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

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

EO-Intertide
Sentinel-2 Satellite shoreline extraction toolset development on the Irish east coast - Final Report

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1. (a) Project information:

Executive summary (approx. 1 page)

Two primary topics were examined, namely: (a) Sentinel-2 satellite image waterline extraction and accuracy testing and (b) extraction and accuracy testing of ICESat-2 nearshore bathymetric data. The ICESat-2 work represented a substantial extension of the research (in direct consultation with GSI) than was originally planned in WP1 and WP2. This was made possible by the extra time that was available due to the challenges (data availability and constraints on water-sampling surveying in 2020 and 2021) that were encountered within WP3.

With regard to the Waterlines section of the project, a customised, repeatable waterline extraction routine (designed and implemented in ArcGIS desktop) was applied to Sentinel-2 satellite imagery for the period from 2015 to 2020. EO-Intertide (EO-I) waterlines were extracted for the full length of the Irish (Republic) eastern coastline using Sentinel-2 Short Wave Infrared (SWIR) band 11. The EO-I waterline extraction toolbar (and accompanying User Guide document) can be extended as an automated process if required in the future. One critical step, the definition of the water/land threshold, was performed by the user interacting with each image, which facilitated fine-tuning of the water/land threshold value. Accuracies of approximately 0.3m were achieved for tide-heighted waterlines from Dublin Bay and Wexford.

GPS (GNSS) low-tide surveys were conducted (July 2020) at 23 beach locations (separated by alongshore intervals of approximately 10km) along the east coast. These GPS data (consisting of four to six transects running between the head of the beach and the survey-time low water level) were acquired for the purpose of validating tide-gauge derived waterline height values. Ten kilometre intervals were selected in order to provide additional GPS transects for the entire east coast, that could be potentially be used for waterline height-attribution in any locations where tide-gauge records might happen to be unavailable. Tide-gauge water-level heights (Malin OD) provided by the Marine Institute (https://erddap.marine.ie) were assigned to waterlines according to Satellite date & time. Dublin bay provided the most complete tide data results. Wexford and Rosslare also provided good tide records for waterline attribution.

The potential for GPS data to be used for waterline height-attribution was also evaluated, for situations where tide-records might not be available. GNSS elevation accuracies were also evaluated at each waterline testing location to confirm GPS suitability for waterline attribution. Digital Terrain Model (DTM) interpolation tests were also applied to the Dublin Bay tide-heighted and GPS-heighted waterlines. The tide-heighted and GPS-heighted waterlines produced results of comparable accuracy.

With regard to the ICESat-2 bathymetric data testing portion of the project, the vertical accuracy of extracted, refraction-adjusted ICESat-2 nearshore marine bathymetric data was evaluated at four test sites around the Irish coast. Extracted ICEsat-2 bathymetric values were compared with Multibeam Echosounder bathymetric survey data and GPS reference data. Mean Absolute Errors of less than 0.15m were observed to depths of 5m, with errors of less than 0.24m (to 6m), 0.39m (to 7m) and 0.52m (to 10m). The occurrence of larger bathymetric errors with depth, which increased to 0.54m at maximum data depths of 11m, appears to have been primarily related to reducing numbers of geolocated photons with depth. Overall, the results suggest that ICESat-2 bathymetric data accuracy may be sufficient to be considered for use in nearshore coastal monitoring applications where shipborne and airborne bathymetric data might otherwise be applied.

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Final project report: **EO-Intertide Project**

(i) Objectives and scientific/engineering targets reached beyond the state of the art (please include additional information in Section 4 below)

All of the core tasks in WP1 & WP 2 have been completed, with some being superseded (in close consultation with GSI) by alternative methods that deliver more effective outcomes than the methods proposed. The completion-status of each sub-task in WP1 & WP2 is detailed outlined in Table 1 below. Challenges that were encountered in delivery within WP3 were countered by expanding (in direct consultation with GSI) the analysis in WP1 & WP2.

Table 1: Milestones for objectives and methods deliverables in all three Work packages (as outlined in the project proposal).

