Spoilt for Choice – When to Use Which Bedform Identification Tool for What Purpose?

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Abstract

Subaqueous dunes are fascinating morphological features that exist in diverse environments such as the deep sea, continental shelves and inland streams or rivers. Due to their rhythmic and oftentimes very frequent occurrence along the predominant flow direction, the analysis of these bedforms is usually assigned to bedform identification tools. Such algorithms automatically determine crest and trough locations and calculate dune dimensions accordingly. Over the last years, the number of these tools has notably increased with specialized methodologies for every environment and bedform scale. Although many of them are readily available to interested researchers, there may be uncertainty as to which method should be applied in view of a specific research question. As authors of some of the most recent bedform identification tools, we have started to systematically compare our approaches by analyzing an agreed set of diverse bathymetric data. The bed features assessed in this context range from river dunes formed under unidirectional flow over tidally constrained compound dunes to bed elevation profiles gained from flume experiments. The resulting dune characteristics, which each scientist obtained by applying his/her particular algorithm, are thereupon contrasted in a qualitative and quantitative manner uncovering the similarities and differences between individual methodologies. Our preliminary results suggest a strong influence of the original focus of each algorithm and therefore corroborate the need for systematic comparison. In the next step, the gained insights will be used to find and explain the optimum fields of application and, in the end, provide user-oriented guidelines that may support the bedform community in deciding which identification tool should be used for what purpose.

Spoilt for Choice – When to Use Which Identification Tool for What Type of Bedform

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Background

MOTIVATION:

Subaqueous dunes are a natural variation of the river or sea bed. They can affect the safety of navigation, the stability of maritime structures or sediment transport.

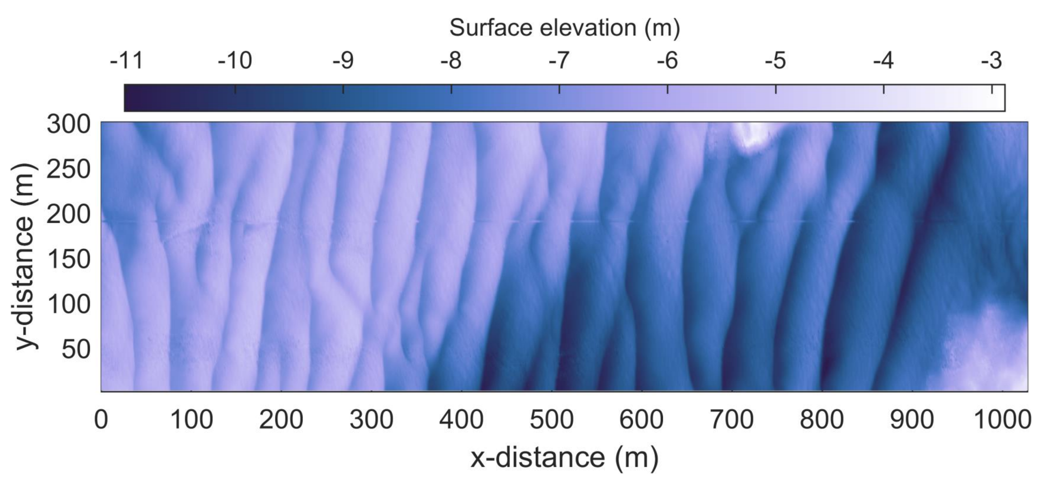

Fig.1 : Exemplary field of subaqueous dunes at the Rio Paraná, Argentina.

Due to their periodic occurrence, dunes are typically assessed by semi-automatic algorithms of which many are readily available. For independent users, however, this makes it hard to choose a specific tool for a given research question.

WORKING GROUP:

To provide sound guidelines for the use of these tools, corresponding authors of some of the most recent publications on dune identification joined forces in an international and diverse working group.

The team consists of six early career researchers at PhD and postdoctoral level, who come from four different continents and represent six individual approaches.

OBJECTIVES:

Our study aims at systematically comparing the behavior of available dune identification tools in order to

- Quantify differences in results
- Understand methodological biases
- Recommend fields of application

Methodology

IDEA:

To ensure correct application, each researcher uses his/her particular dune identification tool to assess a predefined set of different bathymetric environments. Subsequently, resulting dune characteristics can be juxtaposed in comparative statistics.

