Coastal Erosion from Space

Coastal Erosion events:

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

Annex 1 – Summary of Validation and Evaluation for EO products

Ref: SO-TR-ARG-003-055-009-PVP-A1

Date: 13/01/2020

Customer: ESA

Contract Ref.: 4000126603/19/I-LG

This page is intentionally left blank

Signatures

	Name	Company or Institute	Date
Prepared by			
Authorised by			

Applicable and reference documents

Id	Description	Reference
AD-1	Product Validation Plan	SO-TR-ARG-003-055-009-PVP

Contents

List of Figures

Abstract

‘**Validation**’ of *anything*, whether a process, an information, a tool, etc., is the supply of **evidence** that the “*anything*” **fulfills the users’ requirements**, i.e. it is ‘fit-for-purpose’. In the health sector, which is highly regulated, the public authorities make a difference between Verification by internal means of the drug designer, and Validation by external & independent means. For the validation of EO-products which contain geophysical/ chemical/ biological/ ecosystemic information, while *i.* ESA and NASA focus on the expectations of remote sensing scientists (keen on demonstrating that one can give values to Earth system’s parameters which could be measured on-ground or at sea which are as accurate and reliable, implying that EO can replace and expand traditional surveys) as most Space Agencies and request *i.a* ‘match-ups’ of ground data with EO-derived data at the most basic level, *ii.* USGS, which is not a space agency but operates satellites, focuses on the usability of EO-derived information that has no match on-ground but should nonetheless be validated by *ii.a* consistency checks and *ii.b* demonstration that this information leads to discoveries of ‘true’ phenomenon (validation is performed downstream to the EO-products). As such, Space agencies put Calibration of satellite on-board sensors and Validation of EO-products at the same level (the cal/val activities), whereas user organizations customarily put together Quality Control (QC) and Validation —the former being a check of reliability and the latter of accuracy, both being related to their trust in the EO-products which relies on the excellence of the EO data processors.

Because ESA believed originally that the EO-products designed for coastal erosion assessment would be limited to drawing waterlines, i.e. the edge of the water at a given time, “product validation” was supposed to be restricted to *(a)* the detectability of this edge, and *(b)* the proper positioning on maps. For point (a), the issues are the lack of trust of remote sensing scientists with photointerpretation by experts and the demand for ‘scientific’ proofs which is ordinarily supported by ESA (except when training data processors with machine learning algorithms) and conflicts with the views ordnance survey agencies[1]; yet there is no way for the truth evidence not to be delivered by photo-interpreters.

[1] it has hampered the uptake of EOs for decades

Point (b) has nothing to do with coastal erosion and waterlines but geolocation, orthorectification and co-registration of data sets used by the waterlines-retrieval processors.

Following the URD guidance, the RBD has developed a catalogue of EO-products that are less basics than waterlines, and, for which there is no substitute at-sea or on-ground, except aerial surveys, because snapshots from space are instantaneous. Validation Checks shall be done on **consistency** with the results of other surveys, without denying that EO and the aforesaid 'other surveys' provide different and complementary information, but with an intersection of common information where comparisons can be performed. Remains the demonstration that the EO-products fulfill the expectations of the users; yet ESA, departing from the common definition of validation, called it user evaluation ("assess the products' adequacy and utility, and analyse the feasibility of their integration in their working practices") instead of product validation, and dissociated them though directing that "end-users shall report their assessment in User Evaluation Reports that shall be attached to the Product Validation Report". It shall address the ESA request to prove **adequacy** and **utility** vs. original specifications by the users.

Notwithstanding ESA views, the consortium's users are expecting the project to inform them on the best performances they could get ("*detailed specifications on geometrical accuracies of outputs are aspirational requirements needs for the future, and the champion organizations expect to know of the feasibility* [*considering …*]") —this project being a sort of feasibility study when ESA contemplates a definition study, i.e. a development. The consortium members are aware of this discrepancy, and we suggest solving it by assessing the added value of the EO-products in supplying values to formula that calculate the **Coastal State Indicators** (CSIs) which inform scientists and managers on the behavior of the shore and its adjacent areas. These Coast Indicators and Shore Indicators have been summarily reviewed to help define which ones will be attached to the various demonstration sites.

The following paragraphs, i.e. "product validation" and "user assessment" (to be written) will develop the plan accordingly.

1 Definition of 'EO product validation'

ISO does not define 'validation'; accepted definition of the IEEE is taken from the PMBOK guide which defines

- ✓ validation as "*The assurance that a product, service, or system meets the needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers. Contrast with verification*."; whereas
- ✓ "verification [is] *the evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition. It is often an internal process. Contrast with validation*.".

Verification is related to design specifications, i.e.to check that a product, service, or system (or portion thereof, or set thereof) meets specifications. Verification is usually called 'qualification' when constraints have been published, e.g. legal regulations; when qualification is conducted by a standard endorsed third party, the process is called 'certification' (attestation of conformity through inspections and tests).

Validation deals with requirements: to ensure it meets the operational needs of the users. Validation can be expressed by the query "are you building the right thing?" and verification by "are you building it right?". Validation is carried out through User Acceptance Test (UAT). Verification is carried out through Factory Acceptance Test (FAT) or Operational Acceptance Test (OAT).

'Data validation' in software-based systems includes the two, i.e. checking for correctness & meaningfulness: checking that *a.* data are *a.i.* sensible, *a.ii.* fit for purpose, *a.iii.* valid and secure (reliable), and *b*. the uncertainty budget/ error bars are trustworthy, before they are processed. It is expected that 'product validation' has the same meaning for digital products, i.e. data sets but at the end of the processing chains instead at its start.

According to standard definition, EO-products' validation is the search and publication of evidence, i.e. the proof, that the EO-products are usable.
⇒ If EO-products are originally defined incl. the accuracy of variables which are edited by the product

('market pull' mode[2]),

validation = testimonial of success in the fulfillment of the specifications;

if the best accuracy is looked for during the EO-products' design phase ('technology push' mode[3]),

validation = identification of use, demonstration and endorsement by users

For this project of promotion of EO, with professional end-users (BGS, GSI, Spanish gvt, and regional agencies of Québec) whose teams are practitioners of remote sensing from satellites such as Landsat, SPOTi, Pleiades, Quickbird, Ikonos, WV2-3-4, radarsat, TerraSAR-X, etc. and whose hopes lie in the perspectives offered by the COPERNICUS program and the new commercial constellations of nanosats, the EO products' development backbone is mixed, i.e. market-pulled and technology pushed concomitantly.

Yet the end-users have high expectation, cf. the URD:

- **clear shift from shoreline (1D) products to space (2D) and volume (3D) products —while end-users are still interested on shoreline indicators of coastal change (35% of requests are 1D), there is an interest shift to area or geography (24% of requests are 2D) and most evident towards volume / shape or morphodynamics (41% of requests are 3D);**
- **inclusion of the shore in a broader area, the coastal zone which spans inland (sand dunes, marshes, cliffs & hills prone to landslide …) and offshore till the depth of closure (where the motion of sediment is negligible);**
- **replacement of ancient proxy-based shoreline indicators (1D), by datum-based shoreline indicator (1D, 2D) and Topo-Bathymetric Digital Elevation Models which are preferred shoreline indicator for ICZM[4] and CFERM[5] which involves time horizons of 100 years;**

[2] need/requirement for a new product or a solution to a problem, which comes from potential customers (or market research), and a product or a range of products are developed, to solve the original need; focus groups like the consortium end-users are often central to this, when testing a concept design or an existing product (market pull sometimes starts with potential customers asking for improvements to existing products); it is usually new players, i.e. entrants on the market, which lead the show

[3] research and development in new technology drives the development of new products; usually it does not involve market research; it tends to start with an organization developing an innovative technology and applying it to products; the organization then markets the products

[4] Integrated Coastal Zone Management

[5] Coastal Flood and Erosion Risk Management

and the use for which EO-products shall be *validated* is the edition of Coastal State Indicators (CSI[6]) which would get the geometrical information from EO-products -cf. §'Validation' in the remote sensing field does not always refer to the scientific method, i.e. the capacity to deduce proper information from the EO-products, and focuses rather on products' verification (match-up against 'truths') and data processors/algorithms verification (to get a truth); the exception that proves the rule is altimetry as altimetry measurements can be verified on targets for verification and calibration, but the validation is indirect: validation of Topex-Poseidon and ERS1 data for instance was performed through surveys of ocean density and currents to check whether altimetric data calculated from density fields were in accordance with the EO measurements, and if current fields were in accordance with the calculation with altimetry data.

nota: as such it experiences difficulty to demonstrate the genuineness of breakthrough innovations introduced by EO, EO-products looking more like advancement or replacement of current information;

'validation' is the verification of the validity of error-bars, i.e. validation of uncertainty-budgets.

Exercising validation of EO-derived coastal erosion products.

As BGS officially published in the URD:

"*Detailed specifications on geometrical accuracies of outputs are* ***aspirational requirements needs for the future****, and the champion organizations expect* ***to know of the feasibility****, considering results with (i) available EOs of the last 25 years to assess an average erosion rate at the decadal time scales, (ii) COPERNICUS and commercial higher resolution EOs of last 5 years to monitor erosion and accretion for the management of the coastline by local authorities, (iii) using state of the art sub-pixel resolution techniques*."

[6] Not to confuse with risk or vulnerability indicators; CSIs are a "reduced set of parameters that can simply, adequately and quantitatively describe the dynamic-state and evolutionary trends of a coastal system" (quoted from Jimenez & van Koningsveld, COASTVIEW CSI report 2002, in "description of coastal state indicators, deliverable-9 of the CONSCIENCE project, 2010); CSI's major functions are: i. to assess the condition of the environment, ii. to monitor trends in conditions over time, iii. to compare across situations, iv. to provide an early warning signal of changes in the environment, v. to diagnose the cause of an environmental problem, vi. to anticipate future conditions and trends; and it is based on (a) a long-term coastal management vision, (b) an operational objective (CSI shall quantify the problem in hand, and inform whether or not action is required => there is a threshold; CSI shall inform on the impact of the action taken)

Our endeavor is, consequently, a feasibility study: answer to the question "are current EO missions' output usable in practice for ICZM and CFERM by professional surveyors, governmental agencies and authorities?" —a question with no obvious answer despite the flow of papers by academic scientists in peer-reviewed journals.

Because Validation is the proof via extensive investigations that the performance characteristics / information content of EO-products are suitable and reliable for their intended use, this current project shall end with a Proof of Concept (PoC) rather than a validation because, if some **CSIs** have been defined by qualified agencies, they have not been endorsed as standards by national authorities and international organizations, remaining '*site and stakeholder specific*'.

→ 'Validation' is the supply of evidence that the EO products have the published accuracy & reliability, and are correspondingly usable (fit-for-purpose) to calculate CSIs in the frame of a feasibility study on the value of EO for the management of shores & coast, and the studies of coastal erosion.

