ESA Coastal Erosion Project: End-Users validation document

Coastal Resilience and Geohazards Programme

Open Report OR/20/018

BRITISH GEOLOGICAL SURVEY

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Foreword

This is **a Phase-2 mid-term version** of the End-Users Validation Document (EUVD) of the Earth Observation products 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 End-Users team. It contains a detailed validation and synthesis of the products produced by the Service-Provider team against the End-Users Requirement Document (BGS ref. CR/19/055).

The EUVD summarizes the conformity of the different Earth Observation Products provided by the Service Providers (ARGANS, adwäisEO and IsardSAT) with the specifics User Requirement for each one of the enrolled end-user organizations (British Geological Survey (BGS), Geological Survey Ireland (GSI), Subdirección General para la Protección de la Costa (SGPC) advised by the Instituto de Hidraulica Ambiental de la Universidad de Cantabria (IHC) and ARCTUS) and additional requirements from other end-users organized per country (UK, Republic of Ireland, Spain, Canada).

BGS member of staff, Dr Andres Payo has been in charge of compiling and synthesizing all end-user requirements into a standardized format and writing this report, while Dr Michael A. Ellis has reviewed and approved the final version of this document. The main contributors from each one of the enrolled end-users’s organization are: Dr. Xavier Monteys (GSI), Dr Jara Martinez Sanchez (Environmental Hydraulics Institute - Universidad de Cantabria, IHCantabria), Christian Marchese (ARCTUS).

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword, Gareth Jenkins has contributed to the validation assessment included in this report.

In addition to the GSI staff acknowledged in the Foreword, Silvia Caloca and Ronan O’Toole have contributed to the description of the GSI requirements included in this report.

In addition to the IHCantabria staff acknowledged in the Foreword, Paula Gomes has contributed to the validation and evaluation of EO product in the Spanish sites and Raúl Medina, Ana Silió and Veronica Cánovas from IHCantabria and Ana García-Fletcher, Galo Díez-Rubio, and Roberto Díaz-Sánchez from SGPC have contributed to the description of the SGPC requirements included in this report.

In addition to the ARCTUS staff acknowledged in the Foreword, Thomas Jaegler, Steeve Dugas, Christian Fraser and Pascal Bernatchez have contributed to the description of the ARCTUS requirements included in this report.

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

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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

Summary

This is **a Phase-2 mid-term version** of the End-Users Validation Document (EUVD) for the Coastal Erosion Project 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 Coastal Change From Space team. It contains a detailed and End-Users-independent validation of the Earth Observation products against the Users Requirements Document (URD) (BGS ref. CR/19/055).

Each one of the enrolled end-user organizations (British Geological Survey (BGS), Geological Survey Ireland (GSI), Subdirección General para la Protección de la Costa (SGPC) of the Ministerio para la Transición Ecológica y el Reto Demográfico, Vicepresidencia Cuarta del Gobierno (SGPC) and ARCTUS) have filled in the validation and evaluation templates (Annex B of the Statement of Work [SOW]) for each product and validation site. End-Users 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). This document also includes a synthesis of all validation and evaluation statements.

This document is organized in three main sections. The first section contains the key concepts, methodologies and definitions agreed and used by all End-Users. The information of this first section is an updated version of the information outlined in the PVP and has been included to make this report self-explanatory. The second section contains the validation results including an overview of the study sites and EO products validated. The third section contains the evaluation results per product and per coastal type as a synthesis of the detailed and individual End-Users feedback (e.g. filled in Annex B per product and per validation site).

The salient remarks that all enrolled End-Users would like to highlight to the Service Providers and the European Space Agency at this stage of the project are;

- **Results presented on this document are based on a limited number of products and study sites and need be considered with caution**. Out of 23 expected products, only 7 (30%) were available for the study sites at the time of this review (see Table 5 & Figure 7): SDW, SDSL, SDB & LULC. The most abundant product for all sites were the SDW-SAR also covering multiple years span. Most of the products were produced using Sentinel-1 and Sentinel-2 missions data, with the exception of some optical shoreline data being produced using Landsat-8 and Landsat-5 mission data.

- **The lack of metadata delayed the validation activities.** All products information comes in the product's name, which for the majority of products includes: details about mission (i.e. S2: Sentinel 2; L8: Landsat 8), date and time of the satellite acquisition and product creation. End-Users expressed their metadata requirements for each product in the "Product specification section >> Information layers" for each product on the URD (BGS ref. CR/19/055). Many of requested information layers were not present on the provided products. This lack of metadata delayed the validation activities since end-users need to ask for this information. In the future it is expected that information like vertical datum reference, time reference, coordinate system and uncertainties will be available with the data for direct consulting.

- **The lack of quality flags limited the depth of this first validation assessment**. Quality flags are an important metadata that was missing and limited the depth of the validation assessment. For example, BGS requested metadata indicating the presence of "Error lines; Lines that have errors (for instance not closed rings or self-intersections)". From visual inspection, it was clear that many of the provided SDW and SDSL were erroneous but were not flagged. According to PVP, the Service Providers have included these types of error-checking within their validation process (Table 2.4: Validation table of VNIR waterline, Table 2.5: Validation table of SAR waterline in PVP). Action on End-Users: revise the information layer specifications on the URD. Action on

Service-Providers: include quality flags produced during the validation assessment on product metadata.

- **Satellite derived shorelines showed a ‘jigsaw’ aspect due to pixel resolution of satellite images**. Service providers are considering applying the sub-pixel resolution method to improve the visual aspect of shorelines in future outputs.

- **Absolute and relative accuracy of SDSL and SDW-opt showed good agreement with reference and baseline data respectively.** Data for Barcelona coast study site showed good agreement with in-situ measurements, with high BSS (>0.98) and horizontal differences within the range of accuracy of Sentinel products (horizontal accuracy of 10 m). However, the results can be more robust if the same test is carried out for Malgrat, where shoreline changes are especially important. No match was found to compare data from Malgrat beach. The only SDSL and SDW-opt that matched ancillary data in time, did not represent the real shoreline well and was removed in quality check phase.

- **Waterlines from radar sensors resulted in higher errors when compared to the ancillary data**. Variations due to wave action (i.e. setup and run-up) was not considered in the process of extraction of in-situ waterlines from topo-bathymetry. Even though, the variability and curved shape verified in SDW-SAR does not look like wave variations typically observed from waves in the pilot sites. Wave conditions will be further explored in future analysis by the End-Users.

- **The possibility of using optical and radar shorelines and waterlines together may provide data in higher frequency and wider temporal cover, which allow both short- and long-term analysis**. This is an important point in terms of application of such products in current end-user practices. The confidence in waterline products, however, was very low due to inconsistencies verified in great part of SDW (~60% of the all SDW cannot be applied for coastal purposes). Inconsistencies must be solved, and quality flags must be provided to impulse the use of these products instead of current practices. The automation of coastal assessment is essential, and the problems verified in shoreline products up to now make it difficult.

- **End-Users requested a seamless Topography and Bathymetry Digital Elevation Model of the coastal zone (backshore, foreshore & nearshore) but the product received only includes the foreshore and nearshore**.

- **Satellite derived bathymetry validation analysis presented good agreement with in-situ measurements with great part of the error falling within the range of accuracy of Sentinel products (vertical accuracy of 1 m)**. Important discrepancies were verified in depths higher than 10 m and values in these zones needs further attention when applying bathymetry products. The raster SDB 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) but no information regarding the datum used. Although the information could be obtained by consulting the Service Provider, metadata should come with EO Products in the future.

- **Some of the satellite derived bathymetry products were strongly affected by river sediment plume:** Important inconsistencies in bathymetric values were observed in 19 out of 27 SDB provided for Barcelona and 3 out of 4 SDB for Start Bay. Bathymetric information is often affected by the sediment river plume in these areas and extra information (like the quality flags mentioned above) indicating when this kind of issue occur is necessary so the end-user can identify which data can be used for bathymetry purposes.

1 Concept and definitions

1.1 VALIDATION PROTOCOL – A MULTI-STEP PROCESS OF CONFORMITY CHECKING'S

The adopted validation protocol by the Coastal Change Consortium is as a multi-step conformity checking process performed by both the Service-Providers and the End-Users and is illustrated in Figure 1. 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 on the PVP) 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 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.

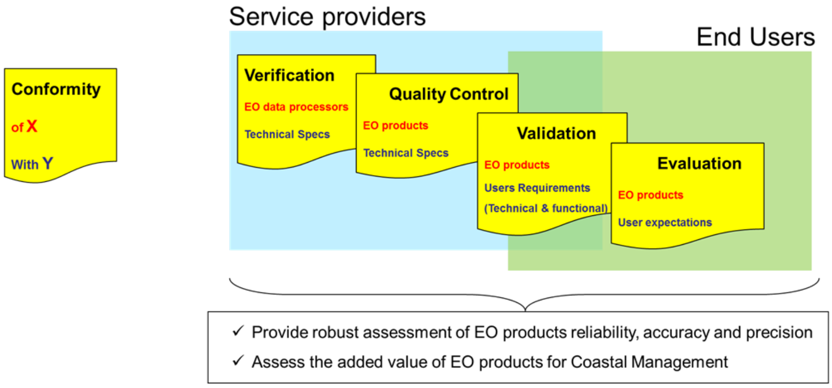

Figure 1: Validation protocol is approached here as a multi-step conformity checking process done by both the Service providers and End-Users.

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 (BGS ref. CR/19/055) and are not repeated here. Table 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 summarized it on Table 2.

Table 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**	: Volume changes on the littoral between two observation time	SDER
CE_ARG_**area**_L5_3D_ER_SDBTM_**area_date_date**.**XXX**		

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 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 Seabed 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 Seabed 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 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, SGPC and ARCTUS covers the whole coastal region of UK, Republic of Ireland, Spain and eastern Québec** (i.e. along the Estuary and Gulf of St. Lawrence). End-users has **pragmatically selected a reduce set of validation sites** (shown in Annex of PVP) 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.

1.4 END-USERS VALIDATION ACTIVITIES

1.4.1 Validation activities for EO products

Figure 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. 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.

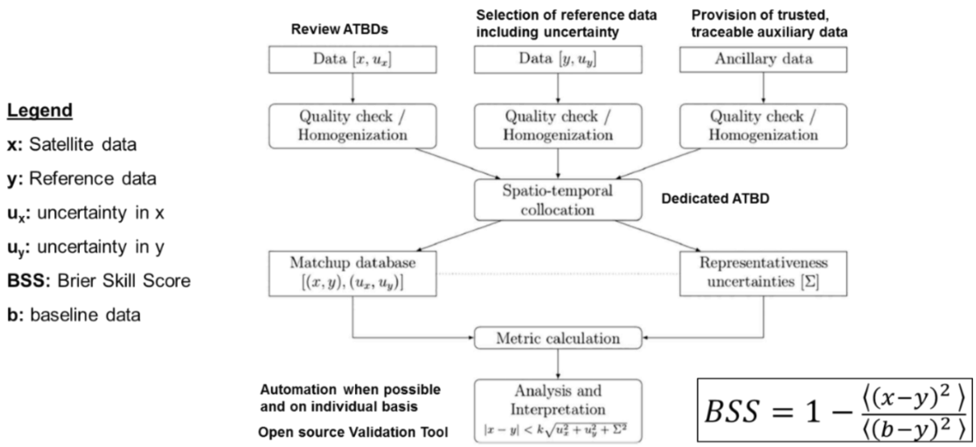

Figure 2: Main end-users validation activities (in bold) over the schematic overview of general validation process adopted by the Coastal Change Consortium.

