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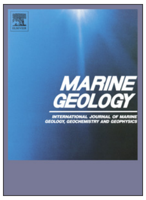

Observations of megaripples in the surf zone

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ABSTRACT

Bedform measurements were obtained under shoaling and breaking wave conditions using a pencil-beam sonar in the intertidal zone at Skallingen, Denmark. Measurements were made during four individual tidal cycles starting from flat bed conditions at low tide and as the tide rose and the instruments entered the surf zone, megaripples appeared when the mobility number exceeded 240, which equates to the classic flat-bed criterion proposed by Dingler and Inman (1976). The megaripples were oriented cross-shore and their wavelength scaled with the wave orbital diameter. Wave ripples were observed when the mobility number was smaller which occurred mainly under shoaling waves. Since all bedforms were erased as the seabed became dry at low tide and perpendicular longshore currents were occasionally strong, the megaripples were of small amplitude but their dimensions were consistent with predictions from the literature. Their migratory behaviour in the first few hours of existence appeared more strongly related to self-organisation rather than to ambient hydrodynamics. A clear gap in bedform spacing at $\lambda = 120$ cm was identified between wave ripples and megaripples.

1. Introduction

Observations of megaripples, their formation and dynamics under natural oscillatory flows are relatively rare which to some extent may be due to logistical difficulties rather than rare occurrence. Based on visual diver observations under low-energy conditions, Clifton (1976) proposed a bedform sequence driven by oscillatory flows on a planar shoreface. Arranged in order from low wave energy (deep water) to high wave energy (shallow water), this sequence begins with two-dimensional wave ripples in relatively deep water progressing through irregular 3D ripples, cross-ripples, lunate megaripples and finally flat beds under the energetic flows in the swash zone. However, since field measurements are rare and megaripples have not been identified under oscillatory flows in the laboratory, this bedform type is often omitted from oscillatory flow bedform stability diagrams and neglected in sediment transport models.

Relatively little information is available on megaripple geometry, dynamics and the conditions under which these bedforms emerge although such information would enhance understanding of the way in which megaripples affect sediment suspension and bottom boundary layer structure. Similar to wave ripples, megaripples affect the nearbed flow by increasing bed roughness, which is of order 2–5 times the flat bed roughness (Ngusaru and Hay, 2004), and hence they most likely affect the generation of near-bed turbulence and sediment re-suspension. It is likely that they also leave an imprint on sediment stratigraphy, since they are thought to be the cause of hummocky cross-stratification in nearshore deposits (Greenwood and Sherman, 1986; Gallagher, 2003).

Megaripples have been identified under both breaking (Davidson-Arnott and Greenwood, 1976; Hay and Wilson, 1994) and non-breaking waves (Vincent et al., 1999), in a bar trough (Gallagher et al., 1998) and in rip channels (Aagaard et al., 1997; Thorpe et al., 2014). Clarke and Werner (2004) undertook remote video observations at Scripps Beach, California over a 1-year period and suggested that megaripples always exist in the surf zone provided that ambient hydrodynamic conditions are not altered too rapidly. This is consistent with measurements by Gallagher et al. (1998); using an array of altimeters they showed that megaripples occurred for about 60% of the time under surf zone conditions.

The presence and stability field of nearshore bedforms have often been related to the mobility number:

$$\psi = \frac{u^2}{(s-1)gD} \tag{1}$$

where u is the horizontal free-stream (orbital) velocity vector, s is the relative sediment density (ρ_s/ρ) where ρ_s and ρ are densities of sediment and water, respectively, g is the acceleration of gravity and D is the mean sediment grain size. The transition from wave ripples to flat beds is often taken as $\psi_s \approx 240$, where the mobility number is based on the 'maximum' wave orbital velocity, $u_s = 2\ u_{\mathrm{rms}}$ (where u_{rms} is root-mean-square orbital velocity; Dingler and Inman, 1976; Hay and Mudge, 2005). However, Gallagher et al. (2003) identified megaripples occurring when $\psi_{rms} = 30$–150 (i.e. $\psi_s = 60$–300). An alternative parameter that has been used to describe bedform stability regime is the

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grain-related Shields parameter:

$$\theta' = \frac{f_w u^2}{2(s-1)gD} \tag{2}$$

where f_w is the fixed grain wave friction factor calculated from the Swart formula with 2.5D as the physical bed roughness (Nielsen, 1992). Based on laboratory observations (that did not include megaripples), Nielsen (1992) identified the transition from wave ripples to flat bed at $\theta_s' = 1$, while megaripples in the field have been observed for $\theta_s' = 0.6$–1.4 (Aagaard et al., 2001; Ngusaru and Hay, 2004) and thus again overlapping the flat-bed criterion. On the other hand, Hay and Mudge (2005) drew attention to the fact that orbital velocity (and hence mobility number and the Shields parameter) was an imprecise megaripple predictor because of significant hysteresis involved in the formation and disappearance of large bedforms. Strong mean flows have been suggested as a prerequisite for megaripple formation (Sherman and Greenwood, 1984) and/or migration (Gallagher et al., 1998; Aagaard et al., 2001), while other studies (e.g. Clarke et al., 2008) have found no statistically significant relationship between megaripple formation and mean flows.