2 Contractual requirement by ESA

ESA requirement for this project is summarized in the various statements of the SOW: "*The Product Validation Plan shall contain a scientifically-sound validation protocol including:*

- ***a description of all the activities planned by the Contractor to obtain the best acceptance of the EO products and service by the end-user organisations;***
- ***a detailed specification and justification of the validation methods and metrics;***
- ***a complete and unambiguous list of the validation input and reference data*****."**

It reminds that validation is <u>user-oriented</u> ("*The fulfilment of the end-user requirements shall be verified following the validation plan described in the Product Validation Plan.*", "*Product Validation Report shall be co-authored by the end-users and shall include: the detailed results of the product validation done by the Contractor in coordination with the end-user organisations, and in compliance with the Product Validation Plan (PVP)*"); yet, it seems to be different from a user evaluation ("*The end-users shall perform an evaluation of the service products, assess the products' adequacy and utility, and analyse the feasibility of their integration in their working practices. The end-users shall report their assessment in User Evaluation Reports that shall be attached to the Product Validation Report. The individual User Evaluation Report shall follow the template of …*"), potential reason being that the validation is performed by the contractor, though reported by end-users as per ESA request, and the evaluation is performed by the users.

In addition, ESA refers to a "*sound and scientifically meaningful validation methodology*", whereby 'sound' is a trite predicate as it means rationale, judicious, accurate, faultless… but the reference to the scientific method is very constraining as it involves careful observations, applying rigorous skepticism about what is observed given that cognitive assumptions/ hypotheses can distort how one interprets the observation, and performing additional experiences to check the truthfulness of the deductions. As this project has nothing to do with (inductive) science, even if it may supply coastal scientists with EO-derived observations to explore the wonders of coastal geo-morphodynamics, but with engineering, we understand that ESA does not look for statistics, but representative tests by independent means when performing the products' validation.

> **ESA requests the consortium to set-up a robust and logical protocol for checking that the EO-products are *fit-for-purpose*.**

Nota: 'logical' means compelling when hypothesis (a priori knowledge) are trusted; and 'robust' means compelling under different legitimate hypotheses whatever.

→ 'Validation' of EO-products shall rely on a protocol which applies the scientific method.

3 Standard validation tests in remote sensing (CEOS view)

NASA and CEOS[7] refers validation to '<u>EO product performance</u>' –but without defining precisely a product's performance whatever the EO product that is delivered by NASA or USGS.
QA4EO[8], which is published by GEO[9] and endorsed by CEOS, discriminates between

- **Quality Assessment ("*valuate product scientific quality with respect to intended performance*", a statement which raise more questions than it explains the action);**
- **Validation ("*quantify product accuracy by comparison with "truth/reference data" distributed over a range of representative conditions*" a statement which is similar to ESA request).**

NASA, as ESA, adds that "*validation is an explicit responsibility of the investigators to assess the accuracy of their products*" allowing to define a product's performance by the accuracy of the information it contains[10]. As such, we deal with errors that may be introduced by numerous causes that include:

a. **Instrument errors,**
b. **Incomplete transmission of instrument and ephemeris data from the satellite to ground stations,**
c. **Incomplete instrument characterization and calibration knowledge,**
d. **Geo-location uncertainties,**
e. **Use of inaccurate ancillary data sets,**
f. **Software coding errors,**
g. **Software configuration failures (whereby interdependent products are made with mismatched data formats or scientific content),**
h. **Errors introduced by the production, archival and distribution processes,**

which are more related to Quality Control (QC), and

i. **Algorithm sensitivity to surface, atmospheric and remote sensing variations, as well as**
j. **Approximation in the formula to retrieve the parameters that are not directly measured (e.g. phytoplankton concentration in waters from radiance of the sea-surface),**

which is more related to the physical science of radiative emission and transfer, and to the formal science of mathematics and its application to computers.

[7] Committee on Earth Observation Satellites, comprising some 60 (inter-)governmental agencies operating some 170 satellites

[8] Quality Assurance Framework for Earth Observation

[9] Group on Earth Observations

[10] accuracy = the degree to which the result of the measurement and the calculation conforms to the correct value

➔ **Validation means 'check of the truth of uncertainty budgets to be delivered with the EO products', these EO-products being indicators of the environment state at a given time, and the time series of EO-products providing information on the dynamics.**

e.g. validation stage hierarchy by the CEOS WGCV Land Product Validation Sub-group:

Stage 1	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in-situ or other suitable reference data
Stage 2	Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and with similar products have been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.
Stage 3	Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products have been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
Stage 4	Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.

Surprisingly, most of the errors (*a.* to *h.*) are errors which are monitored by the EO mission's ground segments with specific tools on specific sites, and the notion of "ground-truth" for point *i.* is fuzzy as

- **there is no radiative standard[11] (e.g. tungsten lamp-standard) with the size of an EO footprint, only indoor reference light sources to calibrate pyrheliometers, pyranometers, photometers…., → scaling matters**

[11] like the standard kilogram, a platinum-iridium cylinder stored at the Bureau International des Poids et Mesures

- **calibration of an EO sensor is a succession of calibrations, as laboratory sensors will be used for inter-calibration of the EO sensors on-ground, prior to launch in space (knowing that there is an optical system between the light sources and the sensor which can affect the calibration), and**
- **calibration is done on-board with the moon, sun (e.g. sun illuminating a white or Erbium doped "Pink" Spectralon TM diffuser plate inserted in the field of view), stars, etc.**

= the calibration of the instruments is approximate, at best; from the measurements (L1 products) one retrieves physical, chemical, biological, and ecological parameters (L2 products, then L3 and L4) with empirical/statistical formula which change with observation's scale. One relies on intercalibration with scaling arrangements such as the one described hereinbelow for EO-derived LAI/FPAR products[12] (VHR and HR satellite sensors + in-situ sensors, not measuring simultaneously, deliver a theoretical MR image to be compared with the data set acquired by the MR sensor) which is the result of calculations on the MR sensor's measurement:

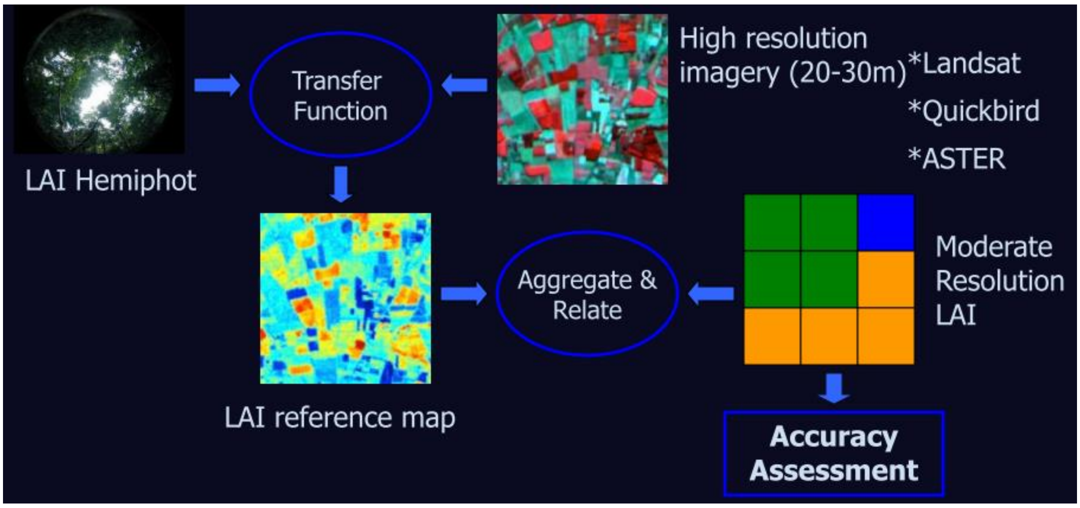


Figure 3.1: Good Practices Protocol document for validation of LAI Products[13]

⇨ **Most of the time the validation, i.e. check of 'truth', is indirect (but errors growing while propagating in the chain…) as the new instrumentation and methodologies do not measure exactly the same thing.**

---

[12] LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies and as half the total needle surface area per unit ground area in coniferous canopies; FPAR is the fraction of photosynthetically active radiation (400-700 nm) absorbed by green vegetation; both variables are used for calculating surface photosynthesis, evapotranspiration, and net primary production

[13] Fernandes, R., Plummer, S., Nightingale, J., Baret, F., Camacho, F., Fang, H., Garrigues, S., Gobron, N., Lang, M., Lacaze, R., LeBlanc, S., Meroni, M., Martinez, B., Nilson, T., Pinty, B., Pisek, J., Sonnentag, O., Verger, A., Welles, J., Weiss, M., & Widlowski, J.L. (2014). Global Leaf Area Index Product Validation Good Practices. Version 2.0. In G. Schaepman-Strub, M. Román, & J. Nickeson (Eds.), Best Practice for Satellite-Derived Land Product Validation (p. 76): Land Product Validation Subgroup (WGCV/CEOS)

Validation (Val), i.e. proving and/or confirming that it is correct or true as per the casual definition of the word, embeds quality control (QC) as per CEOS, in particular abidance to the specified error budgets in order to check 'correctness' —checking the 'truth' being under the ESA casual definition of VAL.

ESA, while recognizing the grouping of Val and QC in its organization of PDGS[14], puts together 'Calibration' and 'Validation' (Cal/Val) but not QC when tackling the performances of the pure observations (radiometry and geometry of the observations), Cal dealing +/- directly with the instruments (photometers, optics,…), whereas Val deals indirectly with the instruments as it involves processing the measurements with auxiliary data (e.g. vicarious validation, cross-mission validation, …) and assessment of uncertainty in the values delivered by the EO-products owing to independent evidence. Why? Because data that are QCed came out with a binary flag -good or bad for exploitation, and calibration, as well as validation, applies only to valid data, i.e. good for exploitation.

Nota: surprisingly, the terms "Quality Control" do not pop up in the QA4EO documents, reason being that "CEOS, (the space arm of GEO) […] established QA4EO to facilitate interoperability of GEO systems", i.e. possibility to use simultaneously data from different EO systems that are flagged as 'valid', and the experts that gather to write it did not care of the effectiveness of the PDGS and the sensor's performance -only the data. Consequently, the QA4EO Quality Indicators (QIs) do not guide QC though fully false data (outliers) could be delivered…

For ESA, dedicated validation tasks are (cf. Sentinel-3):

"
- *Level-2 algorithm verification for all Level-2 products,*
- *Level-2 algorithm validation,*
- *quantification of Level-1 and Level-2 product error estimates,*
- *long term monitoring for consistency and constant quality of Level-2 geophysical products*
- *advising on re-processing campaigns with updated Level-2 algorithms or auxiliary data."*

Nota:

a. (formal) verification of an algorithm, i.e. new words in this §, is checking the correctness of intended algorithms underlying a system with respect to certain properties or behavior, using mathematical/logical methods, i.e. fulfillment of 'proof obligations' ; it does not adjust the parameters of the algorithm, which usually depends on external factors, though verifying

[14] Payload Data Ground Segment of EO missions

algorithm is checking it produces the expected output for the range of inputs (and it eventually terminates), but also the algorithm's efficiency and the run-time efficiency when implemented; Level-2 algorithms takes Level-1 products as inputs to deliver the value of geophysical parameters, using formula and external auxiliary data, which need adjustments; these adjustments/ parametrization is seldom mentioned in the remote sensing academic literature, except under the terms "updates" of the data processors further to validation, although it looks like the calibration of data processors, which should be integrated in the algorithms;

b. whereas the SOW refers to products' validation, as NASA does for its PDGS's outputs, the ESA-COPERNICUS PDGS refers to algorithms' validation; is there a difference between the two actions? no, if verification is rather related to algorithms and data processors (it's static, performed once), validation is related to their outputs, i.e. EO-products (it's dynamics testing).

