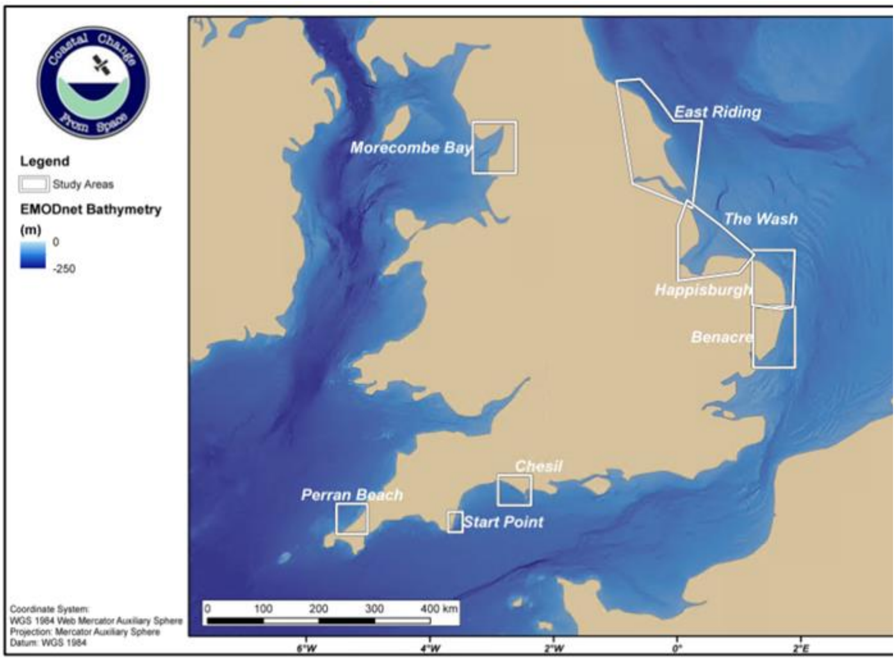
ESA Coastal Erosion from Space: Validation UK products

Coastal Geohazards Programme

Open Report OR/20/040



BRITISH GEOLOGICAL SURVEY

COASTAL GEOHAZARDS PROGRAMME

OPEN REPORT OR/20/040

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Front cover

Map showing the areas of interest identified by the broader end user community consulted during this project.

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ESA Coastal Erosion from Space: Validation UK products

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Foreword

This document (hereinafter referred to as BGSVD) contains the Validation of the Earth Observation products for UK study sites produced by the "Coastal Change from Space" team for the Coastal Erosion Project (BGS ref. NEE6695R) within the Science for Society slice of the 5th Earth Observation Envelope Programme (EOEP-5) run by the European Space Agency (ESA) and written by the BGS team. It contains a detailed validation of the products produced by the Service-Provider team against the End-Users Requirement Document (BGS ref. CR/19/055). Validation has been done following the methodology described in the End-Uses Validation Document (BGS ref. OR/20/018[1]).

The BGSVD summarizes the conformity of the different Earth Observation Products provided by the Service Providers (ARGANS, adwäisEO and IsardSAT) with the specifics User Requirement for the British Geological Survey acting as one of the enrolled end-user organizations. Other enrolled end-users are the Geological Survey Ireland (GSI), Subdirección General para la Protección de la Costa (SGPC) supported by the Instituto de Hidraulica Ambiental de Cantabria (IHC) and ARCTUS which has produced equivalent documents for the Republic of Ireland, Spain, Canada respectively.

BGS member of staff, Dr Andres Payo has been in charge of planning and managing the validation activities, compiling and synthesizing all validation results into a standardized format and writing this report. The main contributors from: G. O. Jenkins (validation vector products and proof-reading report), J. Gafeira (validation raster products), D. Dayton (validation raster products), G. Carter (validation raster products), L. B. Bateson (validation vector products), A. Novellino (validation vector products).

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword, a large number of individuals have contributed to the project.

To all the England Regional Coastal Monitoring Programme managers who has contributed to the study site selection and provided extra auxiliary data for production and validation purposes. In particular, we are thankful to: Ruth Adams (Teignbridge Gov. UK); Becky Stanley (Environment Agency Gov. UK), Charlie E. Thompson (Coastal Channel Observatory); Andrew Martin (Sefton Gov. UK) and Emily Paterson & Neil Mclachlan (East Riding Gov. UK).

The authors would like to thank individuals from other enrolled end-users' organizations for their collaboration on the validation plan development. In particular, we are thankful to: Dr. Xavier Monteys (GSI), Dr Jara Martinez Sanchez & Paula Gomes (Environmental Hydraulics Institute - Universidad de Cantabria, IHCantabria), Thomas Jaegler & Christiane Dufrense (ARCTUS).

The authors would like to thank Olivier Arino as the ESA technical officer in charge of this project.

[1] https://bgs.sharefile.eu/d-s6fb7b9f5dc274607a52b7646ceb41b46

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Summary

This document contains a detailed validation of the products produced by the Service-Provider team for the UK Study sites against the End-Users Requirement Document (BGS ref. CR/19/055). BGS have followed a collaborative but independent validation and evaluation as outlined in the Product Validation Plan (PVP) (ARGANS ref. SO-TR-ARG-003-055-009-PVP, BGS ref. OR/20/018[2]). This document also includes a synthesis of all validation and evaluation statements.

This document is organized into four main sections and associated appendices. The first section provides; an overview of the validation and evaluation aims of this report, describes the UK study sites and provides a summary of the Earth Observation (EO) products requirements as stated in the End-Users Requirement Document for all the UK products that is included here again to make this report self-explanatory. The second section describes the methods and Auxiliary Data used for both production and validation. The third and fourth sections present the validation and evaluation results for all EO products respectively. The contractually required per product evaluation assessment sheets (Annex B of the Statement of Work) are included in Appendix 4.

[2] https://bgs.sharefile.eu/d-s6fb7b9f5dc274607a52b7646ceb41b46

1 Introduction

1.1 VALIDATION AND EVALUATION

The adopted validation protocol by the Coastal Change Consortium is a multi-step conformity checking process, performed by both the Service-Providers and the End-Users, and is illustrated in **Figure 1.1**. This validation protocol assess the degree to which the Earth Observation (EO) products fulfils the technical requirements (reliability, accuracy and precision) as well as the added value of EO products for coastal management purposes. The four steps involved in the proposed validation protocol are: verification, quality control, validation and evaluation. This document contains the results of the **validation** and **evaluation** obtained by BGS as enrolled end-user. Validation is defined here as the conformity check process of the EO products technical and functional specifications against a target specification. Evaluation is defined here as the conformity check process of the EO products against user expectations.

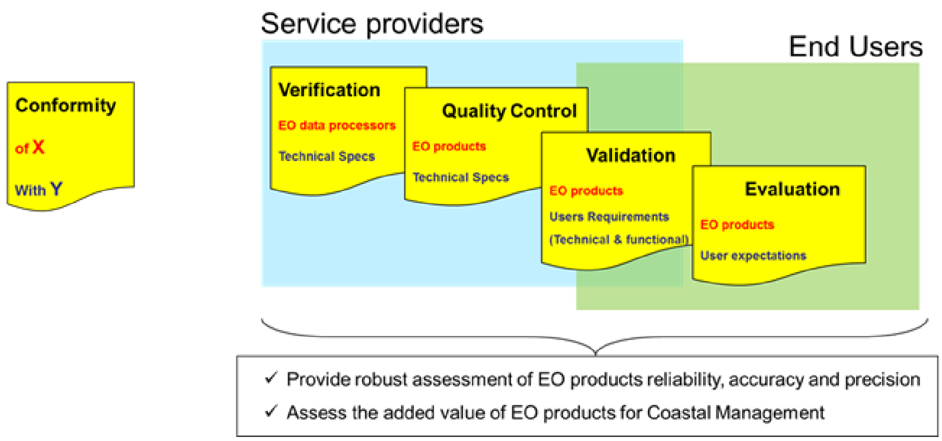


Figure 1.1.- Validation protocol is approached here as a multi-step conformity checking process done by both the Service providers and End-Users.

The target specifications used to validate the EO products used by BGS as an End-User are different from the one used by the Service Providers. **End-users, have used the aspirational end-user requirements** outlined in the User Requirement Document and summarized in Appendix 1, while **service providers have used the requirements of what they considered is feasible** to achieve at present as target specifications for each one of the EO products summarized in the PVP and included in Appendix 2. Interpretation of meeting (or not meeting) the end-users and service providers target requirement need to be interpreted differently. If the service providers target requirement is met, the EO products are considered valid because their functional and technical specifications meet the requirements of what is considered feasible. Notice that meeting this feasibility requirement is agnostic regarding the validity of the EO product for end-users. This validity is assessed against the aspirational end-user target requirements. If the end-users target requirements are met, the EO product will be considered valid for the purposes detailed in Appendix 1. Notice that the EO products could still have value for the end-users, even in the case that the end-user requirements are not met. Assessing this value is the objective of the evaluation process.

1.2 SELECTED STUDY SITES

The initial and finally selected study sites for the UK are shown in **Figure 1.2**. These sites have been selected in collaboration with the five coastal regional programme managers in England. The final study site selection was a trade-off between proposed sites and resources available for this project. The three areas selected are 1) Spurn Head (area from Spurn Head to Lowestoft), 2) Chesil beach (area from Lyme Regis to Hurst Point), 3) Start Bay (area from Prawle Point to Oddicombe beach). These three study sites covers a total coastal length of ca. 684 km. Spurn Head is the largest coastline and about 500km length, Chesil beach and Start Bay are ca. 158km and 26km long respectively.

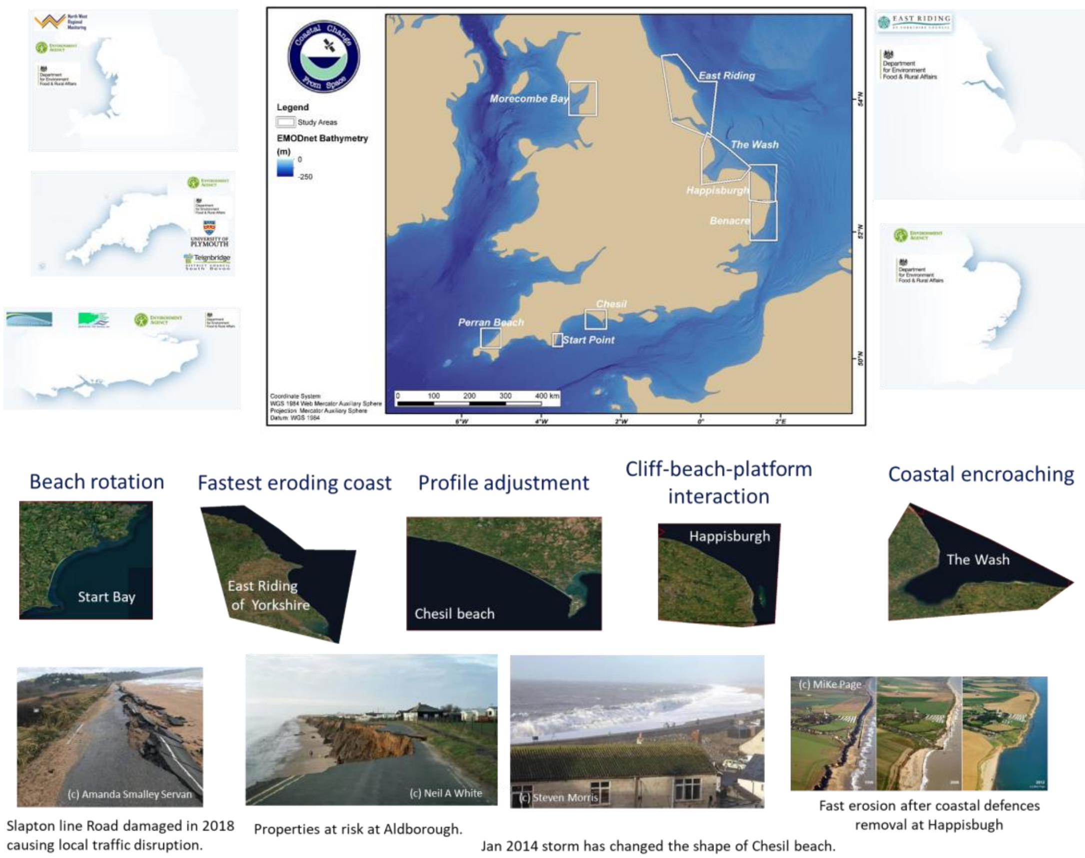


Figure 1.2. Areas of interest identified by broader end user community consulted (top) and selected study sites for which satellite-derived products have been produced and validated (bottom).

1.3 OVERVIEW OF EARTH-OBSERVATION PRODUCTS

Table 1 shows the correspondence between the original products requested by BGS and the four main products provided by the Service Providers which are been validated in this document. Full description of the four products requested by BGS is provided in Appendix 1. Waterlines (WL) and shorelines (SL) are provided as vector products while bathymetry (BT) and land-use and land-cover (LULC) are provided as raster products. Different signals (optical backscatter and Synthetic Aperture Radar) and missions (Landsat-2, 5, 8 and Sentinel-1, 2) has been used to produce different products as indicated in the product file name. For example, waterlines and shorelines have been produced using both optical and radar signals, while bathymetric and land-cover maps have been produced using optical Sentinel 2 data. The product name, contains information on the product type (WL, SL, BT, LC), mission used (S1, S2, L2, L5, L8), date of production, date of the data capture and area coverage. **Table 2** shows the number of products that have been produced for all UK sites. The details of each product's contents and the naming convention is also summarized below.

Table 1.- Correspondence between the products requested by BGS and the products provided by the Service providers.

Name†	**Layperson definition†**	**EO product name**	**Signal†† & Mission†††**
Proxy-based Tidelines	A proxy tideline (a physical feature taken to represent the coastline)	Waterlines (WL)	OPT: S2, L2, L5, L8 SAR: S1
Datum-based Tidelines	A tideline obtained by extracting a contour at different tidal elevations	Shorelines (SL)	Derived from Waterlines and Auxiliary Data provided by end-user
Topo-Bathymetric DEM	Seamless (i.e. no data gaps between topography and bathymetry) Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore)	Satellite-Derived Bathymetry (BT)	OPT: S2
Habitat map	This product is a vector polygon product containing a time stamped Habitat map of the coastal zone (including backshore, foreshore and nearshore).	Land Cover Map (LC)	OPT: S2

†As described in End-Users Requirement Document (BGS ref. CR/19/055)
††OPT & SAR stands for signal type; Optical and Synthetic Aperture Radar respectively
†††L2, L5, L8, S2 and S1 stands for mission name; Landsat-2, 5 and 8 & Sentinel-1 and 2

Table 2.- Summary of file names, formats and number of products provided to BGS by product type and study area.

Type	**Name**	**Format**	**East England**	**Chesil Beach**	**Start Bay**
BT	*_BT_OB_L2_BBox_S2_*	TIFF, JSON	2	6	0
BT	*_BT_0META_BBox_S2_*	TIFF, JSON	2	6	0
BT	*_BT_0MASK_BBox_S2_*	TIFF, JSON	2	6	0
SL	*_SL_DB_BBox**_HAT_Mission_***	ESRI-SHP, JSON	152	113	955
SL	*_SL_DB_BBox**_LAT_Mission_***	ESRI-SHP, JSON	152	113	955
SL	*_SL_DB_BBox**_MHWS_Mission_***	ESRI-SHP, JSON	152	113	955
SL	*_SL_DB_BBox**_MLWS_Mission_***	ESRI-SHP, JSON	152	113	955
SL	*_SL_DB_BBox**_MSL_Mission_***	ESRI-SHP, JSON	152	113	955
WL	*_WL_OB_L2_BBox_**S2**_*	ESRI-SHP, JSON	117	72	47
WL	*_WL_OB_L2_BBox_**L5**_*	ESRI-SHP, JSON	34	27	30
WL	*_WL_OB_L2_BBox_**L8**_*	ESRI-SHP, JSON	19	14	12
WL	* LC_FB_L3_BBox_S2_*	ESRI-SHP	2	0	0
WL	***S1***_IW_GRDH_1SDV_*_ORBI*	JSON	0	0	866
LC	*_LC_FB_L3_BBox_S2_EndDate_ *	GeoTIFF, JSON	2	0	2

* see product details for full filename description

1.3.1 Bathy-Morpho Terrain Models (BMTM)

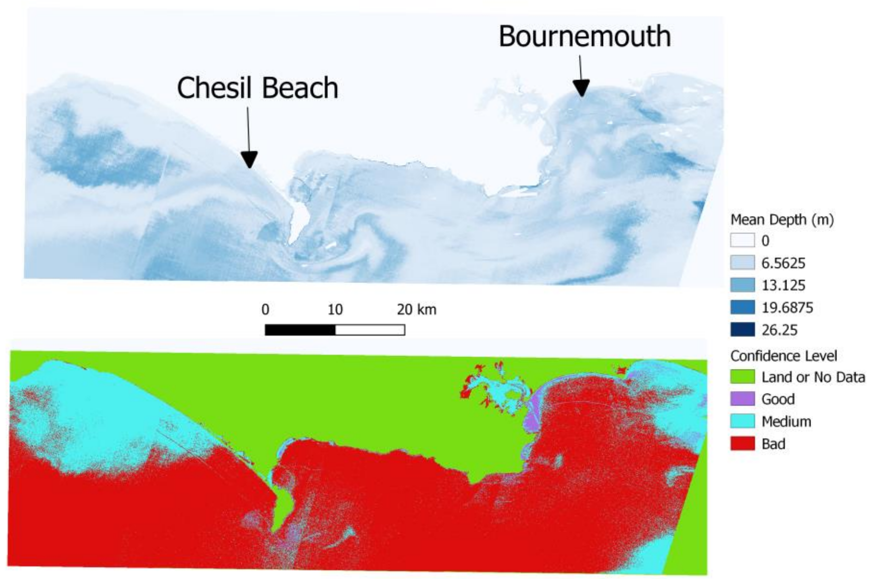


Figure 1.3.- Example of BMTM output produced for Chesil Beach area. Product filename: CE_201805051356_BT_OB_L2_502800N025937W-504821N012650W_S2_20200928

Type	Bathy-Morpho Terrain Model (BMTM)	
Filename	CE_ DateDataCapture _**BT_OB_L2**_BoundingBox_S2_ DateProductCreation.tif DateDataCapture = YYYYMMDDHHMM DateProductCreation = YYYYMMDD	
Format	GeoTIFF	
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected	
Pixel Size	10, -10 meters	
No Data Value	-999	
Additional Meta Data	JSON file	
Auxiliary Data File	CE_YYYYMMDDHHMM_**BT_0META**_BoundingBox_S2_YYYYMMDD	
Auxiliary Data File	CE_YYYYMMDDHHMM_**BT_0MASK**_BoundingBox_S2_YYYYMMDD	
Attribute field	**Description**	**Classes**
Band1: Z_mean	Mean water depth relative to the image reflectance information with no tide correction.	Double [Float32], meters
Band1: Z_median	Median water depth relative to the image reflectance information with no tide correction.	Double [Float32], meters
Band1: Z_90pct_min	Minimum water depth relative to the image reflectance information with no tide correction.	Double [Float32], meters
Band1: Z_90pct_max	Maximum water depth relative to the image reflectance information with no tide correction	Double [Float32], meters
Band1: Z_90pct_range	Difference between min and max water depth relative to the image reflectance information with no tide correction.	Double [Float32], meters

Type	Auxiliary Data File for Bathymetry (BT)	
Filename	CE_YYYYMMDDHHMM_**BT_0MASK**_BoundingBox_S2_YYYYMMDD.tif	
Format	GeoTIFF	
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected	
Pixel Size	10, -10 meters	
No Data Value	-999	
Additional Meta Data	JSON file	
Auxiliary Data File	none	
Attribute field	**Description**	**Classes**
Band1	Quality flag for Bathymetry product. Where 0.0 = Land/No data; 1.0 =Good depth values according to SPM and COM concentrations; 2.0 = Medium quality values according to medium concentrations of SPM and CDOM, 3.0 = no good depth values according to high SPM and CDOM concentrations and negative reflectance values.	[0.0, 1.0, 2.0, 3.0], Float32, no units

1.3.2 Waterlines from optical data (WL-OPT)

Figure 1.4.- Example of Waterline product produced for Humber estuary area. Left: waterline location over an aerial image or the area taken at different date and time than the WL. Right: line location colour coded using the quality flags metadata provided.

Type	Waterline (WL) Optical (OPT)
Filename	CE_ DateDataCapture _**WL_OB**_L2_BoundingBox_**Mission**_ DateProductCreation Mission = S2, L5, L8, DateDataCapture = YYYYMMDDHHMMSS DateProductCreation = YYYYMMDD
Format	ESRI Shapefile
Geometry	Line (MultiLineString)
Units	meters
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected
Meta Data	JSON file

Attribute field	Description	Classes
Id	Unique feature identifier	Integer64, no units
QC_len	The QC_len is looking at the line length, a lot of waterline errors are very short segments, so these are assigned a low value and vice versa. Quality Flag number based on line length. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality.	Integer64, no units
QC_LCI	The QC_LCI uses a Line Confinement Index, it is looking at how compact the segment is relative to it's length. Good waterline segments are usually stretched out (like along a beach), whereas errors are usually squiggly and compact. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality	Integer64, no units
QC_inern	The QC_intern is the mean value between QC_len and QC_LCI, this helps to mitigate against the pitfalls of both QC methods. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality	Integer64, no units

1.3.3 Waterlines from SAR data (WL-SAR)

Figure 1.5.- Example of Waterline (magenta line) derived from SAR data (S1) for Start Bay. Also shown the reference line used by the service provider to assess the quality of the line. Product filename: S1B_IW_GRDH_1SDV_20191020T062303_20191020T062328_018555_022F5A_2372_QC_HM_CLASS_Good

Type	Waterline (WL) Synthetic Aperture Radar (SAR)
Filename	S1B_IW_GRDH_1SDV_ DDCS**T**TDCS_DDCE**T**TDCE_ORBIT_* geojson DDCS = Date Data Capture Start = YYYYMMDD TDCS = Time Data Capture Start = HHMMSS DDCE = Date Data Capture End = YYYYMMDD TDCE = Time Data Capture End = HHMMSS * = for service provider use
Format	JSON file
Geometry	Line (MultiLineString)
Units	meters
CRS	EPSG:4326 - WGS 84 - Geographic

Meta Data	JSON file	
Attribute field	**Description**	**Classes**
Id	Unique feature identifier	Integer64, no units
distance	Distance to a fixed reference shoreline. NaN results are points out of the bounding box, so there is no reference line near them to do the QC	Double [Float32], meters
density	Density of waterlines. The value indicates the % of points falling in the same pixel cell as the one evaluated, NaN results are points out of the bounding box	Double [Float32], %
classification	Flag indicating the labelling applied after the quality check: 0 for good points, distance below 50 meters and density above 2 %; 1 for proxy points, distance between 50 and 100 meters and density above 2 %; 2 for not valid points, distance above 100 meters	Integer64, no units
angles	Angle between the orbit trajectory and the reference shoreline orientation. A mean average of 10 points has been considered. 90 and 270 indicate perpendicular view of the coast.	Double [Float32], deg

1.3.4 Shorelines from optical and SAR WL

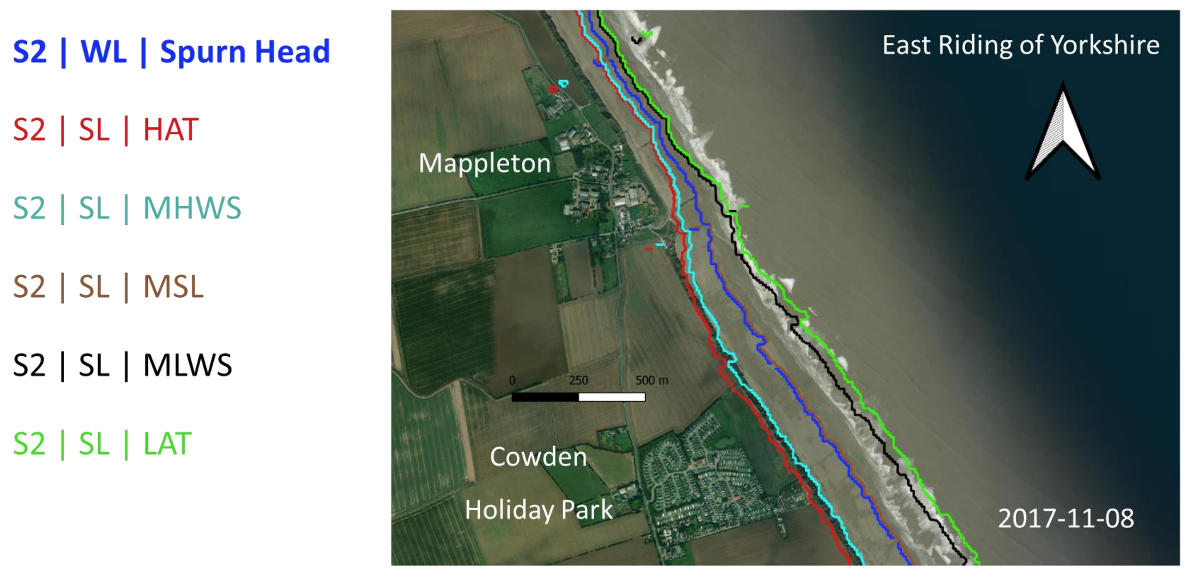


Figure 1.6.- Waterline (WL) is converted to different shorelines (SL) at different user-defined datum elevations (HAT, MHWS, MSL, MLWS, LAT). Example of shorelines produced for a segment of coast of beach backed type, by soft cliff at East Riding of Yorkshire region. Aerial imagery in the background shown for reference and taken at different date and time than shorelines.

Type	Shoreline (SL) from both Optical (OPT) and SAR WLs
Filename	CE_DateDataCapture_**SL**_DB_L2_BoundingBox_**TideLevel**_**Mission**_DateProductCreation TideLevel = Mean Sea Level (MSL), Lowest Astronomical Tide (LAT), Mean Low Water Springs (MLWS), Mean High Water Springs (MHWS) and Highest Astronomical Tide (HAT) Mission = S1, S2, L5, L8, DateDataCapture = YYYYMMDDHHMM DateProductCreation = YYYYMMDD

Format	ESRI Shapefile	
Geometry	Line (MultiLineString)	
Units	meters	
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected	
Meta Data	JSON file	
Attribute field	**Description**	**Classes**
FID	Unique feature identifier	Integer64, no units

1.3.5 Littoral line (LL) and backshore classification maps (LC)

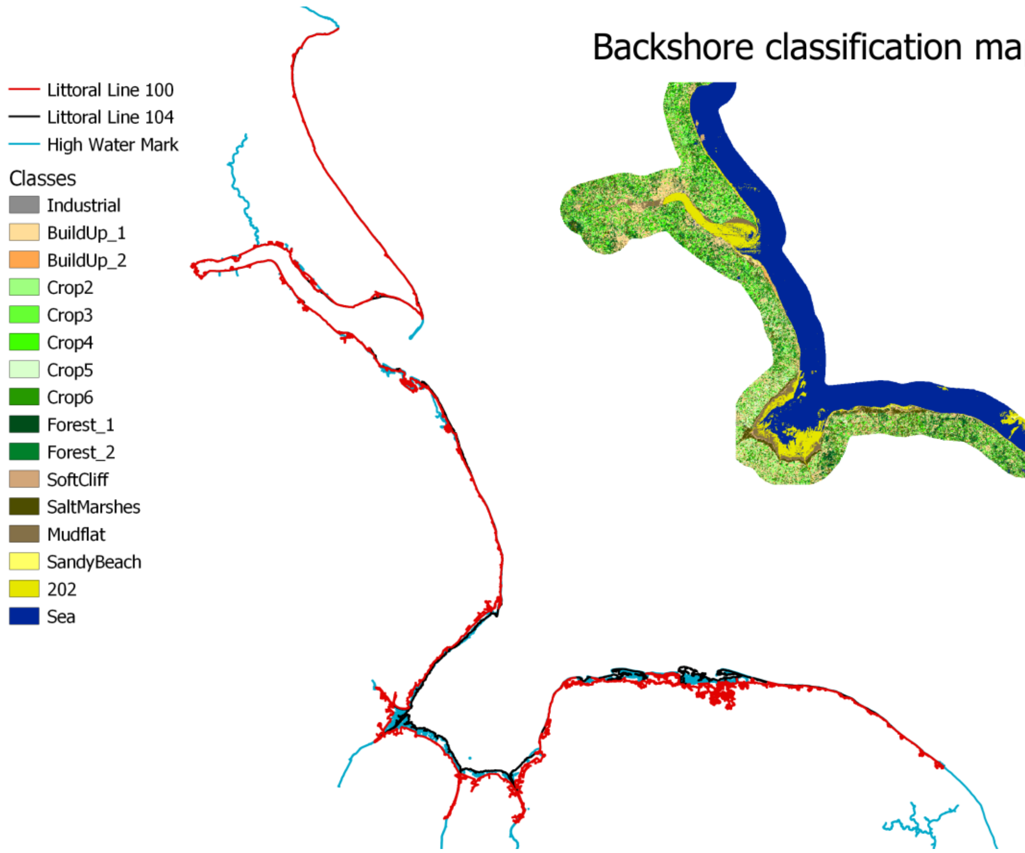


Figure 1.7.- Example of littoral lines extracted from a 2018 backshore classification map produced for the coast from Flambourough Head to Happisburgh at East England.

Type	Littoral line (LL) from Optical (OPT)
Filename	CE_StartingDate _LC_FB_L3_BoundingBox _S2_EndingDate_DateProductCreation _XXX_Line StartingDate/EndingDate = YYYYMMDD DateProductCreation = YYYYMMDD XXX = 100 the line represents the boundary between the backshore with "utile" areas and the intermediate "buffer" area. XXX = 104 the line represents the seafront line, representing the limit between the buffer area and the beach with mudflat, sand, tidal area.
Format	ESRI Shapefile

Geometry	Line (MultiLineString)	
Units	meters	
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected	
Meta Data	----	
Attribute field	**Description**	**Classes**
FID	Unique feature identifier	Integer64, no units

Type	Bakshore classification or Land Cover map (LC)	
Filename	CE_StartingDate_LC_FB_L3_BoundingBox_S2_EndingDate_DateProductCreation StartingDate/EndingDate = YYYYMMDD DateProductCreation = YYYYMMDD	
Format	GeoTIFF	
CRS	EPSG:32630 - WGS 84 / UTM zone 30N - Projected	
Pixel Size	10, -10 meters	
No Data Value	0	
Additional Meta Data	JSON file	
Auxiliary Data File	CE_StartingDate_ConfM_FB_L3_BoundingBox_S2_EndingDate_DateProductCreation Confussion matrix plot	
Auxiliary Information	https://www.linkedin.com/posts/anne-laure-beck-88227813a_activity-6575268536711684097-XjZ4	
Attribute field	**Description**	**Classes**
Band1	Classified pixels based on a number of discrete classes.	Integer, UInt16, Industrial:1 BuildUp_1:2 BuildUp_2:3 Crop2:5 Crop3:6 Crop4:7 Crop5:8 Crop6:9 Forest_1:10 Forest_2:11 SoftCliff:102 SaltMarshes:103 Mudflat:104 SandyBeach:201 TidalAreas:202 Sea:301

2 Methodology and auxiliary data

2.1 GENERAL APPROACH AND DEFINITIONS

2.1.1 Validation activities overview

Figure 2.1 shows the general validation process adopted by the Coastal Change Consortium. The adopted framework is an extension of the framework proposed by [1]. We have adopted this validation framework to acknowledge that while the validation aim is in principle straightforward, the actual implementation represents an extensive process in which each individual step is subject to various assumptions and potentially requires user decisions, which might make it a subjective approach. As noticed by [1] within most EO communities, detailed validation protocols have been established, tailored to the specific products and validation aims but all follow this general structure. We have added the use of a non-dimensional skill score (the Brier Skill Score) which is now of standard use in coastal engineering [2], to quantitatively assess the confidence of the observed changes against scientifically rigorous methods. The combined analysis of the absolute accuracy and the skill of the EO detecting change is anticipated to provide the best assessment criteria of the adequacy of the EO products. The ultimate aim of the validation assessment is to check the conformity of the EO products with the level of accuracy and resolution (spatial and temporal) requested at each validation site as well to assess the skills of the different EO products capturing the observed changes on the ground.

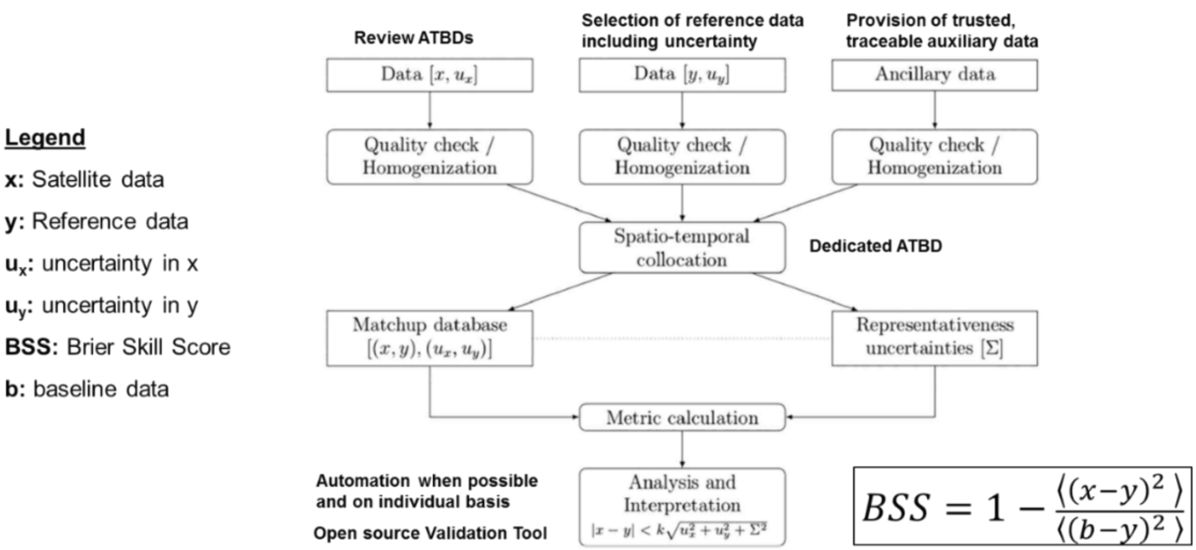


Figure 2.1.- Main validation activities (in bold) over the schematic overview of general validation process adopted by the Coastal Change Consortium.

