Hunstanton Cliffs: Baseline Terrestrial LiDAR Survey

MULTI-HAZARDS & RESILIENCE PROGRAMME
Commercial Report CR/20/003

BRITISH GEOLOGICAL SURVEY

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Hunstanton Cliffs: Baseline Terrestrial LiDAR Survey

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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 a baseline survey 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 2010, 2012, 2017 and 2019.

This is a 'baseline' report, the objective of which was to derive a series of surfaces for the four LiDAR scans and to compare them against the earliest 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 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 the subsequent Purchase Order, dated January 16, 2019, the Council asked the BGS to supply them with a baseline report, based on data acquired from 2010, 2012, 2017 & 2019 surveys, to include the following (Project Code NEE7028R):

- *Change models identifying areas of loss and/or accretion from 'base' year (2010) to 'current' year (2012, 2017, 2019)*
- *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 2010, 2012, 2017 and 2019. 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

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 2010, 2017 and 2019 were much larger than the survey of 2012 and were 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.

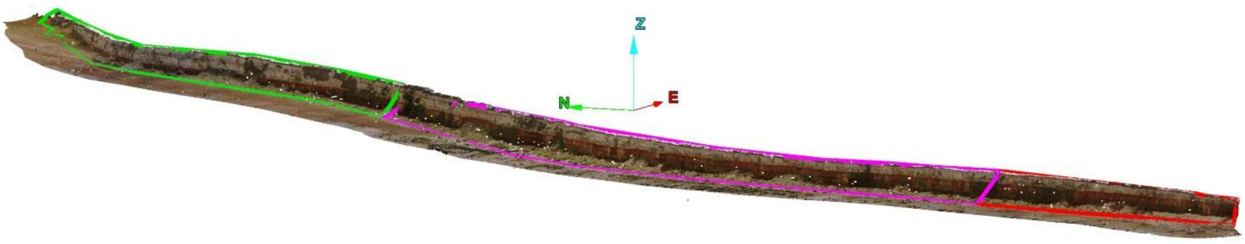


Figure 2 – RGB coloured point cloud of 2019 survey showing sections: Green = North, Magenta = Middle, Red = South (Extents: E 567954 m, N 342450 m to E 567268 m, N 341332 m. Height range = 6.3 m to 18.8 m)

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

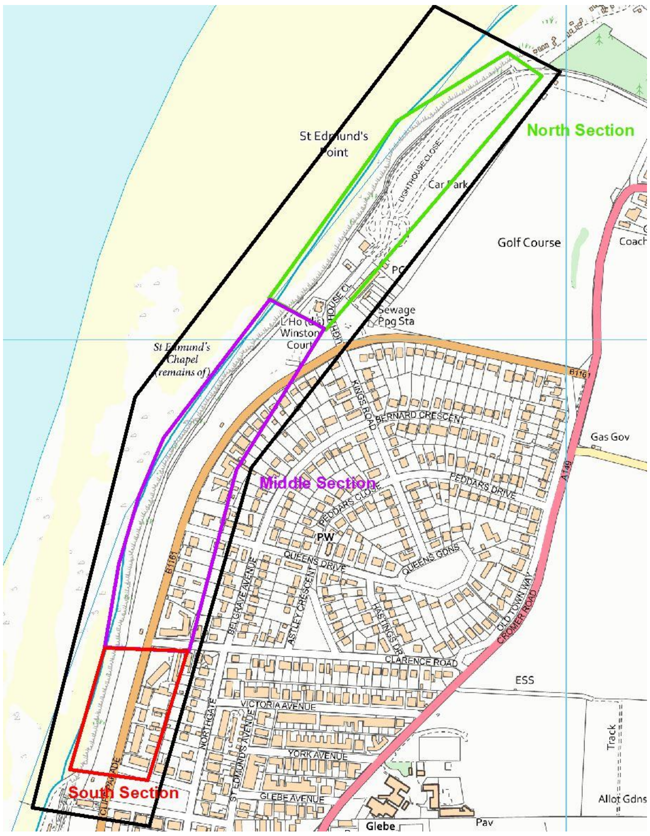


Figure 3 – Plan view of scan area sections: Green = North, Magenta = Middle, Red = South

Figures 4 to 7 show the coverage and extents of the scans from all four surveys. They are displayed as elevation values for 2010 (Figure 4) and 2012 (Figure 5), intensity values for 2017 (Figure 6) and RGB colour values for 2019 (Figure 7).

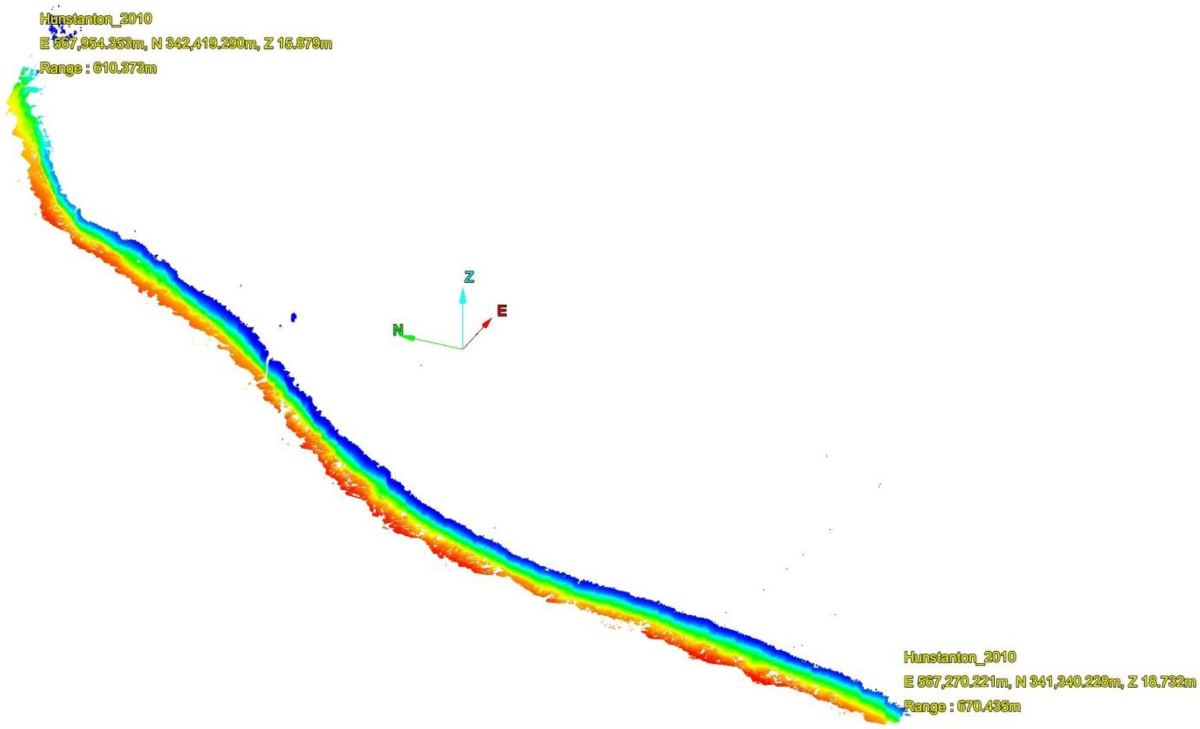


Figure 4 – 2010 point cloud data displayed as an elevation model (Extents: E 567954 m, N 342419 m to E 567270 m, N 341340 m. Height range = 6.3 m to 18.8 m)

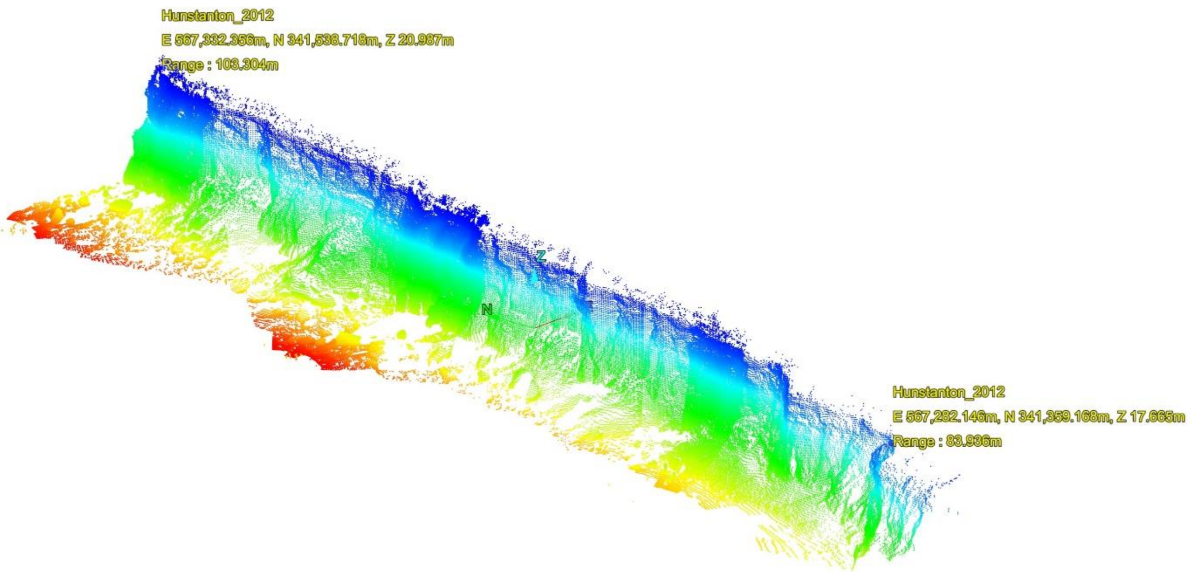


Figure 5 – 2012 point cloud data displayed as an elevation model (Extents: E 567332 m, N 341539 m to E 567282 m, N 341359 m. Height range = 6.3 m to 18.8 m)

Figure 6 – 2017 point cloud data displayed using the intensity values (Extents: E 567930 m, N 342409 m to E 567262 m, N 341319 m. Height range = 6.3 m to 18.8 m)

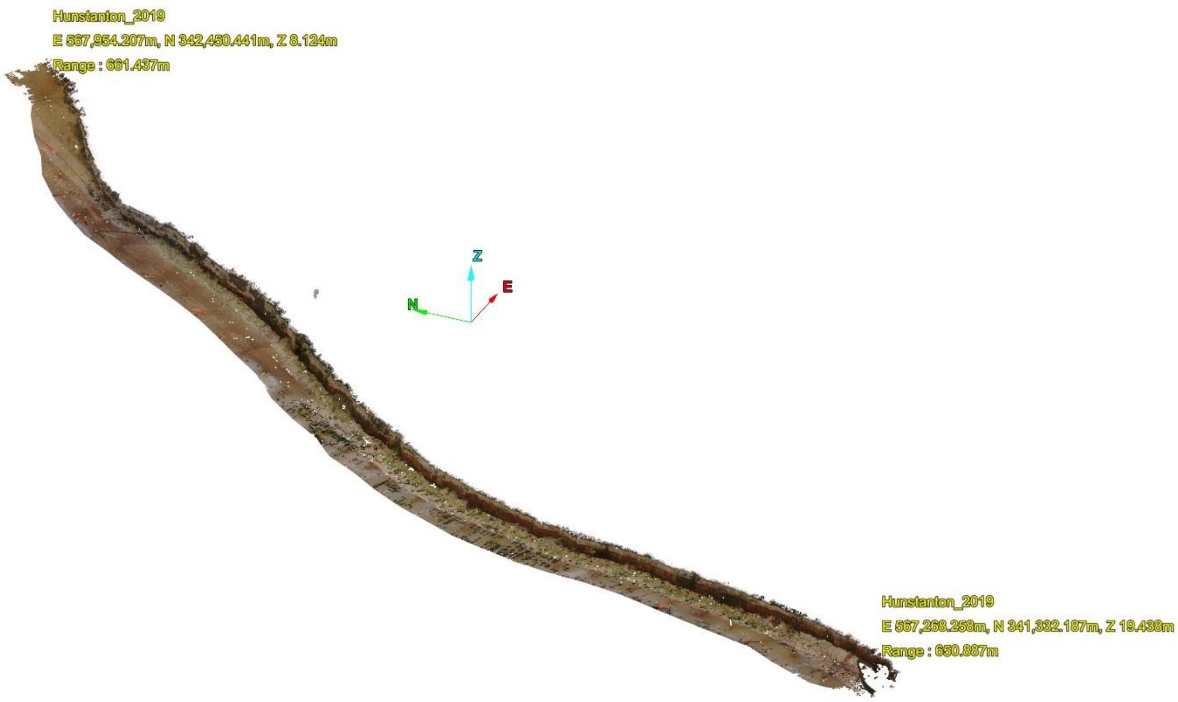


Figure 7 – 2019 point cloud data displayed using the RGB colour values (Extents: E 567954 m, N 342450 m to E 567268 m, N 341332 m. Height range = 6.3 m to 18.8 m)

The point cloud data provided, in .las format, for all four 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 – 2010, 2017, 2019
- Middle – 2010, 2017, 2019
- South – 2010, 2012, 2017, 2019

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 2017, 2010 to 2019, 2017 to 2019 (3)
- Middle – 2010 to 2017, 2010 to 2019, 2017 to 2019 (3)
- South – 2010 to 2012, 2010 to 2017, 2010 to 2019, 2012 to 2017, 2012 to 2019, 2017 to 2019 (6)

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 2019 (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 8), Middle (Figure 9) and South (Figure 10) 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 (days)	Cumulative Time (days)	North Section			Middle Section			South Section		
Start	End			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-10	Mar-19		*3136*		3050	6		6750	12		2350	13
Loss/Year					355			786			274	

North Section			Horizontal Movement (m)	Middle Section			Horizontal Movement (m)	South Section			Horizontal Movement (m)
Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)		Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)		Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	
								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*
	7015	14	*2*		15525	27	*1*		5405	29	*3*
	817				1808				630		

The data show a total loss of 12150 m^3 across the 1.275 km combined sections, relating to an estimated mass of approximately 27945 tonnes* of material. These values work out to 1415 m^3/year, which is 3255 tonnes/year. Graphs showing the cumulative loss of material in cubic metres (Figure 11) and the cumulative loss of material in tonnes (Figure 12) are also presented here.

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 (1415 m^3), the cliff length (1275 m) and the cliff height (16 m) giving a total value of 0.07 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 (apart from the 2019 RGB scan), the mass calculated is based on the average density value of 2.3 kg/m^3.

