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Bedform contributions to cross-shore sediment transport on a dissipative beach

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ABSTRACT

Field measurements of hydrodynamics, suspended sediment transport rates and bedform sediment transport rates were made in the intertidal section of a dissipative sandy beach (D50 = 0.26 mm, slope = 1/80) at Perranporth (UK). Pressure transducers, acoustic Doppler velocimeters, optical backscatter sensors and an acoustic sand ripple profiler were deployed for 12 tides, measuring in a range of wave heights from 0.5 to 2.2 m, water depths from 1 to 6 m, and in current strengths up to 0.4 m/s. Data were analysed in terms of the distance to shore (x) normalised by the surf zone width (xs), and spanned the region $0.4 < x/xs < 3$. Bedform heights up to 30 cm and wavelengths 0.5 to 2.7 m were recorded. Maximum wavelengths were observed just shoreward of the breakpoint. Bedforms were classified as sub-orbital, vortex ripples. Bedform migration was mostly onshore directed, and correlated with positive (onshore) wave skewness. Migration rates increased through the shoaling zone to a maximum of 1.5 cm/min just shoreward of the breakpoint ($x/xs = 0.8$). The bedform component of sediment transport was generally onshore directed, and maximum just shoreward of the breakpoint (0.021 kg/m/s). Point measurements showed that the cross-shore suspended sediment transport 25 cm above the bed was dominated by the mean component, with an offshore directed maximum at $x/xs = 0.5$. Contributions to onshore transport were only made by the incident wave (gravity band) component. The total depth integrated suspended sediment transport was offshore directed and maximum in the mid surf zone (−0.16 kg/m/s). The depth integrated suspended sediment transport dominated over the bedform sediment transport in the inner to mid surf zone ($x/xs < 0.5$) and in the outer shoaling zone ($x/xs > 1.5$). The fractional contribution of the shoreward directed bedform transport to the total absolute transport was up to 100%, and occurred broadly in the region of the breakpoint ($0.5 < x/xs < 1.5$). However, spatial averaging in the cross-shore indicated that a more realistic bedform contribution was up to 15% of the transport, with a maximum at $x/xs = 0.9$. Results from this dissipative beach experiment generally agree with previous findings on intermediate beaches, steep beaches, and offshore sandbars.

1. Introduction

Bedforms are ubiquitous features of sandy nearshore environments, and are prevalent in the shoaling and surf zones. They play an important role in controlling bed roughness (Feddersen et al., 2003; Gallagher, 2003), and their migration makes a contribution to the overall sediment transport budget (Huntley et al., 1991). Bedforms have been shown to contribute to the total sediment transport budget on intermediate beaches (Masselink et al., 2007) and reflective beaches (Aagard et al., 2012). This paper focusses on the contribution of bedforms to the total sediment transport budget on a dissipative beach, and examines the cross-shore distribution of this transport.

In relatively deep water seaward of the surf zone, ripple migration has been shown to be a major component in the overall sediment transport budget. On a sandy ridge in 11 m water depth, Traykovski et al. (1999) measured wave ripples with wavelengths up to 1 m, and amplitude 15 cm moving onshore at rates of up to 80 cm/day. The suspended transport was a factor of 20 less than the transport accounted for by the bedforms in the deep water. On a sand bar in roughly 20 m water depth in the North Sea, Williams and Rose (2001) measured ripples of length 0.44 to 1 m, migrating at up to 1.18 mm/s. The bedform transport was dominant over the suspended transport, with volumetric transport rates up to 8.37×10^{-5} m^2/s while suspended sediment transport rates reached 3.98×10^{-5} m^2/s.

Approaching the surf zone from offshore, Clifton et al. (1971) observed that the wave ripples which typically form in deeper water change to become megaripple features in the surf zone, with larger wavelengths and heights. The shoaling zone and surf zone megaripple heights are typically 0.1 to 0.5 m, and lengths are typically 0.5 m to 5 m (Gallagher, 2003; Gallagher et al., 1998b). Field measurements show that the bed roughness associated with these features is largest at moderate mobility numbers (Gallagher et al., 2003). Megaripples are reported as three-dimensional, and although they may take on a

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regular alongshore structure, they may also develop as hummocks and holes in a less regular distribution (Gallagher, 2003). The direction of megaripple advance is generally shoreward (e.g. Ngasuru and Hay, 2004), and migration rate has been shown to depend on the incident wave skewness (Crawford and Hay, 2001; Gallagher et al., 2003), and the mobility number (Traykovski et al., 1999; Vincent and Osborne, 1993).

Masselink et al. (2007) investigated variations in ripple migration rates on a coarse grained intermediate sandy beach ($D_{50} = 0.7$ mm) at Sennen (UK). Ripple heights of 0.05 m and lengths of 0.35 m were recorded, and migration rates were approximately 0.1 cm/min onshore in the shoaling zone. In low-wave conditions, bedform transport rates (wave ripples) were of the same order of magnitude as suspended load rates. In high energy conditions however, the bedform transport was an order of magnitude lower. In the outer surf, Masselink et al. (2007) measured onshore directed ripple migration rates of 2 cm/min. Here, bedform transport rates were an order of magnitude smaller than the suspended transport. No bedform transport took place in the inner surf.

On a steep beach at Pearl Beach, NSW Australia (gradient = 1/10; $D_{50} = 0.25$ to 0.45 mm), Aagard et al. (2013) found that bedform transport in 2 m water depth was onshore directed in ‘post-storm’ conditions ($H_s \sim 0.5$ m), but offshore directed in the ‘storm’ conditions ($H_s \sim 1$ m). In the post-storm conditions, the net suspended sediment transport was offshore directed and approximately an order of magnitude larger than the net bedload transport. The data for the storm conditions showed variable dominance, due to variability in the suspended sediment transport values.

