Coastal Erosion from Space

Coastal Erosion events:

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

Algorithm Theoretical Baseline Document

Ref: SO-TR-ARG-003-055-009-ATBD-SL

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Version history

Version	Date	Modification
Version 1	30/10/19	–
Version 1.1	14/11/2019	Modification from IHC feedback: - Section 2.3.2, run up information
Version 1.2	06/12/2019	Minor update. - Section 2.
Version 1.3	05/01/2021	Updated for project close. - Section 2, 3, 5.
Verification by	François-Regis Martin-Lauzer	
Authorisation	Craig Jacobs	

Acronyms

CD: Chart Datum

CNES: Centre National d'Etudes Spatiales

CS: Cross-Section

CTM: Coastal Terrain Model

DSI: Datum-based Shoreline Indicators

DAP: Data Access Portal

EO: Earth observation

EPR: End Point Rate

EW: Extra Wide swath

FDBAQ: Flexible Dynamic Block Adaptive Quantization

GIS: Geographic Information Systems

GRD: Ground Range Detected

HAT: Highest Astronomical Tide

HRG: High Resolution Geometric

IW: Interferometric wide swath

LAT: Lowest Astronomical Tide

LCI: Line Confinement Index

MHWN: Mean High Water Neap

MHWS: Mean High Water Spring

ML: Mean Level

MLWN: Mean Low Water Neap

MLWS: Mean Low Water Spring

MSL: Mean Sea Level

OSW: Ocean Swell Spectra

QC: Quality Control

SPOT: Satellite Pour l'Observation de la Terre

SAR: Synthetic Aperture Radar

SLC: Single Look Complex

TOA: Top Of Atmosphere

URD: User Requirement Document

UK: United Kingdom

UTM: Universal Transverse Mercator

WSM: Water Surface Model

WV: Wave Mode

Reference Documents

Id	Description	Reference
AD-1	Requirement Baseline Document	SO-RP-ARG-003-055-006-RBD
AD-2	User Requirement Document	SO-TR-ARG-003-055-URD
AD-3	Geolocation ATBD	SO-TR-ARG-003-055-009-ATBD-GL
AD-4	Waterline ATBD	SO-TR-ARG-003-055-009-ATBD-WL
AD-5	Erosion Rate ATBD	SO-TR-ARG-003-055-009-ATBD-ER

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1 Overview and Background Information

1.1 Product requirement

Figure 1.1: An example of a range of visibly discernible shoreline indicator features, Duranbah Beach, New South Wales, Australia, Boak & Turner (2005)

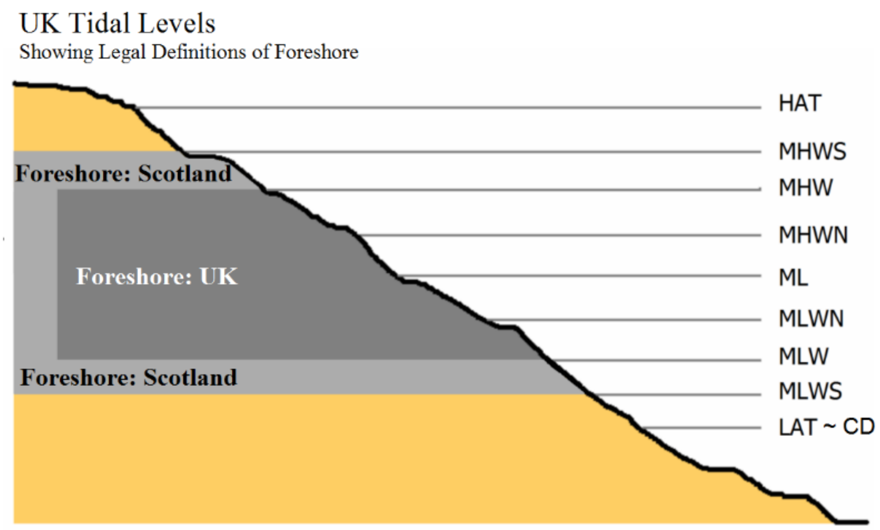

Figure 1.2: Order of tidal datums used within the UK

1.1.1 Information content quality and value

According to partners and end-users' requirements listed in the URD regarding shoreline extraction, the processor will compute datum-based shoreline indicators between the Highest Astronomical Tide (HAT) datum and the Low Astronomical Tide (LAT) datum. This will be achieved using the measured waterline and various auxiliary data including the sea state and beach slope.

A shoreline is defined as the theoretical boundary between land and water surface at a defined water level elevation. The shoreline shown on nautical charts represents the line of contact between the land and a selected water elevation, usually corresponding to a high water tidal datum. In areas affected by tidal fluctuations, this line of contact is usually the Mean High Water (MHW) datum. In confined coastal waters of diminished tidal influence, the Mean Sea Level (MSL) datum is sometimes used. The shoreline is not easy to identify in contrast to the coastline, which is based on a clear morphological shift between the shore and the coast. In areas obscured by marsh, mangrove, cypress, or other type of marine vegetation, a line may be used to represent the apparent shoreline which is the intersection of the appropriate datum with the outer limits of vegetation.