	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	A	S
WP 1: Intertidal data generation		■	■	■	■	■	■	■	■	■	■													
1.1 Develop a tidal-shoreline extraction algorithm			■	■	■	■	■	■																
1.2 Produce a new tidal-shoreline extraction toolbox						■	■	■	■	■	■													
1.3 Attribute tide heights to evert point on extracted shorelines using VORF & tide gauge records							■	■																
1.4 Repeat for multiple Sentinel-2 images that represent the full range of high to low tides							■	■																
1.5 Generate tidal-shoreline DTMs for the east and southeast coasts with cross-validation								■	■	■														
1.6 Assess relative performance of rapid-implementation interpolation approaches									■	■														
1.7 Generate height-uniform water level isolines (MHWM ETC) from the accuracy-validated DTM										■	■													
1.8 Map potential tide-gauge zones, assess relationship of tide-gauge to DTM heights											■													
WP 2: Validation of intertidal DTM elevation accuracy									■	■	■	■	■	■	■									
2.1 Compile validation data that are licenced to, or which are held by GSI	■	■	■	■																				
2.2 Licence incidental intertidal coverage aerial orthphoto DTM from BlueSky, as validation data			■	■	■																			
2.3 Conduct GNSS surveys in key areas as very high-accuracy intertidal validation data								■	■	■	■	■	■	■	■									
2.4 Validate tidal-shoreline-derived DTM accuracy and derived isolines											■	■	■	■	■									
2.5 Generate accuracy validation database, detailinf DTM pixel validation residuals													■	■	■									
WP 3: Application of intertidal DTM data to model climate-change impacts														■	■	■	■	■	■	■	■	■	■	■
3.1 Quantify interannual volume change in key carbon-sink areas with periodic Intertidal DTMs															■	■	■	■						
3.2 Assess relationship of Sentinel-2 shallow-water observed turbidity to volumetric changes																■	■	■	■					
3.3 Comparison of Sentinel-2 derived turbidity with PREDICT project water-sampling data																	■	■	■	■				
3.4 Compare Sentinel-2 derived turbidity with EPA Dublin Port buoys turbidity sensor data																		■	■	■				
3.5 Consider intertidal turbidity vector relationships with Irish Wave Climate software & 'ROMS'																					■	■		
3.6 Consider relationships of Sentinel-2 observed water column turbidity weather & tide cycles																						■	■	

(ii) Implementation (milestones reached, deliverables, project management information, steering committee meetings..)

WP 1: Intertidal data generation

The following numbered lists, detail the implementation tasks that were outlined in the proposal document. Sections of text that are highlighted in italics outline completed work and additional work that was done to provide a more effective alternative than the approaches that were initially planned. Further additional work is detailed under the heading 'Additional work completed within WP 1 & WP2'. This section describes the ICESat-2 nearshore bathymetric extraction, refraction adjustment and accuracy testing work, which was made possible (in direct and continued consultation with GSI) by time availabilities presented as a result of challenges encountered within WP3. The submitted journal article that has derived from the ICESat-2 bathymetric work is outlined the Impacts (section V) under the heading of Publications.

1.1 Develop a tidal-shoreline extraction algorithm – *Completed (Figure 1)*

1.2 Produce a new tidal-shoreline extraction toolbox – *Completed (Figure 2)*

1.3 Attribute tide heights to every point on extracted shorelines using VORF & tide gauge records

The VORF model was found to be insufficiently accurate for needs, and has been replaced with a very high accuracy GPS survey data, acquired along 1km stretches of beach at approximately 20km intervals along the east coast from Rosslare to Dundalk (Figure 3).

1.4 Repeat for multiple Sentinel-2 images that represent the full range of high to low tides – *Shoreline extraction has been completed for all published satellite images up to the end of 2020. Samples are shown in Figure 4.*

1.5 Generate tidal-shoreline DTMs for the east and southeast coasts with cross-validation – *Interpolation approaches were tested, and a three-year DTM was generated for the north and south portions of Dublin bay (figure 5) where complete tide-records were available. The process can be repeated for any locations along the east coast, wherever tide records are available.*

1.6 Assess relative performance of rapid-implementation interpolation approaches – *Completed (Figure 5)*

1.7 Generate height-uniform water level isolines (MHWM ETC) from the accuracy-validated DTM –

DTM accuracies were insufficient to generate meaningful 0-metre (Malin datum) MHWM isolines.

