Progress of the X-Com project and PhD research - Report 3 (v2)

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25th August 2017

CONTENTS

ABBREVIATIONS

DGPS	Differential Global Positioning System
DirP	Peak period direction (degrees)
EA	Environment Agency
Hs	Significant wave height (metres)
MCA	Maritime and Coastguard Agency
Metocean	Meteorological and oceanographical
MHWS	Mean High Water Spring (metres)
MLWS	Mean Low Water Spring (metres)
MWL	Mean Water Level (metres)
NOC	National Oceanography Centre
ODN	Ordnance Datum Newlyn (metres)
SCDC	Suffolk Coastal District Council
X-Com	X-band radar and evidence-based Coastal Management decisions

ACKNOWLEDGEMENT OF FUNDING SOURCES

X-band radar and evidence-based coastal management decisions (X-Com) was a project funded by the Natural Environment Research Council (reference NE/M021564/1). X-Com partners and collaborators include: Bournemouth University (BU), National Oceanography Centre (NOC), Suffolk

Coastal District Council (SCDC), Mott MacDonald, Cefas and residents of Thorpeness. The radar data analysed in the progress reports were collected during the X-Com project, while fieldwork surveys are part of a PhD studentship co-funded by Bournemouth University, Suffolk Coastal District Council and Mott MacDonald.

1 INTRODUCTION

This document is the third report summarising the data collection and preliminary results of the PhD research undertaken in association with the X-Com project. The first report (31st January 2017) presented an overview of data types and methods of data collection and analysis. The second report (31st May 2017) presented preliminary results of changes in nearshore bathymetry (radar data), beach topography (DGPS surveys) and cliff retreat (laser scans) south of the Ness. This report will describe changes in topography (DGPS surveys and data provided by the Environment Agency, EA profiles) and bathymetry around the Ness (derived from X-band radar data, processing version 26th June 2017). All profile elevations and depths are reported in Ordnance Datum Newlyn (ODN).

Bathymetry derived from radar data presented in this report should be considered only for purposes of relative comparison, as the actual depth values may change as a result of reprocessing using algorithms updated by the NOC and following data validation. Validation will be based on bathymetric surveys undertaken in January 2017, when data are made available by the Maritime and Coastguard Agency (MCA).

2 METHODS OF ANALYSIS

This report focuses primarily on topography changes observed along the EA profile TN007, located in the north face of the Ness; which is complemented by the analysis of three other adjacent profiles (Figure 1). For TN007, the beach profile analysis spans 8.5 years, from 7th January 2009 to 27th June 2017 and includes seasonal data provided by the EA (2009 – 2016) and the more frequent X-Com profiles (August 2016 – June 2017). For the other three profiles, only seasonal data from the EA is available.

The complex morphology of the Ness makes impractical the use of laser scanning to measure topography, mainly due to shadow effects associated with gravel ridges. For this reason and to allow comparison with the EA profiles, DGPS surveys along cross-shore transects have been conducted to measure the Ness topography. Differences between X-Com and EA data collection methods result in an uncertainty of less than 1% in the calculated beach volumes, which warrant comparability of the two methods. A list of all profiles used in the analysis and details of the uncertainty assessment is presented in Appendix 1.

Figure 2a shows all the surveys included in the analysis and the reference tidal levels (as indicated in Table 1) used to calculate the area of TN007. Figure 2b shows the range of change in elevation every 0.25 m along the cross-shore to indicate the largest changes in beach levels. Note that the range does not reflect the net change (accretion or erosion) in the period. As the upper part of the profile is relatively stable, analysis of change through time was based on profile area above -1 m ODN (MLWS) seaward of 38 m cross-shore distance (shown as the white area in Figure 2a). To enable consistent comparison, shorter profiles were extrapolated to the -1 m ODN using the mean intertidal beach slope (6.3°) calculated between 1 and -1 m ODN from all available profiles. Note that volume can be inferred by multiplying the area of the profile by an assumed profile width (a distance alongshore showing topography similar to the profile). Therefore, if one assumes that the topography is unchanged for 10 m alongshore, the volume is 10 times the calculated profile area.

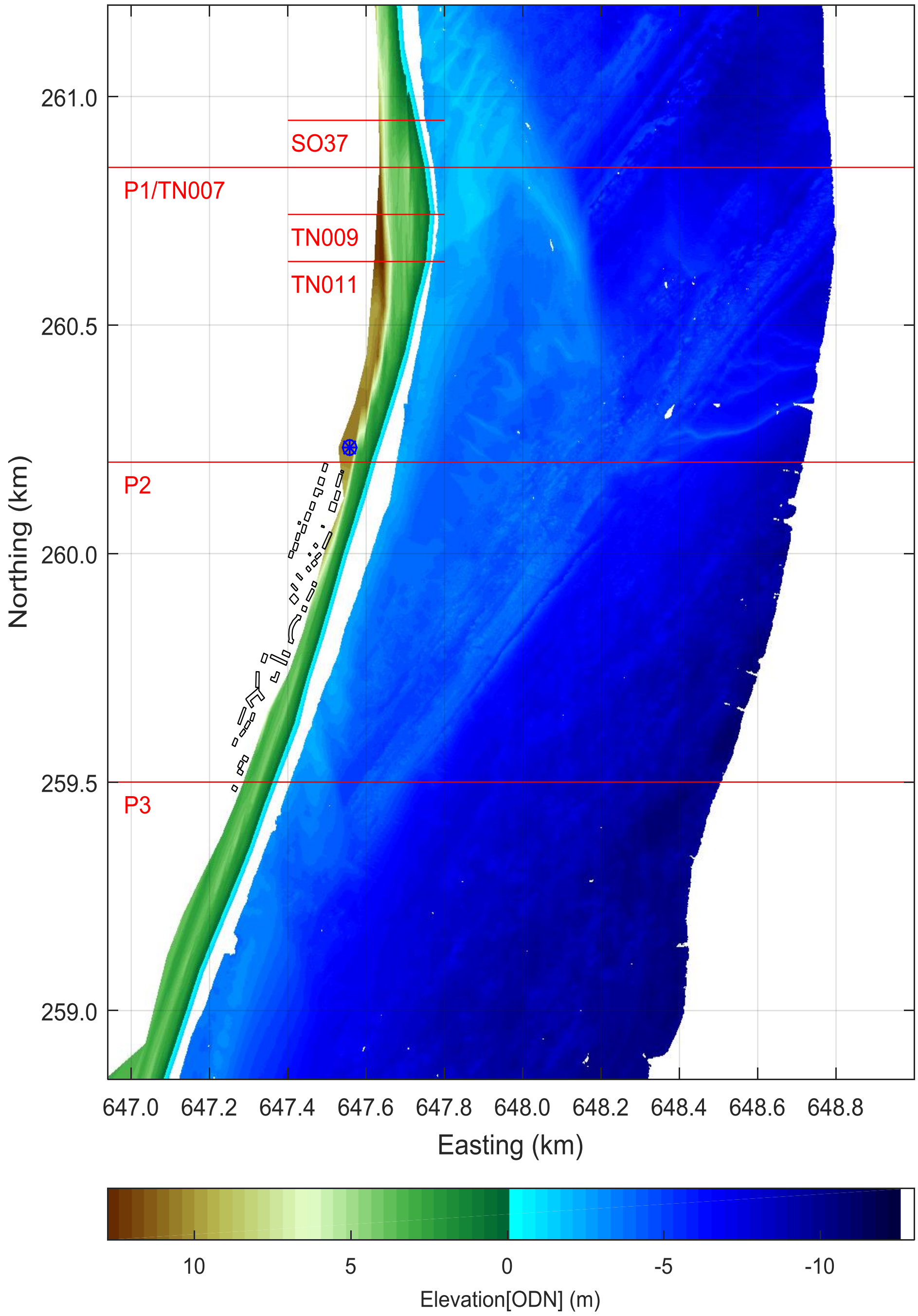

Figure 1. Study area showing the location of profile TN007 and other transects analysed in this report (radar location is shown as a blue circle just north of P2). Beach topography is shown as the interpolation of EA profile data from August 2014 and the nearshore bathymetry is taken from the EA multi-beam survey undertaken in July 2014.

