Towards validation of SWOT in the coastal zone: a radar altimetry and water level gauge case study in the Bristol Channel and Severn River-Estuary system

I.D. Lichtman[1], C. Banks[1], F. M. Calafat[1], C. Gommenginger[1] and P. Bell[1]

[1]National Oceanography Centre

doulich@noc.ac.uk, chris.banks@noc.ac.uk, francisco.calafat@noc.ac.uk, cg1@noc.ac.uk, psb@noc.ac.uk

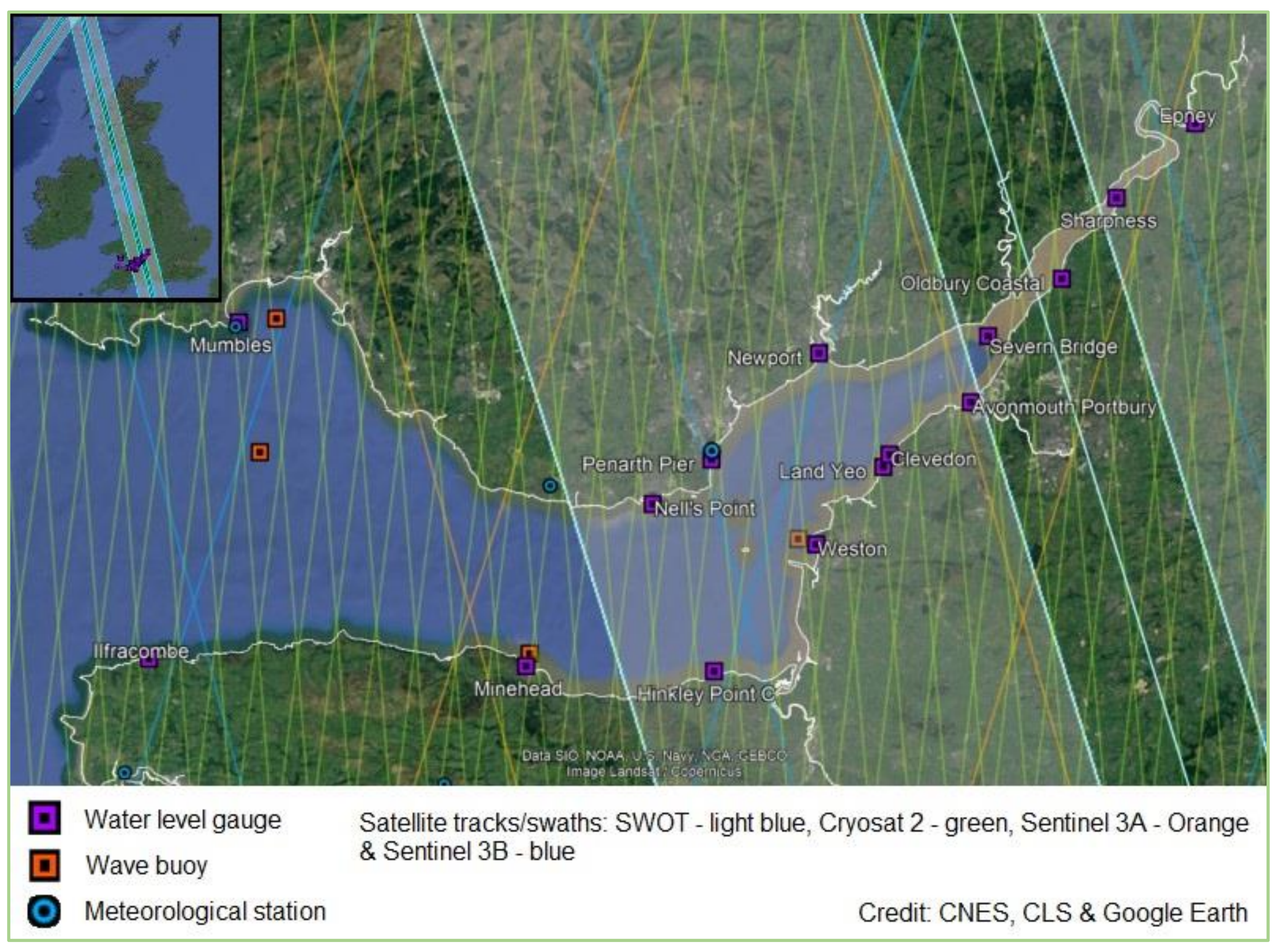
National Oceanography Centre

Surface Water and Ocean Topography (SWOT) mission and SWOT-UK project

SWOT was launched 16 December 2022 to collect 2D maps of marine and terrestrial water level, the first for a satellite instrument. This will provide a global water level budget. Different spatial products are available, from high vertical accuracy and low spatial resolution over the ocean to high spatial resolution and lower vertical accuracy for inshore and coastal waters. The standard orbit will have 21-day repeat, but for the cal/val phase of the mission it was a 1-day repeat.

Here we aim to explore quality of SWOT data in the coastal zone and rivers. For the UK contribution to the international SWOT Science Team validation work, the SWOT-UK project carried out a comprehensive programme of campaigns and multidisciplinary research.

A set of water level gauge (WLG), CryoSat-2 and Sentinel-3 data has been gathered to validate water level and sea surface slope during the 90-day daily repeat SWOT cal/val mission phase. These data were used to assess the consistency and quality of the WLG network, showing the random and systematic errors in the data, and develop a validation scheme for the 2D SWOT altimetry data in coastal and estuarine settings. This will highlight issues of how the coastal dynamics, hydrology and morphology affect the comparison of satellite altimetry and WLGs, and how these features may be seen in the 2D SWOT data. The slope along the satellite passes (across-channel), near-shore coastal dynamics and intertidal morphology have been seen to affect the comparison of satellite altimetry and WLG data, and these geographic characteristics are expected to influence the uncertainty in the comparison with the 2D SWOT data.