Parametrization of algorithms and data processors which deliver the EO-products is usually performed further to the validation step of products, to improve the accuracy and reliability of the products; as such the validation is an assessment of the satisfaction of the users, incl. the 'value' of the products, leading to an adjustment of the processors or the review of the products' content and format.

→ 'Validation' in the remote sensing field does not always refer to the scientific method, i.e. the capacity to deduce proper information from the EO-products, and focuses rather on products' verification (match-up against 'truths') and data processors/algorithms verification (to get a truth); the exception that proves the rule is altimetry as altimetry measurements can be verified on targets for verification and calibration, but the validation is indirect: validation of Topex-Poseidon and ERS1 data for instance was performed through surveys of ocean density and currents to check whether altimetric data calculated from density fields were in accordance with the EO measurements, and if current fields were in accordance with the calculation with altimetry data.
nota: as such it experiences difficulty to demonstrate the genuineness of breakthrough innovations introduced by EO, EO-products looking more like advancement or replacement of current information;

'validation' is the verification of the validity of error-bars, i.e. validation of uncertainty-budgets.

4 Exercising validation of EO-derived coastal erosion products

If trusting the definition of validation given in the first §, which +/- conforms to CEOS, ESA & NASA statements, our EO-derived products shall be validated against *CSI* indicators that can be assessed in the field, either directly or indirectly

—'indirectly'? the 'scientific method' to which ESA refers in the SOW makes use of indirect demonstration of the validity of a model or an hypothesis: one design an experiment that allow check the validity in terms of 'forecast'/ new properties, and, if the observations fit the forecast, it validates the model or the hypothesis, at least for the related property than was checked by the experiment; in our case a CSI is an aforesaid property — =

4.1 Indicators

4.1.1 Background

An indicator can be defined as (OECD, 1993) "*A parameter or a value derived from parameters, which provides information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter value. Indicators possess a synthetic meaning and are developed for a specific purpose*." In our case, the phenomenon is coastal erosion, defined as a transport of coastal materials which create land retreat; and the purpose is ICAM (Integrated Coastal Area Management) or ICZM (Integrated Coastal Zone Management). The CSIs are supposed to "*reduce the number of measurements and parameters which normally would be required to give an 'exact' presentation of a situation*" and "*simplify the communication process by which the information of results of measurement is provided to the user*".

⇨ ***"Indicators should therefore be regarded as an expression of 'the best knowledge available'"*.**

The Intergovernmental Oceanographic Commission of UNESCO (IOC) published a reference guide on the use of indicators for integrated coastal management in 2003[15], making the difference between descriptive indicators'[16], 'environmental indicators'[17], and 'performance indicators'[18].

4.1.2 Coastal indicators

Obviously, coastal indicators target different topics, such as coastal zone extent and characteristics (habitat, landscape patterns, …), water quality, biodiversity, tourism, fisheries, shipping, energy industry (oil & gas, wind farms, hydro generators…). Coastal erosion or loss of land belongs to the first class; $CSI_{erosion}$ are, first of all, 'descriptive indicators' $CSI^{d}_{erosion}$; but we could have 'environmental indicators' related to risks $CSI^{r}_{erosion}$ (usually safety), and 'performance indicators' related to vulnerability $CSI^{v}_{erosion}$, that are called by some authors Key Performance Indicators (KPIs). It was highlighted by IOC that "*there should be a threshold or reference value against which indicators can be compared so that users are able to assess the significance of values associated with them*" — it is obvious that this threshold for $CSI^{d}_{erosion}$, i.e. $Thr_{CSI^{d}_{erosion}}$, depends on the other *CSI*s. The World Resources Institute, which conducted a Pilot Analysis of Global Coastal Ecosystems (PAGE), defined

- $CSI^{v}_{erosion}\left(=KPI_{erosion}\right)$ as shoreline stabilization (even though shoreline retreat might be the preferred option), and

[15] Manual and Guides n°45, Stefano Belfiore, Miriam Balgos, Bernice McLean, Jordi Galofre, Meredith Blaydes, and Danielle Tesch, a document prepared by Environment Canada, the regretted US CSMP, and NOAA

[16] which describe the state of environment in relation to a series of environmental issues, such as loss of arable lands, of biodiversity…; it includes indicators on driving forces which express socioeconomic developments (for example, the growth rate of population in coastal areas) and trends in patterns of production and consumption (e.g. sand mining) responsible for placing pressures on the environment

[17] which reflect trends in the state of the environment, help the identification of priority policy needs and the formulation of policy measures, and monitor the progress made by policy measures in achieving environmental goals

[18] which compare actual conditions vs. desired conditions, expressed in terms of environmental targets, making institutions more accountable for their operations

- $\left\{CSI^{r}_{erosion}, CSI^{d}_{erosion}\right\}$ as a mix between physical parameters, exposure to hazards and vulnerability[19] parameters (assessment of risks),
  i.e. {natural vs. altered land cover, low-lying areas, beach area/profile, severity and impact of natural hazards, vulnerability to erosion and coastal hazard};

  IOC added the following: - coastal zone extent, - human population living in coastal areas & population growth, - coastal habitats (e.g., beaches/dunes, intertidal reefs, intertidal sand/mud flats, mangroves, seagrasses, saltmarshes, estuaries, algal beds, coral reefs, etc.) & loss of habitat, - area of land owned by public + public access areas & area of protected coastal areas and marine protected areas,

  erosion assessment / loss of land.

For the selection and use of indicators $CSI^{d}_{erosion}$, their geographical and time scales must be considered: for instance, Payo et al (2018) have defined *CSI*s for risk management at decadal to centuries time scales (long term or *LTCSI*s), while short term coastal state indicators (*STCSI*s) are mostly used to guide day-to-day coastal management at a given location and ensure sustainable management, including flood and erosion risk. “*STCSIs are strongly driven by monitoring data and extrapolation, with the role of modelling being largely confined to the setting of thresholds, while LTCSIs are mostly model based*” although most of the publications in academic research peer-reviewed papers use long-time series’ analysis since the origin of time (usually the launch of the Landsat EO program!).

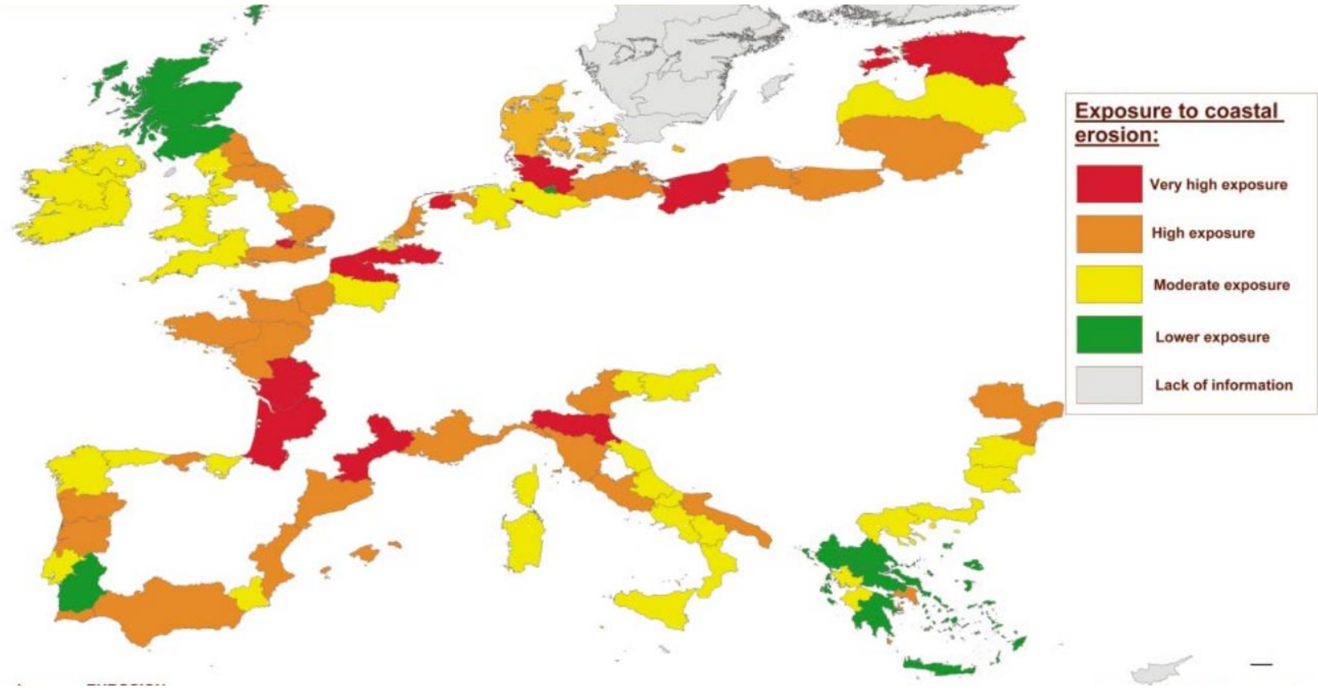
Coastal State Indicators CSIs, which are instruments of evaluating environmental processes, informing decision making, and assessing policies relevance and success, are not restricted to the static status of the shore and the coast, but also the *dynamics* (changes), despite the confusion between “state” and “static”: dynamic state estimation is related to the behavior of the state variable with time (in static state estimation the state model is built on the assumption that the state variable is in steady state or quasi steady state, while for dynamic state estimation the model is built on the assumption of rapid changing behavior of state variable[19].

→ Temporal scales matter

[19] probability and cost of damages

→ Coastal state indicators are built according to different methods, and, at the end, are checked against the truth of damages to human-used land.[20]

Maps such at the next, published by the EUROSION consortium in 2004, which was endorsed by the EC, seems nonetheless of little use because built with 9 indicators of state and pressure and 4 indicators of impact, without knowing how and if they are calculated from models (which ones) or from observations though some of the parameters might be measured ('change of erosion patterns from 1975 to 1990', 'growth of coastal urbanization', 'intensity of engineered frontage'…) — yet the methodology of assessing the shoreline retreat is not documented and, in particular, error bars due to measurement errors and aliasing in the time series by gross sampling or not is unknown -most probably the only accurate measurements are *i.* the loss of property, land of economic value and ecological value, *ii.* the destruction of natural defences, and *iii.* the failures of artificial defences.



reason why the EEA publishes % of eroding coastline and not % of eroded coastline.

[20] Whether the geomorphic processes are in a dynamic steady state (oscillating between maxima and minima around a central mean value) or not

EMODNET, the portal of the EC publishes a map of coastal erosion status (last version 2016), from satellite data which is so different that it puts in question the value of the indicators!!!

