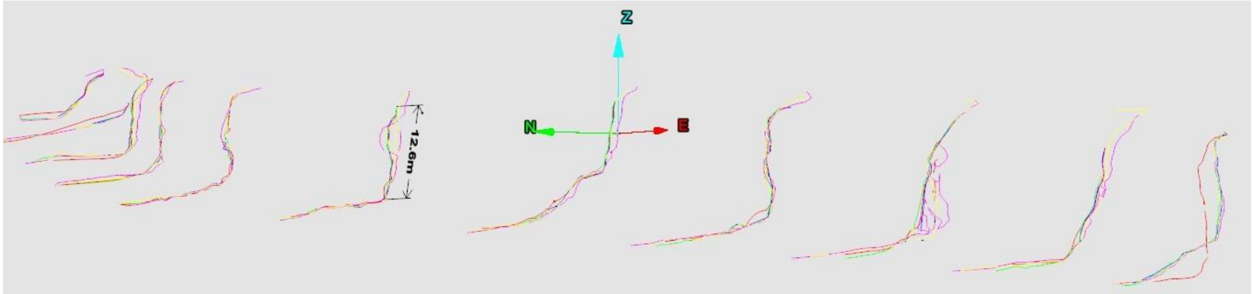


Figure 6 – Cross-sections, at 50 m spacing, for North section: Red = 2010, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021 (Extents: E 567578 m, N 342050 m to E 567934 m, N 342430 m)

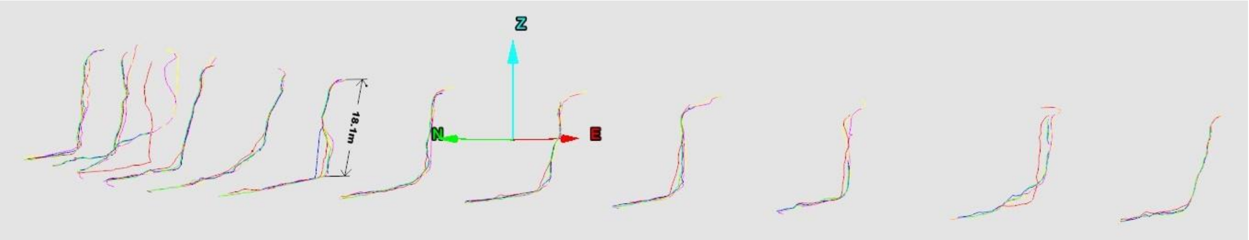


Figure 7 – Cross-sections, at 50 m spacing, for Middle section: Red = 2010, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021 (Extents: E 567314 m, N 341539 m to E 567584 m, N 342052 m)

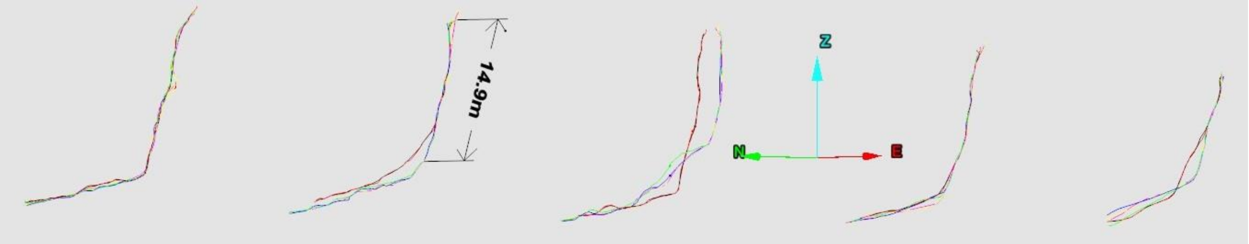


Figure 8 – Cross-sections, at 50 m spacing, for South section: Red = 2010, Black = 2012, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021 (Extents: E 567267 m, N 341356 m to E 567333 m, N 341548 m)

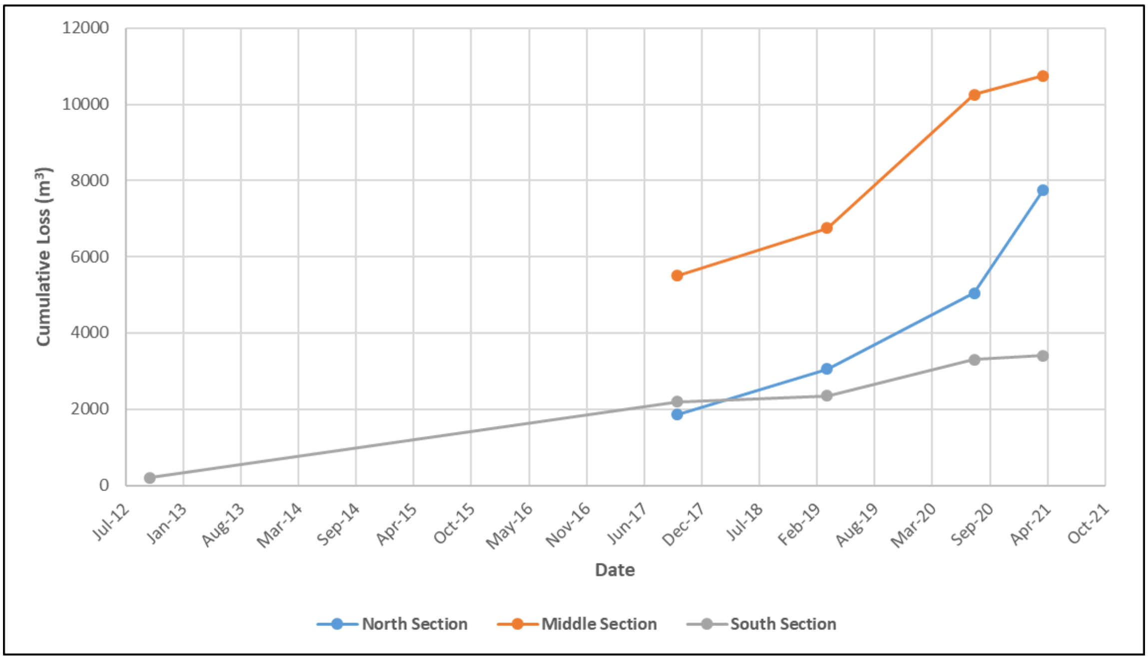


Figure 9 – Cumulative Loss (m^3) v Time

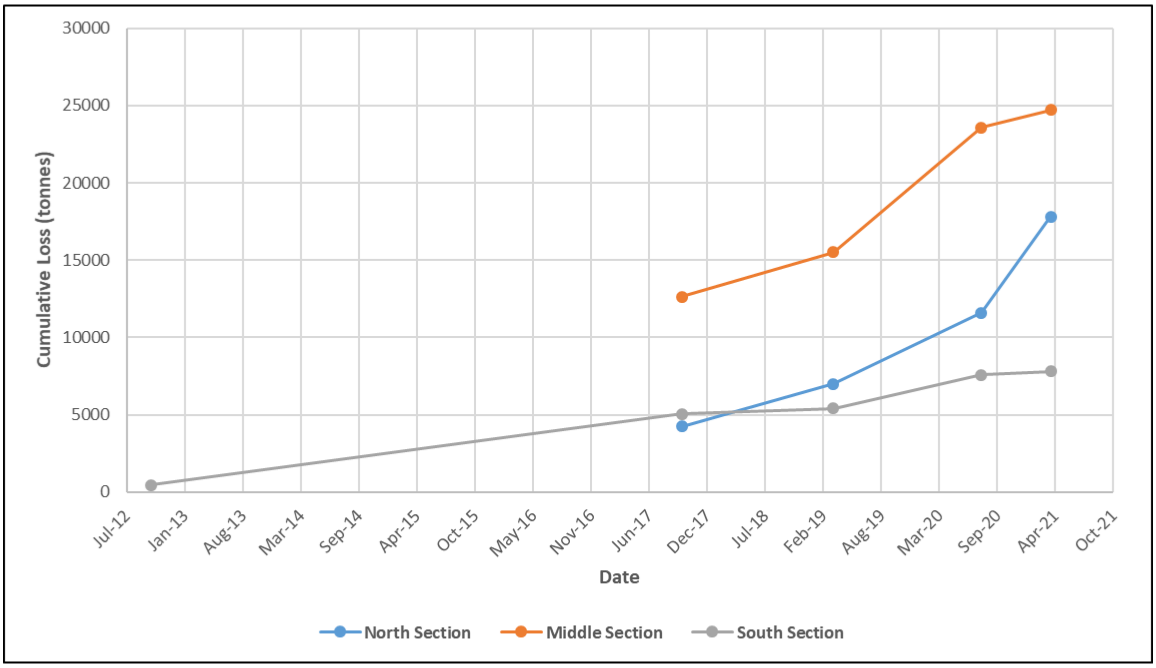


Figure 10 – Cumulative Loss (tonnes) v Time

5 Cloud Compare

An alternative way of visualising the change between the surveys is to use Cloud Compare, which is a 3D point cloud processing software that allows for the manual editing and rendering of point clouds. It also has the ability to compute distances in a cloud-to-cloud nearest neighbour comparison, using the M3C2 (2020) plugin. As this is not a triangulated model it is not able to determine the volume change, however, as a visualisation of the change it is worthy of note. As a point cloud it does not need to be filtered as much and, as such, fewer points are lost. Figure 11 shows the difference between the 2010 and 2019 surveys for the whole section, and Figure 12 shows the difference between the 2010 and 2021 surveys. Red are areas of erosion and blue areas of accretion. These areas are picked up in more detail in section 6, below.

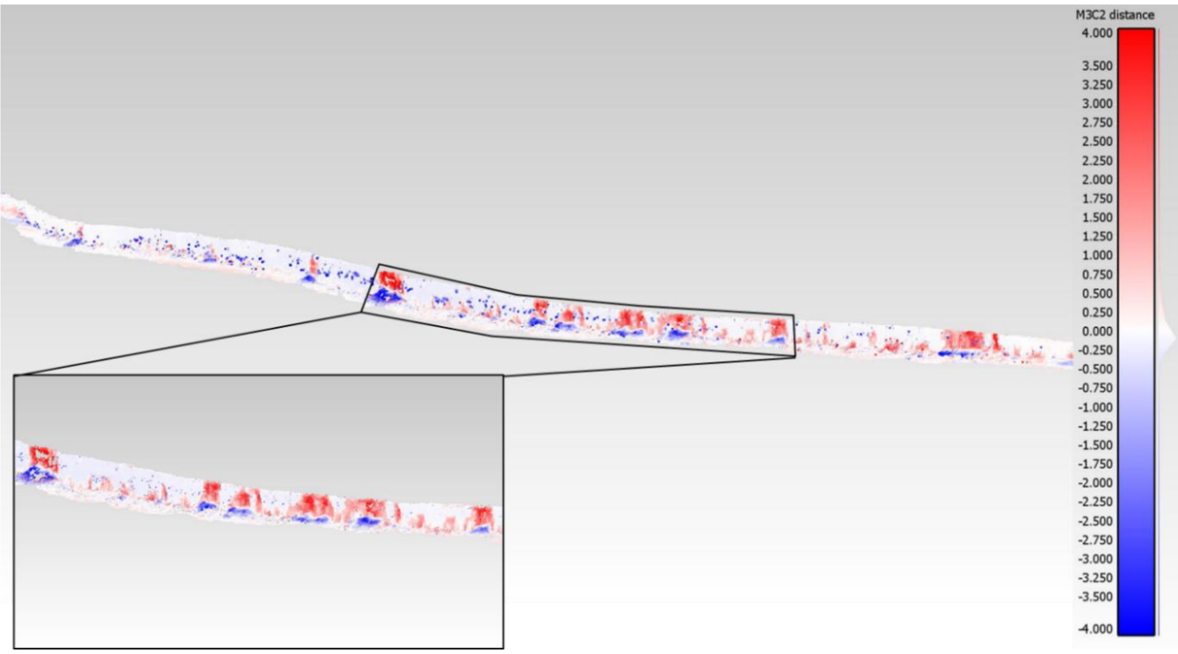


Figure 11 – 2010 to 2019 cloud-to-cloud difference model (Extents: E 567954 m, N 342419 m to E 567270 m, N 341340 m. Height range = 6.3 m to 18.8 m)

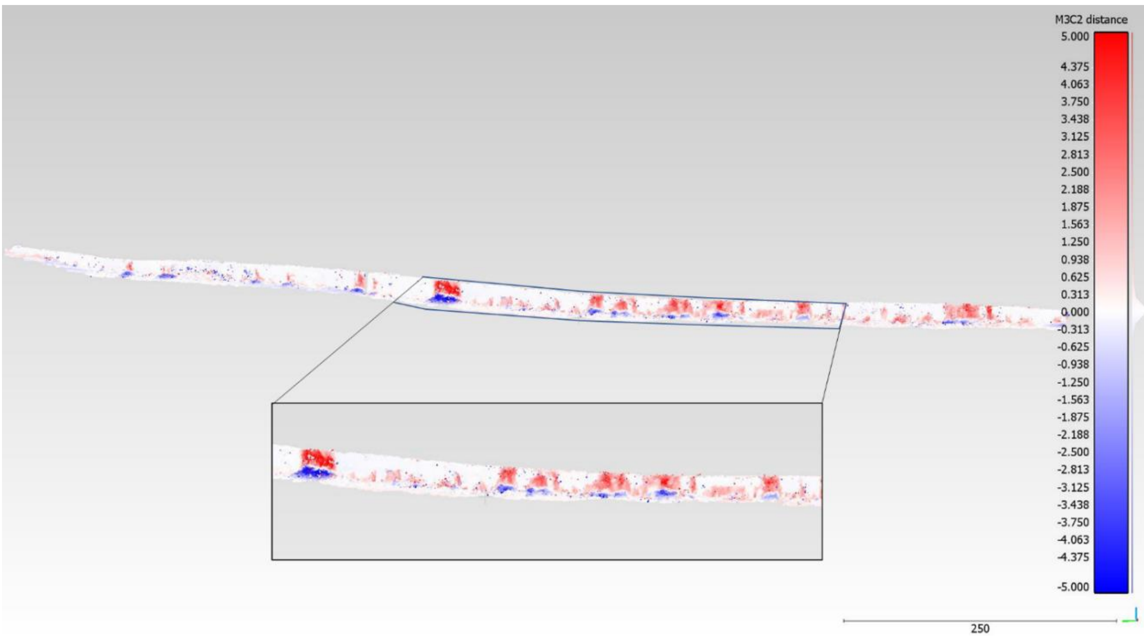


Figure 12 - 2010 to 2021 cloud-to-cloud difference model (Extents: E 567954 m, N 342419 m to E 567270 m, N 341340 m. Height range = 6.3 m to 18.8 m)

6 Analysis of Change

This is an annual report, based on the data obtained from the 2020 and 2021 surveys. For clarity, this discussion of results will refer to the change between the 2010 and 2021 surveys, as these cover the full extent of the area under consideration and the total time extent of the surveys carried out. This discussion will also look at the change between the 2019 and 2021 surveys, as this will provide information on possible changes to the erosion rates. This report will look at the model data by section, giving localised northing co-ordinates, where appropriate; in order to better delineate the results.

6.1 NORTH SECTION

Areas of major change occur within the north section (Figures 13 & 14) at British National Grid (BNG) 342329 m North to 342417 m North (Figure 15) which show that ~3.5 m of loss has occurred in the cliff face and accretion has followed on the foreshore. Further change in this section can be seen at 342195 m North to 342301 m North (Figure 16) where a loss of up to 3.5 m is visible across the cliff face with accretion of approximately 3 m on the foreshore. At the southernmost part of the section, at 342068 m North to 342176 m North (Figure 17), there is a large area of erosion in the cliff face of ~3.5 m, with a similar amount of accretion on the foreshore. This area sits directly in front of the Lighthouse. The legend for these figures can be seen in Figure 18, which shows a histogram of the loss/gain distribution.