The main validation activities undertaken in this study are:

- **Review of ATBDs: importance of colocation mismatch**. The service providers have checked the conformity of the processors with technical specifications (verification step) and of the EO products with the feasibility requirements (QC). Out of these two conformities check they have provided to the end-users with the EO product value, x, and its uncertainty budget, u_x. The main contribution of end-users to the verification has been done via reviewing the processor's Algorithm Theoretical Basis Documents (ATBDs) during phase 1 of the project. The ATBDs has been reviewed by end-users in house EO departments and provided feedback to the service providers that has been included in the consolidated versions of the ATBDs submitted to ESA for the Mid Term Review. During this phase, it became very clear the importance of dedicating an ATBD to the geolocation pre-processing needed for each EO products. This geolocation is needed to provide an estimate of the differences in the representativeness of EO and reference measurements (i.e. Σ value in eq. 1).

- **Selection of reference data including uncertainty of reference values**. From an idealized perspective, the input data x and y (e.g., satellite data and reference data) to the validation process would be traceable to SI reference standards. In practice, this is rarely the case, and the choice of reference data, in particular, is often a pragmatic decision [1]. Typical considerations in this regard include the following questions: (1) Do the data provide scientifically meaningful estimates of the investigated geophysical quantity? (2) Do these data sufficiently cover the potential parameter space? (3) Are the data expected to be accurate enough to be able to draw desired conclusions from the validation process? (4) Are the data publicly available and accessible? Considering these questions, the end-users have pragmatically selected for each validation site, the reference data that will be used for validation. The details of the validation data are included in the products requirements description detailed in the URD.
- **Provision of trusted, traceable auxiliary data**. Traceable data production chains are required that allow to trace back the method used for the production including full traceability of ancillary data used, including their uncertainties. Different auxiliary data is needed for different EO products. These auxiliary data include information about the physical characteristics of the coastline, but also include meteorological and sea state information at the time of EO observation. The end-users have provided these data to the service providers for each validation site as described in the Auxiliary data section.
- **Metrics selection for accuracy (absolute and relative) and skills detecting changes**. Analysis and interpretation can only be made once the final metrics have been obtained and it needs to be judged if the results are compliant with the requirements. However, in many cases, a single application does not exist, and requirements may be numerous and, thus, validation targets would need to be defined, which could then be checked for compliance on an individual basis. Nevertheless, there are some commonalities to our approach that can be summarized as assessing; (1) the coverage factor, k, as shown in eq. 1 and the Brier Skill Score (eq. 2 & 3) of the EO product detecting change.

In its most fundamental form, the consistency check between the differences between two measurements and the reported measurement uncertainties can be written as

$$|x - y| < k\sqrt{u_x^2 + u_y^2 + \Sigma^2} \quad (1)$$

where x and y are the EO and reference measurements, u_x and u_y their respective uncertainties, k the so-called coverage factor, and Σ **the additional variance of the differences due to colocation mismatch**, i.e., differences in the representativeness of both measurements. **The**

coverage factor allows the combined uncertainties to be scaled to a particular confidence level. Where k = 1, the combined uncertainty is consistent with 1 standard deviation. The value k = 2 is frequently used to give a confidence level of 95% (assuming a normal distribution of the combined uncertainty). In addition to the confidence level, we acknowledge that **measuring the skill of observation** (i.e., its performance relative to a simple baseline observation method) **is a more critical test than measuring its absolute accuracy**. We have used the Brier Skill Score (BSS) **to assess the skills of the EO detecting the changes observed in the ground**. The BSS is a particularly useful skill score in coastal engineering [2], because it includes contributions due to errors in predicting amplitude, phase and mean. For assessing the skill of an EO product, the BSS can be expressed as a function of the Mean Square Error (MSE) as

$$MSE = \frac{1}{J}\sum_{j=1}^{J}\left(x_j - y_j\right)^2 \quad (2)$$

$$BSS = 1 - \frac{\langle\left(x_j - y_j\right)^2\rangle}{\langle\left(B_j - y_j\right)^2\rangle} = 1 - \frac{MSE(x,y)}{MSE(B,y)} \quad (3)$$

where x_j, y_j and B_j represents elements of satellite, ancillary and baseline data, respectively, which match in space and time. As we are interested in detecting change, the baseline observation will be assumed equal to the most likely anticipated change by the end-users at each validation site. Depending on the location, the baseline could be equal to the latest observed shoreline or bathymetry available (i.e. no change expected) or a modified waterline or bathymetry (i.e. rotated shoreline for pocket beaches).

Table 3.- Rating of Brier-Skill Scores.

RATING	VALUE OF BSS
BAD	< 0
POOR	0 - 0.1
REASONABLE/FAIR	0.1 – 0.3
GOOD	0.3 – 0.5
EXCELLENT	0.5 - 1

A BSS has a range of - ∞ to 1. If discrepancies between satellite observation, x_j, and the reference value, y_j, are greater than the baseline change (the difference between the baseline value, B_j, and the reference value, y_j), the skill score is negative. Note that these skill scores are unbounded at the lower limit. The perfect agreement gives a skill score of 1 whereas observing the baseline change gives a score of 0. The commonly accepted interpretation of the different BSS values is summarized in **Table 3**. BSS values can be extremely sensitive to small changes when the denominator is low, in common with other non-dimensional skill scores derived from the ratio of two numbers. Therefore, large negative values can be obtained even from observations which predict a small change (of the correct order of magnitude) when the baseline change is very small. In these circumstances, different observations of the same location can still be compared (as the same small denominator will be used) to get a ranking of relative merit. Note that when the denominator reduces to a similar size as the error in the measurements, then the skill score becomes effectively meaningless.

2.1.2 Product representative fraction scale

The primary metric of scale in traditional cartography, the representative fraction, has no well-defined meaning for digital data [3]. The cartographer's representative fraction (e.g., 1:25,000, meaning that 1 cm on the map corresponds to 25,000 cm on the Earth's surface) is widely used to describe digital databases that have been built by digitizing or scanning paper maps, even though there are no distances in a digital database (distances between the locations of bits on the hard drive?) to compare with distances on the ground. The question of what "representative fraction" should one use to characterize the detail in a digital geographical database was explored by [3]. The term **scale** is often used to refer to the extent or scope of a study or project, and the spatial extent is an obvious metric. It can be defined in area measure, but for the purposes of this discussion a length measure is preferred, and the symbol L will be used. For a square project area, it can be set to the width of the area, but for rectangular or oddly shaped project areas the square root of the area provides a convenient metric. Spatial extent defines the total amount of information relevant to a project, which rises with the square of a length measure. The symbol S will be used here to denote the level of detail or **spatial resolution**. For LC and BT raster products, square raster provides the simplest instance, because in this representation of the spatial variation of a field the spatial resolution is clearly the length of a cell side, all variation within cells having been lost. Much more problematic are the vector (i.e. waterlines and shorelines) representations of a field.

This difficulty is related to the fact that in the digital world, the three properties that are conveniently summarized by a representative fraction on the Analog world (positional accuracy, spatial resolution and feature content) are potentially independent. This difficulty has led to a complex system of conventions in an effort to preserve representative fraction as a universal defining characteristic of digital databases. When such databases are created directly from paper maps, by digitizing or scanning, it is possible for all three properties to remain correlated. But in other cases, the representative fraction cited for a digital database is the one implied by its positional accuracy (e.g., a database has a representative fraction of 1:12 000 because its positional accuracy is 6 m); and in other cases, it is the feature content or spatial resolution that defines the conventional representative fraction (e.g., a database has representative fraction 1:12 000 because features at least 6 m across are included). Here, we have calculated the representative fraction, F, as the ratio between the map accuracy standard value of 0.5 mm and (1) the positional accuracy and (2) the minimum size of feature included. These two values or representative fractions are then compared with the spatial scale requested and detailed in the end-user requirements.

2.1.3 Product accuracy

We have adopted the UK Ordnance Survey (OS) three definitions of accuracy:

- **Absolute** or **Positional Accuracy** - compares the location of a position scaled from a map with the true position on the ground *i.e*. how closely the coordinates of a point on the map agree with the coordinates of the same point on the ground (in the British National Grid reference system).
- **Relative Accuracy** - compares the scaled distance between features measured on the map with the true distance on the ground.
- **Geometric Fidelity** (Shape) – the 'trueness' of features to the shapes and alignments of the objects they represent *i.e.* any real-world alignment or shape must be accurately reflected in the map to the required specification

The absolute and relative accuracies of OS Large Scale Mapping are measurable and definitive statements of the expected errors of these by survey scale are given. Geometric fidelity (Shape) cannot be closely defined and is a matter of subjective judgement. The OS guideline is that the detail must be acceptable in terms of geometric fidelity when plotted or displayed at a scale.

Accuracy is expressed as the Root Mean Square Error (RMSE), which is a measure of the distance from the true position within which about 67% of points would be expected to lie. RMSE is the square root of the mean of the sum of the squares of the errors between the observations. The maximum expected geometric error on a map is about three times the RMSE.

Relative accuracy is normally expressed as a constant plus an amount proportional to the distance measured. In general, relative accuracy is more important to map users than the positional. The relative accuracy criteria are perhaps best understood by using an example: a 95% confidence level of the relative accuracy of ±1.0 m (up to 60 m) means that there would be an expectation that 95% of distances between two points of detail 60.0 m apart would be represented in the digital product by a scaled distance of between 59.2m and 60.8m.

2.2 PRODUCT SPECIFIC VALIDATION APPROACH

2.2.1 Qualitative assessment of 1D products: waterlines, shorelines, vegetation line

The qualitative validation aims to visually assess the 1D products (waterlines, shorelines and vegetation line) which had been extracted from the different satellite missions (Landsat 8, Landsat 5, Sentinel 1&2) data. It is desirable to understand three aspects of the extracted waterlines;

1. The ability to closely represent the actual line
2. The ability to do this consistently
3. The ability to capture changes over time.

Although a quantitative assessment is also carried out this only allows the user to understand the numerical measure of differences between the satellite-derived waterline and the chosen benchmark. A qualitative assessment allows the user to understand under what conditions the extracted waterline is closely aligned to the actual waterline and, importantly what conditions cause the extraction technique to not perform as well. This ultimately allows the user to understand where they can have the greatest confidence in the satellite-derived waterline and where they need to exercise caution in its use.

To address the above three aspects of satellite-derived water lines have been visually compared to the following datasets:

1. 1:25 000 scale and 1:12 500 scale colour aerial photography
2. Ordnance Survey Coastline (open data)
3. Ordnance Survey High Water and Low Water Mark lines (open data).
4. Inter-comparison of satellite-derived waterlines from different years.

Firstly, the satellite-derived waterlines were individually visualised at different scales; 1:150 000, 1:20 000 and 1:5 000. This allowed the overall characteristics of the line to be assessed including its completeness, the presence of any spurious lines, loops, and gaps.

The lines were then visualised over the aerial photography, allowing an assessment of where they were capturing the coastline and where there were issues. It was necessary to study the line in a variety of coastal situations;

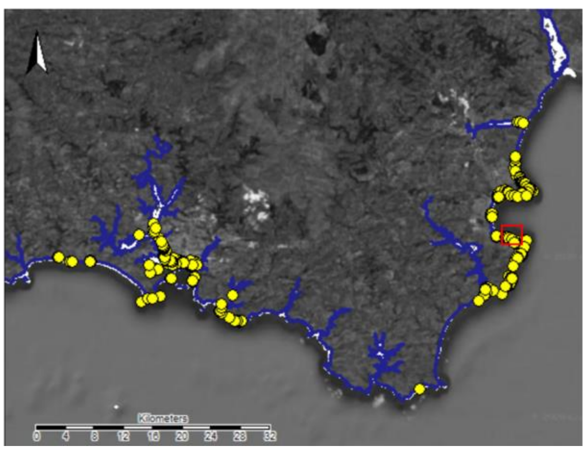
- Rocky coastlines
- Beaches
- Coves and headlands
- Man-made coastlines such as harbours and coastal defences

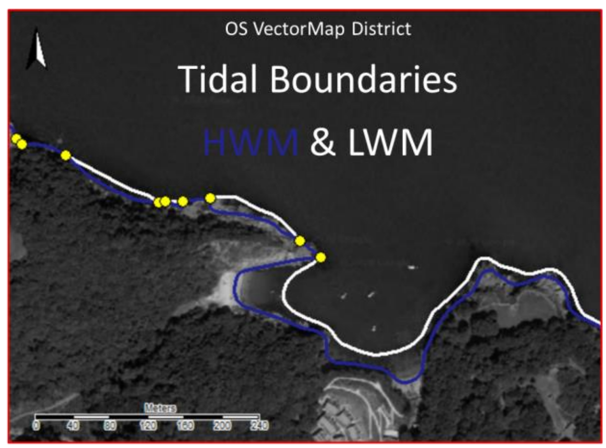
Satellite-derived waterlines were then compared to other satellite-derived waterlines form different times and to OS data to understand if the satellite waterlines are able to detect changes in coastline resulting from erosion.

2.2.2 Quantitative assessment of 1D products: waterlines, shorelines & vegetation line

In order to quantify the accuracy of the 1D products, the British Geological Survey (BGS) undertook analyses that assessed; **absolute accuracy** (location relative to a known point), **relative accuracy** (distance between the points where change is observed) and **type of change** (i.e. erosion, accretion and rotation).

To ensure that the analysis is transparent and can be reproduced by others, the data used in the analysis was obtained from open sources. The data was processed using the System for Automated Geoscientific Analyses (SAGA) GIS software program. SAGA is a Free Open Source Software (FOSS) which enables the user to run, study and modify the program to suit their needs and freely redistribute copies of their work. SAGA is coded in the C++ programming language and has an object-oriented system design.





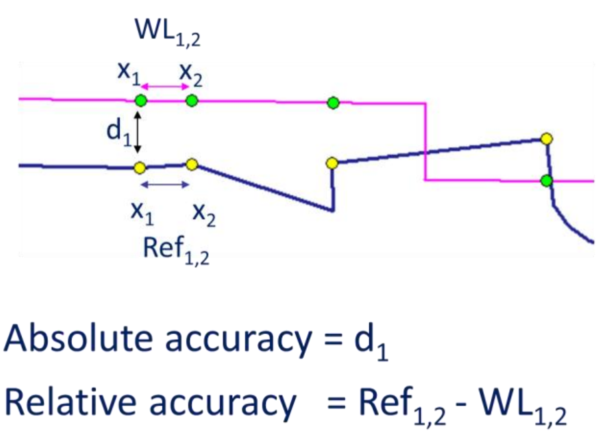


Figure 2.2.- Non-foreshore locations have been extracted (yellow circles) as the locations where the HWM and LWM tidal boundaries of OS VectorMap District lines intersect. Top left: overview of Start Bay study area. Top Right: detail showing the tidal boundary lines. Bottom left: absolute accuracy is measured as the distance between the yellow circles and the closest points (green circles) over the 1D product. Bottom right: HWM (blue), LWM (white) and WL (magenta) lines for a small region of Start Bay area.

There is currently no standard method to assess absolute and relative accuracy of satellite-derived waterlines and shorelines. To minimize the uncertainty associated with the water level differences at the time that the satellite image was taken and the ground truth data, we have chosen comparison points where there is no foreshore. The foreshore is the area exposed between high and low tide. In locations with no foreshore, the waterline will have minimum variations and its position can confidently be compared to both waterlines and shorelines. The non-foreshore locations were extracted from the intersection of the High Water Mark (HWM) and Low Water Mark (LWM) tidal boundary lines from OS Vectormap District dataset[3] (**Figure 2.2**). Vectormap is an open-source dataset, updated twice per year (May and November) and covers the entire Great Britain area with a representative fraction scale of 1:15 000 to 1:30 000. For each waterline, we have extracted the closest points to the “no foreshore” points and measured the absolute and relative distances. The absolute accuracy was obtained by taking the distance between a “no foreshore” point and the corresponding nearest point on the waterline. The relative accuracy was obtained by measuring the distance between two “no foreshore” points and the distance between the corresponding points on the 1D product being assessed. The search of points for the relative accuracy was limited to a circular area of a radius of 500 m to be consistent with the OS definition of relative accuracy standards (**Table 4**). Relative accuracy is normally expressed as a constant plus an amount proportional to the distance measured at different percentages (99%, 95%) of confidence level and RMSE value constrained to a maximum distance (which for maps at a fractional scale of 1:10 0000 is 500 m distance).

Table 4.- Relative Accuracy and the OS Map.

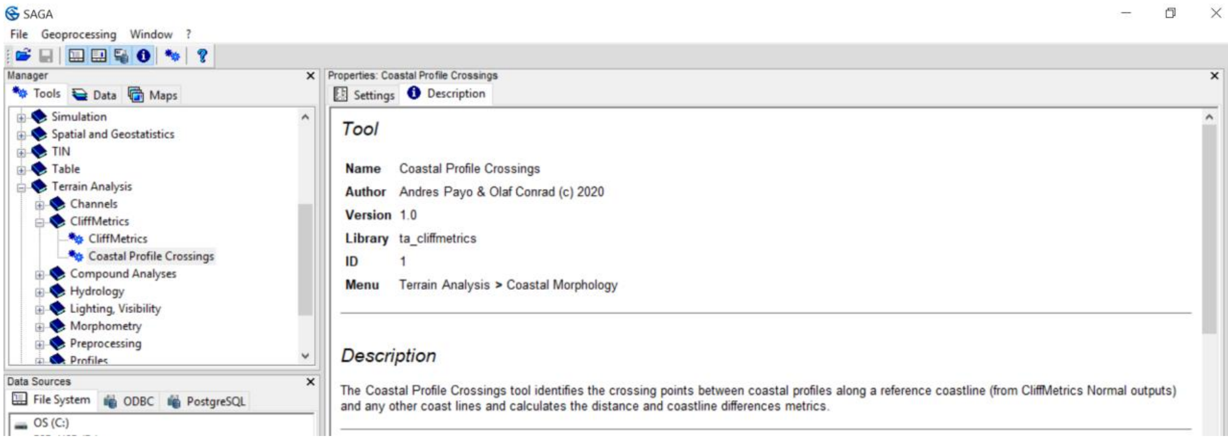
Original Survey Scale	99% confidence level	95% confidence level	Root Mean Square Error (RMSE)
1:10,000	+/- 8.8m (up to 500m)	+/- 6.7m (up to 500m)	+/- 3.5m (up to 500m)
1:1250	+/- 1.0m (up to 60m)	+/- 0.8m (up to 60m)	+/- 0.4m (up to 60m)
1:2500	+/- 2.5m (up to 100m)	+/- 1.9m (up to 100m)	+/- 1.0m (up to 100m)
1:2500 (built-up areas in defined rural towns)	+/- 0.9m (up to 60m)	+/- 0.7m (up to 100m)	+/- 0.4m (up to 60m)
1:2500 (outside of built-up areas in defined rural towns)	+/- 2.3m (up to 100m)	+/- 1.8m (up to 100m)	+/- 0.9m (up to 100m)

Source: https://rosdev.atlassian.net/wiki/spaces/2ARM/pages/66324084/Accuracy+and+Tolerance+of+the+Ordnance+Survey+Map (accessed Feb 2021)

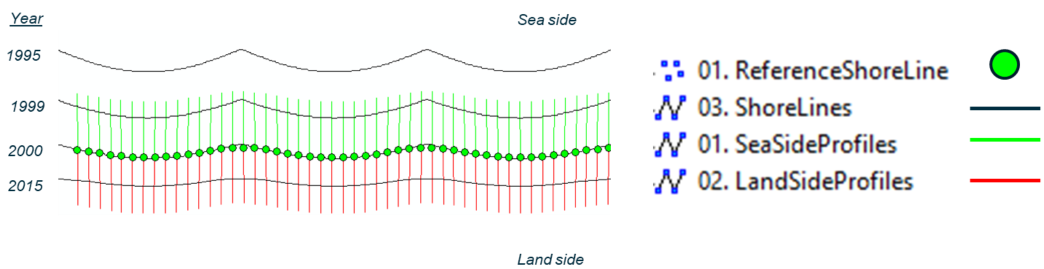
[3] https://www.ordnancesurvey.co.uk/business-government/products/vectormap-district

The type of change has been calculated by measuring the Euclidean distance between the reference 1D product and the intersection of an imaginary line segment, normal to the reference line, and the 1D products being assessed. We have developed a SAGA GIS tool, named ProfileCrossings and a tutorial[4] explaining how this calculation is done. The lines normal to the reference line are obtained using the SAGA GIS CliffMetric tool developed also by BGS [4]. The direction of change (i.e. sea side or land side) is automatically obtained allowing us to interpret the change as net erosion or accretion locally, or net rotation when all line movement is interpreted.

[4] https://bgs.sharefile.eu/d-s010dafacf1b04bf6ba13c33438677ad2



The image below shows all the inputs required for ProfileCrossings tool



This example illustrates a shoreline retreat, starting in year 1995 and ending in year 2015

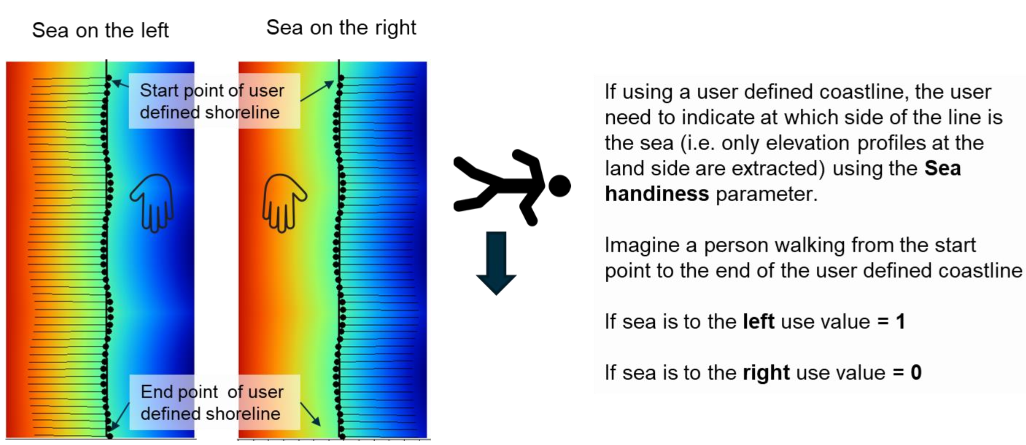


Figure 2.3.- Type of change (accretion, erosion and rotation) has been calculated using the bespoke "Coastal Profile Crossing" tool developed by BGS and now included as part of the SAGA (v 7.9.0) Coastal tools repository[5]. Top: given the reference line, sea side profiles and land sider profiles, this tool calculates the intersection with the normals and the Euclidian distances. Bottom: the line segments are calculated using SAGA CliffMetric tool that allows the user to define the sea-side and land-side of the waterline or shoreline being assessed.

[5] https://sourceforge.net/projects/saga-gis/files/

2.2.3 Vegetation line and backshore classification validation

The vegetation line is a proxy 1D line product extracted from the 2D backshore classification map and therefore the qualitative validation approach followed for the vegetation line is the same as described for the other 1D products. Service providers have provided, together with the backshore classification maps, a confusion matrix as shown in **Figure 2.4**. Guided by the confusion matrix we have visually inspected the skills of the classification map differentiating the different backshore classes.

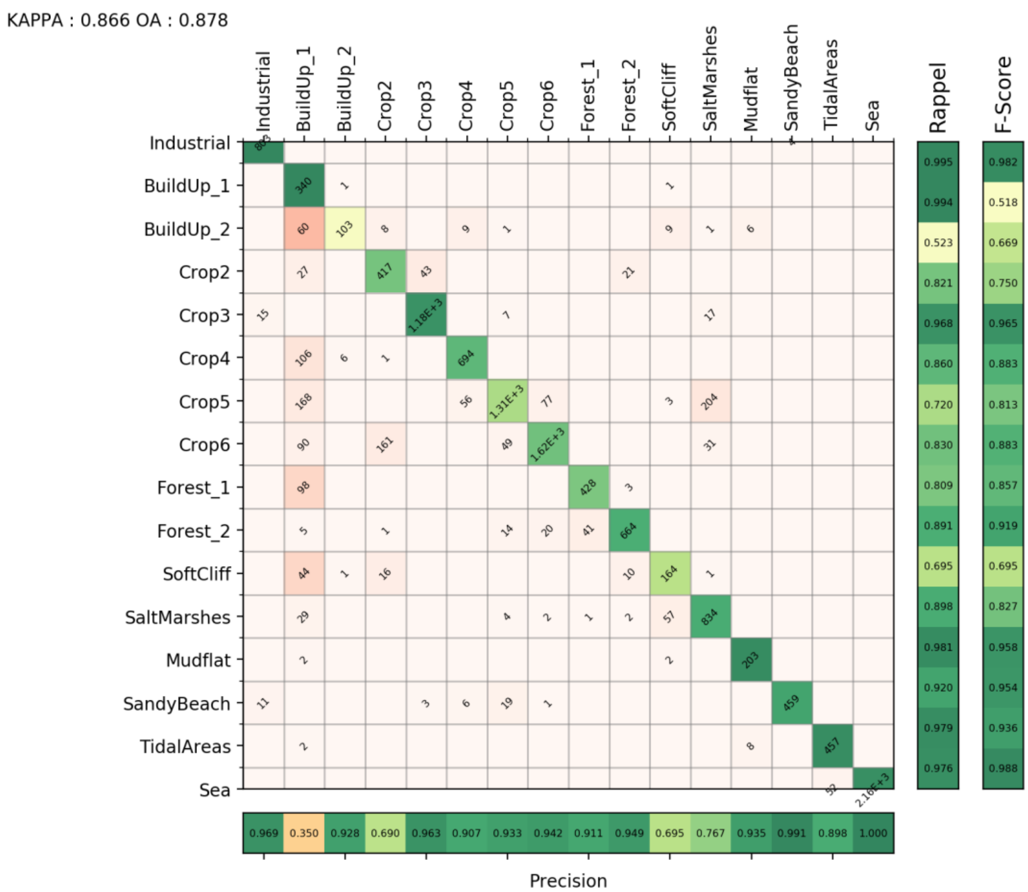


Figure 2.4.- Confusion matrix for backshore classification map for year 2018 for East England region.

We have also assessed the skills of the backshore classification map to detect changes along the vegetation line. We have done this by converting the vegetation line (year 2018) from line to point geometry and extracting the nearest neighbour class value from the raster backshore classification map for years 2018 and 2019 and comparing the differences. To extract the nearest neighbour raster value, we have used SAGA v7.9.0 “Add Grid Values to Points” tool (v1.0).

2.2.4 Bathy-Morpho terrain model validation approach

We note that ARGANS (product developers) intentionally did not label the products ‘satellite-derived bathymetry’ (SDB), due both to the high turbidity of UK waters, and the association of the term SDB with hydrographic charting which requires high vertical accuracy (i.e. seabed depth). SDB are more commonly used in environments with low turbidity, e.g. shallow coral reef environs with low sediment influx, where optical multispectral satellite sensors achieve greater depth penetration [e.g. 5].

Here we undertake an assessment of the accuracy of the BMTMs (qualitatively and quantitatively), as well as assess the ability of the BMTMs to detect and characterise morphological change. The validation protocol we have developed involves comparing and contrasting the satellite products with other available bathymetry datasets, in this case existing high-resolution multibeam echosounder (MBES) bathymetry data. Due to the experimental nature of this study, we have focussed this assessment on a large section of the Dorset coast around Chesil Beach. Due to the expense of acquiring MBES bathymetry, specific coastal areas are frequently only mapped once (if at all), hence the attraction of satellite data which offers the possibility of time-series data to assess active and dynamic environmental processes.

BMTM data were provided within three separate geographic areas around the English coast: 1) Start Bay, 2) Chesil Beach and 3) Spurn Head (**Figure 2.5**). As mentioned within previously , we have concentrated on Chesil Beach, and this is for several reasons: 1) Start Bay data not available at outset of the project, 2) Initial inspection indicated better chance of clearer water conditions at Chesil rather than Spurn Head area (i.e. potential to capture seabed), and 3) time limitations within the project.

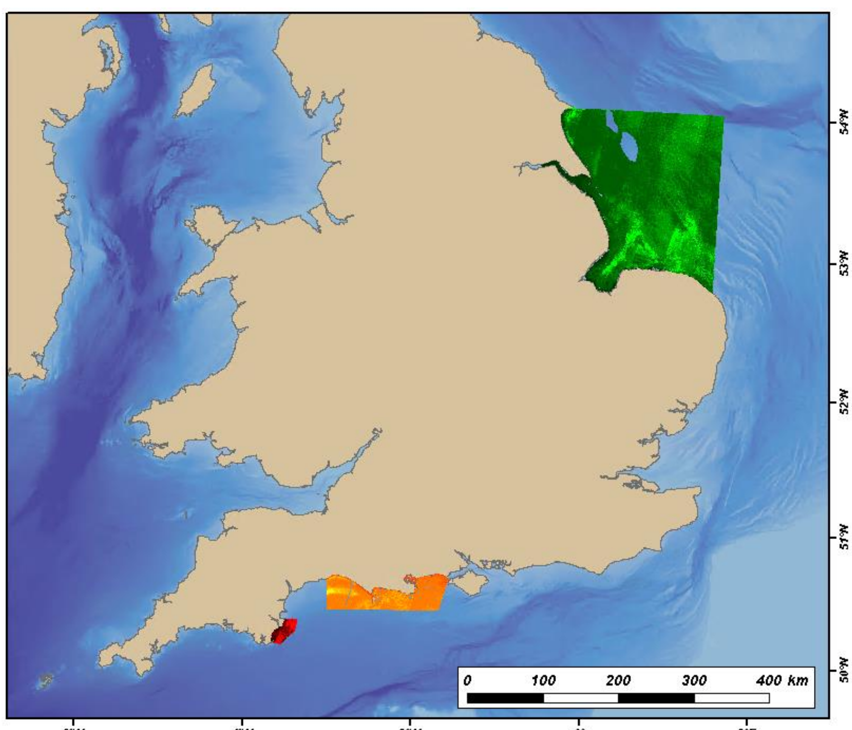


Figure 2.5.- Location map of bathy-morpho terrain models (BMTMs): Start Bay (reds) Chesil Beach (oranges) and Spurn Head (greens). This study focusses on Chesil Beach area.

Within each of these areas, multiple time-stamped datasets were provided (e.g. six BMTM datasets generated from the satellite data collected between May 2018 and May 2021 at Chesil

Beach site; **Table 5**). At the Chesil Beach site, the BMTM data cover an area of ~2,200 km^2 (**Figure 2.6**). The multiple bands are shown in **Figure 2.6** along an example profile.

Table 5.- List of time-stamped datasets provided for Chesil Beach area.

Date	Time	Bounding Box
2018/05/05	13:56	502800N, 025937W - 504821N, 012650W
2018/05/07	13:18	502800N, 025937W - 504821N, 012650W
2018/06/26	11:34	502800N, 025937W - 504821N, 012650W
2019/07/16	12:18	502800N, 025937W - 504821N, 012650W
2019/09/14	13:11	502800N, 025937W - 504821N, 012650W
2020/05/21	12:27	502800N, 025937W - 504821N, 012650W

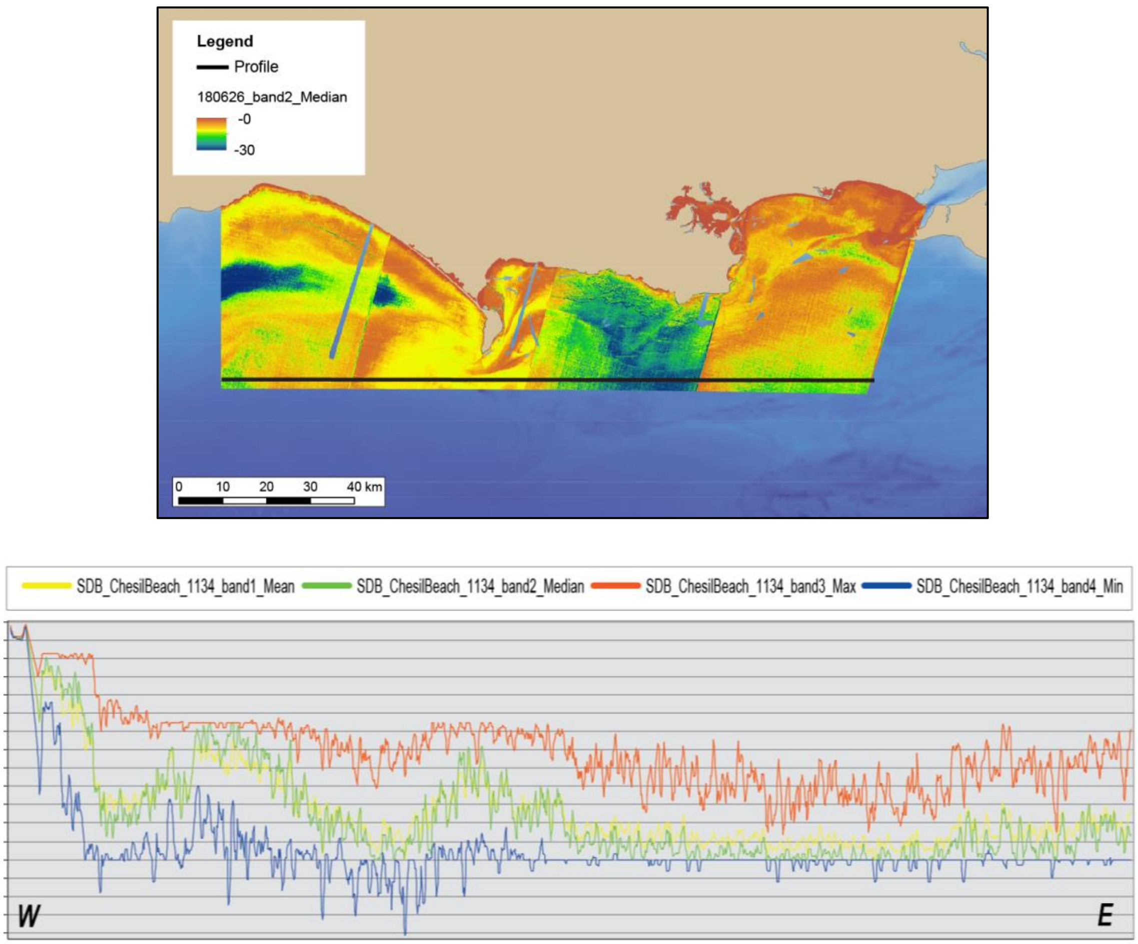


Figure 2.6.- Top: BMTM generated for Chesil Beach from the 2018/06/26 at 11:34, Band 2 (median values). Blue line shows the profile location of elevations shown in the bottom panel. Bottom: Stacked profile of the values extracted from the four bands (Minimum; Median; Mean; Maximum) provided for the BMTM generated from the satellite data collected on the 2018/06/26 at 11:34.