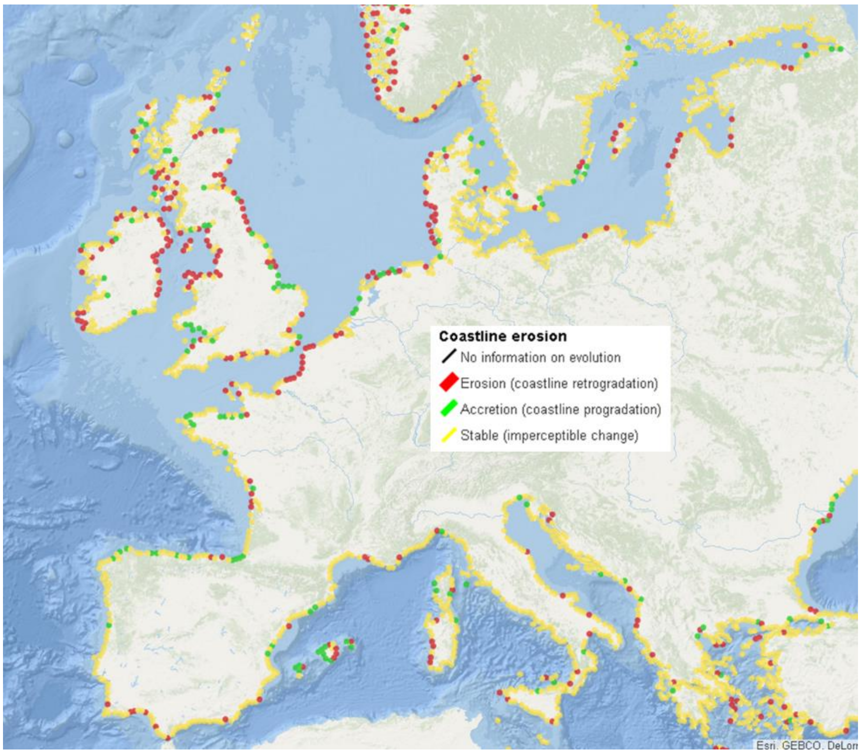


Figure 4.1: Coastal migration, EMODnet[21]

4.2 Geomorphological descriptors

4.2.1 State of the art

Some currently utilized CSI's for the description of the shoreline dedicated to coastal erosion studies and management span 4 sub-groups (Van Koningsveld and Lescinski, 2007):

1. **Shoreline Position (MCL[22])**
2. **Mean High Water Mark location (MHWM)**
3. **Mean Low Water Mark location (MLWM)**
4. **Beach Slope between upper and lower boundaries (?)**
5. **Beach Width**
6. **Total Beach Volume**

---

[21] https://www.emodnet-geology.eu/map-viewer/?p=coastal_behavior

[22] the concept of the Momentary Coastline (MCL) defines the coastline position as a function of the volume of sand in the near shore zone

7. **Total Profile Volume**
8. **Run-up Level**
9. **Berm Level or shingle ridge crest height**
10. **Berm Width or shingle crest width**
11. **Dune Volume**
12. **Dune Erosion Point**
13. **Dune Foot Location (Dune Toe)**
14. **Dune Crest Height**
15. **Dune Width**

to be drawn with help of *i.* surveys, such as EO-based surveys (the EO L1 products), or *ii.* pure calculation, or *iii.* mix of surveys and calculations (such as the EO L2, L3 and L4 products).

Nota: calculations require the following information which are often added to the list of CSIs

- **sediment composition**
- **bathymetry/ altitude such as highest/lowest contour to datum, dune toe position, depth of closure…**
- **wave & wind climate (storminess)**
- **tidal climate**
- **longshore & cross-shore currents**
- **recirculation currents & infragravity wave climate**

15 descriptive parameters are too many to comply with the accepted definition of CSI "*a* *reduced* *set of measurable parameters that can simply, adequately, and quantitatively describe the dynamic-state and evolutionary trends of a coastal system*". Surprisingly, some projects such as EUROSION, DEDUCE, CONSCIENCE… have gone up to 27 indicators. The number is all the higher than it shall be multiplied by 2 to get status + trends.

nota: this list does not introduce the notion of spatial scales when identifying features to map.

Although the European Commission recommends that "*any policy for coastal erosion should increase coastal resilience by restoring the sediment balance and providing space for coastal processes, using the coastal sediment cell perspective*" and "*introduced the concepts of favorable sediment status and strategic sediment reservoirs as elements for a coastal erosion policy*", the previous descriptive parameters of the shorelines are mainly landwards. It is not abnormal if looking at the consequences of coastal erosion, i.e. loss of land, and the protection of the coast, but odd if trying to mitigate / counter coastal erosion.

The previous list focuses on features of the backshore (till the coastline) and the coast (from the coastline to the hinterland), eventually the foreshore zone, but neglects the shoreface/inshore zone down to the depth of closure (DoC), and the assessment of sediment supplies whose lack leads to erosion.

→ To the classic CSIs, i.e. characteristics of features of the backshore & foreshore, one should add not only the features of the inshore (e.g. bars, shallows…) but the global characteristics of these areas, and assessments of all the impact of the cross-shore & alongshore sediment transport in the ocean, the latter being 3D products.

4.2.2 Shoreline indicators and ESA perspective

Out of the 4 subgroups of coast geomorphology indicators of §4.2.1 among the coastal indicators, the first three are related to the shore (the 1st is related to the beachface, the 2nd to the whole shore area, the 3rd to the backshore), and the fourth to the coast. Overall, there are 10 shoreline indicators *SI*s and 5 coast indicators *CI*s. They all belong to the class of *CSI*s: $\{SIs\} \subset \{CSIs\}$ and $\{CIs\} \subset \{CSIs\}$.

4.2.2.1 CSIs for the Coastal Erosion project

According to the contract's title & content, the scope of the work is not the assessment of the shore(line) state but the delivery of EO-products, to "*users communities responsible to monitor and control* [their coastal erosion] *process*" (cf. §2.2 of the SOW), which, consequently expect **<u>coastal erosion indicators</u>** $CSI_{erosion}$.

Yet, the following paragraphs of the SOW exclusively focuses on the "***position of the land-water interface***" which is on the **shoreline**.

Nota: this confusion is ascribed to the ambiguousness of the terms 'coastal erosion', i.e. loss of land, often taken for 'shore erosion', i.e. loss of materials at the edge of the land, as the latter can draw to the former; as well as the equivocation due to the inclusion of the shore area in the coast area (shore ⊂ coast) when speaking casually, although they are different (the shore is formally seaward of the coast). More generally, coast and shore, coastline and shoreline, are commonly used in place of each other…

$$\{CSI_{\text{erosion}}\} = \{CSI^d_{\text{erosion}}, CSI^r_{\text{erosion}}, CSI^v_{\text{erosion}}\} \subset \{CI, SI\} \Rightarrow \{CSI_{\text{erosion}}\} = \{CI_{\text{erosion}}, SI_{\text{erosion}}\}$$

$$\{CI_{\text{erosion}}\} = \{CI^d_{\text{erosion}}, CI^r_{\text{erosion}}, CI^v_{\text{erosion}}\}, \{SI_{\text{erosion}}\} = \{SI^d_{\text{erosion}}, SI^r_{\text{erosion}}, SI^v_{\text{erosion}}\}$$

$$Thr_{CSI^d_{\text{erosion}}} \in \{CSI^r_{\text{erosion}}\}, Thr_{CSI^d_{\text{erosion}}} = Thr_{CSI^d_{\text{erosion}}}(\{CSI^r_{\text{erosion}}, CSI^v_{\text{erosion}}\})$$

In the next paragraphs we will note $\{\text{CI}\} = \{CI, SI\}$.

If, in the aforesaid §2.2, ESA lists exclusively ESA and COPERNICUS related projects, most of the coastal erosion assessment and defense R&D projects have been *i.* funded directly by the European

Commission (EC), such as the famous **EUROSION** and **CONSCIENCE** projects which framed the EC policy, or *ii.* indirectly funded through the LIFE(+) projects, or even *iii.* funded by the European Environment Agency (EEA) —in particular 3 of its 4 Topic Centres, i.e. ETC/ICM (Inland, Coastal and Marine Waters), ETC/SIA (Spatial Information and Analysis), and ETC/CCA (Climate Change and Adaptation); not to mention *iv.* the InterReg funds dedicated to coastal erosion.

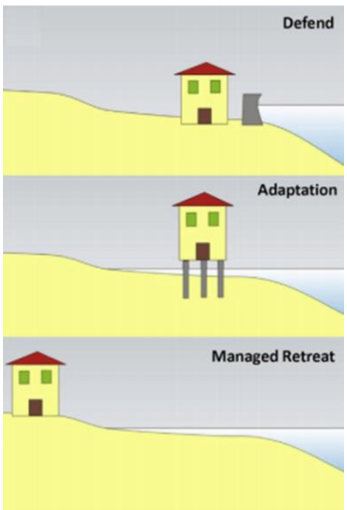
Let's list some of the LIFE R&D projects followed by an implementation phase for which Remote Sensing :

- specific ones

Coastal erosion		
LIFE06 NAT/F/000146	Maintbiodiv	Preservation of the coast biodiversity on the Gâvres-Quiberon site
LIFE04 NAT/ES/000031	Dunas Laida	Dune regeneration on Laida beach (Urdaibai)
LIFE05 NAT/LT/000095	LITCOAST	Natura 2000 site conservation and management on the Lithuanian coast
LIFE96 ENV/UK/000404		Implementing alternative strategies in Irish beach and dune management : community involvement in sustainable coastal development. A demonstration project in sustainable beach and dune management
LIFE00 ENV/IT/000090	SE.L.SY	Sea-Land System: concerted Actions for the Coastal Zone Management

LIFE and coastal management, 2013, doi:10.2779/54470

- coastal erosion and ICZM around Europe: 'PROVIDUNE' project (LIFE07 NAT/IT/000519), 'Coastra' project (LIFE00 ENV/FIN/000666), 'Swedish Coastal Woodlands' project (LIFE02 ENV/S/000355); 'Zantecoast' project (LIFE00 ENV/GR/000751, 'MARIA' (LIFE96 ENV/P/000601, LIFE00 NAT/IRL/007128), 'Prosit' project (LIFE00 ENV/IT/000191), 'Elefsina 2020' (LIFE05 ENV/ GR/000242), 'COASTBEST' in Emilia-Romagna (LIFE08 ENV/IT/000426), 'Vattajan dyyni LIFE' (LIFE05 NAT/FIN/000104), etc.
- restoration of seagrass meadows for coastal defense: 'Posidonia Baleares' (LIFE00 NAT/E/007303), 'Posidonia Andalucia' (LIFE09 NAT/ES/000534), 'POSEIDONE' (LIFE09 NAT/IT/000176), 'Biomares' (LIFE06 NAT/P/000192), etc.
- beach and dune management for coastal defense: 'Maintbiodiv' (LIFE06 NAT/F/000146), 'Dunas Laida' (LIFE04 NAT/ES/000031); 'LITCOAST' (LIFE05 NAT/ LT/000095), 'SELSY' (LIFE00 ENV/IT/000090), two LIFE Nature projects (LIFE00 NAT/E/0007339 and LIFE04 NAT/ES/000044), 'DUNETOSCA' (LIFE05 NAT/IT/000037), etc.
- Saltpan restoration for coastal defence: 'Secovlje' (LIFE03 NAT/SLO/000076) and 'MANSALT' (LIFE09 NAT/SI/000376), 'Comacchio' project (LIFE00 NAT/IT/007215), Lago Salso (LIFE07 NAT/IT/000507), etc.



