Coastal Erosion from Space

Coastal Erosion time series in Happisburgh (GB)

Coastal Erosion events:

in Nerja (Spain) *in Kilkee (Ireland)* *in St Laurent mouth (Canada)*

Products Validation Plan

Ref: SO-TR-ARG-003-055-009-PVP

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Customer: ESA

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Applicable and reference documents

Id	Description	Reference
AD-0	User Requirement Document	TR_CR_19_055
AD-1	Requirement Baseline Document	SO-RP-ARG-003-055-006-RBD_v2
AD-2	Preliminary sites selected for validation	SO-TR-ARG-003-055-009-PVP-A4
AD-3	Annex 1- Written feedback from broader end user community regarding URD	SO-TR-ARG-003-055-009-PVP-A9
AD-4	Annex 2 – Summary of Validation and evaluation for EO product	SO-TR-ARG-003-055-009-PVP-A1
AD-5	In-situ information for validation – Canada	SO-TR-ARG-003-055-009-PVP-A5
AD-6	In-situ information for validation – Ireland	SO-TR-ARG-003-055-009-PVP-A6
AD-7	In-situ information for validation – Spain	SO-TR-ARG-003-055-009-PVP-A7
AD-8	In-situ information for validation – UK	SO-TR-ARG-003-055-009-PVP-A8

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Introduction

The scope of this document is to describe the process and the schedule of the validation and the evaluation of the different processors and products from the Coastal Erosion project. This is the first version of this document, it will be update according to the end-users possibilities and requirements.

To assess precisely the use of EO observation for coastal management, the obtained EO products precision and quality need to be quantified and compare to previous studies and surveys. Therefore, consistency with information and data held by national authorities is essential to allow any comparison.

In the following sections will be presented first the definitions and the concepts within the Validation process, the specifications of processors verification and products validation from the CE project perspective and the final section will present the plan and the schedule to ensure the unbiased validation of CE products and verification of CE processors.

1 Concept and definitions

1.1 Validation protocol – a multi-step process of conformity checking's

Figure 1.1 illustrate validation protocol approached by the Coastal Change Consortium as a multi-step conformity checking process performed by both the Service Providers and the End Users. The validation protocol is the protocol for assessing the degree to which the 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 on the proposed validation protocol are: verification, quality control, validation and evaluation:

1. During the verification step, Service Providers will check that the EO data processors are in conformity with the technical specifications (ATBDs). End-users have contributed to the verification process by reviewing and providing feedback on the ATBDs during phase 1.
2. During Quality Control, the service providers will check that the EO products meets a minimum set of expected requirements (detailed below) of the different EO products.
3. Validation will be performed independently by both, the Service Providers and the End-Users. Validation of the EO products by the service providers will be performed against the requirements outlined in Table 1.2 while Validation and Evaluation of EO products performed by End-Users will be performed against the requirements outlined on the URD for each product. This twofold validation is considered central to ensure impartial assessment of the EO products validity.

Evaluation is the final check where the end users check the conformity of the EO products with their own expectations and including feed-back from a broader end-user community in the UK, Spain, Ireland and Quebec. Evaluation is defined by ESA at the SOW as the user's assessment of the products and will require answering the questions under the main 5 themes detailed in SOW-Annex B.

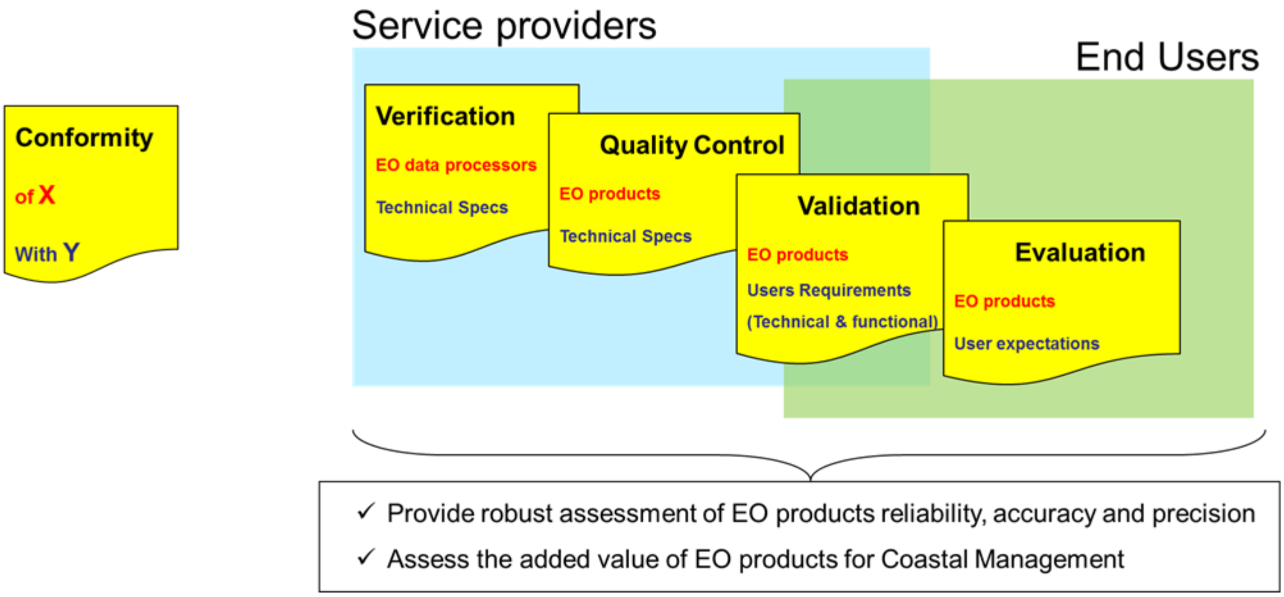

Figure 1.1: Validation protocol is approached here as a multi-step conformity checking process done by both the Service providers and End-Users.

1.2 EO Products to be validated and evaluated

The full list of EO products requested by the end-users were listed in Table 2 on the URD (AD-0) and are not repeated here. Table 1.1 shows the full list of EO products description to be QCed and validated, then evaluated, as well as the data processors which deliver them, to be verified. The End-users have specified the levels of accuracy and resolution desirable for each of their products (Table 2 URD) which were considered aspirational. The service providers have outlined the requirements of what they considered is feasible to achieve at present for each one of the EO products and summarize it on Table 1.2.