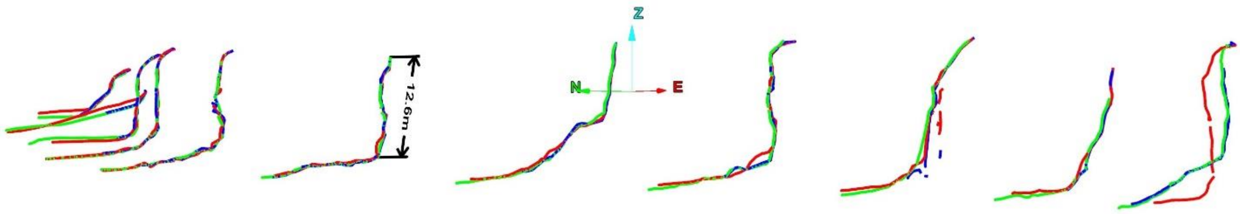


Figure 8 – Cross-sections, at 50 m spacing, for North section: Red = 2010, Blue = 2017, Green = 2019 (Extents: E 567578 m, N 342050 m to E 567934 m, N 342430 m)

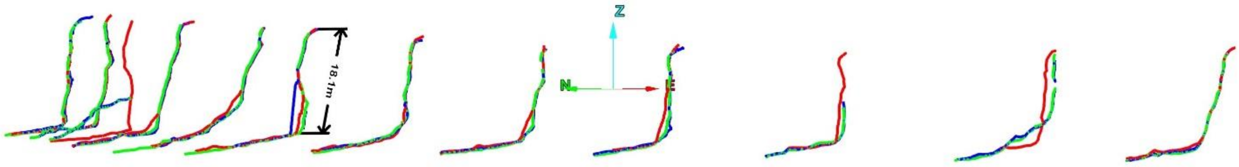


Figure 9 – Cross-sections, at 50 m spacing, for Middle section: Red = 2010, Blue = 2017, Green = 2019 (Extents: E 567314 m, N 341539 m to E 567584 m, N 342052 m)

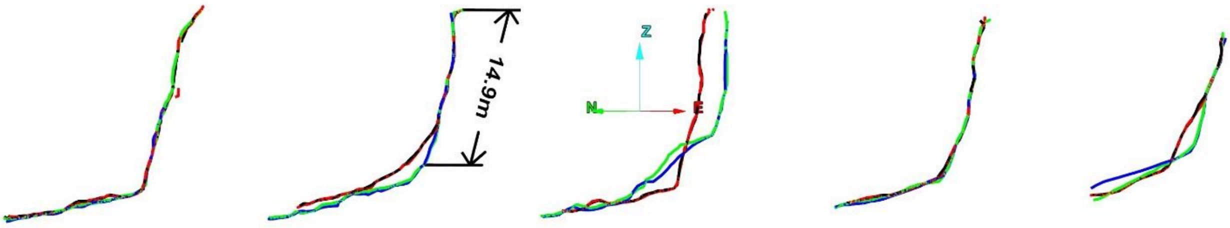


Figure 10 – Cross-sections, at 50 m spacing, for South section: Red = 2010, Black = 2012, Blue = 2017, Green = 2019 (Extents: E 567267 m, N 341356 m to E 567333 m, N 341548 m)

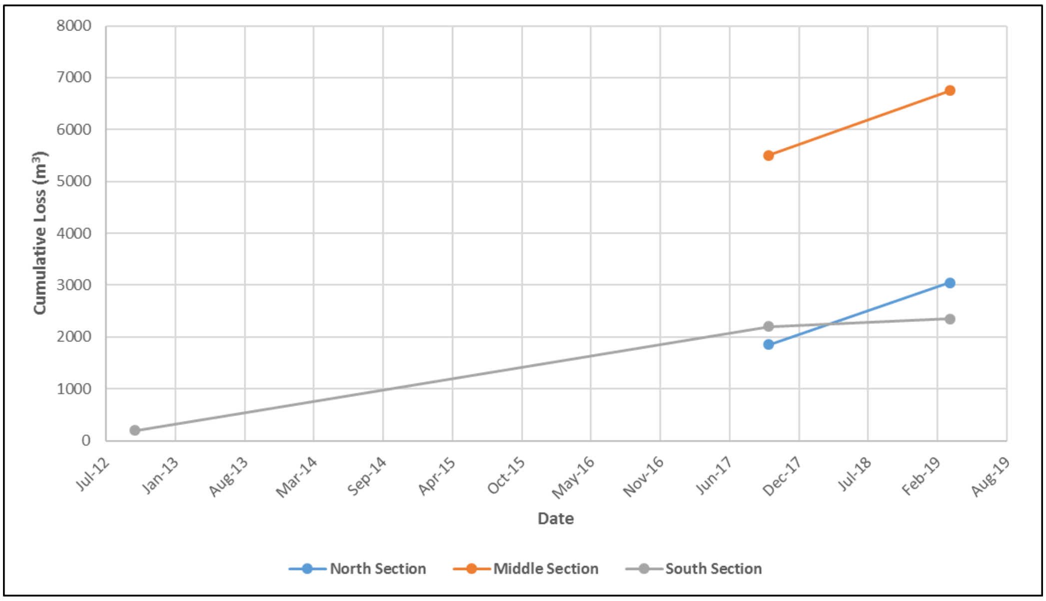


Figure 11 – Cumulative Loss (m^3) v Time

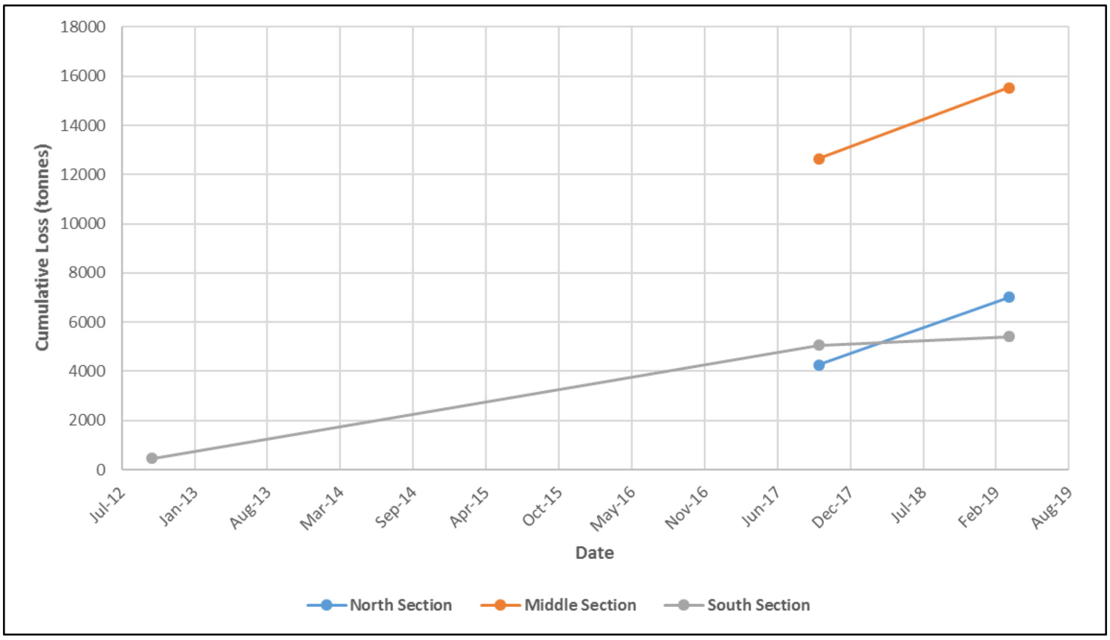


Figure 12 – Cumulative Loss (tonnes) v Time

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 13 shows the difference between the 2010 and 2019 surveys for the whole section, where red are areas of erosion and blue areas of accretion. These areas are picked up in more detail in section 6, below.

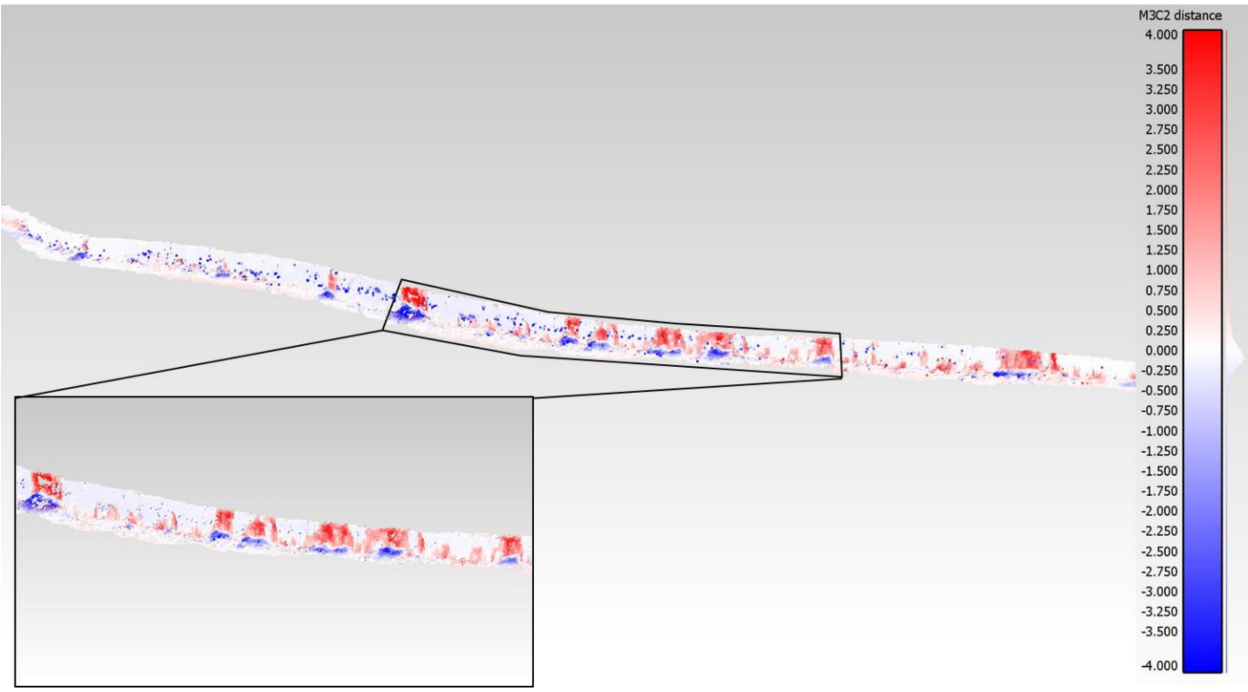


Figure 13 – 2010 to 2019 cloud-to-cloud difference model (Extents: E 567954 m, N 342419 m to E 567270 m, N 341340 m. Height range = 6.3 m to 18.8 m)

6 Analysis of Change

This is the baseline report, based on the 2010 Terrestrial LiDAR Survey (TLS) data, with comparisons to the 2012 (south only), 2017 and 2019 TLS data. For clarity, this discussion of results will refer to the change between the 2010 and 2019 surveys, as these cover the full extent of the area under consideration and give a reasonable period for change to take place. 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 14 & 15) at British National Grid (BNG) 342319 m North to 342280 m North (Figure 16) which show that ~3 m of loss has occurred in the cliff face and accretion has followed on the foreshore. Holes in the data (possibly from shadow areas within the scans) mean that precise values cannot be accurately defined; however, the area and amount of change can be estimated reasonably. Further change in this section can be seen at 342160 m North (Figure 17) where a loss of up to 3 m is visible across the cliff face with accretion of approximately 2 m on the foreshore. At the southernmost part of the section, at 342055 m North (Figure 18), there is a large area of erosion in the cliff face of ~3 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 19, which shows a histogram of the loss/gain distribution.

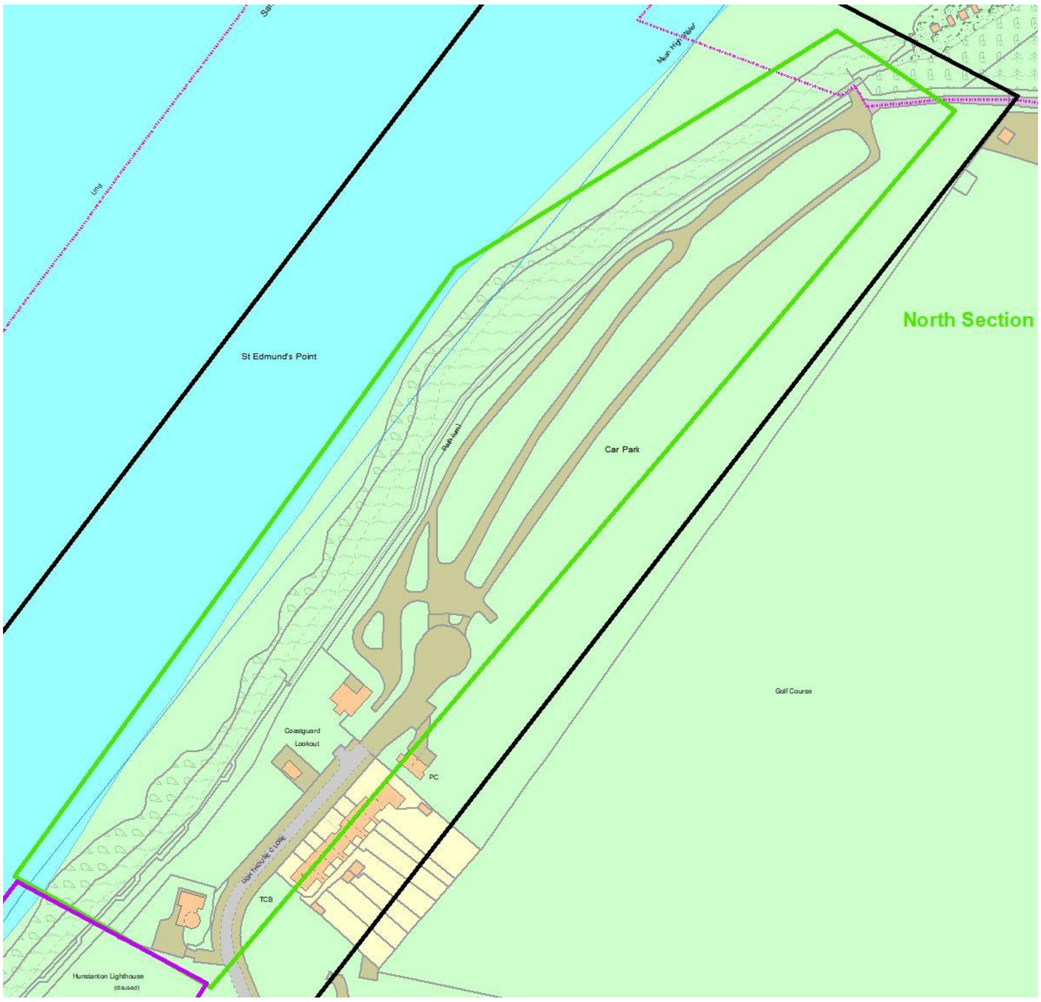


Figure 14 – Plan view of North section

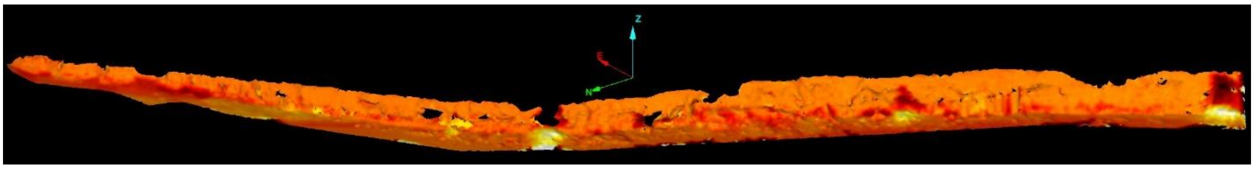


Figure 15 – 3D view of the entire North section

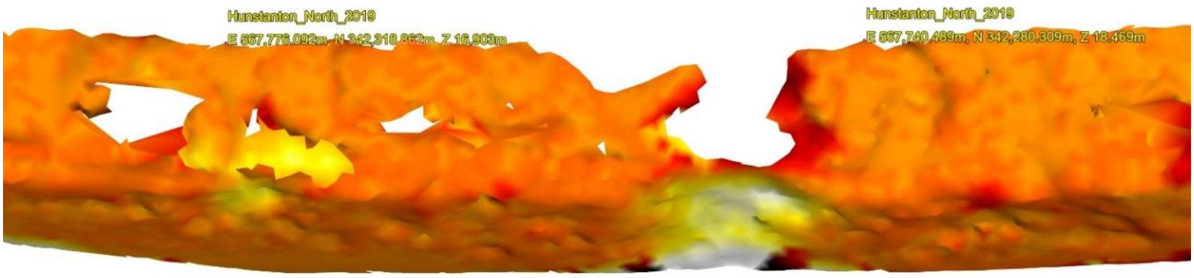


Figure 16 – 2010 to 2019 change model of 342319 m North to 342280 m North (for legend see Figure 19. Height range = 6.3 m to 15.7 m)

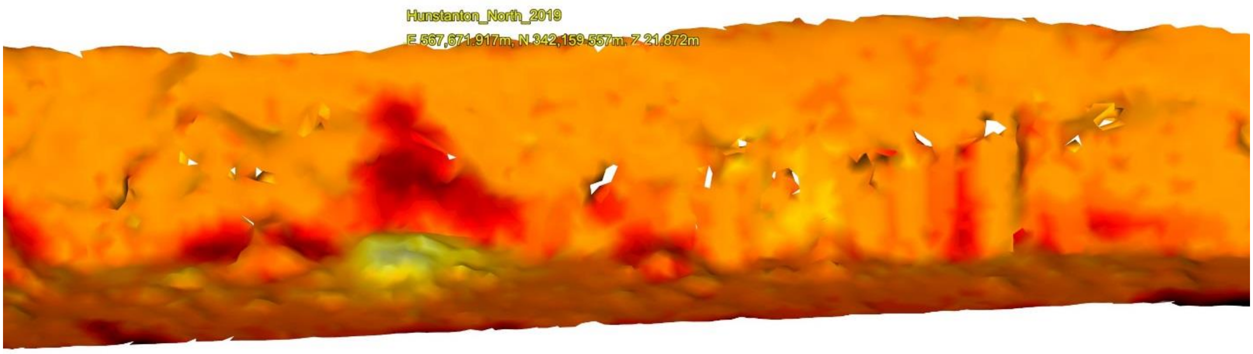


Figure 17 – 2010 to 2019 change model of the area around 342160 m North (for legend see Figure 19. Height range = 6.3 m to 15.7 m)

Figure 18 – 2010 to 2019 change model of the area around 342055 m North (for legend see Figure 19. Height range = 6.3 m to 15.7 m)

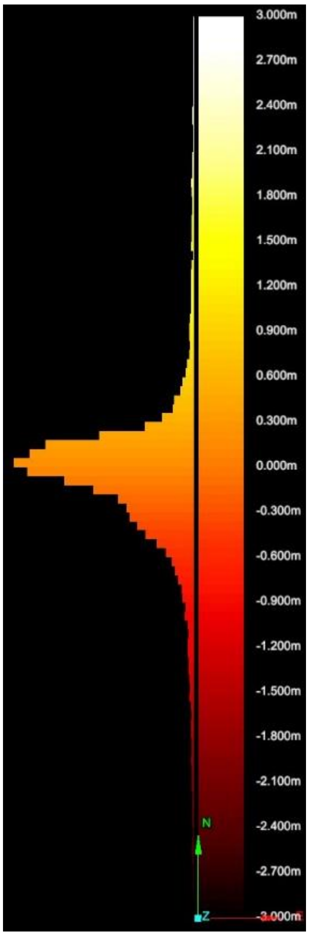


Figure 19 – North section legend (-3 m to 3 m) for 2010 to 2019 change model

6.2 MIDDLE SECTION

Figures 20 & 21 show the Middle section, where at 341952 m North (Figure 22) there is a significant amount (~4 m) of accretion on the foreshore. This must have come from the adjacent cliff face but unfortunately due to a lack of data in this area (possibly due to shadows) there is a hole in the model. However, further areas of loss (~2 m) can be seen south of this point. Farther south, from 341858 m North to 341781 m North (Figure 23), 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 (~1.5 m) values being seen. From 341749 m North to 341596 m North (Figure 24) there are large areas of the cliff face with losses of up to 4 m. Again, this area shows much smaller (~2 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 25.

