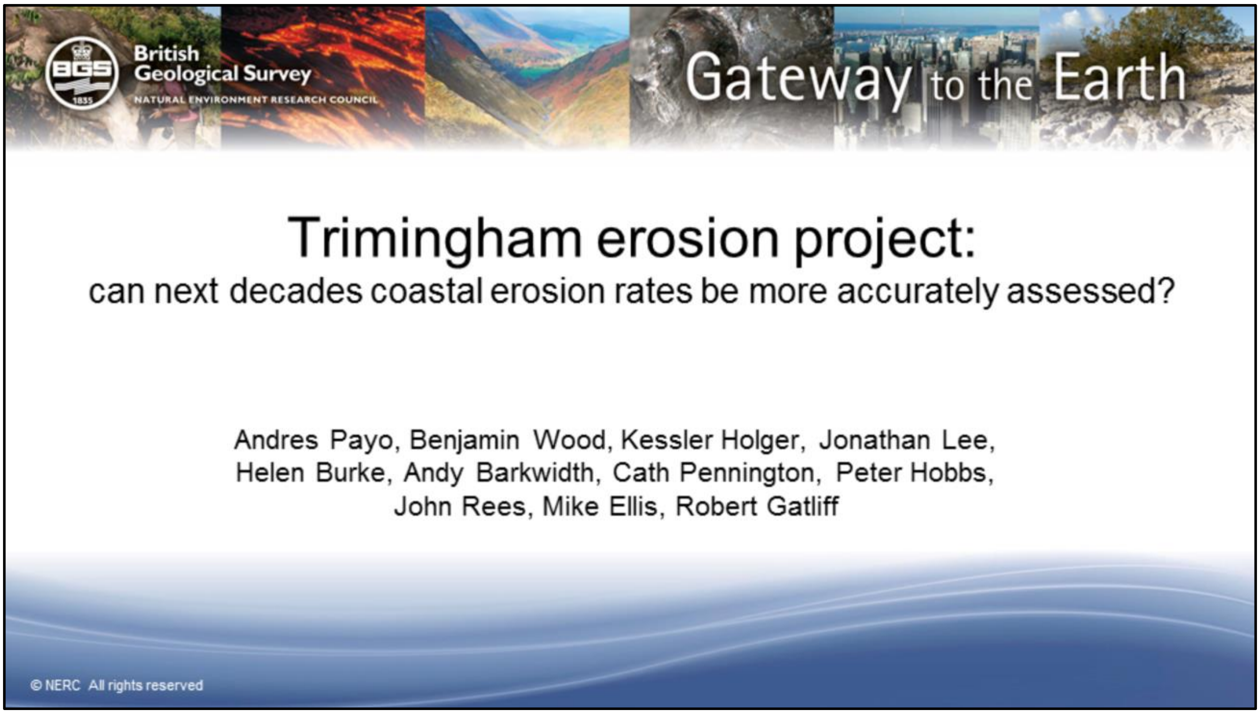


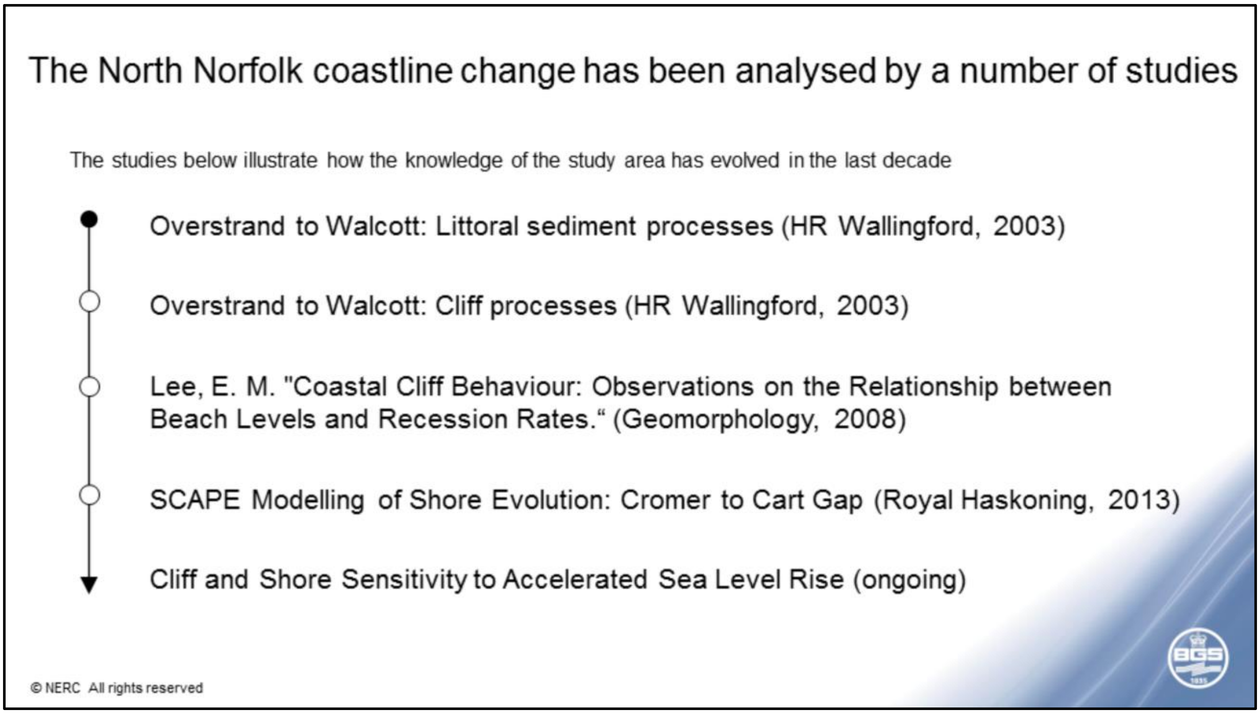
On the 28/03/2017 BGS was contacted by the Environment Agency (Kellie Fisher , FCRM Senior Advisor – Norfolk, Coastal Partnerships & Strategic Overview Team East Anglia Area) to investigate if erosion rates at Trimingham can be more accurately assessed?. Overall erosion rates are relatively consistent when averaged over the years, at any one point along the Trimingham coast there are periods of higher than usual rates of erosion followed by periods of relative stability. This makes erosion rate prediction particularly difficult. Report data suggests that between 1966 and 1985 the cliff eroded between 1.5-2.5 metres per year. Historic mapping data suggests between 50 and 60 metres of erosion over a period of 100 years, which would indicate an erosion rate between 0.5-0.6 metres per year. Shoreline Management Plan mapping indicates that 75-150 metres of erosion could be expected over the next 100 years (0.75-1.5 metres per year). These figures highlight the difficulties in predicting accurate erosion rates. On the 31/03/2017 BGS coastal modellers, Andres Payo and Andrew Barkwith discussed over the phone with Kellie Fisher whether BGS could provide additional evidences to narrow down the expected future erosion rates at Trimingham for the different SMP epochs (0-20, 20-50, 50-100 years from now). This document summarizes the activities that BGS has done, to date 17/09/2017, as part of our National Capabilities to address this issue.

This presentation is the result of work carried by a team of 11 member of BGS's staff with expertise on quaternary geology (Jonathan Lee and Helen Burke) and land sliding processes of the study area (Catherine Pennington and Peter Hobs), state of the art representation of the subsurface (Holger Kessler and Benjamin Woods), and nearshore hydrodynamic, sediment transport and decadal morphodynamic modelling (Andres Payo, Andy Barkwidth). This presentation has been reviewed by Jonathan Rees, Robert Gatliff and Michael Ellis.

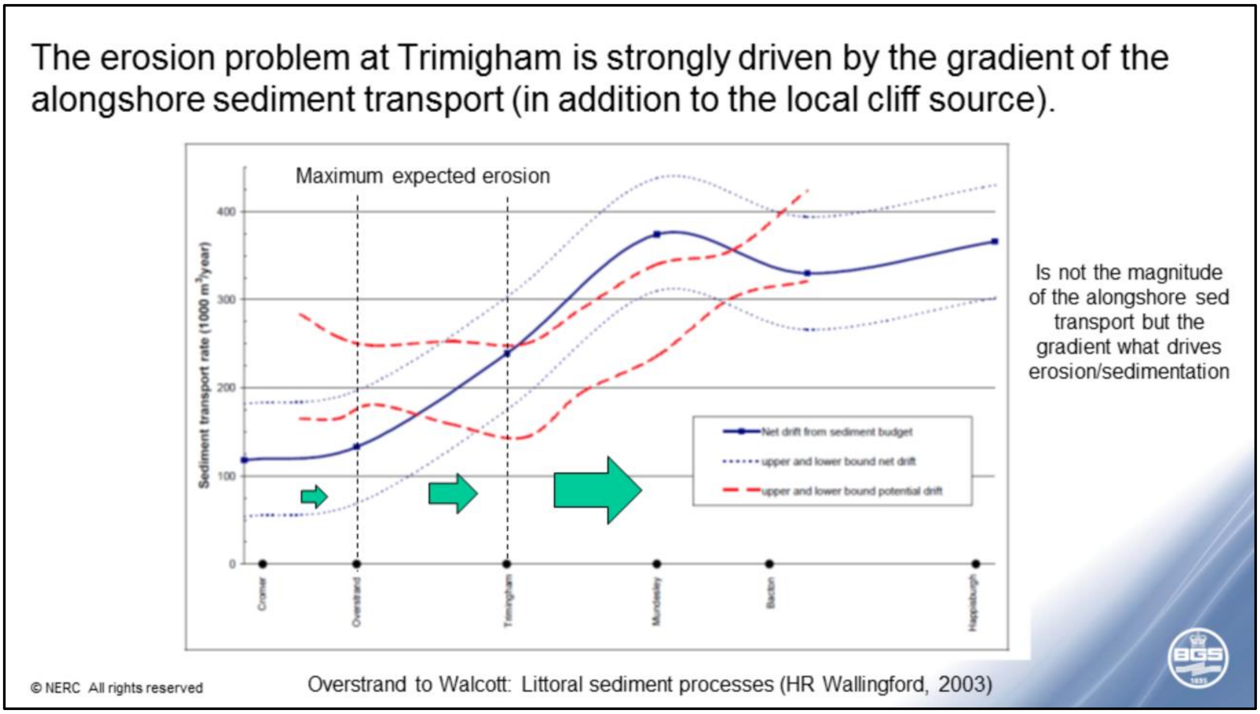
Outline

- Lessons learnt from previous studies
- Better cliff recession assessment by improving:
  - Surface and subsurface representation,
  - Wave propagation and runup,
  - Coastal catch-up
  - Landslide modelling
- Next steps
- Implications for coastal recession assessments

In the following slides we first review the lessons learnt from exiting previous studies on the area.
Limitations of previous assessment are related to: (1) gross representation of the cliff yields and subsurface, (2) over-simplifying assumptions on wave propagation on the nearshore bathymetry and (3) neglected the likelihood of coastal catch up. All these limitations has a direct effect on the assessment of future cliff recession rates.
One novel way of overcoming these limitations is the use of the Coastal Modelling Environment which is a landscape evolution model that incorporates a better representation of the surface and subsurface and wave propagation module. While we argue that the CoastalME approach is scientifically sound and plausible way forward it brings new challenges. The major challenge is the limited information to date to build a sound model of the surface and the subsurface for an area large enough to provide reliable estimations at Trimingham. We outline the work that is still required to produce this reliable assessment and discuss the implications that this are likely to have on previous recession assessments.



The highlight from these studies is summarized in the following slides.

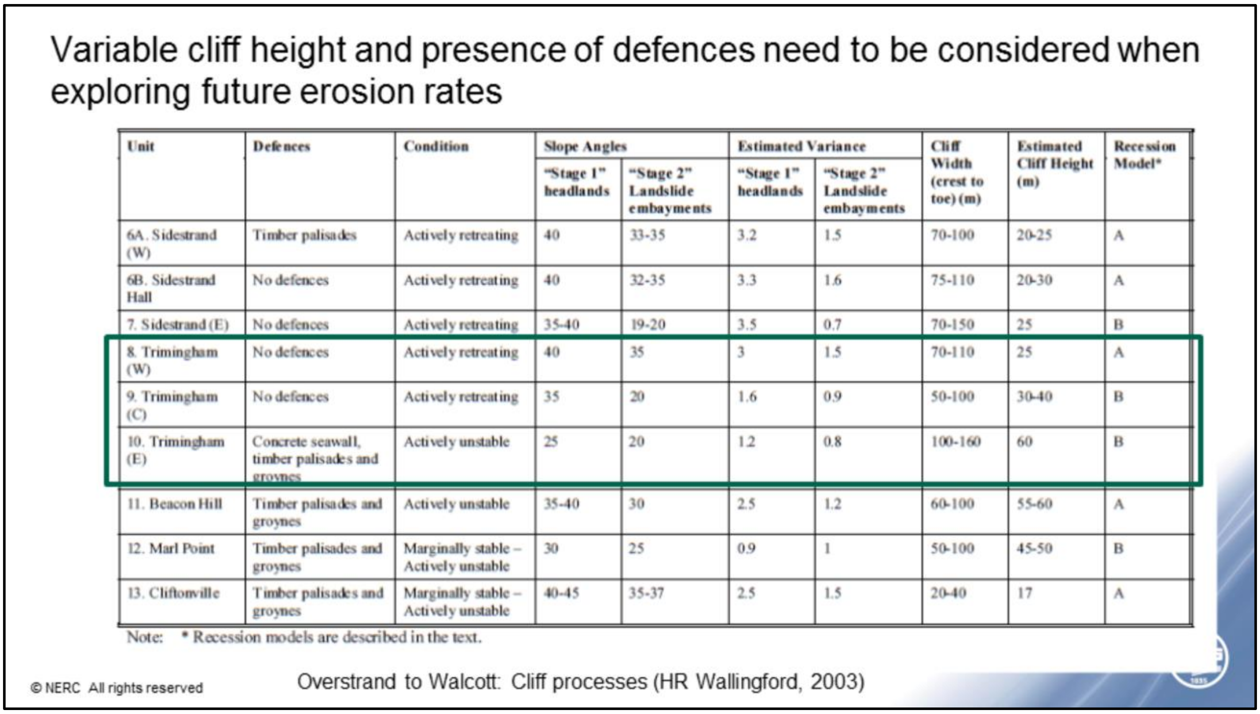


HR Wallingford in 2003 studied the littoral sediment processes in the region between Overstrand and Walcott on the North Norfolk coast have been through observations and modelling.

