Efficient Extraction of Reference Seabed Level from High-Resolution Bathymetric Data Using Percentile Filtering and Parallel Processing

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Presented by

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Abstract

Accurate delineation of the Reference Seabed Level (RSL) is essential for assessing sediment mobility, infrastructure burial risk, and long-term seabed stability in dynamic marine environments.

We present a high-performance tool written in Rust that extracts RSL from large, high-resolution bathymetric datasets using percentile-based sliding window filtering and parallel processing via the Rayon crate.

This method efficiently processes millions of XYZ points at spatial resolutions finer than 0.2 m, enabling rapid analysis across extensive survey areas.

Introduction

- High-resolution multibeam surveys provides detailed images of bedforms and their temporal evolution.
- Marine mobile sediments (ripples, megaripples, sandwaves, and sandbanks) dynamically reshape the seabed because of tidal currents, sediments supply and storms.
- A reference seabed level is essential for measuring changes and guiding the design of pipelines, cables , and offshore installations.
- Continuous monitoring and accurate reference seabed are necessary for ensuring the longevity and safety of marine infrastructure projects.

Why RSL Matters

The reference seabed level is vital for several reasons:

- Design and Construction: Ensuring that infrastructure projects can withstand potential changes in seafloor features.
- Maintenance and Operations: Monitoring the condition of existing structures over time, particularly those located near active mobile sediment areas.
- Environmental Impact Assessments: Evaluating the potential effects of construction activities on the surrounding marine environment.

By establishing a reliable reference seabed level, engineers can make informed decisions that ensure the longevity and safety of seabed infrastructures in dynamic marine environments.

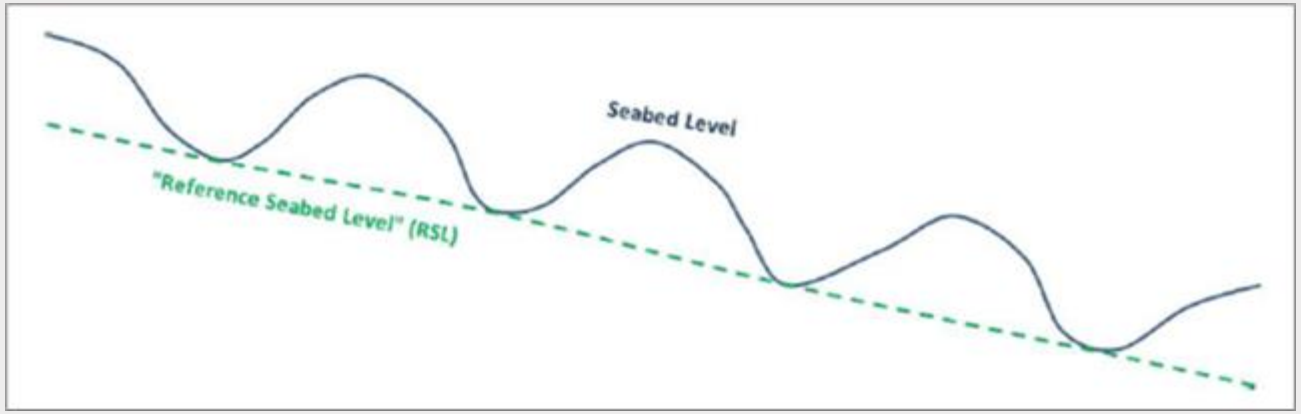


Figure 1. Reference Seabed Level Overview

Percentile Filtering - Conceptual Basis

A percentile-based sliding window filter replaces each point's depth with the p*th* percentile of its local neighbourhood, effectively suppressing mobile bedforms while preserving stable seabed morphology. The two-pass approach mitigates edge effects by reapplying the percentile calculation after the first pass.

$$\mathcal{Z}_{filtered}(x) = percentile_p\left(\{\mathcal{Z}_i | x_i \in N(x)\}\right)$$

Where:

$\mathcal{Z}_{filtered}(x)$: *represents the filtered depth values at point* $\varkappa$*. It is the result of applying the percentile filter to the neighbourhood around* $\varkappa$*.*

$\{\mathcal{Z}_i | x_i \in N(x)\}$: *represents the set of all depth values within the neighbourhood of point* $\varkappa$*. The neighbourhood is defined as a region centered at* $\varkappa$*, typically with a window size r.*

$percentile_p$: *The function computes the* pth *percentile at the set of depth values within the neighbourhood.*

Choosing a lower percentile (e.g., 10 %) effectively selects the deepest depths within the window, thereby suppressing shallow mobile features such as , ripples, megaripples, and sandwaves. Conversely, higher percentiles retain more of the surface expression.

Computational Optimizations

The key to handling high resolution data is efficient neighbourhood construction and percentile filtering.

- Spatial Indexing: k-d tree was used to index all points allowing for rapid retrieval of neighbours within window of size r.
- Approximate Percentiles: Quick select algorithm for large windows.
- Parallelism: Rayon crate distributes operations across all available CPU cores. Because each filtered value depends only on local data, there are no cross dependencies beyond the initial k-d tree construction.
- With these optimizations, a dataset of 10 million points at 0.2 m resolution can be processed in under a few minutes on a modern multi-core computer.

Parameter Sensitivity

Parameters percentile (p) and window size (r) significantly affect the output. Users can perform a sensitivity test to calibrate optimal configurations for different geomorphological contexts.

Parameter	Effect on Output	Typical range
Percentile p	Controls aggressiveness of bedform suppression	5 – 30% for megaripples and sandwaves rich areas 30 - 50% where seabed features needs to be preserved
Window size r (m)	Determine spatial scale of filtering	1 – 10 m for fine-scale features; >10 m for large scale sandwaves and sandbanks

Advantages Over Traditional Methods

Features	Percentile Filter	Gaussian Smoothing	Manual Picking
Preservation of Topography	High (local percentile resists over-smoothing)	Low (kernel blurs edges)	Variable (depends on operator)
Suppression of Mobile Bedforms	Tuneable via p and r	Limited (requires careful kernel design)	Manual, time-consuming
Scalability	Linear with data size; parallelizable	Similar but often requires down-sampling	Not scalable
Computational Cost	Minutes on commodity hardware	Minutes to hours depending on kernel	Hours to days

Method Workflow

Preprocessing

Checks to ensure the data is in the correct format readable by the tool.

Analysis of the seabed features present.

Parameter Calibration

Using a subset to evaluate percentile filter parameters (p, r) and select optimal settings.