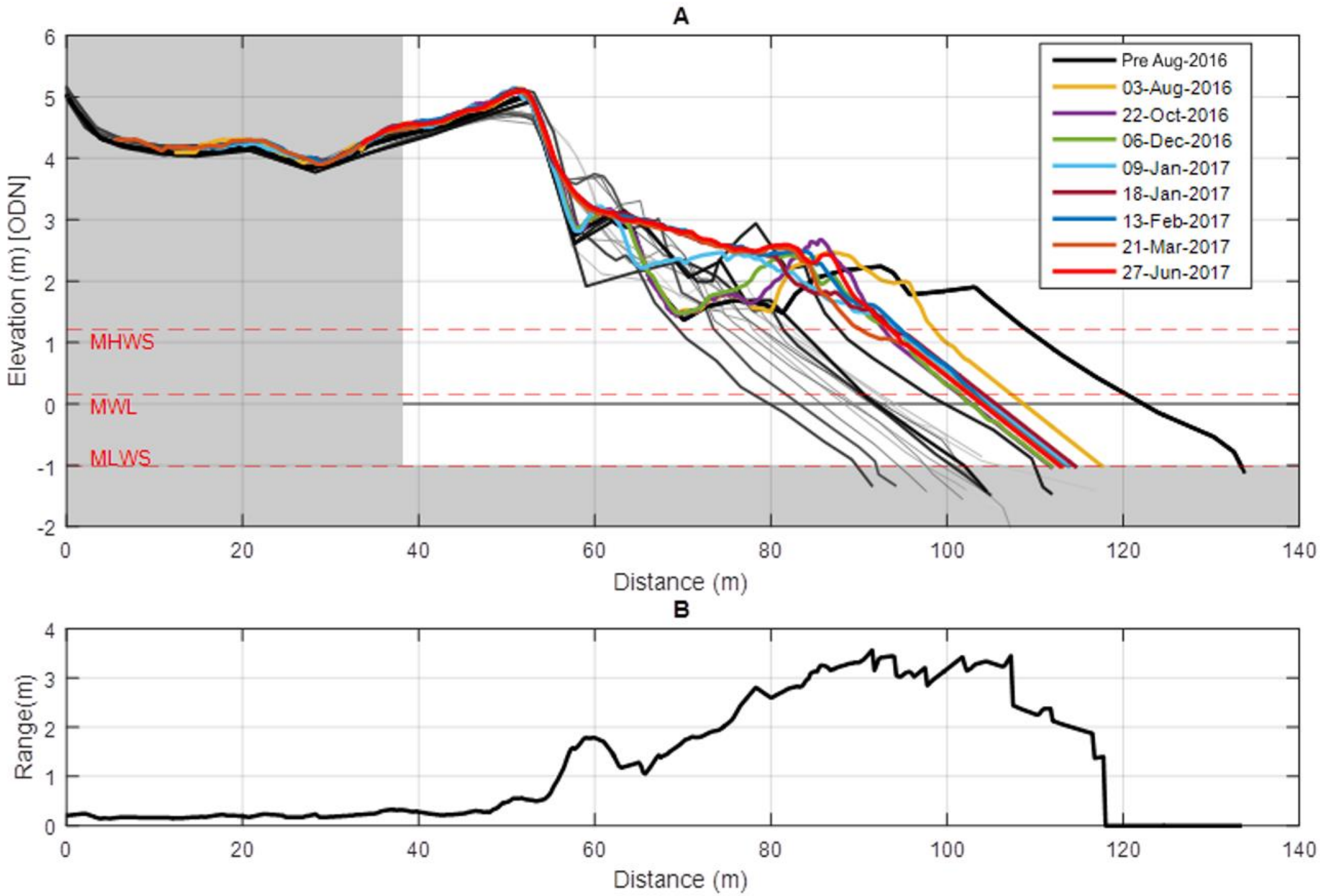

Figure 2. a) Beach profiles measured along transect TN007 between Jan 2009 and June 2017 (EA profiles are shown in greyscale with line thickness increasing towards more recent surveys; X-Com profiles are shown in colour). Calculation of profile area is confined by the MLWS and 38 m chainage, shown as a white background. b) Maximum change in elevation across all surveys estimated at 0.25 m intervals cross-shore.

Table 1. Reference levels used in this report to calculate profile area are based on tidal elevations at Sizewell (HR Wallingford, 2010).

Reference Level		Elevation (m ODN)
MHWS	Mean High Water Spring	1.22
MSL	Mean Sea Level	0.16
MLWS	Mean Low Water Spring	-1.01

Changes in the topography of the Ness will be analysed with focus on profile TN007 complemented by the analysis of one profile to the north (SO37) and two to the south (TN009, TN011), the four profiles are spaced 100 m from each other (Figure 1). The analysis of nearshore change can help understand the sediment pathways linked to the changes observed in beach morphology at the Ness and Thorpeness. This report will focus on the seaward extension of profile TN007 (P1) and two other transects (P2 and P3) further south (Figure 1) to enable an assessment of spatial variation at times coinciding with the beach surveys. The analysis of nearshore changes can only cover the time span of the radar installation (Aug 2015-March 2017). When radar data were not available for the dates of beach surveys, data of the closest date were used; the best match for the beach survey on 5th August 2015 was radar data obtained on 18th September 2015 and for the beach survey on 22nd October 2016, radar data from 2nd November 2016 was used.

3 Changes in the Ness

The profile TN007 shows a stable upper beach (0-50 m) with elevations generally above 4 m ODN and reaching 5 m ODN at its highest crest around cross-shore distance of 55 m (Figure 2). Seaward of the highest crest and above MHWS, the profile morphology is the most variable, sometimes showing multiple ridges, which can move and merge resulting in a smoother and gentler slope. Between MHWS and MLWS the profile morphology is much less changeable, showing a featureless sloping surface that tends to keep its characteristics despite beach narrowing or widening. The differences in morphology observed above and below MHWS may indicate that the former is strongly shaped by wave processes during high water levels, while the latter is flattened out by tidal currents.

Changes in beach elevation between January 2009 and June 2017 are more evident in the time-stacked profiles shown in Figure 3. A sharp lowering of the beach levels and retreat of the crest is evident in 2010 around 60 m chainage distance. The crest position remains roughly the same afterwards, while periods of increased beach elevation are observed between 2011 and 2014 and after early 2015. Between 2011 and summer 2013 prominent gravel ridges are formed and then eroded during the winter of 2013/14. From mid-2015, the profile shows multiple ridges, which seem to give place to an overall accreted profile above MHWS sometime between 9th and 18th January 2017 (Figure 2). Since then, the upper beach (0-80 m chainage) showed little change in elevation.

The beach width along TN007 varied over 40 m at MWL (Figure 2a), with the wider profile observed in February 2016 due to gravel ridges forming further seaward. Between February and August 2016, the gravel ridge seemed to have migrated landward resulting in a reduction in beach width of 10 m (Figure 2a). Despite this beach retreat, profiles measured since February 2016 are wider than previous ones, indicating that at TN007 the Ness has been wider in the period Feb 2016-Jun 2017 than in Jan 2009-Aug 2015.

The increase in beach width is followed by an increase in profile area (Figure 4a,b). The area above MLWS was relatively stable (around 190-210 m^2) between January 2009 and January 2013, reduced to 170 m^2 on 8th February 2014 and has generally increased since then (Figure 4a), reaching around 260 m^2 on February and June 2017 (53% increase over 3 years). The calculated profile areas above the reference tidal levels and changes between surveys are shown in Appendix 2. No obvious seasonal pattern in the change in beach width or profile area was observed. Instead, Figure 4b suggests an interannual cycle, in which every 2-2.5 years the area of the profile is similar to the measured in January 2009 (i.e. change in profile area relative to January 2009 is around 0 m^2). Whether this cycle is particular to the period 2009-2015 or repeating through time can only be assessed through continued monitoring.

