X-band radar system to support coastal management decisions

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Abstract

The difficulties and costs associated with the acquisition of hydrodynamic and bathymetry data in the nearshore is widely recognised. While technological advances have enabled *in situ* measurements at increased precision, the limited spatial and temporal resolution of data continues to hinder evidence-based coastal management. This paper presents selected results from the '*X-Band radar as a coastal monitoring tool*' (X-Com) project which tests the suitability of a land-based X-Band radar system to provide data required for practical coastal management applications. Results are shown from a radar installation at Thorpeness (Suffolk, eastern England) from August 2015 to October 2016. At this location, coastal erosion threatens cliff-top and beach front properties, and the lack of understanding about the local nearshore-shore-cliff interactions has been identified as a key factor limiting the development of a sustainable coastal strategy. A model is used in a preliminary examination of surface current data from the radar. X-Com results indicate that X-Band radar systems have an unrealised potential and could become a cost-effective tool for coastal management applications pending improvements in the automation of data processing, assessment of data accuracy and end user-friendly output formats.

Keywords: X-Band radar, coastal monitoring, coastal modelling

1. Introduction

Evidence-based coastal management requires a good understanding of coastal processes at a range of time and spatial scales. However, management strategies currently rely on limited data resources and numerical modelling studies with inherent inaccuracies. Surveys and other measurements used to inform management decisions are often too infrequent to capture the dynamic nature of coastal processes, especially storm impacts and beach recovery. Poor data availability also limits calibration and validation of models used to design coastal protection and habitat creation/restoration schemes.

The acquisition of hydrodynamic, wave and bathymetric data from the nearshore region is a complex, expensive, and time-consuming task and consequently understanding sediment behaviour in this dynamic region is constrained. Importantly, there is a need to better understand the changes in bathymetry that can occur in the nearshore region due to sediment erosion/accretion and bedform movements. Such changes can be cyclical or permanent and can have a profound effect on the incident wave climate and associated shoreline processes.

The means of acquiring these data is addressed in the X-COM (*X-Band radar as a coastal monitoring tool*) project undertaken by a consortium of researchers at Bournemouth University (BU), the National Oceanographic Centre (NOC) and Mott MacDonald (MM). The primary aim has been to assess the feasibility of using X-Band radar technology to develop a new innovative coastal monitoring tool to support coastal management applications.

2. X-Band radar in coastal studies

As previously demonstrated by past projects (e.g. EU Inlet Dynamics Initiative Algarve, EU COAST3D and EPSRC LEACOAST2), X-Band radar has a capability to measure a range of coastal processes and characteristics at high temporal and spatial resolution over large distances. It has been successfully applied to measure bathymetry [1-3], [13] and surface tidal/wind-driven currents [11], [14]. Temporal changes in sea bed features have been observed and quantified [8], [9], [7] and [15], as well as nearshore processes in the surf/swash zones [12] and [10] and in the intertidal area [6]. While all these studies have demonstrated the abilities of the radar to quantify a wide range of coastal processes and characteristics, no attempt has yet been made to develop X-Band radar to provide the integrated coastal monitoring tool required by National Agencies, Local Authorities, coastal businesses and practitioners.

3. Field site

At Thorpeness on the Suffolk coast (Figure 1) antecedent wave conditions and a storm in 2010 exposed coastal defences dating from the late 1970s along a 200m section of the frontage. Historically, this focussed zone of erosion had occurred previously in 1911 at a location further south. While narrowing of the beach is a precursor to these local erosion events, the exact mechanism is unknown. A paucity of data from the nearshore region was identified as being one of the factors limiting understanding of the coastal processes operating during severe local erosion events. Additionally, the behaviour of the beach sediments, and in particular exchanges observed between the

Ness to the north and the beaches to the south were not fully understood. This incomplete understanding of coastal processes has constrained the development of a local coastal management strategy based on a sound understanding of the coastal system.