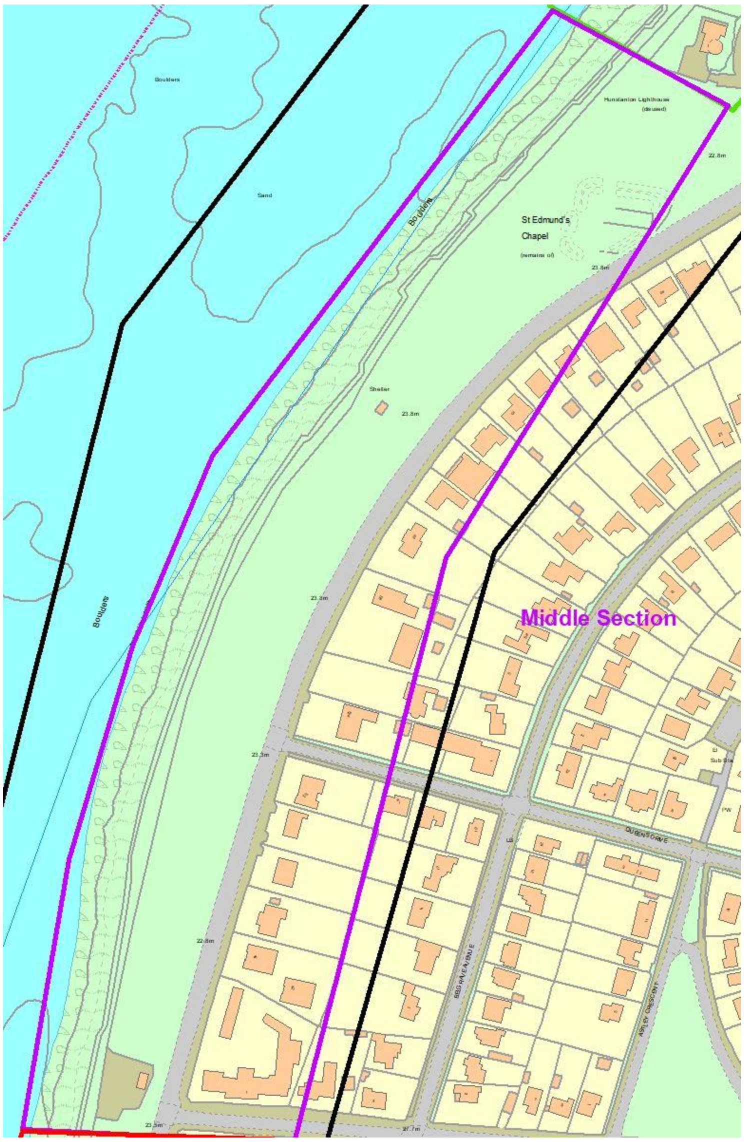


Figure 20 – Plan view of Middle section

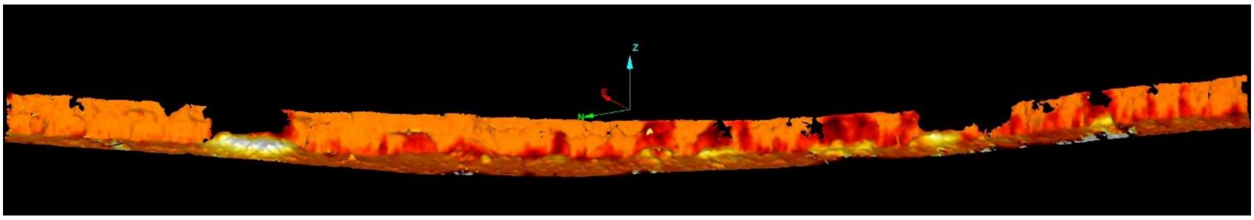


Figure 21 – 3D view of entire Middle section

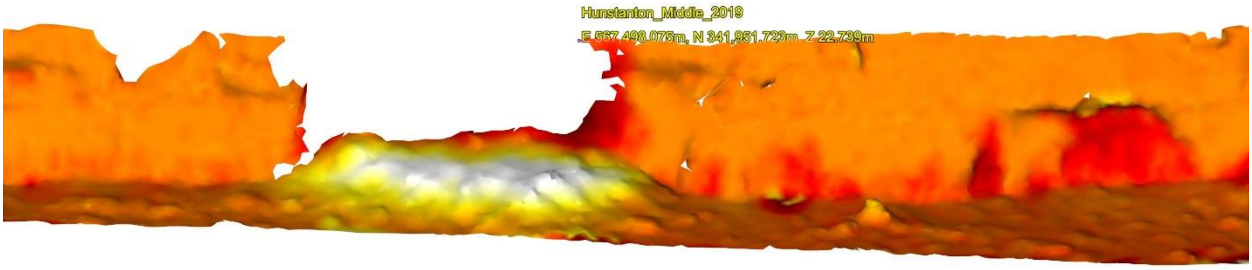


Figure 22 – 2010 to 2019 change model of the area around 341952 m North (for legend see Figure 25. Height range = 16.5 m to 18.8 m)

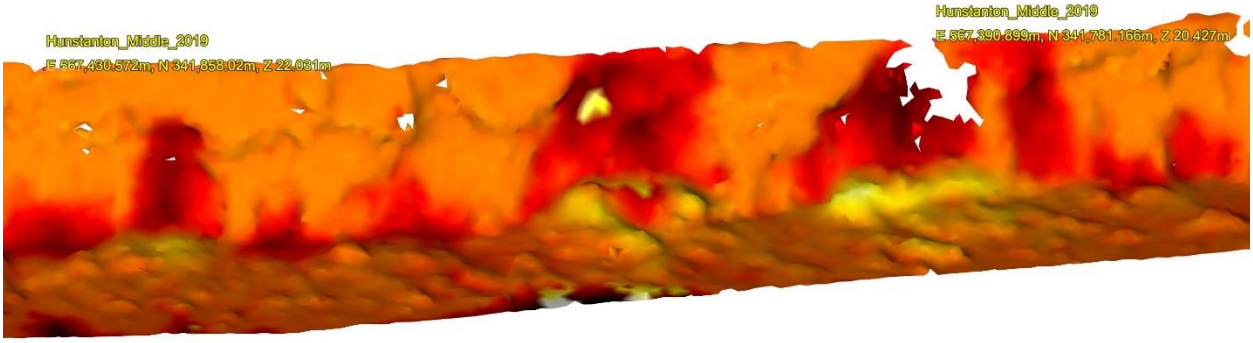


Figure 23 – 2010 to 2019 change model of 341858 m North to 341781 m North (for legend see Figure 25. Height range = 16.5 m to 18.8 m)

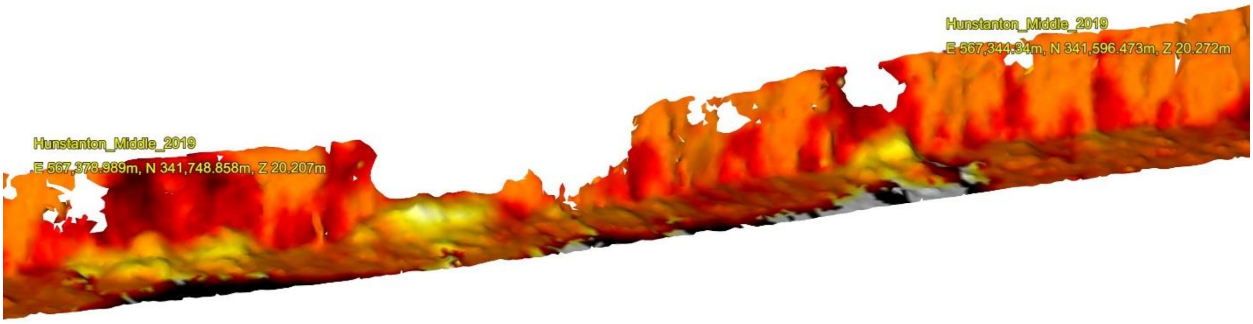


Figure 24 – 2010 to 2019 change model of 341749 m North to 341596 m North (for legend see Figure 25. Height range = 16.5 m to 18.8 m)

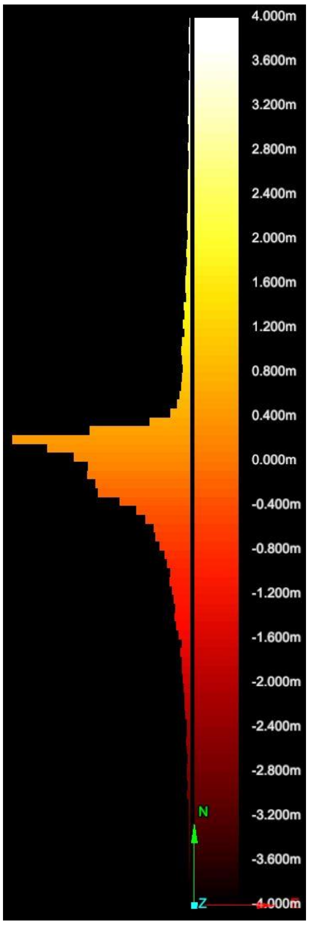


Figure 25 – Middle section legend (-4 m to 4 m) for 2010 to 2019 change model

6.3 SOUTH SECTION

The south section (Figures 26 & 27) 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 341477 m North to 341425 m North (Figure 28) shows a significant amount of erosion of up to 4 m, again with lesser levels of accretion on the foreshore of approximately 2 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 29.

Figure 26 – Plan view of South section

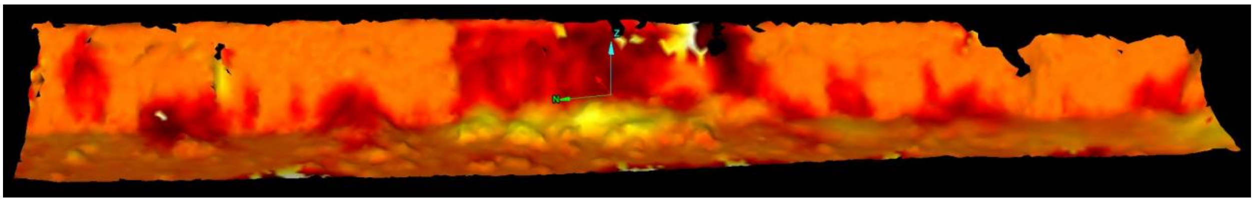


Figure 27 – 3D view of entire South section

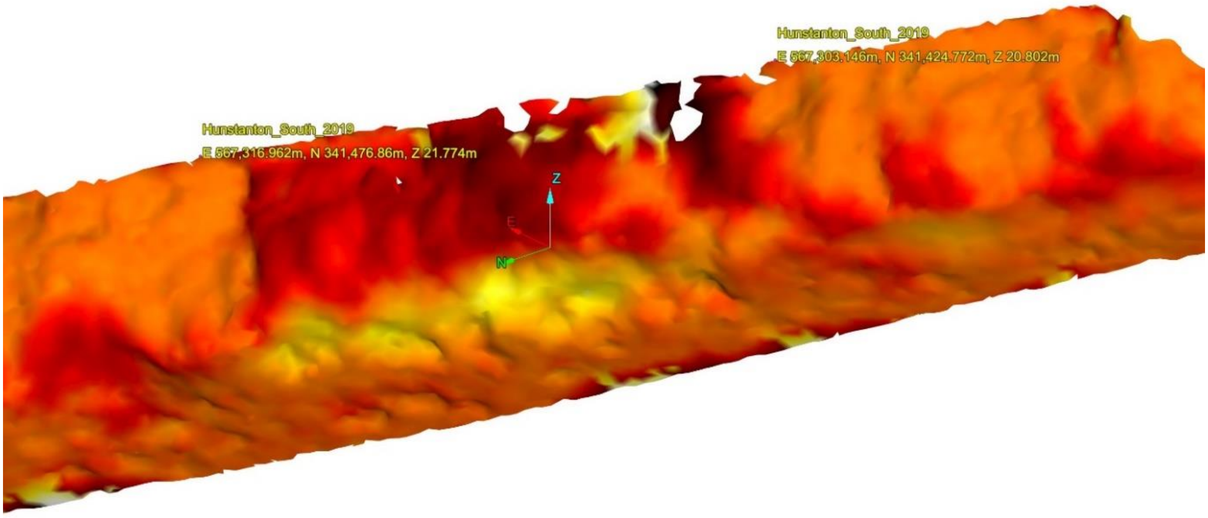


Figure 28 – 2010 to 2019 change model of 341477 m North to 341425 m North (for legend see Figure 26. Height range = 14.0 m to 17.0 m)

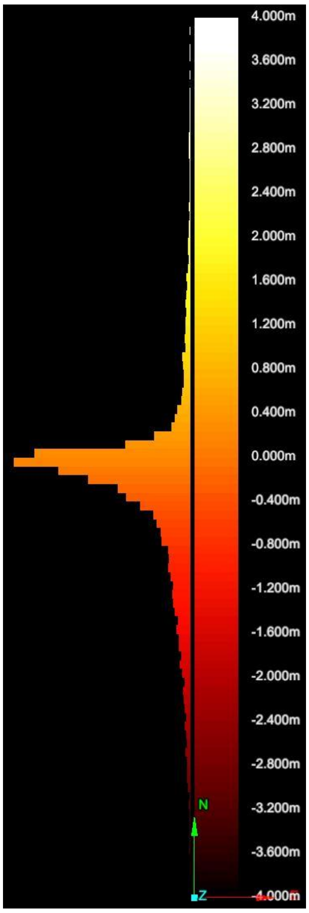


Figure 29 – South section legend (-4 m to 4 m) for 2010 to 2019 change model

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 30 and consist of three shelters and the Lighthouse. Their approximate position, distance to the nearest cliff edge are shown in Figures 31 & 32. 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 30 – Plan of area with 'at risk' properties shown