1.8 Map potential tide-gauge zones, assess relationship of tide-gauge to DTM heights –

The lack of tide gauges along portions of the east coast (particularly the southern portion) presented an opportunity to evaluate an alternative approach. The high-accuracy (0.01m) east-coast GPS provide waterline-crossing transects (figure 3) were used for waterline height-attribution in Dublin bay, comparing the results with tide-heighted DTM (figure 5).

Figure 1: EO-Intertide waterlines extraction process.

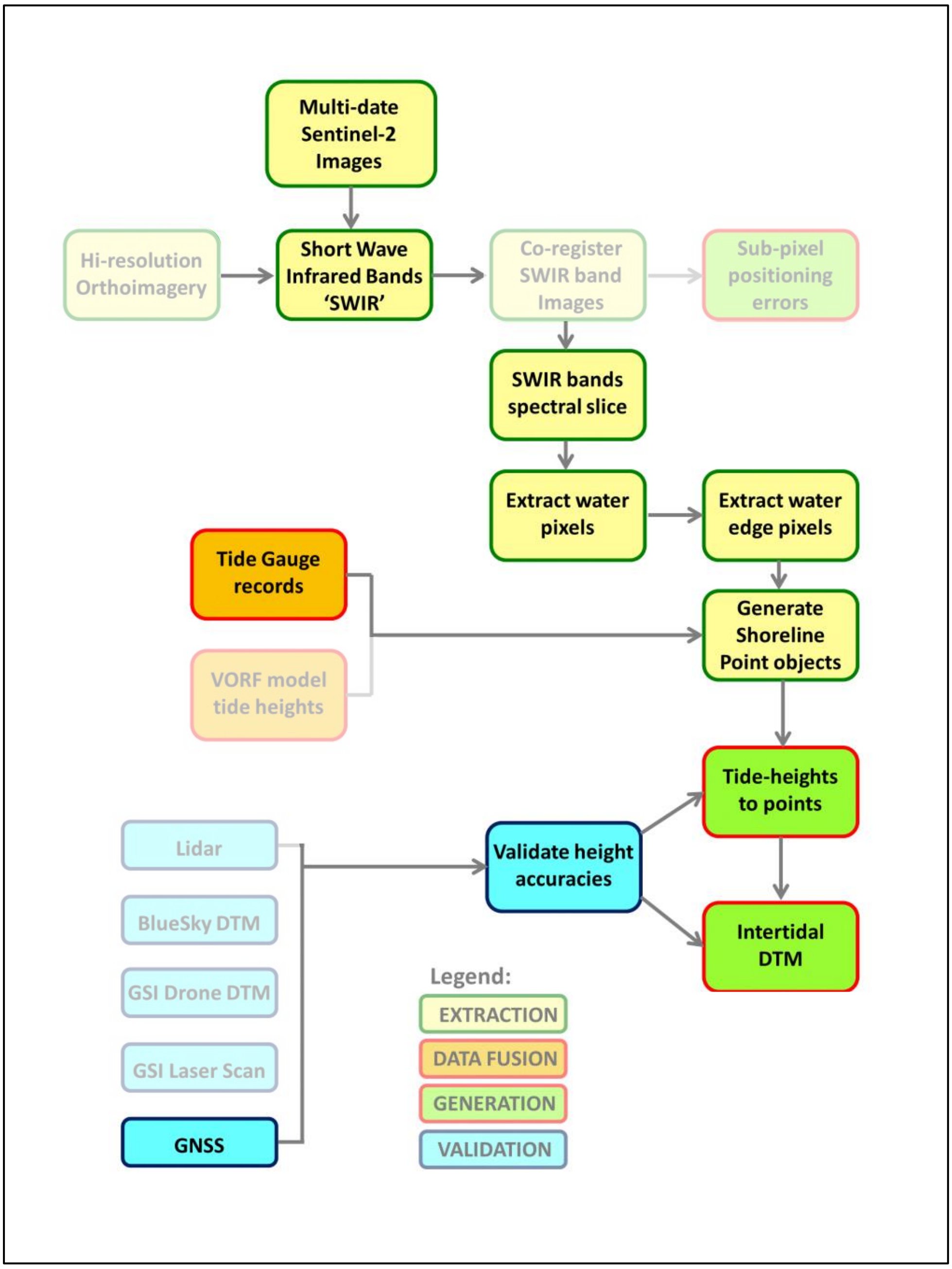

Figure 2: EO-Intertide waterline extraction toolbar / toolset for ArcGIS Desktop 10.x