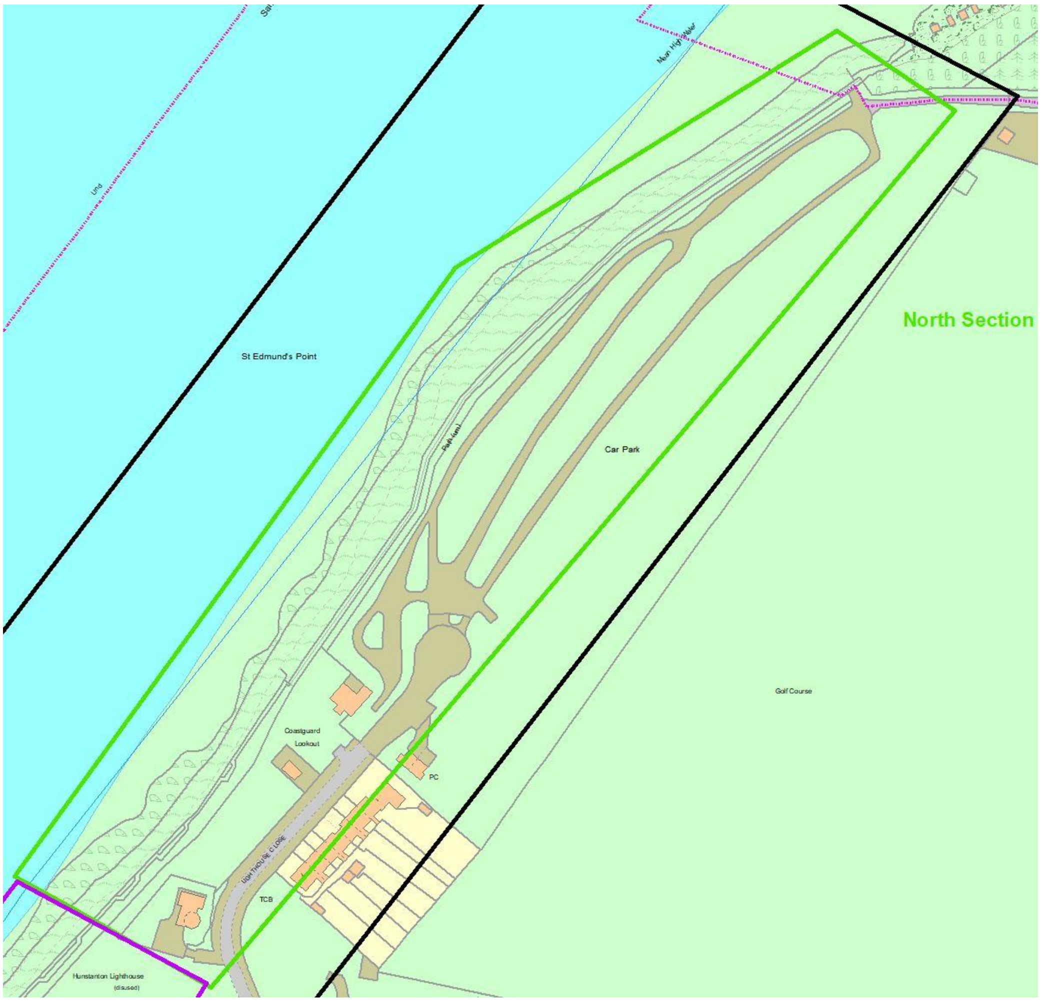


Figure 13 – Plan view of North section

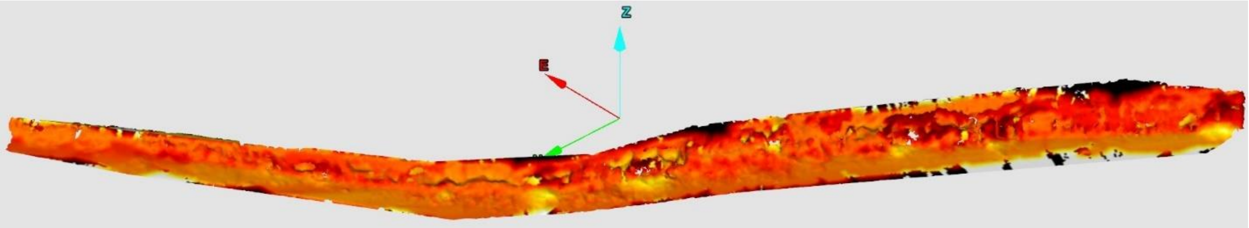


Figure 14 – 3D view of the entire North section

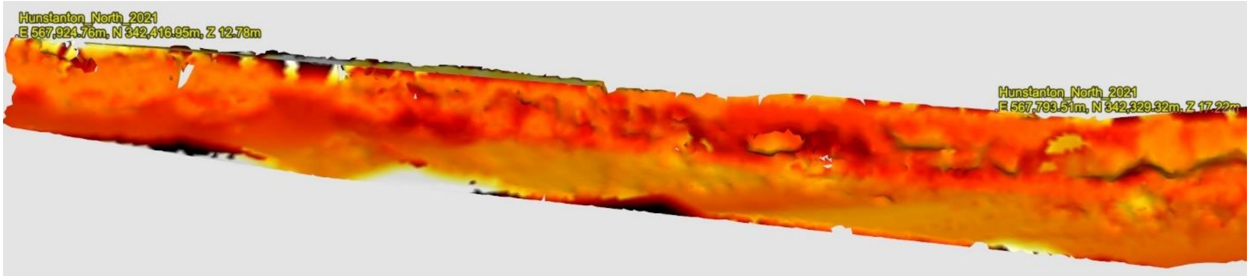


Figure 15 – 2010 to 2021 change model of 342329 m North to 342417 m North (for legend see Figure 18. Height range = 6.3 m to 15.7 m)

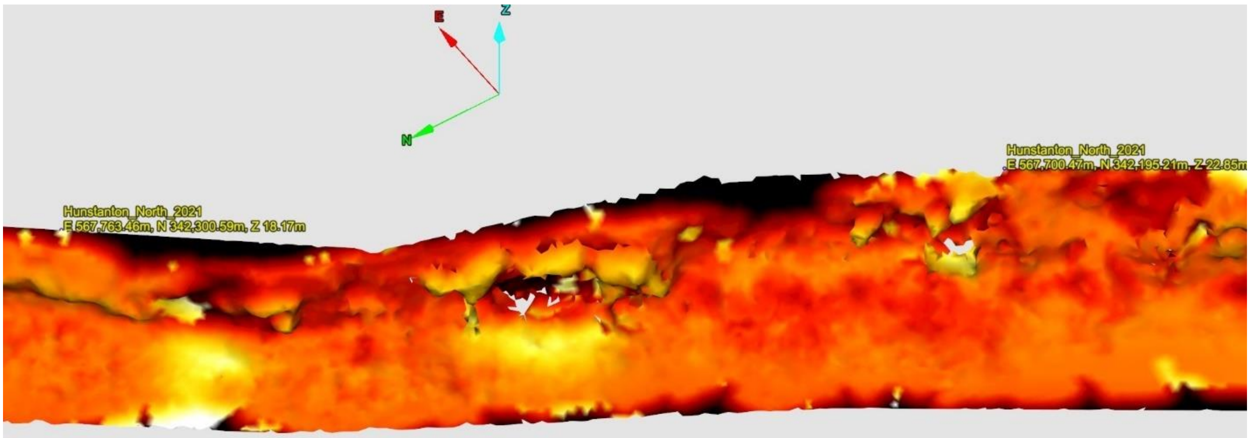


Figure 16 – 2010 to 2021 change model of 342195 m North to 342301 m North (for legend see Figure 18. Height range = 6.3 m to 15.7 m)

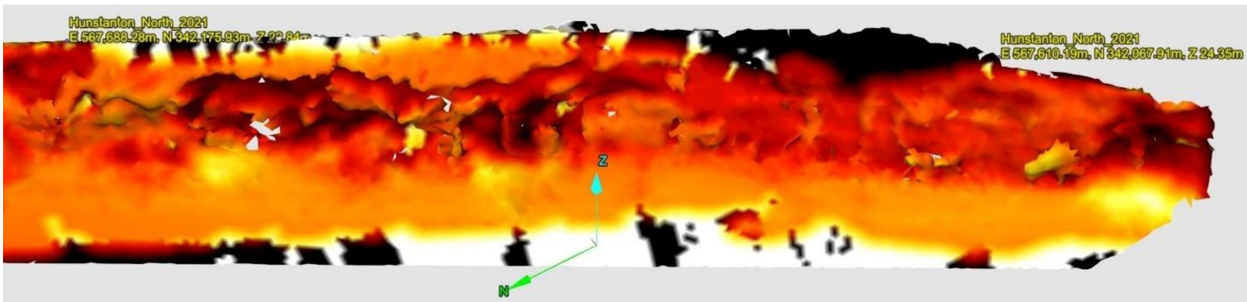


Figure 17 – 2010 to 2021 change model of 342068 m North to 342176 m North (for legend see Figure 18. Height range = 6.3 m to 15.7 m)

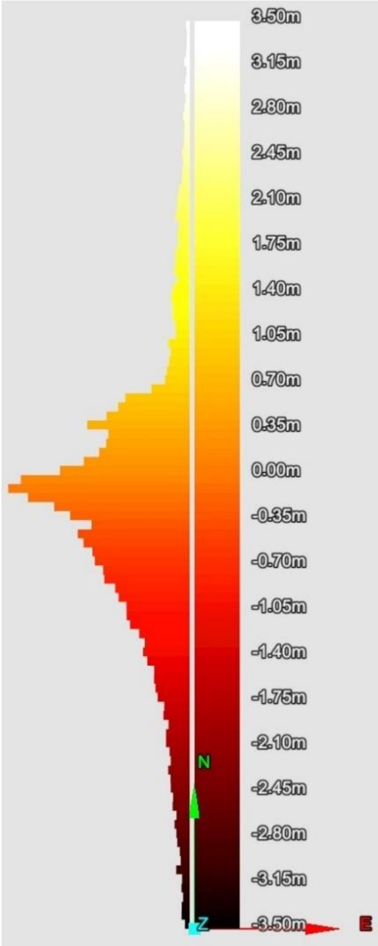


Figure 18 – North section legend (-3.5 m to 3.5 m) for 2010 to 2021 change model

6.1.1 2021 Change Model (North)

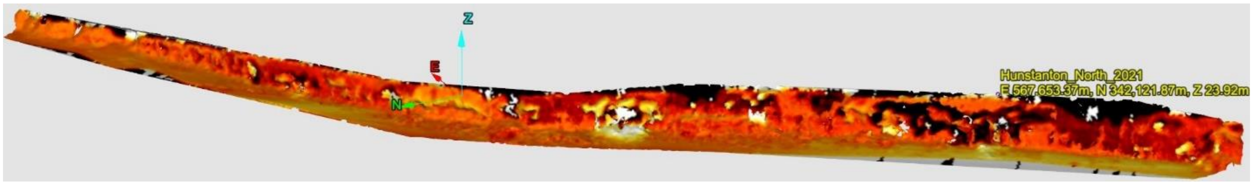


Figure 19 – 2019 to 2021 change model of entire north section (for legend see Figure 20. Height range = 6.3 m to 15.7 m)

Figure 19 shows the change between the 2019 and 2021 surveys, for the entire North section. It shows that the major change occurs between 342300 m North and 342048 m North, with the greatest loss (~2 m) occurring at 342090 m North, 342150 m North, and 342222 m North. It also shows that the largest areas of accretion (~2 m) occur on the foreshore at 342250 m North and in the cliff face at 342200 m North, which could be due to a large fallen block. The legend for Figure 19 can be seen in Figure 20, which shows a histogram of the +/- 2 m loss/gain distribution.

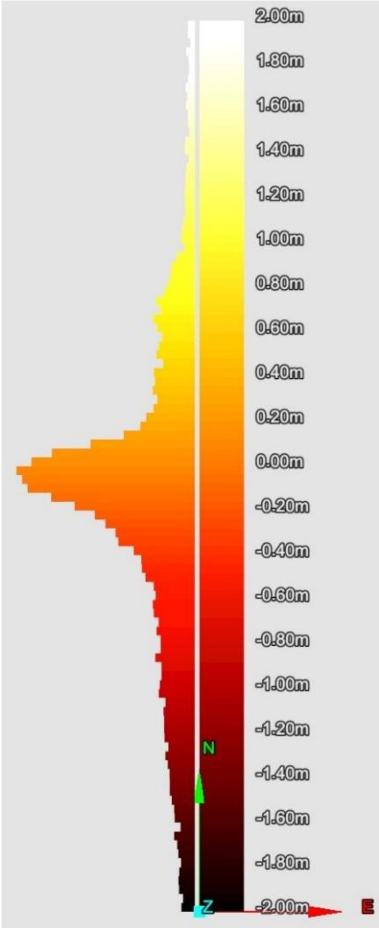


Figure 20 – North section legend (-2 m to 2 m) for 2019 to 2021 change model

6.2 MIDDLE SECTION

Figures 21 & 22 show the Middle section, where at 341956 m North (Figure 23) there is a significant amount (~4 m) of accretion on the foreshore. This has come from the adjacent cliff face, which shows a loss of ~4.5 m. However, further areas of loss (~2.5 m) can be seen south of this point. Farther south, from 341910 m North to 341768 m North (Figure 24), large areas of erosion in the cliff face of up to 3.5 m can be seen. However, it should be noted that this is without the accompanying accretion levels on the foreshore, with much smaller (~2 m) values being seen. From 341605 m North to 341744 m North (Figure 25) there are large areas of the cliff face with losses of up to 4.5 m. Again, this area shows much smaller (~3 m) amounts of accretion in the foreshore. Interestingly, in this area the foreshore shows an amount of erosion of up to 2 m that is not seen further north. The legend for these figures can be seen in Figure 26.

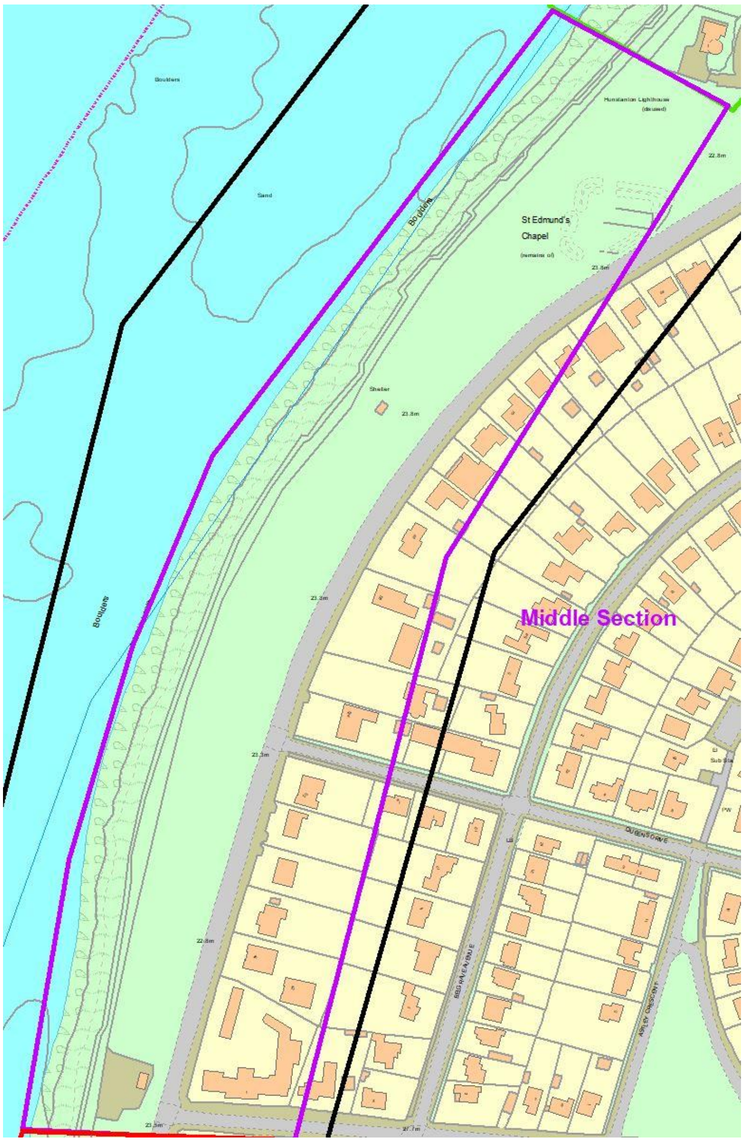


Figure 21 – Plan view of Middle section

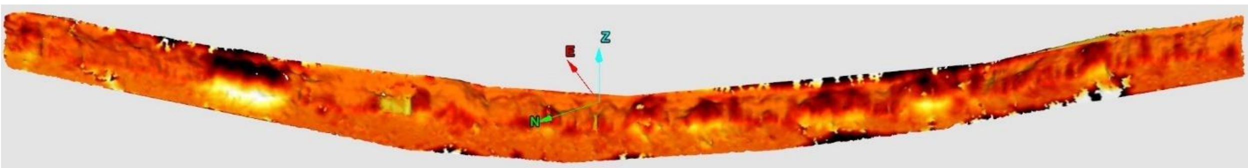


Figure 22 – 3D view of entire Middle section

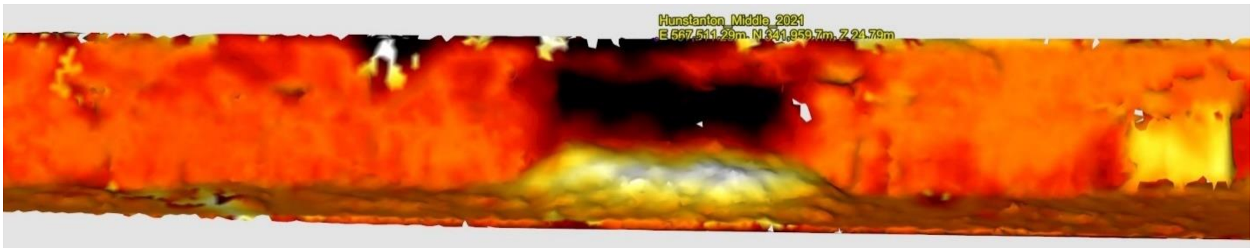


Figure 23 – 2010 to 2021 change model of the area around 341956 m North (for legend see Figure 26. Height range = 16.5 m to 18.8 m)

