# Quantifying rhythmic bedforms from bathymetric surfaces

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RESOURCE MANAGEMENT ASSOCIATION

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## INTRODUCTION

Recent advances in the quality and affordability of geophysical mapping technologies means a resurgence in quantitative analysis of subaqueous environments is underway [1-4]. Application of these measurements is well suited to a range of applications, including: sediment transport; and hydrodynamic modelling; habitat mapping; geological sequence interpretation; and bedform classification. Analysis is split into **spectral** and **spatial** approaches. The former gives **orientation**, **wavelength** and **height**; the latter, height only. **Discrete Fourier Transforms** (DFT) [4] are used, with different **windowing** and **filtering** techniques, to **quantitatively** and **objectively** measure bedform height, orientation and wavelength. **Spatial** analysis [3,4] recovers bedform heights through the identification of crests and troughs.

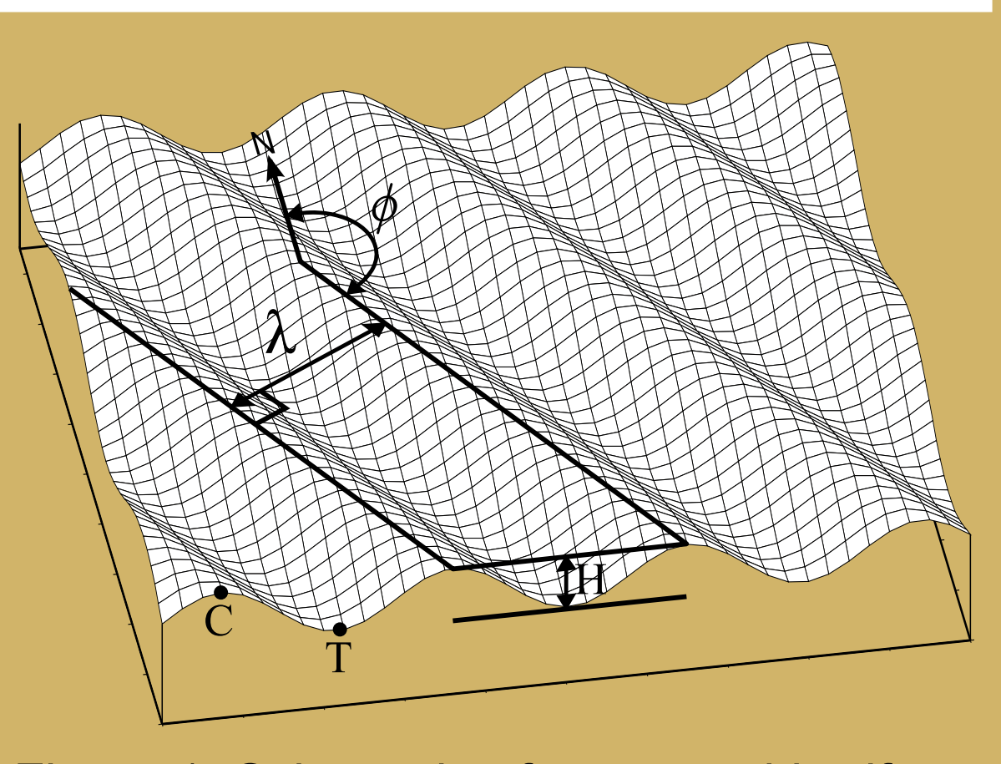
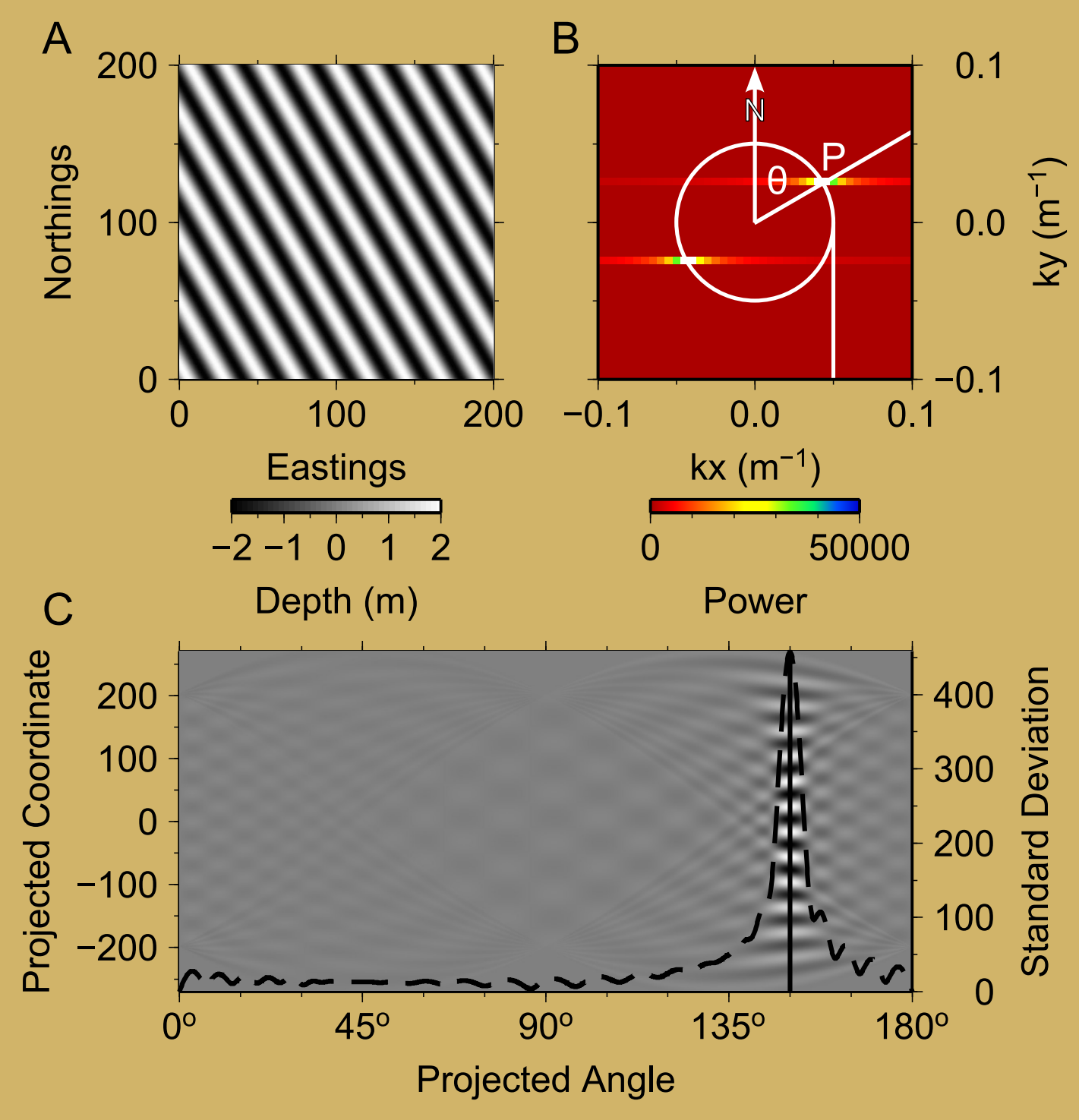


