Coastal Erosion from Space

Coastal Erosion time series in Happisburgh (GB)

Coastal Erosion events:

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

Waterline Verification and Quality Control

Ref:SO-TR-ARG-003-055-PVR-A2

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Applicable and reference documents

Id	Description	Reference
AD-1	Product Validation Plan	SO-TR-ARG-003-055-PVP
AD-2	Product Validation Report	SO-TR-ARG-003-055-PVR
AD-3	Waterline ATBD	SO-TR-ARG-003-055-ATDB-WL

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1.1 VNIR Verification

The verification of the waterline processor aims to check that the EO processor is conforming to the technical specifications laid down in the ATBD (AD-3) and in the Technical Specification Document. The verification process aims to ascertain that the waterline can extract a line at the land/sea interface using satellite images stemming from a host of different sensors and taken amidst a wide range of geographic and environmental conditions, the different possible conditions and tests are listed in the PVP (Table 2.1)

There have been a number of tests conducted to evaluate the ability of the processor to extract continuous waterlines in different environments under a variety of conditions.

The first test verifies that the processor can detect the land/water boundary and extract a continuous line. Below is a comparison of the waterline extraction fromaSentinel-2 tile with different band ratios over Start Bay, UK, which is a predominantly sandy beach with rocky headlands at both ends.

Table 1.1: Test 1 – Verification of the waterline processor's ability to detect the land/water interface

Waterline extraction using a BNDVI index, S2 imagery of 01/12/2017		Success

Waterline extraction using a NDVI index, S2 imagery of 01/12/2017		Failure

As demonstrated by this test, certain band ratios are better fitted to certain locations and conditions, than others to derive a continuous waterline. Both the BNDVI and NDVI waterlines work well on the sandy stretch of the area, however the turbulent water generated by the rocky headland pose problems for the latter.

However, there are conditions, when the waterline simply cannot be extracted, as the second test shows below for the same Start Bay location. High cirrus clouds prompt the processor to identify false edges with all available methods.

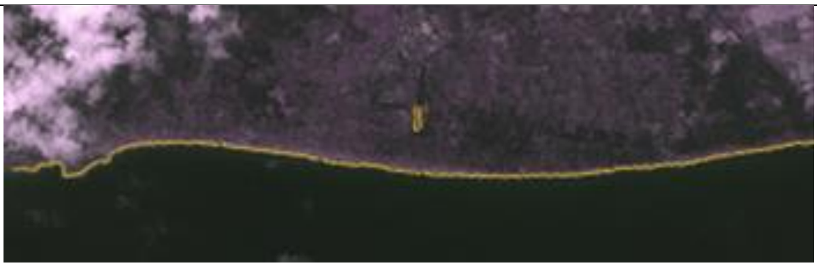
Table 1.2: Test 2 – Test of the waterline processor's ability to work with cloudy images

Waterline extraction using NDVI, BNDVI and GNDVI indices, S2 imagery of 14/06/2017 (band ratios NDVI - green, BNDVI - yellow, GNDVI - purple).		Failure

As the clouds introduce false edges into the final waterline product, image selection is a crucial first step in ensuring that the presence of clouds is minimised as much as possible.

Another crucial step in verification is ensuring that the waterline processor works with different kinds of input data. A third test verifies that the processor produces continuous waterlines from imagery stemming from different sensors on other missions.

Table 1.3: Test 3 – Verification of the waterline processor's ability to produce continuous waterlines from different HR & VHR satellite images

Waterline extraction using Sentinel 2 L2 data (20190324)		Success
Waterline extraction using Landsat 5 L1 data (20110529)		Success

Waterline extraction using Landsat 8 L1 data (20130705)		Success
Waterline extraction using WorldView2 data (20171017)		Success
Waterline extraction using GeoEye data (20110202)		Success, although in this instance white caps on waves are picked up erroneously as edges
Waterline extraction usingIkonos data (20090521)		Success
Waterline extraction using QuickBird data (20040530)		Success

This test at the Barcelona site provided crucial verification that the processor works with a variety of image types. There are plans to expand these capabilities to cover images from the satellite Rapid Eye during the latter stages of Phase 2.

