Special issue: Marine and river bedforms dynamics, MARID VI

Alice Lefebvre1 | Christian Winter2

1MARUM – Center for Marine Environmental Sciences, University of Bremen, Germany
2Institute of Geosciences, Christian-Albrechts-Universität zu Kiel, Germany

Abstract

Marine and river bedforms are rhythmic features driven by unidirectional or reversing currents and waves. They are ubiquitous on the floors of rivers, estuaries, coastal and marine settings. Despite a considerable history of dedicated studies, many aspects of their origin, development and dynamics are still the subject of scientific debate in various disciplines. The MARID conferences series hosts experts from geosciences, physics, engineering and other disciplines to provide a platform for the interdiscipli- nary exchange of fundamental and applied knowledge of marine and river dune dynamics. MARID VI took place in April 2019 in Bremen, Germany. Related scientific contributions are presented in this special issue of Earth Surface Processes and Landforms. An overview of the conference series and the specifics of MARID VI, as well as considerations in the context of equity, diversity and inclusion, are given. This introduction highlights the progress made with the papers published in the special issue.

KEYWORDS

bedform, dune, field, laboratory, MARID, numerical modelling, ripple, sand wave

1 | INTRODUCTION

Rhythmic patterns that form at the interface of a moving flow and mobile matter are commonly found in aeolian, subaqueous and extra-terrestrial environments. In marine and river settings, bedforms develop from the turbulent shear generated by the interaction of flowing water and the underlying mobile sediment. Driven by river flow, wave actions, and wind- and wave-driven or tidal currents, bedforms initiate and develop into a wide range of dimensions, geometries and degrees of complexity. Their spatial scales range from small-scale ripples (spacing on the order of centimetres) to large-scale sand banks (spacing on the order of kilometres), and they are found in environments ranging from shallow to deep water.

Marine and river bedforms have been the focus of applied and fundamental research for many decades, as they are at the centre of complex geomorphological interactions (Figure 1). Their initiation and dynamics as self-organized natural patterns result from the coupling of hydrodynamics and sediment transport (e.g. Duran et al., 2019). Once established, they strongly influence flow dynamics in a continuous mutual interaction, notably through flow acceleration over the stoss side, with possible flow separation at the crest, and deceleration/flow reversal over the lee side (e.g. Nelson et al., 1993).

Bedforms may constitute a major form of bed roughness, as flow separation at the crest and recirculation on the steep downstream side create turbulence and energy loss (e.g. Smith & Mclean, 1977). As they migrate, bedforms move large amounts of sediment and are therefore agents of sediment transport (e.g. Barnard et al., 2011). Bedforms are depositional features, and their stratification is often used to reconstruct paleoenvironments (e.g. Leclair & Bridge, 2001). They are also of relevance to microbiological processes (e.g. Ahmerkamp et al., 2015) and the distribution of biota (e.g. Damveld et al., 2018). Applied research has a strong interest in the study of bedform dynamics, for example, to ensure the depth of navigation waterways, the fate of buried unexploded objects, the safety of offshore constructions and cables or the impact of marine aggregates extraction (e.g. Knaapen & Hulscher, 2002). Despite the considerable history of dedicated studies (see reviews of Ashley, 1990; Best, 2005; Dalrymple & Rhodes, 1995; Venditti, 2013), many aspects of their origin, development and dynamics are still the subject of scientific research in the various disciplines involved. The Marine and River Dune Dynamics (MARID) conference series offers a platform for transdisciplinary discussion on various aspects of bedform research.

This introduction to the special issue on marine and river bedforms is structured as follows: in section 2, the MARID conference...
is presented, with a short description of the history of the conference series and MARID VI specifically, as well as considerations on the subject of equity, diversity and inclusion. In section 3 the papers of the special issue are presented.

