Coastal Erosion from Space

Product Validation Report

Ref:SO-TR-ARG-003-055-PVR

Date: 01/05/2020

Customer: ESA

Contract Ref.: ESA/AO/4000126603/19/I-LG

This page is intentionally left blank

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	Product Validation Plan	SO-TR-ARG-003-055-009-PVP
AD-3	Preliminary sites selected for validation	SO-TR-ARG-003-055-009-PVP-A4
AD-4	Technical specification document	SO-TR-ARG-003-055-009-TSD
AD-5	Satellite Derived Bathymetry ATBD	SO-TR-ARG-003-055-009-ATBD-SDB
AD-6	Annex 1: Pre-processing verification and quality control	SO-TR-ARG-003-055-009-PVR-A1
AD-7	Annex 2: Waterline verification and quality control	SO-TR-ARG-003-055-009-PVR-A2
AD-8	Annex 3: Shoreline verification and quality control	SO-TR-ARG-003-055-009-PVR-A3
AD-9	Annex 4: Seafront verification and quality control	SO-TR-ARG-003-055-009-PVR-A4
AD-10	Annex 5: Topobathy verification and quality control	SO-TR-ARG-003-055-009-PVR-A5
AD-11	Annex 6: ESA Coastal Erosion Project: End-Users validation document	Coastal Resilience and Geohazards Programme Open Report OR/20/018

Contents

List of Figures

List of Tables

Introduction

The purpose of this report is to build upon the knowledge based within the referenced documents and provide the confidence to the reader that a formal checking process has been conducted from the initiation of production through the delivery of the products and then covering the value and utility of those products for the purposes that the user community initially identified.

This Product Validation Report therefore consists of three sections and follows on directly from the processes and procedures outlined within the Product Validation Plan. (see fig 1. Below)

- The Quality Process within production (Verification and Quality Control)
- The Product Validation Review by the user community of the products
- The Evaluation Report by the user community on the utility of the products.

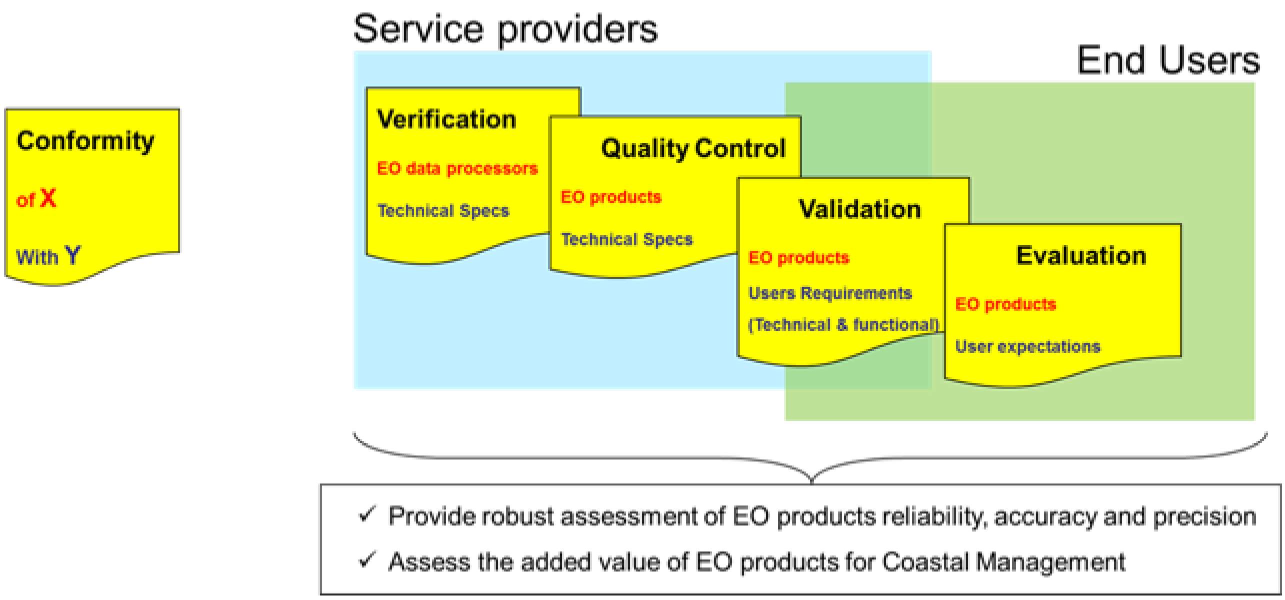

Figure 0.1: Validation protocol is approached here as a multi-step conformity checking process done by both the Service providers and End-Users.