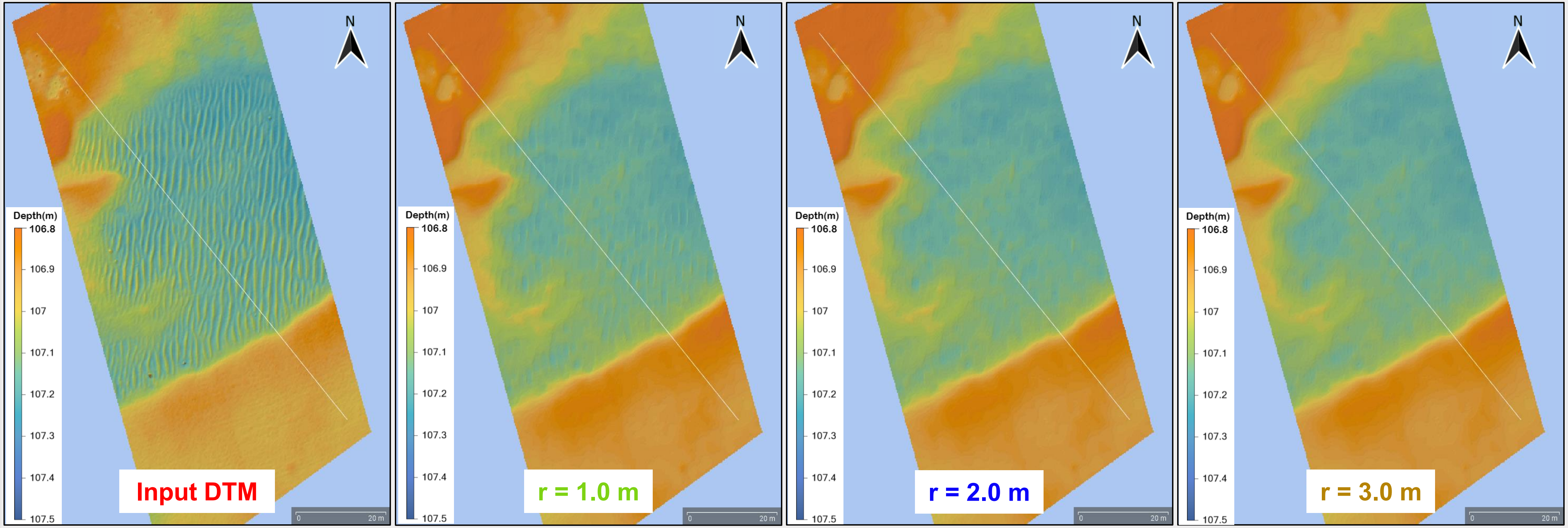
Percentile Filtering

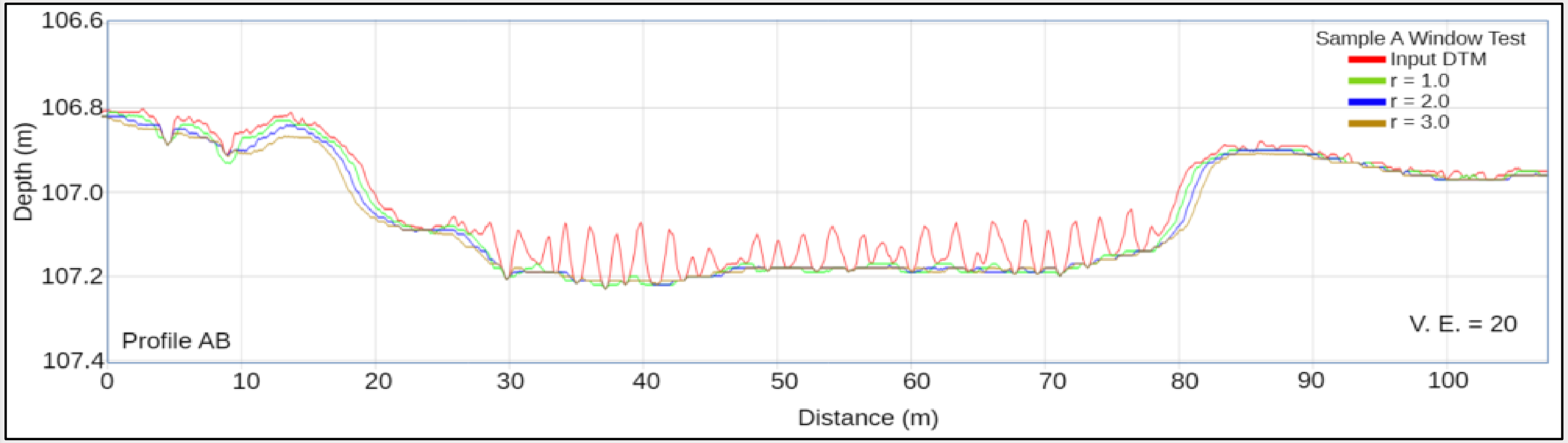
Parallel processing using Rayon for efficient computation

Conversion of Filtered XYZ

Conversion of Filtered XYZ to raster for Display and Quality control

Parameter Test: Sample Data A. Window (r)



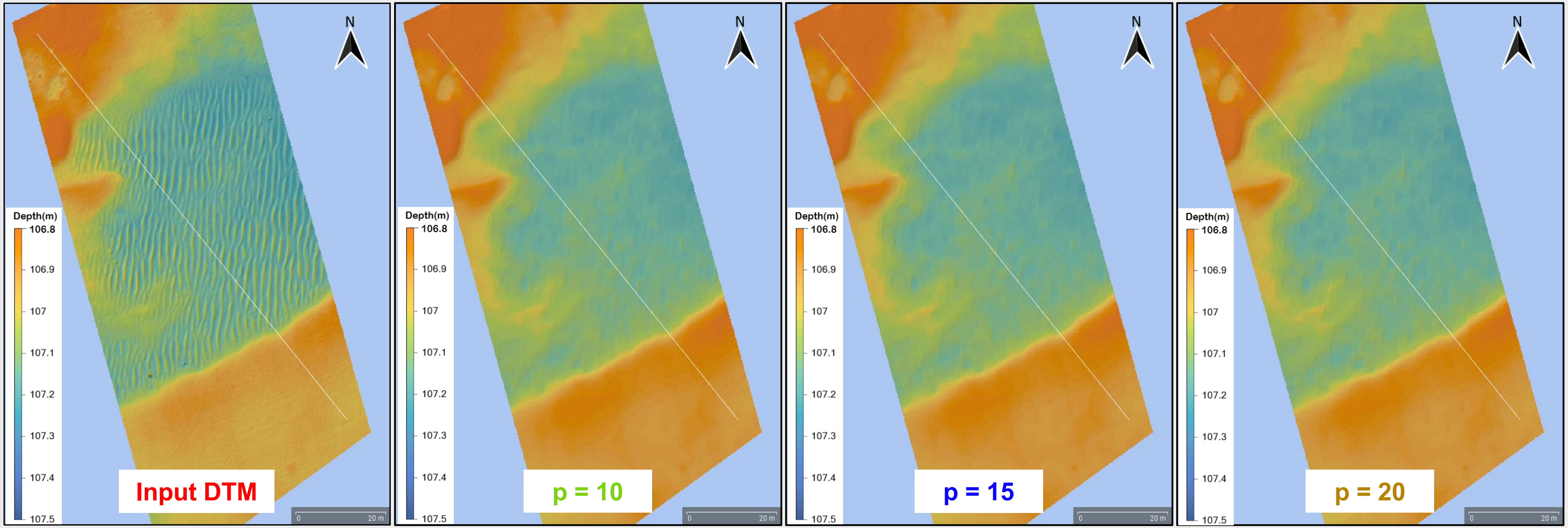


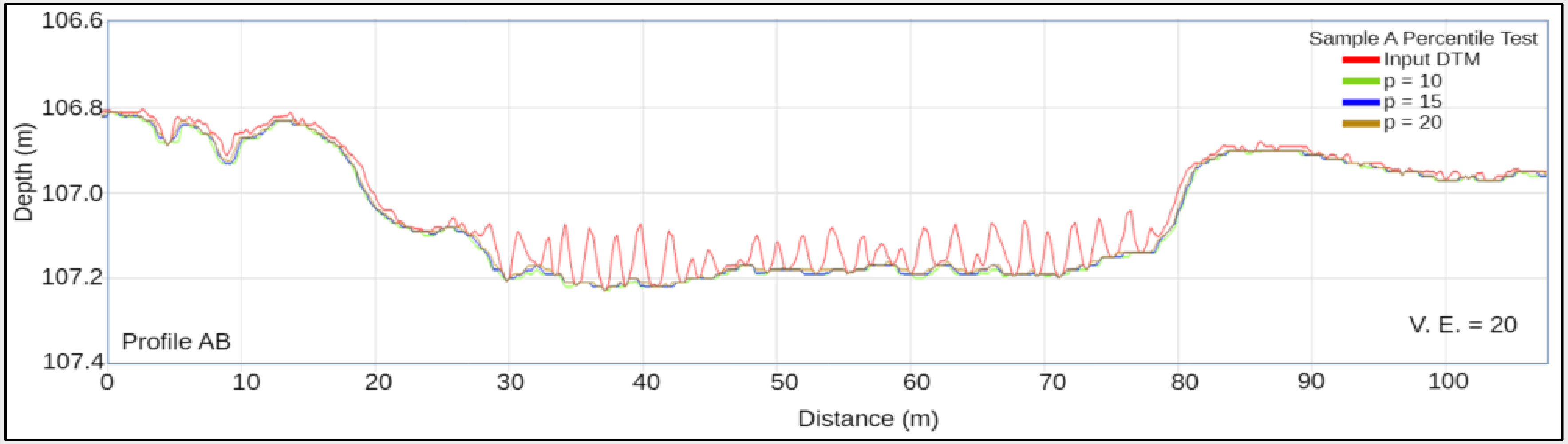
Sample Data A consist mainly megaripples having;

- Amplitudes ranging from 0.1m to 0.16m.
- Wavelength between 1.0m to 2.6m

Parameter Test
r(m) 1.0 | 2.0 | 3.0

Parameter Test: Sample Data A. Percentile (p)