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

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

where x and y are the EO and reference measurements, u_x and u_y their respective uncertainties (as in Figure 2), 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 a particularly useful skill score in coastal engineering, 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

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

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

where x_j, y_j and B_j represents elements of ancillary, satellite, and baseline data, respectively, which match in space and time. 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 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 suggests 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.

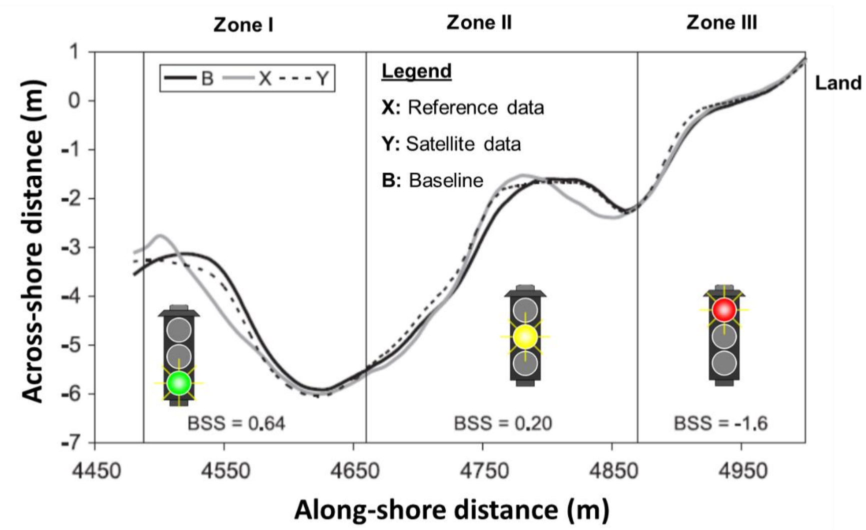

Figure 3: Illustration of how the BSS will inform the skills of shoreline changes from space. End-uses will assess the adequacy of the skill for each application and site using a simple traffic light colour scheme.

Figure 4 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 survey to assess the morphological change that we will use as a reference data to assess the adequacy of the EO derived products. Right panel on Figure 4 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 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.

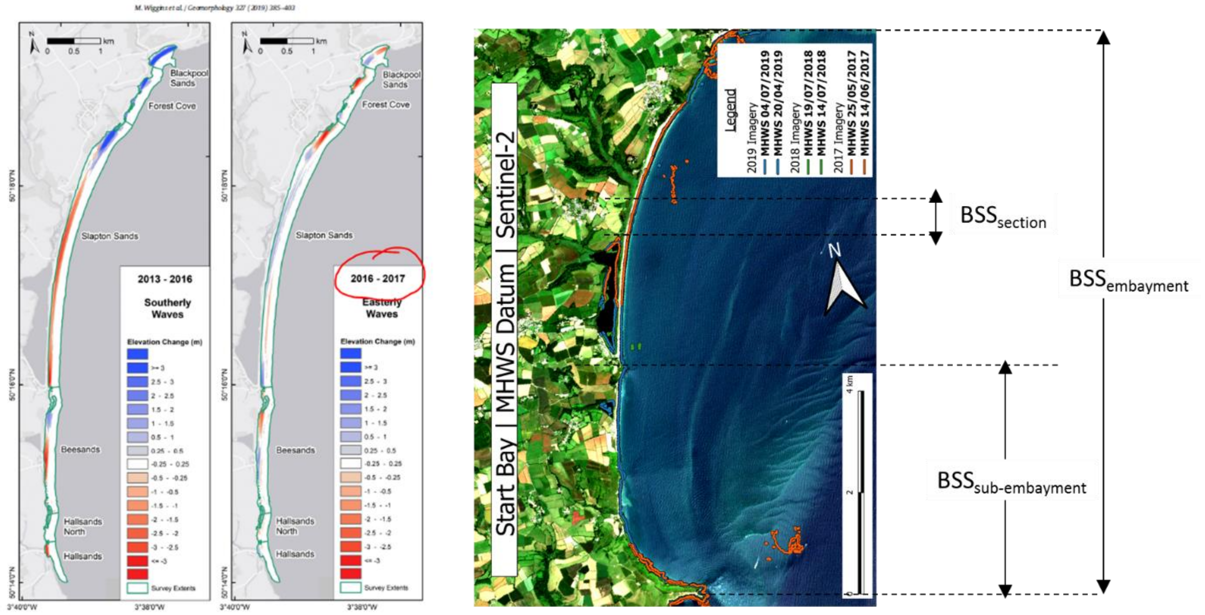

Figure 4: Illustration of baseline data and EO products for Start Bay, UK. The left and central panel shows the topo-bathymetric changes observed at Start Bay for two time periods (2013-2016 & 2016-2017) (from Wiggings et al. (2019)). The beach rotates, clock-wise or counter-clock-wise in function of the direction of the dominant highest waves. The right panel shows the EO derived MHWS lines for different dates.

1.4.2 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 conformities 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)**.

1.4.3 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.

1.4.4 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). The end-users have provided these data to the service providers for each validation site.

Table 3: 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.)

1.4.5 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 (eq. 3) of the EO product detecting change.

1.5 EVALUATION OF EO PRODUCTS: ANNEX B OF THE SOW

The enrolled end-users (BGS, SGPC-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 5.

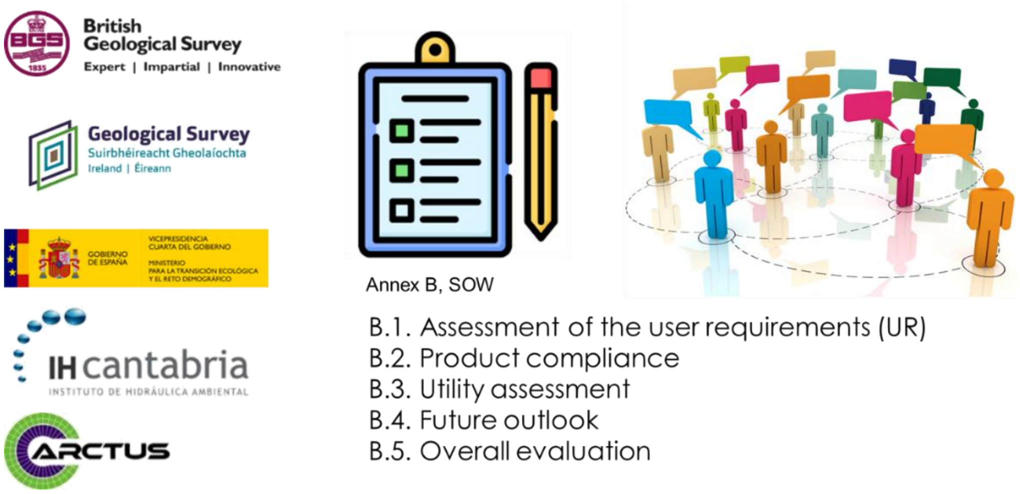

Figure 5: The enrolled end-users together with the broader end-user community will evaluate the 5 themes included in the service assessment Annex B of the SOW.

1.5.1 Assessment of the user requirements

The adequacy of the User Requirements detailed in the URD 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 of PVP).

1.5.2 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.

1.5.3 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.

1.5.4 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 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, SGPC and ARCTUS covers the whole coastal region of UK, Republic of Ireland, Spain and eastern Québec (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.

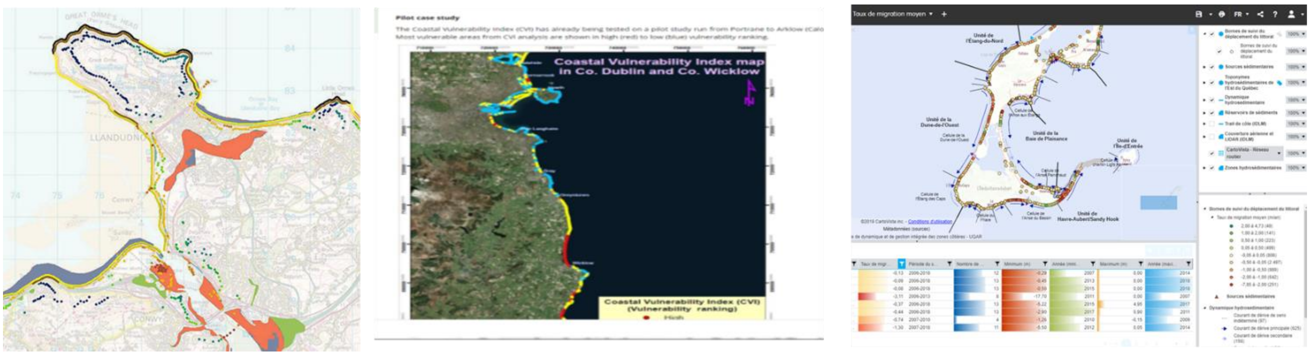

Figure 6: Integration of the EO products into the different Coastal Vulnerability Assessment been performed by the enrolled end-users was early identified in the project as a most likely way of integration into existing practices. From left to right, examples from BGS, GSI and ARCTUS-UQAR

1.5.5 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.

2 Validation results

2.1 OVERVIEW

Table 4 shows all the documents provided by the enrolled End-Users (BGS, GSI, SGPC-IHC, ARCTUS) with the detailed validation and evaluation feedback. To access each document, click on the URL provided for each document or copy and paste the URL into a web browser. The End-Users has provided three types of documents as indicated in the filename by (Annex B, Annex C or validation type), where;

- **Annex B** type contains the filled-in SOW-Annex B for each product type (i.e. waterlines, tidelines, etc…),
- **Annex C** type contains supplementary information that support the feedback provided in Annex B,
- **Validation** type contains the results of each validation activity shown in Figure 2.

Table 4. Filenames and links to the documents provided by End-Users with the detailed validation and evaluation feedback.