Each section can be read as a stand-alone document but together they tell the complete story from initial downloading of selected images (and why those images were selected) to how the user community have exploited the information and products in support of better understanding coastal erosion processes and designing innovative services to those responsible for monitoring and managing the effects of coastal change.

The key tenets of the Quality Process section will be to draw together the Verification steps which are currently identified within each individual processors' ATDB, identify the Quality Control and Assurance process adopted.

The Validation and Evaluation Reports have been compiled by the User Group (BGS, IGS, IH Cantabria and Arctus) and these documents are incorporated here but can also be read as stand-alone documents.

1 Service providers: Verification and Quality Control

The scope of this section is to provide to the end-users the verification and quality control of the processors developed and the delivered products. This version of the document will be updated according to the different requirements of the end-users.

Verification and quality control are necessary steps in the production chain to check that the obtained EO products accomplish the precision and quality expected and enable those products to be compared to previous studies and surveys. Comparison with in-situ measurements is impossible, as EO products come from an instantaneous but greatly repeated satellite snapshot. Thus, validation checks shall be done in consistency with results from previous surveys, considering the temporal and the spatial resolution of the EO products. If previous survey results provide different and complementary information, an intersection of common information is needed in order to perform comparison.

Verification and quality control will provide information on the processor's stability and on the precision of the supplied products. The following sections will present the definitions and concepts that have been considered for the verification and quality control steps.

1.1 Verification protocol – are the processors performing as designed?

1.1.1 General Definition

The different processors developed within the Coastal Erosion project are all detailed in the Algorithm Theoretical Baseline Documents (ATBDs) linked with the Technical Specification Document (TSD, see AD-4). Those documents describe the processing chain, the algorithm main steps and the excepted results regarding preliminary tests conducted within Phase 1. The purpose of the verification of the processors is to prove that they are in conformity with the ATBDs statements; and that they are truly working under any different 'external' conditions.

The verification process should prove the stability of the developed processors and show the reliability that could be expected under different conditions. Both stability and reliability are evaluated against a list of requirements detailed in the product validation plan (PVP, see AD-2) document.

1.1.2 Pre-processing

The verification process of the pre-processing aims to ensure that the co-registration met the requirement needed. The annex 1 (AD-6) summarizes the different tests performed in several conditions.

The co-registration process efficiency relies on the number of tie points required for a good quality of co-registration. Beyond this, the co-registration is unable to be completed and is rejected. The main cause of a lack of tie points is either a cloudy image or the absence of enough urban/defined features to extract reliable tie points.

1.1.3 VNIR & SAR Waterlines

The verification process regarding waterlines aims to ascertain that the processor can extract a line at the land/sea interface under different environmental and geographic conditions, see Annex 2 (AD-7). In the case of the VNIR processor, it has proved to work when applied in different environments, such as intertidal areas, or under different external conditions, such as sun glint. However, image selection becomes a key previous step, as the processor can be affected by the presence of clouds or turbid waters, for example. For the SAR processor, the difference of backscattering coefficient between the coastal area and the sea area are a key factor to extract waterlines. Therefore, it is recommended to select the SAR scenes with sea-to-land observation direction for waterline detection.

1.1.4 Datum Based Shorelines

The shoreline processor verification aims to ensure the current shoreline processor conforms to the requirements. The verification testing regime is set out in two parts. The first test is a perpendicular distance test which aims to ensure the distances between the waterline and theoretical shoreline conform to the mathematical and scientific theory of water level residual. The second test 2 is geometric position testing. It aims to ensure correct shoreline placement and positioning parallel to the waterline. Tests and results are detailed in the Annex 3 (AD-8)

1.1.5 Seafront Mapping

The ability of the processor to identify and class the different land cover classes is tested using different satellite data sets over different types of coast, and different weather conditions. Those tests are detailed in the annex-4 (AD-9). Those tests show that the processor is able to classify land cover using different spectral combination and different type of bio-climate.

1.1.6 Satellite Derived Bathymetry

The objective of the verification tests in the case of SDB is to check how different conditions affect the identification and location of seabed features or the estimation of depth in the Annex 5 (AD-10). IDA processor is able to cope with different levels of glint (when no glint areas are present in the image), providing good near shore (up to 10 m in general cases) depth values. Atmospheric correction is a key factor to perform IDA, and the aerosol optical thickness has proved to be the most important parameter. It is a processor that has proved to be highly impacted by seasonal conditions and by suspended sediment load, and a flag should be provided for those pixels impacted by these conditions. Therefore, image selection is a key previous step to perform good depth retrieval using IDA processor.