A tidal datum-based shoreline indicator is determined by the intersection of land and water at a specified water level corresponding to an average or extreme of the harmonic tidal prediction. These elevations are measured above a fixed datum which varies depending on the country of interest and are subject to occasional updating (For example in the UK, this is either Ordnance Datum Newlyn or Chart Datum)[1]. These tidal datums can be calculated manually from the local tidal regime, however these values are usually available from a regional hydrographic organisation. Datum-based shoreline indicators are important for local authorities, they define legal spatial boundaries, are essential for nautical charting, and provide a fixed reference to accurately monitor coastal erosion rates. These lines can then be used with estimations of lateral land retreat and sediment transport volumes which go on to inform local and regional planning policy[2].

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[1] NIECM (2014) *'A guide to coastal erosion management practices in Europe: lessons learned.'* European Commission Service contract B4-3301/2001/329175/MAR/B3

[2] Burningham, H., & French, J. (2017) '*Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation',* Geomorphology, Vol. 282, pp. 131-149

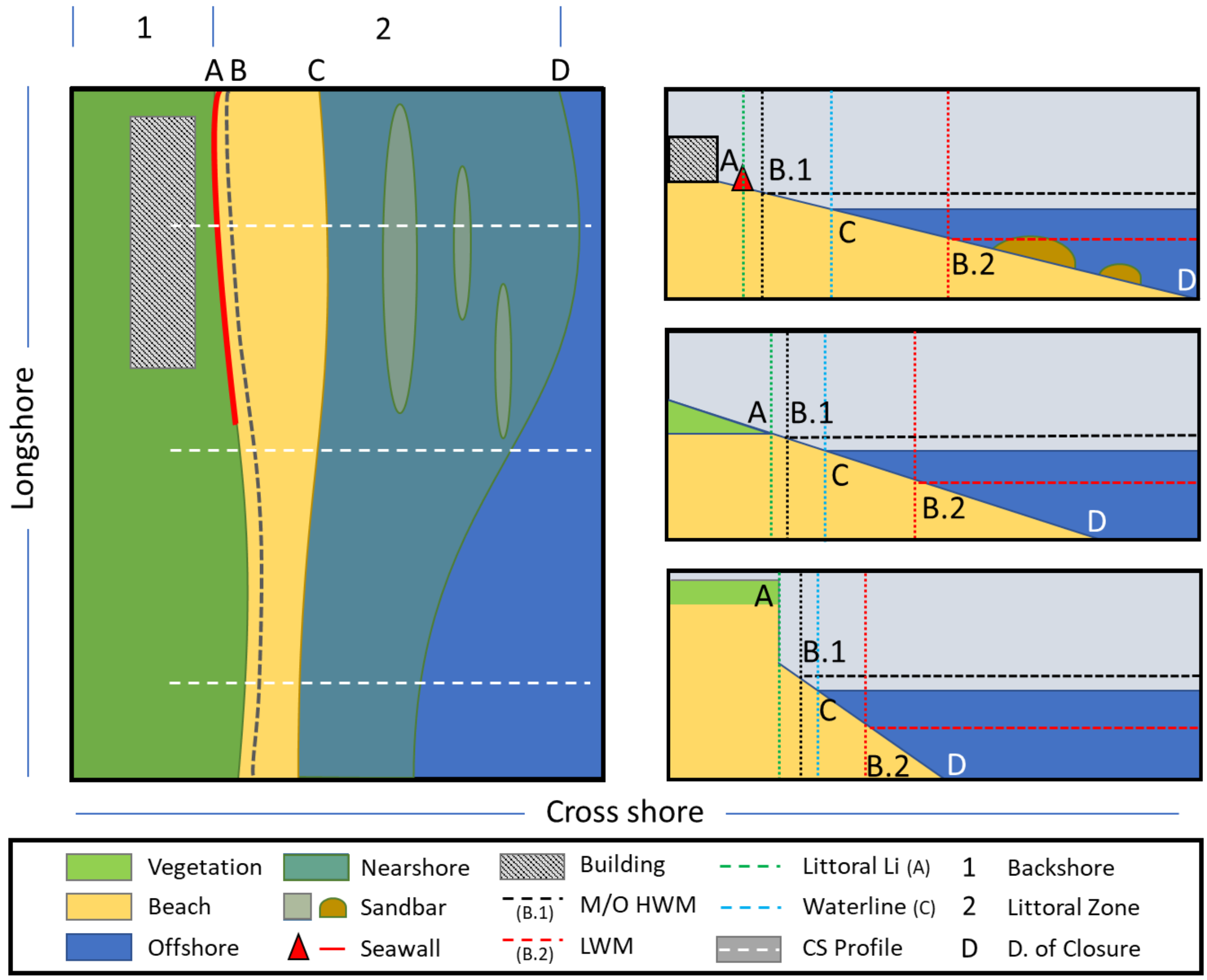

Figure 1.3: Shore and coastal features diagram

1.1.2 Product order and delivery services

A Datum Based Shoreline Indicator will be produced for each waterline, for each defined tidal datum. Lines will be produced for every selected location over the past 25 years, where and when the essential auxiliary data is available. Frequency of production strongly relies on the ability to obtain accurate information on the sea state and beach morphology at the time of the EO acquisition.

Output format will be an individual polyline shapefile for each datum of every processed waterline. The shapefile will be packaged in a .zip file and then accompanied by a metadata file. This will be compatible with GIS software such as ArcGIS and QGIS and projected in Universal Transverse Mercator (UTM). Products will be available via a Digital Access Portal (DAP), delivery will also be provided via ftp transfer.