Table 1.1: List of EO products with their description

EO products naming	Description	processor
CE_ARG_**area**_L2_1D_OB_WL_**sensor**_**date**.shp	: Observed waterline from a single optical snapshot for a specific area and date	SDW-OPT
CE_SAT_**area**_L2_1D_OB_WL_S1_**date**.shp	: Observed waterline from a single Sentinel-1 snapshot for specific area and date	SDW-SAR
CE_ARG_**area**_L2_1D_DB_SL_MHWS_**date**.shp	: Corrected waterline to MHWS (mean high water spring)	SDS
CE_ARG_**area**_L2_1D_DB_SL_MSL_**date**.shp	: Corrected waterline to MSL (Mean Sea Level)	SDS
CE_ARG_**area**_L2_1D_DB_SL_MLWN_**date**.shp	: Corrected waterline to MLWN (Mean Low Water Neap)	SDS
CE_ARG_**area**_L3_1D_DB_SL_MHWS_**date**_**date**.shp	: Time-series of corrected waterline into MHWS	SDS
CE_ARG_**area**_L3_1D_DB_SL_MSL_**date**_**date**.shp	: Time-series of corrected waterline into MSL	SDS
CE_ARG_**area**_L3_1D_DB_SL_MLWN_**date**_**date**.shp	: Time-series position of the MLWN	SDS
CE_ARG_**area**_L2_3D_BT_SDB_**sensor**_**date**.tif	: Bathymetry chart from a single optic EO product (classic SDB)	SDBTM
CE_ARG_**area**_L3_3D_BT_SDB_**sensor**_**date**_**date**.tif	: Time-series & merged chart from several SDB / optic EO products	SDBTM
CE_SAT_**area**_L2_3D_BT_WF_**sensor**_**date**.**XXX**	: Seafloor morphology and depth from a wave field analysis from a single SAR snapshot	SDBTM
CE_SAT_**area**_L3_3D_BT_WF_**sensor**_**date**_**date**.**XXX**	: Time series of seafloor morphology and depth from a wave field analysis of SAR snapshots	SDBTM
CE_ARG_**area**_L2_3D_BT_WF_**sensor**_**date**.**XXX**	: Seafloor morphology, incl. depth & slope from a wave field analysis of a single optical EO snapshot	SDBTM
CE_ARG_**area**_L3_3D_BT_WF_**sensor**_**date**_**date**.**XXX**	: Time series of seafloor morphology, incl. depth & slope from a wave field analysis of optical EO snapshots	SDBTM
CE_ARG_**area**_L4_3D_BT_SDB_WF_**sensors**_**date**_**date**.tif	: Seafloor morphology and depth from a fusion between SDB chart and wave field analysis from a time series	SDBTM
CE_ARG_**area**_L2_2D_FB_LULC_**sensor**_**date**.shp	: LULC map from a single EO product	SDF
CE_ARG_**area**_L2_1D_FB_LL_**date**.shp	: Littoral line (between backshore and littoral) extracted from a LULC map from a single EO product	SDF
CE_ARG_**area**_L2_1D_FB_SF_**date**.shp	: Seafront line (just in case of an inter zone) from a LULC map from a single EO product	SDF
CE_ARG_**area**_L3_2D_FB_LULC_**sensor**_**date**_**date**.tif	: LULC map from a time series of EO optical products	SDF
CE_ARG_**area**_L3_1D_FB_LL_**date**_**date**.shp	: Littoral line (between backshore and littoral) extracted from a LULC map from a time-series	SDF
CE_ARG_**area**_L3_1D_FB_SF_**area**_**date**_**date**.shp	: Seafront line (just in case of an Inter zone) from a LULC map from a time series	SDF
CE_ARG_**area**_L5_3D_ER_SL_**area**_**date**_**date**.**XXX** CE_ARG_**area**_L5_3D_ER_SDBTM_**area**_**date**_**date**.**XXX**	: Volume changes on the littoral between two observation time	SDER

LULC: Land Use / Land Cover
SDW: Satellite Derived Waterline based on both VNIR and SAR analysis
SDF: Satellite Derived Features derived from the feature classification process.
SDBTM: Satellite Derived Bathymetry/Topography Model which will incorporate SAR Wave Field Analysis
SDS: Datum Referenced Satellite Derived Shoreline
SDST: Satellite Derive Sediment Transfer
SDER: Satellite Derived Erosion Rate based on a Stochastic Estimation of Erosion Rates

Table 1.2: 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

1.3 Validation framework adopted by the Coastal Change Consortium

Validation process supplies the evidence that a product, a service meets the users' requirements. From an Earth observation perspective, different validation approaches exist if users are from space agencies or public organizations. Space agencies like ESA and NASA are keen on demonstrating that remote-sensing products are reliable to access Earth measurable information whereas public organisation like USGS rather are interested in the demonstration of the use of EO derived information to access new worthy Earth phenomena validated by consistency checks. If validation from space agency is connected to calibration, for public organisation it is more linked with Quality control. IEEE accepted definition describes **validation as the assurance that a product, service or system meets the need of the customer and other identified stakeholders**. It often involves acceptance and suitability with external customers[1].

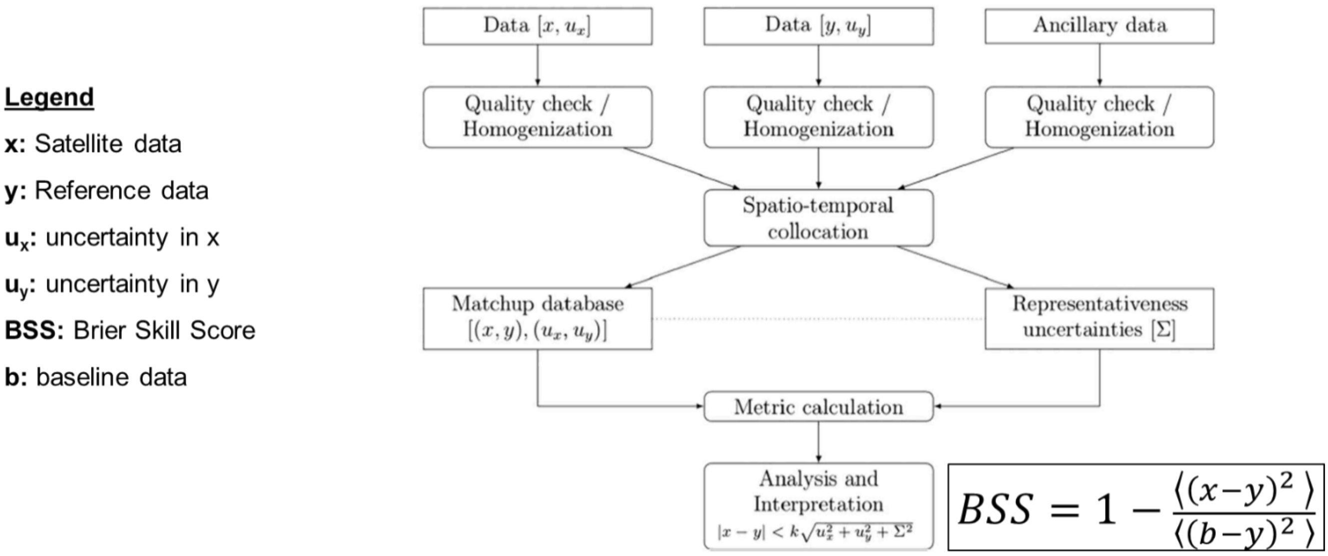

Figure 1.2: Schematic overview of general validation process adopted by the Coastal Change Consortium (after Loew *et al.* 2017). BSS stands for Brier Skill Score (i.e. Sutherland *et al.*, 2004)