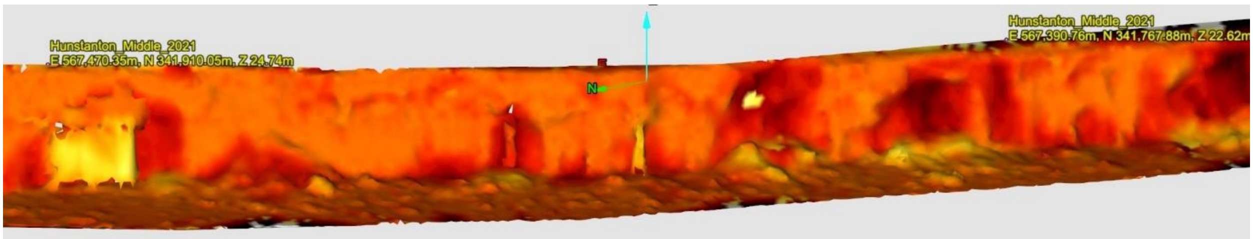


Figure 24 – 2010 to 2021 change model of 341768 m North to 341910 m North (for legend see Figure 26. Height range = 16.5 m to 18.8 m)

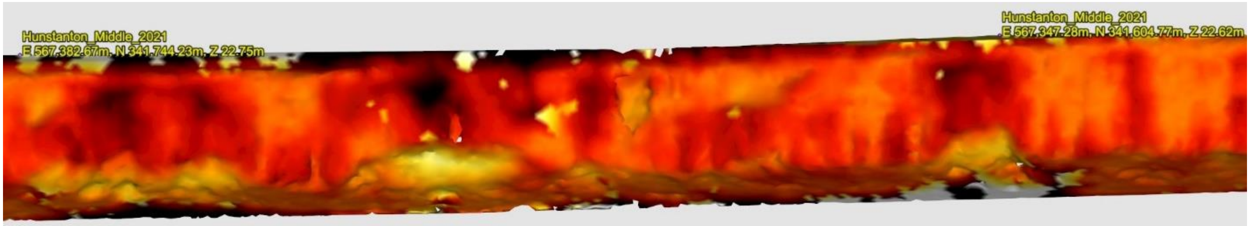


Figure 25 – 2010 to 2021 change model of 341605 m North to 341744 m North (for legend see Figure 26. Height range = 16.5 m to 18.8 m)

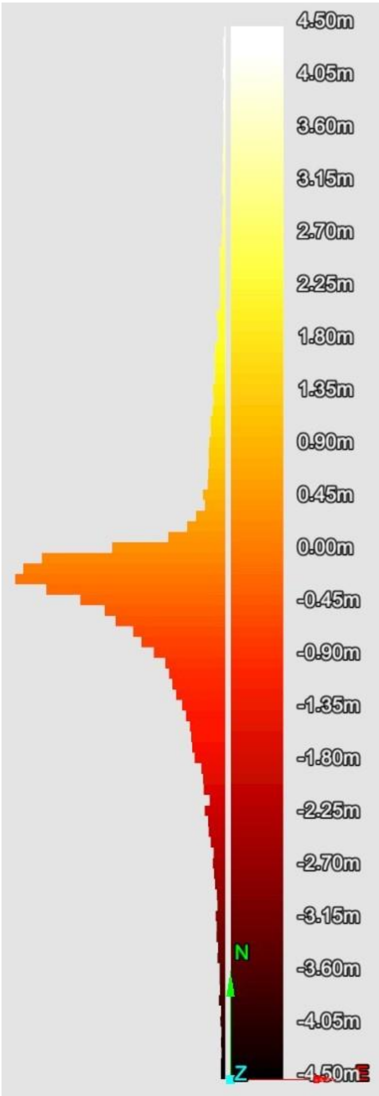


Figure 26 – Middle section legend (-4.5 m to 4.5 m) for 2010 to 2021 change model

6.2.1 2021 Change Model (Middle)

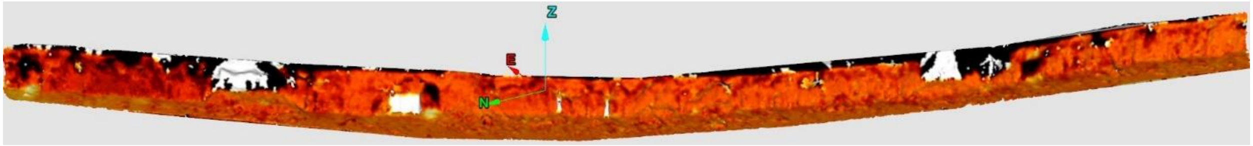


Figure 27 – 2019 to 2021 change model of entire middle section (for legend see Figure 28. Height range = 16.5 m to 18.8 m)

Figure 27 shows the change between the 2019 and 2021 surveys, for the entire Middle section. It shows minor change across the full section from 341550 m North to 342050 m North, with significant areas of loss (~1.5 m) occurring at 342037 m North and 341647 m North. It also shows an area of accretion in the cliff face at 341908 m North of ~1.5 m, which could be due to a large fallen block. The legend for Figure 27 can be seen in Figure 28, which shows a histogram of the +/- 1.5 m loss/gain distribution.

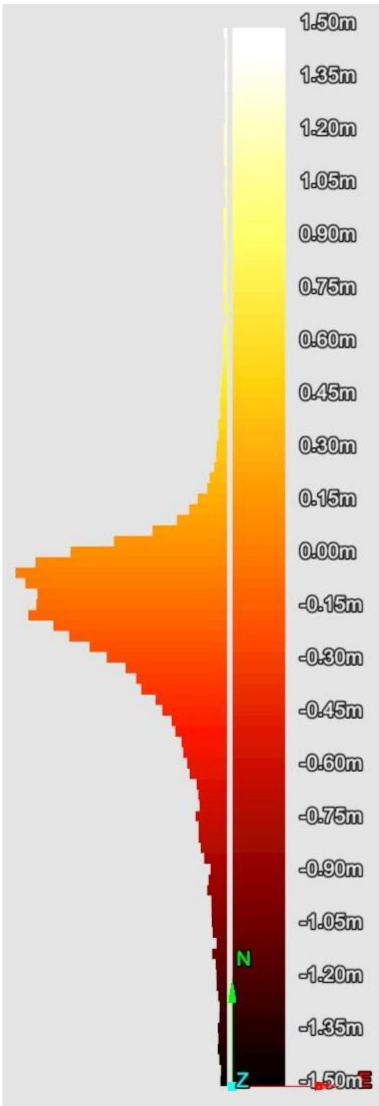


Figure 28 - Middle section legend (-1.5 m to 1.5 m) for 2019 to 2021 change model

6.3 SOUTH SECTION

The south section (Figures 29 & 30) is the shortest section of the survey area, covering a length of the cliffs of approximately 185 m. Within this section the cliff face from 341428 m North to 341474 m North (Figure 31) shows a significant amount of erosion of up to 4 m, again with lesser levels of accretion on the foreshore of approximately 2.5 m. As could be seen in the southernmost part of the middle section this section shows erosion levels reached 1.5 m in the foreshore. This suggests that this section (and the southernmost part of the middle section) are the most active in terms of both erosion from the cliff face but also in the foreshore, probably due to the actions of the sea. Of course, this action can be affected by tidal surges etc. which may cause drastic changes at certain times of the year. The legend for this figure can be seen in Figure 32.

Figure 29 – Plan view of South section

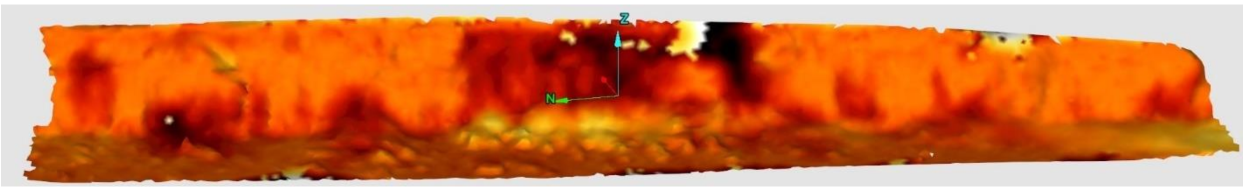


Figure 30 – 3D view of entire South section

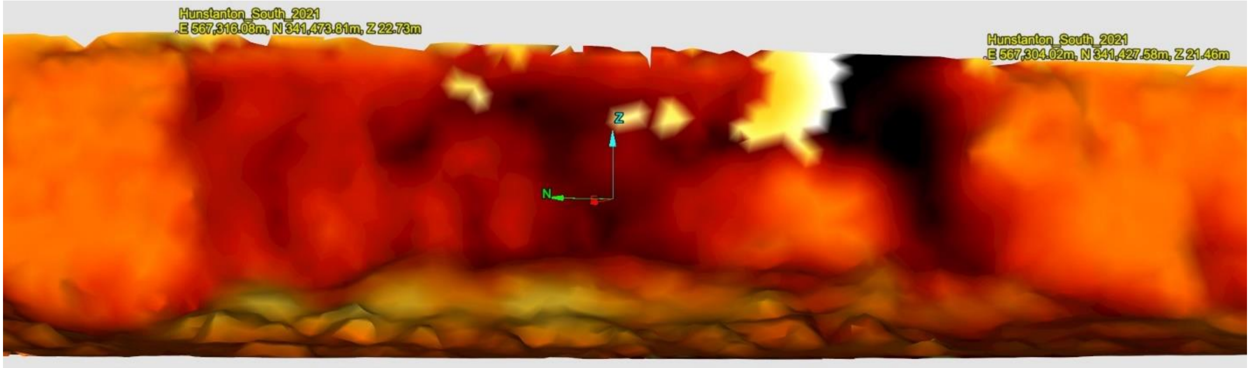


Figure 31 – 2010 to 2021 change model of 341428 m North to 341474 m North (for legend see Figure 22. Height range = 14.0 m to 17.0 m)

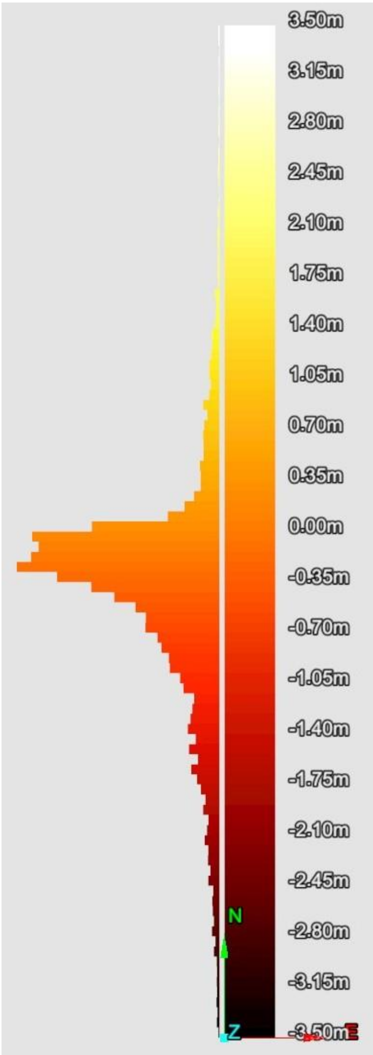


Figure 32 – South section legend (-3.5 m to 3.5 m) for 2010 to 2021 change model

6.3.1 2021 Change Model (South)

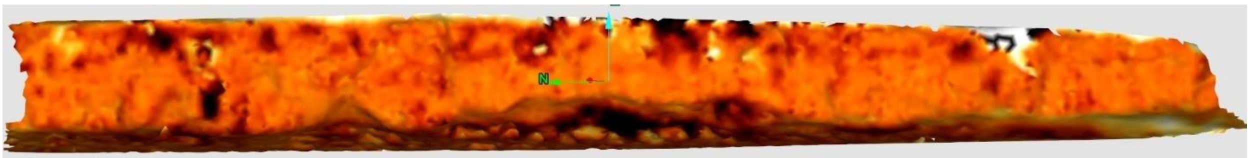


Figure 33 – 2019 to 2021 change model of entire south section (for legend see Figure 34. Height range = 14.0 m to 17.0 m)

Figure 33 shows the change between the 2019 and 2021 surveys, for the entire South section. It shows that there are areas of significant change (~1 m) at 341437 m North, 341449 m North and 341515 m North. It also shows that there is an area of accretion on the foreshore (~1 m) at 341370 m North. The legend for Figure 33 can be seen in Figure 34, which shows a histogram of the +/- 1 m loss/gain distribution.

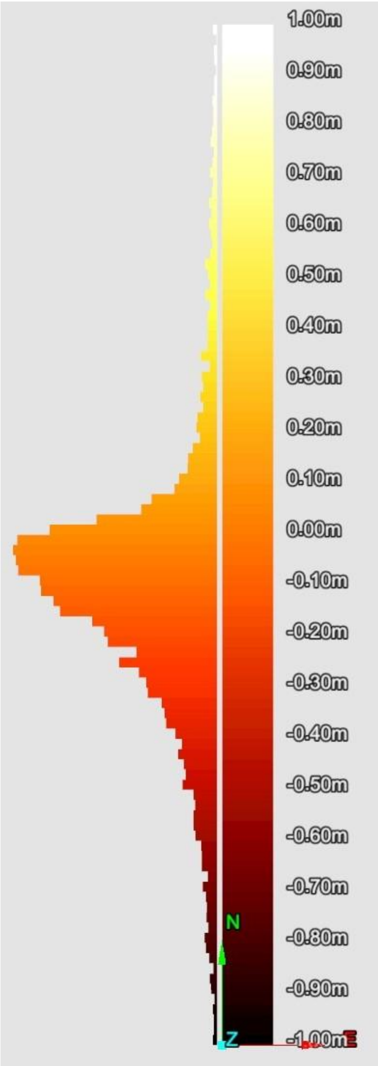


Figure 34 – South section legend (-1 m to 1 m) for 2019 to 2021 change model

7 Estimation of Erosion

In the Interim Baseline Report, compiled as part of the **H**unstanton **C**oastal **M**anagement **P**lan (**HCMP**), four properties were identified as being at risk of erosion, in the next 100 years. These properties are located in Figure 35 and consist of three shelters and the Lighthouse. Four additional properties were added for this (2020-2021) annual survey, along with three positions of the B1161 (Cliff Parade Road) where it intersects with the junctions of King's Road, Clarence Road and Lincoln Square South. The properties are shown in Figure 36 and consist of the Lighthouse Café, the Coastguard Cottages, the Coastguard Lookout and the ruins of St. Edmund's Chapel. Their approximate position and distance to the nearest cliff edge are shown in Figures 37 & 38. By combining these with the recession rates given in Table 3, it is possible to generate an Erosion Risk Rating (Table 4).