1.2 Feasibility review

1.2.1 Satellite sensors and mission

Please refer to the Geolocation ATDB (ref: SO-TR-ARG-003-055-009-ATBD-GL)

1.2.2 Existing EO Products

Please refer to the Geolocation ATDB (ref: SO-TR-ARG-003-055-009-ATBD-GL)

1.2.3 Models specification

There are various methods to which a measured waterline can be used to generate tidal datum based shoreline indicators. For ease of conversion between the measured waterline and tidal datums, most studies suggest scheduling aerial photography / EO acquisitions when the water level is close to the target datum. This however is not always possible due to time/budget constraints or unavailability of suitable data[3]. In this case, the tidal datum shoreline can be calculated using a predetermined waterline combined with auxiliary data. The choice of methodology used to determine the datum-based shoreline indicators from the waterline will depend on the type of auxiliary data available for the area of interest.

The first possible method involves using a coastal terrain model (CTM) that contains topographic information in a narrow zone of the coast and near-shore bathymetry. Li *et al*.[4] propose using high resolution (1 m) stereo imagery. Stereo pairs that are necessary for deriving elevation information of objects can be formed in quasi real-time; the cross-track stereo requires additional time allowing the satellite to revisit the same area from a neighbouring track. The CTM is then built by georeferencing and integrating the topographic, data, LIDAR data, and bathymetric data in the same planimetric and vertical datum. The water surface is depicted by a water surface model (WSM) that can be produced by a hydrological modelling system using meteorological data and coastal physical environmental data as boundary conditions. Then, the shoreline can be derived by a subtraction of the WSM from the CTM where the grid points with differential value of 0 represent the shoreline.

Li et al. also propose using a simplified model such as EPR (End-Point Rate) method to calculate a recession/advancing rate on each transect of the shoreline, this involves using multiple satellite optical images

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[3] Gens, R. (2010) *'Remote sensing of coastlines: detection, extraction and monitoring, review article'*, International Journal of Remote Sensing Vol. 31, No. 7, pp. 1819–1836.

[4] Li, R. *et al*. (2002) Digital Tide-Coordinated Shoreline. Journal of Marine Geodesy, Vol. 25, pp. 27-36.

of the shoreline at varying time intervals. Using this imagery, the desired tidal datum can then be estimated by a temporal interpolation or extrapolation. However, the EPR method assumes that the shoreline position changes in one direction and linearly, which does not match the situation in the real world.

A method using a simplified geometric model assuming constant cross-shore slope can also be performed. This involves calculating the combined height of the variables which contribute to the water level above the predicted tidal height, such as wave run up and atmospheric effects. By combining these variables to the predicted tidal height, the instantaneous water level of the waterline can be estimated. Then, by assuming a constant beach slope and using the differences between the instantaneous water level and the tidal datums, the lateral distance between the waterline and the tidal datums can be calculated.

1.2.4 Auxiliary Data

Various types of auxiliary are needed for extraction of the datum-based shoreline indicators. Below are ideal auxiliary products needed for shoreline processing.

- Measured Water Level from multiple locations
- Measured Nearshore Wave Spectra
- Measured Datum Heights from multiple locations
- Measured Beach Transects
- Offshore reference points

It is also possible to compromise with less ideal auxiliary sources, although using this data will lead to higher uncertainties in the final shoreline position.

- Predicted Tidal Level from a single location
- Modelled Wave Data
- Modelled Datum Heights from a single location
- Waterline derived DEM

1.2.5 Currently known issues

The most significant issue that may impact the processor is the accumulation of uncertainties created from the input waterline and auxiliary data. Primarily, the shoreline processor relies on the output from the waterline processor. This carries forward errors and uncertainties as the delineation of the waterline position is not always entirely accurate and may change depending on the type of sensor used.

Secondarily, the shoreline extraction relies heavily on accurate information of the beach slope, although this data may be available from in-situ measurements, the beach profile can be reshaped on both short and long timescales, meaning even recent slope measurements may become quickly outdated. The beach slope is also often irregular, with steepening occurring towards the backshore. This can provide a source of error when generalising the slope of the entire foreshore, as errors will occur when extrapolating tidal datums. The profile used to create an average slope must cover the entire foreshore, this is often not provided when beach slopes profiles are created from bathymetric surveys. On sandy beaches, using any bathymetric data below the point of the Lowest Astronomical Tide (LAT) instead of a measured foreshore will give an underestimation of the slope, this will result in a misplacement of the shoreline.

Uncertainty will also accumulate when using numerous parameters of the sea state. Due to a lack of in-situ data availability, some of the sea state conditions will be determined from model outputs, these carry significantly increased uncertainty. The effect of these uncertainties will amplify when used in combination (see section 2.3.4), this will reduce confidence in estimations of the waterline's elevation. Using a number of auxiliary data sources harmoniously will also be difficult. Issues may arise due to ensuring data continuity across a long timeseries. Any gaps in auxiliary data will prevent the processor from running effectively, ignoring any missing auxiliary terms will add significant error to the estimation of waterline elevation if an interpolation is not possible. Furthermore, any large quantity of auxiliary data (such as a global model) may be impractical to host without adequate storage and access solutions.

The calculations of wave run up are taken from Stockden *et al*. (2006) as this is the most widely cited and used set of run up equations used within coastal science. The proposed equations are derived from empirical models predominantly from sandy beaches with a limited range of parameter values (slope, roughness, wave height etc). These models may not accurately represent the wave run up of beaches outside of these parameters. Furthermore, this model does not account for wave direction.

