Lessons from strategic coastal monitoring

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Introduction

The strategic management of flood and erosion risks at the coast typically relies on understanding of ongoing coastal processes including the use of records of past shoreline changes and previous extreme events to inform predictions of future coastal risks to assets.

Monitoring of shoreline change data using surveys of beach profiles, aerial photography, topographic and LiDAR surveys is now undertaken regularly as part of the regional strategic monitoring programmes covering the coast of England. Understanding of the drivers for shoreline change is facilitated by the collection of information on forcing conditions including waves and sea level and rainfall data collected both at national and regional scale.

The prediction of trends in coastal change and extreme events requires consistent long term data sets due to the impacts of natural variability in the weather and climate, predictable changes in tides and the possible impacts of longer term climate phenomena such as the North Atlantic Oscillation and forecast changes in climate and sea level.

This paper describes emerging findings from the North East Regional Coastal Monitoring Programme and discusses the implications of the findings of data analyses undertaken so far. Recommendations are also made for future improvements in the programmes to maximise the benefits of future coastal monitoring to long term strategic coastal defence planning.

Regional coastal monitoring programmes in the UK

Strategic regional coastal monitoring programmes have generally been in place for between 7 and 12 years on the English coast. Exceptions are the strategic monitoring of erosion on the Holderness coast, Cell 2a, which has been ongoing since the 1950s and shoreline monitoring on the coast of the former Environment Agency Anglian region, which has been underway since 1991, see Figure 1. While there are also many examples of sites with longer periods of local coastal monitoring these typically cover scheme specific frontages. A strategic monitoring programme for the Welsh coast has been in development since 2010 (WCMC, 2013). Although the Scottish and Northern Ireland governments contribute to the UK wide monitoring of waves and tides, strategic monitoring of shoreline change is not yet undertaken.

The requirements for monitoring data to inform future strategic coastal management largely depends on the risks related to coastal change and coastal management practices undertaken to manage those risks. This has resulted in the strategic monitoring tasks undertaken differing, particularly in terms of scale and frequency of data collection between the six English regions identified in Figure 1.

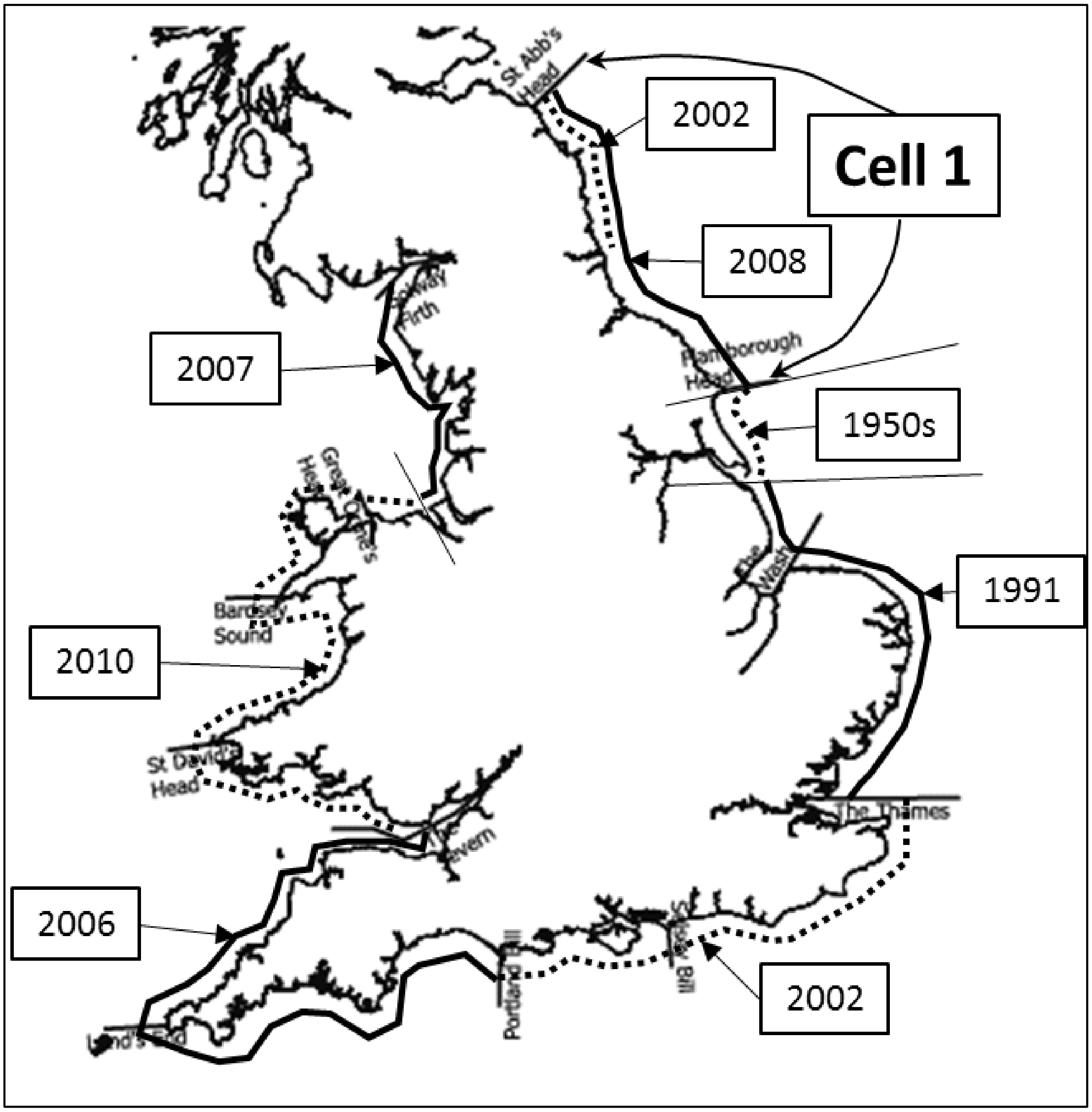

Figure 1. Cell 1 study area and regional monitoring programme inception dates

National coastal monitoring data

The regional strategic coastal monitoring programmes are complimented by national coastal monitoring funded by Defra and the Environment Agency, including the strategic national tide gauge network and WaveNet programme that form components of the UK Coastal Monitoring and Forecast Service (UKCMF).