Figure 7-5: Map showing properties in Unit A at risk of erosion in the next 100 years

Figure 35 – Plan of area with initial 'at risk' properties shown

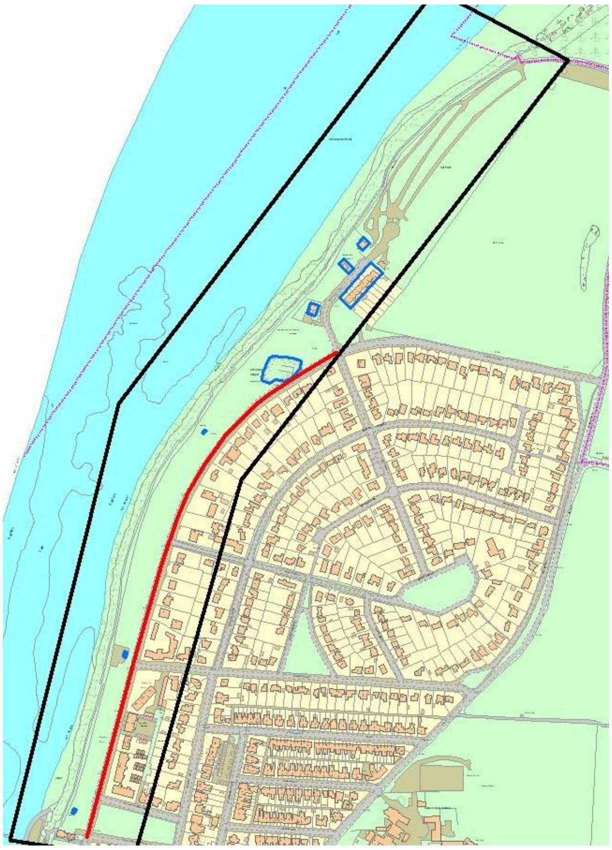


Figure 36 – Plan of section under investigation, showing initial and added 'at risk' properties and road section

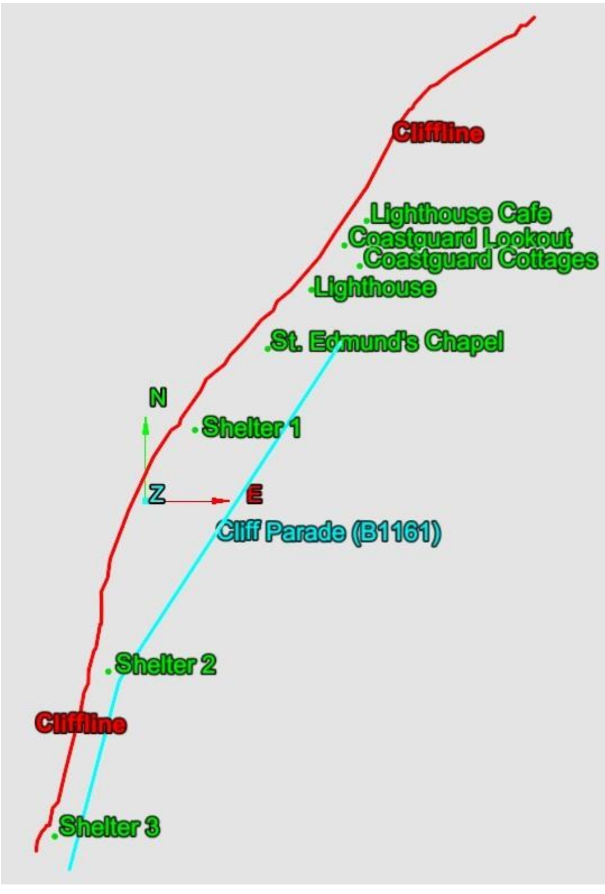


Figure 37 – Position of 'at risk' properties relevant to cliff edge

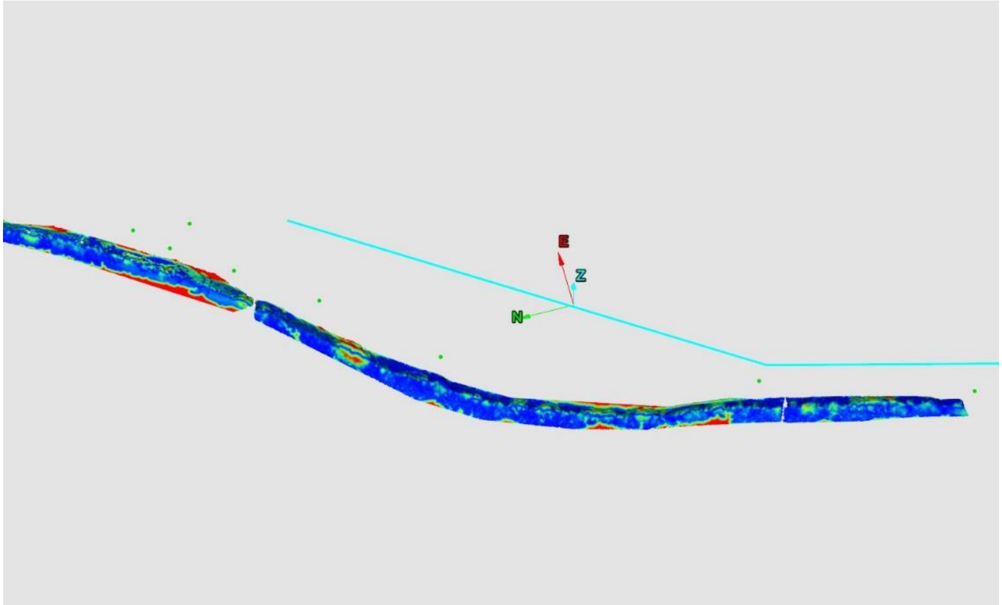


Figure 38 – Position of 'at risk' properties relevant to change analysis

Table 4 – Property Erosion Risk Rating

Property Name	Approx. Easting (m)	Approx. Northing (m)	Closest cliff edge (m)	Horizontal Change (m)	Loss at Property (m)	Risk Rating
Lighthouse	567625	342058	21	2	3.5	*3.3*
Shelter 1	567473	341875	22	2	1	*0.9*
Shelter 2	567360	341560	26	2	1.5	*1.2*
Shelter 3	567290	341345	16	3	2	*3.8*
St. Edmund's Chapel	567568	341981	31	2	2.5	*1.6*
Coastguard Lookout	567668	342116	20	2	2	*2.0*
Coastguard Cottages	567688	342089	51	2	2	*0.8*
Lighthouse Café	567697	342148	25	2	2.5	*2.0*
Cliff Parade (King's Road)	567663	341989	97	2	2.5	*0.5*
Cliff Parade (Clarence Road)	567374	341548	40	2	1.5	*0.8*
Cliff Parade (Lincoln Square South)	567309	341302	49	3	2	*1.2*

In order to calculate the Erosion Risk Rating, the following equation was applied to each 'at risk' property as follows:

$$\boldsymbol{R} = \frac{(\boldsymbol{M}\ \boldsymbol{x}\ \boldsymbol{L})\boldsymbol{x}\ \mathbf{10}}{\boldsymbol{C}}$$

Where: R = Erosion Risk Rating

M = Horizontal Change (m)

L = Loss at Property (m)

C = Closest cliff edge (m)

The properties most at risk (Table 4) are Shelter 3, with an R value of 3.8 and the Lighthouse, with an R of 3.3. Over the monitoring period, the Lighthouse has increased in R from 2.9, whilst Shelter 3 has remained the same. Shelter 1 has increased in R from 0.5 to 0.9 and Shelter 2 from 0.4 to 1.2 – these changes are due to the increase in the Horizontal Change value, up from 1 m to 2 m in both cases, and the increase in the Loss at Property value for Shelter 2.

Additionally, both the Coastguard Lookout and the Lighthouse Café have an R of 2.0. These properties are closest to the cliff edge and are showing both horizontal movement at the cliff edge, and an increased amount of erosion directly below the properties. Following these, the property with the highest risk rating is St. Edmund's Chapel, with an R of 1.6.

8 Standards & Methodologies

All BGS ground-based geomatics surveys follow the methodology set out in Jones (2017) and the specification in Jones (2019). The latter is split into three specific protocols:

- Specification for Collection of TLS Data – this includes pre-survey scanner choice and preparation of equipment; health and safety; use of survey equipment in the field; undertaking the survey; naming convention.
- Specification for Registering of TLS Data – this includes geo-referencing scans to OSGB36, or other national, grid co-ordinates; aligning and combining point clouds; cleaning and validating point clouds; exporting scans.
- Specification for Delivery and Archiving of TLS Data – this includes project deliverables; location of both raw and registered point clouds; file naming; metadata.

9 Technical Summary

This report was produced by the British Geological Survey, for the Borough Council of King's Lynn & West Norfolk. The purpose of this report is to act as an annual record of cliff surveys at Hunstanton, Norfolk, using two LiDAR scans provided to the client by the Anglian Coastal Monitoring Programme, covering the years 2020 and 2021, and consists of the following:

- A review of the data provided and the extents of the two surveys
- Volume calculations (Table 3) of loss, including a series of cross-sections and graphs to illustrate these changes
- An analysis of the change in the cliff, portrayed as 3D Change models of the full section, split into three parts; North, Middle, South
- An estimation of the degree of erosion by determining an Erosion Risk Rating (Table 4)
- Appendices containing a suite of Surface and Change models

In summary, the report found the following:

- The data from the 2020 and 2021 LiDAR scans cover the same section of cliff as those covered by the previous 2010, 2017 and 2019 LiDAR scans. They have been analysed using the same three (smaller) sections of cliff.
- The Volume Calculation data (Table 3) show a total loss of 21900 m^3 across the full 1.275 km section, which is 2059 m^3/year or 4736 tonnes/year (estimated). This is an increase across the entire section of 644 m^3/year or 1481 tonnes/year (estimated). The Middle section remains the most active, with an average loss of 1011 m^3/year (up from 786 m^3), followed by the North section, with an average loss of 729 m^3/year (up from 355 m^3) and finally the South section, with a loss of 320 m^3/year (up from 274 m^3). However, the North section has shown the greatest acceleration of loss across the period 2019 to 2021 of 51%, followed by the Middle section (22%) and the South section (14%).
- These calculations can be deceptive because the Middle section is the largest section and so will lose more material across its greater area. In fact, the South section shows the greatest horizontal movement of the cliff line of 3 m, followed by the North section at 2 m and the Middle section, which has increased from 1 m to 2 m.
- Each section of the cliff was analysed separately:
    - North – The greatest amount of loss (~3.5 m) occurs between BNG 342195 m to 342301 m North (Figure 16). Further large-scale changes in this section (~3.5 m) can be seen between BNG 342068 m to 342176 m North (Figure 17). The largest change between 2019 and 2021 (~2 m) can be seen at BNG 342090 m North, 342150 m North and 342222 m North (Figure 19).
    - Middle – At BNG 341956 m North (Figure 23) there is a significant amount of accretion (~4 m) on the foreshore and loss (~4.5 m) from the cliff face. Between BNG 341605 m and 341744 m North (Figure 25) large areas of erosion (~4.5 m) can be seen. The largest change between 2019 and 2021 (~1.5 m) can be seen between BNG 341550 m and 342050 m North (Figure 27).
    - South – The greatest amount of loss (~4 m) can be seen between BNG 341428 m to 341474 m North (Figure 31). The largest change between 2019 and 2021 (~1 m) can be seen at BNG 341437 m, 341449 m and 341515 m North.
- By combining the results obtained from the Volume Calculations (Section 4) and from the Change Analysis (Section 6) we are able to generate an Erosion Risk Rating for the 'at risk' properties (Table 4). This rating shows that the properties most at risk are Shelter 3 (R = 3.8), Lighthouse (R = 3.3), and Lighthouse café and Coastguard Lookout (R = 2).

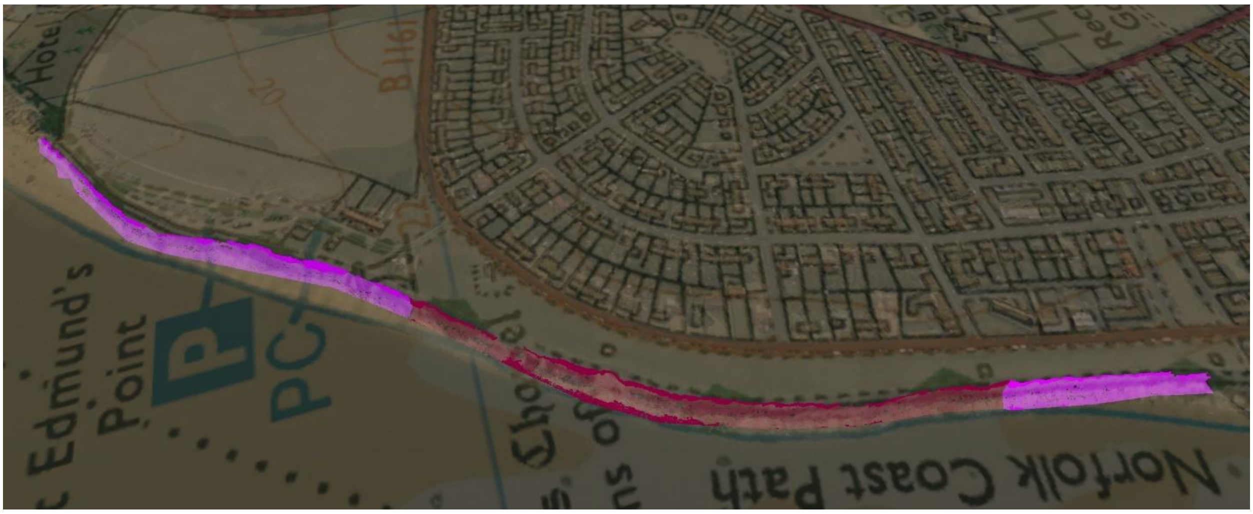
10 Conclusions

The following conclusions can be made from the analysis of the 2020 and 2021 LiDAR data:

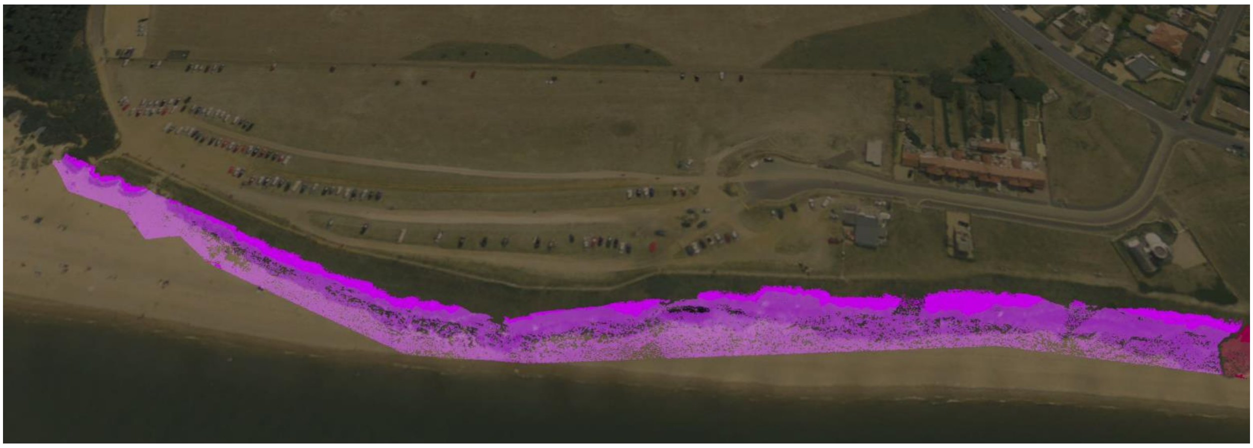
- No accelerated erosion has been observed over the 2019-2020 or 2020-2021 survey periods
- The cliff erosion rates remain in-line with the previous reports
- The current cliff erosion follows the predictions noted in the Hunstanton Coastal Management Plan (HCMP), Interim Baseline Report (HCMP, 2018)
- The annual monitoring and cliff regression analysis and reporting should continue until at least 2024
- The most active area of cliff erosion remains in the southern section of the cliffs, opposite Lincoln Square North and Clarence Road
- No changes are currently required to the active HCMP