1.2.6 Potential Solutions

Higher sampling (at least once per month or twice between storms) will increase the accuracy and precision of the shoreline estimates. In-situ metocean measurements should be utilised instead of modelled data due to the increase in accuracy and precision. Where data continuity issues arise, the missing data can be supplemented with outputs from numerical models or interpolated if the data gap is sufficiently small. To aid with accessing the large quantity of 'mismatched' auxiliary data, all datasets should be assigned the same date format and the sampling interval standardised via interpolation. A database and query system could also be produced to store and handle requests for data subsets needed for the algorithm.

1.3 Product Specifications

The algorithm will use a waterline provided from the waterline processor[5] as the primary data source, the auxiliary data will then be analysed to calculate positions of the shorelines based upon the position of the waterline. The algorithm will assume a simplified geometric model of the foreshore, assuming a constant slope across the length of each cross section analysed. The waterline will be split into a number of cross sections of varying slopes. The most significant limitation is expected to be the uncertainties accompanying the waterline and the limitation created by an assumption of uniform slope along a cross-section.

[5] Refer to document ref: SO-TR-ARG-003-055-009-ATBD-WL for more information.

2 Algorithm Description

2.1 Data Processing outline

2.1.1 *Sketch of the computer program*

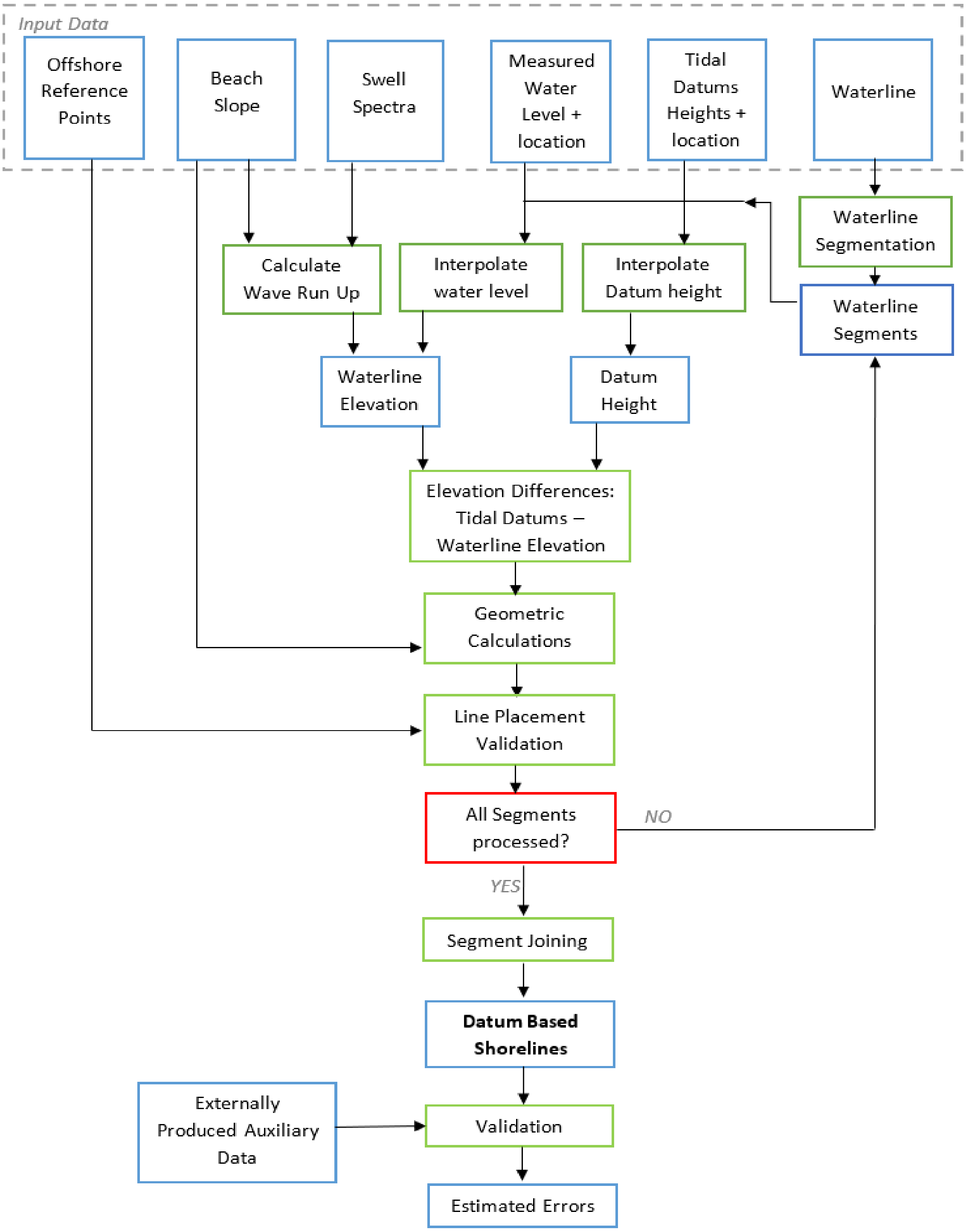

Figure 2.1: Flowchart indicating structure of the algorithm

2.1.2 Pre-requisite

The algorithm requires a waterline as an ESRI shapefile conforming to ARGANS nomenclature, the waterline must be as accurate as possible, as the algorithm does not attempt to mitigate any error in the waterline output. The algorithm also requires accurate slope information for each area, this slope must be representative of the foreshore, and not derived from nearshore bathymetry. The algorithm also needs accurate heights of the required tidal datums, referenced to the same datum as the water level data. Finally, the algorithm needs a full catalogue of metocean data, ideally this information should come from in-situ measurements rather than numerical models to reduce the impact of any uncertainties on the final shoreline output.