Figure 1: Schematic of measured bedform characteristics used for classification. Wavelength (λ), orientation from North parallel to bedform crest (ϕ), height (H), crest (C), and trough (T).

## RESULTS I



- Spectral analysis of the synthetic surface in Figure 2A allows measurement of wavelength (λ), orientation (ϕ) and height (H) from the position of the peak spectral power (P) and its magnitude ($S_p$) in Figure 2B.
- Spatial analyses identify peaks and troughs from raw spatial data (Figure 2A), or **bandpass filtered** spectra, from which heights are calculated.
- **Uncertainties** can be calculated based on spectral resolution and potential variability in the source data.
- Radon Transform (Figure 2C) projects the raw data through 180° to identify crest orientation.

Figure 2: A. Synthetic seabed with λ=20 m, ϕ=150° (therefore θ=60°) and H=4 m; B. Spectrum of A with maximum power at P. Crest orientation (ϕ) measured as perpendicular to the line from the origin through P.; C. Radon transform with overlaid standard deviation used to identify crest parallel maximum energy.

## RESULTS II

- Application each technique to a simple observed seabed tests its suitability for further use.
- The DFT with a spatial Flat Top window and the spatial 2nd Derivative under-report height. The 2nd Derivative and zero-crossing analyses of the Butterworth filtered surfaces are in good agreement with one another and heights from an empirical relationship [5].
- DFT picked orientations agree with each other, but the Radon Transform has picked a stronger signal from the misaligned swaths.
- Further analysis is carried out with DFT orientation and wavelength. Heights are obtained from the zero-crossing of the inverse Butterworth filtered spectrum.

| | |
|---|---|
| **Height (m)** | |
| **1-D Profile** | **0.3** |
| **RMS** | **0.6** |
| **2nd Derivative** | **0.1** |
| **DFT and Flat Top Window** | **0.3** |
| **2nd Derivative of Butterworth** | **0.6** |
| **Zero-crossing of Butterworth** | **0.6** |
| **Predicted [5]** | **0.4** |
| **Manual** | **~ 0.6** |
| **Orientation (°)** | |
| **DFT Weighted Mean** | **151.1** (+1.0, -1.0) |
| **Pre-whitened DFT weighted mean** | **148.7** (+1.0, -1.0) |
| **Radon Transform** | **68.5** |
| **Manual** | **~ 150** |
| **Wavelength (m)** | |
| **DFT Weighted Mean** | **10.1** (+0.2, 0.2) |
| **Pre-whitened DFT weighted mean** | **9.5** (+0.2, -0.2) |
| **Manual** | **~ 10** |