The potential net longshore sediment transport has been modelled (CERC equation), and beach volume changes have been derived from repeated surveys of set profiles. The evolution of high and low water and the changes in beach steepness have been derived from historical maps, while cliff recession and sediment yields have been derived from observations of recession and sediment type. The cross-shore sediment transport due to storms has been modelled using COSMOS model, and some sediment samples have been analysed.

The sources of information have been combined to give a conceptual sediment transport map, and the interactions with adjacent coastal management units have been discussed.

The figure shown compares these determined values of net drift from the conceptual model with the numerically modelled potential drift as discussed in Section 2. The net sediment transport rates are thought to lie within a range reflected by the upper and lower bands. The potential drift at Cromer (calculated by numerical modelling) is much higher than the net drift as calculations of net drift take into consideration mixed sediments on the beach. (The standard CERC equation was adjusted to account for this by setting the time scale coefficient, K1, to a value intermediate to those used for uniformly sand and uniformly shingle beaches.) Approaching Trimingham, both the potential and net drift follow similar increasing trends. The local maxima (net drift of the order of 345,000m3/year) downdrift of Mundesley is caused by accretion of the beach in excess of sediment input from the cliffs. However, while such accretion is observed in the short-term beach profile analyses, it is not thought that this will continue over the long-term.



Unit	Defences	Condition	Slope Angles		Estimated Variance		Cliff Width (crest to toe) (m)	Estimated Cliff Height (m)	Recession Model*
			"Stage 1" headlands	"Stage 2" Landslide embayments	"Stage 1" headlands	"Stage 2" Landslide embayments			
6A. Sidestrand (W)	Timber palisades	Actively retreating	40	33-35	3.2	1.5	70-100	20-25	A
6B. Sidestrand Hall	No defences	Actively retreating	40	32-35	3.3	1.6	75-110	20-30	A
7. Sidestrand (E)	No defences	Actively retreating	35-40	19-20	3.5	0.7	70-150	25	B
8. Trimingham (W)	No defences	Actively retreating	40	35	3	1.5	70-110	25	A
9. Trimingham (C)	No defences	Actively retreating	35	20	1.6	0.9	50-100	30-40	B
10. Trimingham (E)	Concrete seawall, timber palisades and groynes	Actively unstable	25	20	1.2	0.8	100-160	60	B
11. Beacon Hill	Timber palisades and groynes	Actively unstable	35-40	30	2.5	1.2	60-100	55-60	A
12. Marl Point	Timber palisades and groynes	Marginally stable – Actively unstable	30	25	0.9	1	50-100	45-50	B
13. Cliftonville	Timber palisades and groynes	Marginally stable – Actively unstable	40-45	35-37	2.5	1.5	20-40	17	A

Note: * Recession models are described in the text.

From HRW 2003 Overstrand to Walcott: Cliff Processes

Type A – Cliffs prone to repeated high-angled debris slides and lobate mudslides within distinct, narrow gully channels. These cliffs are affected by regular, small-scale recession events, with cliff top losses of probably in the order 1-5m/failure event.

Type B – Cliffs prone to large, episodic landslide events, usually deep-seated rotational slides or compound style failures. Significant cliff top losses can occur during landslide events, probably up to 25-30m in width.

For those areas where the Type A recession model is applicable (i.e. Cliff units 1 and 2 in Overstrand; units 13-16 at Mundesley), the renewal of cliff top recession behind and adjacent to a breach would probably involve:

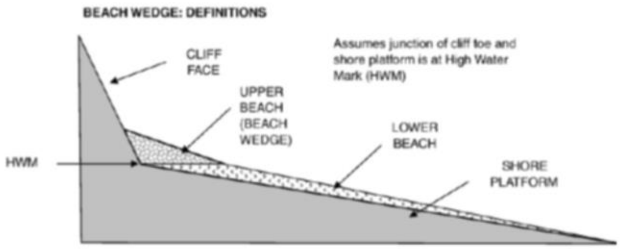
- A dramatic initial surge of cliff top retreat, possibly involving the loss of up to 50m within the first 5 years after defence failure/removal.

- The establishment of a relatively uniform long-term average annual recession rate with episodic events separated by periods of very slow or no retreat. As the cliffs are low (<50m high), the individual landslides are likely to be small-scale failures, possibly involving around 2-5m cliff top loss in a single event.

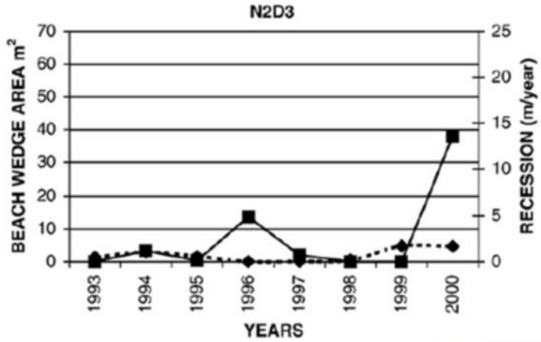
- Dramatic, overnight losses associated with the impact of low probability storm surge events. It is possible that over 30m of retreat could occur in a single event.

For Types B and C recession model areas, the potential for large, episodic loss of cliff top land needs to be superimposed on the Type A recession trend. Such events are likely to be of the order of 25-30m for the Type B sites (i.e. Cliff unit 3 at Overstrand). In contrast, the 1990-1995 losses at Clifton Way suggest that over 100m might be lost over a relatively short period at Type C sites (i.e. Cliff unit 4 at Overstrand).

The small beach volumes at Trimingham drives the high variability of observed annual recession rates which for period 1993 to 2001 ranges from 0 to 15 m/year



From Lee (2008) Geomorphology

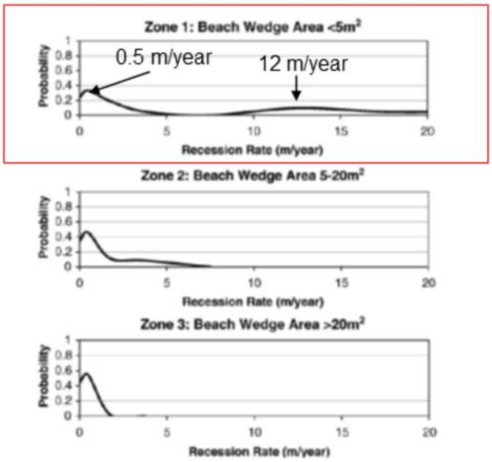


Closest undefended profile to Trimingham

Lee (2008) found an inverse relationship between the beach wedge and the annual cliff recession rate (not shown).
He used the EA bi-annual profiles (from high ground to low water mark) along the Suffolk and Norfolk coast.
For the closest undefended profile to Trimingham no clear relationship can be found. For the period 1993 to 2001 beach wedge area (dashed line on graph) was always below 10 m^2 and cliff recession rates ranges from 0 to 15 m/year (solid line).

Lee, E. M. "Coastal Cliff Behaviour: Observations on the Relationship between Beach Levels and Recession Rates." Geomorphology 101, no. 4 (2008/11/01/ 2008): 558-71.

Combining all profiles on North Norfolk three behaviours can be identified regarding cliff erosion variability



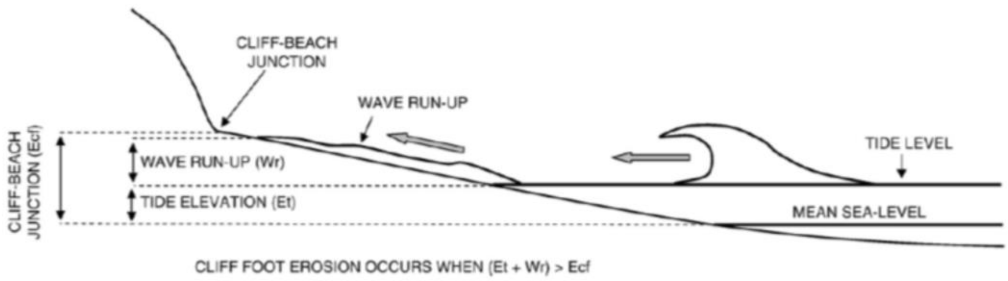
Lee (2008) Geomorphology

The bedrock is exposed at Trimingham constraining the beach volume

http://www.invisibleworks.co.uk/on-the-beach-trimingham/

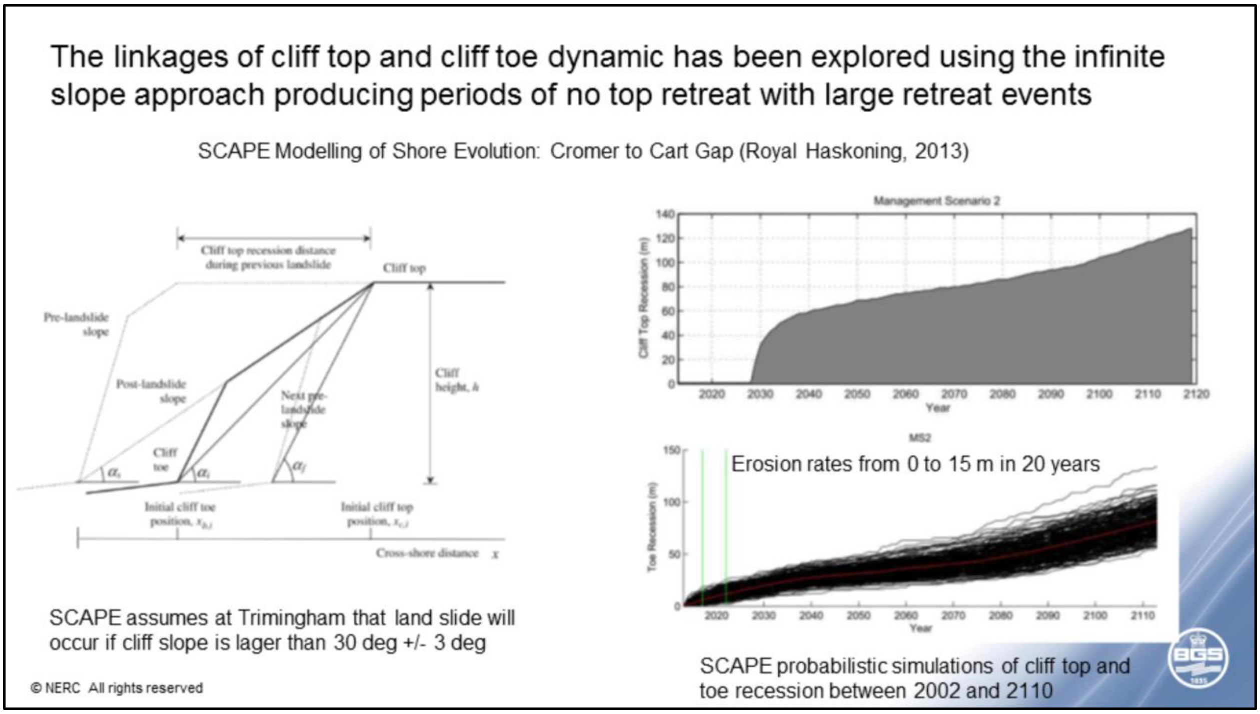
The bedrock outcrops at Trimingham constrains the beach volume making the cliff erosion highly variable.

The expected cliff behaviour is generally closer to a high wave energy input than the progressive change that is typical for many parts of the UK



For this reason it is better to express the long-term recession rate as up to 25m every 10 years rather than 2.5m/year.

The cliff recession process, caused by occasional relatively large landslides, is episodic rather than continuous.
For this reason it is better to express the long-term recession rate as up to 25m every 10 years rather than 2.5m/year.
Large runups such as the one observed during the 1953 (3.7 mOD) storm can erode as much as 30m as observed at the cliffs at Bacton



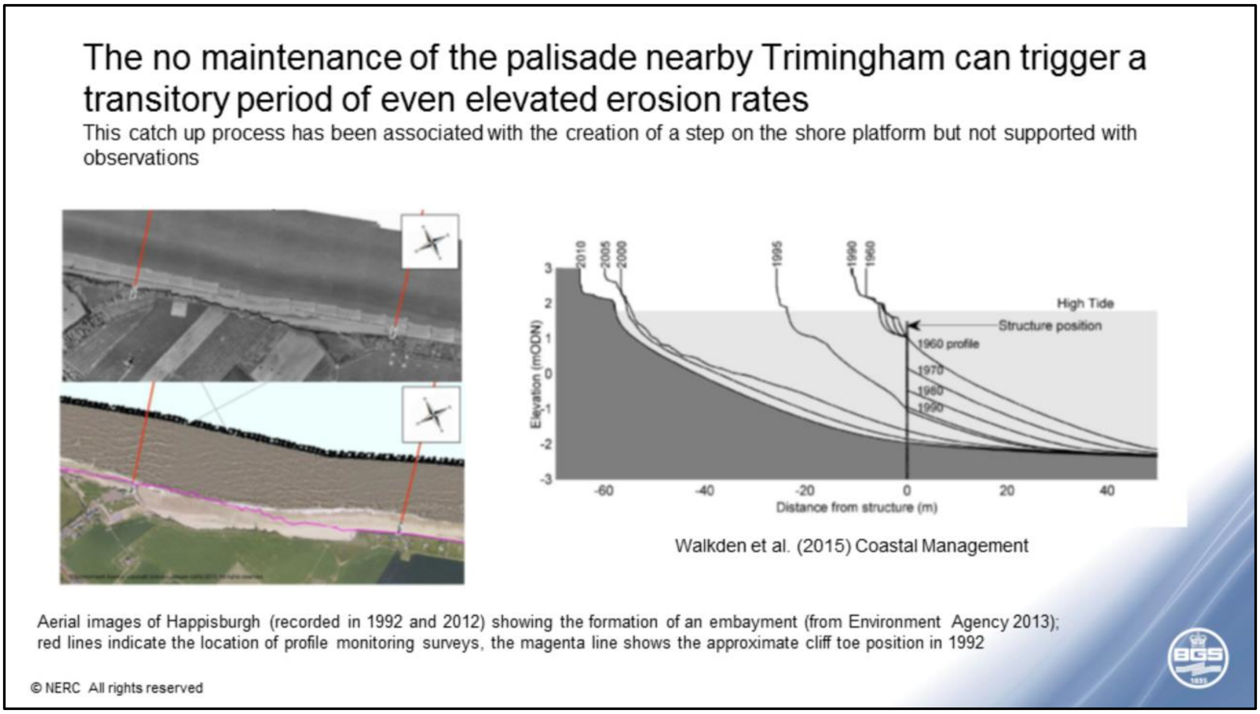
Royal HaskoningDHV was commissioned by Mott MacDonald to run a numerical geomorphological model of the shore of North Norfolk (UK) between Cromer and Cart Gap. This work is an element of the Cromer to Winterton Ness Coastal Study, which Mott MacDonald is undertaking for North Norfolk District Council.