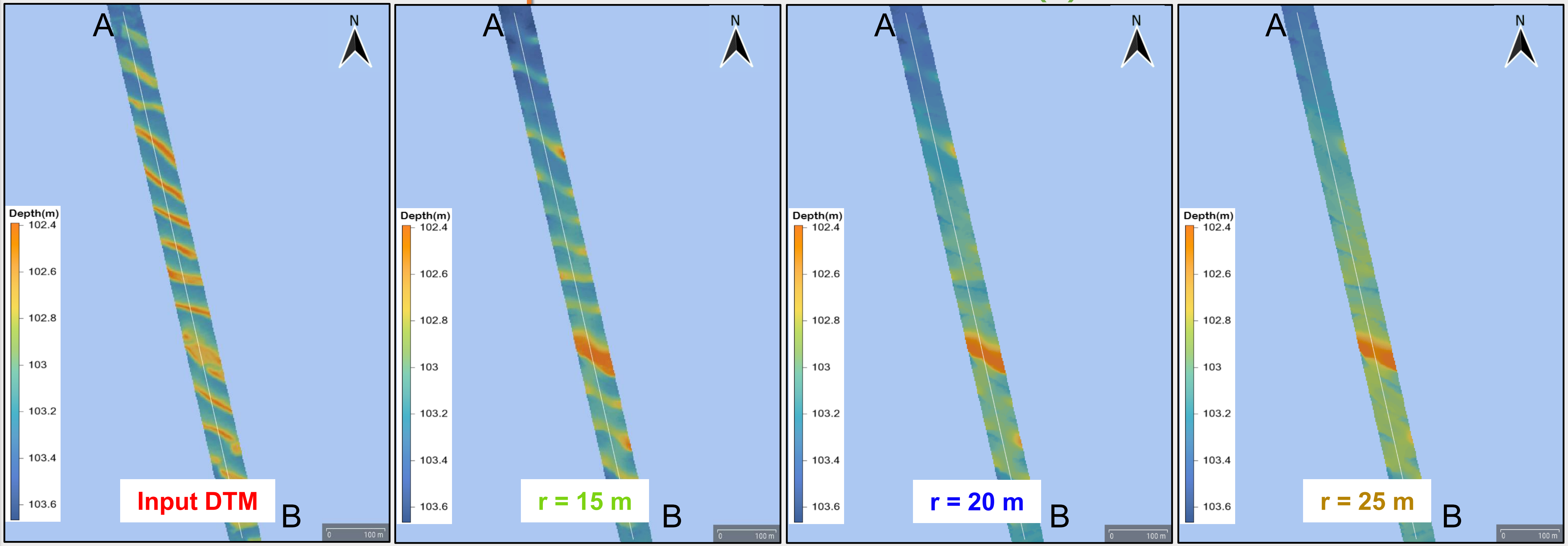


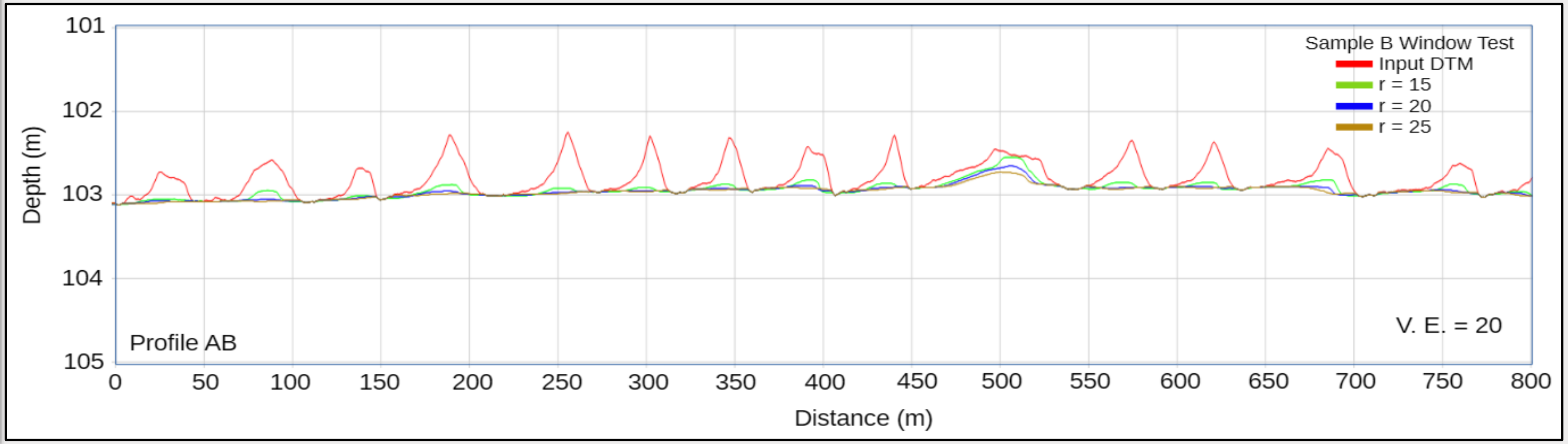
Sample Data A consist mainly megaripples having;

- Amplitudes ranging from 0.1m to 0.16m.
- Wavelength between 1.0m to 2.6m

Parameter Test
p: 10 | 15 | 20

Parameter Test: Sample Data B. Window (r)



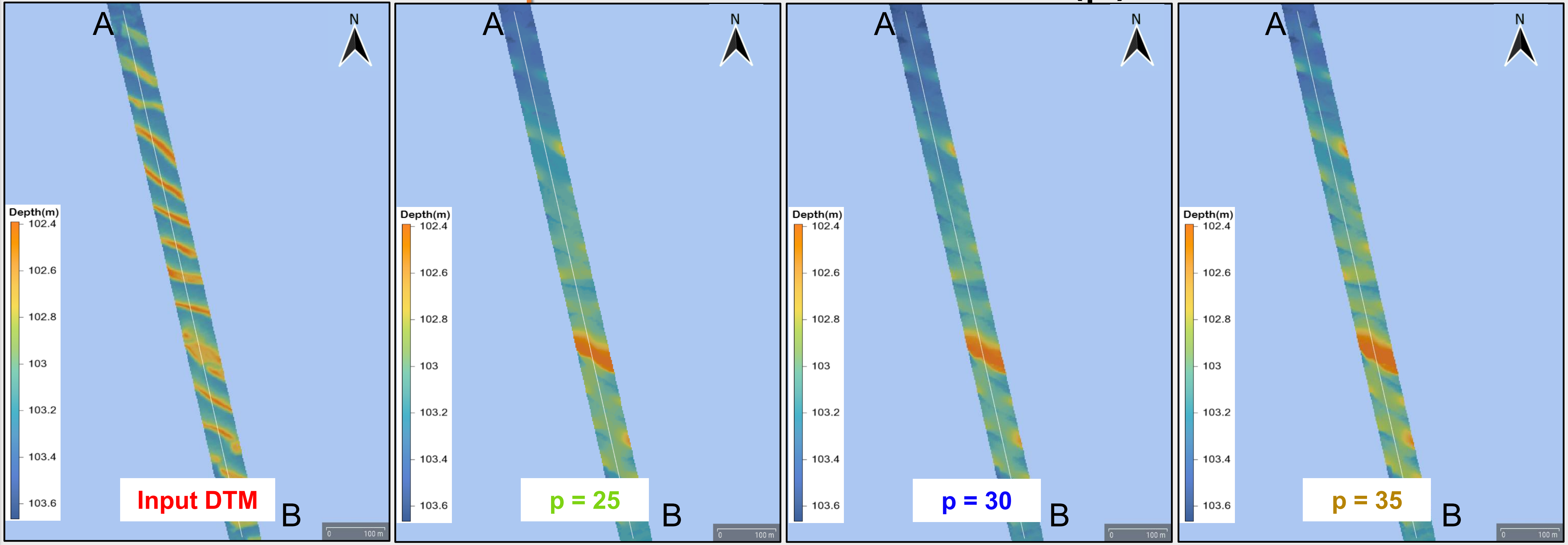


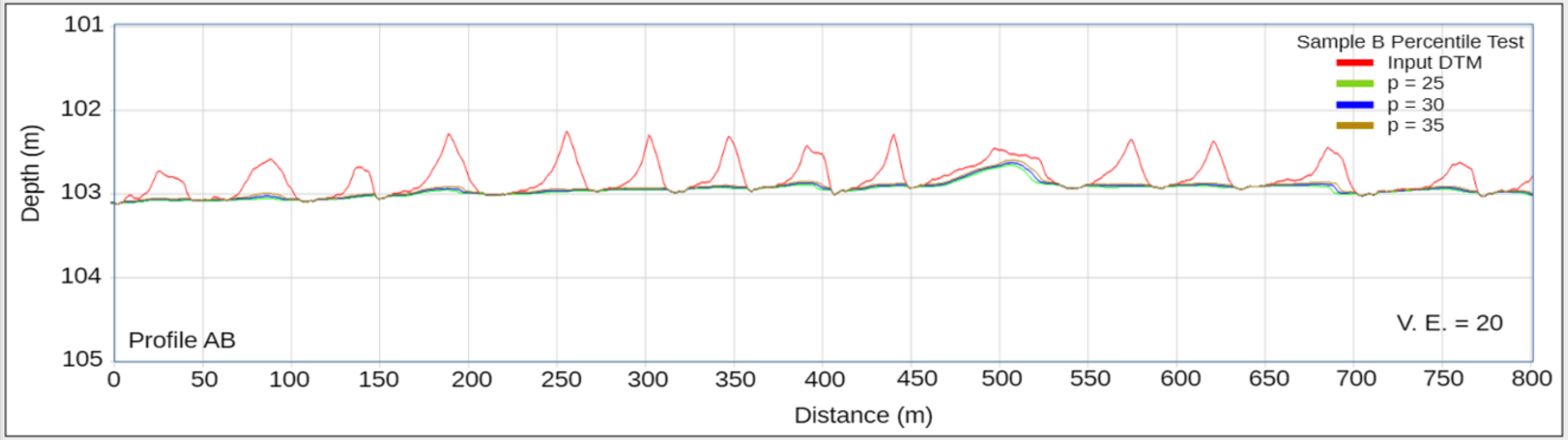
Sample Data B consist mainly sandwaves and Sand Ridges having;

