Coastal Erosion from Space

Coastal Erosion events:

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

Technical Specifications Document (Version 2)

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Signatures

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Acronyms

ARCOED: Assessment of the risk of coastal erosion damages

BNDVI: Blue normalized difference vegetation index

CDOM: Coloured dissolved organic matter

CSI: Coastal state indicator

CZM: Coastal zone management

DoD: Depth of closure

DSI: Datum-based shoreline indicators

DSM: Digital surface model

DTM: Digital terrain model

EO: Earth observation

EO4CE: Earth observation for coastal erosion

ESA: European space agency

FAST: Functional analysis system technique

GNDVI: Green normalized difference vegetation index

L5: Landsat 5

LULC: Land use land cover

MHW: Mean high water

MLW: Mean low water

MHWM: Mean high water mark

MLWM: Mean low water mark

NDSI: Normalized snow index

NDVI: Normalized difference vegetation index

NDWI: Normalized difference water index

NIR: Near infra-red

PRE: Product engineering

RB: Requirement baseline

RCP: Representative concentration pathway

S2: Sentinel-2

SADT: Structured analysis and design technique

SEE: Service engineering

SDB: Satellite derived bathymetry

SDBTM: Satellite derived bathy-topo model

SDCPER: Satellite derived coastal probability erosion rates

SDER: Satellite derived erosion rate

SDF: Satellite derived features

SDS: Satellite derived shoreline

SDW: Satellite derived waterline

SLR: Sea level rise

SOW: Statement of work

TS: Technical specification

UR: User requirements

VHR: Very high resolution

WF: Wave field

WWF: World wide fund

Applicable and reference documents

Id	Description	Reference
AD-1	Requirement Baseline Document	SO-RP-ARG-003-055-006-RBD_v1.0_20190916
AD-2	User Requirements Document	
AD-3	Annex 1 – The products	SO-TR-ARG-003-055-009-TSD-A1
AD-4	Annex 2 – The processors	SO-TR-ARG-003-055-009-TSD-A2
AD-5	Annex 3 – File naming convention	SO-TR-ARG-003-055-009-TSD-A3

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Abstract

Further to the publication of the **Requirement Baseline** (RB) which is the tip of the iceberg of the process of translating **User Requirements** (UR) in functional requirements, the publication of the intermediary version of the **Technical Specifications** (TS) closes the first step of translation of functional requirements in systems requirements: it is the first description of the necessary functions and features of the system to be implemented to fulfil user requirements.

As a reminder:

- The task set by ESA, is to establish how Earth Observation (EO) can supplement and, where technically feasible, surpass current methods of monitoring coastal change and its associated erosion rates, vulnerabilities and risks. It is a “marketing” study including a feasibility and definition phase which concludes by a demonstration to be performed with 1000 km of coasts to be monitored for the last 25 years. In order to deliver the optimum results, a consortium of EO and coastal science experts was formed consisting of a Service Provider Group and an Authoritative User Group, led by ARGANS Ltd.
- This Technical Specification (TS) follows 6 months of focused consumer outreach by the Authoritative User Group, led by British Geological Survey, including IH Cantabria in Spain, Geological Survey Ireland for Ireland, ARCTUS representing the Canadian local communities of Québec, and IGN-FI a commercial representative of the Institut Géographique National of France representing potential overseas exports in developing areas of the world. The culmination of this evidence gathering stage has led to a User Requirement Document (URD), which has been published in its own right, and has been the foundation to building a Requirements Baseline Document (RBD) to optimize what the technology and science can deliver to meet those requirements. From that research follows the detailed Technical Specification laid out in this document, whose first version shall set the direction for production and the delivery of proof of concept products during Phase 1 of the project, i.e. the feasibility phase, prior to Phase 2 of the project, the definition phase, during which the consortium will prototype the service and demonstrate its usefulness.

The resultant work, which starts from a preliminary list of EO products, has established a logical flow from i. ATBDs, through ii. Processor Development to iii. a production system developed by ARGANS Ltd, supported by adwaisEO for data management and calculations, and IsardSAT for the processing of SAR images in addition to the processing of VNIR images by ARGANS Ltd and the transformation of waterlines or feature lines of the shore in shorelines by ARGANS Ltd. The sketched line of production of information from EO analysis delivers a series of intermediate and final products; this catalogue of products will be refined from now to the end of phase 1 through a dialogue with the end-users.

The **Proof of Concept system**, as of today, will consist of a semi-automated pre-processing stage, which includes a co-registration component to render much greater accuracy to the location element, eight Earth Observation Processors – optical waterline extraction (SDW-VNIR), SAR waterline extraction (SDW-SAR), features classification (SDF), optical satellite derived bathymetry (SDBTM), wave field analysis from SAR (SDWF), erosion rate estimation and a suspended sediment (SDSS) – which will deliver the intermediate products (and some repeatable and scalable shorelines indicators) that support two Data Fusion processors which will produce a Satellite Derived Shoreline (SDS) and a Satellite Derived Erosion Rate (SDER). Their associated ATDBs will be delivered as stand-alone documents.

The detail of how a Functional Requirements based approach has been adopted to optimize the design and development of the algorithms required to drive the processor construction is also presented as a separate document

The final stage of phase 1 will deliver sufficient production to prove the algorithms and methodology, verify the processors and validate the products which will be delivered by selecting five coastal regions across the four consortium countries (Barcelona and Tordera areas for Spain, Start Bay in UK, Wexford Bay in Ireland and Longue-Pointe-de-Minganin Canada).

1 Introduction

1.1 Scope of the Document

This document describes the technical specifications of the earth observation (EO) products that will be developed under the Coastal Erosion from Space project. This Technical Specification Document (TSD) represented Version 2 of the document. This TSD includes the design specifications for each of the EO products, which have been designed to meet the requirements of the European Space Agency (ESA) and the authoritative end-user community within the scope of assessment and monitoring of morphological changes of 1000 km (250 km – Phase 1) of coastlines across the four project member states (UK, Ireland, Spain and Canada).