The model was used to explore geomorphic response to two alternative scenarios of coastal management: named ‘Do Nothing’ (or Scenario 1) and ‘SMP Policy 6’ (or Scenario 2). This was achieved in the model by representing the loss or removal of coast protection structures, where this would occur as a consequence of the management policy.

The lack of cliff top recession during the early years, and the projection of (possible) zero recession in this area throughout the next century, arises for a related reason. Each simulation begins with a stochastic estimate of an *initial* cliff slope. In Trimingham that initial slope was estimated to be 35 degrees (as a mean, with a standard deviation of 3 degrees). This is very steep relative to the assumed maximum slope meaning that a cliff failure (and therefore cliff top retreat) is *highly likely* at this location in the early stages of the simulation. This occurs in the simulations (which begin in the year 2000), but because the results are related to cliff position in 2012, this early retreat is filtered out of the results i.e. the model simulates this cliff failure prior to 2012.

The key implication for the project is that the projected absence of recession of the cliff top before around 2030 at Trimingham should be considered to be unreliable. The process of expert interpretation that should be applied to such modeling should pay particular attention to this location with a view to substituting an alternative (non-zero) retreat rate in this location, in the early decades. The cliff toe recession could be used to inform this process (notice that erosion rates ranges from 0 to 15 m/year).

The wide bands of recession (i.e. the possibility of very low cliff top recession at Trimingham throughout the next century) should also be interpreted with caution. This reflects real uncertainty (in conditions of cliff stability) but is also partly an artifact of the process of normalizing model output to the cliff position in 2013.



Understanding coastal 'catch-up' is central to effective coastal management decision making. This is the behaviour exhibited by certain coasts, where the shoreline retreats rapidly after the removal of defensive structures, before returning to a more stable recession rate. This problem will be the subject of an upcoming Environment Agency project, described elsewhere (Hardiman, 2015). Technical elements of this issue have also been studied within the Environment Agency's project SC20017 Cliff and Shore Sensitivity to Accelerated Sea Level Rise (ongoing).

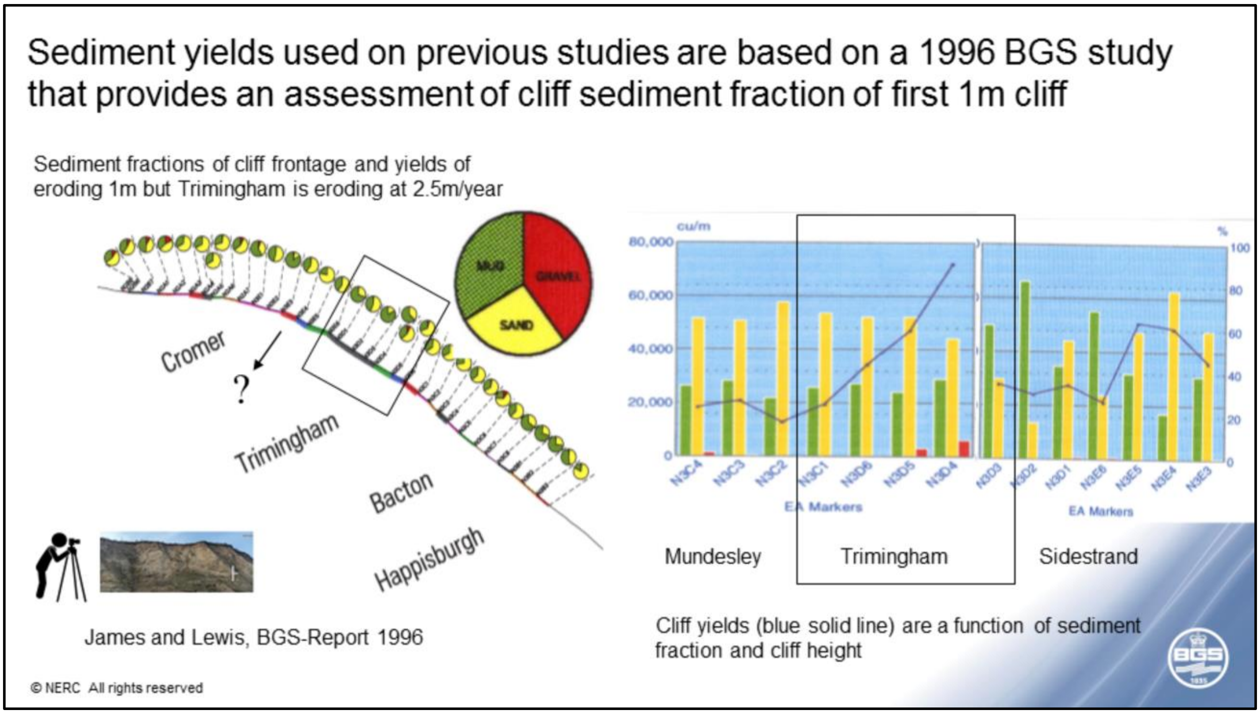
HRW 2003 also stated that:

"Rates of platform lowering can be surprisingly high, especially on coastlines developed in glacial tills or clays, in the order of 0.1-10mm/year. This can become an important consideration in the long-term performance of coastal defence structures. The water depths in front of the structure can increase significantly over its design life, affecting the overtopping performance and standard of protection as well as increasing the risk of undermining.

Shore platform erosion may continue irrespective of the cliff recession process. Thus, when defences fail or are removed, waves can arrive at the cliff foot more frequently than would be the case on a 'natural' (i.e. unprotected) cliff-beach system. This offers a possible explanation for the dramatic, short-term recession rates recorded at Happisburgh. Following the removal of the defences (timber palisades) at this location, the cliffs retreated 50m in a 3-year period from 1996-1999. However, as the cliff-beach system gradually develops a new equilibrium form, the recession rate will decline after a number of years. "

BGS is doing a secondment with WSP Group to explore if the extreme erosion observed at Happisburgh is an isolated issue of is just the synthon of a more acute problem. The novel Passive seismic sensor provides a unique technology to explore if there is an step in front of the palisade and therefore faster erosion rates might occur in case this defences are not maintained in the future.

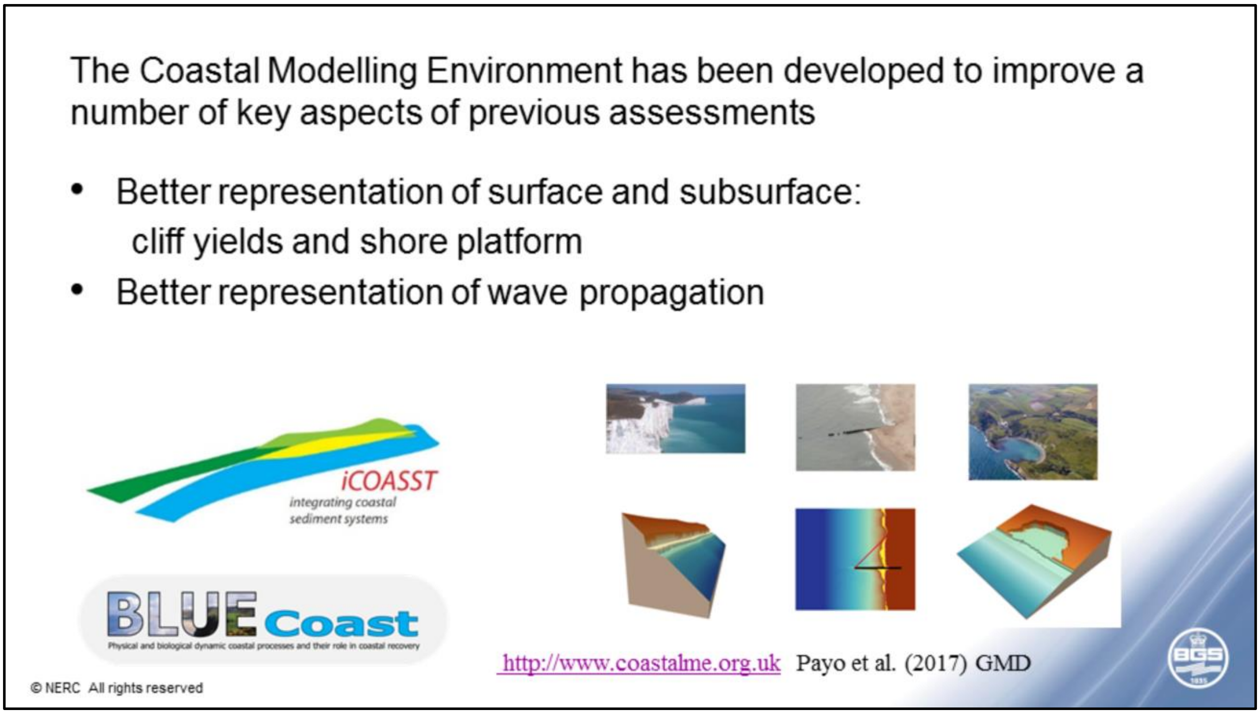
Hardiman, N. (2015) A Short Guide to Doing Nothing at the Seaside, proceedings of Coastal Management 2015, the Netherlands



James and Lewis (1996) estimated that sediment fraction is mostly (65%) sand and mud (35%) at Trimingham. In this region, sediment yields are maximum at sections N3D5 to N3D4 where cliff are highest (60m).

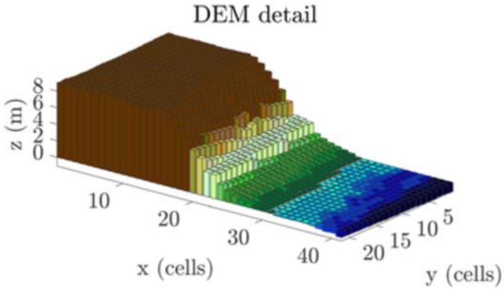
In this report it was stated at the executive summary that “In terms of future sediment inputs from cliff erosion in the areas covered by this study, it appears that the stratigraphy indicated by present cliffs, and the volume and character of the sediments identified by this study are likely to be applicable to any recession scenario invoked for the next hundred years.” In this presentation we challenge this statement.

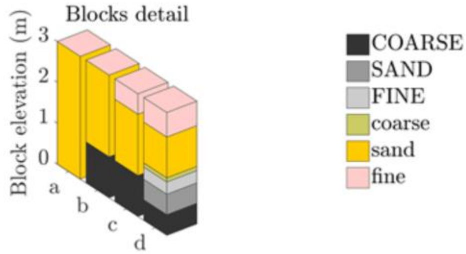
To constrain budget models other sources of new sediment need to be evaluated. Shoreface and nearshore platform abrasion of non-mobile sediment such as till, Crag sand and consolidated Holocene sediment are an important source and complimentary to erosion and retreat of coastal cliffs.



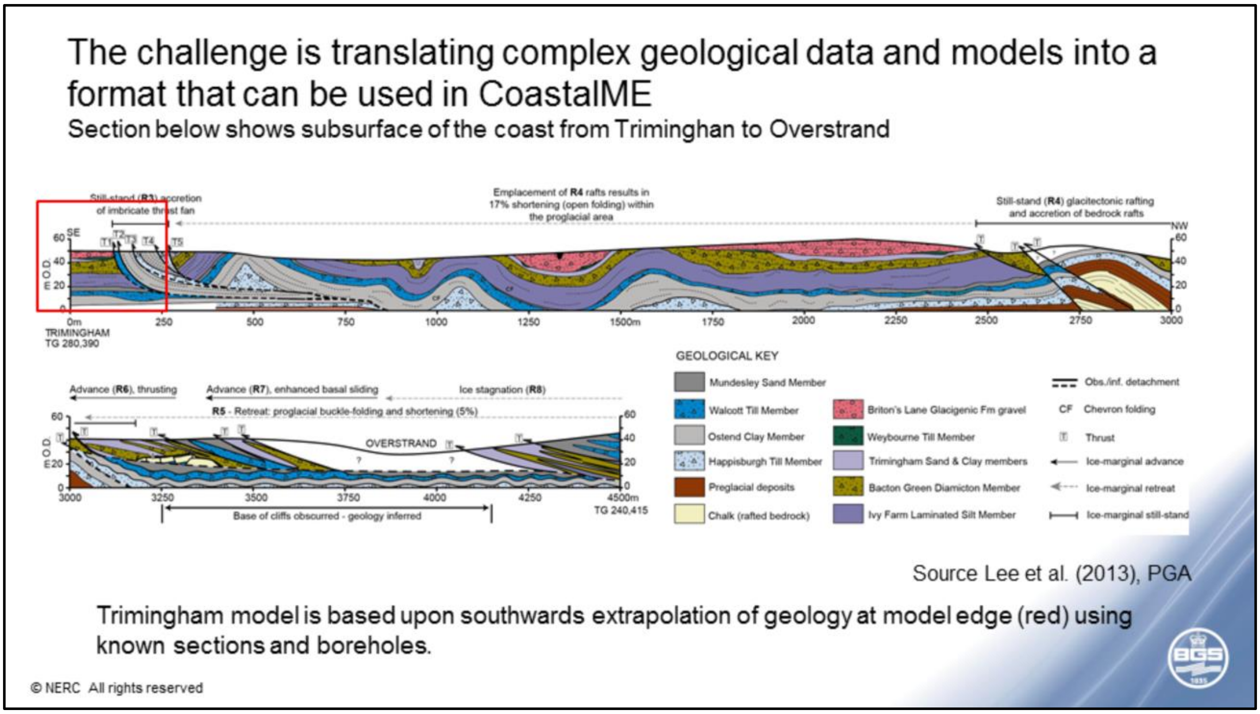
The Coastal Modelling Environment (CoastalME) is a modelling environment developed during the iCOASST project as a proof of concept and further demonstrated in the ongoing BLUECoast project. CoastalME has been specifically designed to overcome some of the key limitations of previous assessments. To demonstrate this at Trimingham we have overcomed two main challenges that are explained in the following slides: (1) the representation of Trimingham complex subsurface and (2) the creation of a model of the surface including the inland and nearshore.