In preparation for the accuracy assessment (and comparison with MBES bathymetry), several simple corrections were made to the BMTM data (using R statistical computing software): 1) extract individual bands as single-band rasters, 2) convert Z-values to negative depth, and 3) set NoData values to -999. The data were then available for further analysis within R, ESRI ArcGIS, and Geomorphic Change Detection (GCD) software (http://gcd.riverscapes.xyz/).

Comparison data – multibeam echosounder (MBES) bathymetry

High-resolution multibeam echosounder (MBES) bathymetry data are generally considered the highest standard for accurate hydrographic charting, and seabed characterisation [e.g. 6]. Horizontal resolution varies between 10's of cms – 10's metres depending on water depth. Vertical resolutions also vary with water depth (and between sensors), but in the Chesil Beach area are expected to be accurate to within 50 cm, or better. The largest programme of MBES bathymetry acquisition in UK waters is the MCA and UKHO's Civil Hydrography Programme (CHP) (https://www.gov.uk/guidance/the-civil-hydrography-programme), and CHP data are the only MBES data available within the Chesil Beach area.

Fortunately, there is a good overlap of existing CHP data with the new BMTM data (**Figure 2.7**). The CHP data were acquired during a number of separate survey campaigns between 2011 and 2015. These separate datasets (horizontal resolutions between 1-8 m) were combined into a single depth raster, with a horizontal resolution of 10 m (to match BMTM data) (**Figure 2.8**). It is important to note that the MBES data due not reach the shoreline, frequently leaving a 'white ribbon' of un-surveyed seabed commonly hundreds of metres in width.

To further aid comparison within the coastal strip, MBES dataset was cropped to 0-20m water depth (i.e. cutting out data in water depths greater than 20 m) (**Figure 2.8**). This is an acknowledgement that even if of high quality, the BMTM would very likely not accurately detect the seafloor below 20 m. Even in the clearest water conditions, satellite-derived bathymetry data extend to a maximum of ~30 m depth.

The BMTM data have not been tide corrected, and we note this is an activity for future analysis. Tidal ranges in the region are relatively low, and typically less than 2 m.

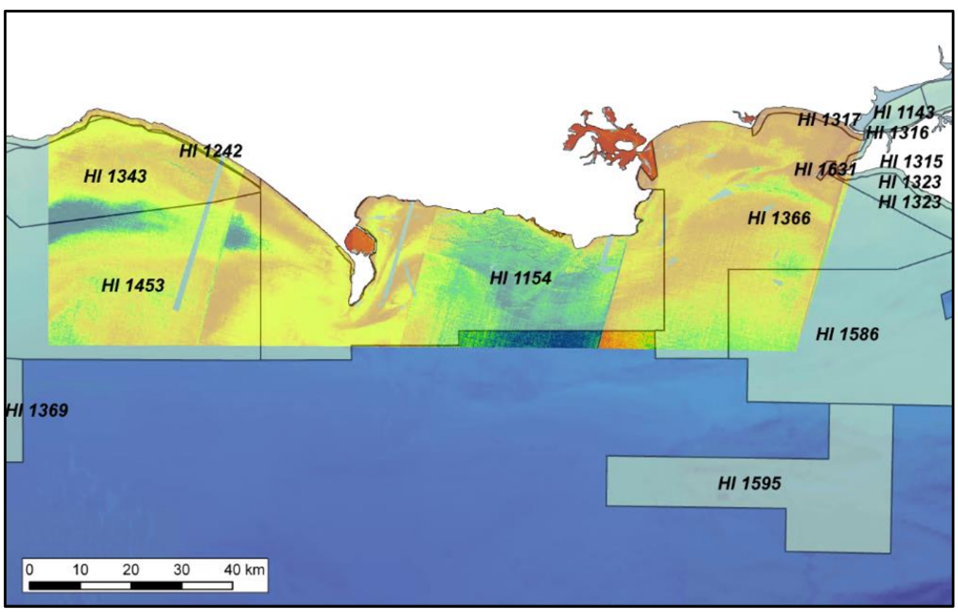


Figure 2.7.- MBES datasets available from the Chesil Beach study area, overlaying BMTM data tile.

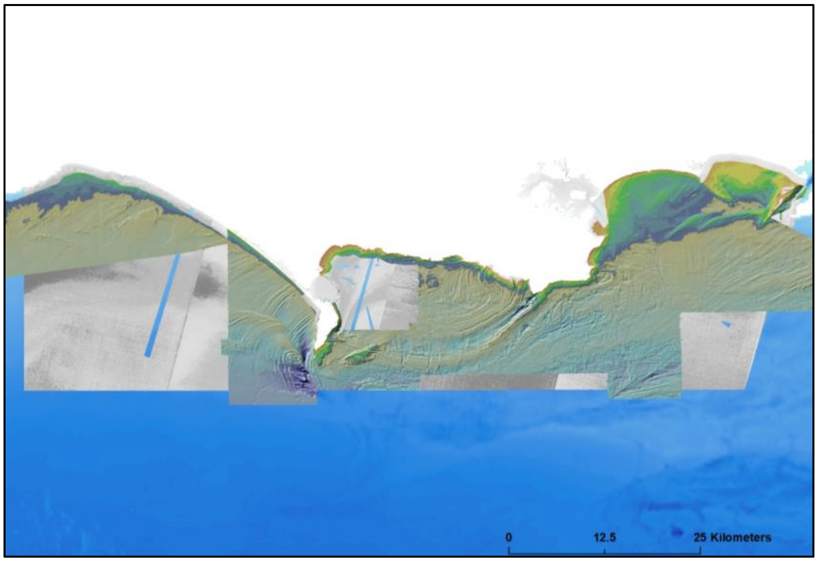


Figure 2.8.- Combined MBES bathymetry grid (0-100 m depth). Bolder colour scale along the coast (orange-blue) shows the MBES data subset between 0-20 m depth.

In addition to the BSS, and in circumstances where the BMTM data exhibit acceptable vertical accuracy, there are other approaches for quantitatively assessing morphological change. For exampke, the DEMs of difference approach [7], specifically measuring morphological change between time-series data [8]. This approach provides a range of useful metrics on the volumetric change between surveys and may be used to develop more accurate sediment transport models.

Attribute	Raw	Thresholded DoD Estimate:			
AREAL:					
Total Area of Surface Lowering (m^2)	12,485,300	12,485,300			
Total Area of Surface Raising (m^2)	295,261,000	295,261,000			
Total Area of Detectable Change (m^2)	NA	307,746,300			
Total Area of Interest (m^2)	307,746,300	NA			
Percent of Area of Interest with Detectable Change	NA	100%			
VOLUMETRIC:				± Error Volume	% Error
Total Volume of Surface Lowering (m^3)	29,784,435	29,784,435	±	0	0%
Total Volume of Surface Raising (m^3)	2,543,022,813	2,543,022,813	±	0	0%
Total Volume of Difference (m^3)	2,572,807,248	2,572,807,248	±	0	0%
Total **Net** Volume Difference (m^3)	2,513,238,378	**2,513,238,378**	**±**	**0**	0%
VERTICAL AVERAGES:				± Error Thickness	% Error
Average Depth of Surface Lowering (m)	2.39	2.39	±	0.00	0%
Average Depth of Surface Raising (m)	8.61	8.61	±	0.00	0%
Average Total Thickness of Difference (m) for Area of Interest	8.36	8.36	±	0.00	0%
Average **Net** Thickness Difference (m) for Area of Interest	8.17	**8.17**	**±**	**0.00**	0%
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	8.36	±	0.00	0%
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**8.17**	**±**	**0.00**	0%
PERCENTAGES (BY VOLUME)					
Percent Elevation Lowering	1%	1%			
Percent Surface Raising	99%	99%			
Percent Imbalance (departure from equilibrium)	49%	49%			
Net to Total Volume Ratio	98%	98%			

Figure 2.9.- Example output on volumetric change from Geomorphic Change Detection (GCD) software (http://gcd.riverscapes.xyz/).

2.3 EVALUATION APPROACH

The adequacy of the User Requirements detailed in the URD has been assessed primarily by BGS members of staff and informed via engagement with the broader end-user community. This engagement started in Phase 1 via sharing the progress of the URD and requesting written feedback from key end-users within each country partner. The written feedback from the engaged broader end-user community was included in annex 1 (AD-3 of PVP) and has been considered on our responses when filling in the contractually required "Service Assessment Sheets" questionnaire. For each product type, we have completed the questions summarized in **Table 6**. For each question, we have provided a short answer, linked to the evidence cited in this report and elsewhere. Based on these evidence we have scored our assessment outcome as three levels of satisfaction; High (H), Medium (M) and Low (L).

Table 6.- Service assessment questionnaire (from Annex B of Statement of Work).

Section	**Product**	WL	WL	SL	SL	LC	BTM
	Sensor	OPT	SAR	OPT	SAR	OPT	OPT
B.1	Adequacy of the User Requirements Document (URD) requirements (including accuracy)	?	?	?	?	?	?
B.2 Product compliance	Overall product compliance to the user requirements	?	?	?	?	?	?
	Product accuracy compliance to the user requirements	?	?	?	?	?	?
	Confidence in the product quality (including accuracy)	?	?	?	?	?	?
B.3 Utility assessment	Confidence in the product quality (including accuracy)	?	?	?	?	?	?
	Impact of the service and products on current end-user practices	?	?	?	?	?	?
B.4 Future outlook	Probability of service integration into existing practices	?	?	?	?	?	?
	Desired service and/or product(s) improvements	?	?	?	?	?	?
	Needs for a large-scale service/product demonstration	?	?	?	?	?	?
B.5 Overall evaluation	Overall service and products evaluation	?	?	?	?	?	?
	Recommendations to the European Space Agency	?	?	?	?	?	?

Questions on sections B.1 and B.2 are related to the validation results and questions on sections B.2 to B.5 are considered the aim of the evaluation of the products. The utility assessment (B.3) and future outlook (B.4) have been assessed throughout the continuous engagement with the broader end-users' community who has been consulted regarding; site selection, user requirement specifications and future outlook. In particular, the programme of the UK workshop celebrated on the 7th of December 2020 has been designed to answer the questions in section B.3 (WS session 2) and section B.4 (WS session 3) (**Figure 2.10**). The WS programme and video recorded sessions are accessible and available for the general public on the dedicated website: https://bgscoastalerosion.siteonsite.es/.

Figure 2.10.- Flyer of UK workshop showing the questions addressed. Full program and speakers available here https://bgscoastalerosion.siteonsite.es/

The recommendations that we provide in section B.5 reflects on the transferability to other locations of the products and services produced as well as any suggestion to move forward these products to an operational stage. Among all validation sites, we will select a set of representative case studies to showcase the utility of each one of the EO products and services produced. Case studies, which focus on a site-specific location and end-user application is an effective way of both communicating the utility of the EO products and engaging with the local end-users.

2.4 AUXILIARY DATA USED

2.4.1 VHR Earth Observation data

Data obtained from the Space for Smarter Government Programme (SSGP) of the UK Space Agency: https://geobrowser.satapps.org. The data is subject to licence. We have used Very High Resolution (VHR) satellite data from PLEIADES[6] (Optical) and Cosmo-Skymed[7] for the co-registration process.

	Full file name
Optical VHR data*	**South England**
	Pleiades_UKSA397_SO18034616-97-01_DS_PHR1B_201810241117508_FR1_PX_W002N50_0219_01542
	Pleiades_UKSA307_SO18034616-7-01_DS_PHR1B_201807241125059_FR1_PX_W003N50_0716_01863
	Pleiades_UKSA236_SO18034615-36-01_DS_PHR1B_201805211117124_FR1_PX_W002N50_0115_01032
	East England
	Pleiades_UKSA20_SO18034613-20-01_DS_PHR1A_201805011120009_FR1_PX_E000N52_0621_02334.zip
	Pleiades_UKSA217_SO18034615-17-01_DS_PHR1B_201804181120093_FR1_PX_E000N52_0624_00596.zip
	Pleiades_UKSA21_SO18034613-21-01_DS_PHR1A_201805011120113_FR1_PX_E000N52_0320_02032.zip
	Pleiades_UKSA387_SO18034616-87-01_DS_PHR1B_201810191105564_FR1_PX_E000N53_0504_01048.zip
	Pleiades_UKSA336_SO18034616-36-01_DS_PHR1B_201809021116324_FR1_PX_E000N53_0107_05319.zip
	Pleiades_UKSA143_SO18034614-43-01_DS_PHR1A_201808221101109_FR1_PX_E001N52_0917_04298
	Pleiades_UKSA191_SO18034614-91-01_DS_PHR1A_201810201058163_FR1_PX_E001N52_0605_03920
	Pleiades_UKSA316_SO18034616-16-01_DS_PHR1B_201808021105149_FR1_PX_E001N52_0910_01578
	Pleiades_UKSA309_SO18034616-9-01_DS_PHR1B_201807281053563_FR1_PX_E001N53_0401_01711
	Pleiades_UKSA30_SO18034613-30-01_DS_PHR1A_201805081115556_FR1_PX_W001N54_1003_00974
SAR VHR data*	**South England**
	CSKS2_SCS_B_HI_01_HH_RA_SF_20151222053258_20151222053305
	CSKS4_SCS_B_HI_03_HH_RA_SF_20151221053906_20151221053912
	East England
	CSKS1_SCS_B_HI_01_HH_RD_SF_20180713181225_20180713181233.zip
	CSKS1_SCS_B_HI_04_HH_RD_SF_20180713181215_20180713181222.zip
	CSKS1_SCS_B_HI_0B_HH_RA_SF_20151224052120_20151224052126.zip
	CSKS2_SCS_B_HI_15_VV_RA_SF_20180718053715_20180718053723.zip
	CSKS4_SCS_B_HI_03_HH_RA_SF_20160121052102_20160121052108.zip
	CSKS4_SCS_B_HI_03_HH_RA_SF_20160121052106_20160121052113.zip
	CSKS4_SCS_B_HI_03_HH_RA_SF_20160121052119_20160121052126.zip
*From Space for Smarter Government Programme (SSGP) subject to licence: https://geobrowser.satapps.org/#register:undefined	

2.4.2 Topographic data

To produce datum-Shoreline from the satellite-derived proxy-waterlines we need auxiliary data of the coastal topography, and in particular the intertidal area. We have used two sources of topographic data for the UK study cases:

- Data obtained from the Channel Coastal Observatory website: http://coastalmonitoring.org/data_management/online_data_catalogue.
- Additional data for East Riding of Yorkshire obtained from the Yorkshire Regional Programme manager. This data is not available on the CCO or coastal explorer website: https://www.eastriding.gov.uk/coastalexplorer/homepage.html. This data includes topographic profiles from 2008 to 2019 which have been extracted from airborne LiDAR DTMs and differ in format from the profiles obtained from the CCO website.

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[6] https://directory.eoportal.org/web/eoportal/satellite-missions/p/pleiades
[7] https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/cosmo-skymed

The topographical data consists of survey transects extending from a landward to a seaward boundary. Transect lines are commonly spaced at ~1 km intervals. 'Strategic' transect lines are routinely surveyed in the summer and winter months. Higher density 'scheme' transects within particular monitoring cells are also included in areas of interest. Transects may also be surveyed in the spring and autumn. The beach is surveyed from a minimum of 20 m inland of the sea defence to the Mean Low Water Spring Level. Elevation measurements are taken at every 5 m interval or every change in gradient or substrate. The substrate type is recorded at each survey point and included in the output text file. Topographic surveys have a 10 mm vertical accuracy. Data are delivered as individual (.txt) text files for each transect line. The files are in an EA Standard Format; detailing chainage, easting, northing, elevation and substrate.

2.4.3 Tide data

To produce datum-Shoreline from the satellite-derived proxy-waterlines we need auxiliary data of the tidal level at the time when the satellite image was taken. We have used both observed and predicted tidal data;

- The Predicted Astronomical tides have been obtained from the National Oceanography Centre (NOC) webpage[8].
- The observed tidal data has been obtained from the British Oceanographic Data Centre webpage[9]. The data has been collected from tidal stations shown in **Table 7**

2.4.4 Datum conversion data

Tidal and bathymetry data are often referred to as Chart Datum (CD) which differs from the Newlyn Datum used for topographical data. The Vertical Offshore Reference Frames (VORF) was used to convert the data between the most often used datums in the UK. Location of stations in degrees and minutes were converted to decimal notation (needed for VORF) using BGS online coordinate conversion tool[10]. More information on VORF is available here[11]. We have provided to the Service Providers transformations to Newlyn (UK Mainland Datum) for the following reference surfaces:

- Chart Datum (CD)
- Lowest Astronomical Tide (LAT)
- Mean Low Water Springs (MLWS)
- Mean Sea Level (MSL2000)
- Mean High Water Springs (MHWS)
- Highest Astronomical Tide (HAT)

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[8] https://noc innovations.co.uk/software/coastal

[9] https://www.bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/processed_customise_time_selection/

[10] https://www.bgs.ac.uk/data/webservices/convertform.cfm

[11] https://www.ucl.ac.uk/civil-environmental-geomatic-engineering/research/groups-centres-and-sections/vertical-offshore-reference-frames-vorf

Table 7.- Tide stations used and an example of VORF datum conversion output: CD to Newlyn.

[Station]	[Latitude]	[Longitude]	[Vertical Diff (m)]	[Uncertainty]	[(V)alid/(I)nvalid]
Bournemouth	50.7167	-1.86667	1.4062	0.0459	V
Blakeney	52.95	1.01667	99999	99999	I
Blakeney-Bar	52.9833	0.98333	2.9994	0.1306	V
Bridport-(West-Bay)	50.7	-2.75	2.252	0.0534	V
Britannia-Pier	52.6	1.75	1.5681	0.0448	V
Caister-on-Sea	52.65	1.73333	1.6359	0.0445	V
Chesil-Beach	50.6167	-2.55	2.0971	0.0459	V
Chesil-Cove	50.5667	-2.46667	2.1602	0.0705	V
Christchurch-(Entrance)	50.7167	-1.75	1.5367	0.1534	V
Cromer	52.9333	1.3	2.7552	0.0421	V
Filey-Bay	54.2167	-0.26667	3.2669	0.1195	V
Boygrift	53.3	0.3	3.7774	0.1903	V
Bridlington	54.0833	-0.18333	3.3354	0.0426	V
Gorleston-on-Sea	52.5667	1.73333	1.5571	0.0413	V
Hull	53.7333	-0.35	3.8663	0.1	V
Hunstanton	52.9333	0.48333	3.7493	0.0488	V
Hurst-Point	50.7	-1.55	1.8367	0.0493	V
Immingham	53.6333	-0.18333	3.9015	0.0419	V
Lowestoft	52.4667	1.75	1.4967	0.0406	V
Lulworth-Cove	50.6167	-2.25	1.0184	0.0424	V
Lyme-Regis	50.7167	-2.93333	2.3465	0.0425	V
Minsmere-Sluice	52.2333	1.63333	1.5839	0.0424	V
Poole-(Entrance)	50.6667	-1.93333	1.3677	0.072	V
Portland	50.5667	-2.43333	0.9866	0.0649	V
Scarborough	54.2833	-0.38333	3.2429	0.0429	V
Skegness	53.15	0.35	3.7568	0.0456	V
Spurn-Point	53.5833	0.11667	3.8802	0.0519	V
Swanage	50.6167	-1.95	1.3947	0.0505	V
Tabs-Head	52.9333	0.08333	3.6991	0.0426	V
West-Lighthouse	52.8167	0.21667	3.4808	0.1416	V
Whitby	54.4833	-0.61667	3.0044	0.0438	V
Weymouth	50.6167	-2.45	1.0009	0.1221	V
Winterton-on-Sea	52.7167	1.7	1.8046	0.0396	V
Salcombe	50.2167	-3.78333	3.0382	0.048	V
Start Point	50.2167	-3.65000	3.0528	0.0654	V
Dartmouth	50.3500	-3.56667	2.6143	0.1	V
Greenway Quay	50.3833	-3.58333	2.6256	0.1	V
Totnes	50.4333	-3.68333	1.2	0.1	V
Torquay	50.4667	-3.51667	2.7777	0.0595	V

The VORF sea datums represent the above tidal levels for the whole UK and EIRE territorial waters to a very high resolution. They have been produced using state of the art techniques and data from the Admiralty Tide Tables (ATT data), satellite altimetry, tidal modelling, the VORF observation campaign and Permanent Service for Mean Sea Level tide gauges (PSMSL data). **Table 7** shows an exemplar of VORF output. The filed Valid/Invalid contains the results for all data points that are valid/invalid for the chosen transformation.

2.4.5 Bathymetry data

The bathymetry data consists of multibeam bathymetry datasets that can be obtained from the Admiralty Marine Data Portal[12]. The data is provided as Bathymetric Attributed Grid (BAG) files. BAG is a hydrographic exchange data format developed and maintained by the ONS-WG (Open Navigation Surface Working Group). The implementation of the BAG format was triggered by the large adoption of gridded bathymetry and the need of transferring the required information about bathymetry and associated uncertainty (i.e., metadata) between processing applications. The BAG format was designed to provide a container able to transfer all of the relevant information of a given bathymetric project. The creation and the access to the format are supported through a code base implemented in C++. More information on the *.bag format is available here[13].

[12] https://data.admiralty.co.uk/portal/apps/sites/#/marine data portal
[13] https://www.hydroffice.org/bag/main

3 Products validation results

3.1 PROXY BASED WATERLINES FROM OPTICAL (OPT) AND SYNTHETIC APERTURE RADAR (SAR)

3.1.1 Waterlines: L8, L2, S1, S2

It was found that the waterlines from L8 lines were predominately continuous and clean with few spurious lines. Some gaps were present, but these did not appear to be too detrimental to the use of the line. Some 'loops' were found which appear to be linked to beaches (as discussed later).

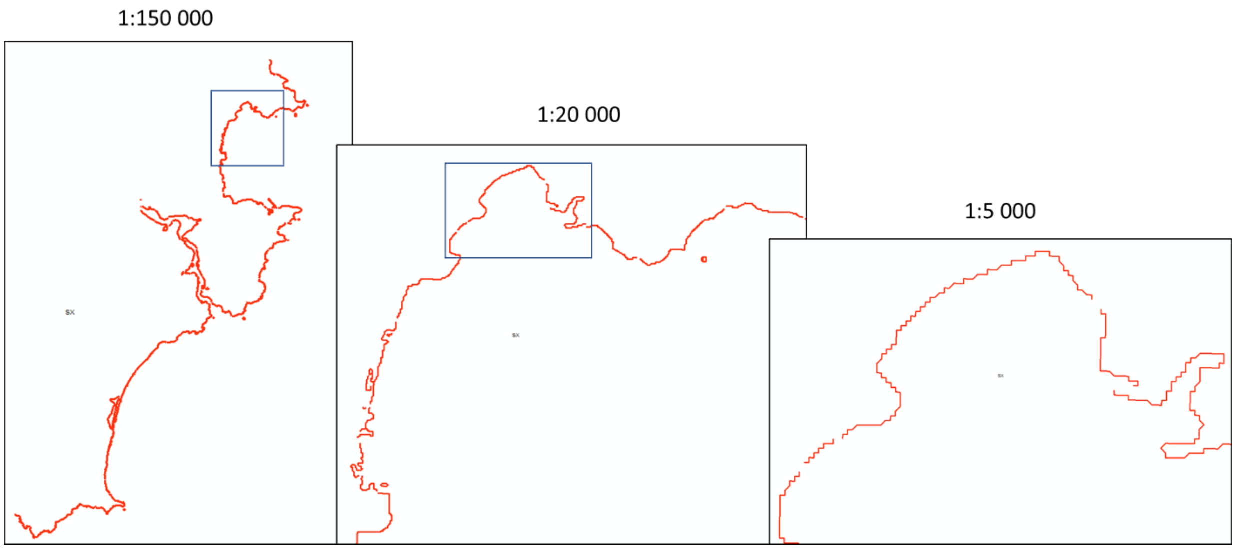


Figure 3.1.- Waterlines derived from Landsat 8 March 2016 image for Start bay visualised at three scales.

Figure 3.1 shows the waterline derive from a Landsat 8 image from the 8th March 2016. Inspection at 1:150 000 scale shows almost complete coverage for this section of coastline. Bays, headlands and estuaries are all captured. There do not appear to be spurious lines, zooming in to 1:20 000 scale in Torbay bay reveals a few small gaps in the waterline and some loops in the western part of the image, the coastline also starts to appear less regular in the Southwest corner compared to the rest of the line. At 1:5 000 scale the line appears 'jagged' reflecting the resolution and hence pixel size of the source image (also reflecting the decision not to artificially smooth the line). Although gaps are evident at this scale it is appreciated that they are small at ≈100m in length.

Figure 3.2.- Waterlines derived from Landsat 8 March 2016 image for Start bay displayed over aerial photography. Left: rocky coasts and headlands. B Right: Torbay Beach areas.

The example of a rocky headland shown in **Figure 3.2**a reveals a good agreement between the waterline captured in the photograph and that extracted from the Landsat 8 data. In the areas of rocky headland the waterline is in good agreement with the photography, whereas in bays and beach areas the agreement is less good: these differences are probably due to differences in tide height.

In large beach areas, such as in Torbay Bay (**Figure 3.2**b) the waterline varies from the photography due to difference in tide. Occasionally 'loops' and spurious lines can be seen, these relate to areas of wet sand where the extraction routine identifies wet sand as water and hence a line is created around it. Also notable at the southern limit of the image in **Figure 3.2**b is that the algorithm has successfully extracted the pier, however, it is wider in the extracted waterline than in the photo. This probably relates to the pixel size of the satellite.

Figure 3.3.- Harbours, piers and defended coastlines at Brixham Harbour.

As with rocky coastlines, the Landsat 8 derived waterline appears to accurately represent the waterline around the hard defended parts of the coast. In **Figure 3.3** the pier is once again seen to be wider than it is in reality, another feature of note is that where boats are closely moored the algorithm is confused into thinking that they represent land. This is only an issue within harbours and **Figure 3.3** provides an idea of where wider spaced boats are recognised as water.

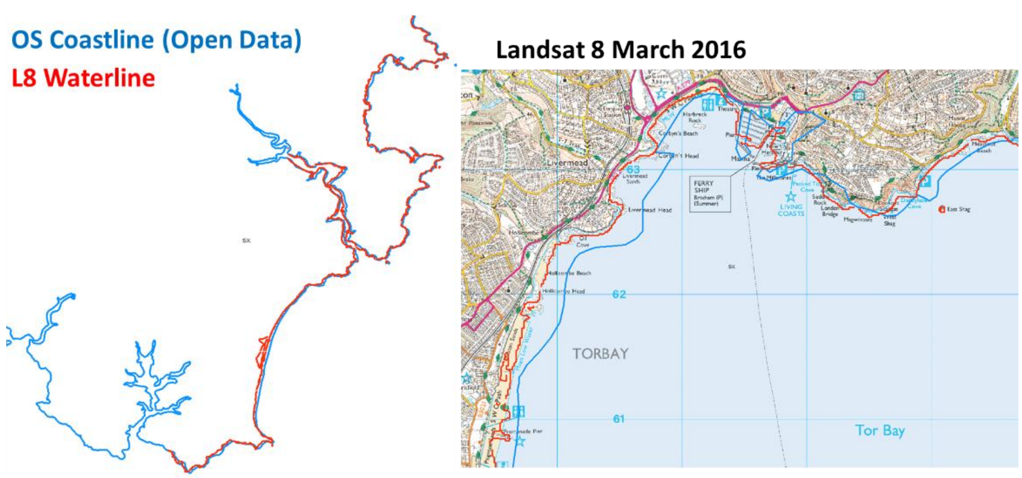


Figure 3.4.- Landsat 8 8th March 2016 waterline compared to the Ordnance Survey open data coastline.

Comparison with the OS open data coastline (**Figure 3.4**) shows that the Landsat 8 derived waterline is significantly better at representing the coastline. This reflects the low resolution/detail nature of the open OS data.

The OS also publish open data which represents the High Water Mark (HWM) and Low Water Mark (LWM) at different times. Comparison with these data (**Figure 3.5**) shows that the Landsat 8 waterline generally tracks within the HWM and LWM, which is what would be expected for an accurate waterline. The areas already observed (i.e. densely moored boats and piers) do show the discrepancies previously identified.

Figure 3.5.- Comparison of OS HWM and LWM and Landsat 8 waterline for Brixham Harbour.

One of the overarching aims of the ESA Coastal Erosion project is to provide technologies capable of capturing coastal change due to coastal erosion, therefore it was desirable to test the ability of the Landsat 8 waterlines to capture changes in the waterline. Six Landsat 8 waterlines spanning a three and a half year period were visually compared (**Figure 3.6**) and areas of maximum difference were identified. It was evident that once tidal ranges were accounted for the waterlines were similar and there did not appear to be areas of significant coastal change. However, the Bay of Torbay did show some significant changes. Here it was evident that the waterline for May 2016 and to a lesser extent October 2017 were further out to sea. It is expected that these are due to exceptionally low tides at the time of image acquisition as the difference is only observed at the beach (**Figure 3.6**).

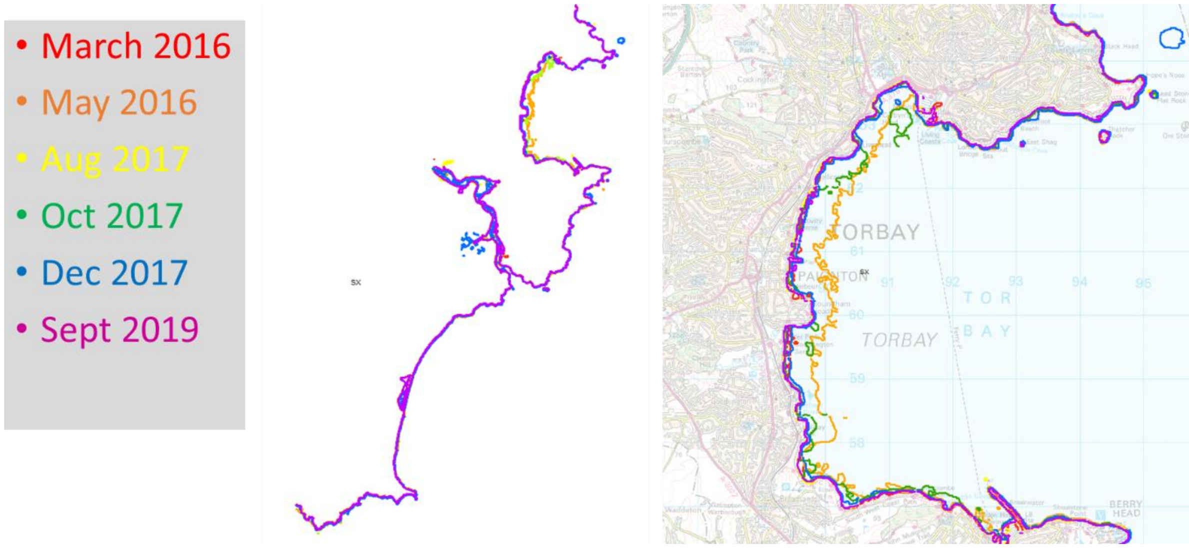


Figure 3.6.- Six Landsat 8 waterlines spanning a 3.5 year period. The only significant difference is seen in the Bay of Torbay.

To further test the ability of the generated waterlines to capture coastal change, an area of coastal change was identified form the OS HWM and LWM data. OS data for 2016 was compared to 2020 to identify differences in the coastline (**Figure 3.7**). The only significant change had occurred in Blackpool Sands (square in **Figure 3.7**).

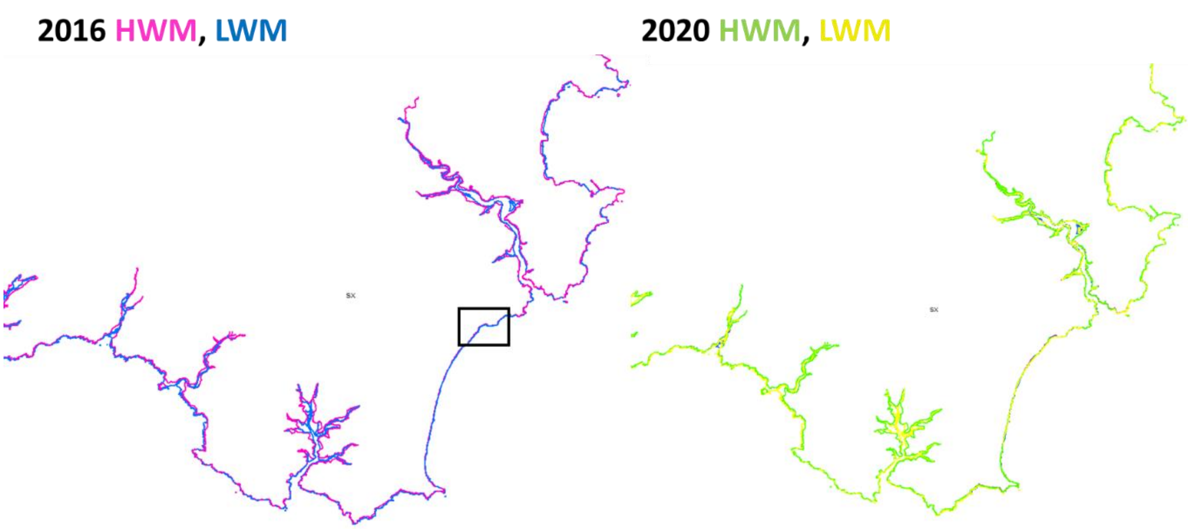


Figure 3.7.- OS 2016 HWM and LWM compared to 2020 HWM and LWM data.

