COASTAL CHANGE FROM SPACE: VALIDATION AND EVALUATION IN SPAIN

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1. INTRODUCTION

Satellite derived waterlines, shorelines and bathy-morpho-terrain models (bathymetry) were generated along four pilot sites in the Spanish coast. The products were validated by IHCantabria in terms of accuracy and in terms of the skill on the analysis of coastal erosion processes. This annex presents a synthesis on the results obtained from the validation analysis in Spain.

2. PILOT SITES

Satellite-derived products were generated for the following pilot sites (Figure 1):

- Malgrat del Mar (Tordera Delta)
- Beaches South of Barcelona
- Castellón-Sagunto
- Gulf of Cádiz

Figure 1: Pilot sites in the Spanish coast.

By assessing satellite data in the Mediterranean coast and in the Gulf of Cádiz it was possible to test the accuracy and skill of those products in areas with various environmental conditions (with regards to cloud coverage, marine climate and tidal range) and to evaluate the capability for producing satellite information in several spatial scales. It was also possible to verify the new satellite-derived products in sites that represent a challenge for remote sensing, since earth observation in those areas is constantly affected by the presence of clouds or high concentration of suspended sediment in the water column.

3. DATA

In this section we present the satellite data and the ground truth (in-situ measurements) used in the validation analysis.

3.1. Satellite derived data

Based on the information from Landsat 5, Landsat 8 and Sentinel 2 missions the following products were developed for the Spanish coast (see also Figure 2):

- Satellite derived waterlines from optical sensors (SDWL): instantaneous interface between water and sand detected in the moment of the image.
- Satellite derived shorelines from optical sensors (SDSL): waterlines corrected to represent a certain water level (e.g. Mean Sea Level, Highest Astronomical Tide and Lowest Astronomical Tide). Auxiliary data (in-situ measurements of topography, sea level and wave series) were used to define the location of these shorelines.
- Bathy-morpho-terrain models (BMTM): Shallow waters depths obtained from optical sensors.

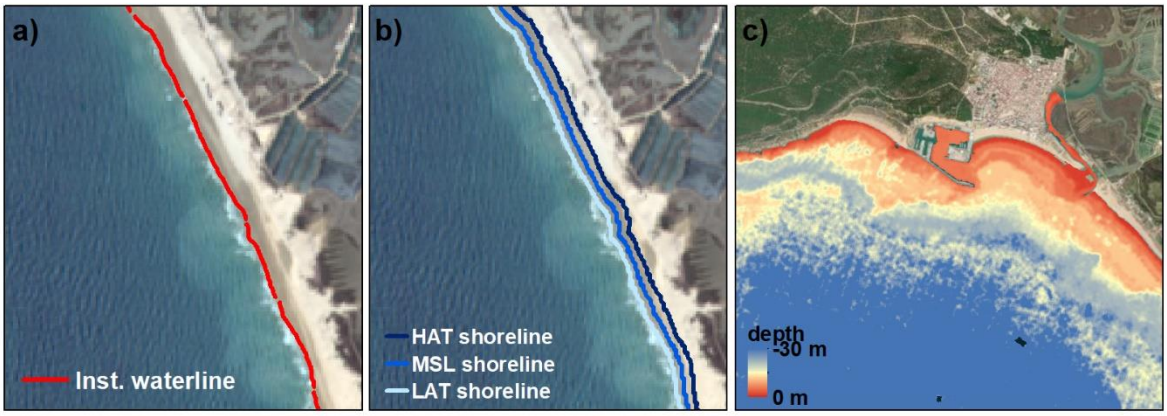

Figure 2: Examples of each type of products: a) waterlines, b) shorelines and c) coastal bathymetry.

Landsat missions provide long temporal series (satellite products since 1994) with 30 m resolution, while Sentinel mission provides higher resolution satellite images (10m) and in higher sampling frequency (re-visiting time is about 2 days) since 2015. The former allows long-term analysis, while with the later it is possible to assess information in short- and mid-term scales. Using data from very-high resolution mission, Sentinel and Landsat images were co-registered. The co-registration increases the precision between images from different missions, providing reliable information to assess coastal changes in multi-temporal scales. Table 1 presents a synthesis of the satellite data developed for the Spanish coast.

Table 1: Satellite derived data developed in the Spanish Coast.

	Tordera (1.4 Km)	**Barcelona (18 Km)**	**Castellón (40 Km)**	**Gulf of Cádiz (230 Km)**
Waterlines	235	221	242	1069
Shorelines	190 x 3 water levels	82 x 3 water levels	133 x 3 water levels	934 x 7 water levels
Bathy-morpho terrain models	8	10	5	8

3.2. In-situ measurements (auxiliary data)

Table 2 shows the details about the ground-truth data used for the validation of the satellite products. In situ measured topo-bathymetries were used in the analys

Table 2: Measured data used for the validation of the satellite products in the Spanish Pilot sites.

	Tordera	**Barcelona**	**Gulf of Cádiz**
Coverage	Malgrat beach	Beaches of South Barcelona (from BCN to Ginesta Ports)*	Camposoto beach El Palmar beach Fontanilla beach La Barrosa beach**
Dates	16/Nov/2015	01/Jun/2016 22/Jun/2016 23/May/2017 13/Jun/2017 20/Apr/2018	12/Jul/2018

Dataset provided by the Port Authority of Barcelona.
** Data provided by "Demarcación de Costas" of Cádiz.

4. VALIDATION METHODOLOGY

SDSLs, SDWs and BMTMs were validated in three main steps. First, a visual analysis was carried out to verify if the products were in accordance with the general aspects of the coast. The second step consisted on the accuracy assessment. The geo-accuracy of the products was tested through a comparison with in-situ measurements. This step depends not only on the satellite data, but also on the availability of in-situ measurements in similar dates. A maximum temporal distance of 7 days from measurements and satellite data was assumed in these analyses. The Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) were used as accuracy parameters:

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

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

where x and y represent measured and satellite data respectively and J is the number of pairs of data. The depths from satellite derived bathymetry in coastal areas was contrasted with the depths from in-situ measurements. The position of the waterlines/shorelines along cross-shore transects was compared to the position of contour lines obtained from in-situ topo-bathymetry (contour lines correspondent to the water level at the moment that the image was taken). Table 3 presents a resume on the amount of satellite data validated in this study (Castellón was assessed in terms of skill only).

Table 3: Total number (N) of satellite data assessed in the validation analysis.

	Tordera	**Barcelona**	**Castellón**	**Gulf of Cádiz**	**N**
Waterlines (Sentinel 2)	-	5	-	4	9
Waterlines (Landsat 8)	1	-	-	-	1
Shorelines (Sentinel 2)	-	5	-	1	6
Shorelines (Landsat8)	1	-	-	-	1
Bathy-morpho terrain models	-	3	-	-	-

Finally, satellite derived bathymetry was used to identify seabed morphology and time-series of satellite derived shorelines were used to assess shorelines evolution in different temporal scales. The skill of satellite products to represent coastal features (seabed morphology) and coastal changes is discussed.

5. RESULTS

5.1. Waterlines

Figure 3 shows some examples of satellite derived waterlines from Lansat-5 (Figure 3a), Landsat 8 (Figure 3b) and Sentinel-2 (Figure 3c) missions developed for different pilot sites. In general, the waterlines agree with the coastline observed in satellite images and represents well both natural and human made features. The lines are displaced on the vicinity of ports structures, within a distance that agree with image resolutions (Figure 3d). Natural coasts are also well represented. Inconsistencies are still verified in some stretches of coast where the sediment plume or the foam resultant from wave breaking may lead to erroneous waterlines. In many cases, those noisy stretches can be identified through the Quality Control Indexes (Figure 3e).

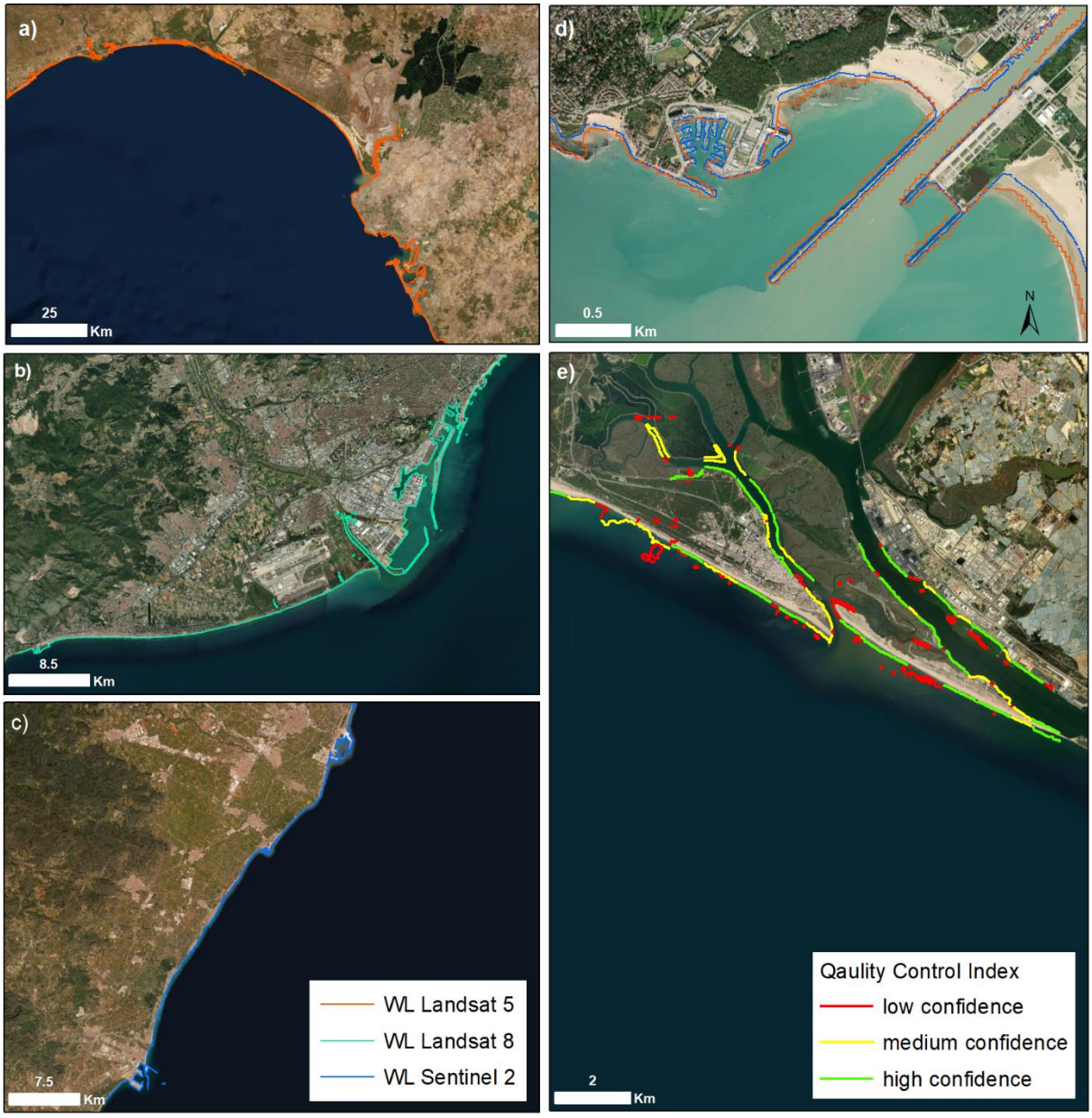

Figure 3: Examples of waterlines from the different missions: a) Landsat 5, b) Landsat 8, c) Sentinel-2; d) visual check of waterlines on hard structures and e) example of waterline with noise and the quality index attributed to each stretch of the line.

The accuracy analysis indicated that MAE and RMSE values were always bellow the pixel resolution of the satellite images from which the products were obtained (Landsat and Sentinel images present 30m and 10m resolution, respectively). Some example of the results from Landsat and Sentinel's missions are presented in Figure 4 and Figure 5.

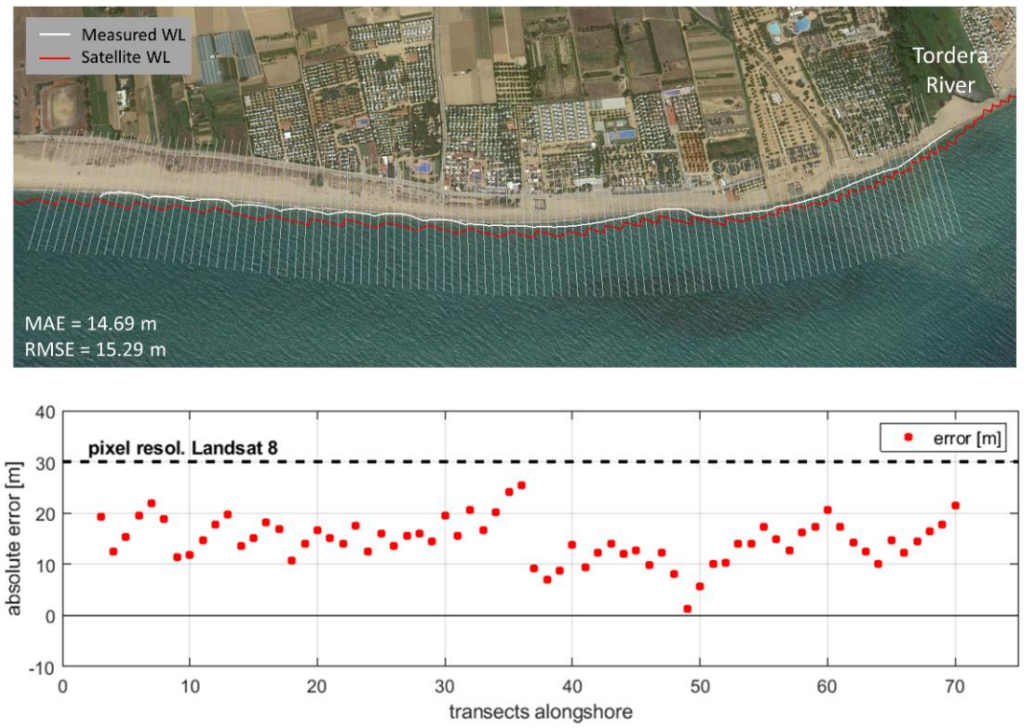

Figure 4: Accuracy of waterline from Landsat 8 in Tordera Delta.