Williams A. et al., 2017

& other habitat restoration: 'BALTCOAST' (LIFE05 NAT/D/000152), 'Humedales Andaluces' (LIFE03 NAT/E/000055), '10GEMETEN' (LIFE04 NAT/NL/000202), 'EE Coastal Meadows' (LIFE00 NAT/EE/007083) and the Finnish 'Gulf of Finland' project (LIFE03 NAT/FIN/000039), etc.

in particular on the Norfolk coast (UK): 'Living with the Sea' (LIFE99 NAT/ UK/006081), Saline lagoons' (LIFE99 NAT/UK/006086), 'Bittern in Europe' project (LIFE02 NAT/UK/008527), 'TaCTICS' project (LIFE07 NAT/ UK/000938), etc.

→ All summarize in the 'RESPONSE' project (LIFE03 ENV/UK/000611) which developed a regional-scale mapping technique to assess current and future risks in five study coastline areas in the UK, Italy and France (local stretches of coast could be divided into 'Coastal Behavior Systems', defining patterns of behavior, sensitivity to climate change, associated risks and consequences, etc.).

All these projects have formatted the needs for coastal indicators CIs, incl. shore indicators SIs.

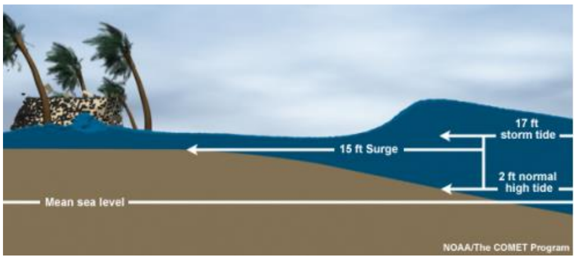
4.2.2.2 ESA target

ESA, in §2.3 of the contractual SOW, has limited the scope of SIs to two:

- "*the position of the land–water interface at one instant in time [which] defines the instantaneous shoreline*" we referred to as WL in the RBD and the TSB (the waterline at the time of the EO),
  instead of bringing it to a formal position, whether geographic or legal, that represents the land-ocean interface such as the extreme sea levels[23], HAT/LAT[24], MSL[25], MHW[26]…

  nota:

  - although ESA recognizes "*the dynamic nature of this boundary WL and its dependence on the temporal and spatial scale at which it is being considered*", and "*that using tidal datum indicators is a*



[23] e.g. 100years highest storm tide (effect of atmospheric pressure, wind piling water at the shore, high waves breaking at the shore and topping the usual land-ocean border, floods), and related storm surge

[24] the highest/lowest levels that can be expected to occur under average meteorologic tidal conditions and under any combination of astronomic tidal conditions

[25] the average observed height of the surface of the sea relative to a stated vertical datum

[26] Mean High Water (MHW) line: the line delineating the shoreline on Nautical Charts

more objective way to identify the shoreline", it believes it a right *SI* for coastal studies[27],

· motive seems to be that "[these corrections] might be very costly"[28];

- "*a feature that is used as a proxy to represent the 'true' shoreline position*".

✓ In both cases, the notion of "truth" which is highlighted by ESA needs some definition, because the **shoreline is not a line** but "the fringe of land at the edge of a large body of water, such as an ocean", a boundary area rather than a boundary line, a strip of land[29] (the coastal wiki makes the classic error to define it by "the intersection between the mean high water line and the shore", the shore line is an area that looks like a thin line on small-scale map, thick line on a medium-scale map, and an area on high scale maps = a long 2D entity);

= this confusion feeds all misunderstandings between remote sensing scientists and coastal scientists, engineers and policy makers.

✓ ESA recognizes in the SOW that "*digital elevation surfaces*" is needed by coastal scientists, engineers and policy makers, but considers them being "derived by means of photogrammetry, LIDAR or ground survey data" or using "unmanned aerial vehicles (UAVs) in coastal environments"; if true, EO won't be of much use by the coastal scientists and coasts managers. Singularly, ESA featured digital elevation surfaces as ways to correct instantaneous shorelines from changes of tide elevation, i.e. tide variation, and not as a goal —what's needed by the coastal scientist.

Similarly, ESA mentioned "high-resolution satellite and airborne imagery with stereo capabilities [to] facilitate extraction of instantaneous shorelines at a high accuracy and low cost" whereas the most obvious output would be to get the *digital elevation surfaces'* holy Grail.

The contractual SOW confuses the coast and the shore, the shoreline (a stretch of land) and the momentaneous land-water interface (WL), and ESA envisions that the WL or any proxy feature of the shoreline that informs on its location could approximate the 'truth'.

→ ESA conception is a bit crude, even if shared by numerous academic labs, whose publications are unfortunately non-usable. CSIs shall derive from the analysis of the shore-coastal system and help understand the state of the system; thresholds are necessary for all *CSI*[d] to inform on the coastal behavior and help implement management policies.

[27] something not recognized by policy makers and the community of coastal scientist

[28] not a convincing argument for the end-users

[29] the Cambridge dictionary and thesaurus gives such an example: "most of the shoreline is swamp"

4.2.2.3 Evolution & its rationale

Conditions for use of ESA SIs

Waterlines (WL) do not inform on the inland reach of the sea, except instantaneous. Proxy lines differ from one country or one county to the other, and they may have different signature on EOs.

→ They do not provide a full and complete description of the shore and the coast, and, being non-unique physical parameters, are useless except if observed in given conditions with a time scale of 1 hour to take a snapshot, thus giving values to unique physical variables.

nota: 1 hour = up to 1/4th of the tidal range *TR*, the location error being then $\delta x_{1h} = TR/4m$ where m is the slope,

e.g. *TR*=5.58m on average at ***Porthleven*** near Plymouth, with *m*=0.17, then $\delta x_{1h} = 8.2\text{m}$ but TR_{max}=7.2m then $\delta x_{1h,max} = 10.6\text{m}$ by chance… ; and,

if we assimilate the WLs to a single shoreline SL which could be the WL at mean sea level, the error is $\delta x|_{MSL} = TR_{usual}/2m$, i.e. **+/-15.5m**,

- ⊢ yet, there is no way of getting an information better than **50 cm per year** (threshold for labeling a coast has being eroded), if the waterline is not sampled every 7 minutes… or, if the sampling was truly random (impossible because of the sun-synchronicity of the satellites trajectography such as Landsat or Sentinel-2), 961 times per year, i.e. some 3 times per day!
- ⊢ **+/-15.5m** to be compared to the precision of location of a WL on a Landsat image which cannot be better than +/-15m in multispectral owing to the image resolution (TM, ETM+ and OLI payloads on Landsat4-5-7-8 satellites), and errors in location and attitude of the satellites in the sky and errors of orthorectification which add up to 70m (Landsat products for the US which have been reprocessed by USGS with Landsat1-to-8, i.e. Collection 1, are divided into 2 categories or tiers: Tier 1 products that have a geodetic accuracy with a 12 m or better Root Mean Square Error (RMSE), Tier 2 products that have a RMSE greater than 12 m -all are brought to +/-15m in the ARD products family for Landsat5 and Landsat7; but nothing similar has been done for the rest of the world). FYI, the Landsat1-to-6 geolocation accuracy performance specification was 536m, the Landsat 7/ETM+ performance 45-to-190m with gyro health, and Landsat8/OLI is 65 m for CE90 accuracy (divide by 2 to get the classic mapping accuracy -> 32.5m) but USGS has shown it was in fact better at 18m; as such for the world except the USA, the WL location accuracy with Landsat 8 is +/-22m; ESA, performing some validation with Landsat7/ETM+ through Magellium got some +/-30.8m; USGS considers that

location accuracy for Landsat TM (Landsat 4 & 5) and ETM+ (Landsat7) is some 50m CE90 worldwide, thus giving a WL location accuracy of +/-29m which is not so different from Magellium assessment; for the record,

- it could be improved if using the panchro bands of Landsat7 and Landsat8, to get +/-26m and +/-12m resp.;
- Landsat RBV payload (Landsat1-2-3 satellites) had a ground sampling of 80m, Landsat MSS payload (Landsat1-2-3-4-5) 57 x 79 m, and Landsat TM payload (Landsat1-2-3-4-5) Landsat

in all cases, the 'randomness' characteristics is not well-known to get statistical estimates because these accuracy assessments mix biases with noise;

→ to get an assessment of an erosion rate of -50 cm per year at better than +/-25cm/year, the minimum number of Landsat EOs in the year shall be, in the best case (Landsat8/OLI, no geolocation bias, use of the panchro band), 6940 EOs !!! obviously, if the dynamics of the sea and the land were stationary, we could span it on 10 years or 20 years or 30 years to get 694/yr, 347/yr and 231/yr resp. when the yearly revisit time authorizes between 20-to-60 / satellite x yr at mid-latitude, without counting the cloud cover which gives, at the end some 6-to-20 EOs/year $\Rightarrow$ not feasible; moreover, the best case only lasted from 2013-on, and Landsat 7, which is difficult to use because of the sensors' failures, gives an additional 17 years of survey, but with a need of 18200 EOs for one year sampling (1820/yr for 10 years, 910 for 20 years…); as for Landsat 5 TM, it is worse because there is no panchro band…

e.g. *TR*=7.56m on average at ***Godrevy*** near St Yves (North Cornwall), with *m*=0.02, then $\delta x_{1h} = 94.7\text{m}$ but TR_{max}=8.3m then $\delta x_{1h,max} = 103.8\text{m}$ by chance… ; and,

if we assimilate the WLs to a single shoreline SL which could be the WL at mean sea level, the error is $\delta x|_{MSL} = TR_{usual}/2m$, i.e. **+/-70m**,

→ to get an assessment of an erosion rate of -50 cm per year at better than +/-25cm/year, the minimum number of Landsat EOs in the year shall explode compared to the previous case

Consequently EO, with its constraints on the operation of satellite and the mishap of environmental changes (e.g. clouds) seldom fulfill the requirements if the *Sl*s are the waterlines…

Nota: it could nonetheless if

- the temporary motion of the WL at the scales of the recovery process further to storms was small compared to the non-recoverable status of the shore and the coast[30], and could be statistically 'smoothed' to retrieve the non-stationary component of the WL motion;
- the WL location by EO is not biased, or the bias is lower than the non-stationary motion scale, and
  the time-sampling is such that the precision of the statistical estimates, based on *i.* the time variability of the WLs, *ii.* the sampling rate, and *iii.* the precision of the WL location, is lower than the non-stationary motion scale;
- the proxy-lines represents the same physical variable, and the positioning follows the same rules as the WL as listed hereinabove;

which is seldom the case, even if microtidal areas such as the western Med.