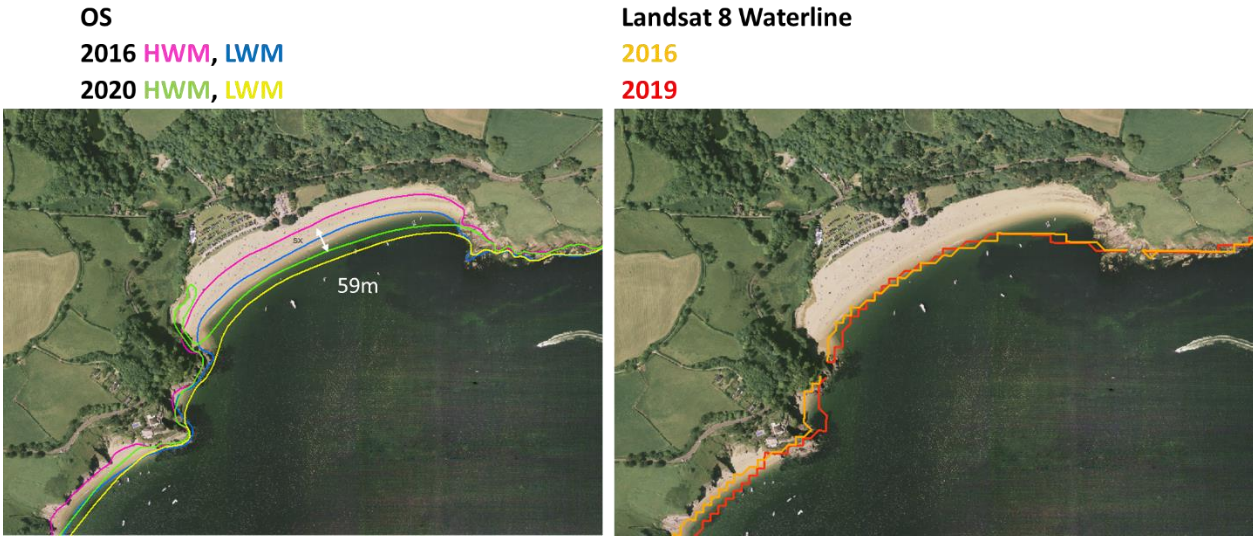


Figure 3.8.- OS HWM/LWM for 2016 to 2020 for Blackpool Sands showing that the beach has extended towards the sea. Landsat 8 waterlines for 2016 and 2019 agree with OS 2020 HWM.

A comparison of the Landsat 8 waterlines for 2016 and 2019 (**Figure 3.8**) shows that they both agree with each other and with the OS HWM from 2020, therefore in this instance, the Landsat 8 data do not pick up the coastal change that is apparent in the OS data. However, this is a small degree of change (~60 m) in a dynamic environment. The Landsat 8 waterlines are consistent with where the waterline should be (i.e. they fit within the current HWM/LWM envelope). It may be that the 2016 Landsat image was captured when the tide was lower than average.

Figure 3.9 and **Figure 3.10** shows the absolute and relative error for two examples of WL derived from S2 and L8 missions. As expected, the absolute error of the S2 derived WL are smaller (RMSE=19.7m) than for L8 derived WL (RMSE=25.7m) when compared with the ca of 1500 non-foreshore points for Start Bay area. The relative accuracy is better than absolute accuracies with values of RMSE = 14.2m and 19.0m for S2 and L8 derived WL. These accuracies are equivalent to representative fraction from 1: 24 800 to 1: 51 400 (**Table 8**) which are comparable with the representative fraction scale for OS VectorMap District of 1: 15 000 to 1: 30 000. These RMSE and representative fraction scale should be considered as a conservative estimation of the WL resolution as we have used all lines, without filtering out the lines flagged as not of good quality. **Figure 3.11** shows that for S2 WL, filtering the lines that have been flagged of good quality (scores closest to 100) will reduce the range of distances to non-foreshore points, reducing the RMSE and improving the representative fraction scale. For L8 derived products, filtering by the quality flag alone is unlikely to reduce the RMSE as we can see that the distances to the non-foreshore points are less sensitive to variations of the quality score (i.e. large distance value spreading for similar score values) which is consistent with the qualitative results shown above. **Figure 3.12** shows how the non-foreshore approach to quantify the products accuracy needs a careful visual inspection of both the fewer non-foreshore points and the closest points to the satellite-derived waterlines. At the east coast of England section, shown in **Figure 3.12**, there are less non-foreshore points because of the gentler foreshore slopes. The few non-foreshore points are located near the built environment (i.e. harbours and levees) where the WL are not always continuous. For those non-foreshore points, where the WL is continuous the absolute error varies from 8.4m to 0.3m for WL-S2.

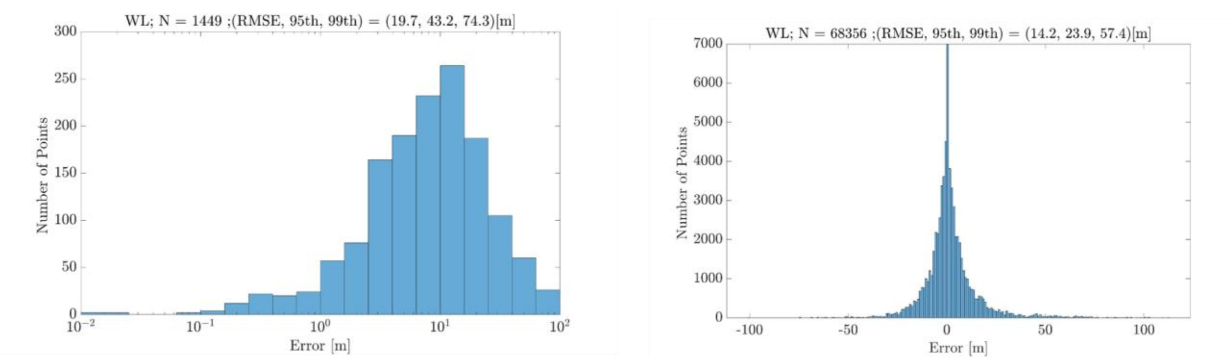


Figure 3.9.- Absolute (left) and relative (right) accuracy results for waterline from optical S2 mission at Start Bay study area. Product filename: CE_20191002112121_WL_OB_L2_501051N102403W-503304N092619W_S2_200923

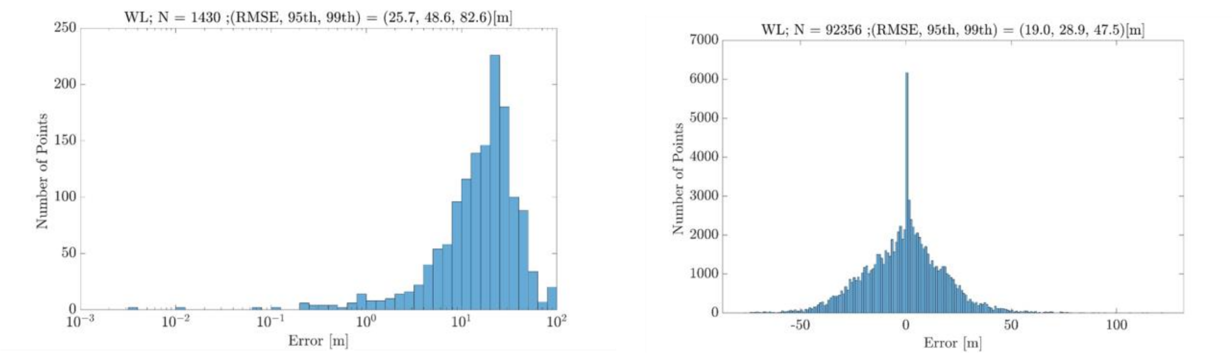


Figure 3.10.- Absolute (left) and relative (right) accuracy results for waterline from optical L8 mission at Start Bay study area. Product filename: CE_20170827110514_WL_OB_L2_501104N094426W-502918N092841W_L8_200923

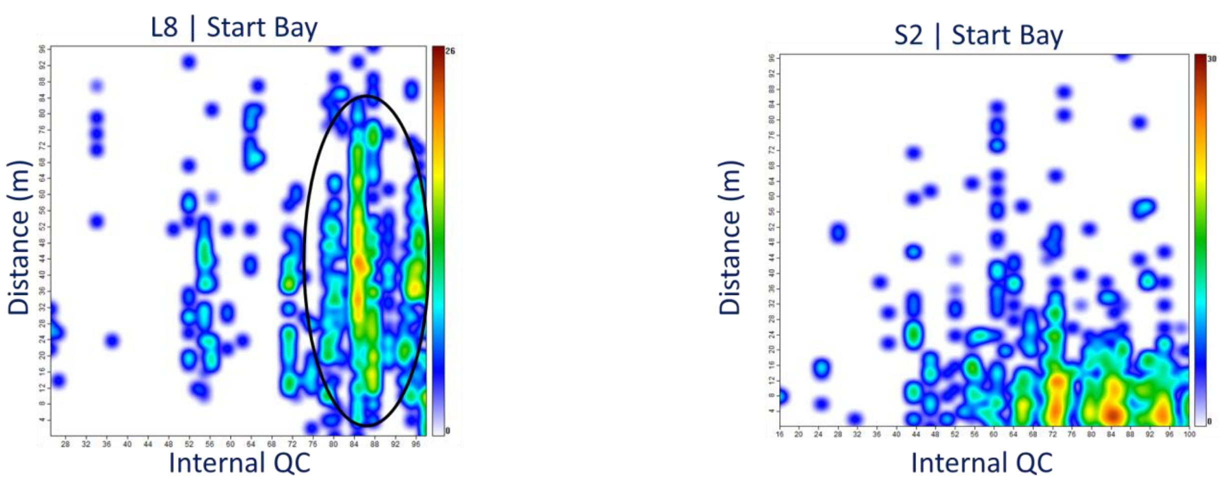


Figure 3.11.- Absolute accuracy results for WL shown in **Figure 3.8** and **Figure 3.9** vs the WL internal quality control score (0 bad and 100 excellent).

Table 8.- Representative fraction values for WL from S2 and L8 products

Mission	RMSE Absolute accuracy [m]	RMSE Relative accuracy [m]	Representative fraction [unitless] (0.5/RMSE [mm])	References
S2	20.0	14.2	1: 40 000 | 1: 24 800	**Figure 3.9**
L8	25.7	19.0	1: 51 4000 | 1: 38 000	**Figure 3.10**

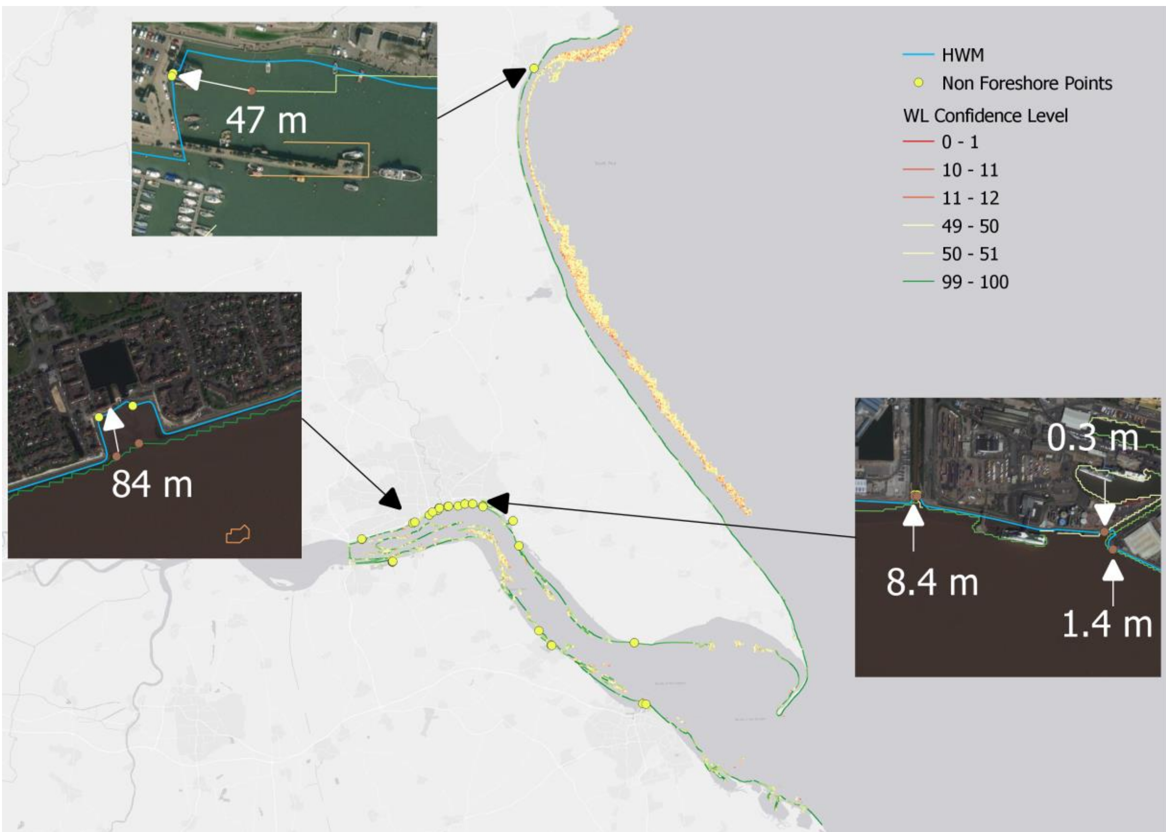


Figure 3.12.- Non-foreshore points for study area from Flamborough Head to Humber estuary and WL-S2. Yellow circle represents the non-foreshore points and brown circles the closest points on the WL. Distances for each point indicated. Product filename: CE_20200625110631_WL_OB_L2_532959N-62749W-540618N-54734W_S2_200924

3.2 BEACH ROTATION

For embayed beaches, where incident wave angles are oblique, morphological changes are often dominated by longshore transport processes, with sediment transported in the direction of wave approach. When directionally sustained, beaches erode and narrow at the up-drift extent and accrete and widen at the down-drift extent, with the subsequent change in planform orientation known as “rotation”. To assess the skills of the 1D products detecting beach rotation we have selected the well documented [9] semi-sheltered gravel barrier at Start Bay, Devon, UK (**Figure 3.13**).

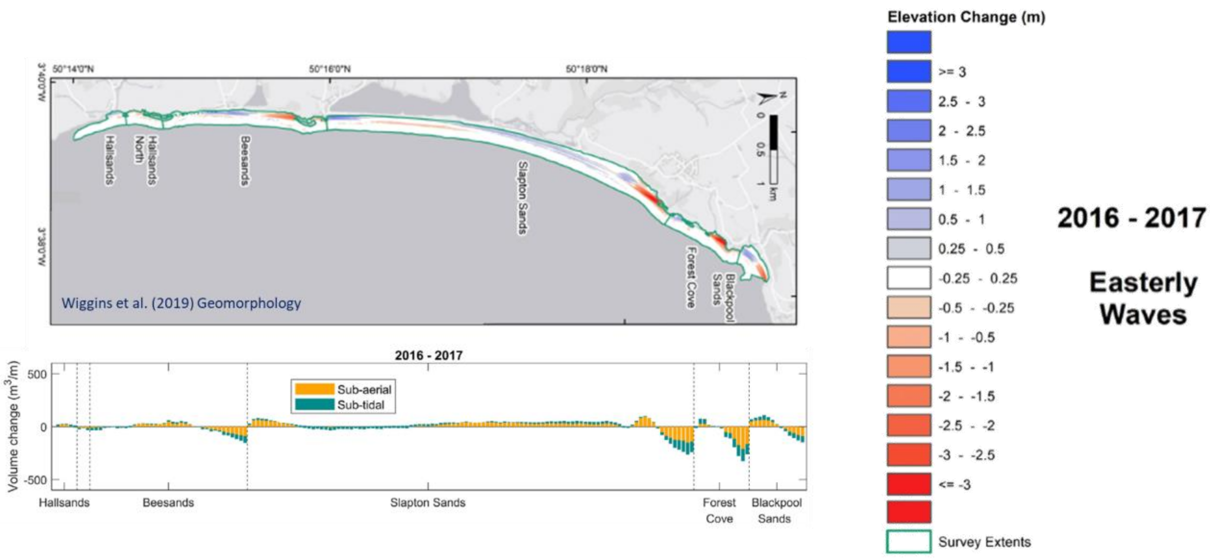


Figure 3.13.- Thresholded DoD's for the easterly period between 2016 and 2017 (Top) and extracted profile volume change, showing intertidal and sub-tidal (≤2 m ODN) contributions (bottom). Elevation changes between epochs are represented as colour intensity from red (erosion) to blue (accretion), with no detectable change represented as a lack of colour. Vertical dashed lines represent the relative location of headlands between sub-embayments. Figure modified from [9].

Start Bay is a 12-km long embayment located on the south coast of Devon, UK. Meso- to macrotidal with neap and spring tidal ranges of 1.8 m and 4.3 m, respectively, the embayment comprises four sub-embayment gravel barrier beaches, named from the south to north as; Hallsands, Beesands, Slapton Sands and Blackpool Sands. Between each sub-embayment lie short headlands/rocky outcrops, extending to approximately 1–4 m below mean low water springs (MLWS), that separate each beach at high tide, trapping laterally moving sediment as it is transported alongshore. Behind the barrier at both Slapton Sands and Beesands, freshwater is held above mean sea level in two lagoons known as Slapton Ley and Widdecombe Ley. The gravel barrier at Slapton Sands rises to 5–6 m above mean sea level with a steep reflective beach face (tanβ = 0.1) composed of fine gravel (D_{50}= 2–10 mm), with the toe of the barrier extending to an average depth of −7.5 m Ordnance Datum Newlyn (ODN). The barrier position has remained relatively stable over the last 3000 years, allowing the sediment (mainly flint) to be reworked by the sea. Within Start Bay, gravel is finer to the east due to the lateral grading of material, with coarser grains transported south west with larger, steeper easterly waves, and finer grains being well sorted and transported north east with smaller but more frequent southerly swells.

Using a multi-method topobathymetric surveys [9] assessed the morphological change of the Start Bay (**Figure 3.13**). Total sediment budgets (supra- to sub-tidal), with spatially-varying uncertainty levels, indicate the embayment is closed. One-third of total sediment flux occurred in the sub-tidal, establishing the importance of sub-tidal transport for this type of coastline. [9] results demonstrate that under the predominance of a given wave direction, rotation first occurs within sub-embayments. Additional sustained and extreme energy levels are then required for full embayment rotation to occur, with significant headland bypassing. In this instance, 6×10^5 m^3 of gravel was transported alongshore during a 3-year sustained period of dominant-southerly waves, including a 1:50 year storm season (full-embayment rotation), whilst 3×10^5 m^3 was returned during a 2-year (2016-2017) period of dominant easterly waves (sub-embayment rotation only).

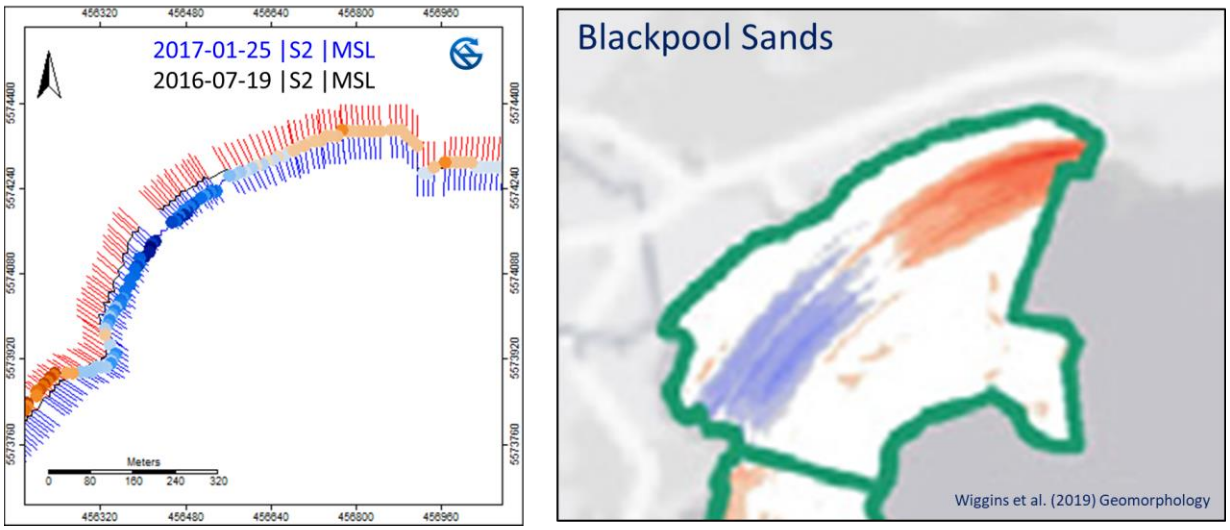


Figure 3.14.- Comparison of embayment rotation at Blackpool Sands extracted from satellite observations (left) and traditional topobathymetric surveys (right). Left: shows two SL-MSL for years 2016 and 2017 and the shoreline normal segments used to measure the distance between SLs. The coloured dots represent the intersection points, with SL-2017, of the shore normal segment to SL-2016. Horizontal distance changes between lines are represented as colour intensity from red (erosion) to blue (accretion), with no detectable change represented as a lack of colour. Right: zoom to Balckpool Sands area from **Figure 3.13**.

Figure 3.14 shows how the rotation observed at Blackpool Sands embayment is captured by the differences of two datum shorelines (SL-MSL) from 19-07-2016 (SL-2016) and 25-01-2017 (SL-2017). The imaginary line segments normal to SL-2016 obtained using the SAGA GIS Coastal Profile crossings tool are shown as blue lines (sea-side of SL-2016) and red lines (landward-side of SL-2016). The intersection of the line segments with SL-2017 is shown as coloured dots indicating accretion in the southern end of the embayment and erosion in the northern end as expected from the analysis of the topobathymetric surveys.

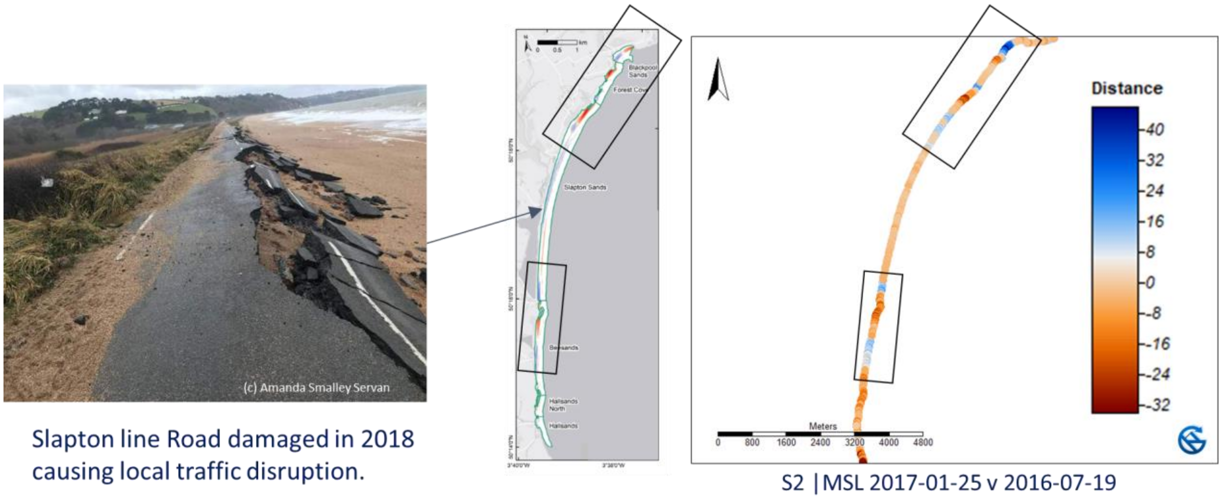


Figure 3.15.- Comparison of all embayment rotation at Start Bay extracted from satellite observations (right) and traditional topobathymetric surveys (right). Left: shows two SL-MSL for years 2016 and 2017 and the shoreline normal segments used to measure the distance between SLs. The coloured dots represent the intersection points, with SL-2017, of the shore normal segment to SL-2016. Horizontal distance changes between lines are represented as colour intensity from red (erosion) to blue (accretion), with no detectable change represented as a lack of colour. Left: road damaged due to an erosion event in 2018. Central: approximate location of road failure on DoD's of differences shown in **Figure 3.13**.

Figure 3.15 shows the horizontal differences between SL-2016 and SL-2017 for all embayments at Start Bay. At this scale, the rotations at the smaller embayments of Blackpool Sands, Forest Cove in the north end, and Beesands in the southern end are still detected. The accretion observed at the northern half of the large Slapton Sands embayment is less evident. **Figure 3.15** shows small landward migration (erosion) of the SL-2017 relative to SL-2016 while the DoDs of the topobathymetric surveys shows a sea-side (accretion) migration. It is important to notice that we are only using two shorelines, each representing a snapshot of the shoreline position at the date the satellite image was taken, while the topobathymetric surveys were collected using a myriad of methods over a longer time window. A more comparable analysis will require the comparison of all shorelines for 2016 vs shorelines for 2017. For this analysis, SAR waterlines are better placed as SAR images are not affected by cloud coverage and a larger number of shorelines can be extracted from EO. **Figure 3.16** shows the details of a SAR waterline for 20th Oct 2019 compared with the 2019 tidal boundaries (HWM and LWM) from the UK OS VectorMap Local. From this visual comparison, it can be seen that the WL-SAR distance to the tidal boundaries does change with the relative orientation of the coast and the type of coast (rocky coast or sand-gravel beach). Additionally, **Figure 3.17** shows the range of variation when all (i.e. ascending and descending images) WL-SAR for 2019 are plotted together. SAR satellite observes obliquely downward not directly below. It is in ascending orbit (northward) that the satellite observes from the west and it is in descending orbit (southward) that the satellite observes from east. While the type of image (ascending or descending) is not indicated in the figure, we have noticed that WL-SAR ability to represent the waterline is also affected by the orbit type.

Figure 3.16.- Comparison of WL-SAR (magenta) vs OS HWM (thick blue) and LWM (thin blue) tidal boundaries (Nov 2019) for Start Bay study area. WL is for date 20th Oct 2019 (Descending image, polarization VH). Product file name: S1B_IW_GRDH_1SDV_20191020T062303_20191020T062328_018555_022F5A_2372_QC_HM_CLASS_Good.geojs on

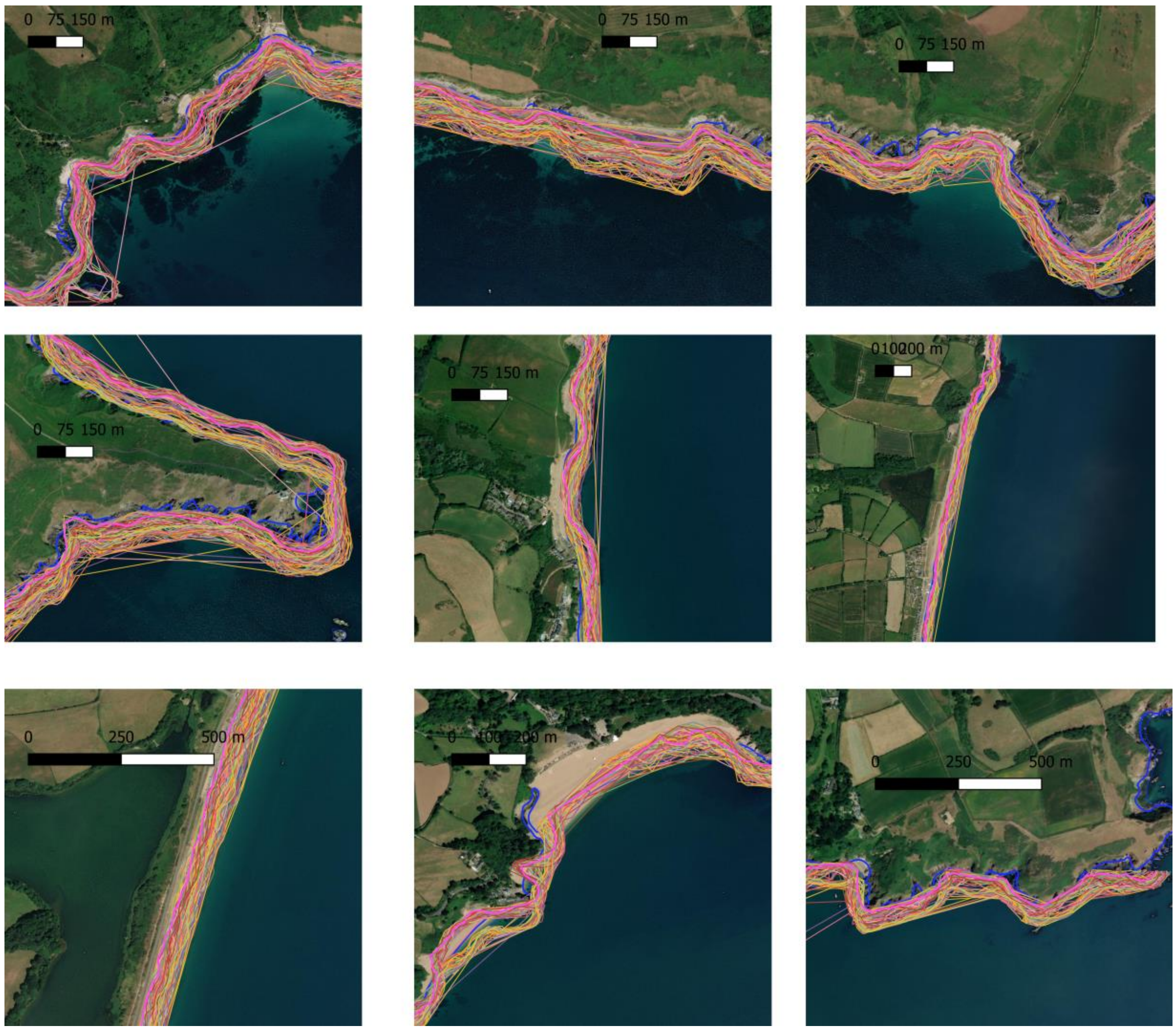


Figure 3.17.- Comparison of ALL WL-SAR for year 2019 vs OS HWM (thick blue) and LWM (thin blue) tidal boundaries (Nov 2019) for Start Bay study area.

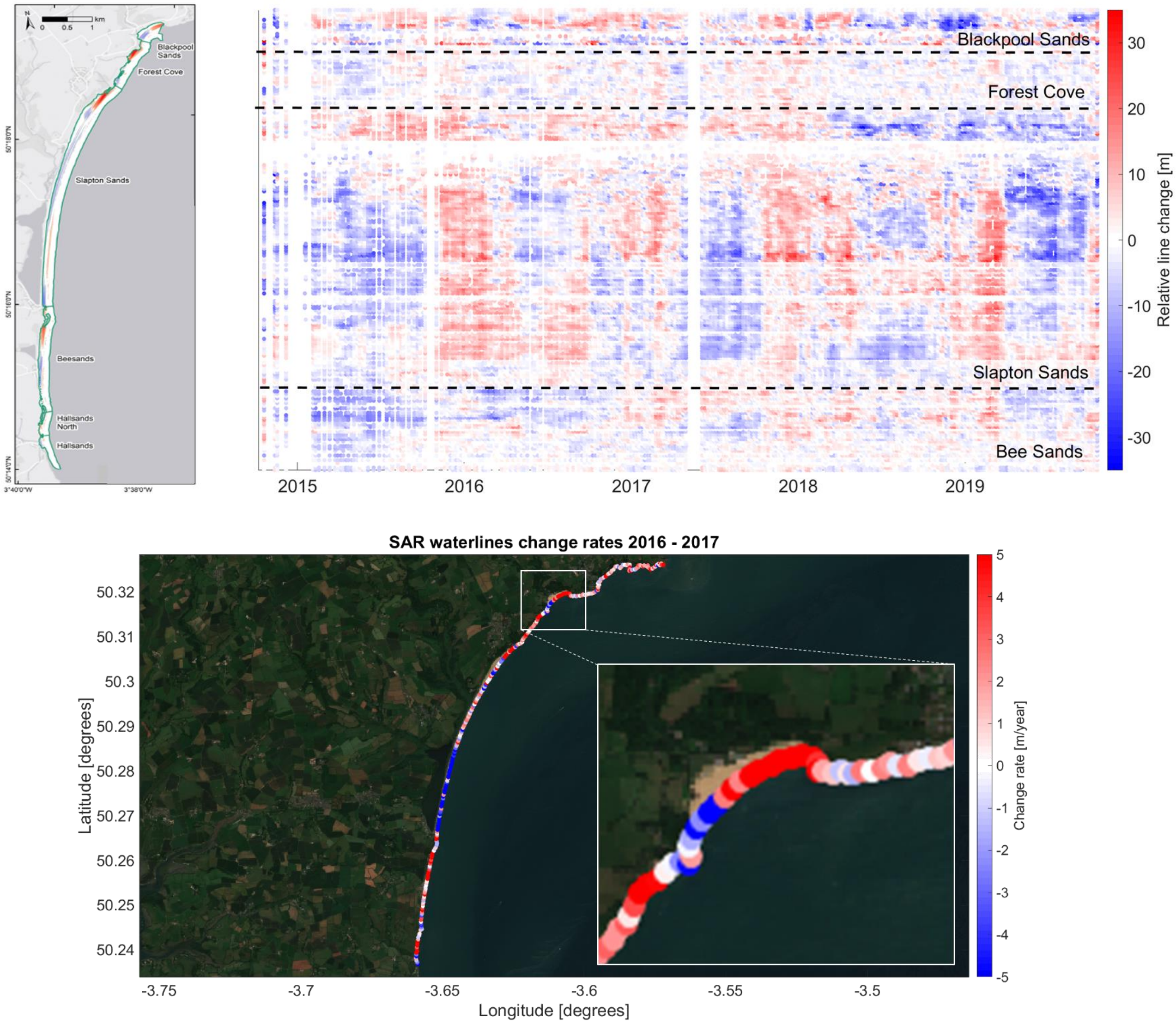


Figure 3.18.- Calculated instantaneous SAR waterline changes for years 2015-2020 (top) and annually averaged for years 2016 and 2017 (bottom). Changes are calculated as initial minus final. Notice that this change definition is opposite to definition used previously by [9] who calculated change as final minus the initial.

Figure 3.18 shows two different approaches to represent the information contained on the large volume of WL-SAR for Start Bay. By calculating the instantaneous differences between each WL-SAR (initial minus final) we obtain the time series shown in the top panel of **Figure 3.18**. If we calculate the average location of the waterline for year 2016 and 2017 and calculate the change (year 2016 minus year 2017) we obtain the average change shown in the bottom panel. From the time series change, it can be seen that for each embayment (indicated by dashed horizontal lines) there seem to be time periods dominated by waterline advancing (reds) and periods dominated by waterline retreating (blues). This is more evident when looking at the yearly averaged differences (bottom panel), where not only the rotation in Blackpool is evident, but also now we can see the rotation on the larger Slapton Sands embayment as expected from the topobathymetric survey analysis.