- Amplitudes ranging from 0.1m to 0.7m.
- Wavelengths up to 65m

Parameter Test
r(m) 15 | 20 | 25

Parameter Test: Sample Data B. Percentile (p)



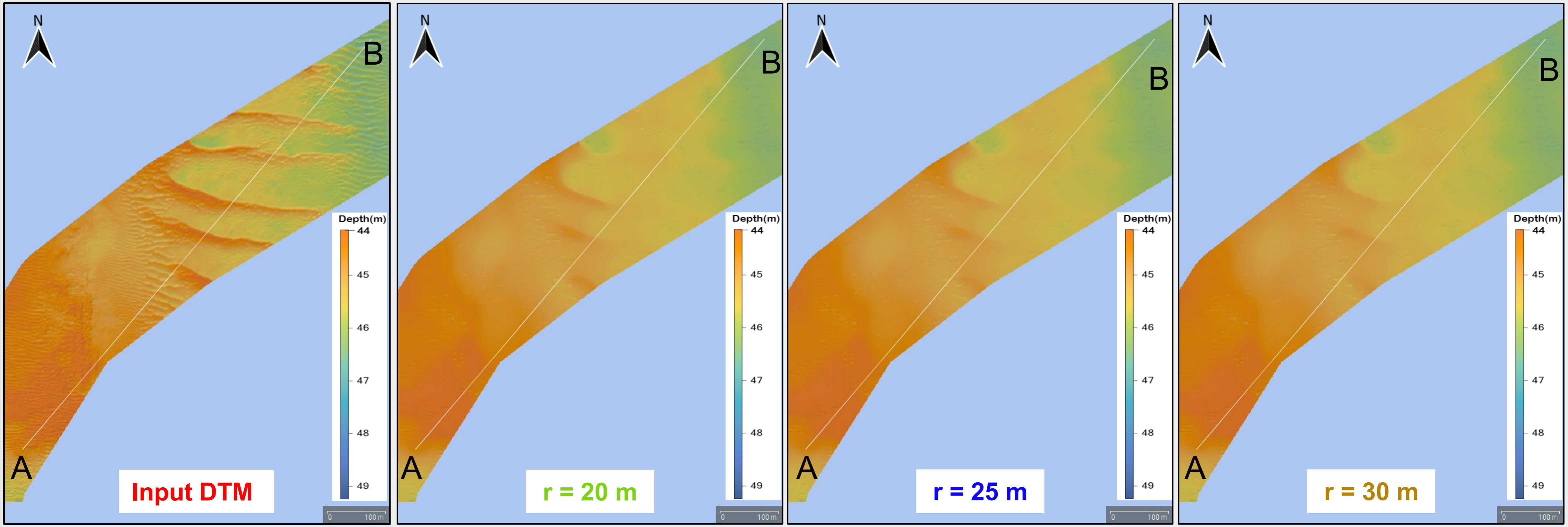


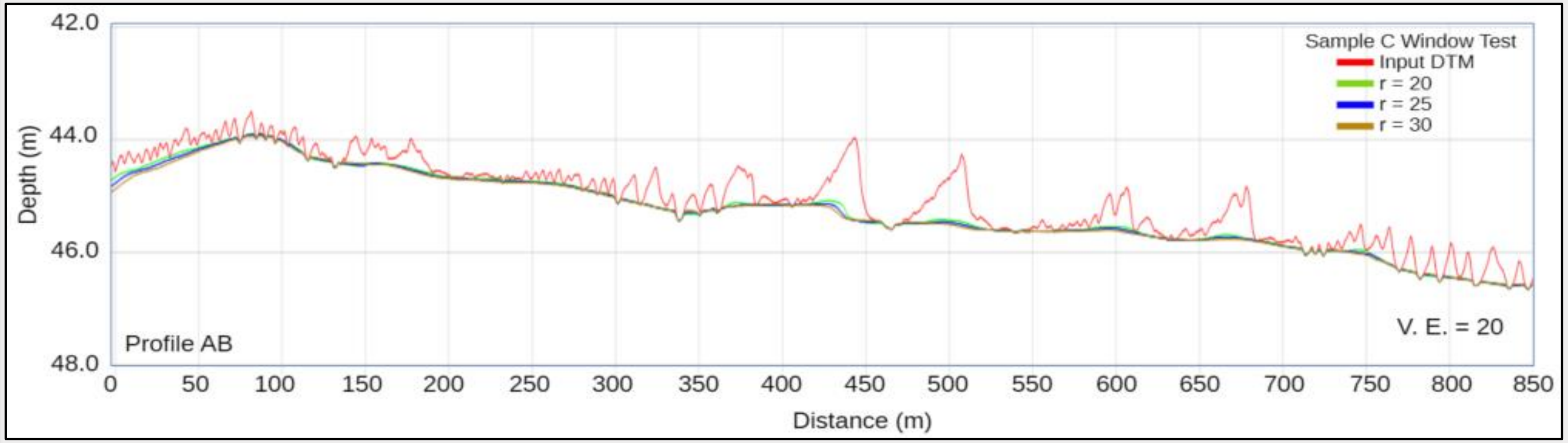
Sample Data B consist mainly sandwaves and Sand Ridges having;

- Amplitudes ranging from 0.1m to 0.7m.
- Wavelengths up to 65m

Parameter Test
p 25 | 30 | 35

Parameter Test: Sample Data C. Window (r)