Appendix 1   Surface Models

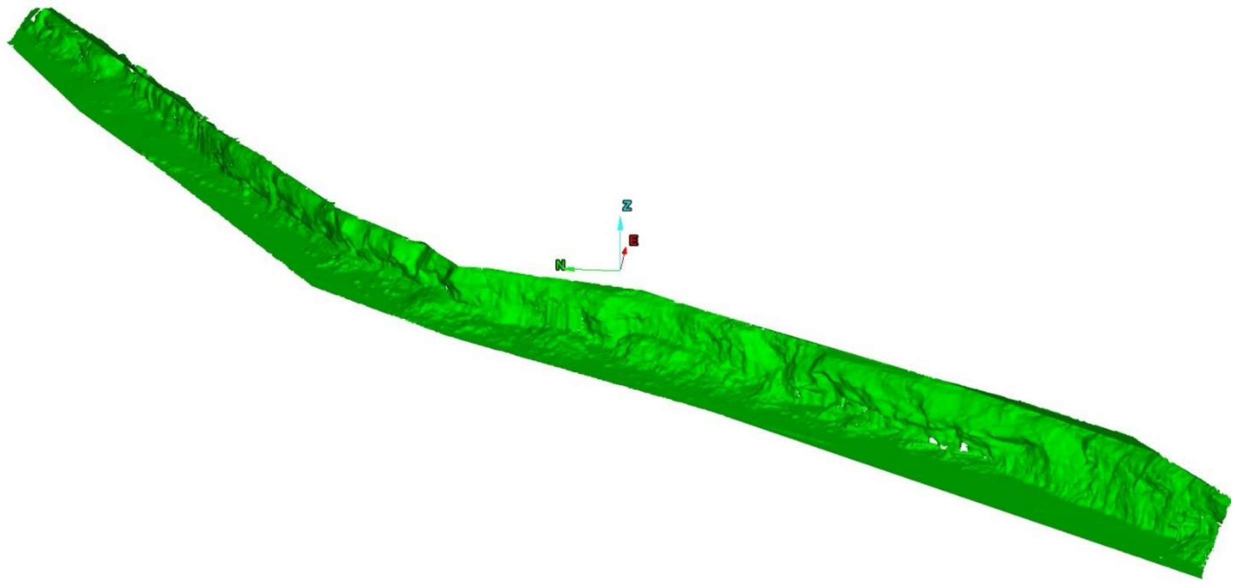
Plan view of all sections



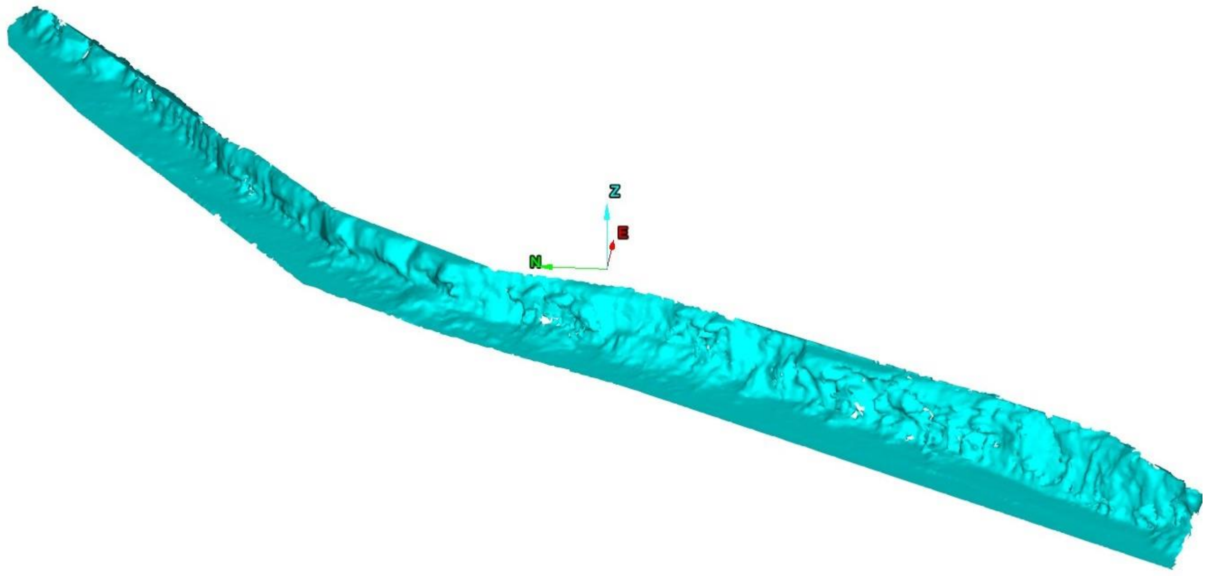
Aerial view of North section (Extent: E 567954 m, N 342450 m to E 567934 m, N 342430 m)



North Section – 2020 (Extents: E 567964 m, N 342439 m to E 567266 m, N 341320 m. Height range = 6.3 m to 15.7 m)

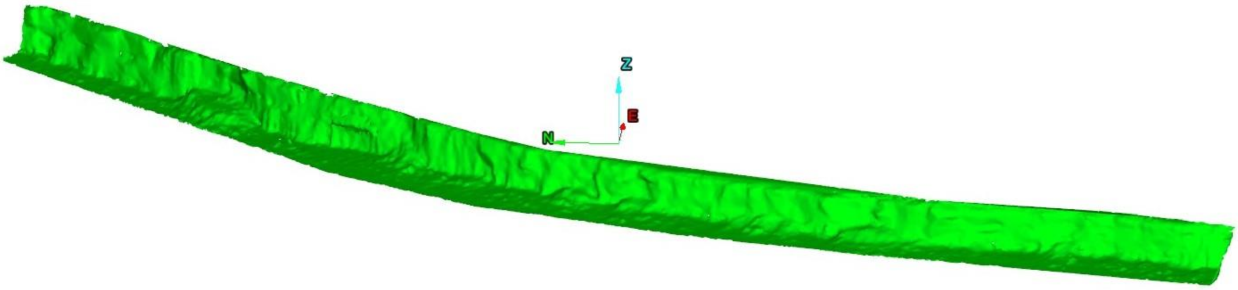


North Section – 2021 (Extents: E 567976 m, N 34247474 m to E 567238 m, N 341307 m. Height range = 6.3 m to 15.7 m)

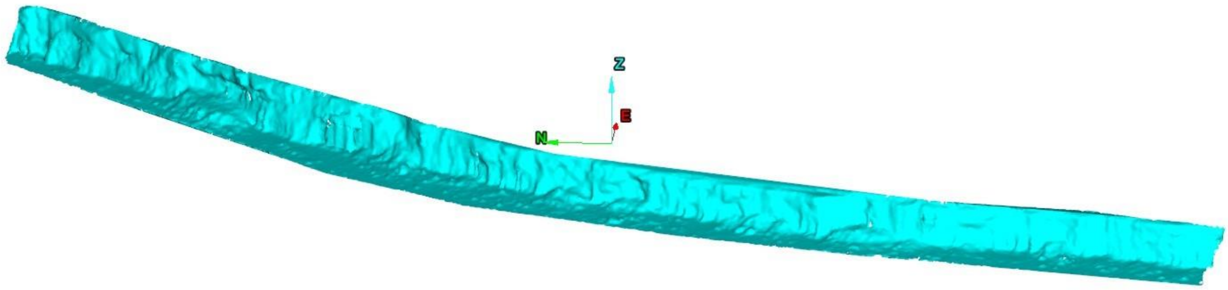


Aerial view of Middle section (Extent: E 567314 m, N 341539 m to E 567584 m, N 342052 m)

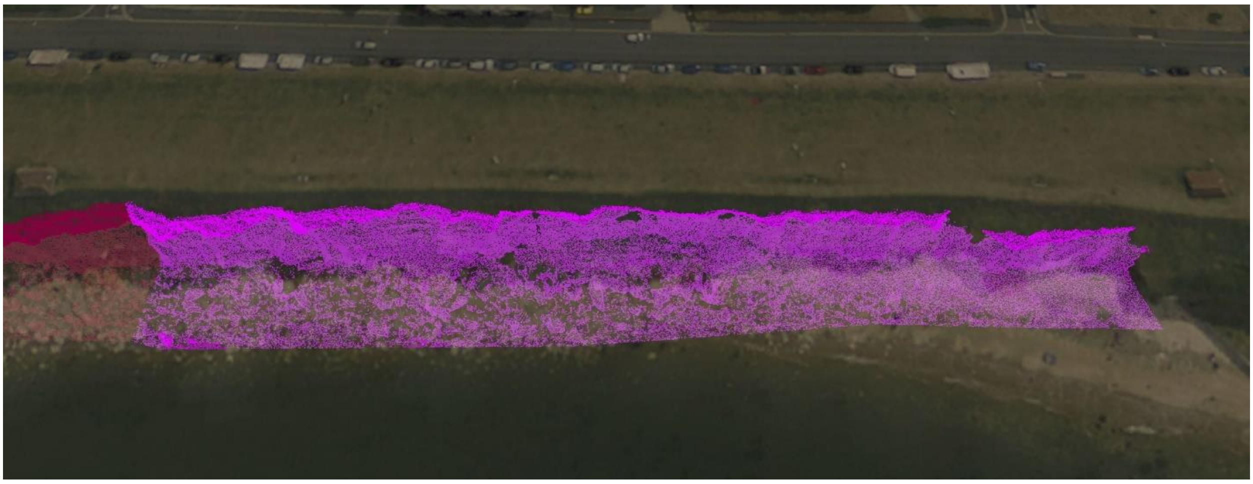
Middle Section – 2020 (Extents: E 567964 m, N 342439 m to E 567266 m, N 341320 m. Height range = 16.5 m to 18.8 m)



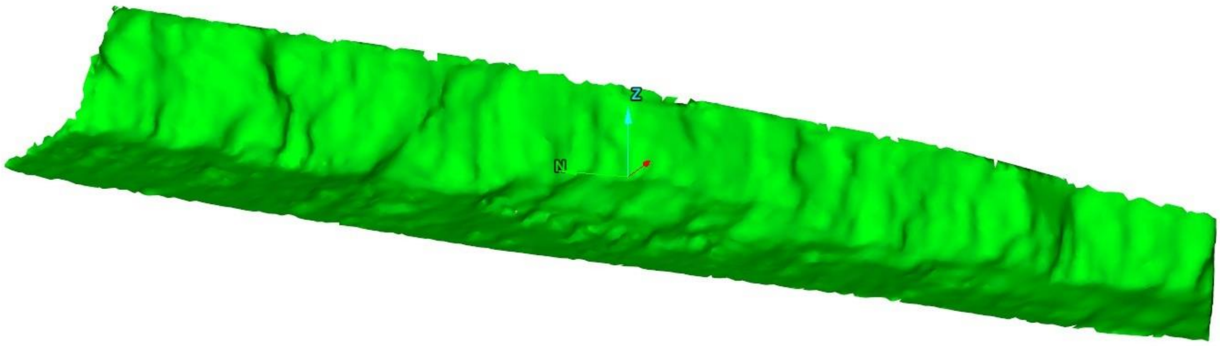
Middle Section – 2021 (Extents: E 567976 m, N 34247474 m to E 567238 m, N 341307 m. Height range = 16.5 m to 18.8 m)



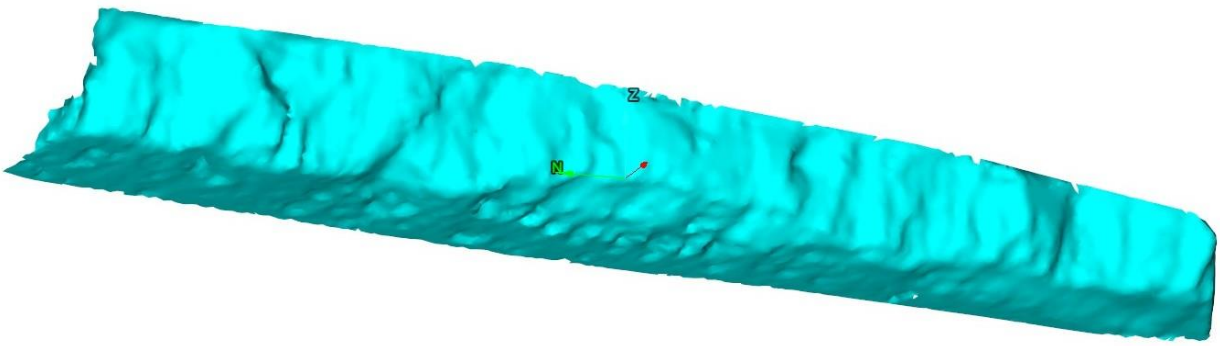
Aerial view of South section (Extent: E 567267 m, N 341356 m to E 567268 m, N 341332 m)



South Section – 2020 (Extents: E 567964 m, N 342439 m to E 567266 m, N 341320 m. Height range = 14.0 m to 17.0 m)



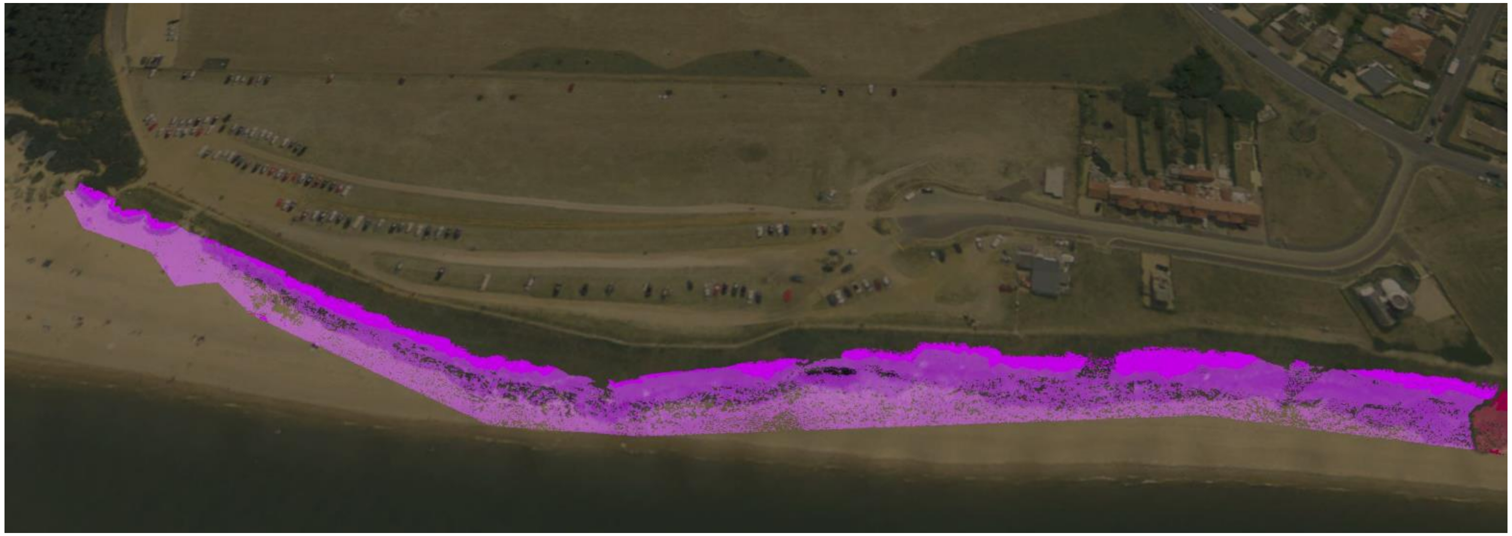
South Section – 2021 (Extents: E 567976 m, N 34247474 m to E 567238 m, N 341307 m. Height range = 14.0 m to 17.0 m)