[1] Rose, K.H. (2013), A Guide to the Project Management Body of Knowledge (PMBOK® Guide)—Fifth Edition. Proj Mgmt Jrnl, 44: e1-e1. doi:10.1002/pmj.21345

Figure 1.2 shows the general validation process adopted by the Coastal Change Consortium. The adopted framework is an extension of the framework proposed by Loew *et al.* (2017). 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 Loew *et al.* (2017) within most communities, detailed validation protocols have been established, tailored to the specific products and validation aims but all follows 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 (i.e. Sutherland *et al.* 2004), 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.

1.4 Validation sites

End users has identified a number of potential validation sites on each area of interest. It is important to notice that in all cases the area of interest is larger than the selected validation sites. **The area of interest for BGS, GSI, MITECO and ARCTUS covers the whole coastal region of UK, Republic of Ireland, Spain and eastern Quebec** (i.e. along the Estuary and Gulf of St. Lawrence). End-users has **pragmatically selected a reduce set of validation sites** (shown in Annex AD-2) as tentative locations where enough knowledge, auxiliary data and reference data exists to allow the validation of the EO products. As we progress validating and evaluating the different products for the case studies selected during phase 1 and also getting the feedback from the broader end user community, these sites are likely to change as the consortium see fit.

2 Service providers: verification, QC and validation

2.1 EO processors verification

The verification process of EO processors is the confrontation of processors and processors' outputs with users' specifications listed in the Technical specification document (TSD).

2.1.1 VNIR Waterline extraction processor

According to the TSD, end-users are interested in a continuous line which characterized the land/sea interface. This line will be extracted from historical optical satellite imageries, to be able to perform a time series analysis.

Table 2.1: Verification tests for the VNIR waterline processor

Specifications	Tests
Continuous line	Automatic detection of the number of segments
Land / water boundary	By eye verification using a RGB NIR image of the position of the extracted waterline
Geographically independent	Extraction on a line over sites of different morphology and land cover.
Independent of weather conditions	Extraction of a waterline during winter / summer and other possible condition
Independent of sea state	Extraction of a waterline at different tide level, waves heights, etc.

2.1.2 SAR Waterline extraction processor

Requirement similar as the VNIR waterline. Test have to be consistent with SAR sensors

Table 2.2: Tests specification for the SAR SDW processor

Specifications	Tests
Continuous line	Automatic detection of the number of segments
Land / water boundary	By eye verification using an RGB NIR image of the position of the extracted waterline.
Geographically independent	Extraction on a line over sites of different morphology and land cover.
Independent weather conditions and time of the day (day/night)	Extraction of a waterline during cloudy / rainy / night and other possible condition
Independent of sea state	Extraction of a waterline at different tide level, waves heights, etc.
Vegetation and other lines	Verify the capability to derive other boundaries when the Land/water boundary gives a clear mismatch but there is a consistency in all the retrieved SAR lines.

2.1.3 Shoreline computation processor

Processor is computing datum-based shoreline indicators between the Mean High-Water mark (MHW) and Mean Low Water mark (MLW) from the waterlines. Auxiliary data will be analysed to calculate positions of the tide based datums based upon the position of the waterline.

Verification process could be performed using known tidal datum shoreline indicators provided by the users.

2.1.4 Features classification and littoral limits extraction

Processor need to realize a classification map of the different areas of interest.

From those classification maps, line for backshore characterization will be extracted.

Table 2.3: Test specification for the SDF processor

Specifications	Tests
Accurate habitats identification	Confusion matrix analysis
Extraction of the boundaries between the different shore habitats	By eye analysis of the lines position

2.1.5 Satellite derived bathy-topo-morphology

Processor is identifying seabed features and depth. Verification is performed through a statistical analysis, analysis of the variance given by the processor. The use of navigation chart and hydrographical surveys will assess a verification of the obtained bathymetric morphology. Comparison of identify cloud/cloud shadow from the processor with other automatic detection methods. Analysis of the obtain uncertainties with sea state (turbidity).

2.1.6 Satellite derived erosion rate processor

Erosion rate obtained from the erosion rate processor will be compare with general study and consistency with common knowledge about coastal erosion rate will be asses.

2.2 Product Verification

Coastal erosion EO-products were supposed to be limited to waterline extraction. Product validation, therefore, was about the detectability of the land/water edge and the true position of the line on maps. However, following end-users' requirements, the Requirement baseline document (RBD) (see ref: SO-RP-ARG-003-055-006-RBD_v1.0_20190916) detailed a catalogue of EO products less straightforward than the waterline. For those products, no equivalent or substitute can be found in ground surveys result as they from instantaneous satellite snapshot. Comparison with in-situ measurement is therefore impossible. Validation checks shall be done in consistency with results from previous surveys. If previous surveys results provide different and complementary information, an intersection of common information is needed in order to perform comparisons.

All EO products should have a measurement model, based on a theoretical or empirical background, which is based on processors' algorithm.

2.2.1 Optical satellite derived waterline

Table 2.4: Validation table of VNIR waterline

<table>
<tr><th rowspan="3">Product</th><th rowspan="3">Quality control</th><th colspan="3">Validation</th></tr>
<tr><th colspan="2">Reference data</th><th>Theoretical truth</th></tr>
<tr><th>Ground truth validation</th><th>Possible checking point</th><th></th></tr>
<tr><td>SDW</td><td>By eye validation of the position of the extracted waterlines – optical and SAR, and assessment of the variance.
Using the same image the waterline (SDW) was computed from, validate by eye whether the overlaid product indeed is at the land-sea interface. Using the same approach, check whether the waterline is not a result of false edges identified between dry and wet sand, or white water and the sea, or features due to suspended sediment and/or nearshore bathymetry.