File name	URL[†]
BGS_ANNEXB_ProxyTideLines_v20042020	https://britishgeologicalsurvey.sharefile.eu/d-saab399e14c944baa
BGS_ANNEXB_SOW_DatumTideLines_20042020	https://britishgeologicalsurvey.sharefile.eu/d-s584c913fcf94a47a
BGS_ANNEXB_SOW_HabitatMap_v20042020	https://britishgeologicalsurvey.sharefile.eu/d-s92ad75a68ed4e928
BGS_ANNEXB_SOW_TopoBathymetries_v20042020	https://britishgeologicalsurvey.sharefile.eu/d-s029845f00534c24b
BGS_ANNEX C_SupplementaryMaterial	https://britishgeologicalsurvey.sharefile.eu/d-s320d59aeef34a46b
SGPC_ANNEXB_Waterlines	https://britishgeologicalsurvey.sharefile.eu/d-s0aa744f1c724b798
SGPC_ANNEXB_Shorelines	https://britishgeologicalsurvey.sharefile.eu/d-s4dc5aca47014bbc8
SGPC_ANNEXB_Bathymetry	https://britishgeologicalsurvey.sharefile.eu/d-s20f749aa97840359
SGPC_ANNEX C_SupplementaryMaterial	https://britishgeologicalsurvey.sharefile.eu/d-s3d64106ac4d43989
SGPC_validation_SPAIN_v0	https://britishgeologicalsurvey.sharefile.eu/d-s8831fd8404a4233a
ARCTUS_ANNEXB_SOW_Shoreline_Waterline_delineation_23042020	https://britishgeologicalsurvey.sharefile.eu/d-s1a30dc29d4146668
ARCTUS_ANNEXB_SOW_nearshore_SDB_23042020	https://britishgeologicalsurvey.sharefile.eu/d-sebc98216ff74e549
GSI_ANNEXB_Waterlines	https://britishgeologicalsurvey.sharefile.eu/d-s29ab606940c4cedb
GSI_ANNEXB_Shorelines	https://britishgeologicalsurvey.sharefile.eu/d-s168ecb07a86461b8
GSI_ANNEXB_LandCover	https://britishgeologicalsurvey.sharefile.eu/d-s99d7763def449138

Figure 7 shows all the validation sites for which End-Users has provided the detailed feedback in the documents listed in Table 4. All these sites combined represents a total observation extent of 676km, from which; 26km are of Start Bay (UK), 127km of Lounge Pointe de Mingan (Quebec), 332km of beaches South of Barcelona (El Prat and Port Ginesta) and Tordera Delta (Spain) and 191km of Dublin Bay (Republic of Ireland).

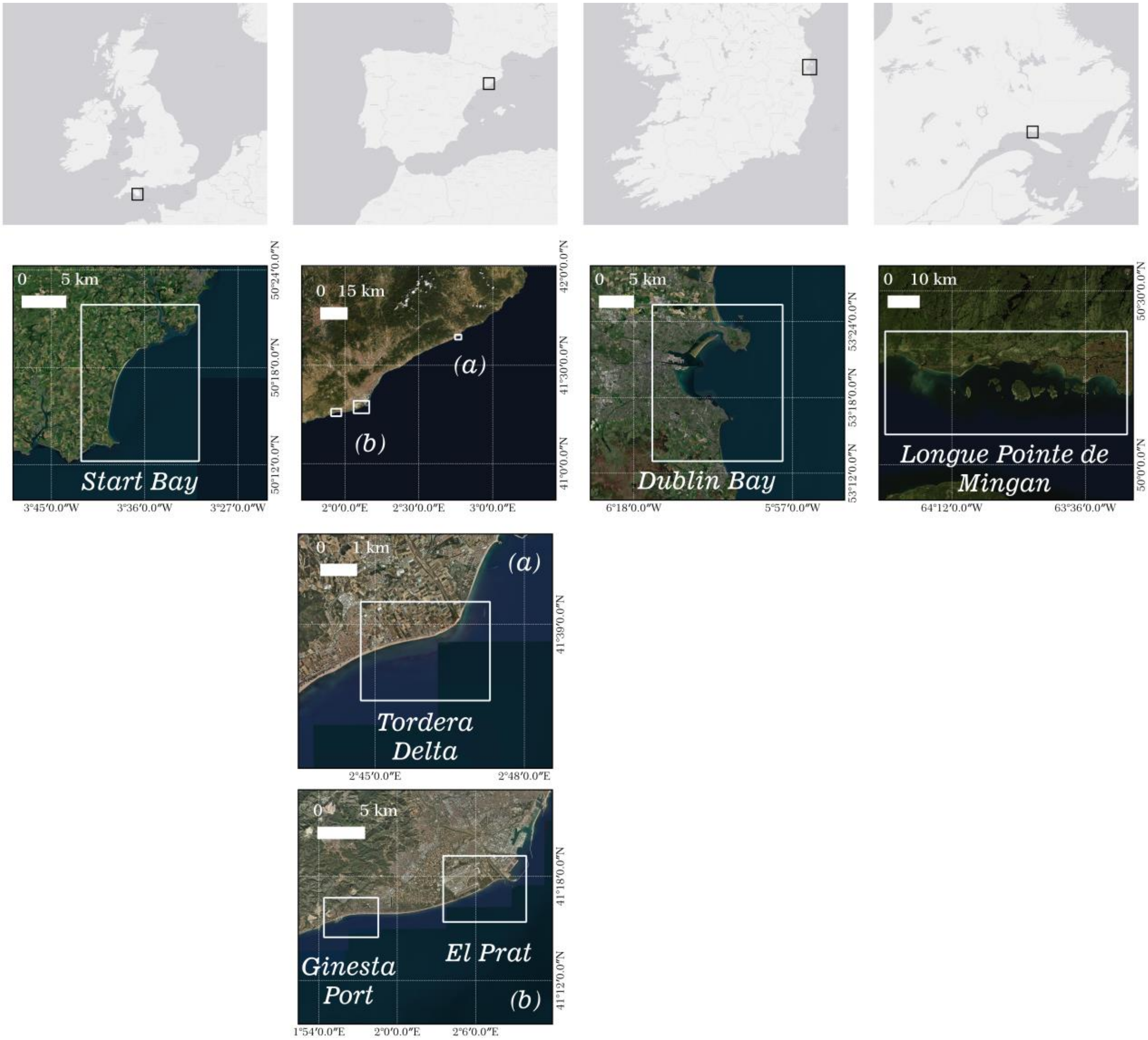

Figure 7: Validation sites included in this document as provided by the enrolled End-Users; BGS for UK, SGPC-IHC for Spain, ARCTUS for Québec, GSI for Republic of Ireland.

The type and number of products validated for each study site varies significantly as shown in Table 5. Out of 23 expected products, only 7 (30%) were available for the study sites at the time of this review. The most abundant product for all sites were the RADAR waterlines also covering multiple years. Most of the products were produced using Sentinel 1 and Sentinel 2 missions data, with the exception of some optical shoreline data being produced using Landsat 8 mission data.

Table 5. Type and number of products per validation site evaluated

Type	EO products naming	Start Bay	Barcelona coast	Tordera Delta	Mingan	Dublin Bay
Waterlines	CE_ARG_**area**_L2_1D_OB_WL_**sensor_date**.shp	13	221	76	39	81
Waterlines	CE_SAT_**area**_L2_1D_OB_WL_S1_**date**.shp	530	798	655	196	236
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_MHWS_**date**.shp	42 (10L8+32S2)	82	36	180	180
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_MSL_**date**.shp	48 (10L8+38S2)	82	36	180	180
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_MLWN_**date**.shp	42 (10L8+32S2)	82	36	180	180
	CE_ARG_**area**_L3_1D_DB_SL_MHWS_**date_date**.shp	---	---	---	---	---
	CE_ARG_**area**_L3_1D_DB_SL_MSL_**date_date**.shp	---	---	---	---	---
	CE_ARG_**area**_L3_1D_DB_SL_MLWN_**date_date**.shp	---	---	---	---	---
Topo-Bathy	CE_ARG_**area**_L2_3D_BT_SDB_**sensor_date**.tif	5	27	7	2	0
	CE_ARG_**area**_L3_3D_BT_SDB_**sensor_date_date**.tif	---	---	---	---	---
	CE_SAT_**area**_L2_3D_BT_WF_**sensor_date.XXX**	---	---	---	---	---
	CE_SAT_**area**_L3_3D_BT_WF_**sensor_date_date.XXX**	---	---	---	---	---
	CE_ARG_**area**_L2_3D_BT_WF_**sensor_date.XXX**	---	---	---	---	---
	CE_ARG_**area**_L3_3D_BT_WF_**sensor_date_date.XXX**	---	---	---	---	---
	CE_ARG_**area**_L4_3D_BT_SDB_WF_**sensors_date_date**.tif	---	---	---	---	---
	CE_ARG_**area**_L2_2D_FB_LULC_**sensor_date**.shp	---	---	---	---	---
	CE_ARG_**area**_L2_1D_FB_LL_**date**.shp	---	---	---	---	---
	CE_ARG_**area**_L2_1D_FB_SF_**date**.shp	---	---	---	---	---
LULC	CE_ARG_**area**_L3_2D_FB_LULC_**sensor_date_date**.tif	2	4	0	0	3
	CE_ARG_**area**_L3_1D_FB_LL_**date_date**.shp	---	---	---	---	---
	CE_ARG_**area**_L3_1D_FB_SF_**area_date_date**.shp	---	---	---	---	---
	CE_ARG_**area**_L5_3D_ER_SL_**area_date_date.XXX**	---	---	---	---	---
	CE_ARG_**area**_L5_3D_ER_SDBTM_**area_date_date.XXX**	---	---	---	---	---

L8: Landsat 8; S2: Sentinel 2; LULC: Land Use & Land Cover;

2.2 QUALITY CHECK & HOMOGENEIZATION

Both, ancillary (in-situ) and satellite derived (Sentinel) data were assessed to ensure the consistence of the initial dataset used for validation.

2.2.1 Satellite data

SHORELINES

A visual analysis of the entire dataset of SDSL was carried out to check if the information was coherent to what would be expected in-situ. When it was necessary, manual edition was performed. Figure 8 shows examples of SDSL that presented some kind of problems. We verified that fictitious extra shorelines in submerged areas were present in the SDSL of both study sites (e.g. Figure 8a, c and g). Moreover, in a few cases, the actual shoreline was not continuous or not properly detected at all (e.g. Figure 8b, d, f and g). These issues are probably the result of a misinterpretation during the automatic process of shoreline identification due to sediment/foam spots over the water, or due to the presence of submerged features under clear water conditions. Inland waterlines from small lakes and channels nearshore were also observed (e.g. Figure 8e and h). For Malgrat beach in the Tordera delta, 44% (16) of SDSL presented extra shorelines nearshore, 64% (23) of SDSL were discontinuous and 11% (4) were excluded from the analysis for not representing the real shoreline at all. In the beaches south of Barcelona, 70% (61) of the shorelines presented inland shorelines, 28% (24) presented extra shorelines nearshore, 24% (21) presented discontinuity and 9% (8) did not represent the real shoreline and were completely excluded. SDSLs were edited and the cases in which the real shoreline was not detected were excluded from the validation process. A resume of the analysis of all EO Products is presented in Table 6.

It is important to highlight that unreal and discontinuous shorelines makes the interpretation of automatically obtained results dubious, and manual and subjective triages and editions are required (previous to the analysis), until these issues are solved. Some of these problems may also limit the use of the EO products for erosion analysis. For example, in Barcelona, part of the discontinuous shorelines showed a lack of information in the zone of critical erosion, southward from Barcelona Port (e.g. Figure 8e).

Table 6: Results of quality check of EO Products from the Spanish coast, with indications of the percentage of data, from the total delivered up to now, considered useful to coastal analysis and to the validation process.

EO Product	Total	Discarded	Useful
SDSL	123	12	111 (90%)
SDW-opt	294	22	272 (92%)
SDW-sar	1453	1009	444 (31%)
SDB	35	19	16 (46%)

Figure 8: Examples of inconsistencies verified in satellite-derived shorelines in both validation sites: Malgrat (left panels) and Barcelona (right panels).

