Space for Shore

ESA EOEP-5

CCN1

Coastal Erosion

Final Report

Document history			
Version	Authors	Date	Note
0.0	Aurélie Dehouck, I-Sea Pawel Kwiatkowski, Kapitech Anna Mironczuk, Kapitech Damian Olszewski, Kapitech Virginie Lafon, I-Sea Manon Besset, I-Sea Silvère Lamy, I-Sea	01/04/2021	First Draft
1.0	Aurélie Dehouck, I-Sea Virginie Lafon, I-Sea Manon Besset, I-Sea Silvère Lamy, I-Sea	01/13/2021	First Release
2.0	Virginie Lafon, I-Sea	01/20/2021	Second Release
3.0			Third release including clarifications asked by ESA
4.0	Manon Besset, I-Sea	08/25/2022	Updated and completed according CCN1

Summary

1 INTRODUCTION

1.1 Scope of the document

This document provides a synthesis of each project steps organized by work packages. Main results included in the deliverables are reported.

The project was carried out over three years from 2019 to 2022 including an additional year (CCN1) (Figure 1).

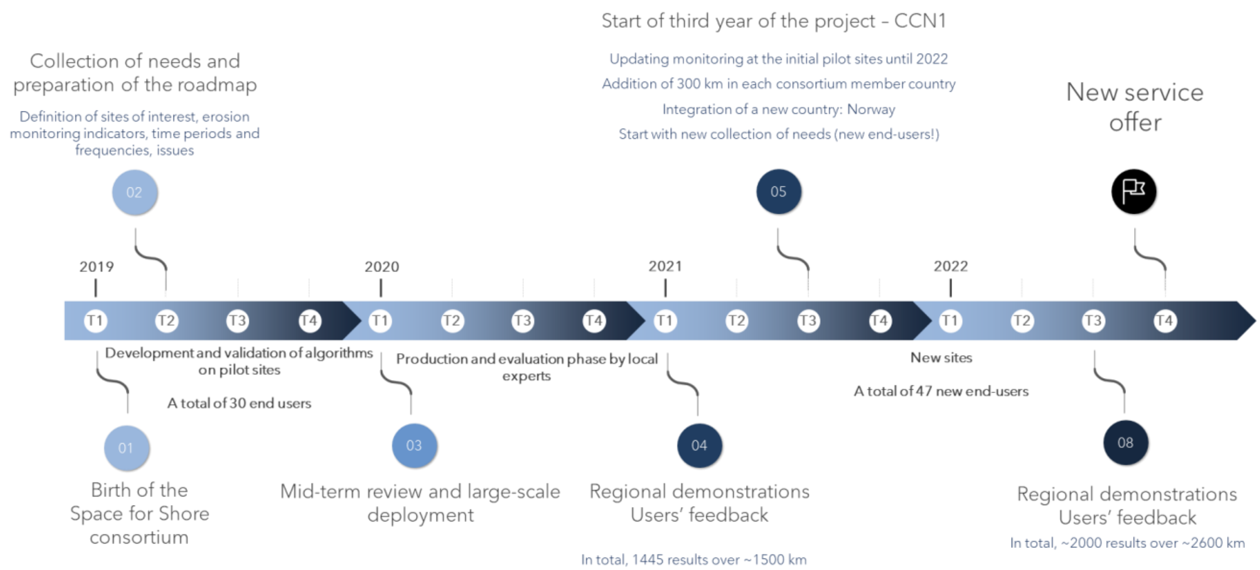

Figure 1 – Overview of the timeline of the ESA Coastal Erosion Project conducted by the Space for Shore consortium.

The first two years (2 phases from 2019 to early 2021) of the project were organized by work package as follows:

- Phase 1 (2019, Figure 2):
    - WP 1.1: User requirement and service specifications
    - WP 1.2: Service and product technical specifications
    - WP 1.3: Proof of concept
    - WP 1.4: Validation plan
- Phase 2 (2020, Figure 3):
    - WP 2.1: New algorithm and methods development
    - WP 2.2: Large scale demonstration and product validation
    - WP 2.3: Roll-out analysis and service perspective

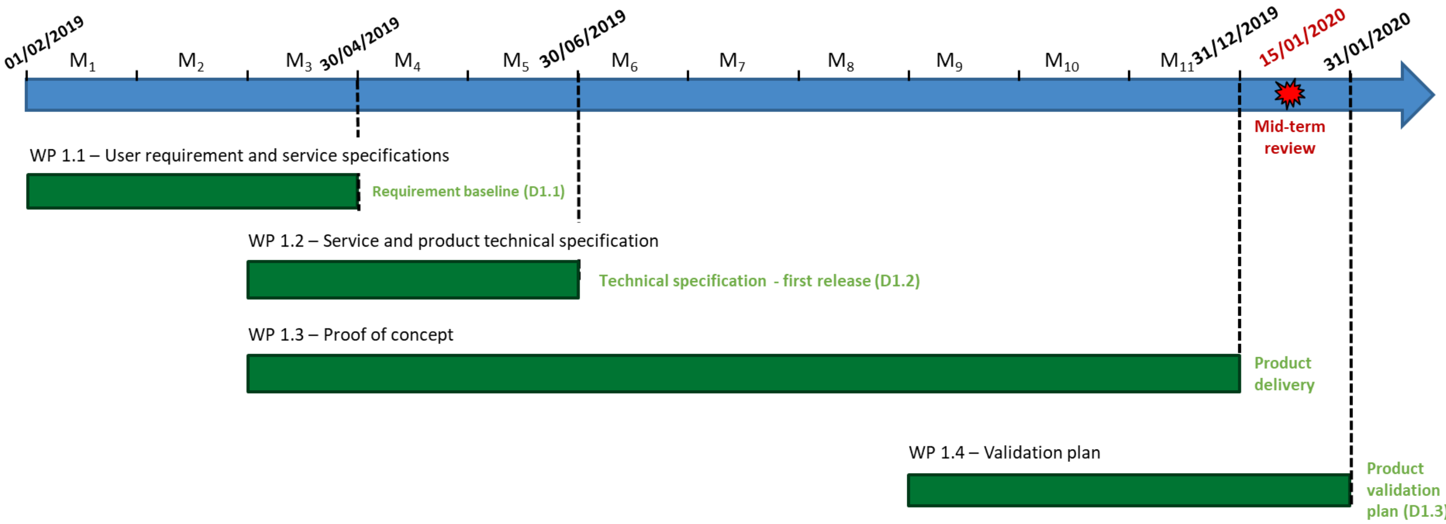

Figure 2 – Phase 1 work breakdown structure and timeline

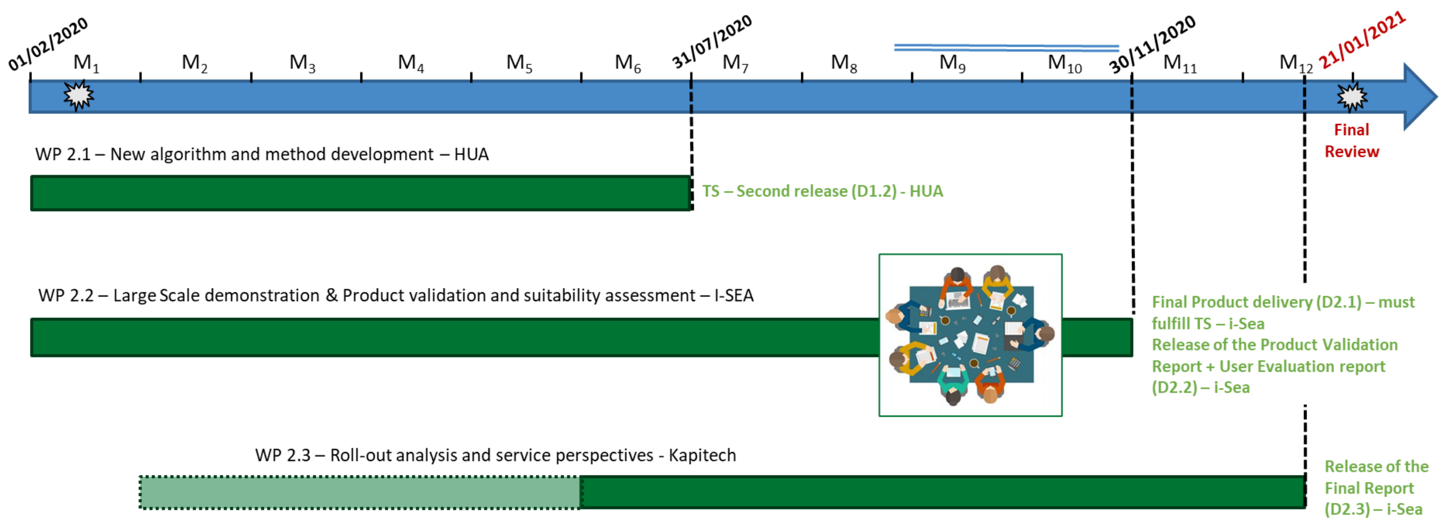

Figure 3 – Phase 2 work breakdown structure and timeline.

Phase 3: In 2021, the European Space Agency (ESA) decided to extend the project (CCN1, Sept 2021 – Sept 2022) to achieve three main objectives:

- Extend the coverage (minimum 300 km) over the past 25 years for the Countries already engaged
- Extend the key coastal state indicators products to Svalbard (minimum 300 km over the past 30 years)
- Update the delivered key coastal state indicators products to the present an extended-third year of project were funded by ESA to expand the coastal monitoring demonstration.

In order to achieve these objectives, the consortium followed, over this one-year period, a workflow similar to the organisation of the project during the first two phases (Figure 4).

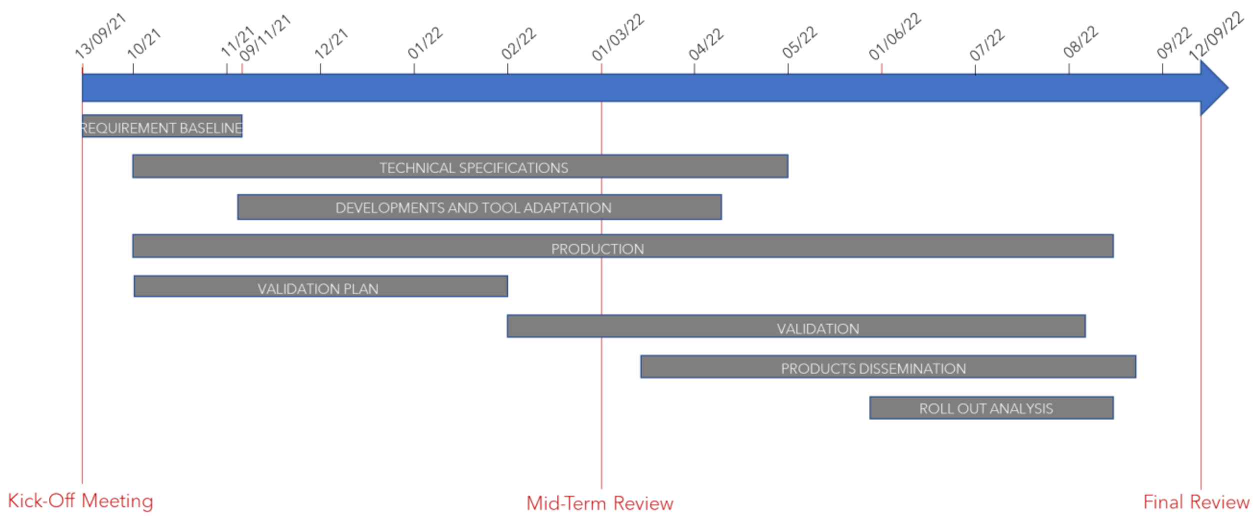

Figure 4 – Phase 3 work breakdown structure and timeline.

2 WORK PACKAGE 0: MANAGEMENT

2.1 Management tools and project follow-up

The management work package regroups all tasks of project management and follow-up. It starts with the definition of the others work packages and the tasks associated, the designation of each responsible for each work package. Then the calendar, the milestones and the deadlines for each task achievement and for each deliverable had to be defined.

Once the overall tasks and the teams are well precisely defined, the follow-up consists of coordinating the consortium teams with monthly meetings, reporting and communication through emails.

The action item list, the Gantt diagram, the production roadmaps and the risk management document were essential tools to manage the whole project. The redaction and/or finalization of each deliverable were also very important in this management work package.

2.2 Discussion

The project was managed by i-Sea, a small start-up: 6 permanent workers before Coastal Erosion. One of the directors of i-Sea was designated as the project main coordinator. It was, on a daily basis, supported by an executive project manager that was recruited short after the project kick-off and that was renewed at mid-term, then for the CCN1.

The 3 successive executive managers were 100% involved in the project, mostly in consortium and project management tasks. They succeeded to coordinate the consortium's actions to achieve the work program and complete the deliveries in a schedule close to the provisional one. Management tools developed (in particular the AIL and risk registers), together with ESA's careful follow-up based on monthly report during the first two phases then bi-monthly during the third one, was found efficient to anticipate any deviation from the timeline or ESA's cardinal requirements. Indeed, Coastal Erosion was found as a great opportunity to develop international management skills and develop performing tools and routines.

Anyhow, deviation from the timeline was almost constantly observed. Management was found fluid despite the large number of partners involved. Very few disagreements needed to be solved, and solutions were always softly negotiated. The partners were, in general, of great support during the project and assumed the roles assigned. However, time dedicated to project management during the first year was far too small, and some adjustments were made between the first two years of the project.

Communication activities, large scale communication in particular, is the only task that was not leaded enough during phases 1 and 2. Although demo meetings and workshops were successful, we have not been active enough with regards to social networks for instance. Major efforts were made during CCN1 and still need to be continued.

3 WORK PACKAGES 1.1 AND 3.1: USER REQUIREMENTS AND SERVICE SPECIFICATIONS

The objective of work package 1.1 was to establish a comprehensive statement of the requirements expressed by coastal managers over the first pilot regions, in terms of tools and products that they are currently using to achieve their missions of coastline surveillance. The objective of work package 3.1 was to repeat the consultation process for the regions added to the project at the beginning of Phase 3 (CC1) of the project.

For that purpose, we held end-user's meetings to collect needs in all the countries targeted by the project, regional partners were named responsible to obtain requirements for intermediate and final end-users. During these meetings, the project was explained, and discussions were developed in order to fill the requirement forms. The goal was also to make early identification of "must have" products, “should have” products and “could have” products.

Then the requirement forms were reworked by the regional partners and new version were approved by the end-users. This work was carried out at the beginning of phase 1 and at the beginning of phase 3.

3.1 Deliverable: Requirement baseline

The following sections present a synthetic report of the deliverable 1.1 (Requirement baseline).

3.1.1 Space for Shore Users

The management of coastal erosion hazards within the European countries is relatively country-specific, which does not facilitate the implementation of universal end-user typology. The different types of organization identified within the Space for Shore end-user community are presented in Table 1 for the former AOIs (first pilot regions) and in Table 2 for the newly added regions during CCN1, along with the number per country. Overall, we received formal and complete answers from 69 end-users, essentially from the public sector.

Table 1 - Space for Shore end-user community description during the first two phases concerning the first regions of interest.

Type of structure		France	Germany	Greece	Portugal	Romania	**Total**
Public	Ministry; National / governmental agency / authority				1	1	2
	Regional authority	3	1	2		1	7
	Intermunicipal cooperation	2					2
	Coastal municipality				2		2
	Natural site manager	2		2			4

	Research center					2	2
	Coastal observatory	2					2
	Other	0	1				1
Private	Insurance company	0					
	Other	0					
Total		9	2	4	3	4	22

Table 2 - Space for Shore end-user community description during the third phase (CCN1) concerning the added regions of interest.

Type of entity		France	Germany	Greece	Portugal	Romania	Svalbard	Total
Public	Ministry; National / governmental agency / authority	3	2					5
	Regional authority	2		1	1			4
	Intermunicipal cooperation	9						9
	Coastal municipality	2		3	8			13
	Natural site manager	3			1	1		5
	Research center	3					3	6
	Coastal observatory	3						3
	Other	1						1
Private	Insurance company			1				1
	Other							
	Total	26	2	5	10	1	3	47

3.1.2 End-user product & Service Requirements

This section aims at grouping all identified indicators for coastal erosion into family of products. The objective is to synthesize the needs in terms of accuracy, frequency of production and delivery time. Products for which a high priority has been identified are highlighted in green within the product family tables.

