Morphological Variability of Cleveleys Beach, UK at Multiannual Timescales Based on Airborne LiDAR Data

Andrew Miles[1], Suzana Ilic[1], Mike James[1], Duncan Whyatt[1]

[1] Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK.
Tel. +44 (0)1524 510991 Email. a.miles@lancaster.ac.uk

Summary: Airborne LiDAR data is used to study morphological evolution along Cleveleys beach in North Lancashire. Map overlay techniques are used to identify regions of change; variations in beach volume are calculated in the form of momentary intertidal coastlines (MICLs) and bar crest positions are extracted from the LiDAR data to provide an indication of sediment transport direction. Results indicate general linear onshore bar movement across the region, but more complex patterns along one section of coast.

KEYWORDS: LiDAR, coastal processes, intertidal bars, MATLAB

1. Introduction

Since the late 1800s much of the coastline around Cleveleys, North Lancashire, has been defended through the implementation of hard engineering solutions, such as sea walls and groynes, designed to provide protection against tidal flooding and erosion (Wyre Borough Council, 2004). These structures interact with waves and currents to directly influence the movement of sediment and resulting beach morphology. However, understanding of how the beach is changing over time is limited. In particular the rates and volumes of sediment transport in the region, and the role played by intertidal bars in influencing beach volumes, are poorly understood. This represents a significant knowledge gap, given that a substantial beach provides an important first line of defence for the low lying hinterland.

This study aims to use GIS and remote sensing methods in order to determine the evolution of intertidal bars over annual to decadal timescales in order to help to address the knowledge gap discussed above. It will also provide a useful first indication of the feasibility of shoreface nourishment as an additional form of coastal defence in this region. This is a soft engineering technique that involves the creation of artificial offshore sandbars which will then dissipate wave energy and provide a source of sediment for beach nourishment onshore (Grunnet & Ruessink, 2005).

2. Methods

Remote sensing methods such as LiDAR can be used to obtain a detailed overview of change that is occurring along the entire stretch of coastline (Stockdon et al, 2009). This study uses an irregular time series of airborne LiDAR data from 1999, 2009, 2010 and 2011 to analyse beach morphological evolution. Prior to 2009 airborne LiDAR data were not collected specifically for the purpose of coastal monitoring in this region and so few datasets providing good coverage of the coastal zone are available. The LiDAR data were provided at plan resolutions ranging from 0.25 m to 2.0 m, but all datasets were resampled to 2.0 m to allow comparable analysis. A potential limitation for this study is the vertical accuracy of the LiDAR data. However, validation of LiDAR elevations relative to Ordnance Survey reference heights indicated a root mean square error (RMSE) of ~0.20 m for all years used in this study. This makes the detection of large scale features such as intertidal bars viable as their longshore, cross-shore and vertical extents are of order 100 m, 10 m and 1m respectively.

Initially, map overlay techniques were used to produce change maps between subsequent years in order to qualitatively assess patterns of beach evolution over time. This was followed by quantitative analysis of beach change including variations in beach volume, calculated in the form of momentary intertidal coastlines (MICLs). The MICL is a proxy for beach volume calculated as shown in figure 1, effectively converting the volume of a 1 m strip of beach into a cross shore position. This can then be mapped and used to visualise changes in beach volume over time, with seaward advance in MICL position indicating increasing beach volumes (accretion) and landward retreat indicating a decrease in beach volumes (erosion). The MICLs were calculated using profiles extracted from LiDAR data at a 50 m alongshore spacing and 2 m cross-shore interval. The positions of intertidal bars were then obtained using the same profiles. These were analysed in MATLAB in order to calculate crest locations within the profiles by identifying positions where the profile slope changed from positive to negative. The resultant data were then imported back in to GIS in order to remove anomalous points and to construct continuous bar crest lines. This type of technique has previously been used to analyse dune systems but has not been used for more subtle features such as intertidal bars.