This document is presented in sections. System Engineering in **Section 3** disseminates the requirement baseline information, producing several functional requirements that need to be considered in delivering the products that have been identified by academic and professional stakeholders. **Section 4** provides an assessment of Value Engineering, identifying how EO products compare to existing techniques currently applied to the needs of the coastal management community. **Section 5** provides a detailed account of the EO products being prototyped to meet the user requirements, including a critical review of potential EO solutions and chosen algorithm description, with the processors captured in **Section 6**. Prototype testing and review procedures are detailed in **Section 7** and details of EO and auxiliary data procurement are described in **Section 8**. Finally, **Section 9** provides a summary of this document.

[redacted]System Engineering.

An information system is defined by its inputs, its outputs, and algorithms which specify the operations (calculation, data processing, etc.).

2.1 Systems specification from customer requirements

1.1.1 Reminder of the requirement by ESA

Representing the client, the project requirements defined by ESA in the statement of work (SOW) represents the key customer requirements of this project (listed in Section 2.1 in RBD (AD-2)). The aim of these requirements is to raise the societal profile of EO derived products and promote the adoption of such products by coastal management authorities and associated industries as well as research labs (i.e. the wider community).

As such, ESA defined two key objectives, including:

I. Develop innovative EO products and methods that utilises a range of EO data platforms from the extensive archive of satellite data over the past 25 years.
II. Develop products and methods that respond directly to authoritative end-user requirements, promoting adaptation by the community for long-term exploitation and development through benefits to those targeted communities.

1.1.2 Products specifications extracted from the URD through the RBD (requirements engineering)

To establish the requirements of the authoritative end-users (objective 2) and thus inform on the design specifications for innovative EO products (objective 1), a requirements baseline needed to be established through consultation with the group of authoritative coastal managers (and their outreach information collection), who are included as partners on this project.

Independently, these users produced a list of requirements needed to derive effective coastal erosion assessments and monitoring. Created as an academic exercise, this list was not constrained by the current capabilities of current EO technology.

This User Requirement Document (URD) was delivered to the service providers, where its contents were refined to meet both the requirements of ESA (i.e. exploitation of the 25-year archive of EO data) and the capabilities of EO data now and throughout the archive history. This analysis resulted in the Requirement Baseline Document (RBD – AD-2).

Importantly, the RBD focused on the unique abilities that EO offers, adding significant and complimentary value to the design of products when compared to expensive and labour-intensive non-EO products currently available to potential stakeholders.

Yet, let’s remind in introduction to this section that the project is based upon selling the value to Coastal Erosion from the Copernicus Sentinels and historical EO missions. It is NOT about replacing current in-situ and ground-based practices performed by competent institutions and authorities, more one of providing complimentary evidence using EO.

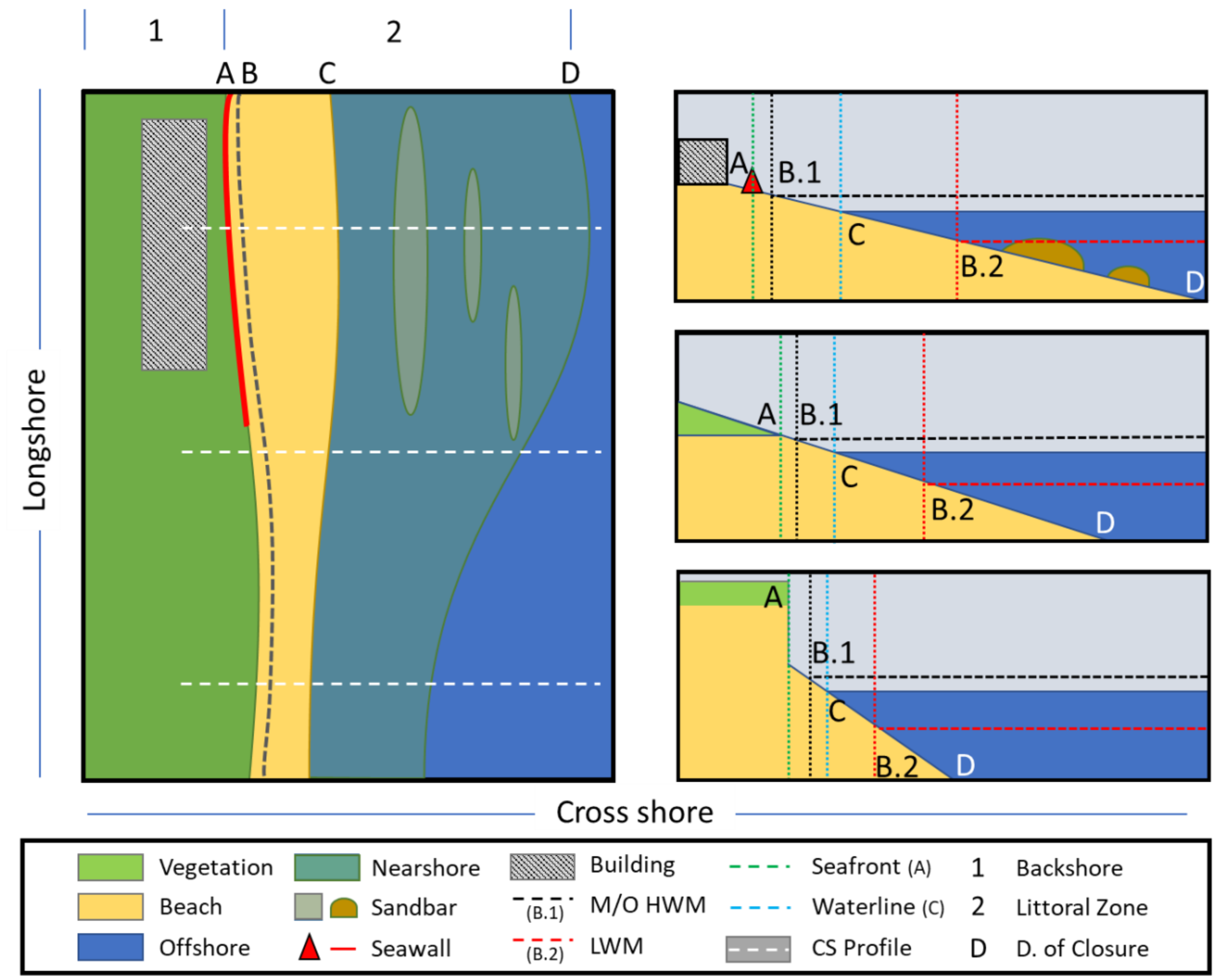


Figure 2.1: description of coastal state indicators (CSI) observed/constructed by Level 2 and Level 3 EO products as part of this project.