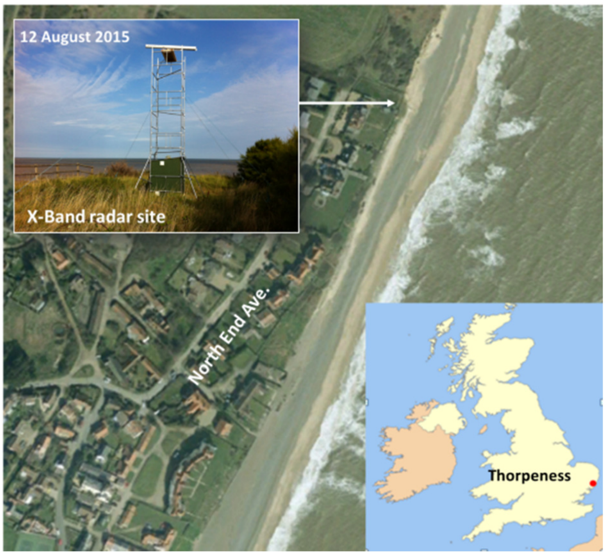

Figure 1: Location of the study site, Thorpeness, Suffolk. The inset top left shows the X-Band radar deployed on a tower close to the cliff edge.

4.1 Bathymetry

The study area covered by the radar has been surveyed recently in relatively high-definition, including multi-beam bathymetric surveys and topography through airborne lidar (both provided by the Environment Agency, EA). A composite bathymetry comprising beach profile, lidar, high-resolutions Swath and SeaZone data is shown in Figure 2.

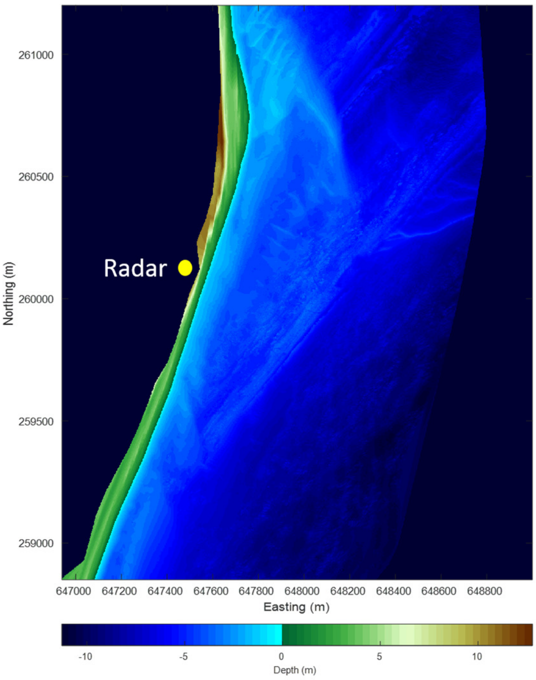

Figure 2: High resolution bathymetry and topography from EA beach profiles and lidar, swath surveys and SeaZone.

4. Measurements

4.1 X-Band radar

An X-Band radar was deployed on private land close to the cliff edge, Thorpeness, UK (Figure 1). This location provided an uninterrupted radial view of the coastal area extending approximately 2km. Power and internet were provided from a neighbouring property. A detail description of the radar is provided by [6]. There were several technical issues with the data recording system and thus continuous monitoring was not possible during the period of the deployment spanning July 2015 to December 2016. Nevertheless, a number of moderate events were captured, and sufficient data to characterise nearshore changes were obtained. The record of data acquisition in the period 2015 to 2017 is shown in Figure 3.

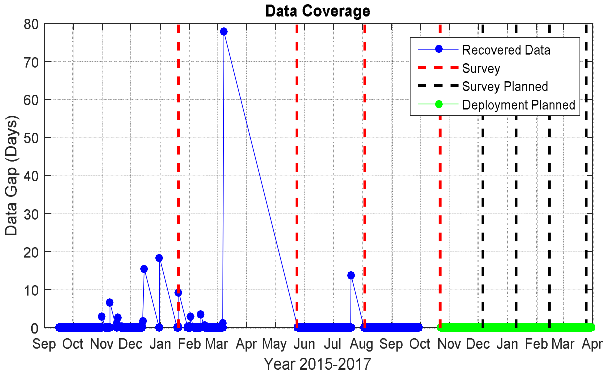

Figure 3: Radar data coverage and survey dates, with planned beach survey and radar deployment period indicated, 2015-2017.