NOTA: The waterline is extracted at the precise moment, its position is “true” just at the date and time of the image. Using VHR images to validate the true position of a waterline is therefore meaningless.</td><td>For ground truth validation, SDW products and SDS products are not discernable, validation of the waterline implies validation of shoreline position (line position)
It is difficult to get ground surveys information at the exact same time the EO imagery was taken. Both products are comparable if the time range between acquisitions is small and if no high tides, nor storm in between.

Example of ground surveys:
□ GPS measurements
□ Tacheometers acquisition campaign
□ Aerial or ground imagery
□ Video records</td><td>□ Compare waterline position from ground survey with the waterline from SDW processor</td><td>Reference papers</td></tr>
</table>

2.2.2 *SAR satellite derived waterline*

Table 2.5: Validation table of SAR waterline

<table>
<tr><th rowspan="3">Product</th><th rowspan="3">Quality control</th><th colspan="3">Validation</th></tr>
<tr><th colspan="2">Reference data</th><th>Theoretical truth</th></tr>
<tr><th>Ground truth validation</th><th>Possible checking point</th><th></th></tr>
<tr><td>SDW</td><td>The accuracy and precision of the waterlines can be directly measured by computing the distance between the SAR waterlines and a reference shoreline. The bias between them should be related with the accuracy and the variance of that distance with the precision.

The precision of the SAR waterlines depends on the co-registration uncertainty, the speckle and the pixel resolution of the input images.

The accuracy of the SAR waterlines depends on the observation geometry (satellite angle of view vs coastline direction), the variability of the scene (tide effects not corrected at this stage) and other artefacts created by man-made structures.

Additionally, in the metadata of the waterline .json file, there are several parameters that can be used to filter out inaccurate waterlines and outliers.
• threshold level
• image mean intensity</td><td>For ground truth validation, SDW products and SDS products are not discernable, validation of the waterline implies validation of shoreline position (line position)
It is difficult to get ground surveys information at the exact same time the EO imagery was taken. Both products are comparable if the time range between acquisitions is small and if no high tides, nor storm in between.

Example of ground surveys:
□ GPS measurements
□ Tacheometers acquisition campaign
□ Aerial or ground imagery
□ Video records</td><td>□ Compare waterline position from ground survey with the waterline from SDW processor

For some geometries, the retrieved lines will be the boundaries between vegetated areas and sand, as the sand will be connected with the water due to the low reflectivity of both.

The precision of the measurement is a good indicator to point out areas where the retrieved SAR lines can be the proxy of other interesting coastal features such as vegetation boundaries.</td><td>Reference papers</td></tr>
</table>

	• water mean intensity • land mean intensity • date + time* • polarisation mode* • orbit (number) information*			

2.2.3 *Satellite derived shorelines*

Table 2.6: Validation table of SDS

Product	**Quality control**	**Validation**		
		Reference data		Theoretical truth
		Ground truth validation	Possible checking point	
SDS	By eye validation of the position of the shoreline. Use LiDAR surveys of beach area to obtain contours which correspond to specific datum heights. Use aerial imagery taken at a time with the water level as close to the target datum as possible, manually delineate the waterline position to obtain datum-based shorelines (preferably with little wave influence). And compare both lines.	From waterline to shoreline, auxiliary data are needed. Some are provided by end-users and others are read or measured from EO observation.	□ Validation of the true position of the shoreline with waterline. □ Validation of auxiliary data used with in-situ measurements. The slope information may come from bathymetric products or from erosion rate. Thus validation of it will come from SDBTM products validation or from SDER products validation.	Reference papers

			◻ Metric for comparison: root mean square error, Pearson correlation coefficient	

2.2.4 Satellite derived features

Table 2.7: Validation table of SDF

Product	**Quality control**	**Validation**		
		Reference data		Theoretical truth
		Ground truth validation	Possible checking point	
SDF	By eye validation, comparison of habitat localisation with identify features on maps, identify and localised environment from previous study. Comparison of major changes with in-situ knowledge. Validation of littoral and seafront line with cadastral information and civil-work identification. *NOTA: For temporal classification a set of historical data need to be used for the validation.* *A knowledge of historical event (storms, floods) is needed to understand changes identify by the temporal classification maps*	Ground truth validation for features extraction products (classification map and Littoral lines) is done by comparison with maps. Different type of maps available: ◻ Official maps realise ◻ Surveys maps ◻ Thematic maps Maps from EO observations (ARGANS will realise one from VHR and Google Earth information)	◻ Using in-situ knowledge of the area, check the consistency of habitat labels. Do the chosen labels reflect the real land cover? ◻ Using referenced and thematic maps to check the true location of habitats, civil works and littoral limits. ◻ Metrics for validation as Cohen's KAPPA index	Reference papers

2.2.5 *Satellite derived bathy-topo-morphology*

Table 2.8: Satellite derived SDBTM

Product	**Quality control**	**Validation**		
		Reference data		Theoretical truth
		Ground truth validation	Possible checking point	
SDBTM	By eyes comparison or automatics comparison are possible according the type of in-situ data available. For some EO products, seabed can by analysed and mapped by photo-interpreters. Thus, a comparison between SDBTM products and bathymetric charts is possible to control the quality of the products.	Previous surveys used different techniques to assess depths. From Lidar to Multibeam Echo Sounder, bathymetric information was used to produce bathymetric charts. Lidar measurements has just recently been introduced for the determination of the bathymetry so it must still be accurately validated, and the spatial resolution must be good enough to be compared to Sentinel-2 data Electronic Navigational Charts (ENC). These charts are used mainly for navigation so they might not always display the exact depth.	▫ Comparison between SDBTM products and bathymetric charts for validation	Reference papers

2.2.6 Satellite derived erosion rates

Table 2.9: Validation table of SDER

Product	**Quality control**	**Validation**		
		Reference data		Theoretical truth
		Ground truth validation	Possible checking point	
SDER		Previous study about coastal areas monitoring provided some erosion information. Comparison of major changes with in-situ knowledge and analyse the result (How?, why?) Areas characteristics may influence erosion process and may be very different a few meters further. *NOTA: Erosion strongly rely on geological conditions and geomorphology of the areas. As in-situ surveys are very located, we cannot rely on them to assess the truth of our erosion products. However, in an area covered by previous studies and by our products, a comparative study can be conducted to analyses their consistency.*	□ Comparison of volumetric erosion rate with some in-situ measurement, erosion "speed"/ rate from previous study.	Reference papers

2.3 Internal product validation -consistency checks

2.3.1 Methodology

According to the end-users requirement and their knowledge of the different study sites, we have for each country a table which summarize some morphological and semi-quantitative information, i.e. knowledge that should be replicated according to the Brier Skill Score methodology described in section 1.3 and in section 3.1

These tables provide general rib behaviours that we should expect to find with our products for the long periods, and for which the end-users will provide the reference measurements and baseline observations vide the Auxiliary Data files. It will be used as an internal validation process to verify that CE products are align with user expectations, before the end-users perform their own external validations.