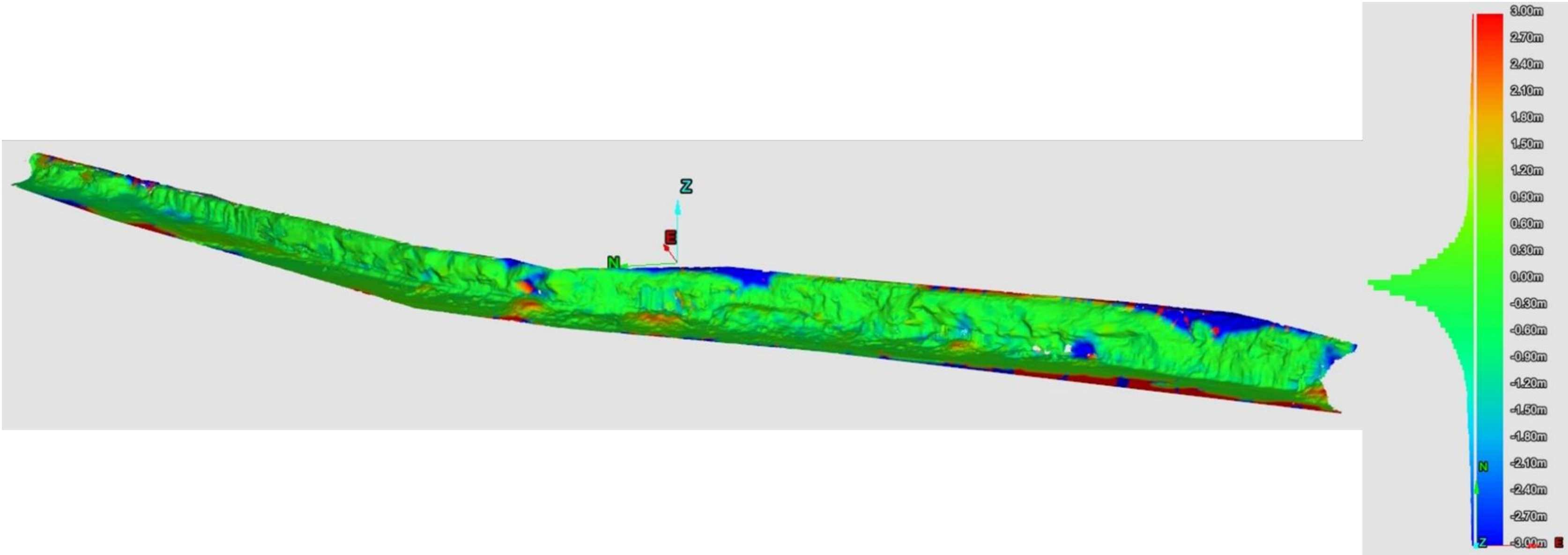


Appendix 2 Change Models

Aerial view of entire section

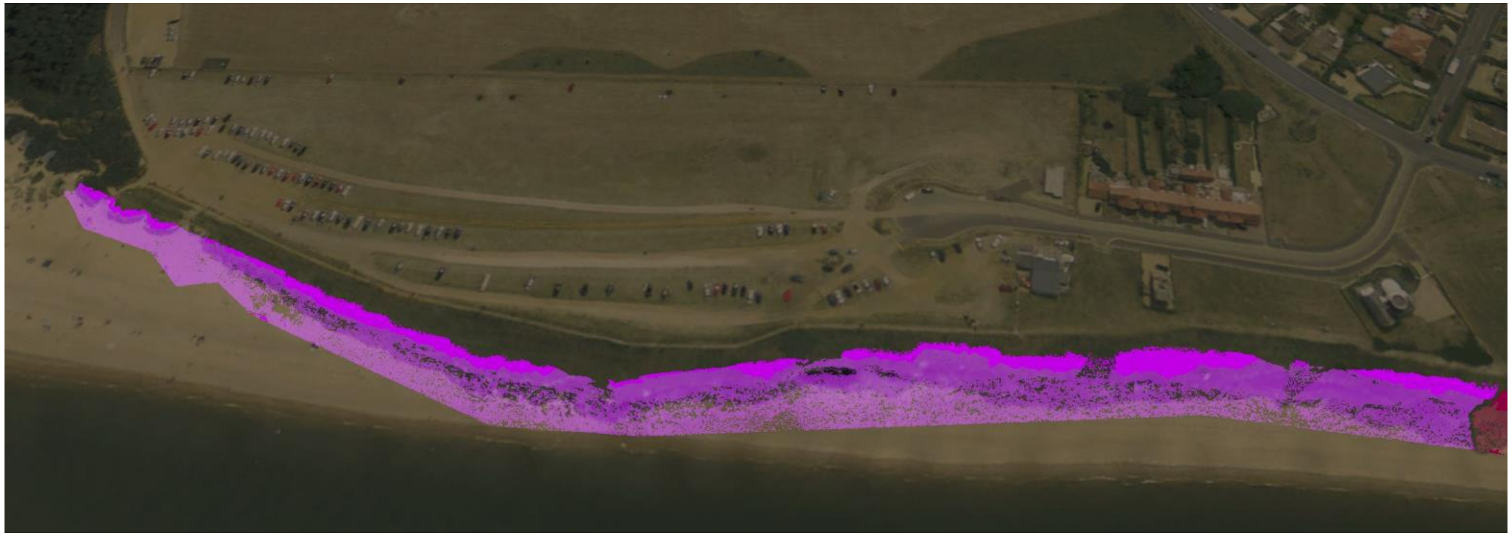
North Section – 2010 to 2020 (Extents: E 567930 m, N 342409 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)

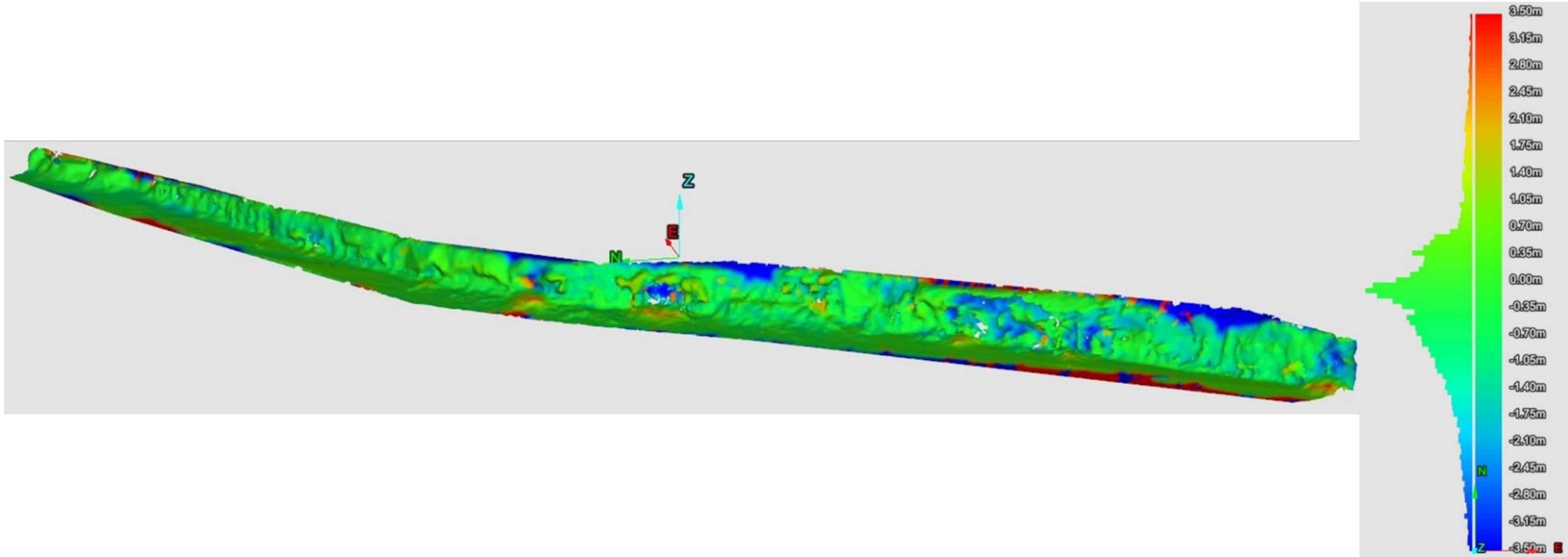




Note: Change = -3 m (Blue) to +3 m (Red)

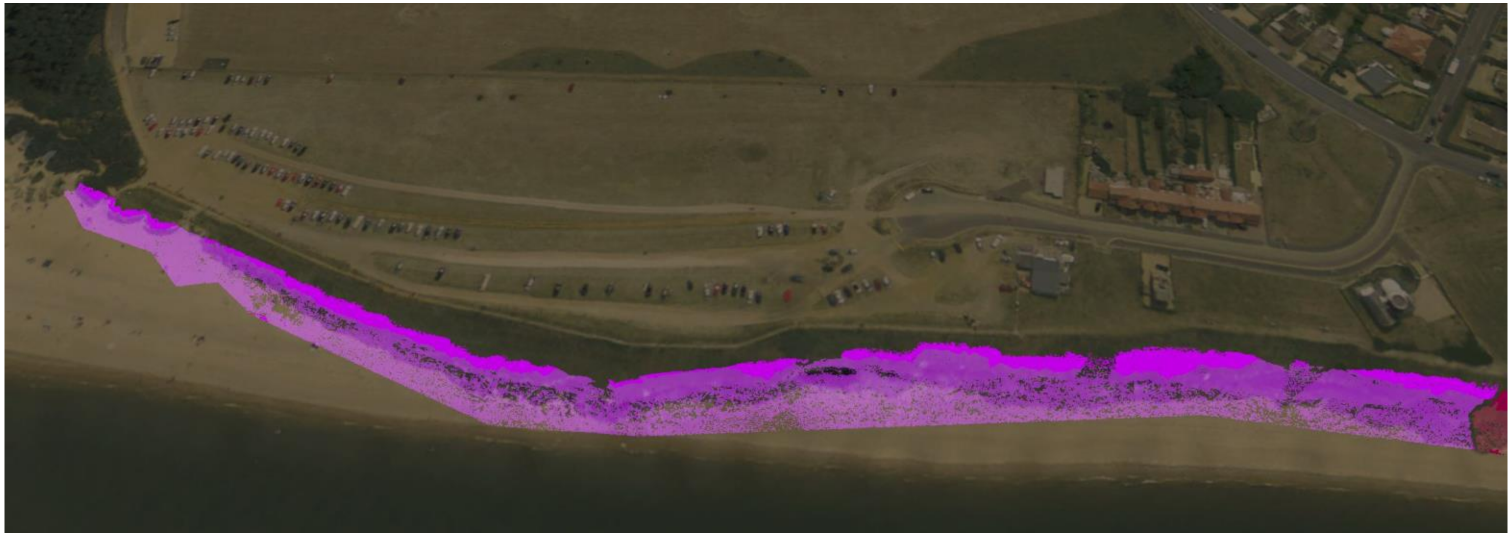
North Section – 2010 to 2021 (Extents: E 567930 m, N 342419 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)

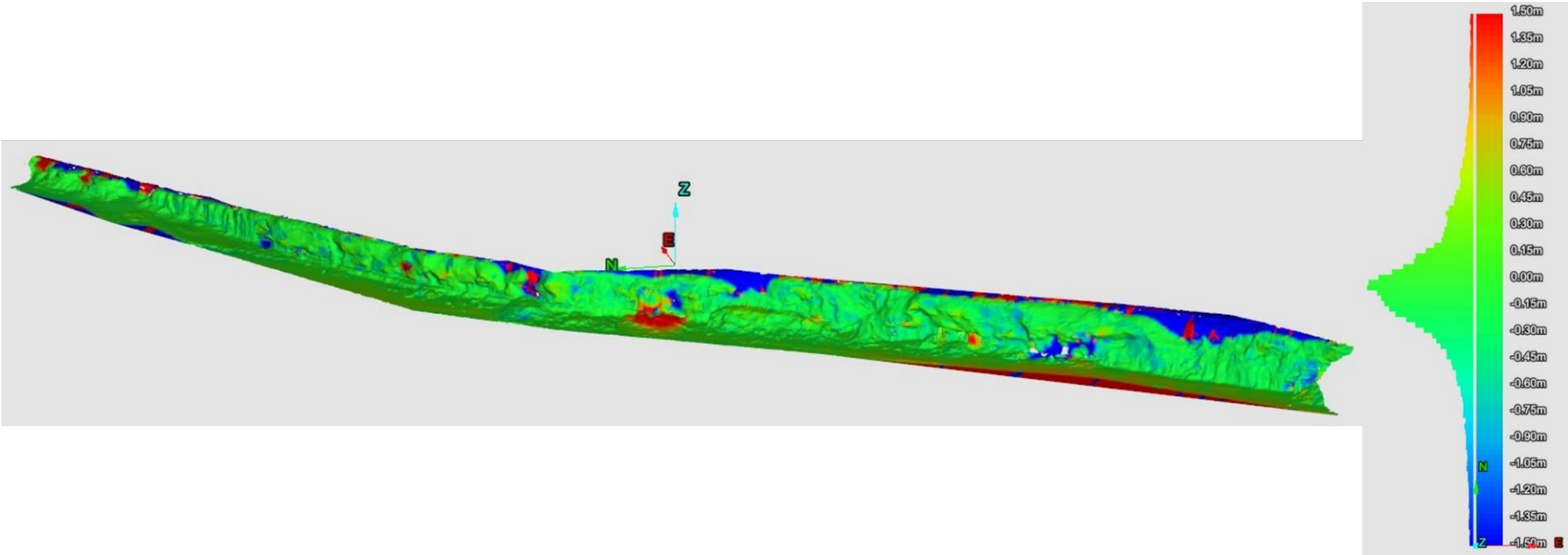




Note: Change = -3.5 m (Blue) to +3.5 m (Red)

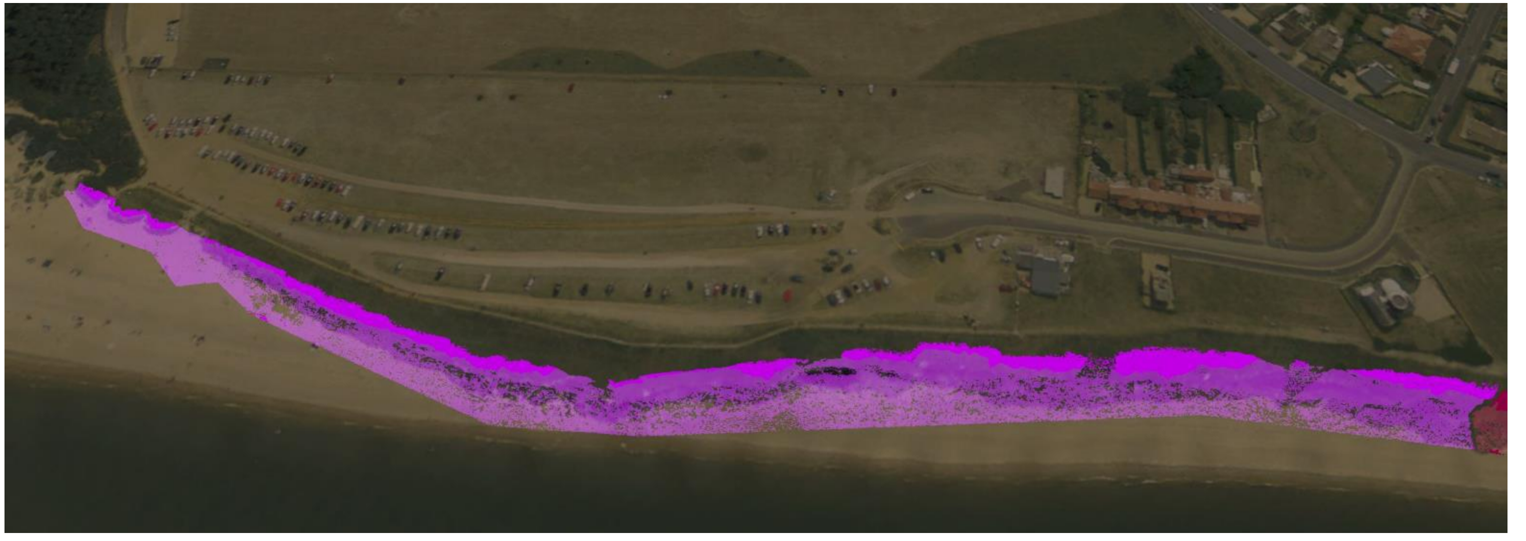
North Section – 2019 to 2020 (Extents: E 567930 m, N 342409 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)

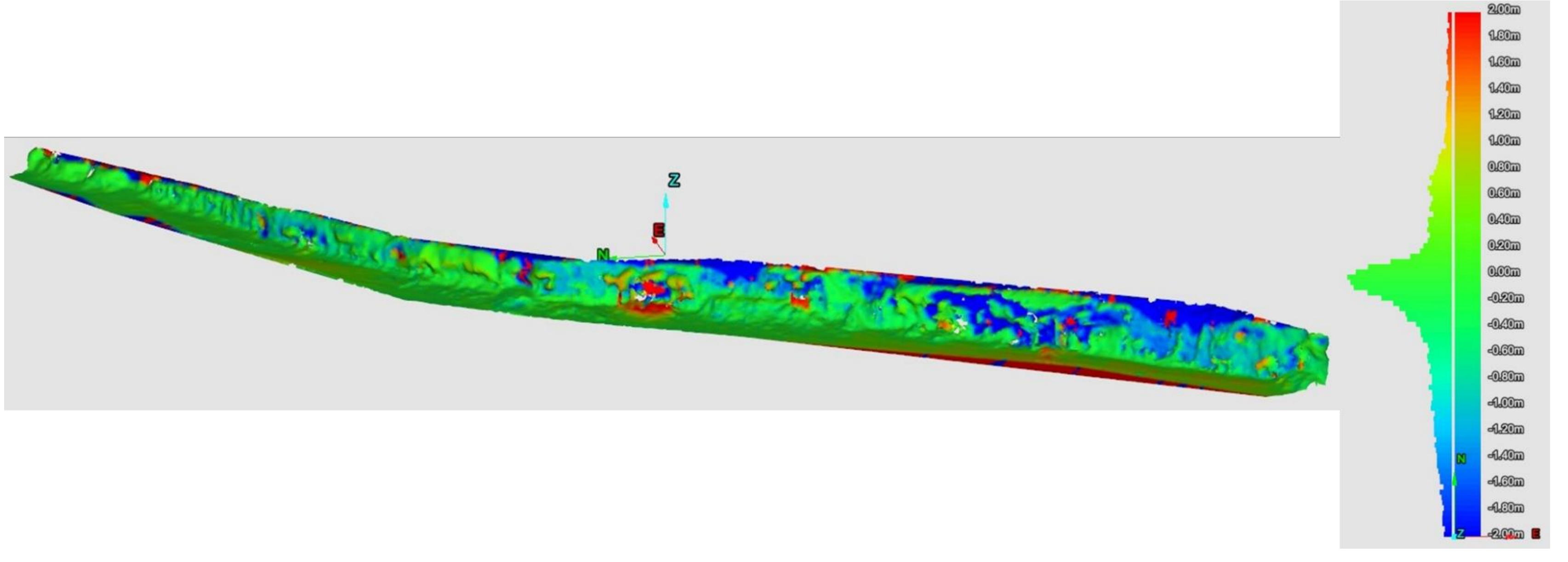




Note: Change = -1.5 m (Blue) to +1.5 m (Red)