Tide datum abbreviations: MHWM = Mean High-Water Mark, LWM = Low-Water Mark.

Proxy tide abbreviation: OHWM = Observed High-Water Mark. D. of Closure = Depth of Closure (i.e. the depth at which sediment transport by wave action became negligible – measured from depth below LWM / conceptual seaward limit of the littoral zone)

The five product types; satellite derived waterline (SDW (VNIR & SAR)), satellite derived features (SDF), satellite derived shoreline (SDS), satellite derived bathy-topo model (SDBTM) and satellite derived erosion rate (SDER), that have been identified will shape the work moving forward as the project refines their definition and designs automated process to seamlessly deliver them. By adding the additional time series component, only really possible by employing the well calibrated Sentinel mission capabilities, and by conducting a co-registration stage in the pre-processing, the project will demonstrate a unique way to observe coastal change and enable traditional modelled approaches to better understand and be re-evaluated. This level of production is only practical and achievable due to the exceptional properties of the Sentinel satellites under the Copernicus programme due to the considerable effort that is placed on their quality control, validation and verification procedures. Without these procedures being in place the ability to compare over time would be almost impossible. The ability to "blend" these attributes with the high definition that commercial VHR satellite data provides via co-registration methods optimises the "best of both" approach and will enable revolutionary insight and understanding of the coastal change processes to be delivered that would be hitherto unrecognised based on current traditional survey procedures.

1.1.3 Rationale flaws: the limits of products' specifications for the definition of a service

The original URD, designed by institutional experts of coastal erosion, listed specifications of EO-products for all type of applications, using the "highest" targets in terms of geographic accuracy and precision, without referring to the use of the EO-products, i.e. the provisions of the service of EO-mining & exploitation.

The consequence had been an overspecification which has been analysed in the RBD, leading to innate failure because the specifications were mere generic wishes of superiority of EO compared to ground & aerial surveys, though EO complement other survey methods.

The following paragraph, which records the outputs of a functional analysis, is meant to put requirements in context so as to refine the specifications of the products, and to find out the specifications of the services.

The detailed approach to the functional analysis conducted for this project was captured in the initial version 1 of the TSD. However, the principles followed adopted a SADT model https://www.sebokwiki.org/wiki/.

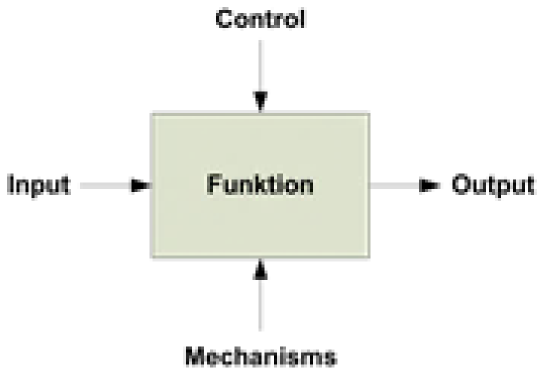
A functional requirement is a declaration of the intended function of a system and/or its components which allows the designer to determine the output that a device or software is expected to exhibit in the case of a certain input; it is embedded in a system design, i.e. a diagram or a set of diagrams which model the decisions, actions, and activities of the system in terms of goals, using a functional modelling language such as SADT 'Structured Analysis and Design Technique' —not to confuse with a functional flow block diagram or flowchart which represents workflows or processes (diagrammatic representation of an algorithm which delivers a solution to a given problem), each functional block being then described by a flowchart.

From this analysis came the following statements:

- To our understanding from the discussion with the end-users, which projected ESA requirements in the endusers' framework of duties, coastal erosion represents the long-term loss of the shore material (volume) relative to a fixed reference line (baseline), and an initial reference volume seaward of this line and above an arbitrary vertical datum, which is always accompanied by the shoreward recession of the shoreline, with, usually, a loss of land area.
- Analysis is often hampered by temporary coastal erosion, i.e. coastal changes, e.g. seasonal changes, or adjustment to extraordinary storm surges or even to civil works, which are not acceptable from a coastal management perspective, even though the coast recovers (sometimes via human intervention).

- Erosion is made of
  i. the structural erosion, i.e. long-term transfer of shore materials, a non-stationary process, and
  ii. temporary erosion, i.e. the take-in of materials before a recovery, a cyclic and stationary process overall.

  P.S. the short-term erosion under equilibrium conditions has an average rate of zero on the long-term, but human action might be required to accelerate the natural recovery process. All the more if short-term events can have a dramatic long-term impact (e.g. failure of the coast)



The critical parameter is the time scale to define 'long-term' and 'temporary':

- when a shoreline is in a natural geomorphological equilibrium as most of the world coast untouched by humanity, pushing aside the climate change and sea-level rise (SLR), the stationarity time scale is 18.6 years, i.e. the Metonic cycle, a period that is nearly a common multiple of the solar year and the synodic (lunar) month, made of 235 lunations (synodic months) after which the Moon's phases recur on the same days of the solar year, in order to avoid confusing tidal effects with climatological trends;
- when the coast has been transformed by civils works, definitive irreversible changes in cross-shore and longshore sediment drifts occur with timescale that shall be shorter than the Metonic time-scale for the adjustment of the shoreline.

In both cases, the take-in, transport and take-back of shore materials is a constant process whose tempo is given by storms; the density of storms (as well as the wave directions) has a seasonal rhythm, and the impact on the coast depends on the seas-surface level which varies with tides.

