Geological Survey of Ireland

ESA Coastal Erosion from Space: Evaluation of Irish Products

Supervised by

Xavier Monteys

Contributors:

Xavier Monteys,Yeray Castillo Campo, Kate Hynes, Seamus Coveney

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Waterlines

ANNEX B. SERVICE ASSESSMENT SHEET

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:

This assessment refers only to products from 4 study areas.

Specifications of satellite derived waterlines (SDW) requirements from the Irish end-user (GSI) were presented in Table 15 of the User Requirement Document. The Irish end-user consider the adequacy to the requirements (including accuracy) of waterlines products high for the following reasons:

1. The positional accuracy of the Sentinel-2 waterlines was in the range of one pixel (*Mean Absolute Error 10 to 15m*) of vertical coastal infrastructure features that clearly demarcate the land-water boundary. The scale consistency and geometric fidelity of coastal features that were represented in the Sentinel-2 waterlines were of a similar quality, deriving from positioning errors of the order a one pixel. Expanded accuracy statistics are presented in the Geopositional Errors Assessment Document.
2. Landsat 8 and Landsat 5 waterlines were also of the order of one pixel (Mean Absolute Errors in the 15-30m range) of permanent vertical coastal features, achieving consequent feature scale-representation and geometric fidelity errors that derived from these small positioning errors. Please refer to the Geopositional Errors Assessment Document for an expanded set of accuracy assessment statistics.
3. VHR derived waterlines were delivered, meeting the 1m horizontal accuracy requirement for this type of product. This type of waterline product is essential for certain services, including the SAR S1 waterlines (SDW-SAR) that were delivered (236 waterlines) for Dublin Bay.
4. The requirements specified in the URD highlighted the need for data that have been obtained in the frequency of months, though this requirement was not fully accomplished.
5. Considering the data obtained from both methods (optical and radar), the whole dataset does encompass the period from 1994 to 2020, which includes almost 26 years of data, accomplishing the user requirement regarding temporal coverage.

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

B.2 Product compliance

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

Comments:

The Irish end-user qualifies the compliance of user requirements for SDW high for the following reasons:

1. Temporal and spatial resolution targets were met.
2. Metadata was delivered with waterline products.

3. Quality indicators were delivered as part of the products and considered to be suitable.
4. Lack of attribute data (i.e. water level and associated weather data) for each waterline.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Waterlines

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

Comments:

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

1. The horizontal accuracy met the specifications regarding source image spatial resolution. Please refer to the Geopositional Errors Assessment Document for accuracy assessment statistics regarding Positional, Scale-Consistency and Geometric Fidelity.
2. Geoposition accuracies are of the order of one pixel for each of the satellite image data sets from which waterline products were derived.

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

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

Comments:

The Irish end-user consider the confidence in the quality of shoreline products as follows:

1. <u>SDW- opt: High</u>
    a. Accuracy assessments are near the pixel resolution.
    b. Quality indicators are suitable to increase confidence in the product.
    c. There are clear artefacts in the waterlines. Particularly visible are the segments in the water bodies and in-land.
2. <u>SDW-sar</u>: Medium
    a. Clear inconsistencies in the waterline representing the coastline. Segments are far away from the coastline.
    b. Lack of useful quality indicators are an impediment to obtain high confidence levels.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Waterlines

B.3 Utility assessment

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

Comments:

1. The Irish end-user qualifies the confidence in product quality as high _for the following reason:
2. Based upon the results of the accuracy assessments, confidence in the optical waterlines can be considered to be high.

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

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

Comments:

1. This type of service is currently not available in Ireland.
2. The optical products can be used in ocean services, such as within oceanographic models.
3. The optical Waterline products can be used to model water-level change over time and space.

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

B.4 Future outlook

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

Comments:

1. The end-user considers that SD Waterlines products can improve and reduce costs relative to current practices.
2. There is a high probability that these EO products can be productively integrated into current practices.

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

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

Comments:

The Irish end-user considers that the following services and improvements would be desirable:

1. Full water-level attribution at node (segment) level should be part of the product. It should be considered to offer a point data definition of the water edge.
2. The optical products can be incorporated into existing DTM services to monitor change at pixel resolution.

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

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

Comments:

1. High interest in the potential of these products.
2. A full national coverage, from 20 years of data with full water level attribution would be desirable, in order to build an archive.
3. Post processing would be required using quality indicators and manual editing.

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

B.5 Overall evaluation

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

Comments:

The Irish end-user evaluates the quality of the products provided as High for the following reasons:

1. Optical Waterlines: horizontal accuracy did meet the aspirations of the end-user in relation to the source image used. The dataset provided is useful for the purposes of waterline analysis.
2. The confidence in SAR Derived waterlines products was medium due to the larger pixel size and a shortage of quality control.

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

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

Comments:

1. VHR archive optical imagery could be made available, particularly for the period between 2000- 2015, prior to Sentinel-2 era.
2. Higher spatial resolution (5m) SAR imagery should be made available to future projects. This type of data is essential in areas of high cloud cover such as Atlantic coasts.
3. Waterlines would increase their value as an EO product, as well as their applicability, if in future versions they would include detailed water level information (using altimetry data) that are for each waterline section or point along the coast.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Shorelines

ANNEX B. SERVICE ASSESSMENT SHEET

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:

This assessment refers to products from four study areas: Dublin Bay (335 shorelines), Cork (410 shorelines), Waterford (580 shorelines) and Wexford (475 shorelines). Specifications of satellite derived waterlines (SDW) requirements from the Irish end-user (GSI) were presented in Table 15 of the User Requirement Document. The Irish end-user consider the adequacy to the requirements (including accuracy) of waterlines products medium for the following reasons:

1. Argans was responsible for providing optical derived shorelines (SDSL-opt) delivered for Dublin Bay (335 shorelines), Cork (410 shorelines), Waterford (580 shorelines) and Wexford (475 shorelines).

2. There are 5 different types of SAR-shorelines: HAT, MHWS, MSL, MLWS and LAT. A total of 4155 radar shorelines (SDSL-sar) were developed for the Dublin study area distributed as follows in the time range from 2014 to 2020: 2014 (15 shorelines), 2015 (285 shorelines), 2016 (595 shorelines), 2017 (930 shorelines), 2018 (960 shorelines), 2019 (1030 shorelines) and 2020 (340 shorelines).

3. Shorelines are obtained from a waterline which in turn are derived from a satellite image. There are 5 different shorelines that are extracted from each individual waterline (HAT, MHWS, MSL, MLWS, LAT).

4. Temporal frequency requirements specified in the URD highlighted the need for data obtained in the frequency of months and this requirement was not fully accomplished. Lack of suitable images had precluded this requirement from being fulfilled. This is more visible in the Landsat 5 period from 1994 to 2013.

5. The whole dataset covers the period from 1994 to 2020, completing almost 26 years of data. It does not meet the end-user's requirement of temporal coverage because the series of images are not continuous. The temporal gaps in the shoreline product can be attributed to lack of suitable images. Some gaps in data have been identified, such as (2012, 2008 and 2005). In some areas other years are not available either:

   a) Dublin (2011, 2010, 2006, 2004, 2003, 2002, 2001, 2000, 1998 and 1996);
   b) Wexford (2020, 2013, 2011, 2010, 2009, 2007, 2006, 2004, 2003, 2002, 2001, 2000, 1999, 1998, 1997, 1996, 1995 and 1994);
   c) Waterford (2000 and 1994);
   d) Cork (2011, 2010, 2009, 2006, 2004, 2002 and 1994).

6. No shorelines have been derived from VHR satellite imagery, thus not meeting the highest horizontal accuracy (1m) for this type of products. This accuracy is deemed essential for certain coastal services.
7. Optical shorelines horizontal accuracy assessments against reference layers (HWM and vegetation lines) show mean errors larger than 20m. Generally, the shorelines have been overestimated onshore.

8. SAR shorelines inspected from one area (Dublin) have horizontal mean errors larger than 100m. They are not suitable for monitoring coastal change

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

B.2 Product compliance

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

Comments:

The end-user qualifies the compliance of user requirements for SDSL as medium for the following reasons:

There is a standardization of the products with a descriptive nomenclature, common reference coordinate system, shapefile format and metadata. Each shoreline is accompanied by its corresponding metadata file where data such as (General info: Product name, product description or product qualifier; auxiliary data like water level and datum height; and ancillary data).

1. Products are compatible with typical GIS software: ArcGIS 10.3 (or higher) and QGIS.

2. Lack of products from 2012,2008 and 2005 in all study areas. There are no images available during these years that have exceeded the cloud cover threshold: Dublin (Landsat 80%, Sentinel 70%); Wexford (Landsat 70%, Sentinel 90%); Waterford (Landsat 70%, Sentinel 91%) and Cork (Landsat 80%, Sentinel 70%). Selection process of images begins with the verification of the data available on both platforms (ESA and NASA).

3. 25 years of continuous shoreline data was desirable to meet the temporal resolution of the end users' requirements in site 1. Although, the lack of shorelines in most cases is due to the deficiency of auxiliary data. There are other facts than can also affect Sentinel 2, Landsat 8 and Landsat 5 shorelines: 1) Short/ no waterline within target area, 2) Water level value bad/out of range or 3) Empty waterline file.

4. Spatial scale of shoreline products was reached. 1:1,000 (urban areas) and 1:2,000 (non-urban areas).

5. Updating frequency for optical shorelines was lower than the user's requirements (1 month). This can be attributed to lack of images during that period of time or its suitability (cloud cover).

6. SAR shorelines has an updating frequency higher than the user's requirements (1 month) for the years: 2016, 2017, 2018 and 2019. While in the following years there are only some months represented: 2014 (November and December); 2015 (from April to December) and 2020 (January, February, March and April).

7. SAR Shorelines did not include metadata file in JSON format.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Shorelines

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

Comments:

The Irish end-user consider the accuracy compliance of shoreline products as medium_for the following reason:

1. The horizontal accuracy did not meet the end-user requirements (1 m horizontal), the dataset provided is still useful for large-scale mapping.
2. A significant number of Shorelines derived from Sentinel 2 images approximate the 20m horizontal accuracy (pixel size). See validation report appended- Shoreline validation.
3. SAR shorelines exceed the horizontal accuracy requirements and cannot be used to monitor coastal change in their current state.
4. SAR and Optical Shorelines include areas (segments) that are clearly incorrect (too offshore, too onshore or with incorrect geometry). These segments possibly could have been filtered out or flagged using Quality Indicators, using a basic distance threshold from a published reference layer.
5. The range of water levels used for interpolation is provided in the shoreline metadata. Accuracy compliance would be higher if the value itself used for each shoreline segment (or point) would have been included.

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

End-User **:** Geological Survey Ireland
Contact **:** Xavier Monteys email: Xavier.Monteys@gsi.ie
Version **:** 12/02/2021
Filename **:** GSI_ ANNEXB_Shorelines

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

Comments:

The Irish end-user consider the confidence in the quality of shoreline products medium for the following reasons:

3. Shoreline products from optical sensors passed through a series of quality control and validation procedures. There are some inconsistencies in shorelines when compared to the co-registered orthophotos, vegetation lines, reference layers and GPS- ground truthing measurements.

4. A number of inconsistencies were identified in shorelines from the study areas, more visible on the HAT shorelines, generally too inland. Although they are less common, there are also stretches of LAT shorelines located in areas too offshore. It is possible that with more accurate auxiliary data this issue could have been minimised.

5. There is a lack of quality indicators as part of metadata to identify products (or segments) with potential large errors. This issue poses a challenge in identifying incorrect products (or segments). Thus, confidence in the results is impacted.

6. Optical shorelines mean errors to reference layers are too large (xxx) to assign a high confidence to this product.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_Shorelines

B.3 Utility assessment

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

Comments:

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

1. Accuracy mean errors larger than 20m using Sentinel 2 optical shorelines limit the product confidence.
2. Quality indicators should be an integral part of the product. Although W waterlines that have been used to derive these shorelines include useful quality indicators, Shorelines Quality indicators would allow an increase of confidence in the product.
3. Full attribution parameters at each node (segment) used to calculate the shoreline position should be included (water level, slope, weather, wave data). This would improve the confidence in the product by allowing a more detailed error analysis.

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

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 satellite derived shorelines, the Irish end-user consider that this product present medium impact on current end-user practices due to the following reasons:

1. Validation along the Dublin and Wexford coasts indicate a general good alignment with currently HWM /LWM shorelines but not as good as the original waterlines.
2. In order to have a higher impact in coastal erosion monitoring services at local and national scale the accuracy should be close to 10m.
3. Shorelines can have a high impact in existing ocean modelling services.
4. Shorelines can have a high impact in large scale mapping efforts at European level such as EU funded EMODnet Geology coastal behaviour services.

***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 Optical Shorelines products can add value to existing practices and become part of the products delivered by GSI via web mapping services in the future if accuracy and quality control issues are improved. Ancillary data is essential to obtain good quality products, therefore availability of accurate modelled water level data and accurate slope transect are key to success.

1. A service to monitor shoreline change over time (yearly) can be included into existing erosion rates services at national and European level (EMODnet Geology).
2. A service to deliver tidal datum from satellite data can be implemented to existing services.
3. Yearly (and decadal) shoreline services can be implemented to validate sea level ocean models.

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

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

Comments:

The Irish end-user consider that shoreline products need further improvements and qualify it as High for the following reasons:

1. VHR Optical shorelines are essential to effectively measure coastal change at the meter scale. While this is not an essential requirement for certain areas with low susceptibility to coastal change, it is essential for vulnerable areas to monitor at the meter scale. VHR Optical spanning for 20 years, is desirable in order to add value to the overall product. Coarse spatial resolution satellite data does not provide accurate enough results to monitor coastal change with uncertainties below 40m.

2. It is essential to have information about quality of EO Products (quality indicators). Although the waterlines from which they have been derived do include quality flags, the shorelines do not contain this information that would increase the value of the product.

3. Water levels applied to each point/section of the shorelines must be included into the metadata. It allows a better understanding of the process followed to obtain SL. In addition to increase the final product value and its applicability. Sentinel 5 data could be used for this purpose.

4. Shorelines derived from Sentinel 2 images approximate the 20m horizontal accuracy (pixel size). Several factors might be

responsible for this error. Ancillary data provided by the end-user is a potential source of error. However, the algorithm used to project waterlines into shorelines could also be a factor to be considered. Further work is needed to develop a comprehensive error model in a control area.

5. Combining optical and radar shorelines may provide data in wider temporal and spatial cover, which would allow a broader approach of shoreline analysis and coastal erosion monitoring.

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

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

Comments:

The Irish end –user considers large-scale service (Optical Shorelines) as high if quality assessment indices and accurate ancillary data are included and meet the requirements. This service would have applications on large –scale tidal datum lines and coastal change measurement – status over time. The temporal scale is considered to be at the seasonal or year temporal frequency.

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

B.5 Overall evaluation

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

Comments:

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

1. Shorelines showed a relatively good general agreement with existing datum-based lines in the Dublin and Wexford areas. Shorelines can provide an initial assessment of coastline change in terms of accretion vs erosion. They can also provide, in selected areas, an estimate of recession-accretion perpendicular to the coast. These estimates carry an error larger than 10m. There are a small percentage of Shorelines that can provide that type of information (approx. 10%).

2. Shorelines should include detailed quality assessment information provided by the processors. This way selection of useful products for different applications can be reached more confidently.

3. Although the horizontal accuracy did not meet GSI requirements, the dataset provided is still useful for future services. If VHR products were available and accurate the overall service would be positively impacted. Most of the changes in this part of the coastline occur at the meter scale.

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

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

Comments:

1. Access to VHR Satellite Optical data (1 to 3 m spatial resolution) to achieve near 1m horizontal accuracy. This is essential for detailed coastline change analysis. In order to obtain meter scale erosion rates it is necessary to use meter scale spatial resolution

2. Shorelines would increase their value as an EO product, as well as their applicability, if in future versions they would include detailed and up to date coastal slope information used in each section or point of the coast. Part of this data could come directly from other ESA missions.