WATERLINES (proxy-based: sea-land interface)

Satellite-derived waterlines were obtained as the instantaneous interface between sea and land by optical (SDW-opt) and radar (SDW-sar) sensors. By the date, the Spanish end-user received 76 SDW-opt and 655 SDW-sar from Malgrat beach. From Barcelona beaches, 221 SDW-opt and 798 SDW-sar are available.

A visual analysis of waterline products revealed strong inconsistencies in SDW. Waterlines from optical sensors showed the same problems observed in SDSL (see Figure 8). Detection issues were also observed in waterlines from radar sensors, such as straight lines ranging from inexistent coordinates to the study area (Figure 9a), unreal waterlines disposed over submerged areas (Figure 9b, c, d and e), non-continuous waterlines (Figure 9b) and unreal inland waterlines (Figure 9b).

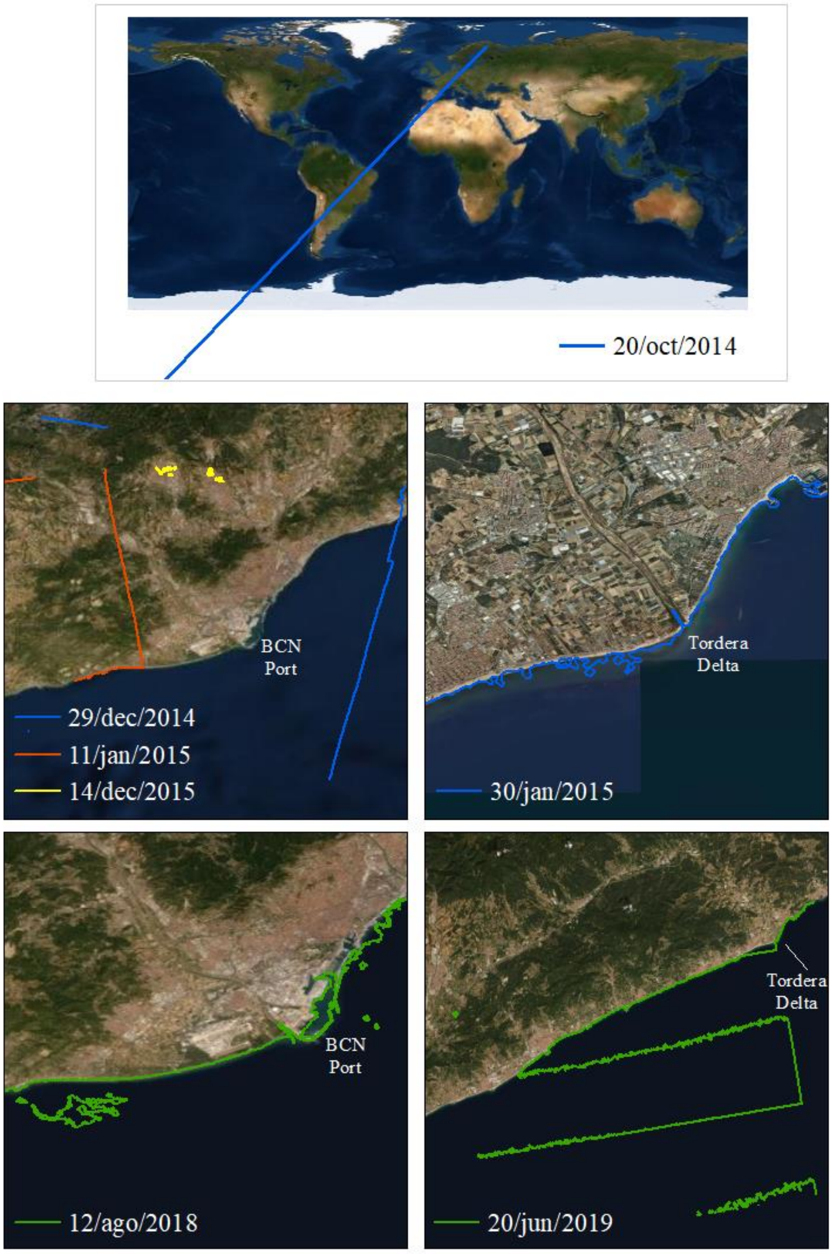

Figure 9: Examples of inconsistencies verified in satellite-derived waterlines from radar sensors (SDW-sar) in both pilot sites: Malgrat (left panels) and Barcelona (right panels). Top panel represents a typical error verified in both pilot sites.

Because of those inconsistencies, we observed that almost the totality of the SDW demands edition and part of the dataset cannot be considered for coastal analysis for not representing the waterline. About 8% of the waterlines from optical sensors cannot be used, while 69% of the waterlines from radar sensors were discarded (see Table 6). For remaining SDW, manual edition was performed when exclusion of inexistent waterlines was necessary.

BATHYMETRY

Up to the moment, bathymetry products available included 8 SDBs for Malgrat and 27 for Barcelona beaches. In the same way as carried out for the previous products, SDB passed by an initial visual analysis to check the existence of incoherent bathymetric values. In Barcelona, we could verify very low depths nearshore in SDB data (intense orange colors in Figure 10a), which are not coherent with values typically observed in measured bathymetry. The sediment concentration from El Prat river plume is the cause of the underestimation and highlight a typical limitation of this type of EO Products in areas where suspended sediment transport is relevant. The SDBs that presented this issue were excluded from the validation analysis. The same problem was not observed in SDBs from Malgrat beach.

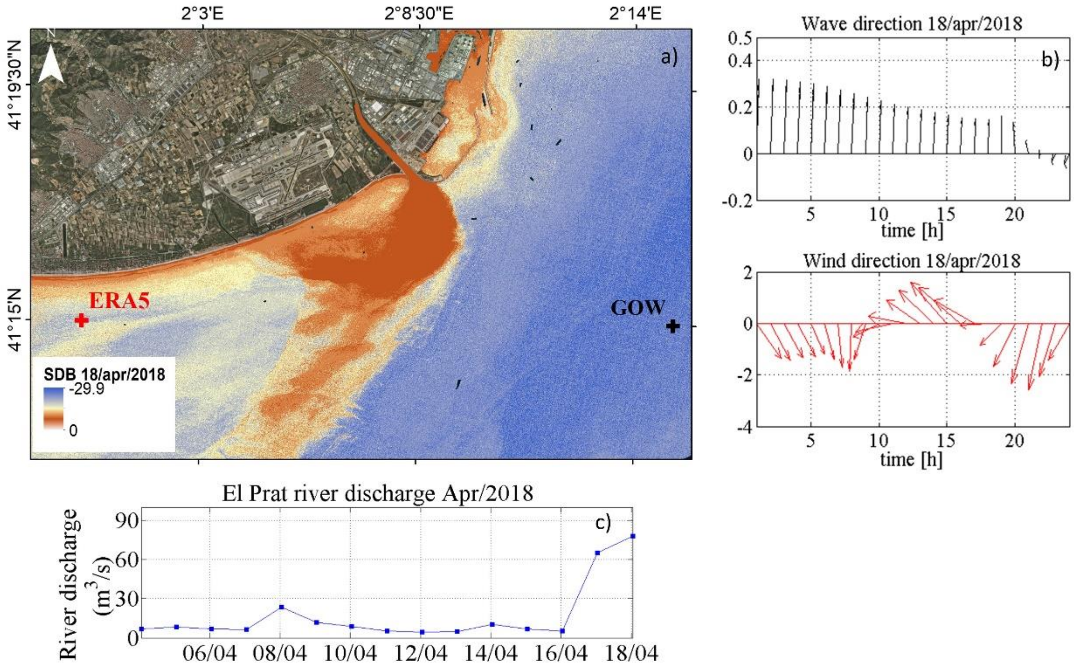

Figure 10: a) Example of problem verified in the SDB due to the sediment plume of El Prat river. b) Wave and wind directions obtained from GOW and ERA5 reanalysis, respectively, along the day the SDB was obtained.. c) Time series of El Prat river discharge along the first weeks of Arpil/2018.

From the 27 SDB provided for Barcelona beaches, 8 (30%) were considered good to be used in validation, while 19 were affected by the presence of the sediment plume (see the synthesis in Table 1). Even though, in the last case, 5 could be useful for validation exclusively in zone 1 (Ginesta), since the plume do not seem to reach the southern area of the beach.

In the future it is expected to have metadata indicating when the EO Products present this sort of issues (quality flags). This is essential to ensure the usability of the products by the end-users. This information can be obtained from satellite-based sediment concentration, which allows to identify dubious SDB. Local data of the dynamics in the study area also can be used as indicators. In Barcelona, for example, the presence of the plume nearshore is a result of the combination of the river discharge (Figure 10c), which indicates the amount of sediment input from inland, and specific wave and wind conditions that move the plume towards the beach (Figure 10b). Such data can, then, be useful to identify problematic events.

Reference data

Time series from Global Ocean Surge and Tide (GOST – IHCantabria) reanalysis were used to identify the water level at the coast in the moment of waterline acquisition. This reanalysis consists in more than 40 years (1979- present) of water level that include astronomical tide, storm surge and the interaction between both. The time series used here were obtained in two points, located seaward of the pilot sites. Figure 11 present the time series obtained in front of Malgrat and Barcelona coast. The reanalysis database was previously validated for the Spanish coast including Catalunya (*e.g.* Cid et al., 2014) and did not need further check.

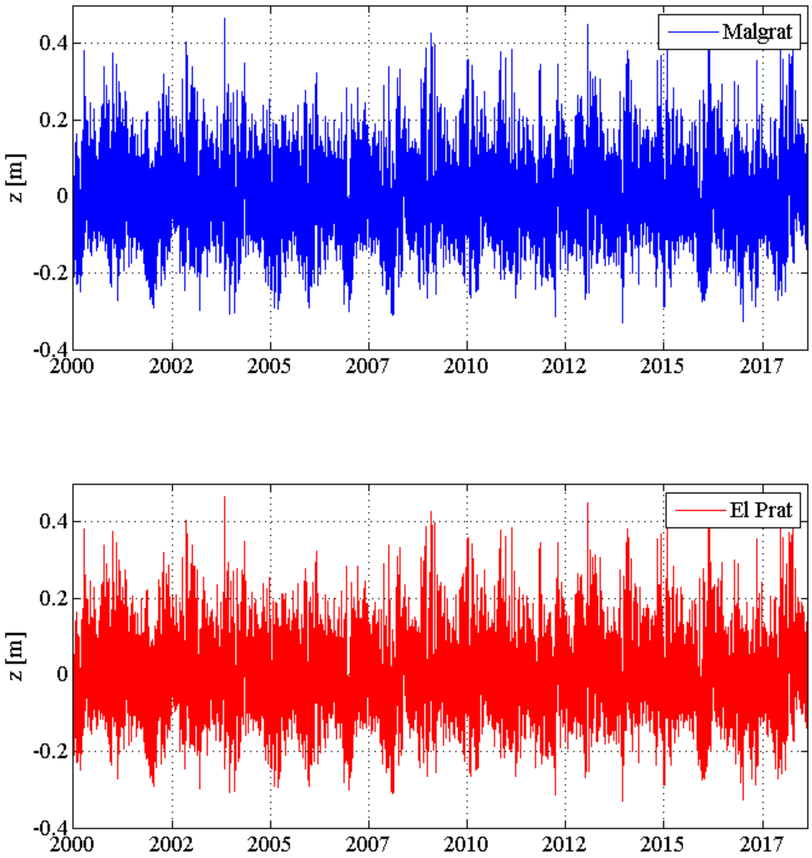

Figure 11: GOST time series obtained from a point in front of Malgrat and Barcelona beaches for the last 20 years.