2.2 Algorithm Input

The processor uses the waterline as a primary input, the various pieces of auxiliary data listed in 1.2.4 are also used for calculations of the waterline elevation. Measured tidal datum waterlines provided by the user can be used later in the algorithm to validate the results.

2.3 Theoretical Description of the Model

2.3.1 Physical Description

Processing starts by splitting the waterline into segments of a pre-defined length, this length is selected by the shoreline processor operator and is dependent on the smaller scale complexity of the coastal geometry at the target site. This is generally about 40-pixel lengths long but will be reduced in areas of more erratic geometry such as around rocky coasts or areas with intertidal sand banks. Each slope measurement point is assigned to the nearest waterline segment, slope values are then interpolated between the bounded waterline segments. Next, the segment is assigned a water level and datum height. This is done by locating the two closest bounding water level measurement points (tide gauges) and interpolating the tidal heights from the measurement points corresponding to the date and time of the waterline's EO snapshot. Both the tidal and datum heights are interpolated based upon the Euclidean distances between the segment and the two bounding gauges. If the segment is not bounded by tide gauges, only the value from the nearest gauge is used. Next, the corresponding wave data is assigned to the segment, the significant wave height is modulated based upon the angle of wave attack relative to the orientation of the waterline segment. Using the tide, slope information and wave run up equations, the instantaneous water level of the waterline is calculated. The lateral distance (as observed from above) between the waterline and tidal datum shoreline is then resolved with a simple trigonometric equation. The nearest offshore reference point is then determined, by comparison of the distances between shoreline, waterline and reference points, the processor ensures that the shoreline is placed on the correct side of the waterline. Finally, the end points between neighbouring segments are joined, providing they are located within a threshold distance.

2.3.2 Mathematical Description and calculation procedures

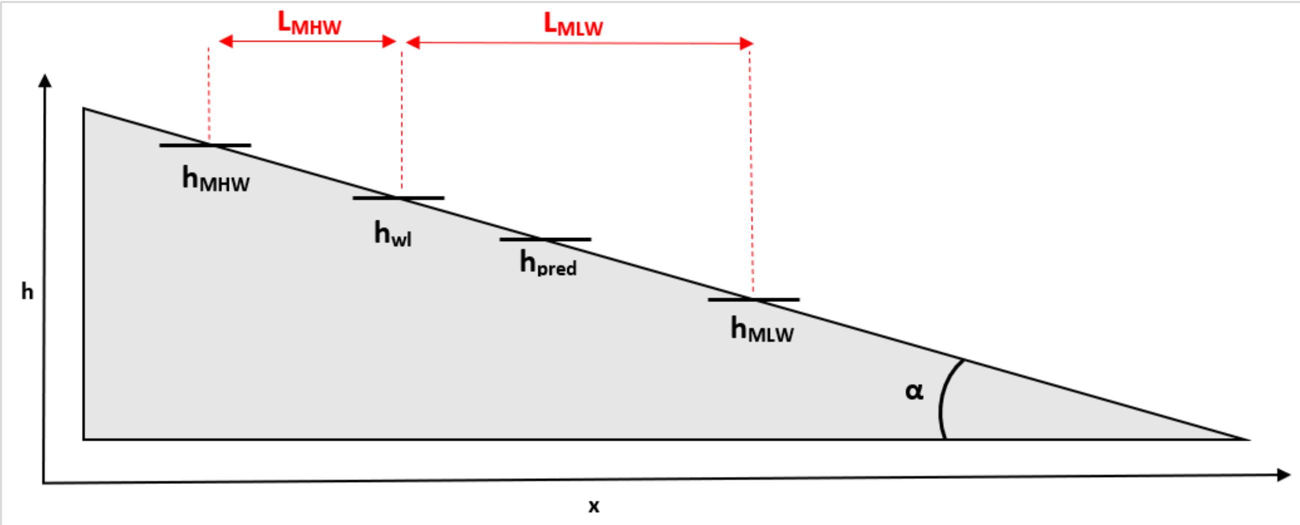

Figure 2.2: Conceptual overview of a single cross-shore profile.

a. Define Variables:

Slope (α) is a fixed value across the specific cross shore profile given as:

$$\alpha = \frac{dh}{dx}$$

The elevation of the tide in still water conditions (h_{pred}) at the time of the EO snapshot (t_0) is given as:

$$h_{pred} = tide(t_0)$$

The wave driven component of sea surface elevation is known as the wave run up. This is composed of the wave set up (the super-elevation of the mean water level above the still water level) and wave swash (the height of the time-varying fluctuation in instantaneous water level above the setup elevation)[6]. The wave set up $\bar{\eta}$ is given below where α is the slope, H_s is the significant wave height and L_p is the peak wave period.

$$\bar{\eta} = 0.35\alpha(H_s L_p)^{0.5}$$

The wave swash S is comprised of both an incident component S_{inc} and an infragravity component S_{ig}. H_s is the significant wave height and L_p is the peak wave period.

$$S_{inc} = 0.75\alpha(H_s L_p)^{0.5}$$

$$S_{ig} = 0.06(H_s L_p)^{0.5}$$

$$S = \sqrt{S_{inc}^2 + S_{ig}^2}$$

In areas of oblique wave attack angle, de Waal & Van De Meer (2012)[7] suggest a reductional factor γ_β for wave run up where β is the wave attack angle relative to the normal of the beach direction.