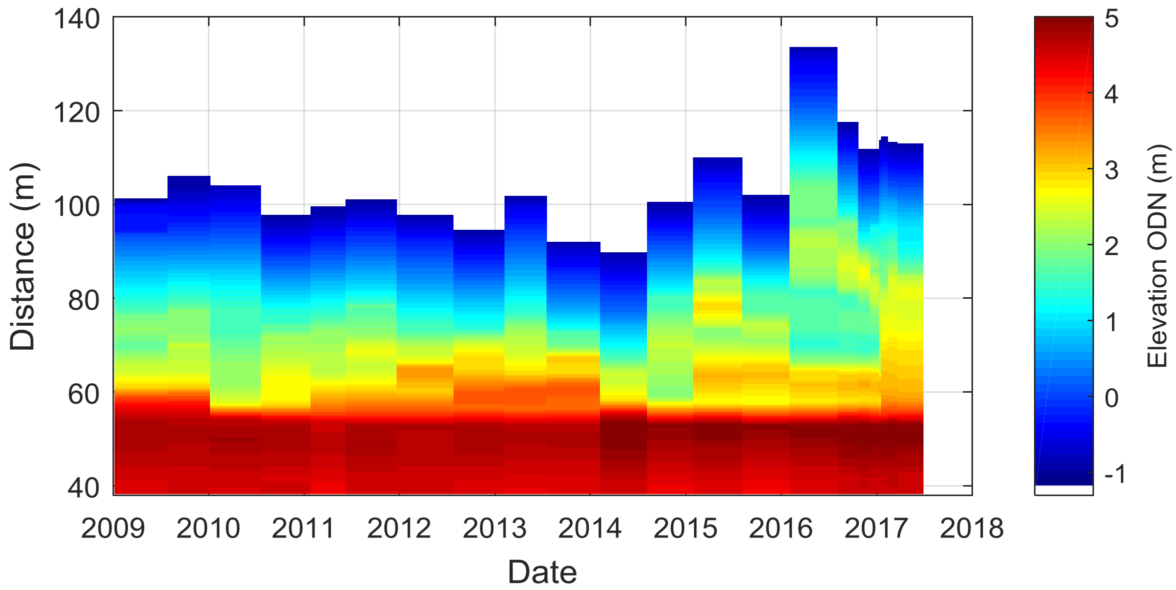

Figure 3. Time-stacked profile data help visualise changes in elevation through time.

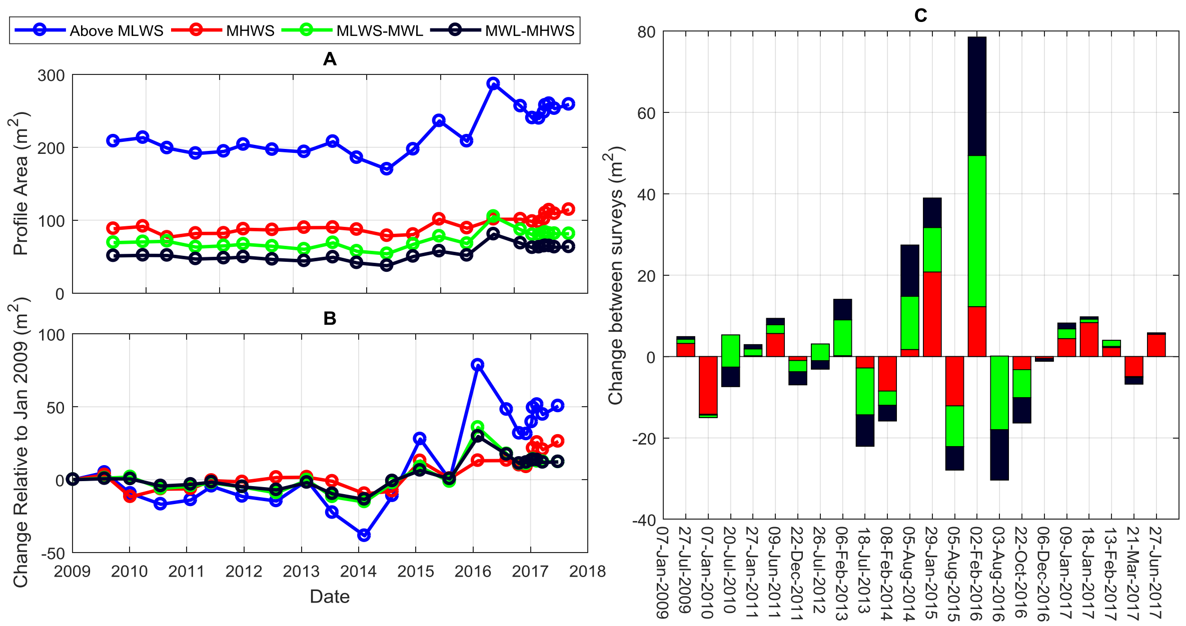

Figure 4. a) Area of TN007 profile from 7th Jan 2009 to 27th Jun 2017 per reference level. b) Changes in profile area relative to 7th Jan 2009. c) Changes in profile area between surveys (note these are biannual until Aug 2016 and more frequent afterwards).

Figure 4c shows changes in area between each survey per beach level (surveys are seasonal between January 2009 and August 2016 and more frequent since then). The magnitude of seasonal changes is highly variable and range from 3 m^2 (Jul 2010-Jan 2011) to 78 m^2 (between Aug 2015 and Feb 2016). The largest increase in profile area between surveys was due to the widening of the lower beach, probably due to the formation of a gravel ridge, which migrates landward resulting in an accreted upper profile and higher elevation in the later surveys, as shown in Appendix 3.

The data indicate that changes in area take place in the three beach levels analysed here, although different proportions and behaviours are observed, particularly above and below MHWS. Between July 2009 and July 2010, erosion dominated, primarily above MHWS in the first six months, followed by accretion in the lower part of the profile in the next six months. Between June 2011 and July 2012, the opposite was observed (Figure 4c). In some periods, most of the changes in area occurred in the upper part of the profile (above MHWS), as can be seen since January 2017, while in other periods changes dominate in the lower part of the profile (MLWS-MWL).

To better understand the spatial variability of changes in the Ness, the topography of three other EA profiles were analysed. Surveys of profile SO37 (north of TN007) cover a time span of 25 years (biannual surveys since August 1991), while TN009 and TN011 (south of TN007) were surveyed from January 2009. The beach profile data presented in Figure 5 allows two striking observations: (a) a clear difference in the behaviour and magnitude of changes between profiles, and (b) profiles SO23 and TN007 measured on 2nd February 2016 are considerably wider than any of the other records; around 30 m wider (at MWL) than the second widest profile. This increase in beach width is much less pronounced (~10 m) in TN009 (Figure 5c) and not present in TN011 (Figure 5d).

TN011 shows a contrasting behaviour in comparison with the other profiles. TN011 was widest on 8th February 2014, while the other three profiles were at their most retreated positions. An increase in elevation of the highest crest at the upper parts of the beach was observed in all profiles, more pronounced southwards in TN009 and TN011. Along SO37, the increase in crest height is associated with a marked retreat and steepness of its slope (Figure 5a). From February 2014 to February 2016 there was a net increase in beach width in the north flank of the Ness, more pronounced from TN009 towards SO37, and a reduction in beach width along TN011 in the south flank. Along TN011 a retreat of around 17 m was observed between 8th February 2014 and 29th January 2015, a slight advance seaward until 5th August 2015, with the beach width remaining stable since then.

A description of the wave conditions in the period between surveys is shown in Appendix 4. The period between August 2015 and February 2016, when erosion was observed at TN011 and increasing accretion northwards, had a strong dominance (83%) of southerly high energy waves. However, similar dominance of southerly high energy waves observed in other periods did not result in the same behaviour or magnitude of change. For example, between February and August 2014 (85% of southerly high energy waves) accretion was observed along all profiles, this time more pronounced along TN009 and less pronounced in S037. In other periods, dominance of southerly highest waves and similar wave heights resulted in erosion along TN007 (including January-August 2015 when 27.91 m^2 of erosion was), so no simple cause-effect can be established.