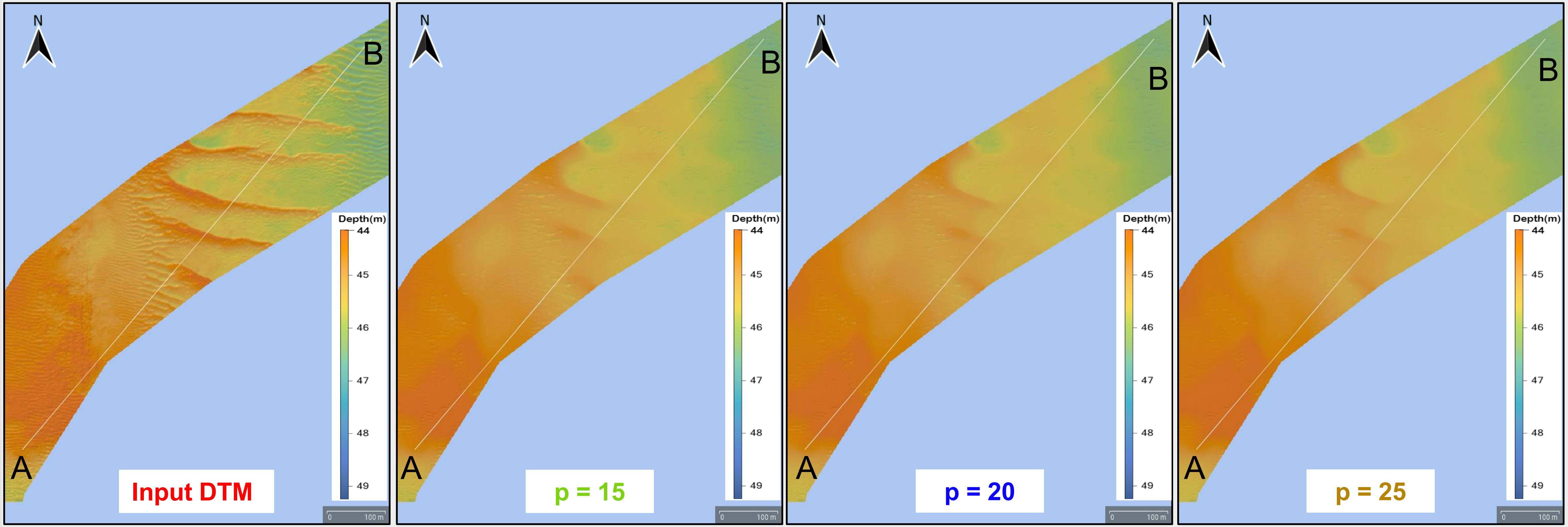


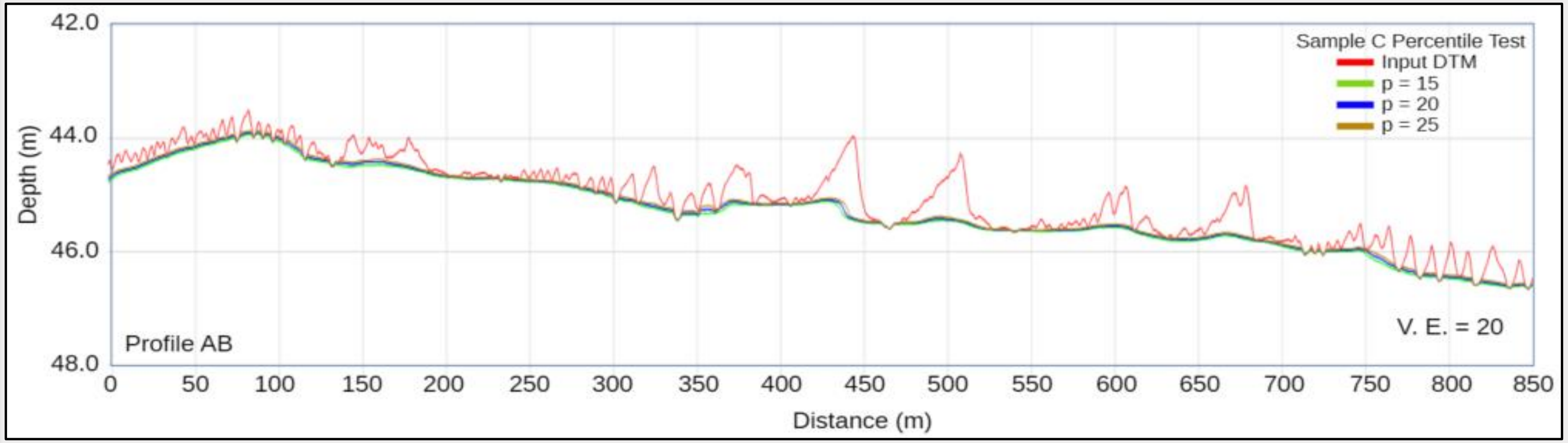
Sample Data C consist mainly sandwaves and megaripples;

- Amplitudes ranging from to 0.1m to 1.47m.
- Wavelengths up to 67m

Parameter Test
r(m) 20 | 25 | 30

Parameter Test: Sample Data C. Percentile (p)





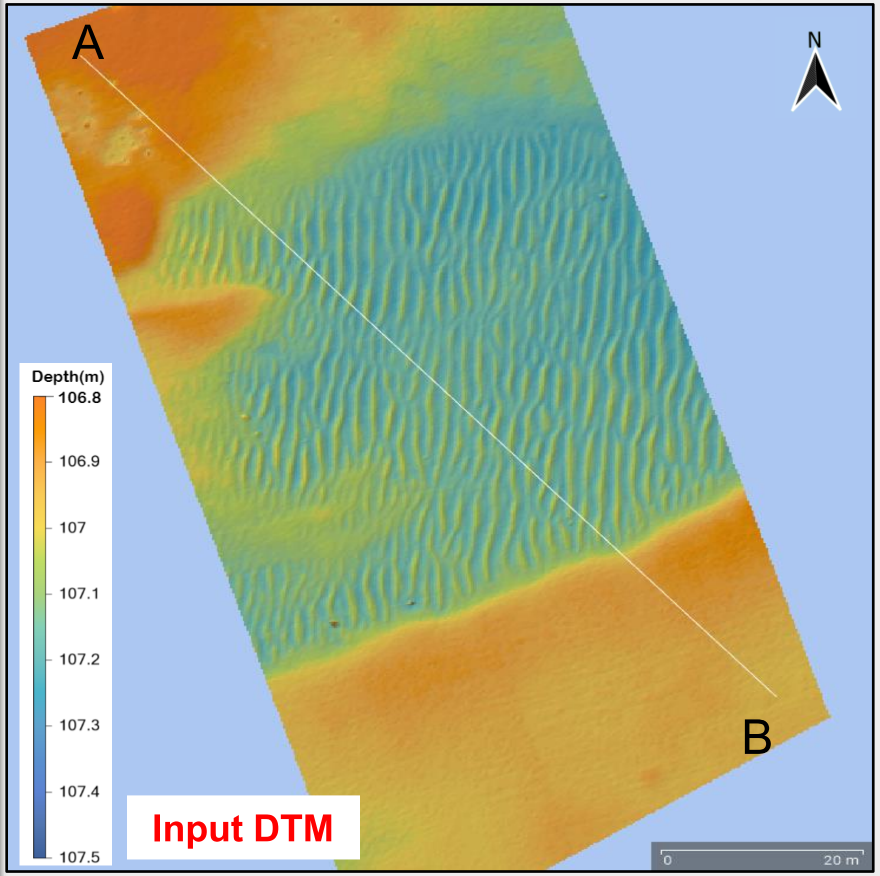
Sample Data C consist mainly sandwaves and megaripples;

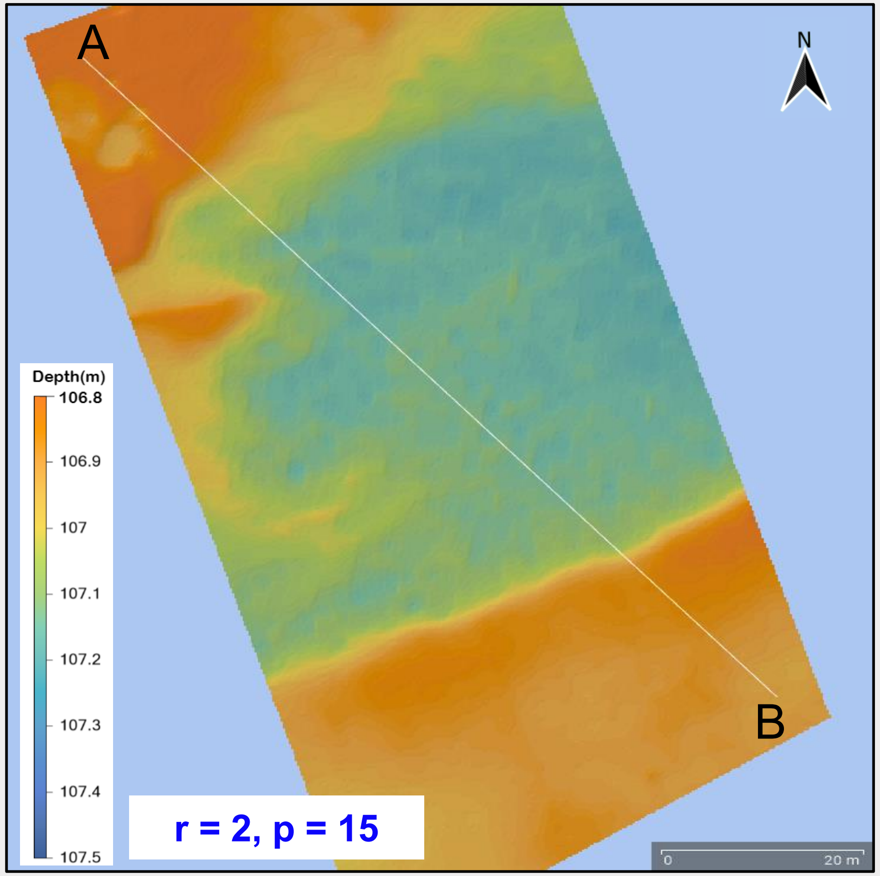
- Amplitudes ranging from to 0.1m to 1.47m.
- Wavelengths up to 67m