Shoreline location and change

This first family of products (Table 3) encompasses all indicators being directly associated with the shoreline definition. These are primary indicators to be considered when addressing the topic of coastal erosion. Specific indicators apply according to the geomorphological and hydrodynamics characteristics of the coastal areas studied.

Table 3 - Product family – Shoreline location and change

	Indicator	Country	Horizontal accuracy (m)	Temporal frequency	Citation number
Shoreline location and change	Cliff foot	FR	1	AQ: 2/year; N: 1/5years, 1 oneshot VHR	10
		GER	10	1/year	
		GR	Ng	1/1-10years	
		PT	1	2/year	
	Cliff apex	FR	1	AQ: 2/year; N: 1/5years	9
		GER	10	1/year	
		GR	ng	1/1-10years	
		PT	1	2/year	
	Dune foot	FR	1-2 m	1/week in emergency, Yearly & before /after storm & Seasonal & 3-4 x/yr (before / after touristic season)	25
		GR	ng	1/1-10 years	
		PT	1 m	2/year; post-storms, yearly	
	Waterline (sea/land interface)	GER	10	1/year	30
		FR	1	3-4 x/yr (before / after touristic season)	
		GR	1	1-2/year	
		PT	1	Seasonal, yearly, post-storm	
		RO	5-10	1/month	
	Waterline (sea/land interface) spring water low tide/high tide	FR	< 10	2-4/year, Storm events	8
	Wet/dry sand boundary dynamics	FR	5-10	2-4/year	2
		GER	10	1/year	
	Middle of swash zone	FR	1-5	2-3/year; 2/month in winter; before/after storms	6
		RO	1-5	1/month	

	Maximum swash (or run-up) excursion	FR	1-5 m	During/after storms	12
		PT	1 m	Seasonal, yearly, post-storm	
		RO	5	1/month	
	Lower vegetation boundary	GER	10	1/year	10
		SVA	5-10	Yearly	
		FR	1	3-4 x/yr (before / after touristic season)	
		GR	maximal	1/1-10years	
	Natural habitat vulnerability to coastal erosion	FR	ng	Ng	2

Extraction and assessment of Changes in Morphological features

This section encompasses a variety of geomorphological features and derived parameters (Table 4) that may be extracted from the EO data over all the relevant coastal compartments, i.e., over the nearshore area, the foreshore, beach system and tidal flats, the coastal dunes and cliffs.

Table 4 - Product family – Extraction and change of morphological patterns

	Indicator	Country	Horizontal accuracy (m)	Temporal frequency	Citation number
Extraction and change of morphological patterns	NEARSHORE / SUBTIDAL				
	Sandbar location	FR	5-10	3/year up to 1/month	25
		GER	10	1/year, seasonal, yearly	
		PT	10	seasonal, yearly, post-storm	
		GR	ng	ng	
		RO	10	1/month, seasonal	
	INTERTIDAL				
	Beach width	FR	1-5	2-4/year, yearly	19
		PT	1	1/year, seasonal, post-storm	
	Lower beach width	FR	1		1

	upper beach width	FR	1-5	2-4/year		3
		PT	1	1/year		
	Ridge and runnel location and orientation	FR	5-10	4/year		2
	Berm location	FR	5-10	4/year		1
	Shingle bar width	FR	0.5-1	1-2/year		1
	Tidal creeks: length, form of edges, form and number of tidal creek endings, and changes	GER	10	1/year to shorter term		5
	Erosion edges of tidal creeks	GER	10	1/year		1
	ROCKY CLIFFS					
	Cliff scars	FR	2	2/year		1
	Cliff front surface	FR	2	2/year		1
	Cliff slope	FR	2	2/year		1
	Landslide volume	FR	ng	2/year		1
	Vegetation dynamics at cliff foot	GER	10	1/year		1
	COASTAL DUNES					
	Dune erosion notches	FR	1	4/year		1
	Blow-out	FR	1	ng		1
	Barrier beach change	GER	ng	ng		1
	EROSION / VULNERABILITY INDEX					
	Erosion index	FR	1	Seasonal and storm events		6
		GE	100	yearly		

Seabed, foreshore and land cover mapping

Another product family (Table 5) emerging from end-users is related to the determination and dynamics of the seabed, foreshore and land cover type. The cover types to be tracked vary from one site to another, as a result of the wide range of environmental conditions encompassed by the project and the different challenges addressed by the end-users.

Table 5 - Product family – Seabed, foreshore and land cover mapping

	Indicator	**Country**	**Horizontal accuracy (m)**	**Temporal frequency**		**Citation number**
Seabed, foreshore and land cover	Underwater seabed type (sandy/rocky/vegetated)	FR	5	ng		9
		PT	1	2/year		

	Upper boundary of alive seagrass	FR	ng	ng	4
	Intertidal / foreshore type (sandy/rocky/shingle/…)	FR	ng	ng	5
		GER	10	1/year	
		PT	1	2/year	
	Presence/absence/envelope of dead seagrass on the beach	FR	ng	2-4/month during autumn and spring seasons	4
	Habitat mapping (several levels)	FR	ng	ng	3
		GR	ng	ng	
		RO	ng	ng	
	Vegetation density over coastal dunes	RO	5 m & 80% classification accuracy	1/month	1
	Coastal area Land Cover (vegetation/forest/urban)	PT	1	1-2/year	3

Coastal DEM

Many of the end-user expressed a strong interest for products related to the 3D coastal morphology (Table 6) and which apply to the below-cited coastal compartments. End-users usually order well-proven techniques to obtain the topography and bathymetry over coastal areas such as single/multi beam echo-sounding (for bathymetry – expensive and non-responsive), UAV photogrammetry (topography – cheap and responsive but spatially limited) and or airborne LIDAR (topography and bathymetry – covering large coastal areas but very expensive and non-responsive) which both offer centimetric-metric horizontal and vertical accuracies. However, topographic and bathymetric products derived from EO data would be complementary approaches even if less accurate, as EO data are acquired regularly over the full extent of end-user areas, offering in turns more reactivity and cheaper costs for coastal management activities.

Table 6 - Product family – Coastal DEM

	Indicator	Country	Horizontal accuracy (m)	Vertical accuracy (m)	Temporal frequency	Citation number
Coastal DEM	UNDERWATER					
	Bathymetry	FR	5-10	0.5-1	2-3/year, yearly	38
		GR	10	max possible	1/5years, yearly	

		PT	10	ng	2/year, yearly	
		RO	10	1	1/month to 1/2years	
	Sandy stocks over rocky substratum	FR	5-10	0.2-1	2-3/year	2
	INTERTIDAL					
	Beach topography	FR	ng	0.1-0.2	up to 4/year	4
		GR	1	ng		
	SUPRATIDAL					
	Coastal cliff DEM	FR	1	1-5	2/year	3
		RO	5	0.5	ng	
	Coastal dune DEM	FR	1	0.2	ng	1

Vertical motion of coastal land

Two end-users manifested a potential interest in products indicating terrestrial vertical movements within low-lying sandy deltas to quantify the subsidence effect (French and Greek end-user) inherent to such areas or at cliff top to detect cliff instability development and to anticipate large landslides and rockfalls (French end-user) (Table 7). End-users did not provide relevant details on expected horizontal and vertical accuracies and update/delivery times, making difficult the critical analysis of their needs regarding existent EO data and methods and consortium production capacity. Therefore, the development of a product indicating the vertical movement of coastal land remained conducted by the Space for Shore consortium over the first pilot sites of the project (phases 1 and 2) and not extended to the newly added regions.

Table 7 - Product family – Vertical motion of coastal land

	Indicator	Country	Horizontal accuracy (m)	Temporal frequency	Citation number
Vertical motion of coastal land	Vertical movement of low-lying sandy deltas	GR	ng	ng	2
		FR	ng	ng	
	Vertical movement at Top-of-the-cliff vertical movement	FR	ng	ng	6
		PT	Ng	ng	

As exposed above, many indicators were considered in order to match the requirements for local coastal stakes. These indicators also include the monitoring of changes during the time which is implied by the large-scale temporal production.

3.2 Discussion

During the project, priorities were attributed to the various indicators according to the frequency of requests mentioned by the end-users, the local issues and the coherence between the observed dynamics and the accuracy able to be reached using spatial data. Several low-priority products were investigated and included in the framework, locally, when these concerned a specific region, high-stakes interest, or even easily detectable indicators.

The Table 8 below presents the list of high-priority products identified for POC activities and their study sites, investigated during the first two years.

Table 8 - List of high-priority products identified for POC activities. Red cells: the most favourable POC sites according to existing validation data. Yellow cells: POC sites that will be further discussed with potential end-users

Family name	Product name	Regions of interest								
		FR AQ	FR NOR	FR PACA	GER WS	GER BS	PT NWC	GR EMT	GR PEL	RO
Shoreline	Cliff foot									
	Cliff apex									
	Dune foot									
	Waterline (sea/land interface)									
	Middle of swash zone									
	Maximum swash (or run-up) excursion during major storms									
Coastal morphological patterns	Sandbar location									
	Beach width									
	Tidal creeks									
	Erosion at tidal creek edges									
Coastal DEM	Bathymetry									
Seabed, foreshore and land cover mapping	Underwater seabed type (sandy/rocky/vegetated)									
	Intertidal / foreshore type (sandy/rocky/shingle/…)									
	Coastal habitat and land cover mapping (several levels)									

The Table 9 presents the list of high-priority products identified over the new AOIs (phase 3). More than 10 products were defined to support current and future practices to manage issues related to coastal erosion. This task enabled to fully characterise the end-user needs in terms of product accuracy as well as the update and delivery frequency. It also evidenced that some products were systematically requested by end-users of different regions of interest, while others were sparsely mentioned. The production effort focused on the most attractive products for the end-users(highest priority and number of end-users) and that could be reasonably produced within this third and last year of project regarding technical specifications of EO data currently available and performed during the last 2 years. In addition, the existence of ground-truth data provided by end-users is required to validate the products generated by the consortium. Thus, availability of validation data influenced the selection of products that will be extracted and analysed.

Table 9 - List of high-priority products identified by the end-users over the added regions of interest (CCN1, phase 3). Red cells: the most favorable indicators per indicator. Light yellow cells: secondary indicators per ROI.

		REGIONS OF INTEREST											
		FRANCE					NORWAY	GERMANY		ROMANIA	GREECE		PORTUGAL
Family	Indicators	OCC	MOR	VEN	ALP	CHA	SVA	LKN	LLUR	DDBRA	RH	CH	All regions
Nearshore	Bathymetry												
	Nearshore sandbars												
	Shallow water sand detection												
	High sands												
	Sediment classification												
Shoreline	Dune foot												
	Upper swash limit												
	Waterline / HWL limit												
	Vegetation limit												
Multi-indicators	Beach width												
	Erosion/vulnerability index												
Rocky coast	Cliff lines												
	Top of cliff movement												
Fjord	Hydrological network												
Intertidal area	Intertidal banks												
	Tidal creeks												

4 WORK PACKAGES 1.2, 2.1 AND 3.2: TECHNICAL SPECIFICATIONS

The work package 1.2 objective is to define all the algorithm needed that are going to be used for the Space for Shore project. In this perspective, we have carried out a state of the art of existing methods and selected an overview of the algorithms to be applied within Space for Shore. The main task of this package was the assessment of the algorithms, and if they match the requirements expressed by the end-users and the indicators proposed by the consortium (resolution, frequency, accuracy, content…).

The work package 2.1 goal is to update the technical specifications document with the new algorithms and methods considered. Indeed, with the 1-year work collaboration with our end-users and experts, new indicators or adjusted indicators were compiled. So new methods and adapted methods were implemented to match these adjustments.

In order to define these adjustments, we followed this processing:

- Contact all partners to define development enhancements or indicators enhanced for a large-scale production
- Establish a development plan coherent with deliverable deadline
- Collect planned developments from each partner of the consortium
- Coordinate the developments between the partners

Based on the same approach and from the work carried out during the first two years of the project, the objectives of work package 3.2 are to consolidate and adapt the methods, and even to develop new ones, in order to improve, optimise, and deploy the extraction and monitoring tools in the new regions of interest that joined the project during CCN1 (Phase 3).

4.1 Deliverable: Technical specifications

4.1.1 Deliverable phase 1 & 2

The deliverable for this work package is an updated version of the Technical specification (deliverable 1.2) with new algorithms and modified algorithms. The**Erreur ! Source du renvoi introuvable.** presents the new list of algorithms organized by groups. The second phase of technical specifications led to the adjustment of 5 modified algorithms. The main adjustments concern the waterline indicator, the different methods have been modified and enhanced in order to be adapted the indicator requirements.

Table 10 - Overview of algorithm groups and algorithms, their maturity level and responsible partner. The last column indicates for which indicators the respective algorithm is relevant. New algorithms are highlighted in orange

Algorithm Group	Algorithm	Maturity level[1]	Partner	Suitable for: Product Name
DEMS	**Algorithm 1a** DSM generation from optical data	3	i-Sea Terra Spatium	Cliff foot Cliff apex

	Algorithm 1b DEM generation from SAR data	3	Harris	Cliff foot Cliff apex
Water Line and Creek Edge Detection	**Algorithm 2a** Water line detection using different methods	2	I-Sea Brockmann Consult Terra Spatium Terra Signa	Waterline (sea/land interface) Upper swash limit Beach width
	Algorithm 2e Edge detection tidal creeks using SAR	1-2	University of Hamburg	Tidal creeks: number, length, form, form and number of tidal creek endings Erosion at tidal creek edges
	Algorithm 2a3f Upper swash limit	3	I-Sea	Upper swash limit using classification maps
	Algorithm 2g Water line detection using binary products from SAR amplitude data	1	Harokopio University	Waterline (sea/land interface)
	Algorithm 2j Decision tree classification based on band ratios and LSU	3	Brockmann Consult	From the classification, the position of tidal creeks is determined. Based on a time series of images, the shifting of tidal creeks can be visualized and thus erosion at tidal creek edges is detected Intertidal habitat mapping
	Algorithm 2k In-land vegetation boundary method based on NDVI index	1-2	Terra Spatium	In land vegetation boundary
Extraction of subaerial morphological structures and changes	**Algorithm 3c** Cliff line extraction using the cross-shore variation of the beach/cliff slope from DEM	2	I-Sea	Cliff foot Cliff apex
	Algorithm 3d Semi-automated linear feature extraction from DEMs	1	Terra Spatium	Cliff foot Cliff apex

	Algorithm 3e Beach width computation	3	I-Sea	Beach width
	Algorithm 3h Dune foot extraction using supervised classification	2	I-sea	Dune foot
	Algorithm 3i Cliff line extraction using supervised classification	1	I-sea	Cliff foot Cliff apex
	Algorithm 3j Top of the cliff movement using PS with ERS and ENVISAT data	2	Harokopio University of Athens	Cliff Movement
Bathymetry	**Algorithm 4b** Quasi-analytical model to retrieve bathymetry from HR/VHR optical data	3	I-Sea	Bathymetry
	Algorithm 4c Bathymetry swell inversion (i-Fourier Fast Transform)	2	University of Aveiro	Bathymetry
	Algorithm 4c Bathymetry swell inversion (ii-Wavelet Transform)	1	University of Aveiro	Bathymetry
Extraction of submerged morphological structures and changes	**Algorithm 6a** Submerged sand banks	3	Terra Signa I-Sea	Sandbar location Submerged sandbar migration
	Algorithm 6b Mapping change of sandbars	1	Brockmann Consult	Submerged Sandbar / sand ridge location and changes

[1] Maturity levels:

1 = innovative or experimental algorithm (not tested yet, want to test ideas in POC sties)

2 = Demonstration algorithm: tested on selected test sites in selected images

3 = mature algorithm – well tested, applied and published algorithm

4.1.2 Deliverable phase 3

The following sections presents a synthetic report of the deliverable 3.2 (Technical specifications Consolidation) that included the deliverable 1.2 (Technical Specifications Phase 1 and update of Phase 2).