It is worth noting that the accretion of beach levels in the Ness observed between 9th and 18th January 2017 occurred after a period of high energy waves and coincided with a storm surge of over 1 m (Figure 66). Profile TN007 showed an increase in area above MHWS of 18 m^2 between 6th Dec 2016 and 18th Jan 2017, of which 10 m^2 were deposited between 9th and 18th Jan 2017, when waves were relatively high (mean Hs=1.35 m and 5% of Hs>2.57 m), with 96% of the highest waves approaching from the N (Appendix 4). In the same period, beach lowering and cliff retreat was observed just north of Thorpeness and very little change in beach levels further south (see Report 2 pages 11 and 16).

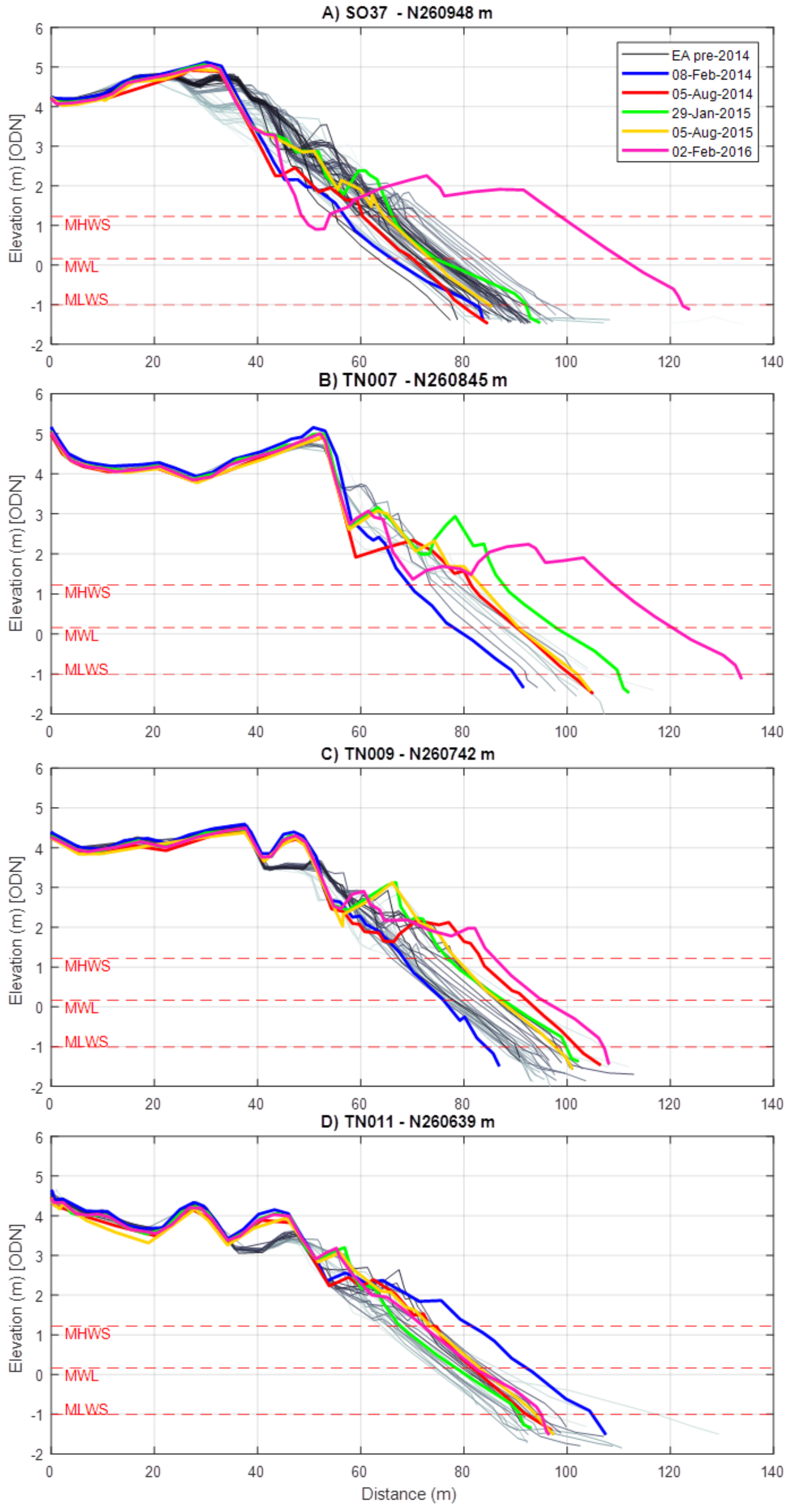

Figure 5. Beach topography measured biannually by the EA along four profiles A) SO37, B) TN007, C) TN009 and D) TN011. Profile S037 has been measured from 1991 and the other profiles from 2009. Surveys between February 2014 and February 2016 are shown in colour.

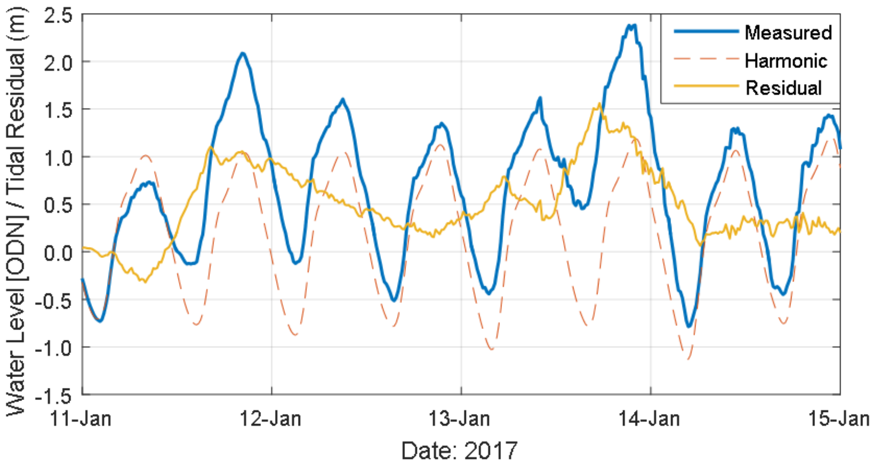

Figure 6. Lowestoft measured and harmonic prediction level with calculated residual for significant storm surge events in January 2017.

No seasonal pattern or clear relationship between erosion/accretion with northerly or southerly wave dominance are evident (accretion and erosion were observed from Jan/Feb to Jun/Jul and vice-versa, independently whether waves were dominantly from the north or south). Some locations, as increasingly evident in Thorpeness, have high temporal and spatial variability of shoreline changes, which can overcome seasonal effects. It is also possible that coastal changes respond to longer cycles and seasonal effects are absent. Additionally, results from the analysis of 'seasonal' measurements are highly dependent on the beach conditions at the time of measurement and do not necessarily reflect 'average' seasonal conditions.

X-Com more frequent surveys indicate that large changes can be observed in shorter periods of time (such as the erosion of 16 m^2 between August-October 2016 and the accretion of 10 m^2 between 9-18 Jan 2017). Quantifying how large these changes can be and how fast they occur depends on timely surveys. Additionally, these surveys provide evidence of variability within seasons and their effect on beach morphology. Appendix 4 describes in more detail the changes in beach topography in profile TN007 between August 2016 and June 2017. These frequent surveys showed that the increase in beach levels occur through the inland movement of gravel ridges, which fill in the areas of lower elevation.

4 Nearshore Changes

The radar-derived bathymetry on the dates best matching the beach surveys (Figure 7) shows a shallower nearshore in the summer (deposition over the spring) and a deeper nearshore in the winter (erosion over the autumn), as described in Report 2. Although it is often assumed that erosion occurs in the winter months as a result of increased storminess, Figure 7 shows evidence of accretion in the nearshore over the winter (Jan-Mar 2017) following the nearshore erosion event (and lowest sediment volume within radar view) in late November 2016 (see report 2, pages 9-11). Changes tend to be more prominent in the central part of the study area (Profile 2) as also evident in Figure 8 and Table 2.