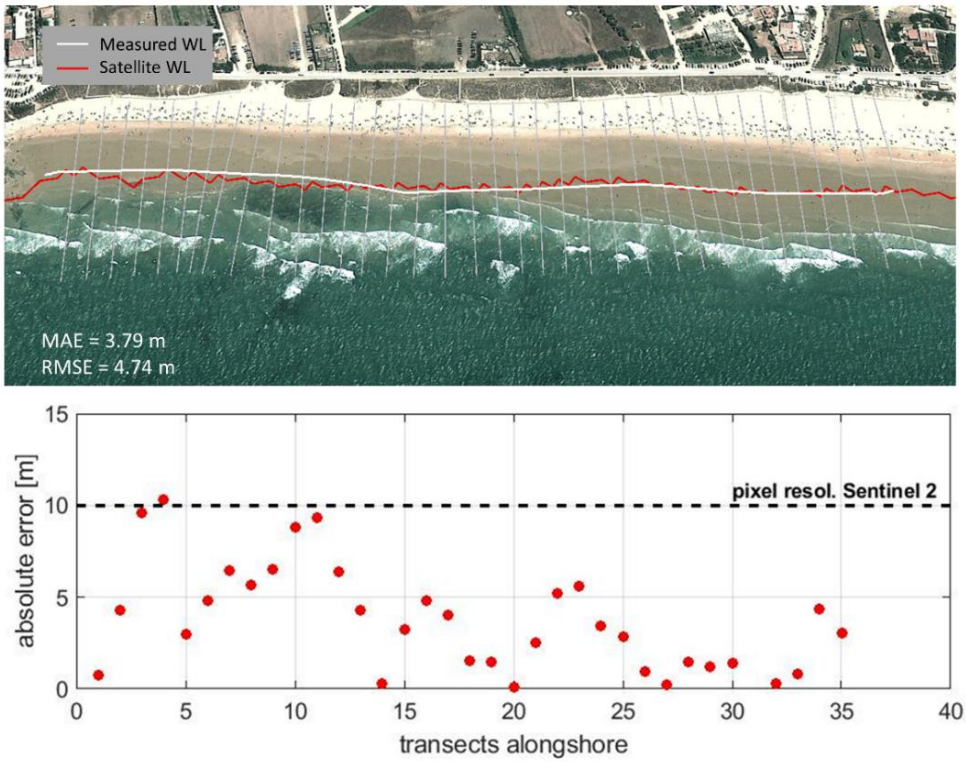

Figure 5: Accuracy of waterline from Sentinel 2 in El Palmar beach (Gulf of Cádiz).

5.2. Shorelines

Figure 6 shows some examples of satellite derived shorelines from Landsat 8 and Sentinel-2 missions developed for the Spanish pilot sites. In general, the shorelines represent correctly the tidal range observed in the pilot sites, which present different tidal regimes. Natural and artificial coastlines are well represented. As observed for waterlines, inconsistencies are present (e.g. shorelines inland in the example of Cádiz – Figure 6 – right pannel) although the lack of quality control index prevent an automatic identification of spurious shorelines in this case.

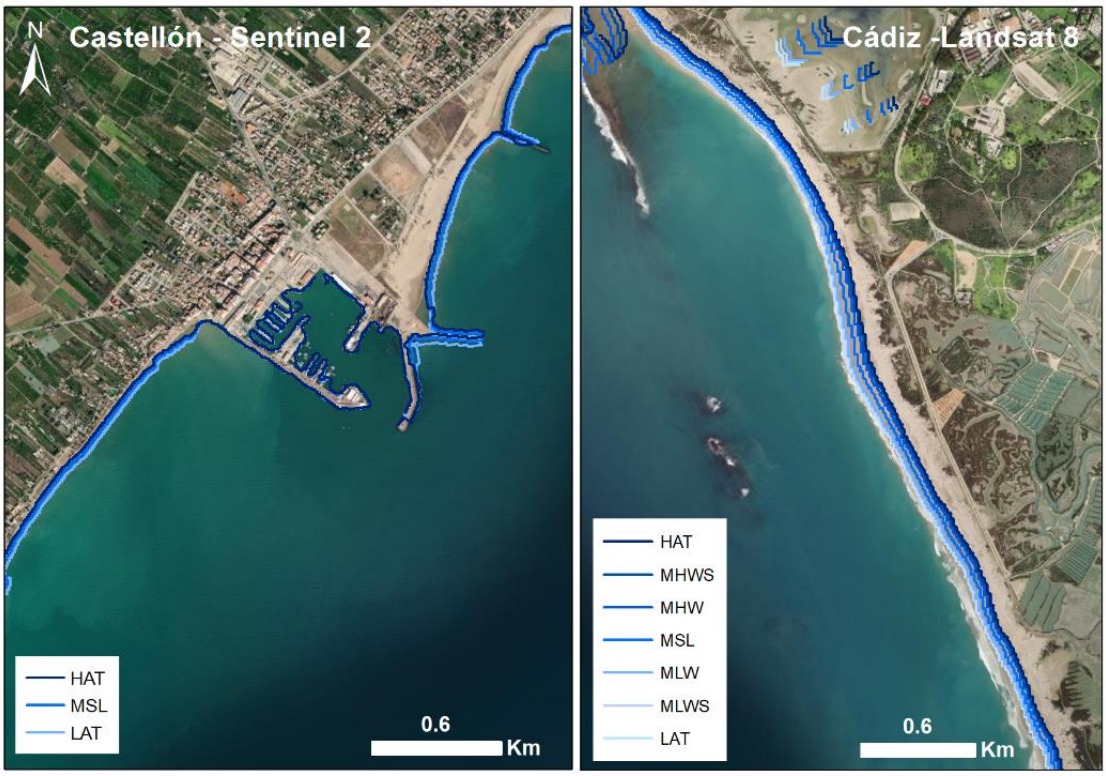

Figure 6: Examples of shorelines from the different missions: a) Sentinel 2 in the coast of Castellón and b) Landsat 8 in the coast of Cádiz. LAT: Lower Astronomical Tide, MHWS: Mean High Water Spring tide, MHW: Mean High Water, MSL: Mean Sea Level, MLW: Mean Low Water, MLWS: Mean Low Water Spring tide, LAT: Lower Astronomical Tide.

The accuracy analysis indicated MAE and RMSE values bellow the pixel resolution of the satellite images from which the products were obtained. Some example of the results from both missions are presented in Figure 7 and Figure 8.

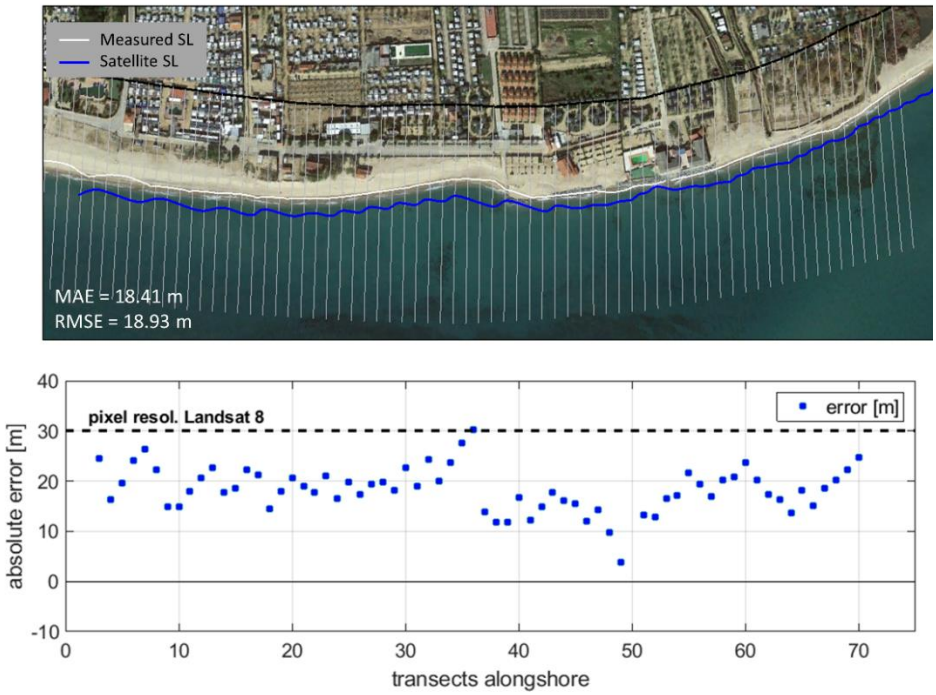

Figure 7: Accuracy of waterline from Landsat 8 in Tordera Delta.

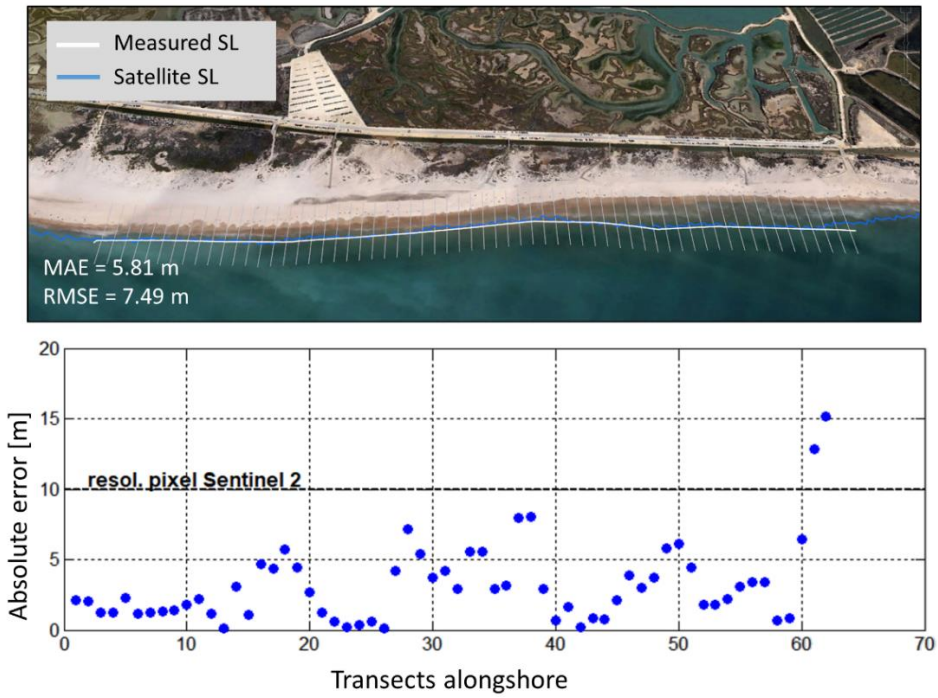

Figure 8: Accuracy of waterline from Sentinel 2 in Camposoto beach (Gulf of Cádiz).

5.3. Bathy-morpho terrain models

The visual check of satellite derived bathy-morpho terrain models indicated underestimation of water depth in areas where the sediment concentration was high (Figure 9). Quality control indexes can be used, in these cases, to identify dataset that may contain erroneous values**.**

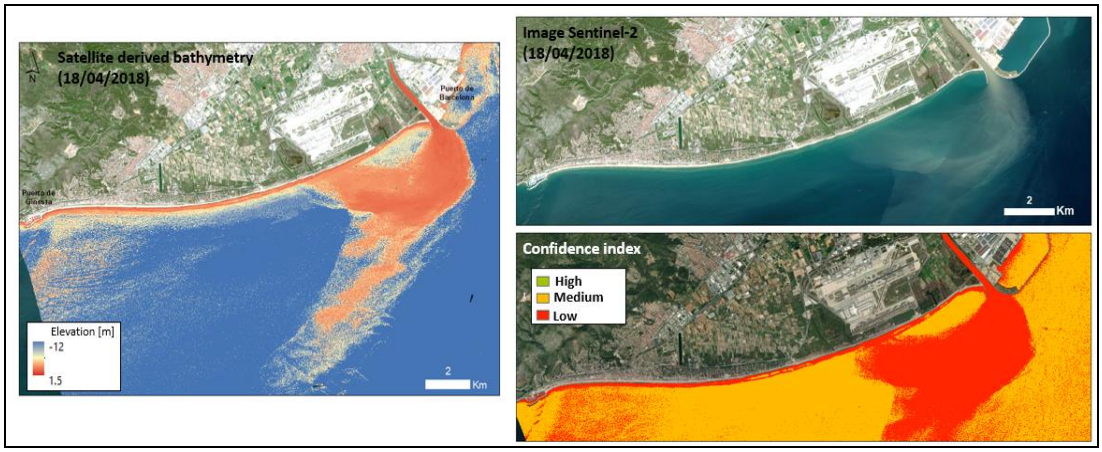

Figure 9: Bathy-mopho terrain model from Barcelona (left), satellite image from which the BMTM was derived from, and quality control index (confidence index) (right).