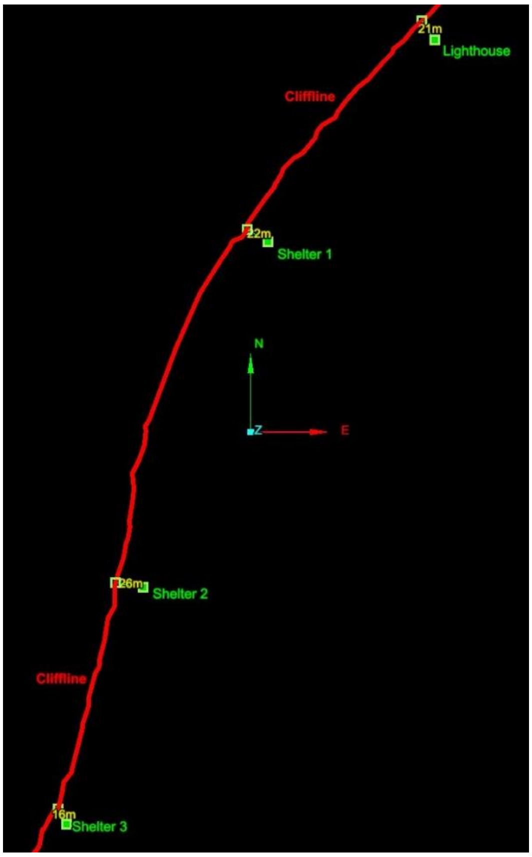


Figure 31 – Position of 'at risk' properties relevant to cliff edge

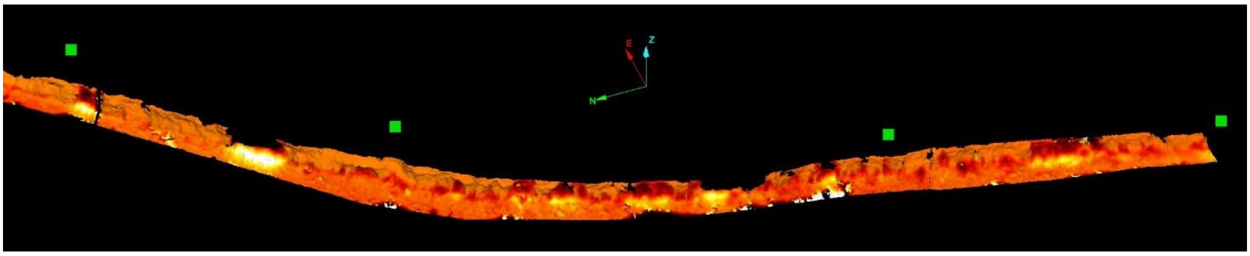


Figure 32 – Position of ‘at risk’ properties relevant to change analysis

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	*2.9*
Shelter 1	567473	341875	22	1	1	*0.5*
Shelter 2	567360	341560	26	1	1	*0.4*
Shelter 3	567290	341345	16	3	2	*3.8*

In order to calculate the Erosion Risk Rating, Equation 1was applied to each ‘at risk’ property as follows:

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

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 2.8. 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.

8 Standards & Methodologies

All BGS ground-based geomatic 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 a baseline survey of the cliffs at Hunstanton, Norfolk, using four LiDAR scans provided to the client by the Anglian Coastal Monitoring Programme, covering the years 2010, 2012, 2017 and 2019.

The report consists of the following:

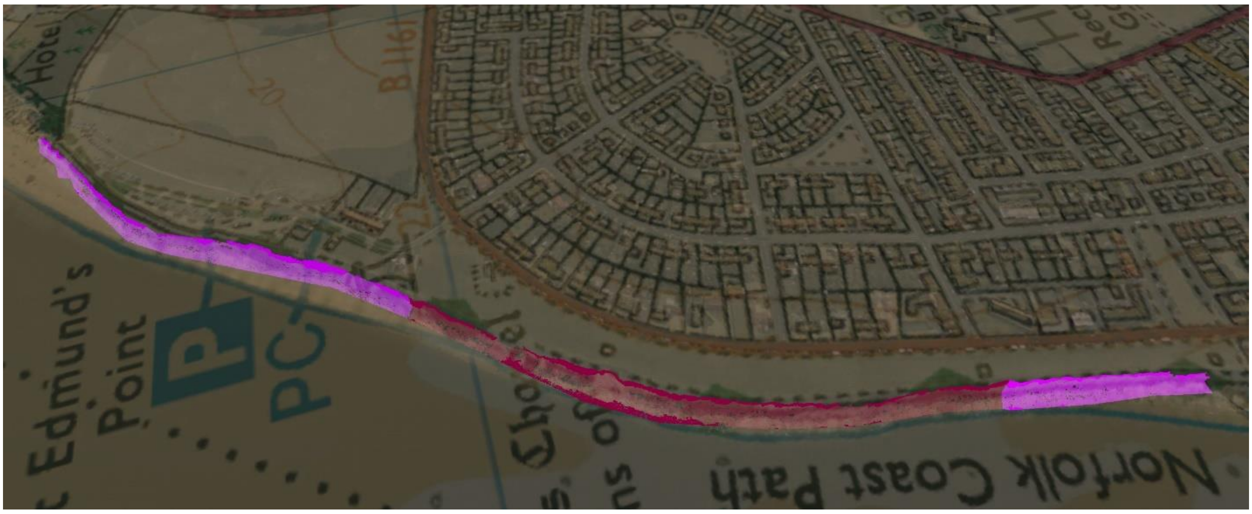
- A review of the data provided and the extents of the four surveys
- An account of how the 3D Fusion Surface and Change models were created
- Volume calculations (Table 3) of loss, including a series of cross-sections and graphs to illustrate these changes
- An analysis of the change in the cliff, portrayed 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
- Appendices containing a suite of Surface and Change models

In summary, the report found the following:

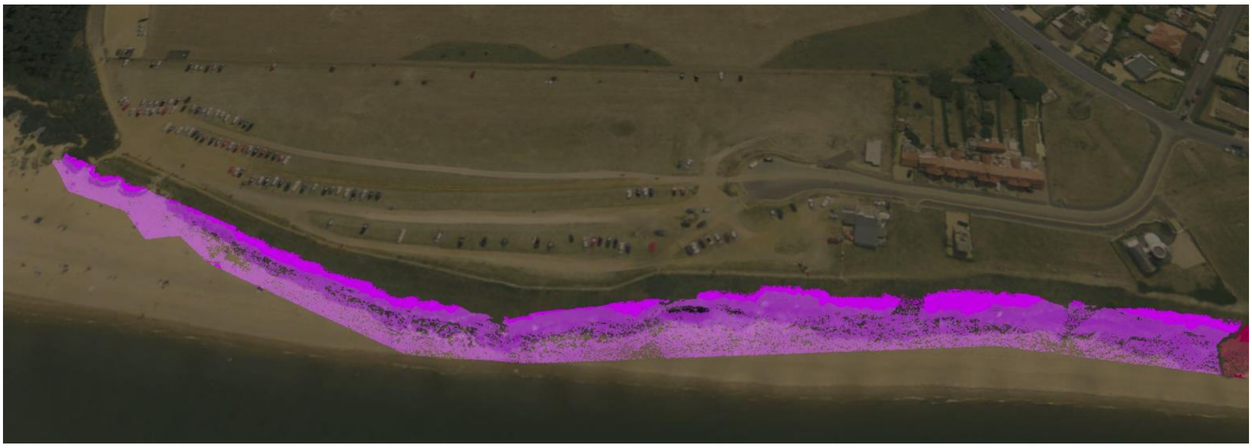
- The data from the 2012 LiDAR scan covers a much smaller section of the cliff than the data from 2010, 2017 and 2019 LiDAR scans. This, plus the large size of the other data sets, led to the division of the section into three smaller sections
- The Volume Calculation data (Table 3) shows a total loss of 12150 m^3 across the full 1.275 km section, which is 1415 m^3/year or 3255 tonnes/year. The Middle section appears to be losing the largest amount of material (786 m^3), followed by the North section (355 m^3) and the South section (274 m^3).
- 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 (3 m), followed by the North section (2 m) and the Middle section (1m)
- Each section of the cliff was analysed separately:
    - North – The greatest amount of loss (~3 m) occurs at BNG 342319 m to 342280 m N (Figure 16). Further large scale changes in this section can be seen at 342160 m N (Figure 17) and at 342055 m N (Figure 18) , directly in front of the Lighthouse
    - Middle – At 341952 m N (Figure 22) there is a significant amount of accretion on the foreshore (~4 m). South from this, between 341858 m N and 341781 m N (Figure 23) large areas of erosion (~3.5 m) can be seen, and from 341749 m N to 341596 m N (Figure 24) losses of up to 4 m can be seen
    - South – From 341477 m N to 341425 m N (Figure 28) a significant amount of erosion (~ 4m) can be seen
- 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 four properties that were outlined as being 'at risk' by BCKLWN (Table 4). This rating shows that the properties most at risk are the Lighthouse (R of 2.8) and Shelter 3 (R of 3.8)

Appendix 1 Surface Models

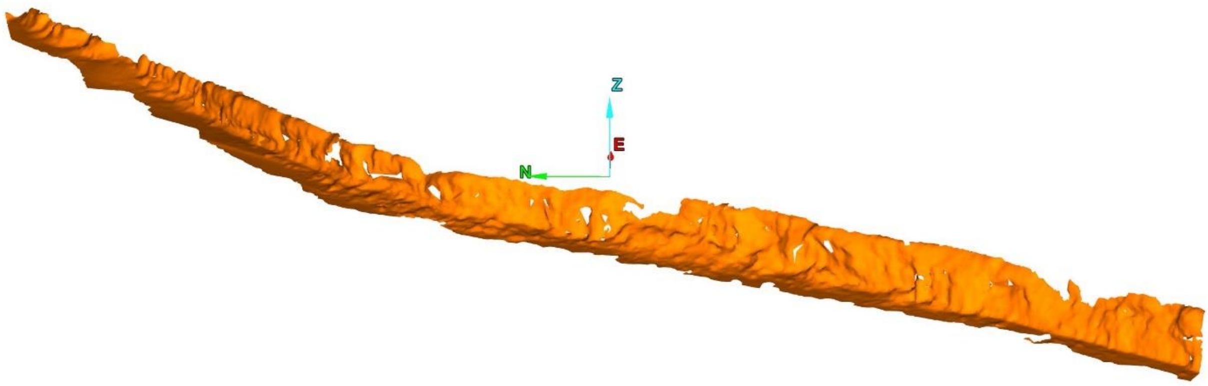
Plan view of all sections



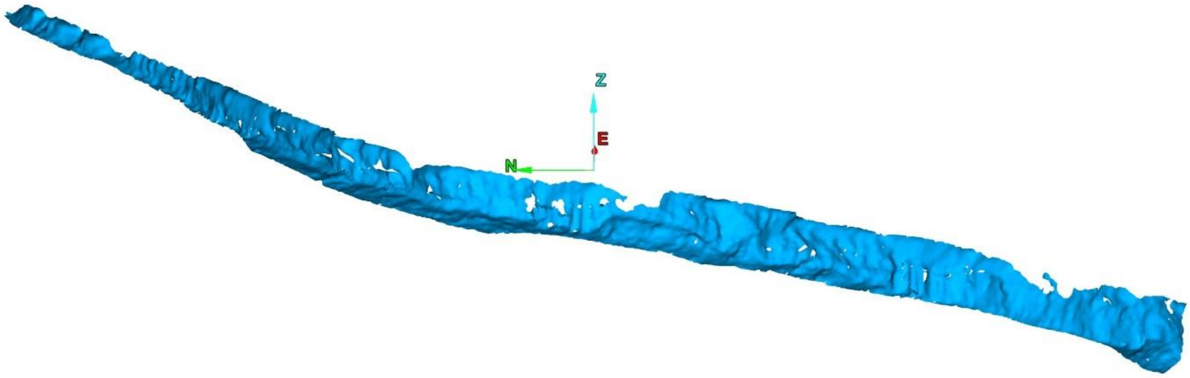
Aerial view of North section (Extent: E 567954 m, N 342450 m to E 567934 m, N 342430 m)



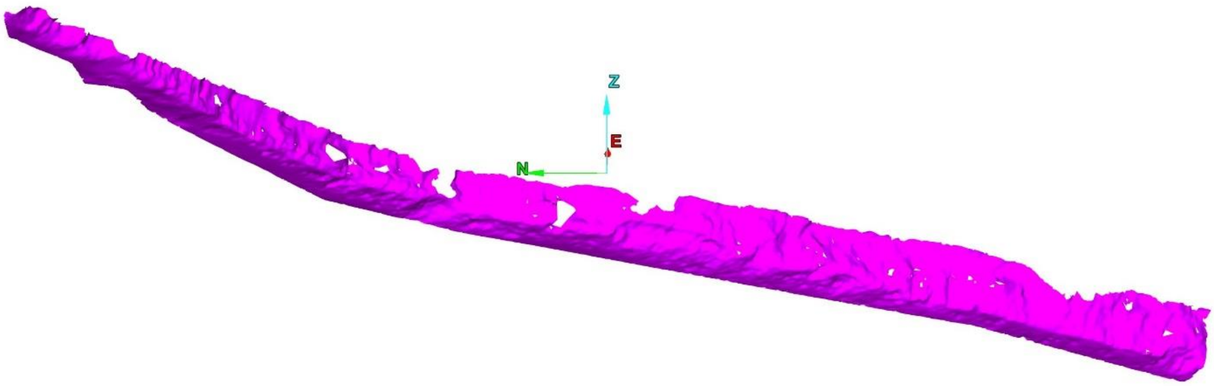
North Section – 2010 (Extents: E 567954 m, N 342419 m to E 567934 m, N 342430 m. Height range = 6.3 m to 15.7 m)



North Section – 2017 (Extents: E 567930 m, N 342409 m to E 567934 m, N 342430 m. Height range = 6.3 m to 15.7 m)

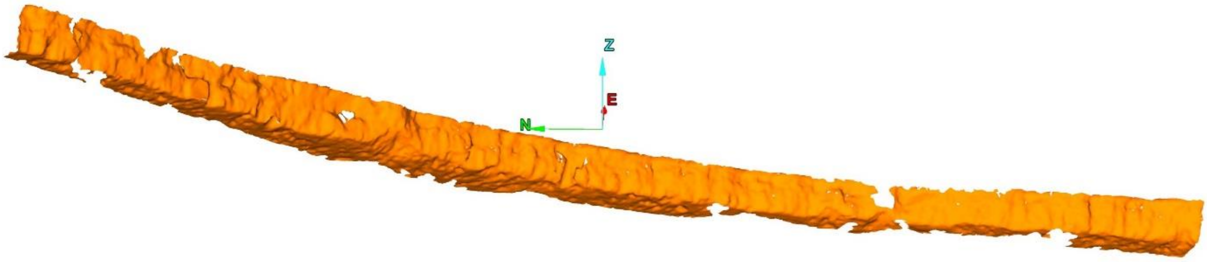


North Section – 2019 (Extents: E 567954 m, N 342450 m to E 567934 m, N 342430 m. Height range = 6.3 m to 15.7 m)

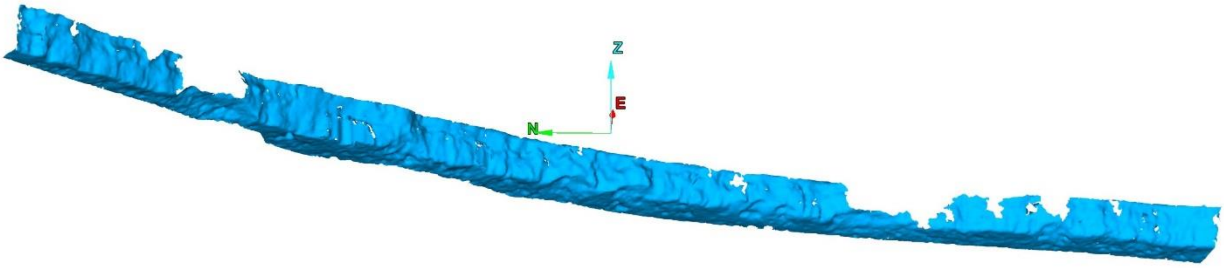


Aerial view of Middle section (Extent: E 567314 m, N 341539 m to E 567584 m, N 342052 m)