2.2.2 Ancillary data

TOPOBATHYMETRY

Topo-bathymetry data obtained from in-situ measurements are available for both beaches. In Malgrat beach, measurements were taken southward of the Tordera river mouth during two surveys (2015 and 2017). In Barcelona, measurements were taken pre- and post-dredging surveys every year from 2007 to 2018 in two main zones: El Prat beach, the zone where the dredged sand is deposited, and Ginesta Port, the zone of sand extraction. The exception is the bathymetry from 2018, which was taken continuously from El Prat river mouth to Ginesta Port.

The same visual analysis carried out for SDB was applied to the auxiliary data and no problems were verified. Table 7 presents the dates of the measured bathymetries to be considered for validation.

Table 7: Dates of measured bathymetry to be considered in the validation process of SDB and SDSL data.

Malgrat	Barcelona
2015/nov/11	2007/mar/01
2017/may/25	2007/jun/14
	2008/may/07

2008/may/30
2009/may/29
2009/jun/09
2010/jun/06
2010/jun/20
2011/oct/03
2011/oct/19
2012/may/30
2013/jan/09
2013/jan/21
2013/jun/05
2013/jun/27
2014/may/20
2014/jun/02
2015/may/12
2015/jul/03
2016/jun/01
2016/jun/22
2017/may/23
2017/jun/13
2018/apr/20

SHORELINES AND WATERLINES

Shoreline and waterline measurements were obtained from those topo-bathymetries using the datum approach, which means that the shoreline is assumed to be the topographic contour line equivalent to the datum/water level of interest. This was possible only for those surveys (and in those areas) that included beach topography.

2.3 SPATIO-TEMPORAL COLLOCATION

2.3.1 Match-up database

SHORELINES

For the validation analysis, we used satellite products obtained in the dates closest to measurement days, with a maximum temporal distance of ±7 days. Table 3 shows the dataset used for validation of SDSL. Unfortunately, following those guidelines, there was no match between satellite-derived shorelines and in-situ measurements for Malgrat beach, mainly because of inconsistencies found in data or due to no match in time.

Table 8: Nearest dates of SDSL and ancillary dataset used for validation.

Site	Ancillary SL	SDSL	Difference in days

Barcelona	2016/jun/01 (2016a)	2016/jun/07	+6d
	2016/jun/22 (2016b)	2016/jun/27	+5d
	2017/may/23 (2017a)	2017/may/23	0d
	2017/jun/13 (2017b)	2017/jun/12	-1d
	2018/apr/20	2018/apr/18	-2d

The spatial match of shorelines consisted in:

i) Projection of SDSL to the same coordinate system as ancillary data (ETRS89).
ii) SDSL is based on mean sea level of REDMAR datum, while ancillary data is based on the Zero of Barcelona Port Datum. The ancillary shoreline position was then obtained as the contour line of topo-bathymetry equal to 0.504m (MSL REDMAR = Zero Barcelona Port + 0.504m).
iii) To obtain pairs of data to be compared, we identified the intersection point of both shorelines with cross-shore transects displaced every 15 m along the coast (Figure 12).

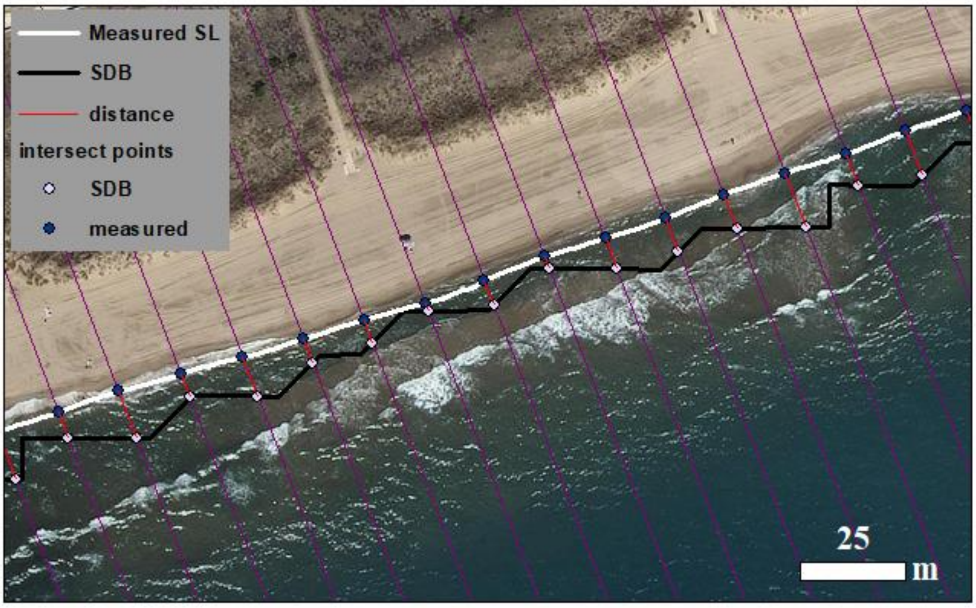

Figure 12: Intersect points and distance between measured and satellite-based shorelines.

WATERLINES

The temporal match of SDW and waterlines obtained from ancillary data followed the same guidelines as presented for shorelines, and the closest data within the period of ±7 days from the measurement day was used. Again, following those guidelines, there was no match to compare SDW-opt with data measured in Malgrat beach. Table 9 and Table 10 present the dataset used for validation of waterlines.

Table 9: Nearest dates of SDW-opt and ancillary dataset used for validation.

Site	Ancillary SL	SDW-opt	Difference in days
Barcelona	2016/jun/01 (2016a)	2016/jun/07	+6d
	2016/jun/22 (2016b)	2016/jun/27	+5d
	2017/may/23 (2017a)	2017/may/23	0d

	2017/jun/13 (2017b)	2017/jun/13	0d
	2018/apr/20	2018/apr/18	-2d

Table 10: Nearest dates of SDW-sar and ancillary dataset used for validation.

Site	Ancillary SL	SDW-sar	Difference in days
Barcelona	2016/jun/01 (2016a)	2016/jun/05	+4d
	2016/jun/22 (2016b)	2016/jun/29	+7d
	2017/may/23 (2017a)	2017/may/25	+2d
	2017/jun/13 (2017b)	2017/jun/12	-1d
	2018/apr/20	2018/apr/25	+5d
Malgrat	2015/nov/11	2015/nov/14	+3d
	2017/may/25	2017/may/25	0d

The spatial match of shorelines consisted in:

i) Projection of SDW to the same coordinate system as ancillary data (ETRS89).
ii) Verifying the water level at the moment of satellite measurement[1] in GOST database.
iii) The ancillary waterline position was obtained as the contour line of the topo-bathymetry equal to the water level.
iv) To obtain pairs of data to be compared, we identified the intersection point of both shorelines with cross-shore transects displaced every 15 m along the coast (see Figure 12).

BATHYMETRY

The temporal match of SDB followed the same guidelines as presented for the previous EO products and the closest data within the period of ±7 days from the measurement day was used. Again, following those guidelines, there was no match to compare SDB with data measured in Malgrat beach. Table 11 presents the dataset used for validation of satellite-derived bathymetries.

Table 11: Nearest dates of SDB and ancillary dataset used for validation.

Site	Ancillary	SDB	Difference in days
Barcelona	2016/jun/01	2016/jun/07	+6d
	2017/may/23	2017/may/23	0d
	2017/jun/13	2017/jun/12	-1d

The spatial match of bathymetric data consisted in:

i) Projection of SDB to the same coordinate system as ancillary data (ETRS89).
ii) Interpolation of ancillary data.
iii) Extraction of both SDB and ancillary values in the same points of a grid inside the area of in-situ measurements. No datum correction was necessary here (Argans informed the end-user that SDB was already referred to the zero of Barcelona Port Datum, as it is the ancillary data).

[1] SDW products presented information about the acquisition time, but no information about the time reference. UC00 was assumed in this case.

2.4 REPRESENTATIVENESS UNCERTAINTY

In this first phase, EO Products did not came with the complete metadata and information about uncertainty could not be included in the analysis. For now, the analyses were carried out taking into account the accuracy obtained with Sentinel products (1 m vertical and 10 m horizontal resolution).

2.5 METRIC CALCULATION

The pairs of data (correspondent satellite and ancillary date values) obtained from shoreline, waterline and bathymetry were assessed using the Mean Absolute Error (MAE, eq. 2) and the Brier Skill Score (BSS, eq. 3). BSS values higher than 0 indicate good estimates, while values lower than 0 indicate strong differences between satellite and measured data. Here, the baseline (B_j) will be taken as the initial condition (pre-dredging/nourishment), the data measured from the first surveys of each year. For example, for 2017, measured data from May will be used as baseline, while ancillary and satellite data from June will represent x_j and y_j respectively. When assessing the shorelines, the absolute error will be calculated considering cross-shore distance between measured shoreline and SDSL.

2.6 ANALYSIS AND INTERPRETATION

2.6.1 Absolute error metrics

SHORELINES

The cross-shore distance between measured and satellite-based shorelines was estimated as presented in Figure 12. The values obtained in each transect can be verified in Figure 13. Negative values indicate SDSL located landward of the measured shoreline, while positive values indicate SDSL located seaward. In great part of the transects, the cross-shore distance was lower than 10 m (86% of the data presented in Figure 13), and MAE was equal to 4.46 m. Higher values can be observed in zones with high sand mobility, such as the connection of small channels with the sea (transects 10 to 30) and for those pairs of data with higher temporal delay between in-situ and satellite measurement (e.g. 2016a). The results obtained for Barcelona are considered to present good agreement with in-situ measurements, given the pixel resolution of Sentinel-2 images, which is typically 10 m (horizontal accuracy).

