High-resolution observation of small-scale variability in a bedform field

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ABSTRACT: Since more than 30 years FWG studied bedform migration with systems placed on the seafloor. At regular intervals ranging between one minute and one hour sand height around the sensors has been recorded even during strong currents that do not permit diver observation. An extremely high small-scale local and temporal variability of bedform movement was observed with several systems deployed at a short distance. The measurements verified a very quick re-orientation of megaripples in reversing tidal currents. The adjustment of megaripples to the prevailing current direction can cause a sand height change of 40 cm in one hour at the recording system. To get a more detailed impression of local small-scale variations a scanning sonar tower was deployed and recorded at regular intervals. A survey of 25 hours with scans every 3 minutes of a circular 50 m range exposes extreme sediment mobility during spring tide. Simultaneous current measurements indicate at 1 m height above sediment of 0.6 cm/s as critical speed for the massive mobilization of sediment.

1 INTRODUCTION

Bedform migration has been studied since more than 30 years by FWG with instruments on the seafloor. The instruments are Burial Recording Mines (BRM, cylinders of 1.70 m length, 0.47 cm diameter and a weight of ca. 500 kg (Wever et al. 2004). Recording intervals range from 1 minute to 1 hour and allowed a detailed description of bedform migration. The burial status is recorded with three rings of 24 light barriers each around the BRM from which buried volume of the cylinder and burial height (i.e., sand height) can be determined. Especially the regular recording under strong current conditions without position uncertainties permitted a reliable estimate of bedform migration speed (Wever & Stender 2000). In contrast to repeated acoustic surveys no errors are introduced resulting from time lags relative to the tidal cycle (Wever 2004). This delivered similar results as the stake experiments of Langhorne (1982) off the British coast. An especially interesting observation was the quick and short re-orientation of deforms under changing current directions.

The deployment of several BRMs in close neighbourhood (30-50 m) revealed unexpected small-scale differences of bedform migration (Wever & Stender 2000).

To acquire an improved overview of bedform migration rotary sonar scans were made. They allowed to investigate a circular area of up to 200 m diameter. This paper describes some of the observations. In recent years the rotary scanning sonar has been modified to allow autonomous recordings at pre-set intervals.

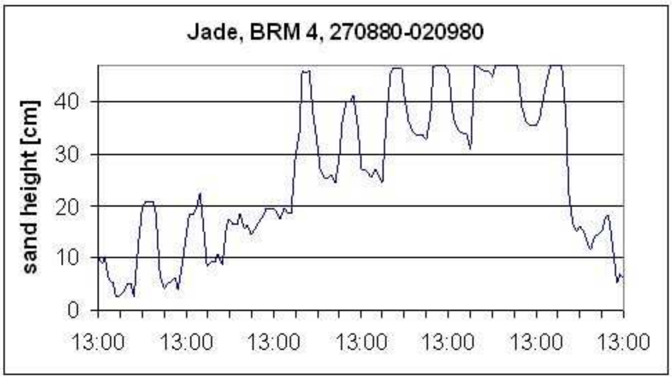


Figure 1. Typical BRM recording in the Jade area (SE German Bight). This six-day recording with 1-hour intervals dispalys the typical tide-dependent sand height around the BRM. Especially noteworthy are the quick changes. This record documents the passage of a megaripple within six days.

2 BRM MEASUREMENTS

The deployment of BRMs on the seafloor allowed to examine bedform migration characteristics. Time series over several weeks demonstrated the influence of tidal current direction on the shape of bedform and current-dependent re-orientation see Figure 1.

Figure 1 displays the passage of a megaripple across the BRM. Theoretical considerations demand a fast coverage of the BRM with the steep megaripple flank that faces towards migration the low-angle back side would imply a slow excavation. However, the opposite is observed: within 4 hours 30 cm (47 cm to 17 cm) sand were moved away from the BRM at the last complete burial phase in Figure 1. This is an often observed yet unexplained phenomenon.