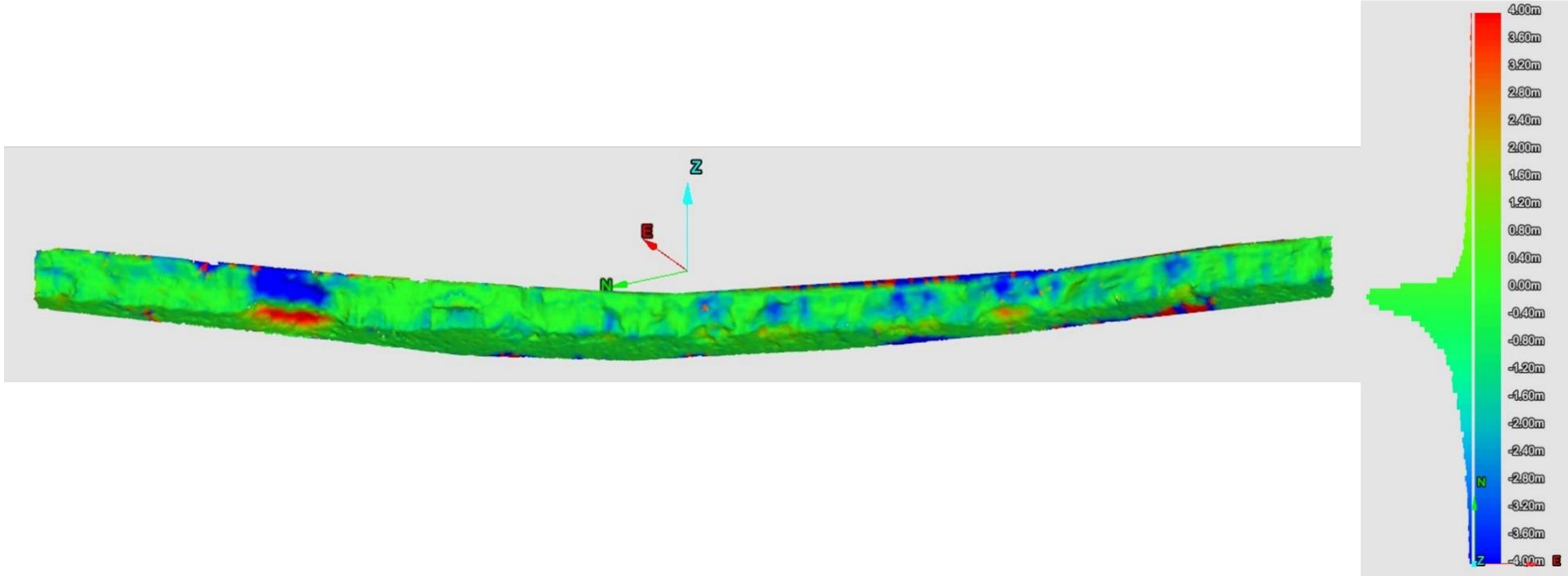
North Section – 2020 to 2021 (Extents: E 567930 m, N 342409 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)





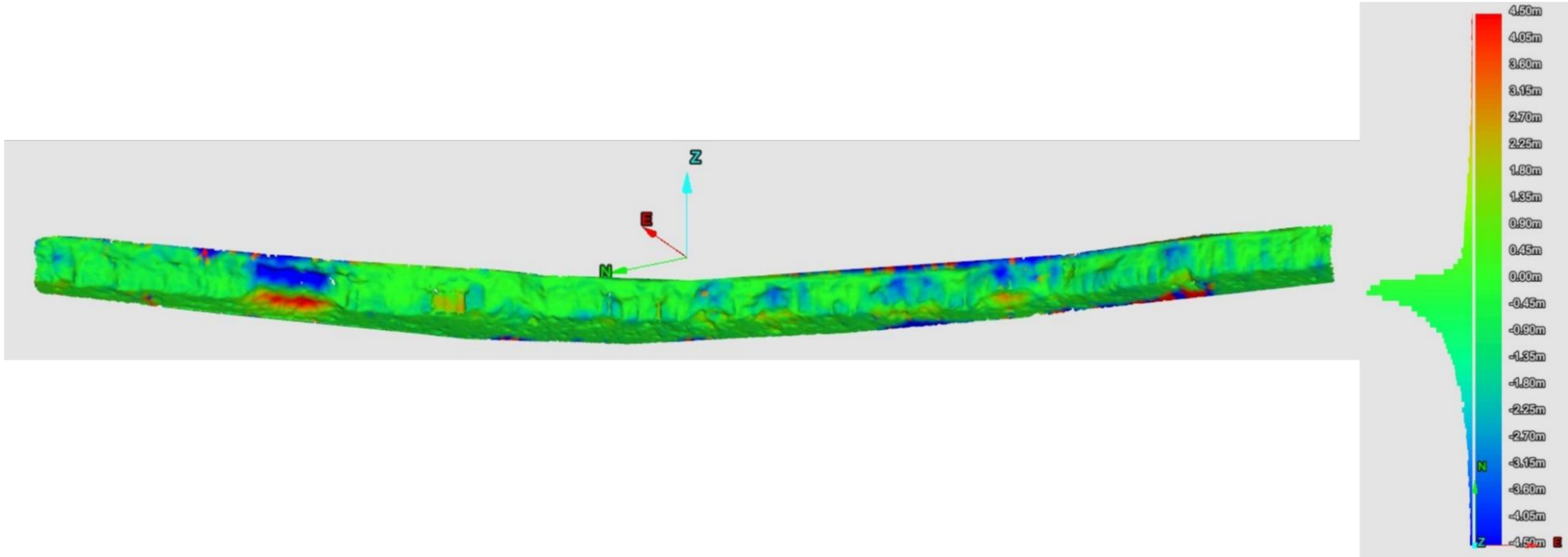
Note: Change = -2 m (Blue) to +2 m (Red)

Middle Section – 2010 to 2020 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



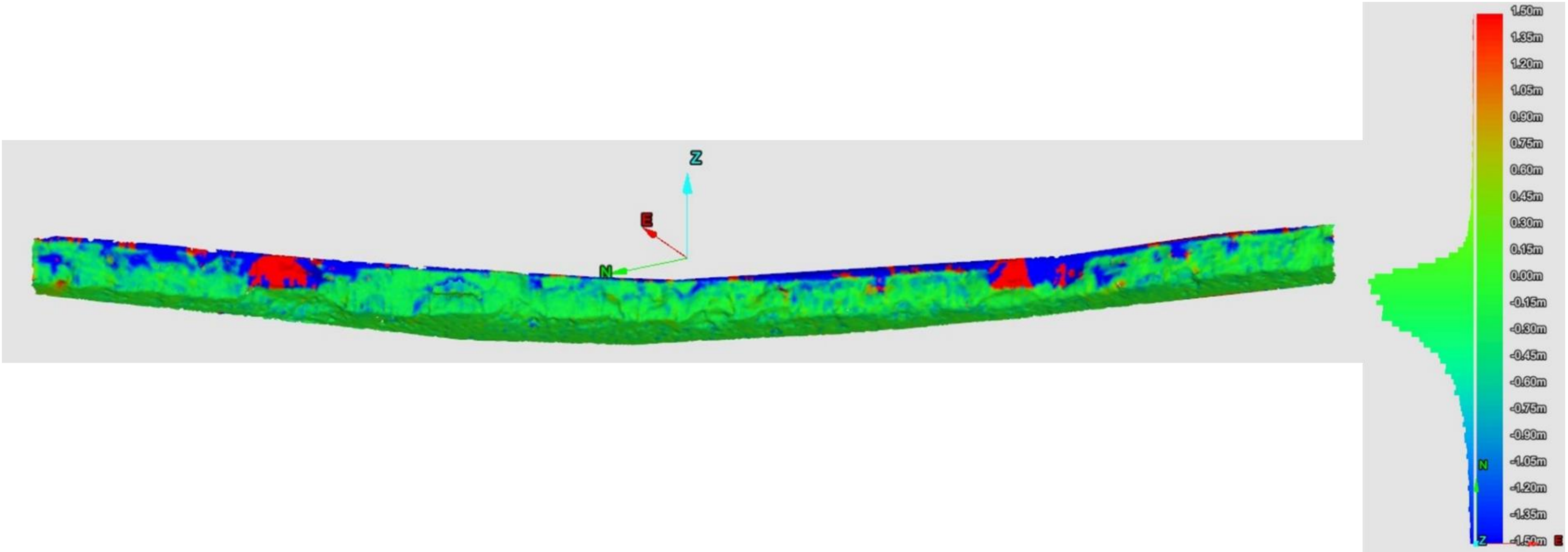
Note: Change = -4 m (Blue) to +4 m (Red)

Middle Section – 2010 to 2021 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



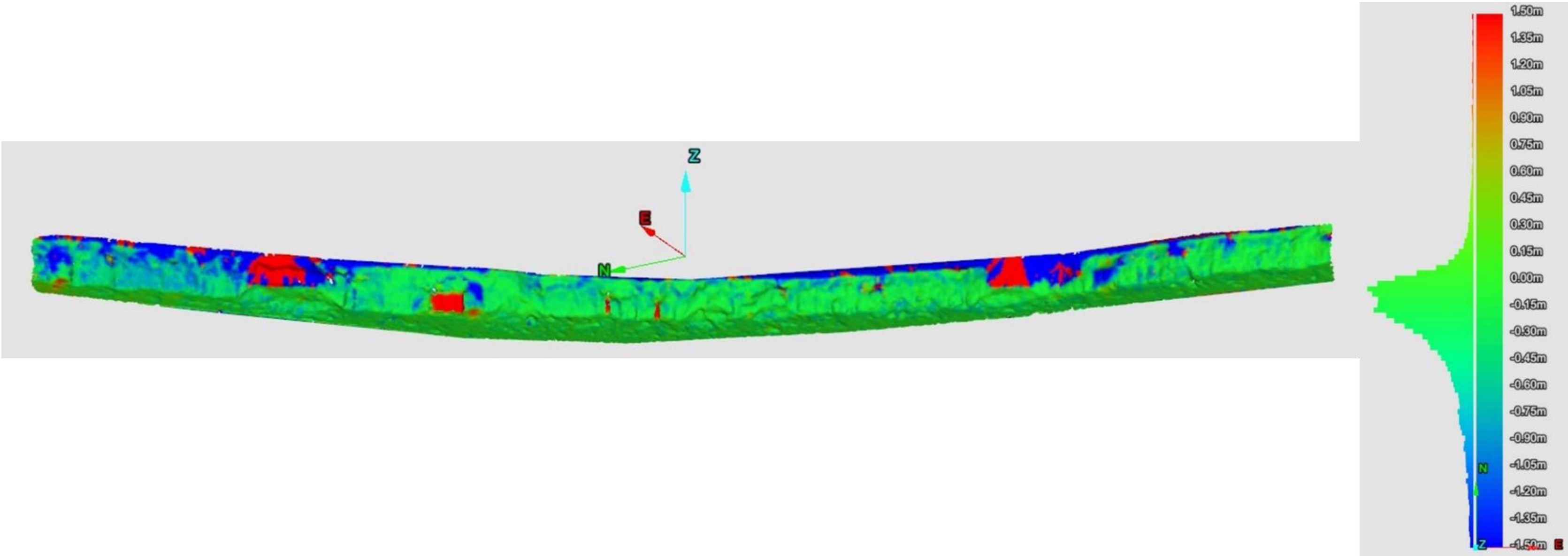
Note: Change = -4.5 m (Blue) to +4.5 m (Red)

Middle Section – 2019 to 2020 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



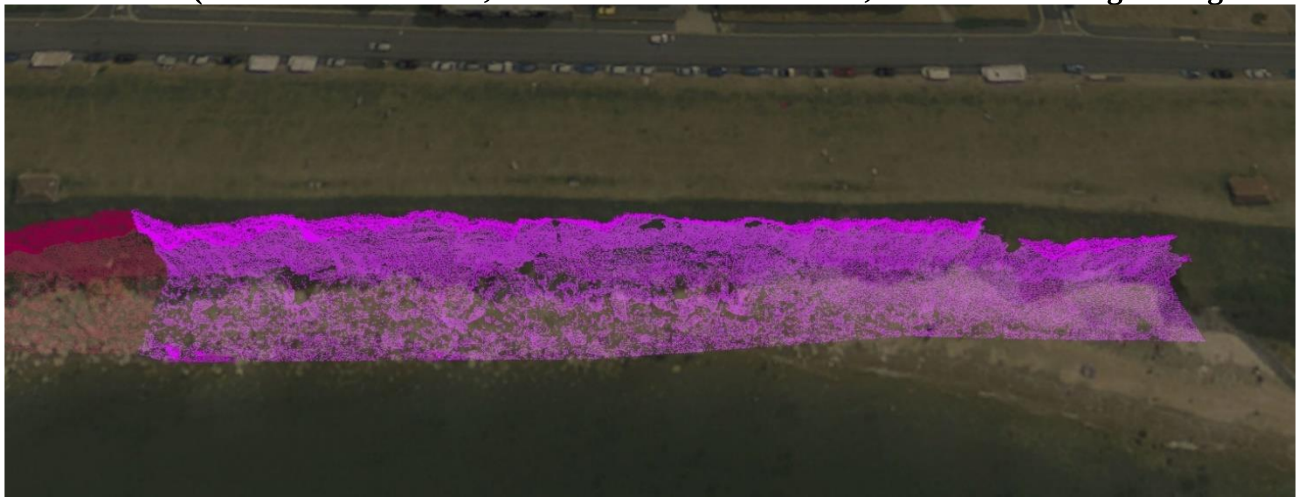
Note: Change = -1.5 m (Blue) to +1.5 m (Red)

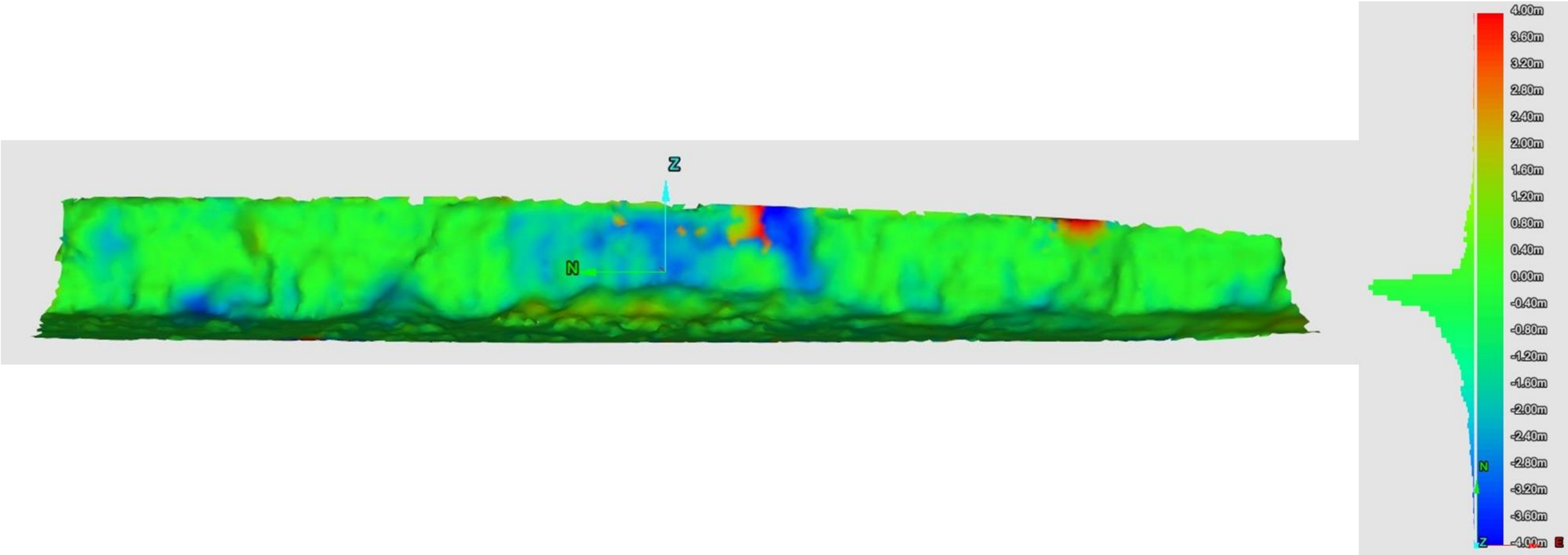
Middle Section – 2020 to 2021 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