2 | MARID CONFERENCE

2.1 | History of MARID

Under the aegis of the North Sea Hydrographic Commission, a workshop on marine sand wave dynamics was organised in the year 2000 by the French Naval Hydrographic and Oceanographic Office (SHOM) and the Lille 1 University (France). Following this workshop, a series of conferences was organised on the topic of marine and river dune dynamics: MARID II in 2004 at the University of Twente, the Netherlands; MARID III in 2008 at the University of Leeds, United Kingdom; MARID IV in 2013 at the Royal Belgian Institute of Natural Sciences, Belgium; and MARID V in 2016 at Bangor University, United Kingdom. These conferences traditionally take place over 3 days: 2 days are dedicated to plenary scientific sessions, including talks from keynote speakers and oral and poster presentations by delegates. A field excursion on the third day allows a convivial exchange between participants while discovering relevant geomorphology near the organising institutions.

The MARID conferences aim to bring together researchers from a wide range of disciplines to discuss recent findings and future research related to bedform dynamics. A particular focus of the conference is to strengthen the dialogue between fundamental researchers and those involved with state-, business-, or client-driven purposes (e.g. water authorities, dredging companies, renewable energy developers, Navy). For MARID VI, in 2019, the largest proportion of attendees (85%) were affiliated with universities and research institutes. Around 10% of attendees were affiliated with authorities (principally from waterways authorities), and there were some participants from instrument manufacturers and consultancy companies.

2.2 | MARID VI

MARID VI took place from 1 to 3 April 2019 in Bremen (Germany), with 64 participants. In keeping with the previous MARID conferences, the concept of a small, focused event with only plenary sessions was maintained to stimulate discussion among disciplines. Three keynote speakers were invited to present their work on bedform dynamics from different perspectives. Prof. Cheng Heqin, East China Normal University (China), gave a keynote lecture on dune dynamics in gravel, sand and coarse silt derived from field data in the middle and lower reaches of the Yangtze River. Prof. Pieter Roos, University of Twente (Netherlands), presented a talk related to sand wave modelling and Prof. Dan Parsons, University of Hull (UK), focussed his keynote on enigmatic bedforms in the deep sea.

A total of 29 short and long talks were given during the six sessions: progress in sand wave research; theories and concepts; methodological advances; geomorphological evolution in tidal environments; bedforms in unidirectional flow; and environmental management. Fourteen posters were introduced by a 2-min pitch and were displayed to be discussed during breaks throughout the conference. For the first time, a short course was offered by Dr Ronald Gutierrez on the Bedforms Analysis Toolkit for Multiscale Modeling (Bedforms-ATM), an open-source MATLAB software proposed to standardise the scale-based discrimination of bedforms (Gutierrez et al., 2018). The meeting concluded with a social event at a scenic restaurant in historic Bremen. A field trip to the Wadden Sea and Weser estuary on the last day was led by Prof. Burg Flemming.

2.3 | Equity, diversity and inclusion considerations

Participants of the conference were mainly European, with a strong representation of researchers coming from Dutch and German universities and institutes (each 28% of participants) but also from the USA, China, Colombia, Norway and Saudi Arabia. The MARID conference series started in Europe and has stayed largely a European conference. Some efforts were made to broaden its international
coverage, for example, by inviting keynote speakers from other continents. However, the conference location has also always been in Europe, thus encouraging European researchers to attend.

Of the 64 participants, 25 (39%) were registered as students (masters and PhD students). The exact number of early career researchers (ECR, broadly recognised as students and postdocs) is difficult to calculate because there is no clear definition of ‘early career’. The proportion of ECR is estimated to be around 60%. This is a somewhat higher proportion than in large conferences. For example, the European Geosciences Union (EGU) reported a fraction of early-career scientists among the overall attendees in the last years of 43% in 2015 increasing to 52% in 2019 (Toth et al., 2020). To promote and support early-career scientists with some first-hand convening experience, the main convenor of each session was always an ECR, usually supported by a senior scientist as a co-convenor.