2.3.2 Canada

Table 2.10: Canadian sites description

Sites	Historical Knowledge based on ground assessments
Coastal area around the St-Jean River at longue pointe de Mingan	The average historical erosion rate for the case site is considered to be some -1.97 m/year between 1948 and 2005; -1.39 m/y between 2000-2017
Peninsula between the Manicouagan river estuary and the Aux-Outardes river	Erosion rates ranging from -0.1 to -3.6 m / year for about 70 years. For the last decade its erosion rate increase to -7 m/y on the sandy beach.
Pointe au Loup / Cap aux Meules - Îles-de-la-Madeleine - Gulf of St Lawrence	Historical migration rate is -0.70 m/year (1963 to 2008) and the expected rate to 2060 is -1.5 m/year.
Pointe au Loup / Cap aux Meules - Îles-de-la-Madeleine - Gulf of St Lawrence	Historical migration rate is -0.03 m/year (1963 to 2008) and the expected migration rate to 2060 is -0.26 m/year.

For a more detailed description please refer to the additional document AD-5,

ref: SO-TR-ARG-003-055-009-PVP-A5

2.3.3 Ireland

Table 2.11: Irish sites description

Sites	Historical Knowledge based on ground assessments
Dublin Bay	6-7 mm sea level rise per year in Dublin Bay was recorded between the years 2000 and 2016, leading to erosion rates of -0.2 to -0.5 m/y
Rush	-25 m to -30m between 1935 and 2005 +5 to +6m between 2000 and 2005
Ballyconnigar & Raven's point	Raven's spit: accretionary tendency as a response to convergent littoral drift. Coastal area of Ballyconnigar: erosion rates between 0.5 and 1.15 m/yr.
Rosslare	Rosslare spit: erosion tendency as a response to convergent littoral drift. Coastal area: erosion up to 1m/yr.
Waterford estuary	Erosion: -0.61 m/y from 1935 to 1958

For a more detailed description please refer to the additional document AD-6, ref: SO-TR-ARG-003-055-009-PVP-A6

2.3.4 Spain

Table 2.12: Spanish sites description

Sites	Historical Knowledge based on ground assessments
Barcelona and Tordera Delta	Barcelona beach: erosion in the northeast part of the beach (values of 0.7 m/y) and accretion at the southwest. Tordera delta: erosion rates of 1.25 m/y (period 1957-2009)
Port of Castellon and Port of Sagunto	Beaches located in the area: period between 1984-2009: erosion in the north (averaged rates of 1.5 m/y); accretion in the south (averaged rates of 0.8m/y).
Cadiz and Mazagon Beach	Beach of Cadiz: period between 2001-2011: southeast part → erosion up to 1m; Middle part → progradation of 0.3 m. Beach of Mazagón: erosion of circa 30 m (northwest) in the last 20 years.
Salinas	Period 1998-2010: erosion at the west (increasing from west to east, from 0.1 to 3.9 m, respectively), accretion at the eastern part
El Puntal of Santander	Between Punta Rabiosa and Somo →retreat of 2.7-3.3 m/y (1875-2014) Las Quebrantas beach (eastern part) → retreat of 3-3.8 m/y (1875-1985) and of 1m (1985-2017).
San Sebastian	Three urban beaches. All suffering major erosion during winter storms.
Maspalomas	Highest beach erosion rates during winter. Decadal recovery.

	2005-2009: El Ingles beach→ stable Maspalomas beach→ accretion of 60 m. La Bajeta cape→retreat higher than 100m. **Submerged area** between 2000-2007: net erosive trend, values of 1m. Maspalomas beach and the deepest sector eastward of El Inglés beach → highest erosion rates, 2m. East of La Bajeta cape and southward from Maspalomas→ accumulative trends, up to 2m.
Las Canteras	The beach is divided in three sections. Accumulation of sediments blocked by the urban developments in the isthmus that hinder aeolian sediment transport from the west to the east side.

For a more detailed description please refer to the additional document AD-7, ref: SO-TR-ARG-003-055-009-PVP-A7.

2.3.5 United-Kingdom

Table 2.13: UK sites description

Sites	Historical Knowledge based on ground assessments
Perranporth	7 years cycle, erosion from mid-2006 to 2008 and accretion till 2012. Seasonal fluctuation during recovery phase. Second erosion strong erosion event (2013/14), -243m^3/m Different speed process between north and south
Start Bay	Rotational behaviour 2000/2001 winter, loss of 5m over a length of 1000m.

	Significant sediment losses during the 2013/2014 storm event
Kent	Winter 2006, loss of 11000 m^3 of beach material 2013/2014, loss of 12000 m^3 beach material
Spurn Head to Hunstanton	Retreating sectors account for ~50.1 km out of 98.5 km (50.8%) of the 391 coastline, whereas naturally accreting sectors extend for ~25.4 km (25.8%) and artificially 392 (nourished) accreting or stable sectors represent ~23 km (23.4%). Holderness cliffs retreated -28 m between mid-1990 and 2010 Variation from cliff retreat (erosion) of -89.8 m to an accretion of +36.9 m near Spurn Head between 1997 and 2010
Chesil Beach	1982, accretion March 1990, erosion 2013/2014, for Chesil protected, -36m3/m, for natural -124 m3/m

For a more detailed description please refer to the additional document AD-8,

ref: SO-TR-ARG-003-055-009-PVP-A8

3 End-Users: Validation and Evaluation Plan

3.1 Validation activities for EO products

Figure 3.1 summarizes the main validation activities planned by the end users to assess the validity of the different EO products listed in Table 2 of URD (AD-0). 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.