It has been demonstrated above that clouds affect the ability of the processor to produce continuous waterlines. There are certain other environmental factors that also similarly hinder the processor from performing its task. The fourth test looks at such a factor, focusing on the level of turbidity. The below test was performed on GNDVI-derived waterlines near the mouth of Riviere Saint Jean, Quebec, Gulf of St Lawrence, where turbid waters are usual occurrence in the ROI.

Table 1.4: Test 4 – Test of the waterline processor's ability to produce continuous waterlines from images with turbid waters

Worked reasonably well for S2 image of 01/07/2019		Success
Discontinuities for S2 image of 01/07/2019		Failure
Discontinuities for S2 image of 26/07/2019		Failure

As this test displayed, the optical waterline extraction method is constrained by issues related to suspended sediments. Turbid waters create discontinuities and can confuse the algorithm in identifying the correct boundary between the wet sand and the turbid water. A fifth test elaborated further on this question, by looking at the dynamically changing Wexford Estuary and its immediate surroundings, where there are shifting sandbanks and considerable sediment transport between inshore and offshore areas.

Table 1.5: Test 5 – Test of the waterline processor's ability to produce continuous waterlines in a complex estuary

		
Success	Failure	
More or less good results, with the sand banks being picked up approximately correctly, as well as the shoreline north of the estuary. The inner estuary remains problematic due to suspended sediments. GNDVI-based Sentinel 2 waterline from 27/06/2019 (LW +4.5hrs)	Shifting sands, suspended sediments & nearshore bathymetry causing false edges Sentinel-2 tiles: NDVI-based waterlines from 22/06/2018 LW +4.5hrs (LHS) and from 27/06/2019 LW +4.5hrs (RHS)	

Estuarine environments have proven to be challenging for the optical waterline approach, however results have been largely improved by testing the algorithm with different band ratios and adjusting the thresholding for the land-water delineation.

Another feature of working with estuaries could mean the waterline processor needs to function in extended intertidal areas. Especially at large tidal ranges, these regions pose complexities in their spectral characteristics, from sand with different levels of wetness to waters with high levels of suspended sediments. Mudflats and puddles in the intertidal zone are also common features, such as sandbanks. Test 6 verified that the waterline processor can produce continuous waterlines in such environments.

Table 1.6: Test 6 – Verification that the processor can produce continuous waterlines for images of intertidal areas at low levels of tide, with S2 waterlines based on images recorded in the period 08/12/2015-27/02/2020 at different levels of tide

The 10 S2 waterlines are based on images representing different levels of tide between 08/12/2015-27/02/2020. The background is a 0.5m resolution Worldview-2 image from 06/22/2014.	

As the above test shows, the waterline processor recognizes intertidal features such as sandbanks and puddles at low levels of tide, and also delineates the sea-land interface.

Another environmental factor to consider was the effect of sun glint on the performance of the processor. For this test, one of the sites in Quebec provided some glinted images. The below illustration demonstrates that the waterline processor can work with such imagery (Table 1.7).

Table 1.7: Test 7 – Verification of the waterline processor's ability to produce continuous waterlines with sun-glinted images from the Longue Pointe de Mingan AOI, Quebec, Canada

Continuous waterline segment at land-water interface from S2 image from 11/06/2019

Continuous waterline segment at land-water interface from S2 image from 11/07/2019