Although issues with instrumentation have limited the data return since deployment, when working, the radar has allowed the deriving of a number or metocean and bathymetric parameters which are outlined with relevant accuracy in Table 1.

Table 1: Overview of key radar parameters range and accuracy.

Name	Range	Accuracy
Cell depth	Variable	+/- 0.5 m
Significant wave ht.	0.75 – 20 m	+/- 10% or +/-0.5 m
Mean and Peak period	4 - 20 s	+/- 0.5 s
Mean wave direction	0 - 360°	+/- 2°
Peak direction	0 - 360°	+/- 2°
Peak wave length	15 - 600 m	+/- 10%
Surface current vel.	0 - 5 m/s	+/- 0.2 m/s
Surface current dir.	0 - 360°	+/- 2°

A cell size resolution of 60 m^2 (Figure 4) was selected for initial processing of the radar images. Although this decrease in resolution means smaller scale features will not be derived, it provides more confidence within each cell and faster data processing speeds. This resolution can be increased for specific areas of interest.

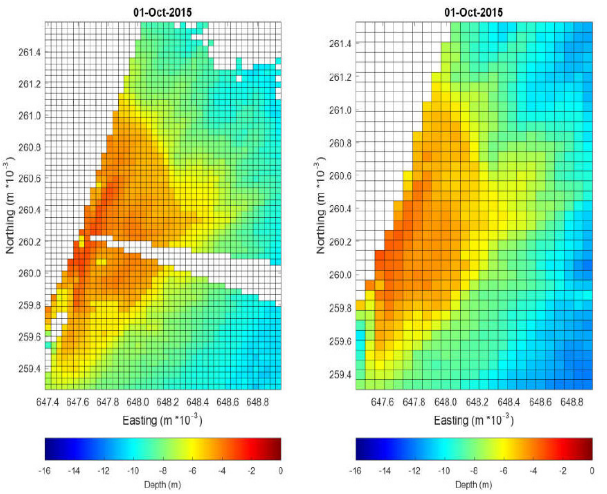

Figure 4: Original radar resolution (*left panel*) and reduced resolution (*right panel*).

5.2 Tide gauge

As the algorithm used to derive bathymetry, [3], depends critically on the local tide plus surge water elevation, water levels were measured at 15-minute intervals between 27th April and 31st July 2016 through the installation of a pressure sensor in a tidal sluice just south of Thorpeness. Together with Class A tide gauge data from sites north and south of Thorpeness the harmonic analysis of data and extraction of residuals provided a way of accurately defining the water levels used when processing the radar-derived wave data and thereby improved the accuracy of the derived bathymetric data.

5.3 Beach surveys

Beach surveys were conducted along the Thorpeness frontage to quantify changes in beach morphology and sediment characteristics. Three types of surveys are undertaken:

- High-resolution beach topography measured using a ground-based Lidar;
- Cross-shore DGPS profiles matching locations surveyed by the UK EA; and
- Sediment samples and digital image analysis for particle size.

5. Results

5.1 Bathymetry

Using analysis of pixel standard deviation, UK EA surveys from June 2014 (Figure 2) are compared in Figure 5 with medium-term (>month) radar derived bathymetry. The left panel shows the standard deviation of each pixel from the 18th September to 17th October 2015. Regions of low and high deviation indicate stable areas (bedrock) and dynamic sediment dominated regions, respectively. Radar-derived (contours) and EA (shading) bathymetries are shown together in the right panel. A number of features are observable:

- Locations in the region ~648000E and ~259750N coincide with the solid geology comprising an exposure of Coralline Crag (also observed in the EA bathymetry);
- Other areas of low deviation coincide with offshore ledge/bed rock features (north and north east); and
- Areas of high standard deviation are coincident with dynamic sediment dominated areas particularly around Thorpe Ness (~648000E and ~261000N) and regions in the central west of the images (~6477500E and ~260500N).

5.2 Seabed features

In certain tidal and wave conditions, features on the sea bed in shallow water (< approx. 10m) express themselves at the sea surface. Figure 6 shows a mean image derived from time-averaging consecutive raw radar images over a period of approximately 20 minutes. It shows the location of the radar and MLW (approx.) and a region populated by distinct and regular bedforms. The wavelength of these features indicates that these bedforms are sand waves.