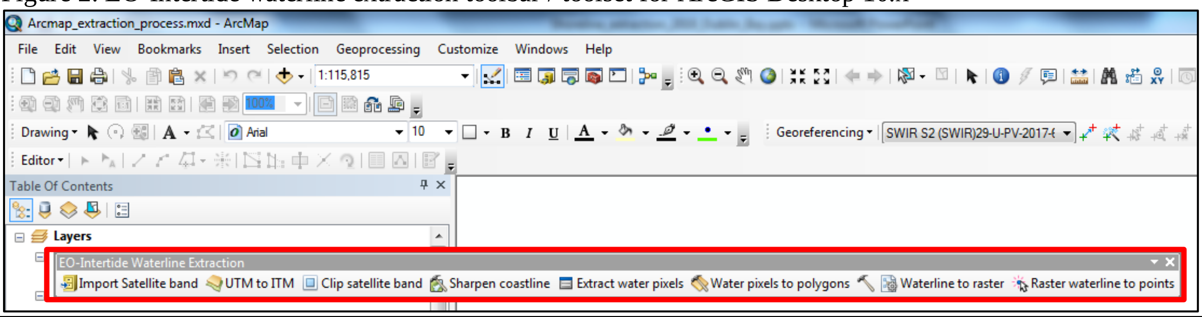

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Figure 3: (a) GPS (GNSS) July 2020 surveys conducted for EO-Intertide project, (b) Dublin region detail map, (c) Dublin region detail map.