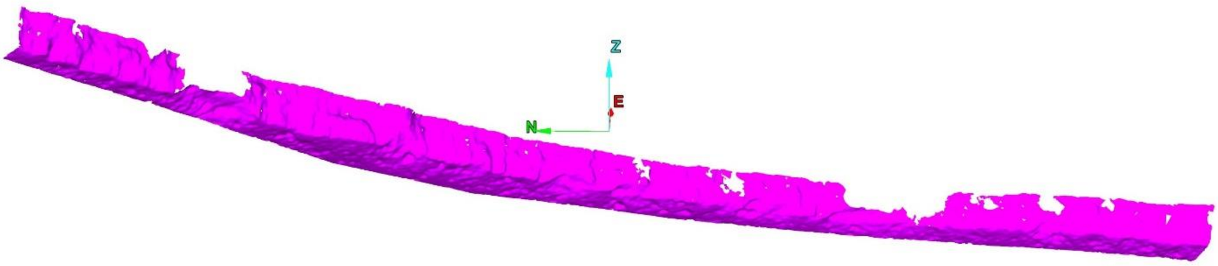
Middle Section – 2010 (Extents: E 567314 m, N 341539 m to E 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



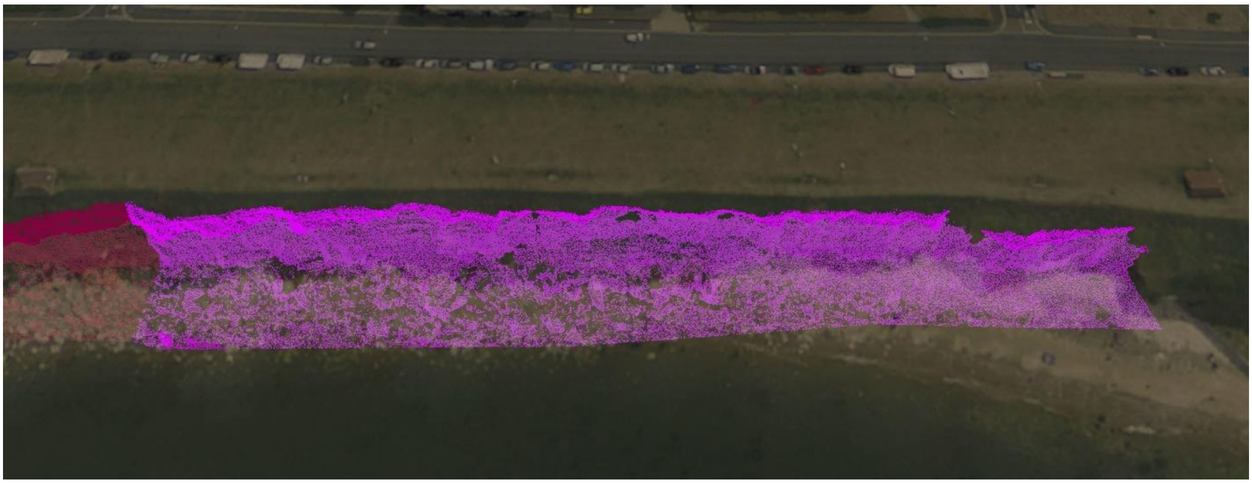
Middle Section – 2017 (Extents: E 567314 m, N 341539 m to E 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



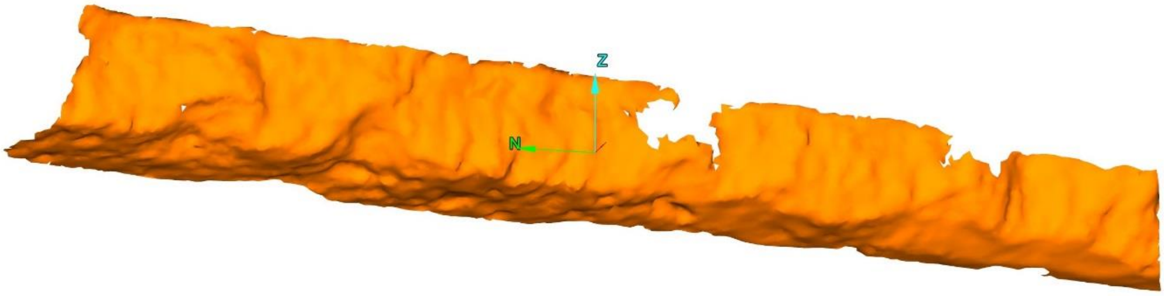
Middle Section – 2019 (Extents: E 567314 m, N 341539 m to E 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



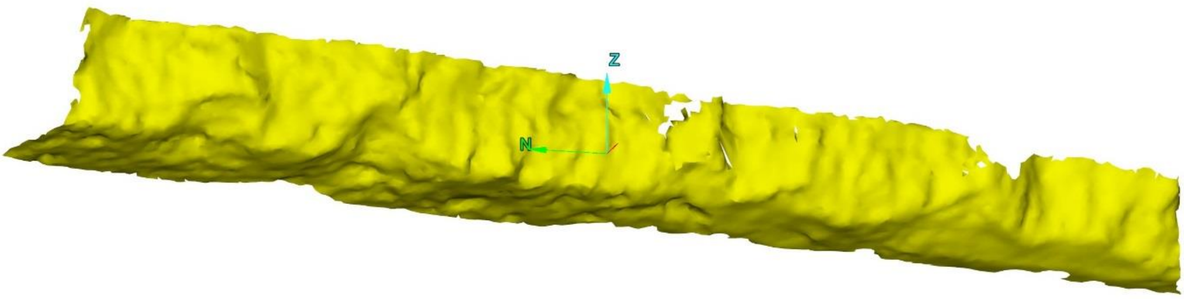
Aerial view of South section (Extent: E 567267 m, N 341356 m to E 567268 m, N 341332 m)



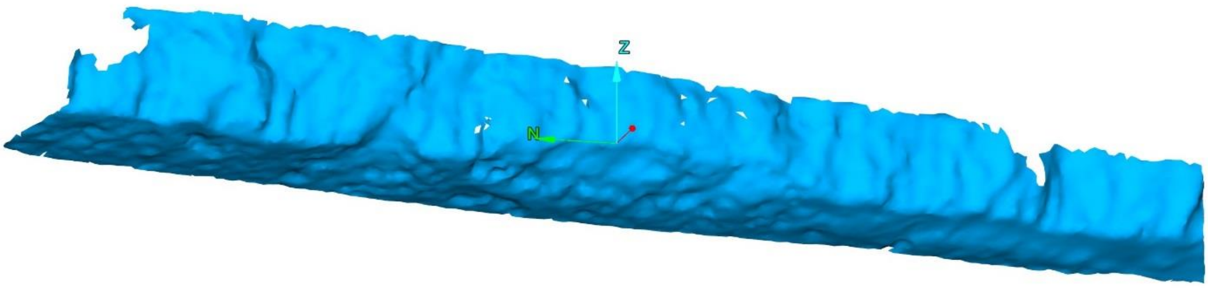
South Section – 2010 (Extents: E 567267 m, N 341356 m to E 567270 m, N 341340 m. Height range = 14.0 m to 17.0 m)



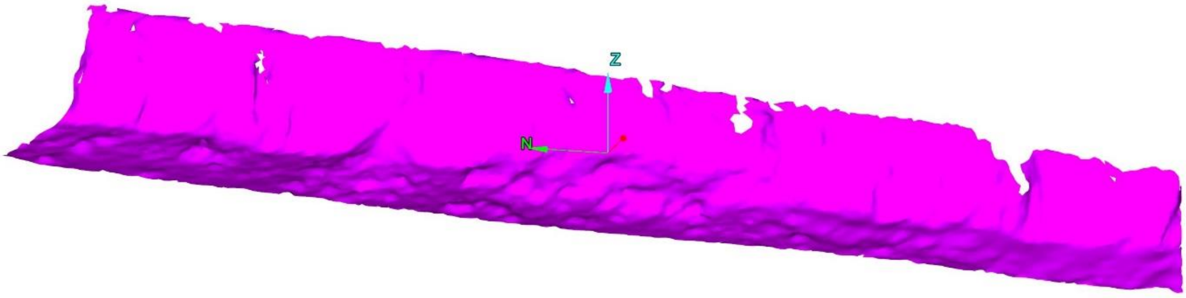
South Section – 2012 (Extents: E 567332 m, N 341539 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)



South Section – 2017 (Extents: E 567267 m, N 341356 m to E 567262 m, N 341319 m. Height range = 14.0 m to 17.0 m)

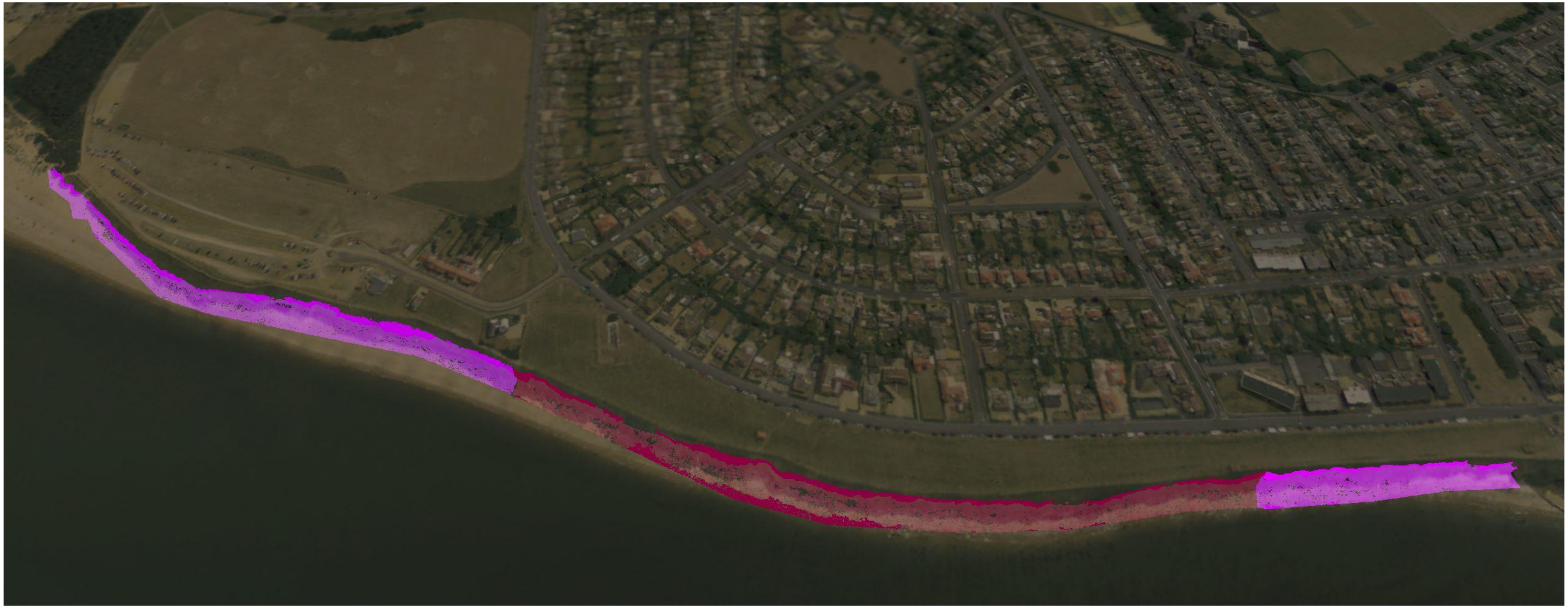


South Section – 2019 (Extents: E 567267 m, N 341356 m to E 567268 m, N 341332 m. Height range = 14.0 m to 17.0 m)