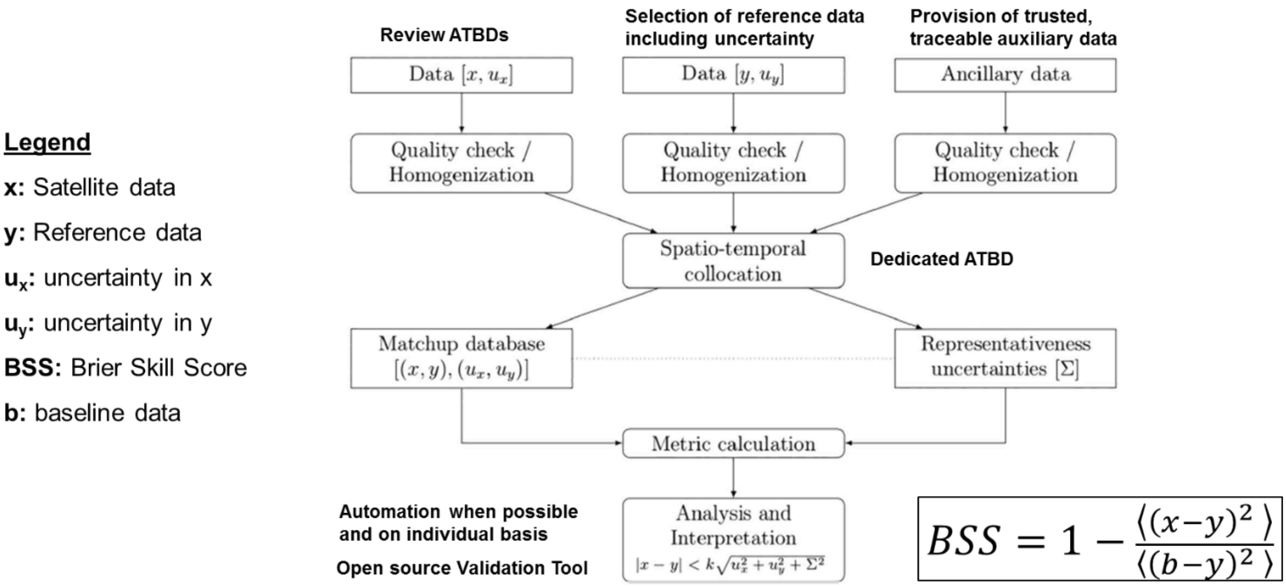

Figure 3.1: Main end-users validation activities (in bold) over the schematic overview of general validation process adopted by the Coastal Change Consortium.

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

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

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 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). Within the coastal engineering community is well accepted (i.e. Ruggiero et al. 2003) that **measuring the skill of a model** (i.e., its performance relative to a simple baseline predictor) **is a more critical test than measuring its absolute accuracy**.

We will use the accepted Brier Skill Score (BSS) (Sutherland *et al.*, 2004) **to assess the skills of the EO detecting the changes observed in the ground**. The BSS is particularly useful skill score in coastal engineering, because 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

$$BSS = \frac{MSE(x,y)}{MSE(b,y)} = 1 - \frac{\langle (x-y)^2 \rangle}{\langle (b-y)^2 \rangle} \quad (2)$$

Where X and Y are the satellite and reference measurements and B is the baseline observation that we will use to compare the two independent observations. As we are interested on 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). Perfect agreement gives a skill score of 1 whereas observing the baseline condition gives a score of 0. If discrepancies between satellite observation and the reference condition are greater than the observed change (referenced to the baseline observation), the skill score is negative. Note that these skill scores are unbounded at the lower limit. Therefore, they 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 measured 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.

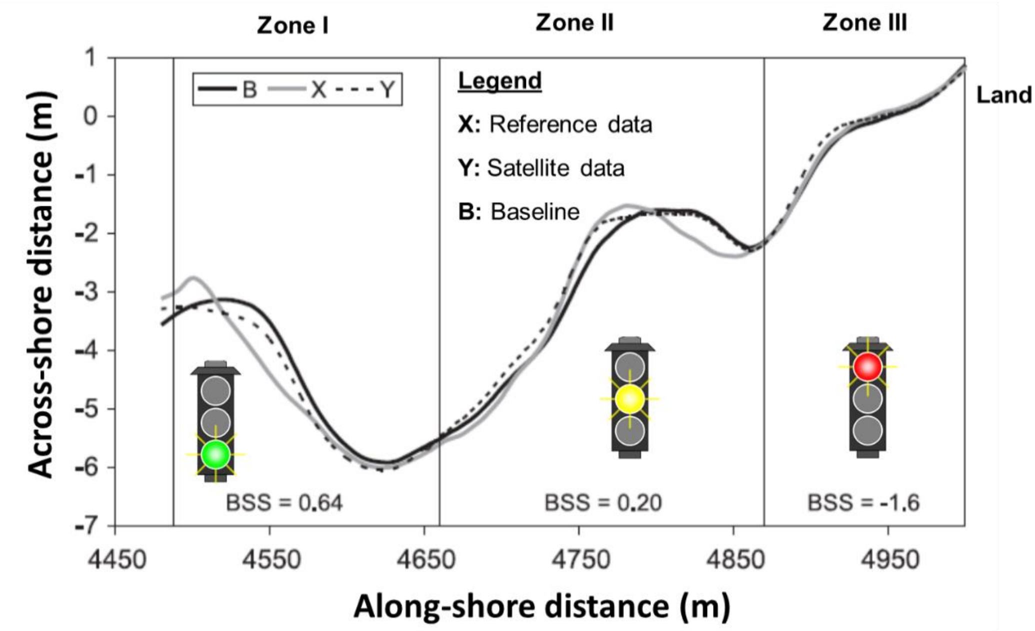

Figure 3.2: Illustration of how the BSS will inform the skills of shoreline changes from space. End-uses will assess the adequacy of the skill for each application and site using a simple traffic light colour scheme.

Figure 3.2 illustrates an example of how the BSS will provide quantitative information regarding the skill of the EO products detecting change. The baseline (i.e. most likely shoreline position expected) is represented as solid black line. This baseline will be defined for each validation site and time period and how has been obtained (i.e. expert assessment, independent observation, morphodynamic model, etc..) described as part of the metadata that will allow end users trace back and repeat the assessment. For this example we will assume that the baseline is represented by the initial shoreline location (i.e. location at the start of the time-period been assessed). The shoreline has been divided in three zones (I, II, III) with BSS values of 0.64, 0.20 and -1.6. The progression of skill scores can be explained as follows. The best skill score (closest to 1) is obtained for zone I where satellite observations were able to observe for most of the zone the seaward progression also captured by the reference data. The skill score is worst (negative) in zone III because the satellite observation suggest a relative much larger landward migration of the shoreline than the one shown by either the baseline or reference data. Zone III illustrates an example where while the absolute changes detected in zone III by the EO product are still small, they are in disagreement with both the reference data and the most likely expected shoreline and therefore has a low skill. In Zone III, satellite observations are correct in modelling little change, but incorrect in predicting the details of this change (BSS is very sensitive to small changes as the denominator is so small). Zone II is an example were the satellite observed shoreline is closer to the baseline than to the reference shoreline. The adequacy of the skill score will be assessed for each site and application and scored using a standard traffic light (green: good, Ambar: fair and red: bad) skills.