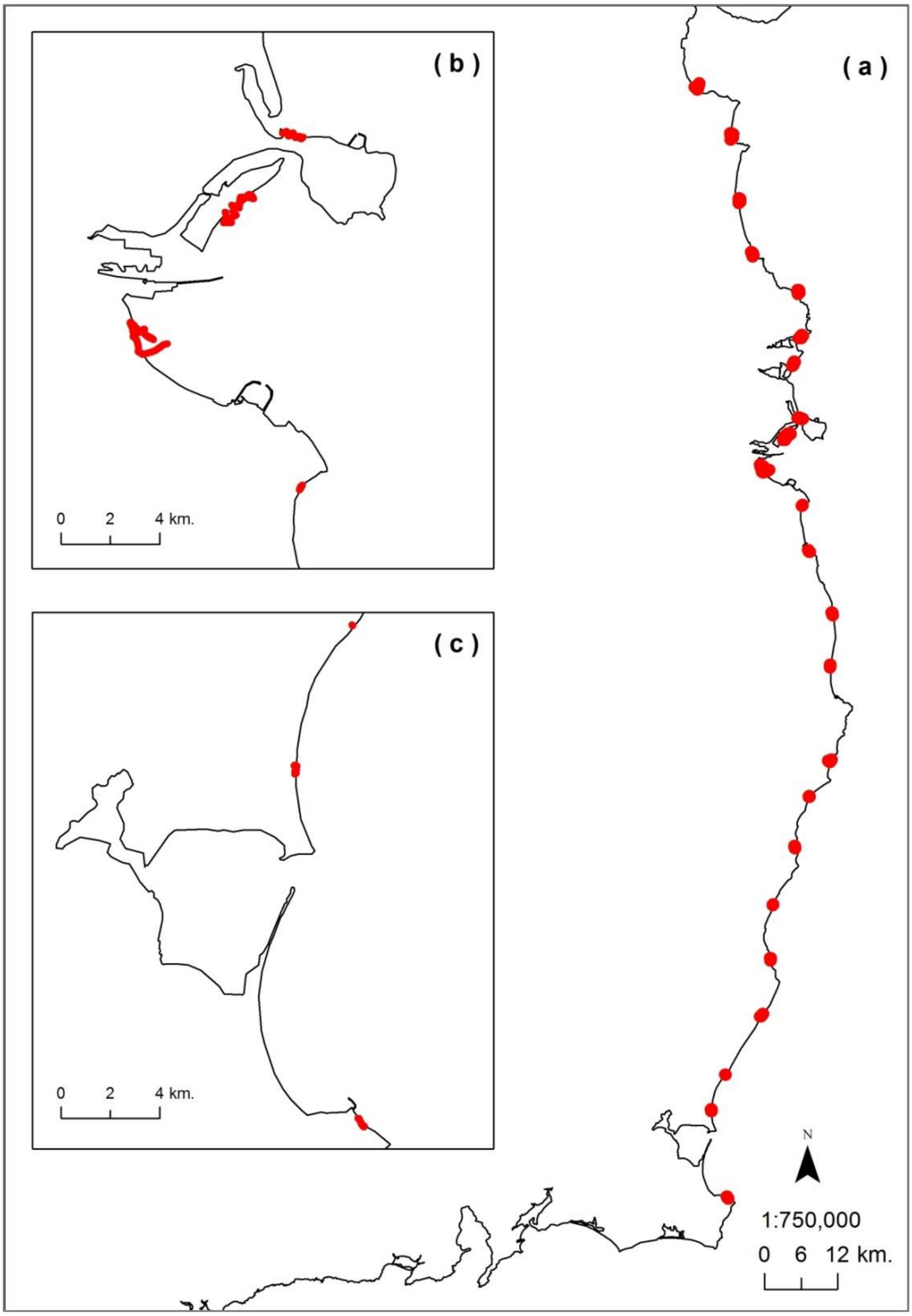
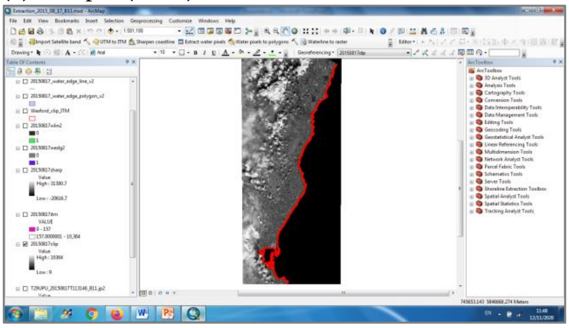
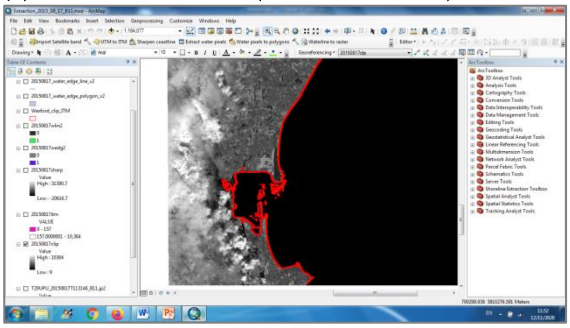


Figure 4: Sample shoreline extractions from Sentinel-2 image (example is from 2015)

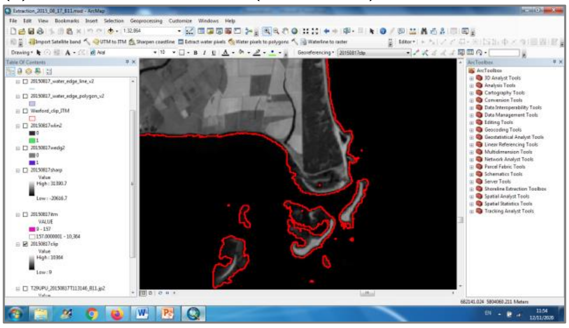
(a) Sample (2015) extracted shoreline



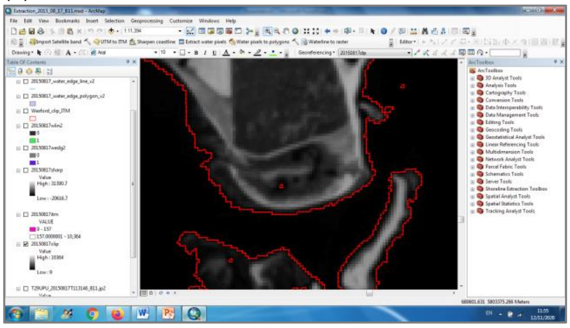
(b) Extracted shoreline (Wexford harbour)