The causes of shoreline changes are well-known: coastal phenomena such as waves, tidal currents, alongshore currents, rip currents, undertow, overwash, winds (aeolian transport) … usually combine together to reshape the sea bottom during a storm, or after a storm when the shoreline comes back to its equilibrium state; it draws an aerial pattern of erosion and accretion, related to an overall gain or loss of shoreline materials' volume. Variations in the wave conditions (period and steepness) have seasonal (cyclic) effects. These factors do not necessarily indicate a long-term change; but they can contribute to it, while changes in sediment supply, sea level rise, coastal subsidence, tectonic events, or meteorological/ climate conditions, are directly responsible for the long-term behavior of the coast over several years/decades.

Consequently, the basic function of the EO4CE service is not the calculation of erosion rates, but the conditional probability of erosion rates (conditional to the MetOc conditions (storms, currents, sea level rise, etc.).

The erosion probability function shall be split between phenomena leading to two different types of damages,

i. the non-recoverable damages (always the case for civil works, households, … whatever the time scale of erosion events)[1] where 'non-recoverable' means that recovery requires human works[2],
ii. the recoverable damages (e.g. seasonal cycle of coastal erosion impact on land, except if an extraordinary event occurs and it "breaks" the seafront) some being unacceptable because the recovery time is too long and therefore human works are required as in case i.

The EO-derived products should then be six-fold instead of five-fold as we shall add a new group of products for the assessment of coastal erosion in the feature depending on various MetOc scenarios (e.g. climate change modelling). They complement the assessment of past coastal erosion.

2.2 Conclusion of the functional analysis of the EO4CE services

2.2.1 Framework: EO4CE within ARCOED (assessment of the risk of coastal erosion damages)

The next question is "shall the identification of assets to be protected constrain the outputs of the EO4CE service?". If the answer is positive, EO4CE is a component of a "disaster management" function, such as the one fulfilled by ARGANS Ltd in the EO4SD-DRR service[3] (https://www.eo4sd-drr.eu/) for International Financing Institutions (IFI´s): protection against costal erosion, tsunamis, flooding, storm surges… in coastal areas.

As mentioned in the SEE-PRE paragraph the system shall assess coastal erosion rates from EOs which

- nurture studies of environmental processes' studies (coastal erosion science),
- feed policy making and rules' enforcement (coastal zone management).

It is the 2nd topic which drives the first, and the main goal of the service is to help assess the risk or exposition of assets to danger, i.e. the probability that negative consequences may arise (erosion) when "hazards" (waves, tsunamis, winds, SLR, …) interact with vulnerable areas (unstable, weak, …) and trigger impact (on people, property, environment, …) called +/- disasters:

"Risk" is a concept which describes a potential set of consequences that may arise from a given set of circumstances. In the professional literature, the formula is

$$Risk = \mathrm{F}(Asset, Hazard, Vulnerability)$$

An Asset is what is supposed to be protected. The hazard is also called the Threat, which is not so hazardous…; it is what we're trying to protect against, e.g. events; because the asset is under threat of a hazard, the asset is also called a Receptor. Vulnerabilities are weaknesses or gaps in the protection efforts.

There is no risk when there is no need to protect the coast… (= a matter of tolerability/ tolerance);

[1] long-term erosion is not recoverable

[2] stationary erosion may also have a non-recoverable impact on man-made assets

[3] Earth Observation for Sustainable Development Disaster Risk Reduction

- but the vulnerability is hazard specific and setting specific; and depends on Protection (prevention/ mitigation measures); as such, the formula might be transformed in
  Risk = G((*Asset, Value*)*, Hazard, Protection*)

- the contrary of Protection is Exposure, and, if one keeps only the setting-specific vulnerabilities, one then gets
  Risk= H(*Hazard, Assets*(*Value, Exposure, Vulnerability*))

The end-users of the EO4CE project are geological survey agencies or labs (UK, Ireland, Spain, Canada), as well as executive bodies (Spain); the former care about the risk of the asset "shore" (beach, cliffs, …) in terms of conservationism and not so much of the assets / human activities that rely on these primary assets, while the latter care the economic value of the environmental and human-built assets.

Risk Assessment is a consequence of hazard identification, together with risk analysis (tolerability) + evaluation/ estimation (impact), and the risk control (actions implementing risk evaluation decisions, i.e. monitoring, re-evaluation, and compliance with decisions).

The risk is quantified by the probability of consequences further to hazards:

Risk = (probability) x (consequence)

To forecast the risk without needing observing the consequences, one looks for a formula with the functions F, G or H:

Risk = function (*p, e, s, v*)

where *p* is the nature and probability of the hazard (the source of the risk),

e is the degree of exposure of the Receptors (numbers of people and property) to the hazard,

s is the susceptibility of the Receptors to the hazard (it quantifies the likeliness to be harmed), and

v is the value of the Receptors;

obviously, the function depends on the process by which the hazard will trigger valuable consequences on the Receptors.

For the record, this formula allows to get rid of the concept of vulnerability, which is a consequence of a hazard (it quantifies the likeliness to be threatened): *Vulnerability* = function (*s, v*)

Please refer to annex SO-TR-ARG-003-055-009-Annex_ARCOED for the functional analysis of an ARCOED service.

2.2.2 Data collection/pre-processing/processing/QC, metadata generation, data bases, data distribution

. The approach adopted within phase 1 has been to demonstrate the feasibility of observing and extracting meaningful data about the position of a waterline that can be translated via the use of local auxiliary data to datum based lines which will define the shoreline and enable changes to measured and analysed over time. This has proved to be a labour and processing intensive process which will be refined and much more heavily automated during the second phase of the contract.

2.2.3 File Naming Convention

A file naming convention is an important component of any collaborative exercise; it is important that folders, documents and records are named in a consistent and logical manner so that they can be located, identified and retrieved as quickly and easily as possible.

There are a few general precepts that are considered as 'best practice' for file naming conventions. These can be summarised simply:

1. Never use spaces to delimit elements in a filename. If compound words are needed then use CamelCase, also known as Pascal case, in which each word begins with a capital letter e.g. StartBay or WexfordBay.

2. Keep filenames as short as possible, while still ensuring that they are meaningful.

Beware not to use reserved characters, even if your operating system allows, that have special meaning in certain other operating systems.