However, not only the reduction in sand height around the BRM is a quick process. Also the burial (increase of sand height) is fast. A representative example is shown in Figure 2. Here, a sand height increase of 40 cm was observed within 60 minutes. Although this is an extreme height change it is no exception, neither for sand height nor required time.

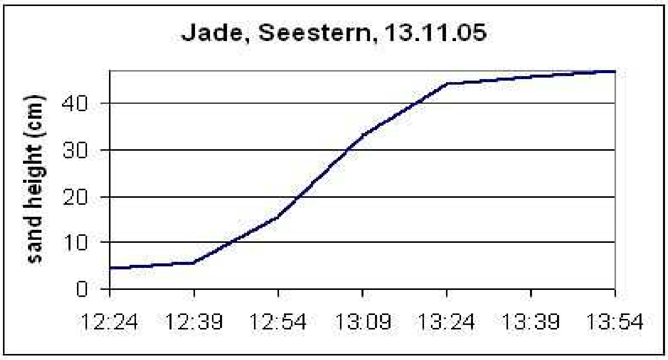


Figure 2. BRM recording (15 min interval) in the Jade area (SE German Bight). This 90 minutes long record demonstrates the quick sand height changes in response to the current direction reversal (approximately 180° in the Jade). The sand height changed from 4 cm at 12:24 to 44 cm at 13:24 (47+ cm at 13:54).

Once a BRM has quickly reached its maximum coverage with sand during a tidal phase this does not change. The burial is pretty constant until the next flow direction reversal (Figure 3).

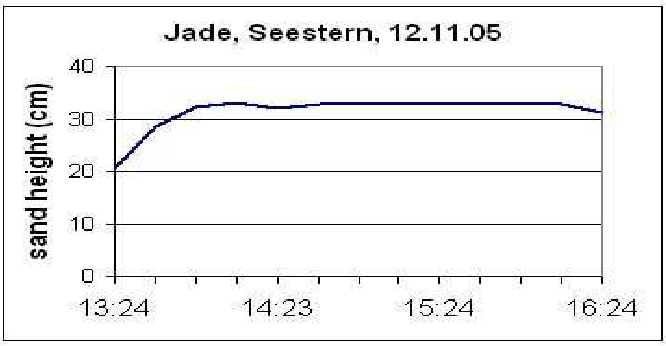
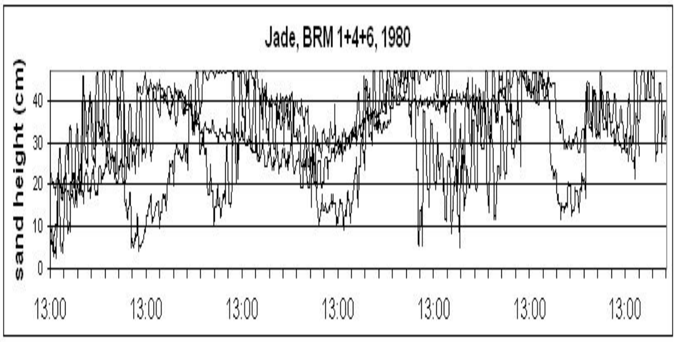


Figure 3. BRM recording (15 min interval) in the Jade area (SE German Bight). This 3 hours long record demonstrates the constant sand height once a BRM is buried.

Altogether this data shows very quick responses to flow reversal and stable conditions during a flow phase. In total a BRM recording time of ca 7,500 hours have been made in sea areas with dominant bedforms, most of them mobile. Bedform migration rates have been shown to be extremely variable, fitting well into spread that has been observed worldwide (Wever 2004).

Mapping of bedform fields in the Jade area have been made over several years with side scan sonar. Mosaicing allowed construction ofmaps from several profiles. An approach to derive further information from maps of different campaigns demonstrated the need of repeated surveys with intervals of not more than 3-4 months, at least in the Jade area. Otherwise higher bedforms may not be identified correctly.

The small-scale local variability is high as can be shown seen from a different six-week deployment in



Jade. Three BRMs were deployed at a distance of 110 m (Figure 4).