The strategic national tide gauge network, see Figure 2, includes 44 tide gauges around the UK coast and was set up to inform flood warnings following the 1953 storm surge which caused widespread coastal flooding on the east coast of the UK. The network now provides consistent and quality controlled medium to long term sea level data that can aid the interpretation of coastal change data and the prediction of extreme events. Two of the strategic national tide gauges, North Shields and Whitby, are located within the Cell 1 frontage.

The North Shields tide gauge site has one of the longest records of sea level in the UK, enabling investigation of extreme events and also trends in relative sea level, with monthly mean data available since 1895 and hourly records available through BODC from 1946. The Whitby tide gauge record has data available from 1980.

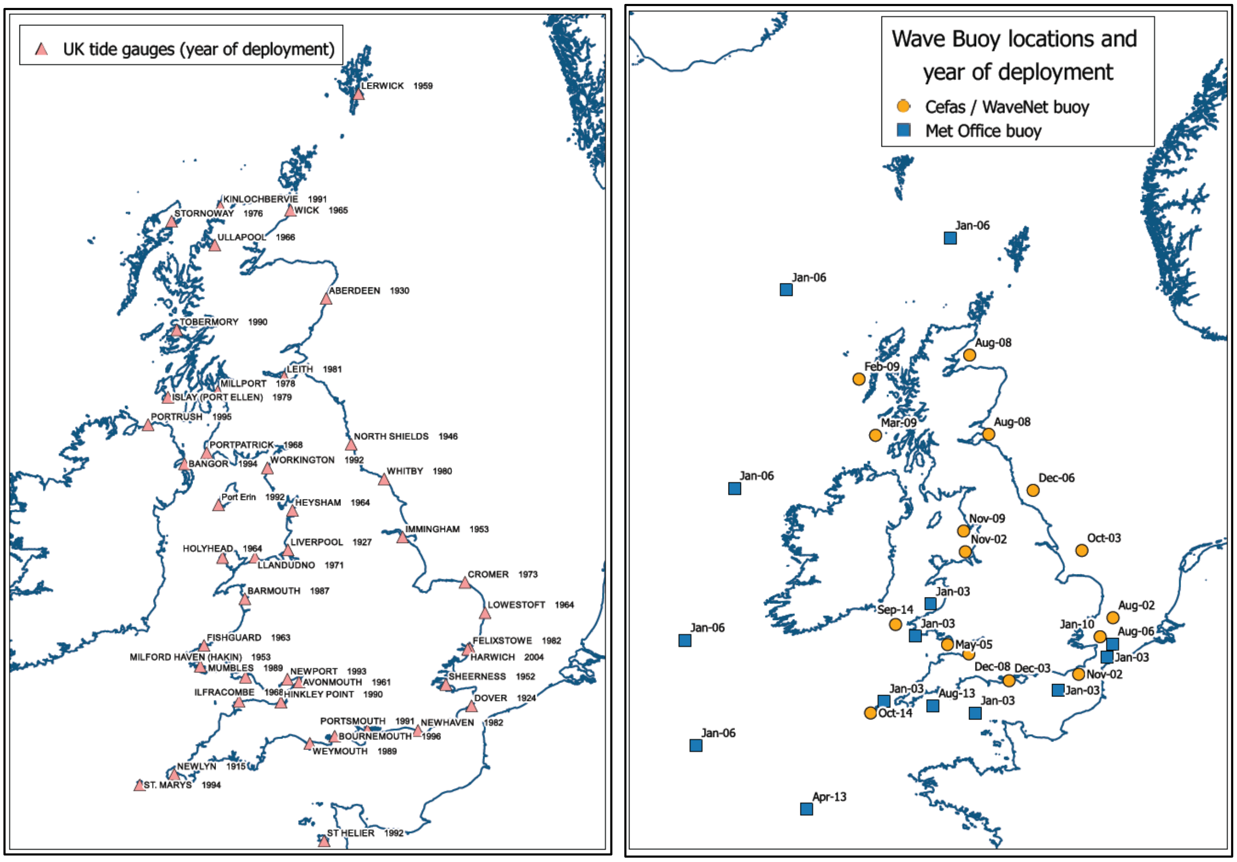

Figure 2 Location of the UKCMF tide gauges and WaveNet wave buoys showing deployment year for each site

The strategic national wave monitoring programme known as WaveNet was set up with funding from Defra in 2002 following a scoping report, Hawkes et. al. (2001) that considered options for siting the buoys taking into account coastal risks. The programme now provides strategic wave monitoring data with durations of 6 to 12 years, see Figure 2. The Cefas WaveNet website, http://cefasmapping.defra.gov.uk/Map also hosts data from UK Met Office wave buoys, which are also shown in Figure 3 together with a large number of other active and historical wave buoys owned by energy companies and wave buoys deployed under the regional coastal monitoring programmes. The WaveNet Tyne-Tees buoy which has data from 2006 is located offshore from the Cell 1 study frontage. In addition to measured data, the Cefas wavenet website also distributes hindcast wave data from the Met Office Wave Watch III model of UK waters, and data covering the period from 1st January 1980 to 31st December 2012 was obtained for the Cell 1 programme.