2.2.4 Coastal Change File Formats

Some general rules have been considered as a consistent file naming convention. Note that many of the products are lines and consequently will be ideally stored in shape files. There are two options:

- ArcGIS .shp file format would be a typical format but requires additional mandatory files i.e. a .sbx shape index format; a positional index of the feature geometry and a .dbf file containing attribute format. Other non-mandatory files are .prj files providing the projection description and .shp.xml providing geospatial metadata.

- KML (Keyhole Markup Language) as used by Google Earth is perhaps more simplified because a single file can be used to including points, lines, polygons, and imagery, as well as related content like graphics, pictures, attributes, and HTML. Whereas datasets in ArcGIS are typically seen as separate and homogeneous elements (for example, point feature classes can only contain points, raster files can only contain cells or pixels and not features), a single KML file can contain features of different types as well as imagery.

- GeoTiff files will be used for raster data as it allows georeferencing information to be embedded with the image data including map projection and coordinate system. Although metadata attribute pairs can be embedded in GeoTiff it may be more convenient to have associated XML files if the stored metadata is large and to have the name of the metadata XML file encoded as a metadata attribute:value tuple within the GeoTiff.

Steve's comment on Metadata

2.2.5 Customers/Users relationship

2.2.5.1 Having followed a process of capturing the User Requirements via a series of outreach events and processes, these were published within the BGS URD and formed the foundation of the Requirements Baseline Document and this Technical Specification Document. The relationships that have been adopted throughout the project have been one of constant dialogue between the User Group and the Service Provider Group as well as internally within each sub-group. The team have presented the work at various conferences and will be continuing this approach throughput phase 2. EO products validation

- The TSD and associated ATBDs describe the process and theory. The processors are designed based on those technical specifications and they all need **VERIFICATION** that we have followed the design and that they work as planned. This task is for the **Service Providers**. How we will do this needs describing in the PVP (and should really sit within each ATBD)…in a car production line this would equate to a Factory Acceptance Test….”does it work and deliver as designed?”
- The RBD describes the products requirements. These products need to be **VALIDATED** ie ground truthed where possible and potentially assessed against known wisdom and knowledge. This is a task for **Local Expertise** and again a description of how this will be done needs describing in the PVP. In theory the expertise should be independent, however within this project **the Local Experts are the User Groups** and also their “outreach” support. Service providers (us & IsardSAT) can help with “how we would do that”
- The URD describes the use case, ie what the User Group hope to gain from the exercise. This process is one of **EVALUATION** of the worth or value of the products ie an assessment. Does the utility give you something new or novel? Do they change how you think or act in the future? Did they meet you expectation? Again for phase 1 we need you to describe how you will evaluate the worth. This is a task for **User Group.**

2.2.5.2 Return-of-Experience

To be included within phase 2

2.2.5.3 Collection of new requirements

To be included within phase 2

2.3 End-Users Viewpoint

To be provided at the MTR and included within phase 2.

[redacted] Value engineering

3.1 Value engineering

Value Engineering is used by several industries to analyse the cost/benefit of a product or service relative to the project goal, or the planned improvement.

3.1.1 Core value of the project

In the case of this "Coastal Erosion" project, the aim is not so much to develop EO processors and models to define the shoreline, derived from observed waterlines, and to assess coastal erosion rate to enable models or estimate material transfer, because such an endeavour has been undertaken by dozens of academic labs, and EO is already used by most of the national agencies in charge of coastal erosion assessment, whereas NGOs and aid-agencies use it also when developing projects in support of local communities (e.g. WWF). For the record, numerous scientific papers by academic labs have been published these last 5 years, the most recent in Nature on 29 Oct (Nature Communications volume 10, Article number: 4844, 2019), to assess coastal risks worldwide, but seldom with error bars on the assessments, hence reducing their value apart from social communication and humanities. The goal of the consortium is rather to set-up a production chain of EO-derived information on coastal change which is of economic and (physical) scientific value, whose outputs can be used 'safely' by national agencies, international institutions dedicated to 'development', local authorities, civil work companies, etc.,; such a production chain shall re-use algorithms components for EO data processing, incorporate uncertainty budget modelling, and apply existing concepts after a strong re-engineering review over time and geographic scale in order to assess a value either to resupply sediment or mitigate against infrastructure and Land Use damage.

A Value Engineering method shall allow the work of academic labs which has been published extensively vide peer (researcher)-review papers in scientific journals to reach its targets, i.e. the users of such information. It follows the stage of 'Requirement Engineering' whose outputs are published in the Requirement Baseline document (RB), and the stage of 'System Engineering' whose outputs are published in the chapter of same name in the Technical Specification document (TS).

3.1.2 Climate change adaptation and mitigation of non-sustainable coastal development

Climate Change is one of the most significant challenges that will dominate our lives in the decades to come, and, although significant wave height may decrease over the North Atlantic and over the Mediterranean Sea[4], local sea levels that historically occurred once per century (historical centennial events, HCE) will come greater and more frequent because of an increased energy within the natural system (refer to figure 4.1). Sea level is predicted to rise between 43cm to 84cm this century[7], and with that an increase to coastal erosion with associated costs to society, the environment and to our finances.

[4] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]