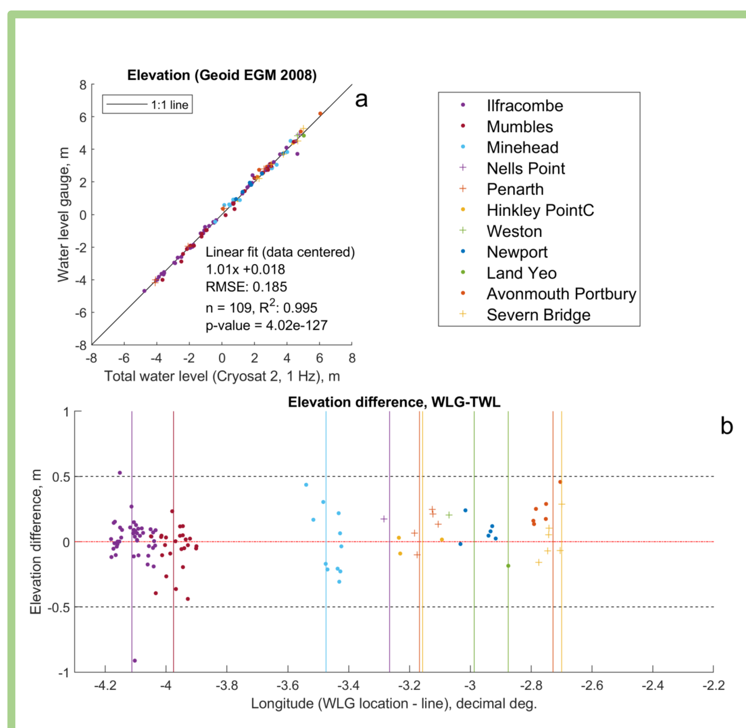


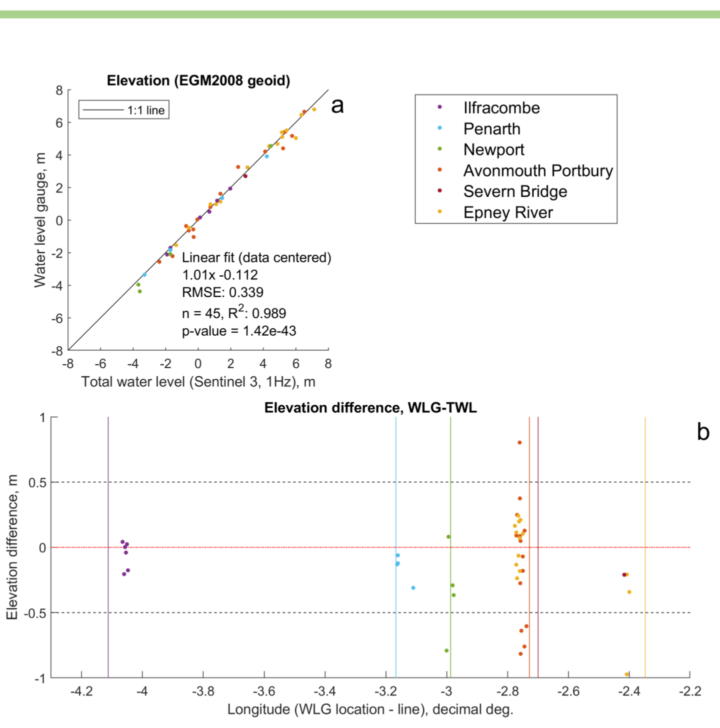
Bristol Channel and Severn River-Estuary system

The Bristol Channel and Severn River-Estuary system is highly dynamic with one of the largest tidal ranges in the world (> 14 m) and strong currents and a tidal bore in the upper reaches. Waves can reach over 7 m at the western limit but are small upriver. The area has highly mobile sedimentary bedforms ranging from mud ridges to gravel waves and dunes.

The coastline surrounding these waters and upriver is covered by a network of water level gauges (WLGs), which has been continuously operational for a period of decades (Figure 1). This makes it an ideal area for the validation of new satellite altimetry sensors. Additional in-situ GNSS-IR WLGs, using the interference between the direct and reflected navigation signals, were deployed to fill gaps in the existing WLG network. Some of the WLGs are of unknown levelling quality and this work will help identify problematic gauges using the altimetry data.

Figure 1: Map of the Bristol Channel and Severn River-Estuary system showing the locations of the water level gauges and satellite tracks used in this study.





Cryosat 2 and Sentinel 3 validation with water level gauge data

The satellite altimetry data were corrected for atmospheric transmission and geophysical effects (Andersen and Scharroo, 2011; Bonnefond, Haines & Watson, 2011). The data were filtered for extreme values outside the expected range of tide and wave height (Dhoop, 2019). The Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG. Wessel and Smith, 1996) was used to provide a shoreline mask, at one arc-second resolution, to remove data over land.

As tidal models are inaccurate in the study area, due to resolution and morphological effects, the altimetry and water level gauge (WLG) data were not corrected for tide. The Dynamic Atmospheric Correction was not applied to the altimetry data, as the WLG were not corrected for these effects. All the data were corrected to EGM2008 geoid for comparison.