As a small and focused conference, MARID is especially suited to allow networking opportunity. To encourage students to attend the conference, student grants are generally offered by the organising committee. For MARID VI, ten applications were received and five of them could be granted. Awards were also given for the best abstract, the best short talk, the best long talk, and the best poster. More than the actual monetary reward, awards are particularly helpful to formally recognise the excellent contributions of students and may be especially useful for a student’s early career.

Around one-third of the MARID participants were women, which corresponds to the general proportion of women attending conferences in the field of geosciences (e.g. 32–36% of EGU attendees were women (Toth et al., 2020)). During the conference, equal representation was fostered by pairing a woman and a man to chair each session. Selection of presentation type, travel grant and awards was done based on scientific merit only; gender was not considered during these decisions. There was no conscious positive or negative discrimination towards attributing presentation type, and so the proportion of women presenting was similar to the proportion of women attending the conference. In total, 40% of student travel grants were awarded to women, which corresponds to the percentage of women student participants. The percentage of women as first authors of the proceedings was 36%, similar to the percentage of women attendees, and corresponding well to numbers reported by the EGU (percentage of female colleagues among first authors: 33–34%, (Toth et al., 2020)).

Finally, the gender of authors who published papers in the special issue was also examined. Women were first authors of 6 of the 13 manuscripts (46%). The total percentage of female authors is 24%, comparable to the 29% of women among authors in Earth and Planetary Sciences in the EU (Elsevier, 2020). It should also be noted that 4 of the 13 papers were authored by men only. No manuscript was authored by a woman-only team.

3 | ORIGINAL CONTRIBUTIONS

The MARID conference series started in 2000 with a workshop focusing mainly on marine dunes. In the second conference, research related to river bedforms was also presented, and the difference between the marine and fluvial bedforms was discussed (Hulscher & Dohmen-Janssen, 2005). Since then, the range of bedform types, the environments in which they are studied and the driving mechanisms of their formation and dynamics have widened, as can be recognised from the collection of papers published in this special issue (Table 1). Bedforms under discussion range from ripples to ridges, with analysis based on laboratory experiments, field measurements and numerical models.

The MARID community advocates open and data-driven science practices in bedform dynamics research. In this special issue, Gutierrez et al. (2020) highlight that bedform research would greatly benefit if data and methods were openly and freely shared. In bedform research, as in many other research areas, very large datasets are now commonly being collected. However, processed data are not always comparable, as there is no standardised way to analyse them. Therefore, sharing of raw data would greatly benefit the community, together with formal recognition of the scientists who collected the data. Open-source software should also be made available to analyse data in a coherent and harmonised way.

3.1 | Bedform identification

An ongoing theme in bedform research is related to bedform identification and characterisation. As the methods to measure bathymetry evolved, large datasets of bedform at high spatial and/or temporal

| Bedform types | Forcing | Environment |
|---------------|---------|-------------|
| Yuill et al., 2020 | “engineered” dune | unidirectional flow | flume |
| Terwisscha Van Scheltinga et al., 2019 | dunes | unidirectional flow | flume |
| de Ruijsser et al., 2020 | dunes | river flow | river |
| Chatterjee et al., 2019 | ripples | waves and unidirectional flow | flume |
| Nnafie et al., 2020 | sandbars | waves | nearshore and beach |
| Brakenhoff et al., 2020 | wave-current ripples | tidal currents and waves | ebb tidal delta |
| Scheiber et al., 2021 | tidal dunes | tidal currents | tidal channel |
| Wang et al., 2020 | compound dunes | tidal currents | tidal continental shelf |
| Coudrey et al., 2020 | isolated tidal dune | tidal currents and infrastructure | tidal continental shelf |
| Damveld et al., 2020 | sand waves | tidal currents and fauna | numerical modelling of tidal continental shelf |
| Durán et al., 2020 | sand ridges | storms | tideless continental shelf |
| Miramontes et al., 2020 | sand dunes | internal waves | continental slope |
resolution have become common. To characterise bedform dynamics, bedform parameters need to be calculated. The bedform-tracking tool from Van der Mark and Blom (2007) was one of the first tools developed to calculate bedform characteristics in an automated and replicable way. Since then, this question has remained open. In this special issue, two papers present new methods to identify bedforms and determine their characteristics.