3. SAR data should be close to 5m spatial resolution in order to be used to monitor coastal change at the required accuracy levels. This type of data is essential in cloud cover areas such as the Atlantic coast.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_LandCover

ANNEX B. SERVICE ASSESSMENT SHEET

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 Land Cover requirements from the Irish end-user (GSI) were presented in Table17 of the User Requirement Document. The Irish end-user consider the adequacy to the requirements (including accuracy) of LAND COVER BACKSHORE CLASSIFICATION products medium for the following reasons:

1. Dublin Bay, Wexford, Waterford and Cork areas were assessed. The frequency required for this EO Product (seasonal, 4 times a year) was not accomplished. Even though, the available S2 data allows seems to be sufficient at least for two maps/year.
2. There is a lack of product metadata containing basic attribution and images used.
3. There is insufficient detail in the class description.
4. There is a lack of cohesion between the classes used for each area. Each classification map has a different amount of detail, e.g. the Ballyconnigar map has far more classes than the neighbouring Dublin map. Classes present in one land classification map would not be present in another, or some classes were labelled differently between the maps i.e., in one map built-up areas would be called “houses” and “urban” but in another they would be called “built-up” and “industrial”. (see validation report-Land cover).

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

B.2 Product compliance

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

Comments:

The Irish end-user qualifies the compliance of user requirements for LAND COVER BACKSHORE CLASSIFICATION medium for the following reasons:

.

1. Lack of metadata and ancillary information (e.g. images used, number of classes).
2. The frequency required for this EO Product (seasonal, 4 times a year) was not accomplished.
3. Accuracy of land cover maps appears to be lower on the coastline than further in-land.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_SDB

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

Comments:

The Irish end-user consider the accuracy compliance of LAND COVER BACKSHORE CLASSIFICATION as medium for the following reason:

1. The geolocation and spatial accuracy meet the specifications set in the URD document.
2. Lack of enough temporal range and frequency.
3. More info on classes is still missing to perform final validations.

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

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

Comments:

The Irish end-user consider the confidence in the quality of Land Cover products medium due to:

7. An accuracy assessment was done using pseudo-ground truth data and the accuracy of the land cover maps was deemed to be high (e.g. kappa coefficient > 0.7).
8. Lack of full class descriptions (particularly for crop classes), metadata and additional attributes precludes from a high confidence.
9. Only one classification map is produced each year, therefore the seasonal changes in land cover over the space of year cannot be assessed, only changes that occur on a year-to-year basis.

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

B.3 Utility assessment

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

Comments:

The Irish end-user qualifies the confidence in the product quality (utility) as high.
An accuracy assessment was done using pseudo-ground truth data and the accuracy of the land cover maps was deemed to be high (e.g. kappa coefficient > 0.7).
Changes observed in the yearly classification are likely to be image driven (as opposed to permanent changes in land cover). This could be further assessed by inspecting more images (seasonal).

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

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

Comments:

Given the few results obtained the Irish end-user qualifies the expected impact as high.
Coastal land cover maps can be used in current mapping services (e.g CVI mapping) if minor issues are addressed.
Land cover coastal services can be included with current geomorphological coastal services.
Potentially it could be used for coastal habitat services.

***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 land cover monitoring tailored to coastal change classes can be of use to the wide end –user community.			

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

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

Comments:

The Irish end-user consider that Land Cover could be improved by:

1. Adding additional attributes to the classification layers (tide, weather, sun angle…).
2. 2 to 4 images per year.
3. Image suitability criteria.
4. Extending coverage as a continuous layer for the entire Irish coastline with a unique classification scheme.
5. A more cohesive land cover class system, with more detail needed for the crop classes.
6. A more detailed research on class categories should be undertaken by the end-user and service provider, including specific coastal vegetation and geomorphological classes.
7. Land Cover – Backshore supervised classification products should target the coastal zone geomorphological classes and the intertidal zone. Capturing change over time should be the primary focus.

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

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			x
Comments: The Irish end-user considers that this product taking into account the processing effort would benefit from a 100 % coverage (entire coastline).			

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

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	
Comments: The Irish end-user evaluates products provided up to now as medium for the following reasons: 1. Land Cover outputs meet the spatial resolution but not the frequency (4 times a year). 2. Classification results, while not yet fully validated due to inability to perform field work (Covid-19 restriction since late February 2020), seems satisfactory. 3. An accuracy assessment using pseudo-ground truth data shows that the accuracy of the land cover classification maps are high, however the accuracy is lower in coastal areas. 4. Lack of metadata and attributes impede a more structured assessment.			

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

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
Comments: None			

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_SDB

ANNEX B. SERVICE ASSESSMENT SHEET

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 Irish end-user (GSI) were presented in Table 13 (page 49) of the User Requirement Document.

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

1. 21 SDB products for four pilot sites in Ireland: Dublin (8), Waterford (6), Cork (1) Wexford (6). This met the end-user requirements regarding coverage.
2. Results met the end user requirements in terms of data format and metadata.
3. Temporal range and frequency were not met. This was due to the lack of suitable images. With cloud cover and water sediment suspended areas, obtaining suitable images in a year can be a challenge.
4. Spatial resolution requirements were not met. However, the 10 m resolution from S2 was considered as acceptable as this is the only source of reliable data to perform SDB given the constrains to obtain suitable image from VHR datasets.
5. Vertical accuracy requirements for bathymetric products (0.1 m vertical) were not accomplished. These requirements were aspirational and possibly cannot be achieved using optical satellite derived bathymetry in the targeted environments.

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

B.2 Product compliance

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

Comments:

The Irish end-user qualifies the compliance of user requirements for SDB medium for the following reasons:

1. The products delivered were compliant in terms of coverage, data formats, metadata and quality indicators.
2. The products were not compliant in terms of temporal frequency and spatial resolution but as explained previously this was due primarily to image availability.
3. The products were not compliant in terms of vertical accuracy.

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

End-User : Geological Survey Ireland
Contact : Xavier Monteys email: Xavier.Monteys@gsi.ie
Version : 12/02/2021
Filename : GSI_ ANNEXB_SDB

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

Comments:

The Irish end-user consider the accuracy compliance of SDB as <u>low</u> for the following reason:

1. The vertical accuracy levels do not meet the user requirements and are not suitable for monitoring purposes.
2. High variability in SDB timeseries precludes the use of these images for monitoring sediment dynamics in the near shore areas evaluated.

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

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

Comments:

The Irish end-user consider the confidence in the quality of satellite derived bathymetry as <u>low</u> for the following reasons:

1. Cross validation with ground truthing in two areas show accuracy levels larger than 2m (MAE) between 0 to 10m. See report in SDB validation.
2. High time series variably in the results from all the sites are not suitable to monitor water depth changes.
3. Extensive banding along the coastal can be observed in most of the SDB products. This artefact is present in shallow environments producing unrealistic water depth values in shallow environments.

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

B.3 Utility assessment

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

Comments:

The Irish end-user qualifies the confidence in product quality as Low for the following reason:

1. Water depth accuracy levels are considered insufficient to confidently produce bathymetry maps in the validated coastal areas between 0 to 10m.
2. High temporal variability significantly reduces the confidence in the results.
3. The Quality indices provided add confidence to the bathymetry outputs.

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

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

Comments:

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

1. Vertical accuracy levels obtained are not good enough to develop bathymetry layers with acceptable confidence levels. Time series water depth high variability in certain areas further confirms the low confidence (annex c).

2. Accurate and consistent results could have a high impact in current services in very shallow water.

***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 low for the following reason:

1. The accuracy levels obtained are not good enough yet to become a service for monitoring shallow coastal change and sediment dynamics. Further research is required to obtain consistent accurate outputs in water depths between 0 to 6m.

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

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

Comments:

The Irish end-user consider that SDB qualifies the need for further improvements as high for the following reason:

1. Satellite derived bathymetry has potential to generate water depth information in very shallow environments where water clarity allows for it. With consistency in the results, water depth information from multiple images can be processed together minimizing local variations. Increasing number of S2 images over time can play a role.
2. A combined approach using empirical and analytical based models can further improve the methodology and final results.
3. Image suitability indices regarding water quality, sea surface and sun incidence angle are essential as quality indicators and should be part of the attribution.
4. Terrestrial satellite techniques are better suited for the intertidal zone to derive elevation models and should be prioritized.

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

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

Comments:

The Irish end-user considers large-scale bathymetry as important and qualifies this need as medium.
In Irish coastal areas where consistent time series satellite derived bathymetry can be obtained in depths between 0 to 6 m with accuracies lower than 0.5 m (MAE), the end-user considers it as a key service to monitor large scale change.

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

B.5 Overall evaluation

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

Comments:

The Irish end-user evaluates the service and products as Low for the following reasons:

1. Water quality issues are main challenge to obtain useful satellite derived bathymetry. Particle concentration in the water is high in many areas of the East coast (Ireland) throughout the year. Accurate SDB products could not be generated for all of the pilot sites.
2. High variability in the satellite derived bathymetry time series in the Dublin area is not likely linked to sediment dynamics but to image variability.
3. The accuracy obtained in the Dublin area was not in accordance to recent published work carried in the same area using empirical (Casal et al, 2019) and physics based approaches (Casal et al, 2020) A different approach could have been employed using a combination of empirical and analytical methods. Intertidal areas (in Ireland up to 5 m water depth range) were the primary target for the end–user. Bathymetry data from the intertidal can be extracted from Waterlines and employed in the empirical models.
4. The methodology developed brought interesting features in quality control side (quality indices) that could be employed in more suitable water environments. This type f information would allow confidence area outputs and possibly multiple images could be processed together.

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

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

Comments:

None

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Geological Survey of Ireland

ESA Coastal Erosion from Space: Validation of Irish Products

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Supervised by

Xavier Monteys

Contributors:

Xavier Monteys, Yeray Castillo Campo, Kate Hynes, Seamus Covenery

Table of Contents

Tables

<u>Figures</u>

Summary

The following report is a document containing detailed

1. Introduction

2. Waterlines Validation

Data

Satellite data sources

Sentinel-2	Optical
Landsat-8	Optical
Landsat-5	Optical
RapidEye	Optical
Sentinel-1	SAR

Table 2.1: Satellite data sources

2.1. Methodology

Geo-positioning accuracy is assessed using the following methods:

1. Ordnance Survey Absolute or Positional Accuracy – 'closeness' of map feature position, to the position of that feature on the ground.

Figure 2.1: Location of Dunleary within Dublin bay, and a selection of Waterline positional accuracy measurements observed within a Dublin (Dunleary) Sentinel-2 Waterline (02/02/2019)

Positional accuracy is quantified in a GIS (ArcGIS 10.x) by defining the horizontal separation between all waterline feature vertices and vertical pier edge features.

Figure 2.2: Positional accuracy measurements within a Wexford (Rosslare) Sentinel-2 Waterline

2. Ordnance Survey Relative Accuracy - comparison of scaled distance between map features, and the actual distance measured on reality.

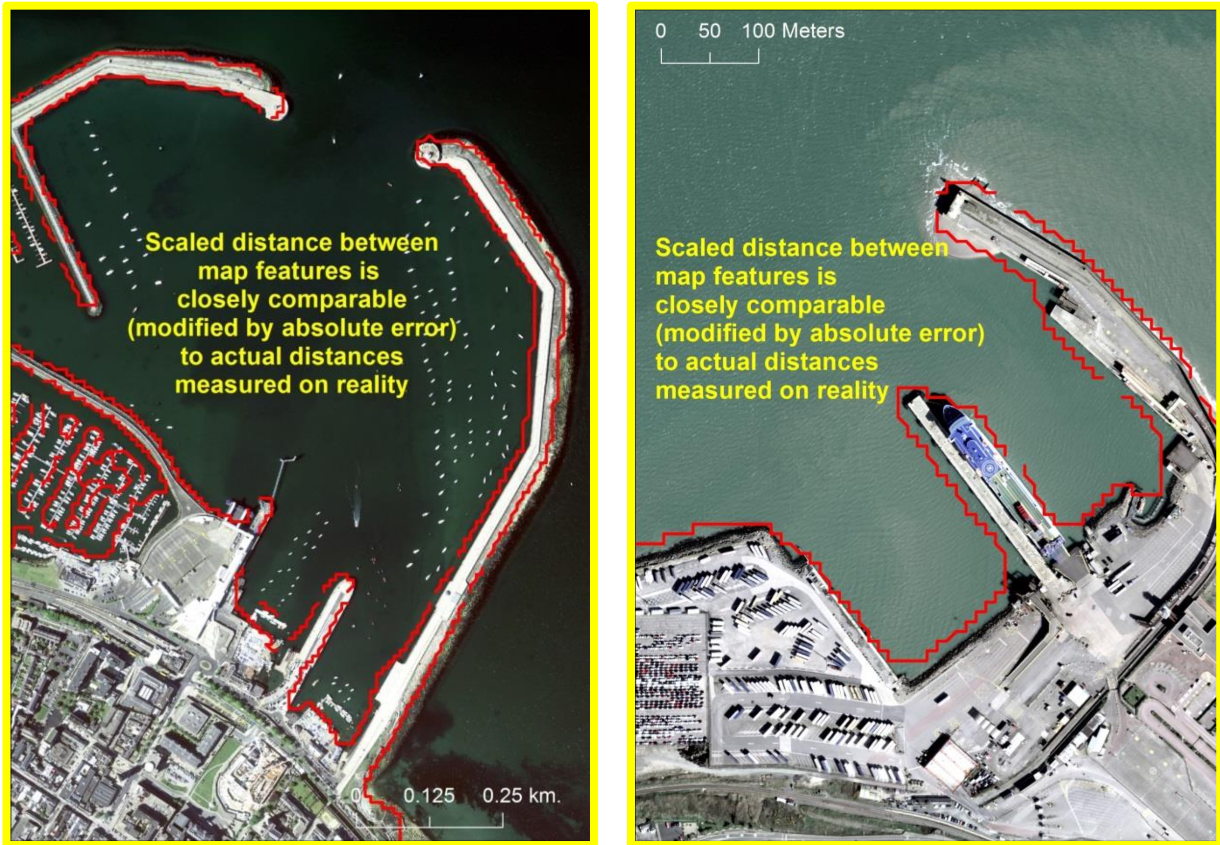

Figure 2.3: Feature scale representation in Dublin & Wexford Waterlines

Relative (feature scale) Accuracy is quantified by defining the area (m^2) ratio between Minimum Bounding Rectangle envelopes that encapsulate a pier edge feature and a set of waterline segments that represent this feature. Accuracy statistics are presented in the Results section.

3. Ordnance Survey Geometric Fidelity – the 'trueness' of map feature shapes, to the shapes and alignments of the features in the real-world.

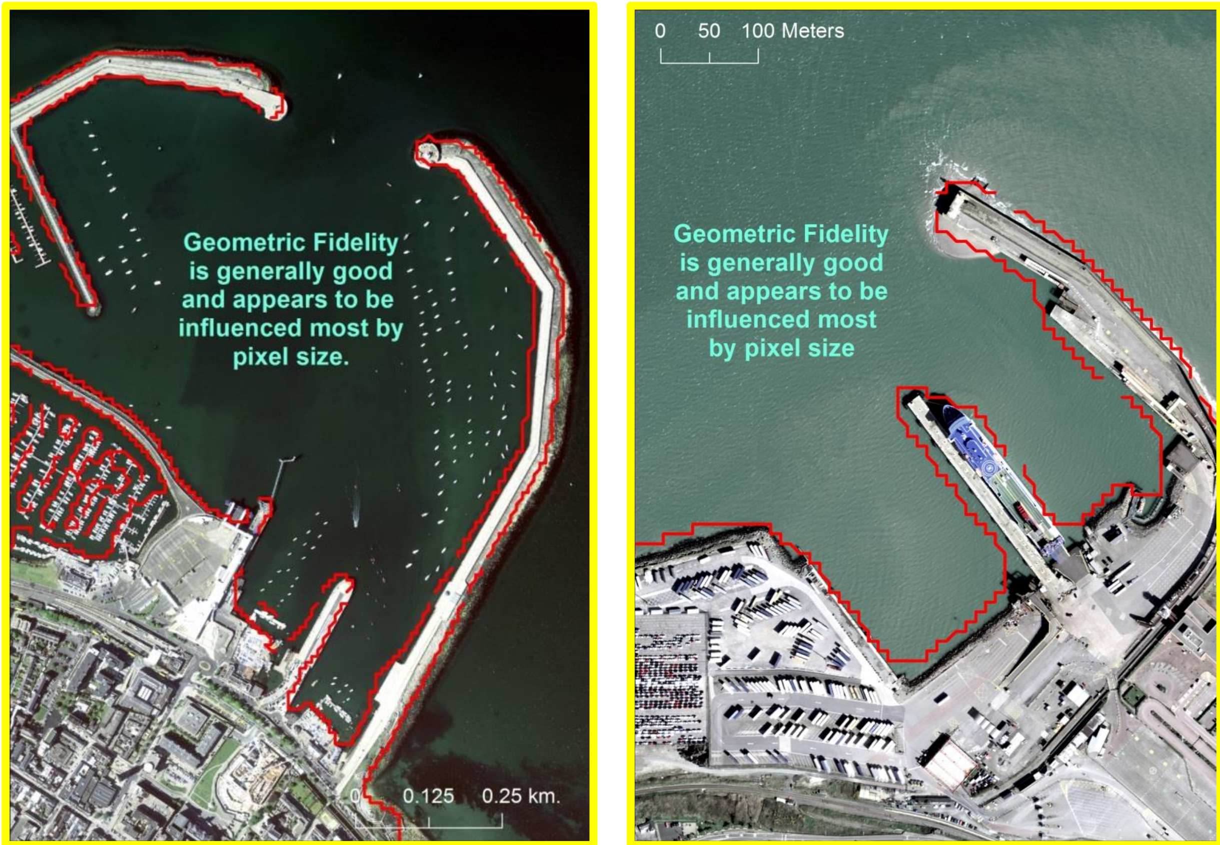

Figure 2.4: Geometric Fidelity representation in Dublin & Wexford Waterlines

Geometric Fidelity is quantified by defining the length (m) ratio between an actual pier edge feature and the average length of a set of waterline segments that represent this feature. Accuracy statistics regarding geometric fidelity are presented in the Results section also.