Total Water Level = Altitude – Atm. Corrected Range - Solid Earth Tide - Pole Tide - Sea State Bias

Altimetry data was selected using a 6 km radius around each WLG site. The WLG data were interpolated to the time of the altimetry measurements before regression analysis. The satellite data have not been corrected for water surface slope, so some scatter is due to the distance of the measurement from the WLG.

From the Cryosat 2 and Sentinel 3 regression analysis (Figures 2 and 3) it would be expected that the comparison between WLG and SWOT data would have a near 1:1 line with a RMSE of about 0.2 – 0.4 m.

Figure 2 (left): Cryosat 2 data with water level gauge data. a) Regression analysis, b) Elevation difference with longitude. 1 January 2012 to 28 June 2023.

Figure 3 (right): Sentinel 3 A & B data with water level gauge data. a) Regression analysis. b) Elevation difference with longitude. 16 May 2016 to 1 January 2023.

SWOT validation with water level gauge data

The L3 product is merged from the KaRIn swath and nadir altimeter data, with a resolution of 2 km. To make the data comparable to the Water Level Gauges (WLG), and the Cryosat 2 and Sentinel 3 analysis, the L3 SSHA data had the ocean tide, MSS & DAC corrections removed. Crossover correction is included in the L3 product.

The L3 products are named Unedited and Noiseless, where the 'noise' near the coast has been removed. The sea surface slope and nearshore processes (Figure 4) are expected to be the dominant sources of uncertainty. For the L3 Noiseless data, the Hinkley Point C site had the best fit (Figure 5), probably as it is on the end of a long pier. Compared to the Cryosat 2 and Sentinel 3 analysis (Figures 6 & 7), the SWOT data are of similar quality with slope close 1:1 and RMSE 0.2 – 0.4 m with the noiseless data showing the improvement of removing data close to the shore.