CoastalME ground elevation is characterized as a set of regular square blocks made of consolidated and unconsolidated sand, gravel and fine





http://www.coastalme.org.uk Payo et al. (2017) GMD



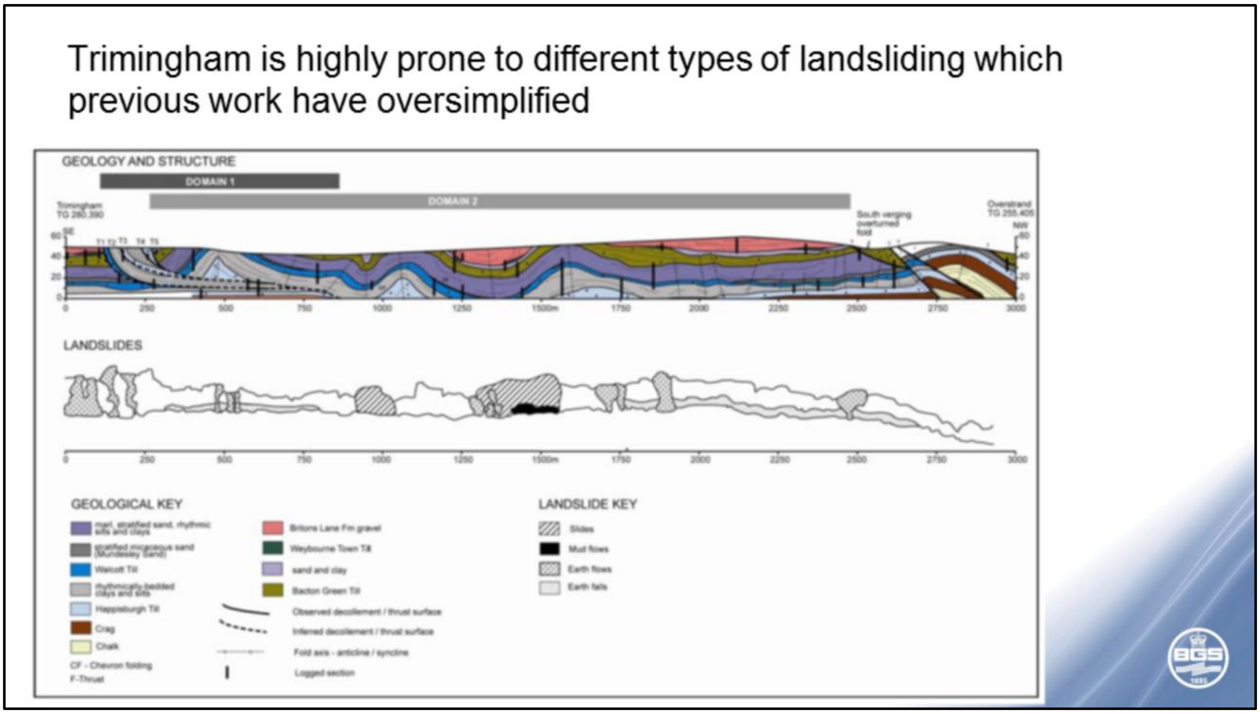
Key points:

- Cliff exposures in the study area are poor.
- Southwards extrapolation of the geology (see geological key) from the northern edge of the model (red box).
- Supported by the limited cliff exposure and borehole records.

- Cretaceous Chalk (base)

- Early Pleistocene marine deposits

- Middle Pleistocene glacial deposits
    - Glacial sequence >50 metres thick
    - Site overridden by ice at least six times
    - Very complex glacitectonic information
        - 16% lateral shortening (thickening)
        - Thrust fan complexes
        - Displaced bedrock ‘rafts’



Coastal landslides form an active geomorphological component along much of the North Norfolk coast, but the Trimingham area in particular is highly prone to instability (Hobbs *et al*., 2008; Hutchinson, 1976). The distribution and type of landslides are controlled in-part by the level of coastal management (e.g. coastal defences) plus the lithology and structure of deposits within the cliffs (see Figure).

Between 0-270 m, landslides consist of a number of individual and coalescent earth flows and falls in the upper cliff, that cascade down the cliff profile and are deposited in low gradient or flat areas. The first 250m, includes cliff protected by coast-parallel wooden revetments. The dominant landslide style is earth flows. Flows create a distinctive cliff profile with scallop-shaped bowls created within the upper erosional zone of the landslide. Repeated failure and flow causes
these bowls to coalesce and the upper cliff to recede. This creates a distinctive bench feature midway down the cliff.

Landsliding along the remainder of the coastal traverse is largely controlled by the open synclines and anticlines. It consists mainly of large slides, with localised debris flows and falls. Large composite slides occur between 900-1025 m and 1300-1570 m, and are primarily deep-seated movements that have a dominant rotational

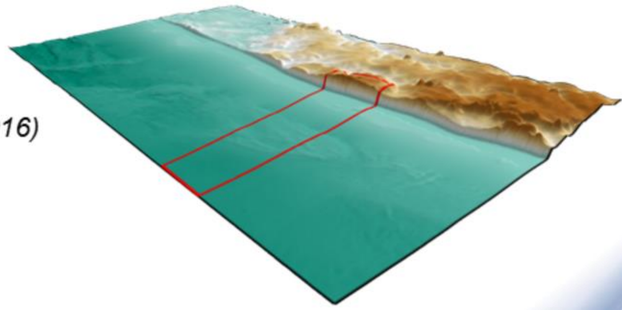
component, but are in-part translational. They coincide with the large open synclines and are constrained laterally by structural anticlines that form sharp morphological buttresses. Between 1300-1570 m, the basal shear surface of the slide extends beneath the beach platform following the form of the syncline with an upthrusting component of movement at the toe. Repeated sliding has formed a deeply-incised to elongate embayment that is arcuate in plan-form, with backscarps aligned parallel to the coastline. The deep-seated slide has resulted in back-tilt and extension features on the cliff slope, which have
led to the formation of seasonal ponds. Seepage from these ponds often leads to the reactivation of shear planes and can cause minor sliding, or the development of minor earth and mud flows. This is especially the case where seepage occurs within the stratified sand and clays that form the Sheringham Cliffs Formation. Further westwards, landsliding is characterised predominantly by earth flows and falls.

Trimingham: structural architecture of the Cromer Ridge Push Moraine complex and controls for landslide geohazards
Jonathan R. Lee, Catherine V.L. Pennington and Peter R.N. Hobbs
http://nora.nerc.ac.uk/16198/1/Trimingham.pdf

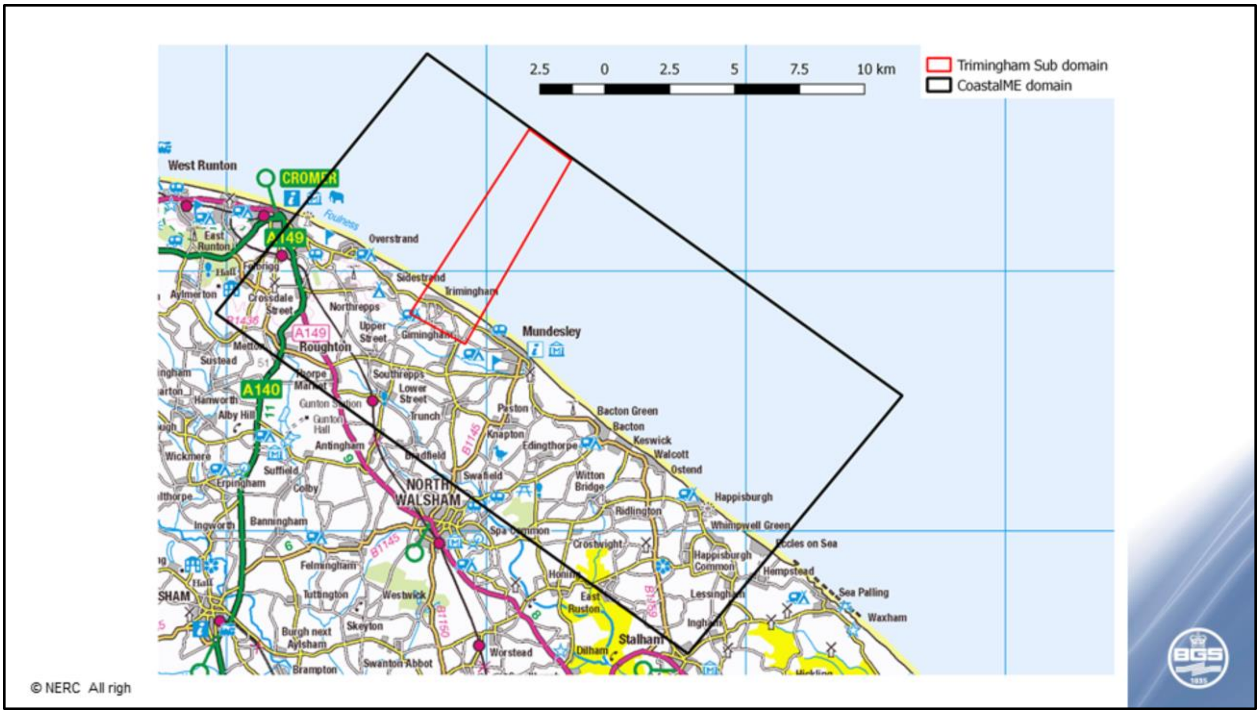
An additional challenge is creating a Digital Terrain Model of the inland topography and the nearshore bathymetry

We have merged different high resolution data set to create a DTM of the study area

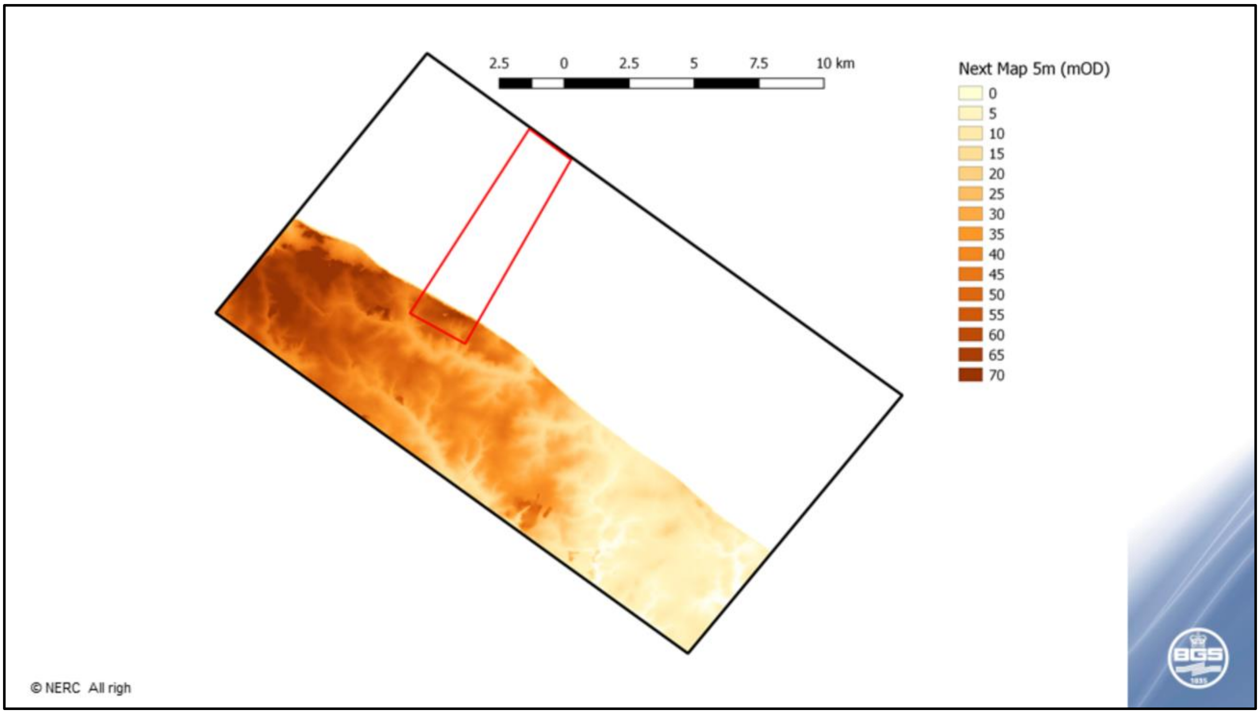
- *Next Map (year 2002-2003)*
- *EA Lidar DTM at 2m resolution (2016)*
- *UKHO bathymetric data (2015)*
- *Merged and interpolated (10m)*



Continuous Digital Terrain Model around Trimigham study area
(elevation exaggerated 10 times for illustration purposes)



Two sub domains has been defined for different purposes.
The domain named “Trimingham sub domain” (shown as small red polygon) is the domain for which the 3D model of the subsurface will be built for this study.
The domain named CoastalME (shown as large black polygon) is the domain used to run the Coastal Modelling Environment.
The CoastalME domain is chosen to minimize the interference of the boundary condition with the simulations at Trimingham study area (see slide on alongshore gradient).
The model used to build the 3D subsurface model is significantly smaller because the interpretation of the subsurface requires time and time resources are limited for this study.


