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Morphodynamic variability of high-energy macrotidal beaches, Cornwall, UK

Tim Poate [a,*], Gerhard Masselink [a], Paul Russell [a], Martin Austin [b]

[a] School of Marine Science and Engineering, Plymouth University, Plymouth PL48AA, UK
[b] School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, LL59 5AB, UK

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ABSTRACT

Spatial data collected over three years are presented to assess the extent of morphological variability under seasonal and storm waves on two high-energy macrotidal beaches on the north Cornish coast. Of particular interest was the degree to which the beaches displayed bar/rip morphology and a novel approach to quantify the three-dimensionality of the beach based on the curvature of the bottom contours is adopted to identify and classify the three-dimensional beach response to changes in the dominant forcing conditions. Morphologically, the beaches range from dissipative to intermediate and are characterised by low tide bar/rip morphology which plays a key role in the nearshore dynamics and beach safety. Real-time kinematic (RTK) GPS surveys were undertaken using an all-terrain vehicle to measure the three dimensional (3D) morphology. In addition, nearshore wave data, in-situ hydrodynamic measurements, local tide gauges and Argus video data allowed detailed analysis of process–response mechanisms for long term (yearly); seasonal (monthly); storm (weekly/daily); and tidal (hourly) morphological behaviour. Both sites exhibited net long term accretion derived from the intertidal beach volume. Throughout the survey period, inter-site similarity in beach response was observed in response to storm waves, yet coupling between the seasonal wave climate and the beach morphology was not evident at either of the sites. Increased wave conditions (exceeding $H_s = 4$ m) during sustained storm events (>50 h) led to offshore transport from the beachface to the subtidal bar region. Post-storm recovery was characterised by onshore transport and the development of substantial 3D low tide morphology. Under normal wave conditions ($H_s = 1.6$ m), the dominant 3D features smoothed out as channels in-filled and bar prominence reduced over a period of 2–3 months. Overall, the beaches exhibited a significant storm-dominated morphological response cycle, unlike the more familiar winter/summer seasonal response.

1. Introduction

Most studies of nearshore morphodynamics investigating beach response to wave forcing over a range of spatial and temporal scales have focused on micro-mesotidal environments, with only few comparative macrotidal studies (Battiau-Queney et al., 2003; Masselink et al., 2007; Reichmüth and Anthony, 2007). The importance of short-term beach response to hydrodynamic conditions is clear and such studies have done much to further our understanding and modelling capabilities of coastal processes (e.g., Wright et al., 1985). Although there have been several medium to longer term (>1 year) studies into the behaviour of high-wave energy/macrotidal environments (Jago and Hardisty, 1984; Reichmüth and Anthony, 2007), as well as more intensive short-term studies (Masselink et al., 2007), these datasets have used multiple cross-shore profiles at varying alongshore spacing to assess beach response. Work by Ruggiero et al. (2005) and Hansen and Barnard (2010) has utilised longer three dimensional (3D) datasets (~5 years) to assess seasonal variability for more energetic mesotidal sites with a focus on larger scale shoreline response and beach management. There remains a relative paucity of consistent, detailed 3D morphological data from energetic macrotidal beach localities.

Rapid beach profile response to energetic wave conditions is seen most noticeably on micro-mesotidal beaches (Komar, 1985). The presence of a large tidal range forces the transitions of morphodynamic zones across the beachface, resulting not only in the suppression of morphological features (Masselink et al., 2007), but also in increased relaxation times and relatively stable beaches (Wright et al., 1982). The complex dynamics exhibited through more subtle cross-shore and longshore morphological changes on large tidal beaches requires 3D analysis over a wide spatial extent to promote understanding of such systems as a whole. Large tidal beaches at the intermediate/dissipative beach state boundary (which are always relatively high energy beaches) exhibit quasi-seasonal low tide bar/rip systems (Scott et al., 2011) which are of significant interest to beach users in terms of surfing and as potential hazards (Scott et al., 2007). The sensitivity of the 3D

* Corresponding author. Tel.: +44 1752 586181.
E-mail addresses: timothy.poate@plymouth.ac.uk (T. Poate), gerd.masselink@plymouth.ac.uk (G. Masselink), paul.russell@plymouth.ac.uk (P. Russell), martin.austin@plymouth.ac.uk (M. Austin).

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morphology to shifts in forcing conditions requires a multifaceted approach to further understand the dominant processes and the subsequent beach response.

This paper comprises the first long-term (3 year) dataset of monthly 3D morphological survey data collected at two high-energy macrotidal beaches. Real-time kinematic (RTK) GPS survey data are supported by almost continuous Argus images at two sites and information on the hydrodynamic forcing is provided by a nearshore directional wave buoy. The principal aim of the dataset is to assess the nature and variability of the morphological response at each site to the seasonal and storm-induced variations in the hydrodynamic forcing. Within this central aim, specific objectives are to: (1) identify the variability in 3D morphology between the two sites; (2) identify site-specific 2D/3D morphological behaviour; (3) characterise site-specific response to storm conditions; and (4) quantify the temporal and spatial variability of response under normal and storm conditions.

