SEEING SENSE

Developing multiple quality control parameters to assist in the interpretation and understanding of X-band radar derived bathymetry

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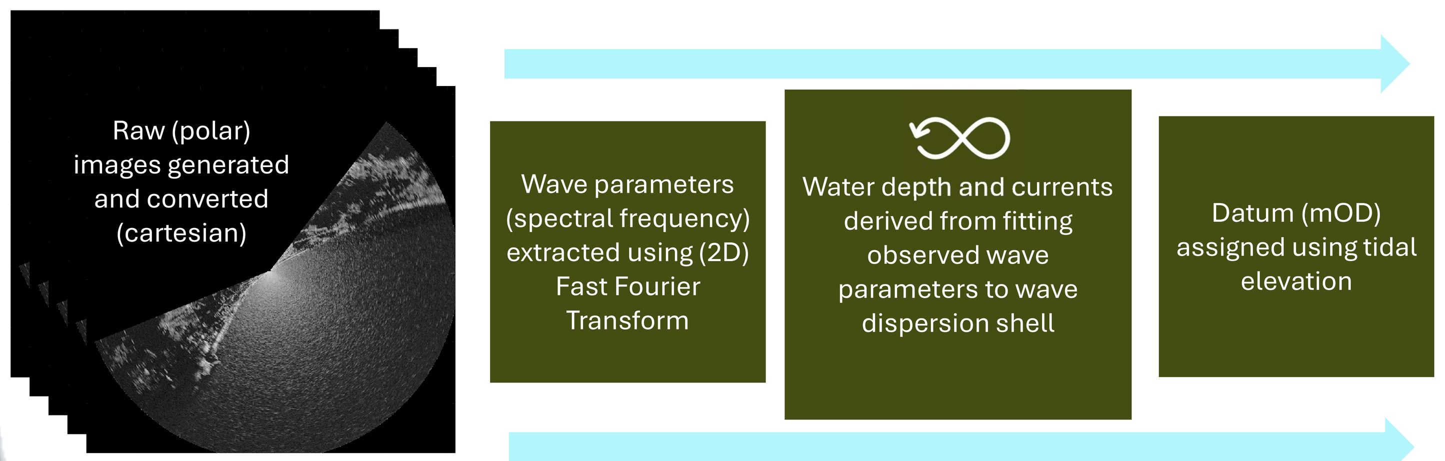
Introduction

The nearshore zone is widely understood to be an area of intense sediment motion resulting from the interaction of waves, currents and tides. Despite this, high frequency systematic collection of bathymetry data from the subtidal zone is globally scarce due to the physical limitations of surveying a large shallow zone by vessel.

X-band radar derived bathymetry offers an exciting insight into this zone, however, understanding the variability from the different sources of error currently limit the techniques wider applicability. Here we outline the sources of error and define 5 quality control parameters to assist in the interpretation of X-band radar derived bathymetry.

How it works (in a nutshell)



Raw images are taken with every rotation of the marine radar antenna. These 'sea clutter' images show a snapshot in time of the sea surface, showing wave fronts as areas of high intensity (strong return signal) and the back of the wave is shadowed out. This shadowing is essential in capturing the frequency and speed of the waves.

SOURCES OF ERROR

PLANNING STAGE

1. WATER LEVELS

Accurate tidal observations or predictions are required to effectively assign a datum or benchmark to the derived bathymetry. This significantly increases the value of the data as it allows for comparison to other datasets. Water level is therefore a critical component in assessing origins of error (Table 1).

3. SENSOR RANGE

With increasing distance from the sensor, image resolution decreases and image quality deteriorates (Atkinson et al., 2018). The range is a function of the signal strength and also the height of the sensor, *i.e.* increased elevation of the marine radar increases the field of view.

4. SIGNAL TO NOISE RATIO (SNR)

The ability of the Fast Fourier Transform to correctly interpret signals is partially dependent on the signal to noise ratio. Storm events have large wave heights and provide a strong signal which increases the SNR and reduces error (Grossmann et al., 2019). In calm conditions, smaller waves equate to a weaker signal, lowering the SNR, whilst atmospheric effects can also reduce SNR by increasing the noise.