2.5 0 2.5 5 7.5 10 km
Next Map 5m (mOD)
0
5
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25
30
35
40
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60
65
70
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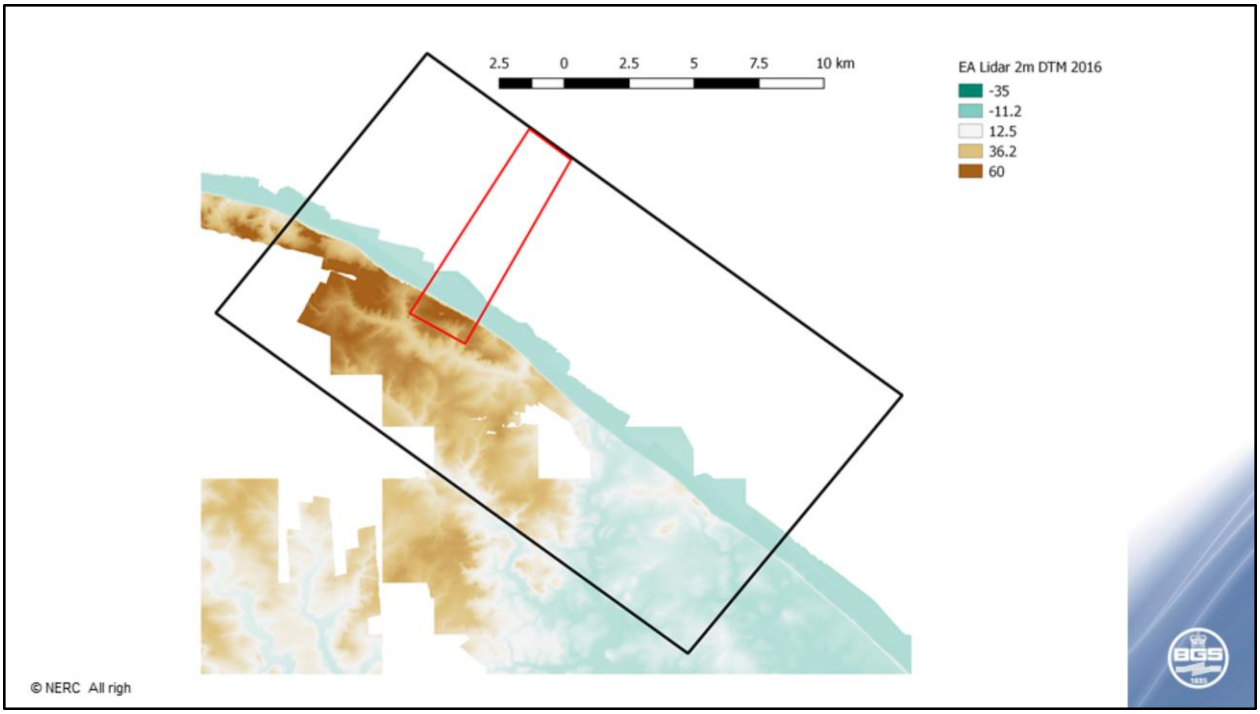
2.5
0
2.5
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10 km
EA Lidar 2m DTM 2016
-35
-11.2
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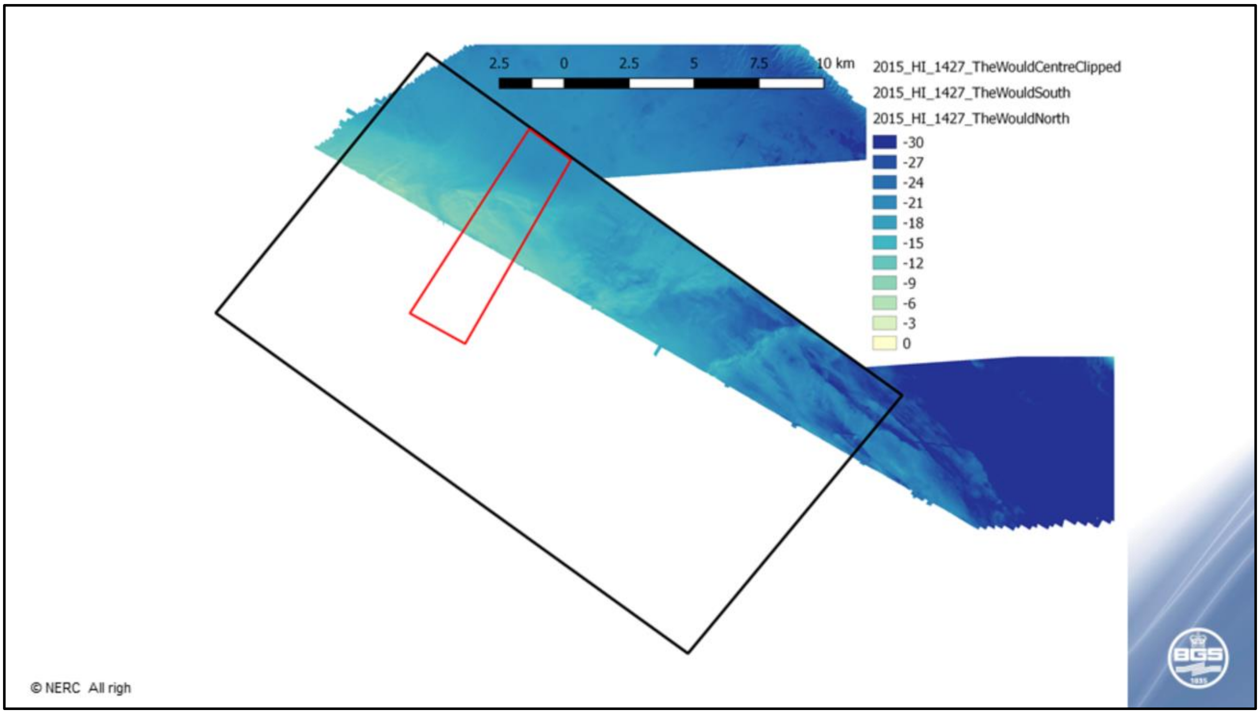

2.5
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2.5
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10 km
2015_HI_1427_TheWouldCentreClipped
2015_HI_1427_TheWouldSouth
2015_HI_1427_TheWouldNorth
-30
-27
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-21
-18
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-3
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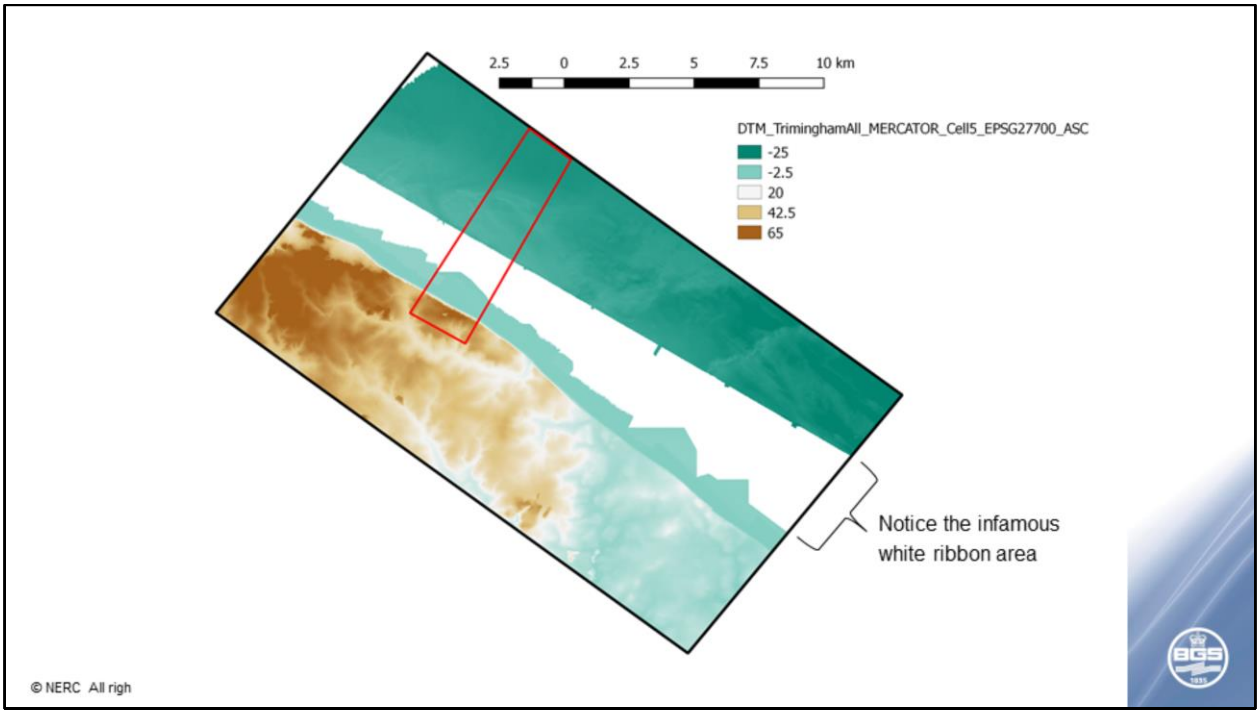
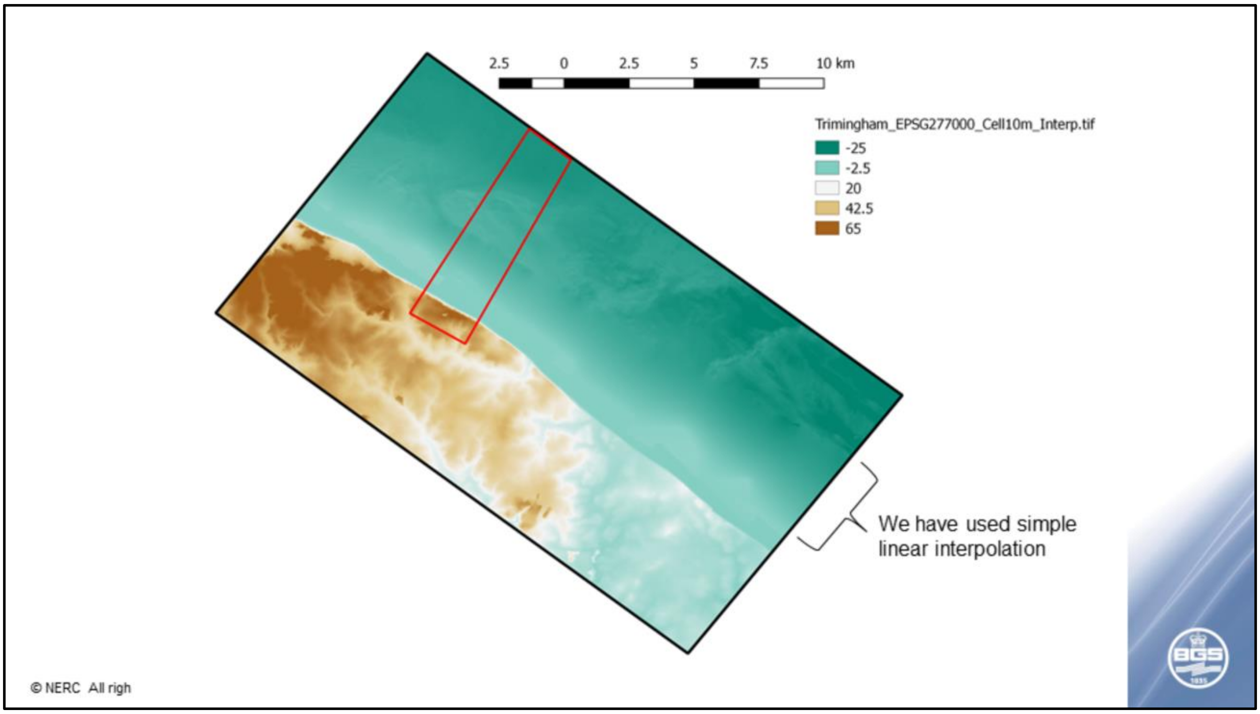
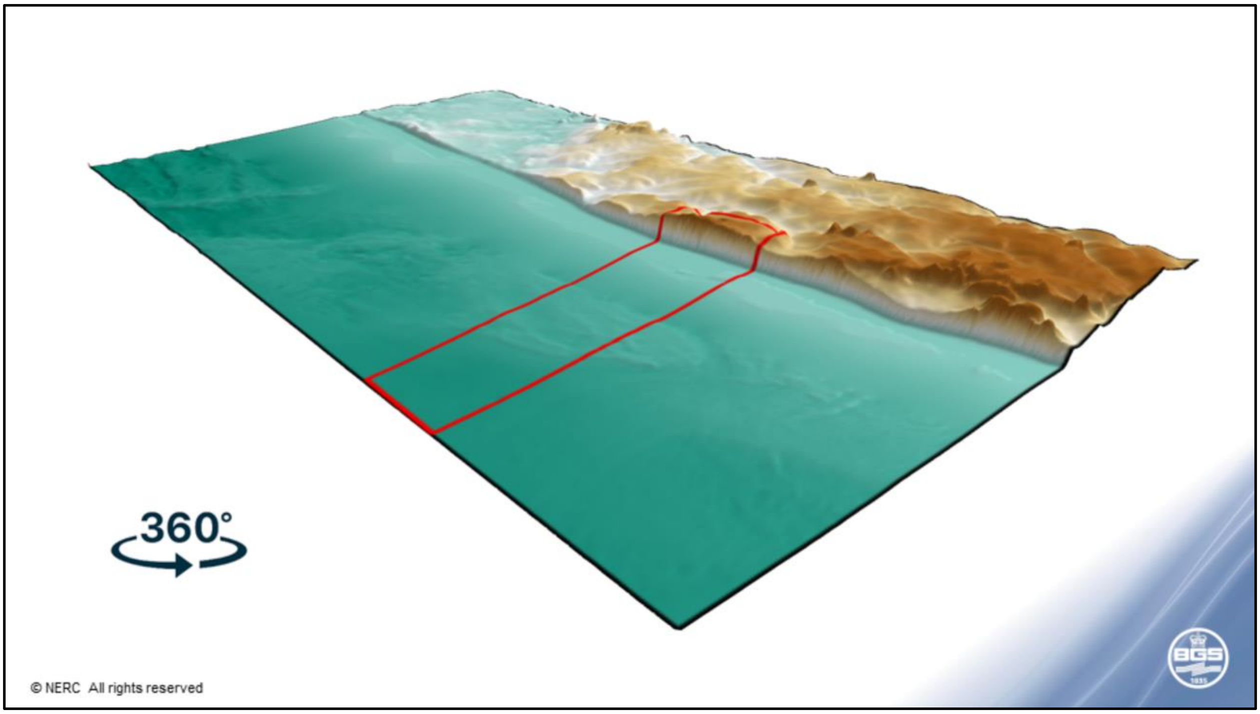