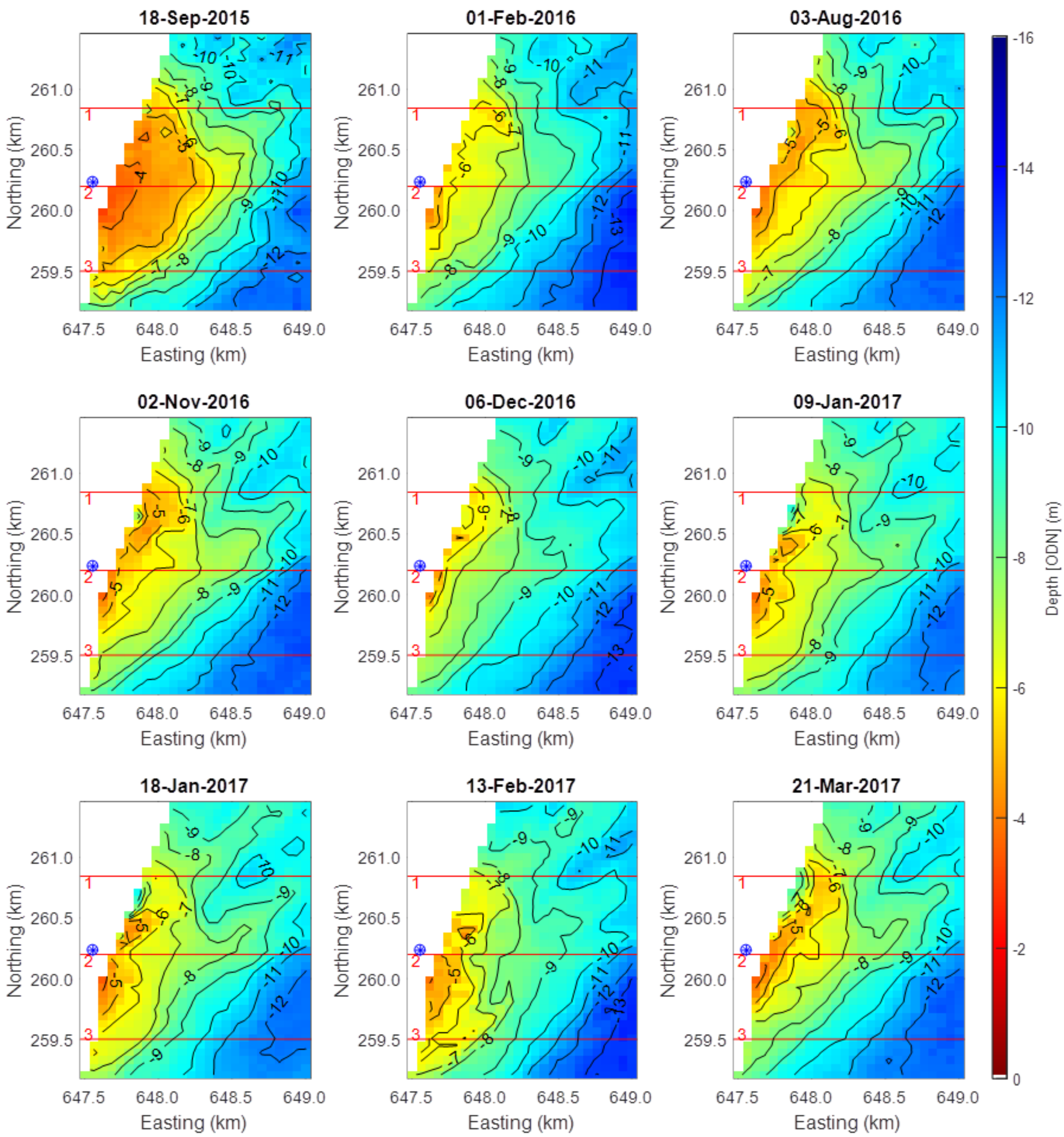

Figure 7. Radar derived depths at dates closest to beach surveys. Red lines show the position of the three nearshore transects and the blue circle shows the position of the radar.

Profile 1 (extension of TN007) shows a feature in the offshore (around 648.8 km), which may be a sand/gravel ridge controlled by underlying geology, which becomes less evident further south. Maximum changes in depth reach 3.5 m in the middle of transect 2, mainly due to an accreted profile on 18th September 2015. As indicated in the analysis of Figure 7, the most accreted nearshore profile was observed in September 2015 and the most eroded was in February 2016 and December 2016 (Table 2). Accreted nearshore profiles were observed in all seasons, although the largest volumes may be found at different parts of the profile in different seasons. Note that the beach accretion observed at February 2016 and between 9th and 18th January 2017 is not as evident in the nearshore.

At the time scales shown in Table 3, no clear patterns of cross-shore change were found between erosion or accretion in the nearshore and the Ness. Periods of accretion and erosion at the beach coincided with both erosion and accretion in the nearshore. Generally, alongshore differences in the pattern of change in the nearshore can be related to the direction of approach of the highest waves. When highest waves are dominantly from the north (such as in Jan-Feb 2017, Appendix 3), erosion occurs in the north (P1) and accretion in the south (P3, Table 2). The opposite is observed when highest waves are dominantly from the south (such as in the period Feb-Mar 2017).