APPROACHES:

The applied methods comprise both spectral and statistical analyses and can be differentiated according to their specific focus:

- Three-dimensional shape of dunes *(Cisneros et al. 2020; Lefebvre et al. 2021)*
- Separation of dune scales *(Gutierrez et al. 2018; Wang et al. 2020; Zomer et al. 2021)*
- Decomposition of compound dunes *(Scheiber et al. 2021)*

All tools are currently implemented in MathWorks' MATLAB. Detailed descriptions are given in the respective publications.

BATHYMETRIC DATA:

Allowing for the multitude of research focuses, the chosen benchmarking data sets include the following diverse dune environments:

- Riverine dunes (Rio Paraná, Argentina)
- Tidally-constrained compound dunes (Weser Estuary, Germany)
- Scaled dunes from flume experiments (Simon Fraser University, Canada) *(Bradley and Venditti 2019)*
- Multi-scale synthetic dune data (Supplement to BedformsATM) *(Gutierrez 2017)*

Preliminary Results

PERFORMANCE:

Depending on the assessed bathymetry, the number of identified dunes varies by nearly two orders of magnitude. Similarly, relative computation times vary between 0.1 and 1700 ms/dune.

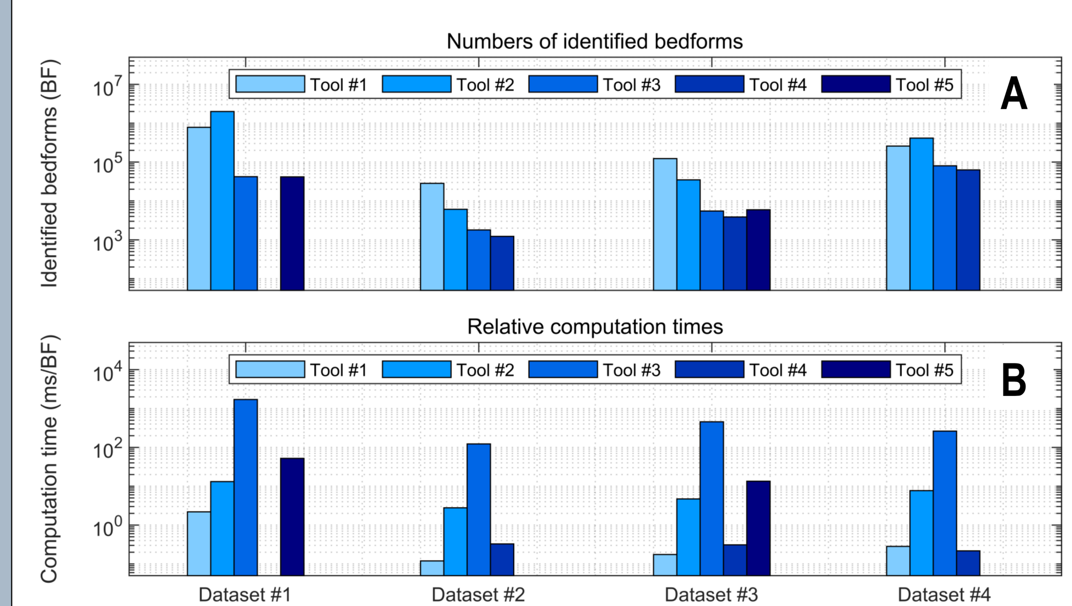

Fig.2: Performance of different dune identification algorithms in terms of A) the number of identified dunes and B) the relative computation times.

A look at the congruence of obtained dune characteristics corroborates the hypothesis that results highly depend on the focus of the utilized tool. A Venn diagram visualizes how nearly 2/3 of all identified dunes are found by only one of the algorithms, while 2 % of the results are unequivocal.