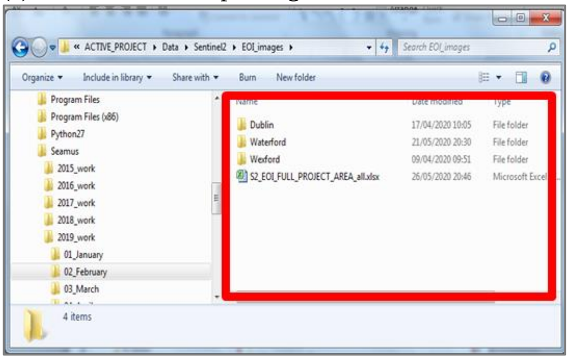
(c) Extracted shoreline (local view)



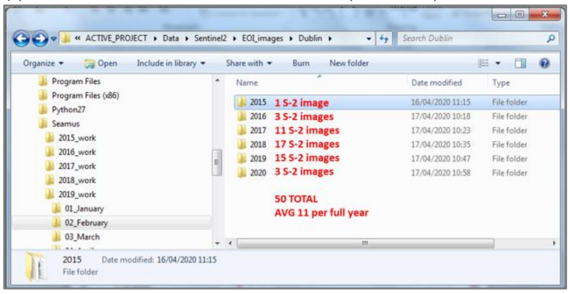
(d) Close view



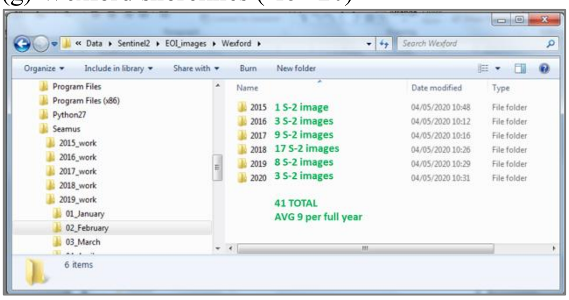
(e) Sub-areas encompassing east coast



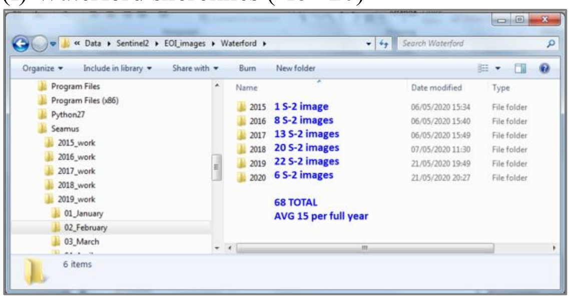
(f) Dublin shoreline extractions ('15-'20)



(g) Wexford shorelines ('15-'20)



(f) Waterford shorelines ('15-'20)



WP 2: Validation of intertidal DTM elevation accuracy

2.1 Compile validation data that are licenced to, or which are held by GSI
A review of all available data and assembly of data was completed