Suspended sediment transport rates are often described in terms of their cross-shore position relative to the surf zone (e.g. Marino-Tapia et al., 2007a). Observations of onshore directed sediment transport in shoaling waves outside the surf zone (e.g. Hanes and Huntley, 1986), offshore directed sediment transport by undertow inside the surf zone (e.g. Osborne and Greenwood, 1992; Russell, 1993), and onshore directed sediment transport in the swash zone (e.g. Masselink and Russell, 2006; Miles et al., 2006) have led to ‘shape functions’ that parameterize cross-shore transport rates as a function of distance from the shore, normalised by surf zone width (Russell and Huntley, 1999; Tinker et al., 2009). This approach has given some success in replicating morphological features such as surf zone bar crest position (Marino Tapia et al., 2007b). These studies have not yet been able to incorporate bedform transport rates, but the cross-shore distribution approach offers a useful framework within which to consider the contribution of bedforms.

The general understanding of the bedform contribution to sediment transport is that in deep water, the bedform component is onshore, and large compared to the suspended component. Towards the shore (through the shoaling and surf zones), the suspended transport becomes progressively more important. This observation is based on data from offshore sandbars (e.g. Traykovski et al., 1999), macrotidal coarse grained steep beaches (e.g. Masselink et al., 2007), and microtidal fine grained intermediate beaches (e.g. Ngasuru and Hay, 2004). In this paper, analysis of the cross-shore distribution of bedform sizes, migration rates and contribution to sediment transport are presented from a dissipative beach. The data extends from relatively deep water (~6 m) through shoaling wave conditions with skewed waves, into the surf zone where incident waves and offshore directed undertow contribute to controlling the sediment dynamics.

2. Field measurements

Field measurements were made at Perranporth (Cornwall, UK), where a macrotidal, dissipative sandy beach faces WNW into the Atlantic Ocean (Fig. 1) (Miles et al., 2014a). A rig of instruments was deployed near the low water mark, close to LW springs. The wave climate at the site gives a mean offshore wave height of 1.6 m (Davidson et al., 1997), and the mean tidal range is 6.1 m.

Data is presented here spanning twelve separate high tides, from May 2011 (6 tides) and October 2011 (6 tides). The beach profile was reasonably linear, with an average slope of 1/80 (Fig. 2). The tide flooded and ebbed over the instrument rig, and measurements were therefore possible in water depths up to 6 m, and at different cross-shore locations relative to the surf zone. Sediments sampled at the rig location were medium sand ($D_{50} = 0.28$ mm).

The general layout of the instrument rig is shown in Fig. 3. A pressure transducer (PT) was mounted at bed level to measure water depths and wave heights. Flow velocities were measured using an acoustic Doppler velocimeter (ADV). The sensing volume was 25 cm above the bed. The sensor was carefully aligned to measure on-offshore velocities. Two optical backscatter sensors (OBSs) were used to measure suspended sediment concentrations. These were deployed at 5 and 15 cm for the first six tides and at 25 and 40 cm above the bed for the second six tides. Bedform elevation measurements were made using a sand ripple profiler (SRP). This was positioned 90 cm above the bed, taking a shore-normal line scan of length 2 m, once per minute. SRP data was processed to give regular horizontal (on-offshore) resolution of 1 cm over the scan.

The ADV, OBS and PT data were recorded continuously at 16 Hz (first six tides) and 8 Hz (second six tides). The data were separated into sequential 10-minute long sections (runs), and these were analysed to give hydrodynamic and sediment dynamic parameters. Corresponding bedform parameters were calculated from the SRP data. Data is presented here from when the water depth was greater than 0.9 m, when all instruments were submerged and functioning simultaneously.

3. Hydrodynamics

Hydrodynamic conditions for each of the tides recorded at the rig are shown in Fig. 4. Dry periods at low water between experiments have been removed. Water depths when all instruments were submerged and functioning were in the range 0.9 to 6 m. Wave heights (H_s) were calculated using a standard $H_{1/3}$ zero up-crossing method, having first corrected for depth attenuation. H_s was in the range 0.48 to 2.19 m. Wave period, calculated as $T_{1/3,}$ showed that the site experienced mostly swell waves ($T_{1/3} = 10$ to 11 s), although data were also collected for $T_{1/3} = 7$ to 8 s.

The instruments in this experiment measured processes at different cross-shore locations in the surf zone, due to the large tidal range at the site. A normalised expression for the cross-shore distance from the shore to the instruments (x) in relation to the surf zone width (x_s) was identified from the water depth (h) and the break point water

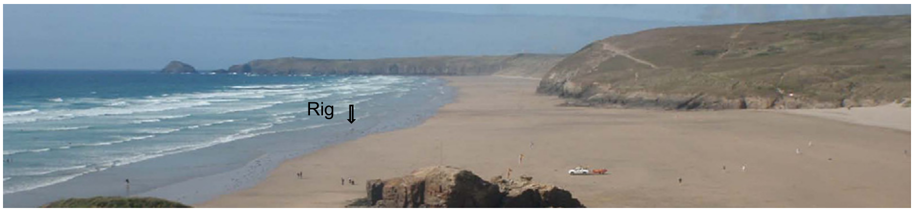

Fig. 1. General view of Perranporth beach during the experiments in May 2011, showing the rig position at approximately LW springs.