3.3 CLIFF EROSION AND BEACH ACCRETION

To assess the skills of the EO products detecting beach and cliff erosion and accretion we have chosen the well documented [10-13] area of Happisburgh, East coast of England, UK. Happisburgh is a village situated in North Norfolk, on the soft sediment coasts of eastern England (Figure 2). Sea levels at this location have been rising for millennia, and under natural conditions, the coast of Norfolk is erosional. In response to the 1953 flooding, a continuous line of defences was constructed in the 1960s to protect the village, extending 15 km from Happisburgh to Trimingham to the northwest. These comprised sheet piles, crested with a sloping timber palisade, fronted by groins. The design was intended to reduce the cliff recession rather than entirely prevent it, and to allow some sediment to sustain the beaches. Since 1996, the Environment Agency (EA) has undertaken a series of beach nourishments (around 150,000 m^3/yr on average) at Sea Palling, about 5 km to the south and down-drift of Happisburgh. The nourishment scheme aims to offset the concomitant reduction in sediment supply from cliff erosion along the Happisburgh–Trimingham coastal section and to maintain sea defence. In the early to mid-1990s, deterioration of the Happisburgh structures led to their progressive failure. Sheet piles were buckled and palisades and groins were broken and destroyed by wave action. This led, very rapidly, to the formation of an embayment, partially stabilized at its northern end by a series of placements of a rock armour revetment. The EA report that, following structure failure, up to 140 m (7 m/yr) of recession occurred within the Happisburgh embayment between 1992 and 2012.

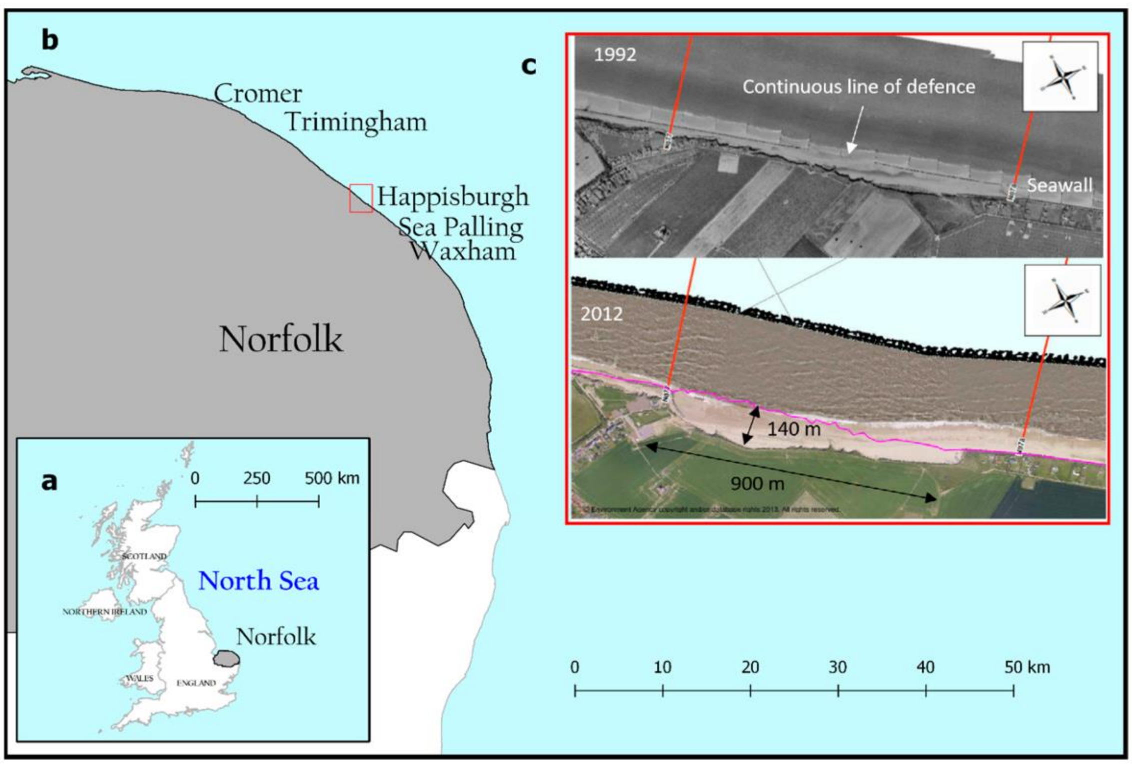


Figure 3.19.- Study location: (a) Happisburgh is located in county of Norfolk (grey polygon) on the east coast of England, the grey lines represent the administrative boundaries of the different UK regions; (b) study site location (red rectangle) and nearby locations; (c) aerial images of Happisburgh taken in 1992 and 2012 by the Environment Agency; showing the formation of an embayment. Red lines indicate the location of profile monitoring surveys, and the magenta line shows the approximate cliff toe position in 1992. (Figure from [13])

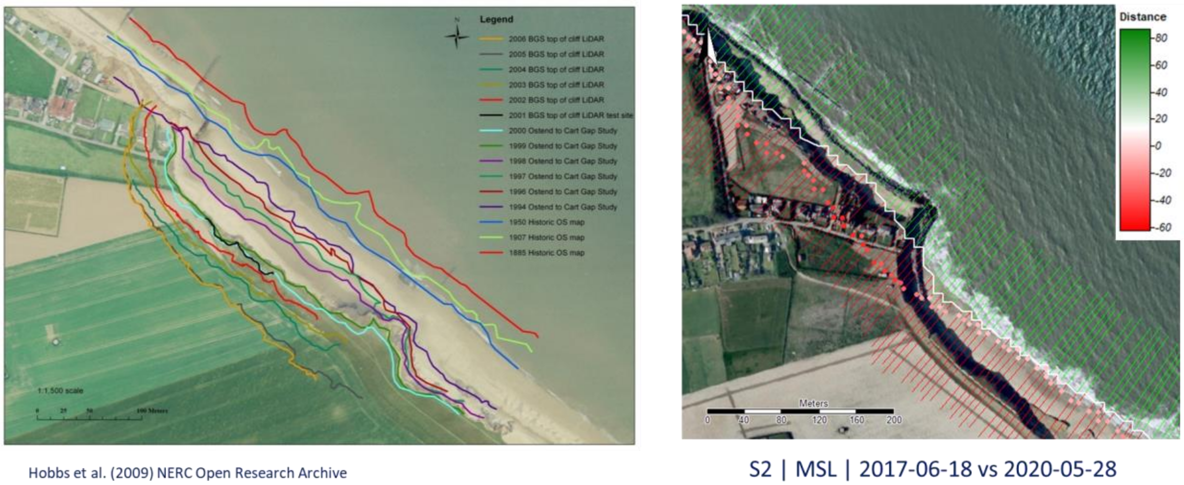


Figure 3.20.- Historical cliff edge retreat lines between year 1885 and 2006 (left) and observed change between year 2017 and 2020 by comparison of two EO derived SL-MSL.

Figure 3.21.- Net erosion and accretion derived from differences between EO shorelines (SL-MSL) for 18-06-2017 and 28-05-2020. Left: general overview of erosion at Happisburgh village and accretion around Sea Palling.

Figure 3.20 shows the historical location of the clifftop at Happisburgh from 1885 until 2006. The distance between the cliff top lines indicates how the erosion rate has been decreasing; lines are more separated when erosion is faster between years 1950 and 2000 and erosion rate is smaller (lines closer together) between years 2000 and 2006. Erosion at present times is mostly focused where the rock armour are shown in the image, which is what we have derived from the comparison of two SL-MSL for year 2017 and 2020. **Figure 3.21** shows the larger scale picture of how the coast is eroding near Happisburgh village and beach is growing in the south, near Sea Palling, where EA periodically nourish the beach and also the net longshore sediment transport move the eroded sediment from Happisburgh.

3.4 VEGETATION LINE AND BACKSHORE CLASSIFICATION MAP

Inspection at 1:150 000 scale of the littoral lines for year 2018 (**Figure 3.22**) shows complete coverage for this section of coastline. As expected, the littoral lines (100 and 104) are landward to the HWM at most places. The difference between the LL100 and LL104 are clearly visible in places with large intertidal areas like the Wash and Blakeney Point: LL100 delineates the vegetation edge between the vegetated area and the nearshore and LL104 delineates the edge of the beach and the mudflat area or the beach and the intertidal. Littoral lines along the high cliffs coast of Flamborough Head are the only exception where the littoral line is consistently mapped seaward than HWM. Features like Spurn Point spit and Blakeney Point are rightly not delineated, as expected by LL100 due to the limited vegetation, but should be delineated by LL104. We found that LL104 does delineate the spit at Blakeney but fails to delineate the full length of the spit at Spurn Point. Blakeney Point extends 6.4 km (4 mi) and consists of sand, shingle and dunes. Spurn Point is one of the most striking features of Britain's coastline, stretching for 5.6 km (3 mi) across the Humber Estuary. This curving spit is only 50 m wide in places, making it look like an elongated tongue. Spurn is made up of a series of sand and shingle banks held together by Marram grass and Seabuckthorn. There is a series of sea defence works built by the Victorians. The backshore classification map shows how at the thinness section of the spit where the littoral line ends and the backshore is classified as sand or mudflat and that explains why the LL104 terminates there.

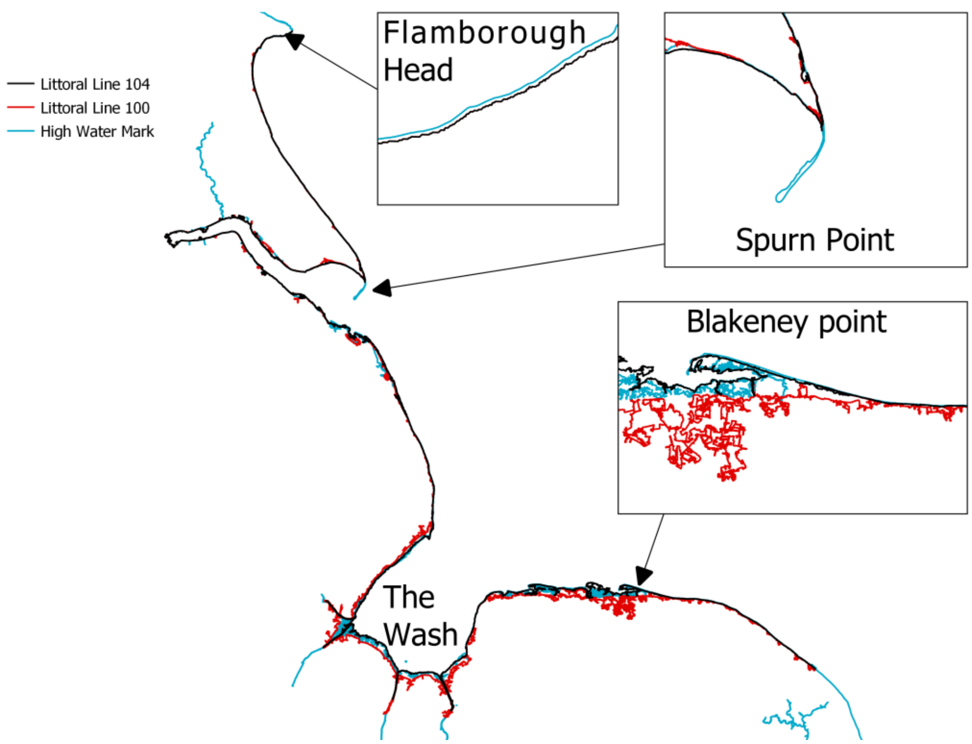


Figure 3.22.- Littoral lines for year 2018 from Flambourough head to Happisburgh shown at scale 1:150 000.

As shown by the confusion matrix for years 2018 and 2019 (**Figure 3.23**, **Figure 3.24**) the backshore classification algorithm has been optimized to detect the following landforms types: soft cliff, salt marshes, mudflats and tidal areas. For these classes, the confusion matrix confidence indicators (Rappel and F-score) are higher than for the other classes. We noticed that overall confidence levels for year 2018 are better than for year 2019. This change in the level of confidence results in backshore classification for year 2018 showing higher granularity than for year 2019. This is clear for the three different environments (large intertidal areas, beach backed by a soft cliff and built environment) as shown in **Figure 3.25**. When the backshore class relative frequency along the 2018 littoral line location is compared with the classes extracted at the same location but from 2019 map, the differences are clear (**Figure 3.26**) and mostly attributed to the change in overall confidence level than actual backshore class change.

Figure 3.27 shows the littoral lines for two cliffed coastlines. The LL104 is able to detect the edge of the soft cliff at both sites: the non-defended coastal stretch at Happisburgh in East England (highlighted area in **Figure 3.27**) and along the Hunstanton cliff. The cliff heights along these sections are of similar height and about 10m height and have different orientations.

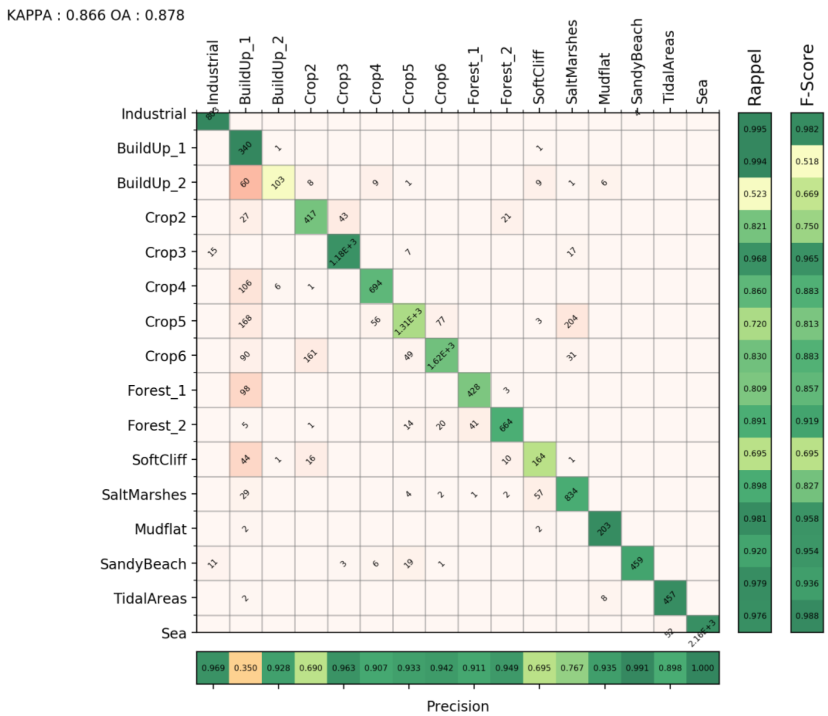


Figure 3.23.- Confusion matrix of the 2018 backshore classification map for East England study site.

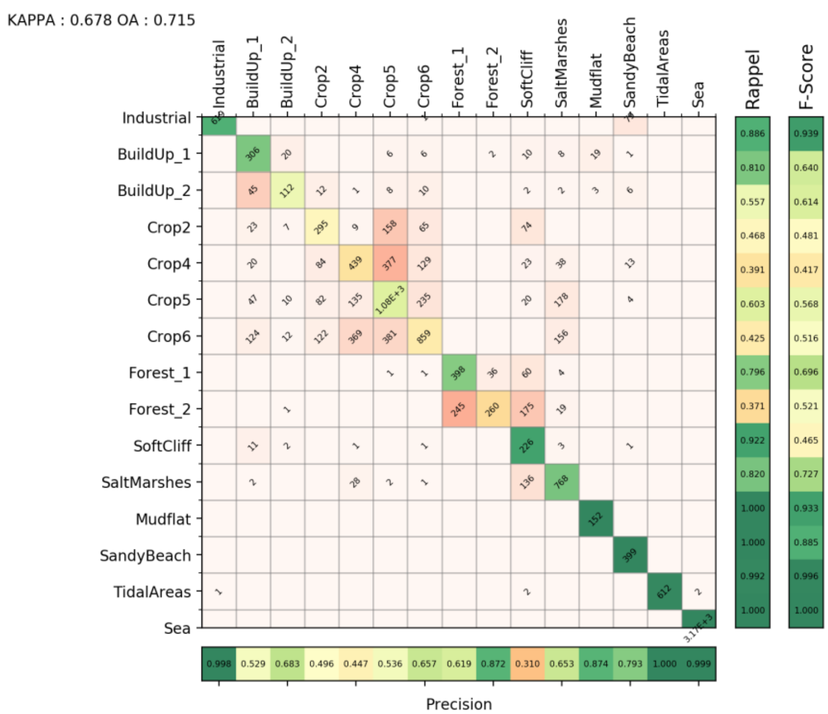


Figure 3.24.- Confusion matrix of the 2019 backshore classification map for East England study site.

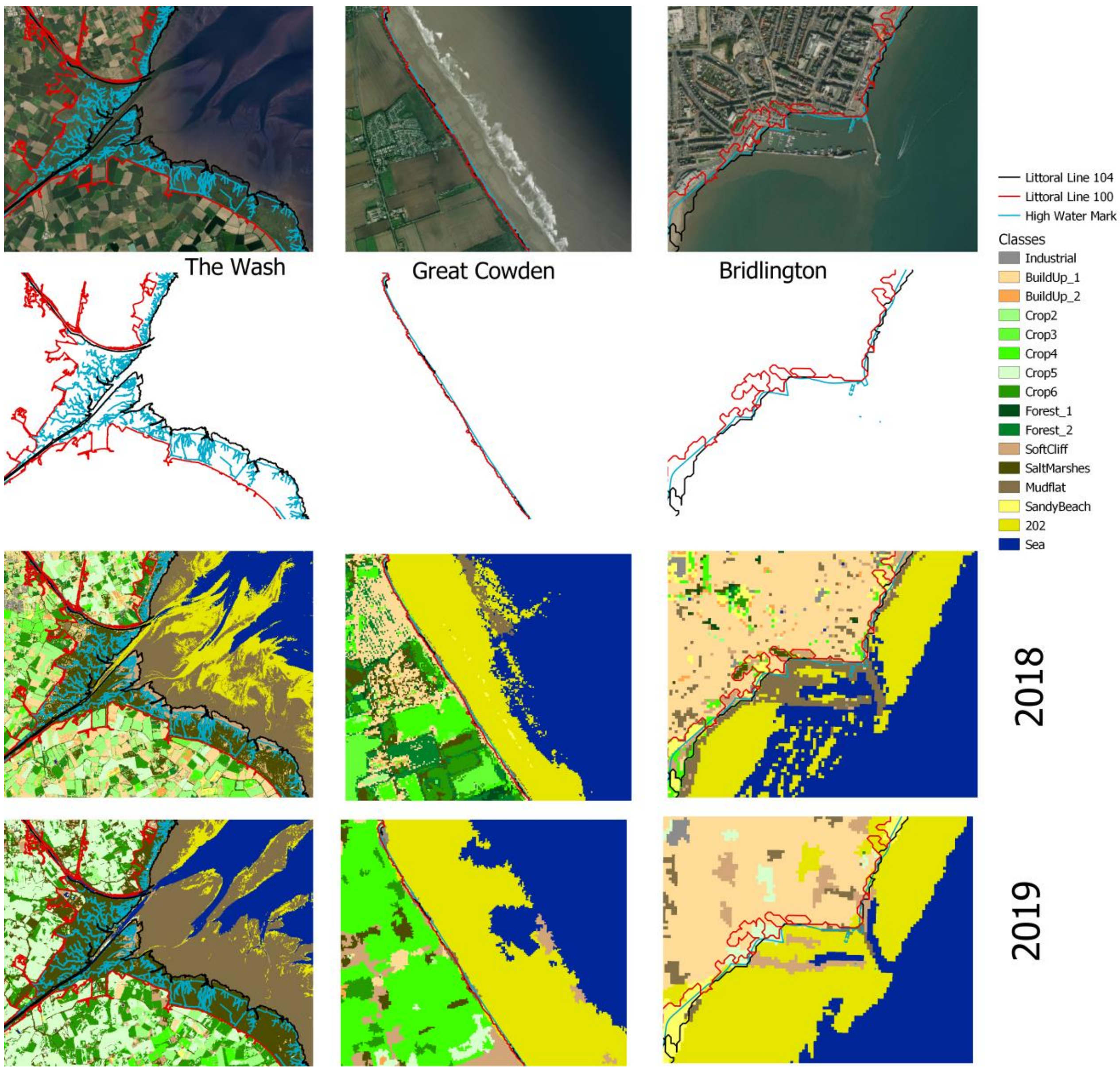


Figure 3.25.- Details of littoral lines for year 2018 for three different environments: large intertidal areas (The Wash), beach backed by soft cliff (Great Cowden) and built environment (Bridlington).

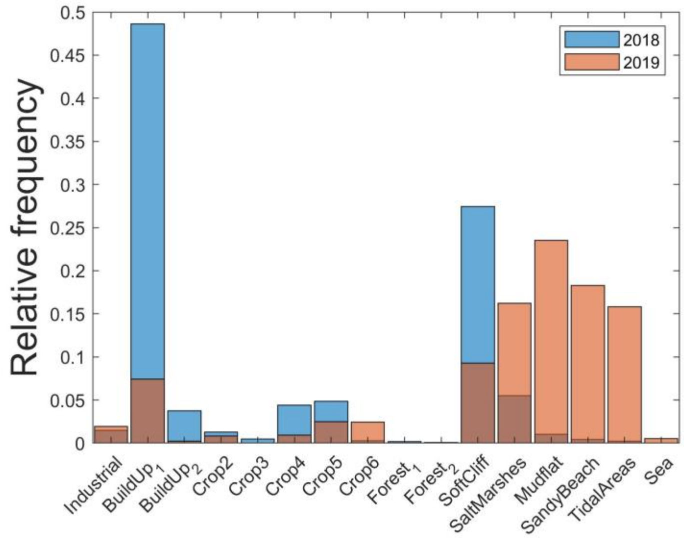


Figure 3.26.- Backshore classes relative frequency along the 2018 littoral line 104 nodes locations extracted from 2018 and 2019 maps.

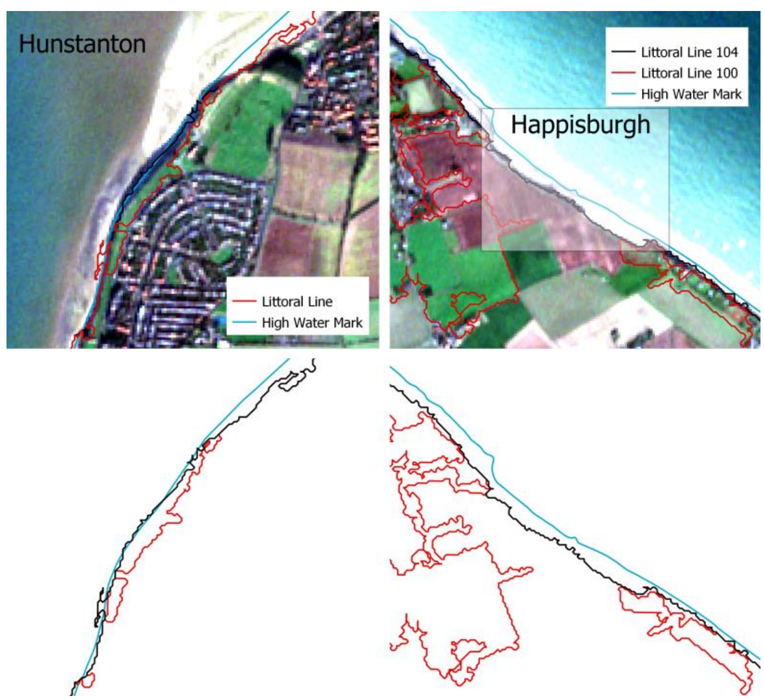


Figure 3.27.- Littoral lines for the cliffed coast of Hunstanton and Happisburgh. The background image is the co-registered RGB Sentinel 2 image for 18th November 2018 (which is one of the 66 images used to generate the classification map for year 2018).

3.5 BATHY-MORPHO TERRAIN MODELS

Within the Chesil Beach study area, MBES bathymetry data show water depths reach ~100 m (structural basin to southwest of Isle of Portland; **Figure 2.8**, **Figure 3.28**). The seabed along this stretch of coast is characterised by a diverse range of features. Bedrock features include ridges, exposed bedrock strata, faulting, and wave-cut platforms (e.g. Sanderson et al., 2017). Current-induced bedforms include large sediment banks and mobile sediment bedforms (e.g. sediment waves, mega-ripples, and sediment ribbons).

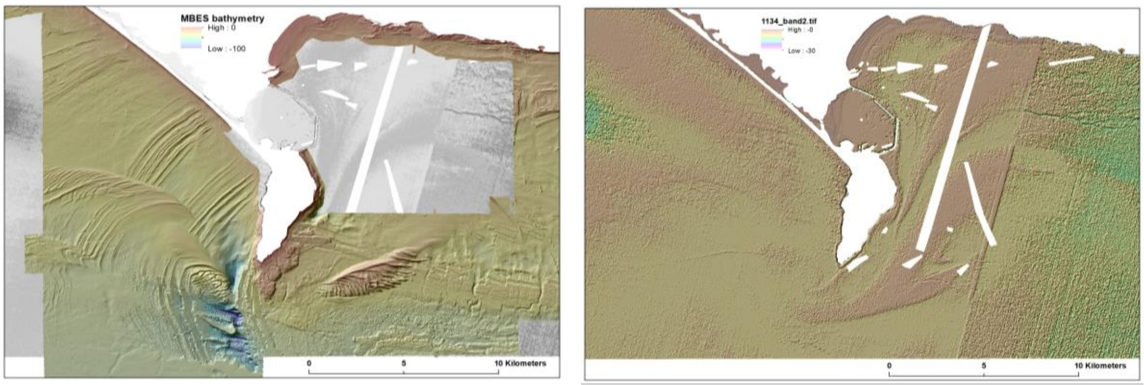


Figure 3.28.- Left: MBES bathymetry (0-100 m) surrounding the Isle of Portland Right: BMTM data over same inset area, using the same colour scale for depth.

3.5.1 Qualitative Assessment

The first step was to visually review the BMTM within a GIS environment. It was initially clear that there are variations in the predicted depths with the BMTM bands, but also there are significant variations in the data properties within individual bands (i.e. from separate satellite passes) and between bands. After review, we determined that band 2 (median water depth) appeared least affected by noise and erroneous values, and was the most suitable for follow-on quantitative analysis.

The next step was to view the BMTM together with the MBES bathymetry data, primarily within the 0-20 m depth range. Through traversing along the coast, it is clear that the BMTM data does not detect many morphological features observed within the MBES data, including bedrock structures (not prone to morphological change over the 3 to 7 years period between MBES and BMTM acquisition). Below 20 m, the BMTM data are highly uncorrelated (as anticipated) with the MBES data with variation in the BMTM more likely reflecting characteristics within the water column (e.g. suspended particulate matter plumes?).

It is also clear however that the BMTM does reflect several general trends in the MBES, e.g. general shoreface inclination, and positively detecting several shoal areas (**Figure 3.28**). To further investigate this potential relationship, we calculated the difference between the BMTM and MBES datasets (i.e. 'DEMS of Difference', and assessed how these varied spatially (e.g. Williams, 2012) (**Figure 3.29**). We stress that different values are significant within the 0-20 m depth range with mismatches commonly up to ±20 m. At the shoreline, the BMTM data appear to commonly overestimate data, whereas the BMTM appear to increasingly underestimate in deeper waters. Interestingly the best match appears to consistently be between 4-6m water depth, but the reason for this relationship is not currently understood. To highlight this, **Figure 3.30** reveals the thin geographic strip where the BMTM and MBES data match to within ±2m.

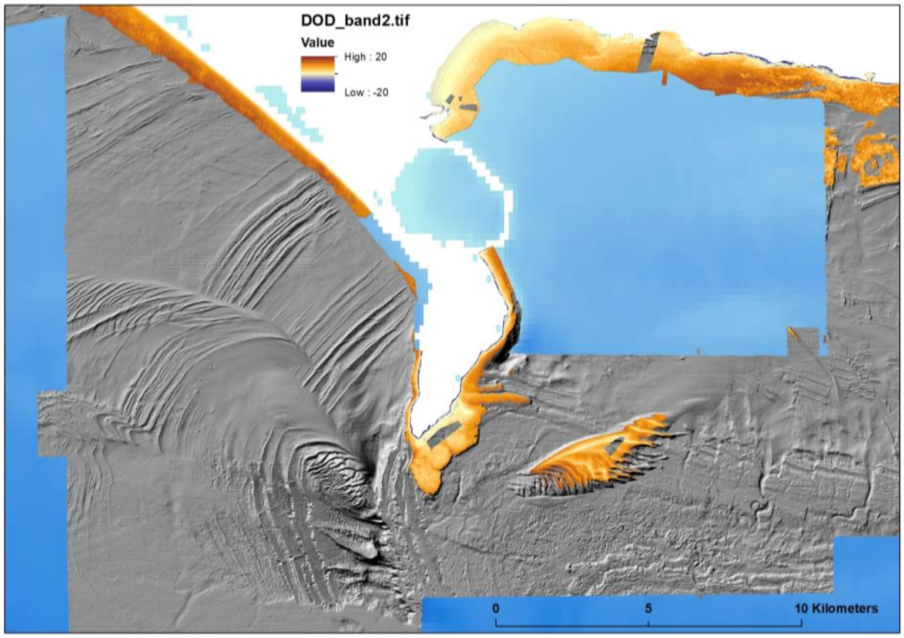


Figure 3.29.- Calculated difference (±20 metres) between BMTM and MBES bathymetry.

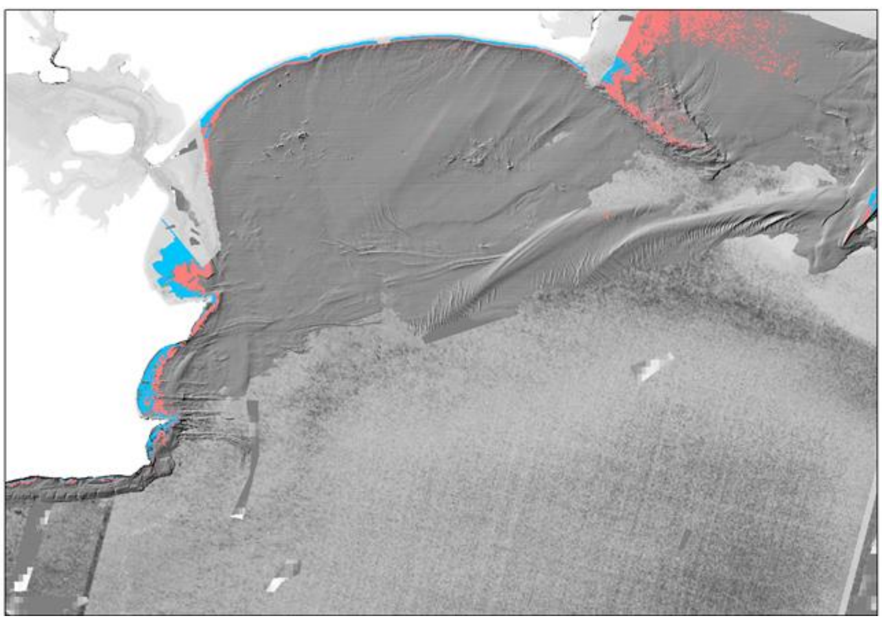


Figure 3.30.- Agreement of BMTM and MBES to within ± 2m.

The qualitative side-by-side visual comparison, and the semi-quantitative DEMs of Difference assessment demonstrated that the vertical accuracy of the BMTM depths within the Chesil Beach study area is generally poor, and considered unreliable for surveying continuous areas of seabed in an accurate, reliable manner. A preliminary view of the Spurn Head study area suggested similar findings, if not more affected by turbidity in the water column.

3.5.2 Quantitative comparison

Simultaneous to undertaking the qualitative assessment of the BMTM data accuracy, we also identified and adapted methods that may be employed to more quantitatively assess vertical accuracy in the event that these data showed promising accuracy, or in other environments more favourable to satellite-derived bathymetry.

The first step was to undertake a spot calculation between the BMTM and MBES data, choosing a static site not susceptible to change over short timescales (e.g. bedrock feature). **Figure 3.31** shows one example in water depths shallower than 20 m ~2 km offshore. Bedrock features were manually digitised and then used to sample data values from the BMTM data. As common across the area, there were significant discrepancies in the BMTM predicted depths (~7-13 m)

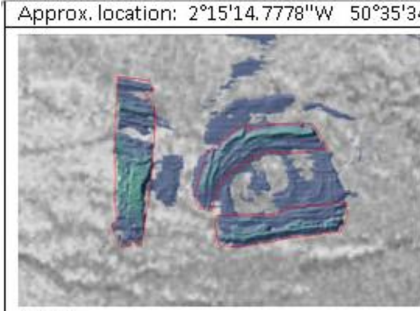
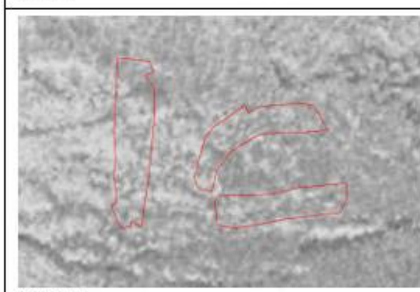
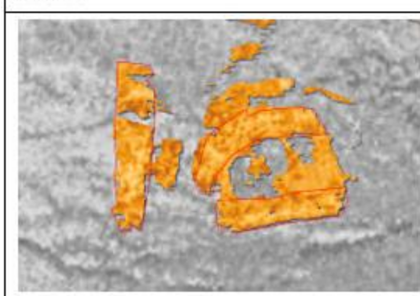
CHESIL BEACH DATASETS	
Approx. location: 2°15'14.7778"W 50°35'34.8461"N	
 MBES	MBES clipped to 20 m maximum water depth, clearly showing bedding planes around a major fold structure in the outcropping bedrock. The same area is then shown with just SDB (Band 2 - median), and then a difference map between the two bathymetric datasets (lighter colours imply less difference between the datasets). Example profiles show discrepancies between the two bathymetric datasets along the same transect line, with upper profile line (SDB) showing erratic depths between ~7-13 mbsl, compared with the lower profile (MBES) which shows a clear bedrock high with several individual bedding planes rising above a seafloor of ~19-20 mbsl. <u>Reason for interest</u>: An area of static seabed reference points for future analyses to target, which is ~2.0 km offshore, making it more distal from the coast than the majority of other locations.
 BMTM	
 Difference	

Figure 3.31.- Example of static site comparison between BMTM and MBES data.

