Field measurements of small scale bedform dynamics in tidal environments in the German Bight

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ABSTRACT: In a series of field campaigns an autonomous sea floor observatory has been deployed at a number of representative locations in the German Bight. For periods covering semidiurnal tidal cycles of ca. 25 h, these measurements yield information on the hydrodynamic forcing due to tidal currents and waves and their effect on the properties and dynamics of small scale bedforms. Data from several campaigns allow the assessment of seafloor dynamics for different sedimentary environments under different forcing conditions.

1. INTRODUCTION

The dynamics of bedforms like ripples and dunes in sandy sediments are well studied in laboratory flume experiments (Yalin, 1985; Baas, 1994) and in field measurements in rivers (Vanoni, 1974; van Rijn, 1984). Field observations in shallow shelf sea tidal environments with alternating or rotating tidal flow directions and varying wave conditions are rare (Bolaños et al., 2012) and so far do not systematically cover different sedimentary environments. We make use of autonomous sea floor observatories to measure hydrodynamic forcing and the response of the sea bed in terms of existence of small scale bedforms, their dimensions and migration rates. Within the project *NOAH* (*North Sea Observation and Assessment of Habitats*) this information is integrated together with biological data on microbiology and benthic fauna to characterize sea floor habitats and their dynamics.

Nine sites of different sedimentary characteristics in the North Sea have been investigated repeatedly. Water depths range from 28 to 41 meters. Bed sediments range from well-sorted fine sand to coarse sand with shell fragments. 10-minute averages of near bed peak tidal flow velocities range from 0.1 to 0.4 m/s. Small scale bedforms (ripples) of a few centimeters in height and 10-20 cm in length are abundant at most of the stations. Observed conditions span moderate tidal driven periods and moderate wave conditions up to storm events with significant wave heights exceeding 2 m.

2. METHODS

2.1. Observation platform and devices

The autonomous seafloor observatory *SedObs* is a quad pod steel frame which provides installation space for instruments at the four legs and on a platform located ca. 1.8 m above the sea bed. The observatory has been deployed at a number of representative sites for periods of at least 25 hours to cover the semidiurnal daily inequality in the tidal cycle. A photo of the recovery of the SedObs observatory is shown in
Figure 1.

The lander instrumentation comprises hydroacoustic and optical sensors for the measurement of hydrodynamic forcing and morphodynamic response of the sea floor. The bathymetry below the platform in a range of around 3 m is recorded by a 3D profiling pencil beam sonar similar to the one described by Bell and Thorne (2007). Upward and downward looking ADCPs contribute information on wave parameters and current velocity. Pointwise measurements of flow velocity and turbulence characteristics are recorded at two heights above the sea floor by Vector velocimeters. A LISST device is used to obtain the grain size distribution of suspended sediments while a CTD records pressure and environmental parameters. The sensors are operated continuously with sampling frequencies of 1 Hz (ADCPs, CTD and LISST) or in successive 8 minute bursts with a sampling frequency of 32 Hz (ADVs). The sonar takes 12 minutes for a complete 360° bathymetry scan.

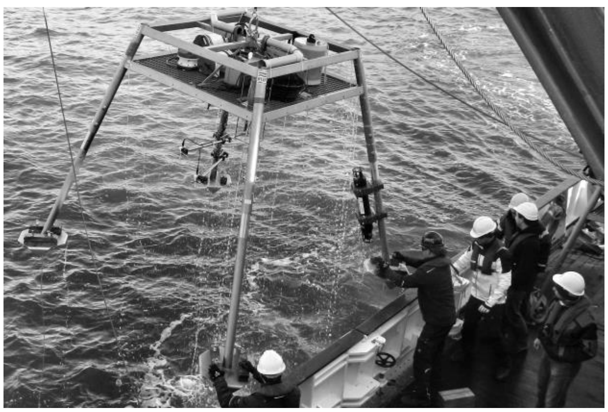

Figure 1. Recovery of seafloor observatory SedObs. Instruments visible are the upward looking ADCP on the instrumentation platform as well as two Vector-ADVs and the LISST device on the legs.

Sedimentological data such as grain size distribution statistics are calculated from Coulter laser diffractometer analysis of bed grab samples taken at the deployment sites.