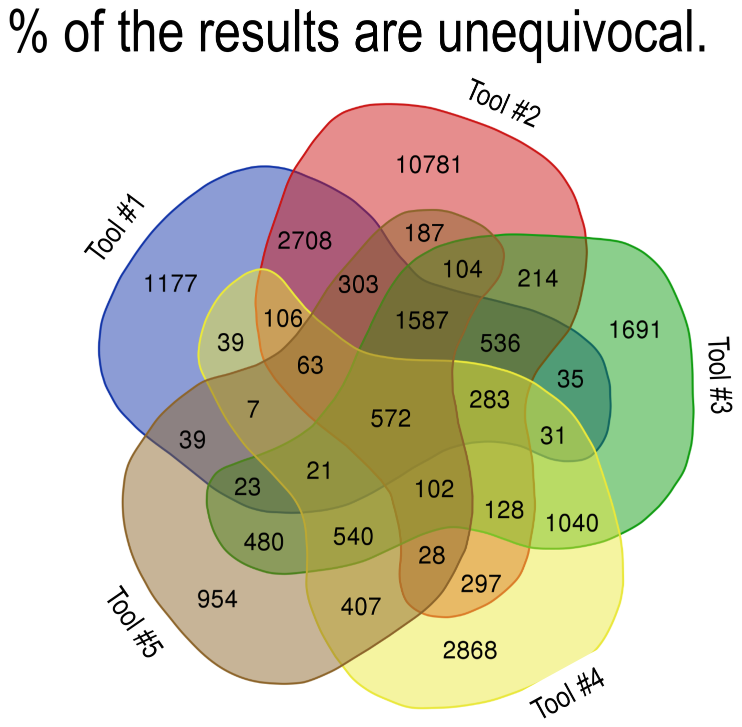

Fig.3: Venn diagram of unique dune characteristics highlighting the small number of unequivocal results obtained by the different methods. Visualization based on web application: http://bioinformatics.psb.ugent.be/webtools/Venn/

COMPARATIVE STATISTICS:

The observed differences become clearer when directly comparing the specific scales of obtained dune characteristics, which reflect the original purpose of each dune identification algorithm.

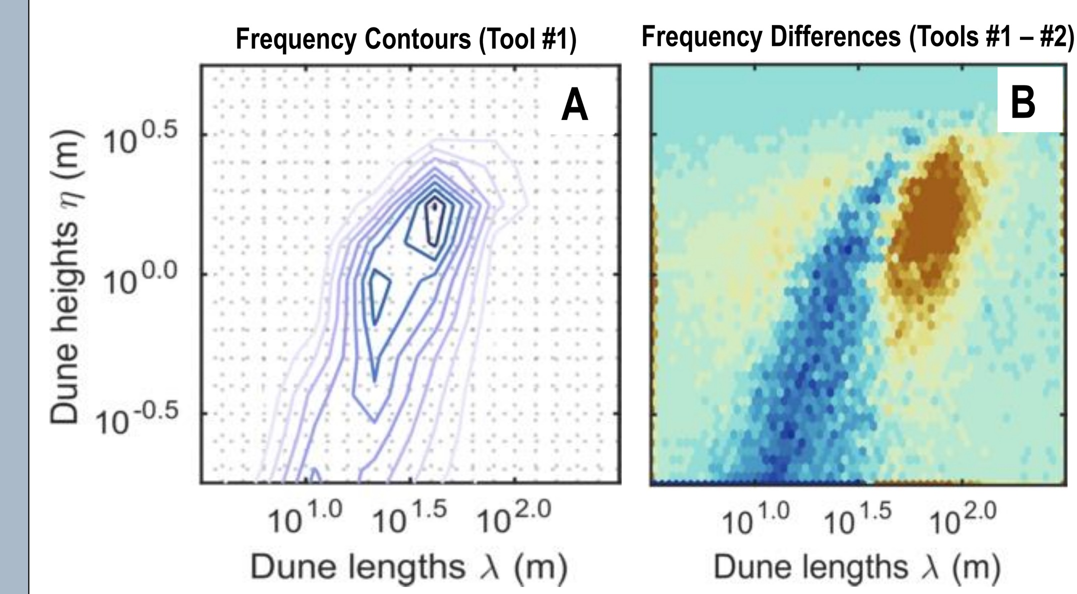

Fig.4: Co-domains of identified dune characteristics. While A) shows a contour plot of dune length/height tupels obtained from a first algorithm, B) highlights the differences between the dune characteristics from this one and a second algorithm in the form of frequency density differences.

Furthermore, differences in length/height frequency can be quantified by statistical measures, like the Kantorovich–Rubinstein metric or the Jensen–Shannon divergence.

Conclusions

SUMMARY:

Subaqueous dunes can be assessed by a multitude of semi-automatic identification tools. However, the results that can be obtained from these algorithms differ significantly with regard to number, location and dimensions of identified dunes.

Our international and diverse working group, uncovers geomorphometric differences in a systematic and quantitative manner and provides methodological explanations.

OUTLOOK:

Based on the realization that each tool was developed for a specific focus, detailed recommendations will be elaborated as to which algorithm should be applied for what type of bedform.

The findings of this collaborative study are the basis for a comprehensive toolbox, the Bedform Analysis Toolbox (BAT), which combines the available approaches and provides a user-friendly interface.

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