2.2. Results

Sentinel-2 Waterlines: Dublin (Dunleary)

Horizontal error statistics (m)

Waterlines evaluated	21
Data years	2016-2020
MAE	10.027
RMSE	11.502
Median	9.7193
Mode	17.109
Standard Deviation	5.635
Minimum	0.233
Maximum	27.511
WL vertex (sample) count	5643

Table 2.2: S2 Dunleary Horizontal Error Statistics

Histogram (horizontal error)

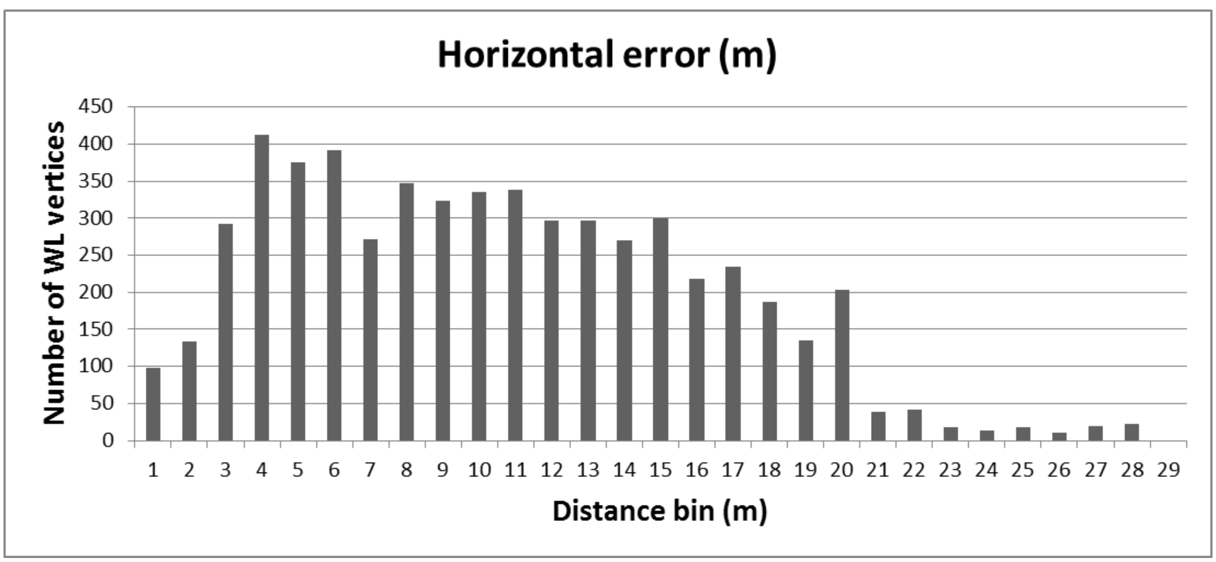

Figure 2.5: S2 Dunleary Horizontal Error Histogram

Relative Accuracy (scale consistency) Error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.97
Relative Accuracy (scale consistency)	excellent

Table 2.3: S2 Dunleary Relative Accuracy (Scale Consistency) Error

Geometric Fidelity Error

Reference feature (pier wall) length	1060m
Mean WL length	1335m
Ratio WL length / feature length	1.26
Geometric Fidelity	Very good

Table 2.4: S2 Dunleary Geometric Fidelity Error

Sentinel-2 Waterlines: Wexford (Rosslare)

Horizontal Error Statistics (m)

Waterlines evaluated	15
Data years	2018-2020
MAE	15.095
RMSE	18.909
Median	12.283
Mode	20.232
Standard Deviation	11.391
Minimum	0.357
Maximum	63.216
WL vertex (sample) count	2430

Table 2.5: S2 Wexford Horizontal Error Statistics

Histogram (horizontal error)

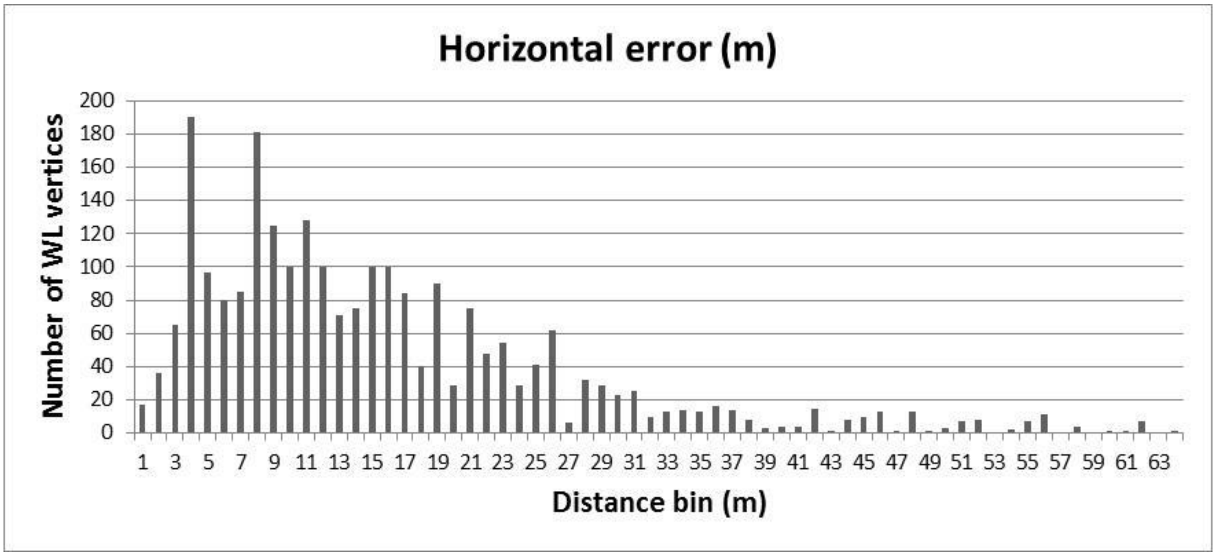

Figure 2.6: S2 Wexford Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.88
Relative Accuracy (scale consistency)	very good

Table 2.6: S2 Wexford Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	319m
Mean WL length	374m
Ratio WL length / feature length	1.17
Geometric Fidelity	very good

Table 2.7: S2 Wexford Geometric Fidelity error

Landsat-8 Waterlines: Dublin (Dunleary)

Horizontal error statistics (m)

Waterlines evaluated	8
Data years	2020
MAE	30.332
RMSE	33.994
Median	31.521

Mode	17.015
Standard Deviation	15.356
Minimum	0.416
Maximum	62.68
WL vertex (sample) coun	957

Table 2.8: Landsat-8 Dunleary Horizontal Error Statistics

Histogram (horizontal error)

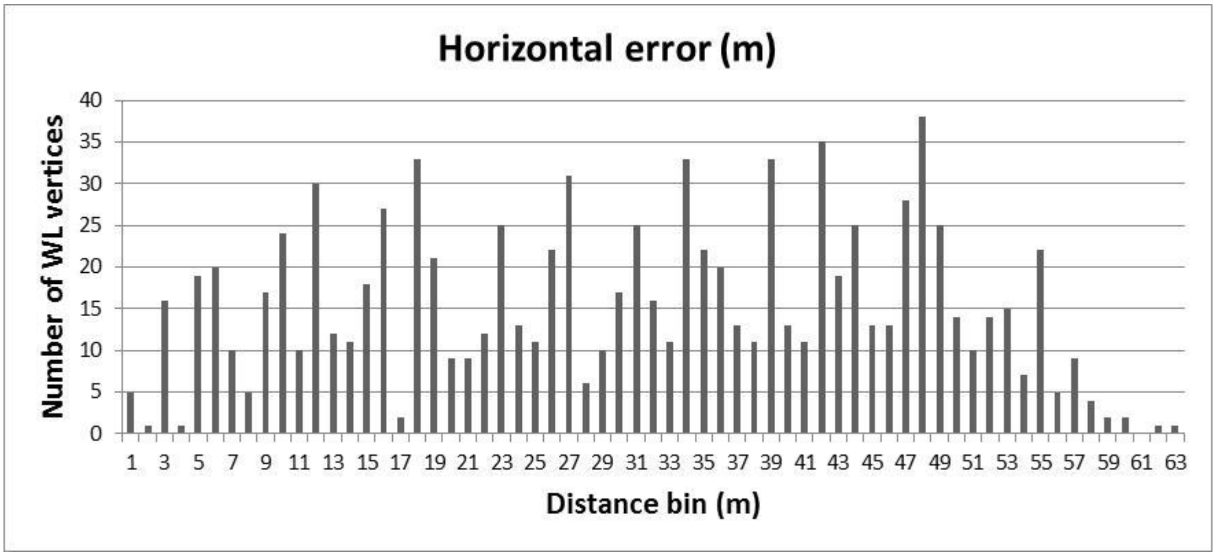

Figure 2.7: Landsat-8 Dunleary Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.94
Relative Accuracy (scale consistency)	excellent

Table 2.9: Landsat-8 Dunleary Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	1098m
Mean WL length	1055m
Ratio WL length / feature length	0.96
Geometric Fidelity	excellent

Table 2.10: Landsat-8 Dunleary Geometric Fidelity Error

Landsat-8 Waterlines: Wexford (Rosslare)

Horizontal error statistics (m)

Waterlines evaluated	15
Data years	2020
MAE	16.995
RMSE	19.474
Median	15.96
Mode	16.15
Standard Deviation	9.513
Minimum	2.392
Maximum	43.684
WL vertex (sample) count	1042

Table 2.11: Landsat-8 Wexford Horizontal Error Statistics

Histogram (horizontal error)

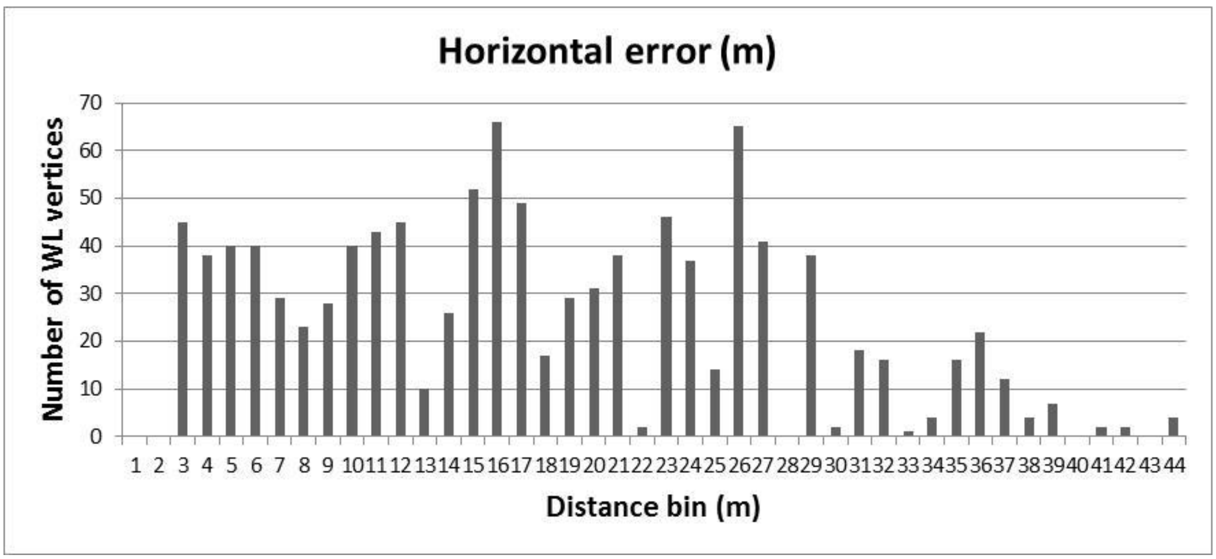

Figure 2.8: Landsat-8 Wexford Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.95
Relative Accuracy (scale consistency)	excellent

Table 2.12: Landsat-8 Wexford Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	319m
Mean WL length	418m

Ratio WL length / feature length	1.31
Geometric Fidelity	good

Table 2.13: Landsat-8 Wexford Geometric Fidelity Error

Landsat-5 Waterlines: Dublin (Dunleary)

Horizontal error statistics (m)

Waterlines evaluated	22
Data years	2020
MAE	5.821
RMSE	6.678
Median	4.982
Mode	#N/A
Standard Deviation	3.28
Minimum	0.233
Maximum	15.387
WL vertex (sample) count	217

Table 2.14: Landsat-5 Dunleary Horizontal Error Statistics

Histogram (horizontal error)

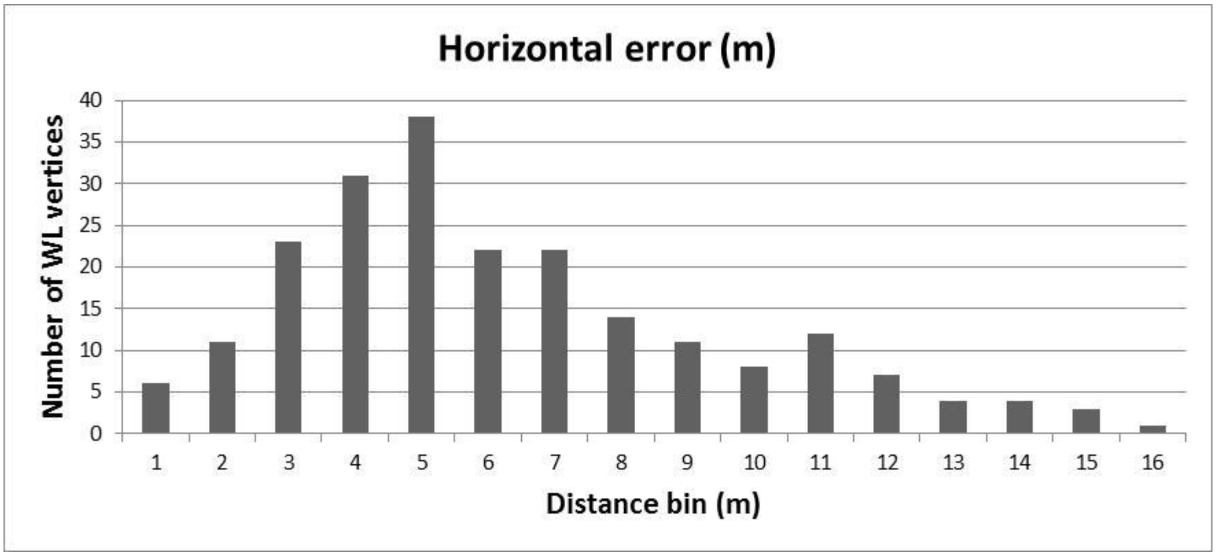

Figure 2.9: Landsat-5 Dunleary Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	1.11
Relative Accuracy (scale consistency)	very good

Table 2.15: Landsat-5 Dunleary Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	319m
Mean WL length	310m
Ratio WL length / feature length	0.97
Geometric Fidelity	excellent

Table 2.16: Landsat-5 Dunleary Geometric Fidelity Error

Landsat-5 Waterlines: Wexford (Rosslare)

Horizontal error statistics (m)