The BSS score could only be applied to the limited area where overlaying datasets were available (**Figure 3.32**). The Baseline Bathymetry corresponds to the "initial" state, therefore, the oldest dataset available and the Reference Bathymetry corresponds to the dataset that is considered as the measured state – i.e. the measured water depths values. Therefore, three surveys (HI1242, HI1343, HI1453 – both Block 3 & 4) were merged and used as the reference bathymetry, whereas the older and lower resolution dataset (H202) was used as the baseline bathymetry.

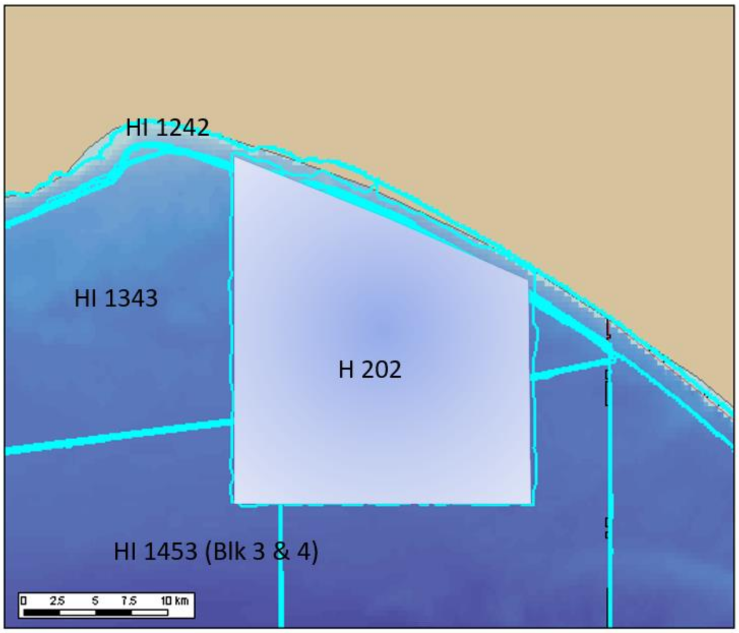


Figure 3.32.- Location map of the datasets used as reference bathymetry (HI1242, HI1343, HI1453) and baseline bathymetry (H202) to calculate the BSB values.

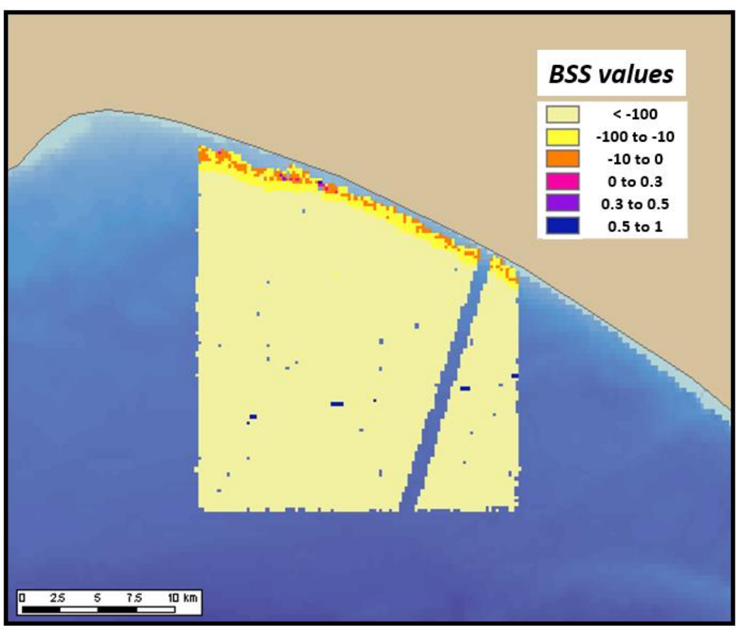


Figure 3.33.- BSS values calculated for the BMTM assessment.

The BBS values calculated, shown in figure **Figure 3.33** are indicative of a general higher match between the reference bathymetry and the baseline bathymetry than with the BMTM. The limited cells with positive BBS scores are located in the most proximal areas. The lack of tidal correction may aggravate the scoring obtain but it is considered that the poor performance of the BMTM is due to discrepancies in water depth values beyond what could be justified due to the lack of tidal correction.

3.5.3 Assessment summary

Following both qualitative and quantitative assessments on the accuracy of BMTM data, our results indicate the following:

- Both qualitative and quantitative assessments of the satellite-derived bathy-morpho terrain models (BMTM) demonstrate these data are not effective at accurately detecting seabed depths, both in accurately predicting depth, and consistently capturing morphological features present at the seabed. This is likely to be the case in most coastal environments around the UK, where coastal waters exhibit prohibitively high turbidity;
- The BMTM data do however frequently (if sometimes discontinuous within/between datasets) capture seabed morphological features, whose lateral distribution (despite lack of accurate vertical datum) may prove highly useful to change detection studies due to the current absence of other time series data.

4 Products evaluation results

4.1 OVERVIEW

Table 9 summarizes the evaluation scores (L: low; M: medium; H: high) for each section of the Annex B in the SOW for all product produced at UK study sites and the highlights of the overall evaluation assessment are presented below. The full-service assessment sheet with the detailed per product assessment is included in the Appendix 4.

Table 9.- Evaluation scores for all UK products.

Section	Product	WL	SL	BTMT	LL & LC
B.1	Adequacy of the User Requirements Document (URD) requirements (including accuracy)	H	H	L	M
B.2 Product compliance	Overall product compliance to the user requirements	H	H	L	H
	Product accuracy compliance to the user requirements	H	M	L	M
	Confidence in the product quality (including accuracy)	H	M	H	H
B.3 Utility assessment	Confidence in the product quality (including accuracy)	H	H	L	M
	Impact of the service and products on current end-user practices	H	H	L	H
B.4 Future outlook	Probability of service integration into existing practices	H	H	L	H
	Desired service and/or product(s) improvements	H	H	H	H
	Needs for a large-scale service/product demonstration	H	H	H	H
B.5 Overall evaluation	Overall service and products evaluation	H	M	L	M
	Recommendations to the European Space Agency	H	H	H	H

4.2 WATERLINES: OPT & SAR

WATERLINES, derived from both OPTICAL and SAR images, has received a HIGH score on the overall evaluation for the following main reasons;

1. **Required accuracy is comparable to UK OS VectorMap District and is considered valid**. The WL has shown to be accuracies on the order of 1:20 000 to 1: 40 000 which are

comparable with the accuracies of OS VectorMap District (1: 15 000 to 1:30 000). Although the accuracy requirements for waterline products specified in the URD end-user in the URD were not accomplished, those requirements were mainly aspirational, and the products are still useful for many of the purposes of BGS's practices.

2. **Required updating frequency of waterlines has been fully accomplished**. The required updating frequency specified in the URD was from events scale (pre and post storms) to monthly scale and this requirement has been accomplished. The variation in the number of products among sites is not due to changes in the frequency feasibility but to the limited project time to produce all possible products. The frequency of SAR WL production is much higher than requested with an average of 216 lines per year.
3. **Required temporal range of waterlines has been accomplished**. The URD specified 25 years of the historical record has been reached for the optical waterlines that covers a period starting in 1994 to 2020.

4. **Quality control indexes were developed and provided for each product:** these indexes were required by the end-users and allow the automatic identification of the waterlines that may be the result of detection errors. Quality flags have been provided for all WL products (optical and SAR).

4.3 SHORELINES: OPT & SAR

The overall service and product performance are evaluated by BGS as MEDIUM for the reasons expressed in sections B.1 to B.4 and summarized below.

1. **The SL has shown to have accuracies equal or inferior to the original WL from which has been derived**. Although the accuracy requirements for waterline products specified in the URD end-user in the URD were not accomplished, those requirements were mainly aspirational, and the products are still useful for many of the purposes of BGS's practices (i.e. SL-MSL has been able to capture beach erosion near a vertical cliff and beach accretion).
2. **Required updating frequency of shorelines has been fully accomplished**. The required updating frequency specified in the URD was from events scale (pre and post storms) to monthly scale and this requirement has been accomplished. The variation in the number of products among sites, is not due to changes in the frequency feasibility but to the limited

project time to produce all possible products. The frequency of SAR SL production is much higher than requested with an average of 216 lines per year.

3. **Required temporal range of waterlines has been accomplished**. The URD specified 25 years of historical record has been reached for the optical shorelines that cover a period starting in 1994 to 2020.
4. **Quality control indexes were developed and provided for WL from which SL are derived but has not been included in the SL**. These indexes were required by the end-users and allow the automatic identification of the shorelines that may be the result of detection errors.

4.4 LITTORAL LINES AND BACKSHORE CLASSIFICATION MAPS

Littoral lines (LL) and backshore classification maps (LC), has received a MEDIUM score on the overall evaluation for the following main reasons;

1. **LL and LC frequency requirements have been met**. The requested updating frequency was aspirational and varies from one month to a year. We have received a littoral line for year 2018 and yearly backshore maps for two years.
2. **Confidence on classification results is high for littoral line but medium to backshore classification maps**. A visual inspection of the LL for year 2018 suggested that the LL delineates the edge of the foreshore and backshore correctly but the backshore classification map shows significant variation between year 2018 and year 2019 that seems to be attributed to the classifier errors instead of actual changes of the backshore type. As we did not have the LL for year 2019 to assess how changes in the classification might have affected the LL location, we have evaluated both (LL and LC) with medium score.
3. **Metadata and attributes descriptions provided facilitates user confidence assessment**. A confusion matrix has been provided as part of the metadata of the backshore classification map. Adequacy of land uses and coverage have been partially accomplished (i.e. tuned to better resolve the intertidal area) and classes description has been provided. BGS required classes descriptions similar to the Environment Agency habitat descriptions for CASI and LIDAR habitat maps but assumed that some modification might be needed. The habitat descriptions provided were: Urban; House; Crops1; Crops2; Forest; Sandy Beach; Rocks; Mudflats; Sea. These classes seem like a good trade-off between classes required and what it was feasible. The intermediate raster habitat map has been provided

(i.e. not the vector format requested) but this format has found good enough for the analysis of backshore type along the littoral line.

4.5 BATHY-TOPO MORPHO TERRAIN MODELS (BTMT)

BTMT, has received a LOW score on the overall evaluation for the following main reasons;

1. **The end-user required a seamless (i.e. no data gaps between topography and bathymetry) Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore) but the product received only includes the foreshore and nearshore**. The raster BTMT product received contains 5 bands with different elevation metrics (Band 1: Z_mean; Band 2: Z_median; Band 3: Z_90pct_min; Band 4: Z_90pct_max; Band 5: Z_90pct_range) with all elevation relative to the surface elevation at the time of satellite image from which the BTMT has been derived.
2. **The accuracy requirements for bathymetric products (0.1 m vertical, 1 m horizontal) were aspirational and has not been accomplished due to turbidity levels being too high for the UK study sites.**
3. **The frequency required for this EO Product (monthly) was not meet due to cloud coverage and high turbidity values**. There were not enough good images per month for the UK study sites at Start Bay, Chesil beach and Spurn Head to meet the requested frequency. The BTMTs provided for which cloud coverage was good enough has been found to have too high turbidity values to extract bathymetry changes with confidence.
4. **Quality control indexes were developed and provided for each product:** these indexes, required by the end-users during the project, allow the automatic identification of the bathymetries that may represent erroneous values.

Appendix 1

This appendix contains the requirements details against which the BGS has validated the EO products against. The tables have been copied from the User Requirement Document (BGS ref. TR/CR/19/055).

PRODUCT DESCRIPTION BGS #1: PROXY-BASED TIDELINES

<table>
<tr><th colspan="2">Description of product no. 1</th></tr>
<tr><td>General Description</td><td>A proxy tideline (a physical feature taken to represent the shoreline) at different tidal elevations</td></tr>
<tr><td>General service/product description:</td><td>We would like to be able to produce proxy tidelines that are consistent with tidelines mapped by the UK Ordnance Survey (OS) on the County Maps.

Tidelines on County Series maps usually came from measured line surveys with offsets [1]. A proxy tideline (a physical feature taken to represent the shoreline) was surveyed. High tide lines were captured by one of two methods:

1. Objects were placed on the beach at the time of high water. The positions of the objects were surveyed and the surveyed points were joined to form the Mean High Water (MHW) or Mean Low Water (MLW) mark.

2. The mark left by high tide was surveyed. Winterbotham (1934) (ref in [1]) noted that high tide “generally leaves a clear mark … there is not much difficulty in surveying this line”.

Different nations within UK use different definitions of MHW and MLW:

In Scotland, Ordnance Survey (OS) maps consistently shows high and low water marks for ordinary spring tides, which “generally occur the third of fourth tide after new or full moon” as the main tidelines;
The line reflecting the alignment of the mean spring high tide is attributed with a Function of ‘Mean High Water Spring Mark’ (MHWSM).
The line reflecting the alignment of the average mean spring low tide is attributed with a Function of ‘Mean Low Water Spring Mark’ (MLWSM).
If the alignments are coincident then the line is attributed with a function of ‘Mean High Water Spring Mark and Mean Low Water Spring Mark’.
In England and Wales, the tide lines mapped on the OS County Series maps has changed over time:
Since 1879 are Low Water Mark of Ordinary Tides (LWMOT) and High Water Mark of Ordinary Tides (HWMOT) which are “those of high and low water of ordinary tides (i.e. tides half way between neaps and springs) which define the limit of the foreshore”.
The OS’s 1905 instructions to field examiners contained similar advice: surveys of Mean High Water (MHW) and Mean Low Water (MLW) were taken from “tides half way between a spring and a neap, and should generally be taken at the fourth tide before new and full moon”. The name changes from MHWOT to MHW and MLWOT to MLW are not significant as the definitions remained the same. Note, however, that MHW and MLW are not given in Admiralty Tide Tables, which is not a problem provided consistent calculations of MHW and MLW are performed.
Since about the 1970s the OS has mainly provided tide line data from aerial surveys preferably using black & white infrared film as this shows the water/foreshore interface more clearly. Admiralty tide tables were examined to find high and low tides which were within ± 0.3metres of MHW and MLW.
In Northern Ireland, coast wide erosion mapping and extrapolation studies have not been undertaken as in the rest of UK. Historical maps (1832-1963) exists for but does not cover the</td></tr>
</table>

	entire shoreline and the level of detail included in the maps also varies, with some including high and low water contours and elevation contours [2]. [1] Sutherland, James. "Error analysis of Ordnance Survey map tidelines." Maritime Engineering (2012). [2] DAERA & DFi, (2018). "Baseline Study and Gap Analysis of Coastal Erosion Risk Management NI" www.infrastructure-ni.gov.uk/
Uses and benefits:	County Maps are the only widespread source of information which can be used to quantify trends in coastal evolution over periods greater than about 70 years in the UK. Tidelines is of legal interest and also used as an indicator of standard of protection. This product allows management authorities of flood and coastal erosion risk to create a coastal erosion baseline from which other decisions can be made and priorities flow. Will allow coastal engineering practitioner and research community to better understand process of change and validate conceptual and numerical models used to assess coastal change and adaptation options.
Product Specifications	
Spatial scale:	1:2,500 in rural areas, 1:1,250 in urban areas and 1:10,000 in upland areas (Scales chosen to be consistent with the standard scales used by OS mapping as described by Olivier 2005) Oliver R (2005) Ordnance Survey maps: a concise guide for historians (2nd edition). The Charles Close Society, London, UK.
Minimum cell size: (or mapping unit)	To be consistent with OS MasterMap revision policy on the Coastal zone the minimum change mapped due to natural erosion and deposition in the coastal zone is the one resulting in a change of alignment of more than 10 m over a length of more than 100 m for the following coastal features when well defined; Top and bottom of cliffs; and Coastal slope limits.
Information layers:	Spatial Reference System (EPSG 277000 British National Grid) Tidelines; vector lines for different tide elevations (LWMOT, HWMOT, MLWSM, MHWSM) Error lines; Lines that have errors (for instance not closed rings or self-intersections) Date and time; of the image used to delineate the tideline Uncertainty in the elevation of the tide level Uncertainty in the elevation due to waves and atmospheric processes Uncertainty in the horizontal location of the tideline associated to uncertainty on vertical elevations
Product format:	Vector format; GML (Geography Markup Language) ESRI Shapefile
Software platform compatibility:	The products should be compatible with the following commercial and open source GIS: ArcGIS & ArcMap 10.3.1, Quantum GIS 2.18
Product accuracy:	To be consistent with OS accuracy definitions we define accuracy in three different ways: **Absolute accuracy** – how closely the coordinates of a point in the dataset agree with the coordinates of the same point on the ground (in the British National Grid reference system). **Relative accuracy** – positional consistency of a data point or feature in relation to other local data points or features within the same or another reference dataset.

<table>
<tr><td></td><td> Geometric fidelity – the ‘trueness’ of features to the shapes and alignments of the objects they represent -when testing the data according to the dataset specification against the ‘real world’ or reference dataset.
The following table represents the absolute and relative accuracy applicable to the scale at which the product was surveyed.
<table>
<tr><td><u>Survey scale</u></td><td><u>RMSE*</u></td></tr>
<tr><td>1:1,250</td><td></td></tr>
<tr><td>Absolute Accuracy</td><td>0.5 m</td></tr>
<tr><td>Relative Accuracy</td><td>+/- 0.5 m (up to 60 m)</td></tr>
<tr><td>1:2,500</td><td></td></tr>
<tr><td>Absolute Accuracy</td><td>1.1 m</td></tr>
<tr><td>Relative Accuracy</td><td>+/- 1.0 (up to 100 m)</td></tr>
<tr><td>1:10,000</td><td></td></tr>
<tr><td>Absolute Accuracy</td><td>4.1 m</td></tr>
<tr><td>Relative Accuracy</td><td>+/- 4.0 m (up to 500 m)</td></tr>
</table>
*RMSE (root mean squared error) is the square root of the mean of the squares of the errors between the observations. </td></tr>
<tr><td colspan="2">Service Specifications</td></tr>
<tr><td>Years of interest:</td><td>Interested in years since 1970s until present</td></tr>
</table>

Temporal range:	Not applicable
Updating frequency:	It varies accordingly with OS MasterMap revision policy. https://www.ordnancesurvey.co.uk/about/governance/policies/os-mastermap-revision.html Today, major coastal and non-coastal defences designed to reduce the risk of flooding are in the OS Category A, which means they will be captured as part of a continuous revision process within six months of completion. Mean high and low water when affected by changes to other features (such as coastal defences or jetties) and significant changes to tidelines (when evident from aerial photography conducted as part of the national sweep or when notified by a customer) are classified as Category B and will be captured as part of a national sweep programme, which occurs every few years [1].
Temporal baseline:	1948* based on Defra interest on assessing property lost since data is available. *The baseline year correspond with the first Royal Air Force (RAF) aerial imagery.
Ordering:	Web based ordering system
Delivery time required:	Within 6 months of ordering
Delivery format:	Web-based (http), ftp
Validation data	
Available at the end-user's premises:	As a Public Sector Organization, BGS has access to; OS historic maps and MasterMap up to 2015 for the whole UK under OS/PSMA terms and conditions. Vertical Offshore Reference Frames (VORF) to provide the vertical correction from Chart Datum to Newlyn Ordnance Datum (reference datum used in UK for tides) for any location around UK and UKCS.
Available elsewhere:	Storm surge levels reports can be downloaded from: https://www.ntslf.org/storm-surges/monthly-surge-plots Registered tide levels can be downloaded from: https://www.bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/processed_customise_time_selection/ Admiralty Tide Tables are available from http://www.ukho.gov.uk/easytide/EasyTide/SelectPort.aspx Aerial Photography (oblique and orthophotography) are collected regularly and made publically available by DAERA, EA, SEPA Beach profiles for England can be downlowaded from www.channelcoast.org Continuous measurements of wave energy fluxes (i.e. height, direction and wave period) for the entire UK can be downloaded from http://wavenet.cefas.co.uk/Map
Planned collection and when:	For planned OS MasterMap collection and publication see https://www.ordnancesurvey.co.uk/business-and-government/help-and-support/products/os-mastermap-refresh-dates.html For planned data collection of other auxiliary data indicated above, visit the indicated links.

PRODUCT DESCRIPTION BGS #2: DATUM-BASED TIDELINES

Description of product no. 2	
General Description	**A tideline obtained by extracting a contour at different tidal elevations**
General service/product description:	An increasing volume of beach level data (i.e. beach profiles, LiDAR surveys and RADAR flights) is being regularly and systematically collected along UK coastline, from which the positions of contours representing MHW, MLW and other datum elevations can be obtained. Proxy-based and datum-based shorelines might differ [1]. A series of shoreline repeatability and variability experiments as well as data from a beach monitoring program along the high-energy US Pacific Northwest coast, indicate total uncertainty estimates of the horizontal position of proxy-based shorelines to be approximately ± 50-150 m for T-sheets and aerial photography and approximately ± 15 m for datum-based shorelines derived from ground- or air-based topographic surveys. The differences between the two do not appear to have been analyzed in the UK [2]. Datum-based tideline are therefore obtained from a Digital Elevation Model (DEM) of the coastal zone (backshore and foreshore) and an automatic contour extraction method. As end user we are interested on both, the datum-based contour and DEM derived from satellite imagery. [1] Ruggiero P, Kaminsky GM and Gelfenbaum G (2003) Linking proxy-based and datum-based shorelines on a High-Energy coastline: Implications for shoreline analyses. Journal of Coastal Research Special Issue 38: 57-82. [2] Sutherland, James. "Error analysis of Ordnance Survey map tidelines." Maritime Engineering (2012).
Uses and benefits:	Tidelines is of legal interest and also used as an indicator of standard of protection. This product allows management authorities of flood and coastal erosion risk to create a coastal erosion baseline from which other decisions can be made and priorities flow. Will allow coastal engineering practitioner and research community to better understand process of change and validate conceptual and numerical models used to assess coastal change and adaptation options.
Product Specifications	
Spatial scale:	1:2,500 in rural areas, 1:1,250 in urban areas and 1:10,000 in upland areas (scales chosen to be consistent with the standard scales used by OS mapping)
Minimum cell size: (or mapping unit)	To be consistent with the methodology used recently in Scotland to assess the historical rates of coastal change [3] a minimum cell size of 10 m is desirable. [3] Fitton, J. M., J. D. Hansom, and A. F. Rennie. "Dynamic Coast-National Coastal Change Assessment: Methodology." (2017).
Information layers:	Spatial Reference System (EPSG 277000 British National Grid) Tidelines; vector lines for different tide elevations (LWMOT, HWMOT, MLWSM, MHWSM) Digital Elevation Model; used to extract the different tide contours Error lines; Lines that have errors (for instance not closed rings or self-intersections) Date and time; of the image used to delineate the tideline Uncertainty in the elevation of the tide level Uncertainty in the elevation due to waves and atmospheric processes Uncertainty in the elevation of the DEM Uncertainty in the horizontal location of the tideline associated to uncertainty on vertical elevations

Product format:	Vector and Raster formats; Vector for the tidelines: GML (Geography Markup Language), ESRI Shapefile Raster for the DEM: ASCII, TIFF & GeoTIFF uncompressed and compressed (LZW, ZIP)
Softwareplatform compatibility:	The products should be compatible with the following commercial and open source GIS: ArcGIS & ArcMap 10.3.1, Quantum GIS 2.18
Product accuracy:	Same accuracy requirements as for proxy-based tidelines and to be consistent with OS accuracy definitions (see definitions and accuracy on proxy-based tidelines product description).
Service Specifications	
Years of interest:	Interested in years since 1970s until present
Temporal range:	Not applicable
Updating frequency:	Same updating frequency requirements as for proxy-based tidelines and to be consistent with OS accuracy definitions (see explanation on proxy-based tidelines product description). Frequency might varies from six months since change observed or work completion to few years.
Temporal baseline:	1948 (or as close as possible)
Ordering:	Web based ordering system
Delivery time required:	Within 6 months of ordering
Delivery format:	Web-based (http), ftp
Validation data	
Available at the end-user's premises:	In addition to the data described on Proxy-based tideline product description, BGS as a Public Sector Organization, BGS has access to; NEXTMap® Britain provides users with highly accurate Digital Elevation Models which model the ground surface in great detail [Intermap Technolgies, 2009]. Produced by Intermap, was derived from airborne Interferometric Synthetic Aperture Radar (IFSAR). The dataset covers all of England, Wales and Scotland ✓ An elevation point provided every five metres and a vertical accuracy of one metre ✓ Selected more densely populated areas are available with a vertical accuracy of 50 centimetres ✓ A digital orthorectified radar image (ORI) data set is also available providing a highly detailed grey scale image of the earth's surface ✓ Available as a DSM, DTM and Contours at 5m or 10m postings Intermap Technologies (2009): NEXTMap British Digital Terrain (DTM) Model Data by Intermap. NERC Earth Observation Data Centre, date of citation. http://catalogue.ceda.ac.uk/uuid/998a28d8a5ed4564863a0daa0f731e8d
Available elsewhere:	In addition to the data described on Proxy-based tideline product description: LiDAR data (raw data and DTM and DSM at 1 m, 50 cm raster cell) along England, Wales, Scotland and Northern Ireland coastal zone are available from; EA for England and Wales and Scottish Natural Heritage (SNH) for Scotland and DAERA and OpenDataNI for Northern Ireland.
Planned collection and when:	For planned OS MasterMap collection and publication see https://www.ordnancesurvey.co.uk/business-and-government/help-and-support/products/os-mastermap-refresh-dates.html For planned data collection of other auxiliary data indicated above, visit the indicated links and Agencies web sites.

PRODUCT DESCRIPTION BGS #3: SEAMLESS TOPO-BATHY METRIC DIGITAL ELEVATION MODELS

Description of product no. 3

General Description

Seamless (i.e. no data gaps between topography and bathymetry) Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore)

General service/product description:

Any policy for coastal erosion should increase coastal resilience by restoring the sediment balance and providing space for coastal processes (EUROSION, 2004). In this context, coastal managers have shifted their interest from coastline management (1D) to volume and space management (3D) over time (4D). This has created a demand on the surveyors to create seamless TPDEM of the coastal zone to allow them assess close sediment balance.

This product is a raster product containing a time stamped Digital Elevation Model of the coastal zone (including backshore, foreshore and nearshore). This product will be delivered as both a Digital Surface Model (DSM) and Digital Terrain Model (DTM).

Uses and benefits:

Assess geomorphic change and volumes of sediment eroded and deposited by subtraction of two independent DTM surfaces to produce a DTM of Difference (DoD), with each grid cell value representing a measure of the vertical elevation difference.

Extract information of a number of Coastal State Indicators used for coastal management [1]:

CSI*	Quantity represented	Spatial separation	Time between measurements	Case Study
Dune strength	SoP for storm	250 m	5 years	Dutch coast
Barrier width	SoP for storm	180 m	1 month	Pevensey, UK
Total barrier volume	SoP for storm	180 m	1 month	Pevensey, UK
Backshore width	SoP for storm	Mean 1.75 km	1 year	Black Sea
Dune zone width	SoP for storm	Mean 1.75 km	1 year	Black Sea
Dune zone height	SoP for storm	Mean 1.75 km	1 year	Black Sea
Momentary coastline	Position & boundary condition for SoP	250 m	1 year	Dutch coast
Beach width	Boundary condition for SoP of hard defence	100 m	6 months	Costa Brava, Spain
Barrier crest position	Position	180 m	1 month	Pevensey, UK
Shoreline position	Position	Few m	4 to 5 years	Black Sea
Shoreline position	Position	≤ 500 m	1 year	Hel peninsula, Poland
Coastline position	Perception of safety	Irregular	Event-driven	Inch Strand, Ireland
Coastal foundation	Rise with sea level	250m	Several years	Dutch coast
Shoreface volume	Flood and coastal erosion risk	500m	4 years	Hel peninsula, Poland
Coastal slope	Flood and coastal erosion risk	Mean 1.75km	4 to 5 years	Black Sea

SoP: standard of protection

[1] Payo et al., 2018. Geomorphic State Indicators for coastal management over decades and longer time scales. DOI: 10.13140/RG.2.2.27099.05923

Product Specifications

Spatial scale: Not applicable

Minimum cell size: (or mapping unit) A minimum cell size of 5 m is desirable.

Information layers:

Timestamp; date of data collection of images used to create TBDEM

Spatial Reference System (preferred EPSG 277000 British National Grid)

Datum (preferred for Great Britain is Ordnance Datum Newlyn and Belfast Ordnance Datum for Northern Ireland)

Digital Surface Model; raster surface elevation model

Digital Terrain Model; raster relief elevation (i.e. excluding structures and vegetation)

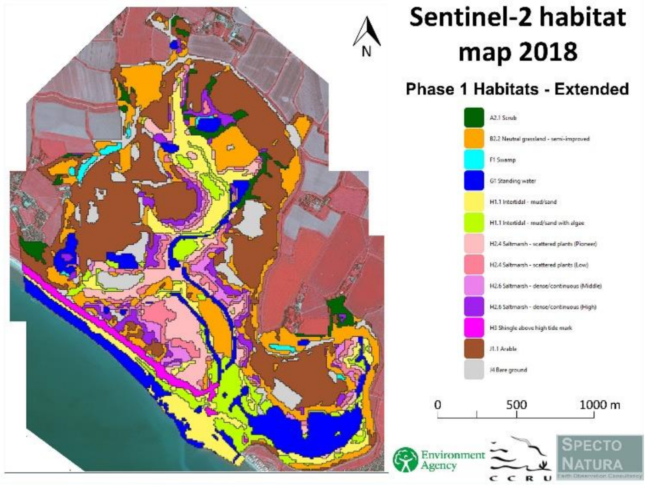
Uncertainty in the elevation of DSM

Uncertainty in the elevation of DTM

Product format:	Raster: ASCII, TIFF & GeoTIFF uncompressed and compressed (LZW, ZIP)
Software platform compatibility:	The products should be compatible with the following commercial and open source GIS: ArcGIS & ArcMap 10.3.1, Quantum GIS 2.18
Product accuracy:	+/-15cm RMSE (to allow comparison with with EA LiDAR data)
Service Specifications	
Years of interest:	Interested in years since 1970s until present
Temporal range:	Not applicable
Updating frequency:	Frequency might varies from one month to five years (see table on Uses description).
Temporal baseline:	1948 (or as close as possible)
Ordering:	Web based ordering system
Delivery time required:	Varies with updating frequency from 15 days for 1 indicators that have a 1 month updating frequency to 6 months for those with few years updating frequency.
Delivery format:	Web-based (http), ftp
Validation data	
Available at the end-user's premises:	Same as data described for Proxy-based tideline and datum-based tideline products description.
Available elsewhere:	In addition to the data described on Proxy-based tideline & Datum-based tideline products description: Bathymetries for the whole UKCS from the Admiralty Data Portal web site which includes Bathymetric surveys from various sources including over 4,000 bathymetry surfaces from 1970 to present day. The bathymetry data is updated every three months and a large number have been funded by the MCA, an executive agency sponsored by the Department for Transport, under the Civil Hydrography Programme. (https://data.admiralty.co.uk/portal/apps/sites/#/marine-data-portal)
Planned collection and when:	For planned OS MasterMap collection and publication see https://www.ordnancesurvey.co.uk/business-and-government/help-and-support/products/os-mastermap-refresh-dates.html For planned data collection of other auxiliary data indicated above, visit the indicated links and Agencies web sites.

PRODUCT DESCRIPTION BGS #4: HABITAT MAP

Description of product no. 3	
General Description	**Habitat map**
General service/product description:	This product is a vector polygon product containing a time stamped Habitat map of the coastal zone (including backshore, foreshore and nearshore). The size of the backshore area is defined by the end users preferred height values corresponding to tidal limits. The minimum level of classes to be identified are the Sentinel-2 based habitat map [1]. An enlarged copy of the figure below showing the different classes can be found here https://sentinel.esa.int/documents/247904/3833380/Sentinel-2-Medmerry-habitat-map-full.jpg). This habitat map is a remotely sensed product which classify site relevant habitats visible at the time of satellite capture. The classification uses supervised classification techniques; these are techniques which are trained using ground data. The EA habitat descriptions for CASI and LIDAR

	habitat maps are proposed to be used [1] but we are aware that some modification might be needed [2] (Figure below).  [1]EA CASI and LIDAR Habitat Map. https://data.gov.uk/dataset/1707e638-6a2d-48f5-a534-1db0b240cc37/casi-and-lidar-habitat-map [2]https://sentinel.esa.int/web/sentinel/home/-/journal_content/56/247904/3834405
Uses and benefits:	Habitat creation achieved as part of coastal managed realignment schemes has been estimated to provide environmental benefits valued at between £680 and £2,500 per hectare, including carbon storage benefits. Furthermore, the Climate Change Committee (2013)1 advised that 6200 ha of coastal habitat created nationally by 2030 (costing £10-15M per annum) would save £180-£380M in capital and maintenance costs on coastal flood and erosion management over the long-term when compared to the cost of replacing/maintaining hard defences. The successful implementation of such schemes, however, requires trustworthy data and information from existing schemes and that, in turn, requires replicable, cost-efficient, and fit-for purpose monitoring programmes of both existing and planned future schemes.
Product Specifications	
Spatial scale:	Not applicable
Minimum cell size: (or mapping unit)	For a class to be mapped on site there must have been samples collected for it on site.
Information layers:	Timestamp; date of data collection Spatial Reference System (preferred EPSG 277000 British National Grid) Vector polygon with the different habitats. Habitats types described in [1]
Product format:	Vector polygon GML (Geography Markup Language), ESRI Shapefile
Software platform compatibility:	The products should be compatible with the following commercial and open source GIS: ArcGIS & ArcMap 10.3.1, Quantum GIS 2.18
Product accuracy:	Quantitative accuracy assessment carried out on them in the form of a confusion matrix using ground data set aside and not used in training the classifier
Service Specifications	
Years of interest:	Interested in years since 1970s until present
Temporal range:	Not applicable
Updating frequency:	Frequency might varies from one month to a year.
Temporal baseline:	1948 (or as close as possible)
Ordering:	Web based ordering system

Delivery time required:	Varies with updating frequency from 15 days for 1 indicators that have a 1 month updating frequency to 6 months for those with one year updating frequency.
Delivery format:	Web-based (http), ftp
Validation data	
Available at the end-user's premises:	Same as data described for Proxy-based tideline, Datum-based tideline, TBDEM products descriptions.
Available elsewhere:	In addition to the data described on Proxy-based tideline, Datum-based tideline and TBDEM products description: CASI and LIDAR Habitat Map from EA. A habitat map derived from airborne data, specifically CASI (Compact Airborne Spectrographic Imager) and LIDAR (Light Detection and Ranging) data. The habitat map is a polygon shapefile showing site relevant habitat classes. Geographical coverage is incomplete because of limits in data available. It includes those areas where the Environment Agency, Natural England and the Regional Coastal Monitoring Programme have carried out sufficient aerial and ground surveys in England. Habitat maps generated by Geomatics are often derived using multiple data sources (e.g. CASI, LIDAR and OS-base mapping data), which may or may not have been captured coincidentally. In instances where datasets are not coincidentally captured there may be some errors brought about by seasonal, developmental or anthropological change in the habitat. URL: https://data.gov.uk/dataset/1707e638-6a2d-48f5-a534-1db0b240cc37/casi-and-lidar-habitat-map
Planned collection and when:	For planned OS MasterMap collection and publication see https://www.ordnancesurvey.co.uk/business-and-government/help-and-support/products/os-mastermap-refresh-dates.html For planned data collection of other auxiliary data indicated above, visit the indicated links and Agencies web sites.