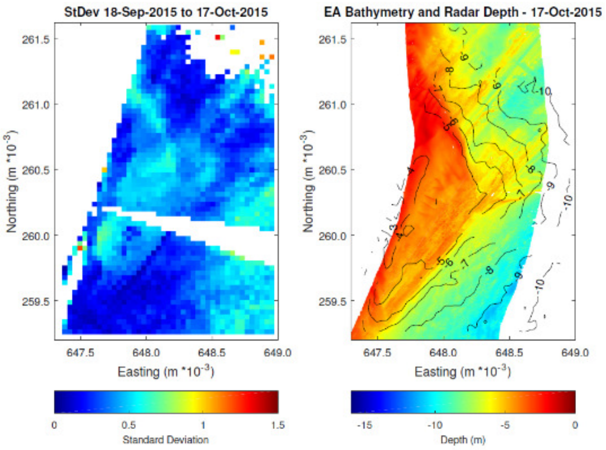

Figure 5: Standard deviation of each pixel for 1 month (*left panel*) and EA bathymetry overlaid with radar derived contour lines (*right panel*).

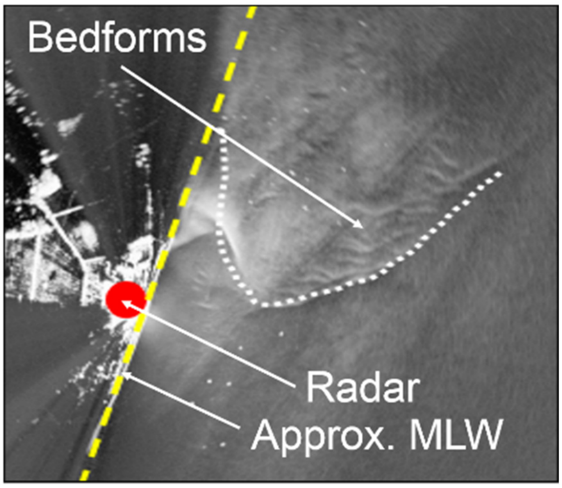

Figure 6: Time-average radar image showing the presence of sand waves offshore from the coast.

5.3 Bathymetric changes

Figure 7 shows wave and tide conditions during a north easterly storm event occurring over 8 hours on the 13th October 2015 (Hs peaking at 3.65 m; storm power index (SPI) = 79.11). The pre- and post-storm bathymetry (left and middle panels) and the resulting change (right panel) are shown in Figure 8. There is evidence of erosion around the inner shore banks with limited accretion in a small number of cells to the north.

Figure 9 shows wave and tide conditions over two clustered storm events occurring between the 28th November and 1st December 2015. The storms were fairly short in duration (approximately 5 hours) with Hs peaking at 3.6 and 4.3 m respectively and SPI values of 24.98 and 26.04. Both storms were from the south east, and the effect of this can be observed in Figure 10 where areas of erosion in the south coincide with accretion around the Ness in the north. Importantly, these events illustrate the impact of different storm tracks on Thorpeness beach and nearshore, particularly the effect lower power storms can have when clustered and from the south.

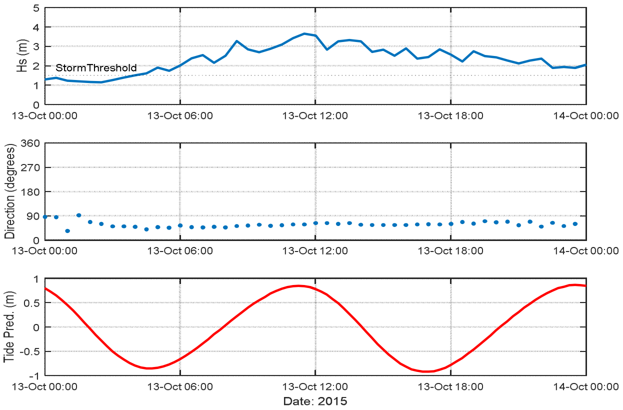

Figure 7: Wave height (*top panel*), mean direction (*middle panel*) and harmonically predicted water level at Thorpeness between 13th and 14th October 2015.