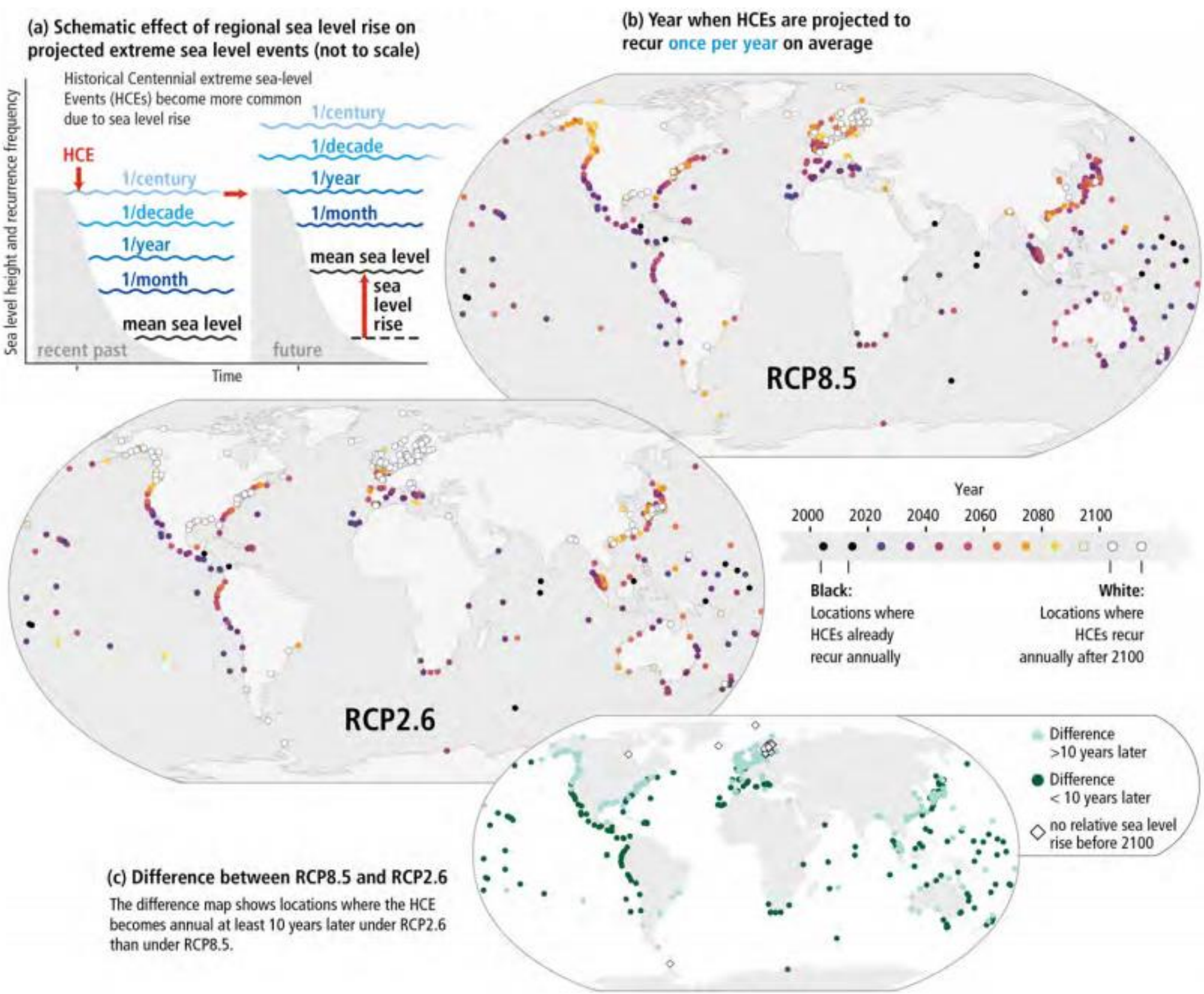


Figure 3.1: The effect of regional sea-level rise on extreme sea level events at coastal locations. a) Schematic illustration of extreme sea level events and their average recurrence in the recent past (1986–2005) and the future. b) The year in which HCEs are expected to recur once per year on average under RCP8.5 and RCP2.6, at the 439 individual coastal locations where the observational record is sufficient. The darker the circle, the earlier this transition is expected. The likely range is ±10 years for locations where this transition is expected before 2100. c) An indication at which locations this transition of HCEs to annual events is projected to occur more than 10 years later under RCP2.6 compared to RCP8.5.

As part of a climate change adaptation strategy, there is considerable potential for a coastal erosion monitoring services to add significant value to determining where investment by governments (National, Regional and local) should be focused and how managed realignment can be best targeted, and landowners and occupiers compensated.

3.1.3 The value of reliability, precision and accuracy of EO-derived information

According to the U.K. Government within their draft consultation paper on National Flooding and Coastal Erosion, there has been a planned £2.6 billion expenditure between 2016-2021. The U.K. Environment Agency, District Councils, Highways authorities, risk management authorities and regional coastal committees will have some seriously tough decisions to make if climate resilience is to be achieved as will the authorities in the other consortium countries and beyond (which is why IGN FI are part of the consortium representing potential export markets in Africa).

A key component of the national strategies will need to focus on land use decisions, protecting from coastal change and most importantly accepting that some areas will sacrificially flood and erode to protect others of more economic or societal (environmental and emotional) value.

- The extent of expenditures on coastal protection against erosion is such that the EO-derived information shall be accurate and reliable, and quickly available on request.

3.2 Our value proposal

3.2.1 From EO to the assessment of coastal erosion, coastal vulnerability and risks

The value of conducting a large scale collaborative Coastal Erosion project, working with an Authoritative User Requirement Group made up of partners that advise or influence those accountable departments who are both budget holders and decision makers from the British Geological Survey, Geological Survey Ireland, IH Cantabria (Spain), Arctus (Canada) on behalf of the government of Québec, and the Institut Geographic National - France International ensures that the correct user need is captured which will deliver the best return on the investment via an Earth Observation and Auxiliary Data fused processed service.

The value proposition outlined in phase one of the study as described within this version 1 of a Technical Specification has specifically focused on a processing chain that will deliver intermediate mapping (waterline extraction, land-use extraction and terrain model calculation) that in turn will be analysed from a "threat" perspective, incl. the identification of assets and the environmental changes, to deliver bespoke (to the decision maker) services such as a Coastal Vulnerability Index to identify those areas of coastline that will be subject to change that in turn will enable a Coastal Risk Index to be assigned, i.e. an assessment of loss, damage or destruction of assets that would penalize coastal communities. Such services, however, will become the resultant capability derived from the next phase of this project as feasibility is translated to implementation and production in phase 2 and then services can be developed in a subsequent phase.

It should be stressed that value is not just accrued by those engaged in Coastal Erosion investment from government but also to those industries (construction and civil engineering) that are contracted to mitigate or repair the damage and also to those who insure or are engaged with coastal flooding and associated cost from damage or investment to mitigate. Such a level of insight will enable planning to be based on interpolation and analysis from very cost-effective observation at scale that can be monitored regularly through time.