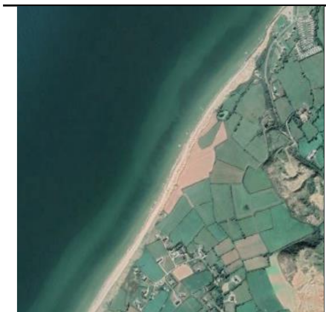
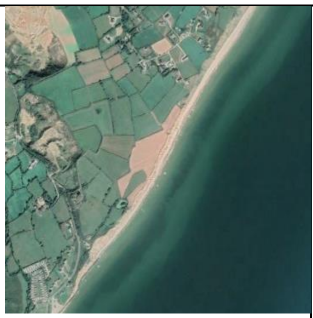
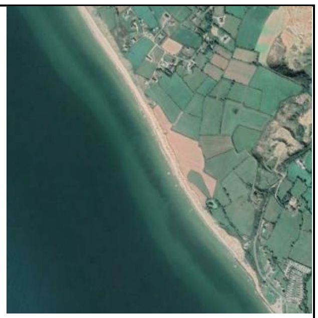
Discontinuous waterline segment from at land-water interface S2 image from 11/06/2019

Discontinuous waterline segment at land-water interface from S2 image from 11/07/2019

As the above test showed, it was not sun glint that posed problems for the waterline processor. In the above two images, it worked relatively well and produced continuous waterlines. However, some false edges could also be observed on those images, as the processor picked up offshore features due to sediments and/or pronounced underwater morphology. The below two snapshots are from the same respective S2 images and show serious discontinuities in the waterlines. The different colours of water that can be observed in these images allude to the origin of the discontinuities and the false edges: turbid waters and nearshore bathymetry. Therefore, it can be concluded that sun glint, does not pose a hindrance for the correct functioning of the waterline processor.

1.2 SAR Waterlines Verification

As a side looking instrument, the orientation between the SAR antenna and the surface of interest is key factor. The difference of backscattering coefficient between the beach and the sea, tends to yield higher value in the scene with the observation direction of sea-to-land rather than that with the land-to-sea observation direction especially on the coasts with coarser beach materials. It is, therefore, recommended to select the SAR scenes with sea-to-land observation direction for shoreline detection. With the purpose of classifying the where the SAR waterline will not be good the orbit characteristics are including in the metadata of the products. The theoretical favourable geometries for ascending and descending passes are exemplified in the following table.

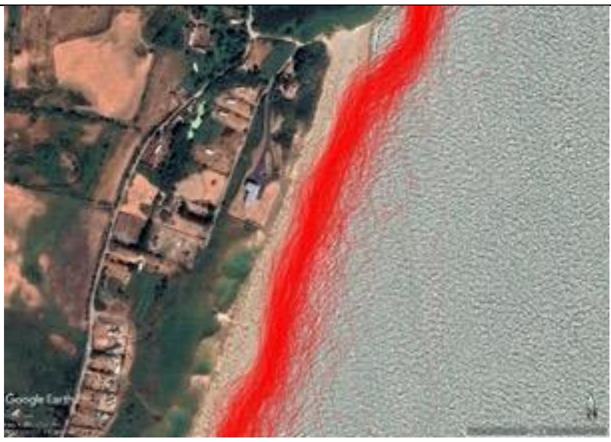
			
Ascending GOOD	Ascending BAD	Descending GOOD	Descending BAD

A number of tests have been conducted in order to identify geometries where the SAR images may not be able to retrieve waterlines properly.

Case 1 – Cliffs

Case 2 – Large Beach

	
Ascending passes	Descending passes

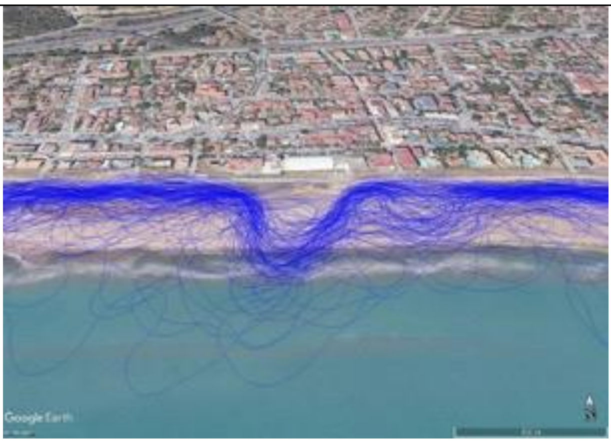
Case 3 – Beach and dunes/hills nearby

	
Ascending passes: The slope of the dunes is shadowing the shore.	Descending passes

Case 4 – Beach with barriers

	
Ascending passes:	Descending passes: The barriers create a strong signal shadowing the shoreline interface.