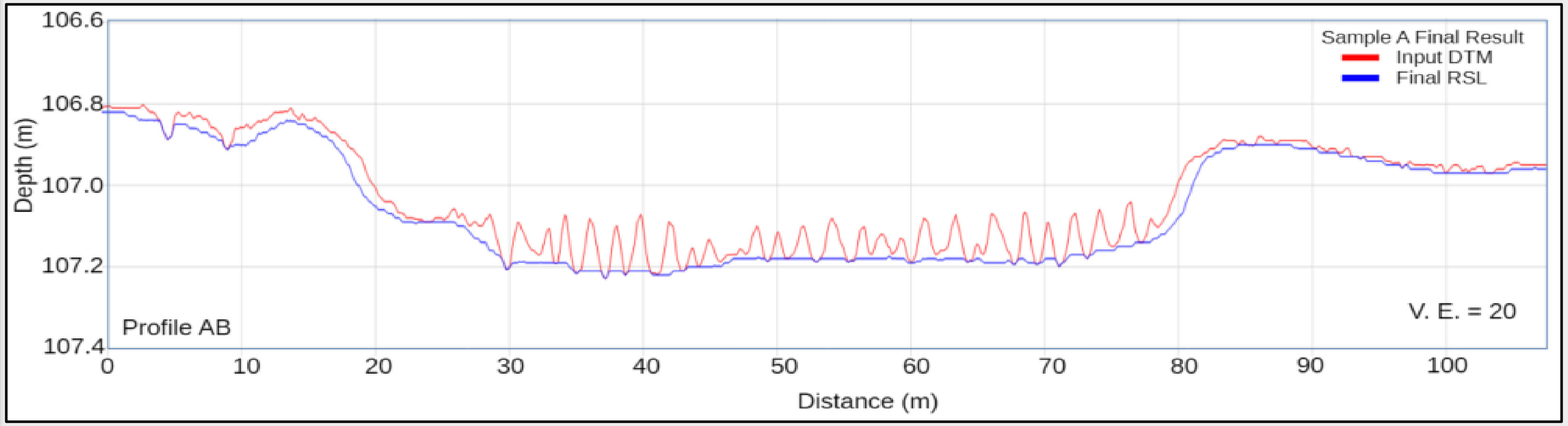
Parameter Test

p 15 | 20 | 25

Results - Data Sample A 1/2







The Reference Seabed Level extraction tool was applied to Sample A DTM (left image) from the Irish Sea.

The result (right image) shows that the tool effectively removed mobile seabed features, predominantly megaripples, while preserving the topography of the seabed.

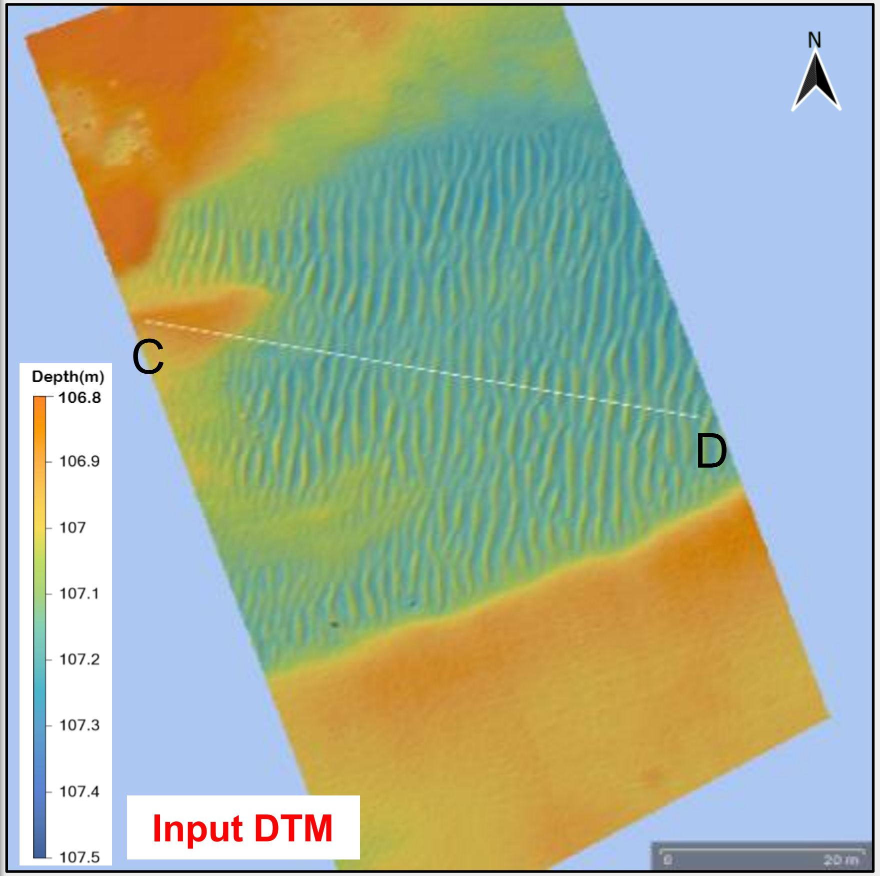
The depth distance plot (bottom image) displays profile AB taken across the megaripples seabed feature.

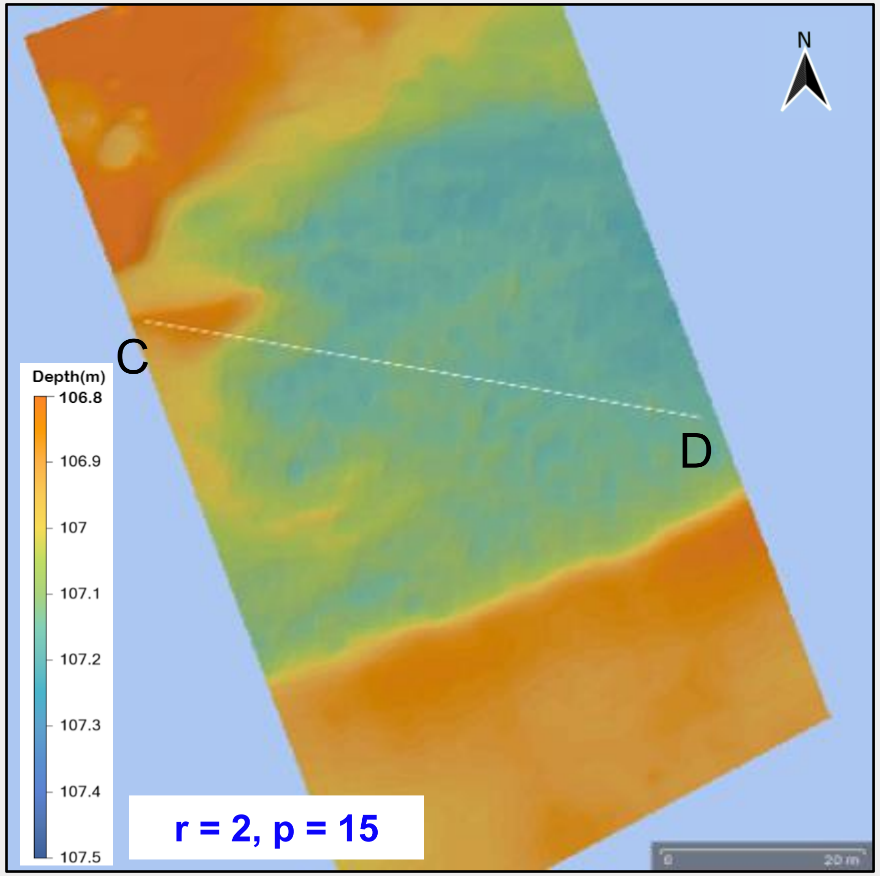
Input DTM is shown in **red**, and the **Final RSL** is displayed in **blue**.