We provided an overview of the algorithms proposed by the Space for Shore consortium to produce the main coastal erosion indicators requested by the interviewed end-users (refer to the Requirement Baseline and User Requirement Document Book), which usually address short-time scale monitoring. Some of these algorithms are also designed to produce the latter indicators over longer timescales with the perspective of demonstrating the potential of ESA Earth Observation data archives and other past/currently growing freely available archives in the study of coastal erosion in the past 25 years at European scale. The individual algorithms are provided and described by the partners and form the algorithm candidates for the different indicators. A maturity status of the algorithms is given.

Based on the end-user requirements, a set of coastal erosion indicators and their level of priority have been provided in the Requirement Baseline document. Overall, more than 60 end-users had been interviewed within the public sector including national governmental agencies, regional authorities, intermunicipal cooperation and municipalities, as well as natural site managers, research centers and coastal observatories. From this panel of potential users of Space for Shore services, 16 products were requested to support current and future practices to manage issues related to coastal erosion. To help synthesize end-user requirements these products were previously grouped in 5 product families (here, we do not mention those of the first category, i.e., those related to DEM). This task enabled to fully characterize the end-user needs in terms of product accuracy as well as the update and delivery frequency. It also evidenced that some products were systematically requested by end users of different regions of interest, while others were mentioned only by one or two end users.

The algorithms that are described in this Technical Specification document are organized in four groups, based on the algorithms that will be used in Phase 3 (some algorithms, notably those in Group 1, are not described here because they were not used). These groups were built to ease the presentation of the algorithms, as many of these aim at producing similar outputs and/or apply with similar environmental constrains. Each algorithm group is introduced by an introductory and a state-of-the-art section followed by the description of the main features of algorithms (input data, algorithm type / processing chain, output products and tools needed). In addition, information about validation and application range is given for each algorithm. This also includes the information on whether an algorithm is mature enough or shall be tested.

Table 11 - Overview of algorithm groups and algorithms, their maturity level and responsible partner. The last column indicates for which indicators the respective algorithm is relevant.

Algorithm Group	Algorithm	Maturity level[1]	Partner	Suitable for: Product Name
Water Line and Creek Edge Detection	Algorithm 2a Water line detection using different methods	2	I-Sea Brockmann Consult Terra Spatium Terra Signa	Waterline (sea/land interface) Upper swash limit Beach width
	Algorithm 2e Edge detection tidal creeks using SAR	1-2	University of Hamburg	Tidal creeks
	Algorithm 2a2f Upper swash limit	3	I-Sea	Upper swash limit
	Algorithm 2a3f Upper swash limit generic model	3	i-Sea	Upper swash limit
	Algorithm 2g Water line detection using binary products from SAR amplitude data	1	Harokopio University	Waterline (sea/land interface)
	Algorithm 2k In-land vegetation boundary method based on NDVI index	1-2	Terra Spatium	In land vegetation boundary
Extraction of subaerial morphological structures and changes	Algorithm 3e Beach width computation	3	I-Sea Terra Spatium	Beach width
	Algorithm 3h Dune foot extraction using supervised classification	2	I-sea	Dune foot
	Algorithm 3i Cliff line extraction using supervised classification	1	I-sea	Cliff foot Cliff apex
Bathymetry	Algorithm 4b Quasi-analytical model to retrieve bathymetry from HR/VHR optical data	3	I-Sea	Bathymetry
Extraction of submerged morphological structures and changes	Algorithm 6a Submerged sand banks	3	Terra Signa I-Sea	Sandbar location Submerged sandbar migration
	Algorithm 6b Mapping change of sandbars	1	Brockmann Consult	Submerged Sandbar / sand ridge location and changes
	Algorithm 6c Mapping sandbanks	1	I-Sea	Submerged sand banks location

[1] Maturity levels:

1 = innovative or experimental algorithm

2 = Demonstration algorithm: tested on selected test sites in selected images

3 = mature algorithm – well tested, applied, and published algorithm

4.2 Discussion

The first release of technical specifications exposed all the methods considered to match the indicators required. The algorithms and methods presented on technical specifications deliverable were updated once during phase 2 according to the results of each method (proof of concept work package) and to the adjusted requirements survey for the large-scale production operated on phase 3.

The most recently updated document, named Technical Specification Consolidation, which concerns the third year of the project (CCN1), focuses on the algorithms used during this third phase on the new regions of interest. An overview of all available algorithms for producing indicators that were developed and tested during the first two phases of the project is available in the previous technical specification reports. The mapping of the algorithms to the user requirements provides a good assessment on which algorithms were used for which coastal type and which site. It also gives the overall picture of the possible combinations of algorithm and EO data type (HR vs VHR) that can be used to address coastal erosion on the short-term (event to annual timescales) with a maximal accuracy or on the long-term (interannual to decadal scales) usually coming with a poorer accuracy.

The algorithms differ in their level of maturity and while some are already mature, well validated and applied to many different locations, others still on an experimental stage. This document was updated accordingly, providing further input for validation and application range of the single algorithms. This allowed us to identify which algorithm performs best for each couple indicator/site.

During Phase 3, major efforts were made to automate and regionalize the treatments in order to enhance large-scale erosion monitoring.

5 WORK PACKAGE 1.3: PROOF OF CONCEPT

The objective of the proof-of-concept work package is to prove the validity of each method considered of the technical specifications to match the indicators identified. Another key statement for this work package was to prove the exploitability of archive images to fulfill the 25 years of large-scale temporal monitoring for all indicators and all algorithms.

Products were tested, developed and delivered by each team of the consortium. A focus was put to assess the feasibility of the methods on available imagery archive. Another Criteria for POC selection was the existence of abundant field observations (validation data) and of sufficient science background about coastal dynamics behavior thanks to more than a decade of research work historical ground truth data.

For the dissemination of the products, the Eugenius platform was used to handle the large number of products and reach the expected visibility of the products. After the production, we initiated a detailed critical assessment of indicators, their relevance and adequacy. A first Quality Control was operated to check the integrity of the product, then a second Quality Control was operated by thematic experts for a qualitative check of the indicator either on the EUGENIUS platform or on independent QGIS. If the conclusion of these 2 first quality check steps was positive the indicator is marked as ready for public dissemination. If the conclusion of the quality check was negative, then the partner associated with the indicator was invited to ensure the product integrity and reprocess by following recommendations provided by the thematic experts in charge of the quality check. End-users were also involved to verify the products where results seem doubtful to the experts.

The Figure 3 and Figure 6 below present the 11 coastal erosion indicators over 22 sites.

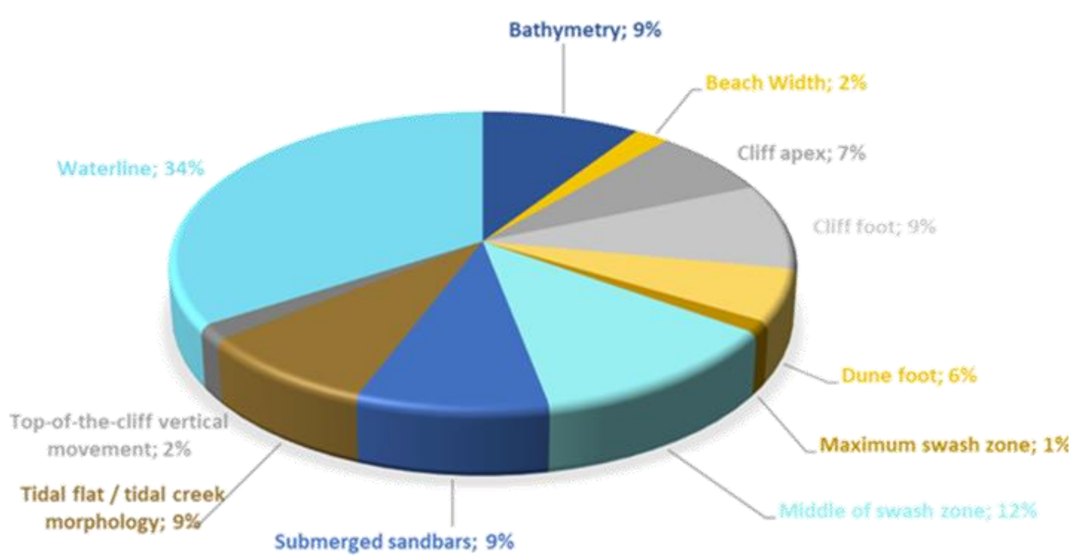

Figure 5 – Product number percentage per indicator

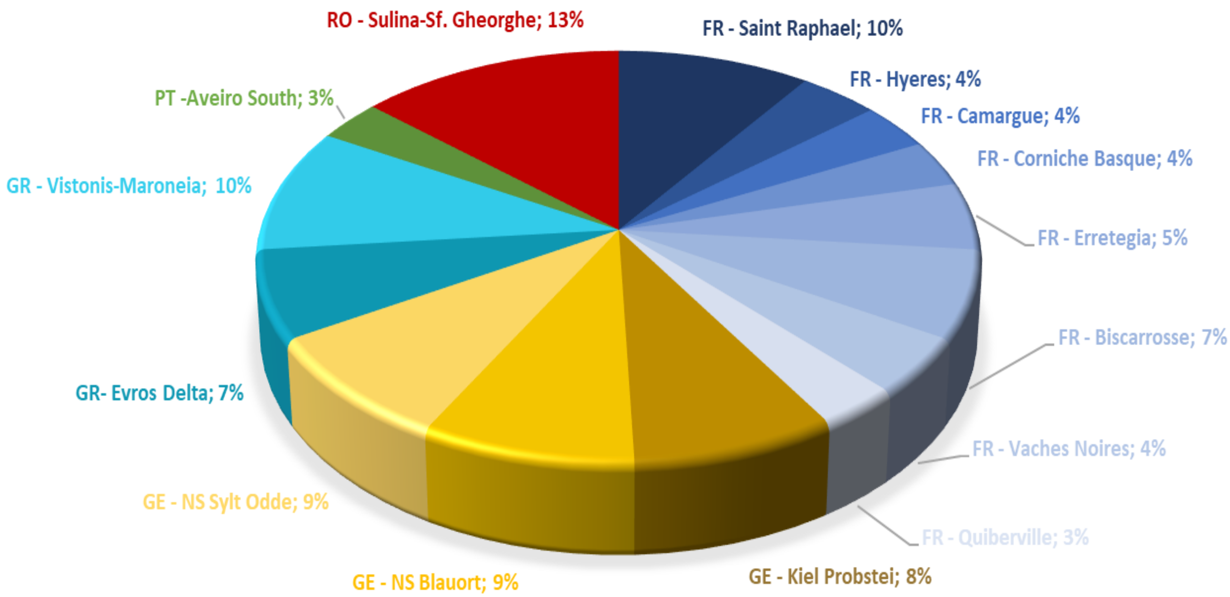

Figure 6 – Product number percentage per site

A total of 245 final products were anticipated, based on 907 individual images, 237 optical and 670 SAR imagery as presented below on Figure 7.

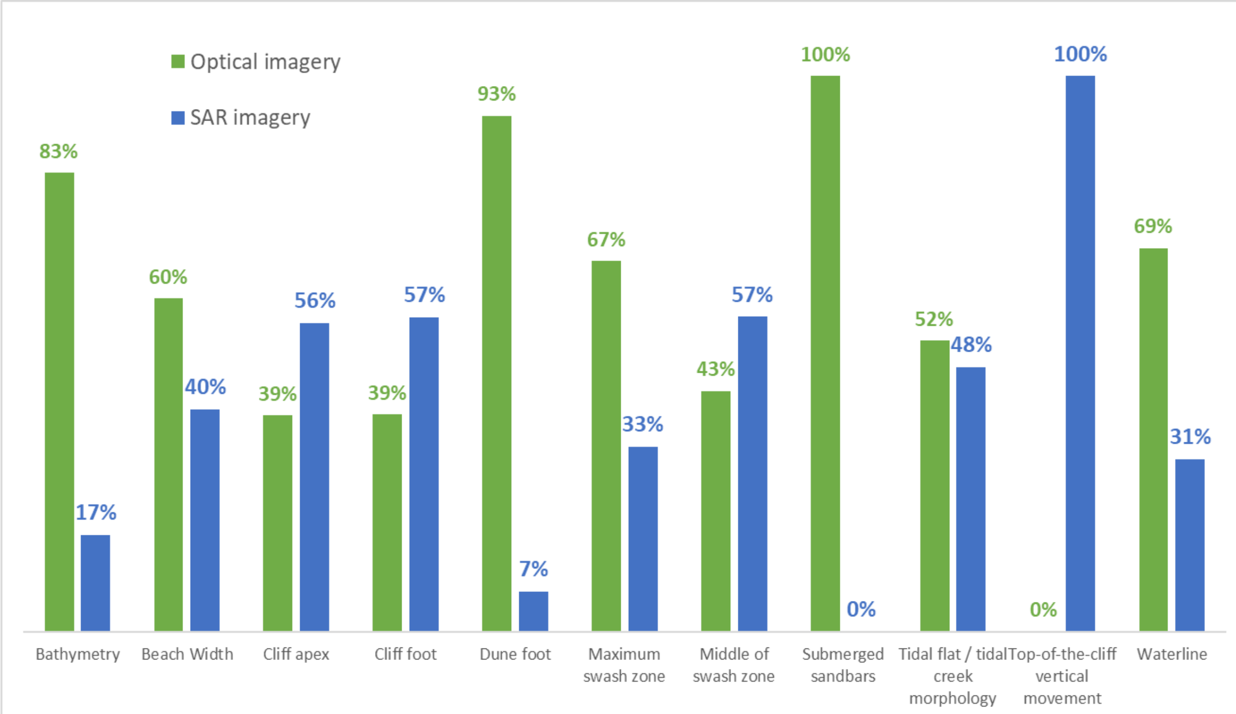

Figure 7 – Product number percentage per sensor

Sentinel-1 and Sentinel-2 imagery have been extensively used as presented below on Table 12. 42 final products are based on VHR imagery, 17% on the total products and about 4.6% of the total amount of images used. 32 TPM imagery products have been ordered.

5.1 Discussion

A total of 245 final products were planned, and production was initiated for all of them. The final number of products included in Eugenius platform is of 170. Products were not included because:

- several products based on SAR imagery were of low quality (waterlines and cliff lines): it was not possible to let them unexplained on the diffusion platform to the self-analysis of the end-users (counterproductive),
- maximum runup products were not included since results were not conclusive,
- some of Landsat-7 images were of low quality,
- some other images were not appropriate (e.g., with regards to turbidity or unsuitable water level).

This discrepancy should not hide the fact that 245 products have been carefully analyzed and corrective actions and measures have been decided in phase 2 to improve our results each time it was needed and/or possible.

Table 12 - Overview of satellite images used

Family	Satellite	N° of products used
Optical imagery	Landsat 5	1
	Landsat 7	5
	Landsat 8	34
	SPOT 1 – 4	16
	SPOT 5	14
	Sentinel 2	133
	SPOT 6 & SPOT 7	11
	Pleiades	14
	Kompsat	1
	Worldview	9
SAR imagery	ERS ENVISAT	32
	Sentinel-1	636
	CosmoSkyMed	2

6 WORK PACKAGES 1.4 AND 3.4.4: PRODUCT VALIDATION PLAN

The main goals of the validation activities are:

- to improve Technical Specification Report,
- to drive the development of some innovative algorithms,
- to present objectively the accuracy of the produced indicators,
- to convince the end-users the products delivered fit their expectations in terms of horizontal and vertical accuracies.

6.1 Deliverable: Product validation plan

During the project, two reports were delivered at two distinct stages: during the first phase of the project to validate results over the former AOIs, and during the CCN1 (Phase 3) to complete the validation process over the recently added AOIs. This last document is an update of the previous Validation Plan, and it relies on the basis of the first two years of the project. It provides an overview of the methodologies for validation of current indicators produced by the Space for Shore Consortium as well as the prospect of methodologies for validation of indicators or algorithms that were not tested during phase 2. Additionally, the validation results obtained for some indicators produced at different POC sites during the second phases of the project are also presented. These results disclose the necessity of future work (*e.g.,* field surveys at some POC sites, new techniques of field data acquisition).

All the details about the validation plan are presented in the fourth section of the present document.

As the validation actions were carried out over the former AOIs during phases 1 and 2, the planned actions summarized in Table 13 concern only validations planned during CCN1 over the new AOIs.

Table 13 - Synthesis of the planned validation action, sensor names in bold and algorithm codes in italics are included.