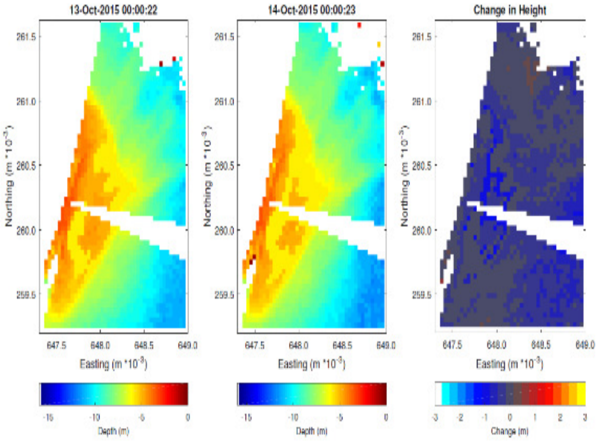

Figure 8: Water depth pre- (*left panel*) and post- (*middle panel*) storm events and resultant change in height (*right panel*) between 13th and 14th October 2015.

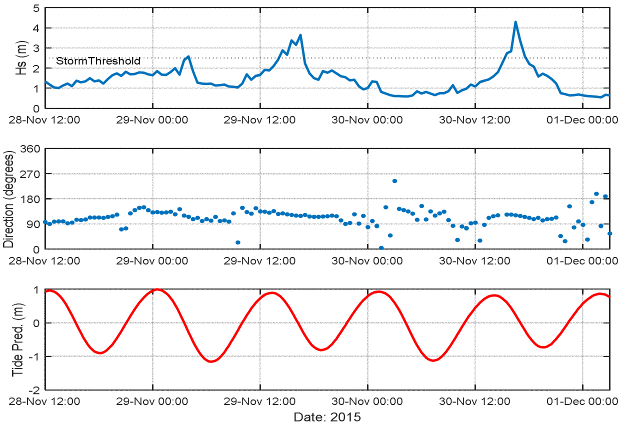

Figure 9: Wave height (*top panel*), mean direction (*middle panel*) and harmonically predicted water level at Thorpeness between 28th November and 1st December 2015.

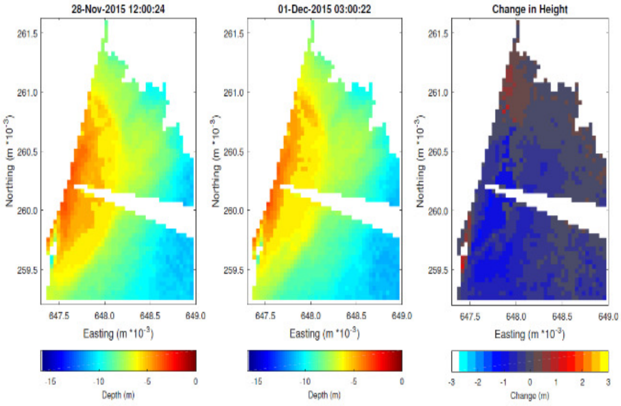

Figure 10: Water depth pre (*left panel*) and post (*middle panel*) storm events and resultant change in height (*right panel*) between 28th November and 1st December 2015.

6. Numerical modelling

Work to support X-COM involved setting-up and calibrating a MIKE 21 numerical modelling of the field site. The MIKE21 FM model uses the X-COM bathymetry (Figure 11) and includes modules to simulate hydrodynamics (HD), waves (SW, Figure 12) and sediment transport (ST).

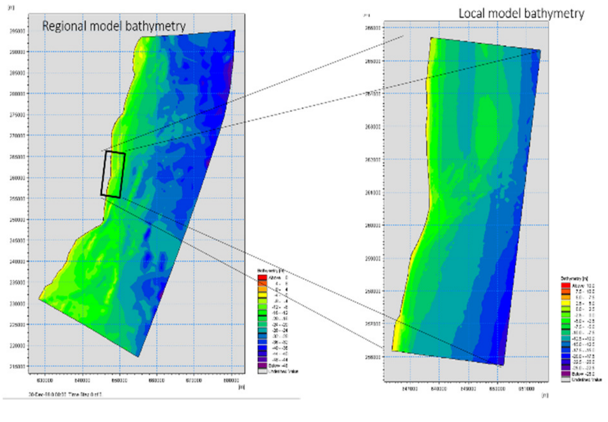

Figure 11: MIKE21 bathymetry showing the regional scale (*left panel*) and local scale (*right panel*).