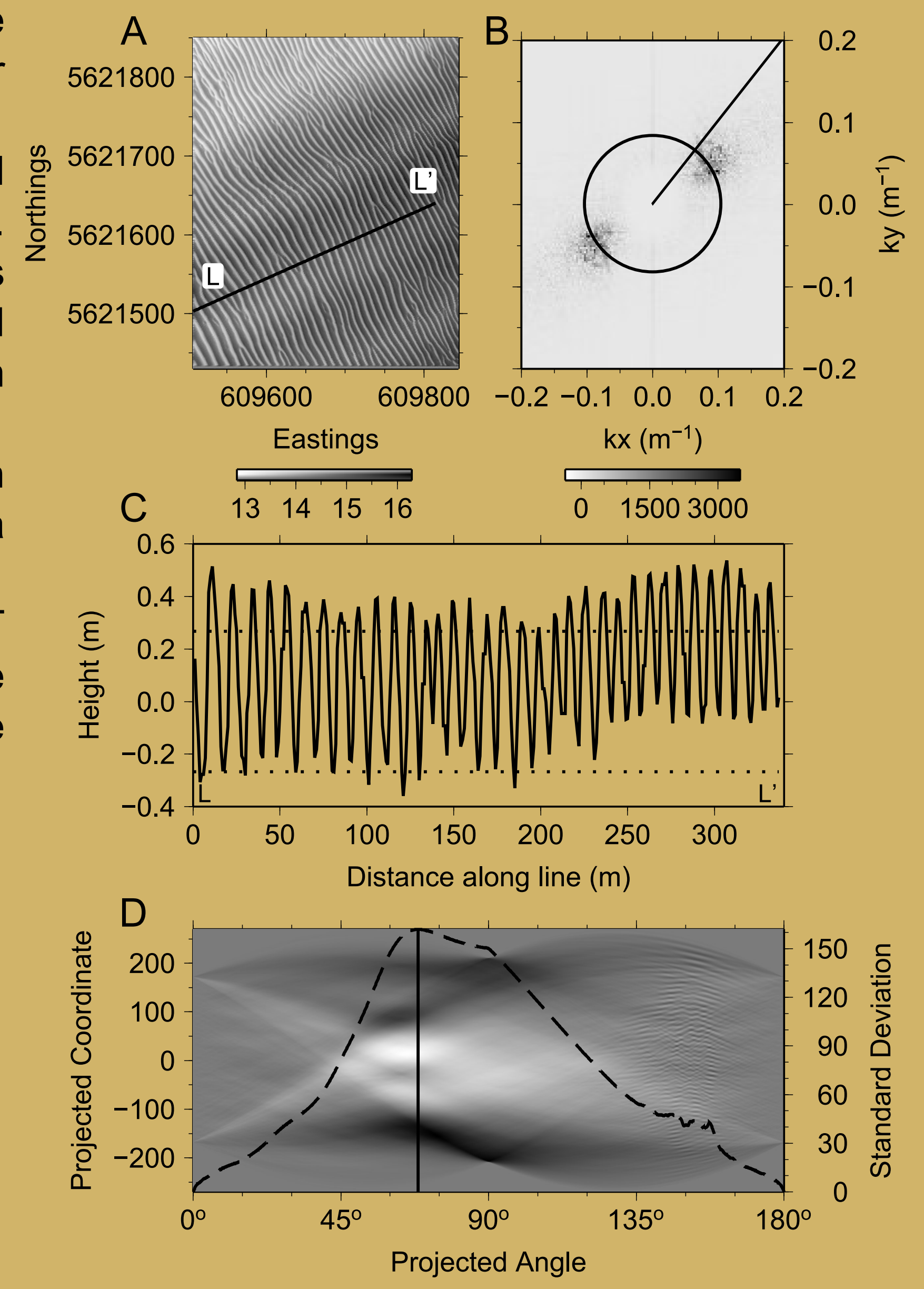


Figure 3: A. West Solent, UK bathymetry. L-L' orientated based on the results of the DFT; B. Butterworth filtered DFT spectrum. Ring shows picked wavenumber. Vector orientated based on the weighted mean peak in the spectrum; C. Depth profile from the surface generated with the inverse DFT of the Butterworth filtered spectrum (B). Dotted line is the recovered height from zero-crossing technique; D. Results of Radon Transform of A.

## SUMMARY

- **Objective measurements** of bedform parameters are of critical importance for **sediment transport modelling**, **hydrodynamic modelling**, **habitat mapping** and **ancient deposit interpretation**.
- A range of **quantitative techniques** from the literature are explored for their suitability for objectively extracting **bedform wavelength**, **orientation** and **height**.
- Increasingly **complex seabeds** are successfully analysed and bedform characteristics are extracted, with **associated uncertainties**.
- **Large-scale**, **automated analysis** is applied to bathymetry of a shingle bank in order to extract **spatially varying** bedform parameters.
- A quantitative analysis-based **seabed morphology classification** becomes possible due to the large number of data points.

## RESULTS III

A range of increasingly complex environments are tested, including a bed with regional morphological depth variability of 10 m (Figure 4A), irregularly spaced bedforms (Figure 4B) and finally a bed of cuspate bedforms (Figure 4C).