Figure 4. BRM recordings (1 hour interval) in the Jade area (SE German Bight) over a period of 6.5 weeks. A very fast burial of one mine (20 cm within the first hour) is obvious. The times are given every seventh day, the tick marks mark days.

In contrast to this example also similar sand height changes can be observed (Figures 5 and 6). During the campaign in the outer Elbe near Scharhörn the mines were also separated by a distance of 105 m (Fig. 5) and 115 m (Fig. 6). Although the systems were overrun by different megaripples on the flanks of different sand dunes a correlation seems to exist.

A reason for the similarity of sand height changes in the Elbe River may be the permanent river outflow that interacts with tidal currents and causes a more homogeneous flow system compared to the Jade. There, slack water conditions with very slow currents that change the direction seem to allow 3-dimensional flow patterns before the maximum current speed is reached. Also other investigations give evidence for this process. The most prominent is the appearance of temporary ripples perpendicular to the sand dunes and megaripple crests. The ripples appear mostly in the troughs between the sand dunes.

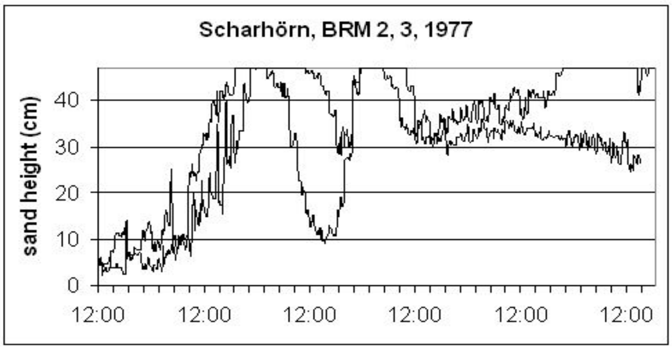


Figure 5. BRM recordings (1 hour interval) in the outer Elbe river mouth near the island Scharhörn (SE German Bight) over a period of 5.5 weeks. Distance between BRMs: 105 m. The times are given every seventh day, the tick marks mark days.

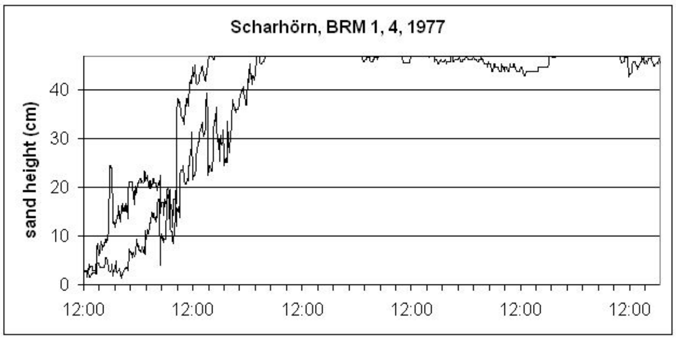


Figure 6. BRM recordings (1 hour interval) in the outer Elbe river mouth near the island Scharhörn (SE German Bight) over a period of 5.5 weeks. The distance between the two BRMs is 115 m. Same time scale as in Figure 5.

3 ROTARY SONAR MEASUREMENTS

The deployment of BRMs helped to unravel details of the bedform migration process. The deployment of up to six BRMs in close neighbourhood indicated a strong small-scale local variability of bedform migration. Even several systems deployed at short distance delivered only isolated data sets.

To gain a better understanding of differences in bedform migration a different approach was required to replace point-like observations by a wider image. Already in the 1980s a rotary scanning sonar was installed on a 5 m high tower that was deployed on the seafloor. This system was ship-bound, i.e., it required a docking of the ship at slack water for measurements. The 380 kHz sonar delivered images during flood and ebb tides. The circular images recorded with a 50 m range showed differences in location of megaripple crests of several meters. The same was observed for 4-5 m high sand dune crests.

The time interval between different measurements of 6.5 hours was too long for a doubtless interpretation and analysis. Therefore, a new system was constructed to allow measurements at any desired interval. The tower included power supply and recording equipment along with current meters (Figure 7). The rotary sonar was installed at a height of 4.5 m. After a few tests in 2003 first successful deployments were made in the Jade area in 2005.