COUNTRY – SITE(S)	WATERLINE	BEACH WIDTH	TIDAL FLAT / TIDAL CREEK MORPH.	DUNE FOOT	CLIFF LINES	BATHY.	SUBMERGED SANDBARS	LATERAL EXTENT FJORD
GE - HALLIGEN	**Sentinel-2** *(2AI)*							
ROMANIA – SOUTH	**Sentinel-2 Landsat-8** *(2AIII)*							
GR – EVIA ISLAND		**Sentinel-2 Landsat-5** *(3E)*						
GE - OSSENGOT			**Sentinel-1 Sentinel-2** *(2E, 2J)*					

FR – CHARENTE-MARITIME				**Sentinel-2** *(3H)*				
PT - ALMADA	**Sentinel-2** *(2A2F)*			**SPOT1-5 Sentinel-2** *(3H)*	**SPOT Landsat Sentinel-2** *(3I)*	**SPOT Landsat Sentinel-2** *(4B)*		
FR – MORBIHAN	**Sentinel-2** *(2AIV)*					**Sentinel-2** *(4B)*		
FR – OCCITANIE	**Sentinel-2** *(2AIV)*					**Pléiades** *(4B)*		
FR – ALPES-MARITIMES						**Pléiades, Sentinel-2** *(4B)*		
GE – NORTH SEA							**Sentinel-2** *(6A- 6B)*	
SVALBARD	**Sentinel-2** *(2AIII)*							**Sentinel-2** *(2AIII-SVA)*

Methodology

The methodology for the validation of 2D morphological indicators (waterlines, dune foot, cliff foot/apex and submerged sand bars and tidal creeks) shows two approaches: a quantitative approach (known as baseline method).

This approach implemented for waterline, dune and cliff lines, middle of swash zone and submerged sandbars consists in computing with Digital Shoreline Analysis (DSAS) software, an add-in to ESRI ArcGIS desktop, or other software the distance between measured/observed in-situ (dashed-green line in Figure 8) and baseline (red line) along cross-shore transects spaced from the baseline and the distance between satellite derived lines (yellow line) and baseline along the same cross-shore transects. After that, the distance between measured and satellite derived lines is obtained as a difference between the distance to baseline of in-situ measured line and the distance to baseline of satellite derived line.

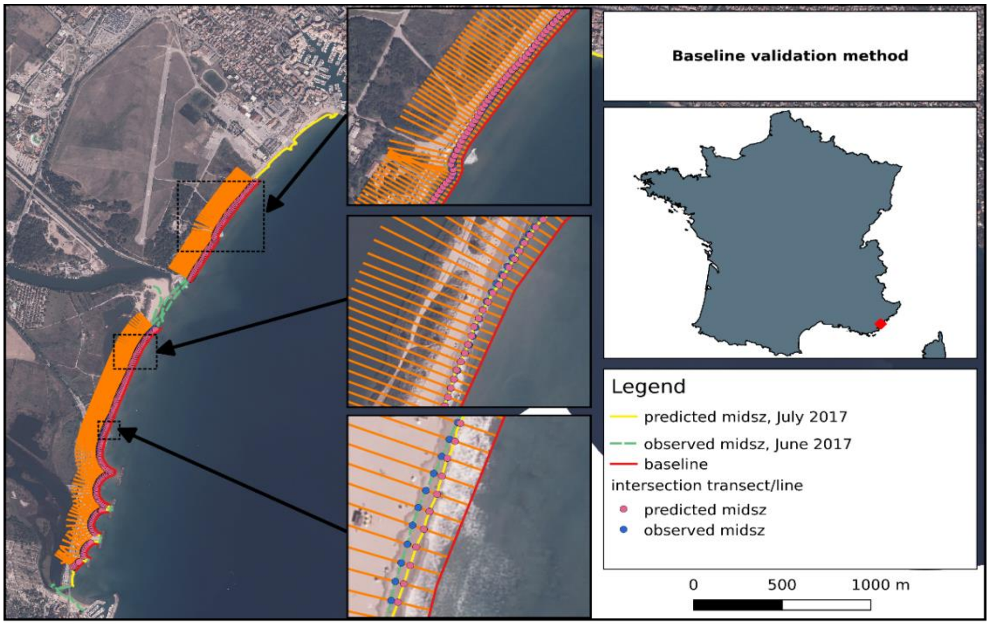

Figure 8 – Map with baseline, measured and satellite derived lines and cross-shore transects

The second approach is a qualitative one that consists in the comparisons with high resolution images in Google Earth (as in this case **Erreur ! Source du renvoi introuvable.**where you can see a Google Earth image of the closest passing Sentinel-2 superimposed with Sentinel-2 derived waterlines) or airborne orthophotos.

The data for validation activities have been provided by end-users as well as by project partners (Table 14).

Table 14 - Synthesis of the number of available validation data. Note: Data to be collected during the project duration have been indicated in red after the symbol plus. “x” denotes existing data, but for which the inventory is in progress.

SITE	WATERLINE	BEACH WIDTH	TIDAL FLAT / TIDAL CREEK MORPH.	DUNE FOOT	CLIFF LINES	BATHY.	SUBMERGED SANDBARS	LATERAL EXTENT FJORD
GE – HALLIGEN	Orthophotos derived coastlines (x)							
ROMANIA – CONSTANTA-VAMA VECHE	GPS (1)							
GR – EVIA ISLAND		Orthophotos derived coastlines (2)						
GE – OSSENGOT			GPS (2) Orthophotos (x)					

FR – CHARENTE-MARITIME				VHR images derived coastlines (1)				
PT - ALMADA	GPS (x)			Optical images derived coastlines (7)	DTM (1)	Bathymetry extracted from DTM (6+)		
FR – MORBIHAN	UAV Photogram. surveys (3)					Topo-Bathymetric data (1) UAV Photogram. (3, +x)		
FR – OCCITANIE	GPS (2)					Bathymetric surveys (x)		
FR – ALPES-MARITIMES	GPS					Bathymetric surveys (6)		
GE – NORTH SEA							LaserScan (+1)	
SVALBARD	GPS (12, +x)							GPS (12, +x)

The types of provided data are: lidar topo-bathymetric surveys, multibeam echosounder bathymetry surveys, airborne orthophotos, UAV photogrammetric surveys and topographic surveys with GPS and LTS.

6.2 Discussion

The outcomes of this validation first phase gave a good performance achieved for the upper swash zone retrieval and waterline extraction, except for SAR-ERS based retrieval. We also graded a good performance obtained for depth retrievals from optical and SAR imagery, and for the submerged sandbar detection. Then, we classified as promising results for the dune foot detection and the cliff lines detection based on optical data (including Landsat imagery).

Large scale deployment for the following indicators is secured for:

- Bathymetry
- Upper swash zone
- Waterline
- Submerged sandbars
- Beach width
- Dune foot

Large scale deployment for the following indicators is promising for:

- Tidal flat and tidal creek morphology
- Top-of-the-cliff vertical movement

7 WORK PACKAGE 2.2: LARGE SCALE PRODUCTION AND VALIDATION – PHASES 1 AND 2

The work package 2.2 is organized around the release of the large-scale production. All partners were involved to provide the planned production. The final goals of this work package 2.2 are the delivery of the production through Eugenius platform, the organization of demonstration meetings for each production sites (regions) to present the results to the potential users, and the delivery of the validation report.

7.1 Deliverable: Product delivery

All in all, 1445 products were delivered during the large-scale production of Phase 2. A fraction of the products (170) already completed during the POC were considered as relevant an included during the demonstration meetings. The percentage of new products delivered are shown in Figure 9 per country and in Figure 10 and Figure 11 per indicator. In Figure 10 and Figure 11, the production countries are reported.

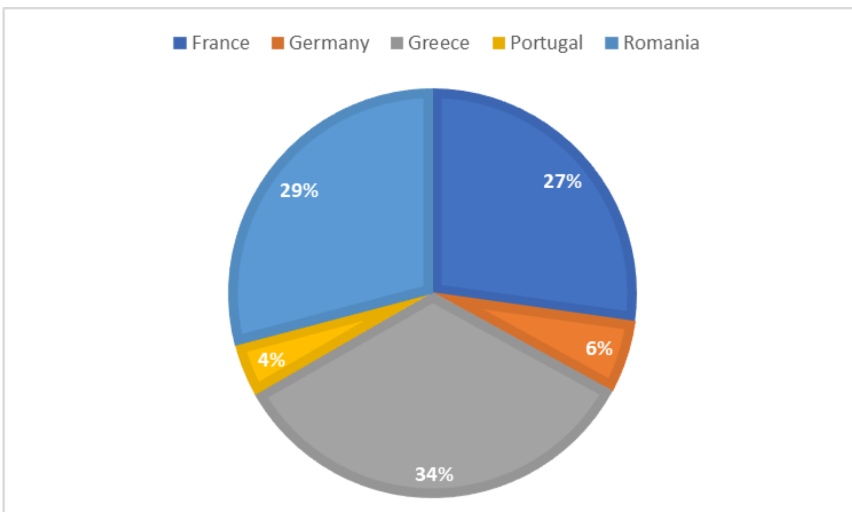

Figure 9 – Percentage of products delivered per country

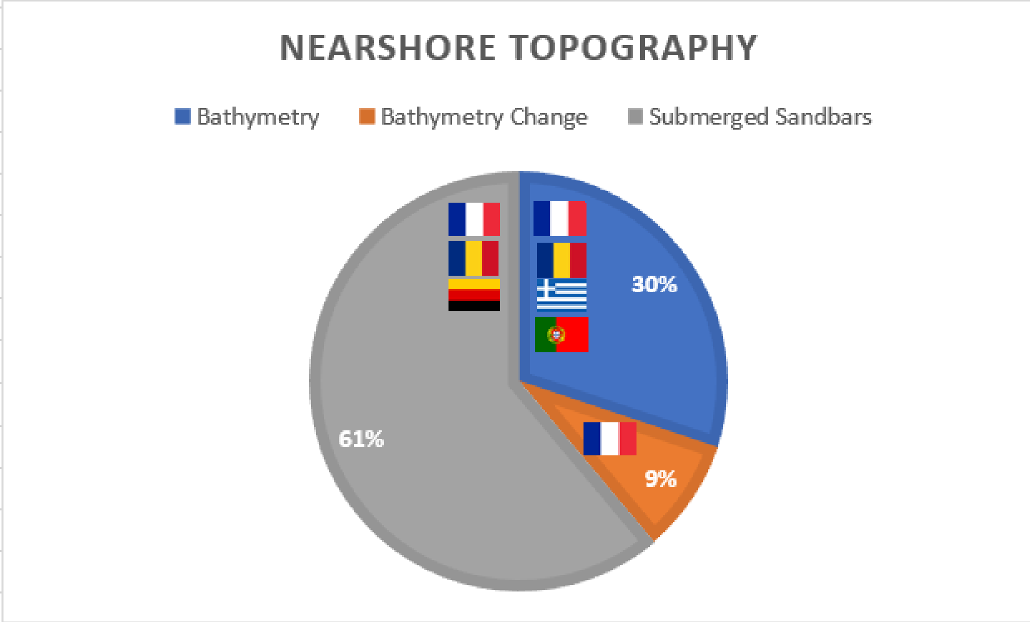

Figure 10 – Percentage of products delivered per indicator of the nearshore topography and change

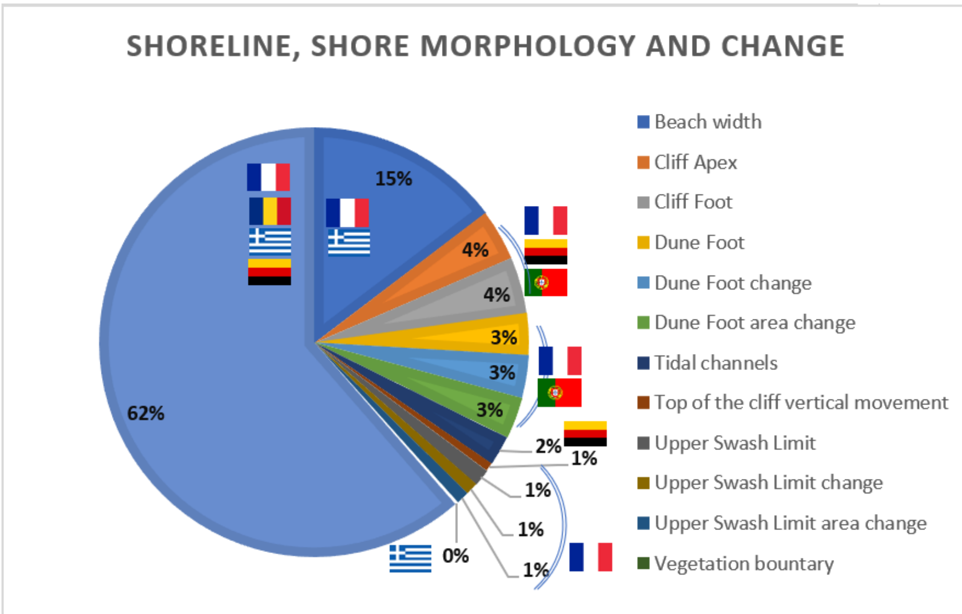

Figure 11 – Percentage of products delivered for the shoreline, shore morphology and change

Between the POC and the large-scale demo, it was decided to abandon the development of maximum swash excursion during storm event. Problems of data availability and lack of specification and validation data explain this decision. Also, five products describing the nearshore and shoreline topography changes were elaborated.

SAR imagery is used to derive the following products:

- Bathymetry,
- Top of the cliff vertical movements,
- Tidal channels,
- Waterlines.

During phase 1 and 2, massive efforts were made to use SAR imagery to derive cliff lines, but the results achieved are not compatible with end-user requirements. All products are derived from optical data processing, with the exception of top of the cliff vertical movements. Finally, it must also be noted that intermediate products are also obtained in order to derive one of the high-priority erosion indicators, such as DEM derived from Pleiades data to carry out cliff lines.

All details about demonstration products are included in Table 15 and Table 16. With regards to overall production effort, total coastline length involved is much higher than 1000 km (2420 km). In several cases, the same coastline was selected to demo several erosion indicators and perform erosion analysis based on individual products.

Erosion indicators were further exploited to provide erosion analysis, or at least coastal dynamics analysis in relation with erosion monitoring, as shown in Table 16. All in all, temporal analysis was performed over a coastline of 1264 km in length, in 5 different countries, and many different regions per country. However, quantitative analysis was only performed over 975 km, with variable analysis area according to the product. Also, according to the product, the area investigated varies from 15 to 140 km and the demonstration was sometimes carried out in one single country, even in one single region in two cases. In addition, quantitative erosion assessment was achieved for sandy and rocky coastlines only. Erosion quantification for tidal flat is still being investigated. The method is currently being developed. It must be underlined that coastal dynamics was demonstrated over

We identified 5 ready-to use first-level erosion products:

- Submerged sandbars, based on Landsat, SPOT or S2,
- Optical bathymetry, based on Landsat, SPOT, S2, Pléiades,
- Cliff lines, based on S2 or Pléiades,
- Upper swash limit based on S2 and Pléiades,
- Waterline, based on S1, Landsat, SPOT, S2, Pléiades
- Dune foot, based on SPOT, S2, Pléiades

We shall also consider 2 addition ready-to-use products useful for coastal management:

- Beach width, based on S2 or Pléiades,
- SAR bathymetry (in turbid waters and high-energy environments), based on S1.

Three more products are promising but need further development:

- Top-of-the-cliff vertical movement, based on ERS, ENVISAT, S1

- Erosion at tidal channels and tidal creeks, based on ERS, ENVISAT, S1, Landsat, S2,
- Landslide volume (cliff environment), based on Pléiades,
- Rock fall, based on SPOT-5 and S2.

Over past 25 years at least we produced times series for the following indicators (9 in total):

- Submarine sandbars, including demo of sandbar dynamics analysis over past 30 years in Romania (total demo length : 140 km),
- Bathymetry, including sediment budget analysis for the past 27 years in France (PACA region, total demo length: 15 km),
- Cliff vertical movement, including ground deformation analysis for the past 25 years in France (Nouvelle Aquitaine and Normandy, total demo length : 30 km),
- Beach width,
- Waterline, including shoreline changes analyzed over analysis over past 30 years in Romania (total demo length : 140 km),
- Cliff apex and cliff bottom, including cliff line dynamics for the past 25 years in France (Normandy and Nouvelle Aquitaine, total demo length: 100 km),
- Dune foot, including dune foot change analysis for the past 33 years in France (Normandy and Nouvelle Aquitaine, total demo length: 63 km),
- Tidal channels.