The North East Coastal Monitoring Programme

The North East Coastal Monitoring Programme covers the coastline from St Abb's Head at the border with Scotland to Flamborough Head in the East Riding of Yorkshire (Figure 3). This encompasses coastal sediment cell 1 and covers almost 300km of diverse coastline including dunes, hard and soft rock cliffs, periodically active landslides and numerous settlements, harbours and other coastal assets.

The strategic monitoring of shoreline change on the northern part of the Cell 1 frontage from St Abb's Head to the River Tyne, commenced in 2002. The southern part of Cell 1 from the Tyne to Flamborough Head was integrated with the northern part in a combined programme which commenced in 2008 (Cooper et al. 2009) in order to meet the strategic monitoring requirements of the two shoreline management plans that cover Cell 1.

The core component of the Cell 1 programme is the annual survey and analysis of 248 beach profiles, 31 beach topographic surveys and cliff recession monitoring at 14 locations to document change since the previous survey and since the baseline. Repeat surveys at selected locations are also undertaken every 6 months. In addition to these regular topographic surveys, wave buoys have been deployed at three locations along the coastline to provide real time data.

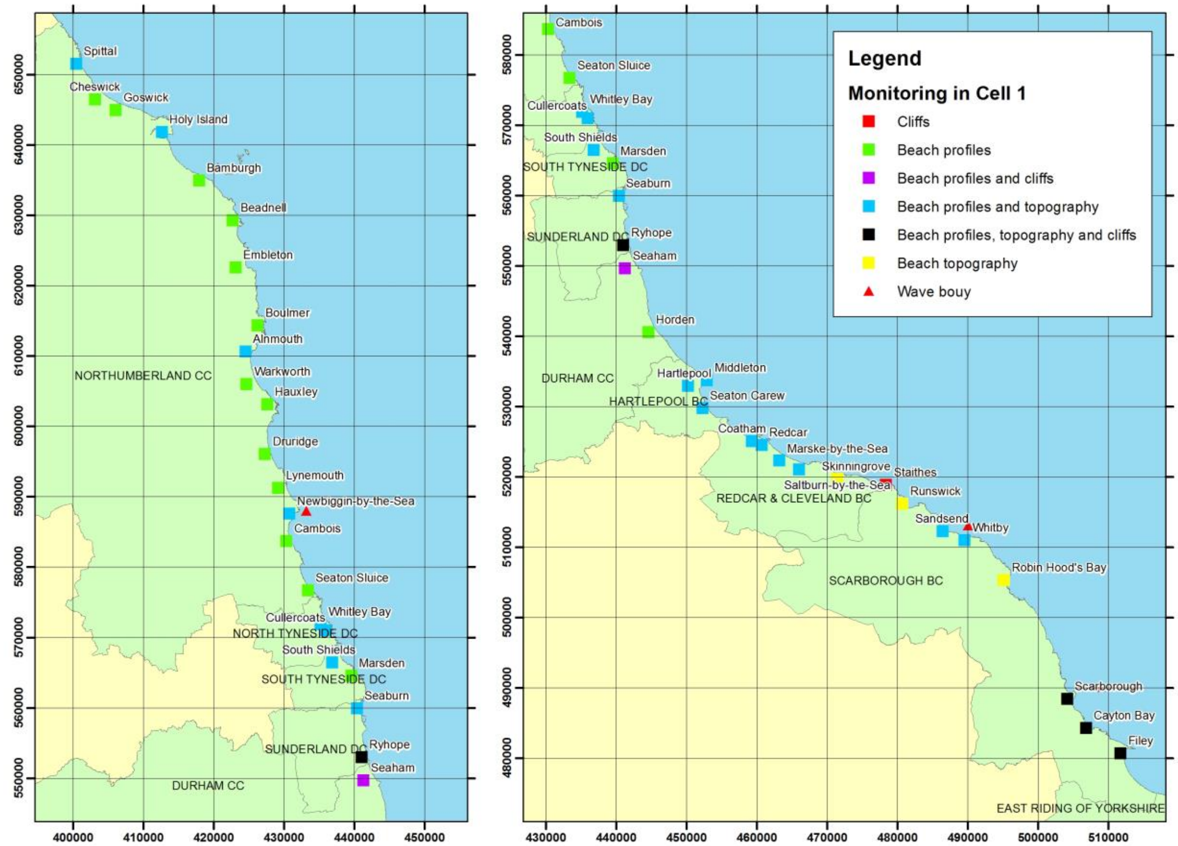

Figure 3. Main data collected under Cell 1 monitoring programme

Rapid walk over condition inspections of the cliffs and coastal landslides, engineered assets and are also undertaken biennially to document defence and shoreline change and to update information on coastal cliff instability risk. Aerial surveys, using LiDAR, vertical photography and multispectral techniques are also undertaken every two to three years to document cliff recession rates and patterns of dune evolution. These data have also been used to map coastal habitats and investigate the regions archaeological resource. A baseline bathymetric survey, including sediment sampling, has been undertaken at main settlements and a more extensive repeat survey is planned to document offshore sediment movements. All data and analytical reports are freely available to all users on the programme website: http://www.northeastcoastalobservatory.org.uk/

Emerging lessons

Long term data on mean sea level change

Mean sea level data from North Shields (data provided by PSMSL, 2014) show a long term trend of relative sea level rise of 1.91mm/yr over the last century, see Figure 4. There does not appear to be any clear change in rate of rise over the last 50 years. However, the annual mean data show variability of order of +/-100mm about the trend line over 10 to 20 years, which may partly relate to tidal and climatic cycles. Analysis of trends in the monitoring data require long term change to be identifiable from short term variability, suggesting that >50 years of data are required for detection of mean sea level trends. The Whitby data period is 32 years, but there are significant gaps in the record with ten missing annual mean data points.