Waterlines evaluated	22
Data years	2020
MAE	29.843
RMSE	35.591
Median	83

Mode	84
Standard Deviation	12.826
Minimum	30
Maximum	100
WL vertex (sample) count	689

Table 2.17: Landsat-5 Wexford Horizontal Error Statistics

Histogram (horizontal error)

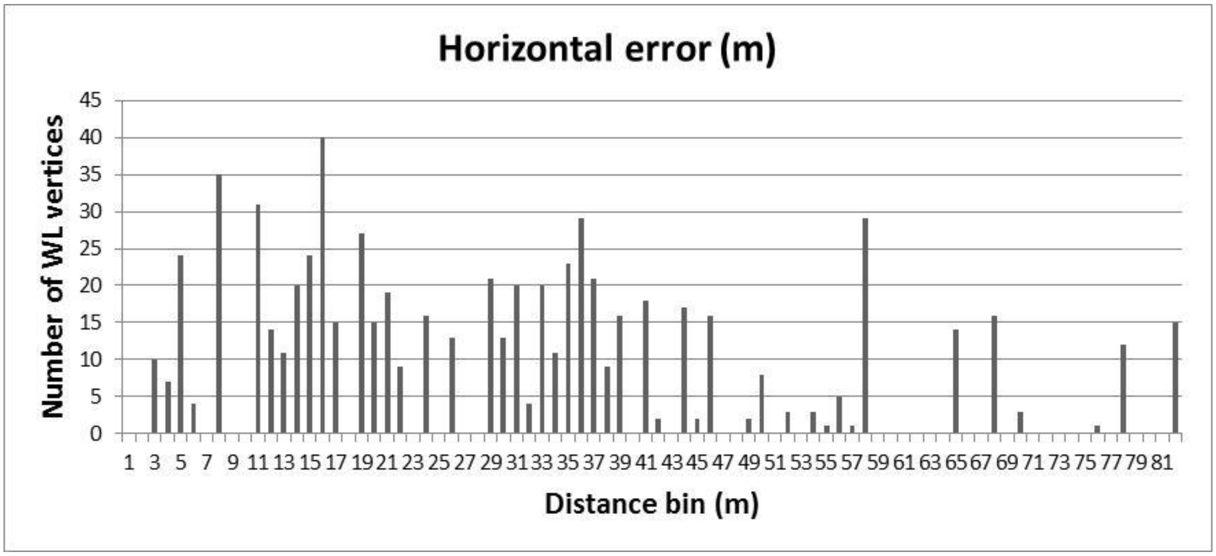

Figure 2.10: Landsat-5 Wexford Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.90
Relative Accuracy (scale consistency)	very good

Table 2.18: Landsat-5 Wexford Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	319m
Mean WL length	309m
Ratio WL length / feature length	0.97
Geometric Fidelity	excellent

Table 2.19: Landsat-5 Wexford Geometric Fidelity Error

RapidEye Waterline: Dublin (Dunleary)

Horizontal error statistics (m)

Waterlines evaluated	1
Data years	2009
MAE	8.295
RMSE	9.595
Median	7.806
Mode	0.491
Standard Deviation	4.823
Minimum	0.491
Maximum	29.885
WL vertex (sample) count	2235

Table 2.20: RapidEye Dunleary Horizontal Error Statistics

Histogram (horizontal error)

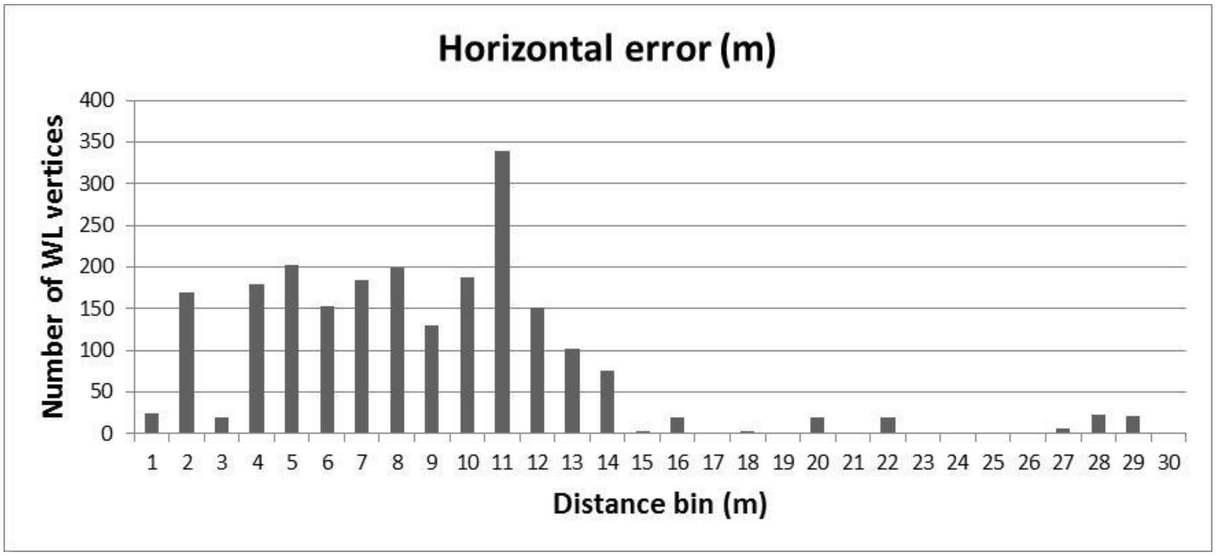

Figure 2.11: RapidEye Dunleary Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.974
Relative Accuracy (scale consistency)	excellent

Table 2.21: RapidEye Dunleary Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	741m
Mean WL length	1098m
Ratio WL length / feature length	1.48
Geometric Fidelity	good

Table 2.22: RapidEye Dunleary Geometric Fidelity Error

RapidEye Waterline: South Bull wall

Horizontal error statistics (m)

Waterlines evaluated	1
Data years	
MAE	9.406
RMSE	9.5
Median	9.551
Mode	#N/A
Standard Deviation	1.339
Minimum	6.119
Maximum	11.715
WL vertex (sample) count	138

Table 2.23: RapidEye South Bull Wall Horizontal Error Statistics

Histogram (horizontal error)

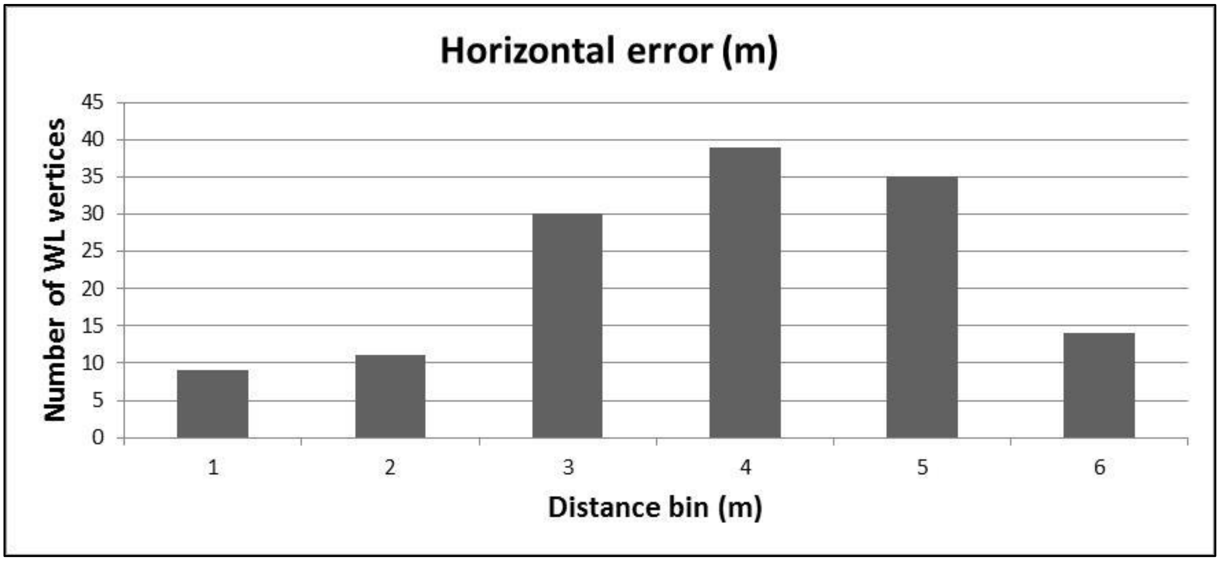

Figure 2.12: RapidEye South Bull Wall Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	1.01
Relative Accuracy (scale consistency)	excellent

Table 2.24: RapidEye South Bull Wall Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	701m
Mean WL length	694m
Ratio WL length / feature length	0.99
Geometric Fidelity	excellent

Table 2.25: RapidEye South Bull Wall Geometric Fidelity Error

Sentinel-1 (SAR) Waterlines: Dublin (Dunleary)

Horizontal error statistics (m)

Waterlines evaluated	142
Data years	2014-2020
MAE	31.484
RMSE	43.95
Median	21.33
Mode	28.229

Standard Deviation	30.664
Minimum	0.032
Maximum	323.112
WL vertex (sample) count	60383

Table 2.26: SAR Dunleary Horizontal Error Statistics

Histogram (horizontal error)

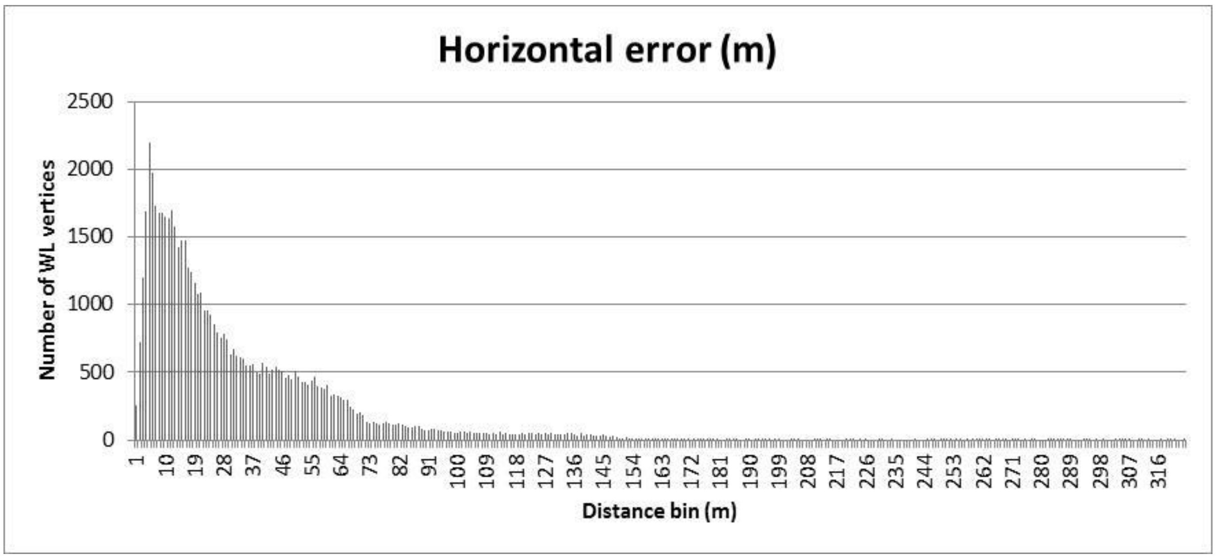

Figure 2.13: SAR Dunleary Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.94
Relative Accuracy (scale consistency)	excellent

Table 2.27: SAR Dunleary Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	1098m
Mean WL length	889m
Ratio WL length / feature length	0.81
Geometric Fidelity	very good

Table 2.28: SAR Dunleary Geometric Fidelity Error

Sentinel-1 (SAR) Waterlines: Wexford (Rosslare)

Horizontal error statistics (m)

Waterlines evaluated	33
Data years	2016-2019
MAE	32.863
RMSE	39.439
Median	30.434
Mode	28.612
Standard Deviation	21.807
Minimum	0.202
Maximum	102.751
WL vertex (sample) count	4324

Table 2.29: SAR Wexford Horizontal Error Statistics

Histogram (horizontal error)

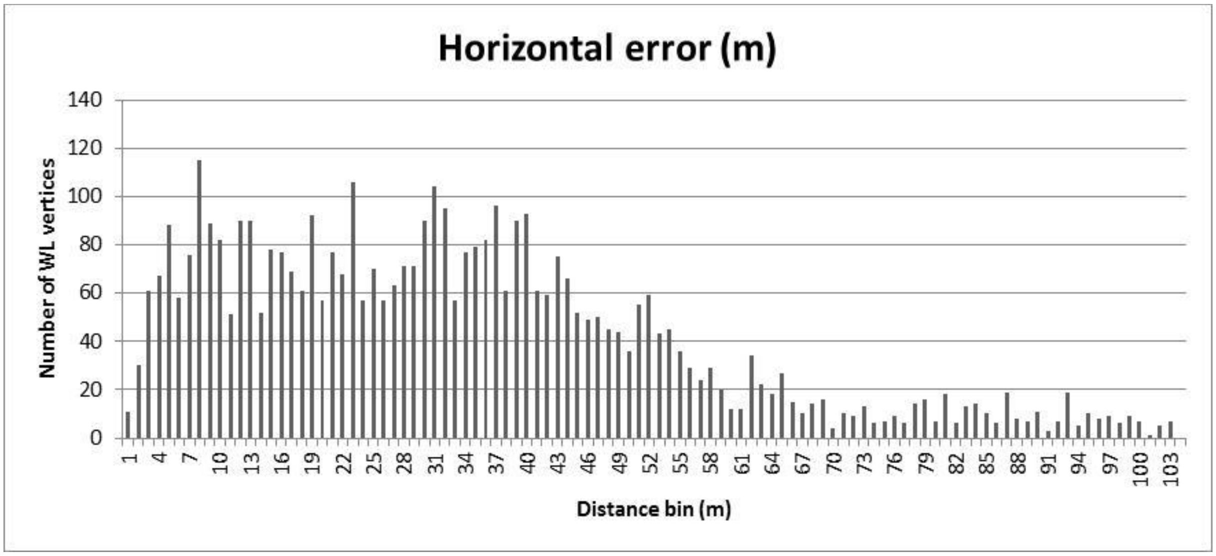

Figure 2.14: SAR Wexford Horizontal Error Histogram

Relative Accuracy (scale consistency) error

Area m^2 of feature envelope / Area m^2 of multi-waterline feature envelope	0.80
Relative Accuracy (scale consistency)	excellent

Table 2.30: SAR Wexford Relative Accuracy (Scale Consistency) Error

Geometric Fidelity error

Reference feature (pier wall) length	319m
Mean WL length	322m
Ratio WL length / feature length	1.01
Geometric Fidelity	excellent

Table 2.31: SAR Wexford Geometric Fidelity Error

Evaluation of tide-heighted waterlines

Four of the Sentinel-2 waterlines happened to overlap with recent (2020) high-accuracy (<0.02m height errors) GNSS/GPS survey data from Rosslare (county Wexford). The four available waterlines were assigned tide heights, based upon satellite image acquisition time, from nearby tide gauge stations at Wexford and nearby Rosslare (county Wexford). These tide-heighted waterlines were found to be characterised by accuracies in the range of 1.07 to 1.61m.

	S-2 WL A	**S-2 WL B**	**S-2 WL C**	**S-2 WL D**
S-2 Waterline date	2019/02/02	2019/02/10	2019/06/27	2019/08/26
Rosslare Tide Gauge date	2019/02/02	2019/02/10	2019/06/27	2019/08/26
S-2 Waterline time	11:33	11:43	11:33	11:33
Rosslare Tide Gauge time	11:35	11:45	11:35	11:35
WL GNSS height (ellipsoidal)	55.035m	55.564m	55.96m	55.636m
Rosslare Tide Gauge height	56.492m	57.132m	57.272m	57.242m

Rosslare tide-height error	1.457m	1.568m	1.312m	1.606m
WL GNSS height (ellipsoidal)	55.035m	55.564m	55.96m	55.636m
Wexford Tide Gauge height	56.102m	57.002m	56.922m	56.872m
Wexford tide-height error	1.067m	1.438m	0.962m	1.236m

Table 2.32: Comparison of height-attributed waterlines with local high-resolution GNSS data

2.3. Conclusions

- The accuracies of the tested waterlines are good, with positional, scale-representation and geometric fidelity accuracies appearing to be influenced most by pixel size.