Merged Next Map + EA Lidar + UKHO



Interpolated to a 10m cell resolution


360°
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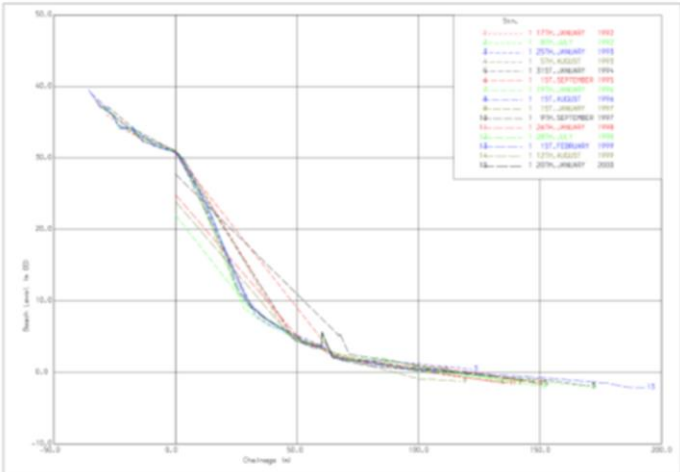
BGS

The interpolation seems to be on good agreement with the profiles monitored in the area

N3D4, southward limit of Trimingham



Notice the gentle sloping of the under 0.0 profile (~ 2.5 m elevation change in 100 m distance = 0.025 slope)

We have extended Groundhog Desktop GSIS to export the CoastalME block structure from 3D digital subsurface model

Free to use under UK's Open Government Licence

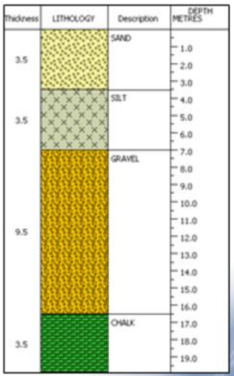
- *Boreholes logs*
- *Digital sections*
- *Interpolated 3D digital model*
- new *Exported to CoastalME input layers*

Groundhog GSIS is a software that create a 3D digital model of the subsurface from sparse qualitative data

To build a 3D subsurface model: borehole logs records are searched, descriptions interpreted and encoded digitally

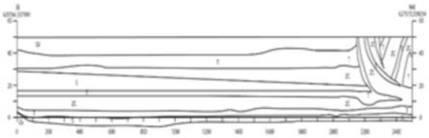
Sparse location of boreholes logs around Trimingham

Borehole log

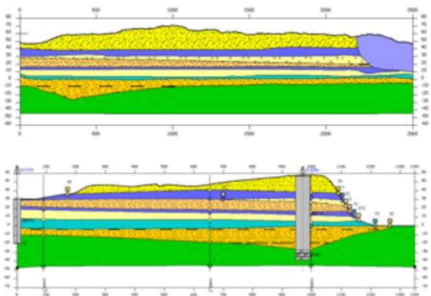


Digital borehole

Conceptual models are also integrated to produce subsurface sections at a user defined network of interlocking cross-sections

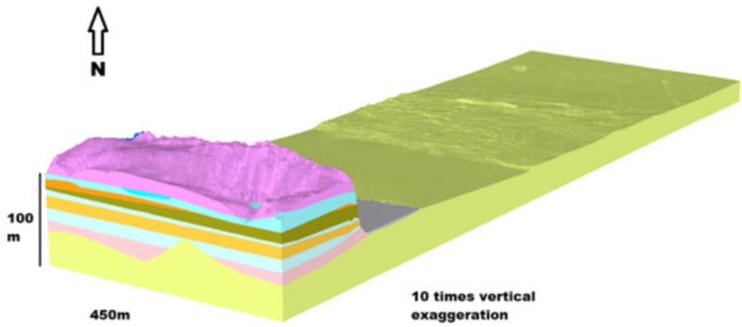


Conceptual model



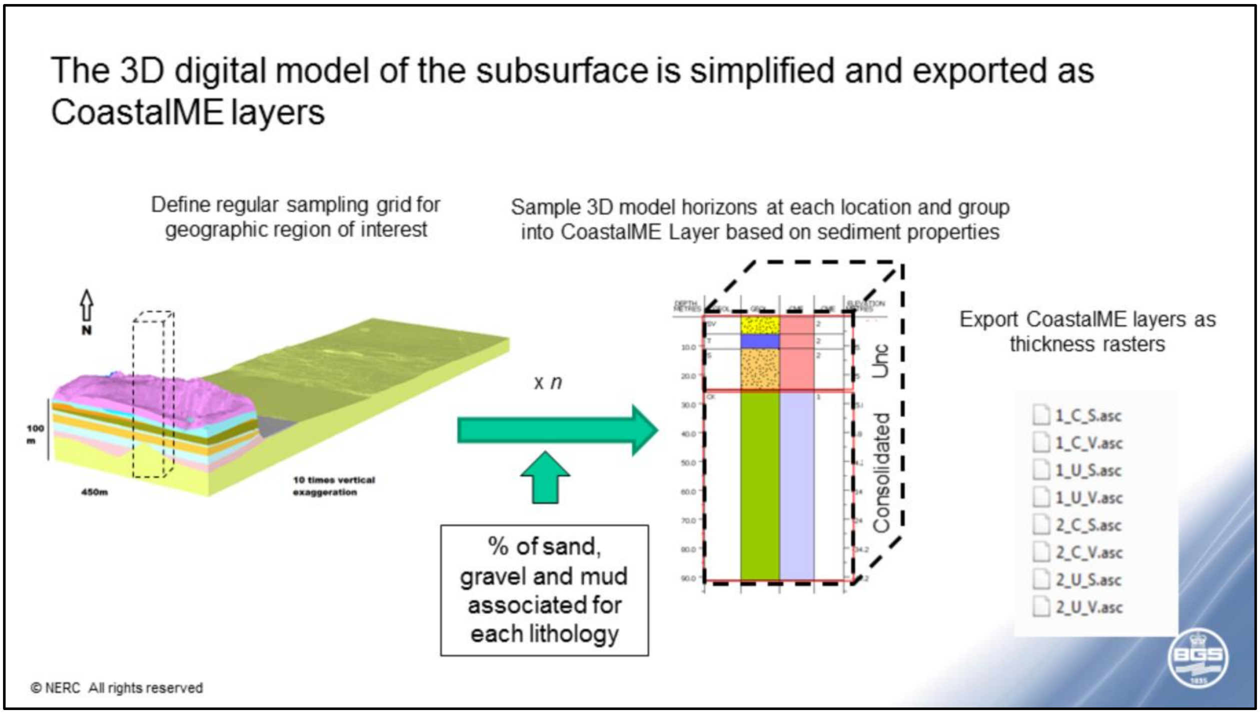
Spatially-referenced, digitized geological cross-sections incorporating conceptual model and borehole data

Geological layer extent maps are digitized and combined with the sections to produce 3D subsurface digital model



Geological layer extent maps digitized

Vector linework from map and section interpolated to form stack of horizons (using 3D software)



The 3D digital model of the subsurface is simplified and exported as CoastalME layers
Define regular sampling grid for geographic region of interest
N
100 m
450m
10 times vertical exaggeration
x n
% of sand, gravel and mud associated for each lithology
Sample 3D model horizons at each location and group into CoastalME Layer based on sediment properties
Unc
Consolidated
Export CoastalME layers as thickness rasters
1_C_S.asc
1_C_V.asc
1_U_S.asc
1_U_V.asc
2_C_S.asc
2_C_V.asc
2_U_S.asc
2_U_V.asc
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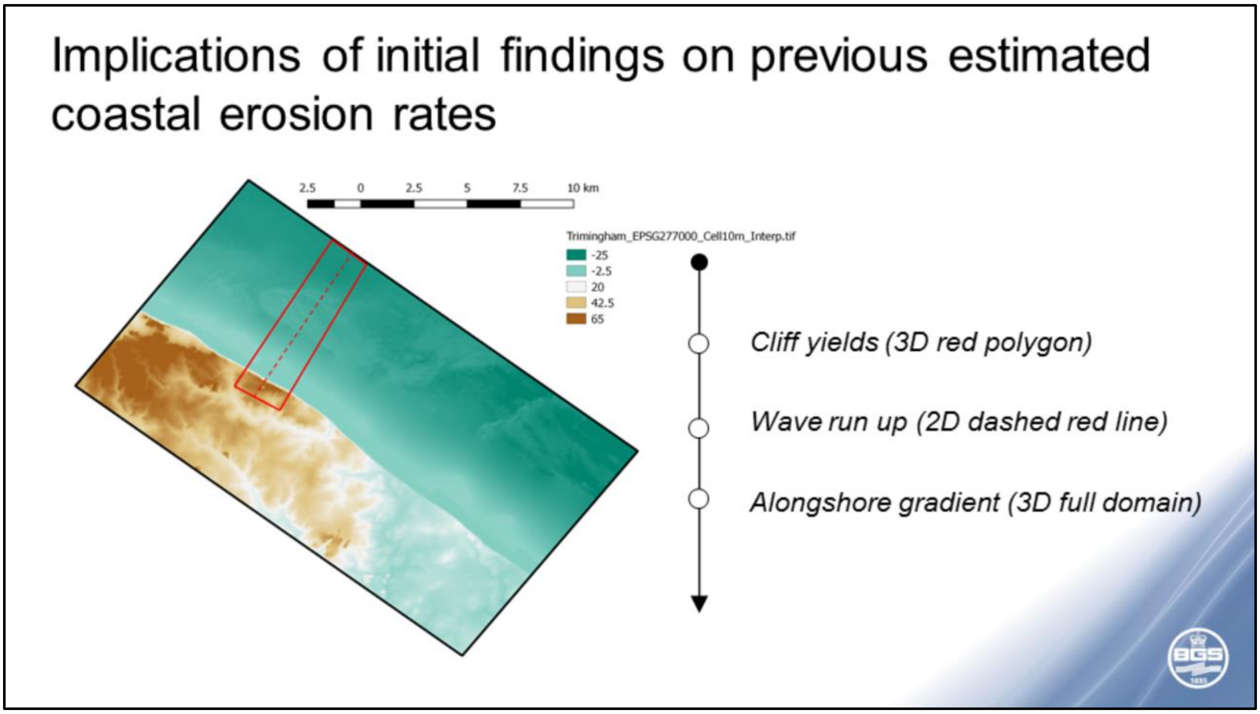
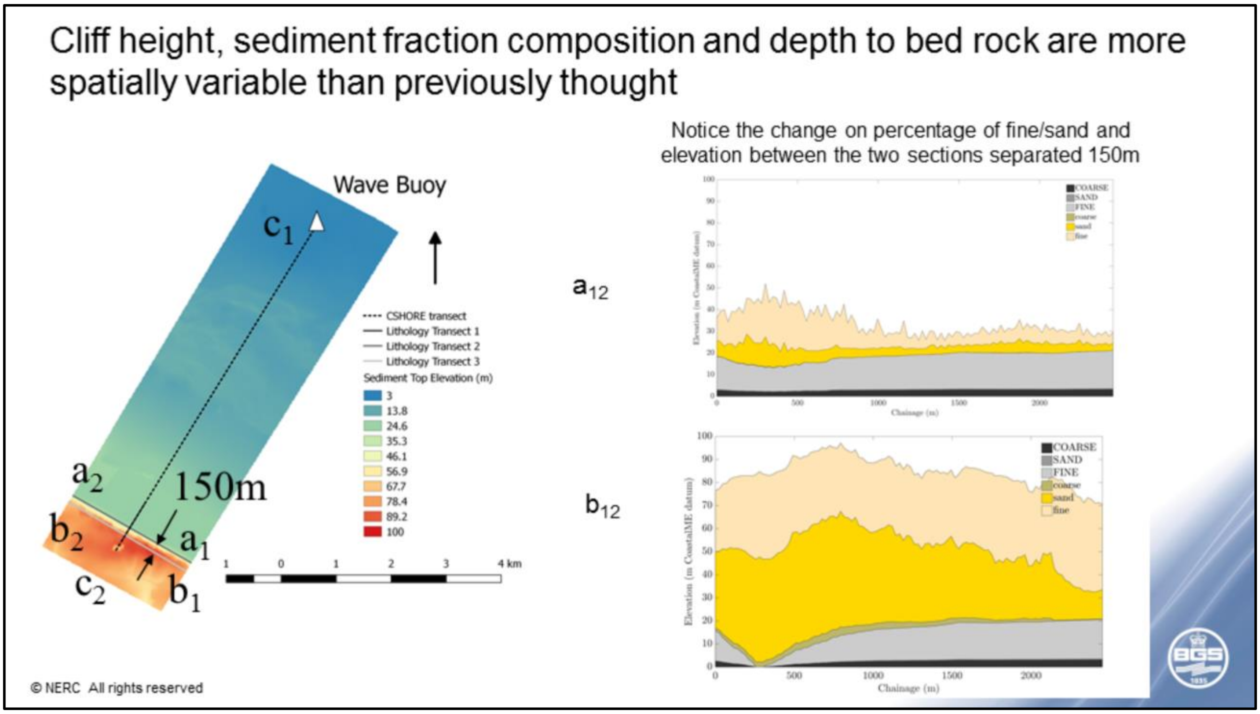
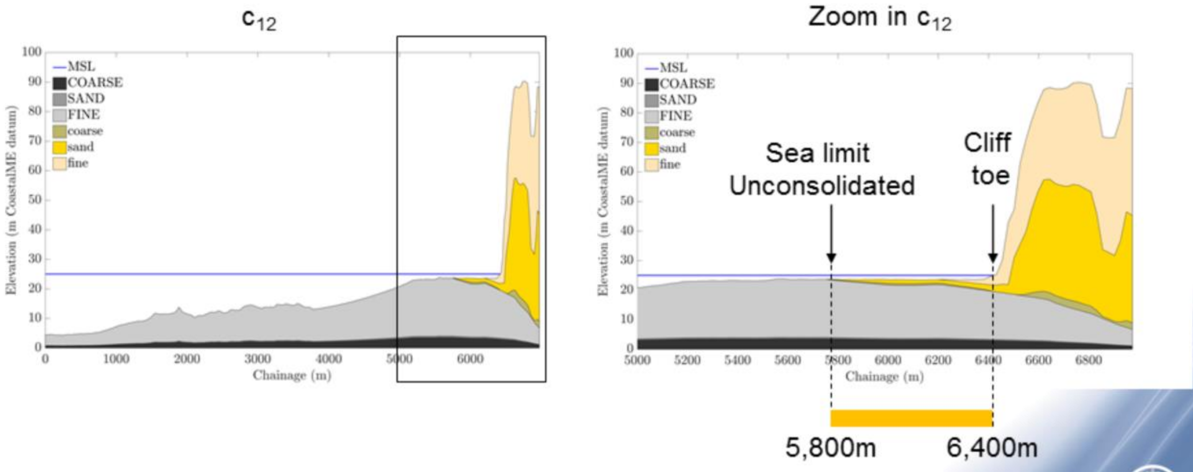