INTERPRETATION STAGE

5. DEPTH DEPENDENT ALGORITHM

The wave inversion derived bathymetry is based on linear wave theory, which relates the speed of the waves to water depth. The algorithm is not be able to derive bathymetry in deep water.

6. WAVE DIRECTIONALITY

Wave crests are effectively imaged by shadowing (Nieto-Borge, 2013). Therefore in areas where the wave rays and radar signal are directly aligned (and the waves are big) clear wave signals are detected. In areas where the wave rays are at right angles to the radar signal, it is not possible to effectively image the crest, which means that the algorithm which derives the bathymetry cannot work.

7. WAVE CURRENT ALIGNMENT

Currents can be significant in the shallow nearshore and can affect the speed of the wave, which in-turn affects the water depth calculated by the algorithm. When currents are travelling in the same, or opposite direction to the incoming waves, it is possible to derive the speed of the current through the doppler shift effect. However, in areas where the current flows at a right angle to the incoming wave direction, this is more difficult and the ability to detect the current and therefore the ability to estimate the seabed effectively decreases.

ERROR HANDLING

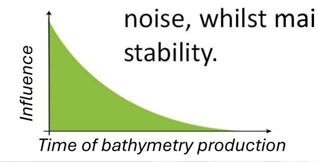
PROCESSING STAGE

1. WATER LEVELS

Ensure water level data available across the domain for assigning a datum.

2. HALF-LIFE DECAY FOR STABILITY

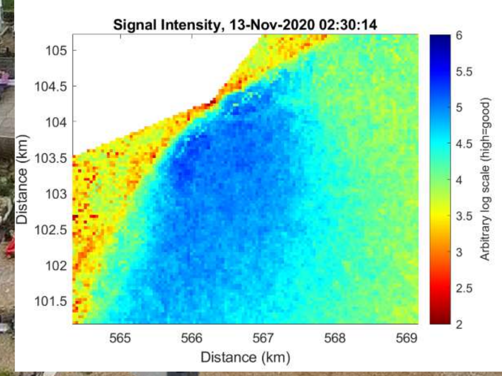
Bathymetry is calculated from a roughly two week series of inputs using a half life decay function to help minimize effects of noise, whilst maintaining stability.



3. SIGNAL INTENSITY

This indicator is an integration of the energy detected on the fitted wave dispersion surface. A greater value indicates a stronger return of energy.

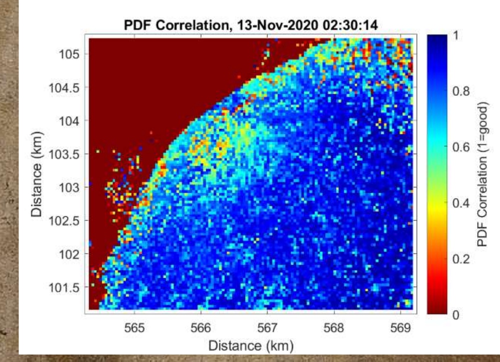
Value range: 0 + (log scale), usually values fall between 2 and 7.



4. PDF CORRELATION

Calculated by comparing the instantaneous probability density function for depth with the non-instantaneous using Pierson's Correlation. Outputs with a high SNR returns a larger number, whilst data with a low SNR return a smaller number.

Value range: 0 (poor) to 1 (good).