The SW model (Figure 12) is driven by hindcast wave data from a Met Office WWIII wave model data location at the outer boundary of the MIKE model. The predicted waves have been compared favourably with measured wave data from the West Gabbard buoy located well within the model domain. The hydrodynamic model is driven by MIKE tidal harmonics. The resulting water levels compare well in both magnitude and phase with measured values examined so far.

Figure 13 shows an example of tidal and wave-induced currents in a section of the model domain that includes the Ness. In this snapshot a region of flow recirculation to the north of the Ness is evident. It is thought that flows of this nature contribute to the development and maintenance of the Ness feature, which in turn plays an important role in moderating the local sediment budget.

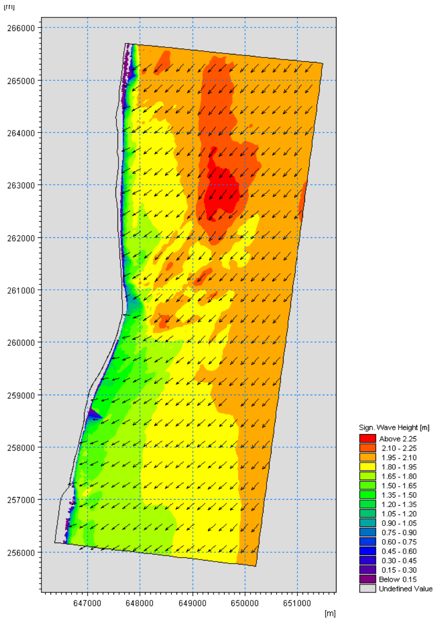

Figure 12: Example of MIKE21 Spectral wave output at the local scale. Colours indicate spatial variation in significant wave height over the model domain and arrows show wave direction.

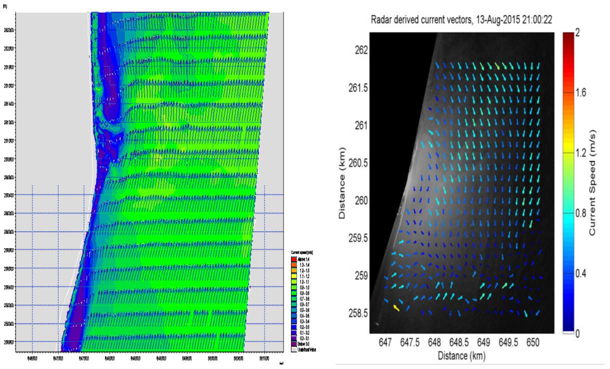

Figure 13: Example of tidal and wave driven currents from the MIKE21 model (*left panel*) and radar-derived surface current vectors from 21h00 13 August, 2015 (*right panel*) showing similar flow features in the vicinity of the Ness.

The bathymetry before and after a short model simulation of a minor storm during November 2016 is shown in Figure 14. This MIKE run includes the new *Shoreline Morphology* module and shows changes occurring in the nearshore region. Similar changes are recorded by beach surveys and by the radar.

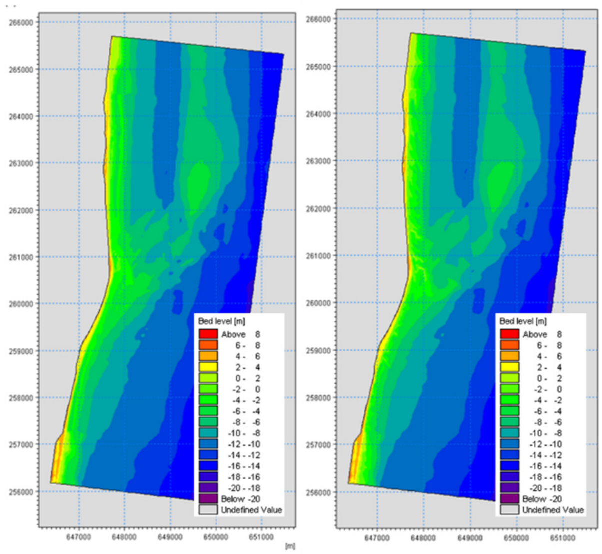

Figure 14: Bathymetry at the start (*left panel*) and end (*right panel*) of the simulation (note changes in nearshore morphology).