Therefore, although the data for Whitby in Figure 5 show a significantly higher rate of rise, calculated as 6.7mm/yr, the trend is likely to be unreliable. However, restricting the analysis at North Shields, to the same data years available at Whitby gave a rate of rise at North Shields of 3mm/yr, less than half that found at Whitby, suggesting that there may be differential land level changes between the two sites. This indicates that further investigation may be warranted and that reliance on regional land level changes such as those used in UKCP09 for predictions of future relative sea level rise could be inadequate.

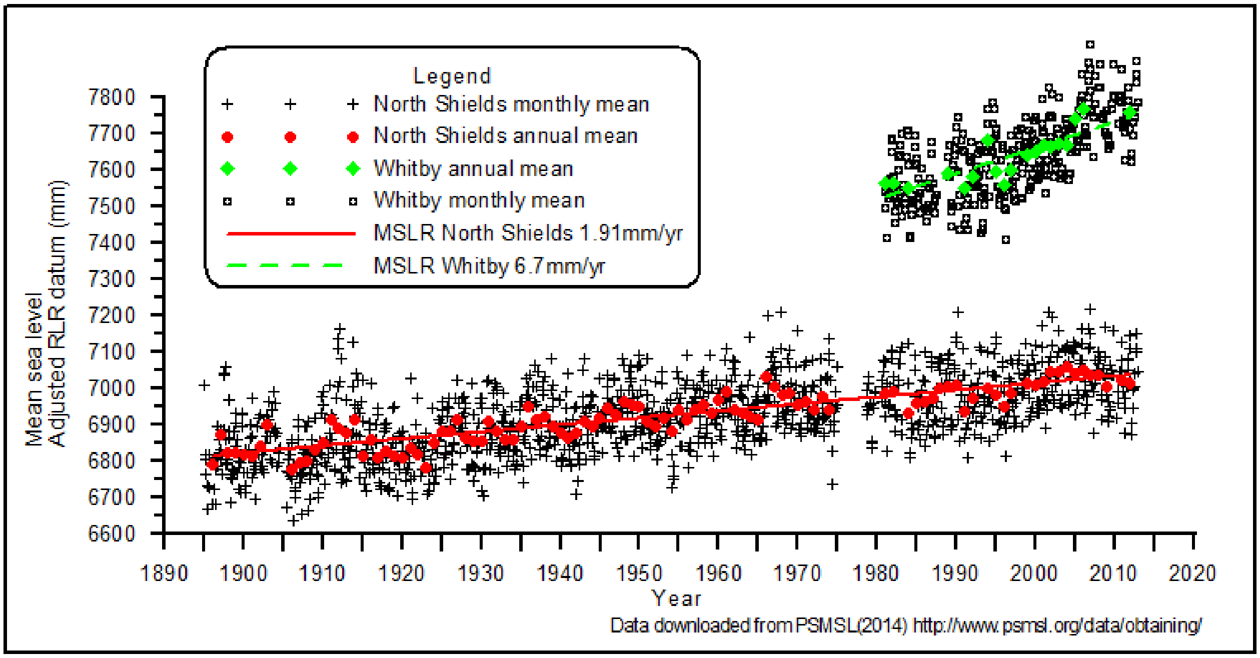

Figure 4 Monthly and annual mean sea level data in Cell 1 from 1895 to 2012

Extreme sea levels

Results from analyses of extreme sea level using gauge data from the national tide gauge data sets from Whitby and North Shields and the Cell 1 programme tide gauge at Scarborough, which has data from 2004, compared very closely with the EA (2011) coastal flood boundary conditions results when data up to the end of November 2013 were analysed. The highest recorded sea levels in Cell 1 occurred during the 5th/6th December 2013 storm surge event. At North Shields the peak water level of 3.98mOD, on the 5th December 2013 significantly exceeding the previous maximum recorded sea level of 3.56mOD on 31st January 1953. Based on the preceding extreme sea level statistics the 2013 surge event had an Annual Exceedance Probability (AEP) of about 1 in 500 at North Shields, although accounting for uncertainty the range of could be between 1 in 100 and over 1 in 1000 AEP.

The extreme statistics were re-evaluated at the three sites taking into account the recorded data from December 2013 (see Table 1) and it was found that the predicted extreme water levels increase, with the levels for the 1 in 100 AEP event raised by between 0.1 and 0.3m. At North Shields, which has the longest data set with data from 1948 onwards the change is only 0.1m, but at Whitby and Scarborough, where the data records do not go back to the 1953 surge, inclusion of the December 2013 surge has a larger impact on the predicted extremes, which are increased by 0.2 to 0.3m.