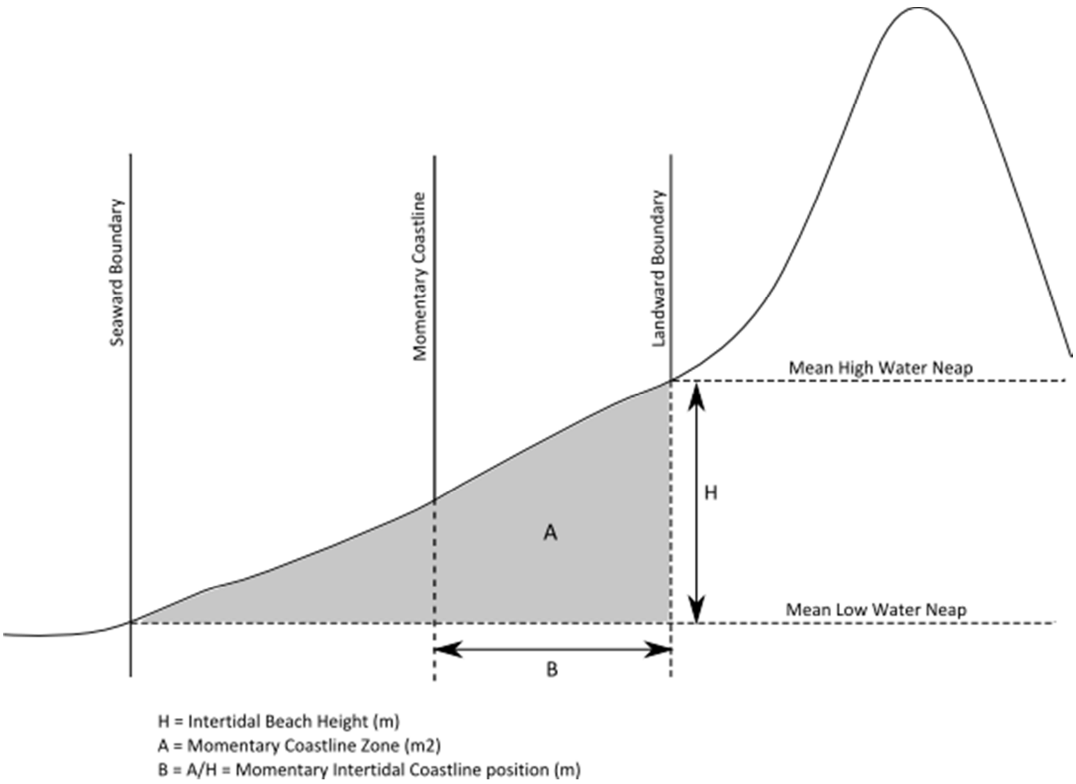


Figure 1. Calculation of Momentary Intertidal Coastline (MICL) (Based on van Koningsveld & Mulder, 2004)

3. Results

3.1 Qualitative analysis

The change maps indicate bars have been migrating across the beach in a linear fashion, indicated by alternating areas of increased and decreased elevation, with the exception of an area towards the centre of Cleveleys where the pattern of bar migration becomes confused and there are indications that more complex hydrodynamics may be occurring (Figure 2). This is the case between 2010-2011, 2009-2010 and even during the much longer spacing between 1999-2009, although over this time period bar movements are more apparent than at annual intervals. This suggests that different processes may be occurring along this section of beach.

