Marine Geology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

The extreme 2013/2014 winter storms: Beach recovery along the southwest coast of England

Tim Scott [a,*], Gerd Masselink [a], Tim O'Hare [a], Andrew Saulter [b], Tim Poate [a], Paul Russell [a], Mark Davidson [a], Daniel Conley [a]

[a] Coastal Processes Research Group, School of Marine Science and Engineering, Plymouth University, United Kingdom
[b] United Kingdom Met Office, Exeter, United Kingdom

ARTICLE INFO

Article history:
Received 8 January 2016
Received in revised form 27 October 2016
Accepted 28 October 2016
Available online xxxx

ABSTRACT

Sand and gravel beaches naturally act as a coastal buffer, absorbing wave energy and dynamically adapting to the seasonal and long-term wave climate. Significant shifts in nearshore morphology can occur during extreme wave events, which can have a significant impact on coastal vulnerability. During the winter of 2013/14, the Atlantic coast of Europe received an unprecedented sequence of very energetic wave conditions (8-week mean offshore $H_s = 4.4$ m). These events caused extensive physical (beach and dune erosion) and socio-economic (flooding, damage to infrastructure) impacts throughout the west coast of Europe. Many monitored sites in the UK and France were in their most eroded state since morphological records began (5–10 years). We consider the geomorphological significance of the storm response at 38 natural beaches in the southwest of England, ranging from semi-sheltered reflective gravel barriers to ultra-dissipative exposed sand beaches with dunes. The extent and patterns of post-storm recovery are examined in detail at three beaches with characteristic storm response behaviours. Exposed sandy beaches were dominated by cross-shore transport processes leading to significant loss of sediment offshore from the intertidal zone (>200 m^3/m); exposed gravel beaches were dominated by overwash with significant loss landward; and semi-sheltered sites exposed to more oblique wave forcing were dominated by a rotational response due to alongshore sediment redistribution. Due to these contrasting responses, mechanisms and timescales for beach recovery displayed strong inter-site and intra-site variations. In offshore and rotational cases, the recovery processes were multi-annual, comprising seasonal to decadal signals and were intrinsically linked to the storm response mechanisms, while permanent losses occurred when overwash dominated. We show that post-storm recovery does not necessarily occur during calm periods and that in many cases high-energy wave events appear to be essential for recovery of sediment (offshore and counter-rotation). Our results highlight the significance of dominant climatic oscillations, multi-annual storm sequencing, storm tracks and resultant variations in wave angle, in controlling the impact that extreme wave events have on contrasting sand/gravel beaches in exposed/sheltered locations.

1. Introduction

Sand and gravel beaches naturally act as a coastal buffer (Stive et al., 2002), absorbing wave energy and dynamically adapting to the seasonal and long-term wave climate. In the short- to medium-term (seasons to years), significant shifts in nearshore morphology can occur during extreme events (single large storms or storm clusters), causing lowering of intertidal beaches and scarping of dune systems (Splinter and Palmsten, 2012), reducing the protection offered to subsequent storm events and elevating risks of coastal inundation (Elko et al., 2014). High-energy wave events will also mobilise offshore sediments at depth, advected by storm driven nearshore currents, like bed return flow (e.g., Roelvink and Stive, 1989; Özkan-Haller, 2013) and rip currents (e.g., Loureiro et al., 2012), modifying the position of offshore bars and shoals, and hence nearshore wave transformation (Senechal et al., 2011; Coco et al., 2014; Lewis et al., 2014). These erosional responses can result in reduced or modified beach levels, which have short- to medium-term impacts for coastal vulnerability (Masselink et al., 2015). Therefore, understanding post-storm recovery mechanisms and timescales, throughout a range of coastal environments, is critical for future coastal hazard prediction, as well as long-term coastal evolution modelling (Ranasinghe et al., 2013).