Table 1 Impact of the December 2013 surge on 1 in 100 AEP tide levels in Cell 1

Location	Extreme Level (mOD) from EA CFB Study (2011)	Confidence intervals (m) from EA CFB Study (2011)	Analysis of North Shields NTSLF data to November 2013 (mOD)	Analysis of North Shields NTSLF data to February 2014 (mOD)
North Shields	3.8	0.2	3.8	3.9
Whitby	4.0	0.3	4.0	4.3
Scarborough	4.0	0.3	4.1	4.3

This indicates that the December 2013 event could not have been predicted by the previous events and that the EA (2011) CFB national data set should be updated to take into account the winter 2013/14 storm events.

Long term rainfall data

Rainfall records from Whitby that cover the period 1962 to present have a long-term average of 575mm per year (Figure 5). The data show a marked increase in rainfall in the last 10 to 15 years with the five wettest years on record occurring in 2012 (883mm), 2010 (839mm) and 2004 (811mm), 2008 (782mm) and 2002 (762mm). These data are likely to have a strong influence on the coastal cliff instability risk that is determined in part by periods of high and sustained rainfall, which act to elevate groundwater levels and weaken slope materials.

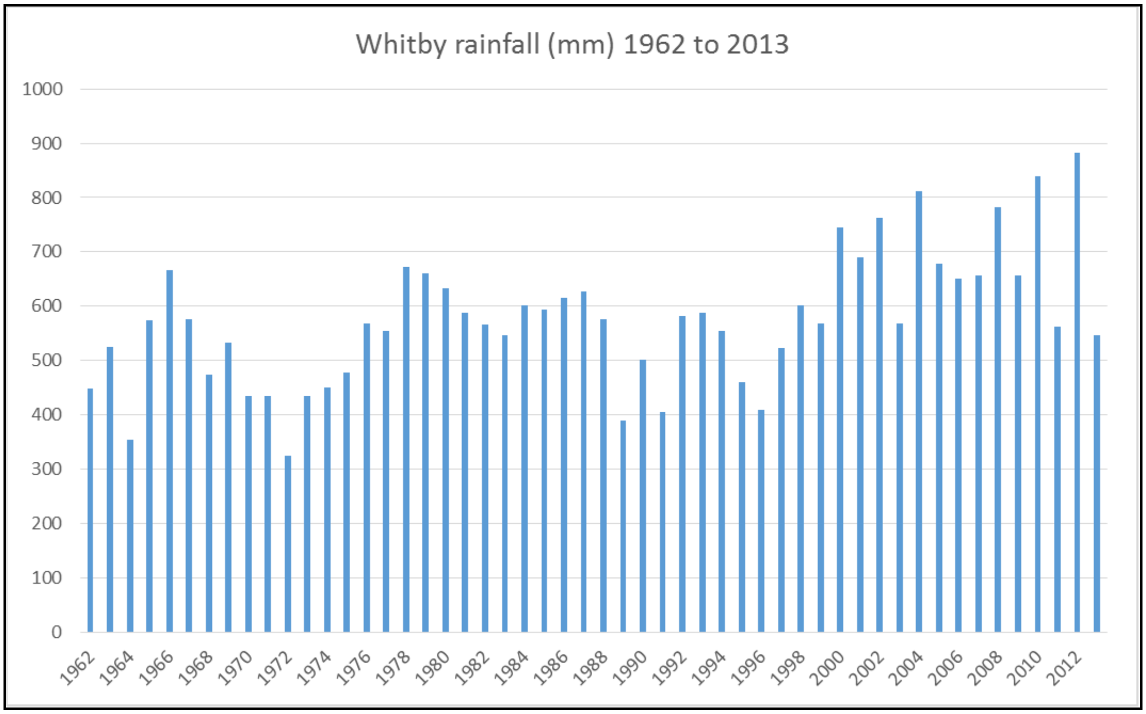

Figure 5. Annual rainfall data for Whitby

Wave data analysis

Offshore wave monitoring data is available from 2006 from the Tyne Tees WaveNet buoy. The near shore buoys deployed at Scarborough, Whitby and Newbiggin have data periods of less than 3 years, whilst the Tyne Tees WaveNet buoy has data for 8 years. Storm analysis of the wave data has been undertaken to aid interpretation of the beach monitoring data and this is now being incorporated in annual monitoring reports. A wave energy plot in Figure 5 identifies storms with significant offshore wave heights above 4m. The storm analysis shows that there are between 3 and 13 storms each year, with 2010 having most and 2014 the fewest. The three biggest storms on the record occurred over the winter 2007 to 2008.

A comparison of the Met Office modelled data at the nearest location to the Tyne Tees buoy found that the hindcast wave data, which is available from 1980 to 2012, show a very similar temporal record to the measured data at Tyne Tees, but the peak wave height on most storms is significantly under-estimated, with peak wave heights often 0.5m or more less than measured, see example plot in Figure 5. This indicates that the model calibration is not good for peak storms in this location and that caution should be used and consideration given to adjusting or calibrating the Met Office hindcast offshore data if it is to be used for boundary conditions in coastal modelling studies.