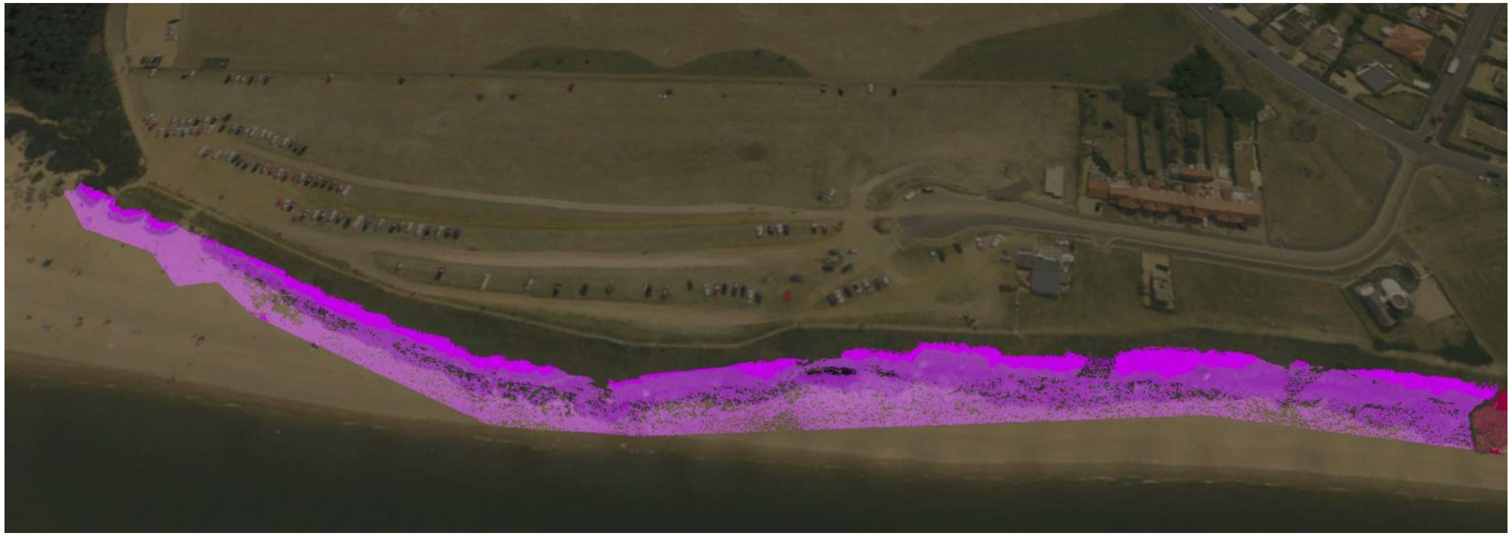


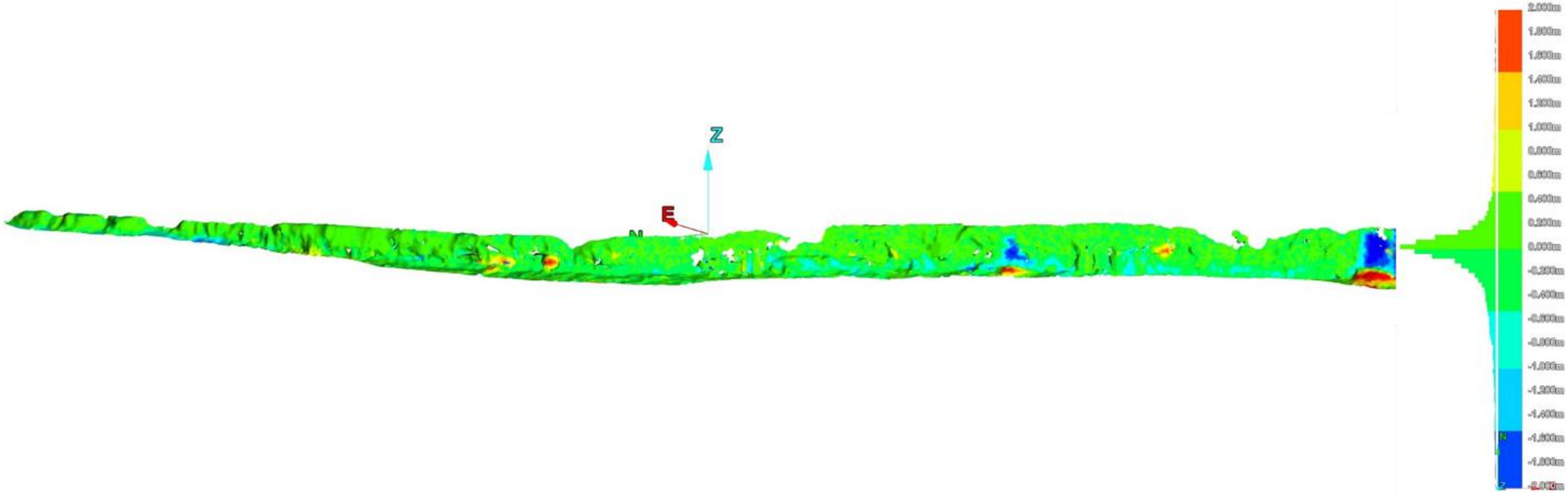
Appendix 2 Change Models

Aerial view of entire section



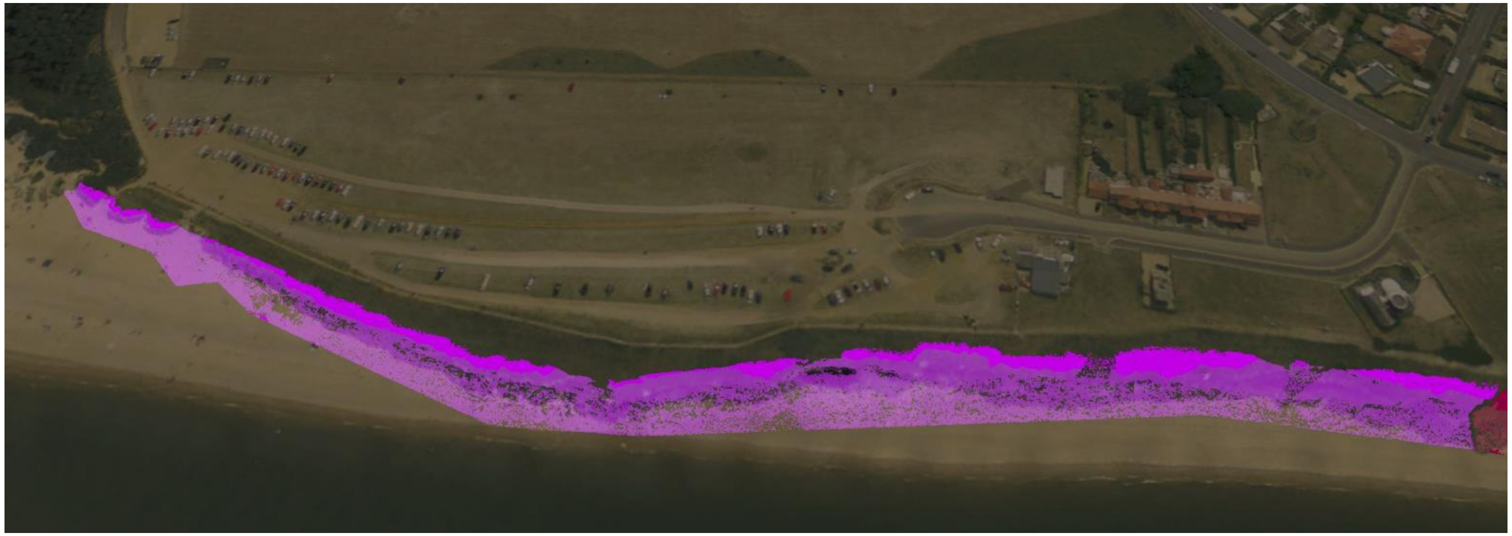
North Section – 2010 to 2017 (Extents: E 567930 m, N 342409 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)

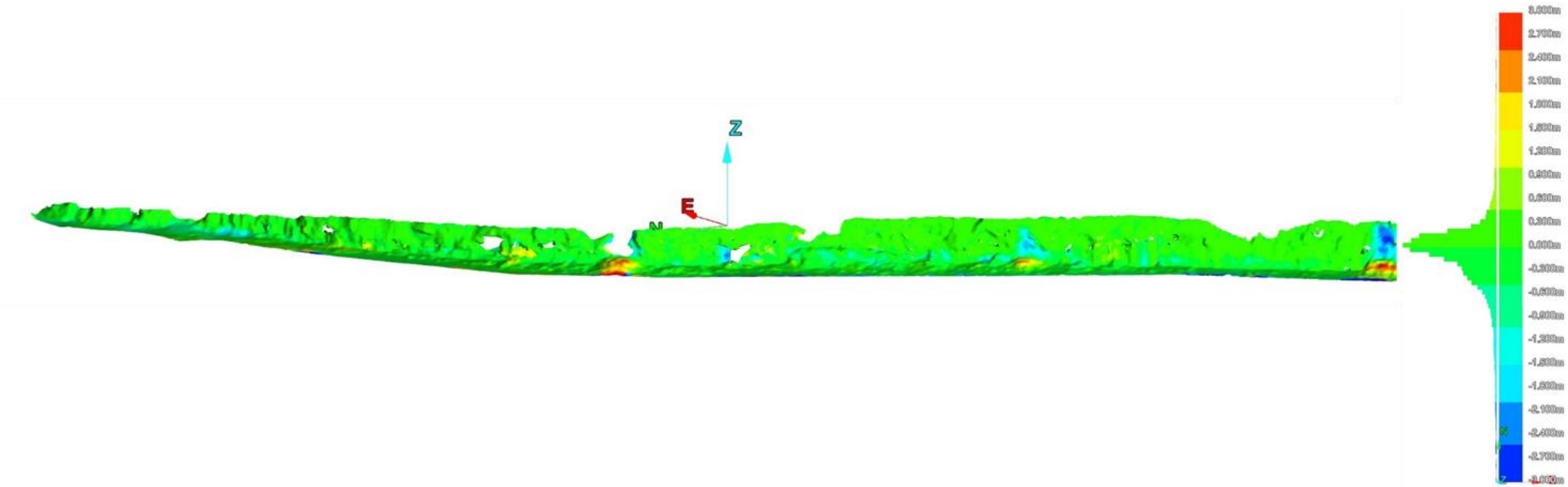




Note: Change = -2 m (Blue) to +2 m (Red)

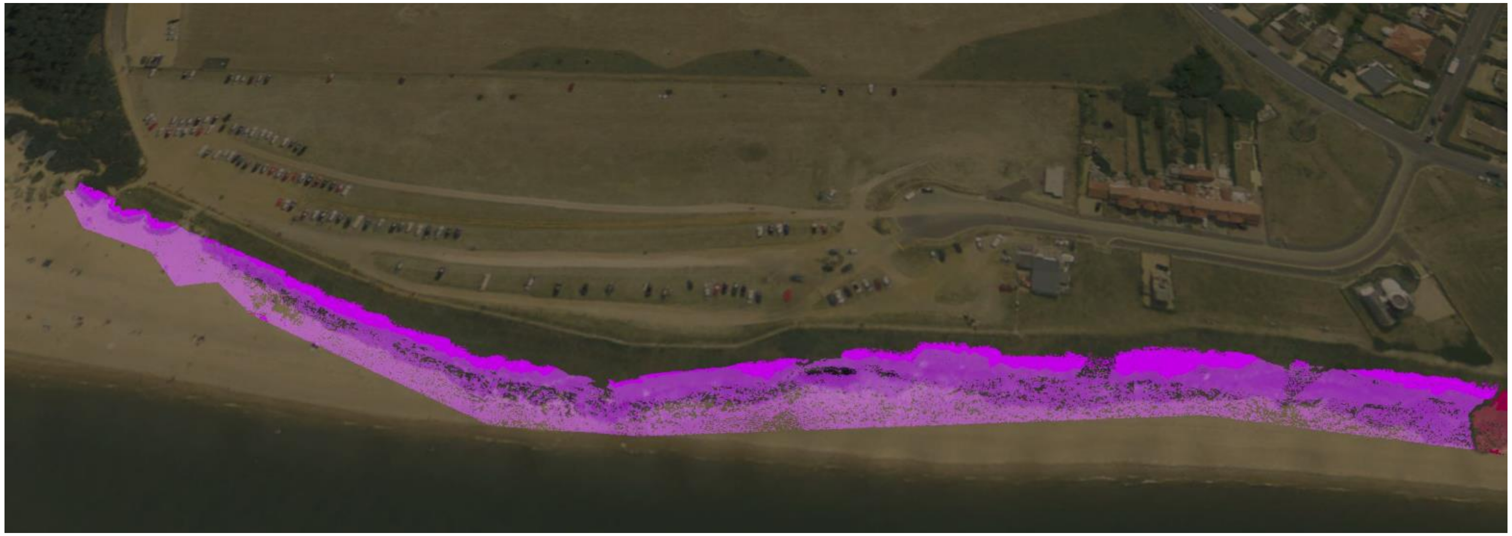
North Section – 2010 to 2019 (Extents: E 567930 m, N 342419 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)

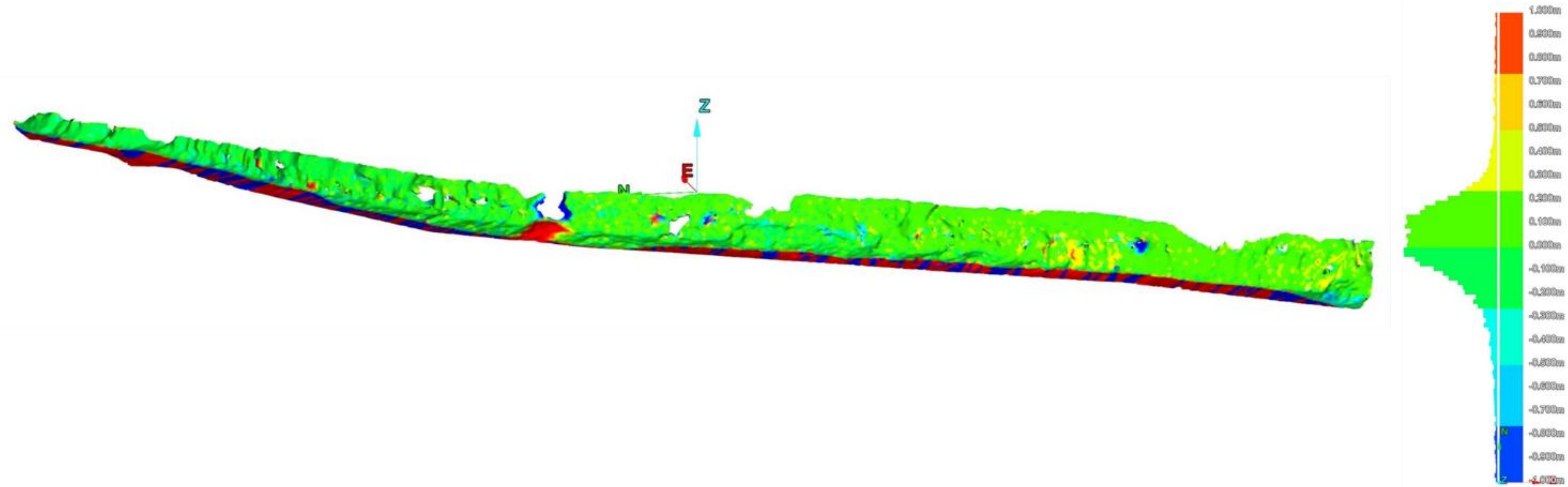




Note: Change = -3 m (Blue) to +3 m (Red)

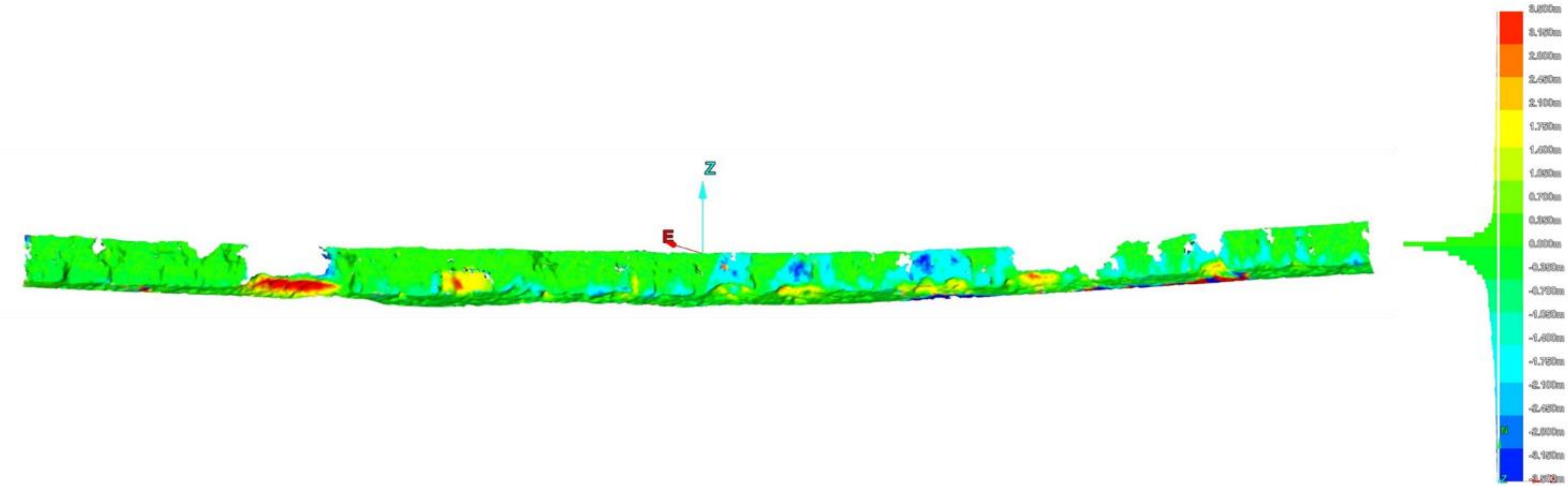
North Section – 2017 to 2019 (Extents: E 567930 m, N 342409 m to E 567270, N 341340 m. Height range = 6.3 m to 15.7 m)





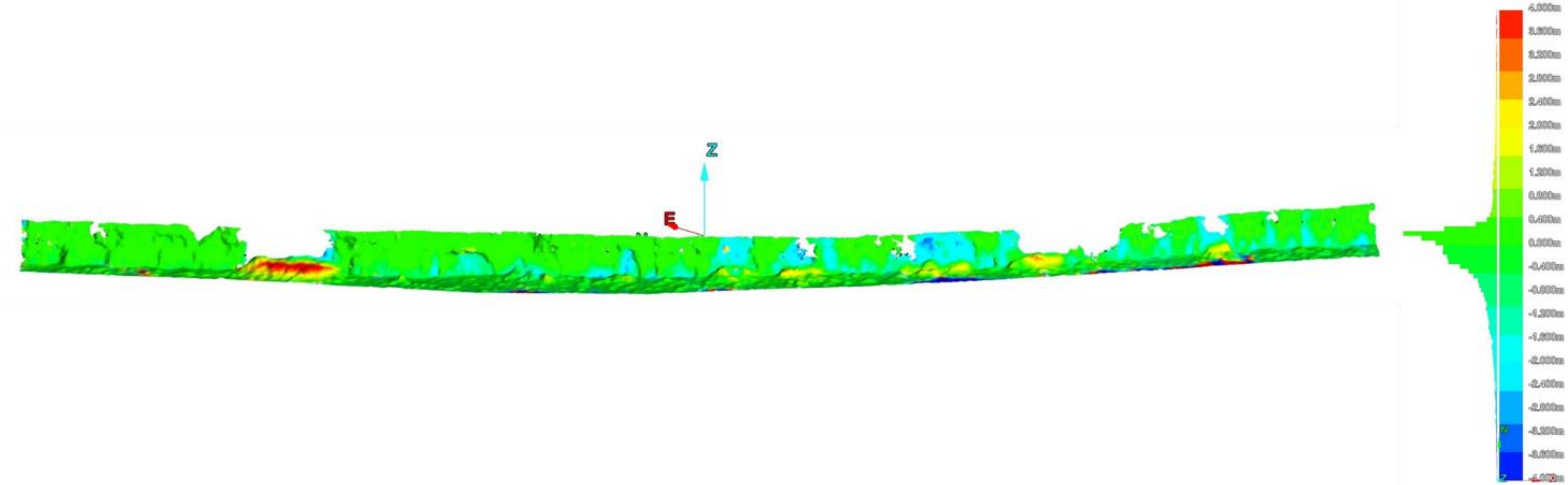
Note: Change = -1 m (Blue) to +1 m (Red)

Middle Section – 2010 to 2017 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



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

Middle Section – 2010 to 2019 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