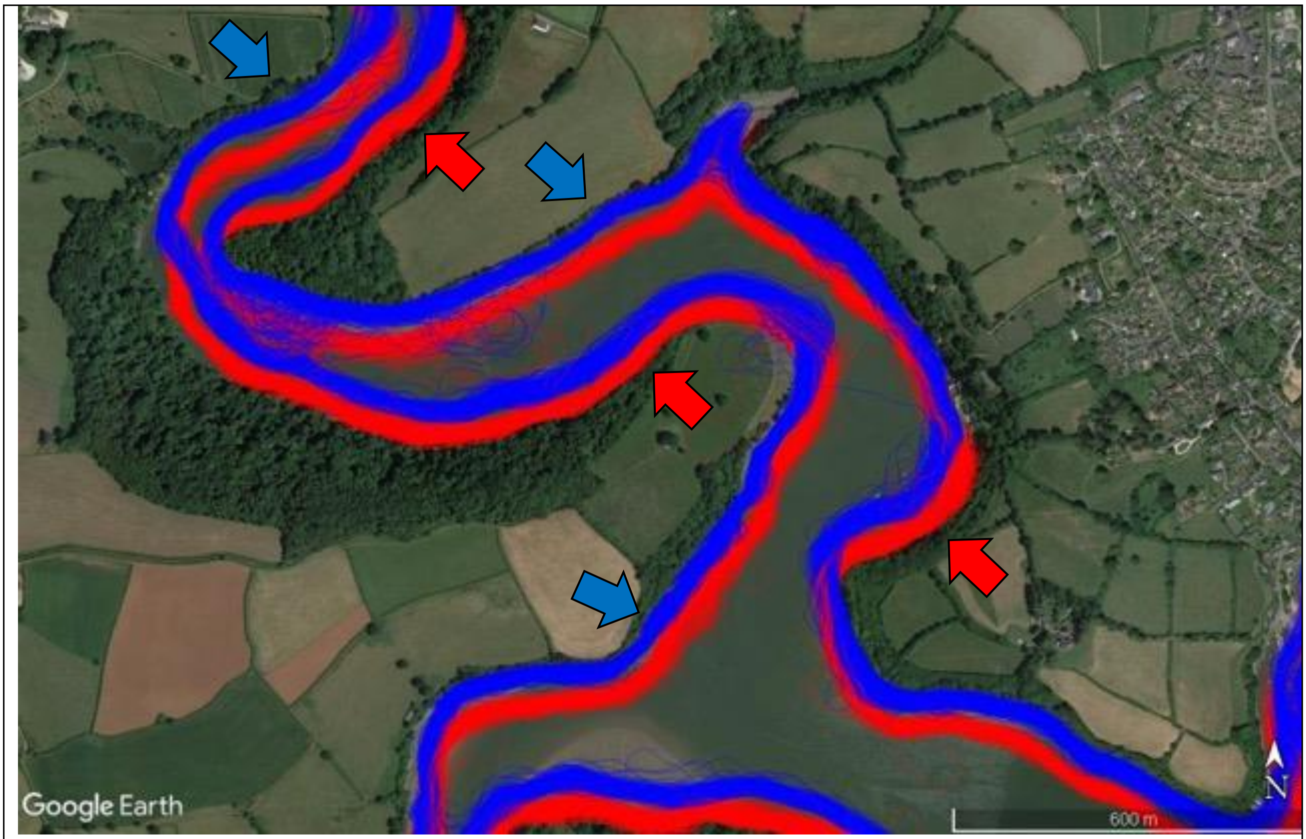
Case 5– Buildings

	
Ascending passes:	Descending passes: Buildings can create strong signal shadowing the shoreline.