2. Field setting

Two study sites located on the north Cornish coast were chosen for the monitoring programme: Perranporth and Porthtowan (Fig. 1). The sites were selected to provide comparison of different beach shapes and their importance for beach users. The north Cornish coast is macrotidal (mean spring tidal range MSR 6.1 m) and exposed to a highly energetic wave climate (mean offshore $H_s = 1.6$ m) of both local wind-generated seas and North Atlantic swell (Davidson et al., 1997; Poate et al., 2009). Both beaches have a W-NW orientation and are exposed to the dominant wave approach (Table 1).

Perranporth (subsequently referred to as PPT) forms the largest survey area with a cross-shore intertidal region of 500 m and a longshore extent of 1.2 km. The wide and highly dissipative beach has a low tide beach gradient of $\tan\beta \approx 0.012$ and is composed of medium sand ($D_{50} = 0.35$ mm). The relatively high carbonate content of the sand (~50%; Merefield, 1984) suggests that offshore sediment sources are of importance. The beach is relatively featureless throughout the upper intertidal region, but a well-developed bar system interspaced with rip channels is exposed at spring low water combined with a linear to crescentic subtidal bar system (Austin et al., 2013).

To the south of PPT is Porthtowan (subsequently referred to as PTN; Fig. 2). PTN is situated in a valley flanked with high Devonian slate cliffs (70 m ODN) creating a narrow pocket beach from mid to high tide. At low tide PTN extends up to 600 m cross-shore, depending on the bar/rip morphology present, with the alongshore survey area increasing to 500 m (Fig. 2). The sediments across the lower slope ($\tan\beta \approx 0.015$) consist of medium sand ($D_{50} = 0.38$ mm; Table 1), whereas the upper beach ($\tan\beta \approx 0.05$) comprises a mixture of gravel and sand with exposed boulders during periods of sand removal resulting from beach erosion.

Wave data presented throughout this paper are derived from the directional wave buoy located off PPT which provides real-time wave data, as well as archive files for the duration of the survey schedule. Detailed summary wave conditions including significant wave height H_s, peak wave period T_p, zero-crossing wave period T_z and wave direction are presented in Fig. 3. The seasonal variability in the wave climate is evident with wave height increasing during the winter months together with long period wave conditions, whereas during the summer wave height and period are reduced. Large wave events are more prevalent during winter, although the conditions at the end of March 2010 stand out to extend this period compared with sustained calm conditions experienced for the remainder of the year. Dominant westerly waves form the majority of the wave directions and are generated during the passage of Atlantic low pressure systems; however, there is also a small, but significant, amount of energy from northerly waves which often occurs following sustained high pressures and northerly winds.

3. Method

This study uses a combination of in-situ and remote methods of data collection, complemented by data from third parties. Survey data presented here were collected using a real-time kinematic global positioning system (RTK GPS), mounted on an All-terrain Vehicle (ATV) to enable collection of morphological data over an extensive intertidal region during spring low tide. A total of 72 topographic surveys were undertaken at the two sites over a three-year period with data collection occurring during the lowest spring tide each month (~every four weeks). In addition, opportunistic post-storm surveys were also undertaken in response to energetic wave conditions.

The eastings, northings and elevation points were logged using the OSGB36 Ordnance survey grid, and were subsequently transformed with rotation and translation onto a local alongshore/cross-shore

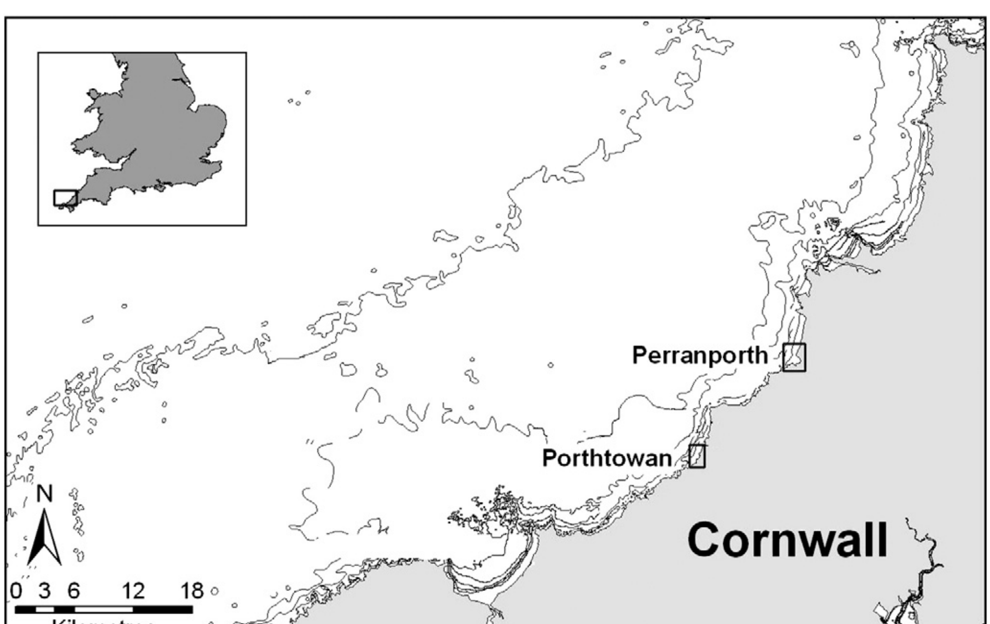

Fig. 1. Location map of the two survey sites: Porthtowan and Perranporth.