Table 15 – Total production as a function of sensor type and pilot country or region (FR, GE, GR, PT and RO stands for France, Germany, Greece, Portugal and Romania, respectively)

Erosion indicator name	Total production area		Production country (Region)
	SAR	optical	
Bathymetry		188 km²	FR (Nouvelle Aquitaine, PACA, Normandy), GR, RO
	1039 km²		PT
Beach width		120 km	FR (Nouvelle Aquitaine), GR
Cliff foot & apex		80 km	FR (Nouvelle Aquitaine, Normandy), GE, PT
DEM (Pléiades)		30 km	FR (Nouvelle Aquitaine), GE, PT
Dune Foot		116 km	FR (Nouvelle Aquitaine, Normandy), PT
Submerged Sandbars		230 km	FR (Nouvelle Aquitaine) RO GE
Tidal channels and creeks	240 km²	240 km²	GE
Top of the cliff vertical movement	30 km²		FR (Nouvelle Aquitaine, Normandy)
Upper Swash Limit		97 km	FR (PACA)
Waterline		1260 km	FR (Nouvelle Aquitaine, PACA), GE, GR, RO
	186 km		GR

Table 16 – Detail about erosion analysis performed, based on products delivered during the project

Erosion indicator name	Demo country	Production periods	Investigated area (km)	Result	N° of analysed products
Bathymetry based on optical data	FR - PACA Rhône	1993 - 2020	19	Yearly quantitative assessment of erosion and accretion volumes	23
	FR - PACA Camargue	2013 - 2020	90		17
	FR - PACA Beauduc / Lecques	2015 - 2020	30	Seasonal quantitative assessment of erosion and accretion volumes	35
	FR - Nouvelle Aquitaine	2017 - 2018	40	Yearly quantitative assessment of erosion and accretion volumes	4
	FR - Normandy	2015 - 2020	18		11
Bathymetry based on SAR imagery	PT - Aveiro, Mondegi, Figueira Foz, Leira	2011/2015 - 2020	198	Qualitative assessment of product usage	49
Cliff foot & apex	FR - Normandy & Nouvelle Aquitaine	1995 - 2020	100	Quantitative coastal retreat assessment	69
DEM (Pléiades)	FR - Nouvelle Aquitaine	2014 and 2017	15	Landslide volume quantitative assessment	2
Dune Foot	FR - Nouvelle Aquitaine	1987 - 2020	63	Seasonal to annual quantitative assessment of dune foot dynamics	85

	FR - Normandy	2017 - 2020	41	Seasonal quantitative assessment of dune foot dynamics	15
Submerged Sandbars	RO - Danube delta coastline	1990 - 2020	140	Monthly quantitative analysis of sandbar dynamics	200
	FR - Nouvelle Aquitaine	2015 - 2020	42		35
	GE - Sylt, Kiel Probstei, Heiligenhafen and Fehmarn	2015/2016 - 2020	50	High-frequency quantitative description of the sandbar location change	10 - 40 / year
Tidal channels and creeks	GE - Wadden Sea	1992 - 2020	41	Interannual to annual qualitative change analysis (e.g., channel creation = erosion)	694
Top of the cliff vertical movement	FR – Nouvelle Aquitaine & Normandy	1995 – 2020	30	Monthly quantitative vertical ground deformation	794
Upper Swash Limit	FR – PACA (Camargue & Fréjus)	2015 – 2020	97	Monthly & seasonal quantitative shoreline change assessment	66
Waterline	RO – Danube delta coastline	1990 – 2020	140	Monthly quantitative coastline dynamics assessment	200
	GE – Sylt, Kiel Probstei, Heiligenhafen	2001 – 2020	60	Annual to interannual	40

				coastline dynamics assessment		
	GR – Various locations	1995 -2020	50	Qualitative yearly shoreline change assessment	579	

7.2 Deliverable: Demonstration meetings

Germany

The regional Workshop in Germany took place on 30th October 2020. The workshop was hold as online meeting due to Covid-19 Situation. Few days before the meeting, new regulations were announced by administration so that travelling, and meeting of several people was not possible.

The participants were welcomed by Christian Reimers and welcome talks were held by the Director of LLUR (Matthias Hoppe-Kossak) and the Head of Department Water (Dirk van Riesen). The importance of remote sensing for administrations was pointed out and that the technology needs to be integrated into daily workflows. The presentations started with introduction of the coastal environment and geology (Klaus Schwarzer), coastal development in Sylt (Lutz Christiansen) and Blauort (Christian Reimers). This was followed by introducing optical and Radar remote sensing (Kerstin Stelzer, Martin Gade). The Space for Shore project was introduced to show the European frame and goals, followed by detailed presentation and discussion of the results for German North Sea and Baltic Sea coasts (Kerstin Stelzer, Martin Gade).

The discussions were lively, and good questions were asked to the presenters. The overall feedback was very positive, also expressed as short feedback in the chat of the meeting room.

Users showed interest – besides the presented indicators (water line, underwater sandbars, tidal creeks) – for bathymetry, submerged habitat mapping and cliff information. If Space for Shore could demonstrate such products at the German coast (North Sea and Baltic Sea), users would be very interested. Bathymetry might be challenging because North Sea is turbid and Baltic Sea water has is quite dark. Cliff information would require VHR data as the cliffs in Germany are rather small and S-2 is not sufficient to provide useful information.

Three participants expressed interest in future cooperation and possible services.

Portugal

All productions derived during the projects have been demonstrated: products carried out specifically for the Portuguese coast and also examples of products derived for other regions. In addition, information about land-use / land cover approach based on RS data was detailed.

Results were found interesting, in particular bathymetric maps based on wave crest inversion. Although the accuracy is not really high, the potential of such a product for coastal monitoring was approved by all participants. Clarifications about the future of the project were asked for. The attendees expect a follow-up to the projects. Funding solutions were not discussed.

Next step will consist in final identification of the products of interests, then are selecting locations and number of products to be delivered each year, in order to the team to set up a price. Based on this evaluation, APA will have the capacity to determine if it can purchase the service or not. These considerations will be highlighted during the final meeting, in January.

France South region

Results were found interesting, in particular bathymetric maps based on watercolor on sentinel-2 images. Although the 25 years of observation products could not be presented, the potential of such a product for coastal monitoring was approved by all participants. The attendees expect a follow-up, and some coastal managers are ready to go to next step of purchase.

Scientific community took an important place in the meeting by witnessing the high interests of such products for the scientific knowledge of coastal geomorphology.

Then, the high public institutions such as Regional environment direction or Regional coastal observatory engaged themselves to organize regional events gathering local coastal managers during which our products could be introduced.

France New Aquitaine region

The 25 years monitoring for dune foot indicators with Sentinel-2 and SPOT satellites were found interesting for use, it could be complementary to existing monitoring services because of the erosion distance on some areas. The 25 years monitoring for cliff foot monitoring was found interesting but is more suitable for worldwide regions with few data.

Users showed high interest about bathymetry indicator using Sentinel-2 and they would like to see similar products for many different coastal areas. The capacity to identify areas of sand accumulation is promising and coastal managers are very interested to identify these locations for sands collection.

Local experts of the BRGM testified of promising products, especially for sandbars detection very useful for understanding sediment cycles and it could be integrated to services of safety alerts.

France Normandy region

Please find below end-user's evaluation expressed during the demonstration meeting.

Satellite bathymetry: end-users found the results promising and ready to use for coastal managers. It is not possible for rocky areas with no sand, unfortunately for some end-users.

Dune foot: the frequency of acquisition and the archive are real assets to monitor storm events according to end-users. The lack of precision for some end-users can be enhanced if needed with Pleiades images.

Cliff lines: Results are satisfying but the resolution of Sentinel-2 is not sufficient for many French coastal managers monitoring cliffs. This indicator is more suitable for worldwide monitoring of areas with no data. Anyway, a derivative product of the cliff lines using Sentinel-2 is being developed (many false positive for now), it aims at identifying and localizing areas of rock falls, it could be complementary to in-situ studies.

Ground deformation using SAR satellites: Hight interests from end-users. The results lack of interpretations, and the validation is not really possible with this new kind of data. A meeting is scheduled with end-users and our developer partners from Greece to understand and interpret better the data.

Dissemination of products: the managers of the regional data platform present at the meeting ensured us the possibility to share the results on the regional platform in order to match the visibility for local coastal managers.

Greece

The regional Workshop in Greece took place on 10thNovember 2020. The workshop was hold as online meeting due to Covid-19 Situation. Few days before the meeting, new regulations were announced by administration so that travelling, and meeting of several people was not possible.

The participants were welcomed by Professor Issaak Parcharidis, along with a welcome speech and an introduction to the project. The coastal environment and geology, as well as coastal development in Greece were pointed out, while focus was put on the importance of remote sensing for Coastal Erosion Monitoring.

The presentations started with introduction to the project scope, its ambitions, as well the results from the first project year, by Georgia Kalousi. Also, the European frame of Space for Shore project and goals, followed by detailed presentation and discussion of the results for Greek Demo areas were illustrated. This was followed by introducing Optical and Radar remote sensing (Georgia Kalousi and Konstantina Bantouvaki).

The presentations were interactive, giving enough time in between for question-and-answer sessions, and fruitful discussions. Interesting questions were asked to the presenters specifically addressing the project Demo results. The overall feedback was very positive, also expressed as short feedback in the chat of the meeting room.

Users showed interest about all the indicators, and they would like to see similar products for many different Greek coast areas. According to the participants, many areas face similar problems as the ones we have already studied in northern Greece. Moreover, they would like to see surface deformation products for Greek areas as in recent years many coastal areas face problems such as landslides.

Many participants expressed interest in future cooperation and possible services, while all of them stressed out the importance that the technology needs to be integrated into their daily workflows and operational activities.

Romania

The demo meeting for the Romanian pilot site was organized on October 22nd, 2020, as an online event. It gathered seventeen participants from twelve potential intermediate and end users. This relative broad range of interested stakeholders denoted a high interest for the results of the Space for Shore project in particular and for the use of Earth Observation for coastal monitoring and management activities in general. Concrete usage of products was very discussed.

7.3 Deliverable: Product validation report

The validation phase guarantees the scientific rigor of our approach since it included a quantitative and/or qualitative assessment of all the algorithms as well as of each product extracted from satellite imagery. Through this effort, we have demonstrated the accuracy of the results, we compared the outputs from different satellite sources, we compared adopted methods, and we identified the contextual, technical, and technological limits in a transparent manner.

Intervention and consultation with site and processes experts were initiated from the start of the project. The specialists were mobilized in the continuous evaluation of the results and the adopted development strategies. Specialists as well as several end users holding very high precision field data provided material to quantitatively assess the accuracy of several results in the cases where the dates and locations matched those extracted from satellite images.

The validation was reported in a document developing the methods and the validation data used for each algorithm, presenting the synthetic results and an overall interpretation with a general validation assessment. A table presenting the results exhaustively has been associated with this deliverable.

In a first report drawn up during the first phase of the project (year 2019), the validation plan was established to decide on the appropriate methods for validating the results and to decide on the actions to be carried out in phase 2 (year 2020) in the framework for the quantitative result evaluation. In phase 1, most of the algorithms have already been validated, at least evaluated, and tested. The objective of phase 2 was therefore to validate the remaining algorithms, and those which required improvements, but also to systematically estimate the errors of the products, when validation data exists. The phase 1 validation plan therefore made it possible to improve algorithms, identify technical and contextual limits for extracting indicators, and plan the definition of the product accuracy. This validation step is essential to convince end users about the robustness and potential of the results as well as to give scientific value to this work and this innovative challenge based on spatial sources.

Some validations planned in phase 1 could not be carried out (Table 17) due to i) an absence of validation data, ii) a non-correspondence between the field data and that of the dates selected to extract the indicators from the satellite images, or iii) a change of indicator or algorithm. In addition, unplanned validations were able to be carried out thanks to the provision of field data that did not yet exist in year 1, or due to new productions not initially planned.

Table 17 – Number of sites validated vs planned

Number of sites validated VS planned	Bathy.	Beach Width	Cliff apex	Cliff foot	Dune foot	~~Maximum swash zone~~	Submerged sandbars	Tidal flat / tidal creek morph.	Top-of-the-cliff vertical movement	Waterline and Middle of swah Zone
Landsat-5	-	-	0/2	0/1	-	-	1/1	-	-	-
Landsat-8	1/1	-	0/2	0/2	0/1	-	-	1/1	-	6/7
SPOT-2	-	-	2/2	2/2	-	-	-	-	-	-
SPOT-4	-	-	2/2	2/2	-	-	-	-	-	-
SPOT-5	-	-	2/2	2/2	1/3	-	-	-	-	-
SPOT-7	-	-	0/1	0/1	-	-	1/1	-	-	3/3
Sentinel-2	2/2	1/1	5/5	4/4	3/3	-	5/5	1/1	-	7/8
Sentinel-1	1/1	0/1	3/3	3/3		-		0/1	0/4	2/3
Pléiades	1/1	-	2/2	2/2	1/1	-	1/1	-	-	2/2
ERS	-	-	-	-	-	-	-	-	-	1/2
CosmoSkyMed	-	-	0/3	0/3	-	-	-	-	-	-
WorldView	-	-	0/1	0/1	0/1	-	-	-	-	-

8 WORK PACKAGES 3.3 AND 3.4: LARGE SCALE PRODUCTION AND VALIDATION – PHASE 3 (CCN1)

8.1 Deliverable: Product delivery

All in all, around 2000 products were delivered during the large-scale production of Phase 3. The percentage of new products delivered are shown in Figure 12 per country and in Figure 13 per indicator. In Figure 10 and Figure 11, the production countries are reported.

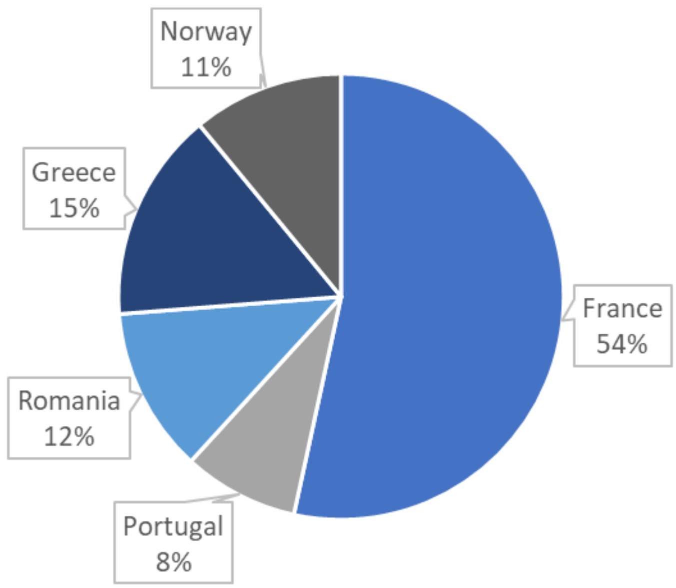

Figure 12. Percentages of products per country during the CCN1.

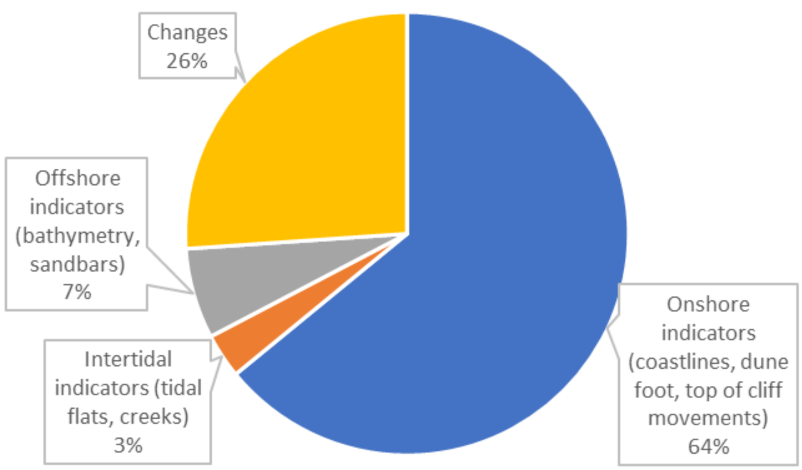

Figure 13. Percentage of products per indicator family during the CCN1.