The accuracy assessment was carried out using BMTMs that did not show inconsistencies due to sediment concentration. MAE and RMSE values obtained from three bathymetries from the beaches of South Barcelona were equal to 0.83 m and 1.13 respectively (Figure 10). High correlation between measured and satellite depths indicates the agreement of both sources of data and the majority of the dataset present error ranging between -1 and 1m (84% of the dataset) (Figure 11). Higher errors were observed in higher depths, highlighting the limitation of the method used to estimate the bathymetry when applied to depths higher than 8m. The histograms of the errors between measured and satellite depths indicate that higher errors are observed in deeper waters (Figure 12). By limiting the analysis to depths lower than 8 m, MAE and RMSE were equal to 0.63 m and 0.77, respectively.

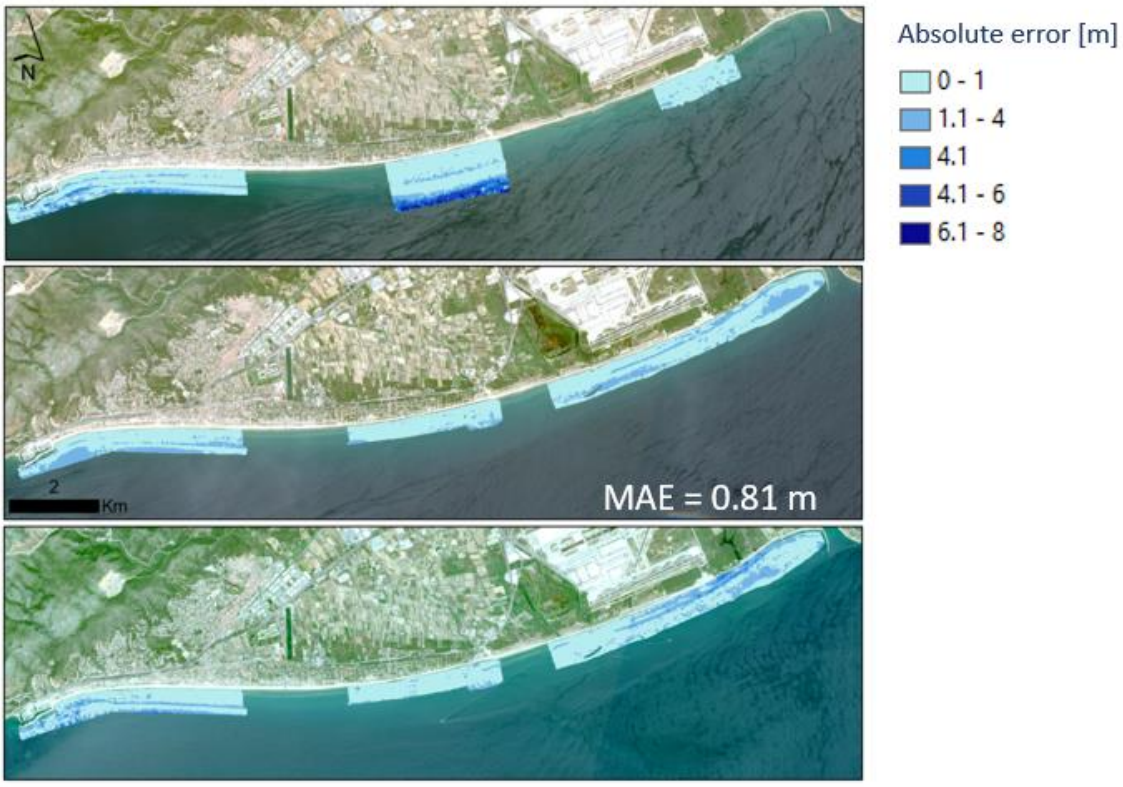

Figure 10: Absolut error (scale of colors) and MAE estimated from three satellite bathy-morpho terrain models from Barcelona.

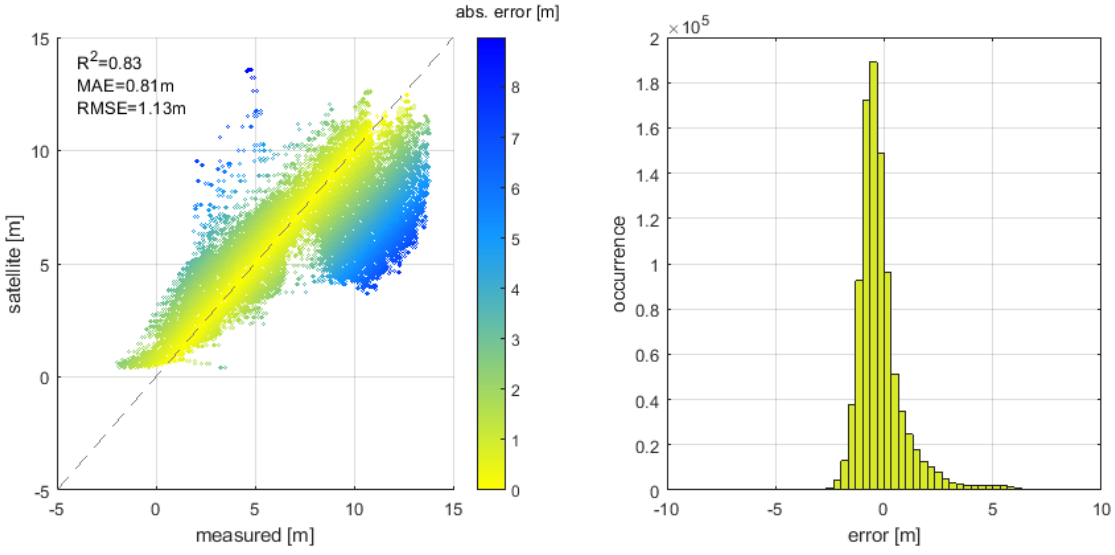

Figure 11: Correlation between measured and satellite depths (left) and histogram of errors estimated from the three bathy-morpho terrain models from Barcelona (right).

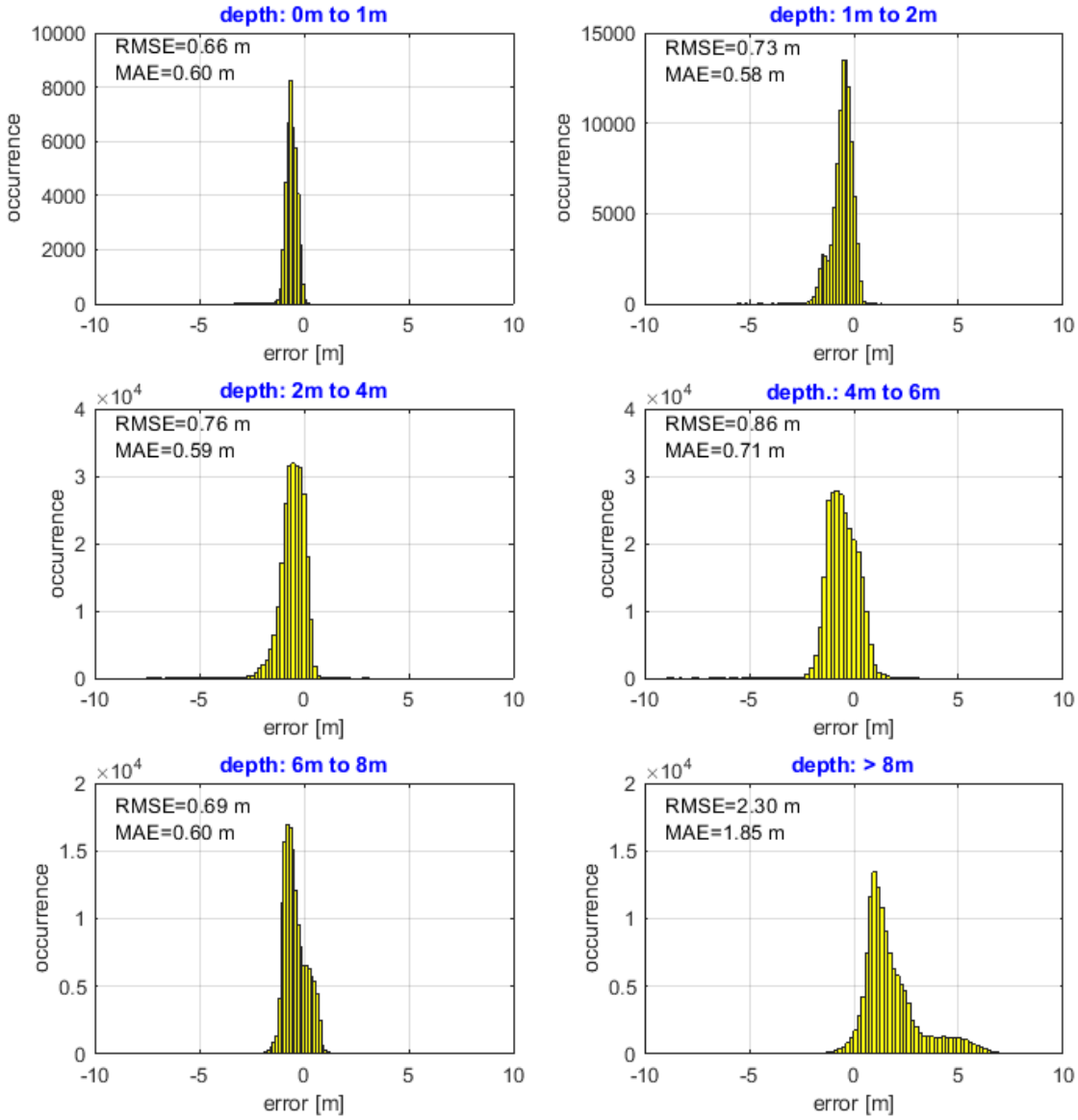

Figure 12: Histogram of errors estimated from three satellite bathy-morpho terrain models from Barcelona per range of depth.

6. DISCUSSION

6.1. Overall accuracy of satellite data

The accuracy assessment showed in the previous sessions indicate high agreement between satellite data and the ground truth. Table 4 shows the overall accuracy obtained from all dataset considered in the analysis (from all pilot sites and from the different dates). The errors estimated from all products were lower than the image resolution. For waterlines, specifically, the error was around half of the pixel size, which highlight the value of the satellite data developed.

Table 4: Overall accuracy of satellite products.

Satellite data	N	RMSE [m]	MAE [m]
Waterlines (Landsat)	1	15.29	14.69
Waterlines (Sentinel-2)	9	6.98	5.11
Shoreline (Landsat)	1	18.93	18.41
Shoreline (Sentinel-2)	6	9.93	7.49
Bathymetry (Sentinel-2: depths<8m)	3	0.77	0.63

6.2. Skill of satellite data to detect coastal features and coastal change processes

The skill of satellite products on reproducing changes and on the detection of particular coastal features was tested through several study cases on the Spanish pilot sites. The following items describe the changes detected in each case to evaluate the skill of satellite data and to show the potential of reproducing coastal changes in different temporal and spatial scales with co-registered satellite products.

6.2.1. Long-term shoreline changes in Tordera Delta

A long-term analysis was carried out in Malgrat beach using 24 years of satellite data (184 shorelines). The analysis was carried out along 68 cross-shore transects as presented in Figure 13. The cumulative shoreline movement and the resultant variation rate (calculated with a linear regression method) obtained from the long-term analysis are also represented in the Figure. Negative values indicate erosive processes. A retreat tendency is observed along the whole beach, with maximum of -6 m/year in the central area and minimum of -2.5 m/year in the northern zone. The most critical area shows a retreat of almost 150 m during the period of 24 years analyzed (e.g. transect 33). This critical zone corresponds to the area typically used by camping services (example of urban services occupying the dry beach) and which was completely removed due to long-term processes and due to extreme storm events. Shoreline variation rate, calculated using SDSLs, also agrees with values presented before. Blasco (2011) used high-resolution aerial photographs and obtained an average erosion tendency of –4.68 m/year between 1995 and 2009 in the coast southward of Tordera river moth, a value similar to the one obtained here using the SDSL (-4.79 m/year) for the same period.