In the following we will present some implications of our initial findings on previous estimated coastal erosion rates.
These implications are limited due to the model of the subsurface being limited in extension (red polygon).
Nevertheless we are in the position to explore some on the assumption made on previous assessment on cliff yields, wave run up and alongshore sediment transport gradient.



Even for this small section, the depth to bedrock and sediment fractions composition changes significantly.

Alongshore and across shore sediment transport might be constrained by the bedrock being exposed



We have explored the hydrodynamic and sediment transport alongshore and across shore variability using CSHORE model

CSHORE: **C**ross-**shore** numerical model

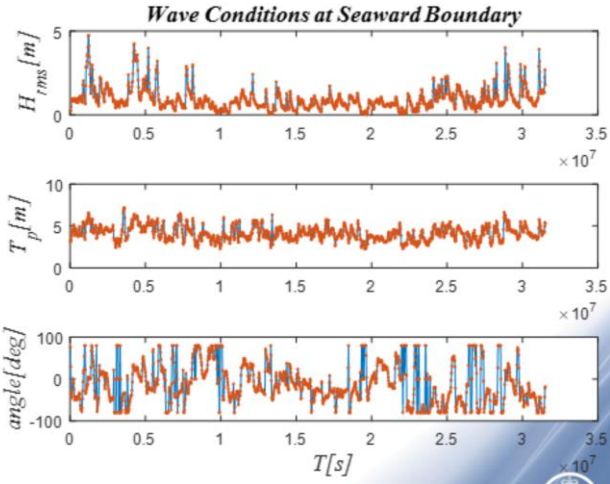
Andres Payo

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

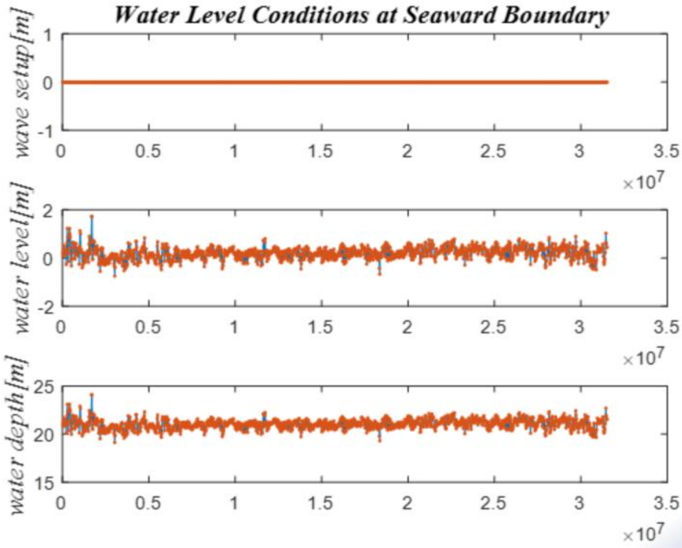
SUMMARY

- CSHORE is a one-dimensional time-averaged nearshore profile model for predictions of wave height, water level, wave-induced steady currents, and beach profile evolution and stone structural damage progression.
- This is NOT an open source code, developed by the USACE and Delaware University. Executable and manual can be downloaded from https://sites.google.com/site/cshorecode/
- Applied to spatial scales of 100m to 10 kms and time scales of hours to days (decadal simulation under development)
- Profile change is driven by gradients in alongshore suspended and bed-load sediment transport.
- Shallow water hydrodynamics driven by wind and waves
- Profile can be made of sediment types and three sediment fractions (sand, gravel or stone)
- Representation of swash zone and over-topping

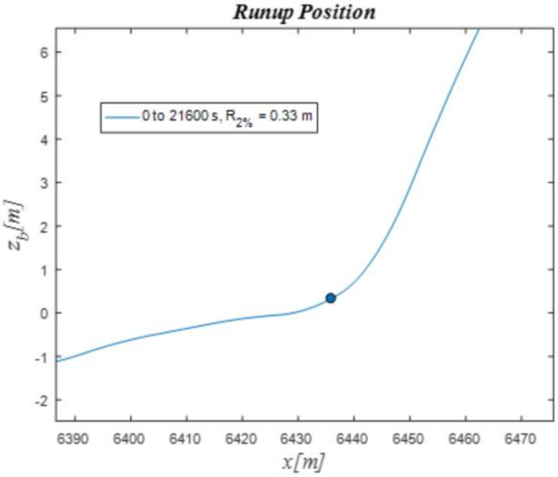
CSHORE has been run for profile c12, forced by waves provides by UKCP09 Year 2002



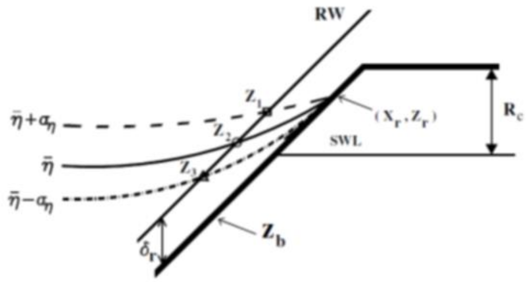
CSHORE has been forced by observed tidal level at Cromer for year 2012

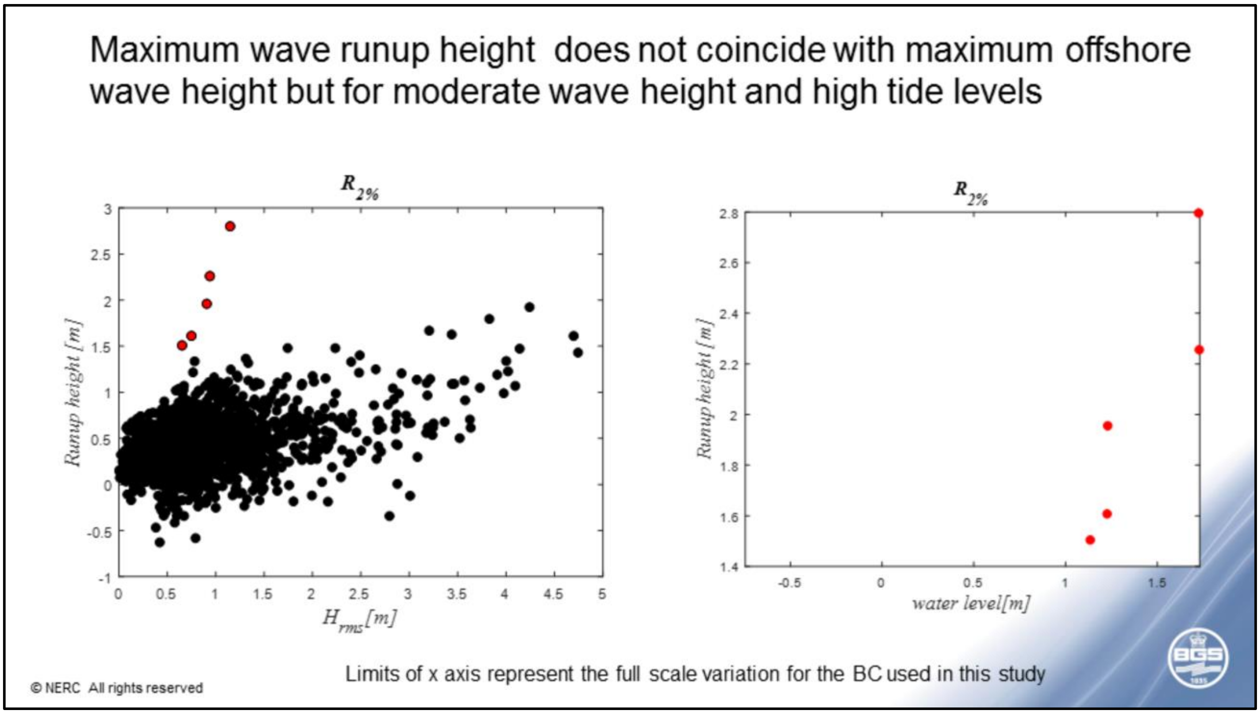


For each sea state CSHORE calculates the runup height for the 2% exceedance probability