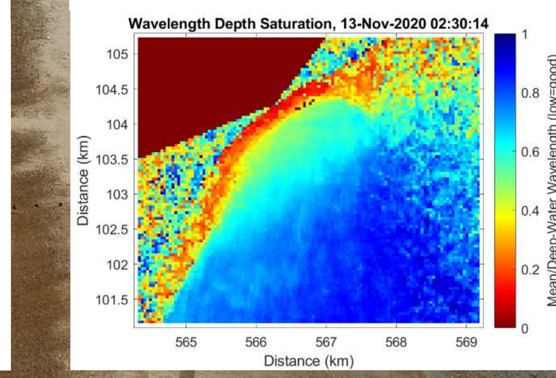
5. DEPTH SATURATION

This indicator indicates how well the waves are 'feeling' the seabed. Calculated as the ratio between the average detected wavelength ($\bar{\lambda}$) is and the deep water wavelength (λ_o), where the deep water wave length is estimated using Airy (1845) linear wave theory:

$$\lambda_o = \frac{9.81 * \bar{T}^2}{2\pi}$$

where $\bar{T}$ is average period.

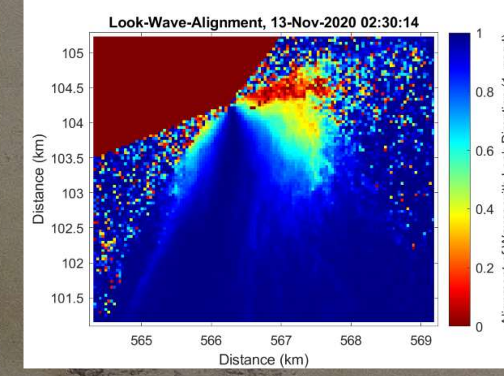
Value range: 0 (good) to 1 (poor). N.B. occasionally this number may exceed 1 as the mean wavelengths and mean wave periods are used.



6. WAVE LOOK ANGLE

Calculated from the cosine of the angle between the radar antenna look direction and the peak direction from the 2D wave image spectra.

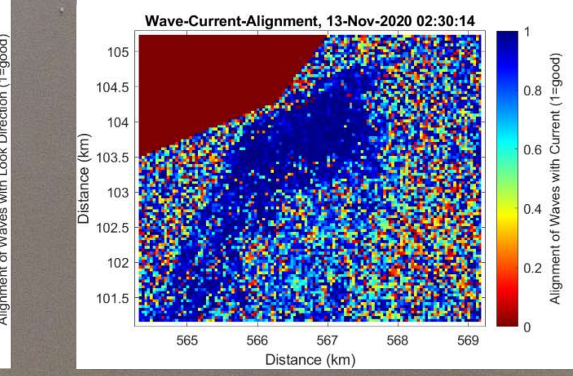
Value range: 0 (poor) to 1 (good).



7 . WAVE CURRENT RELATIVE DIRECTION

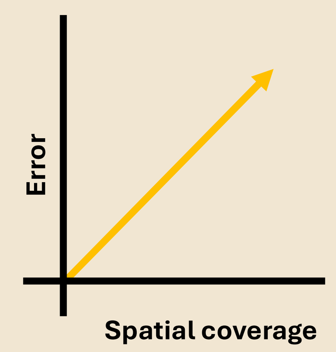
Calculated from the cosine of the angle between the average wave direction and the detected current direction.

Value range: 0 (poor) to 1 (good).



Magnitude of error

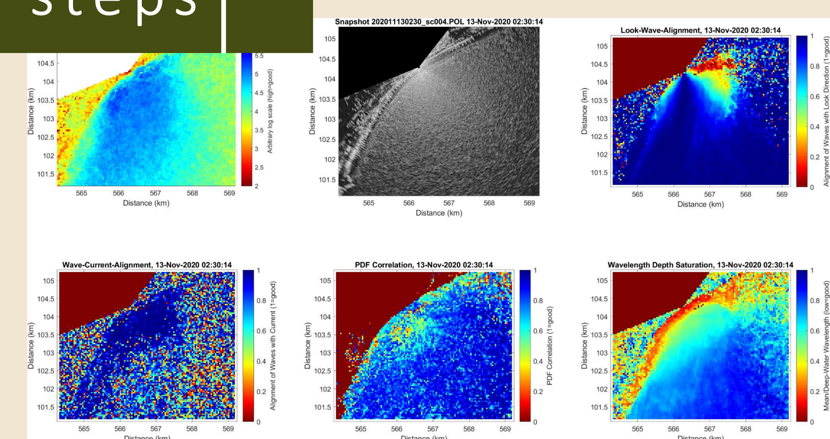
The table below outlines a series of existing studies which aim to quantify the bathymetric elevation error, the spatial footprint, and the resolution. Overall, higher spatial resolution and lower error can be gleaned from analysing a smaller area closer to the radar tower, whilst if a larger area is required, there is a trade-off in terms of error. This is partially due to the wider spread (and thus lower resolution) of the radar signal with distance from the base.