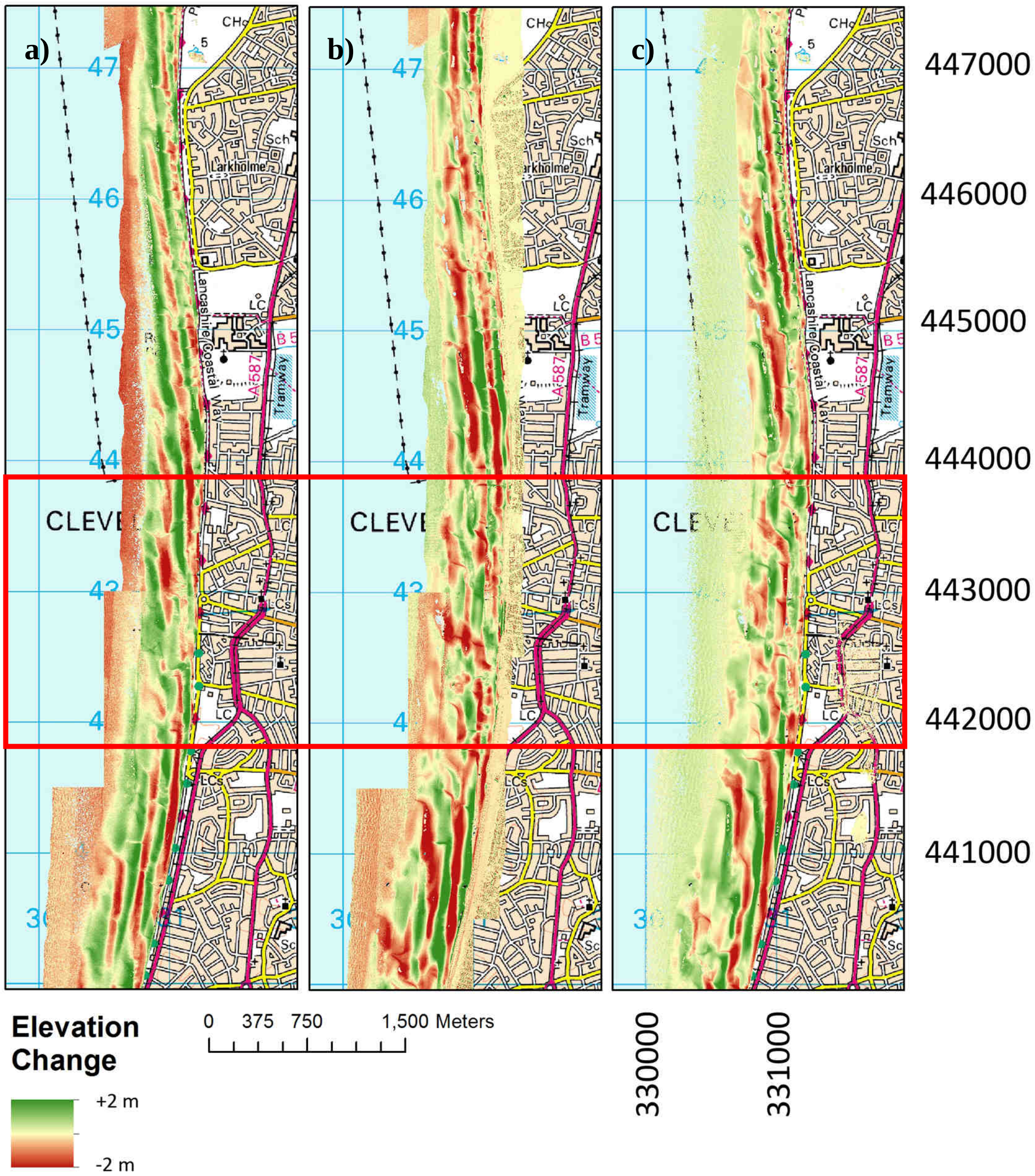


Figure 2. Change maps between a) 1999-2009, b) 2009-2010 and c) 2010-2011 demonstrating regions of linear bar migration and an area of more complex hydrodynamics (red box)

3.2 Momentary Intertidal Coastlines

The calculation of MICLs provides an indication of how beach volumes have been changing over time as well as allowing spatial variations to be observed. Figure 3 shows the MICLs for 2 km of beach. There is no clear pattern in the MICLs over time on this stretch of coastline, with similar findings apparent along the whole coast. Despite being temporally discontinuous from the other datasets the 1999 MICL does not stand out as differing substantially from the other three years. This suggests that while there are clearly variations in the MICL position it may remain relatively stable over the longer term, with changes reflecting shorter term hydromorphological processes.