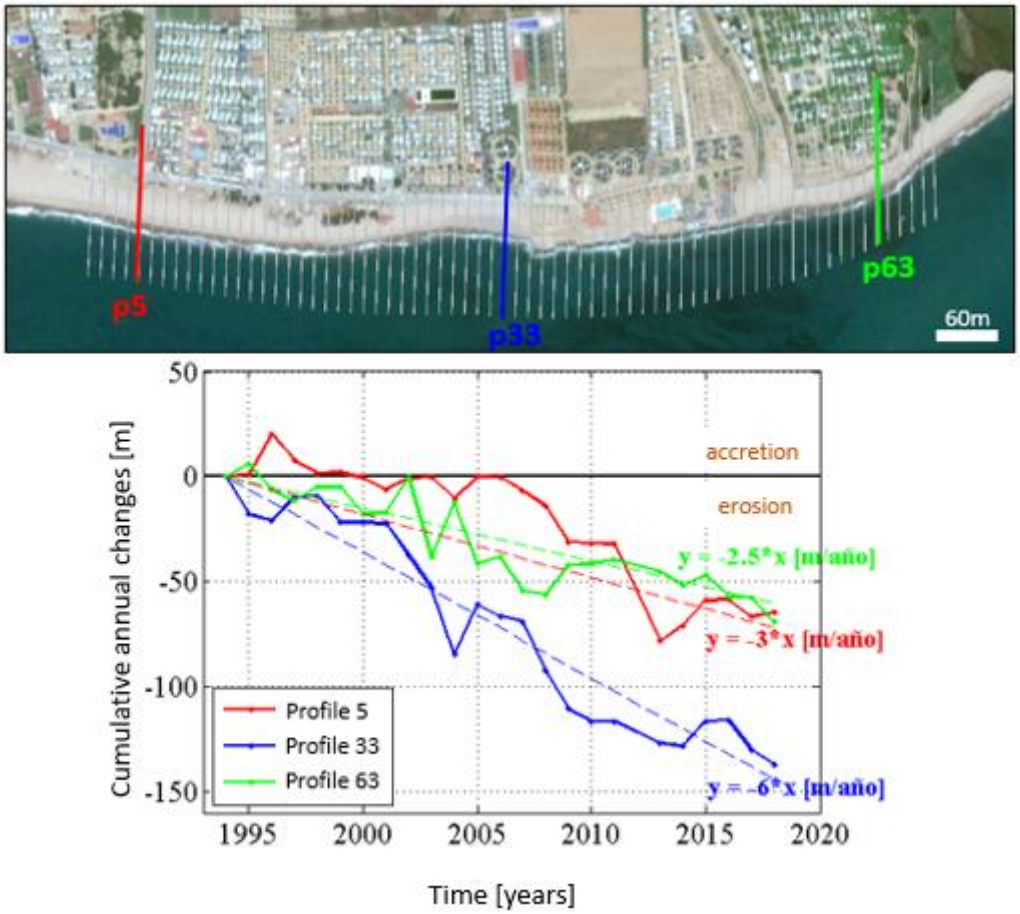

Figure 13: Long-term shoreline changes in Malgrat del Mar beach (Tordera Delta).

6.2.2. Short-term shoreline changes in Tordera Delta: detection of nourishment and erosive events

The historical shoreline variation at Malgrat beach is characterized by a sequence of retreats due to storm induced erosion events alternated with punctual human-induced actuations that takes to the shoreline advance seawards. In May 2015, for example, the continuous erosion required the authorities to carry out a nourishment project to restore and protect the beach. In the following November, a storm event hit the Cataluña coast and a significant amount of the sand dumped on the beach in the previous months was lost. Here, we analyze the shoreline evolution during 2015 events by assessing the shorelines registered immediately before and immediately after those events (Figure 14). The values obtained corroborate to those observed in-situ, highlighting the potential of this kind of data to assess short-term changes.

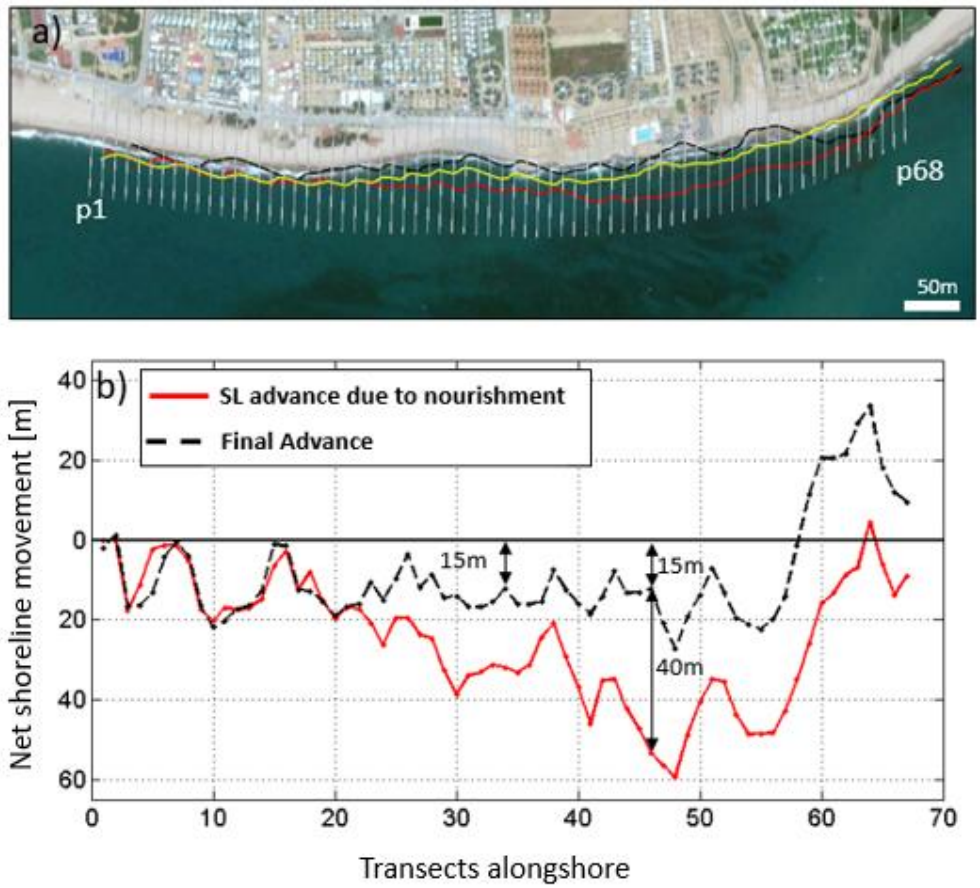

Figure 14: Short-term analysis of the events from 2015. a) Satellite derived shoreline previous to the nourishment (black line), SDSL after the nourishment (red line) and SDSL after the storm in November/2015 (yellow line). b) net shoreline movement respect to the initial (pre-nourishment) position.

6.2.3. Mid-term changes in Castellón: seasonal beach rotation

Seasonal beach rotation was reported previously in the Spanish Eastern Mediterranean coast (e.g. Ojeda and Guillén, 2008; Castelle et al., 2020). Satellite shorelines were used here to assess that process in three beaches in Castellón. Using heatmap of shorelines we could verify the difference in their main position from the summer of 2017 to the winter of 2018, and from the winter of 2018 to the summer of 2018 (Figure 15). During winter, the waves approach the coast of Castellón mainly from Northeast, taking to a longshore sediment transport southward. During summer, the waves are predominantly from Southeast, what takes to a northward drift. That seasonal process can be clearly verified with the satellite derived shorelines.

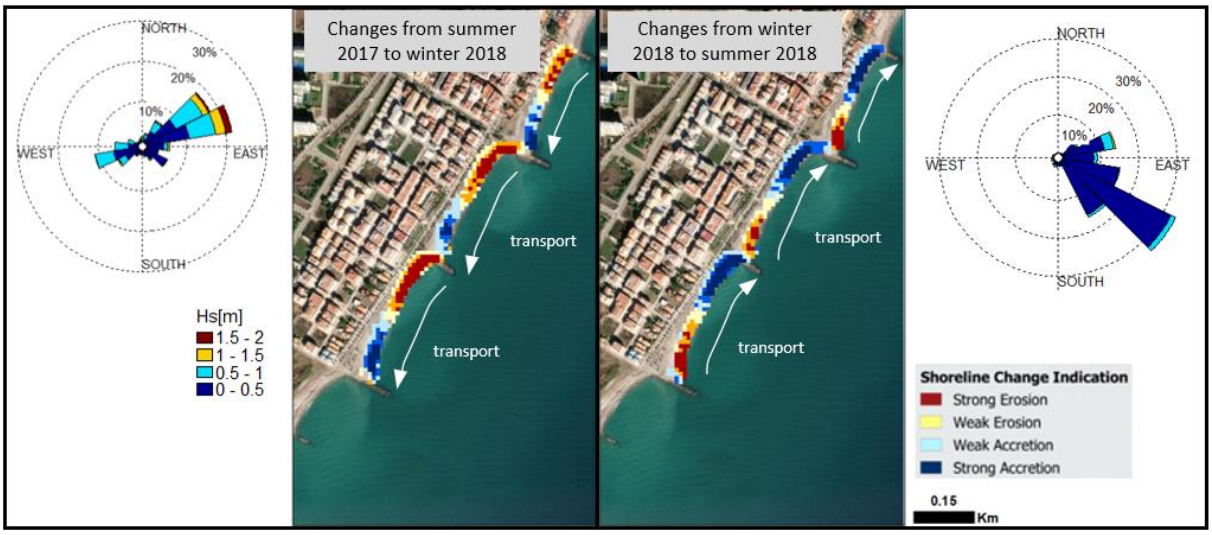

Figure 15: Seasonal beach rotation in beaches from Castellón. Left: shoreline erosion in the north and advance southwards due to the predominance of northeast waves. Right: shoreline accretion in the north and erosion southwards due to the predominance of southeast waves.

6.2.4. Long-term changes in large areas: identifying erosion hotspots in the Gulf of Cádiz

Large scale shorelines time-series were used to assess the coastal evolution along the whole Gulf of Cádiz. Shorelines from 1995 to 2019 (from Landsat and Sentinel missions) were used to obtain erosion/accretion rates in cross-shore profiles displaced every 200m (Figure 16). A general view on those trend values allows the identification of erosion and accretion hotspots. The most critical areas are identified and discussed here.

According to those results, the most critical areas in the province of Cadiz are the Punta del Montijo (Figure 16d) and the Los Toruños Spit (Figure 16e). That is in accordance to what is verified by the coastal management authorities. Punta del Montijo, for example, was identified as an area under high level of erosion by the government agency responsible for protecting the coast, the Directorate General for the Coast and the Sea – Ministerio para la Transición Ecológica y el Reto Demográfico (DGCM - MITECO) (MITECO, 2021). According to that report, historical fishing pools built with blocks of stones in front of the Punta del Montijo (see Figure 16d) facilitate the accumulation of sediment on the up drift and, consequently, its lost to deeper waters. Government and private initiatives have built breakwaters along the coast in this area, but the measures did not prevent erosion to occur. The southern part of Los Toruños Spit is a naturally dynamic estuarine area, and it was identified as presenting significant erosion rates. The area is mostly preserved and presents low degree of occupation/urbanization and the erosion, in this case, does not affect the use of the coast. Still, DGCM highlights that attention should be taken in this zone. Relatively high level of erosion was also observed in La Victoria beach (Figure 16f) which is partially related to the construction of solid structures to stabilize Santa María del Mar beach, located northwards. Those spits interrupt the input of sediment through

the longshore drift, which drives sand from North to South in this area. Erosion problems are also observed southwards from La Victoria, along El Chato beach (Figure 16f), although due to constant nourishments, that spot did not showed critical trend in this particular zone.

Some hotspots are also observed in the coast of the province of Huelva. According to CEDEX (2013) the Islantilla and Matalascañas beaches are areas of critical erosion in which the reduction of the beach width exposes the backshore during storm wave conditions. These hotspots were identified in the long-term analysis presented here (Figure 16a and Figure 16b). There is also coherence regarding areas that presents shorelines accretion. CEDEX (2013) reported the shoreline advance in the up drift of the Mazagón Port, for example. The same pattern could also be verified in our results (Figure 16b).