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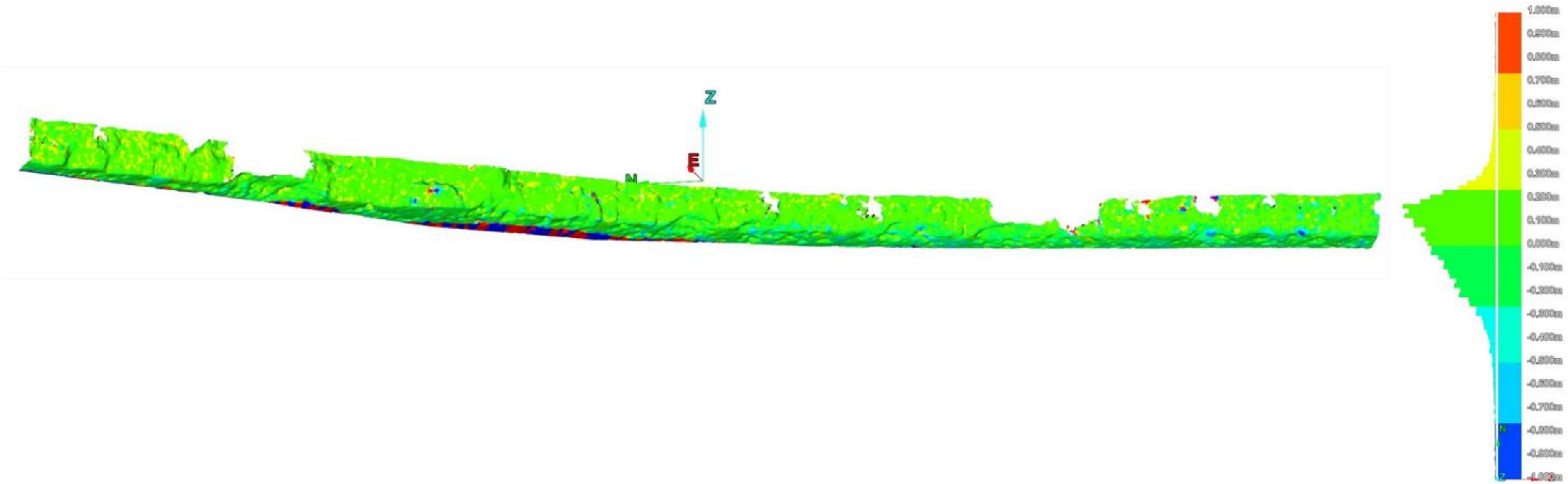
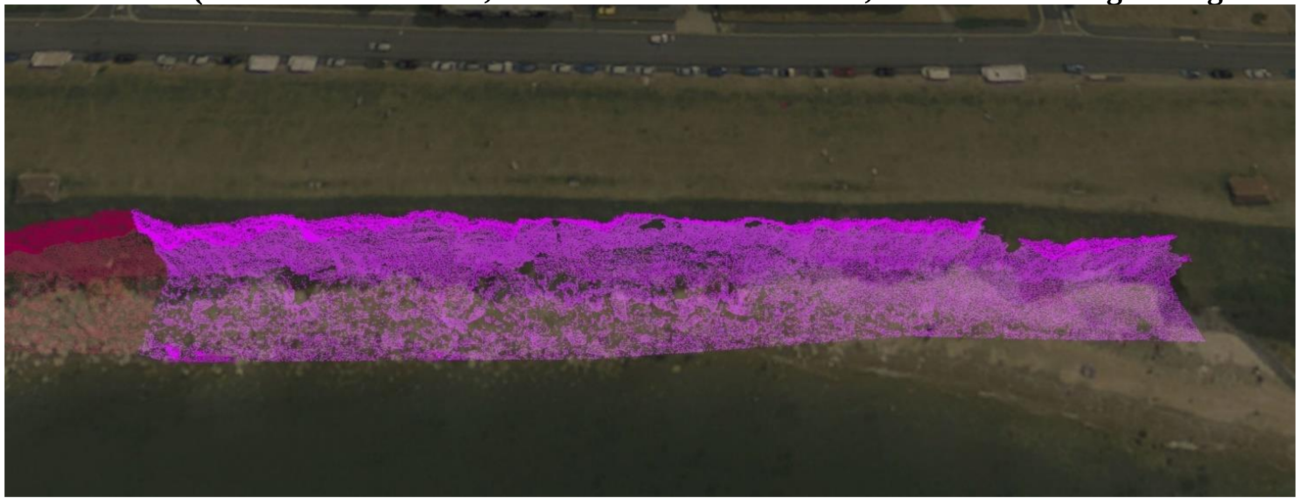
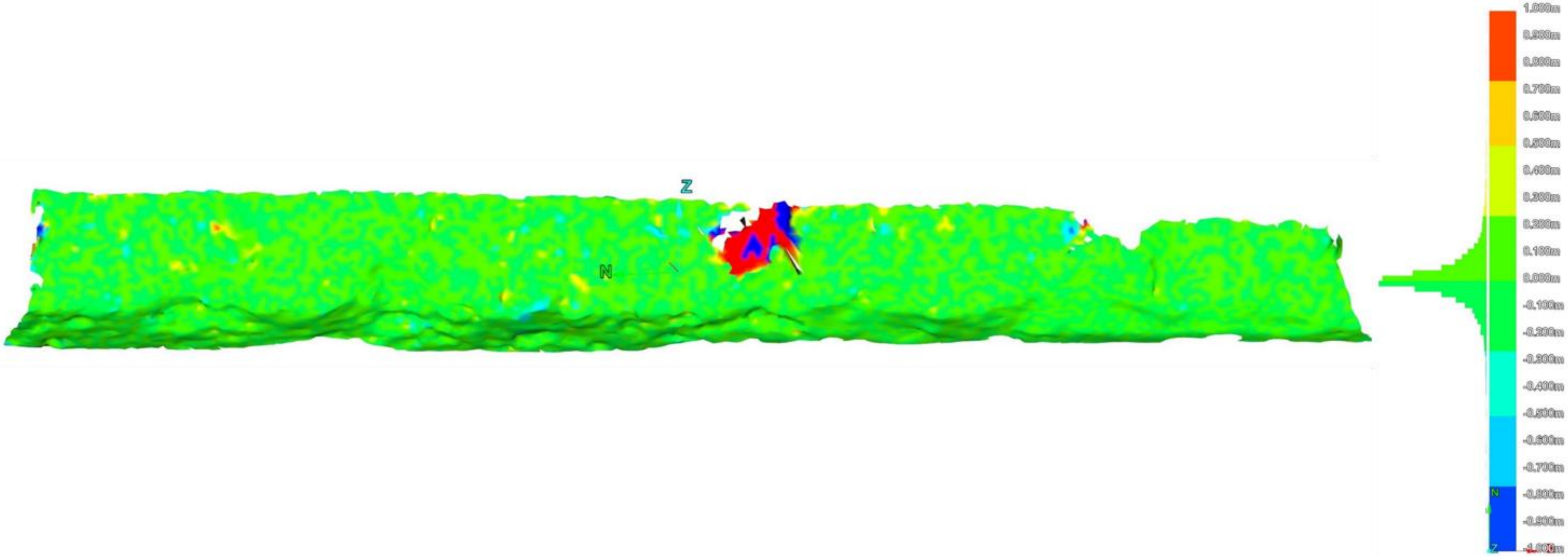
Middle Section – 2017 to 2019 (Extents: E 567314 m, N 341539 m to 567584 m, N 342052 m. Height range = 16.5 m to 18.8 m)



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

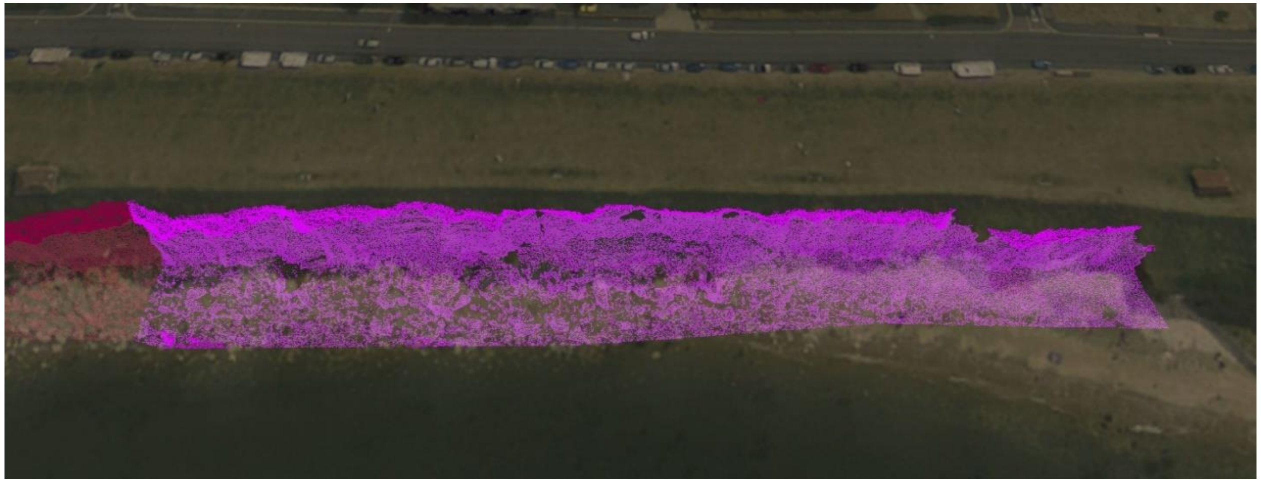
South Section – 2010 to 2012 (Extents: E 567332 m, N 341419 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)

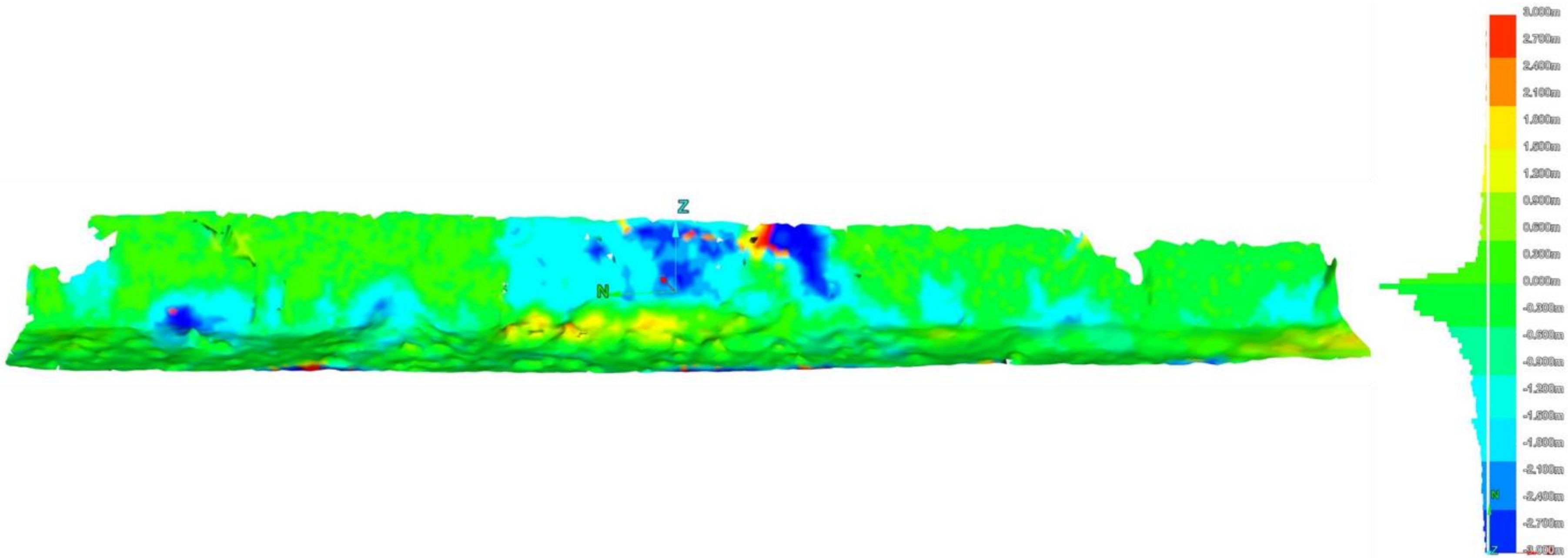




Note: Change = -1 m (Blue) to +1 m (Red)

South Section – 2010 to 2017 (Extents: E 567267 m, N 341356 m to E 567270 m, N 341340 m. Height range = 14.0 m to 17.0 m)





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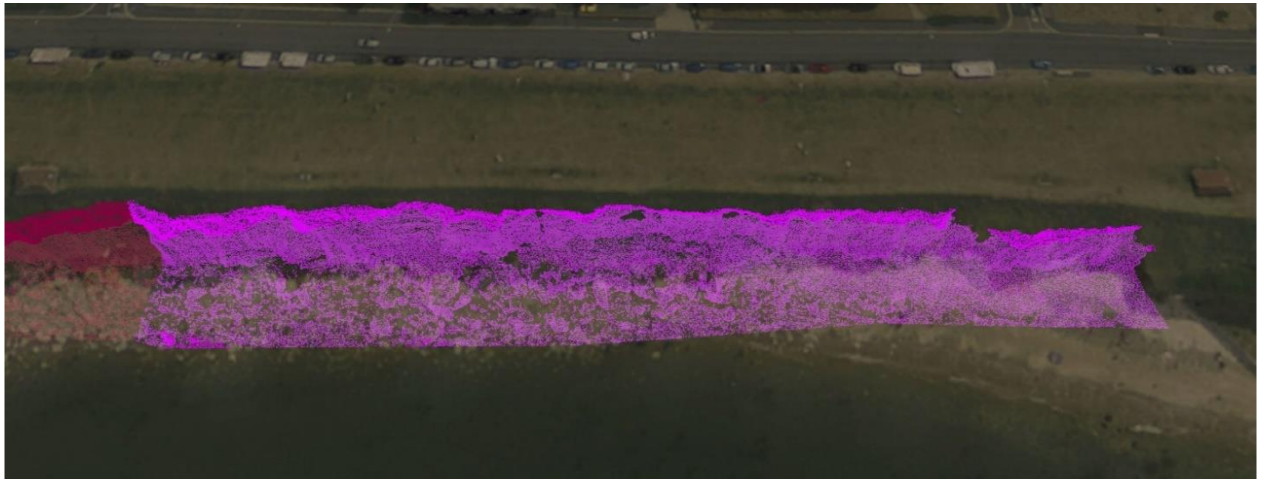
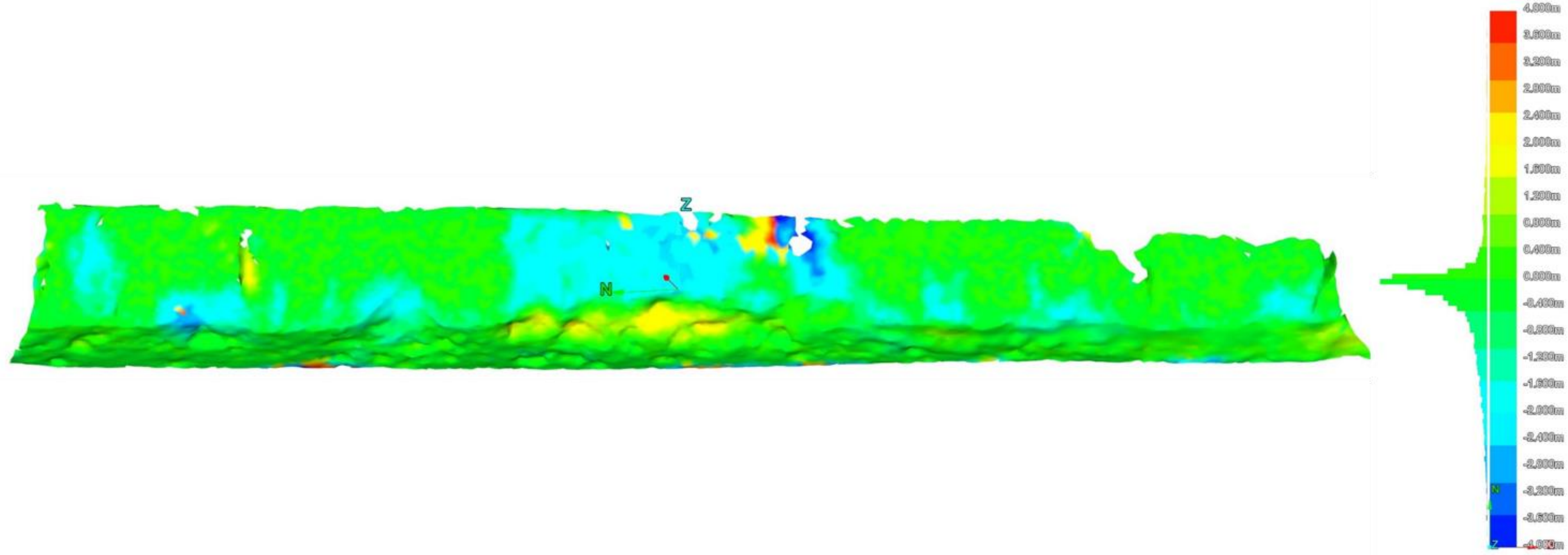
South Section – 2010 to 2019 (Extents: E 567267 m, N 341356 m to E 567270 m, N 341340 m. Height range = 14.0 m to 17.0 m)