The method developed by Wang et al. (2020) was designed specifically to calculate the dimensions of compound bedforms in an open tidal environment. The wavelength of interest as well as its orientation can be automatically determined by a series of 2D Fourier analyses. With these, the crests and troughs of each bedform scale can be identified on bedform profiles taken through the bedform main orientation, and the dune wavelength, height and leeside angles can be calculated.

The method presented by Schelber et al. (2021) was developed to analyse compound bedforms in a tidal channel. The developed tracking algorithm relies on repeated evaluation of unfiltered bed elevation profiles according to five predefined length classes. From these, the height and length, as well as the crest and trough depths, can be calculated. In a second step, morphological trends can be assessed in the form of bed migration rates, bed slope asymmetries and net sediment changes.

3.2 | Small-scale bedform dynamics

To understand and to predict the mutual adjustment of bedforms and hydrodynamics, it is necessary to assess the velocity of sand particles above bedforms and how it varies. Terwisscha van Scheltinga et al. (2019) describe a new measuring technique which allows researchers to track individual sand grains moving above a bedform in the laboratory and, thereby, to measure their velocity. They showed that the mean particle velocity increases from the lower part of the bedform stoss side towards its crest. In the meantime, the standard deviation of the mean particle velocity decreases from the lower- towards the upper-stoss side-slope.

Because of the interaction between flow and a complex bed shape, the movement of sand grains above a bedform differs from that of sand grains above a flat bed. Through numerical modelling, Yuill et al. (2020) showed that settling velocities were reduced by up to 50% above bedforms compared with over a flat bed. This is due to the eddies generated in the bedform wake and, to a lesser extent, to turbulence arising from velocity shear at the bed which maintain sediment in suspension over the bedform lee side and trough.

In certain special conditions, a current flowing in opposing directions to waves can create a wave-blocking phenomenon. Chatterjee et al. (2019) observed from physical experiments in a flume that under such waves blocked by a counter current, three bedform zones can be identified. On the downstream face, asymmetric ripples with a steep slope are induced by the incoming current. Beneath the wave-blocking zone, flat sand bars are formed. Symmetric ripples are found below the wave-dominated region on the downstream side.

Small-scale bedform dynamics can also be studied in the field, which helps improve characterisation of large-scale dynamics. Brakenhoff et al. (2020) examined ripples on a Dutch ebb tidal delta under mixed current and wave conditions. They observed that ripple dimensions did not change significantly with variations in hydrodynamic conditions. All the ripple dimension predictors they tested over-predicted the measured ripple height, most likely because of the small grain size at the study area. These results have important implications for the calculation of bed roughness as they suggest that a constant roughness might be more appropriate for small-scale wave-current ripples than a roughness varying depending on the hydrodynamic conditions.

3.3 | Large-scale bedform dynamics

On the scale of a bedform field, several factors may influence bedform properties. de Ruijsscher et al. (2020) observed that the size and shape of dunes in the Waal river were controlled by their position compared with the underlying morphology, made of a pattern of bars and pools. The dunes located on bar tops were measured to be longer, shorter and with a lower lee side angle compared with the dunes situated in pools. Furthermore, the dunes in the pool migrated faster than those on the bar, which induced a tilting of the dune crestslines.

The temporal variations in hydrodynamic forcing may also have a strong influence on bedform morphology. Nnafie et al. (2020) analysed the impact of time-varying wave angle on the presence and characteristics of shore-transverse sandbars. Using a numerical model in which the wave angle varied in time, they showed that bars forming with time-varying wave angles have a longshore crest-to-crest spacing unlike those which form with time-invariant wave angles. Other bar characteristics, such as bar presence, height and oscillation, depend strongly on the properties of the wave angles, particularly on their amplitude and period.