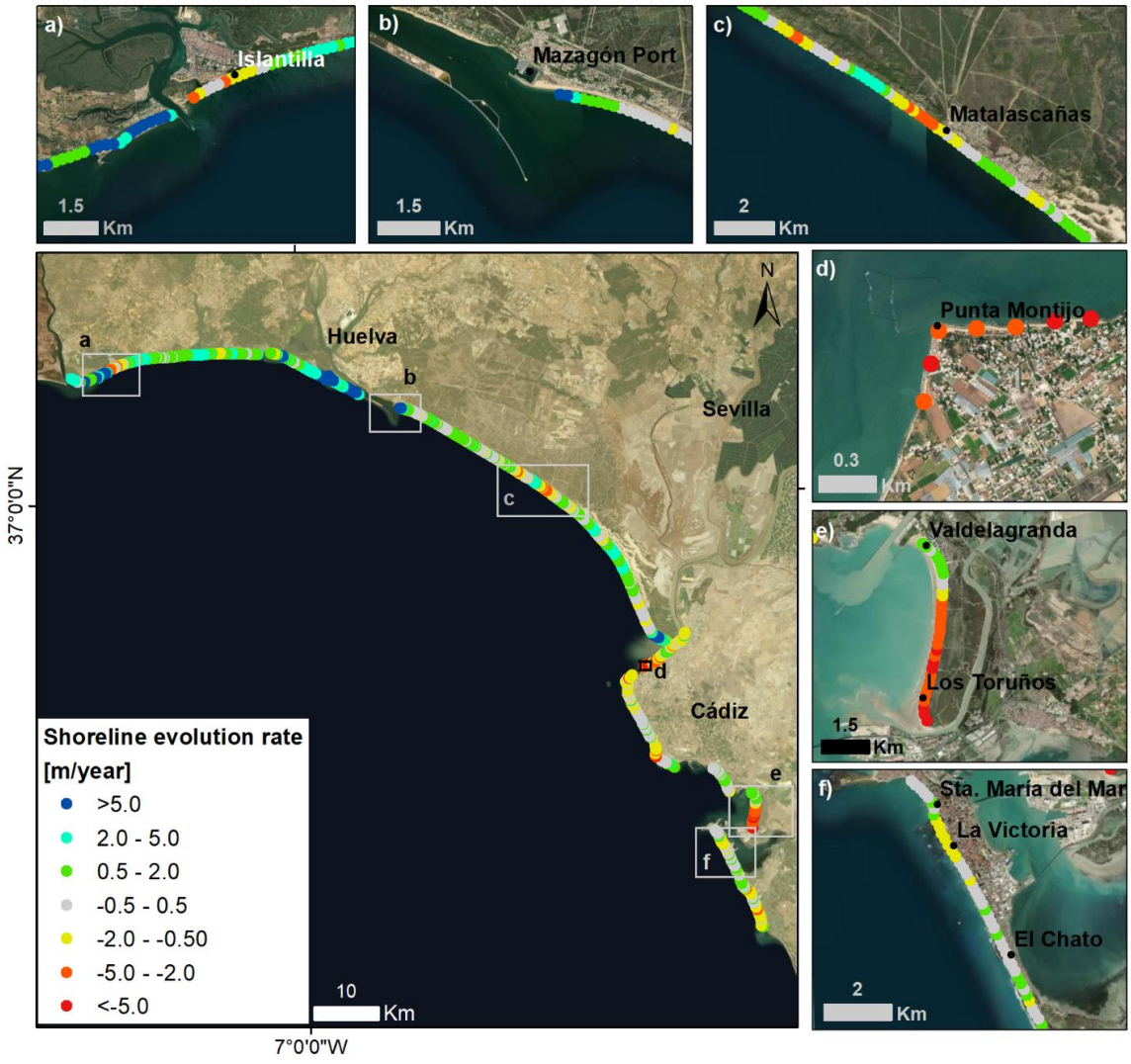

Figure 16: Long-term shoreline evolution rate along the Gulf of Cádiz. Positive (negative) values indicate erosive (accretive) trends. In detail, example of areas where critical erosive/accretive trends were verified in Huelva (a, b and c) and Cádiz (d, e and f) coasts.

6.2.5. Identification of seabed features in Barcelona

To verify if satellite bathy-morpho terrain models can be used to identify seabed morphology, the dataset from 13th June 2017 (satellite) was compared to the data from 12th June 2017 (in-situ). A longshore bar can be observed in both dataset (Figure 17) and, although some underestimation of depth values was verified, the shape of the bars was similar in both datasets (Figure 18).

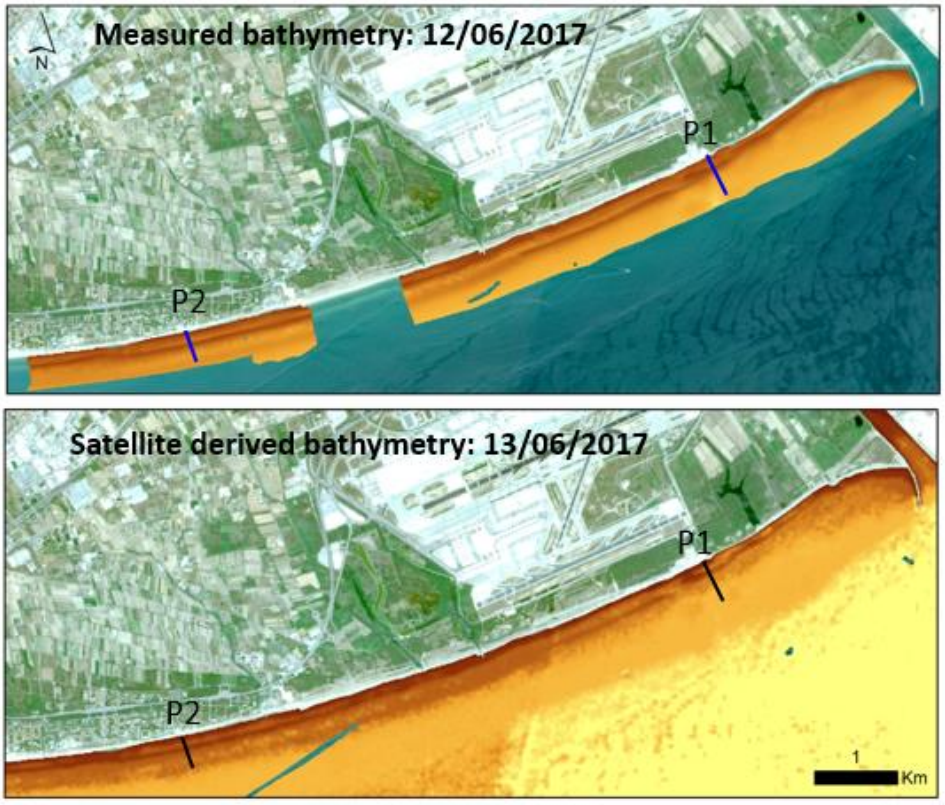

Figure 17: Measured (top image) and satellite (bottom image) bathymetries. In both, a longshore bar can be observed near the coast. P1 and P2 are the cross-shore profiles.

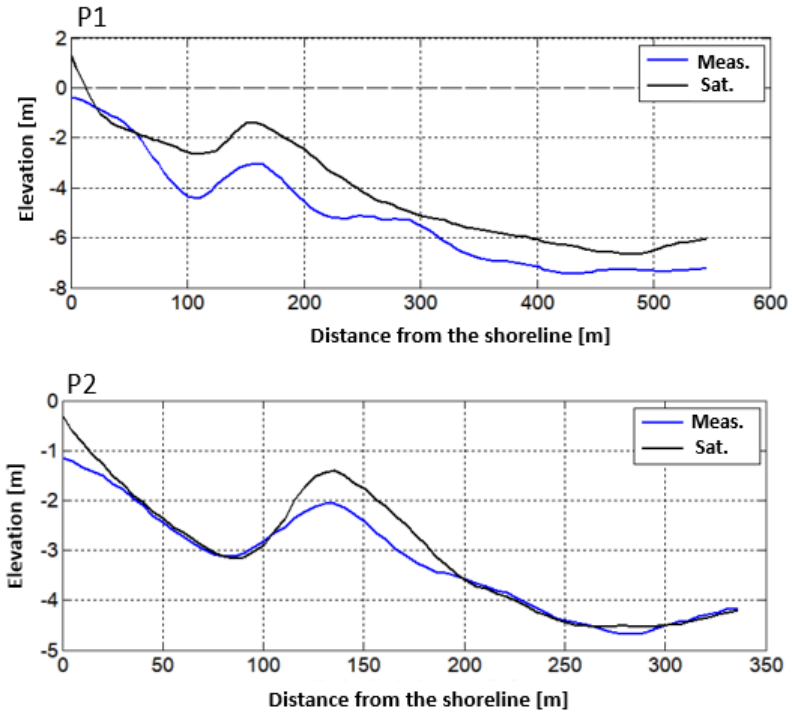

Figure 18: Measured (blue) and satellite (black) bathymetries along profiles P1 and P2. Profiles location are presented in Figure 17.

6.3. Improvements with respect to satellite waterlines obtained from existing open source tools

Recently, some open-source tools were developed with the aim of providing automatic waterlines from Google Earth Engine information (e.g. Vos et al., 2019). Those tools are useful and have been widely used by the coastal community. However, they were calibrated with data from a few beaches, and may not work perfectly for all sites, especially those with particular characteristics that do not coincide with calibration areas. This may be true, for example, during low tide in areas where the tidal range is significant. To test that hypothesis, the satellite derived waterlines from the coast of Cádiz (mesotidal) and Castellón (microtidal) were assessed and compare to those obtained from CoastSat Tool (Vos et al., 2019) (Figure 19). As expected, during low tide in Cádiz coast, the waterline detected by CoastSat tool, is displaced landward, in the middle of the intertidal area, while the detection seems to be more accurate in Castellón's coast.

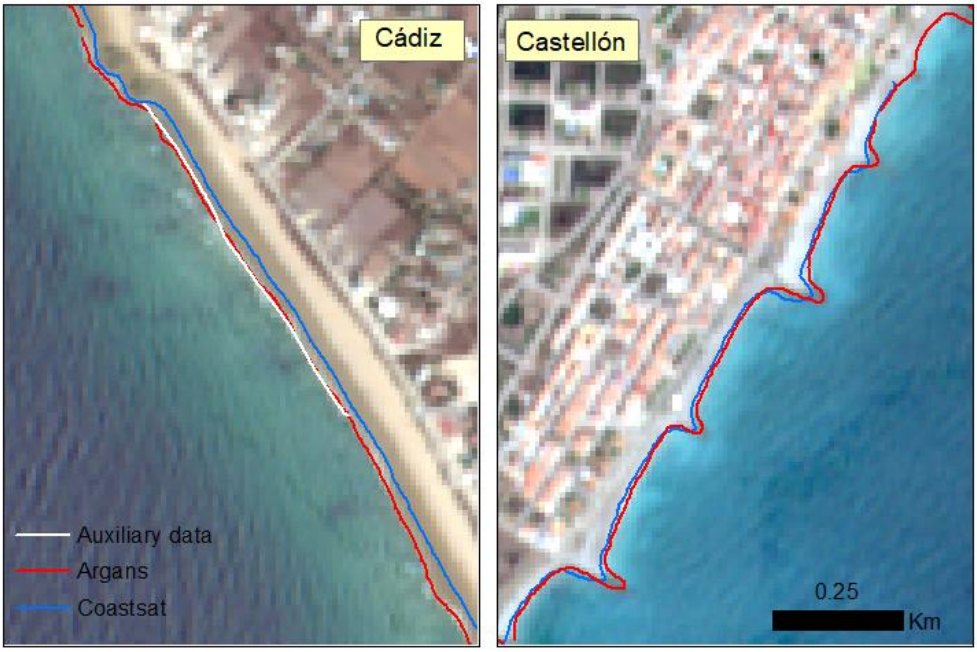

Figure 19: Waterlines obtained from in-situ measurements (white line), satellite data from Argans (red line) and satellite data from CoastSat tool (blue line).

7. CONCLUSIONS

Based on the results obtained from the validation analysis the following conclusions were obtained:

- The set of selected pilot sites made possible to validate satellite derived products in a wide variety of spatial scales and under different marine conditions.
- The satellite data presented an error (depending on the image resolution) lower than the image resolution.
- The satellite derived waterlines presented similar accuracy on microtidal areas when compared to those generated from currently available tools. Although there was significant improvement on waterlines detection in areas of significant tidal range, especially during low tide.
- The shorelines allowed the assessment of morphodynamic processes in different temporal scales and the identification of critical zones.
- It was verified that, even in areas of high sediment concentration in the water, it is possible to generate quality bathymetry under

There are still some limitations that should be highlighted:

- The sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, what affect the analysis of changes and identification of seabed morphology.

- To obtain high quality products, some auxiliary data (in-situ measurements) are still necessary. The amount of these required auxiliary data is very little in comparison to the in-situ measurements required for the traditional monitoring methods.

- The validation procedure was applied to products derived from optical sensors. The development of coastal information from radar sensors is quite challenging and satellite derived products were not assessed in the Spanish pilot sites. Nevertheless, some advances were made in terms of improving the knowledge on this kind of sensors for coastal analysis, and similar long-term changes could be already observed. Because of the nature of radar detection (e.g. SAR detection is not sensible to the presence of clouds), the use of radar information represent a big step in terms of coastal change analysis since it can fill the gaps from optical data and increase the temporal frequency of the time-series. Recent advances regarding radar products may change the way coastal monitoring is carried out nowadays.

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ANNEX B – SERVICE ASSESSMENT SHEET – PRODUCTS EVALUATION HIGHLIGHTS

Waterline Highlights

Optical waterlines in the Spanish pilot sites cover various environmental conditions (different tidal range, wave conditions and cloud cover) and under different spatial scales. It is remarkable that the optical products developed proved to be applicable at larger scales, as per the pilot site that covers the whole Gulf of Cadiz. Time series covered the period from 1995 to 2020, a total of 25 years of data, which accomplishes with the user's requirement of temporal coverage.

Although the accuracy requirements for waterline products specified by the Spanish end-user in the URD were not accomplished (1 m horizontal), those requirements were mainly aspirational, and the results obtained show that the products are still useful for many of the purposes of SGPC's practices. Some practices, however, still demand higher accuracy, which is expected to be achieved with higher resolution images from future EO missions.

The knowledge on the processing of radar information to obtain coastal products is still limited and SAR products could not achieve the end-user's requirements. On the other hand, the analysis of waterline (SAR) evolution showed good agreement with those obtained from long term analysis using optical shorelines in Tordera. This highlights the potential of this kind of products to predict coastal change.

Shoreline Highlights (SDSL)

The results obtained for SDSL-opt indicate high accuracy, according to the image resolution.

Optical shorelines (SDLS-opt) were delivered in shapefile format as required by the end-user. Regarding the auxiliary data required to derive shorelines from waterlines, a metadata file for each product provides the complete information about the raw data and the dataset used by the processors. Products names are now standard and provide the basic information for the end-user. However, there are some inconsistencies in the shorelines that cannot be automatically detected due to the lack of a confidence index.