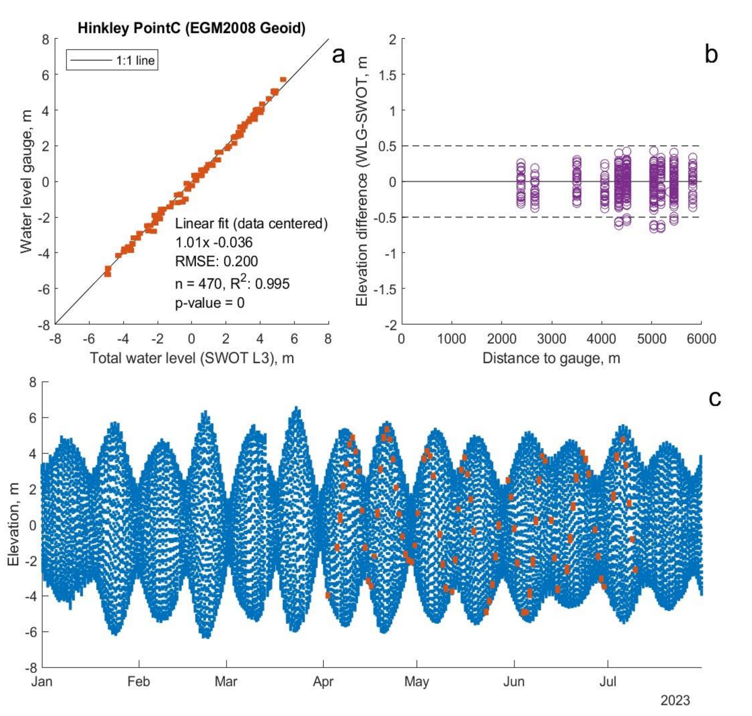


Figure 5: a) SWOT L3 noiseless product for Hinkley Point C site. a) Regression analysis, b) Elevation difference with distance to gauge, c) Water elevation for water level gauge – blue, and SWOT - orange.

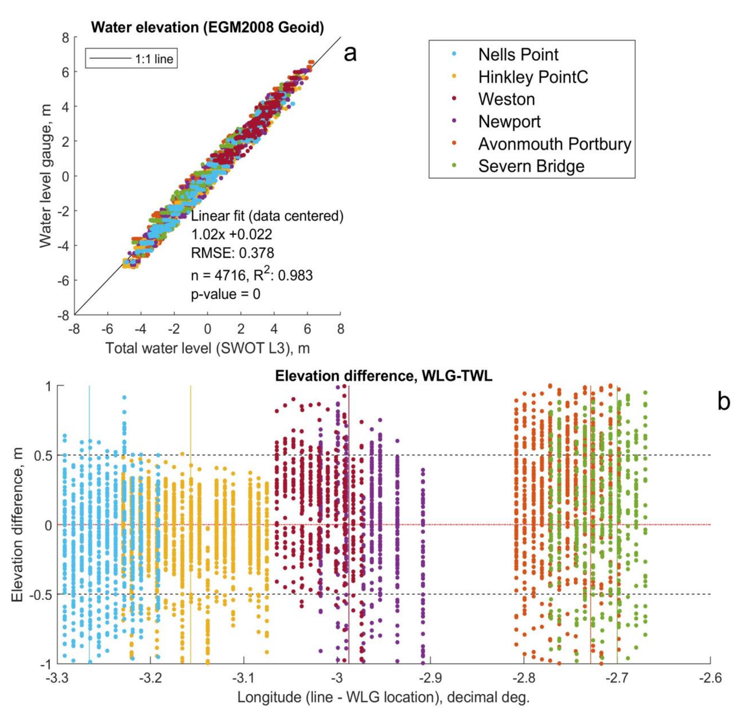


Figure 6: SWOT L3 Unedited product data with water level gauge data. a) Regression analysis, b) Elevation difference with longitude. Data for April-July 2023.