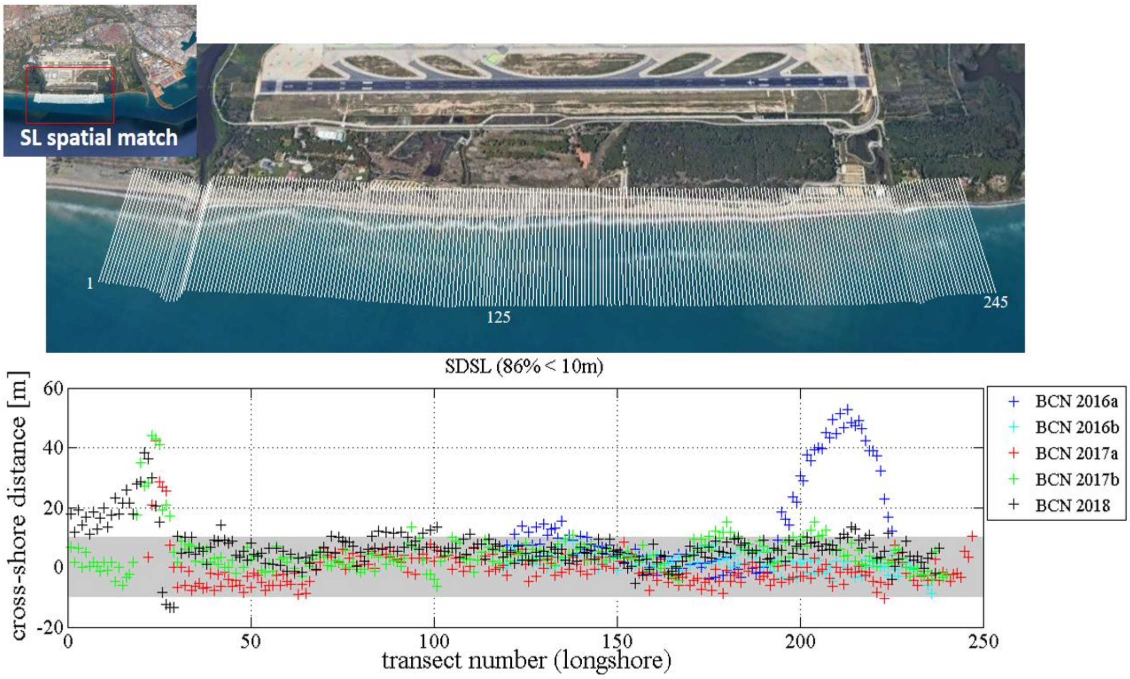

Figure 13: Cross-shore transects displaced in the area where the shorelines match (upper panel) and distance verified between measured and satellite-based shorelines in each of those transects. The gray area indicate the range between ± 10 m.

WATERLINES

The cross-shore distance between measured and satellite-based waterlines was estimated as presented in Figure 12. Figure 14, Figure 15 and Figure 16 present the results of those distances obtained for Malgrat and Barcelona, respectively.

The results indicate good agreement between the waterline obtained from the optical sensor and those obtained from measurements in Barcelona beaches (Figure 15b). 90.3% of the points were displayed in distances lower than 10 m from ancillary waterlines, which is the typical horizontal accuracy from Sentinel products. The MAE was equal to 5 m in this case.

The results obtained from radar sensors show higher errors in waterline estimates for both pilot sites (Figure 15 and Figure 16c). The resulting MAE was 31 m in Barcelona and 30.2 in Malgrat. In these cases, 21% and 11% of the data fall within the range of ± 10 m, respectively. This waterlines often present curved shapes that are not observed in situ and, sometimes, the detection of sea-land limit is not exactly positioned in the wet-dry interface (see Figure 16). It is important to highlight that variations due to wave action (*i.e.* setup and runup) was not considered in the process of extraction of in-situ waterlines from topo-bathymetry. Even though, the variability and curved shape verified in SDW-sar does not look like wave variations typically observed from waves in the pilot sites. Wave conditions will be further explored in future analysis.

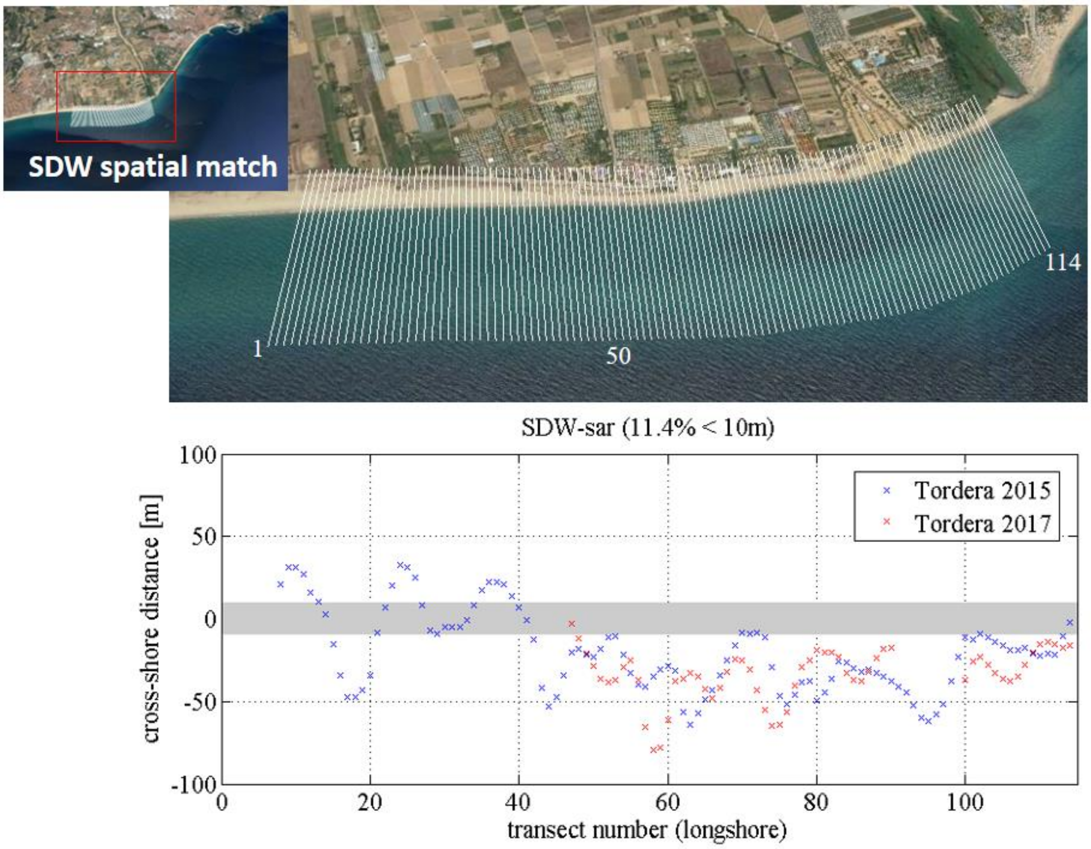

Figure 14: Cross-shore transects along the coast of Malgrat – Tordera Delta (a) and the distance between waterlines obtained from in-situ measurements and SDW-sar (b). The gray area indicates the range between ± 10 m.

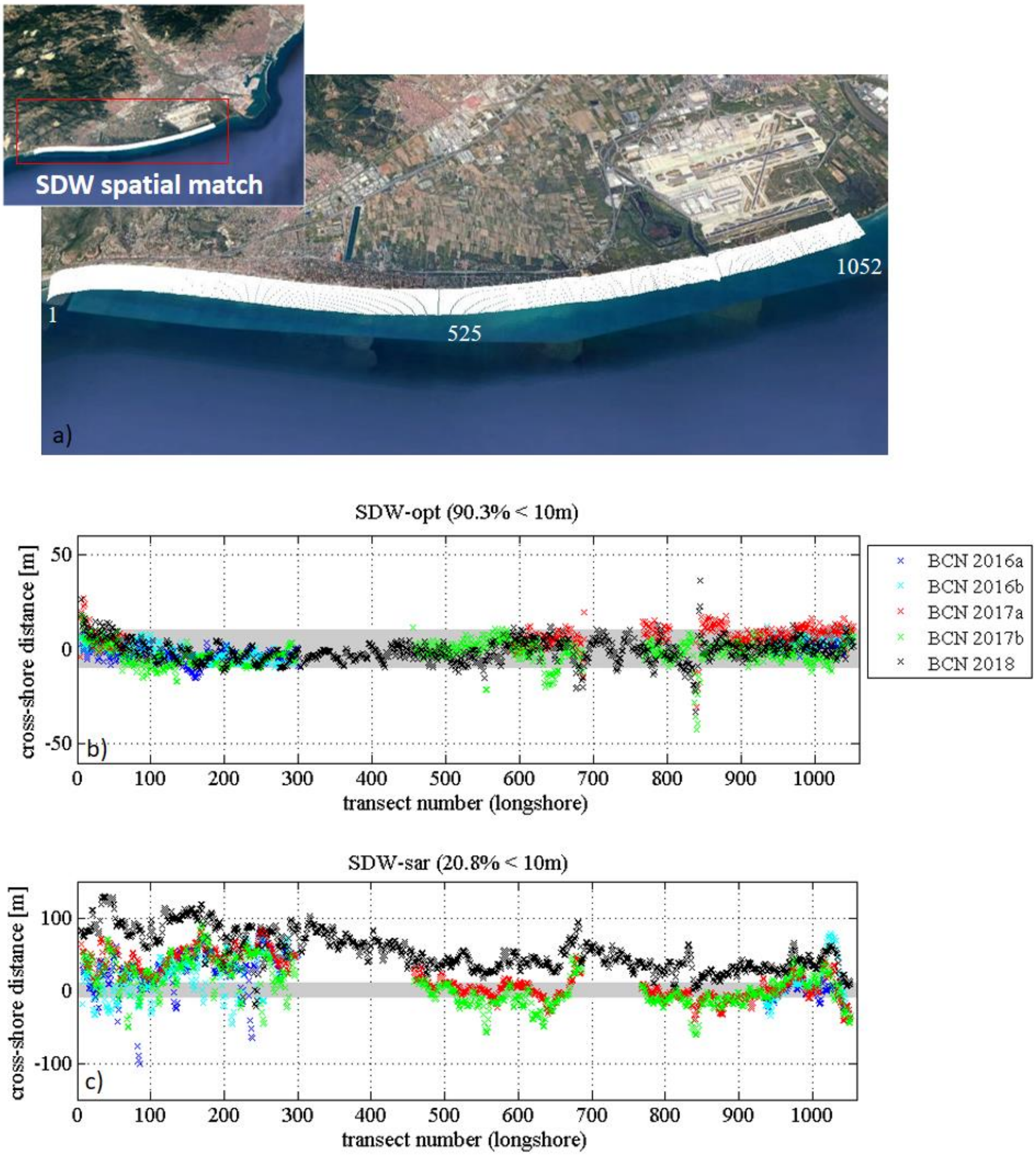

Figure 15: Cross-shore transects along the coast from El Prat to Ginesta - Barcelona (a) and the distance between waterlines obtained from in-situ measurements and SDW-opt (b) and SDW-sar (c). The gray area indicates the range between ± 10 m.

Figure 16: Examples of waterlines obtained from in-situ measurements, SDW-sar and SDW-opt in Malgrat (upper map) and Barcelona (lower map).

BATHYMETRY

Measured and satellite derived bathymetry, and the difference between both are presented in Figure 17, Figure 18 and Figure 19. Great part of the satellite data showed differences lower than 2 m with respect to the measured data. 65% of the data showed differences lower than 1m, which is the vertical accuracy of data from Sentinel products. At this point, it is important to highlight that differences of about 2 m may have important effect on the analysis of nearshore morphodynamic, since seabed features may have size in the same order of magnitude as the errors obtained. The higher differences observed reached values of about 9 m and were mainly observed in deeper zones.