3.2.2 Planned improvement to the current available services

Current methods of monitoring Coastal Erosion are well established. Consisting primarily of the use of aerial photography and ground surveys, they are geographically limited, costly and irregular or non-existent in many areas of the world. Despite some limitations, EO from Satellites is the only way to get a regular and synoptic view of the shore globally, on demand or in a few hours as a costly snapshot from VHR satellites or every few days for free from public HR satellites. This offers a game changing opportunity for investigation and monitoring coastal erosion at great speed, relatively low cost and at a scale and regularity unachievable using current methodologies. However, in highly monitored areas, EO from satellites is complementary to ground & aerial surveys whereas in much of the world, which is not surveyed, it offers a step change in the ability to investigate and monitor coastal erosion regularly, cost effectively and at scale.

In order to achieve a systematic and organised approach to providing the necessary functions at the lowest possible cost it is essential to assess the value and cost of substituting or adding value to incumbent coastal zone management products and methods with satellite derived product types. These value-added elements include:

- **Consistency** by creating a standard that can be applied consistently across the globe derived initially from quality Sentinel data.
- **Speed** automation of the processors will enable large portions of the coastline to be analyses in a fraction of the time it takes to arrange an aerial or ground survey or analyse the data retrieved. We have been able deliver shorelines in 15 minutes compared to a ground survey that took 4 days after a natural disaster.
- **Cost** compared to the use of aerial or ground surveys the cost of collecting HR data from the Sentinel satellites is negligible. The use of VHR data is more costly than the public EO mission data and therefore will be used sparingly at this stage. However, one can reasonable expect the cost of VHR data to fall over time as more missions and constellations are launched, competition increases and economies of scale are achieved.
- **Regularity** the Sentinels mission can produce data approximately every five days, whilsts an Aerial and Ground surveys are repeated much less regularly for example every three to five years except in very limited areas of high interest. These field also surveys take considerable planning and often require a tendering and evaluation process.
- **Repeatability** the repeat coverage of the earth by satellites and the automation of processing is a step change from incumbent methodologies for drawing shorelines and waterlines. This means that it is possible to update information as often as required by season or specific events such as storms.
- **Scalability** Satellite EO automation will enable the possibility to deliver EO satellite derived products anywhere in the world that it is required at a consistent international standard.

[redacted] List of EO products

4.1 Recap of Requirement Baseline Document

4.1.1 Product Themes

There have been six Product Groups identified as pertinent to the User defined requirements;

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

4.1.2 List of EO products

The initial list of 18 EO products will be tested during the feasibility stage, however the key outputs will be those derived products of shoreline and erosion rate. Due to the complexity of specifying and formatting products, as well as checking the feasibility for the expected use, verifying the processors that deliver them and validating the EO products, it will be discussed with the end-users/partners which of them take priority, apart from the following which are top of the list:

- [EO]-L2_1D_FB/WL _{area/date/hour} [Alg(L2)]
- [EO]-L2_1D_DB/[tide level]-SL_{area/date/hour} [Alg(L2)]
- [EO]-L2_3D_BTM/SDB_{area/date/hour} [Alg(L2)]
- [EO]-L3_1D_SL/ES-classification_{area/date/hour-[Δt]} [Alg(L2)]
- [EO]-L4t_1D_DB/CSL_{area/date/hour-[Δt]} [Alg(L3)]

At the annex is a more comprehensive list and the validation/utility and ease of automating these products in phase 2 will determine which product lines form part of an emerging service.

[redacted] List of processors

The processors broadly sit in two groups, those that deliver EO products (both Optical and SAR) and those that are Data Fusion processors. To support the outcomes of both there is need to pre-process data ready for the processors and on completion data management and validation will be required in a post processing step.

Therefore, there should be nine processors.

- A pre-processing processor
- Five EO processors:
    - Waterline Identification (Optical) – delivering Satellite Derived Waterline (SDW)
    - Waterline Identification (SAR) – delivering Satellite Derived Waterline (SDW)
    - Mapping/Feature Classification – identifying Satellite Derived features (SDF)
    - Satellite Derived Bathymetry (Optical) - delivering Satellite Derived Bathymetry for (SDBTM)
    - Wave Field Analysis (SAR) – delivering Satellite Depth Assessment for (SDBTM)
- Two Data Fusion processors:

    - Shoreline Extraction – delivering a Datum Referenced Satellite Derived Shoreline (SDS)
    - Stochastic Estimation of Erosion Rates – delivering a Satellite Derived Erosion Rate (SDER)
- A post-processor

Each of the processors will have an accompanying Algorithm Theoretical Baseline Document (ATDB) and each one will be unique and vary in the level of detail depending on whether the processor is completely new or includes modules of pre-existing processors. These ATDBs have been initially developed by the Service Provider group but will be validated by the User Group, once version one for each have been delivered and once the resultant processors start to deliver results.

The ATDBs are added as an Annex to this TSDv1.

The pre-processor provides several functions both spatial e.g. clipping, mosaicking, geo-referencing, projecting, co-registration and spectral e.g. radiometric correction. The post-processor adds metadata (both from inputs and processor history) and formats file type conversions and file naming.

The Processors require two input types: EO satellite images (SAR & optical) + auxiliary data files (ADFs). The Metadata from either input types will, perhaps selectively, be propagated to the output products (module included in pre-processing / post-processing).

The Waterline Identification (1-D) produces **one product**, but it can be generated from either the Waterline (optical) processor or the Waterline (SAR) processor.

Both input and output data will be stored in a common data storage layer accessible via at least FTP/SFTP with file location stored in a persistent layer i.e. a database to enable script-based processing chains and query/retrieval protocols for data dissemination. The file naming convention has been identified within section 3.3.2 above.