An example of a hoax?

Conclusions of peer-reviewed papers such as "The State of the World's Beaches" by A. Luijendijk et al., 2018[31], are highly questionable[32]: working on Google Earth Engine (GEE) with 33 years of Landsat images (1984-2016) for the whole world, they 'identified' beaches (with Sentinel-2 images) and delivered accretion and erosion rates for all of them (with Landsat images, but, probably, also VHR images), even

- informing about the rates by continent:
  - North America: +0.12m/yr
  - South America: +0.26m/yr
  - Europe: +0.09m/yr
  - Africa: -0.07m/yr

---

[30] the WL motion further to an extraordinary strong storm or succession of storms is much higher than the oscillating or trendy seasonal WL motion scale

[31] Arjen Luijendijk, Gerben Hagenaars, Roshanka Ranasinghe, Fedor Baart, Gennadii Donchyts & Stefan Aarninkhof, The State of the World's Beaches, Nature/ SCIENTIFIC REPORTS | (2018) 8:6641

[32] even laughable as the authors pretend to have solve an observation issue that stalls geographic institutes around the world, but do not try to 'sale' their methods, but just 'sale' outputs of the application of their method to a scientific journal and not to users….

Asia: +1.27 m/yr

Australia: -0.2 m/yr

and

- listing hotspots with erosion or accretion rates of 0.5-to-2m/yr (erosion-accretion), 2-to-5m/yr (intense erosion-accretion), 5-to-10m/yr (severe erosion-accretion) and >20m/yr (extreme erosion-accretion), rates being calculated on sections of 10-to-30 km;

but without taking care of the tides to correct their WLs, called SDS (Satellite-Derived Shores) to get datum-based SLs before performing any statistics.

If, they showed convincing results on a few examples such as four selected cases of beach erosion and accretion due to human interventions, using all satellite images provided by Google Maps (Landsat, Terrametrics, CNES/Airbus, IGP/DGRF, and DigitalGlobe data sets) were erosion rates were intense to extreme

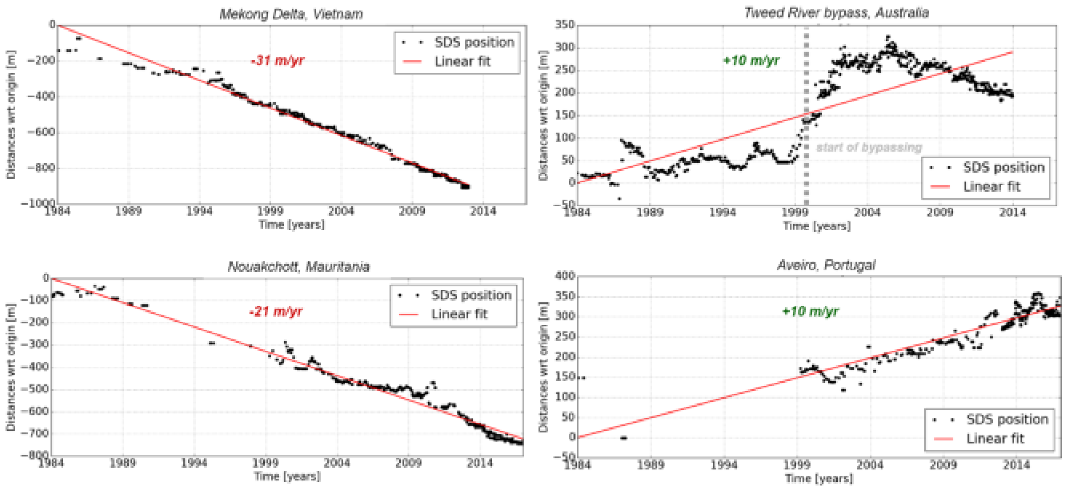
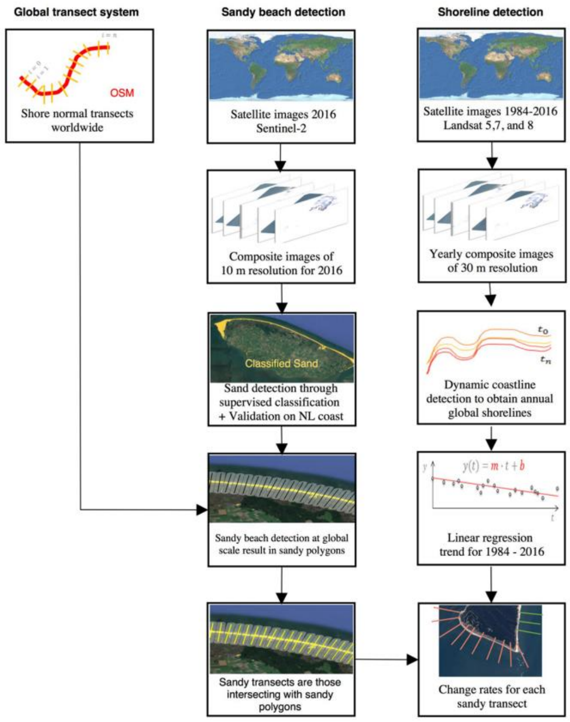


Figure 4.2: Examples of the satellite derived shorelines for four selected cases of beach erosion and accretion due to human interventions. The left column presents two erosive cases while the right column shows two accretive cases. In each figure, the blue line indicates the oldest SDS shoreline while the red line is the most recent SDS shoreline. The graphs below indicate the shoreline positions over time at the white dashed transect for each case; the upper graphs correspond to the images on the upper row. The indicated change rates (m/yr) are obtained from fitting a line-of-best fit to the shoreline position data for each transect.

“The State of the World’s Beaches” by A. Luijendijk et al., 2018

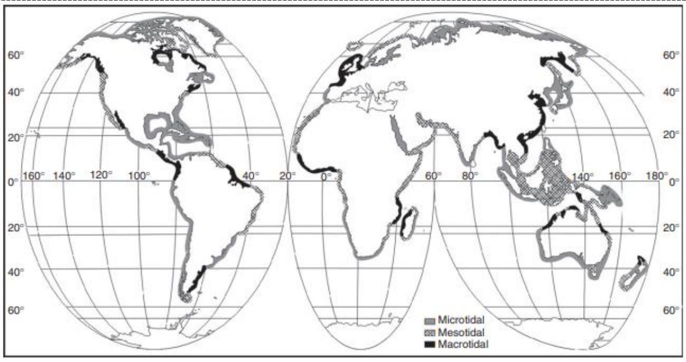
these results are not surprising because the tidal ranges are lower than those of South and North Cornwall (1m for Nouakchott, 2 m in the Mekong delta, 2.5m in Aveiro, and 1.5m at the Tweed Sand Bypass in Australia) for beach slopes that are similar (e.g. m=0.03 for the Tweed Sand Bypass), and the points scatters are similar to the range of WL's motion with tides.

Yet, apart from these extreme cases, the methodology can't provide meaningful assessment of erosion & accretion rates. The authors did not expand on it but provided the following arguments to justify the non-justifiable:

original text	what's wrong?
"The spatiotemporal scales associate with this study (i.e. global scale, 33-year analysis) and the large amount of satellite images that therefore need to be analysed necessitates the use of robust automated image analysis techniques.	The analysis technique that the authors describe does not particularly comply with the definition of "robust" (ability to withstand or overcome adverse conditions or rigorous testing) if we believe the workflow, they published at figure 4 which does not show any of the difficulties: 

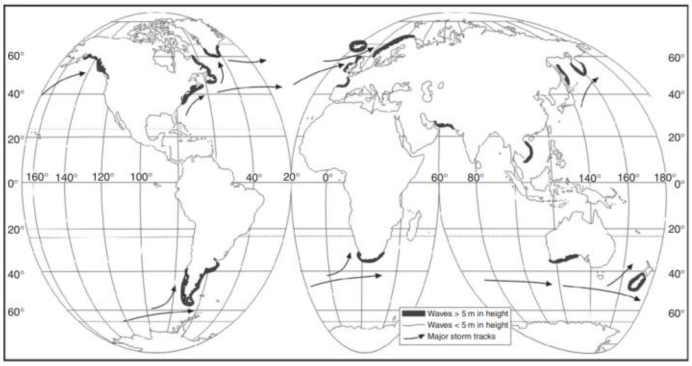
≅ no complex image analysis technique and no demonstration of robustness against difficult cases	difficulties being to assign an error bar on each waterline before performing any statistical analysis to retrieve trends, while the waterline may be confused with waves breaking offshore or with the seafront if using their algorithm (calculation of NDWI and thresholding), astronomical and atmospheric tides being ignored, same for the wave set-up and wave swash…
Machine learning and image processing techniques that lend themselves to such automated analyses are readily available. ≅ no reason to invoke machine learning and image processing techniques for so simple operations	the authors did not use any for waterline drawing, only for the classification of shores as sandy beaches, an easy task that does not call for "machine learning" as beaches have yellow materials on the edge of the ocean and no other shore class can be confused with beaches; calculating the Normalized Difference Water Index (NDWI), applying a Canny edge detector, estimating the position of the water-land transition by thresholding (choosing the threshold on a local gray-level histogram) are just basic image processing technique used for the last 30 years;
However, to be able to use satellite derived shoreline positions for real-world applications such as reliably estimating trends and structural damage to infrastructure, a horizontal resolution of at least 10–20 m is required. For example, shoreline change rates above 0.5 m/yr over a long period are typically employed to flag a coastal area as one experiencing	it is obviously false as the authors forgot to account for the rise and fall of sea level caused by astronomical conditions (which is regular and predictable), and meteorological conditions: meso-tidal (tidal range between 2 and 4 m) and macro-tidal (tidal range between higher than 4 m) areas are neglected

chronic (=long term i.e. decades to centuries) erosion or accretion. Over a period of 30 years that would mean a total displacement of just 15 m.



Whitfield A and Elliott M (2011)

though they represent half of the world coast; same for the effects of storms:



Briggs, D. et al. (1997)

→ if, for assessing 0.5m/yr erosion, the horizontal resolution was 50cm (VHR image), the issue would be the co-registration of images at 25 cm to get value from it, and the tide range…;

≅ it is not a problem of image resolution only, but image geolocation, and shoreline variability spectrum as demonstrated in the previous §

Previous studies have evaluated the positional accuracy of satellite derived shorelines (SDS) based on single images to range between 1.6 and 10 m.