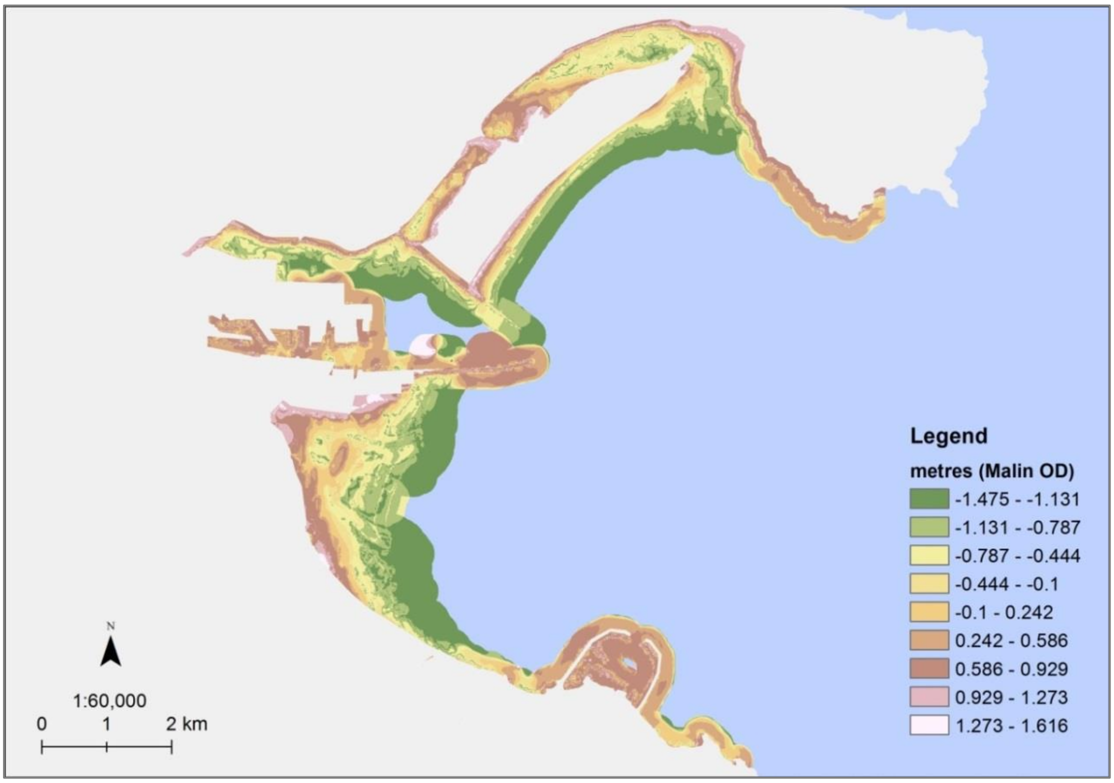
a. Licence incidental intertidal coverage aerial Orthophoto DTM from BlueSky, as validation data
BlueSky LiDAR and photogrammetric DTM data were evaluated, but were found to focus on land above high water, presenting insufficient intertidal coverage for use here.

b. Conduct GNSS surveys in key areas as very high-accuracy intertidal validation data
A more extensive GPS survey was conducted than was originally planned, encompassing the entire east coast, at 20km intervals (figure 3).

c. Validate tidal-shoreline-derived DTM accuracy and derived isolines
An average number of 15 waterlines per year was insufficient to generate accurate intertidal DTM data, so a DTM was generated from the three full years that produced the largest numbers of waterlines (figure 4). The accuracy of waterlines was ≤0.3m (figure 6). However, DTM elevation accuracies were approximately twice as large. Therefore, generating annual DTMs from waterlines proved to be challenging, although this may be possible in years when many waterlines can be extracted from suitable cloud-free satellite images.

d. Generate accuracy validation database, detailing DTM pixel validation residuals
Due to the small number of available years for DTM generation, the accuracy of the waterlines upon which DTM may be generated was reported instead. Better DTMs will be possible as more satellite data becomes available for waterline extraction/

Figure 5: (a) Dublin tide-heighted WLs visualised as an IDW Digital Terrain Model DTM.



(b) GPS (GNSS)-derived DTM (i.e. using no tide data) generated using IDW interpolation for Dublin Bay.