In 2005 a 1-week recording was made with an interval of 10 minutes. In 2006 strong currents pulled it over resulting in no recordings. In 2007 a 25-hour data set was recorded at 3 minutes intervals. From both data sets (2005: ca 1000 scans, 2007: ca 500 scans) movies were constructed to allow the observation of minimum changes among subsequent records that cannot be recognized from static images. The strong variability in the 50 m radius circle along with the current information at 1 m above seafloor gives a good impression of processes at the seafloor. The movies illustrate also that substantial sediment movement starts after a minimum current speed of 60 cm/s is reached.

Figure 7. Scanning sonar tower during deployment. The total height to the rotary sonar is 4.5 m. The power supply and recording electronics are in the container near the centre of the stabilizing construction, two current meters can be seen on the far right leg and near the centre of the stabilizing construction. For improved stability lead weights were attached to the vertical legs of the tower.

The close inspection of the records reveals several interesting peculiarities of the bedform migration process. Some of them are:

(1) Megaripples tend to break up, and merge with other megaripples in front or behind.

(2) Megaripples build up at low current speeds (<0.4 m/s @ 1 m above sediment) and are flattened at speeds >0.5-0.6 m/s @ 1 m above sediment).

(3) Ripples with an orientation perpendicular to the sand dune exist in the troughs of sand dunes.

(4) The crests of 4 m high sand dunes can move ca 4-5 m within 6.5 hours (between ebb and flood slack water).

(5) Two megaripples can merge to form one new bedform, but this can split again.

(6) Megaripples that form straight crests during one tide may form irregular crests and even break up to the next.

(7) A strong lateral variability can be observed in megaripple size and presence.

Some of the mentioned observations can be illustrated on records made at flood slack water on two subsequent days (Figure 8).