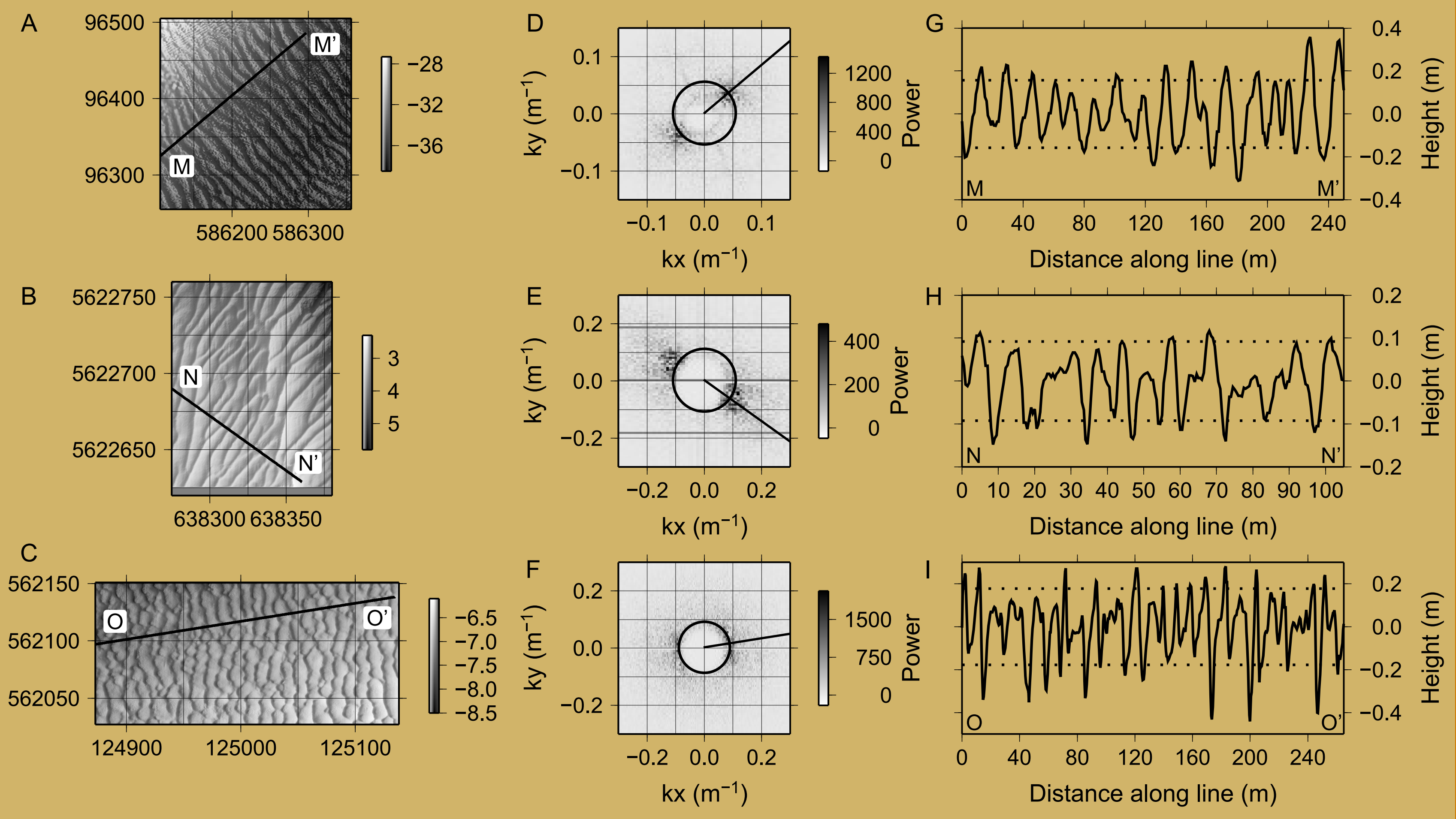


Figure 4: A. Hastings Shingle Bank, UK in the eastern English Channel (British National Grid); B. East Solent, UK (UTM Zone 30); C. Burgzand Wreck site in the Netherlands (Rijksdriehoeksmeting). D-F: Butterworth bandpass filtered spectra for A-C. Ring centred on the origin is wavelength; vector orientated through picked weighted mean location of power peak, giving θ. G-I: Profiles through surface generated from inverse DFT of Butterworth filtered spectrum for A-C, orientated based on the results of the DFT (D-F). Dotted lines indicate the median height from the zero-crossing analysis.

| Site | Height (m) | Orientation (°) | Wavelength (m) |
|---|---|---|---|
| **West Solent (Figure 3A)** | **0.6** | **151.1** (+1.0, -1.0) | **10.1** (+0.2, -0.2) |
| **Hastings Shingle Bank (Figure 4A)** | **0.4** | **139.9** (+3.0, -3.0) | **18.6** (+0.9, -1.0) |
| **Invincible Site (East Solent) (Figure 4B)** | **0.2** | **35.6** (+3.4, -3.3) | **10.6** (+0.2, -0.2) |
| **Burgzand Wreck Site (Figure 4C)** | **0.4** | **171.0** (+2.8, -2.8) | **12.1** (+0.2, -0.2) |

- The results of the analyses provide objective and quantitative measurements with defined uncertainties.
- Input data quality determines the confidence and precision of these measurements.

## REFERENCES

[1] Cataño-Lopera, Y. A. and García, M. H. (2006). Coastal Engineering, 53:767-780.
[2] Cataño-Lopera, Y. A. and García, M. H. (2006). Coastal Engineering, 53:781-792.
[3] van der Mark, C. F., Blom, A., and Hulscher, S. J. M. H. (2008). Journal of Geophysical Research, 113(F03020).
[4] van Dijk, T. A. G. P., Lindenbergh, R. C., and Egberts, P. J. P. (2008). Journal of Geophysical Research, 113.
[5] Flemming, B. W. (1988). Bochumer Geologische und Geotechnische Arbeiten, 29:44-47.

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## RESULTS IV

- Analysis of a large (70 km$^2$) bank with 300 m subsets in order to analyse bedforms with λ < 30 m.
- Wavelength, orientation and height analysis takes 3 minutes for the bathymetry of the entire bank.