Radar shorelines (SDSL-sar) were not developed for the Spanish pilot sites.

Land Cover (LC) map Highlights

No LC was developed for those sites where the end-user has specific interest on monitoring changes in land cover, such as Tordera, San Sebastian, Salinas, El Puntal and Maspalomas. LC maps were developed in some of the Spanish Pilot sites with the aim to support the waterline detection in certain areas. However, the Spanish end-user (SGPC) is specifically interested on monitoring the spatial cover of ecosystems and infrastuctures, and the use of the products for that purpose could not be tested.

Satellite Derived Bathymetry (SDB) Hightlights

The analysis of SDB from Barcelona showed that, in some areas of high suspended sediment concentration, it is possible to generate quality bathymetry under certain conditions. Still, accurate SDB could not be generated for all tested pilot sites.

Generally speaking, the sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, and the temporal range and sampling frequency required for this EO Product could not be accomplished.

The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products.

Although some results indicate the potential of SDB products, the end-user considers that further research is necessary to relate coastal erosion with changes in those 3D products.

ANNEX B. SERVICE ASSESSMENT SHEET–WATERLINES

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

Specifications of satellite derived waterlines (SDW) requirements from the Spanish end-user (SGPC-MITECO/IHC) were presented in Table 27 of the User Requirement Document (page 92 – same as shorelines). The evaluation process was carried out considering the perspective of the champion end-user based on the results of the product's validation, but it was also backed up by the evaluation of the broad end-user community (see details of the evaluation procedure in Annex C).

The Spanish end-user considers the adequacy of the requirements (including accuracy) of waterlines products high for the following reasons:

- Optical waterlines (SDW-opt) were delivered in four pilot sites. 1767 waterlines were provided for Tordera (235), Barcelona (221), Castellón-Sagunto (242) and the Gulf of Cádiz (1069). The products could not be developed for all sites mentioned in the URD, since service providers and end-users agreed that efforts should be focused on improving the quality of the products instead of enlarging the spatial coverage. Still the results obtained from those four sites allowed verifying the quality of the waterlines in areas with different environmental conditions (different tidal range, wave conditions and cloud cover) and under different spatial scales.

- Although the accuracy requirements for waterline products specified by the Spanish end-user in the URD were not accomplished (1 m horizontal), those requirements were mainly aspirational, and the results obtained show that the products are still useful for many of the purposes of SGPC's practices.

- SDW-opt time series covered the period from 1995 to 2020, a total of 25 years of data, which accomplishes with the user's requirement of temporal coverage.

- Radar waterlines (SDW-sar) were delivered for two pilot sites in Spain: El Prat (Barcelona) and Malgrat (Tordera Delta) beaches. A total of 798 waterlines (proxy-based: instantaneous position of sea-land interface) were provided for Barcelona coast, while 655 were produced for Tordera Delta coast. The knowledge on the processing of radar information to obtain coastal products is still limited and SAR products could not achieve the end-user's requirements. On the other hand, the analysis of waterline (SAR) evolution showed good agreement with those obtained from long term analysis using optical shorelines in Tordera. This highlights the potential of this kind of products to predict coastal change.

- Finally, it is important to highlight that the interest of the end-user goes beyond the 25 years historical record, to build longer time-series (horizon of 100 years). The end-user confirmed the utility of SDW-opt for applications in near future, although the development of the products for the next 75 years would be conditioned by future funding opportunities.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user qualifies the compliance to the user requirements for SDW as high for the following reasons:

- Waterlines from optical sensors accomplished most of the requirements. Spatial scope, temporal coverage and temporal resolution allowed the analysis in different temporal and spatial scales.
- Although the accuracy requirements for waterline products specified by the Spanish end-user in the URD were not accomplished (1 m horizontal), those requirements are mainly aspirational, and the results obtained show that the products are still useful for many of the purposes of SGPC's practices. Yet, more details about the precision of the method used to extract the waterlines from images are still desirable to ensure the credibility of such products, a point highlighted by some of the key end-users from the broad community (see Annex C).
- The waterlines were developed in 4 of the 9 pilot sites in Spain. Still, the analyses of the waterlines in those sites allowed assessing the products under different environmental conditions.
- Products names are now standard and provide the basic information for the end-user. Besides, a metadata file for each product provides the complete information about the raw data and the dataset used by the processors.
- Optical waterlines were delivered in the format as required by the end-user.

The points listed above could not be verified in radar products and the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user consider the accuracy compliance of waterline products as high for the following reasons:

- Although the accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for some of the purposes of SGPC's practices, such as coastal characterization and the detection of some coastal change processes.
- Some practices, however, still demand higher accuracy. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C). Higher accuracy is expected to be achieved with higher resolution images from future EO missions.

The accuracy obtained from radar products, however, is still not enough to allow the use of these products in current practices, and the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user consider the confidence in the quality of waterlines products high for the following reason:

- The products from optical sensors passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in those satellite products allow the identification of the stretches of waterlines that may be the result of errors from the detection technique.

The same is not true for radar products and the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user qualifies the confidence in product quality as high for the following reasons:

- The products from optical sensors passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in those satellite products allows the identification of the stretches of waterlines that may contain erroneous information. This kind of information facilitates the automatization of the pre-processing of waterlines and so, enhance the utility of the products.

- High accurate products from co-registered images, ensure that changes verified along the time series (with images from different missions) are more reliable.

- Still, more details about the precision of the method used to extract the waterlines from images would increase the credibility of such products, a point highlighted by some of the key end-users from the broad community (see Annex C).

Radar products did not accomplish the end-user requirements and cannot be used in coastal monitoring practices yet, since further research on SAR processing is still necessary. Thus, the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
			x

Comments:

The end-user considers that the impact of the service and products on current practices is high because of the following reasons:

- The results obtained for SDW-opt indicate high accuracy, according to the image resolution.
- The SDW-opt can be developed in different spatial scales (from small beaches to regional scales).
- The use of co-registered images allowed to achieve long temporal coverage (25 years) and high frequency sampling (from recent Sentinel missions).
- The final time-series allows the assessment of coastal change in different spatial and temporal scales.

There was high expectation on radar products and, for now, those data cannot be incorporated into current practices. Thus, the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user considers that the probability of integrating service and products provided for waterlines to existing practices is high for the following reasons:

- Given the reasons pointed in items B.2 and B.3, the end-user consider that SDW-opt products can be integrated in current practices in near future.
- Some practices still demand higher accuracy, which is expected to be achieved with higher resolution images from future EO missions. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).

The advances on SDW-sar were not enough to allow the incorporation of radar data into monitoring practices, and more research on that topic is still necessary. The HIGH score in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

End-User : SGPC (MITECO) - IHC
Contact : Dr Jara Martinez Sanchez email: jara.martinez@unican.es
Version : 17/02/2021
Filename : SGPC_ANNEXB_Waterlines

ANNEX B - PRODUCTS EVALUATION

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:
The Spanish end-user consider that part of the waterline products needs further improvements and qualify it as medium for the following reason:

- More details about the precision of the method used to extract the waterlines from images would be desirable to ensure the credibility of such products, a point highlighted by some of the key end-users from the broad community (see Annex C).

- SDW-sar still need further improvements and more research on methods for processing radar information are still necessary to achieve the development of reliable products. The possibility of using optical and radar shorelines and waterlines together may provide data in higher frequency and wider temporal coverage, which would allow a complete change in the approach of waterline analysis. This deserves further attention in the future.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user consider the need for large scale demonstration as low for the following reason:

- The examples of optical products developed to the whole Gulf of Cadiz proved that the methodologies applied are applicable to larger scales.

As mentioned in previous items, further improvements on SAR products in both, short and large spatial scales are still necessary. Thus, the LOW evaluation presented in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
			x

Comments:
The Spanish end-user evaluates products provided as high for the following reasons:

- Although the horizontal accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for the purposes of SGPC's practices.
- High accurate products from co-registered images, ensure that changes verified along the time series (with images from different missions) are more reliable.
- Although it was not possible to develop the products for all pilot sites mentioned in the URD, the results obtained from those four sites allowed verifying the quality of the waterlines in areas with different environmental conditions (different tidal range, wave conditions and cloud cover) and under different spatial scales.
- The products from optical sensors passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in EO Products allows the identification of the stretches of the waterlines that may contain erroneous information. This kind of information facilitates the automatization of the pre-processing procedures and so, enhance the utility of the products.

The advances on SDW-sar, however, were not enough to allow the incorporation of radar data into monitoring practices, and more research on that topic is still necessary. Thus, the HIGH evaluation presented in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			x

Comments:

The possibility of using optical and radar shorelines together may provide time series with higher temporal frequency, which would allow a complete change in the way that shoreline analysis is carried out nowadays. More research on that topic is still necessary to achieve dataset reliable for the use in coastal monitoring.

***L**ow; **M**edium; **H**igh

ANNEX B. SERVICE ASSESSMENT SHEET– SHORELINES

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

Specifications of satellite derived shorelines (SDSL) requirements from the Spanish end-user (SGPC-MITECO/IHC) were presented in Table 27 of the User Requirement Document (page 92). The evaluation process was carried out considering the perspective of the champion end-user based on the results of the product's validation, but it was also backed up by the evaluation of the broad end-user community (see details of the evaluation procedure in Annex C).

The Spanish end-user consider the adequacy of the requirements (including accuracy) of shorelines products high for the following reasons:

- Optical shorelines (SDSL-opt) were delivered in four pilot sites. 7753 shorelines (considering different datum references) were provided for Tordera (190 x 3 datums), Barcelona (82 x 3 datums), Castellón-Sagunto (133 x 3 datums) and the Gulf of Cádiz (934 x 7 datums). The products could not be developed for all sites mentioned in the URD, since service providers and end-users agreed that efforts should be focused on improving the quality of the products. Still the results obtained from those four sites allowed verifying the quality of the waterlines in areas with different environmental conditions (different tidal range, wave conditions and cloud cover) and under different spatial scales.

- Although the accuracy requirements for shoreline products specified by the Spanish end-user in the URD were not accomplished (1 m horizontal), those requirements were mainly aspirational, and the results obtained show that the products are still useful for many of the purposes of SGPC's practices.

- SDSL-opt time series covered the period from 1995 to 2020, a total of 25 years of data, which accomplishes with the user's requirement of temporal coverage.

- Radar shorelines (SDSL-sar) were not developed for the Spanish pilot sites. The knowledge on the processing of radar information to obtain coastal products is still limited and, since SAR waterlines did not achieve the end-user's requirements, no shoreline were delivered. Initial analysis of SAR waterline evolution showed good agreement with those obtained from long term analysis using optical shorelines in Tordera. This highlights the potential of this kind of products to predict coastal change. The possibility of using optical and radar shorelines together may provide time series with higher temporal frequency, which would allow a complete change in the way that shoreline analysis is carried out nowadays. More research on that topic is still necessary to achieve dataset reliable for the use in coastal monitoring.

- Finally, it is important to highlight that the interest of the end-user goes beyond the 25 years historical record, to build longer time-series (horizon of 100 years). The end-user confirmed the utility of SDW-opt for applications in near future, although the development of the products for the next 75 years would be conditioned by future funding opportunities.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user qualifies the compliance of user requirements for SDSL as high for the following reason:

- Shoreline from optical sensors accomplished most of the requirements. Spatial scope, temporal coverage and temporal resolution allowed the analysis in different temporal and spatial scales.
- Although the horizontal and vertical accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for some of the purposes of SGPC's practices.
- The shorelines were developed in 4 of the 9 pilot sites in Spain. Still, the analyses of the SDSL-opt in those sites allowed assessing the products under different environmental conditions.
- Products names are now standard and provide the basic information for the end-user. Besides, a metadata file for each product provides the complete information about the raw data and the dataset used by the processors.
- Optical shorelines were delivered in shapefile format as required by the end-user.

Shorelines from radar sensors were not assessed and the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user consider the accuracy compliance of shoreline products as high for the following reasons:

- Although the accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for the purposes of SGPC's practices, such as coastal characterization and the detection of some coastal change processes.
- Some practices, however, still demand higher accuracy, which is expected to be achieved with higher resolution images from future EO missions. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).

Shorelines from radar sensors were not assessed and the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user consider the confidence in the quality of shorelines products medium for the following reason:

- The products from optical sensors passed through a series of verification, quality control and validation procedures. However, there are some inconsistencies in the shorelines that cannot be automatically detected due to the lack of a confidence index.

Shorelines from radar sensors were not assessed and the MEDIUM evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user qualifies the confidence in product quality as medium, for the following reasons:

- The products from optical sensors passed through a series of verification, quality control and validation procedures. However, there are some inconsistencies in the shorelines that cannot be automatically detected due to the lack of a confidence index.

- High accurate products from co-registered images, ensure that changes verified along the time series (with images from different missions) are more reliable.

Shorelines from radar sensors were not assessed and the MEDIUM evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
			x

Comments:
The end-user considers that the impact of the service and products on current practices is high because of the following reasons:

- The results obtained for SDSL-opt indicate high accuracy, according to the image resolution.
- The SDSL-opt can be developed in different spatial scales (from small beaches to regional scales).
- The use of co-registered images allowed to achieve long temporal coverage (25 years) and high frequency sampling (from recent Sentinel missions).
- The final time-series allows the assessment of coastal change in different spatial and temporal scales.