- Definition of the water edge is good for all waterlines, again demonstrating a close relationship with pixel size.

- Clouds affected portions of a significant number of Sentinel-2, Landsat-8 and Landsat-5 images, but the large numbers of waterlines derived from each of these presented ample multi-date coverages for the purpose of accuracy evaluations. The SAR waterlines were unaffected by cloud.

3. Shoreline Validation: Portrane (Dublin)

3.1. Introduction

The objective is to evaluate Sentinel 2 shorelines produced within the Coastal Erosion from Space project funded by ESA (European Space Agency). To achieve this, we will identify the differences between the Sentinel 2 shorelines (derived from the waterlines obtained from the available satellite sentinel 2 co-registered images) and our reference layers. All the Shorelines from six years spanning from 2015 and 2020 were selected, for a total of 48 shorelines.

3.1.1. Site- Study Area

Portrane is a small town located in North Dublin. It separates the Rogerstown Estuary from the Irish Sea. The area is of significant environmental importance, holding an important number of National and European protection plans. On its east side, a sandy beach is the natural barrier of this settlement against the waves coming from the Irish sea. It is strongly influenced by the tides of the estuary that is located on the other side.

Portrane beach is around 2 km long. It is in the southern part where the evaluation of shorelines takes place in a segment of approximately 1.2 km along which the 10 control transects of the study stretch.

3.2. Methodology

Using ARCGIS 10.8, transects are drawn perpendicular to the coastline defined by the reference layer, which in this specific case was Ordnance Survey Ireland -HWM (High Water Mark). Next, the vegetation line corresponding to the co-registered RGB image of the shoreline to be compared is digitized.

Finally, a quantitative comparison is made to measure the metric differences between the digitized vegetation line and the shoreline S2 obtained. The polarity of the results is as follows: positive values indicate a shoreline shift towards land, while negative values correspond to offshore displacement.

3.3. Results

All Sentinel 2 shorelines received for the Portrane study area (Fig.1) have been evaluated. There are a total of 48 shorelines spread over 6 years (from 2015 to 2020). All the results shown below are based on observations in the study area, so these indicators could vary significantly if we modify the evaluation area. The preference for this area is due to the existence of auxiliary data available and the monitoring of coastal erosion studies developed in the area.

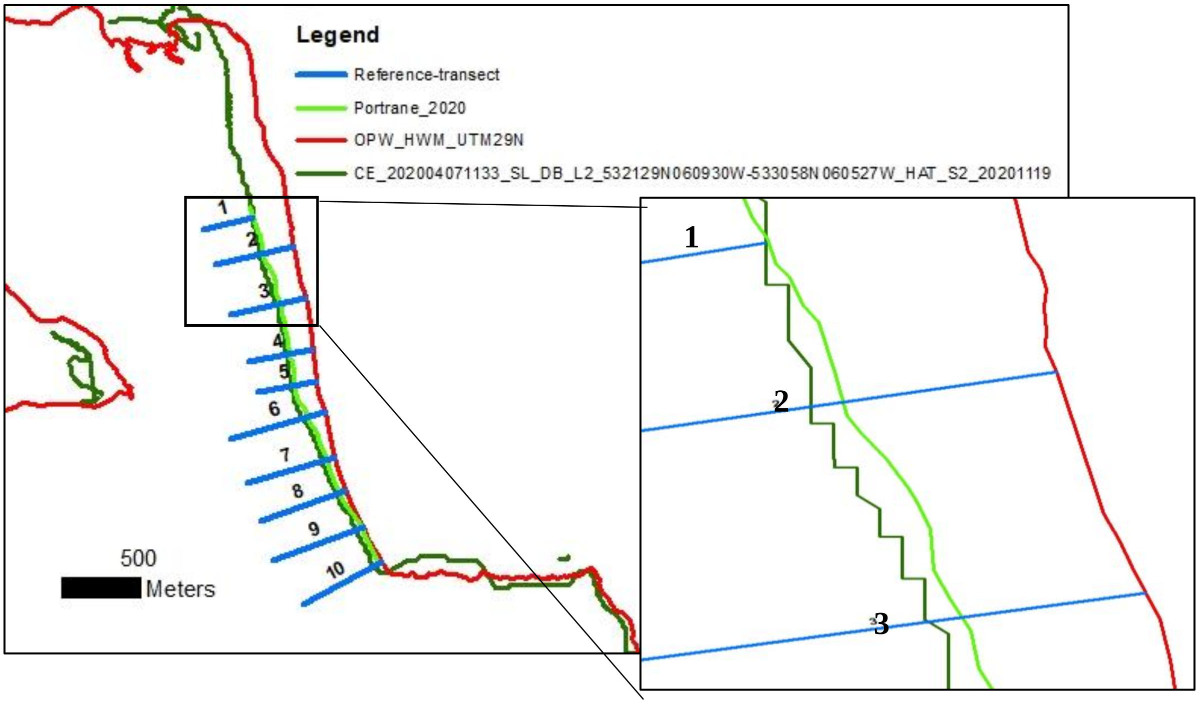

Figure 15: Segment studied in Portrane beach with the ten reference transects perpendicular to the coast

Shorelines have been classified into three categories based on the following criteria:

1.- Shorelines (HAT) are within 20 meters of distance to the digitized Reference Line (vegetation line).

2.- Shorelines are displaced towards land or sea more than 20 meters from the reference line but they present a continuous coastline shape throughout the study area and that maintains the expected profile.

3.- The shorelines are discontinuous in some section of the study area or in all of it. Present artefacts or the shape of the shoreline does not correspond to the shoreline.

Year	TOTAL SL S2	Within 20 metres	SL Offset	SL Irregular/ Discontinuous
2015	1	0	1	0
2016	4	0	1	3
2017	10	0	2	8
2018	15	2	4	9
2019	10	2	3	5
2020	8	1	4	3
Year	**TOTAL SL S2**	**Within 20 metres**	**SL Offset**	**SL Irregular/ Discontinuous**
2015	1	0%	100%	0%
2016	4	0%	25%	75%
2017	10	0%	20%	80%
2018	15	13.34%	27%	60%
2019	10	20%	30%	50%
2020	8	12.50%	50%	37.50%

Table 33: Classification by year of the 48 HAT S2 shorelines in the Portrane beach area.

.

The mean errors calculated in shorelines within 20 meters of error are in the range between 5.6 and 17.8 meters (Table 3.2). However, the shorelines identified with a greater displacement vary between 26 meters and more than 125 meters (Table 3.3).

There are no shorelines within the 20 m threshold for 2015, 2016 and 2017, with the exception of 2015, which shows 100% displacement shorelines since there is only one for this year. The rest show a lower percentage of shorelines that are shifted. However, the percentage of erroneous shorelines, with artifacts or discontinuous, decreases progressively over the years from 75% (2016) and 80% (2017) to 37.50% (2020).

Date/Image	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Mean Error
CE_201805161143_SL	15	18	-10	6	10	25	30	35	23	26	**17.8**
CE_201802021133_SL	5	6	0	0	6	5	6	6	12	10	**5.6**
CE_201912141134_SL	-10	-12	0	0	-11	-13	-5	0	-12	0	**-6.3**
CE_201902071133_SL	0	-6	-6	6	16	15	0	7	15	15	**6.2**
CE_202004071133_SL	2	15	15	15	13	15	13	12	20	11	**13.1**

Table 34: Values obtained in each of the 10 transects of the HAT S2 shorelines classified as acceptable

Date/Image	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Mean Error
CE_201512081144_SL	39	58	71	72	44	50	49	41	53	67	**54.4**
CE_201601141134_SL	40	47	165	166	144	146	157	146	150	106	**126.7**
CE_201704081133_SL	60	60	43	68	78	80	93	92	94	55	**72.3**
CE_201704081133_SL	36	71	63	46	60	76	76	86	79	87	**68**
CE_201707121133_SL	75	49	49	72	74	75	87	81	86	64	**71.2**
CE_201805311143_SL	32	24	3	16	27	28	30	35	33	30	**25.8**
CE_201810101133_SL	-27	-24	-32	-33	-29	-24	-32	-25	-26	-34	**-28.6**
CE_202003261143_SL	14	28	28	30	24	35	35	32	32	16	**27.4**
CE_202002271133_SL	73	92	97	95	93	103	94	109	142	173	**107.1**
CE_202004201143_SL	73	92	97	95	93	103	94	109	142	173	**107.1**

Table 35: Values obtained in each of the 10 transects of the HAT S2 shorelines classified as displaced

3.4. Conclusions

- 48 HAT Sentinel 2 shorelines have been obtained and evaluated for the Portrane beach study area for the time range between 2015 and 2020.
- 5 HAT shorelines (10.42% of the total) have been classified as acceptable since they were within 20 m threshold. These EO products belong to the years 2018, 2019 and 2020.

- Partial analysis of it can significantly vary the results obtained. Shorelines classified as irregular or discontinuous can present a good partial fit in certain areas.
- Correction of the offset identified through the applied algorithm would allowfor an acceptance of a greater number of shorelines, getting a better representation of the time range 2015-2020.
- HAT S2 Shorelines categorized as acceptable show positive results for monitoring coastal evolution. Inclusion of quality flags in future versions of the product will facilitate its use and application.

4. Land Cover Classification Validation

4.1. Introduction

A series of land cover classification maps for four areas on the South-East and East coast of Ireland were created using Sentinel-2 imagery acquired over a period three years (2017-2019). Each map has different numbers and types of classes, but they broadly fall under the following land cover types; sea, built-up areas (urban, houses), crops (broken down further into different crop classes depending on the reflectance value), tidal areas, beaches (sandy beaches or beach vegetation) and forests.

4.2. Methodology

The land classification maps were created using a supervised classification method. This involves the use of training sites that group pixels into classes based on what is seen in a reference image or from data taken on-site. The maps analysed here were created by generating training sites using co-located HR and VHR imagery.

The accuracy of these classification maps were analysed in ArcGIS Pro using pseudo-ground truth points. Once the land classification maps were generated, a shapefile containing 500 stratified random points was created in ArcGIS Pro. The attribute data of each point contained the class value at that location and a ground truth value, which was initially left as the default value of -1 when the point layer was first created.

Using Sentinel-2 imagery and VHR imagery on Google Earth, the ground truth field in the accuracy assessment point layer was populated using pseudo-ground truth values. This involved manually assigning a ground truth class value to each point based on what was observed in the Sentinel-2 image or VHR image at that point.

In maps where there were multiple crop and vegetation classes, a NDVI and/or false colour composite was created in order to help distinguish the classes when RGB imagery alone was not enough. The NDVI was created with the raster calculator in ArcGIS Pro using the following formula:

$$\frac{B8 - B4}{B8 + B4}$$

The result of this formula was a raster file that contains values of between +1 and -1. The closer the value was to +1 the healthier the vegetation was and the closer the value was to -1 the more barren and rockier the area was. The false colour composite was created using S2 bands 8, 4 and 3 to further highlight the differences in land cover for the purposes of assessing the classification accuracy.

A confusion matrix was then generated to provide the U (user) accuracy score, the P (producer) accuracy score and the Kappa coefficient for each of the land classification maps.
The Kappa coefficient is indicative of how accurate the classification is. The Kappa coefficient can be categorised as follows:

Kappa Co-efficient	Classification accuracy
Below 0.4	Poor
0.41 to 0.6	Moderate
0.61 to 0.75	Good
0.76 to 0.80	Excellent
0.81 and above	Almost Perfect

Table 36: Kappa Co-efficient Categories ((Shivakumar and Rajashekararadhya, (2018))

4.3. Results

4.3.1. Dublin

Class Value	Class Name

1	Urban
2	House
4	Crops1
5	Crops2
7	Forest
10	Sandy Beach
11	Rocks
12	Mudflat
13	Sea

Table 37: Dublin Land Cover Classes

2019

OBJECTID *	ClassValue	C_1	C_2	C_4	C_5	C_7	C_10	C_11	C_12	C_13	Total	U_Accuracy	Kappa
1	C_1	7	0	0	0	0	2	1	0	0	10	0.7	0
2	C_2	9	32	8	1	1	0	4	0	0	55	0.581818	0
3	C_4	0	0	45	0	3	0	1	0	0	49	0.918367	0
4	C_5	0	0	6	66	1	0	0	0	0	73	0.90411	0
5	C_7	0	0	2	0	32	0	0	0	0	34	0.941176	0
6	C_10	1	0	2	1	0	4	2	0	0	10	0.4	0
7	C_11	4	4	11	2	1	0	14	1	2	39	0.358974	0
8	C_12	0	0	0	0	0	0	0	9	1	10	0.9	0
9	C_13	0	0	0	0	0	1	0	3	232	236	0.983051	0
10	Total	21	36	74	70	38	7	22	13	235	516	0	0
11	P_Accuracy	0.333333	0.888889	0.608108	0.942857	0.842105	0.571429	0.636364	0.692308	0.987234	0	0.854651	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.80407
	Click to add new row.												

Figure 16: 2019 Dublin Confusion Matrix

The Kappa coefficient for the 2019 classification map was determined to be 0.80407, which is considered to be excellent.

However, from examining the confusion matrix table some outliers were observed. C_1 (Urban) and C_11 (Rocks) had very low P Accuracy and U Accuracy rates. This could be attributed to rocks having a similar spectral signature to man-made, hardcore objects like urban areas, houses, roads etc. Having rocks as its own class is limiting, as majority of the time areas that were flagged as "Rocks" were roads, car parks or farm and building yards. For this reason, the rocks class should be renamed to “hard surface”, as the imagery was not of a high enough resolution to distinguish between what were rocks and what were areas with cement or tarmac surfaces.

C_10 (Sandy Beaches) also had relatively low U accuracy and P accuracy values. This could partially be attributed to the small amount of accuracy assessment points that fell into areas that could be classed as a sandy beach, as sandy beaches made up a small percentage of land cover in this area. Another reason for the low accuracy score is that fallow ground and sand have similar spectral signatures. Similarly, two urban areas were classified as being a sandy beach.

The accuracy of the remaining classes were high, with forestry and water having particularly high U Accuracy and P Accuracy scores.

2018

OBJECTID *	ClassValue	C_1	C_2	C_4	C_5	C_7	C_10	C_11	C_12	C_13	Total	U_Accuracy	Kappa
1	C_1	8	0	3	1	0	0	1	0	1	14	0.571429	0
2	C_2	13	36	4	1	2	1	4	1	1	63	0.571429	0
3	C_4	0	0	37	2	0	0	1	0	0	40	0.925	0
4	C_5	1	0	9	79	3	0	0	0	0	92	0.858696	0
5	C_7	0	0	3	3	24	0	0	0	0	30	0.8	0
6	C_10	1	0	4	0	0	6	1	0	3	15	0.4	0
7	C_11	1	2	6	1	0	0	7	0	7	24	0.291667	0
8	C_12	0	0	0	0	0	0	0	11	5	16	0.6875	0
9	C_13	0	0	0	0	0	0	0	2	227	229	0.991266	0
10	Total	24	38	66	87	29	7	14	14	244	523	0	0
11	P_Accuracy	0.333333	0.947368	0.560606	0.908046	0.827586	0.857143	0.5	0.785714	0.930328	0	0.83174	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.772995

Figure 17: 2018 Dublin Confusion Matrix

The Kappa coefficient for the 2018 classification map was determined to be 0.772995, which is considered to be excellent.

Similar P and U accuracy score patterns to the 2019 confusion matrix were seen here, with C_1 (urban) , C_11 (rocks) and C_10 (sandy beaches) having a lower U or P accuracy score than the other classes in the classification. Again, this could be attributed to the similarity in spectral signatures between these classes. The classes with the highest U and P accuracy scores were crops_2, sea, forestry, and mudflats.

2017

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_4	C_5	C_7	C_10	C_11	C_12	C_13	Total	U_Accuracy	Kappa
1	C_1	6	0	0	2	0	1	1	0	0	10	0.6	0
2	C_2	3	36	5	1	1	1	7	0	8	62	0.580645	0
3	C_4	0	2	50	7	2	0	0	0	0	61	0.819672	0
4	C_5	0	0	1	71	2	0	0	0	0	74	0.959459	0
5	C_7	0	1	0	2	22	0	1	0	0	26	0.846154	0
6	C_10	0	1	3	3	0	2	1	0	0	10	0.2	0
7	C_11	0	5	4	2	1	0	15	0	0	27	0.555556	0
8	C_12	0	0	0	0	0	0	1	8	1	10	0.8	0
9	C_13	0	0	0	0	0	0	0	5	223	228	0.97807	0
10	Total	9	45	63	88	28	4	26	13	232	508	0	0
11	P_Accuracy	0.666667	0.8	0.793651	0.806818	0.785714	0.5	0.576923	0.615385	0.961207	0	0.852362	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.799825

Figure 18: 2017 Dublin Confusion Matrix

The Kappa coefficient for the 2017 classification map was determined to be 0.799825, which is considered to be excellent.