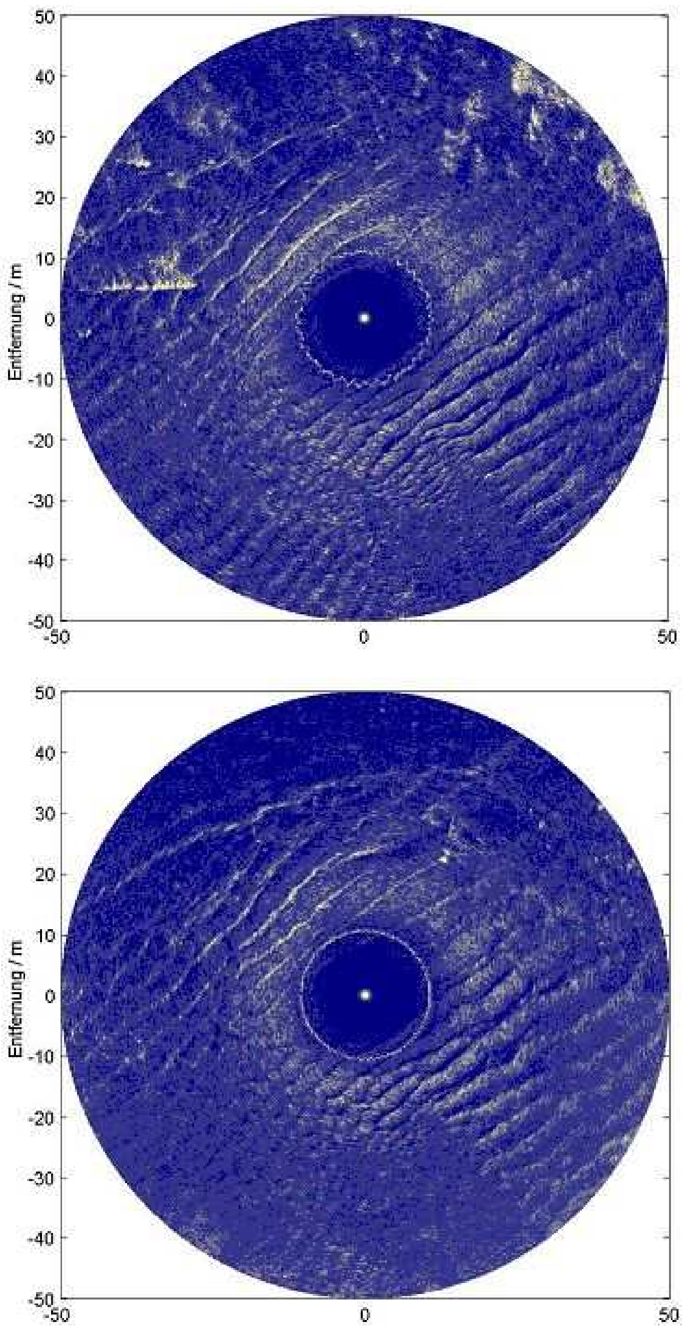


Figure 8. Scanning sonar records during flood slack water. Top: 9 Nov. 2002 (16:12), bottom: 10 Nov 2002 (15:56). North direction is towards the top. The diameter of the sonar images is 100 m. The straight line in the upper figure crossing megaripple signatures is a reflection from the ships hull. The northernmost long crest results from the sand dune on which flank the tower was deployed. Here, the change is obvious. The central circular ring results from a reflection from the sea surface, in the upper figure the wavy appearance results from surface waves.

Some of the phenomena observed in tidal current conditions are similar to those reported by Rubin (2000) in unidirectional currents of Colorado River. However, in contrast current reversals cause an adjustment of bedform shape to the prevailing regime. For megaripples this can imply a complete reorientation of the bedform. The movement of megaripple crests can exceed 6 m within 6 hours. Even the crest of 4-5 m high sand dunes were observed to change their position that much.

In addition to bedform migration an interesting phenomenon is the occurrence of clouds of suspended sediment during strong current situations. Examples are shown in movies recorded with 3 minutes and 10 minute intervals.

4 SUMMARY

Quasi-continuous surveying of bedform movement under the influence of reversing tidal currents revealed a strong variability. The variability is expressed both in location and time.

Under tidal currents sand dunes of 4-5 m height in the Jade area as well as megaripples of a few decimeters height change their crest position up to 6 m per tide. Investigations of bedform migration based on repeated surveys need to consider this in the planning and measurement phase. It is a basic demand that profiles are repeated at identical periods of the tidal phase, relative to flood or ebb slack water.

The observed local variability of bedforms includes their dimensions. Bedforms in immediate neighbourhood may exhibit differences in cross-section length of a factor of two.

Successive megaripples are observed to merge and to separate again under different current directions. This makes a correct identification of single bedforms impossible and underlines the need to resurvey bedforms always under identical conditions.

Megaripples have been observed to break up along their crest length and to merge with successive or earlier megaripples. This differential movement is another indication of a strong lateral variability and underlines the need to include wider areas in the analysis of bedform-related sediment transport.

On homogeneous flanks of sand dunes megaripples may occur directly beside bedform-free regions. An explanation for this observations is not yet available. Lack of sediment does not seem to be a prominent cause.

Ripples are observed in the troughs of sand dunes. In some cases they are oriented perpendicular to the general current direction. This is a strong indication for three-dimensional flow conditions.

5 CONCLUSIONS

The long distance of up to six meters that bedform crests move in opposite currents require identical conditions under which repeated surveys with towed or ship-bound systems are made. The best approach is the start of repetition profiles at the same time related to identical slack water (ebb or flood).

This tide-determined surveying at short intervals with non-stationary acoustic systems also helps to improve the identification process of individual bedforms.

The observed local variability of bedform dimensions and bedform occurrence points to the importance of three-dimensional processes even under reversed current direction without a tidal flow ellipse.

For estimates of sediment transport a wider area has to be surveyed in order not to base the calculations on isolated strongly or weakly mobile areas.

The major change of sediment height at a position is fast. Changes of up to 40 cm of sand height per hour have been observed.

If tidal currents interact with unidirectional river currents, a more stable sediment transport dominates, probably because at or near slack water conditions always a stable current acts.

6 REFERENCES

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