Shorelines can recover from storm-induced erosion, but beach recovery rates are highly variable. Significant recovery can occur within days (Birkemeier, 1979; Poate et al., 2015), but more typically takes several months. In some cases, full recovery from severe storms can take up to a decade (Thom and Hall, 1991), if at all, especially where sediment

* Corresponding author.
E-mail address: timothy.scott@plymouth.ac.uk (T. Scott).

http://dx.doi.org/10.1016/j.margeo.2016.10.011
0025-3227/

has been lost to the system, either offshore, alongshore or landward. It is the balance between storm response, storm frequency and recovery rates that controls the long-term coastal evolution and vulnerability, but our understanding of coastal storm response is limited by the quality and appropriateness of the datasets available (Coco et al., 2014), particularly for quantitative measurements throughout a full sequence of beach recovery.

During winter, the coasts of western Europe are exposed to strong easterly-tracking extratropical cyclones, which can arrive explosively in high-frequency (order days) storm sequences during particularly high-energy seasons, often associated with positive North Atlantic Oscillation (NAO) index (Donat, 2010; Bromirski and Cayan, 2015). Recent studies have shown that the NAO and extreme storm clustering can be dynamically linked to atmospheric Rossby wave breaking (Woollings et al., 2008; Hanley and Caballero, 2012) and quasi-annual stratospheric east-west wind reversals associated with the Quasi-Biennial Oscillation (QBO; Baldwin et al., 2001). The QBO influences the stratospheric polar vortex and hence the winter NAO and Atlantic-European climate, especially in winter (Marshall and Scaife, 2009). These mechanisms collectively contribute to climate variability, which has been shown over recent decades to modify the wave climate (Dodet et al., 2010; Bromirski and Cayan, 2015) and subsequently beach morphological state (Masselink et al., 2014).

While there is currently little consensus on long-term changes in Atlantic storminess, an analysis of satellite observations over NW Europe by Young et al. (2011) showed a significant increase in extreme wave heights ($H_{s\ 1\%}$) over the past 20 years (1985–2008), greater than anywhere throughout the global oceans. Donat et al. (2011) showed upward trends in European storminess and demonstrated strong decadal variability in extreme wind storms over the last century in NW Europe, with some climate research suggesting that the northeast Atlantic is predicted to experience significant increases in winter and autumn extreme values of significant wave height (H_s) by the end of the this century (Wang et al., 2012). Most importantly, large amounts of inter-annual and decadal variability in the climate-ocean system leads to the potential for significant coastal morphological changes that can expose coastal communities to sequences of higher levels of flood risk than the long-term background.

The storm events described by Masselink et al. (2015) that took place during the winter of 2013/14 along the Atlantic coast of Europe represented an unprecedented sequence of very energetic wave conditions occurring over a 3-month period. The peak value of the 8-week averaged significant wave height (8-week mean offshore $H_s = 4.4$ m) measured offshore of southwest England during the winter of 2013/14 was extremely rare.

Analysis of a 60-year hindcast wave model record (validated by offshore wave buoy measurements) by Masselink et al. (2016) suggests that with the exception of the far north region (Ireland), the 2013/2014 winter was the most energetic since 1948. In this study, a Generalized Extreme Value (GEV) analysis of annual maxima (Coles, 2001) in peak 8-week average wave heights suggest the 2013/2014 storm sequence had a minimum return period of 1 in 50 years and a best fit estimate of order 1 in 250 years. Measured offshore wave data from the southwest of England (wave platform 30 km offshore in 60 m water depth; refer to Fig. 1 for wave platform location) showed that H_s during the largest recorded storm exceeded 9 m with a peak wave period (T_p) of 23 s. These storms caused extensive physical (beach and dune erosion) and socio-economic (flooding, damage to infrastructure) impacts throughout the west coast of Europe (Ireland, UK, France, Spain and Portugal). Throughout monitored sites in the UK and France, most were in their most eroded state since morphological records began (5–10 years; Poate et al., 2014; Castelle et al., 2015; Masselink et al., 2015), highlighting the vulnerability of the Atlantic coast of Europe to such coastal hazards (Castelle et al., 2015).