An observation made while conducting the pseudo-ground truthing for this classification map was that there were areas that are classified as C_2 houses in the middle of the sea. This could be due to choppy sea conditions, suspended sediment or cloud cover in the imagery. Breaking waves, sediment and clouds can have a similar reflectance rate to buildings when using an RGB image for classification.

The confusion matrix generated showed similar patterns of accuracy to the 2018 and 2019 confusion matrixes, in that the classes with the highest P or U accuracy were the sea, crops, mudflat and forestry classes and that the class with the lowest P or U accuracy was the sandy beach class.

Dublin Results

- Lower accuracy score for sandy beaches, rocks, and urban classes due to similarity in reflectance values.
- Over-representation of rocks along the coast.
- Sandy beach often classified in-land.
- House class present in the middle of the sea, possibly due to clouds in imagery, suspended sediments or choppy sea conditions.

4.3.2. Waterford

Class Value	Class Name
1	Urban

2	House
3	Crops1
4	Crops2
5	Crops3
6	Forest
10	Beach Vegetation
11	Rocks
20	Sandy Beach
21	Tidal Area
22	Mudflat
30	Sea

Table 38: Waterford Land Cover Classes

The classes for Waterford differed from the Dublin classes slightly. In the Waterford classification maps, there was an additional crop class (crops3) and two other new classes called Beach_Veg and Tidal Area.

2019

aap_2019_wat | conmatrix19wat

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	C_10	C_11	C_20	C_21	C_22	C_30	Total	U_Accuracy	Kappa
3	C_3	0	0	42	14	4	1	0	0	0	0	0	0	61	0.688525	0
4	C_4	0	1	5	44	1	3	0	2	0	0	0	0	56	0.785714	0
5	C_5	0	1	7	6	34	0	0	0	0	0	0	0	48	0.708333	0
6	C_6	0	0	1	2	0	16	0	0	0	0	0	0	19	0.842105	0
7	C_10	0	1	4	0	5	1	3	3	0	0	0	0	17	0.176471	0
8	C_11	2	1	1	0	0	0	0	2	1	1	0	3	11	0.181818	0
9	C_20	0	1	0	0	1	0	0	0	8	0	0	0	10	0.8	0
10	C_21	0	0	0	0	0	0	0	0	1	7	0	3	11	0.636364	0
11	C_22	0	0	0	0	0	0	0	0	0	1	6	4	11	0.545455	0
12	C_30	0	0	0	0	0	0	0	0	0	1	0	254	255	0.996078	0
13	Total	6	12	68	66	53	21	5	14	13	11	6	264	539	0	0
14	P_Accuracy	0.5	0.583333	0.617647	0.666667	0.641509	'61905	0.6	0.142857	0.615385	0.636364	1	0.962121	0	0.790353	0
15	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.71198

Click to add new row.

Figure 19: 2019 Waterford Confusion Matrix

The Kappa coefficient for the 2019 classification map was determined to be 0.71198, which is considered to be good.

The classes with the lowest U accuracy were the beach vegetation and rock classes. These classes were over-represented in areas with bare earth. This can be attributed to these classes having a similar reflectance value to bare earth. As seen with the other land cover maps, the sea and forest classes had a high accuracy rate due to their distinctive reflectance values. The other coastal classes, tidal areas and mudflats, had a moderately good U accuracy score of ~0.64 and 0.55 respectively.

2018

conmatrix18wat

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	C_10	C_11	C_20	C_21	C_22	C_30	Total	U_Accuracy	Kappa
1	C_1	1	0	2	1	6	0	0	0	1	0	0	0	11	0.090909	0
2	C_2	1	7	2	1	2	0	1	1	0	0	0	0	15	0.466667	0
3	C_3	0	2	79	2	1	3	0	0	0	0	0	0	87	0.908046	0
4	C_4	0	0	0	27	1	0	0	0	0	0	0	0	28	0.964286	0
5	C_5	0	0	1	1	15	0	0	0	0	0	0	0	17	0.882353	0
6	C_6	0	0	1	4	0	23	0	0	0	0	0	0	28	0.821429	0
7	C_10	0	3	5	6	8	0	4	0	0	0	0	0	26	0.153846	0
8	C_11	0	5	5	1	4	1	0	5	1	0	0	0	22	0.227273	0
9	C_20	1	1	0	0	0	0	0	0	8	0	0	0	10	0.8	0
10	C_21	1	0	0	0	0	0	0	0	0	8	0	1	10	0.8	0
11	C_22	0	0	0	0	0	0	0	0	0	2	7	1	10	0.7	0
12	C_30	0	0	0	0	0	0	0	0	0	0	0	262	262	1	0
13	Total	4	18	95	43	37	27	5	6	10	10	7	264	526	0	0
14	P_Accuracy	0.25	0.388889	0.831579	0.627907	0.405405	0.851852	0.8	0.833333	0.8	0.8	1	0.992424	0	0.847909	0
15	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.785096

Click to add new row.

Figure 20: 2018 Waterford Confusion Matrix

The Kappa coefficient for the 2018 classification map was determined to be 0.785098, which is considered to be excellent.

This classification map had a higher kappa coefficient score than the previous map, but still had a similar scoring pattern to the 2019 map. The beach vegetation and rocks classes scores remained low, however the urban class now had the lowest U_accuracy score at 0.09. Crops3 (C5, detected as agricultural areas that have been ploughed or are fallow) appeared to have been misrepresented as urban in the classification multiple times.

From looking at the classification map, it appears that the rock class was over-represented, and the house class under-represented to the west of the classification map, leading to their low accuracy scores.

2017

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	C_10	C_11	C_20	C_21	C_22	C_30	Total	U_Accuracy	Kappa
1	C_1	5	1	2	0	5	0	0	0	1	1	0	0	15	0.333333	0
2	C_2	6	8	3	0	1	3	0	4	0	0	0	0	25	0.32	0
3	C_3	0	0	59	5	2	1	1	2	0	0	0	0	70	0.842857	0
4	C_4	0	0	3	46	0	1	0	2	0	0	0	0	52	0.884615	0
5	C_5	0	0	1	0	25	0	0	0	0	0	0	0	26	0.961538	0
6	C_6	0	0	2	8	4	17	1	0	0	0	0	1	33	0.515152	0
7	C_10	0	0	3	1	10	0	5	0	0	0	0	0	19	0.263158	0
8	C_11	0	0	0	1	1	1	0	8	0	0	0	0	11	0.727273	0
9	C_20	1	0	0	0	2	0	0	0	7	0	0	0	10	0.7	0
10	C_21	0	0	0	0	0	0	0	1	0	7	0	2	10	0.7	0
11	C_22	1	0	0	0	0	0	0	0	0	2	7	0	10	0.7	0
12	C_30	0	0	0	0	0	0	0	0	0	0	0	265	265	1	0
13	Total	13	9	73	61	50	23	7	17	8	10	7	268	546	0	0
14	P_Accuracy	0.384615	0.888889	0.808219	0.754098	0.5	0.73913	0.714286	0.470588	0.875	0.7	1	0.988806	0	0.840659	0
15	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.779844

Figure 21: 2017 Waterford Confusion Matrix

The Kappa coefficient for the 2017 classification map was determined to be 0.779844, which is considered to be excellent.

Similar patterns can be seen here as in the previous two maps, however the rock class now had a higher U accuracy rate at ~0.73 and the forestry class had a lower U accuracy rate of ~0.52. The classification classified crops2 (C_4, detected as agricultural land with near consistent vegetation cover) as areas of forestry.

Waterford Results

Over-representation of the house class in the classification, under-representation of urban class.

Similarities in reflectance values of fallow ground and sand/ rocks, leading to false classifications of respective areas. This was also seen with crops and beach vegetation.

Accuracy of mudflats and tidal area was good.

As with Dublin, forestry and sea classes had a high accuracy score.

4.3.3. Cork

This land classification map differs from the previous as it had no mudflat, tidal area or beach vegetation classes and there were only two classification maps available for this area, 2018 and 2019.

Class Value	Class Name
1	Urban

2	House
3	Crops1
4	Crops2
5	Crops3
6	Forest
10	Sandy Beach
11	Rocks
12	Sea

Table 39: Cork Land Cover Classes

2019

conmatrix19cork

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	C_10	C_11	C_12	Total	U_Accuracy	Kappa
1	C_1	6	0	0	2	1	1	0	1	1	12	0.5	0
2	C_2	4	9	4	3	2	9	0	3	11	45	0.2	0
3	C_3	0	0	54	2	4	0	0	0	0	60	0.9	0
4	C_4	0	0	2	143	1	4	0	0	0	150	0.953333	0
5	C_5	0	0	0	0	8	1	0	1	0	10	0.8	0
6	C_6	0	0	0	2	0	11	0	1	0	14	0.785714	0
7	C_10	0	1	0	0	0	0	4	0	7	12	0.333333	0
8	C_11	0	1	0	0	0	0	1	3	7	12	0.25	0
9	C_12	0	0	0	0	0	0	0	0	203	203	1	0
10	Total	10	11	60	152	16	26	5	9	229	518	0	0
11	P_Accuracy	0.6	0.818182	0.9	0.940789	0.5	0.423077	0.8	0.333333	0.886463	0	0.851351	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.79454

Click to add new row.

Figure 22: 2019 Cork Confusion Matrix

The Kappa coefficient for the 2019 classification map was determined to be 0.79454, which is considered to be excellent.

U Accuracy scores among the crop classes, forestry class and sea class were all high. The sandy beach and rock classes had low accuracy values due to the similar reflectance values and the classification map having a limited number of classes. Many of the areas identified as sandy beach or rocks would have fit in better in a tidal area, mudflat or beach vegetation class, however since those classes were not used in the Cork maps the classification classed these areas as rocks or sandy beaches.

2018

conmatrix18cork

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	C_10	C_11	C_12	Total	U_Accuracy	Kappa
1	C_1	3	2	4	1	0	0	0	0	0	10	0.3	0
2	C_2	4	14	9	8	1	0	0	3	0	39	0.358974	0
3	C_3	0	0	23	1	0	0	0	0	0	24	0.958333	0
4	C_4	0	0	7	158	3	2	0	0	0	170	0.929412	0
5	C_5	0	0	0	5	8	2	0	0	0	15	0.533333	0
6	C_6	0	0	0	2	0	8	0	0	0	10	0.8	0
7	C_10	2	1	1	0	0	0	2	0	5	11	0.181818	0
8	C_11	0	0	7	0	0	1	1	3	3	15	0.2	0
9	C_12	0	0	0	0	0	0	0	0	217	217	1	0
10	Total	9	17	51	175	12	13	3	6	225	511	0	0
11	P_Accuracy	0.333333	0.823529	0.45098	0.902857	0.666667	0.615385	0.666667	0.5	0.964444	0	0.853229	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.787244

Click to add new row.

Figure 23: 2018 Cork Confusion Matrix

The Kappa coefficient score for the 2018 map was 0.787244, which is considered to be excellent, Similar pattern in scores seen here as in the 2019 confusion matrix. Crop, forestry, and sea classes had a moderate to high accuracy score while beach, rocks, urban and houses had lower scores.

Cork Results

This land classification map has no mudflat, tidal area or beach vegetation classes, making it the least useful for coastal analysis out of all four areas.

As this classification map had no classes for tidal areas, many of those areas along the coast were classified as "rocks", as the classification deemed that as the most appropriate class for areas exposed at low tide.

Over-representation of the house class, the classification frequently identified areas of trees and their shadows as houses.

4.3.4. Ballyconnigar

Ballyconnigar had the most classes out of all the land cover maps. It introduced a new class called natural (bare, mountainous areas), added a new forestry class, and removed the urban and house classes in favour of industrial and built-up classes.

Class Value	Class Name
1	Industrial
2	Build Up
3	Crop1

4	Crop2
5	Crop3
7	Crop9
8	Crop6
9	Crop7
10	Natural
11	Forest_1
12	Forest_2
101	Beach Vegetation
201	Sandy Beach
202	TidalAreas
301	Sea

Table 40: Ballyconnigar Land Cover Classes

2019

aap19_bally | conmatrixbally19

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_7	C_8	C_9	C_10	C_11	C_12	C_101	C_201	C_202	C_301	Total	U_Accuracy	Kappa
1	C_1	3	0	0	1	3	0	0	1	2	0	0	0	0	0	0	10	0.3	0
2	C_2	0	10	0	0	5	0	1	0	0	0	0	0	0	0	0	16	0.625	0
3	C_3	0	3	57	0	1	0	6	0	0	0	1	0	0	0	0	68	0.838235	0
4	C_4	0	0	4	12	0	0	0	0	0	0	0	0	0	0	0	16	0.75	0
5	C_5	0	2	4	0	24	1	0	0	0	0	0	0	0	0	0	31	0.774194	0
6	C_7	0	0	1	0	0	7	2	0	0	0	0	0	0	0	0	10	0.7	0
7	C_8	0	0	4	0	0	0	41	0	0	0	0	0	0	0	0	45	0.911111	0
8	C_9	0	0	0	1	1	0	1	7	0	0	0	0	0	0	0	10	0.7	0
9	C_10	0	0	0	1	0	0	0	0	12	0	0	0	0	0	0	13	0.923077	0
10	C_11	0	0	0	0	0	0	0	0	0	17	0	0	0	0	2	19	0.894737	0
11	C_12	1	3	2	0	5	0	4	1	0	2	29	0	0	0	0	47	0.617021	0
12	C_101	0	3	0	0	5	0	0	0	0	0	0	2	0	0	0	10	0.2	0
13	C_201	0	0	0	0	2	0	0	0	0	0	0	0	8	0	0	10	0.8	0
14	C_202	0	0	0	0	0	0	0	0	0	0	0	0	0	8	2	10	0.8	0
15	C_301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	222	222	1	0
16	Total	4	21	72	15	46	8	55	9	14	19	30	2	8	8	226	537	0	0
17	P_Accuracy	0.75	0.47619	0.791667	0.8	0.521739	0.875	0.745455	0.777778	0.857143	0.894737	0.966667	1	1	1	0.982301	0	0.854749	0
18	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.815057

Click to add new row.

0 of 18 selected

Filters: 100%

Figure 24: 2019 Ballyconnigar Confusion Matrix

The Kappa coefficient for the 2019 classification map was determined to be 0.815057 which is considered to be almost perfect.

This classification map had the highest kappa coefficient score of all the classification maps. The areas that had the lowest U accuracy scores were the beach vegetation and industrial classes. Beach vegetation was over-represented in-land as it had a similar reflectance value to crops3. Areas with bare earth for some portion of the year were also identified as industrial areas.

From inspecting the classification map, some obvious classification errors jumped out. One being that forestry was frequently identified as being in the sea, or areas of sandy beaches being classified far in-land.

2018

aap18_bally | conmatrixbally18

Field: Add | Calculate | Selection: Select By Attributes | Zoom To | Switch | Clear | Delete | Copy

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_7	C_8	C_9	C_10	C_11	C_12	C_101	C_201	C_202	C_301	Total	U_Accuracy	Kappa
1	C_1	3	0	1	0	6	1	0	0	0	0	0	1	1	0	0	13	0.230769	0
2	C_2	0	12	4	1	6	0	2	0	1	0	1	1	0	0	0	28	0.428571	0
3	C_3	0	3	46	0	1	0	4	0	0	0	1	0	0	0	0	55	0.836364	0
4	C_4	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	1	0
5	C_5	0	2	0	0	18	0	0	0	1	0	0	0	0	0	0	21	0.857143	0
6	C_7	0	0	1	1	0	6	2	0	0	0	0	0	0	0	0	10	0.6	0
7	C_8	0	4	7	0	0	0	70	0	0	2	1	0	0	0	0	84	0.833333	0
8	C_9	0	0	0	0	1	1	0	8	0	0	0	0	0	0	0	10	0.8	0
9	C_10	0	1	2	0	0	0	0	0	16	0	0	0	0	0	0	19	0.842105	0
10	C_11	0	0	0	0	0	0	0	0	0	22	0	0	0	1	5	28	0.785714	0
11	C_12	0	0	0	0	1	0	0	0	0	0	16	0	0	0	0	17	0.941176	0
12	C_101	0	0	2	0	2	3	2	0	1	0	0	2	0	0	0	12	0.166667	0
13	C_201	0	2	0	0	1	0	0	0	0	0	0	0	7	0	0	10	0.7	0
14	C_202	0	0	0	0	0	0	0	0	0	0	0	0	0	8	2	10	0.8	0
15	C_301	0	0	0	0	0	0	0	0	0	0	0	0	0	9	204	213	0.957746	0
16	Total	3	24	63	12	36	11	80	8	19	24	19	4	8	18	211	540	0	0
17	P_Accuracy	1	0.5	0.730159	0.833333	0.5	0.545455	0.875	1	0.842105	0.916667	0.842105	0.5	0.875	0.444444	0.966825	0	0.82963	0
18	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.786809

Click to add new row.