8.2 Deliverable: Product validation report

This document compiles all the efforts to evaluate the accuracy and robustness of the algorithms developed and the results produced during the three years of the project. As the developments and initial monitoring were carried out in pilot regions in each country, the associated validations are more numerous, benefiting from three years of investigations. Validation was nevertheless also carried out in the new regions that joined the project during the third year. This document is therefore an update of the validation report published in 2020.

This document provides an exhaustive synthesis of the product validation results of current indicators produced by the Space for Shore Consortium as well as the associated methodologies for validation of indicators or algorithms (Table 18).

An interpretation of the validation results is provided, with a critical conclusion for each algorithm, depending on the morphological indicators, the methods, and the satellite data used, but also the limitations of the validation data itself.

Table 18 - Synthesis of the validation actions during CCN1 over the new AOIs.

	Bathymetry	Cliff lines	Dune foot	Submerged sandbars	Tidal flat / tidal creek morph.	Top of the cliff movement	Waterline and Upper swash limit
FR - Fréjus- St Raphaël	Landsat-8, Sentinel-2, Pléiades (4)						Sentinel-2, Landsat, Pléiades (2a2f)
FR - Camargue	Sentinel-2 (4b)						
FR - Corniche Basque		Sentinel-2, Pléiades, SPOT (3i)					
FR - Erretegia							
FR- Nord Médoc			Sentinel-2, SPOT (3h)				
FR - Vaches Noires		Sentinel-2, SPOT (3i)					
FR - Quiberville							
FR – Vendée			SPOT (3h)				
FR – Morbihan	Sentinel-2 (4b)						
FR – Charente-Maritime	Sentinel-2 (4b)						
FR - Occitanie							Sentinel-2, Pléiades (2a3f)
FR – Alpes Maritimes	Sentinel-2, Pléiades (4b)						Sentinel-2, Pléiades (2a3f)
GE - Kiel Probstei				Sentinel-2			Sentinel-2, Landsat (2ai)
GE - NS Blauort					Sentinel-2, Landsat (2j) ERS, ENVISAT, Sentinel-1 (2e)		Sentinel-2 (2ai)

GE - NS Dithmarschen					ERS, ENVISAT, Sentinel-1 (2e)		
GE - NS Halligen					ERS, ENVISAT, Sentinel-1 (2e)		
GE - NS Sylt Odde				Sentinel-2	ERS, ENVISAT, Sentinel-1 (2e)		Sentinel-2, SPOT, Landsat (2ai)
GE - Fehmarn				Sentinel-2			Sentinel-2, Landsat (2ai)
RO - Sulina-Sf. Gheorghe				Sentinel-2, Landsat, SPOT, Pléiades (6a)			Sentinel-2, SPOT, Pléiades, Landsat (2ai, 2aii, 2aiii), Sentinel-1, ERS (2g)
RO - Constanta							Landsat 8, Sentinel-2 (2aiii)
PT - Leiria		Sentinel-2 (3i)					
PT - Aveiro	Sentinel-1 (4c)						
PT - Mondego	Sentinel-1 (4c)						
PT - Figueira Foz	Sentinel-1 (4c)						
PT - Algarve	Sentinel-2 (4b)			Sentinel-2 (3h)			Sentinel-2 (2a3f)
GR - Chalkida							Sentinel-2 (2aii)

GR - Evia							Sentinel-2 (2aii)
GR - Euboa							
SVA							Sentinel-2 (2aiv)

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8.3 Deliverable: Demonstration meetings

8.3.1 France

In France, three subsequent meetings were recently organized, two in coastal regions newly concerned by the project (South Brittany / Pays de Loire + Occitanie) and one other meeting in the South Region (Provence Alpes Cote d'Azur) with a limited group of coastal managers who many of them had already participated in the previous meeting. These 3 demo meetings have been held on-site and gathered about 15 people each in both Saint-Jean-de-Monts (Vendée – Pays de Loire region) and in Sète (Occitanie) plus a few other participants connected remotely, and 3 people in Saint-Raphaël (South region), totalizing 33 participants from 26 organizations (24 new organizations and potential customers). A couple of other key organizations in the two new coastal areas (engaged as final end-users) were planning to participate to the demo meetings but finally did not manage to make it for several different reasons.

8.3.2 Greece

In Greece, three successive meetings were organised, first two meetings were physical ones, while the third was virtual meeting in order to ease all end-users that couldn't travel. First meeting was held in the premises of Municipality of Chalkis, where several end-user entities participate regarding this area of interest. The second and third meeting were held in Athens, were also several different end-user entities participated. In total, in these tree demo meetings 19 people participated both in physical and remote mode from 8 different entities. Several people didn't manage to participate due to summer vacation period, though initially expressed their interest to be present. For those we will run a virtual demo meeting in the first half of September 2022.

8.3.3 Portugal

In Portugal, during the third phase of the project (CCN1), one hybrid demonstration meeting was held on June 2022. For this meeting fifteen end-users at national (Portuguese Environmental Agency) and regional level (coastal municipalities), two port administrations (Figueira da Foz and Algarve), one state Laboratory (Hydrographic Institute) and two universities were invited to join the event. A group of four end-users participate (three of the remotely and one in person). The participants represent various organizations including the Portuguese Environmental Agency, three coastal municipalities (Vagos, Alcobaça and Sesimbra) and one university (Algarve). One questionnaire was filled after the workshop.

8.3.4 Germany

In Germany, two additional workshops were held. The first one focussed on demonstrating the new tools developed for shoreline extraction and tidal creek morphological changes. This workshop was dedicated to one user institution with 5 participants. A second workshop was a general presentation of the project and results achieved for the German coasts. This second workshop was attended by 16 participants from 9 different institutions. The participants represented regional and national agencies responsible for different aspects of the coast. The meetings were held online which enabled more people to participate but which also limited the discussion among the participants. 10 questionnaires were filled and returned after the workshop.

8.3.5 Romania

In Romania, during the third phase of the project, one online demonstration meeting was held on July 2022. A group of twelve persons from various organization such as National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar, University of Bucharest, National Institute for Marine Research and Development "Grigore Antipa" joined the meeting. It is to mention that a couple of other organization were invited to join the event but could not attend it in the end from various reasons. 7 questionnaires were filled after the workshop.

8.3.6 Norway – Svalbard

In Svalbard, which is a new Space for Shore country, no demonstration meeting has been organized at the time of issue of this document. Coastal end users have been poorly engaged in the project at the exception of UNIS (University of Svalbard, Dr Maria Jensen) and its French scientific counterpart, University of Nantes (Dr Agnès Baltzer), who are together leading joint coastal research programs in Svalbard. Engagement of these last two has been limited during the last year of activity and as a consequence, no relationship with Svalbard authorities has been possible without the active support of UNIS who acts as the leading science institution in the area.

9 WORK PACKAGE 2.3: SERVICE ROLL-OUT ANALYSIS

9.1 End-user feedbacks

This deliverable provides a business description in short of the Space for Shore project. It focuses on the feedbacks of the end users who participated in the project and to the participants to the demonstration meetings. All the other aspects, the target market, the competitive landscape, and all business aspects are fully developed in the Service Roll Out Analysis deliverable.

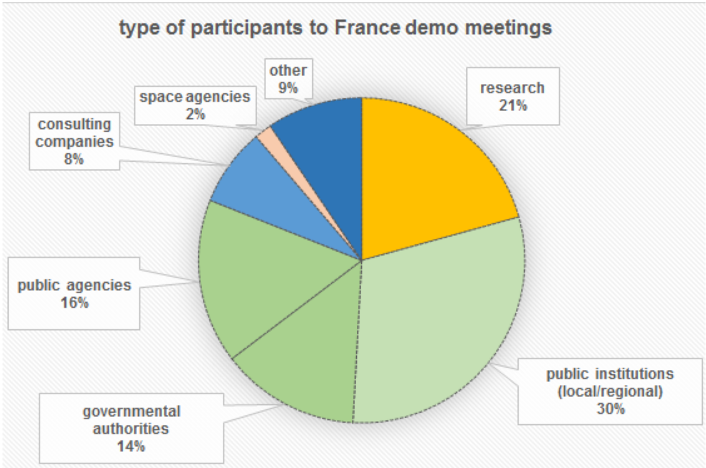
During the project, three user-requirements survey campaigns were conducted. The first concerned the selected users in the initial phase, the second was carried out at the end of the second phase of the project after a series of workshops in all countries with pilot areas in 2020. The third survey was realised at the end the CCN1 (third phase) in 2022 after a second session of regional workshops that concerned the newly integrated AOIs.

9.1.1 Feedbacks from participants to the demo meetings in 2020

The workshops were conducted in October and November 2020 in 5 pilot countries (France, Greece, Germany, Portugal, and Romania). A total of 7 demonstration meetings were held, only one physically in Aix-en-Provence, with south of France end-users and the related coastal community, all the others remotely. More than 200 people attended the meetings (127 in France, 21 in Germany, 30 in Greece, 17 in Romania, 12 in Portugal). The audience was mainly composed of public stakeholders (e.g., 60% in France, 70 participants representatives of public administrations, governmental authorities and associated environmental agencies in charge of coastal areas monitoring and management along the Atlantic, English Channel / North Sea and Mediterranean coasts (**Erreur ! Source du renvoi introuvable.**).

9.1.1.1 *Outcomes from the demonstration meetings*

Right after the meeting it was proposed they shared their feedbacks through a concise survey in the form of fast and easy questions in the form of single-choice questions or short texts. This survey was completed by 51 participants along the 5 countries.



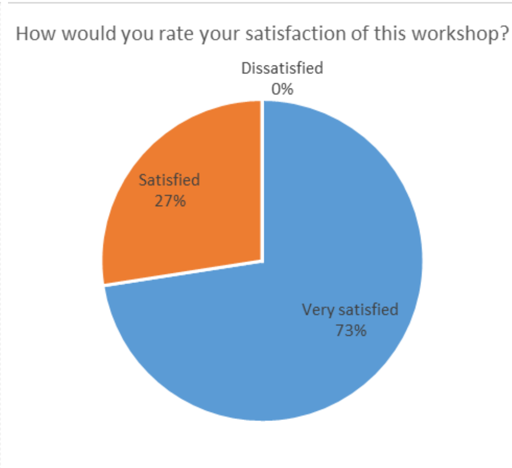
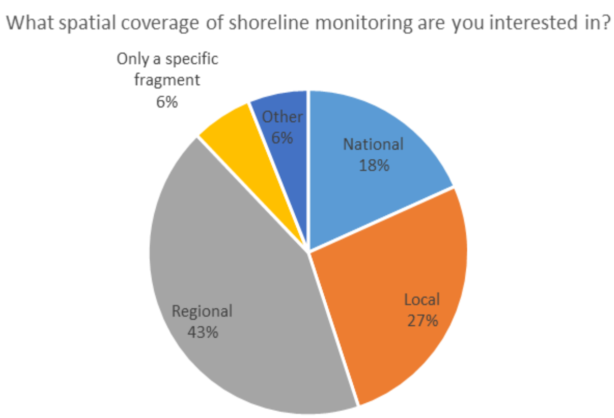


Figure 14 - Participants in French demo meetings (green is for public administrations and stakeholders) and overall satisfaction of participants to the workshops



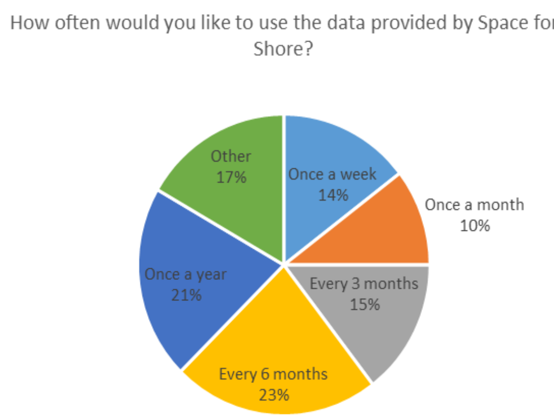
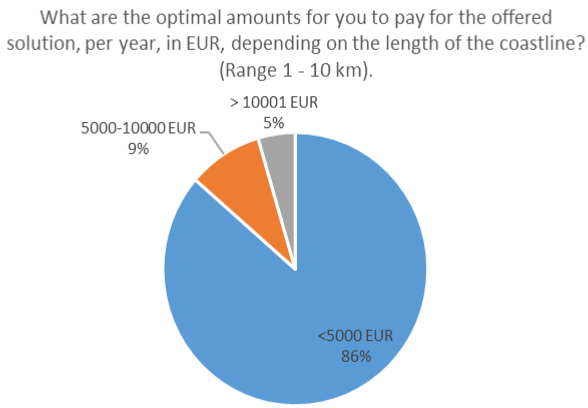


Figure 15 – Coverage of shoreline monitoring and frequency of observations expressed by Space for Shore participants to the demo meetings

The last part of the survey was optional. It mainly concerned financial issues, the possibility of commercialization of the project. The participants were presented a table with the price ranges proposed for the packaged coastal erosion service with products as demonstrated in the project (**Erreur ! Source du renvoi introuvable.**). In this section of the questions, only those prone to buying the service answered. Analysing the percentage of people who answered in the previous sections, it looks as follows, Romania - 100%, Portugal - 88%, Greece 75%, France 54%, while representatives from Germany didn't provide answers in this part.



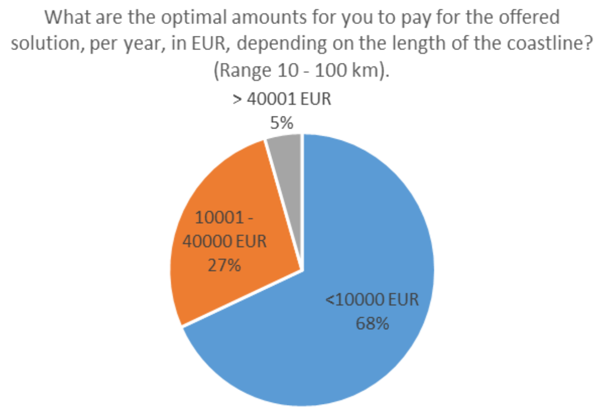


Figure 16 – Optimal amounts to pay for the offered solution, depending on the length of the coastline (left: Range 1 - 10 km, right: Range 10 - 100 km)

Overall, the satisfaction of the people participating in the workshops was quite positive and rewarding. Most of the participants expressed their approval on the outcome of the event. When it comes to questions about the services offered, most participants are people with no experience with satellite data and would like to use the data in a simple and easy way. Data does not have to be shared frequently, but the response to orders in connection with extraordinary events should be fairly quick. Services are best offered at the regional level when selecting the most strategic areas in Europe in the initial stage of the offer, in the next stage it is necessary to think about expanding the offer on a global scale. As for the price, it is best to optimize it in relation to the services offered, if these are to be basic services, the fees from the lowest level should be selected. The survey shows that more advanced users are willing to pay higher fees, even those in the highest price range. According to the participants of the workshop, a long-term subscription is not required, or it should be personalized to the area under study and its in-depth analysis, which time frame would be the most appropriate to sell its services to potential users.

9.1.1.2 *France*

High general level of interest and satisfaction of French end-users. Satellite coastal erosion products have been demonstrated in a wide range of coastal environments (sandy/rocky, micro/macrotidal, wind/wave-dominated).

- Mediterranean area: very successful demo meeting with expressed interest of Camargue and Var stakeholders in buying satellite-derived coastal erosion products. In PACA / French Mediterranean region, there is currently no systematic observation monitoring infrastructure, thus room for deploying satellite-based service over this virgin territory. EO-derived products of shoreline and nearshore bathymetry could be provided routinely twice a year for a better acknowledgement of sediment stocks related to coastal dynamics, and local beach management.