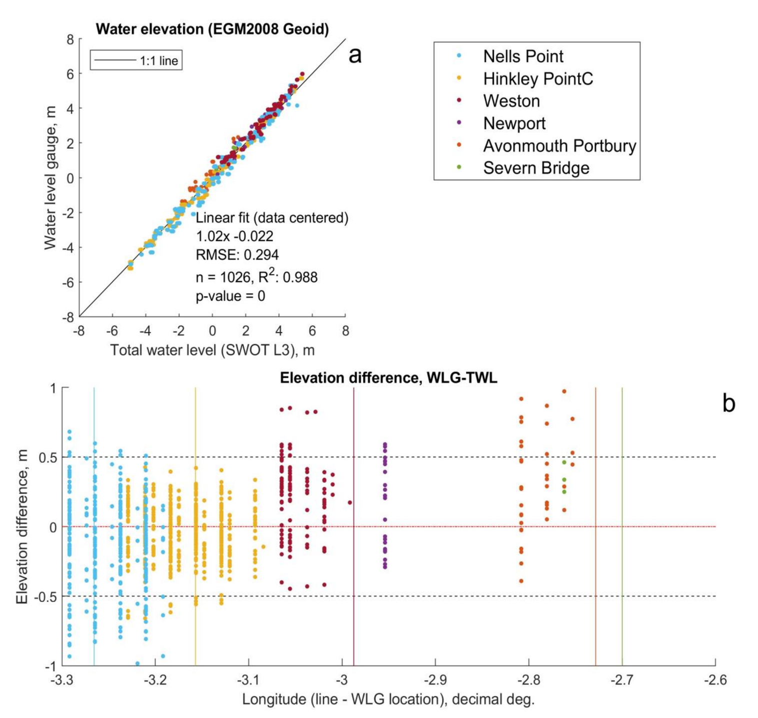


Figure 7: SWOT L3 Noiseless product data with water level gauge data. a) Regression analysis, b) Elevation difference with longitude. Data for April-July 2023.