With the progress of techniques to observe and model bedforms, new factors with the potential to influence the dynamics of bedform fields are now being explored. Damveld et al. (2020) modelled the interactions between small-scale mounds representative of the tube-building worm *Lanice conchilegais* and large-scale sand waves using a two-way coupled process-based model. Their model manages to replicate field observations that the highest worm densities are found in sand wave troughs. The presence of the mounds is predicted to accelerate sand wave growth, and their time to reach equilibrium. Interestingly, the sand waves are likely to be initially shorter than they would be in an abiotic environment. Near equilibrium, however, the modelled wavelengths tend towards their abiotic counterparts.

Thanks to repeated measurements of large areas covered by dunes, the long-term dynamics of bedform fields can be characterised and the impact of anthropogenic activities assessed. Dunes in fairway channels are regularly subjected to human intervention to ensure navigation safety. In the Jade tidal channel (North Sea), water injection is regularly carried out to remove dune crests. Schelber et al. (2021) observed that this leads to a gradual levelling of the bedform field, as the sediment eroded from the crest is redistributed in the trough, as well as an overall bed aggradation.

With the increase of offshore constructions, it becomes essential to estimate how these structures will interact with migrating bedforms. Couldrey et al. (2020) followed an isolated barchan dune as it moved through a monopile installed in the North Sea. The dune was visibly affected when passing through the manmade structure, with deep scour around the monopile and a change in the dune morphology.
However, a couple of years after passing through the structure, the dune was observed to have recovered. Overall, the dune migration through the monopile had little effect on its morphology.

Bedforms are not restricted to shallow water and hydrodynamically active environments. They can also be found in deeper water, and in places with weak hydrodynamics. Duran et al. (2020) explored bedforms in the Western Mediterranean outer shelf, in water depth of 55–85 m. The sandy bedforms they described are large and flat (height 1.5–7 m, length 600–1,100 m). They are interpreted as being storm-generated sand ridges which formed in times of lower sea level. The mud layer which covers them suggests that they are no longer active. Most of them are being degraded, becoming smaller and flatter, but a few are being preserved as some storms generate hydrodynamic forces strong enough to reactivate them.

Dune fields in water depth between 120 m and 250 m, on the upper continental slope of the Mozambique margin, are described by Miramontes et al. (2020). The dunes are medium to large (height 0.15–1.50 m, length 20–150 m). Their size decreases upslope, and their asymmetry suggests an upslope migration. They are hypothesised to be formed by internal waves. In the zones where barotropic tidal currents are weak, internal solitary waves propagate shelf-wards, generating upslope-flowing bottom currents, which may be at the origin of the dune field. Other large-scale sedimentary features in the area (plastered drifts and contourite terraces) are thought to be generated by geostrophic currents.

4 | CONCLUSIONS

The MARID conference series is dedicated to present research on marine and river bedforms. MARID VI took place in Bremen, Germany, in April 2019. This special issue comprises an overview of ten papers on different topics raised at the conference, and three with related subjects published recently in Earth Surface Processes and Landforms.

Knowledge on bedform dynamics is continuously improving. A variety of spatio-temporal scales and processes are now considered: from the movement of individual particles to small-scale ripples in shallow water, and large bedforms on the continental shelf and slope, but also the long-term dynamics of bedform fields, the influence of time-varying hydrodynamic forcing and the effect of the underlying morphology on bedform morphodynamics. The mutual influence of bed morphology and biota activity as well as the interaction between bedforms and anthropogenic structures is now being considered. Different methodological approaches (numerical modelling, laboratory studies and field data) are developed and combined to provide an integrated understanding of bedform dynamics.

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ORCID

Alice Lefebvre https://orcid.org/0000-0002-9234-8279
Christian Winter https://orcid.org/0000-0002-8043-2131

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