$$\gamma_\beta = 1 - 0.0022\beta$$

The wave driven component of sea surface elevation is therefore:

$$h_{wave} = \gamma_\beta\,(\bar{\eta} + S)$$

b. Determine the elevation of the measured instantaneous waterline (h_{wl}):

Water level can be interpolated to each individual waterline segment if two measurement locations are bounding the waterline segment. This is also applicable for interpolating datum heights (h_{datum}). h_1 is the tide height at the first measurement location, d_1 is the Euclidean distance from the waterline segment to the first measurement location. A waterline segment is bounded if the distance between the two tide gauges is longer than any of the distances between waterline and tide gauges.

$$h_{interp} = h_1\frac{d_2}{(d_1 + d_2)} + h_2\frac{d_1}{(d_1 + d_2)}$$

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[6] Stockdon *et al.* (2006) Empirical parameterization of setup, swash, and runup. *Coastal Engineering 53*. Pp 573 – 588.

[7] De Waal, J. & van der Meer, J. (2012) Wave run-up and overtopping on coastal structures. Proceedings of 23rd Conference on Coastal Engineering, Venice, Italy. pp. 1758-1771.

With the measured water level now interpolated, the elevation of the waterline is simply:

$$h_{wl} = h_{interp} + h_{wave}$$

c. Determine the lateral distance L_{datum} from the waterline to the chosen tidal datums:

As the slope is assumed to be constant, the lateral distance from the waterline to the tidal datum based shoreline L_{datum} is calculated as shown below. h_{datum} is the still water elevation of the target tidal datum above a predefined reference datum.

$$\frac{dy}{dx} = \alpha = \frac{h_{wl} - h_{datum}}{L_{datum}}$$

$$L_{datum} = \frac{h_{wl} - h_{datum}}{\alpha}$$

A positive value of L_{datum} implies the datum is seaward of the waterline, a negative value implies the datum is landward of the waterline.

d. Polylines are then created parallel to the respective point on the waterline, with the spacing between these lines proportional to the lateral distances L_{datum} calculated above.

2.3.3 Error Estimation

Estimating the error in shoreline position is essential for calculating uncertainties in erosion rates calculated by subsequent processors[8]. Below, the potential sources of error and methods of quantifying this error are highlighted.

Various sources of errors are identified. Primarily, the shoreline processor relies on the output from the waterline processor. The calculation of the waterline position is subject to accuracy and precision errors from the instrument, the satellite sensor resolution, the product pre-processing and radiometric correction. These errors will create uncertainty which will carry forward and become inherent to the shoreline. Errors will also be created from using auxiliary data. These errors occur from uncertainties in measurement and errors accumulated through the methodology. For example, the beach slope is often irregular with steepening occurring towards the backshore rather than a gradually sloping surface. This provides a significant source of inaccuracy when calculating the position of the shorelines. Errors may also accumulate when using numerous measurements of the sea state. Calibration issues and limits in measurement resolution for the various oceanographic instruments used to collect the auxiliary data may lead to erroneous calculations of run up and sea surface height, this in turn will affect the calculated positions for of the shoreline indicators.

Regionally, in the Atlantic, a large source of error is the discrepancy between the reference level and the tidal level at time of the EO snapshot, which is not given by any metocean forecast. In the Mediterranean, the main source of error is related to the metocean conditions, with errors created in the shoreline position of up to 10 m, if the storm surge and the wave runup are not calculated correctly. Errors can be quantified by totalling the uncertainty ranges of the measurements. For example, with a tide height of 5 m ± 0.2, a wave run up of 1 m ± 0.4 and a wind set up of 0.3 m ± 0.1. Totalling these values would lead to an expected water level at the waterline of 6.3 m ± 0.7 (assuming no h_{SLR} or h_{atm} terms). Uncertainty ranges for the auxiliary data measurements are obtained from the complimentary metadata files.

[8] Refer to document ref: SO-TR-ARG-003-055-009-ATBD-ER

2.4 Algorithm Output

2.4.1 Product content

The Shoreline product will contain a continuous vector line. This line will carry information such as the quality control score, as well as the date and time at which the original product was taken. The shapefile will be packaged in a compressed .zip file format.

2.4.2 Product organisation.

Datum-based shoreline products will be organized in different directories according to the study area. For each area, the partners will access the shoreline with all metadata and the instantaneous waterline from which the shoreline was calculated.

2.5 Algorithm Performance Estimates

2.5.1 Test specification

This testing aims to ensure the current shoreline processor conforms to the requirements set out in the ATBD. The testing regime is two-part. First, to ensure the positioning of the shorelines conform to the mathematical and scientific baseline outlined in the ATBD, basic geometric waterlines with varying metocean /morphological parameters test each function to ensure they contribute to shoreline position correctly. The second stage is geometric testing. This uses various waterline shapes at various scales to test correct shoreline placement and positioning. This is assessed more subjectively than the mathematical testing. Further future testing may include general processor stability using inputs that do not conform to recognised processor inputs.

2.5.2 Test Datasets

Waterline: 1 km long Sentinel-2 subset, 10m pixel size. SW-NE Orientation | Slope: 3 points. Constant 0.01 dy/dx. | Wave: 0.01m, @ 1s, SE Direction. | Projection: WGS84(UTM) 29N.

2.5.3 Verification

Summary verification results for version 1.0.0 of the processor are presented below.