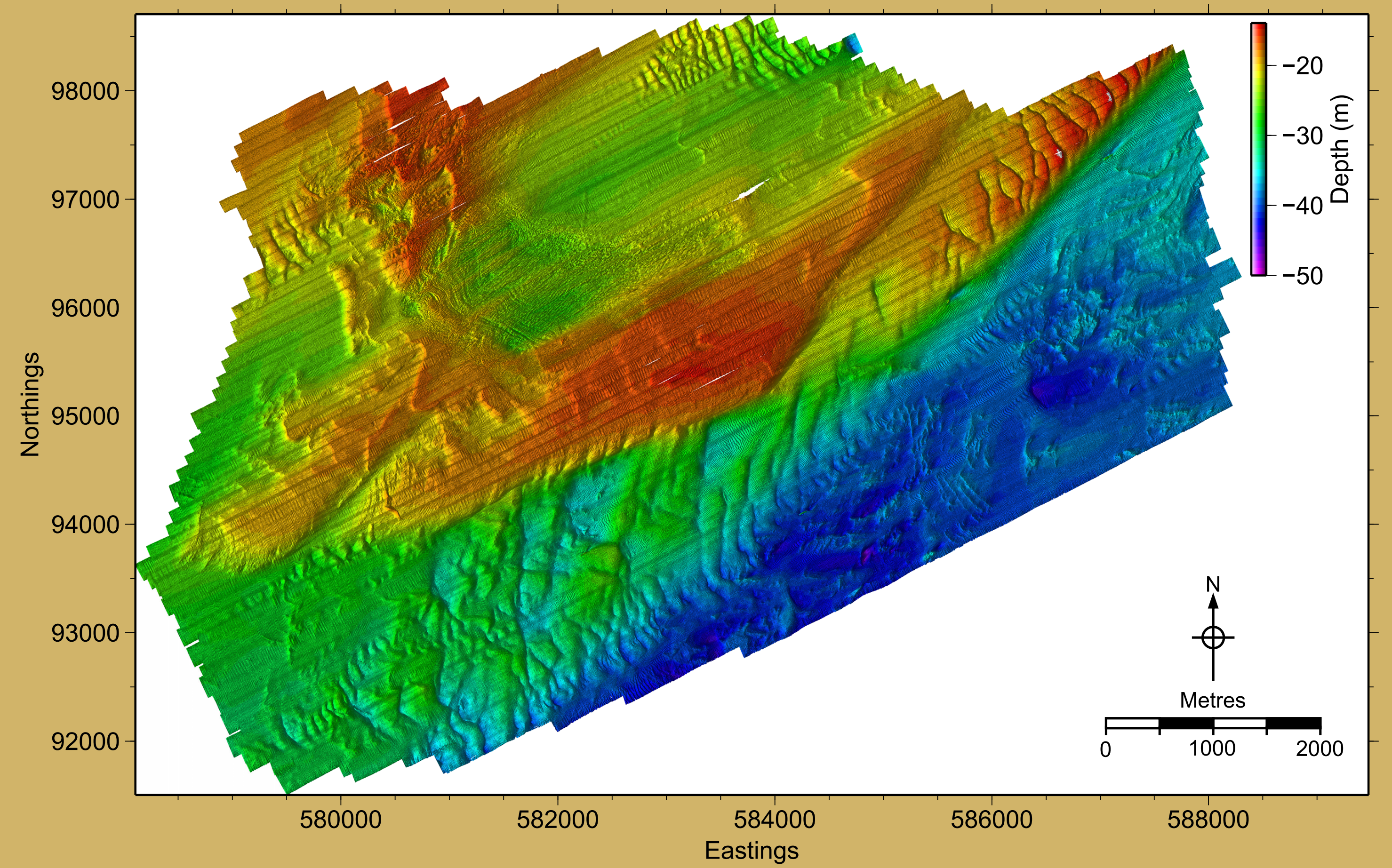

Figure 5: Swath bathymetry of Hastings Shingle Bank, UK. Gridded at 1 m, illuminated from the south-west.