Figure 25: 2018 Ballyconnigar Confusion Matrix

The Kappa coefficient for the 2018 classification map was determined to be 0.786809 which is considered to be excellent.

In the 2018 map, the kappa coefficient score was slightly lower than the 2019 map but the accuracy score pattern was the same. Crop, sea, tidal and forestry classes had high accuracy scores while industrial, built-up and beach vegetation had lower scores.

Ballyconnigar Results

Accuracy highest among all the areas classified.

Overrepresentation of forest_2 in areas where there were roads, built up areas, crops3 and some coastal areas.

Underrepresentation of built-up areas.

Areas in-land falsely identified as beach vegetation or sandy beach.

4.4. Conclusions

While it is important that the classification maps have a high accuracy score, when using these maps for research or analysis it is just as important to have land cover classes that are suitable for use in the chosen area of research. For example, when using these maps for coastal change detection, it would be appropriate to use classification maps that have coastal classes (e.g. the Waterford, Ballyconnigar maps) rather than maps that have classes more of use for in-land monitoring (Cork).

By visually inspecting the land cover maps and by taking the kappa co-efficient scores and suitability of classes into account, a ranking of the classification maps most suitable for use in coastal monitoring can be produced.

1. Ballyconnigar
2. Waterford
3. Dublin
4. Cork

An issue with these maps is the lack of cohesion between them in terms of classes. None of these maps have the same number of classes or class types as each other, and the classes they do have in common may not represent the same land cover type in every map (i.e. crops3 in one map may appear different to crops3 in another map). This makes comparison between the maps difficult.

4.4.1. Geo-Accuracy

A shift of approximately 10-15 metres was detected in some areas of the classification maps when comparing the S2 imagery used to create the land cover maps to the ArcGIS Pro Maxar VHR imagery.

This was most likely due to the lower spatial resolution of the S2 imagery compared to the VHR imagery. Objects in the lower resolution imagery have less defined edges than in the higher resolution imagery, making the object appear distorted or shifted when switching between viewing the object in HR and VHR imagery. Therefore, when taking this into account the geo-accuracy of the land cover maps can be deemed as high.

5. BTM : Satellite derived bathymetry validation

Satellite Derived Bathymetry (SDB) validation was carried out in several locations using multibeam depth data and additional results from empirical models developed by the end-user. Here we present results for one location in Portrane (Dublin) with multiple time series outputs.

5.1. Study area: Portrane- Rush (Dublin)

6 SDB outputs were validated ranging from 2017 to 2020 with a pixel resolution of 10x10m

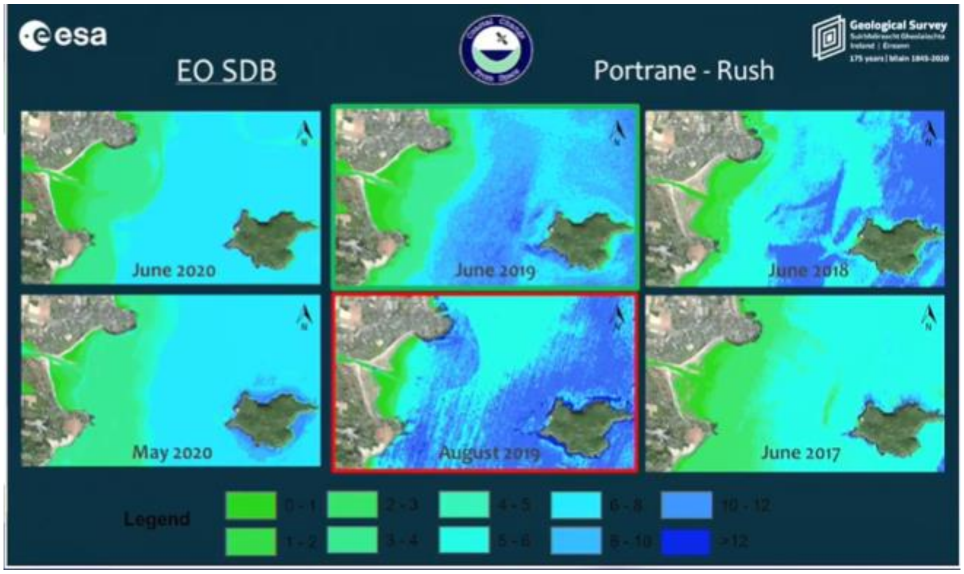

Figure 26: Selection of images using the same colour legend (0 to +12m)

5.2. Methodology

5.2.1. Regression analysis

Validation was performed to all the SDB outputs using ship multibeam bathymetry data (order 1 IHO). SDB outputs were join to the closest averaged (10m) validation value. Image tide values were corrected on the validation depth values to align the water depths intervals compared

Regression analysis was carried out to the six SDB outputs using the same multibeam validation dataset from 2019.

Linear regression results show in general weak correlations between SDB and validation values with R2 ranging below 0.5 in the interval between 0-10m. R2 coefficients in the 0 to 6m interval range from 0.5 to 0.73.

Significant image banding can be observed in all the plots probably related to methodological artefacts in the model.

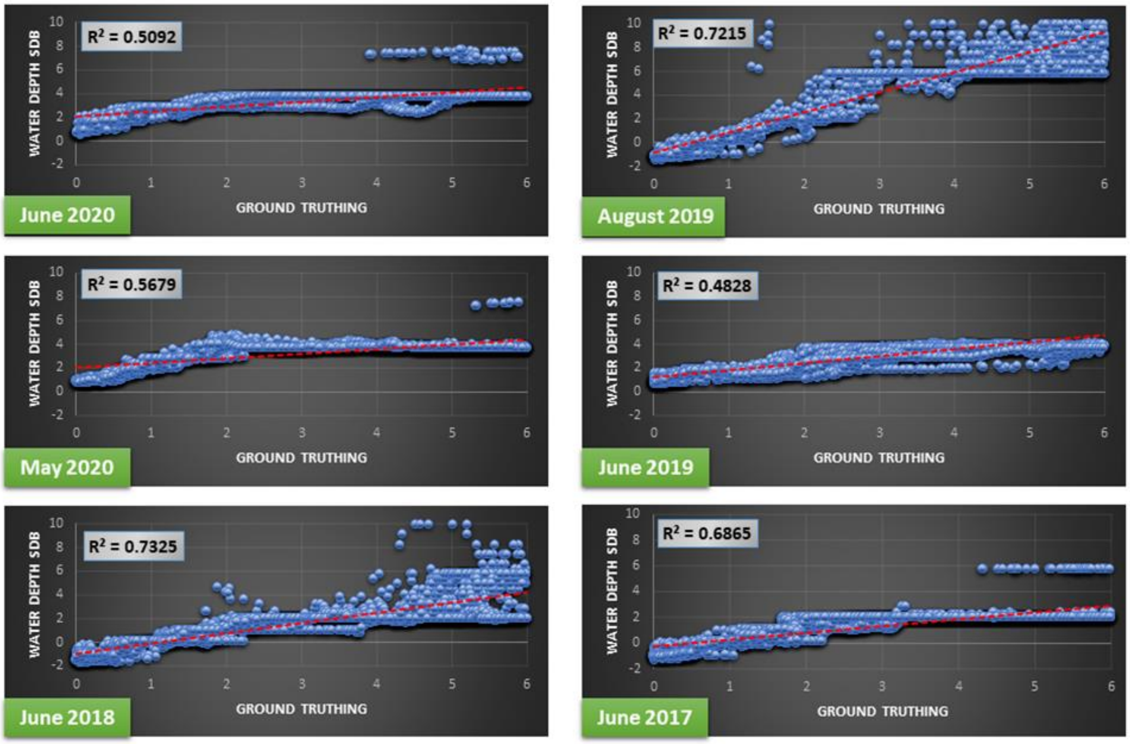

Figure 27: Regression plots with associated R2 for the six images

Mean error values (MAE) between 0 to 6m show values larger than 1m for 5 out of the SDB outputs ranging from 1.04 to 1.7m. One SDB output (June 2019) shows the highest R2 and the lowest MAE (0-6) (see table SDB1).

Date S2 Image	**Jun-20**	**May-20**	**Aug-19**	**Jun-19**	**Jun-18**	**Jun-17**
MAE (6m)	1.044 m	1.137 m	1.790 m	0.900 m	1. 507 m	1. 752 m

Table 41: SDB1 MAE values for all images interval 0-6

5.2.2. Variability study

A high variability amongst the different SDB outputs was found between 0 to 10m with a standard deviation larger than 1m.

5.2.3. Comparison with empirical model

SDB output from June 2019, with the lowest MAE (0 -6), was cross compared against the empirical model developed for the same image using Stumpf et al.2003 methodology.

The SDB validation results show a moderate linear correlation between SDB WD and validation data between 0 and 6 m (R2=0.68). The overall MAE (0-10m) is larger than 1m, while the interval (0-6m) MAE is 0.9m.

The empirical model shows a strong linear regression R2 = 0.81 between 0 to 10m and an MAE (0 to 6m) below 1 m, while the MAE (0 to 4) m is 0.6 m. The regression is stronger in the 0-7m interval suggesting this could be the maximum depth of light penetration in the water.

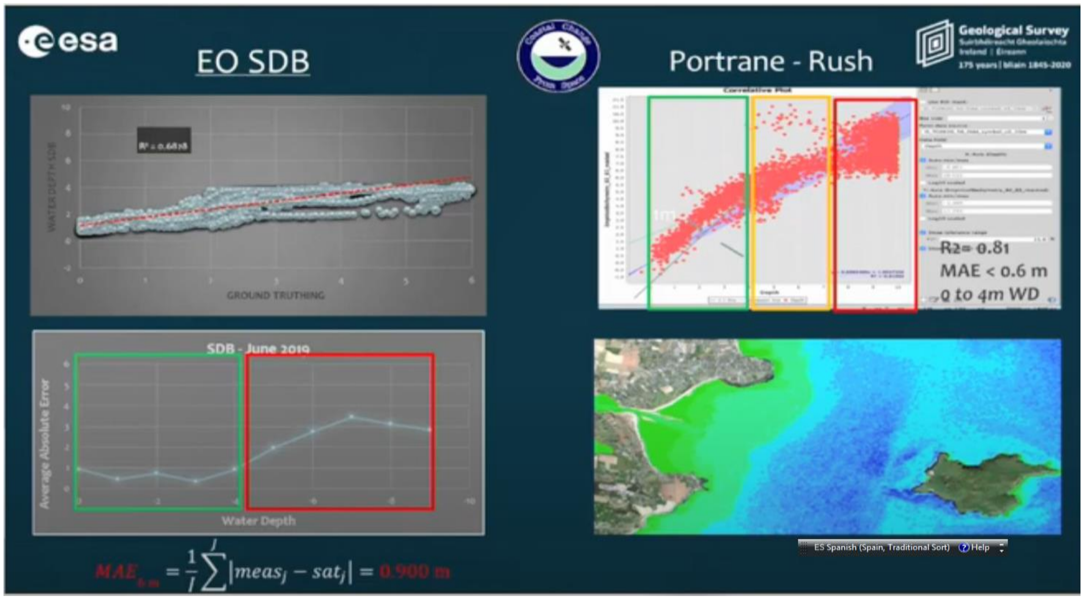

Figure 28: Comparison between SDB product (June 2019) with empirical model from the same image using validation data

5.3. Preliminary conclusions

The SDB results in Portrane show Mean Absolute Errors (MAE) larger than 2 m in the 0 to 10m WD interval. MAE is reduced when considered the interval between 0 to 6m to an averaged MAE for the six images of 1.355 m.

One image, June 2019, shows Mean Absolute Errors less than 1m in between 0 to 6m (MAE=0.9m).

The images selected were considered suitable for SDB using empirical models.

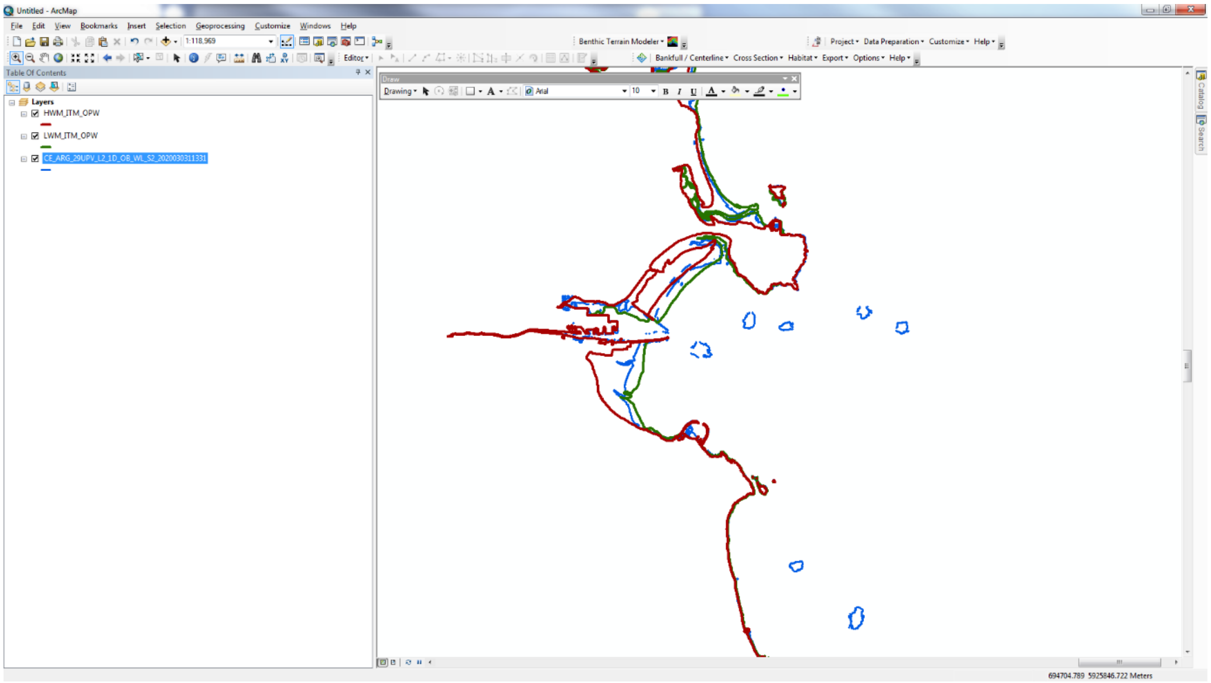

Figure 29: Waterlines – a) Example of inconsistencies identified in the OSWL from Dublin Bay with segments offshore (blue polygons)