Appendix 2

EO PRODUCTS VERIFICATION, QC AND VALIDATION ESTIMATED FEASIBLE AT PRESENT BY THE SERVICE PROVIDERS

SPECIFICATION OF *VALIDATION* STEPS	validation				verification & validation	Quality Controls		
	conclusions		geolocalization		objects' detect. & charact. (Truth of the observations)	time-sampling		spatial resolution
EO products naming	erosion rates	other coastal sate indicators	geomorphological changes	geomorphology		climate change	storm / flood /beach nourishment events	
CE_ARG_area_L5_3D_ER_SL_area_date_date.XXX CE_ARG_area_L5_3D_ER_SDBTM_area_date_date.XXX	900 m3/y per transect (200m)		< 3			4 images / Year (seasonal change)	> 10 images /year	< 15 m (30 years)
CE_ARG_area_L2_1D_OB_WL_sensor_date.shp		3 m Proxy-based shoreline	< 3m	10m	90% of the waterline	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_SAT_area_L2_1D_OB_WL_S1_date.shp		3 m Proxy-based shoreline	< 3m	10m	90% of the waterline	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L2_1D_DB_SL_MHWS_date.shp		3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L2_1D_DB_SL_MSL_date.shp		3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L2_1D_DB_SL_MLWN_date.shp		3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L3_1D_DB_SL_MHWS_date_date.shp	µ = 0.5m/y (on a 30 year basis)	3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15 (30 years)
CE_ARG_area_L3_1D_DB_SL_MSL_date_date.shp	µ = 0.5m/y (on a 30 year basis)	3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15 (30 years)
CE_ARG_area_L3_1D_DB_SL_MLWN_date_date.shp	µ = 0.5m/y (on a 30 year basis)	3 m Proxy-based shoreline	< 3m	10m	90% of the shoreline	4 images / Year (seasonal change)	> 10 images /year	< 15 (30 years)
CE_ARG_area_L2_3D_BT_SDB_sensor_date.tif		slope Sediment Seadbed morphology	< 3.5	12 m	80% Identified seabed features > 0,8 accuracy of seabed classification	4 images / Year (seasonal change)	> 10 images /year	< 10
CE_ARG_area_L3_3D_BT_SDB_sensor_date_date.tif	µ =0.2m/y in the Δy direction (per year)	slope Sediment Seadbed morphology	< 3.5	12 m	80% Identified seabed features > 0,8 accuracy of seabed classification	4 images / Year (seasonal change)	> 10 images /year	10 m

CE_SAT_area_L2_3D_BT_WF_sensor_date-.XXX			< 4	12 m	70% Identified seabed features	4 images / Year (seasonal change)	> 10 images /year	2 m nearshore (Imagery resolution)
CE_SAT_area_L3_3D_BT_WF_sensor_date_date.XXX	μ =0.4m/y in the Δy direction (per year		< 4	12 m	70% Identified seabed features	4 images / Year (seasonal change)	> 10 images /year	3 m nearshore (Imagery resolution)
CE_ARG_area_L2_3D_BT_WF_sensor_date-.XXX			< 4 m	12 m	70% Identified seabed features	4 images / Year (seasonal change)	> 10 images /year	4 m nearshore (Imagery resolution)
CE_ARG_area_L3_3D_BT_WF_sensor_date_date.XXX	μ =0.4m/y in the Δy direction (per year)	Vulnerability	< 4 m	12 m	70% Identified seabed features	4 images / Year (seasonal change)	> 10 images /year	5 m nearshore (Imagery resolution)
CE_ARG_area_L4_3D_BT_SDB_WF_sensors_date_date.tif	μ =0.4m/y in the Δy direction		< 4 m	12 m	75% Identified seabed features	4 images / Year (seasonal change)	> 10 images /year	6 m nearshore (Imagery resolution)
CE_ARG_area_L2_2D_FB_LULC_sensor_date.shp		10m For flood monitoring 10m for change analysis	< 4 m	15m	Classification accuracy OA ≥ 0,85 KAPPA ≥ 0,7	4 images / Year (seasonal change)	> 10 images /year	< 5m for small civil work < 10m for local/detailed habitats identification <30m global/general morphology
CE_ARG_area-_L2_1D_FB_LL_date.shp		10m For flood monitoring 10m for change analysis	< 4 m	10m	80% of the Littoral line	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L2_1D_FB_SF_date.shp		10m For flood monitoring 10m for change analysis	< 4 m	10m	80% of the Seafront line just in	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L3_2D_FB_LULC_sensor_date_date-.tif		10m For flood monitoring 10m for change analysis	< 4 m	10m	Classification accuracy OA ≥ 0,9 KAPPA ≥ 0,85	4 images / Year (seasonal change)	> 10 images /year	< 5m for small civil work < 10m for local/detailed habitats identification <30m global/general morphology
CE_ARG_area_L3_1D_FB_LL_date_date.shp		10m For flood monitoring 10m for change analysis	< 4 m	10m	80% littoral the Littoral	4 images / Year (seasonal change)	> 10 images /year	< 15m
CE_ARG_area_L3_1D_FB_SF_area_date_date.shp		10m For flood monitoring 10m for change analysis	< 4 m	10m	80% of the Seafront	4 images / Year (seasonal change)	> 10 images /year	< 15m

Appendix 3

METADATA FILES FOR THE DIFFERENT EO PRODUCTS.

Type	Auxiliary Data File for Bathymetry (BT)	
Filename	CE_YYYYMMDDHHMM_**BT_0META**_BoundingBox_S2_YYYYMMDD.tif	
GDAL Format	JSON	
Auxiliary Data File	none	
Attribute field	**Description**	**Classes**


```
{
  "Version": "1.1.0",
  "GeneralInfo": {
    "ProductName": "Bathymorphology Terrain Model",
    "ProductDescription": null,
    "ProductType": "BT",
    "ProductCategory": "OB",
    "ProductLevel": "L2",
    "ProductBBox": null,
    "ProductQualifier": "S2",
    "LastModifiedDate": "20200928T1726",
    "ProductURI": null,
    "ProductPath": null
  },
  "ImageData": {
    "AquisitionDateTime": "20180505T112159",
    "TimeSeriesStartTime": "20180505T112159",
    "TimeSeriesEndTime": "20180505T112159,
    "LocationID": null,
    "LocationName": "Chesil Beach area",
    "LocationLongName": "Chesil Beach area",
    "ImageBBox": "502800N 025937w, 504821N 012650W",
    "CoordSystem": "WGS 84-EPSG 4326",
    "NODATA": null
  },
  "SensorData": {
    "Platform": {
      "PlatformCode": null,
      "OrbitDirection": null,
      "SensorInstrument": "S2"
    },
    "SensingInfo": {
      "SolarZenithAngle": "35.4930837362462",
      "SolarAzimuthAngle": "163.958521556655",
      "ViewZenithAngle": "7.5537452192911",
      "ViewAzimuthAngle": "287.082594165448",
      "SolarRadiance": null,
```

"EarthSunDistance": null
}
},
"Processing": {
"Processor": {
"ProcessorName": "IDA",
"ProcessorVersion": null,
"ProcessingDateTime": "20200928T1726",
"ProcessorLogName": null,
"ProcessorLogURI": null,
"ProducedBy": "nzorrilla@argans.co.uk",,
"ProductionFacility": "ARGANS Ltd."
},
"InputData": {
"SourceFileName": null,
"SourceFileURI": null
},
"AuxillaryData": {
"ADFname": null,
"ADFlinkURI": null,
"ADF_TAG": {
"WaveHeight": null,
"WavePeriod": null,
"WaveDir": null,
"WaterLevel": null,
"DatumBenchmark": null,
"DatumHeight": null
}
},
"AnciliaryData": {
"CommandLine": null,
"CL_PARAMS": {
"WL_BandRatio": null,
"SL_SlopeBufferSize": null,
"SL_MaxJoinLength": null,
"SL_SegmentLength": null,
"SL_SkipWave": null,
"SL_SkipSlope": null,
"BT_Tide": "0",
"BT_WindspeedU10": "0.000204",
"BT_AOT": "0.0121559",
"BT_DepthRefValue": "30",
"BT_Phytoplankton": "0.06",
"BT_CDOM": "0.2",
"BT_BackScatter": "0.1",
"BT_AerosolType": "MAR99"
},
"AnciliaryDataURI": null
},

```
    "ProcessingHistory": {
      "SourceMetadataFileName": null,
      "SourceMetadataFileURI": null,
      "ProcessingRecord": null
    }
  },
  "QualityIndicators": {
    "WL_QualityControlVersion": null,
    "WL_PercentageCloudCoverage": null,
    "WL_AverageSegmentScore": null,
    "WL_LCILowThreshold": null,
    "WL_LCIHighThreshold": null,
    "SL_QualityControlVersion": null,
    "SL_AverageSegmentScore": null,
    "BT_QualityIndicatorMap": "MASK",
    "LC_ConfidenceMap": null,
    "LC_ValidityMap": null,
    "LC_UncertaintyMap": null
  }
}
```

Type	Meta Data File for Waterline (WL) Optical (OPT)	
Filename	Same as Waterline product	
GDAL Format	JSON	
Attribute field	**Description**	**Classes**


```
{
  "Version": "1.1.0",
  "GeneralInfo": {
    "ProductName": "Waterline",
    "ProductDescription": "This is an observation based waterline extracted from a VNIR sattelite product",
    "ProductType": "WL",
    "ProductCategory": "OB",
    "ProductLevel": "L2",
    "ProductBBox": "525014N-54151W-530933N-42158W",
    "ProductQualifier": "S2",
    "LastModifiedDate": "20200924T0936",
    "ProductURI": null,
    "ProductPath": null,
    "ProductFileName": "CE_20180201111259_WL_OB_L2_525014N-54151W-530933N-42158W_S2_200924",
    "LocationName": "Spurn Head",
    "LocationID": "30UYD"
  },
  "ImageData": {
    "AquisitionDateTime": null,
    "TimeSeriesStartTime": null,
    "TimeSeriesEndTime": null,
    "LocationID": null,
    "LocationName": null,
    "LocationLongName": null,
    "ImageBBox": null,
    "CoordSystem": "EPSG:32629",
    "NODATA": null
  },
  "SensorData": {
    "Platform": {
      "PlatformCode": null,
      "OrbitDirection": "DESCENDING",
      "SensorInstrument": "MSI"
    },
    "SensingInfo": {
      "SolarZenithAngle": null,
      "SolarAzimuthAngle": null,
      "ViewZenithAngle": null,
      "ViewAzimuthAngle": null,
      "SolarRadiance": null,
      "EarthSunDistance": null
    }
  },
```

"Processing": {
"Processor": {
"ProcessorName": "waterline_toolkit.py",
"ProcessorVersion": null,
"ProcessingDateTime": "20200728T1852",
"ProcessorLogName": null,
"ProcessorLogURI": null,
"ProducedBy": "smiles@argans.co.uk",
"ProductionFacility": "ARGANS Ltd."
},
"InputData": {
"SourceFileName": "S2B_MSIL2A_20180201T111259_N0206_R137_T30UYD_20180201T133146.SAFE",
"SourceFileURI": null
},
"AuxillaryData": {
"ADFname": null,
"ADFlinkURI": null,
"ADF_TAG": {
"WaveHeight": null,
"WavePeriod": null,
"WaveDir": null,
"WaterLevel": null,
"DatumBenchmark": null,
"DatumHeight": null
}
},
"AnciliaryData": {
"CommandLine": "waterline_operator.py /mnt/Projects/CoastalErosion/01-OPERATIONS/input/SpurnHead/SpurnHead_30UYD/S2/S2L2/S2L2/7/ /data/coastal/01-OPERATIONS/output/Waterline/S2/SpurnHead/SpurnHead_T30UYD_NDVI/ S2 -r /mnt/Projects/CoastalErosion/Waterline/ROIs/latlon_locations/Phase2sites/SpurnHead_T30UYD_roi.txt -m 2 -c /mnt/Projects/CoastalErosion/Waterline/MultipleCoastlines/SpurnHead_T30UYD/7/SpurnHead_T30UYD.shp -buf 3000 -b NDVI -md /mnt/Projects/CoastalErosion/Waterline/Metadata/metadata_template_SpurnHead_T30UYD.json",
"CL_PARAMS": {
"WL_BandRatio": "NDVI",
"SL_SlopeBufferSize": null,
"SL_MaxJoinLength": null,
"SL_SegmentLength": null,
"SL_SkipWave": null,
"SL_SkipSlope": null,
"BT_Tide": null,
"BT_WindspeedU10": null,
"BT_AOT": null,
"BT_DepthRefValue": null,
"BT_Phytoplankton": null,
"BT_CDOM": null,
"BT_BackScatter": null,
"BT_AerosolType": null
},
"AnciliaryDataURI": null
},

```
    "ProcessingHistory": {
      "SourceMetadataFileName": null,
      "SourceMetadataFileURI": null,
      "ProcessingRecord": null
    }
  },
  "QualityIndicators": {
    "WL_QualityControlVersion": null,
    "WL_PercentageCloudCoverage": null,
    "WL_AverageSegmentScore": null,
    "WL_LCILowThreshold": null,
    "WL_LCIHighThreshold": null,
    "SL_QualityControlVersion": null,
    "SL_AverageSegmentScore": null,
    "BT_QualityIndicatorMap": null,
    "LC_ConfidenceMap": null,
    "LC_ValidityMap": null,
    "LC_UncertaintyMap": null
  }
}
```

Type	Meta Data File for Shoreline (SL)	
Filename	Same as SL product	
GDAL Format	JSON	
Attribute field	**Description**	**Classes**


```
{
  "Version": "1.1.0",
  "GeneralInfo": {
    "ProductName": "Shoreline",
    "ProductDescription": "This is a datum based shoreline derived from a waterline",
    "ProductType": "SL",
    "ProductCategory": "DB",
    "ProductLevel": "L2",
    "ProductBBox": "525026N001331E-530452N013725E",
    "ProductQualifier": "HAT",
    "LastModifiedDate": "20201027T1715",
    "ProductURI": null,
    "ProductPath": null,
    "ProductFileName": "CE_201704091056_SL_DB_L2_525026N001331E-530452N013725E_HAT_20201027",
    "LocationName": "Spurn Head",
    "LocationID": "30UYD"
  },
  "ImageData": {
    "AquisitionDateTime": null,
    "TimeSeriesStartTime": null,
    "TimeSeriesEndTime": null,
    "LocationID": null,
    "LocationName": null,
    "LocationLongName": null,
    "ImageBBox": null,
    "CoordSystem": "EPSG:32630",
    "NODATA": null
  },
  "SensorData": {
    "Platform": {
      "PlatformCode": null,
      "OrbitDirection": "DESCENDING",
      "SensorInstrument": "MSI"
    },
    "SensingInfo": {
      "SolarZenithAngle": null,
      "SolarAzimuthAngle": null,
      "ViewZenithAngle": null,
      "ViewAzimuthAngle": null,
      "SolarRadiance": null,
      "EarthSunDistance": null
    }
  },
```

```
"Processing": {
  "Processor": {
    "ProcessorName": "SL_1_3_0.py",
    "ProcessorVersion": "1_3_0",
    "ProcessingDateTime": "20201027T1622",
    "ProcessorLogName": "30UYD_PROCESSING_ERRORS.log",
    "ProcessorLogURI": "None",
    "ProducedBy": "smiles@argans.co.uk",
    "ProductionFacility": "Argans Ltd."
  },
  "InputData": {
    "SourceFileName": "CE_ARG_30UYD_L2_1D_OB_WL_S2_20170409105651.shp",
    "SourceFileURI": "None"
  },
  "AuxillaryData": {
    "ADFname": null,
    "ADFlinkURI": null,
    "ADF_TAG": {
      "WaveHeight": "null",
      "WavePeriod": "null",
      "WaveDir": "null",
      "WaterLevel": "INTERPOLATED VALUES: -2.29 - 0.31",
      "DatumBenchmark": "OD",
      "DatumHeight": "INTERPOLATED VALUES: 1.33 - 4.53"
    }
  },
  "AnciliaryData": {
    "CommandLine": "SL_1_3_0.py /home/smiles/miniconda3/Processor/Shoreline/",
    "CL_PARAMS": {
      "WL_BandRatio": "NDVI",
      "SL_SlopeBufferSize": "800",
      "SL_MaxJoinLength": "200",
      "SL_SegmentLength": "60",
      "SL_SkipWave": "True",
      "SL_SkipSlope": "False",
      "BT_Tide": null,
      "BT_WindspeedU10": null,
      "BT_AOT": null,
      "BT_DepthRefValue": null,
      "BT_Phytoplankton": null,
      "BT_CDOM": null,
      "BT_BackScatter": null,
      "BT_AerosolType": null
    },
    "AnciliaryDataURI": null
  },
  "ProcessingHistory": {
    "SourceMetadataFileName": null,
    "SourceMetadataFileURI": null,
```

```
            "ProcessingRecord": null
        }
    },
    "QualityIndicators": {
        "WL_QualityControlVersion": null,
        "WL_PercentageCloudCoverage": null,
        "WL_AverageSegmentScore": null,
        "WL_LCILowThreshold": null,
        "WL_LCIHighThreshold": null,
        "SL_QualityControlVersion": null,
        "SL_AverageSegmentScore": null,
        "BT_QualityIndicatorMap": null,
        "LC_ConfidenceMap": null,
        "LC_ValidityMap": null,
        "LC_UncertaintyMap": null
    }
}
```

Appendix 4 Service Assessment Sheets

PROXY WATERLINES OPTICAL & SAR

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			X

Comments:

At the time of writing this evaluation sheet, more than one year has passed since BGS requirements specification were outlined early in the project. Our understanding of the product requirements has evolved by working with the service providers and iteratively assessing the product adequacy over the second phase of the project. Here we describe how some of our initial requirements has changed and how these have been met.

The adequacy to the BGS-URD requirements for the PROXY TIDELINES OPTICAL & SAR (WL-OPT & SAR) product are considered adequate with HIGH score for the following reasons:

Spatial scale and product accuracy

The absolute and relative accuracy of WL products from Optical sensors have been found to correspond with representative fraction scale values equivalent to 1: 24800 to 1: 51 400 (**Table 8**) and comparable with the representative fraction scale of UK OS VectorMap District[14] which is of 1:15 000 to 1:30 000. These representative fraction scales are larger than the aspirational fraction scale values specified in the requirements (1:2,500 in rural areas, 1:1,250 in urban areas and 1:10,000 in upland areas) but we have seen evidences that by filtering out those lines with lower quality score and passed the visual inspection, the absolute accuracy can be reduced to values as low as 1.4 m (**Figure 3.12**) which are equivalent to representative fraction scale of 1:2800.

The assessment of the absolute and relative accuracy of WL products from SAR sensors has been more challenging than for the WL-OPT. A visual inspection of the WL-SAR for Start Bay revealed that the location accuracy is sensitive to coastline orientation and the satellite orbit (ascending and descending) (**Figure 3.16**, **Figure 3.17**). For Start Bay, we were only able to identify one non-foreshore point to calculate the absolute and relative accuracies which is not enough to produce conclusive statistically robust assessment but the visual inspection suggested that accuracies of the order of 15 m can be achieved which are equivalent to representative fraction scale of 1: 30 000.

Minimum cell size (or mapping unit)

We have seen evidences of WL skills detecting change (**Figure 3.6**, **Figure 3.18**) to be consistent with OS MasterMap revision policy on the Coastal zone the minimum change mapped due to natural erosion and deposition in the coastal zone is the one resulting in a change of alignment of more than 10 m over a length of more than 100 m for the following coastal features when well defined; Top and bottom of cliffs; and Coastal slope limits.

Information layers

The WL product received contains information in the metadata of the Spatial Reference System used and we were able to transform it to our desired SRS which for the is: EPSG 277000 British National Grid.

Error lines; Lines that have errors (for instance not closed rings or self-intersections) were indicated by the product quality scores, which are different for optical and SAR WLs.

Date and time; of the image used to delineate the tideline was provided in the metadata

Uncertainty in the elevation of the tide level, elevation due to waves and atmospheric processes and in the horizontal location of the tideline associated to uncertainty on vertical elevations at the time of the image was collected, was not provided in the metadata but this information is known to BGS via auxiliary data (section 2.4.3).

Product format

We requested the format of the product to be provided as GML (Geography Markup Language) and ESRI Shapefile and received them as ESRI shp (WL-OPT) and geojson (WL-SAR) which was agreed between service providers and end-user during the production phase of the project.

Software platform compatibility:

We have found the WL products to be compatible with the following commercial and open source GIS: ArcGIS (v10.7.1) & ArcMap 10.3.1, Quantum GIS v3.12 and SAGA v7.9

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[14] https://www.ordnancesurvey.co.uk/business-government/products/vectormap-district

Years of interest

We have received data since 1994 (WL-OPT) and 2015 (WL-SAR) which is when first mission data was available

Updating frequency

The frequency of the WL-OPT is of several lines per month which is much higher than the twice per year comparable OS VectorMap District products. The frequency of the WL-SAR is much higher with an average of 216 lines per year.

Temporal baseline

In England the authority in charge of coastal flooding and erosion policy development is the Department of Food and Rural Affairs (Defra) and uses the 1948 baseline year which correspond with the first Royal Air Force (RAF) aerial imagery available. The WL product baseline is limited to the date of first mission data available which is 1994 (WL-OPT) and 2015 (WL-SAR).

Delivery format

We have received the data via the two requested delivery formats:

- ftp = ftp.adwaiseo.eu, user name = ftp_costal_erosion
- web-service = https://coastalerosion.argans.co.uk/science.html

*Low; Medium; High

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			X

Comments:

The overall PROXY TIDELINES OPTICAL & SAR (WL-OPT & SAR) product compliance to the user requirements are evaluated as HIGH.

For the reasons outlined in section B.1. we have scored the different product as service specification as:

Requirement item	**Comment**	**Score**
Spatial scale and product accuracy:	Representative fraction scale comparable to UK OS VectorMap District which is of 1:15 000 to 1:30 000 if products are filtered by visual inspection and quality score	H
Minimum cell size (or mapping unit)	Requirements has been met	H
Information layers	Requirements has been met	H
Product format	Requirements has been met	H
Software platform compatibility:	Requirements has been met	H
Years of interest	Requirements has been met	H
Updating frequency	Requirements has been exceeded	H
Temporal baseline	Requirements has been met	H
Delivery format	Requirements has been met	H

*Low; Medium; High

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			X

Comments:

The product accuracy compliance to the user requirements has been evaluated as HIGH for the reasons outlined below;

To be consistent with OS accuracy definitions we define accuracy in three different ways:

Absolute accuracy – how closely the coordinates of a point in the dataset agree with the coordinates of the same point on the ground (in the British National Grid reference system).

Relative accuracy – positional consistency of a data point or feature in relation to other local data points or features within the same or another reference dataset.

Geometric fidelity – the 'trueness' of features to the shapes and alignments of the objects they represent -when testing the data according to the dataset specification against the 'real world' or reference dataset.

The geometric fidelity has been assessed by visual inspection of as sample of the WLs (OPT and SAR) produced and we have found that there is a good geometric fidelity. This was clear when looking at how the product have delineated the geometry of the built environment (i.e. harbours, levees, jetties) even for the smaller resolution L8 images.

The absolute and relative accuracy of WL products from Optical and SAR sensors have been found to correspond with representative fraction scale comparable with the representative fraction scale of UK OS VectorMap District[15] which is of 1:15 000 to 1:30 000.

*Low; Medium; High

Confidence in the product quality (including accuracy)	Evaluation*		
	L	M	H
			X

Comments:

The confidence in the product quality (including accuracy) is evaluated by BGS as HIGH for the reasons outlined below.

Service providers has provided a quality score indicating their level of confidence on the product which includes

For WL-OPT:

- The QC_len is looking at the line length, a lot of waterline errors are very short segments, so these are assigned a low value and vice versa. Quality Flag number based on line length. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality.
- The QC_LCI uses a Line Confinement Index, it is looking at how compact the segment is relative to it's length. Good waterline segments are usually stretched out (like along a beach), whereas errors are usually squiggly and compact. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality
- The QC_intern is the mean value between QC_len and QC_LCI, this helps to mitigate against the pitfalls of both QC methods. It varies from 0 to 100, where 0 is the worst quality and 100 is the best quality.

For WL-SAR

- Distance to a fixed reference shoreline. NaN results are points out of the bounding box, so there is no reference line near them to do the QC
- Density of waterlines.The value indicates the % of points falling in the same pixel cell as the one evaluated, NaN results are points out of the bounding box
- Classification flag indicating the labelling applied after the quality check: 0 for good points, distance below 50 meters and density above 2 %; 1 for proxy points, distance between 50 and 100 meters and density above 2 %; 2 for not valid points, distance above 100 meters
- Angle between the orbit trajectory and the reference shoreline orientation. A mean average of 10 points has been considered. 90 and 270 indicate perpendicular view of the coast.

Very High Resolution images for the co-registration process has been used (section 2.4.1)

The products has shown able to capture a range of observed coastal change (beach rotation, cliff erosion and beach accretion) at the study locations (Start Bay and Happisburgh)

We have independently calculated the absolute and relative accuracies using publicly available data and Free Open Source Software (SAGA GIS)

*Low; Medium; High

15 https://www.ordnancesurvey.co.uk/business-government/products/vectormap-district

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
			X

Comments:

The utility of the WL products is evaluated by BGS as HIGH for the reasons outlined below.

The motivation of BGS requesting this product was to produce proxy waterlines that are consistent with the tidelines mapped by the UK Ordnance Survey (OS) on the County Maps, and the more recent (since 2015) OS VectorMap District Tidal boundaries[16]. Different nations within UK use different definitions of tidelines or tidal boundaries. In Scotland, Ordnance Survey (OS) maps consistently shows high and low water marks for ordinary spring tides, which "generally occur the third of fourth tide after new or full moon" as the main tidelines. In England and Wales, the tide lines mapped on the OS County Series maps has changed over time but since about the 1970s the OS has mainly provided tide line data from aerial surveys preferably using black & white infrared film as this shows the water/foreshore interface more clearly. Admiralty tide tables were examined to find high and low tides which were within ± 0.3metres of MHW and MLW.

The utility of the WL as evaluated high because it has a level of accuracy comparable to the OS VectorMap district and can be converted into tidelines provided that enough auxiliary data is available. The WL products does represent a tideline at the time of the satellite image is taken. As the end user have information of the tide level at the time of the image was taken (i.e. from observed or astronomical tide tables) the WL can be filtered to the desired tide level.

Additionally, we have found how both optical and SAR WL, without the need of tide correction are able to reproduce the coastal change observed at two very different environments. At the multiple embayments of Start Bay, with alternating sections of gravel beach and rocky headlands and at the soft cliff and fast eroding coast of Happisburgh.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
			X

Comments:

The impact of the service and WL products on current end-user practices is evaluated as HIGH mostly due to the high updating frequency that this product offers compared to existing practices.

The comparable OS VectorMap tidal boundaries are only updated twice per year, while the updating frequency of the WL-OPT is several times per month (number subject to cloud coverage for optical) and in excess of 200 lines per year for the WL-SAR. This updating frequency, together with the accuracy levels, and quality scores of the WL products has the potential to produce more accurate coastal recession rates for the whole Great Britain by revisiting the historical database since 1994 until present. I also offers the opportunity of assessing coastal change at weekly time scale O(7 days) which is two order of magnitude faster than the current update frequency.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

[16] https://digimap.edina.ac.uk/webhelp/os/data_files/os_manuals/os-vector-map-user-guide.pdf

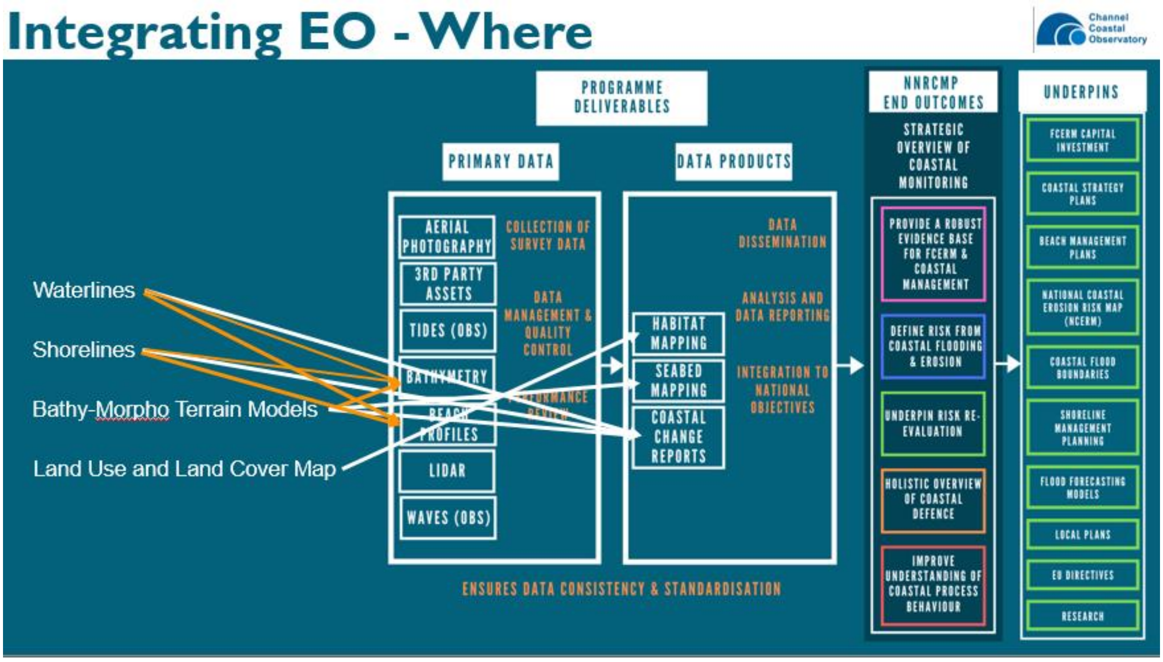
Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
			X

Comments:

The probability of service integration into existing practices has been evaluated by BGS as HIGH.

The study sites selected for the demonstration of the products in the UK has been selected in collaboration with the England regional coastal monitoring program leaders. The sites were selected because they all are actively changing due to coastal erosion and have a data gap that BGS and the consulted end-users were interested on assessing if this product could potentially help filling.

The WL products are very close to be at the maximum level of technology readiness level (TRL9)[17]. At present the WL TRL is assessed to be at TRL7 or inactive commissioning level: product has been tested and factory trials done using inactive simulants comparable to that expected during operations. To reach the maximum operational level (TRL9) will need first to go through active commissioning (TRL8). Before this active commissioning can be roll-out the question of how this new technology should be integrated within all other current coastal erosion monitoring activities need careful consideration. This specific question was addressed during the third session of the UK national workshop and full discussion is available here https://bgscoastalerosion.siteonsite.es/. The slide below was presented by the Coastal Channel Observatory director as an attempt to map the products produced within the current monitoring activities in England.



BGS is actively seeking the progression to TRL8 via; (1) providing geo-scientific advice to our stakeholders, (2) internal national capability funding to continue the validation and evaluation of all products received and (3) leading a proposal that has brought together UK engineering consultants and researchers to develop a methodology to assess historical coastal change in England and Wales for Defra. If successfully funded, this proposal will provide the appropriate discussion platform to effectively integrate the WL products in not only BGS existing practices but more broadly among UK end-users community.

*Low; Medium; High

Desired service and/or product(s) improvements	Evaluation*

[17] www.gov.uk/government/news/guidance-on-technology-readiness-levels

	L	M	H
			X
Comments: WL-OPT products require no further improvement as they have found to meet all BGS requirements but we have HIGH interest on continue improving the WL-SAR. The volume of WL-SAR produced has been large (866 lines) and we have only started to scratch the surface of the value of this product. In particular, we have noticed that the accuracy (absolute, relative and geometric fidelity) seems to be sensitive to the coast orientation and the orbit of the image (ascending or descending) used to extract the WL-SAR (**Figure 3.16**). The quality metadata provided by the service providers is useful, but we feel that we might not have the expertise to confidently derive a robust quality control protocol without the support of the service providers.			

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	M	H
			X
Comments: The need for a large-scale service/product demonstration is HIGH. The mandate of monitoring coastal change due to coastal erosion is devolved in the UK (England, Wales and Scotland, Ireland). The service and product demonstration provided by this project has focussed mostly in England who has the longest coastal monitoring program of all nations. As BGS provides geoscientific advice to all nations, we would like to extend the service and product demonstration to the other UK nations (Wales, Scotland and North Ireland). All nations suffer from coastal erosion at present and are likely to continue suffering the impact of coastal erosion in the future. As each nation has different coastal environments, regulations and access to auxiliary data this extension will allow BGS to effectively assess the adequacy of this new products to the whole UK territory.			

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	M	H
			X
Comments: The overall service and product performance are evaluated by BGS as HIGH for the reasons expressed on sections B.1 to B.4 and summarized below. 1. The WL has shown to be accuracies on the order of 1:20 000 to 1: 40 000 which are comparable with the accuracies of OS VectorMap Disctrict (1: 15 000 to 1:30 000). Although the accuracy requirements for waterline products specified in the URD end-user in the URD were not accomplished, those requirements were mainly aspirational, and the products are still useful for many of the purposes of BGS's practices. 2. Required updating frequency of waterlines have been fully accomplished. The required updating frequency specified in the URD was from events scale (pre and post storms) to monthly scale and this requirement have been accomplished. The variation on the number of products among sites, is not due to changes on the frequency feasibility but on the limited project time to produce all possible products. The frequency of SAR WL production is much higher than requested with an average of 216 lines per year. 3. Required temporal range of waterlines have been accomplished. The URD specified 25 years of historical record has been reached for the optical waterlines that covers a period starting in 1994 to 2020. 4. Quality control indexes were developed and provided for each product: these indexes were required by the end-users and allow the automatic identification of the waterlines that may be the result of detection errors. Quality flags has been provided for all WL products (optical and SAR).			