- Atlantic area: positive feedbacks were in majority given out, despite the general lack of coherence between both HR optical/radar derived products (for waterline, shoreline, and cliff lines) and the end user initial (submetric) accuracy requirements. Even though it has been demonstrated that historical datasets computed using 10-m resolution EO data may be relevant in some cases where coastal erosion is very intense (≥ 5 m per year, e.g. North of Gironde Medoc region) enabling then to catch trend for annual shoreline change and/or assess impacts of major storm events when responsible of retreats larger than 10 m. Additionally, coastal erosion products derived from 10-m resolution data may also bring added value in a wider extent by the hybridization of series of geomorphological indicators (e.g. beach morphology / sandbar location/ beach width) and this has been stated to be of relevance for the assessment in routine of beach sediment stock in support to beach nourishment operations. But this must be explored more in detail with follow-on activities. Temporal series of SAR interferometry products over coastal cliffs have also raised the interest of local stakeholders having to deal with chronic ground movements and coastal landslides (particularly relevant in south of Aquitaine “Pays Basque” and Normandy regions). These products could feed an early-warning alert system, but here also this contribution must be confirmed with further investigation.

VHR Pléiades-like products received general approbation for monitoring a wide range of coastal erosion geomorphological indicators over both sandy shores and cliff areas. Even if this was not the main purpose of the activities in the project, there were found relevant for cliff DEM reconstruction, top-of-cliff extraction, landslide detection in cliff areas, and shoreline (dune foot) monitoring along coastal dunes. These VHR products paves the way to a commercial coastal erosion service which could serve many of the European coastlines and places in erosion around the world, i.e., where erosion retreat is low (< 1m per year) to moderate (2-3 m per year).

- English Channel / North Sea coast: the audience only composed of representatives of the regional coastal observatory of Normandy Hauts-de-France (no local stakeholders participated to the demo meeting) has been enthusiastic. This was certainly the most challenging region in France where to experiment and demonstrate EO capabilities for coastal erosion. Same results over the cliff area in Seine Maritime than in South of Aquitaine / Pays Basque, efforts must be pursued along with the support of regional academic experts to assess the potential of 10-m resolution EO data for ground movement and coastal landslide detection through a soundful interpretation of gained results. The Sentinel-2 nearshore bathymetry product has been demonstrated in some pilot locations defined along with end users and offers a promising potential over this coastal region while well-known for its high turbidity background, this result highly interested the end users. Sandy stretches of coastline offers ideal environments for EO-derived products like demonstrated along the French Mediterranean and Atlantic regions, this has been also confirmed in the south of Normandy / Cotentin sandy-dominated area.

9.1.1.3 *Germany*

High general level of interest of German participants. Both, the products for the Baltic Sea as well the North Sea have been received with interest. The users engaged in the project were from mainly from administrations, while in the workshop also universities and research institutions participated. The products defined in the beginning and presented during the workshop covered the coastlines detection and coastline change (North Sea and Baltic Sea), the changes of intertidal creek systems (North Sea, Wadden Sea) and the detection and monitoring of submerged sandbars (North Sea and Baltic Sea). Especially the latter was new to the community and raised some interested comments, questions. Additional products that are provided by the consortium but not produced for the German test sites could be taken into account in the future to assess their usability.

The feedback from our main end users, who was also closely involved in the project, was pointing at the need for further development, but that the Space for Shore products already provide a valuable basis for these developments. The interest and the need exist to continue the good cooperation for this topic. This includes the optical as well as the SAR products. The spatial resolution of products is an important point. It is a trade-off of costs for VHR data with sufficient resolution and the need for cost-efficient monitoring methods. The big advantage of Sentinel data which are acquired routinely for free is known compared to VHR data which need to be ordered, cover less area, and come with data costs.

9.1.1.4 *Portugal*

High general level of interest of Portuguese audience (i.e., end-users, Harbour Administration and researchers). Satellite derived products have been demonstrated in the mesotidal, wave-dominated coastal stretch from Ovar to Peniche, which includes sandy beaches backed by dunes and cliffs. Some examples of products derived for other regions such as submerged sandbars, land microdeformations were also presented. In addition, information about land-use / land cover approach based on RS data was detailed.

Nearshore bathymetry product derived from the promising Wavelet Transform method was well received in spite the current accuracy doesn't allow to perform quantitative assessments as was pointed by Agência Portuguesa do Ambiente (APA) (end-user). Nevertheless, APA think that it is useful to have qualitative perspective, and thus, it might be included in their current activities. Harbour Administration from Figueira da Foz highlighted the importance of this product to have information when high-energy wave climate conditions prevent to perform bathymetric surveys. They think that this product might be a good complement.

Dune foot product awaken interest of our end-users because dunes are protecting human settlements, in fact, APA indicated that this product is extremely pertinent in the context of climate change since storms will be worst. However, APA ask for sub-metric accuracy because their main interest is the coastline evolution at short-term. Consequently, VHR satellite images would be needed to accomplish their requirements.

Cliff apex product would be appealing by APA in the south coast of Portugal where cliffs have quick evolution and the current method would drive to suitable results. Otherwise, the method would need to be improved to be able to detect changes in these slow evolution cliffs.

The end-users expressed their concern about the future of the project. The end-users from municipalities indicated that currently their annual budgets have suffered important cutbacks and it is difficult to have a specific budget allocation to invest in acquisition of VHR satellite images to support us to obtain satellite derived products.

9.1.1.5 *Romania*

The northern part of the Romanian coastal area, one of the pilot regions of the project, is characterized by low sandy beaches and intense dynamics in terms of coastal erosion. It is part of the Danube Delta Biosphere Reserve, one of the most important wetlands in Europe. Therefore, end-users are mostly interested in indicators that can be used to assess and monitor the changes that occur in this area at different time scales. The most important ones, as depicted by the stakeholders, are waterline position, submerged sandbars locations and bathymetry for shallow areas. Availability of long-term datasets was also an important criterion.

The demo meeting for the Romanian pilot site was organized on October 22nd, 2020, as an online event. It gathered seventeen participants from twelve potential intermediate and end users. This relative broad range of interested stakeholders denoted a high interest for the results of the Space for Shore project in particular and for the use of Earth Observation for coastal monitoring and management activities in general.

In terms of waterline indicator, the satisfaction degree of the potential users was significant. The new products showed them a new and complementary approach to the old methodology of coastal erosion rates estimation of comparing singular sets of images. With approximately 200 waterline positions available, spanning 30 years, it was possible to show, for the first time, different rates of accumulation or erosion for specific sectors. Thus, a first-time glimpse of how the deltaic coastal region "breathes" was possible. For the submerged sandbars, the algorithm developed and validated proved to be a valuable one for long-term analysis. It represents the first approach, based on satellite images, to detect these important coastal geomorphologic features, of utmost importance for beach protection against erosion.

Due to the above-mentioned results, the overall feedback received from local stakeholders was positive. The methodologies and products developed within the Space for Shore project have the potential to be further integrated into added-value services and processing chains that will be at the basis of a sound integrated coastal zone management strategy and action.

9.1.1.6 *Greece*

Greek end-users showed interest about all produced indicators within the Hellenic demonstration areas, in particular the waterline indicators (waterline and beach width) and the deformation products that are of high importance in their everyday operational processes. More specific, they were interested in the multitemporal series of products for waterlines and the relevant changes detected, mostly over areas prone to severe erosion problems. The interest was even more intense in coastal rural areas, which by the way is a common issue for several large Greek cities, where a significant part of the national rural network is located on the coast.

Moreover, several end-users are Natura2000 coastline managers and for whom the beach width product is of high importance. For example, in the demonstration area on the Zakynthos island where it is the habitat of sea turtles caretta-caretta (Natura2000 protected area), the development of the beach width over time is really crucial for the turtles' population.

In the same scope, interest was observed on the coastal vegetation boundary products for the protected Natura2000 area of Vistonis, which is an important indicator for monitoring the coastal in-land flora. This flora is being affected (damaged) by the illegal campers that find shelter in numbers over those coasts.

Also, both the Natura2000 areas of Vistonis and Evros, include Deltaic areas which are susceptible to constant changes over not only the coastal waterline but in the in-land waters, where part of rivers and lagoons exist. For these end-users the extend of the products beyond the coastal waters is also important for them.

Last but not least, the private insurance company acting as end-user (i.e., actuary department, responsible for assessing risks and thus setting the basis for the insurance fees) was interested on the coastal deformation products, specifically over areas where critical infrastructure is present (i.e. large hotel resorts, industries, etc.). The long-term monitoring of these deformations can lead to important conclusions on the structural vulnerability of the superimposed buildings. Moreover, in the cases of the large hotel resorts the development of the beach width is also of high importance due to its recreational role for the tourists.

Finally, it was witnessed that many participants expressed interest in future cooperation and possible services, while all of them stressed out the importance that the technology needs to be integrated into their daily workflows and operational activities.

9.1.2 Feedbacks from participants to the demo meetings in 2022

9.1.2.1 *France*

A second demo meeting in **PACA** region has been organized in July 2022 with a couple of existing end users already aware of the benefits of EO-based coastal erosion products and with whom discussions are still ongoing since the first demo meeting. A new organization in charge of coastal planning and flooding / coastal erosion risk mitigation enters the pool of regional PACA coastal end users and was thus discovering the project results over its area of interest. After a careful meeting opening, the results shown were discussed and several advices were made. Some about the indicators (e.g. mean swash limit would be in some case more appropriate than upper swash limit) and displays (bathymetry layer exhaustivity shall be improved). The coastal erosion hazard shall be calculated based on long term observations and given as an envelope (to account for impacts caused by major storms). Hazard envelopes for different horizons could be also calculated and displayed. Coastal managers need this level of information for decision making. The erosion risks were also strongly discussed. It was concluded that the natural and socioeconomical issues should be distinguished. General rules could be applied when attributing values to environmental issues. For buildings and other infrastructures, issues should be evaluated by the local competent administration. However, the interest of the information obtained combining hazard and issues was appreciated. Last recommendation was made to integrate the shallow water bathymetry change in the coastal erosion hazard assessment. All in all, Space for Shore products were acknowledged and recognised as useful to contribute to the establishment of local strategies to face the coastal erosion risk. The attendees are confident that satellite-based coastal erosion indicators will be integrated into the surveillance strategies, at the regional scale, in a very near future.

Occitanie is a new Space for Shore coastal region which has been selected to enter the project in 2021. This is a particularly interesting region because here, some regional organizations have been experimenting satellite remote sensing along with other technologies (e.g. aerial lidar surveys) for coastal monitoring since a decade now. The demo meeting in Occitanie put together about 14 people from 10 organizations, being regional and national institutions, as well as local municipalities. We must highlight that two elected representatives from cities and intercommunal structures have actively participate in the meeting. Unfortunately, several other key participants were missing. However, coastal task officers attending the meeting demonstrated a sufficient thematic expertise to bring relevant critical advices. Questions and suggestions were raised by the participants all along the meeting. The product accuracy, in particular bathymetry retrieval, has been warmly welcome. However, we were warned to precisely specify the product accuracy in the deliverable. Product metadata must include this information. The coastal erosion hazard assessment display was also appreciated. But major concerns arose in the use of generic issue qualification to determine the exposition of the coast to erosion risk. It was concluded that each municipality shall decide individually the value of each issue. With regards to the intense and appropriate participation of the attendees, the meeting was a success. Market opportunities were also finally discussed. It was concluded that service purchase should be considered at the regional level.

South Brittany / Vendée / Charente Maritime: this is also a new coastal region covered by the project since 2021. The demo meeting of July 2022 was organized on-site at Saint-Jean-de-Monts, in Vendée. Most of the technical people in charge of coastal erosion in Vendée coastal cities were present at the meeting along with representatives of the local and regional governmental authorities and of the Pays de Loire Regional Council. Some end users from Charente Maritime and south Brittany were also attending the meeting, but in very few numbers. Note also that the director of the regional coastal observatory was there and actively participated to the discussion about result significance and EO product relevance for multi-scale coastal erosion monitoring. In average, the coastal erosion products were warmly welcomed, and many of the audience agreed about the benefits of EO Copernicus-like sensors for long-term monitoring and assessment of shoreline change. Having now concrete results in front of them, the participants all affirmed their willingness of sharing their own field datasets to strengthen validation over their respective areas of interest, which should help them increasing their maturity and for some of them, move gradually forward up to service purchase. The regional coastal observatory representative concluded positively, local/regional environmental authorities also provided great feedbacks about the satellite coastal erosion products and are definitely supporters of Earth Observation. Next is to work closely with them, stimulate and support them in the appropriation and use of the Space for Shore satellite products, in the comparison with their own datasets, and then, have follow-up group meetings region by region to increase their willingness to buy and implement the satellite products in their monitoring strategy.

9.1.2.2 *Germany*

The feedback of the closely involved users (16 attendees, 9 organisations) during the third year was very positive for the improvements achieved during the third year and the tools that have been developed. These tools were very welcomed as they show the potential to fill the gap between the raw satellite data and potential applications at the agencies. Together with our main users, we tried to develop a model how the tools can be used in future collaborations and how the users can learn to work with data themselves. In general, the users were enthusiastic in seeing what is possible with satellite data meanwhile and developed further ideas for future applications.

During the workshop held in July 2022, additional requirements were collected, as some users are not only interested in morphological changes but also in sediment types, biology (habitats) and water quality. Some of them are already using BC products and services and further collaboration might be possible in the future with additional users.

9.1.2.1 *Portugal*

The feedback received from the end-users at the end of the meeting were positive although it was notorious that the resolution achieved in the validation analysis for the selected indicators do not match the expectations of the end-users present in the event (personal communication after the event). As example, it was mentioned the Upper swash limit, waterline, frontal dune baseline validation results although under the values of pixel size (e.g frontal dune baseline mean absolute error of about 18 m) or even lower (e.g upper swash limit mean absolute error of about 6 m) exceeds in most of the cases the pluriannual observed variations and only under a decadal analysis can have some interest. The Portuguese Environmental Agency was the only organization available to fill the questionnaire highlighting the potential interest of the remote sensing to provide large scale coastal erosion indicators. However, the present resolution should be improved to metric or submetric values.

9.1.2.2 *Romania*

The demo meeting was organized on July 4th, 2022, as an online event. It gathered twelve participants, with different skills in the subject of shoreline monitoring, who were really interested in the Space for Shore results. If during the first demo meeting, we managed to show them how we improved the methodology and the results that were obtained for Sulina – Sfantu Gheorghe area, during the second demo-meeting we managed to show them (in accordance with the validation results) that the methodology for the waterline indicator leads to high accuracy over the southern littoral too.

The southern littoral shoreline dynamics was of particular interest for them, due to the big investments that have been made in recent years for the beach nourishment activities. What is more, it was possible, for the first time, to show them different rates of accumulation or erosion for specific sectors over the entire Danube Delta shoreline for the last 32 years.

Due to the above-mentioned results, the overall feedback received from local stakeholders was positive. The methodologies and products developed within the Space for Shore project have the potential to be further integrated into added-value services and processing chains that will be at the basis of a sound integrated coastal zone management strategy and action.

9.1.2.1 *Greece*

During the third project phase demo meetings, all old test sites were fully covered, yet a lot of emphasis was placed over the new areas. In particular for each new area:

Evia Island

For the Evia Island, focus was placed over the coastline of the southern part of the island, where the capital city of Chalkis is located as well as many other smaller cities, villages, and coastal settlements. Indeed, all these areas are suffering from coastal erosion problems and during the demo meetings the areas with the most crucial waterline changes were highlighted regarding its change for each period. Some of the identified areas facing high erosion problems were defensed with beach nourishment techniques over the years and the produced by us waterline change indicators has showed that in some cases the works where successful, while in others the erosion problem returned with the same magnitude. Therefore, the end-users witnessed with their own eyes the fact that our products are un-biased because in our results the coastline appeared to be retrieving during the periods that the interventions were made on shoreline (beach nourishments) for which no information was shared among us. Moreover, in the same way, they were able to see the results of these interventions, which unfortunately in half of the cases stalled the problem for 3-4 year at least. In the produced by us coastline changed indicators within those areas the material used for beach nourishment was naturally displaced due to coastal mechanics as well as by the effects of climate changes procedures within 5-years period. Finally, a lot of focus was placed over the delta area of Lilas river, where a coastal settlement is located, and which is suffering from erosion as well as coastal floods. Therefore, the waterline change indicator was highly appreciated since is providing qualitative information with high accuracy and providing the exact location of hot spots that are severely stricken by erosion issues. Meantime, the beach width indicator was also warmly welcomed since it also serves issues of coastal zone financial exploitation through mostly touristic operations. Several operators from these entities applied for access rights on the Deimos platform, so that they investigate more the produced results and be able to merge these datasets with data that host locally in their premises. There is an open date to visit the city of Chalkis again and elaborate on any other areas that appear to be unstable.