1.2 Image selection for EO processors

Taking into consideration the different verification tests performed for each processor, it has been observed that each of them needs precise characteristics to work properly. Thus image selection before running the developed EO processors becomes a key factor. This key step will take into consideration the different results obtained on the verification tests when performing the identification of images that should be used to estimate each of the products.

As highlighted above, the presence of clouds is a critical constraint for the waterline processor. Therefore, the aim was to minimize cloud cover as much as possible during image selection. Ideal conditions would also exclude environmental phenomena that could introduce false edges, such as turbid waters, pronounced nearshore bathymetry and stormy conditions.

In the case of SDB, the different performed verification tests have led us to better define the criteria used to perform a quicker identification of the images that should be used to estimate seabed bathymetry depths. For example, they shouldn't present sun glint in the totality of the image, or summer images should be preferred, unless a perfect winter image (appropriate light penetration in near shore coastal areas, low suspended particulate matter concentration and constrained sun glint) is present.

1.3 Quality Control – "were the processes correctly implemented?"

At this step, the service providers will check that the EO products deliver a fair reflection of the expected features taking into account the temporal and spatial resolutions of the source imagery. Considering that, the provided products are under a quality control process that follows a list of necessary conditions to be achieved before being delivered (see PVP table 1.2.).

The Quality Control measures implemented are type specific to each product type. Therefore, each product should be controlled using a different methodology. Even though the provided EO products should be comparable to reality, different options are possible depending on the product and the defined requirements.

1.3.1 Pre-processing

Quality control of the pre-processing procedure ensures that the co-registered Sentinel-2 and Landsat 5/8 imagery is performed to a suitable accuracy. The quality of a co-registration can only be as good as the images being used in the co-registration and so image selection both the VHR and the matching Sentinel/Landsat image is a critical stage.

1.3.2 VNIR & SAR Waterlines

Quality control in the case of VNIR waterline products can be conducted by overlying the waterline shapefile and the scene from which it was derived performing a by eye quality control. However, as this process is time consuming, steps are being taken to automate the outlier detection and produce quality flags and potentially delete obviously erroneous outliers.

1.3.3 Datum Based Shorelines

Quality Control for shorelines is challenging due to a general lack of availability of good quality reference data. The derived shoreline needs to be compared with in-situ data, however obtaining a shoreline from ground measurement at an exact datum is unfeasible. Other tests are possible and are detailed the Annex-3.

1.3.4 Seafront Mapping

The quality control of the classification maps is evaluated via a “by-eye” comparison of the classification result with the associated satellite image. The different classes need to match the different land cover type.

These tests conducted over different areas show the localisation accuracy of the classification.

1.3.5 Satellite Derived Bathymetry

In the case of SDB, two different quality controls are going to be performed. The first one is focused on the obtained depth values, and a comparison with bathymetric charts is done to control the quality in the different areas of the scene. The second one is related to the detection of seabed features: it is performed by eye comparison and they should be located no more than 10% of the accurate location of the features. In the case of SDB time series, the quality control of the tendency of the seabed features based on theoretical truth (reference papers) and on reference data. In addition, a suspended particular matter and a depth of penetration stage can be performed to indicate the ability for seabed reflectance to occur in sufficient quantity to be observed.

2 End-Users: Product Validation Review

2.1 Validation activities for EO products

The formal report from the User Group is attached as Annex 6, however the summary is presented here. It should be noted that for this interim PVR the validation and evaluation has been combined within a single review based predominantly on the products delivered within phase. These products were the result of the “feasibility” investigation and as Phase 2 evolves the focus is on production, introducing the QC checks and providing the metadata associated with the products.

2.1.1 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 viii

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 SDWopt 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.

3 End-Users: Evaluation Report

For this interim PVR the user group evaluation has been incorporated within the Annex 6 report. A more complete evaluation will be possible once the phase 2 production over the 26 sites across the four nations has been completed. This will be incorporated within the Final Report.

4 Conclusions

This PVR represents the first review of the products and is largely formed on examination of the Phase 1 set of products which was very much addressed in a research and foundation methodology. The Phase 1 products have enabled the consortium to analyse both the production capability and their value in order to deliver planned improvements throughout phase 2. This first phase also provided the opportunity to work with a professional User Group who refined the requirement from their stakeholders and matched them to what could be achievable to support coastal erosion management by using remote sensing technology and in particular the ESA Sentinel mission.

That phase looked at what could be technically "**feasible**" and an innovative approach adopting a geolocation processor to co-register the Sentinel images was developed alongside other processors that would extract an instantaneous waterline, a derived set of shorelines that would be corrected for tidal height and connected to a datum. These "line" products are also accompanied by a seafront mapping product that would classify the seafront objects in order to support erosion calculations and bathy-topographical terrain models based upon satellite derived bathymetry where sediment load and water column reflectance allow.