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			X

Comments:

This product has been highly valued by BGS and the consulted broader end user community within the UK.

By including the end-users requirements as the main driver for the product design and production this has been a truly problem driven project (not a technology push project) which has resulted in products at TRL7 and very close to become operational in the UK.

As the lead of BGS Coast and Estuaries research program, I see the value of these products (WL-OPT and SAR) and I am actively seeking the active commissioning of this service that will allow this product to progress to TRL8 and eventually become fully operational (TRL9).

The mandate of monitoring coastal erosion is devolved among the UK nations but we have mostly focussed on England study cases. Allowing the extension of the service and product demonstration to a few study sites the other UK nations (Wales, Scotland and North Ireland) will provide evidences for sites across all UK territories facilitating the progression of TRL level.

***L**ow; **M**edium; **H**igh

DATUM SHORELINES OPT & SAR

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			X

Comments:

The adequacy to the BGS-URD requirements for the DATUM TIDELINES OPTICAL & SAR (SL-OPT & SAR) product are considered adequate with HIGH score for the following reasons:

DATUM SHORELINES (SL) are produced from the satellite derived proxy-Waterlines (WL) in combination with auxiliary information such as topographical data and tidal levels. Most of the assessment of SL-OPT and SAR is therefore similar to the assessment for the WL-OPT and SAR and is not repeated here in full and reader is referred to the assessment sheet for WL-OPT and SAR.

Spatial scale and product accuracy

The absolute and relative accuracy of SL-OPT and SAR is found to be equal or inferior to the accuracy of the WL from which the SL has been derived from. The cause of the inferior absolute accuracy of the SL is directly related to the discrete nature (in space and time) of the auxiliary data used to convert the WL to a given SL and to the un-constrained estimation of the SL location. This is more evident on cliffed coast like the one along the East Riding of Yorkshire coast and SL with reference datum above MSL (SL-HAT and SL-MHWS). These SLs are sometimes estimated to be on the top of the cliff which is unrealistic (i.e. the almost vertical face of the cliff should be the mapped as the SL instead). Also, the SL location at non-foreshore points (i.e. their location should be the same for all reference datum) shows different locations because the WL to SL transformation is interpolating the spatially discrete topographical information. The non-realistic displacement of non-foreshore points results on inferior relative accuracy and geometrical fidelity than original WL. The above is valid for both, SL-OPT and SAR.

Minimum cell size (or mapping unit)

The skills of SL detecting change at Happisburgh (**Figure 3.20**, **Figure 3.21**) has been found to be consistent with OS MasterMap revision policy on the Coastal zone the minimum change mapped due to natural erosion and deposition in the coastal zone is the one resulting in a change of alignment of more than 10 m over a length of more than 100 m for the following coastal features when well defined; Top and bottom of cliffs; and Coastal slope limits.

Information layers

The SL product received contains information in the metadata of the Spatial Reference System used and we were able to transform it to our desired SRS which for the is: EPSG 277000 British National Grid.

Error lines; Lines that have errors (for instance not closed rings or self-intersections) were NOT included in the SL attribute but are available on the original WL.

Date and time; of the image used to delineate the tideline was provided in the metadata

Uncertainty in the elevation of the tide level, elevation due to waves and atmospheric processes and in the horizontal location of the tideline associated to uncertainty on vertical elevations at the time of the image was collected, was not provided in the metadata but this information is known to BGS as we provided the topographical and tidal auxiliary data used to obtain this product (section 2.4.3).

Product format

We requested the format of the product to be provided as GML (Geography Markup Language) and ESRI Shapefile and received them as ESRI shp (SL-OPT and SAR)

Software platform compatibility:

We have found the WL products to be compatible with the following commercial and open source GIS: ArcGIS (v10.7.1) & ArcMap 10.3.1, Quantum GIS v3.12 and SAGA v7.9

Years of interest

We have received data since 1994 (WL-OPT) and 2015 (WL-SAR) which is when first mission data was available

Updating frequency

The frequency of the SL-OPT is of several lines per month which is much higher than the twice per year comparable OS VectorMap District products. The frequency of the SL-SAR is much higher with an average of 216 lines per year.

Temporal baseline

In England the authority in charge of coastal flooding and erosion policy development is the Department of Food and Rural Affairs (Defra) and uses the 1948 baseline year which correspond with the first Royal Air Force (RAF) aerial imagery available. The WL product baseline is limited to the date of first mission data available which is 1994 (WL-OPT) and 2015 (WL-SAR).

Delivery format

We have received the data via the two requested delivery formats:

- ftp = ftp.adwaiseo.eu, user name = ftp_costal_erosion
- web-service = https://coastalerosion.argans.co.uk/science.html

***L**ow; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			X

Comments:

The overall DATUM TIDELINES OPTICAL & SAR (WL-OPT & SAR) product compliance to the user requirements are evaluated as HIGH.

For the reasons outlined in section B.1. we have scored the different product as service specification as:

Requirement item	**Comment**	**Score**
Spatial scale and product accuracy:	Representative fraction scale equal or inferior that orginal WL due to discrete auxiliary data used and non-constrained transformation of WL to SL (i.e. by vertical cliff face)	M
Minimum cell size (or mapping unit)	Requirements has been met	H
Information layers	Requirements has been met	M

Product format	Requirements has been met	H
Software platform compatibility:	Requirements has been met	H
Years of interest	Requirements has been met	H
Updating frequency	Requirements has been exceeded	H
Temporal baseline	Requirements has been met	H
Delivery format	Requirements has been met	H

*__L__ow; __M__edium; __H__igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The product accuracy compliance to the user requirements has been evaluated as MEDIUM for the reasons outlined below;

The absolute and relative accuracy of SL-OPT and SAR is found to be equal or inferior to the accuracy of the original WL from which the SL has been derived from. The cause of the inferior absolute accuracy of the SL is directly related to the discrete nature (in space and time) of the auxiliary data used to convert the WL to a given SL and to the un-constrained estimation of the SL location. This is more evident on cliffed coast like the one along the East Riding of Yorkshire coast and SL with reference datum above MSL (SL-HAT and SL-MHWS). These SLs are sometimes estimated to be on the top of the cliff which is unrealistic (i.e. the almost vertical face of the cliff should be the mapped as the SL instead). Also, the SL location at non-foreshore points (i.e. their location should be the same for all reference datum) shows different locations because the WL to SL transformation is interpolating the spatially discrete topographical information. The non-realistic displacement of non-foreshore points results on inferior relative accuracy and geometrical fidelity than original WL. The above is valid for both, SL-OPT and SAR.

*__L__ow; __M__edium; __H__igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The confidence in the product quality (including accuracy) is evaluated by BGS as MEDIUM for the reasons outlined below.

The transformation from WL to SL has no constrain on the landward location of the SL which, for the SL with reference datum above MSL on cliffed coast might result on unrealistic SL landward location.

Service providers has provided a quality score indicating their level of confidence on the WL from which the SL are derived but these quality scores have not been exported to the derived SL.

Very High Resolution images for the co-registration process has been used (section 2.4.1)

The products have shown able to capture a range of observed coastal change (cliff erosion and beach accretion) at the study locations (Happisburgh)

*__L__ow; __M__edium; __H__igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*

	L	M	H
			X

Comments:

The utility of the SL products is evaluated by BGS as HIGH for the reasons outlined below.

The motivation of BGS requesting this product was to produce proxy waterlines that are consistent with the tidelines mapped by the UK Ordnance Survey (OS) on the County Maps, and the more recent (since 2015) OS VectorMap District Tidal boundaries[18]. Different nations within UK use different definitions of tidelines or tidal boundaries. In Scotland, Ordnance Survey (OS) maps consistently shows high and low water marks for ordinary spring tides, which “generally occur the third of fourth tide after new or full moon” as the main tidelines. In England and Wales, the tide lines mapped on the OS County Series maps has changed over time but since about the 1970s the OS has mainly provided tide line data from aerial surveys preferably using black & white infrared film as this shows the water/foreshore interface more clearly. Admiralty tide tables were examined to find high and low tides which were within ± 0.3metres of MHW and MLW.

The utility of the SL as evaluated high because it has a level of accuracy comparable to the OS VectorMap district and has been provided a tidelines relative to the end user requested reference elevations (HAT, MHWS, MSL, MLWS, LAT).

Additionally, we have found SL-MSL is able to detect the shoreline changes near vertical soft cliff and fast eroding coast of Happisburgh.

*Low; Medium; High

Impact of the service and products on current end-user practices	Evaluation*		
	L	M	H
			X

Comments:

The impact of the service and SL products on current end-user practices is evaluated as HIGH mostly due to the high updating frequency that this product offers compared to existing practices.

The comparable OS VectorMap tidal boundaries are only updated twice per year, while the updating frequency of the SL-OPT is several times per month (number subject to cloud coverage for optical) and in excess of 200 lines per year for the SL-SAR. This updating frequency has the potential to produce more accurate coastal recession rates for the whole Great Britain by revisiting the historical database since 1994 until present. It also offers the opportunity of assessing coastal change at weekly time scale O(7 days) which is two order of magnitude faster than the current update frequency.

*Low; Medium; High

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	M	H
			X

Comments:

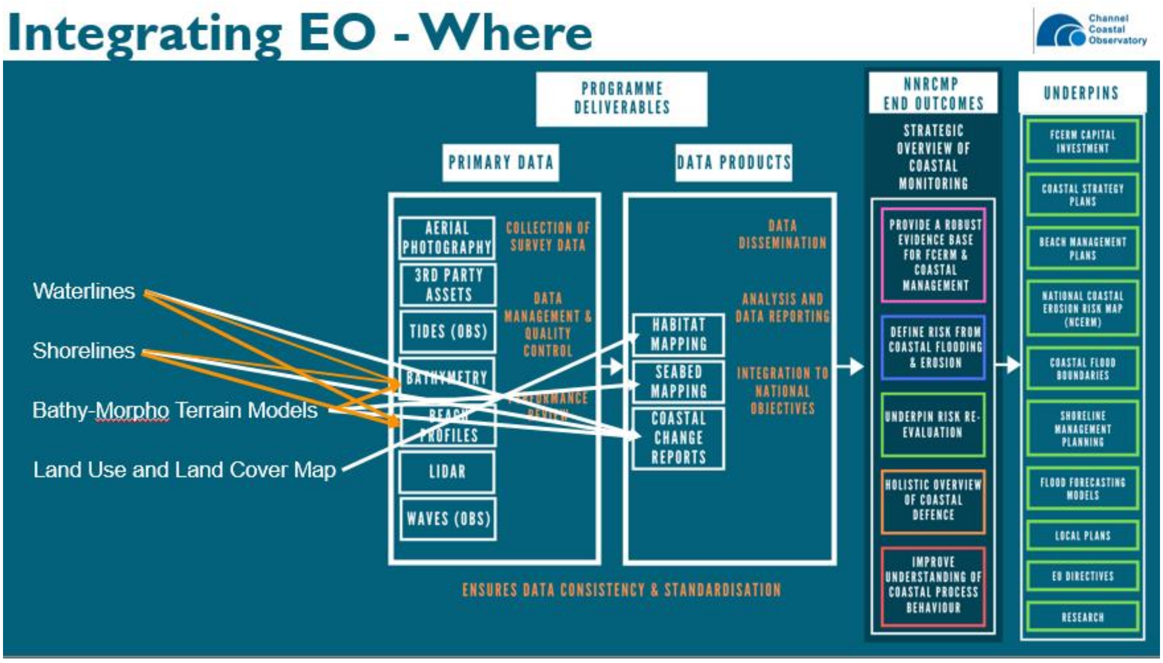
The probability of service integration into existing practices has been evaluated by BGS as HIGH.

The study sites selected for the demonstration of the products in the UK has been selected in collaboration with the England regional coastal monitoring program leaders. The sites were selected because they all are actively changing due

[18] https://digimap.edina.ac.uk/webhelp/os/data_files/os_manuals/os-vector-map-user-guide.pdf

to coastal erosion and have a data gap that BGS and the consulted end-users were interested on assessing if this product could potentially help filling.

The SL products are very close to be at the maximum level of technology readiness level (TRL9)[19]. At present the SL TRL is assessed to be at TRL7 or inactive commissioning level: product has been tested and factory trials done using inactive simulants comparable to that expected during operations. To reach the maximum operational level (TRL9) will need first to go through active commissioning (TRL8). Before this active commissioning can be roll-out the question of how this new technology should be integrated within all other current coastal erosion monitoring activities need careful consideration. This specific question was addressed during the third session of the UK national workshop and full discussion is available here https://bgscoastalerosion.siteonsite.es/. The slide below was presented by the Coastal Channel Observatory director as an attempt to map the products produced within the current monitoring activities in England.



BGS is actively seeking the progression to TRL8 via; (1) providing geo-scientific advice to our stakeholders, (2) internal national capability funding to continue the validation and evaluation of all products received and (3) leading a proposal that has brought together UK engineering consultants and researchers to develop a methodology to assess historical coastal change in England and Wales for Defra. If successfully funded, this proposal will provide the appropriate discussion platform to effectively integrate the SL products in not only BGS existing practices but more broadly among UK end-users community.

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
			X

Comments:

We have HIGH interest on continue improving the SL-OPT and SAR service and product.

An obvious improvement of the product will be the inclusion of the quality scores used on the original WL from which the SL has been calculated into the SL layer information. An additional quality score for SL is required indicating the distance along the line and source of the auxiliary data (topographical and tidal) used to calculate the SL from the original WL.

[19] www.gov.uk/government/news/guidance-on-technology-readiness-levels

Related with the previous comment, the service could be improved by defining the minimum auxiliary data required and format standard to make the service more operational.

The service could also be improved by constraining the landward location of the datum SL, for example using the Littoral Line derived from the backshore classification map. The littoral like has found to accurately delineate the edge of the cliff and could be used as a constrain.

*Low; Medium; High

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			X

Comments:

The need for a large-scale service/product demonstration is HIGH.

The mandate of monitoring coastal change due to coastal erosion is devolved in the UK (England, Wales and Scotland, Ireland). The service and product demonstration provided by this project has focussed mostly in England who has the longest coastal monitoring program of all nations. As BGS provides geoscientific advice to all nations, we would like to extend the service and product demonstration to the other UK nations (Wales, Scotland and North Ireland). All nations suffer from coastal erosion at present and are likely to continue suffering the impact of coastal erosion in the future. As each nation has different coastal environments, regulations and access to auxiliary data this extension will allow BGS to effectively assess the adequacy of this new products to the whole UK territory.

*Low; Medium; High

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The overall service and product performance are evaluated by BGS as MEDIUM for the reasons expressed on sections B.1 to B.4 and summarized below.

The SL has shown to have accuracies equal of inferior to the original WL from which has been derived. Although the accuracy requirements for waterline products specified in the URD end-user in the URD were not accomplished, those requirements were mainly aspirational, and the products are still useful for many of the purposes of BGS's practices (i.e. SL-MSL has been able to capture beach erosion near a vertical cliff and beach accretion).

Required updating frequency of shorelines have been fully accomplished. The required updating frequency specified in the URD was from events scale (pre and post storms) to monthly scale and this requirement have been accomplished. The variation on the number of products among sites, is not due to changes on the frequency feasibility but on the limited project time to produce all possible products. The frequency of SAR SL production is much higher than requested with an average of 216 lines per year.

Required temporal range of waterlines have been accomplished. The URD specified 25 years of historical record has been reached for the optical shorelines that covers a period starting in 1994 to 2020.

Quality control indexes were developed and provided for WL from which SL are derived but has not been included in the SL. These indexes were required by the end-users and allow the automatic identification of the shorelines that may be the result of detection errors.

*Low; Medium; High

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			X

Comments:

This product is highly valued by BGS and the consulted broader end user community within the UK.

By including the end-users requirements as the main driver for the product design and production this has been a truly problem driven project (not a technology push project) which has resulted in products at TRL7 and very close to become operational in the UK.

As the lead of BGS Coast and Estuaries research program, I see the value of these products (SL-OPT and SAR) and I am actively seeking the active commissioning of this service that will allow this product to progress to TRL8 and eventually become fully operational (TRL9).

SL product and service could have been highly valued on accuracy and utility should the recommended product and service improvements are implemented.

The mandate of monitoring coastal erosion is devolved among the UK nations but we have mostly focussed on England study cases. Allowing the extension of the service and product demonstration to a few study sites the other UK nations (Wales, Scotland and North Ireland) will provide evidences for sites across all UK territories facilitating the progression of TRL level.

*Low; Medium; High

BATHY-TOPO MORPHO TERRAIN MODEL (BTMT)

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
	X		

Comments:

The adequacy to the BGS-URD requirements for the BTMT product are evaluated with LOW score for the following reasons:

<u>Spatial scale and product accuracy</u>

The end user required a seamless (i.e. no data gaps between topography and bathymetry) Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore) but the product received only includes the foreshore and nearshore. Product accuracy was scored

The qualitative side-by-side visual comparison, and the semi-quantitative DEMs of Difference assessment demonstrated that the vertical accuracy of the BMTM depths within the Chesil Beach study area is generally poor, and considered unreliable for surveying continuous areas of seabed in an accurate, reliable manner. A preliminary view of the Spurn Head study area suggested similar findings, if not more affected by turbidity in the water column.

<u>Minimum cell size (or mapping unit)</u>

A minimum cell size of 5 m was requested as desirable but the provided maps with 10 m cells was also considered valid.

<u>Information layers</u>

The SL product received contains information in the metadata of the Spatial Reference System used and we were able to transform it to our desired SRS which for the is: EPSG 277000 British National Grid.

Quality flag for Bathymetry product were provided on the metadata. Where quality flag value is 0.0 = Land/No data; 1.0 =Good depth values according to SPM and COM concentrations; 2.0 = Medium quality values according to medium concentrations of SPM and CDOM, 3.0 = no good depth values according to high SPM and CDOM concentrations and negative reflectance values.

<u>Product format</u>

We requested the valid format for the BTMT to be any of the following ASCII, TIFF & GeoTIFF uncompressed and compressed (LZW, ZIP) and we have received GeoTIFF and metadata as GeoJSON which are considered compliant.

Software platform compatibility:

We have found the WL products to be compatible with the following commercial and open source GIS: ArcGIS (v10.7.1) & ArcMap 10.3.1, Quantum GIS v3.12 and SAGA v7.9

Years of interest

Requested historical data has not being produced due to lack to cloud free images and low turbidity values.

Updating frequency

The frequency requested were aspirational ranging from monthly to five years has not been met.

Delivery format

We have received the data via the two requested delivery formats:

- ftp = ftp.adwaiseo.eu, user name = ftp_costal_erosion
- web-service = https://coastalerosion.argans.co.uk/science.html

*Low; Medium; High

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	X		

Comments:

The overall BTMT product compliance to the user requirements are evaluated as LOW.

For the reasons outlined in section B.1. we have scored the different product as service specification as:

Requirement item	Comment	Score
Spatial scale and product accuracy:	Accuracy levels too low for sediment volume change analysis	L
Minimum cell size (or mapping unit)	Requirements has been met	H
Information layers	Requirements has been met	H
Product format	Requirements has been met	H
Software platform compatibility:	Requirements has been met	H
Years of interest	Requirements has not been met	L
Updating frequency	Requirements has not been met due to cloud coverage limiting to less than one image per month	L
Delivery format	Requirements has been met	H

*Low; Medium; High

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	X		

Comments:

The product accuracy compliance to the user requirements has been evaluated as LOW due to the poor accuracies obtained for the UK study cases.

*Low; Medium; High

Confidence in the product quality (including accuracy)	Evaluation*

	L	M	H
			X

Comments:

The confidence in the product quality (including accuracy) is evaluated by BGS as HIGH because service providers has provided a quality score indicating their level of confidence that match our qualitative assessment of the products received. We have therefore a high-level confidence on the quality of the BTMT product been correctly scored as poor.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	M	H
	X		

Comments:

The utility of the BTMT products is evaluated by BGS as LOW due to the poor accuracies obtained for the UK study cases.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	M	H
	X		

Comments:

The impact of the service and SL products on current end-user practices is evaluated LOW due to the poor accuracies obtained for the UK study cases.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	M	H
	X		

Comments:

The probability of service integration into existing practices has been evaluated by BGS as LOW due to the poor accuracies obtained for the UK study cases.

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	M	H

			X

Comments:

We have HIGH interest on continue improving the BTMT product.

For the Start Bay study case we have shown how useful these seamless topo-bathymetric models are to better understand the nearshore sediment budget changes on sediment starving coastlines such as the UK coastline.

The BTMT service developed on this project has been proven useful on places with clear water and limited cloud coverage (from study cases in Spain) but is clearly not appropriate for the UK coast with high turbidity and all year around cloud coverage.

*Low; Medium; High

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			X

Comments:

The need for a large-scale service/product demonstration is still HIGH.

Should the BTMT service and product significantly improved for the type of atmospheric conditions and turbidity levels that we have along the UK coastline, our interest on demonstrating this product at large scale is still high. To be clear, we are convinced that the current version of the BTMT is not appropriate for UK coastal environment but our need of developing a service and product able to produce seamless topo-bathy metric model still high.

*Low; Medium; High

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
	X		

Comments:

BTMT has received a LOW score on the overall evaluation for the following main reasons;

The end user required a seamless (i.e. no data gaps between topography and bathymetry) Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore) but the product received only includes the foreshore and nearshore. The raster BTMT product received contains 5 bands with different elevation metrics (Band 1: Z_mean; Band 2: Z_median; Band 3: Z_90pct_min; Band 4: Z_90pct_max; Band 5: Z_90pct_range) with all elevation relative to the surface elevation at the time of satellite image from which the BTMT has been derived.

The accuracy requirements for bathymetric products (0.1 m vertical, 1 m horizontal) were aspirational and has not been accomplished due to turbidity levels being too high for the UK study sites.

The frequency required for this EO Product (monthly) was not meet due to cloud coverage and high turbidity values. There were not enough good images per month for the UK study sites at Start Bay, Chesil beach and Spurn Head to meet the requested frequency. The BTMTs provided for which cloud coverage was good enough has been found to have to high turbidity values to extract bathymetry changes with confidence.

Quality control indexes were developed and provided for each product: these indexes, required by the end-users during the project, allow the automatic identification of the bathymetries that may represent erroneous values.

*Low; Medium; High

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			X

Comments:

While the BTMT product has been scored low on the overall evaluation**, the need for seamless topo-bathymetric models of the nearshore remains HIGH** to better manage the risk of coastal erosion along the UK coastline. A good example, is the Start Bay study case where we have shown how useful these seamless topo-bathymetric models are to better understand the nearshore sediment budget changes on sediment starving coastlines such as the UK coastline.

***L**ow; **M**edium; **H**igh

LITTORAL LINE & BACKSHORE CLASSIFICATION MAPS

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The adequacy to the BGS-URD requirements for both the Littoral Lines (LL) and Backshore classification map (LC) products are described here together (LL are derived from LC) and has been evaluated with MEDIUM score for the following reasons.

Spatial scale and product accuracy

Metadata and attributes descriptions provided facilitates user confidence assessment. A confusion matrix has been provided as part of the metadata of the backshore classification map. Adequacy of land uses and coverage have been partially accomplished (i.e. tuned to better resolve the intertidal area) and classes description has bee provided. BGS required classes descriptions similar to the Environment Agency habitat descriptions for CASI and LIDAR habitat maps but assumed that some modification might be needed. The habitat descriptions provided were: Urban; house; Crops1; Crops2; Forest; Sandy Beach; Rocks; Mudflats; Sea. These classes seem a good trade-off between classes required and what it was feasible. The intermediate raster habitat map has been provided (i.e. not the vector format requested) but this format has found good enough for the analysis of backshore type along the littoral line.

Minimum cell size (or mapping unit)

A minimum cell size of 5 m was requested as desirable but the provided maps with 10 m cells was also considered valid.

Product format

We requested the valid format for LL and LC to be ESRI Shape file have received the LL as ESRI shp and LC as GeoTIFF which we also considered compliant.

Software platform compatibility:

We have found the WL products to be compatible with the following commercial and open source GIS: ArcGIS (v10.7.1) & ArcMap 10.3.1, Quantum GIS v3.12 and SAGA v7.9

Years of interest

Delivery format

We have received the data via the two requested delivery formats:

- ftp = ftp.adwaiseo.eu, user name = ftp_costal_erosion
- web-service = https://coastalerosion.argans.co.uk/science.html

***L**ow; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**

		X	

Comments:

The overall LL and LC product compliance to the user requirements are evaluated as MEDIUM.

For the reasons outlined in section B.1. we have scored the different product as service specification as:

Requirement item	**Comment**	**Score LL/LC**
Spatial scale and product accuracy:	Representative fraction scale equal or inferior that orginal WL due to discrete auxiliary data used and non-constrained transformation of WL to SL (i.e. by vertical cliff face)	M
Minimum cell size (or mapping unit)	Requirements has been met	H
Information layers	Requirements has been met	M
Product format	Requirements has been met	H
Software platform compatibility:	Requirements has been met	H
Years of interest	Requirements has been met	H
Updating frequency	Requirements has been exceeded	H
Temporal baseline	Requirements has been met	H
Delivery format	Requirements has been met	H

*__L__ow; __M__edium; __H__igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		X	

Comments:

Product accuracy compliance has been evaluated with MEDIUM score.

Confidence on the delineation of the littoral line is high but medium for the backshore classification maps. A visual inspection of the LL for year 2018 suggested that the LL delineates the edge of the foreshore and backshore correctly but the backshore classification map shows significant variation between year 2018 and year 2019 that seems to be attributed to the classifier errors instead of actual changes of the backshore type. As we did not have the LL for year 2019 to assess how changes on the classification might have affected to the LL location, we have evaluated both (LL and LC) with medium score.

*__L__ow; __M__edium; __H__igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
			X

Comments:

The confidence in the product quality (including accuracy) is evaluated by BGS as HIGH because service providers has provided an appropriate quality score in the form of confusion matrix indicating their level of confidence that match our qualitative assessment of the products received.

*__L__ow; __M__edium; __H__igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The confidence in the product utility is MEDIUM.

Confidence on classification results is high for littoral line but medium to backshore classification maps. A visual inspection of the LL for year 2018 suggested that the LL delineates the edge of the foreshore and backshore correctly but the backshore classification map shows significant variation between year 2018 and year 2019 that seems to be attributed to the classifier errors instead of actual changes of the backshore type. As we did not have the LL for year 2019 to assess how changes on the classification might have affected to the LL location, we have evaluated both (LL and LC) with medium score.

*__L__ow; __M__edium; __H__igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
			X

Comments:

The impact of this service and product on current end-user practices is evaluated as HIGH as it provides useful information on the type of backshore being eroded historically which is at present missing for most of the UK coastline.

*__L__ow; __M__edium; __H__igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
			X

Comments:

The probability of service integration into existing practices has been evaluated by BGS as HIGH for the same reasons already outlined for the WL and SL products which are not repeated here.

*__L__ow; __M__edium; __H__igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
			X

Comments:

We have HIGH interest on continue improving the LL service and product.

We still need to validate if the LL can confidently capture the changes of the interface between the foreshore and backshore. To do so we need to improve the consistency of the backshore classification algorithm between years and produce a longer time series of LL to assess it skills detecting coastal change.

Additionally, the LL service could be used to improve the SL service and product by constraining the landward location of the datum SL.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			X

Comments:

The need for a large-scale service/product demonstration is HIGH.

The analysis presented here is limited by the number of LL and LC produced and will benefit from extending the service and products produced, at least temporally at same study areas already selected in England.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		X	

Comments:

Littoral lines (LL) and backshore classification maps (LC), has received a MEDIUM score on the overall evaluation for the following main reasons;

LL and LC frequency requirements has been met. The requested updating frequency was aspirational and varies from one month to a year. We have received a littoral line for year 2018 and yearly backshore maps for two years.

Confidence on the delineation of the littoral line is high but medium for the backshore classification maps.. A visual inspection of the LL for year 2018 suggested that the LL delineates the edge of the foreshore and backshore correctly but the backshore classification map shows significant variation between year 2018 and year 2019 that seems to be attributed to the classifier errors instead of actual changes of the backshore type. As we did not have the LL for year 2019 to assess how changes on the classification might have affected to the LL location, we have evaluated both (LL and LC) with medium score.

Metadata and attributes descriptions provided facilitates user confidence assessment. A confusion matrix has been provided as part of the metadata of the backshore classification map. Adequacy of land uses and coverage have been partially accomplished (i.e. tuned to better resolve the intertidal area) and classes description has bee provided. BGS required classes descriptions similar to the Environment Agency habitat descriptions for CASI and LIDAR habitat maps but assumed that some modification might be needed. The habitat descriptions provided were: Urban; house; Crops1; Crops2; Forest; Sandy Beach; Rocks; Mudflats; Sea. These classes seem a good trade-off between classes required and what it was feasible. The intermediate raster habitat map has been provided (i.e. not the vector format requested) but this format has found good enough for the analysis of backshore type along the littoral line.

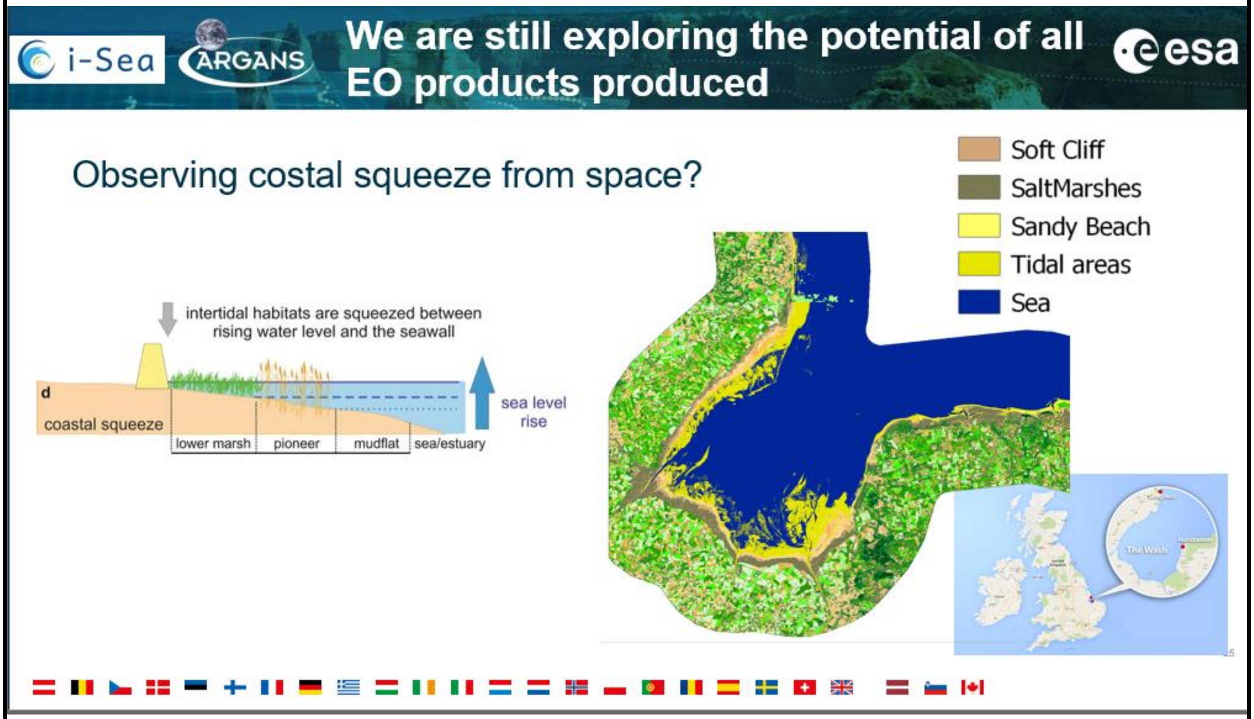
***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			X

Comments:

This product is highly valued by BGS and the consulted broader end user community within the UK.

As presented at the ESA Webinar (see slide below), we see great potential of this product to assess the historical coastal squeeze that has been sparsely monitored across the UK and LL and LC product has the potential to better assess these changes. This will require more interaction between the service providers and end users to be able to assess this application.



*Low; Medium; High

Glossary

ARCTUS	is a private R&D company providing research, development and applications in remote sensing, Earth Observation (EO) and Geographical Information System (GIS) technologies for governmental agencies, scientific communities and the general public. Enrolled End-User from Québec.
ATBD	Algorithm Theoretical Basis Document
BGS	British Geological Survey. Enrolled End-User from the United Kingdom and End-Users champion.
BSS	Brier Skill Score
Enrolled End-Users	Team members of the Coastal Change from Space Consortium representing the EO end-user community which includes: BGS, GSI, SGPC-IHC, ARCTUS.
EUVD	End User Validation Document (i.e. this document)
GSI	Geological Survey of Ireland. Enrolled End-User from the Republic of Ireland.
IHC	Instituto de Hidráulica Ambiental de la Universidad de Cantabria. Enrolled End-User from Spain and technical assistant of SGPC.
LULC	Land Use and Land Cover maps. An intermediate product used to produce Proxy-Based shorelines.
MAE	Mean Absolute Error
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MSL	Mean Sea Level
PVP	Product Validation Plan
SDB	Satellite Derived Bathymetry.
SDBTM	Satellite Derived Bathymetry/Topography Model
SDER	Satellite Derived Erosion Rate
SDF	Satellite Derived Features
SDSL	Satellite Derived Shore Lines. Also known as Datum-Based shorelines
SDST	Satellite Derive Sediment Transfer
SDW	Satellite Derived Waterlines. Also known as Proxy-Based shorelines. Can be from RADAR images (SAR) or OPTICAL images (OPT).
Service Providers	Team members of the Coastal Change from Space Consortium in charge of EO production which includes: ARGANS, adwäisEO and IsardSAT.
SGPC	Subdirección General para la Protección de la Costa. Enrolled End-User from Spain. SGPC is a government agency and technically assisted by IHC.
SOW	Statement of Work document.
VNIR	Visible and Near Infra-Red

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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