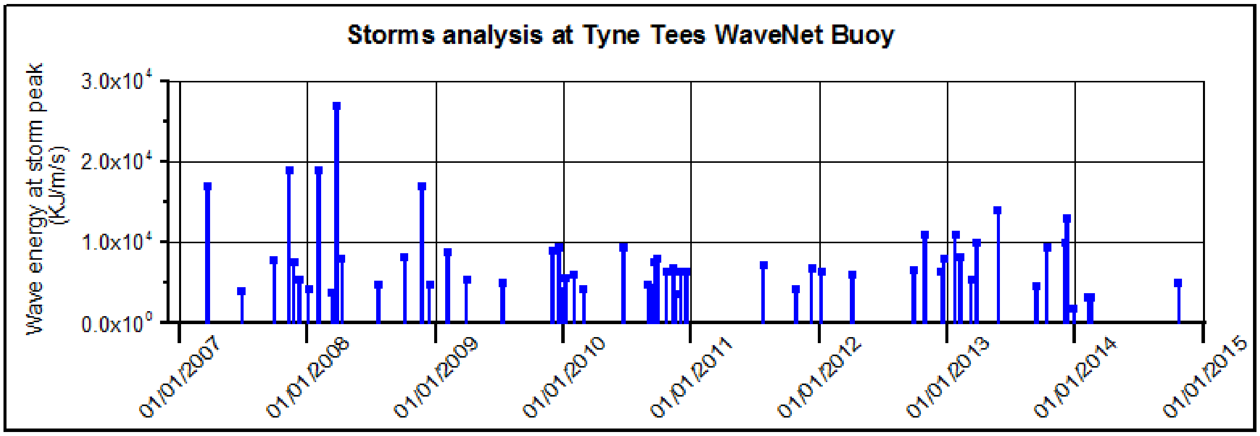

Figure 6 Annual variability of offshore storms using data from 07/12/2006 to 07/12/2014

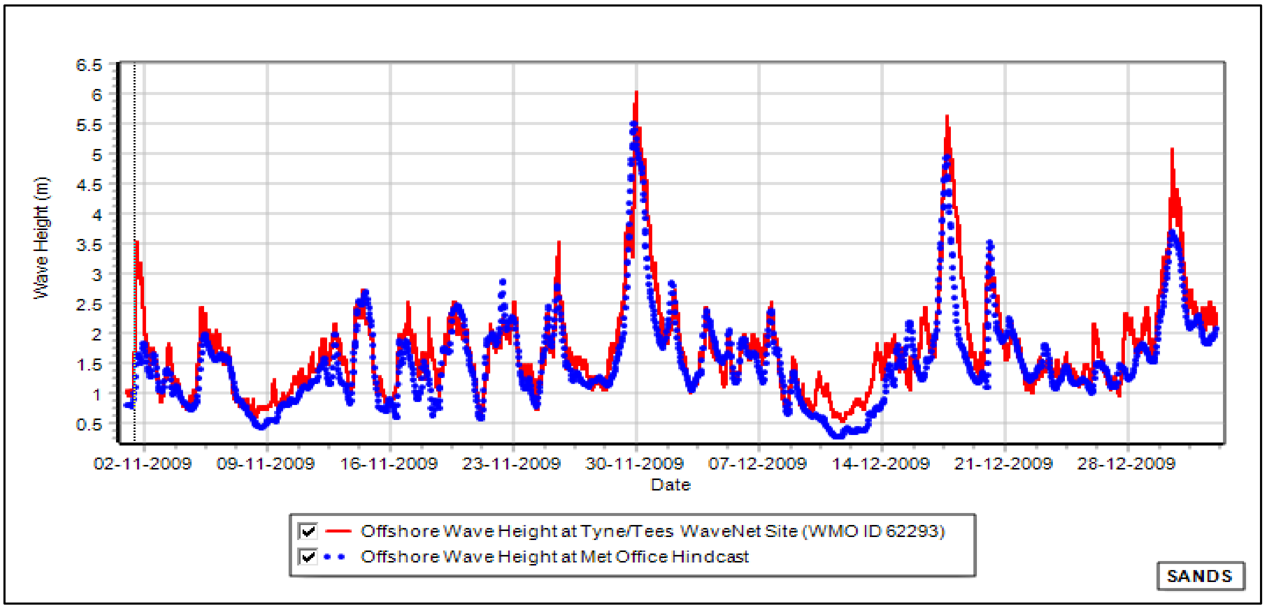

Figure 7 Example plot of hindcast and measured wave data at Tyne Tees in winter 2009

Beach topographic and profile monitoring data

Topographic and profile surveys of beaches have been undertaken for at least 6 years, with more than 10 years available for some profile locations north of the Tyne, allowing short to medium-term trends to be investigated. However, at all locations where topographic data are available the magnitude and pattern of change between the baseline and most recent surveys is almost identical to that shown when comparing annual surveys. This indicates that seasonal/annual sediment movement is considerable and it masks any underlying trends for erosion or accretion. Collection of longer-term datasets will be required to highlight subtle underlying trends.

The beach profile data also shows large year to year variability in most locations. However, trends can begin to be established from the data in some locations (see Figure 8). The wave data shows that there were relatively few storms in 2011 and more than normal storms in 2013 (see Figure 6). The data collected to date in Cell 1 are limited to beach levels above low tide, which limits the understanding of sediment movements. In other regional monitoring programmes bathymetric extensions to beach profiles are surveyed, generally less frequently than the land based surveys. Bathymetric surveys have been completed along a limited number of narrow sections already and more comprehensive surveys are planned for Cell 1 in the future. Along with other regional programmes, consideration will be given to the use of innovative approaches to capturing the beach profile below low water and rapid post storm surveys of upper beach topography using remote survey techniques such as Unmanned Surface Vehicles (USVs), Unmanned Aerial Vehicles (UAVs) and Autonomous Underwater Vehicles (AUVs).