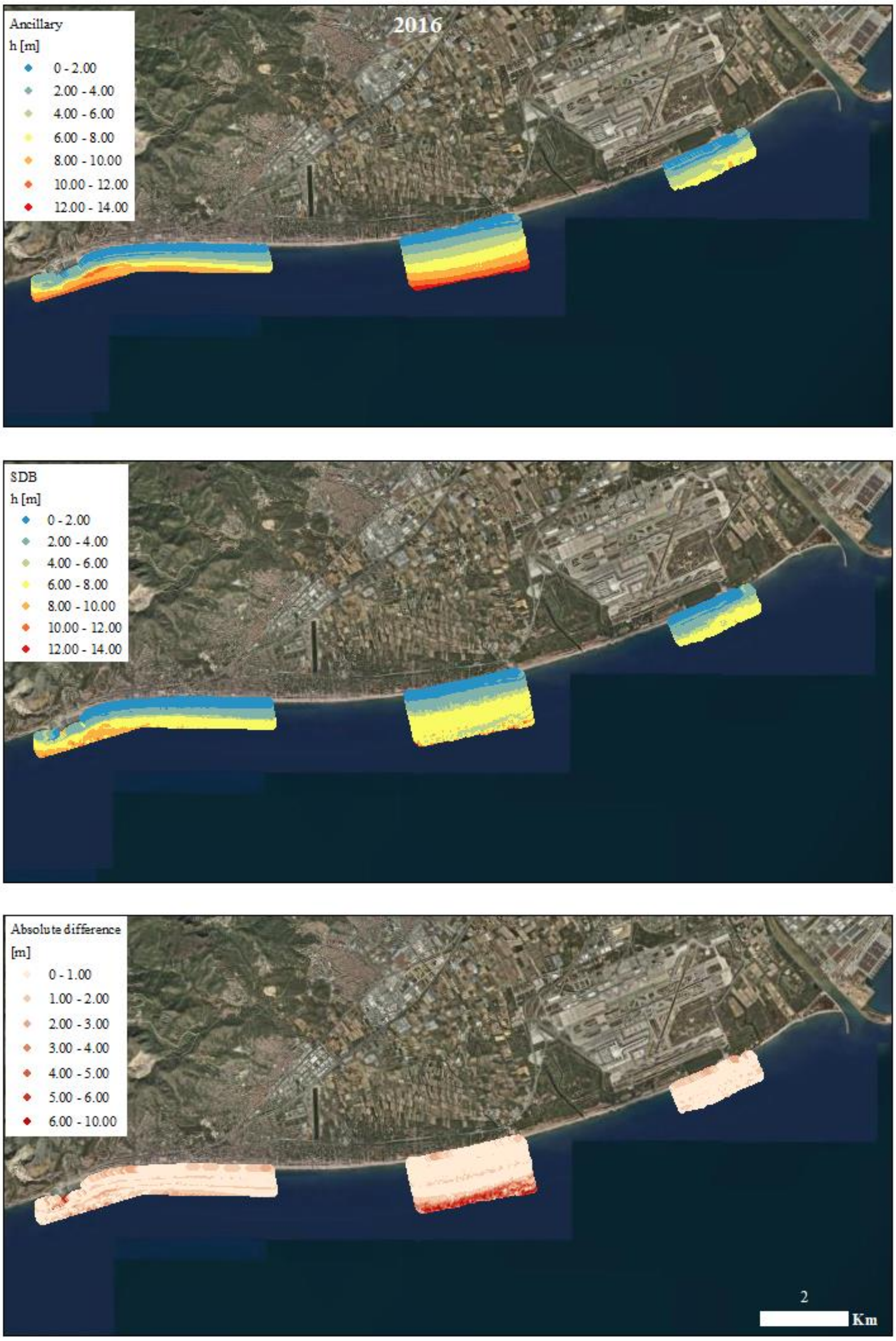

Figure 17: Measured (01/jun - upper panel) and satellite-based bathymetry (07/jun - mid panel) from 2016 and the absolute difference between both (lower panel).

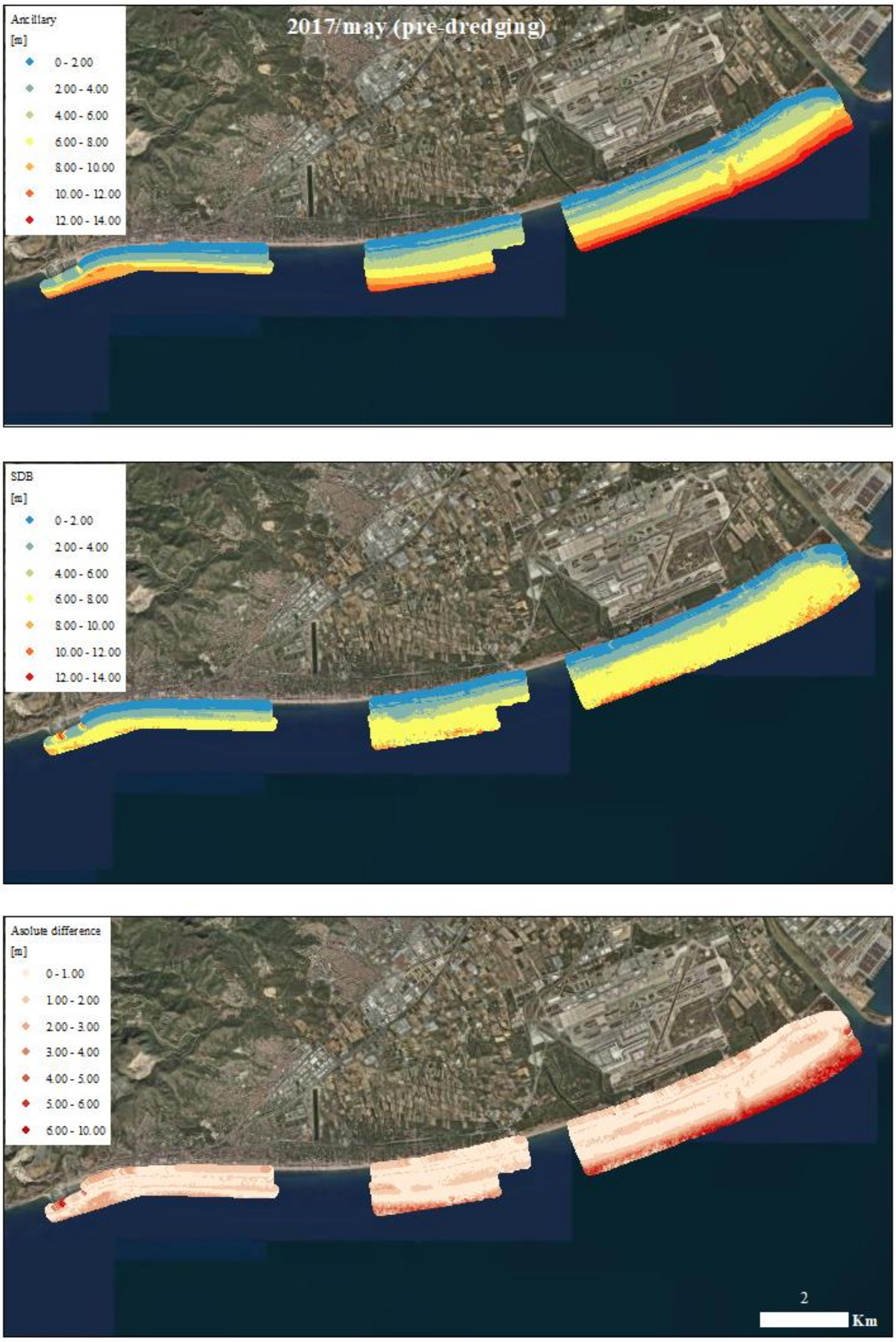

Figure 18: Measured (23/may - upper panel) and satellite-based bathymetry (23/may - mid panel) from 2017 and the absolute difference between both (lower panel).

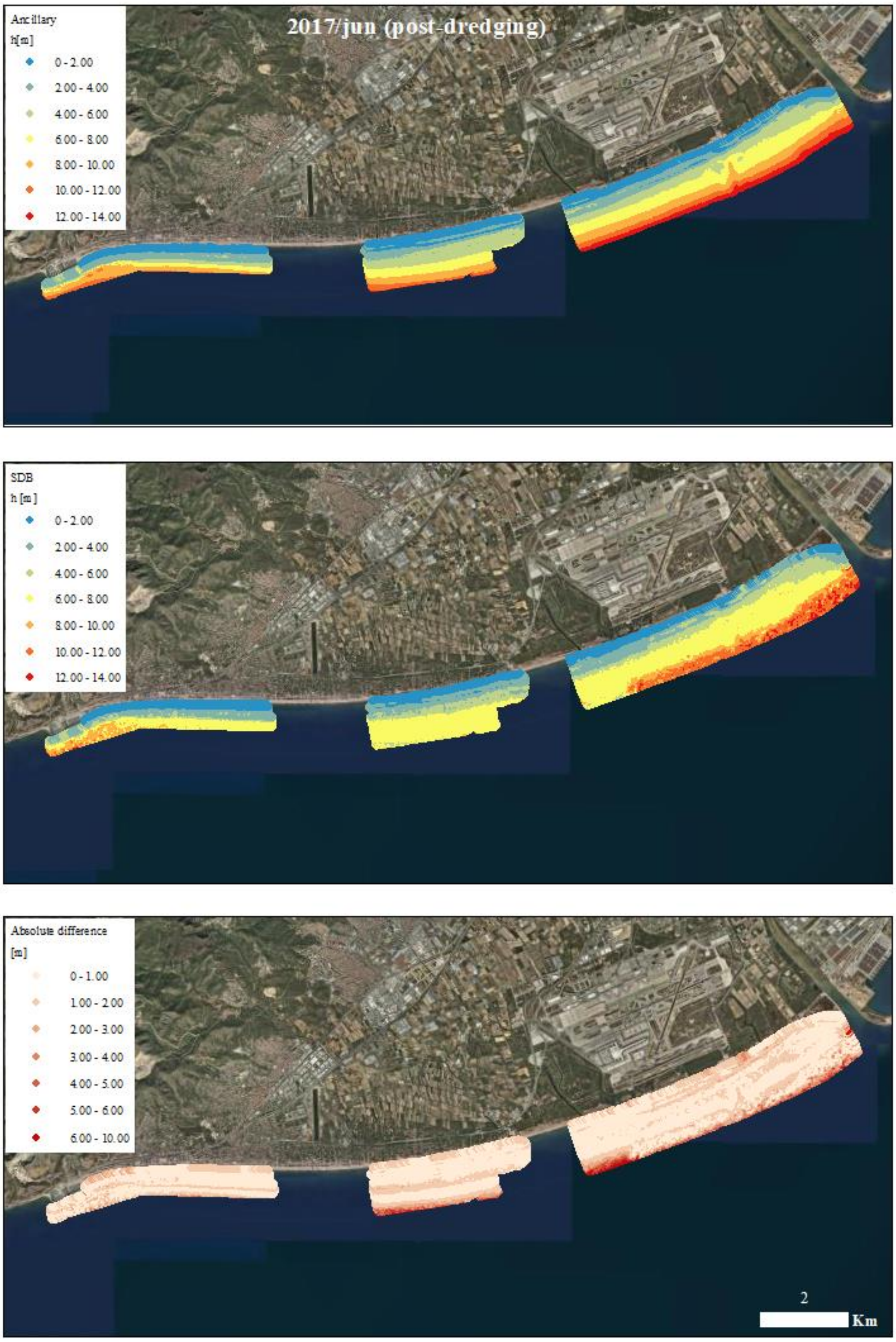

Figure 19: Measured (13/jun - upper panel) and satellite-based bathymetry (12/jun - mid panel) from 2017 and the absolute difference between both (lower panel).