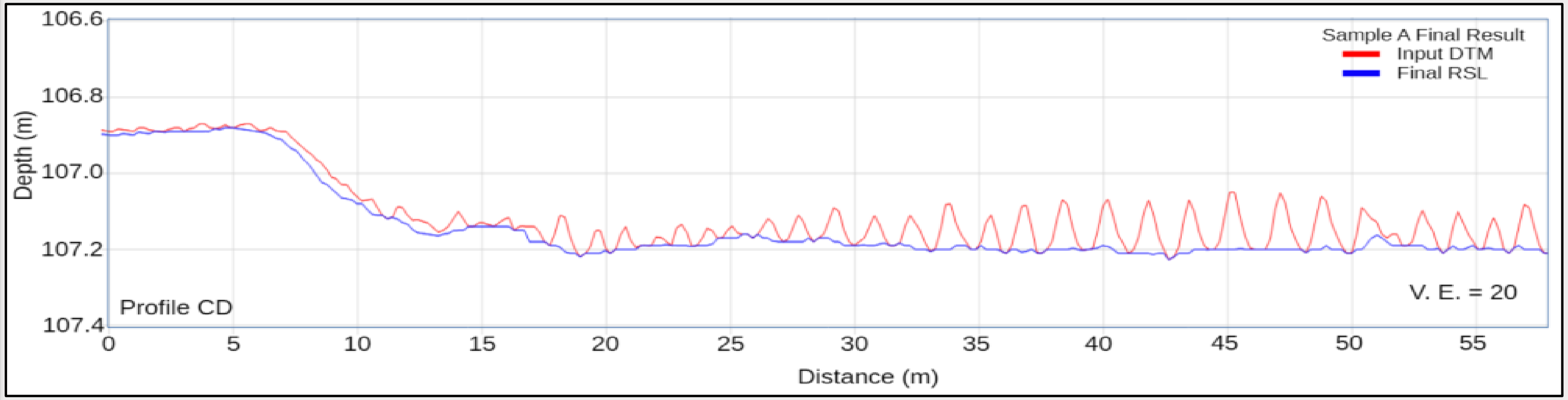
Final parameters for the analysis are as follows:

- Window r = 2
- Percentile filter p = 15

Results - Data Sample A 2/2







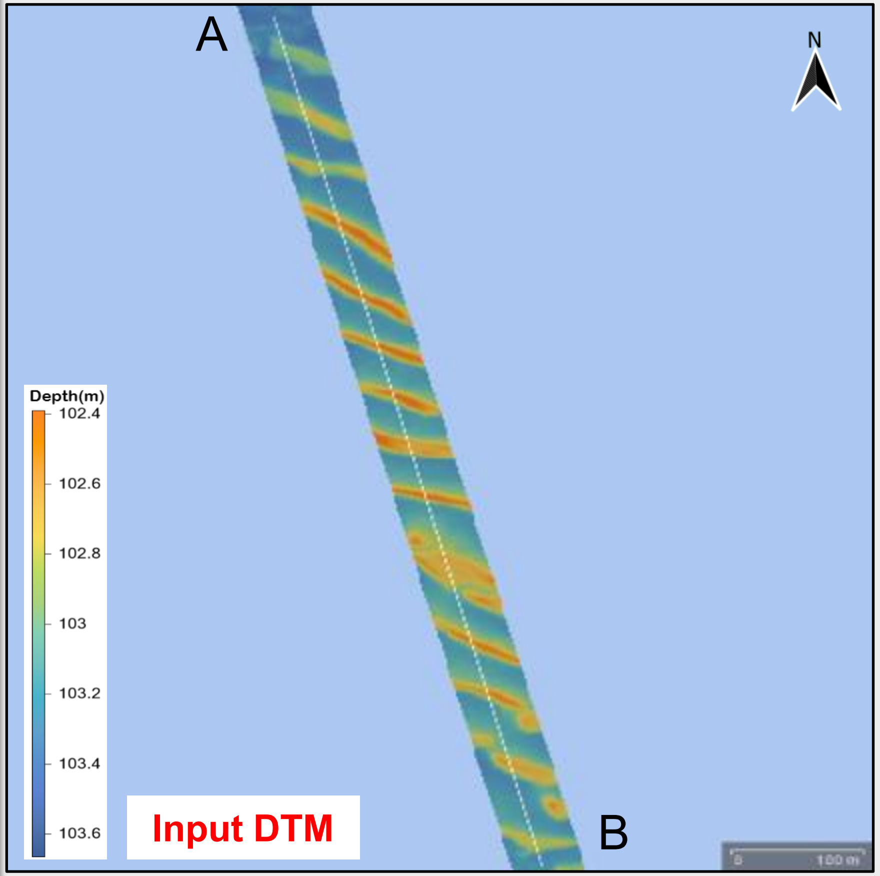
The depth distance plot (bottom image) displays profile CD taken across the megaripples seabed feature.

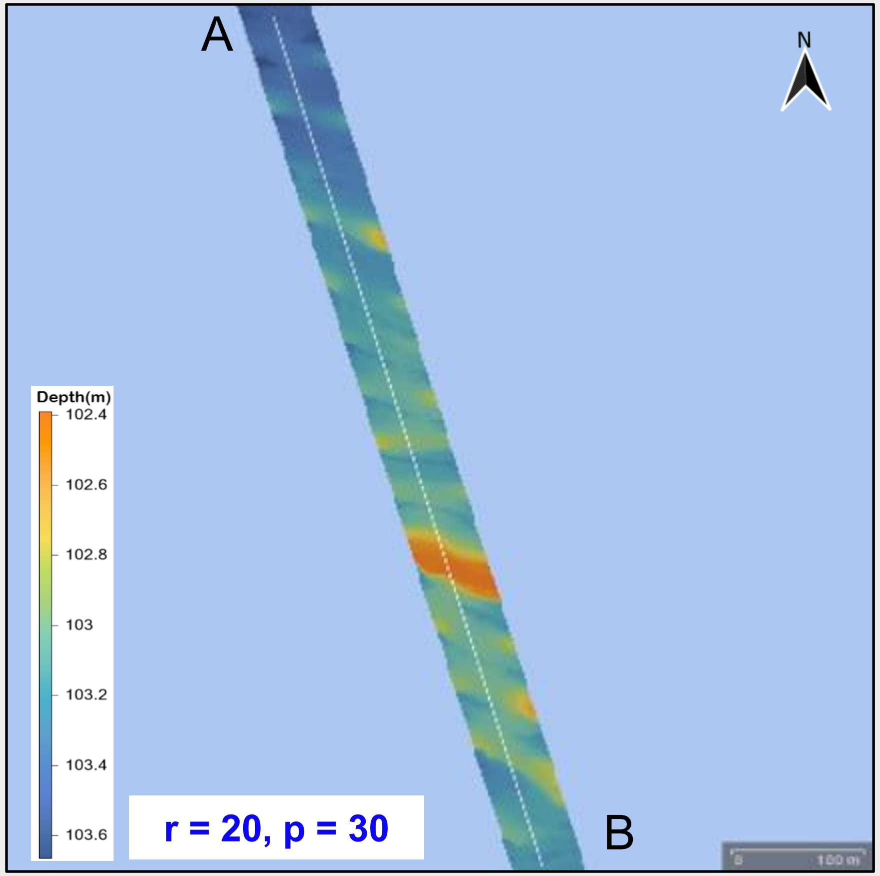
Input DTM is shown in **red**, and the **Final RSL** is displayed in **blue**.

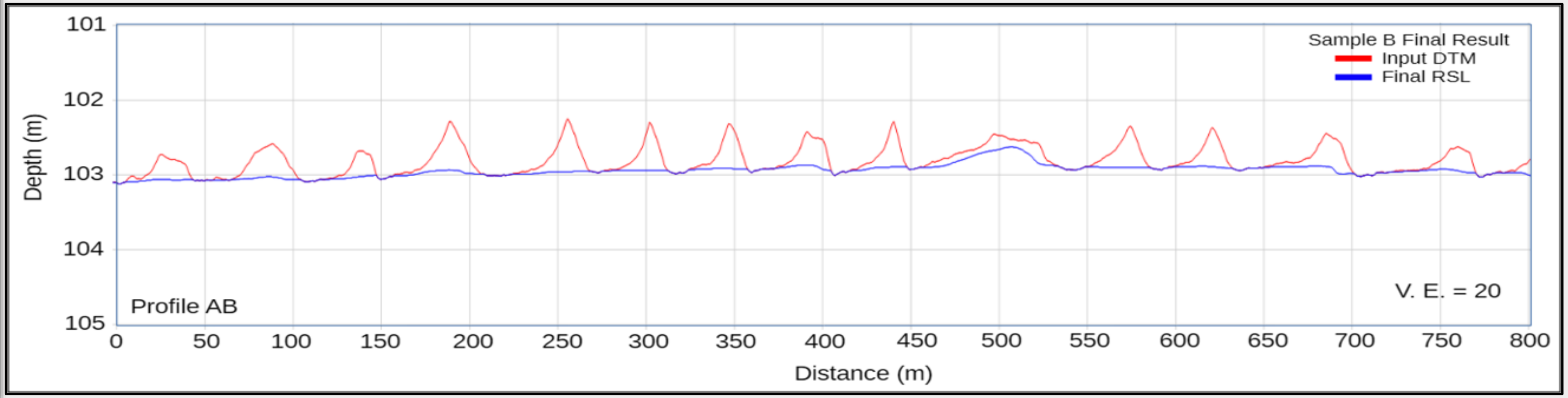
Final parameters for the analysis are as follows:

- Window r = 2
- Percentile filter p = 15

Results - Sample Data B







The Reference Seabed Level (RSL) extraction tool was applied to Sample B data (left image) from the Irish Sea.

The resulting image on the right shows that the tool effectively suppresses mobile seabed features primarily sandwaves and occasional sandbanks while preserving the underlying seabed topography.