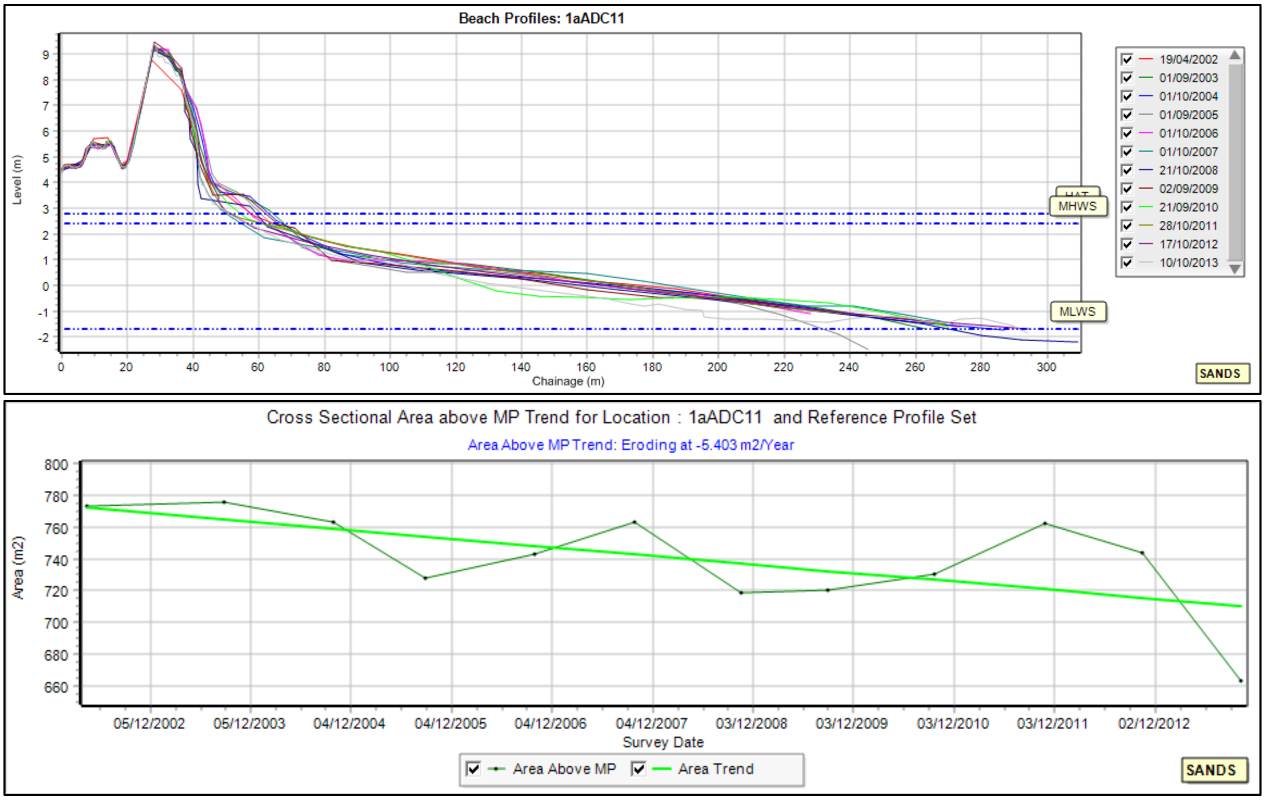

Figure 8. Example trend analysis from beach profile data at Alnmouth, Northumberland

Cliff recession analysis

Cliff recession monitoring has been undertaken using biannual field survey at a small number of sites and analysis of aerial survey data of the entire Cell 1 frontage captured in 2003, 2008, 2010, 2012/13. Field surveys are prone to errors principally caused by problems in precise identification of the cliff top in the field, particularly where thick vegetation has developed. This has generally led to short-term cliff recession data being unreliable. However, now that a record of at least 6 years' data is available, erosion patterns are becoming clearer and more reliable cliff recession rates can start to be provided. In contrast, aerial surveys can provide recession data for an infinite number of cliff locations and are only limited by the accuracy of the ortho-photos, which is better than ±0.1m with contemporary technologies. Representative cliff profiles can be identified by first mapping the cliff behaviour units (Lee and Clark, 2002). The interpretation of CBUs and recognition of the cliff edge is greatly aided by the use of LiDAR data typically collected simultaneously with digital imagery.

Field survey data collected from Filey Bay between November 2008 and September 2014 are summarised in Figure 9, which shows a record of cliff recession from four profiles out of a total of 28 currently monitored. They highlight that at some locations there has been little or no cliff recession (Profile 16 and 20), but that at other locations, episodic erosion has occurred (Profiles 5 and 7). The episodic erosion is characterised by recession of several metres in a six month period (in fact probably in a single event in a day) separated by a period of years where no detectible cliff recession occurs. The data from Profile 5 shows 3.5m recession in the 6 months between November 2008 and April 2009 and a further 2.1m recession between October 2009 and March 2010. Recession has been much less significant between March 2010 and September 2014, with only 0.8m erosion in this time. From a total of 28 measured profiles in Filey Bay, the average recession rate between 2008 and 2013 has been 0.1m/yr, but rates range from 1.3 to 0.0 m/yr. The data highlight that the most significant cliff recession events occurred between November 2008 to March 2010 (recorded in Profile 5), with other notable failures occurring in the spring/summer of 2011 (Profile 7), spring/summer 2012 (Profiles 7 and 16). The rainfall records from nearby Whitby (Figure 5) show that 2008, 2010 and 2012 were all exceptionally wet years (in the top 5 wettest years since 1962) and these have been plotted on the chart. The data suggest there is a relationship between high rainfall and accelerated cliff recession. Periods of below average beach levels are often associated with accelerated cliff recession (Lee, 2008; Pye and Blott, 2015) and data from nearby profiles are also marked on the chart. The beach data collected from Filey Bay are inconclusive, with periods of low beach level typically unrelated to phases of cliff recession. Collection of longer-term data on cliff recession, rainfall and beach levels will allow these relationships to be further investigated and better understood. In addition, analysis of slope monitoring equipment installed in areas of high cliff instability risk along the Scarborough Borough Council frontage will allow relationships between rainfall, groundwater level and slope failure to be explored.