3.3 Bar Crest Positions

Extracting bar crest locations from the LiDAR data provides an indication of the direction in which sediment transport has been occurring, particularly in the cross shore direction. Longshore movement is harder to determine due to a lack of fixed features and the transient nature of rip channels (natural drainage channels that run across the beach and form the most obvious features for determining longshore movement). A general onshore migratory trend is apparent across the region, although there are localised instances of offshore bar migration occurring, particularly in the region where linear bar movement was less apparent from the change maps. Bar migration rates vary considerably across the region, with maximum migration rates in the order of 50-75 m per year occurring in some locations while in others bar migration is negligible (Figure 4).

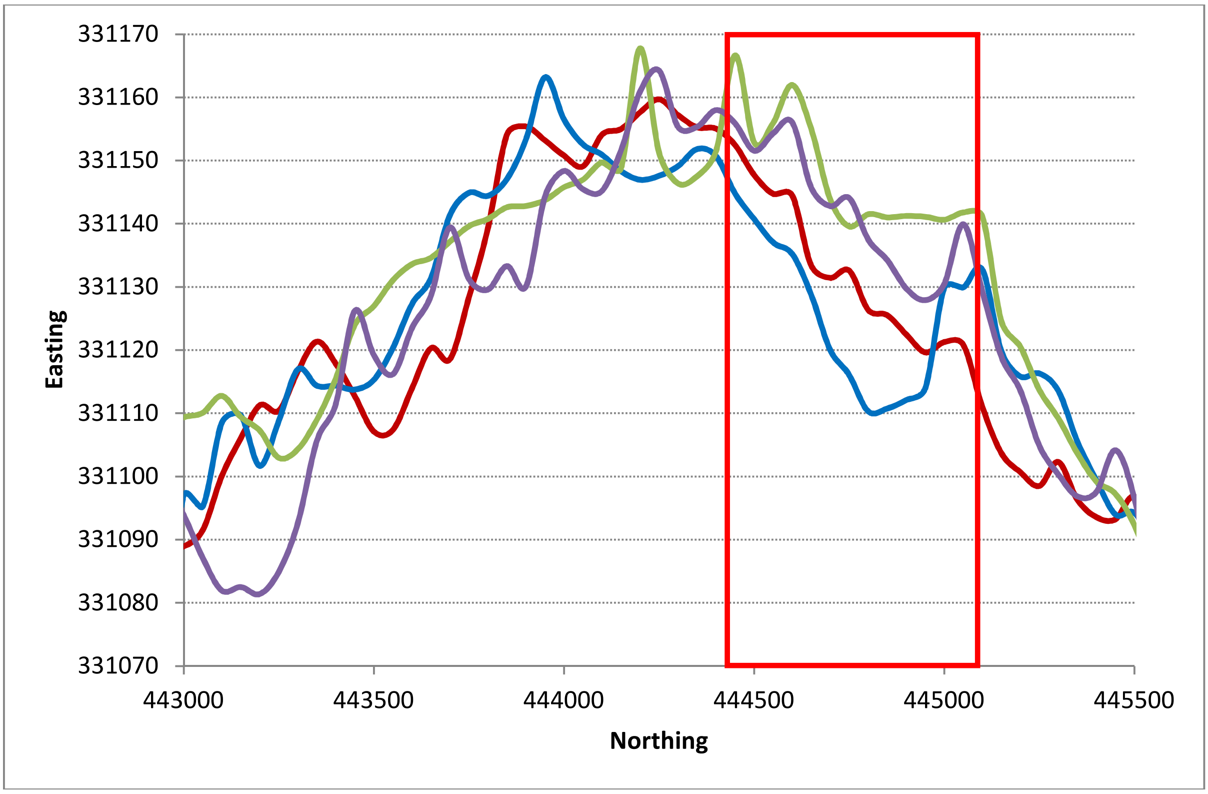


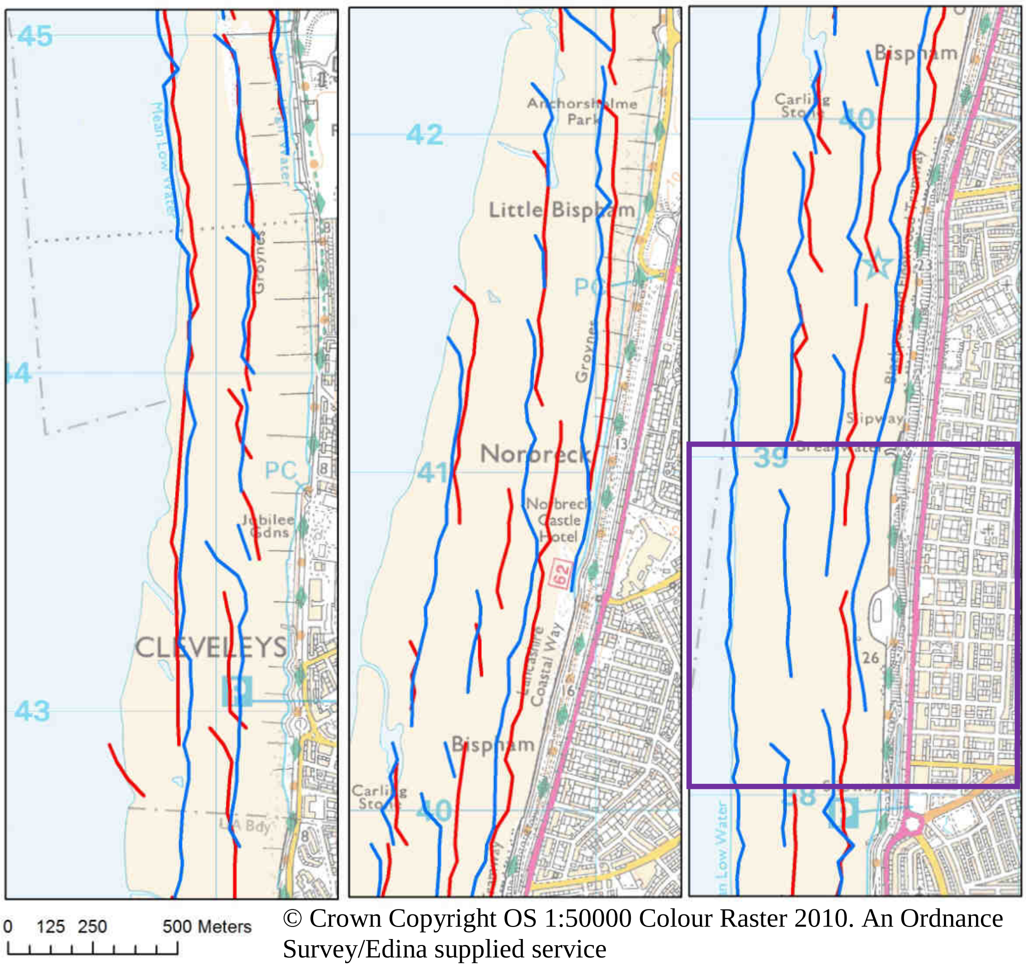
Figure 3. MICL positions in 1999 (purple), 2009 (green), 2010 (blue) and 2011 (red). The region highlighted in red indicates the vicinity of Rossall School

4. Discussion

It is apparent that the hydromorphology of Cleveleys beach varies at different locations. The area of more complex hydrodynamics identified from the change maps corresponds to the centre of a small embayment highlighted by a red box in figure 2, which may act to focus wave energy and explain the disruption to the pattern of linear bar movement that is seen elsewhere.