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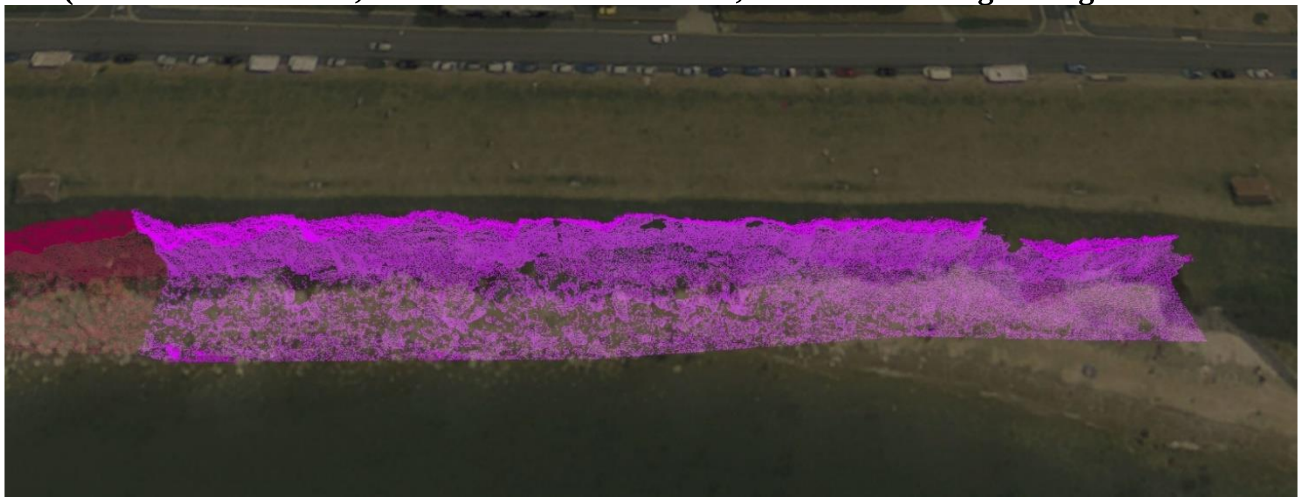
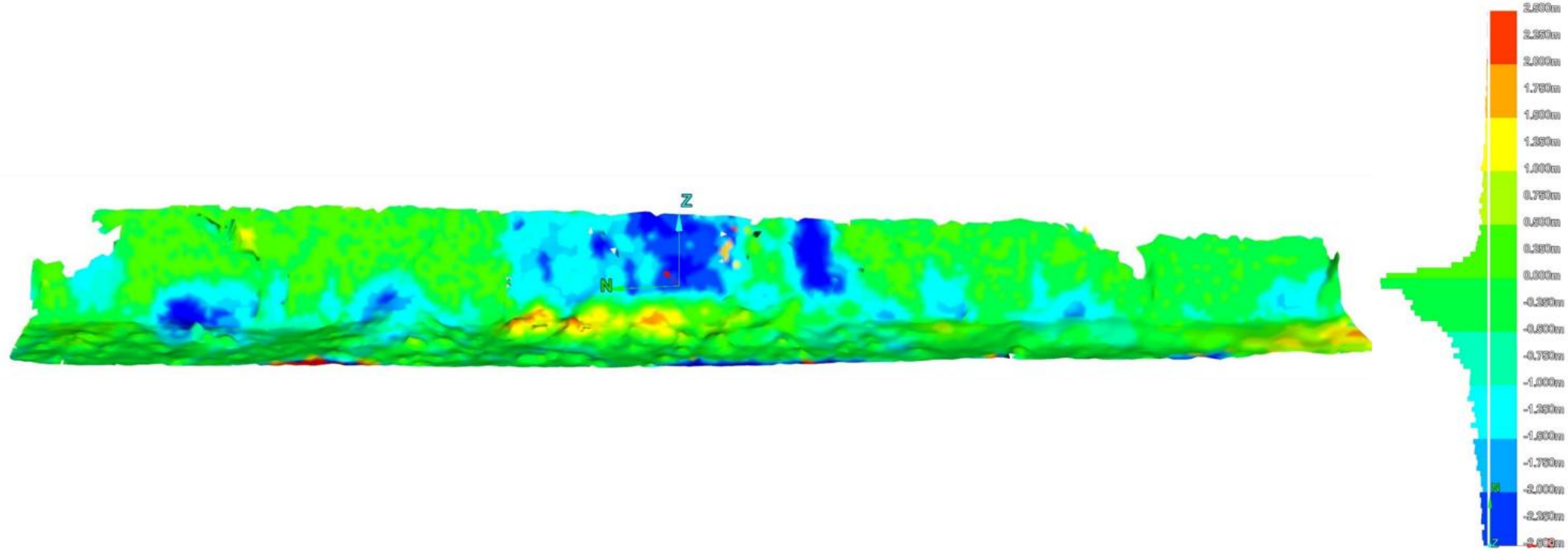
South Section – 2012 to 2017 (Extents: E 567332 m, N 341409 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)





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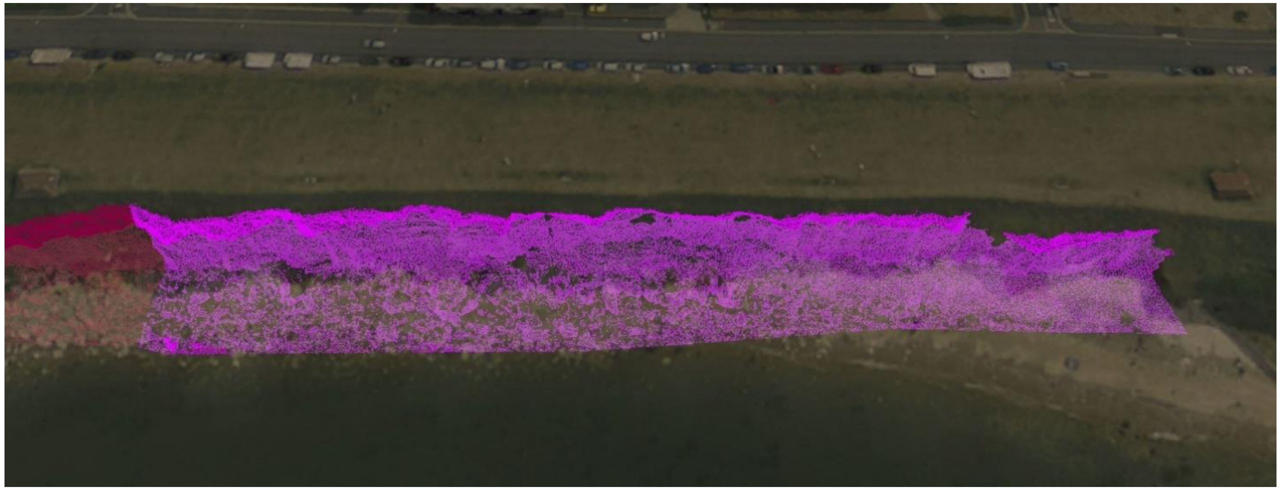
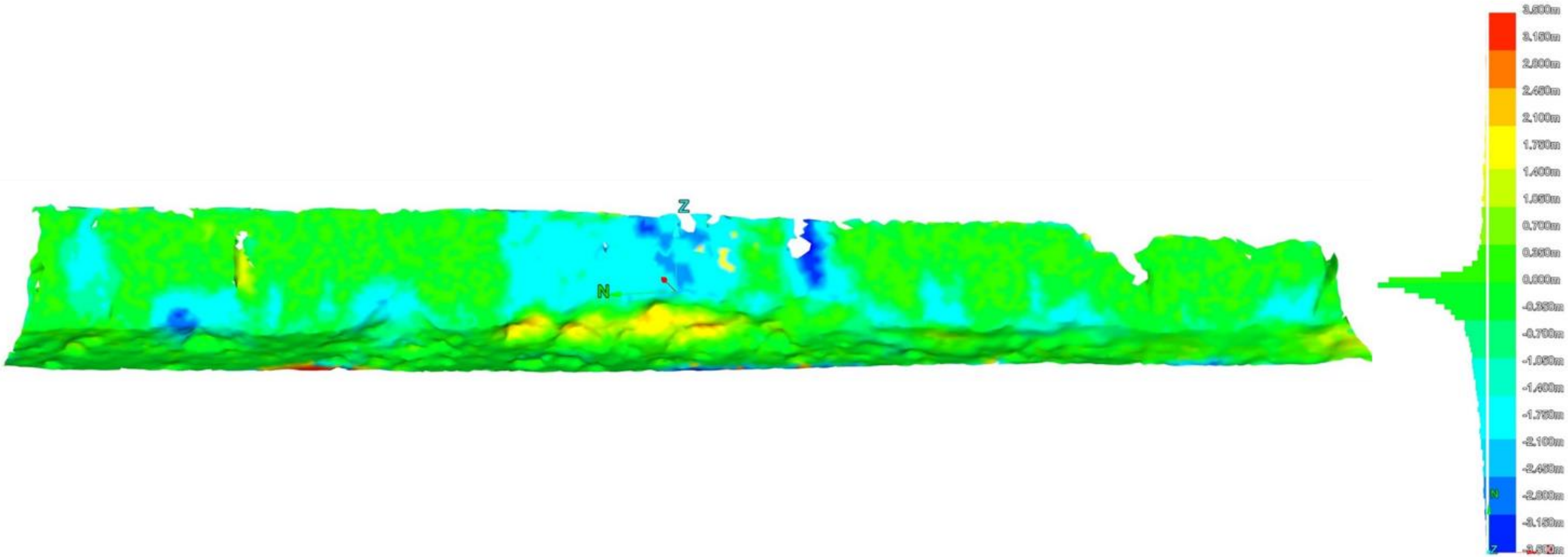
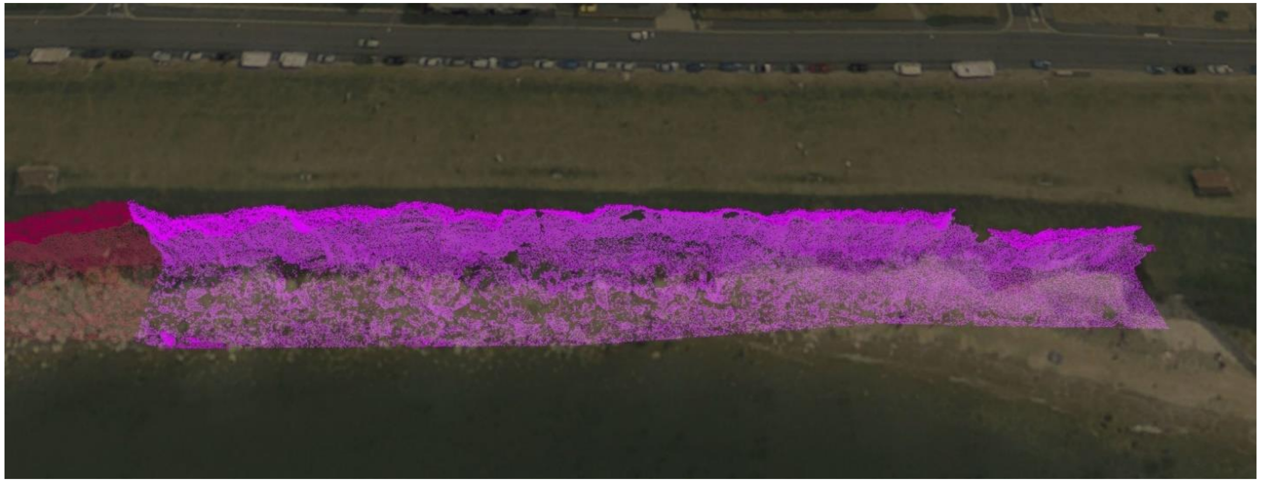
South Section – 2012 to 2019 (Extents: E 567332 m, N 341450 m to E 567282 m, N 341359 m. Height range = 14.0 m to 17.0 m)

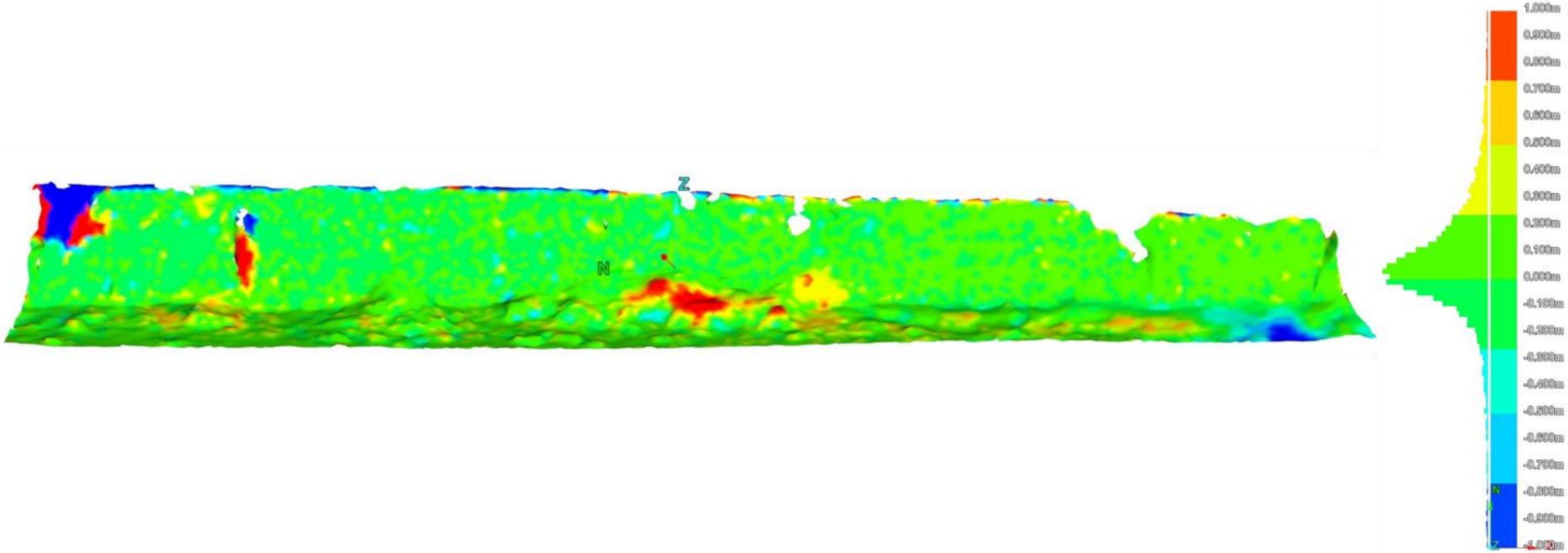




Note: Change = -3.5 m (Blue) to +3.5 m (Red)

South Section – 2017 to 2019 (Extents: E 567267 m, N 341356 m to E 567268 m, N 341332 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.

JONES, L D. 2019. GROUND-BASED GEOMATIC SURVEYS: SPECIFICATION FOR TERRESTRIAL AND MOBILE LIDAR SCANNING. BRITISH GEOLOGICAL SURVEY OPEN REPORT, OR/19/33, 33PP.

JONES, L D. 2017. GROUND-BASED GEOMATIC SURVEYS AT THE BGS - A MANUAL FOR SPECIALIST DATA COLLECTION AND PROCESSING. BRITISH GEOLOGICAL SURVEY OPEN REPORT, OR/17/40, 43PP.

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