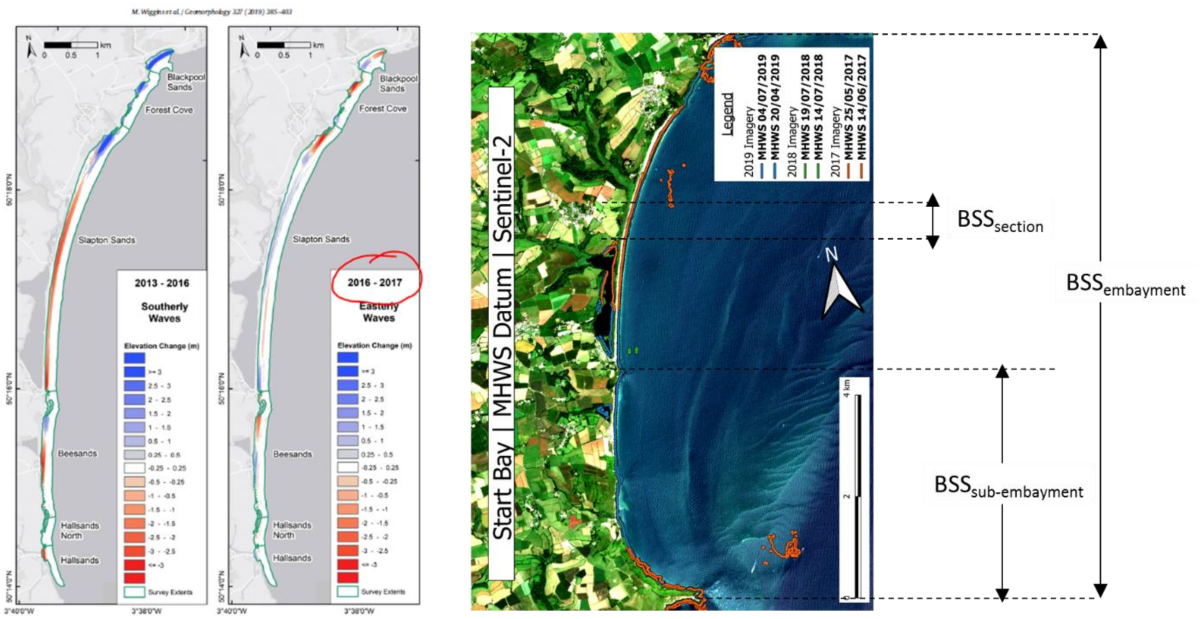

Figure 3.3: Illustration of baseline data and EO products for Start Bay, UK. The left and central panel shows the topo-bathymetric changes observed at Start Bay for two time periods (2013-2016 & 2016-2017) (from Wiggings et al. (2019)). The beach rotates, clock-wise or counter-clock-wise in function of the direction of the dominant highest waves. The right panel shows the EO derived MHWS lines for different dates.

Figure 3.3 illustrates the reference data that will be used for the case of Start Bay, in south England. Wiggings et al. (2019) demonstrated that for the semi-sheltered embayment (Start Bay, Devon, UK) the total sediment budgets (supra- to sub-tidal), with spatially-varying uncertainty levels, is closed. They have used a multi-method topo-bathymetric surveys are used to assess the morphological change of that we will use as a reference data to assess the adequacy of the EO derived products.

Right panel on Figure 3.3 shows the datum shorelines derived from different years. For this particular study case, the baseline assumption that we will use to calculate the BSS will be that there is no change on the shoreline (or bathymetry) of the embayment. We will provide a BSS value for at different scales (i.e. embayment scale, sub-embayment scale, and equal distance sections) that will then be used to assess the adequacy of the EO derived products.

3.1.1 Review of ATBDs: importance of colocation mismatch

The service providers will check the conformity of the processors with technical specifications (verification step) and of the EO products with the feasibility requirements (QC). Out of these two conformity check they will provide 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 of the processors ATBDs during phase 1. 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 MTR. 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 representativeness of EO and reference measurements (i.e. Σ value in eq. 1)**.

3.1.2 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 (Loew *et al.*, 2017). 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 has 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 (AD-0) (Figure 3.4)

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

Figure 3.4: Validation data has been specified by the end-users within the URD. This example shows the validation data suggested by BGS to be used to validate the Proxy-tidelines.

3.1.3 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 the different EO products. These auxiliary data include information about the physical characteristics of the coastline, but also include meteorological and sea state information at time of EO observation (see Table 3.1). The end-users has provided these data to the service providers for each validation site.

Table 3.1: List of Auxiliary data required from each site for each EO acquisition period

EO Data	VHR data
	Historical Images (EO + Air-borne)
	Sampling Frequency
Validation	Erosion Rates
Meteorological	Wind speed and direction
	Atmospheric pressure
	Precipitation
Waves	Wave Height (mean or significant)
	Wavelength or wave period
	Direction
Tide	Astronomical tides
	Storm surges
Sea Defences	Groynes
	Beach nourishment
	Seawalls
Altimetry	Backshore
	LIDAR
	Beaches
	Offshore sandbars
Bathymetry	Depth of Closure
	Hydrographic information
	Nautical maps
Geology	Superficial deposits
	Land/sea cover maps (vegetation, sands, muds, rocks etc.)

3.1.4 Metrics: 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 in shown in (eq. 1) and (2) the Brier Skill Score of the EO product detecting change.

3.2 Evaluation of EO products

The enrolled end-users (BGS, MITECO + IHCantabria, GSI, ARCTUS) together with the broader end user community (i.e. Coastal Area Regional Programme Managers, European Environment Agency, Hydrographic Offices, etc.) will evaluate the different EO products against the five themes included in the end users product assessment (Annex B of the SOW) and summarized in Figure 3.5.

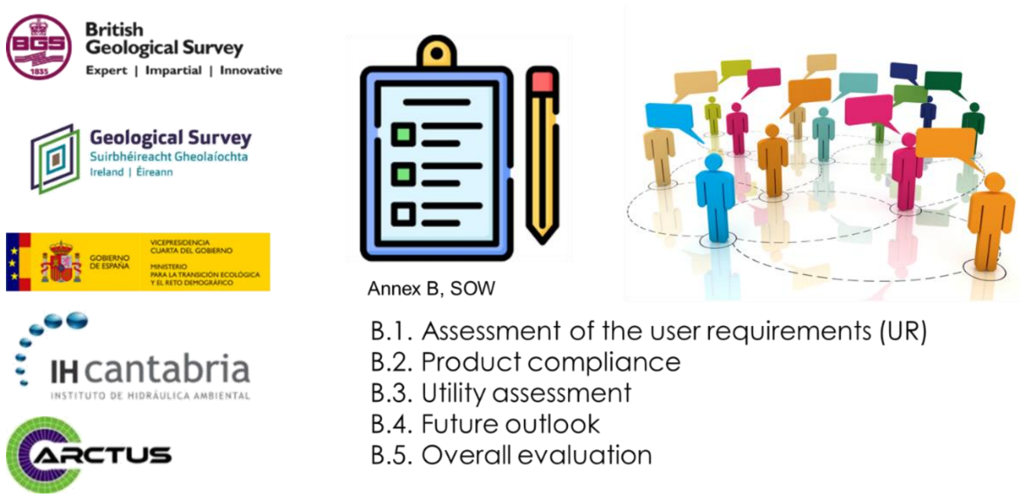

Figure 3.5: The enrolled end-users together with the broader end-user community will evaluate the 5 themes included in the service assessment Annex B of the SOW.