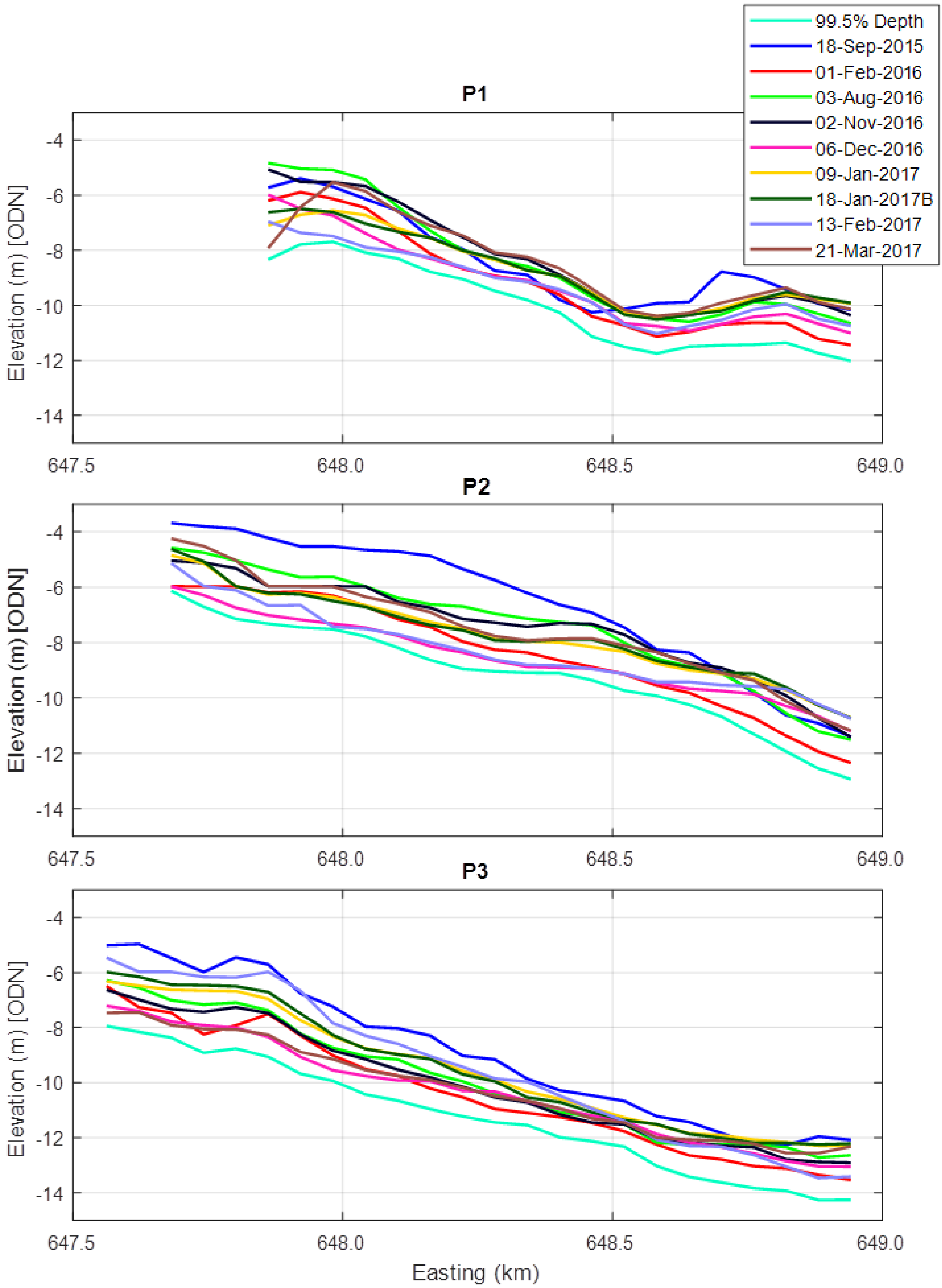

Figure 8. Bathymetry along the three selected transects for dates best matching the beach surveys.

Table 2. Changes in area along the three nearshore transects P1, P2 and P3 calculated for the period between the selected dates and as a mean daily rate (m^2/day).

	P1	Change		**P2**	Change		**P3**	Change	
Radar Date	**Area** (m^2)	m^2	**m^2/day**	**Area** (m^2)	m^2	**m^2/day**	**Area** (m^2)	m^2	**m^2/day**
18-Sep-15	1762.15	-		3246.457			3234.698		
01-Feb-16	950.47	-811.69	-5.97	972.58	-2273.87	-16.72	1161.45	-2073.25	-15.24
03-Aug-16	1729.04	778.58	4.23	2233.66	1261.08	6.85	1831.23	669.79	3.64
02-Nov-16	1841.06	112.02	1.23	2173.36	-60.30	-0.66	1615.02	-216.22	-2.38
06-Dec-16	927.22	-913.84	-26.88	791.58	-1381.78	-40.64	1276.90	-338.12	-9.94
09-Jan-17	1453.02	525.80	15.46	1775.57	983.98	28.94	2326.20	1049.30	30.86
18-Jan-17	1439.74	-13.28	-1.48	1814.23	38.67	4.30	2364.59	38.39	4.27
13-Feb-17	823.96	-615.78	-23.68	1064.61	-749.62	-28.83	2446.38	81.79	3.15
21-Mar-17	1757.69	933.73	25.94	2029.82	965.20	26.81	1403.04	-1043.34	-28.98

Table 3. Changes in area through time for the beach profile (TN007) and its nearshore extension (P1).

	TN007			**P1**	
Survey	Area above MLWS (m^2)	Change (m^2)	Radar Date	Area (m^2)	Change (m^2)
05-Aug-15	208.17	*-27.91*	**18-Sep-15**	1762.15	-
02-Feb-16	286.66	*78.49*	**01-Feb-16**	950.47	-811.69
03-Aug-16	256.30	*27.54*	**03-Aug-16**	1729.04	778.58
22-Oct-16	239.97	*-16.34*	**02-Nov-16**	1841.06	112.02
06-Dec-16	239.50	*-0.46*	**06-Dec-16**	927.22	-913.84
09-Jan-17	247.75	*8.24*	**09-Jan-17**	1453.02	525.80
18-Jan-17	257.50	9.75	**18-Jan-17**	1439.74	-13.28
13-Feb-17	259.70	2.19	**13-Feb-17**	823.96	-615.78
21-Mar-17	252.90	-6.79	**21-Mar-17**	1757.69	933.73

5 SUMMARY

This report has primarily focused on the analysis of changes in the Ness and adjacent nearshore. The beach topography of the Ness was analysed using beach surveys along four EA profiles, with focus on profile TN007 over a period of 8.5 years (from 7th January 2009 to 27th June 2017) including seasonal EA data (2009 – 2016) and the more frequent X-Com surveys (August 2016 – June 2017). The analysis of profiles north and south of the Ness allows better understanding of spatial and temporal variability of changes in the Ness. Analysis of changes in the nearshore along transects south and north of Thorpeness helped understand spatial variability in the study area and identify whether linkages between nearshore and beach changes are evident. Results have highlighted the temporal and spatial variability of beach and nearshore changes and the lack of seasonal patterns or cross-shore linkages between the nearshore and the Ness. Periods of accretion and erosion at the beach coincided with both erosion and accretion in the nearshore. However, alongshore differences may be attributed to the direction of the highest waves, although other factors (yet to be identified) seem to enhance or mask patterns and magnitudes of change. When highest waves are dominantly from the north, nearshore erosion occurs in the north and accretion in the south; the opposite is observed when highest waves are dominantly from the south.

The more frequent X-Com surveys have elucidated that beach erosion in the Ness occurs through the narrowing and steepening of gravel ridges while they migrate landwards (a reduction of 16 m^2 in profile area was observed between August and December 2016). Accretion then takes place when the migrating ridge seems to merge with other ridges further inland losing shape and filling out the topographic depressions resulting in raised levels and a concave profile (December 2016 to February 2017). In 9 days (9th to 18th January 2017), the profile area increased 9.75 m^2 while the adjacent nearshore reduced in area, which may have provided the sediment for the accretion at the Ness and/or the nearshore areas further south. Considering the strong northerly dominance of highest waves, it is likely that sediment was moving southwards. Modelling simulations in the next stages of the research will help understand the processes involved in the beach changes observed.

6 RESEARCH PLAN AND FUTURE STEPS

An important part of future work is the validation of radar-derived bathymetry, which will be conducted when the multi-beam survey data undertaken in January 2017 by the MCA becomes available. Results of validation will indicate the accuracy of the radar data and whether corrections may be required. Once the bathymetric survey becomes available, the numerical modelling phase of the study will start with model development and training being supported by Mott MacDonald.

Beach surveys are planned for 25th September 2017, January and March 2018, which may be complemented by pre- and post-storm surveys if events of interest occur and equipment is available. Additionally, sediment particle size of samples already collected during fieldwork need to be analysed, which require laboratory work for the sand fraction and digital image processing for the gravel fraction. Particle size data will be used to produce sediment coverage maps for the survey dates. Knowing how the proportion of sand/gravel change through time will help understand sediment pathways and their relationship with beach erosion and accretion. Analysis of spatial and temporal patterns of change will continue to elucidate how changes occur at different temporal scales and the key drivers of change.

7 References

HR Wallingford, 2010. Sizewell Power Station Extreme Sea Level Studies. Joint Probability of Waves and Sea Levels and Structure Response. Technical Note 01. Report to EDF Energy, HR Wallingford, Wallingford.

Appendix 1

When combining different datasets, in this case EA and X-Com beach profiles, it is important to assess whether differences in the methods of data collection do not compromise comparability of results. The EA and X-Com topographic data were obtained through DGPS surveys along the same cross-shore transect using equipment of similar precision. The key difference in the two datasets is the frequency in which elevation was recorded; elevation was measured with average spacing of 0.59 m in the X-Com surveys and 3.35 m in the EA profiles. The EA profiles also consisted of the back beach dune ridge (of around 12 m) whereas the X-Com profiles focused on the more active area of the beach profile in higher spatial resolution and relatively more accurate representation of the topography. Table 4 presents descriptive characteristics of each beach profile survey along transect TN007 analysed in this paper.

Table 4. Profile information for analysed TN007.