7. Morphological changes

Clear seasonal bathymetric changes were observed during the first year of radar data. Figure 15 shows the bathymetry (represented by 1m contours) on three occasions, reflecting: (a) the end of summer (1st Oct 2015); (b) the end of winter (1st March 2016); and (c) the end of spring (15th June 2016).

At the end of summer, a shallow nearshore region is noticeable (orange shades), reflecting deposition of sediment typical of fair-weather summer conditions. By March 2016, much of this sediment had been removed except for a small feature around the Ness (-6 m contour towards the north). By June 2016, the feature had reduced in size (reflecting removal of sediment) while sediment accumulation becomes evident in the south. This deposition of material in the nearshore suggests initial restoration of conditions observed in October.

The changes in bathymetry through time evident in Figure 15 are shown more clearly in Figure 16. While to accuracy of the bathymetry extracted from the radar is at worse in the range ± 0.5m, bathymetric changes shown in Figure 15 and Figure 16 are larger than the potential error and reflect real changes to the bathymetry. For example, in the southern nearshore area, increases in depth exceeding 3m (between October 2015 and March 2016) and reductions in depth of around 2m (between March and June) are evident. It is clear then that the southern nearshore shows greater seasonal changes than areas in the northern part of the study site.

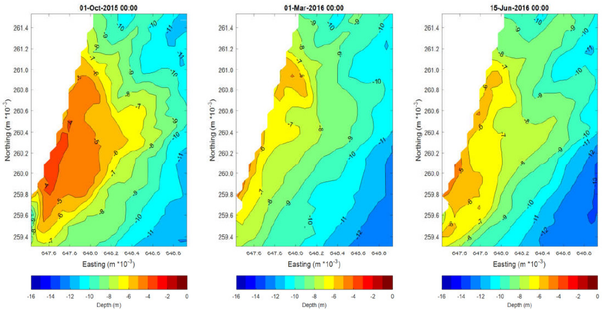

Figure 14: Bathymetry extracted from radar data represented as 1 m contours. October 2015 (*left panel*) reflects conditions at the end of summer, with a shallower nearshore, which deeper due to sediment removal in March (*middle panel*) and deposition seems to in June 2016 (*right panel*).

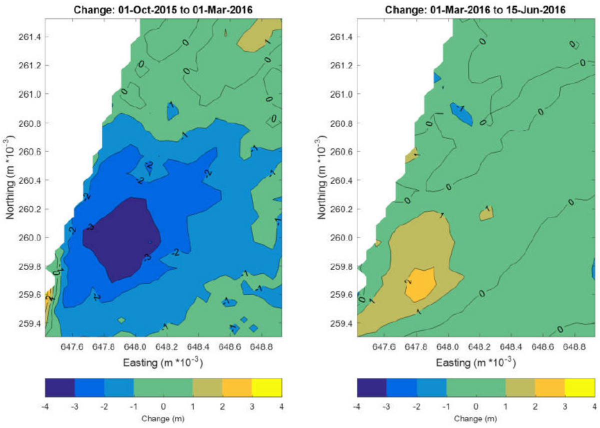

Figure 15: Seasonal change in bathymetry between October 2015 and March 2016 (*left panel*) and between March 2016 and June 2016 (*right panel*).

To demonstrate recent changes observed on the beaches of Thorpeness Figure 16 shows: (a) erosion north of the radar on 6 November 2016 attributable to a storm from the northeast; and (b) the resulting sediment transport to area south of the radar on 7 November 2016. These and other similar event continue to be observed by the radar and quantified by field surveys when practicable.

Figure 16: (a) NE storm erosion north of the radar on 6 November 2016; and (b) sediment transport to area south of the radar on 7 November 2016.