What has become clear is that the processors outlined above work effectively from a feasibility perspective and meet the initial requirements with the quality of the initial products being sufficient to enable a critical review to be conducted by our partners which has identified (as anticipated) that Quality Checking and Assurance is a key requirement to be further developed during the production phase of the project.

The project has now commenced the second phase, that of "production, analysis and dissemination", and the next focus will be to bring in standard production techniques that will enable a quality processes to weed out those data that are not of use or require to be flagged with appropriate caveats. The feedback provided via the initial validation review has been a vital step and what has been satisfying is the level of agreement between the User Group and the Service Provider Group.

The accuracy and precision of the derived products is very much subject to two key factors, namely the limitation of the source earth observation imagery and the availability of auxiliary data to enhance and compliment the earth observation imagery, however the utility of the products will be based on their reliability and hence it is quite right that quality control features highly in our future plan. The aspirational accuracy requirements of the User Community can only be currently met by employing very expensive commercially available VHR imagery.

The initial processors and resultant products have shown that Earth Observation, with its large spatial and temporal coverage coupled to the quantum advance that the resolution and revisit rate from the Sentinel mission deliver is a game changer. The fact that these products after phase 1 need some refinement is not a surprise and shouldn't detract from the value already achieved and the future value anticipated once the QC process has been fully implemented.

It must also be recognised that VNIR multispectral imagery with its known reliance on cloud free conditions does give vastly superior results to the SAR imagery. SAR based lines also have an additional complication of shoreline attitude to satellite path geometrical relationship leading to a large variation often being observed between ascending and descending observations, however they are obviously not hampered by cloud cover, which for most of the study sites has been an ever present obstruction.

As the project develops and working closely with constructive feedback from the User Group, some key areas for further evolution within the remaining part of the contract will now be factored into the production chain. Although the list is not exhaustive and will need to be prioritised, Phase 2 will not only deliver the volume contractually required but will deliver a production system with a quality control component that will include some if not all of the following:

- A range of different product formats support GIS expert user and novice alike
- sub pixel analysis for waterlines and shorelines
- data gap estimation
- GIS data cleaning/weeding/filtering for obviously erroneous outliers
- a consistent naming convention (additionally a requirement for the web service)
- appropriate meta-data to enable product history to be tracked and re-generated
- confidence flagging for unusual/unpredicted looking data
- interpolation of SAR lines to fill the gaps between VNIR time gaps (caused by clouds)
- polygon search criteria for cloud masking in S2 selection (so not to automatically discount tiles with large % cloud if the coast is clear
- Seafront line definition

What is also clear is the production goal of a Coastal Monitoring Service engine has many similarities to the Mission Performance Centres and the aim of this project is to deliver a capability that can translate to any nation and incorporates the key components of imagery selection and retrieval, geolocation, line and feature extraction, a quality process including verification and validation with large volume back-end storage supported by front-end web service access.

5 References

Han, B., Loisel, H., Vantrepotte, V., Meriaux, X., Bryere, P., Ouillon, S., Dessailly, D., Xing, Q. and Zhu, J. Development of a Semi-Analytical Algorithm for the Retrieval of Suspended Particulate Matter from Remote Sensing over Clear and Very Turbid Waters. *Remote Sensing*, 8, 211, **2016**.

Scheffler, D.,Hollstein, A. , Diedrich, H.,Segl, K.and P. Hostert.AROSICS: An automated and robust open-source image co-registration software for multi-sensor satellite data.*Remote Sensing,* 9,7, 676, **2017**.

Loew, A., Bell, W.,Brocca, L.,Bulgin, C.E.,Burdanowitz, J.,Calbet, X., Donner, R. V. et al. Validation practices for satellite-based Earth observation data across communities.*Reviews of Geophysics,* 55, 3, 779, **2017.**

Ruggiero,P.,Gelfenbaum, G., Sherwood, C.R., Lacy, J.andBuijsman, M.C. Linking nearshore processes and morphology measurements to understand large scale coastal change. In: *Proceedings of Coastal Sediments, v*ol. 3,**2003**.

Sutherland, J., Peet, A.H., and Soulsby, R.L.J. Evaluating the performance of morphological models.*Coastal engineering* 51, 8-9, 917, **2004**.

Wiggins, M., Scott,T.,Masselink, G., Russell, P.andMcCarroll, R.J. Coastal embayment rotation: Response to extreme events and climate control, using full embayment surveys. *Geomorphology,* 327, 385,**2019**.

Appendix

End of Document