??? it depends on the images and the local condition; and this statement does not inform on the existence of outliers, and, by the way, the paper does not describe the Quality Controls (QC);

≅ unfounded statement

It should be noted that these studies suffered from limitations such as [*i.*] the

[*i.*] the reference to multiple images is surprising when the authors previously mention "single

number of images used, [*ii.*] the quality of the in-situ data used for validation or [*iii.*] the magnitude of changes in observed shoreline position. ≅ the authors did not provide new figures for the positional accuracy of SDS though questioning previous studies	images"; we believe it is due to the fact that they mosaic images to cover the areas under study; it would have been expected them to inform how they proceed with waterlines that are discontinuous at the borders of images; [*ii.*] the authors raise a compelling question about 'validation' of WL (SDS) positioning with in-situ data, as there is seldom a ground survey exactly concomitant to the EO with which the WL was drawn… (the good question being "do we need ground data when looking at a photo? can't we trust photo-interpreters as ordnance survey agencies do?") [*iii.*] this is the first and last time this issue is introduced in the paper;
Recently, Hagenaars et al. presented a long-term, but local-scale satellite image analysis on shoreline trends, that overcomes all of the aforementioned limitations. They found the accuracy of the SDS derived from moving average composite images to be of subpixel precision (~half a pixel size, i.e., 15 m for Landsat and 5 m for Sentinel-2).	Gerben Hagenaars (who is the 2nd author of the paper under scrutinization) and colleagues have only stated that "In the ideal case of a cloud free satellite image without the presence of waves, with limited morphological changes between the time of image acquisition and the date of the in-situ measurement, the accuracy of the SDS is with subpixel precision (smaller than 10 – 30 m, depending on the satellite mission) and depends on intertidal beach slope and image pixel resolution." —we can agree on that, even if not resorting to subpixel resolution enhancement methods, because the satellite images were georeferenced with respect to the first available

≅ this statement is openly misleading as Hagenaars et al. only chose carefully the images for being cloud free and without waves, and the papers' authors did not inform the reader how they selected automatically images with these characteristics obviously the limitation due to the variability of water lines at hourly, daily, monthly and seasonally scales was not considered	image by manual georeferencing by means of six ground control points on a georeferenced aerial photo; yet, this is not what the authors are doing worldwide!!! "For the highest resolution images [they] find an average offset of 1 m between the SDS position and the in-situ shoreline in the considered domain. The accuracy deteriorates in the presence of clouds and/or waves on the image, satellite sensor corrections and georeferencing errors." —reasons are provided in the sentence!!! And the following statement "The case study showed that especially the presence of clouds can lead to a considerable seaward offset of the SDS of multiple pixels (e.g. order 200 m). Wave-induced foam results in seaward offsets in the order of 40 m." but I si also mentioned in the paper "The inter tidal beach slope [which] ranges from 1:24 m to 1:200 m, indicating large alongshore variabilities"; nota: the offset was calculated using a method of ascribing a standard error σ to the ground-truth WL but values of σ are not provided the sampling issue is not tackled;
The accuracy of <15 m, reported by Hagenaars et al. for composite Landsat images, matches the required displacement of 15 m for reliable shoreline change classifications over the last 30 years. For that reason, we adopt the same	as mentioned several times hereinabove, nobody took care of the variability of waterline positions at temporal scales less than 15 years (30 years duration)

approach in this study, yet at a global scale."

ESA insight and the consortium's feedback

It is apparent that ESA did not realize that European and Canadian coasts are in meso-and-macro tidal areas, except the Med, albeit mentioning the tides in its list of shoreline indicators (e.g., high-water line [HWL], mean high water [MHW]).

In the former case, the main problem is to get from waterlines to datum-based shorelines whatever the pain. In the latter, we could resort to the methodologies of the past.

ESA, focusing on remote sensing, i.e. image processing, comprehensively did not apprehend that waterlines or shorelines derived from EO, were not the definite *SI*s or *CI*s or *CSI*s: EO products for coastal erosion cannot be limited to it.

If, in https://eo4society.esa.int/2019/08/03/european-coastal-erosion-under-the-spotlight/ ESA asserted that "the challenge […] is developing adequate algorithms to achieve the necessary high precision in products", the consortium deciphered it as it the challenge is developing adequate algorithms for EO-derived $CSI_{erosion}$ products which achieve the necessary high reliability, accuracy and precision to fulfill end-users' expectations.

Denouement

The end-users/ partners of the consortium have requested not only an evolution to get from 1D features +/- instantaneous (WL) to altitude datum-based 1D features, then 2D and 3D features, but to care about the temporal variability of the waterline position

→ These end-users representing the most authoritative end-users in the ESA member states, i.e. national or regional government offices with the mandate of managing the coast, or governmental agencies acting on their behalf, and ESA emphasizing the need to be customer/user-focused, the project has changed course accordingly.

4.3 Coastal State Indicators for coastal erosion

As per the conclusions of the CONSCIENCE project (J. Sutherland, HR Wallingford), the functions of *CSI*s shall

a. assess condition of environment
b. compare across situations
c. monitor trends
d. diagnose problems
e. anticipate need for intervention

to help implement policies, usually to hold the line, reduce erosion, prevent damage, maintain beach configuration and width, to strengthen the coast, etc. "*Not just data; Integrate policy, system understanding and modelling*".

- The most obvious goal is to prevent coast breaching, *CSI*s being then: Dune strength, Barrier width, Backshore width, Dune zone width, Dune zone height, and Total barrier volume.
- To maintain position, *CSI*s are: Basal coastline, Beach width, Barrier crest position, MCL position, etc.

4.3.1 Return to ESA original contractual specifications

The SOW originally limited the *CSI*s to the following shoreline indicators, which shall fit to function a. of *CSI*s listed hereinabove:

"
1. visible discernible features in coastal imagery (e.g., high-water line [HWL]),
2. tidal datum-based indicators determined by the intersection of the coastal profile with a specific vertical elevation, defined by the tidal parameters (e.g., mean high water [MHW])
3. shoreline indicators based on the application of image-processing techniques to extract proxy shoreline features from digital coastal images. These are not necessarily visible to the human eye. "

Yet, the line of seaweeds and trash that marks the HWL (cf. point 1.) is rather a Spring HWL (or can span the area from the highest high-water line [MHWS] to the lowest high water line [MHWN]); it is most imprecise.

Tidal datum-based waterlines (cf. point 2.) need an appropriate calculation of the sea surface height (vs. geodetic control points) to label the waterlines, and a transformation to get to a fixed sea surface height (e.g., mean high water [MHW]) which depends on the knowledge of shore slopes.

As for 'proxy shoreline features' (cf. point 3.), the 'visible discernible features' of point 1. belonging to that class, ESA states that "[they] are not necessarily visible to the human eye": it plausibly rings all properties' change for properties that are not visible at the scale of the image (e.g. wet vs. dry sand), or not visible by eye but with sounders (e.g. basal bed).

For functions b. and c. of *CSI*s as per the conclusions of the CONSCIENCE project, ESA looks for a step further to "1. extraction of the shorelines/coastline/water line from our satellite data":

"2. trace the shoreline erosion-accretion trends starting from the results of (e.g. vectors representing shorelines at different time)".

Step 1 for the consortium's EO products has already been detailed in the RBD, the STD and the ATBDs of the data processors which describe how they will be produced. Step 2 is still in infancy because the method used by USGS, i.e. the Digital Shoreline Analysis System (DSAS), to plot the transformation of a shoreline at t_0 to the shoreline at t_1 does not portray any physical process of sediment transport. Therefore, it fulfills req. b., but not c. and e.

4.3.2 *Relevance of indicators with regards to KPIs*

4.3.2.1 Descriptive indicators

The CONSCIENCE project listed some $CSI^d_{erosion}$ against $CSI^r_{erosion}$ for various sites, the $CSI^d_{erosion}$ being a bit different from those of Van Koningsveld and Lescinski (but not so much):

$CSI^d_{erosion}$	quantity represented ($CSI^r_{erosion}$)
Dune strength	Standard of protection (SoP) for storm
Barrier width	idem
Barrier volume	idem
Backshore width	idem
Dune zone width	idem
Dune zone height	idem
Momentary coastline	Position & boundary condition for SoP
Beach width	Boundary condition for SoP of hard defence
Barrier crest position	Position
Shoreline position	idem

Coastline position	Perception of safety
Coastal foundation	Growth with sea level rise
Shoreface volume	Flood and coastal erosion risk
Coastal slope	idem

Payo et al., made a list of 74 CSIs, but only 33 are geographic (putting together 'state', 'pressure' and 'impact') —listed hereinbelow:

Shoreline evolution trend status (stable, eroding, accreting);

Shoreline changes from stability to erosion or accretion between the most recent and the previous version of the database;

Vertical elevation relative to Mean Sea Level;

Geological coastal type (likely erodible versus non-likely erodible);

Areas of high ecological value within flood and coastal erosion risk areas;

Length of defended coastline;

Length of dynamic coastline;

Area and volume of sand nourishment;

Dune strength;

Barrier width;

Total barrier volume;

Backshore width;

Dune zone width;

Dune zone height;

Momentary coastline (MCL);

Beach width;

Barrier crest position;

Shoreline position;

Coastal foundation or shoreface sediment volume;

% of infrastructure which needs to be upgraded;

Annual loss of land (km 2 /year) / average erosion rate (m/year);

% of sediment trapped in reservoirs;

Existence of dykes/embankments along delta distributaries;

Intertidal habitat area including mudflat and saltmarsh;

Area of built-up space in the coastal zone (both the emerged and submerged area of the coastal zone);

Areal extent of coastal erosion and coastal instability;

Coastal urbanization (in the 10km land strip);

% urban area, urbanization rate;

% area vulnerable for flooding / number of vulnerable people / value of vulnerable assets;

% of delta under irrigation;

Density of infrastructure, number of ports;

Developed area and development activities;

Economic assets at risk of storm surges and coastal flooding.

If we were to put all the distinct CSIs from the various lists together, we would reach a number of some 80 CSIs considered as $CSI^{d}_{erosion}$, which is even worse than the list of §**Error! Reference source not found.** in terms of lack of synthesis. However, it introduces to "coastal squeeze" when highly urbanised coastal zones draws nearer to the shoreline due to urbanization or coastal erosion: as long as there is enough space and buffer zones on the coast, erosion does not cause grave problems as buildings and residents are less exposed to possible damages from flooding and erosion. It also introduces to other types of damages, i.e. to risks.

Descriptive CSIs shall inform on shore & coastal processes and help calculate the risks in terms of (potential) damages due to coastal erosion from *i.* land exposure*, ii.* land vulnerability, and *iii.* hazards (or structural changes). This issue has been touched on in the Technical Specification Document (TSD) at §3.2.3/figure 2.5.

→ If descriptive indicators are too many, they can't inform better than a model built on observations, hypothesis, and theoretical laws.

4.3.2.2 Descriptive indicators vs. proxy-based shorelines & shoreline indicators

The User Requirement Document (URD) defines:

- **a datum-based shoreline indicator as a shoreline indicator determined by the intersection of the coastal profile with a specific vertical elevation;**
- **a proxy-based shoreline indicator as based on discernible coastal feature;**
- **a shoreline indicator as a feature that is used as a proxy to represent shoreline change;**
- **a coastal state indicator, being is treated as a sub-category of 3D products, and most of them derives from a Topo-Bathymetric Digital Elevation Model (TBDEM).**

The last definition defers from the conclusion of the review hereinabove; yet, it is only a matter of dictionary: the end-users stressed the necessity to have volumetric and 3D information to model coastal erosion processes, then their impact on land.

The {proxy-based shoreline indicators + datum-based shoreline indicators + shoreline indicators+ coastal indicators} of the URD are not different from the descriptive CSIs ($CSI^{d}_{erosion}$) which have been reviewed in the previous §s for the description of the state and possible changes of the shore-coast physical system.