Table 2.1 Processor geometry calculation verification

Mathematical Testing					
Tested Function(s)	**Input**	**Expected Output (Or ATBD requirements)**	**Actual Output**	**Result**	**Comments**
All	Standard	ΔL= 0.80m	ΔL= 0.80m	PASS	
Stockdon2006 GeomCalc	Standard: Wave Period + 10s	ΔL= 7.99m	ΔL= 8.02m	PASS	
Stockdon2006 GeomCalc	Standard: Wave Height + 2m	ΔL= 11.30m	ΔL= 11.32m	PASS	
WaveAngleCalc GeomCalc	Standard: Wave Direction + 45°	ΔL= 0.72m	ΔL= 0.78m	PASS	Discrepancy due to the fact the test dataset is not exactly normal to the incoming wave direction.
GeomCalc	Standard: All slope+0.1	ΔL= 0.16m	ΔL= 0.16m	PASS	
GeomCalc	Standard: One Slope point + 0.1	End1&2 ΔL= 0.80m Mid ΔL= 0.16m	End1&2 ΔL= 0.80m Mid ΔL= 0.16m	PASS	Slopes are assigned to segments and not interpolated evenly, should review whether this was intended or not.
GeomCalc	Standard: Water level +1m	ΔL= 100.80m	ΔL= 100.66m	PASS	
GeomCalc	Standard: Datum + 1m	ΔL= -99.20m	ΔL= -99.37m	PASS	

2.6 Product Quality Control

2.6.1 Specifications

The Quality Control (QC) step aims to provide product users with confidence in the validity of the products, i.e. *Is this section of shoreline likely to be a good representation of the actual shoreline?* The shoreline product is susceptible to inherit errors propagated through the image selection, geolocation and waterline processing steps, these errors can be identified and flagged. The QC takes an internal and external approach. Internal QC analyses the shoreline within the processor, while judging quality based upon the shoreline's own merits. External QC is applied post processor, and assesses quality based upon external products such as other processed shorelines or waterlines derived from other methods.

Differences in geometry characteristics between known shoreline segments and known errors can be exploited as a way to provide QC. A QC Score between 0 and 100 is created by each methodology for each shoreline segment, this is calibrated according to the results of the QC method testing. The QC Scores from each test are then blended, calibrated according to the results of the testing, to create a final internal QC score. This final internal QC score is created to mitigate against the limitations of each methodology. Higher QC scores correspond to a higher confidence that the waterline is a good representation of the true shoreline, and vice versa. The QC is graduated, rather than a binary pass or fail, this is to allow users to use their expert knowledge of the local area to determine whether a shoreline segment is a good representation or not. QC Scores can be used to colour code the line Red, Amber, Green in GIS software, this allows for clear visual representation of QC Scores.

2.6.2 Internal Quality Control

The Line Confinement Index method (LCI) is an internal process that exploits the compactness of a line segment to determine its accuracy. A large proportion of observed errors are 'squiggly' with a long line in a confined space, quantifying this quality allows these erroneous segments to be isolated. This methodology uses a Line Confinement Index, which is the ratio of the spatial extent to the length of the line. As the shoreline is generally continuous, the line is split into 1000m intervals where applicable. The equation below, where x_{max} is the maximum x position of the line on a cartesian plane. L is the total line length.

$$LCI = \frac{(x_{max} - x_{min}) + (y_{max} - y_{min})}{L}$$

Shoreline sections along beaches are generally long and straight, and will have a higher LCI. Whereas errors in the offshore zone will often present as circular or erratic features. The LCI has the advantage of detecting common errors created by the processor but will often flag man-made structures such as harbours and rocky coastal areas. The LCI scoring is graduated as shown below, this score is based upon calibration using QGIS.

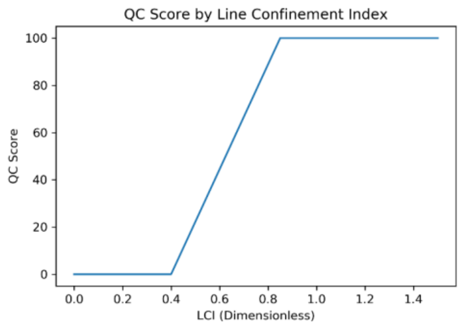

Figure 2.3: QC Score assigned for the Line Confinement Index

2.6.3 External Quality Control

This methodology is an external QC process that uses a density map of shoreline positions to determine likely positions of accurate shoreline. Most shoreline products will contain accurate shoreline positions, with some randomly scattered errors due to erroneous waterline being processed. Therefore, repeating segments are likely to represent true shoreline position with non-repeating segments likely to represent an error created by the waterline processor. The selected shorelines for the heatmap presents a distinct trade off, to reduce the QC score being affected by the inherent uncertainties, a large number of shorelines must be used, however the mean position of the shorelines will move over time and will often take an extreme positioning during storm events. Therefore, care must be taken when selecting the timeseries range to analyse.

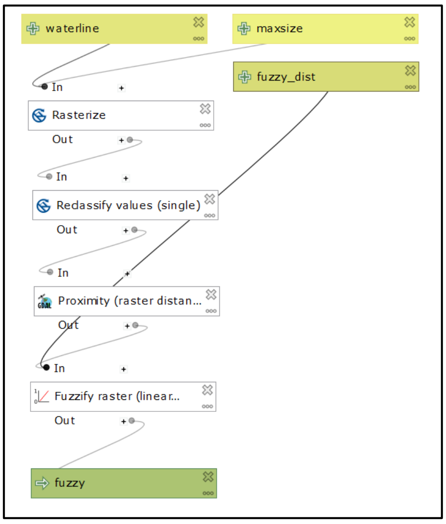

Figure 2.4: QGIS Processing chain of the heatmap algorithm.