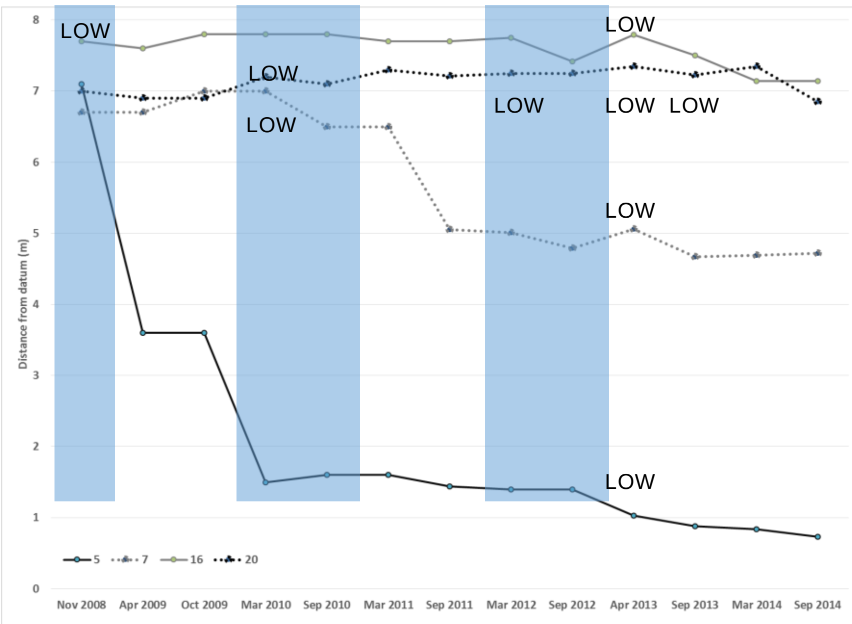

Figure 9. Cliff recession data (distance to cliff edge) measured in Filey Bay. Wet years are highlighted by shaded zones. Periods of lower than average beaches are marked “LOW”.

The analysis of aerial survey data covering Filey Bay indicates average recession rates between 2008 and 2012/13 ranged from 0.0m/yr in the composite cliffs at Bempton (till over chalk) to 0.27m/yr in the simple landslides (mudslides in till) around Hunmanby Gap. Data from 2010 to 2012/13 highlights that recession rates can be higher over shorter time periods, reflecting the impact of episodic landslide events and rates of over 2m/yr are recorded in some simple landslide CBUs. The aerial survey dataset has also been used to monitor dune systems that are prevalent along the Northumberland coastline. The data collected to date indicates significant variability in the position of the dune frontage, with periods of both accretion and erosion indicated at rates that are commonly up to 5m/yr, but reaching 10m/yr in certain locations.

In summary, the recession rates derived from aerial survey and field-based techniques are in close agreement and highlight the significant variability in cliff recession rates over time and in different CBUs, which may be missed in smaller datasets covering shorter periods of time or with more limited spatial coverage. However, the relatively short time period covered by the data and the variability over time and in different CBUs means that understanding the relationships between recession, rainfall and low beach levels is uncertain and longer-term changes in the recession rate, potentially in response to climate change and relative sea level rise, are unclear.

Conclusions

The North East Monitoring programme was designed to improve strategic understanding of coastal risks and ongoing coastal change. Beach and cliff monitoring data is now available for 5 to 10 years and analysis of the data is beginning to show trends and improve understanding of coastal change. Continued monitoring will allow better informed decisions on coastal management to be taken in future.

The key lessons and recommendations from analysis of Cell 1 data available so far include:

- Consistent long term monitoring is required to underpin strategic shoreline management decisions. The Cell 1 programme is in its infancy and quality controlled consistent data collection needs to be continued in a manner for at least a further decade to identify trends.

- Analysis of datasets to determine long term coastal change forcing factors, such as sea level rise and rainfall, demonstrate that short term variability can mask longer term trends.
- A relationship between phases of accelerated cliff recession, low beach levels and periods of wet weather is suggested, but longer-term datasets are needed to better understand these complex inter-relationships. The high variability and short-term nature of the currently available data means that relationship between cliff recession and relative sea level rise is unclear.
- Modelled offshore waves have been shown to underestimate peak storm waves offshore Tees Bay, highlighting the need to continue wave buoy deployments and use the data to improve national and regional scale wave modelling in future.
- Relative sea level rise may differ locally from regionally recommended values, but longer term data is required to confirm.
- The extreme sea levels experienced during the December 2013 event could not have been predicted by the data from previous events. The EA (2011) CFB national data set should be updated to take into account the winter 2013/14 storm events.
- Strengthening of similarities between the regional programmes is recommended to ensure that analysis of data can be undertaken at a national scale.
- The magnitude and pattern of change between the baseline and most recent surveys is almost identical to that shown when comparing annual surveys. This indicates that seasonal/annual sediment movement is considerable and it masks any underlying trends for erosion or accretion. Collection of longer-term datasets will be required to highlight subtle underlying trends

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