Location	Error	Spatial Footprint	Resolution	Reference
Thorpeness, Norfolk, UK	R^2 = 0.93 90% coverage ± 1 m 60% coverage ± 0.5 m	1,500 m x 2,200 m	40 x 40 m	(Atkinson et al., 2018)
Hilbre Island, Dee Estuary, UK	± 1 m	4 km²	50 x 50 m within 2 km range 100 x 100 m within 4 km range	(Bell, 2008)
New River Inlet, North Carolina, USA	R^2 = 0.68 to 0.96 RMSE = 0.05 to 0.19 m	1.5 km²	25 x 25 m	(Díaz Méndez et al., 2015)
Duck, North Carolina, USA **Benson Beach, Washington, USA**	RMSE = 0.49 m RMSE = 0.35 m	810 m x 1,900 m 1,600 m x 1,800 m	3 x 3m 3 x 3m	(Honegger et al., 2019)
Western coast of Taiwan	Pearson's correlation coefficient = 0.92	3750m	7.5 x 7.5m grid	(Wu et al., 2017)
Fort Macon Coast Guard station at Beaufort, North Carolina	RMS = 1.13 and bias of -0.04m RMS = 1.19 and bias of 0.28m	5km	9m pixel	(Zuckerman and Anderson, 2018)

Current use and next steps

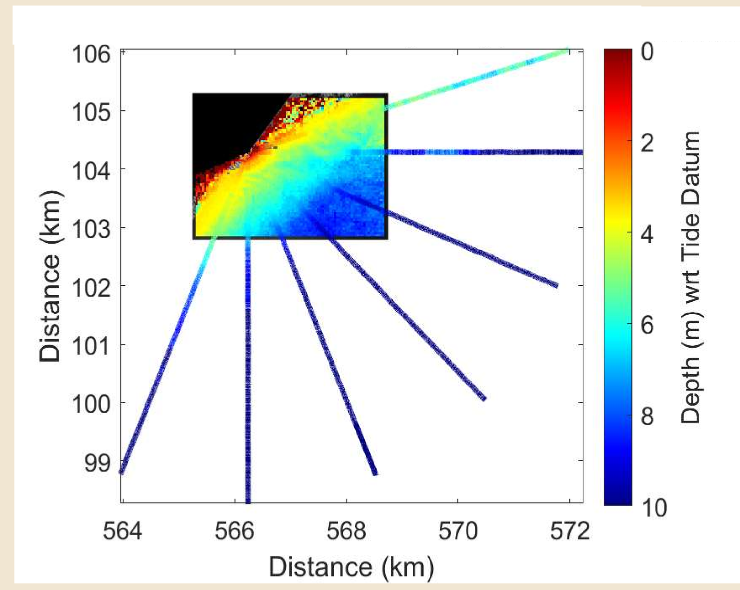
Currently the quality control parameters can be used to **qualitatively describe** the bathymetry data results. They were not designed to be used as an **absolute** measure of good or bad, but instead describe why the data might not be representative of the seabed at any one location.



QC-parameters for manual data 'sense' check

However, our next steps are to explore the use of fuzzy logic to see if we can create an index, combining the quality control parameters. This would allow **quantitive description** of an area and would enable dynamic filtering of an area. This approach is used in other areas of geospatial science, such as habitat suitability mapping, where multiple environmental parameters are combined to identify areas where habitats can be found, or not found.

This will be done by comparing bathymetry data surveyed during the X-Band radar deployment at Pevensey in March 2021.



X-Band radar bathymetry overlaid with SBES survey data

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