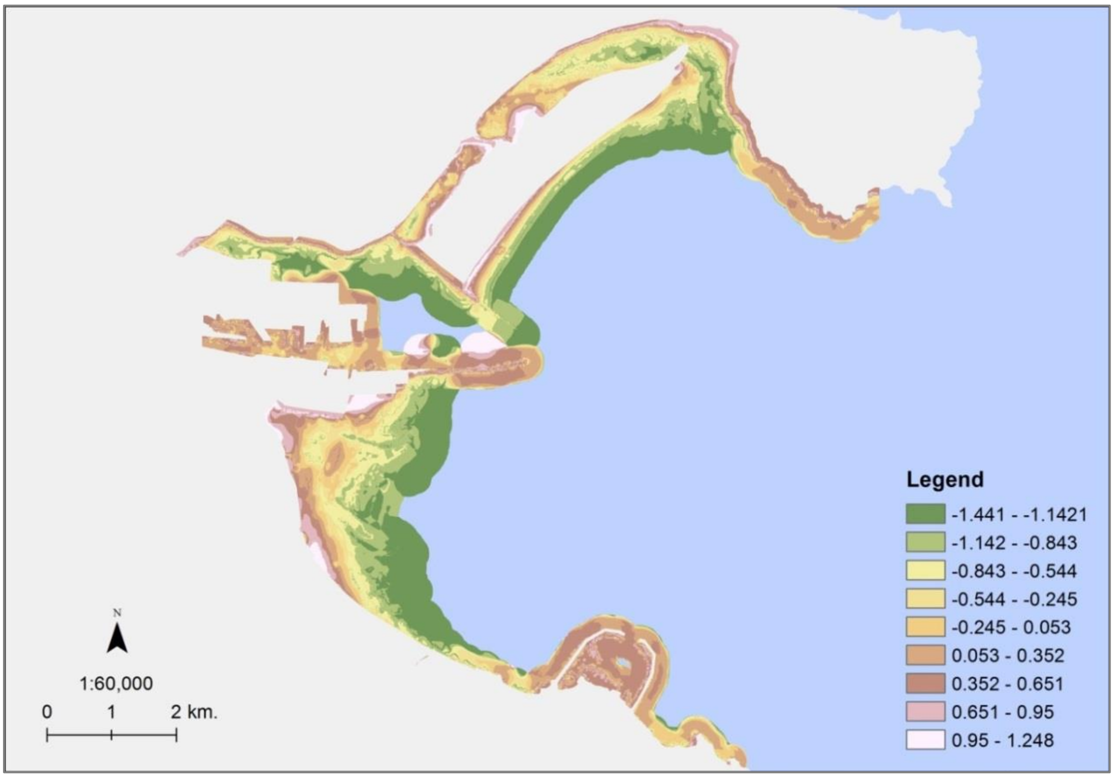


Figure 6 (a): Comparison of Dublin EO-Intertide waterline tide heights with 2020 GPS (GNSS) surveys.

Number of height comparison points	241,654 pts
Mean elevation difference	0.145m
Std. Dev. of all elevation differences	0.278m
Maximum negative elevation difference	-0.825m
Maximum positive elevation difference	0.555m

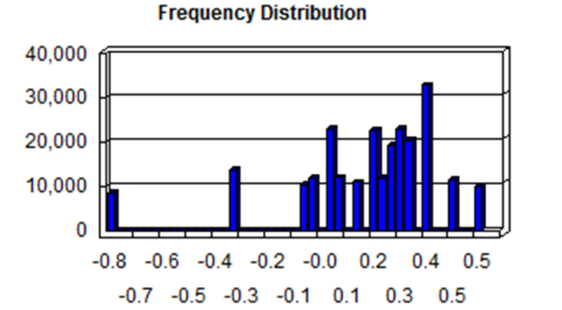
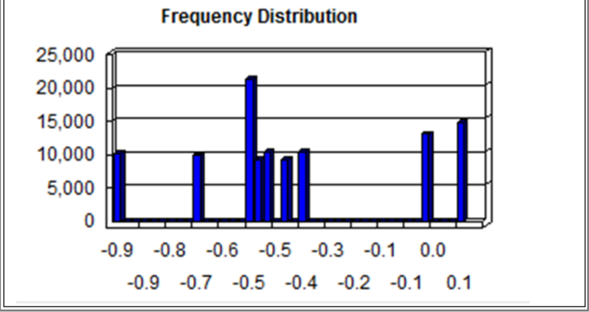


Figure 6 (b): Comparison of Wexford EO-Intertide waterline tide heights with 2020 GPS (GNSS) surveys.

Number of height comparison points	108,534
Mean elevation difference	-0.387m
Std. Dev. of all elevation differences	0.31m
Maximum negative elevation difference	-0.933m
Maximum positive elevation difference	0.122m



Actual Project Budget spend <u>to date</u> *(double click on table below to activate).*

Item	*Original Budget*	*Actual expenditure*
Personnel costs		
Consumables		
Equipment		
Travel (incl. Fieldwork)		
Other (describe)		
Other (describe)		
Overhead Contribution		
Total	**0.00**	**0.00**
In kind contributions		

Please explain any deviations from the original budget:

Signature & stamp of the Host finance office:

2. Supplemental information/datasets