CSHORE, uses a probabilistic model for irregular wave runup

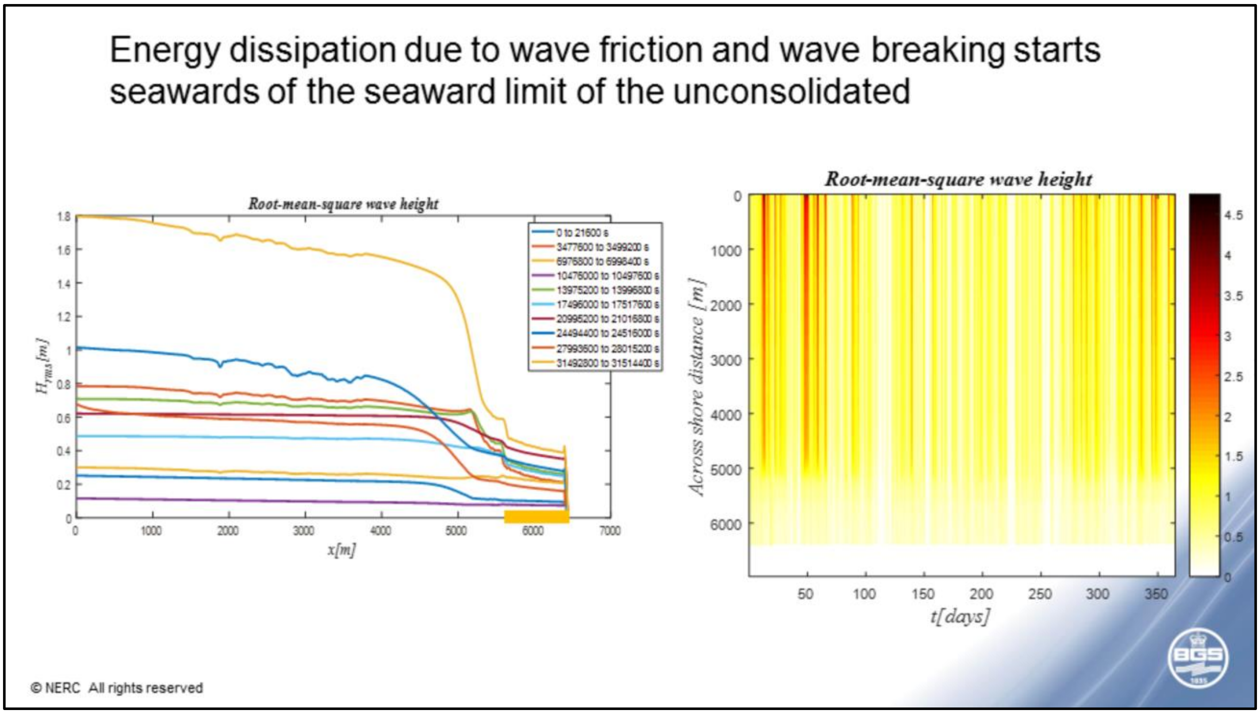




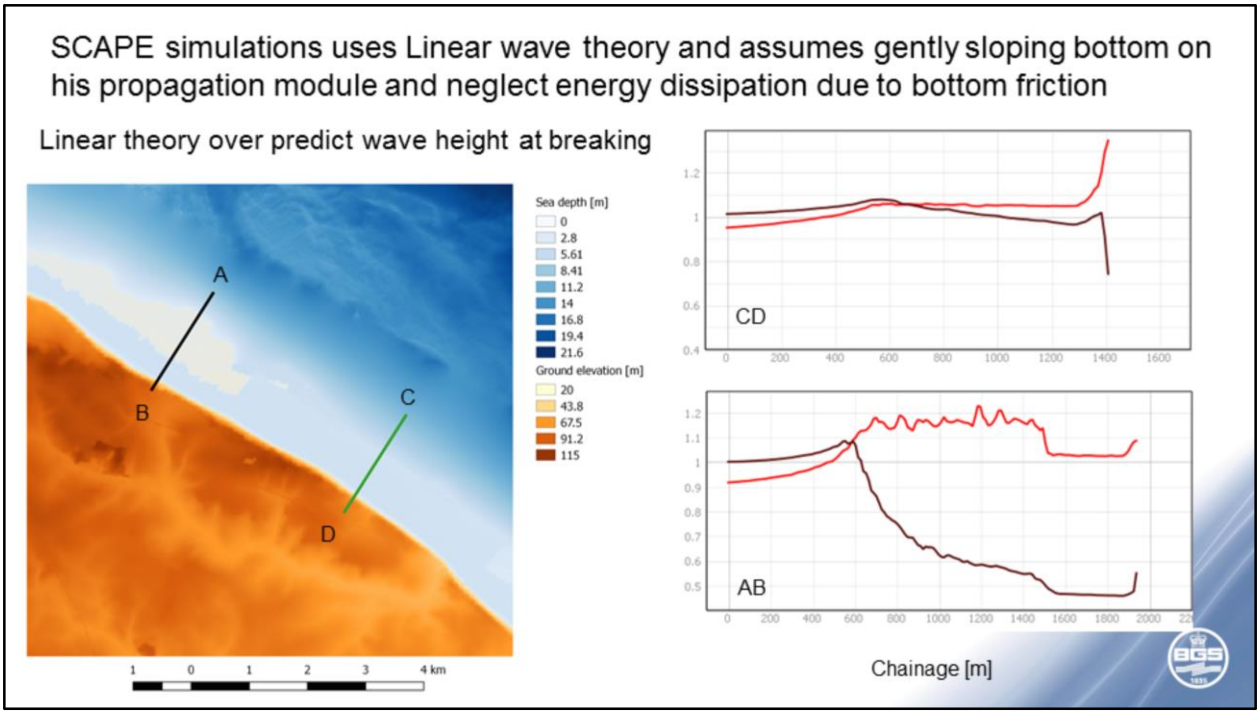
This has implications for the estimation of future episodic cliff erosion events.
An increase on the wave height is unlikely to increase the wave runup and therefore the number of cliff recession events.
An increase of relatively mild wave energy (0.5 < Hrms < 1.0m) with Tp ~ 4s and dir ~160deg occurring at high tide is more likely to increase the runup and the frequency of episodic cliff recession events.

For reference, the level of the 1953 storm surge was estimated at 3.67 m (Babtie, 1996).

Babtie, Birbeck College, University of London, 1996. Spits and Nesses: Basic Processes and Effects on Long-term Coastal Morphodynamics. Technical Report CSA 3052, London..



Because the shallow bathymetry, significant energy is lost before breaking due to bottom friction. The combined energy dissipation due to bottom friction and wave breaking makes the energy reaching the cliff toe weakly linked with the offshore wave energy. This is coherent with the observation that there is not a direct link between the forcing and the recession process because of the dissipative nature of the system (Lee, 2008).



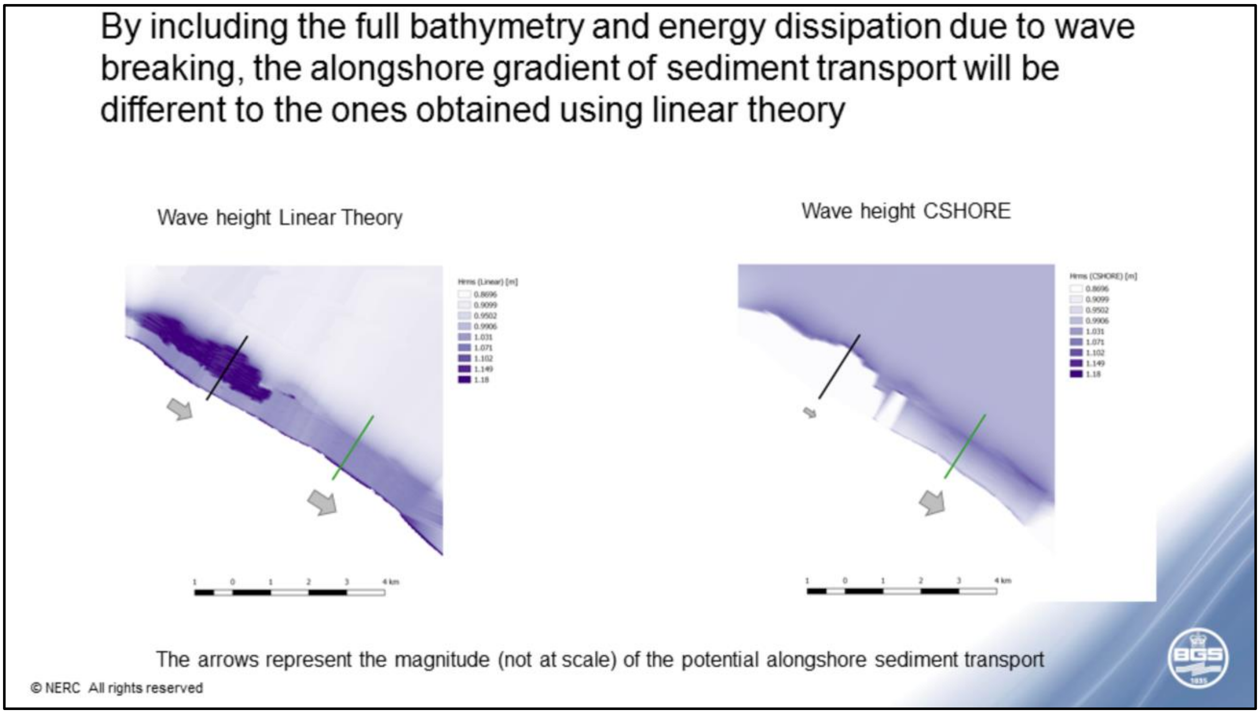
The graphs compares the wave energy cross shore variation obtained using linear wave theory (red line) and CSHORE (black line) for two transects AB and CD. Transect CD has a more gently sloping bathymetry, closer to the assumptions of linear theory and therefore the differences are mostly due to the effect of energy dissipation due to bottom friction. Transect AB has a more irregular profile (i.e. it crosses a shoal) deviating significantly from linear wave assumption of gently sloping bottom and energy at breaking are very different.

By assuming linear wave theory and neglecting energy dissipation due to bottom friction SCAPE projections are less dissipative and more subjected to offshore wave variability.

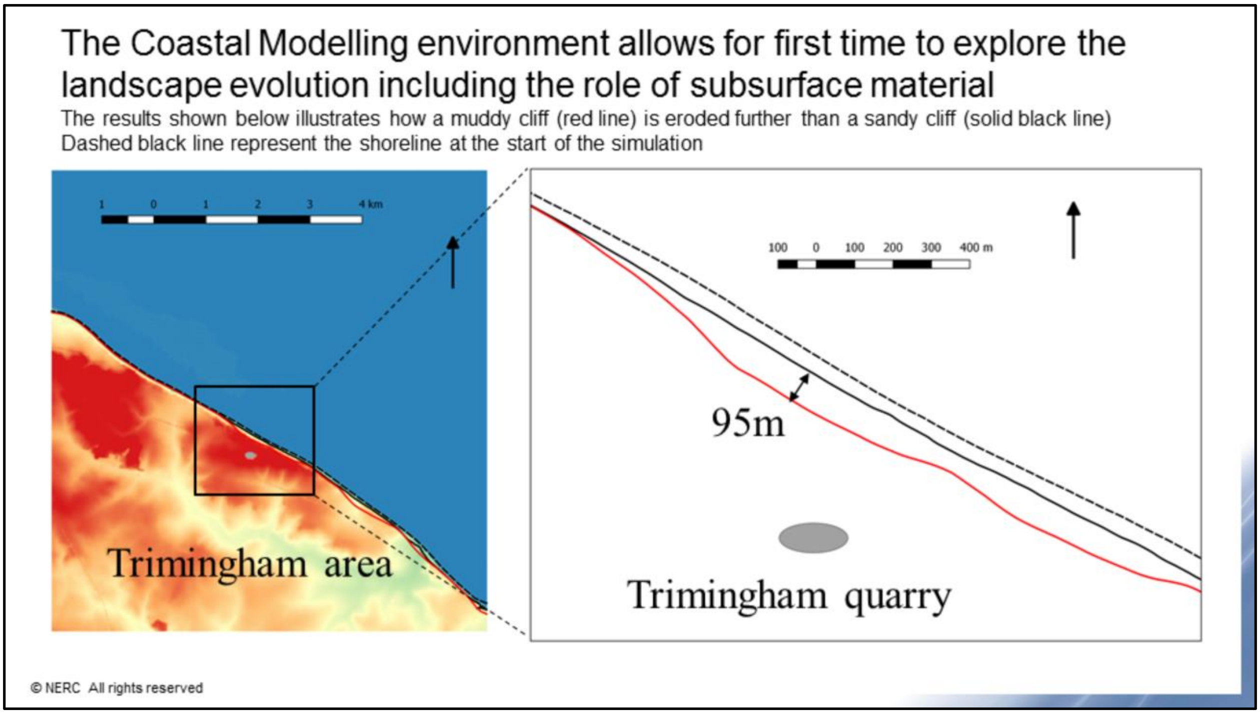
The inclusion of wave friction will reduce the variability associated to wave climate, reducing the uncertainty on cliff recession.
The assumption of gently sloping and parallel bathymetry deviates significantly from wave propagation patterns obtained if full bathymetry is included.

On the other hand, assuming gently sloping and parallel bathymetry also reduces the variability of the alongshore sediment transport gradient on the 3D model.

In short, by including the energy dissipation and full bathymetry it is unsure if the uncertainty on cliff recession rates will be reduced but it will be better attributed.



Wave dissipation for nearly normal incident waves is greater at the northern edge of Trimingham.
If energy dissipation due to bottom friction is neglected (Linear Wave Theory) the wave height at breaking at the northward transect is (Hrms = 1.1m) similar to the one at the southward profile (Hrms = 1.25m).
If is included (CSHORE), the wave energy at breaking is significantly smaller (Hrms=0.55m) than on the southern transect (Hrms = 1.0m).
The alongshore sediment transport is proportional to the square of the wave height (small differences on wave height are amplified).
The alongshore gradient of the alongshore sediment transport will therefore be larger for the CSHORE case and larger cliff erosion rates will result.



To illustrate the importance of the subsurface on the Trimingham coast recession rates we have run CoastalME for Trimingham for two scenarios, changing only the subsurface composition while keeping everything else the same.

In one scenario we have assumed that the cliff is made 100% of fine material (i.e. when eroded is lost in suspension and does not contribute to the nearshore sediment budget) and a cliff made 100% of sand material (i.e. when eroded becomes part of the beach volume).

For this example, waves are assumed constant propagating normal to the coastline (230 deg relative to North), 1 m significant wave height and 8 sec period.
This waves have been run for 25days. This is just to illustrate the high impact that different subsurface models will have on the landscape evolution at Trimingham.

Lines shows the shoreline position at the start of the simulation (dashed black line), and the end of the simulation for the mostly muddy (red line) and mostly sandy (green line) scenarios.

The differences between the two scenarios indicate that the shoreline evolution at Trimingham is very sensitive to cliff yields.

This sensitivity is due to a direct effect of the yield on the beach volume and a non direct morphodynamic effect.
The sediment yield per unit of eroded cliff is a function of the cliff height and sediment fractions.
Large yields can even advance the shoreline by increasing the width of the beach.
Wider and thicker beaches reduces the energy reaching the cliff toe (i.e. reducing the backwearing rate) and the energy reaching the shore platform (i.e. reducing the downwearing).

Summary 1/2

A subsurface model of a small segment of Trimingham suggest that cliff yield is more variable than previously assumed (i.e. both elevation, bed rock depth, sed. fractions)

Energy dissipation due to bottom friction seems non negligible when the full bathymetry is included. Previous simulations, which neglected it, are more sensitive to wave climate variability and result in smaller alongshore gradients of sediment transport.

Cliff erosion is episodic and it is better to express the long-term recession rate as up to 25m every 10 years rather than 2.5m/year.

Extreme (2% excedance) wave runups are not associated to extreme wave heigthts but with moderate offshore wave heights (Hrms~ 1m) but coinciding with high tidal water levels

Summary 2/2

Cliff recession rate at Trimingham can range from 0 to 15m per year. This is larger than the multi yearly averaged cliff erosion rates (0 to 2.5m/year).

Cliff recession rate predictitibility is constrained by the beach volume (i.e. zone 1, 2, 3 defined be Lee, 2008). Beach volume at Trimingham is constrained by the downwearing of the chalk shallow bedrock and inputs/outputs of sed from cliff and nearby area.

There are analogies with Happisburgh suggesting that coastal catch up might also occur at Trimingham inducing erosion rates larger than historically observed.

The distribution and type of landslides are controlled in-part by the level of coastal management (e.g. coastal defences) plus the lithology and structure of deposits within the cliffs.

Suggested next steps

Need to expand the geological sections northwards and southwards of Trimingham to better quantify the cliff yields.

When UKCP18 is released (early march), the frequency of large episodic runup events can be statistically explored using CSHORE and representative profiles.

A limited number of passive seismic surveys can be carried out to quantify the beach thickness at Triminghan (i.e. a proxy for predictability of cliff erosion) and explore the presence of a step on the shore platform (i.e. evidences of risk of coastal catch up).

Need to conceptualize better the different types of landsliding mechanisms observed at Trimingham (direct effect on cliff yields and coastal dynamic)

Possibility of NERC matching EA-City council funds to further study this issue