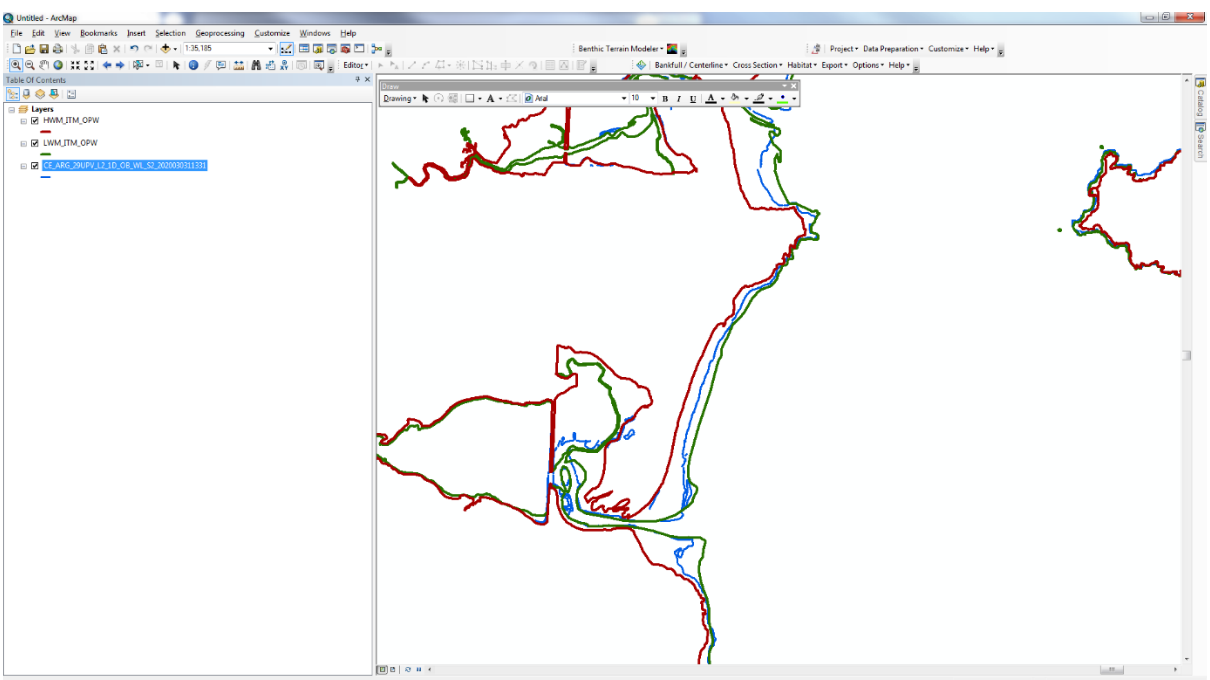

Figure 30: Waterlines – North Dublin. Example of generally good vectorized waterline with minor issues (small pockets – pools)

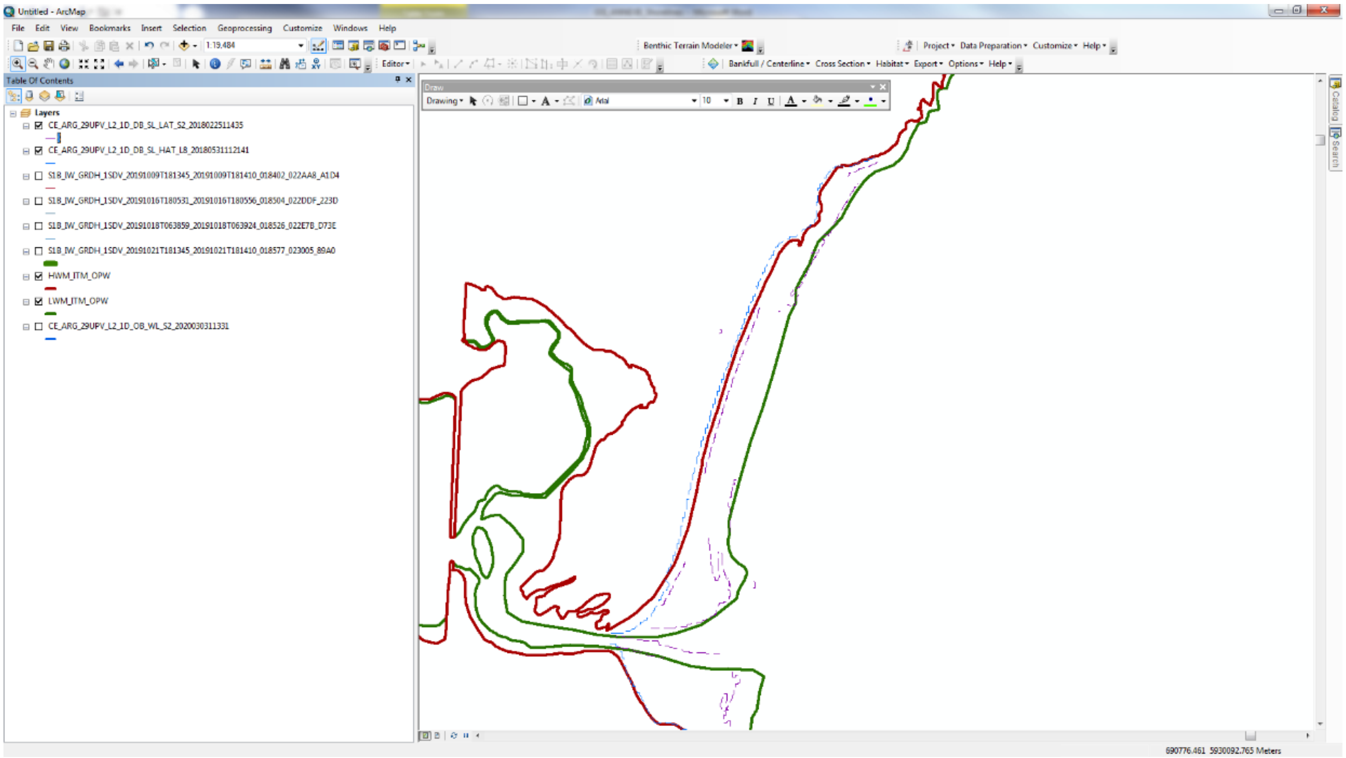

Figure 31: Shorelines (Datum-based): Examples of possible incorrectly assigned LAT shoreline (purple) close to LAT existing shorelines (red)

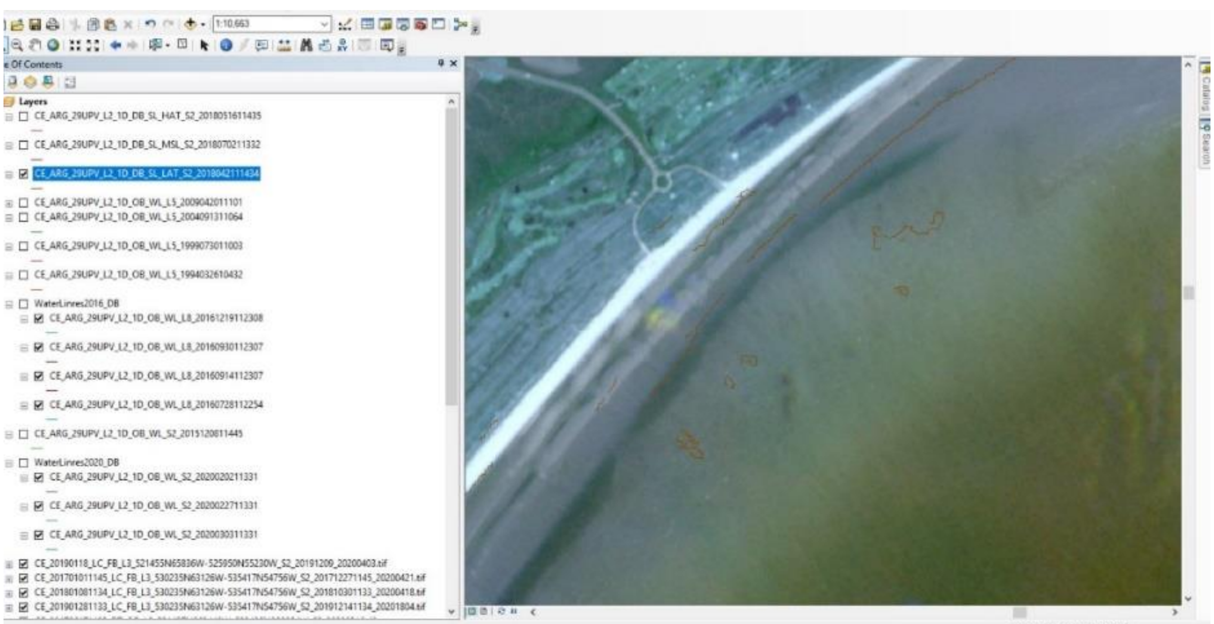

Figure 32: Shorelines Dublin bay - Examples of inconsistencies identified in LAT image. Pockets of LAT polygons (brown) in areas where a more accurate representation is present

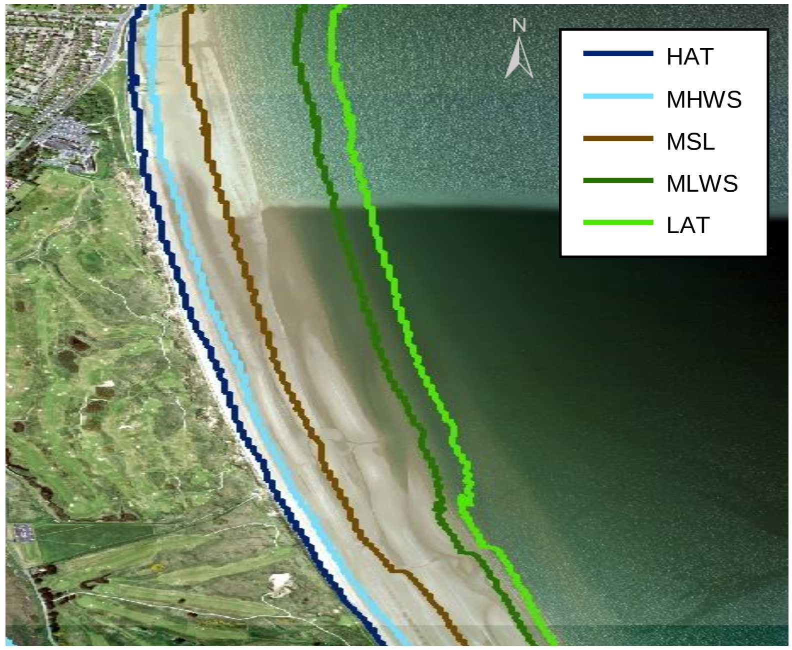

Figure 33: Shorelines Portmarnock – Examples of the 5 optical shorelines extracted from each individual waterline

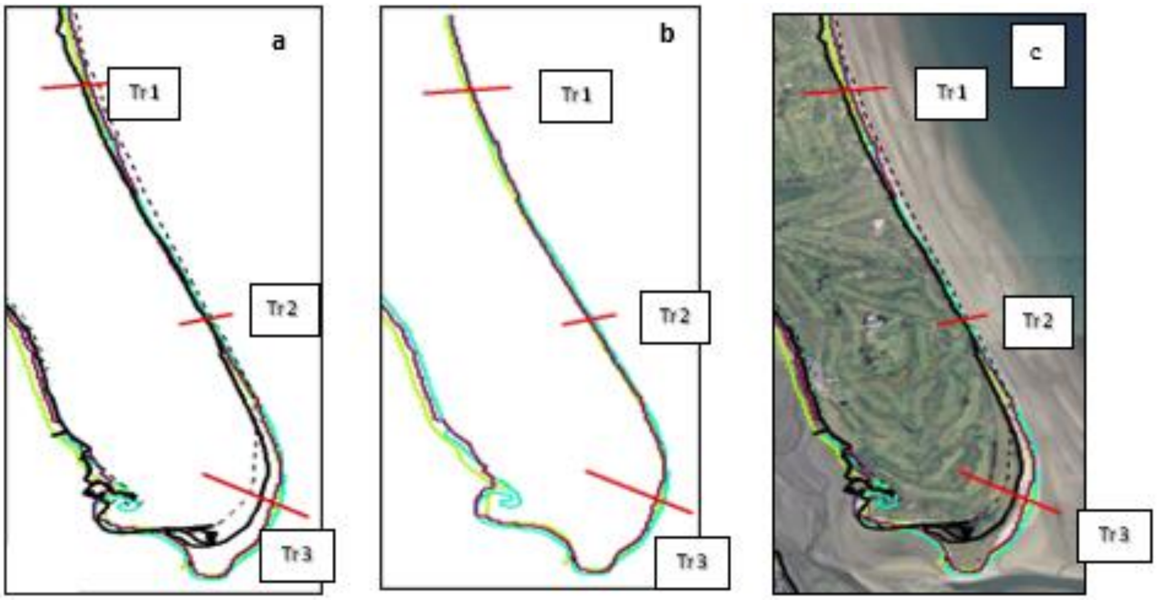

Figure 34: Shorelines Portmarnock

The images above from left to right represent a validation sequence in which reference data is added. Image a shows three shorelines from the same year. Image b shows these three shorelines compared to OSI reference lines. Image c includes an orthophoto from 2014.

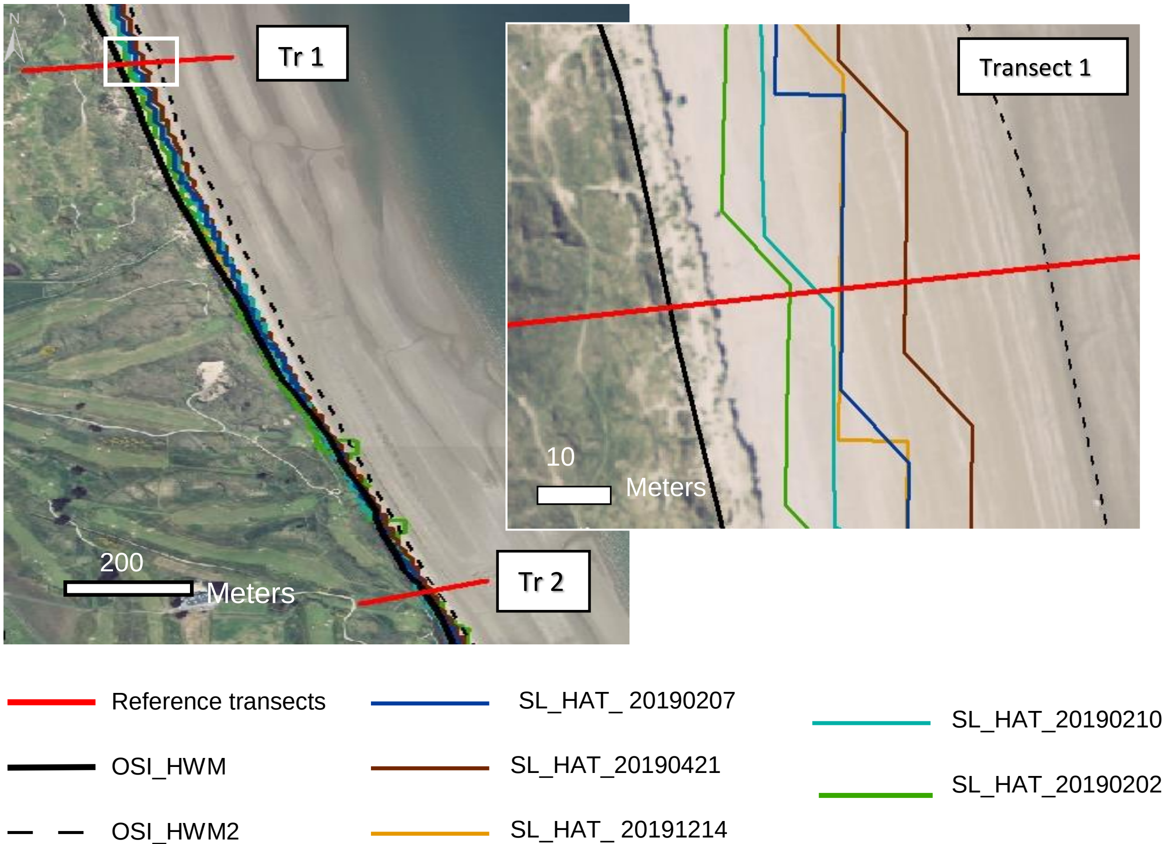

Figure 35: Example in Portmarnock beach where all the shorelines are within the reference layers

6. References

Casal, G., Monteys, X., Hedley, J., Harris, P., Cahalane, C., & McCarthy, T. (2019). Assessment of empirical algorithms for bathymetry extraction using Sentinel-2 data. *International journal of remote sensing*, *40*(8), 2855-2879.

Casal, G., Hedley, J. D., Monteys, X., Harris, P., Cahalane, C., & McCarthy, T. (2020). Satellite-derived bathymetry in optically complex waters using a model inversion approach and Sentinel-2 data. *Estuarine, Coastal and Shelf Science*, *241*, 106814.

B R, Shivakumar & S V, Rajashekararadhya. (2018). An Investigation on Land Cover Mapping Capability of Classical and Fuzzy based Maximum Likelihood Classifiers. International Journal of Engineering & Technology. 7. 939-947. 10.14419/ijet.v7i2.10743.