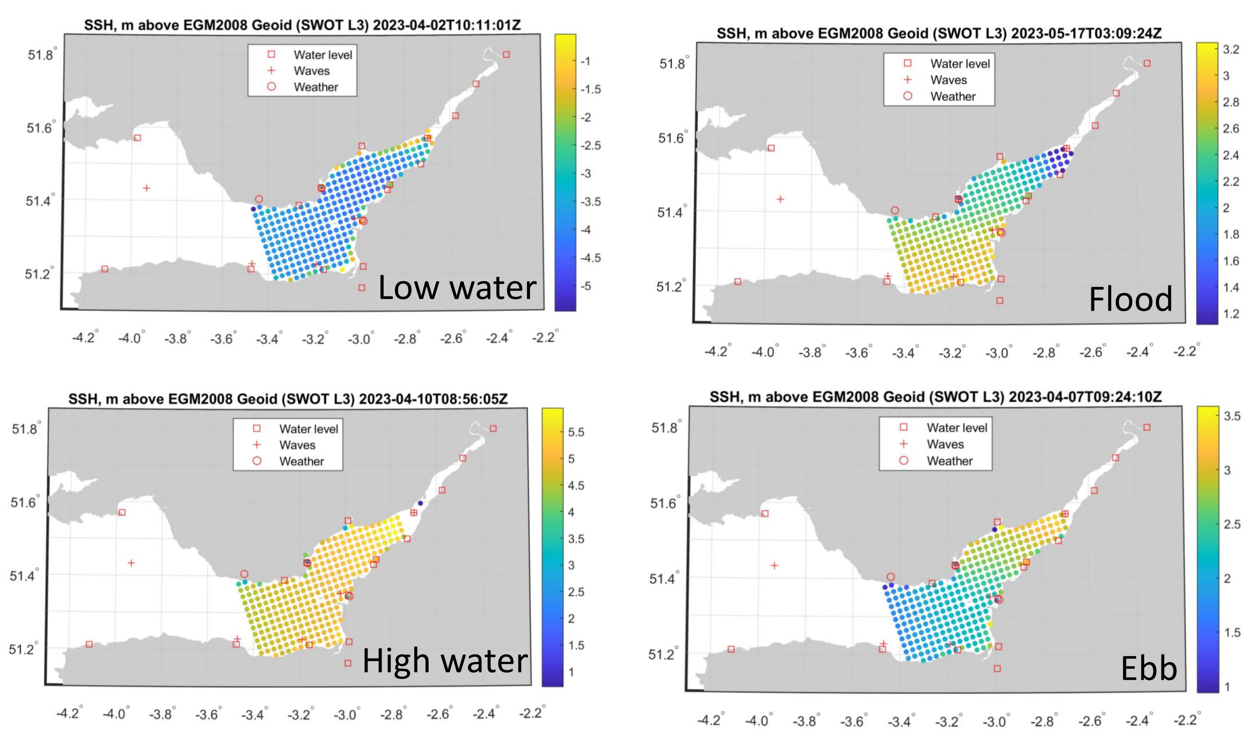


Figure 4: SWOT L3 Unedited product, shown for examples of different states of tide. These plots highlight the water surface slope and possible intertidal areas at low water (see Figure 8).

Sources of uncertainty:

- Levelling/orbit – estimated to be 0.02 to 0.29 m for individual Water Level Gauges (WLG)
- Along channel slope (tidal phase), between WLGs and satellite tracks - few cm to tens of cm
- Across channel slope (circulation), between WLGs and satellite tracks - few cm to tens of cm
- Vertical land movement effect on WLGs - ~ 0.01 m over 10 years
- Quality of sea state bias correction (based on wave and wind data from altimeter, and algorithm not tuned to coastal areas) – should be small as waves are small in the study area
- Dry and wet tropospheric atmospheric corrections – DTC degrades towards the coast and WTC is highly variable, estimated a few cm to tens of cm (Andersen and Scharroo, 2011)

Nearshore coastal processes and Intertidal areas

Satellite measurements close to the coast have been considered noisy. This may be due to backscatter from non-water sources. However, in shallow waters wave shoaling, set up and set down could influence altimetry measurements (Abessolo *et al*, 2023). In addition to this, in enclosed bays or estuaries, cross-channel slope can be cause by trapped tidal waves.

As intertidal flats and banks exposed by the ebbing tide will still be wet, returned signals will be higher than the tidal water level (Figure 8). This could be considered a source of noise or that the SWOT data has the potential to map changing intertidal banks and flats, as they erode, accrete and move with the currents.

The next steps

- Correction for tidal phase/slope between water level gauges and satellite tracks/pixels.
- Comparison of L2 HR data to the WLGs