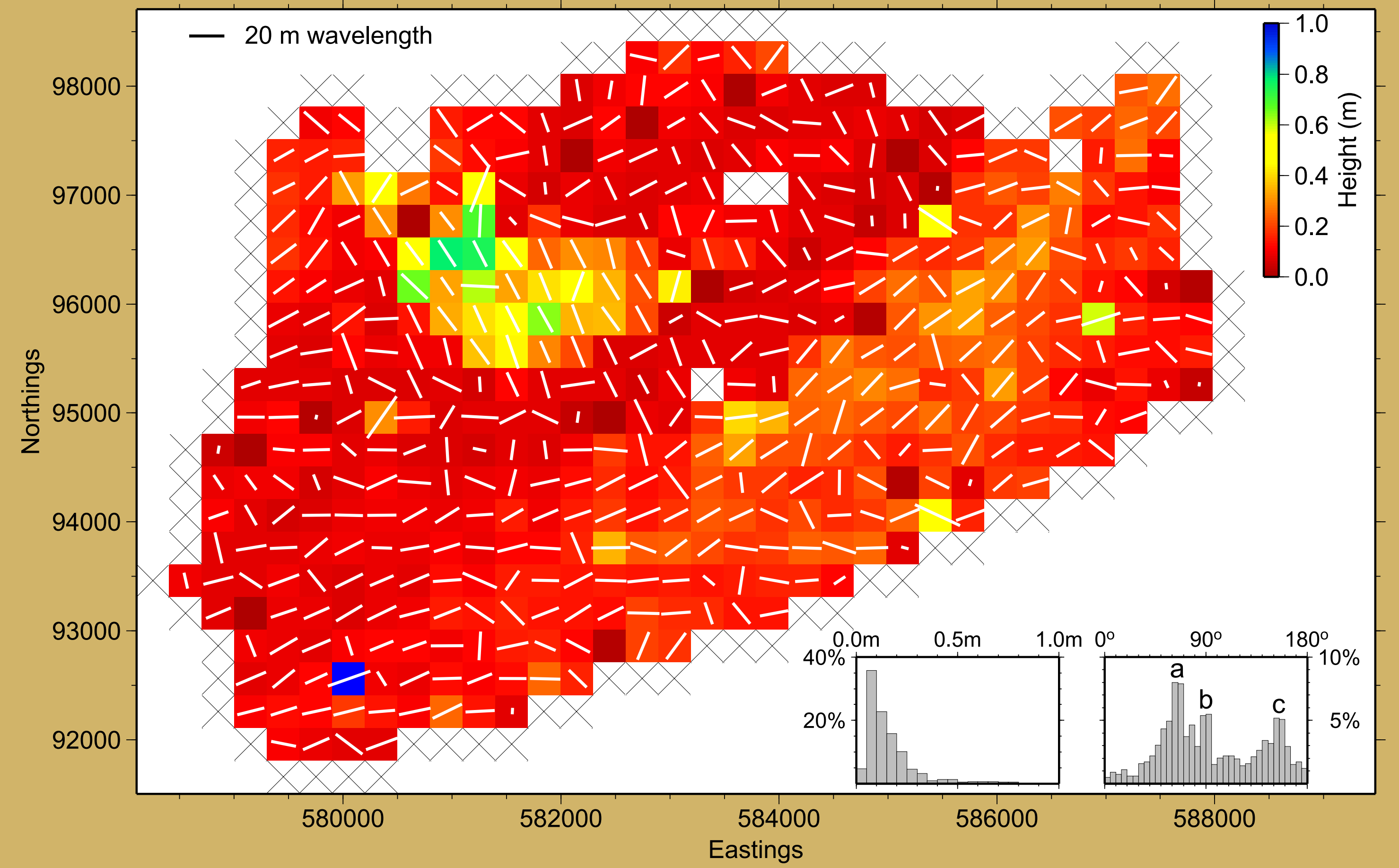

Figure 6: Results of the orientation, wavelength and height analyses at Hastings Shingle Bank for a 300 m subset size. Subset frequency histograms show the distribution of heights and orientations across the entire bank in 0.05 m and 5° bins. Hatched cells indicate no result due to incomplete bathymetry coverage.

- The orientation histogram shows three orientation groups. a) Bedforms present in the south-east, west and north-west appear as peak at 60-70°. b) Noise from acquisition and processing is identified as orientations of 85-95°. c) Dredging the bank centre and edge beam artefacts are the peak at 150-160°. The artefacts and dredging are parallel and indistinguishable. It is imperative that data are obtained and processed to the highest standards possible.
- Height measurements allow a broad three-region classification: north-south separation from the south-west to the north-east segregates generally flat beds from those with bedforms. The third region is the dredging region identified as the bed with the highest heights.

## CONCLUSIONS

- **A range of quantitative, automated bedform analysis techniques is tested on a series of small- and large-scale bathymetric surfaces.**
- **Measurements of orientation, wavelength and height are successfully extracted across a range of environments.**
- **Some commonly employed techniques prove ineffective at identifying parameters when real-world surfaces are analysed.**
- **Objectivity is maintained through a number of universally applied assumptions.**
- **Seabed classification is enhanced through height and bedform orientation analyses.**
- **A large number of results allow statistical analyses of potentially very large data sets.**
- **Application of the techniques are suitable for analysis of any spatially contiguous data (e.g. LIDAR, Sidescan Sonar, Sector-scanning sonar etc.).**