Note: Change = -1.5 m (Blue) to +1.5 m (Red)

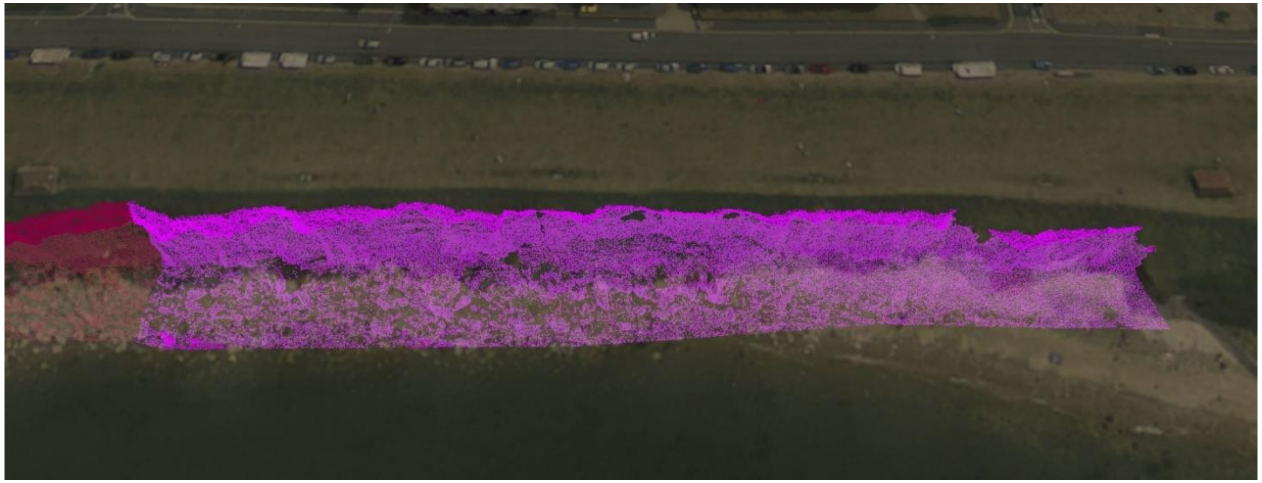
South Section – 2010 to 2020 (Extents: E 567332 m, N 341419 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)

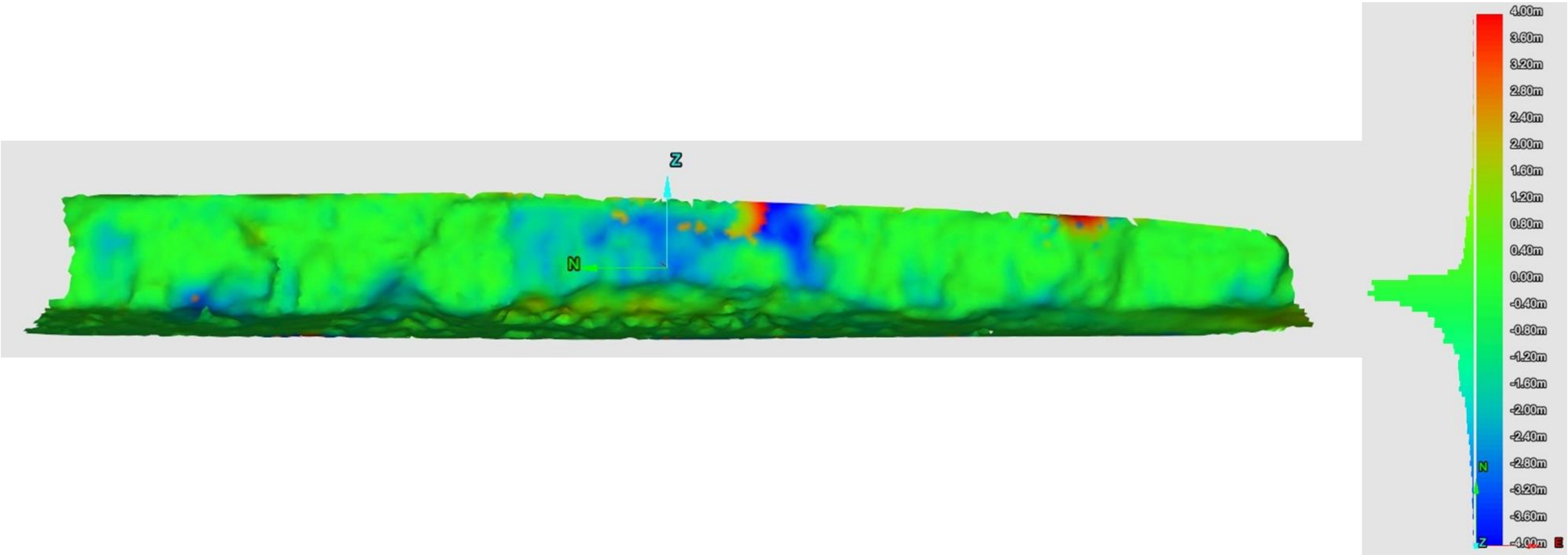




Note: Change = -4 m (Blue) to +4 m (Red)

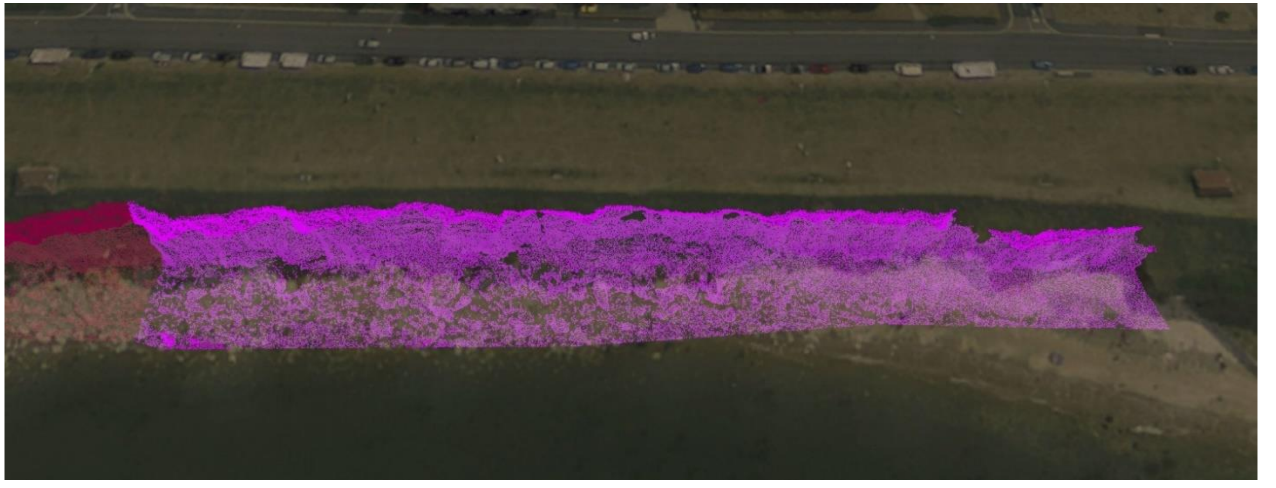
South Section – 2010 to 2021 (Extents: E 567267 m, N 341356 m to E 567270 m, N 341340 m. Height range = 14.0 m to 17.0 m)

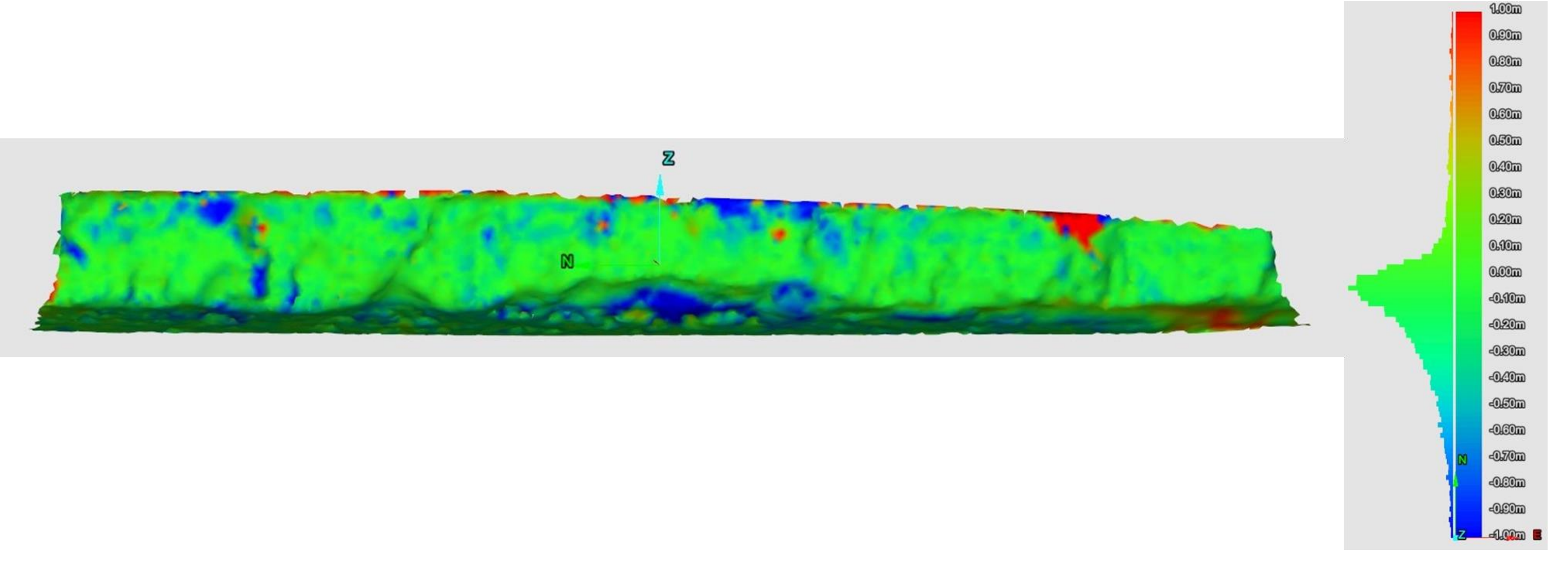




Note: Change = -4 m (Blue) to +4 m (Red)

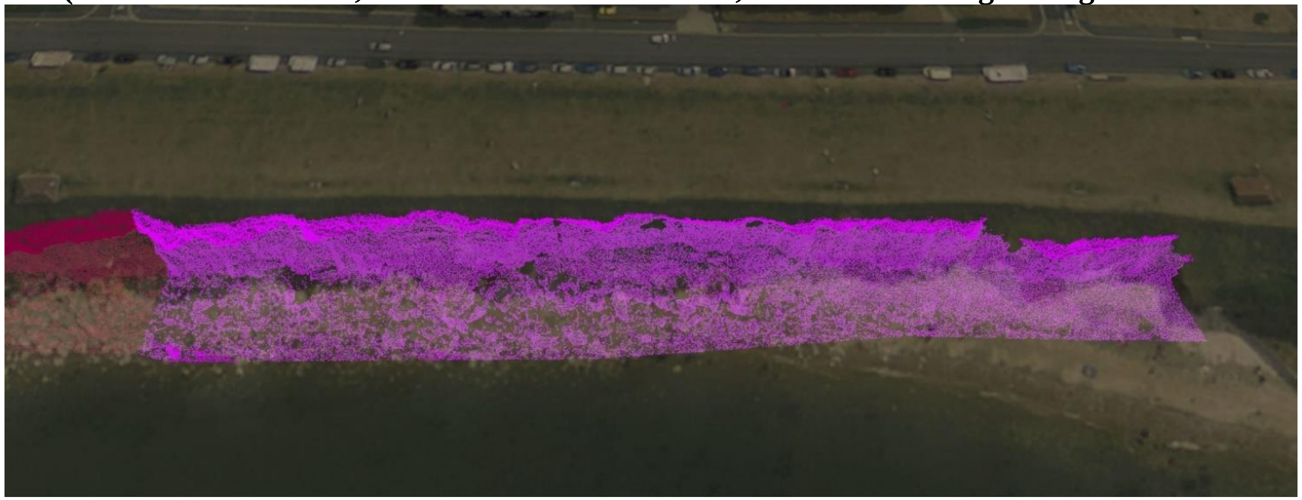
South Section – 2019 to 2020 (Extents: E 567267 m, N 341356 m to E 567270 m, N 341340 m. Height range = 14.0 m to 17.0 m)

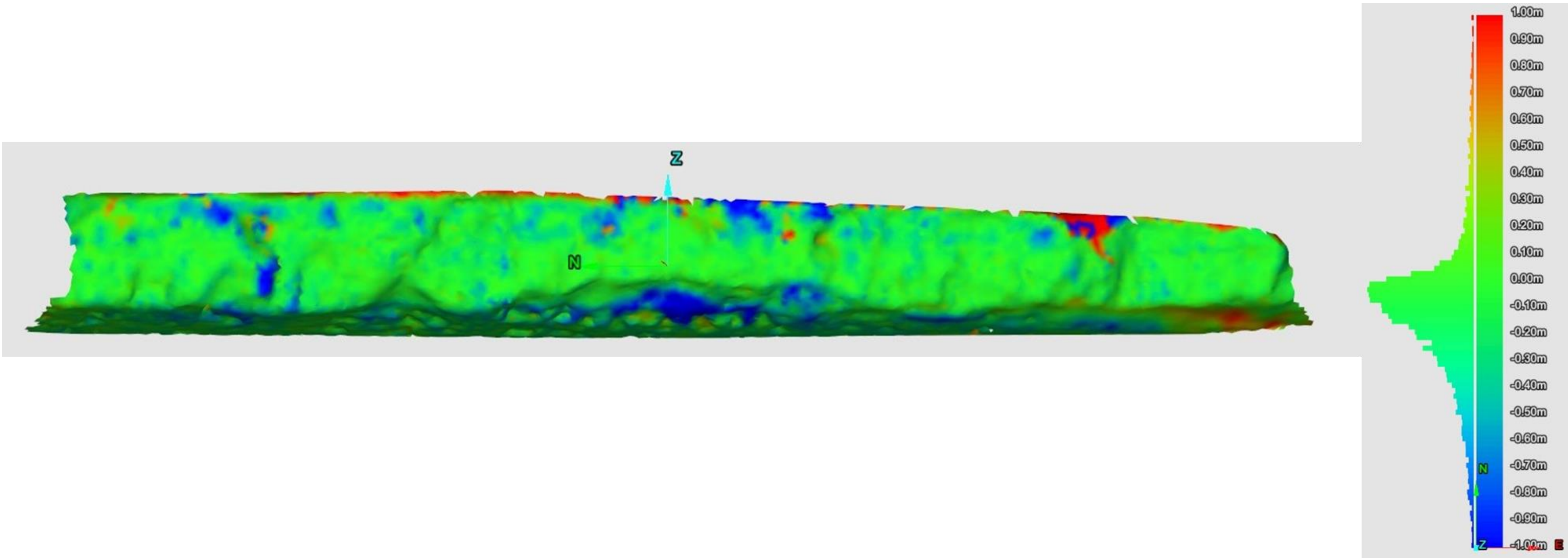




Note: Change = -1 m (Blue) to +1 m (Red)

South Section – 2020 to 2021 (Extents: E 567332 m, N 341409 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)





Note: Change = -1 m (Blue) to +1 m (Red)

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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