Megaripples can be lunate or oval in planform shape and this shape is possibly dependent upon whether the ambient flow is dominated by mean or oscillatory motions, such that lunate forms would be found predominantly under strong unidirectional mean flows (Gallagher, 2003). Cross-sectional heights, $\eta = 2$–50 cm have typically been reported, with spacings of $\lambda = 50$–290 cm and migration speeds between $C = 10$–40 cm/h (Hay and Bowen, 1993; Vincent et al., 1999; Aagaard et al., 2001; Gallagher et al., 2003; Ngusaru and Hay, 2004), although migration speeds up to $C = 1$ m/h have been observed (Miles et al., 2013). Ngusaru and Hay (2004) reported onshore migrating megaripples when mean flows (with speeds up to $U = 20$ cm/s) were directed offshore, and it has been suggested that rather than being driven by mean flows, megaripple migration is caused mainly by wave orbital skewness (Gallagher et al., 1998; Miles et al., 2013).

It is still unclear what exactly triggers megaripple formation and growth. According to Gallagher (2011) formation from a flat bed requires an initial bed perturbation and Clarke and Werner (2004) observed that megaripple formation occurred within a time span of 1.7–3.1 h after surf zone conditions had been established; bedform growth was linear over the first 12 h and subsequently logarithmic with time.

In this paper, we report detailed measurements of megaripples in the surf zone of a dissipative beach under low- and moderate-energy conditions. Observations were made in the intertidal zone, where the seabed was exposed at low tide such that any bedforms that had formed on the previous tide were erased as the swash zone traversed the instrument location on the ebbing (and rising) tide. The aim of the paper is to document cross-sectional bedform dimensions and growth as well as to identify the megaripple stability field and finally, the relationship between hydrodynamic processes and sediment transport due to form migration will be addressed.

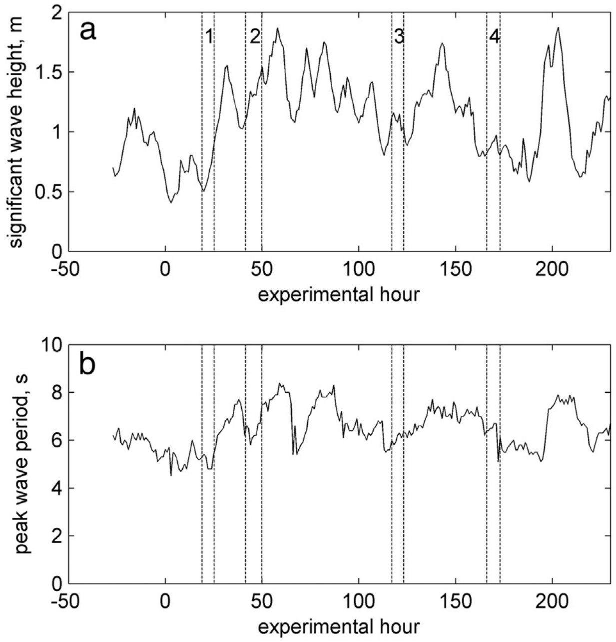

Fig. 1. Significant wave height (a) and peak spectral wave period (b) seaward of the surf zone during the experimental period. The numbered days of bed profile data collection are indicated by the vertical dotted lines. Experimental hour 0 is September 27, 1600 h.

2. Field site and experimental conditions

The field measurements were conducted between September 26 and October 6, 2012 at Skallingen on the Danish North Sea coast. Skallingen is a multi-barred, dissipative beach exposed to wind waves. Swell is largely absent, and the mean tidal range at the site is 1.5 m. Fig. 1 shows significant wave height (H_s) and spectral peak wave period (T_p) recorded seaward of the surf zone at 6 m water depth off Fanø, located 13 km south of the field site. Offshore wave conditions were low-to-moderate with H_s ranging between 0.4–1.8 m and $T_p = 5$–8 s. The cross-shore profile change in a transect across the instrument frame is shown in Fig. 2. The field instruments were installed close to the mean water level on the seaward slope of an intertidal bar. Initially, the instruments were located landward of a wide trough separating two intertidal bars but the outer of those two bars migrated significantly onshore during the experimental period. Sediment samples were collected at the instrument position during each daily low tide and the mean grain size was found to vary between $D = 180$–270 μm, with a mean for the sample set of $D = 240$ μm.

3. Instrumentation and data analysis

The instruments were mounted on a stainless steel tripod and consisted of a Sontek 5 MHz ADVOcean acoustic current meter fitted with a Druck strain-gauge pressure sensor, two optical backscatter sensors (OBS-3+), and an Imagenex 881A pencil-beam sonar (Fig. 3). The ADVO was oriented to measure positive flows onshore, upward and to the north, and data were collected at a sampling frequency of 16 Hz for periods of 17 min every half-hour over the duration of the experiment. Velocity time series from acoustic sensors tend to become noisy in highly turbulent or aerated flows that may occur within the surf zone and signal correlation values recorded by the ADVO were used to correct spurious data points. For the sampling frequency used here, the threshold signal correlation indicating inaccurate data for a particular acoustic beam is <62%. A low-pass filtered record of the original despiked velocity time series was constructed using a filter cut-off frequency of 2.5 Hz; data points in the original velocity time series that had a signal correlation below the threshold were replaced with the corresponding point from the filtered time series.

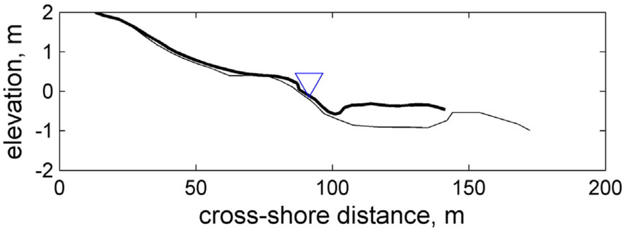

Fig. 2. Cross-shore profiles at the instrument frame measured on September 29 (thin line) and October 6 (thick line). The position of the instrument frame is marked by the triangle.