8. Beach morphology

Mapping the morphology of intertidal areas is a logistically challenging, time consuming and expensive task. However, the analyses of a series of time-exposure radar images over the course of a two-week tidal cycle presented here provides the elevation of the wetting and drying transitions at each pixel in the radar images, thereby building up a morphological map of the target intertidal area [5]. An example of the data from this '*waterline*' approach is shown in Figure 17.

While providing further useful data on the state of the beach, the waterline method in this case is constrained by the steepness of the shingle beach and thus the spatial extent of the information is limited. Nevertheless, this analysis of X-Band radar data provides useful routine information on beach levels which in turn may provide an early warning for authorities tasked with beach management.

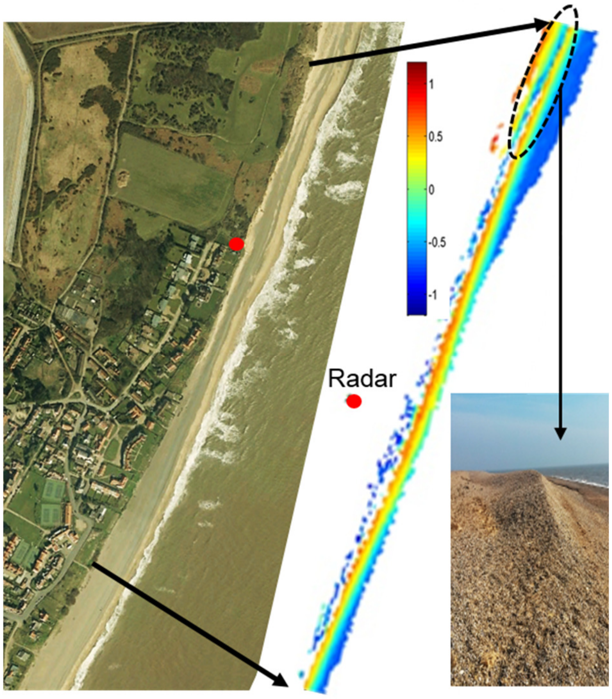

Figure 17: Aerial view of the beach at Thorpeness (*left panel*) and the beach morphology derived using the '*waterline'* method from X-Band radar data. The inset photo (*bottom right*) shows the shingle ridge deposit on the Ness clearly evident in the X-Band-derived beach morphology.

9. Summary

Based on the evidence from the Thorpeness study reported here it is demonstrated that the analysis of X-Band radar using the X-COM toolkit provides a low-cost and low-risk alternative to conventional hydrodynamic, wave and bathymetric data acquisition methods on the beach and from nearshore and offshore areas. It provides also the high temporal and spatial resolution data needed to better understand the changes in bathymetry that can occur in the nearshore region due to sediment erosion/accretion and bedform movements. These data combined with numerical modelling are now revealing the cyclical alongshore and cross-shore movement of sediments at Thorpeness that effect the incident wave climate and associated shoreline processes.

The pilot study at Thorpeness has shown that type of data acquired by the regular monitoring of coastal and nearshore changes by X-Band radar. While previous work has demonstrated the accuracy of the radar-derived bathymetry (e.g. Bell, 1999), it is planned to undertake a full validation of the present bathymetry by mid-2017 using data from a swath bathymetric survey commissioned by the UK Maritime and Coastguard Agency in January 2017. This work will be reported in a short follow-up paper.

The X-COM project team is now working closely with Suffolk Coastal District Council to use radar-derived data to support the development of a coastal management strategy. This work may lead in the future development of simple end-user tools that utilise a combination of X-Band radar-derived data and numerical modelling to alert managers to trends in coastal behaviour that may lead to critical beach conditions and erosion pressure.

10. References

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11. Acknowledgements

X-COM is a project funded by the Natural Environment Research Council (reference NE/M021564/1). John Atkinson thanks Bournemouth University, Suffolk Coastal District Council and Mott MacDonald for co-funding of his PhD. The authors would also like to acknowledge the generous support of Suffolk Coastal District Council (Paul Patterson and Bill Parker), the residents of Thorpeness and Mott MacDonald.