There was high expectation on radar products and, for now, those data cannot be incorporated into current practices. Thus, the HIGH evaluation in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user considers that the probability of integrate service and products provided for shorelines to existing practices is high for the following reasons:

- Given the reasons pointed in items B.2 and B.3, the end-user consider that SDSL-opt products can be integrated in current practices in near future.
- Some practices still demand higher accuracy, which is expected to be achieved with higher resolution images from future EO missions. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).
- The need for in-situ topography to define the beach slope used to develop reliable shorelines may limit the applicability to other pilot sites or to dates in which auxiliary information is not available (as highlighted by some of the key end-users - see Annex C). Still, the possibility of using satellite waterlines and tidal gauges information to obtain those values, may overcome that issue.

The advances on SDW-sar were not enough to allow the development of SDSL-sar and the incorporation of radar data into monitoring practices. More research on that topic is still necessary. The HIGH score in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

End-User : SGPC (MITECO) - IHC
Contact : Dr Jara Martinez Sanchez email: jara.martinez@unican.es
Version : 17/02/2021
Filename : SGPC_ANNEXB_Shorelines

ANNEX B - PRODUCTS EVALUATION

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user consider that part of the shoreline products needs further improvements and qualify it as medium for the following reason:

- More details about the precision of the method used to extract the waterlines from images would be desirable to ensure the credibility of such products, a point highlighted by some of the key end-users from the broad community (see Annex C).
- There are some inconsistencies in the shorelines that cannot be automatically detected due to the lack of a confidence index. In the future, shorelines should inherit the same quality index attributed to the original waterline.
- Given the accuracy obtained from SAR waterlines, the shorelines from radar sensors were not developed. Further improvements and more research on methods for processing radar information are still necessary to achieve the development of reliable products. The possibility of using optical and radar shorelines together may provide data in higher frequency and wider temporal cover, which would allow a complete change in the approach of shoreline analysis. This deserves further attention in the future.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
	x		

Comments:
The Spanish end-user consider the need for large scale demonstration as low for the following reason:

- The examples of optical products developed to the whole Gulf of Cadiz proved that the methodologies applied are applicable to larger scales.

As mentioned in previous items, further improvements on SAR products in both, short and large spatial scales are still necessary. Thus, the LOW evaluation presented in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
			x

Comments:
The Spanish end-user evaluates products provided as high for the following reasons:

- Although the horizontal accuracy did not accomplish the aspirations of the end-user, the dataset provided is still useful for the purposes of SGPC's practices.
- High accurate products from co-registered images, ensure that changes verified along the time series (with images from different missions) are more reliable.
- Although it was not possible to develop the products for all pilot sites mentioned in the URD, the results obtained from those four sites allowed verifying the quality of the waterlines in areas with different environmental conditions (different tidal range, wave conditions and cloud cover) and under different spatial scales.
- The products from optical sensors passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in shorelines when compared to the ground truth, the quality indexes included in EO Products allows the identification of the stretches of the shorelines that may contain erroneous information. This kind of information facilitates the automatization of the pre-processing procedures and so, enhance the utility of the products.

The advances on SAR waterlines, however, were not enough to allow the development of radar shorelines and, thus, their incorporation into monitoring practices. More research on that topic is still necessary. The HIGH evaluation presented in this item concerns optical products only.

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			x

Comments:

- There are some inconsistencies in the shorelines that cannot be automatically detected due to the lack of a confidence index. In the future, shorelines should inherit the same quality index attributed to the original waterlines from which they come from.
- The possibility of using optical and radar shorelines together may provide time series with higher temporal frequency, which would allow a complete change in the way that shoreline analysis is carried out nowadays. More research on that topic is still necessary to achieve dataset reliable for the use in coastal monitoring.

***L**ow; **M**edium; **H**igh

ANNEX B. SERVICE ASSESSMENT SHEET – LAND COVER MAPS

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Specifications of Land Cover (LC) map requirements from the Spanish end-user (SGPC-MITECO/IHC) were presented in Table 28 (page 95) of the User Requirement Document.

The Spanish end-user consider the adequacy of the requirements (including accuracy) of LC maps medium for the following reasons:

- 7 LC maps were developed for two pilot sites in Spain: Barcelona (4) and the Gulf of Cádiz (3). No LC was developed for those sites where the end-user has specific interest on monitoring changes in land cover, such as Tordera, San Sebastian, Salinas, El Puntal and Maspalomas. However, from what was seen from the results obtained for other countries, there is potential on developing and applying those LC in the required sites, what takes to believe that there was no limitation regarding that requirements.
- The products delivered for the Spanish sites did not presented the frequency necessary to monitor seasonal changes (4 months). Although, LC maps were developed with the aim of supporting the waterline detection in certain areas, and the development of this type of products with the specific goal of monitoring land cover changes could not be tested. From the results obtained in other countries, the end-user assumes that there is potential to develop the products in the desired temporal frequency in the future.
- Further research is still necessary to relate coastal erosion/changes with those 2D products.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user qualifies the compliance to the user requirements for LC maps as low for the following reasons:

- No LC was developed for those sites where the end-user has specific interest on monitoring changes in land cover, such as Tordera, San Sebastian, Salinas, El Puntal and Maspalomas.
- The products delivered for the Spanish sites did not presented the frequency necessary to monitor seasonal changes (4 months).
- LC maps were developed with the aim of supporting the waterline detection in certain areas, and the development of this type of products with the specific goal of monitoring land cover changes could not be tested.
- The results presented from other countries suggest that there is a potential on the use of LC products. However, the main goal on the use of LC is different from country to country. The Spanish end-user is specifically interested on monitoring the spatial cover of ecosystems and infrastuctures, and the use of the products for that purpose could not be tested.
- The products delivered for the Gulf of Cádiz showed the potential to develop that type of products in large spatial scale, although the quality still must be tested.
- The products delivered for Barcelona and Cádiz accomplished some of the requirements regarding layer contents (classes of land cover).

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user consider the accuracy compliance of LC maps as low for the following reason:

- LC maps were developed for Barcelona and the Gulf of Cádiz, and no auxiliary data was available in those sites to validate the products.

***L**ow; **M**edium; **H**igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user consider the confidence in the quality of LC maps products as low for the following reasons:

- LC maps were developed for Barcelona and the Gulf of Cádiz, and no auxiliary data was available in those sites to validate the products.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user qualifies the confidence in product quality as low for the following reason:

- The products are still in a very early stage of development to allow to make an evaluation of the utility of the products.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user consider that this product present low impact on current end-user practices for the following reasons:

- The products are still in a very early stage of development to allow to make an evaluation of the utility of the products.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The end user considers that the probability of integrating LC maps into existing practices is medium for the following reason:

- LC maps were developed with the aim of supporting the waterline detection in certain areas, and the development of this type of products with the specific goal of monitoring land cover changes could not be tested.
- Although the products developed for the Spanish sites could not be tested, the results presented by the other champion end-users indicates that the products could be integrated in current monitoring practices in far future.
- The Spanish end-user has great interest in those products and specific research on developing LC maps with the aim of monitoring coastal areas/coastal diversity would be desirable. The end-user also highlights the need to solve possible problems related the detection of coastal diversity in current spatial resolution.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
	x		

Comments:The Spanish end-user qualifies the need for further improvements in LC maps as high for the following reason:

- LC maps were developed for Barcelona and the Gulf of Cádiz, and no auxiliary data was available in those sites to validate the products.
- Although the products developed for the Spanish sites could not be tested, the results presented by the other champion end-users indicates that the products could be integrated in current monitoring practices in far future.
- The Spanish end-user has great interest in those products and specific research on developing LC maps with the aim of monitoring coastal areas/coastal diversity would be desirable. The end-user also highlights the need to solve possible problems related the detection of coastal diversity in current spatial resolution.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user qualify the need for large-scale LC maps demonstration as high for the following reason:

- It would be interesting to have some demonstration on the development of land cover maps on both local and regional scales.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user evaluates products provided up to now as low for the following reasons:

- No LC was developed for those sites where the end-user has specific interest on monitoring changes in land cover, such as Tordera, San Sebastian, Salinas, El Puntal and Maspalomas.
- LC maps were developed for Barcelona and the Gulf of Cádiz, and no auxiliary data was available in those sites to validate the products.
- The products delivered for the Spanish sites did not presented the frequency necessary to monitor seasonal changes (4 months). LC maps were developed with the aim of supporting the waterline detection in certain areas, and the development of this type of products with the specific goal of monitoring land cover changes (on ecosystems and infrastuctures) could not be tested.

***L**ow; **M**edium; **H**igh

End-User : SGPC (MITECO) - IHC
Contact : Dr Jara Martinez Sanchez email: jara.martinez@unican.es
Version : 17/02/2021
Filename : SGPC_ANNEXB_LandCover

ANNEX B - PRODUCTS EVALUATION

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
Comments:			

***L**ow; **M**edium; **H**igh

ANNEX B. SERVICE ASSESSMENT SHEET– BATHY-MORPHO TERRAIN MODELS

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Specifications of satellite derived bathymetry (SDB) requirements from the Spanish end-user (SGPC-MITECO/IHC) were presented in Table 26 (page 89) of the User Requirement Document. The evaluation process was carried out considering the perspective of the champion end-user based on the results of the product's validation, but it was also backed up by the evaluation of the broad end-user community (see details of the evaluation procedure in Annex C).

The Spanish end-user consider the adequacy of the requirements (including accuracy) of SDB products medium for the following reasons:

- 31 SBD products were developed for four pilot sites in Spain: Tordera (8), Barcelona (10), Castellón-Sagunto (5) and the Gulf of Cádiz (8).
- The sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, and the temporal range and sampling frequency required for this EO Product could not be accomplished.
- Although the accuracy requirements for bathymetric products (0.1 m vertical, 1 m horizontal) were not accomplished, those requirements are mainly aspirational. The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue.
- Even in areas of high sediment concentration in the water, it is possible to generate quality bathymetry under certain conditions. Still, accurate SDB could not be generated for all pilot sites.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user qualifies the compliance to the user requirements for SDB as medium for the following reasons:

- The sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, and the frequency required for this EO Product was not accomplished.
- The analysis of SDB from Barcelona showed that, even in areas of high sediment concentration in the water, it is possible to generate quality bathymetry under certain conditions. Still, accurate SDB could not be generated for all pilot sites.
- The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).
- Further research is still necessary to relate coastal erosion with changes in those 3D products.

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user consider the accuracy compliance of SDB as medium for the following reason:

1. The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).
2. The analysis of SDB from Barcelona showed that, even in areas of high sediment concentration in the water, it is possible to generate quality bathymetry under certain conditions. Still, accurate SDB could not be generated for all pilot sites.
3. Although some results indicate the potential of SDB products, the end-user considers that further research is necessary to allow incorporating SDB in coastal monitoring practices in far future.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user consider the confidence in the quality of SDB products as medium for the following reasons:

- The analysis of SDB from Barcelona showed that, even in areas of high sediment concentration in the water, it is possible to generate quality bathymetry under certain conditions. Still, accurate SDB could not be generated for all pilot sites.
- Although the accuracy necessary to quantify coastal changes was not achieved, the presence of some submerged features could be verified in a qualitative analysis. Still, more research is necessary to identify whether those features are real or the results of sediment in the water column.
- SDB products passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in those satellite products allow the identification of those products that may contain erroneous information.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user qualifies the confidence in product quality as medium for the following reason:

- SDB products passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in those satellite products allow the identification of those products that may contain erroneous information.
- The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).
- Although the accuracy necessary to quantify coastal changes was not achieved, the presence of some submerged features could be verified in a qualitative analysis. Still, more research is necessary to identify whether those features are real or the results of sediment in the water column.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Given the results obtained from validation assessment of SDB, the Spanish end-user consider that this product present medium impact on current end-user practices for the following reasons:

- The sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, and the temporal range and sampling frequency required for current practices were not accomplished.
- The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products. This was particularly highlighted by the key end-users that use such information to monitor the changes for dredging and beach recover, for example (see Annex C).
- Although the accuracy necessary to quantify coastal changes was not achieved, the presence of some submerged features could be verified in a qualitative analysis. Still, more research is necessary to identify whether those features are real or the results of sediment in the water column.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The end user considers that the probability of integrating SDB products in current practices is medium for the following reason:

- Although some results indicate the potential of SDB products, the end-user considers that further research is necessary to allow incorporating SDB in coastal monitoring practices in far future.
- The accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products. Further research on new techniques to obtain nearshore bathymetry are still necessary.
- Although the accuracy necessary to quantify coastal changes was not achieved, the presence of some submerged features could be verified in a qualitative analysis. Still, more research is necessary to identify whether those features are real or the results of sediment in the water column.

***L**ow; **M**edium; **H**igh

End-User : SGPC (MITECO) - IHC
Contact : Dr Jara Martinez Sanchez email: jara.martinez@unican.es
Version : 17/02/2021
Filename : SGPC_ANNEXB_Bathymetry

ANNEX B - PRODUCTS EVALUATION

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
			x

Comments:

The Spanish end-user qualifies the need for further improvements in SDB products high for the following reason:

- The accuracy obtained with SDB products showed the potential of using this kind of data for coastal monitoring purposes. However further research on new techniques to obtain nearshore bathymetry are still necessary to allow the incorporation of SDB products in existing coastal monitoring practices in far future.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
	x		

Comments:

The Spanish end-user do not consider large-scale bathymetry are important and qualify this need as low.