The processing chain (Figure 2.4) highlights the steps taken to transform a shoreline to a fuzzy raster. First the shorelines are transformed from a vector to a raster with grid spacing proportional to the sensor resolution, this is done over the extent of the area of interest (maxsize). Next, no data values are replaced with zeros, leaving a binary raster. This raster is then run through a Euclidean distance function, this creates a raster where each no data pixel is assigned a value according to its minimum distance to the nearest shoreline pixel. Next, the raster is fuzzified using linear membership with a transition zone between 0 m and a value corresponding to the uncertainty of the shoreline position (fuzz_dist), this ensures correct raster overlap regardless of the inherent product uncertainty. This creates a raster with values between 0 and 1, dependant on the values within the Euclidean distance raster. Finally, the fuzzy rasters for each shoreline are summated then averaged in the raster calculator. Optionally, these can then be normalised between 0 and 100. The final raster is then mean sampled by shoreline segment through a bespoke python script. The QC scores are then stored within the shoreline shapefile.

3 Conclusion

3.1 Assessment of limitations

Despite strong results in production and validation, the shoreline processor has various limitations which limit the quality and accuracy of the shoreline products. Some of these limitations are inherent and result from input data constraints, whereas other limitations are actionable and result from the methodology used to derive shorelines. These actionable limitations could be mitigated in future versions of the shoreline processor.

3.1.1 Inherent Limitations

The main source of error and uncertainty in shoreline position is due to the quality of auxiliary data provided. The quality of the auxiliary data is determined by its measurement type, measurement location relative to the shoreline, temporal resolution, and measurement uncertainty. As the processor uses four primary sources of auxiliary data, the uncertainties of each data source will compound and result in a higher final uncertainty in shoreline position. This compounding effect is especially relevant when using modelled datasets, as these will have much higher uncertainty than measured data.

The shoreline quality is also limited by the quality and accuracy of the input waterline products. The waterline processor has its own limitations which lead to misplacement of the waterline, these errors generally manifest as squiggly, erratic lines, broken sections and misplacement onto the backshore. The shoreline processor has no way to correct or identify these errors, these will then be passed onto the shoreline product.

Coastlines with a changing intertidal area also present significant problems for the shoreline processor. In areas where prominent sand banks, mudflats, creeks and channels are exposed at low tide, the processor has no way to transform a high tide waterline to a low tide shoreline (and vice versa). The processor has no innate knowledge of the changing waterline geometry between high and low tide and therefore will set an erroneous shoreline position.

3.1.2 Actionable Limitations

The interpolation method used for water level can create positional error when transforming the waterline to shoreline. The water level is interpolated based upon the ratio of Euclidean (straight line) distances between shoreline and tide gauges. Using the Euclidean distance does not account for coastal features such as headlands and peninsulas, these may impact the progression of shallow water harmonic tidal constituents (overtides) and lead to a non-linear water level differential across the two tide gauges. This will result in over or underestimation of the water level used for processing. To account for this it could be possible to use smoothed length estimates of the coastline rather than Euclidean distance when interpolating between multiple tide gauges.

The shoreline processor uses wave run up estimations based on equations from Stockdon et al. (2006). Although these are widely cited as acceptable for use in coastal engineering and research, the equations are empirical and based upon a best fit of various experiments conducted across a range of different beach types. Therefore, the equations may not accurately model wave run up at each location analysed. To account for this, it may be possible to calibrate the wave run up equations to the target location based upon in-situ experiments of the beaches provided by partners.

A major limitation highlighted in production is poor performance in low slope coastal environments with extensive intertidal range. This results in high shoreline positioning error and poor line continuity. Due to the trigonometric nature of the waterline to shoreline shift (Refer to Section 2.3.2), small changes in slope lead to large changes in shoreline positioning. This is coupled with the inability of the shoreline processor to scale waterline segments and correct segment overlapping, this can lead to large gaps between shoreline segments and incorrect point joining. To correct this, it would require a complete overhaul of the point joining algorithm to fix these problems.

Last, in areas with a foreshore and steep cliff, where the waterline touches the toe of the cliff during much of the tidal cycle, abrupt changes to the slope profile result in a misplacement of shoreline datums. This can lead to high tide shorelines being pushed in land. To correct for this encroachment, it is possible to incorporate littoral lines derived from classification maps to define the theoretical landward limit of shoreline position. Any shoreline segments landward of this line can be corrected.

3.2 Mitigation

Redesign of the algorithms used within the shoreline processor are the most appropriate course of action to account for problems caused by tidal interpolation, low slope environments and cliff areas as highlighted in section 3.1.2.

To mitigate the inherent limitations highlighted in section 3.1.1, two approaches can be used. First the QC parameters from the waterlines can be utilised to filter out waterline segments from the processing. However the waterline QC process only indicates confidence in product accuracy and any omissions may lead to a loss of viable shoreline product. Second, to account for inherent uncertainties created by the input data, it is possible to use GIS techniques to analyse multiple shorelines of the same datum and derive mean positions and rates of change. Assuming the errors in shoreline position are random rather than systematic, density analysis techniques can be used as a tool to locate areas of coastal change, this can be used in combination with external shoreline analysis software that run analysis on multiple shorelines.

4 References

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