Date	Data source	Number of Points	Mean Sampling distance (m)	Maximum elevation (m)	Minimum elevation (m)	Cross shore distance (m)
07-Jan-09	EA	47	3.38	12.07	-1.72	155.26
27-Jul-09	EA	44	3.41	12.16	-1.40	146.44
07-Jan-10	EA	42	3.42	12.07	-0.86	140.32
20-Jul-10	EA	49	2.94	12.09	-1.40	141.17
27-Jan-11	EA	36	4.35	12.29	-2.05	152.36
09-Jun-11	EA	42	4.21	12.09	-1.26	172.41
22-Dec-11	EA	44	3.11	12.09	-1.55	133.76
26-Jul-12	EA	42	3.60	12.23	-1.42	147.55
06-Feb-13	EA	34	4.03	12.14	-1.00	133.14
18-Jul-13	EA	51	2.51	12.09	-1.34	125.51
08-Feb-14	EA	50	2.51	12.10	-1.35	122.79
05-Aug-14	EA	38	3.62	11.84	-1.49	133.80
29-Jan-15	EA	59	2.48	12.15	-1.47	143.70
05-Aug-15	EA	42	3.40	12.11	-1.43	139.51
02-Feb-16	EA	53	2.24	12.07	1.37	116.69
03-Aug-16	X-Com	145	0.63	5.16	0.69	90.42
22-Oct-16	X-Com	198	0.28	5.12	0.98	56.02
06-Dec-16	X-Com	124	0.60	5.08	-0.64	73.24
09-Jan-17	X-Com	133	0.60	5.16	1.09	79.26
18-Jan-17	X-Com	115	0.77	5.12	-0.99	87.75
13-Feb-17	X-Com	147	0.61	5.13	-0.08	89.31
21-Mar-17	X-Com	140	0.65	5.09	0.86	91.02
27-Jun-17	X-Com	104	0.61	5.11	0.81	63.34

The effect of the different sampling distances on the calculation of profile area was quantified by resampling one of the X-Com profiles using the 3.35 m distance between measurements and comparing the results. Figure 9 presents the profile measured on 6th December 2016 and the result from subsampling. The area above MHWS, MWL and MLWS of each profile was then calculated using trapezoidal integration linearly interpolated at 0.25 m spacing. Figure 8 shows the calculated areas and the resulting differences between the two methods. Differences were <1% which is considered acceptable and warrant comparability of the datasets.

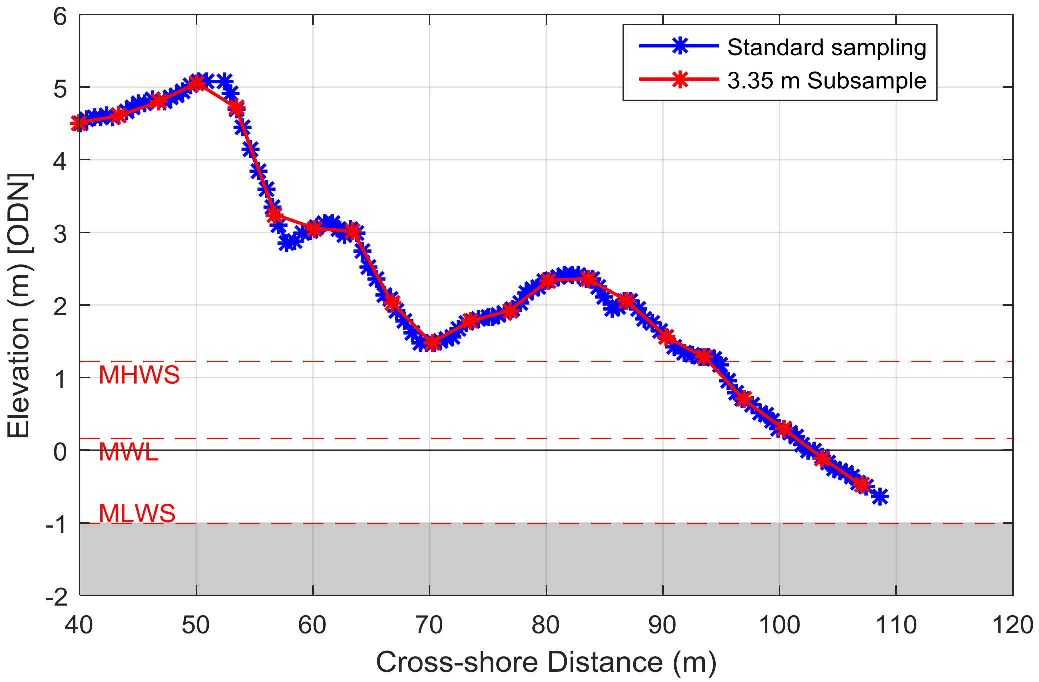

Figure 9. X-Com survey of profile TN007 on 06-Dec-2016 (blue) and resulting profile resampled with spatial resolution of 3.35 m (red) to mimic the EA profiles.

Table 5. Profile area of the standard profile (as measured in the field) and the profile resampled at 3.35 m spacing.

	Profile Area (m^2)		**Difference (m^2)**	**% Difference**
	Standard	**3.35 m**		
MLWS	229.83	230.38	0.55	0.24
MSL	151.97	152.57	0.60	0.39
MHWS	91.11	91.79	0.68	0.74

APPENDIX 2

Table 6. Area of profile TN007 above and between reference tidal levels and the change in area between surveys.

Date	Area Calculation (m^2)									
	MHWS	Change	MWL	Change	MLWS	Change	MLWS -MWL	Change	MWL - MHWS	Change
07-Jan-09	88.14	-	139.14	-	**208.22**	**-**	69.09	-	51	-
27-Jul-09	91.36	3.22	143.01	3.87	**213.13**	**4.91**	70.11	1.02	51.65	0.65
07-Jan-10	76.36	-15	127.82	-15.19	**198.78**	**-14.35**	70.91	0.8	51.46	-0.19
20-Jul-10	81.66	5.3	128.31	0.49	**191.33**	**-7.45**	63.02	-7.89	46.65	-4.81
27-Jan-11	81.85	0.19	129.57	1.26	**194.27**	**2.94**	64.7	1.68	47.71	1.06
09-Jun-11	87.51	5.66	136.8	7.23	**203.65**	**9.38**	66.85	2.15	49.29	1.58
22-Dec-11	86.53	-0.98	132.6	-4.2	**196.68**	**-6.97**	64.08	-2.77	46.07	-3.22
26-Jul-12	89.61	3.08	133.58	0.98	**193.56**	**-3.12**	59.99	-4.09	43.97	-2.1
06-Feb-13	89.81	0.2	138.84	5.26	**207.64**	**14.08**	68.79	8.8	49.03	5.06
18-Jul-13	86.99	-2.82	128.3	-10.54	**185.59**	**-22.05**	57.27	-11.52	41.31	-7.72
08-Feb-14	78.5	-8.49	115.96	-12.34	**169.72**	**-15.87**	53.76	-3.51	37.46	-3.85
05-Aug-14	80.23	1.73	130.31	14.35	**197.13**	**27.41**	66.82	13.06	50.07	12.61
29-Jan-15	101.01	20.78	158.33	28.02	**236.08**	**38.95**	77.74	10.92	57.32	7.25
05-Aug-15	88.87	-12.14	140.41	-17.92	**208.17**	**-27.91**	67.75	-9.99	51.54	-5.78
02-Feb-16	101.13	12.26	181.78	41.37	**286.66**	**78.49**	104.88	37.13	80.65	29.11
03-Aug-16	101.25	0.12	169.52	-12.26	**256.3**	**-30.36**	86.78	-18.1	68.27	-12.38
22-Oct-16	98.02	-3.23	160.08	-9.44	**239.97**	**-16.33**	79.89	-6.89	62.05	-6.22
06-Dec-16	96.88	-1.14	159.59	-0.49	**239.5**	**-0.47**	79.91	0.02	62.72	0.67
09-Jan-17	101.29	4.41	165.45	5.86	**247.75**	**8.25**	82.29	2.38	64.16	1.44
18-Jan-17	109.63	8.34	174.36	8.91	**257.5**	**9.75**	83.14	0.85	64.73	0.57
13-Feb-17	113.61	3.98	178.07	3.71	**259.7**	**2.2**	81.63	-1.51	64.46	-0.27
21-Mar-17	108.68	-4.93	171.48	-6.59	**252.9**	**-6.8**	81.42	-0.21	62.8	-1.66
27-Jun-17	114.34	5.66	177.52	6.04	**258.73**	**5.83**	81.2	-0.22	63.18	0.38