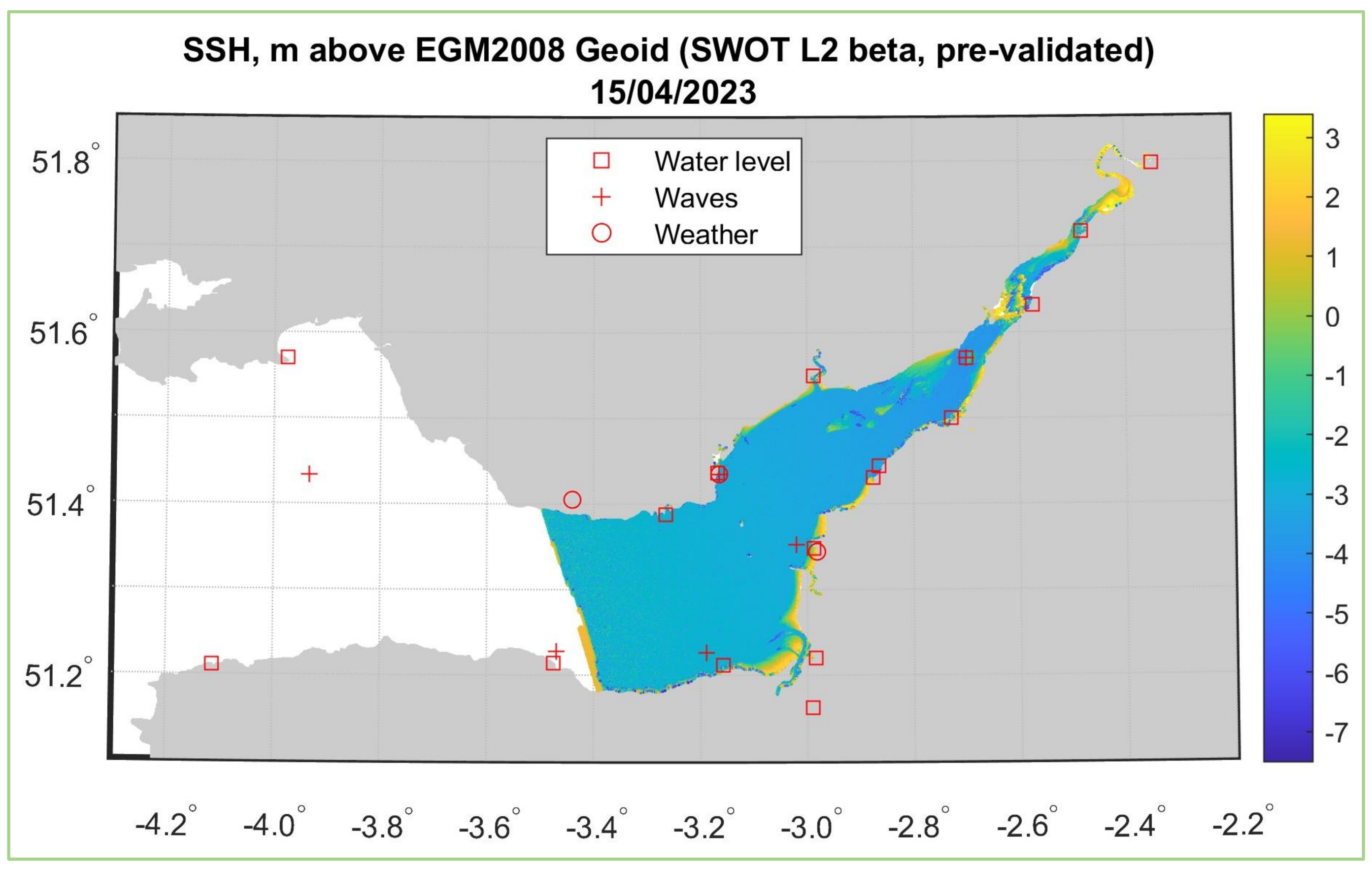


Figure 8: SWOT L2 HR Pixel product. Intertidal areas are shown to give elevations metres above the water level. At the western edge of the swath, there are artefacts where intertidal areas are not found.

Acknowledgements

The SWOT data was supplied by CNES, L3 alpha v0.2 – DOI: 10.24400/527896/A01-2023.018 and L2 KaRIn SSH expert v1 – DOI: 10.24400/527896/a01-2023.015

References

Abessolo, G. O., Birol, F., Almar, R., Léger. F., Bergsma, E., Brodie, K., Holman, R., 2023. Wave influence on altimetry sea level at the coast, Coastal Engineering, 180, 104275, https://doi.org/10.1016/j.coastaleng.2022.104275.

Andersen, O.B., Scharroo, R. (2011). Range and Geophysical Corrections in Coastal Regions: And Implications for Mean Sea Surface Determination. In: Vignudelli, S., Kostianoy, A., Cipollini, P., Benveniste, J. (eds) Coastal Altimetry. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-12796-0_5.

Bonnefond, P., Haines, B.J., Watson, C. (2011). In situ Absolute Calibration and Validation: A Link from Coastal to Open-Ocean Altimetry. In: Vignudelli, S., Kostianoy, A., Cipollini, P., Benveniste, J. (eds) Coastal Altimetry. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-12796-0_11.

Dhoop, T., 2019. Coastal Wave Network Annual Report 2018. Channel Coastal Observatory. Available at: https://www.coastalmonitoring.org/reports/ [accessed 7 September 2022].

Wessel, P., Smith, W. H. F. (1996). A global, self-consistent, hierarchical, high-resolution shoreline database, J. Geophys. Res., 101(B4), 8741–8743, doi:10.1029/96JB00104.

National Oceanography Centre | UKRI Natural Environment Research Council | UK Space Agency | University of Bristol | Prifysgol Bangor University | NOC.AC.UK

The SWOT-UK project is funded by the UK Natural Environment Research Council and the UK Space Agency under grant number NE/V009168/1 (NOC), NE/V009125/1 (Bristol) and NE/V009109/1 (Bangor)

Find SWOT-UK at projects.noc.ac.uk/swot-uk/