Case 6– Sea Ice (Quebec)

	Descending passes not available in Canada.
Ascending passes: Sea Ice dynamics creates lines far from the shoreline.	Descending passes:

Case 7– Estuaries and curvy shores



Ascending passes: Good retrievals on areas pointed with the red arrows. The lines that are not following the waterline can be used as a proxy of the vegetation.	Descending passes: Good retrievals on areas pointed with the blue arrows. The lines that are not following the waterline can be used as a proxy of the vegetation.

2 VNIR & SAR Waterline QC

2.1 VNIR QC

The QC step of the production process checks the quality of the waterlines. Since the waterline per definition is an instantaneous feature on a single satellite image, it is not possible to build a QC process by comparing the waterlines to the results of ground surveys. They are, indeed, derived from instantaneous satellite snapshots and comparisons with in-situ measurements are therefore impossible.

The quality control of the waterline products can be conducted by overlaying the waterline shapefile on the co-registered satellite image it was derived from, in GIS software (QGIS, ArcMap, etc). Then the analyst undertaking this task checks where exactly the product overlays on the image. This by eye quality control identifies whether the overlaid product indeed is at the land-sea interface. Using the same approach, the analyst checks whether the waterline is not a result of false edges identified due to clouds or features due to suspended sediment and/or nearshore bathymetry; or between the following features: dry and wet sand, or white water and the sea.

The below two tables provide a brief demonstration of the steps in the QC process, with the identification of outliers among the waterlines as potentially bad quality products (Table 2.1) and the selection of good quality waterlines that would feed into the production of shorelines (Table 2.2).

Table 2.1: By eye quality check of GNDVI-based S2 waterlines for the ROI containing Dublin Bay and Rush, underlaid S2 image taken on 17/07/2017

The 1st step of the QC process is to overlay a subset of the produced waterlines on an RGB composite of the ROI and observe them for outliers.	
An outlier found: The waterline corresponding to the underlaid image picks up nearshore underwater features as false edges between water and land. Therefore, this waterline can be considered to be discarded from further analysis.	

After discarding the bad quality waterlines from further analysis, the good ones are shared with the partners and are also the base of derived products. Three examples of them that passed the QC process are illustrated in the below table (Table 2.2).

Table 2.2: By eye quality check of GNDVI-based S2 waterlines for the ROI containing Dublin Bay and Rush, LHS underlaid S2 image taken on 17/07/2017, middle underlaid S2 image taken on 14/03/2016, RHS underlaid S2 image taken on 08/12/2015

As demonstrated above, the QC process can be reasonably time-consuming. Currently there are steps taken to automate the outlier detection of the QC process and speed up this step.

2.2 SAR Waterline and other SAR lines QC

In particular scenarios, the lines computed by the SAR processor may not be properly measuring the boundary between the water and the land interface as the backscattered signal from the sand can be shadowed by other surfaces more specular. The geometry between the scenario being observed and the satellite line of sight is key to identify where the waterlines will be more likely to be hidden and the lines that are retrieved are in fact vegetation lines, cliff edge lines or other interfaces that can produce the same backscattering effect in the SAR image.

A quality control method has been designed in order to classify the lines in three different categories:

good, proxy and bad.

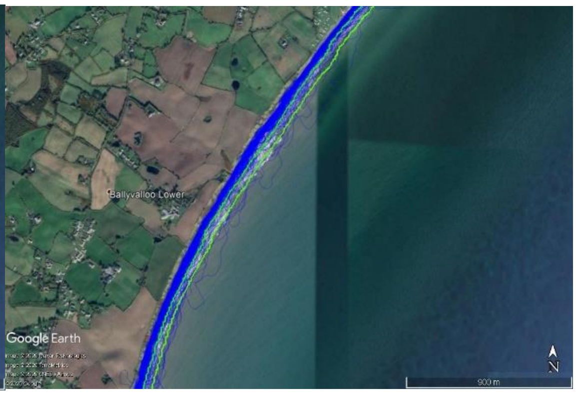
Two quality parameters, precision and accuracy, will be retrieved by comparing each of the lines with a reference line. The good lines should have both parameters under the quality thresholds, the proxy can have the accuracy over the threshold, but the precision should be good, and the bad ones will have the precision over the threshold.