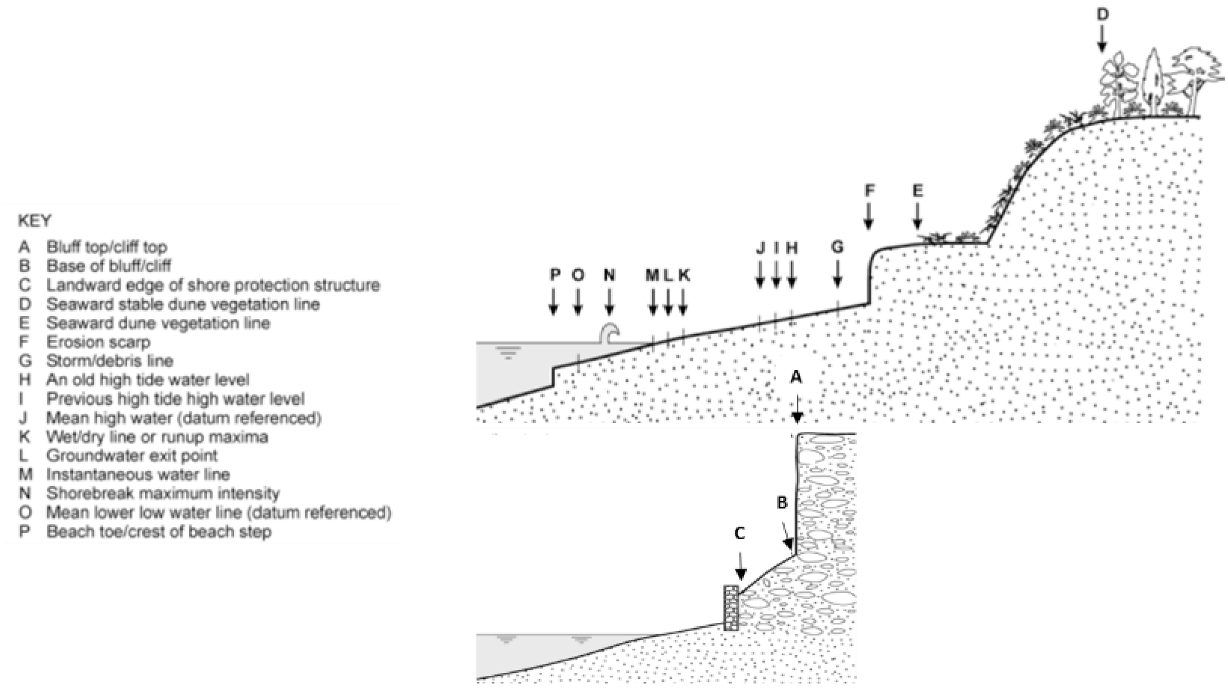


Figure 4.3 : Sketch of the spatial relationship between many of the commonly used shoreline indicators **© Boak & Turner, 2005; cf. figure 3.2 of RBD**

The reader will notice that (datum-based) shoreline positions from EO-derived waterlines represent less than 4% of the CSIs listed in the previous §, and proxy-based shoreline position 20% of the CSIs, reason why the scientists and coast managers are expecting more from EO. For EO to be considered as valuable, it should deliver more than shorelines…

→ Coastal state indicators are built according to different methods; and, at the end, are checked against the truth of damages to human-used land.[33]

4.3.3 Validation vs. matchups

4.3.3.1 ESA original view, i.e. match-ups, and the consortium's appreciation

At the outset, i.e. publication of the SOW, it was believed that the main obstacle to an enhanced adoption of EO by coastal geomorphologists was the plight to reliably extract shorelines/coastline/water line from EOs, and ESA quoted the methods that were called to solve it:

"
- Image classification (e.g. thresholding, band indexing, supervised/unsupervised classification, soft classification);

[33] whether the geomorphic processes are in a dynamic steady state (oscillating between maxima and minima around a central mean value) or not

- Artificial intelligence (e.g. neural networks, support vector machines) —AI ;
- Morphological operations (e.g. edge detection, tracing algorithms, segmentation);
- Various combinations of the above methods."

Image processing, i.e. image classification using AI & morphological operations, has been used since the first distribution of EOs using the tools primarily developed for photogrammetry purposes and the exploitation of aerial multi/hyperspectral sensors. An analysis of the ESA reference papers related to SAR and VNIR images has been published in the RBD, conclusion being that it was not the critical point and current R&D was superfluous. The significant impediment was the lack of reliability of the line extractors, due to *i.* the dearth of thorough and complete investigations of the EO signature of the lines in all conditions (weather, landscape), and *ii.* disregard of quality controls (QC). If these investigations had been achieved, it would have been possible to apply AI methods through machine learning. Because of the contract's terms, i.e. working on 1000 km of coast of interest to partners and not all the European and Canadian coasts, it was not deemed feasible to perform the investigations and to develop the data processing chain accordingly, ergo validate results by blind tests on un-chartered areas where the data processors have not been parametrized before.

The basic validation of waterlines' location from VNIR images is by photointerpretation (an external evidence involving an expert) **—as demonstrated at length by Deltares and Delft Un. of Technology though it did not need it because conspicuous…; and from SAR images by comparison with results from VNIR images.**

4.3.3.2 Validation of new EO products

Most of the EO products that have been specified for coastal erosion studies & management have no substitutes, except aerial photography (yet it has never been requested that aerial photography should be validated, only cameras to be calibrated and verified, and photos to be QCed). It prevents performing matchups with ground-truths. All the more than

- **the advantage of EO is the revisit, i.e. at least every month on large spatial scales, at least 40 km, which can't be easily obtained with on-ground means;**
- **the yearly erosion of most eroded coast is below 1m/year, 2m/year in the most serious cases[34], to be compared to waterline motions of 10s of m/day in macro-tidal areas, and seasonal shoreline motion of 10m, which highlights that sampling in the issue (sampling without spatial localization biases -imprecision is permitted!).**

---

[34] average annual rate of erosion of the Holderness Coast in north-east England = around 2 metres per year; in central Algarve, South Portugal retreat rates of 2.27 m/year have been observed; etc. = figures not to be used as such because it could be temporary erosion instead of structural erosion.

Yet, EO products needs validation by independent means. Which ones?

It is suggested to validate the EO products by drawing maps of the shore, landward and seaward, and compare it with published maps in order to check the consistency.

Another possibility is to predict the adverse impacts of coastal erosion most frequently encountered in Europe i.e. (i) coastal flooding (as a result of complete dune erosion), (ii) undermining of coastal protection associated with foreshore erosion and loss of buffering coastal habitats, and (iii) retreating cliffs, beaches and dunes (loss of lands of economic and ecological values), then checking if it is the case.

→ the validation is based on an analysis of *i.* the results in terms of consistency with prior knowledge, *ii.* veracity of the (theoretical) uncertainty budgets, and *iii.* additional value of the EO-product's content compared to the a-priori information which was already sustaining knowledge of the areas' morphodynamics;

Nota: main issue is data gaps to get proper indicators of coastal erosion, not the accuracy of individual measurements.

5 Semantics clarification

5.1 Validation & Evaluation

Validation of the EO-products shall be related to the fitness-for-purpose of the aforesaid products "*to obtain the best acceptance of the EO products and service by the end-user organizations*" as ESA specifically requested for deliverable 1.3.

Question being if it's ESA that drives the acceptance of the EO products, or the prime contractor or the end-user organizations? In the negotiation meeting and the Kick-Off meeting, the ESA representatives stated

⇨ Yet, no generic validation methods is available and the EO products' acceptance tests will depend on the expectations of the end-users for the fulfillment of their specific requirements as per the demonstrations;
consequently, metrics shall be set by/with each end-users.

nota:

a. the objective being to deliver new information , it is meaningless to deliver in advance "*a complete and unambiguous list of* […] *reference data*" as requested by ESA because there is no definite reference data except a priori information on coastal erosion that our EO-products could even challenge;
b. the validity of the EO-Products information content shall be proved theoretically by uncertainty assessment, following guidance of the Joint Committee for Guides in Metrology of the BIMP (Bureau International des Poids et Mesures) which is published in the VIM (International vocabulary of metrology – Basic and general concepts and associated terms) and the GUM (Evaluation of measurement data — Guide to the expression of uncertainty in measurement).

However, ESA makes a difference between product validation and user evaluation when stating
"
- *the fulfilment of the end-user requirements shall be verified following the validation plan described in the Product Validation Plan*
  the results of the product validation shall be documented in the Product Validation Reports"
"
  → delivery of Product Validation Reports
- *the end-users shall perform an evaluation of the service products, assess the products' adequacy and utility […], and report their assessment in User Evaluation Reports that shall be attached to the Product Validation Report*";
  → delivery of User Evaluation Reports

= a difference between validation and evaluation, truth vs. adequacy/utility/integrability.

→ The SOW differentiates between
- **truth's evidence**, to be brought by photo-interpreters who are used to draw shorelines on aerial photographies and to recognize features on SAR images, and by remote sensing experts in multi-spectral multi-bands sensing of coastal areas; = **validation**
- **usability**, to be checked by the end-users; = **evaluation**

5.2 Verification of the data processors and Quality Control of the EO-products

The main issue is to express an uncertainty relating to the measurement of a fuzzy-defined quantity —fuzzy because the measurand has different values according to the 'scale' of observation (to be translated in scale characteristics of the instrument, e.g. time of integration, field of view,…). It cannot be characterized by an essentially unique true value; the difference being errors also called measurements' uncertainties due to *i.* the measuring system incl. the parametrization, calibration…., *ii.* the measurement procedure, *iii.* the skill of the operator, *iv.* the environment, and *v.* other effects. Measurements are characterized by offsets and dispersion, i.e. bias or systematic errors, and noise or random errors. But also by gross errors delivering measurements that are 'outliers'.

As per the GUM principles, all the EO-products should have a measurement model which is based on the data processors' algorithm and the measurement models of the inputs, i.e. a model which

→ The verification of the data processors shall be a re-engineering process after gaining experience, and shall be performed pursuant to the measurement model.

In phase 2, when automating the EO-derived information's production, a QC framework shall be developed.

5.3 Demonstrations

When ESA refers to "*pilot service demonstration*" for EO-products to be "integrated, where possible, into the end-users' application environment" in order "to validate the products and make a qualitative and quantitative assessment of the information provided and its suitability", the aforesaid demonstrations becomes the test cases.

In the SOW, ESA assigned to the end-users the task to "perform an evaluation of the service products, assess the products' adequacy and utility, and analyse the feasibility of their integration in their working practices": "in addition to the desired products and specifications for the service, the end-user shall describe their requirements for the product delivery schedules, for the product demonstration scenarios, for the validation and correlative validation data availability".

The pilot-service demonstrations demanded by ESA support the validation and evaluation of the EO-derived products, but also prepare for a QC framework.

Nota: the pilot service demonstration do not allow for the verification of the data processors which shall be performed in a phase 3, beyond the end of the ESA contract.

→ The pilot service demonstrations are the events for the EO-products validation.

End of Document