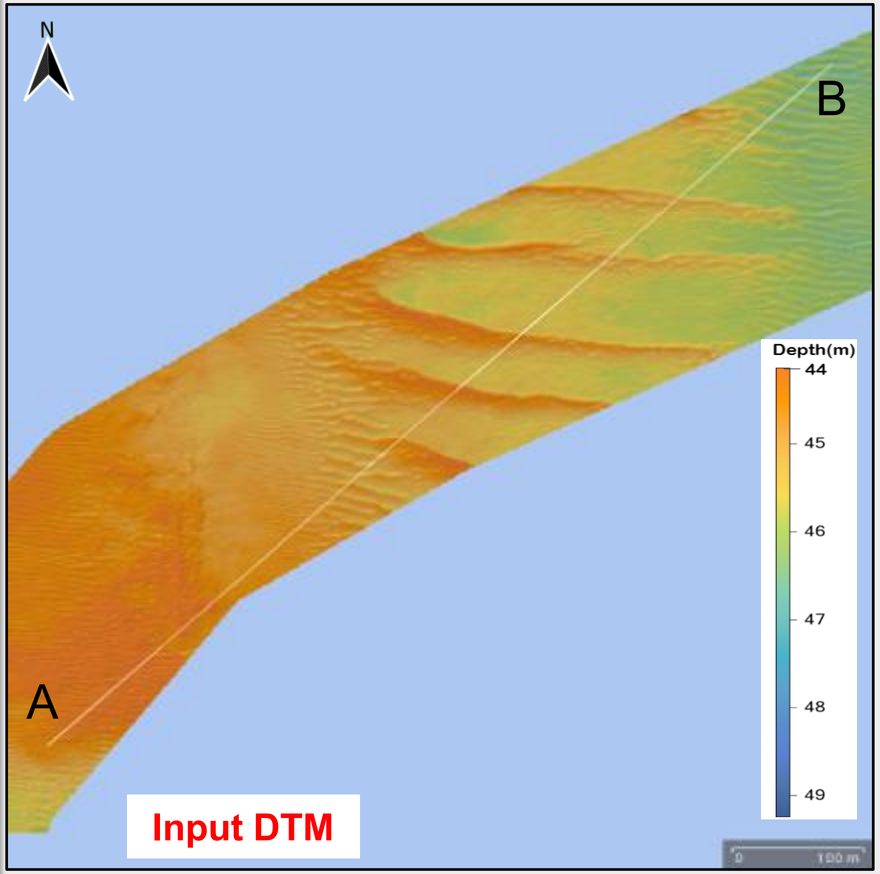
The depth-distance plot at the bottom displays profile AB, which traverses both sandwaves and other seabed features.

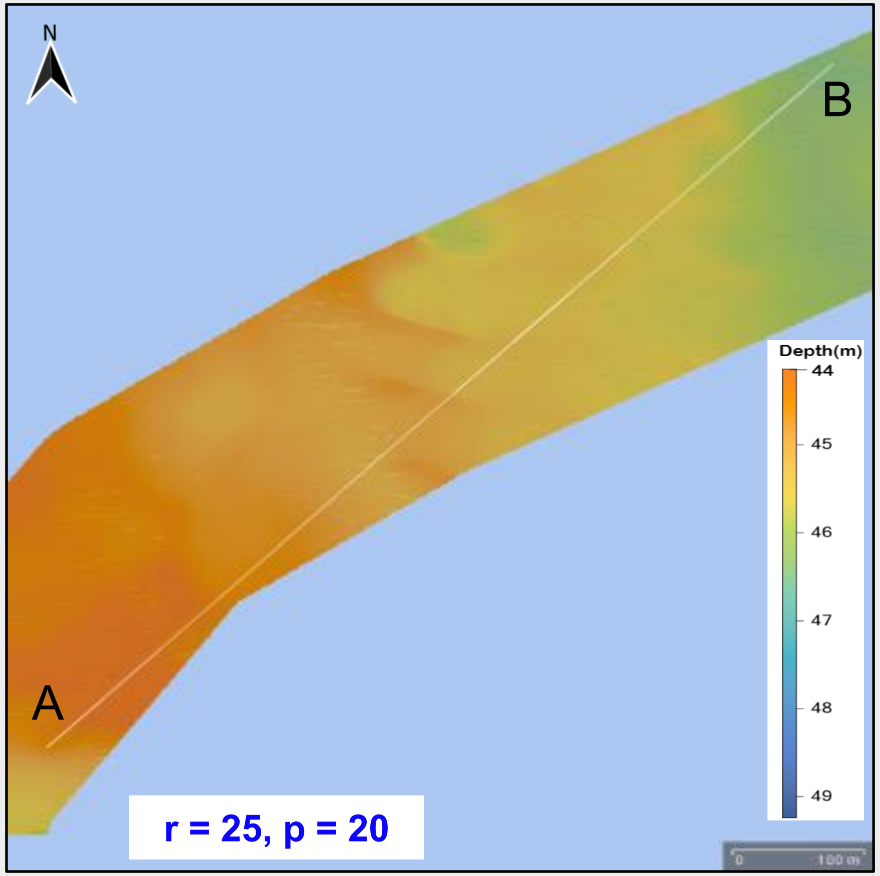
Input DTM is shown in **red**, and the **Final RSL** is displayed in **blue**.

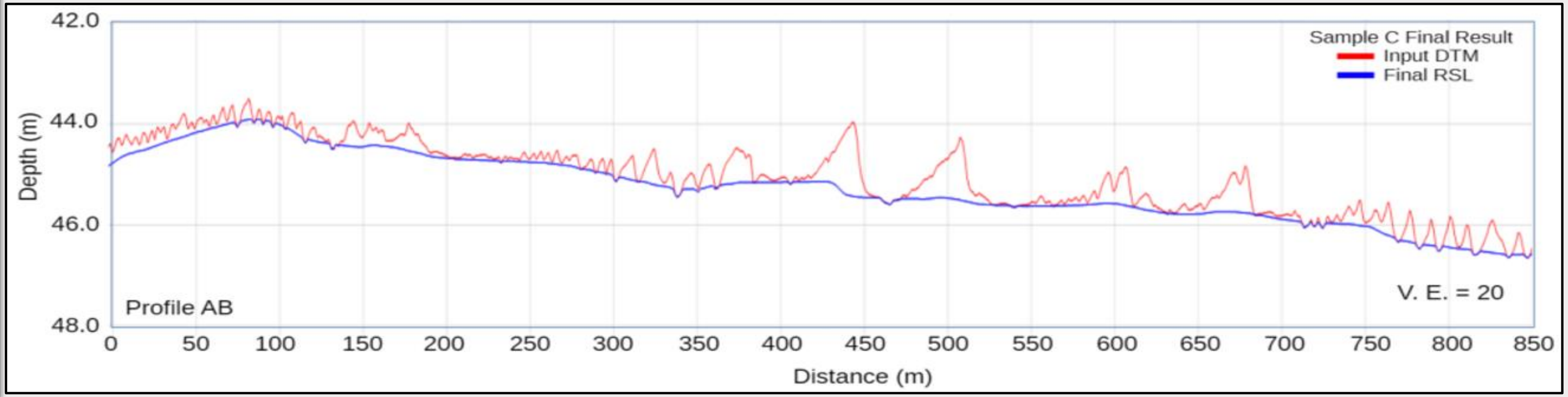
Final parameters for the analysis are as follows:

- Window r = 20
- Percentile filter p = 30

Results - Sample Data C







The Reference Seabed Level extraction tool was applied to Sample C data from the Southern North Sea (left image).

The resulting image on the right demonstrates that the tool effectively suppressed mobile seabed features mainly sandwaves and megaripples while preserving the underlying seabed topography.

The depth-distance plot at the bottom shows profile AB, which traverses the megaripples and sandwaves features.

Input DTM is shown in **red**, and the **Final RSL** is displayed in **blue**.

Final parameters for the analysis are as follows:

- Window r = 25
- Percentile filter p = 20

Conclusion

The percentile-based RSL extraction method offers an efficient solution for extracting the reference seabed levels which is important for seabed mobility, infrastructure burial risk and seabed stability assessment in dynamic marine environments.

Results obtained shows the tool effectively extract the RSL while preserving the topography of the seabed.

The tool is scalable to millions of points at sub-meter resolution, enabling rapid analysis across extensive survey areas.

Acknowledgement

Special thanks to Next Geosolutions for providing the opportunity and resources that made this analysis – focused on determining the reference seabed level – possible.

I would also like to thank the Hydro 2025 Conference organizing committee for selecting this paper for presentation.

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