***L**ow; **M**edium; **H**igh

ANNEX B - PRODUCTS EVALUATION

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Spanish end-user evaluates products provided up to now as medium for the following reasons:

- Although some results indicate the potential of SDB products, the end-user considers that further research is necessary to allow incorporating SDB in coastal monitoring practices in far future.
- The sediment concentration in the water is still a challenge to obtain satellite derived bathymetry in areas of significant erosion, and accurate SDB products could not be generated for all pilot sites.
- The accuracy observed in the SDB from challenging sites (like Barcelona) was in accordance with the accuracy obtained in recent studies using satellite information in sites where the sediment concentration in the water is not an issue. However, the accuracy that can be achieved by recent remote sensing techniques is still not enough to allow the fully shift from the use of in-situ measurements to satellite derived products.
- SDB products passed through a series of verification, quality control and validation procedures and, although there are some inconsistencies in waterlines when compared to the ground truth, the quality indexes included in those satellite products allow the identification of those products that may contain erroneous information. This was an important output, since with that kind of information, the users can easily identify the data that may contain erroneous information.

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**

Comments:

***L**ow; **M**edium; **H**igh

ANNEX C - SERVICE ASSESSMENT SHEET - SUPPLEMENTARY INFORMATION

This Annex C contains the supplementary information for the Annex B Service Assessment Sheets. It has been produced by the Spanish end-user.

SYNTHESIS OF THE EVALUATION IN SPAIN

The evaluation process in Spain was carried out considering the opinion of the champion end-user (SGPC – MITECO) and the broad end-user community. The results compiled here were obtained through three different approaches:

i) The champion end-user evaluated the main aspects of the project results, considering the requirements presented in the User Requirement Document (URD).

ii) Key members of the broad end-user community were consulted at the initial and final phases of the project to evaluate, first their degree of accordance with the user requirements and then the degree of accomplishment of the products regarding those requirements. Members from private company (1), academy (2) and government institutions (3) were consulted. The key end-users attended the Spanish workshop and the evaluation was based on the results presented during the event.

iii) The general public of the broad end-user community were consulted through a poll during a virtual Workshop organized by the Spanish end-user, carried out on November 17th 2020. The workshop included participants from private companies, academy and government institutions from 13 countries. (Workshop's presentations were recorded and can be assessed in this links: https://vimeo.com/480717649 , https://vimeo.com/480714920).

Here we present a synthesis of the results obtained from those consults and the main points discussed by end-users.

EVALUATION BY THE CHAMPION END-USER:

The Spanish champion end-user evaluated the results of the CE Project regarding the requirements presented in the URD and to the specific results obtained from each product. The main results and comments are presented below.

A) How do you evaluate the products developed according to the general requirements proposed in the URD?

Requirement	Level of accomplishment	Comments
Clear shift from shoreline (1D) products to space (2D) and volume (3D) products	**M**	Some developments in 3D have been developed
Spatial scope limited to the coastal zone but end users has interest beyond coastal zone.	**L**	Products have not shown usefulness in order to certainly determine the coastal zone. However this problem arises from coastal complexity.
Constrains imposed by non-satellite derived shoreline indicators on the preferred shoreline indicators requirements.	**H**	Shorelines have been developed and might be useful for some coastal management purposes.
Interest of End-Users on listed products goes beyond the 25 years historical record.	**H**	Related to 1D products, the project has prompted the interest for boosting EO projects in the near future. 2D and 3D might be considered in the far future.
Coastal State Indicators.	**L**	
Accuracy requirements	**H**	

Now, regarding the specificities of each product developed:

B) How do you evaluate the adequacy of the products to the end-user requirements regarding the **accuracy**?

Satellite product	Adequacy level	Comment
Waterlines	**H**	
Shorelines	**H**	
Bathymetry	**L**	
Classification maps	**L**	No product was developed.

C) How do you evaluate the adequacy of the products to the end-user requirements regarding the **coastal change detection and coastal characterization**?

Satellite product	Adequacy level	Comment
Waterlines	**H**	
Shorelines	**H**	
Bathymetry	M	
Classification maps	**L**	

D) How do you evaluate the adequacy of the products to the end-user requirements regarding the **temporal and spatial scale?**

Satellite product	Adequacy level	Comment
Waterlines	M	
Shorelines	M	
Bathymetry	M	
Classification maps	L	

E) How do you evaluate the adequacy of the products to the end-user requirements regarding the **pilot sites cover?**

Satellite product	Adequacy level	Comment
Waterlines	M	
Shorelines	M	
Bathymetry	M	
Classification maps	L	

F) How useful are the satellite data to the current end-user's monitoring practices?

Satellite product	Adequacy level	Comment
Waterlines	H	
Shorelines	H	
Bathymetry	M	
Classification maps	L	No product was developed.

G) How immediately can the products be incorporated to the current coastal monitoring practices?

Satellite product	Adequacy level	Comment
Waterlines	H	
Shorelines	H	
Bathymetry	M	
Classification maps	H	Based in other projects/use cases

H) Any additional comment regarding the results obtained, desired improvements and the expectations for future developments:

1D products have shown a good performance and might be the first derived product potentially useful for coastal purposes.

Further research is needed in order to relate coastal erosion with changes in 1D, 2D, and 3D products.

A specific research in Classification maps-land use coastal zone will be needed. Some troubles might have arised related to spatial resolution and coastal diversity.

3D products in clear waters seem to deliver useful results.

3D products require more research related to water turbidity.

The project has prompted the interest for boosting EO projects in near future for 1D products. 2D and 3D might be considered in far future.

EVALUATION BY THE KEY MEMBERS OF THE BROAD END-USER COMMUNITY:

The key end-users evaluated the results of the Coastal Erosion Project in terms of:

- Accomplishment of the user's requirements
- Utility of the products in end-user's current practices
- Interest on the products developed for the pilot sites

A synthesis of the results and the main aspects of the evaluation are presented in the following items.

General requirements:

The average degree of accomplishment of the requirements varied from medium to high from the perspective of the key end-users. However, the specific points of the requirements received different punctuation according to the product and to the interest and use that each key end-user intends to give to it (see Table 1). Bellow we present the main points that were highlighted.

Table 1: Evaluation of the general requirements by the key end-users in terms of degree of accomplishment: L (low), M (medium) and H (high) accomplishment.

	Requirement	Key end-user 1	Key end-user 2	Key end-user 3	Key end-user 4	Key end-user 5
Degree of accomplishment of the general end-user's requirements	Shift from 1D to 2D and 3D products		M	M	M	M
	Spatial Scope		M	M	H	M
	Shoreline indicator requirements		-	M	H	M
	Interest on products beyond the 25 years		-	L	H	L
	Coastal State Indicators		-	M	H	M
	Products accuracy		L	M	M	M

Key end-user 1: AZTI
Key end-user 2: Port authority of Barcelona
Key end-user 3: Marine Hydrographic Institute (IHM), Spanish Navy
Key end-user 4: Polythechnic University of Catalonia
Key end-user 5: Polythechnic University of Valencia

- Regarding the end-users interest on a **shift from shoreline (1D) products to space (2D) and volume (3D) products**: the degree of accomplishment was considered medium by all end-users**.**
- Regarding the **spatial scope limited to the coastal zone, although end users has interest beyond coastal zone:** The degree of accomplishment varied from **medium to high**. The products were developed and validated only over coastal areas (no results for deeper shallow waters), thus high evaluations may indicate that some of the end-users are mainly interested in products from the coastal zone and the absence of data in deeper waters was not considered an issue.

- Regarding the interest on **constrains imposed by non-satellite derived shoreline indicators on the preferred shoreline indicators requirements:** The degree of accomplishment varied from **medium to high.** Datum-based shorelines were generated for all pilot sites, although in some areas they were restricted to the periods/areas in which auxiliary data was available.
- Regarding the **interest on products beyond the 25 years historical record: The degree of accomplishment varied from low (majority) to high**, which indicate that most of the end-users did not see a clear way to continue developing those products in the future.
- Regarding the interest on **Coastal State Indicators:** The degree of accomplishment varied **medium to high.** Although only primary products were developed (no coastal state indicators were provided), these evaluations indicate that the end-users see the possibility of applying those primary products to obtain the CSI.
- Regarding the **products accuracy:** The degree of accomplishment varied from **low to medium.** Low evaluation are related to need for higher accuracy in specific applications (such as bathymetry monitoring for dredging operations) and to the lack of information about the detection methods. Some end-users highlighted that more information on the method for waterline extraction would be necessary and that without results of a systematic analysis contrasting satellite and ground truth data for different dates at the same pilot site, it is not possible to ensure the precision of such methodology. Besides, the need for in-situ measurements of topo-bathymetry (auxiliary data) to obtain shorelines took some end-users to question the applicability of the method on global scales or to the whole period in which the images are available. They highlight, however, that once the waterlines are considered accurate, the beach slope can be obtained from them and from sea level time-series.

Utility of the products in end-users current activities:

The key end-users evaluated the utility of the products in their current practices (see Table 2). Comments on the results for each product are presented below.

Table: 2: Evaluation of the general requirements by the key end-users in terms of degree of utility: L (low), M (medium) and H (high) utility.

Product	**Key end-user 1**	**Key end-user 2**	**Key end-user 3**	**Key end-user 4**	**Key end-user 5**

Products' utility in end-user's current practices	Waterlines	**L**	**H**	**H**	**M**
	Shorelines	**L**	**L**	**H**	**M**
	Shoreline evolution information	-	**M**	**M**	**M**
	Bathymetry and bathymetric changes on time	**L**	**L**	**M**	**M**

Key end-user 1: AZTI
Key end-user 2: Port authority of Barcelona
Key end-user 3: Marine Hydrographic Institute (IHM), Spanish Navy
Key end-user 4: Polythechnic University of Catalonia
Key end-user 5: Polythechnic University of Valencia

- **Waterlines:** the degree of utility varied from **low to high.** Most of the end-users considered the products of high utility. Low value is mainly related to the fact that the end-user are not sure about the precision of the extraction method applied.

- **Shorelines:** the degree of utility varied from **low to high.** Some end-users highlighted the need for higher accuracy in specific applications (such as coastal monitoring for dredging and beach recovery operations) as an issue. Besides, the need for auxiliary data, which may limit the applicability to other pilot sites, were indicated as a limiting factor.

- **Shorelines evolution:** the degree of utility was considered **medium** by all key end-users. Erosion rates and other values indicating shoreline temporal changes were not developed as products, but some results were presented in the workshop to show the potential of the products to define them. The evaluation indicate that the end-users see the possibility of applying those primary products to obtain the shoreline change.

- **Bathymetry and bathymetric changes on time:** the degree of utility varied from **low to medium.** Again, low evaluations are related to need for higher accuracy in specific applications (such as bathymetry monitoring for dredging operations). Although the accuracy of the bathymetry data was considered high (in terms of remote measurements), some end-users highlighted that the results of coastal changes based on that data still need to be evaluated. Besides, the low frequency of the bathymetry products (affected by sediment concentration, clouds and atmosphere) is still an issue for coastal monitoring.

<u>Degree of interest in the products developed for the Spanish pilot sites:</u>

Table 3 presents the range of interest expressed by the end users on the products developed. It is worth noting that, apart from the technical value that end-users see in the products, the degree of interest also reflects the area of competence of the different end-users. That means that some end-users may have no interest in some pilot sites.

Table 3: Degree of interest on the satellite products developed for the Spanish coast.

	Product	Key end-user 1	Key end-user 2	Key end-user 3	Key end-user 4	Key end-user 5
Interest on the products from the pilot sites	Waterlines (Tordera)		None	M	H	M
	Waterlines (Barcelona)		H	M	H	M
	Waterlines (Castellón-Sagunto)		None	M	M	M
	Waterlines (Gulf of Cádiz)		None	H	M	M
	Shorelines (Tordera)		None	L	H	M
	Shorelines (Barcelona)		H	L	H	M
	Shorelines (Castellón-Sagunto)		None	L	L	M
	Shorelines (Gulf of Cádiz)		None	H	None	M
	Bathymetry (Barcelona)		H	H	H	L

Key end-user 1: AZTI
Key end-user 2: Port authority of Barcelona
Key end-user 3: Marine Hydrographic Institute (IHM), Spanish Navy
Key end-user 4: Polythechnic University of Catalonia
Key end-user 5: Polythechnic University of Valencia

EVALUATION BY THE GENERAL COMMUNITY:

The general community evaluated the products through a quick poll during the workshop. 55 attendees participated on the poll. Here we address the main conclusions on those results:

- Auxiliary data are necessary to develop high quality satellite products. All participants confirmed to have access to, at least, some of the auxiliary data required. Still, 48% do not have access to the totality of the dataset. **The lack of auxiliary data may be a limiting factor for products developments in some countries. For the Spanish coast, all datasets are publicly available, and it does not represent an issue.**
- The satellite products developed by the consortium were considered **very by 70% of the attendees.** Besides, **88%** considered that the **products could be incorporated in their current practices immediately or in the near future**. This reflects the value of the advances presented during the workshop.