Rhodes Island

For the island of Rhodes, focus was placed on the southern-eastern part of the island, where several coastal settlements are located and large touristic resorts. In particular, for the last one's high interest was expressed by Interamerican SA, a Greek insurance company, that belongs to the ACHMEA Group, a leading international insurance Group based in the Netherlands. Interamerican has a portfolio of several grand resorts over this coastline and their task is to insure these establishments for the case of extreme events. The insurance fees are calculated according to the risk that are subjective to and are a painful task of the Actuary department. This office is responsible for assessing risks, setting the basis for the insurance fees and is executives are mainly people with background on finance and statistics rather that environmental sciences or any other relevant geoinformation studies. Therefore, the access and handling of geodata is not so easy on their behalf and need support to it. The Actuary department was interested on the waterline changes indicator, the long-term monitoring of which can lead to important conclusions on touristic beaches that are managed by the grand resorts. Moreover, in the cases of the large hotel resorts the change of the beach width is also of high importance due to its recreational role for the tourists. For this year several bathymetry products were produced, giving the opportunity to the end-users to have a more spherical idea both on the land as well as the seabed changes. Having in mind the fact that the coastal erosion relies on a high degree on the procedures that take place under the sea surface, this product was of high interest to the end-users. Again, in this case, several operators from this entity applied for access rights on the Deimos platform, so that they investigate more the produced results and be able to merge these datasets with data that host locally in their premises. There is an open date to visit them again and provide them clarifications or any other supportive information.

9.1.2.2 *Outcomes from the ESA survey*

In the weeks that followed the demonstration meetings, the engaged final end-users were asked to fill the forms about their satisfaction, compliance of the developed products with regards to their initial requirements, benefits, and impacts of the project on their practices. The result is given as follows:

9.1.2.2.1 Assessment of user requirements

1. Adequacy of the User Requirements Document (URD) requirements (including accuracy)

Overall evaluation - Medium/High

Users need valuable information on the many aspects of coastal zone monitoring, both on land and at sea. Each of the requirements depends on the characteristics of the coast. Some of the users specified precise requirements such as information on the morpho dynamic processes taking place on sandy coasts or remote sensing indicators. Some of the user requirements have been met in the first stages of the project, while some still expect clearer information about the services offered in order to better plan management processes.

9.1.2.2.2 Product compliance

2. Overall product compliance to the user requirements

Overall evaluation – High

According to the users, the developed products meet the users' requirements very well. Particular attention was paid to the products of dynamics and indicators of the coastline. With easy access and understanding of the project outputs, there is great potential to achieve the intended goals. Many areas for targeted analysis meet the needs for satellite monitoring. Some users advise that in the future the service will be more personalized to customer requirements. Concerns about user requirements were mainly based on the project implementation time being too short, and therefore recommends looking for ways to further develop services after the end of the project.

3. Product accuracy compliance to the user requirements

Overall evaluation – Medium/High

Most of the users described the accuracy of the products as sufficient and in line with their expectations, mainly in the case of sandy shores. As a result, users expressed their interest in using the services of the *Space for Shore* Project in the future. Each study area has different characteristics and users have expressed concern for areas such as narrow coasts or cliffs, because the evolution of the coastline is too small and the need for satellite images of better quality than 10 meters, or objects in the coastal area are lower than the assumed resolution. The overall assessment is satisfactory for users; however, attention should be paid to the enrichment of satellite data with data of better quality in problem areas.

4. Confidence in the product quality (including accuracy)

Overall evaluation – High

According to users, by comparing other methods of acquisition (LIDAR, orthophotos, in-situ campaigns) it is possible to achieve a product of very high quality. The quality of the product is considered to be satisfactory (data sets, metadata, etc.), therefore the products guarantee high quality and even exceed expectations in terms of data processing techniques. However, their current resolution for the purposes of high-resolution monitoring of coastal areas poses the risk of insufficient quality.

9.1.2.2.3 Utility assessment

5. Benefits of the demonstrated service and products

Overall evaluation – High

The benefits that the presented *Space for Shore* services can bring are consistent with the recommendations and needs of users. The products presented are of great importance in assessing the long-term trends in the evolution of the coastline, which directly affects coastal management. They can also assist in decision-making when planning coastal protection interventions and climate change adaptation measures. The ability to carry out analyses of the dynamics of the coastline and changes in high spatial and temporal scales will allow for high-quality assessment of evolutionary trends in coastal zone management. The use of *Space for Shore* services for Earth observation is expected to allow coastal managers to reduce their monitoring effort in the field, which is valuable for local stakeholders. These products offer alternative, complementary datasets to those available under regional field research programs. Users also stressed that the data can be used in many areas, such as optimal use of tourism, aspects of sustainable regional development, regional planning of technical works, etc. They envisage that the systematic use of Space for Shore products will provide them with high economic savings in the long term.

6. Impact of the service and products on current end-user practices

Overall evaluation – High

Users plan to include *Space for Shore* services in future hydromorphological, erosion or advection monitoring plans and in coastal crisis management as they expand the range of remote sensing methods used so far. The newly developed service and products will allow a new, in-depth understanding of coastal dynamics at previously unavailable spatial and temporal scales. The Romanian partners want to focus on multi-year analysis on monthly and seasonal analysis of shoreline changes.

9.1.2.2.4 Future outlook

7. Probability of service integration into existing practices

Overall evaluation – High

As mentioned by end-users, the results of *Space for Shore* will be immediately integrated into their current operating procedures, in particular as inputs to optimize existing management practices, coastal defence planning and monitoring. The use of *Space for Shore* services will enrich the work carried out so far on many aspects related to the monitoring of coastal areas. Ultimately, such actions will significantly improve the quality of previously performed work.

8. Desired service and/or product(s) improvements

Overall evaluation – High

In the current level of the EDC data market, other significant improvements are difficult to implement. The developed products are still at the evaluation stage. There should be more time for the necessary service optimization. Users hope that in the future the accuracy of non-commercial satellite images will be higher (even pixel resolution up to 1 meter). And in the future, it will be accurate to within a few centimetres. Another important aspect is the implementation of more specialized services. Better interaction, more meaningful exchange of satellite data and field observation with operators (applicants and applicants) is proposed, followed by a "summary". Another suggestion is to develop a suitable user interface to view satellite origin datasets, products / results along with other coastal / shoreline erosion data (e.g., soil data) and other associated MeteOcean parameters. Report generation and technical assistance to understand the importance of the results (in terms of thematic knowledge) are also expected to provide a suite of decision support services.

9. Needs for a large-scale service/product demonstration

Overall evaluation – Medium

According to users, *Space for Shore* will make a valuable contribution to national coastal protection and the implementation of marine protection directives. The main attention was to develop a uniform strategy for all countries that cover one research area / region. Such action would allow optimization of the proposed services. A large-scale demonstration would help to optimally monitor hot spots (*e.g.*, erosion) and provide an overview of the situation for further corrective and preventive action. Users also noted that product testing is still needed, for example during a one-year pre-operational phase, before going into the routine production of services.

9.1.2.2.5 Overall evaluation

10. Overall service and products evaluation

Overall evaluation – Medium

Given the general interest and great usability potential, the overall rating is generally positive. The work undertaken by i-Sea has allowed French end users to recognize and increase their awareness of the opportunities and benefits of Earth observation to support its current work. Depending on the end user requirements for the accuracy and space-time scale used in studying coastal dynamics, these products can be useful. From the user's point of view, there is an urgent need to continue and further develop the progress achieved. This would enable the optimization and more efficient processing of tasks related to coastal protection and coastal zone monitoring, and the planning of beach activities as well. Considering the very promising nature of the service provided, users hope that it will continue to be developed even if it does not reach the recommended resolution levels immediately. The service and products fully meet the requirements of users and offer high-quality data with good accuracy in average on large spatial and temporal scales. This is very beneficial for scientists, coastal managers, policy makers and other stakeholders. Some satellite products are suitable, but a pre-operational testing phase is needed to consolidate routine production capacity and associated costs.

11. Recommendations to the European Space Agency

Overall evaluation – none

By funding projects such as *Space for Shore*, ESA is going in the right direction in promoting EO applications and reaching and supporting local and regional end-users. Users express their hope that in the future, ESA will finance similar projects. Coastal erosion is an ongoing issue that will pose many problems for many areas around the world in the future. Local and regional entities constantly need to increase their knowledge of the dynamics of coastal areas as the first step in implementing ICZM policy. However, field research is time consuming and costly, so it is crucial to continue investing in the development of alternative technologies such as Earth observation to provide stakeholders with accurate, easily upgradable, and cost-effective products that underpin their decisions. Offering open and innovative data with high accuracy is the best way to deal with these problems, engaging many types of data creators and users and finding the best solutions. The European Space Agency is recommended to consider funding sources to facilitate free access to products manufactured by European end-users. It was also recommended to incorporate more commercial sensors with better resolution into the project.

Collected information from ESA surveys provided a lot of valuable information about the needs of external recipients. Along with the previously conducted consultation described in chapters 5.3.1, 5.3.2 and 5.3.3, a considerable number of comments were collected. The experience of the interviewees on their knowledge of the satellite data market was very useful. It also helped to pay special attention to the opportunities that the implementation of Space for Shore services on the market brings, but also allowed for particular attention to the risks and barriers that may arise during the implementation of services. The above survey is a valuable contribution to future activities at the final stage of the project implementation but will mainly be heavily considered during the project commercialization stage.

9.2 Swot analysis

The SWOT analysis provides a general understanding of internal and external drivers and barriers in *Space for Shore*. It is helpful because it presents risks and opportunities that may occur. This SWOT also provides a number of important considerations for decision-makers, useful for the initiation and evaluation of activities.

The SWOT analysis for the *Space for Shore* (Table 19) has been prepared in order to indicate possibly all factors having an impact on the current and future project development situation.

Table 19 - SWOT analysis Space for Shore

INTERNAL

	STRENGTHS	WEAKNESSES	
POSITIVE	• Many EO data sources available and easily accessible -> range of coastal erosion indicators from standard to specific = "EO-product flexibility" • Flexible satellite products: from local fine scale (<10 km) to regional coverage of areas where coastal erosion info is not sufficient • Experience and knowledge in using EO for coastal erosion = maturity and complementary thematic expertise if required for result interpretation • Technology Advancement: high revisit frequency, easy to update, capabilities for on-demand VHR EO products (routine and/or emergency modes) • Innovative qualitative Sentinel-based hybrid products can also bring added value pushing on updating/revisit/automation/affordability • Historical and actual data, as well as the forecast • Safer method (obtain data in areas that may be difficult to enter) • Alarming about occurrence of the phenomenon in near real time • Possibility to create dedicated services based on basic data / Free data • Rises the awareness over the uses of space imagery • Cheaper in terms of mapping a large area	• Low interest in using satellite techniques on a commercial basis by public administration • Relatively low resolution of Sentinel derived products for detailed coastal services (not adapted for seasonal/yearly monitoring requiring VHR and high-accuracy products) • No full automatization of processes • Level of maturity of the service to be increased with follow-on activities involving final end-users: move from products towards a service (user interface/reporting functionalities/on-demand expertise/....) • Coastal erosion information is not sold to the private sector on a large scale (need for specific user interface to be investigated)	NEGATIVE
	OPPORTUNITIES	**THREATS**	
	• Adhesion of local stakeholders (group of coastal cities) in purchasing the service = early adopters on which to build for regional deployment • Interest of the private sector (insurance) in considering coastal erosion for emergence of new niche parametric insurance solutions (mid-term) • A small number of EO commercial services dedicated to coastal erosion in the market	• A small awareness of the possibilities of satellite data • Possible competition with direct / indirect parties having monopole situations (universities, national public agencies,...) • Difficulties in entering the market in well developed countries where the topic of coastal erosion is already addressed with precise/accurate technologies even if costly	

	• Exchange of good practises among the partnership • Copernicus / Green Deal / Climate Change favourable to raise concern about coastal erosion issue and need for geospatial information • International / national ICZM policies for mitigation of coastal erosion in response to human impact and climate change (*e.g.*, WACA program, UNEP Plan Bleu….) • Active role in Copernicus market uptake • Networking with other projects • Support EC international partnership for Copernicus • Providing more and more satellite data from the new Copernicus program	• No local market / buying capacity (coastal cities) in many EU countries (*e.g.*, PT, GR, RO,...) and very long lasting commercial efforts to catch very few national tenders	

EXTERNAL

9.3 Business and exploitation Plan

According to the partners who have gathered knowledge about the exploitation plan, they allow the sale of products through the entire consortium and through each partner who will independently endeavour to sell the service to the largest possible group of customers. It will depend on the nature of the units in which the partners work. If units provide commercial services, individual sale of the product is allowed, mainly on the domestic market. The proposed option is also to place the algorithms in the already existing ESA platforms, and the end user will pay the Space for Shore consortium fee.

Another aspect was to consult on the sale of products in countries other than those from which the project consortium members originate. It would be a good move to open up the market to Africa (West Coast) and South and North America (West Coast) as they are regions with similar coastal processes. The algorithms developed by the consortium may be as efficient as on the European coasts. Moreover, there are no structured field-based coastal erosion monitoring programs in Africa and South America as in Europe. Therefore, the national authorities in these regions can welcome the proposed services. As proven by the study of the distant archipelago of Svalbard, satellite products are very useful for the study of these remote and difficult to access environments. Deploying this service more widely to isolated island territories (i.e. all archipelagos in the Indian, Atlantic and Pacific oceans, including low lying islands for example) that are highly exposed to the expected consequences of climate change could be of significant benefit to society.

You will need to spend time exploring the products, integrating the products into your workflow, and learning how to use them to report responsibilities or other analyses that need to be performed.

The proposed revenue from services for *Space for Shore* Project is projected at between 10,000 and 30,000 EUR per year per customer.

- About 86% of users can spend only less than EUR 5,000 for services within a coastal range of 1 to 10 km.
- About 68% of users can spend only less than EUR 10,000 for services within a coastal range of 10 to 100 km
- About 65% of users can spend only less than EUR 20,000 for services with a coastal coverage of more than 100.

An estimation of the reachable market can be given considering the number of European coastal regions. The potential turn-over in Europe may reach about 1 Million Euro when considering doing business with local and regional coastal authorities in several European Member States.

9.4 Conclusions

Satellite monitoring is an increasingly common practice used in many aspects of social life and work of many individuals. The market for solutions similar to those offered in the *Space for Shore* Project is more and more open, and the increasing awareness of the quality of the services offered contributes to its development.

Active cooperation throughout the duration of the project allowed to create innovative solutions that have the possibility of further development after the end of the project. The cooperation between the people implementing the project and external recipients was carried out during most of the project. This allowed fruitful discussions in some cases trying to enlarge the scope of use of EO data to obtain new user-oriented advanced products, in addition to more standard coastal erosion products, thus started personalizing the services to specific users. During the project, many consultations and workshops were carried out, which allowed to define users' opinions on the quality of the project. According to the surveys, the response was positive to the project's success forecasts, however, one should pay attention to many barriers that may negatively affect the project's success. Thanks to the consultations, the consortium learned that many users need services tailored to each other expecting products to be adequately fitted for integration into their daily workflow and some coastal expertise to be provided along with the Space for Shore service. If necessary, services should be combined with already existing solutions, *e.g.*, their existing field/aerial datasets, data from the Copernicus website, etc. As many coastal areas have specific processes, the Space for Shore consortium's commitment has ever been to design the most relevant range of EO products to cover most of the European coastal environments, and in the meanwhile offering readiness for large-scale market deployment.

It is recommended to further promote the public opinion project about the benefits of using satellite data in today's world. And also cooperate with local administration and non-governmental organizations that may refer the project at a later stage. Carrying out active activities to the commercialization of the project will allow the *Space for Shore* to build trust in the proposed services. The awareness of the use of satellite data in Space *for Shore* Project is growing every year and this trend should be maintained in order to prepare the proposed services in the best possible way until their commercialization. In the next stages, it is recommended to analyse the current situation on the European and world market regarding current solutions related to the subject of the project.

– End –