The lack of a clear trend in MICL positions indicates short term fluctuations but long term stability in beach levels. There is some evidence to suggest that this may be linked to the number of bars that are present on the beach. In the vicinity of Rossall School an increase in the number of bars between 2009-2010 corresponds to a substantial advance in MICL position (Figure 3, red box). However, between 2010 and 2011 the MICL position advanced slightly despite a reduction in the number of bars from three to one (Figure 4, purple box). This may suggest that while the number of bars does influence beach levels it is also possible for more general increase in beach volume to occur. It is also possible that wide, shallow bars are present at this location which are not detected due to limitations of the current methodology.

The dominance of onshore bar migration suggests that net onshore sediment transport will also be prevalent. While further confirmation is necessary in order to demonstrate this conclusively it would be beneficial in the context of shoreface nourishment, where the onshore transport of nourished material is a desired outcome of the project.



© Crown Copyright OS 1:50000 Colour Raster 2010. An Ordnance Survey/Edina supplied service

Figure 4. Bar crest locations in 2010 (blue) and 2011 (red); the purple box indicates the north shore region. Images stack north to south consecutively.

5. Conclusions

Based upon an irregular time series of airborne LiDAR data between 1999 and 2011 it is possible to determine that the hydromoprohlogical conditions vary along Cleveleys beach. Cross shore bar migration appears to represent the dominant mode of morphological evolution along much of the coastline while conditions towards the centre of the embayment are more complex, possibly due to the refraction of wave energy. Beach volumes as represented by MIL positions suggest that while beach volumes experience substantial variations from year to year they remain relatively stable over the longer term, with annual variations at least partially due to the number of intertidal bars resident on the beach at a given time. The direction of bar migration is predominantly onshore; supporting the feasibility of shoreface nourishment in this region as nourished material will be carried onshore resulting in increased beach volumes. However the centre of the embayment may be a less suitable location for nourishment due to the more complex pattern of sediment transport occurring there.

These conclusions are limited by the timeseries available. While they provide useful insights into the current evolution of the beach, future datasets will be used to extend the work.

By utilising GIS and MATLAB to analyse remotely sensed data it is possible to calculate useful metrics for large stretches of coastline at relatively fine spatial scales. It also allows outputs to be visualised effectively in a way that will benefit coastal managers. Future work will focus on using this information to inform a numerical modelling study, which will allow scenarios for future coastal management options to be investigated.

6. Acknowledgements

The authors would like to thank Wyre Borough Council and Stena Line for funding this project and the Environment Agency and the Cell Eleven Regional Monitoring Group for kindly supplying data that was used in this study.

7. References

Grunnet, N.M. & Ruessink, B.G., 2005, Morphodynamic Response of Nearshore Bars to a Shoreface Nourishment. *Coastal Engineering*, 52, 119-137

Stockdon, H.F., Doran, K.S. and Sallenger Jr., A.H., 2009. Extraction of Lidar-Based Dune-Crest Elevations for Use in Examining the Vulnerability of Beaches to Inundation During Hurricanes. *Journal of Coastal Research*, SI53: 59-65

Van Koningsveld, M. and Mulder, J.P.M. (2004) Sustainable Coastal Policy Developments in the Netherlands. A Systematic Approach Revealed. *Journal of Coastal Research*, 20, 375-385

Wyre Borough Council, 2004. Wyre Flood and Coastal Defense Strategy Plan.

8. Biography

Andrew Miles is a 2nd year PhD student researching the feasibility of shoreface nourishment at Cleveleys UK. His research interests lie particularly in the application of GIS and remote sensing methods to these problems.

Suzana Ilic is a Lecturer in coastal science at Lancaster University. Her research interests are in understanding coastal hydrodynamics, sediment transport and the resulting morphological changes; and in developing tools for coastal managers and consultants that can be used to predict future changes.

Mike James is an RCUK Academic Fellow in Environmental Informatics whose research involves understanding physical aspects of Earth surface change, with emphasis on volcanic processes. Areas of particular interest are lava flows and volcanic domes, coastal erosion and sediment dynamics, and the development of appropriate and adaptive field methodologies.

Duncan Whyatt is a Senior Lecturer in GIS with the Lancaster Environment Centre, Lancaster University.