APPENDIX 3

The X-Com frequent surveys allowed a detailed understanding of beach profile changes between August 2016 and June 2017 (**Error! Reference source not found.**). In August 2016, the beach profile was the widest and one of the most accreted (256.30 m^2 one of the largest areas). Between 3rd August 2016 and 18th Jan 2017, the profile changed from having multiple gravel ridges and high relief to a convex surface with no prominent features. During this period, the changes in topography were due mainly due to the inland migration of the most seaward ridge, which merged with other ridges, gaining volume and width while losing elevation and infilling lower areas. Note that a reduction in profile area of 16.34 m^2 was observed between August and October 2016, due to the narrowing of the seaward ridge, when it starts to move inland. Afterwards the profile area increases with the largest profile area measured on 13th February (260 m^2) when a new ridge started to develop. The profile area remained relatively stable between February and June 2017, with minor changes in morphology observed in the lower parts of the profile.

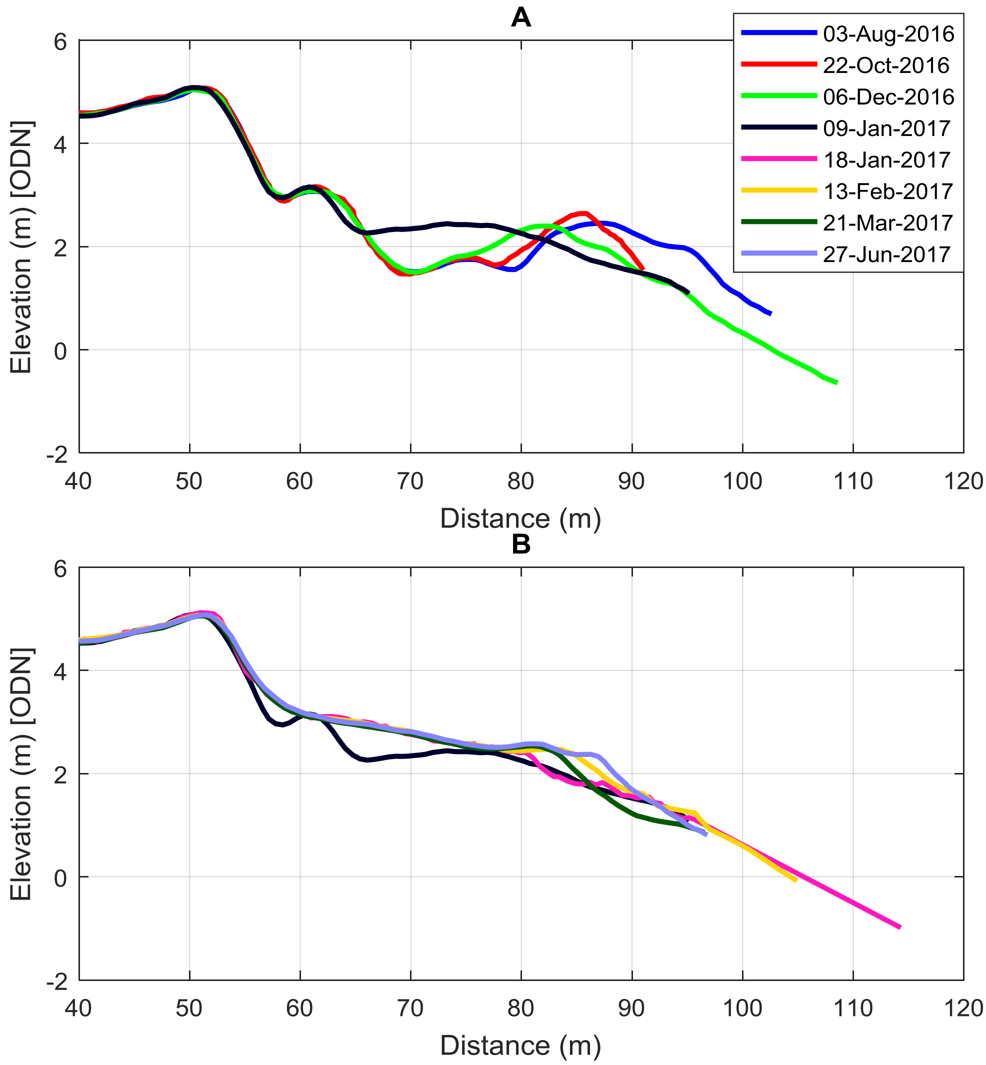

Figure 10. Changes in beach morphology along transect TN007 (prior to extrapolation), a) 3rd August 2016 – 9th January 2017, b) 9th January 2017 – 27th June 2017.

APPENDIX 4

Table 7. Wave conditions between surveys at West Gabbard buoy (periods of interest discussed in the text are indicated in grey).

		Significant Wave Height, Hs (m)				Direction			
Dates		**95%ile**	**Max**	**Mean**	**Peak Hs (DirP°)**	**N (%)**	**S (%)**	**Hs>2.5 N (%)**	**S (%)**
07-Jan-09	**27-Jul-09**	1.81	3.28	0.86	180	60.57	39.43	45.07	54.93
27-Jul-09	**07-Jan-10**	2.61	5.06	1.23	028	42.41	57.59	50.43	49.57
07-Jan-10	**20-Jul-10**	2.05	4.24	0.92	045	64.88	35.12	79.02	20.98
20-Jul-10	**27-Jan-11**	2.51	4.55	1.21	034	59.42	40.58	74.23	25.77
27-Jan-11	**09-Jun-11**	1.97	3.28	0.91	045	55.48	44.52	44.44	55.56
09-Jun-11	**22-Dec-11**	2.14	4.09	1.10	180	34.56	65.44	14.08	85.92
22-Dec-11	**26-Jul-12**	2.14	4.24	1.01	039	54.51	45.49	56.25	43.75
26-Jul-12	**06-Feb-13**	2.32	4.09	1.15	219	38.63	61.37	37.01	62.99
06-Feb-13	**18-Jul-13**	2.41	3.80	1.08	045	69.17	30.83	86.60	13.40
18-Jul-13	**08-Feb-14**	2.61	5.06	1.24	186	40.87	59.13	21.88	78.13
08-Feb-14	**05-Aug-14**	1.97	4.39	0.92	191	56.66	43.34	15.02	84.98
05-Aug-14	**29-Jan-15**	2.33	3.89	1.20	170	45.11	54.89	32.34	67.66
29-Jan-15	**05-Aug-15**	2.06	3.55	0.97	188	50.90	49.10	35.00	65.00
05-Aug-15	**02-Feb-16**	2.52	4.42	1.30	028	37.76	62.24	17.11	82.89
02-Feb-16	**03-Aug-16**	2.28	4.83	1.05	201	53.71	46.29	44.98	55.02
03-Aug-16	**22-Oct-16**	2.02	2.83	0.99	221	51.89	48.11	46.67	53.33
22-Oct-16	**06-Dec-16**	2.78	4.18	1.25	024	64.69	35.31	61.63	38.37
06-Dec-16	**09-Jan-17**	2.02	2.94	1.03	015	28.78	71.22	60.00	40.00
09-Jan-17	**18-Jan-17**	2.57	3.23	1.35	343	58.43	41.57	96.30	3.70
18-Jan-17	**13-Feb-17**	1.86	2.62	0.96	025	44.60	55.40	100.00	0.00
13-Feb-17	**21-Mar-17**	2.33	3.48	1.06	245	29.67	70.33	26.09	73.91
21-Mar-17	**27-Jun-17**	1.78	4.50	0.83	222	57.14	42.86	0.00	100.00