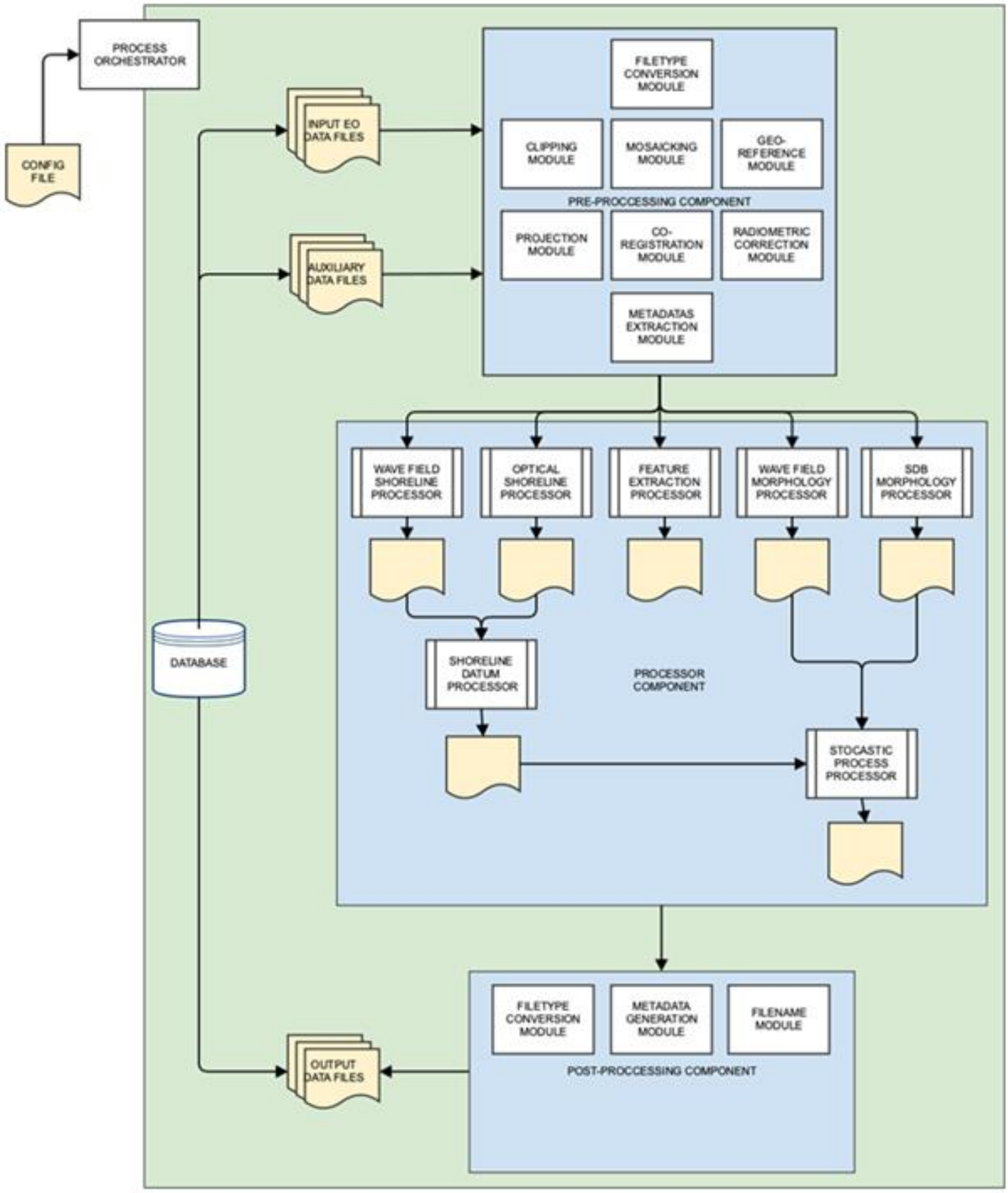


Figure 5.1: System architecture for Coastal Change assessment and monitoring service.

[redacted] Experimental and Critical Analysis

The process that has been adopted within Phase 1 has been to deliver a representative sample of the various lines and profiles that ably demonstrate that they can be manufactured in a semi-autonomous way and these "products" have been delivered working closely with the User Group community. The principles of the concepts behind the ATBDs has been rigorously reviewed by the User Group and the process of verification has been agreed and will be identified in more detail within the Product Validation Plan as a pre-cursor set of statements. In addition, the User Group have been instrumental in identifying how the products from this verified processing methodology will be validated and most importantly evaluated for their utility. This level of detail will be captured within the PVP.Prototyping

. Prototyping at this stage has been conducted in stride with the ATDB development and the feasibility production to identify what works best. However, at this phase it should be stressed that the prototyping is a continuous task and will be developed further within phase 2 as the processors become much more automated.

6.1 Review / analysis

The ATBDs are now developed such that they are stand alone documents, however they are designed and delivered to a level commensurate with delivering a feasibility set of products. The next stage (in phase 2) will be to further develop the ATDBs to incorporate issues learned from greater bulk production and the need to make as much of the data process automated. This will also include an ability to harvest the auxiliary data required adopting a more hands-off approach, identifying the uncertainties within each system and enabling a "command line" remote processing strategy to play a much more active role. However, at this stage each of the ATDBs has been "endorsed" by the Authoritative User Group but at a level appropriate to a feasibility demonstration.

[redacted] Data procurement plan

The data procurement plan will be delivered as part of phase 2 as the project matures to a production footing. What has become transparent during this feasibility phase is that the Copernicus Earth Observation data is a vital component to changing how coastal erosion can be monitored, however for greater accuracy, co-registration employing higher resolution commercial imagery has enabled a blend of data stability and continuity match with accuracy that has not been delivered before. Additionally, the vast amount of bespoke local auxiliary data required to support the Earth Observation has been delivered in a very "manual" and tailored method. This approach will need to be revised in the next phase to enable a more automated approach to gain the value of scalable and repeatable EO.

[redacted] Conclusion

The Technical Specification Document and its accompanying Algorithm Theoretical Baseline Documents are fit for purpose and will enable the production of waterlines and derived shorelines to be manufactured. Currently the process is labour and processor intensive but does deliver accurate and repeatable data that can be validated and perhaps more importantly evaluated by an authoritative user community who have been engaged in the design and development process throughout. This document, however, must be considered a "living" document and will evolve as experience of large production increases in phase 2 and as production leads to the design and development of "services".

[redacted] References

[redacted] Annexes

Annex 1 Level 2-4 products

Annex 2 The Processors

Annex 3 Naming Convention

End of Document