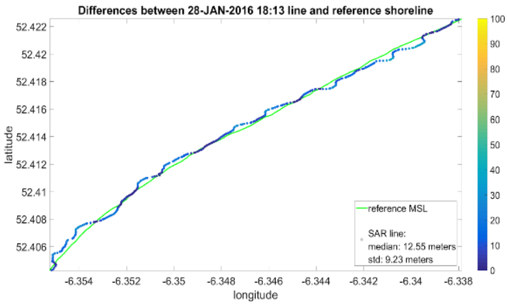
The threshold will be higher in the sites with higher tide range, allowing the retrieved lines to vary along the tide.

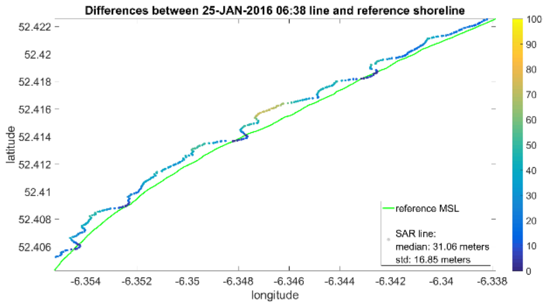
In the following example over the Wexford pilot site (Ireland east coast) it can be seen the Sentinel 1 water lines (2016-2019) split in ascending and descending. The top plot shows HAT and LAT lines in green and the superposition of all the water lines in red for ascending and blue for descending. In the middle there is an example of the distance computation between the reference and the computed water line. The colour indicates the distance between the corresponding point and the closest point of the reference line. In the bottom, the computation of the accuracy (median distance) and the precision (standard deviation of the distance) for each line computed.

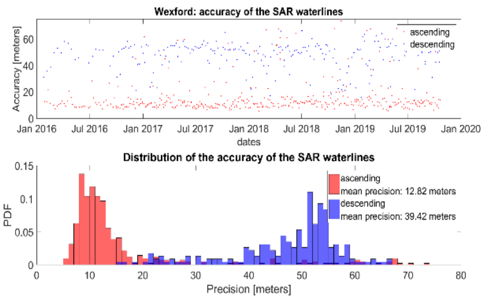
In this particular site, the threshold has been set to 20 meters for both accuracy and precision which means that, lines with accuracy and precision over 20 meters have been classified as bad (mainly outliers for both geometries), lines with precision under but accuracy over 20 meters have been classified as proxy (most of the descending passes) and the ones under 20 meters are considered good and can be further processed to a shoreline level.

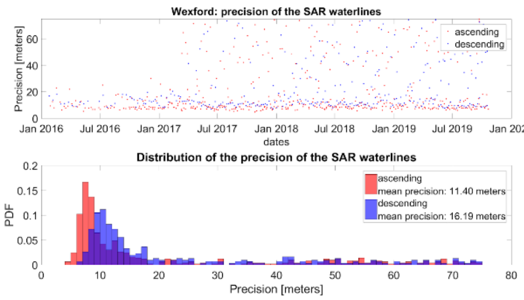

Ballyvalloo Lower
Google Earth
900 m


Ballyvalloo Lower
Google Earth
900 m


Differences between 28-JAN-2016 18:13 line and reference shoreline
latitude
longitude
reference MSL
SAR line:
median: 12.55 meters
std: 9.23 meters


Differences between 25-JAN-2016 06:38 line and reference shoreline
latitude
longitude
reference MSL
SAR line:
median: 31.06 meters
std: 16.85 meters


Wexford: accuracy of the SAR waterlines
Accuracy [meters]
dates
ascending
descending
Distribution of the accuracy of the SAR waterlines
PDF
Precision [meters]
ascending
mean precision: 12.82 meters
descending
mean precision: 39.42 meters


Wexford: precision of the SAR waterlines
Precision [meters]
dates
ascending
descending
Distribution of the precision of the SAR waterlines
PDF
Precision [meters]
ascending
mean precision: 11.40 meters
descending
mean precision: 16.19 meters

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