2.2. Data processing

The raw data recorded by the different sensors is processed to gain a set of parameters for further analysis. Seabed characteristics are extracted from the water column echo of the profiling sonar by picking the maximum echo amplitude. The resulting scattered points are gridded with a resolution of 25 mm to obtain digital elevation models (DEMs) of the bathymetry. The central area of 2 × 2 m is cropped for further analysis (Figure 2).

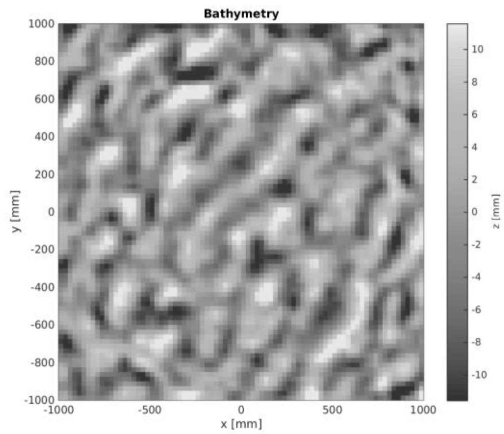

Figure 2. Exemplary dataset of small scale bedforms visible in detrended bathymetry DEM from 3D profiling sonar.

After detrending, the individual scans are subjected to image processing techniques to identify individual bedforms as objects defined by connected pixels exceeding a given threshold height. The orientation of the bedforms is used to rotate the scan which can then be analyzed in transects perpendicular to the average bedform crest orientation. Bedform dimensions height η and length λ are identified in the individual transects by detection of local extremes. Different methods for the assessment of bedform migration are applied: Bedform migration rates are derived from successive scans using either 1D cross correlation of individual transects and successive averaging of the displacement or by 2D spatial cross correlation methods related to particle image velocimetry (PIV).

To relate observed bedform migration to the tidal forcing, bottom shear stresses $\tau_{0,c}$ exerted by the tidal currents are computed by fitting a logarithmic profile to the measured velocity profile in the lower water column (Soulsby, 1997). Wave induced shear stresses $\tau_{0,w}$ are derived from wave properties (T_p, H_s) by computing wave orbital velocities using linear wave theory and a wave friction factor (Soulsby, 1997).

3. RESULTS AND DISCUSSION

Preliminary results include the observation of bedform dimensions, critical thresholds for bedform migration, and bedform celerity for consecutive tidal cycles. These are related to common predictors like the grain size dependent critical shear stress of particle motion τ_{crit}. Time series for shear stress from currents and the ripple migration rates indicate critical thresholds and their dependency. It can be shown that the results for ripple migration are similar for different analysis methodology, thus the results are considered reliable.

Interestingly, bedform migration may commence already at the threshold of bed motion, thus much longer in the tidal cycle than expected. On the other hand tidal currents may be asymmetric, resulting in bedform migration into one direction only (Figure 3).

The comparison of different sedimentological environments and hydrodynamic regimes will evaluate the validity of common bedform descriptors.

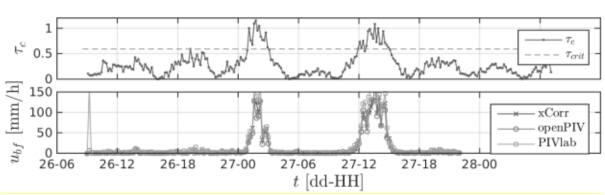

Figure 3. Current shear stress and bedform migration rates. In the upper panel, the dashed line indicates the critical shear stress computed for the median grain size. The lower panel shows the bedform migration rates computed by three different methods.

4. CONCLUSIONS

Field data on bedform characteristics in tidal environments helps to understand the dynamics of seabed ripples under varying hydrodynamic forcing conditions. Different analysis methodology has been evaluated. As the same field sites were investigated repeatedly in different situations, thresholds for bedform migration due to tidal currents and waves can be described and compared to models in literature. Furthermore, the methods outlined above allow for the computation of a robust set of parameters describing hydrodynamic forcing and morphodynamic response of the sandy sea bed. Commonly used thresholds for the initiation of motion are evaluated.
Information on bedform dimensions and migration rates can be further transferred into sediment reworking rates. These are important boundary conditions for the distribution of nutrients and oxygen for benthic organisms and bacteria in the upper part of the sea floor (Ahmerkamp et al., 2015).

5. ACKNOWLEDGMENT

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