Figure 20 shows a scatterplot between measured and satellite-based depths. Higher dispersion can be observed in depths higher than 10, where SDB is particularly underestimated. These results are in accordance to previous works that indicate that satellite derived bathymetry are less accurate in deeper waters, where the method of bathymetry estimation is less efficient. We will take that fact into account in the next phases of this project.

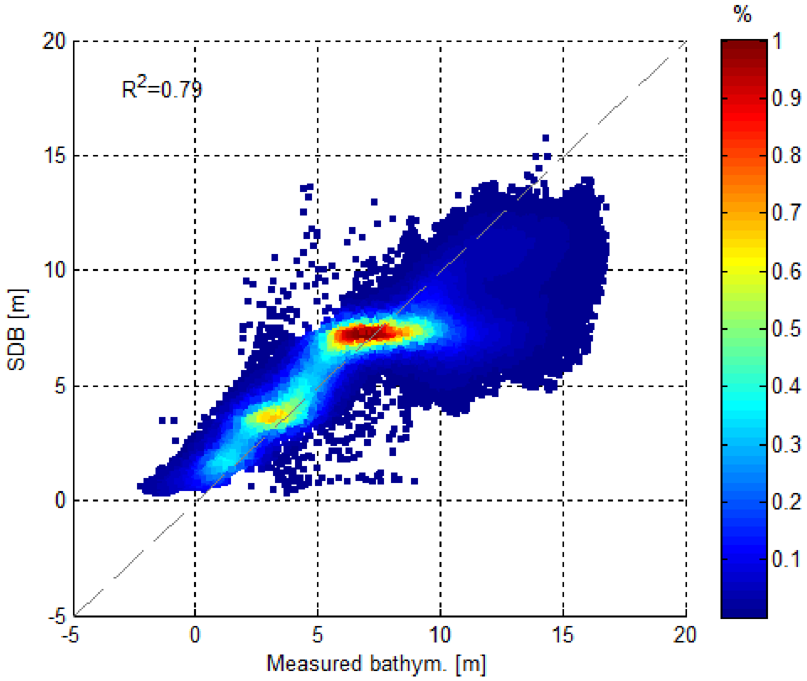

Figure 20: Scatterplot between measured and satellite derived bathymetry. The escale of colors indicate points' density, in percent.

2.6.2 Relative error metrics:

Brier Skill Score

To evaluate the errors obtained from satellite estimates relative to typical changes observed in each site, we applied the BSS to shoreline and bathymetry data.

When assessing shorelines, the values of BSS were calculated for 2016 and 2017, considering as baseline the values measured during the first field survey (pre-dredging/nourishment surveys). Shoreline analysis resulted in BSS equals to 0.98 and 0.99 for 2016 and 2017, respectively. Those values indicate good quality of this EO Products in this study site.

When assessing the bathymetry data, the BSS was calculated using pre and pos-dredging data from 2017. In this case, BSS was equal to -0.0018, what indicates that bathymetry estimated from satellite information, does not represent quite well what it is observed in-situ. These results can be related to the underestimation of the bathymetry in depths higher than 10 m, verified earlier in this document (see Figure 11 to Figure 13), and need further attention.

3 Evaluation results

3.1 EVALUATION PER EARTH OBSERVATION PRODUCT TYPE

Table 12, Table 13, Table 14 and Table 15 summarizes the evaluation scores (L: low; M: medium; H: high) for each section of the Annex B in the SOW for the following EO products: waterlines, shorelines, land Cover and Use maps, satellite derived bathymetries. Sections B.1 and B.2 has been filled in by all End-Users where product was available for the validation study site. At present, the products are on very early stages of development to make an informed assessment of sections B.3 to B.5. Some End-Users (i.e. BGS and ARCTUS) have preferred not to provide an assessment on these sections until products are more advanced while other End-Users (i.e. GSI and SGPC-IHC) has provided an assessment under the assumption that some of the problems listed on sections B.1 to B.2 are solved. For some of the items in sections B.3 to B.5 end users has provided suggestions as text (i.e. indicated by txt on each table) but not a score. In the following, we summarize the overall score for each product, the main reasons for the score and propose some actions to continue improving the scoring when possible.

Table 12. Evaluation scores for Optical (OPT) and RADAR (SAR) "Waterlines"

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

txt: user provided comments as text but not score (see doc for details);
---: no score or comment provided

WATERLINES, derived from both OPTICAL and SAR images, has received a MEDIUM score on the overall evaluation (Table 12) for the following main reasons;

1. **Lack of metadata**. All product information comes in the product's name, which for the majority of products includes: 1) details about mission (i.e. S2: Sentinel 2; L8: Landsat 8), 2) date and time of the satellite acquisition and product creation. End-Users expressed their metadata requirements for each product in the "Product specification section >> Information layers" for each product on the URD (BGS ref. CR/19/055) that are not present on the provided products. For example, BGS requested metadata indicating the presence of "Error lines; Lines that have errors (for instance not closed rings or self-intersections)" (URD, page 32, Table 6 Product description BGS #1: Proxy-based Tidelines). According to PVP, the Service Providers have included these types of error-checking within their validation process (Table 2.4: Validation table of VNIR waterline, Table 2.5: Validation table of SAR waterline in PVP). Action on End-Users: revise the

information layer specifications on the URD. Action on Service-Providers: include validation outcomes on product metadata.

2. **Product format not always compatible with user specifications**. Optical derived waterlines were provided as ESRI shape files (*.SHP) while RADAR derived waterlines were provided as geojson (*.GEOJSON). ESRI shape files is the preferred format for all End-Users, and while most of the enrolled End-Users (BGS, GSI, ARCTUS) have the software flexibility and GIS knowledge to work also with geojson files, the SGPC would like that all waterlines (optical and SAR) are provided as ESRI Shapefile in the future to maximize usability.
3. **Required accuracy was not reached but products are still considered valid**. Although the accuracy requirements for waterline products specified in the URD end-user in the URD were not accomplished, those requirements are mainly aspirational, and the products are still useful for many of the purposes of SGPC's practices. Lack of VHR optical waterline products is still a requirement for GSI.
4. **Required updating frequency of waterlines seems feasible and have been partially accomplished**. While the number of products per End-User varies among sites and End-User (see Table 5), the required updating frequency specified in the URD was from events scale (pre and post storms) to monthly scale and this requirement was accomplished.
5. **Required temporal range of waterlines seems feasible and have been partially accomplished**. While the number of products per End-User varies among sites and End-User (see Table 5), the length of the temporal range, which was on the order of decades, specified seems feasible and have been in some study sites accomplished. For example, in the Barcelona coast study site and considering data obtained from both methods (optical and radar), the whole dataset cover the period from 2000 to 2019, completing almost 20 years of data, which accomplishes with the users requirement of temporal coverage. With these series the end-users expect to achieve the temporal range necessary for short and long-term analysis, from intra/inter-annual to decadal scales (URD specified 25 years was desirable).

SHORELINES, has received a MEDIUM to HIGH score on the overall evaluation (Table 13) for the following main reasons;

1. **Shorelines showed good agreement with in-situ measurements and are useful to coastal analysis**. The products can improve and reduce the costs of current end-user's practices.

2. **Although the horizontal accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for the purposes of End-Users practices**. If VHR products were available and accurate the overall service would be positively impacted. Shoreline change over time generally occur at the meter scale. Most of the changes in this part of the coastline can be captured at the meter scale.
3. The possibility of using optical and radar shorelines and waterlines together may provide data in higher frequency and wider temporal cover, which allow both short- and long-term analysis.
4. **The confidence in shoreline products however is low due to inconsistencies verified in great part of SDSL**. Inconsistencies must be solved, and quality flags must be provided to impulse the use of these products instead of current practices. The automation of coastal assessment is essential, and the problems verified in shoreline products up to now makes it difficult.

Table 13. Evaluation scores per End-User for "Shorelines"

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

txt: user provided comments as text but not score (see doc for details);
---: no score or comment provided

LAND COVER AND LAND USE MAPS, has received a LOW to MEDIUM score on the overall evaluation (Table 14) for the following main reasons;

1. **Land Cover outputs meet the spatial resolution but not the frequency**. The required updating frequency was aspirational and varies from one month to a year. At this early stage of production it is unclear if the updating frequency was not reached due to lack of good quality images or time to generate the products.
2. **Confidence on classification results still under review**. For the Dublin Bay study site, while not yet fully validated due to inability to perform field work (Covid-19 restriction

since late February 2020), the classification results seems satisfactory. For the Start Bay study case, a visual inspection revealed that some of the mud flats in 2018 were classified as Sandy Beach in 2017 which seems an unrealistic change and Crop lands visible in 2017 were unrealistically classified as house class in 2018.

3. **Lack of metadata and attributes descriptions impede a more structured assessment**. No error neither confusion matrix has been provided as part of the metadata. Adequacy of land uses and coverage have been partially accomplished but classes description is needed. 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 seems a good trade-off between classes required and what it was feasible. At the time of this evaluation, the end-users does not know the difference between Crops1 and Crops2 and only the intermediate raster habitat map has been provided (i.e. not the vector format requested).

Table 14. Evaluation scores per End-User for "Land Cover & Use maps"

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

txt: user provided comments as text but not score (see doc for details);
---: no score or comment provided

SATELLITE DERIVED BATHYMETRIES, has received a LOW to MEDIUM score on the overall evaluation (Table 14) 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 SDB 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) but no information regarding the datum used. Although the information could be obtained by consulting the Service Provider, metadata should come with EO Products in the future.

2. **Although the accuracy requirements for bathymetric products (0.1 m vertical, 1 m horizontal) were not accomplished , those requirements are mainly aspirational and the products are still useful for many of the purposes of the End-Users practices**.
3. **The frequency required for this EO Product (monthly) was not accomplished**. The SDBs provided up to date allows to accomplish some of the purposes for SDB in Barcelona, specifically those related to monitoring dredging and nourishment areas. On the other hand, there was no match between SDB delivered so far and in-situ measurements for Tordera Delta, which does not allow a proper verification of the products for this area.
4. **Lack of quality flags to identify products that may present erroneous values. For example, strong inconsistencies in bathymetric values were observed in 19 out of 27 SDB provided for Barcelona coast and on 3 out of 4 SDB for Start Bay**. Bathymetric information is often affected by the sediment river plume in these areas and extra information indicating when this kind of issue occur is necessary so the end-user can identify which data can be used for bathymetry purposes.

Table 15. Evaluation scores per End-User for "Satellite Derived Bathymetries"

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

txt: user provided comments as text but not score (see doc for details);
---: no score or comment provided

3.2 EVALUATION PER COASTAL TYPE

End-Users anticipate that the same product might be valid for some coastal types but not for other. The coastal types covered includes; **gravel pocket-beach** (Start Bay), **estuaries on temperate** (Dublin Bay) **and high latitudes** (Lounge Pointe de Mingan), **sandy beaches on micro-tidal environment** (Tordera beaches, El Prat), **deltas** (Tordera Delta) and **macro-tidal environment** (Dublin Bay). The number of coastal types for which products were available at the time of writing this report was considered too low to produce a meaningful assessment and is not included in here yet.

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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