3.2.1 Assessment of the user requirements

The adequacy of the User Requirements detailed in the URD (AD-0) will be assessed through continuous engagement with the broader end user community. This engagement has already started in Phase 1 via sharing progress of the URD and requesting written feedback from key end users within each country partner and with pan-European institutions such as the Joint Research Centre of the

European Commission. The written feedback from the engaged broader end user community are included in annex 1 (AD-3).

3.2.2 Product compliance

The **product accuracy compliance** to the UR will be assessed via the consistency check between the differences between the satellite observation and ground truth observation measurements and the reported measurement uncertainties for each validation site (see eq. 1). The coverage factor, k, 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).

The confidence in product quality will be provided as a skill score index (Brier Skill Score or BSS). Perfect agreement gives a skill score of 1 whereas modelling the baseline condition gives a score of 0. Baseline prediction will be chosen for each validation site as If the model prediction is further away from the final measured condition than the baseline prediction, the skill score is negative. Note that these skill scores are unbounded at the lower limit. Therefore, they 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. Large negative values can be thus obtained even from models that predict a small change (of the correct order of magnitude) when the measured change is very small. In these circumstances, different models of the same experiment 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.

3.2.3 Utility assessment

The **benefits** of the demonstrated service and products **and the impact on current end-user practices** will be assessed throughout continuous engagement of with the enrolled end-users and the broader end-user's community within each area of interest. We will ask, in a similar way as we have done for phase 1, for written feedback on the utility of the service and products. The different validation sites will be used as case studies that will be presented to the end users for them to reflect on the utility. The enrolled end-users will act as champions for each country and will be in charge of keeping the broader end-user community regularly updated, facilitate the access to project study cases (i.e. translating them into Spanish, French when needed) and fetching their written feedback. The enrolled end-users will then analyse all the feedback received and produce a synthesis in the format requested in the Annex B of the SOW.

3.2.4 Future outlook

We will evaluate the (1) probability of service integration into existing practices, (2) any desired service and product improvements and (3) the needs for a large-scale service product/demonstration. During phase 1 it was early identified that the EO products outlined in the URD has the potential to fill in the gaps of the different Coastal Vulnerability Assessment that the enrolled end-users are doing for their respective areas of interest (Figure 3.6). During phase 2, and as the different products are becoming available and validated for accuracy and skills, the way forward to integrate them into current practices will be explored by each of the enrolled end-users. As the area of interest for BGS, GSI, MITECO and ARCTUS covers the whole coastal region of UK, Republic of Ireland, Spain and eastern Quebec (i.e. along the Estuary and Gulf of St. Lawrence), the needs for a large-scale service/product demonstration is likely. The enrolled end-users will reflect on the lessons learnt from the 1000km of products delivered by the end of phase 2 and outline the rationale for a larger demonstration as they see fit.

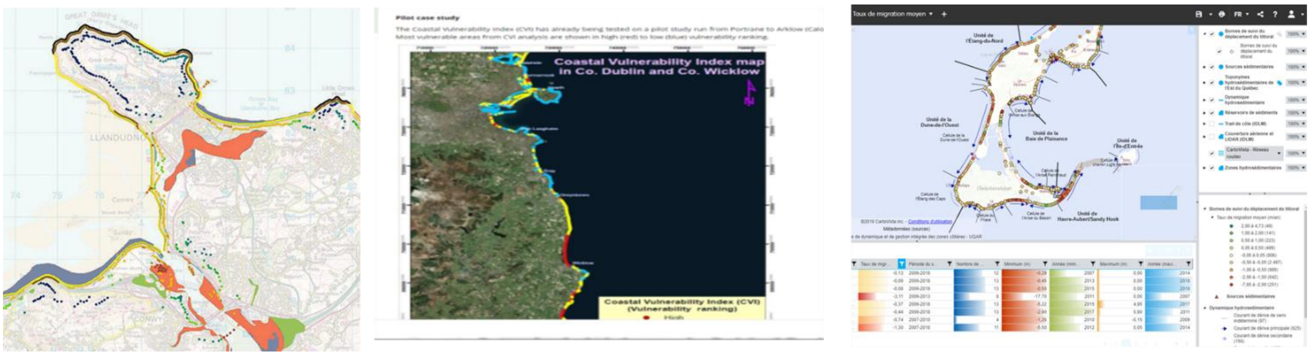

Figure 3.6: Integration of the EO products into the different Coastal Vulnerability Assessment been performed by the enrolled end-users was early identified in the project as a most likely way of integration into existing practices. From left to right, examples from BGS, GSI and ARCTUS-UQAR

3.2.5 Overall evaluation

An overall evaluation of the product and services developed during phase 2 will be provided as a set of coastal case studies for each country partner as well as a set of recommendations to the European Space Agency. The recommendations will reflect 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. All enrolled end-users use case studies to regularly communicate with their clients and stakeholders. Building on this experience, we will produce a set of case studies that could also be used during the project final workshop.

4 References

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Ruggiero P, Gelfenbaum G, Sherwood CR, Lacy J, Buijsman MC. Linking nearshore processes and morphology measurements to understand large scale coastal change. In Proceedings of Coastal Sediments 2003 (Vol. 3).

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Appendix

SO-TR-ARG-003-055-009-PVP-A1: Summary of Validation and evaluation for EO product

SO-TR-ARG-003-055-009-PVP-A4 : Preliminary sites selected for validation

SO-TR-ARG-003-055-009-PVP-A5: In-situ information for validation – Canada

SO-TR-ARG-003-055-009-PVP-A6: In-situ information for validation – Ireland

SO-TR-ARG-003-055-009-PVP-A7: In-situ information for validation – Spain

SO-TR-ARG-003-055-009-PVP-A8: In-situ information for validation – UK

SO-TR-ARG-003-055-009-PVP-A9: Written feedback from broader end user community regarding URD

End of Document