To assess and mitigate coastal impacts of future extreme storm events, consideration of forcing mechanisms operating over short- (weeks-months; individual storms), medium- (months-years; storm clusters/patterns) as well as long-term (years-decades; climatic variability) time scales is required. Recent work by Masselink et al. (2015) reported on a preliminary analysis of the beach response in southwest England during the extreme winter of 2013/14 in Europe. In addition to highlighting the important roles played by storm characteristics

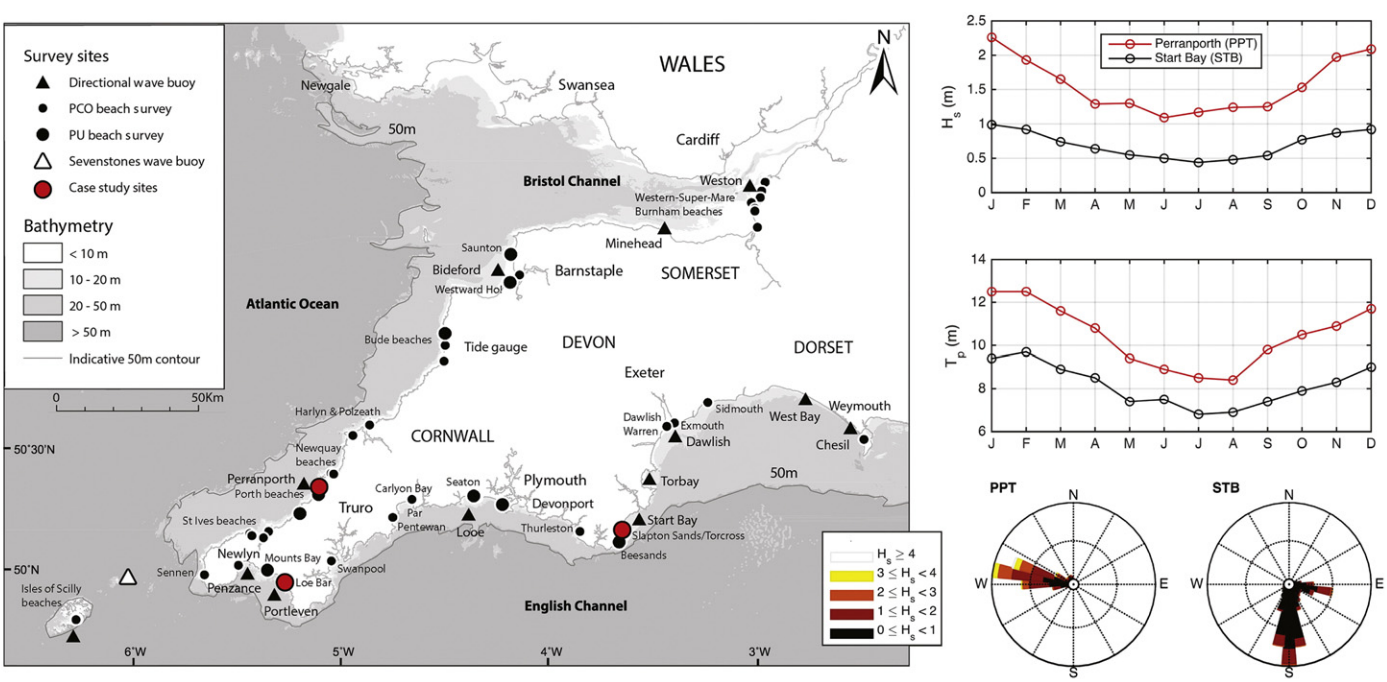

Fig. 1. Location of data sources. Left panel: map of the southwest of England showing location of offshore and nearshore directional wave buoys, beaches regularly monitored by the Plymouth Coastal Observatory (PCO), sites that are part of the Plymouth University (PU) coastal monitoring programme and specific case study sites discussed further in this study (red circles). The 50-m depth is indicated. Upper right panels: nearshore mean monthly significant waves height (H_s) and peak wave period (T_p) measured at Perranporth (exposed west coast; red) and Start Bay (semi-exposed; black) south coast in 16 m and 10 m depth, respectively. Bottom right panel: directional wave rose for both sites indicating distribution of H_s. Wave data represents a 9-year record from 2006 to 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Please cite this article as: Scott, T., et al., The extreme 2013/2014 winter storms: Beach recovery along the southwest coast of England, Marine Geology (2016), http://dx.doi.org/10.1016/j.margeo.2016.10.011