Estuarine, Coastal and Shelf Science 164 (2015) 301–312

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Comparison of storm cluster vs isolated event impacts on beach/dune morphodynamics

Pushpa Dissanayake [a, *], Jennifer Brown [b], Paul Wisse [c], Harshinie Karunarathna [a]

[a] Energy and Environment Research Group, College of Engineering, Swansea University, Singleton Park, Swansea, SA2 8PP, UK
[b] National Oceanographic Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool, L3 5DA, UK
[c] Sefton Metropolitan Borough Council, Magdalen House, Trinity Road, Liverpool, L20 3NJ, UK

A R T I C L E I N F O

Article history:
Received 13 January 2015
Received in revised form
17 July 2015
Accepted 30 July 2015
Available online 6 August 2015

Keywords:
Storm cluster
Dune erosion
XBeach
Sefton coast
Liverpool Bay
Formby point

A B S T R A C T

Two-dimensional numerical simulations were used to investigate the impacts of storm clustering on the beach/dune evolution of the Sefton coast, Liverpool Bay, UK. A storm cluster consisting of a series of closely spaced seven events was identified using observed wave and surge data during the 2013/2014 winter period. First event in this cluster is regarded as exceptionally intense and the occurrence of seven storms within a very short time period, is unique. The XBeach coastal area model was used to simulate beach change from 1) the storm sequence (*Clustered events*) and 2) the same storms considering them as *isolated events*. Offshore metadata was transformed to the nearshore area using the Delft3D and SWAN models. Resulting evolution was first compared with the available post-storm profiles measured at a number of locations along the Sefton coast. Analysis of the *Clustered* and *Isolated* simulations showed the effect of clustering on the Sefton beach/dune system when compared to the impact of isolated events occurring on a fully recovered beach system. Morphological change occurred during each storm in the *Cluster* was influenced by the preceding storm(s), such that the evolution is not proportional to the storm power of the event, as it would be for *Isolated* events. Both storm cases resulted in heavy erosion at Formby Point (i.e. central of the Sefton coast) and accretion in the north and south. The *Cluster* prevented system recovery with the area of erosion continually extending south along the coast compared with that in *Isolated* events. The initial storm within the *Cluster* caused large bed level changes in the nearshore ridge-runnel system, enabling the subsequent storms to penetrate further south. The local convex geometry of the Sefton coast is found to have more influence on the beach/dune morphodynamics than the clustering effect. This study enhances the understanding beach/dune response to storm clusters, to interpret observed morphological changes and to develop tools for sustainable coastal management particularly in the Sefton coast and generally in similar systems worldwide.

1. Introduction

Beach/dune systems are natural barriers against coastal inundation, and are often under threat due to storm-induced erosion (Harley and Ciavola, 2013). Therefore, erosion is of concern for coastal safety and sustainable development in the areas where frontal dune systems are present. Damages to beach/dune systems from storm impacts depend on a number of factors. Large storm events with higher wave heights generally cause greater damage while storm duration, direction, peak wave period and water level also significantly contribute to the extent of the damage (Karunarathna et al., 2014; Cox and Pirrello, 2001). Furthermore, the occurrence of a series of storms could result in more severe impact compared with that of a single storm with the same characteristics (Lee et al., 1998). Investigations of beach/dune system evolution due to a series of storms are presented in Karunarathna et al. (2014), Ferreira (2005), Callaghan et al. (2008) and Vousdoukas et al. (2012). Karunarathna et al. (2014) found that clusters of small storms occurring at close intervals can cause more damage than large isolated storms along the Narrabeen Beach Australia. Ferreira (2005) compared erosion due to storm clusters and single events using a long-term wave record for northwest Portuguese coast and found that storm clusters with small return

* Corresponding author.
E-mail addresses: p.k.dissanayake@swansea.ac.uk (P. Dissanayake), jebro@pol.ac.uk (J. Brown), paul.wisse@sefton.gov.uk (P. Wisse), h.u.karunarathna@swansea.ac.uk (H. Karunarathna).

http://dx.doi.org/10.1016/j.ecss.2015.07.040
0272-7714/

levels induced average erosion volumes equivalent to a single storm with a larger return period. Callaghan et al. (2008) showed the impact of closely spaced storm events on the erosion volumes using a probabilistic approach. Beach erosion and recovery processes due to consecutive storms were investigated by Vousdoukas et al. (2012).

Intense storms can cause episodic erosion of a beach/dune system, however, the system generally recovers during calm weather conditions. The time period required for a system to recover to its pre-storm state is defined as the '*recovery period*'. If a second storm event attacks within the recovery period of the first event, more damages are expected on beach/dune due to the fact that the system is more susceptible to erosion after the first storm event. By definition, a cluster of storm events should result in increased erosion of beach/dune systems compared with that of a single occurrence of a more intense storm. However, the effects of storm clustering also depend on the local geometry of beach/dune systems, particularly whether the beach/dune profiles have steep or gentle gradients, and the coastline geometry relative to wave attack.

Process-based numerical models developed to investigate the storm driven coastal morphodynamic evolution, have rapidly been advanced over the last years with increased physical processes embedded to predict more accurate and reliable beach/dune changes (Stive and Wind, 1986; Larson and Kraus, 1989; Roelvink and Stive, 1989; Bosboom et al., 2000; Larson et al., 2004; Roelvink et al., 2009). The XBeach model (Roelvink et al., 2009) is one of the latest developments and an *off-the-shelf* model which is being continually improved by applications to different coastal environments worldwide. This model has proven to be capable of predicting storm impacts on morphodynamics of beach/dune systems in numerous case studies (Splinter et al., 2014; Dissanayake et al., 2014; Souza et al., 2013; Harley and Ciavola, 2013; Splinter and Palmsten, 2012; Harley et al., 2011; Williams et al., 2011; McCall et al., 2010; Lindemer et al., 2010). These previous applications motivated us to use XBeach in the present study to investigate the effects of storm clustering on the beach/dune evolution of the Sefton coast, Liverpool Bay, UK.

Few studies have focused on applying numerical models to investigate beach/dune response to storm events along the Sefton coast (Dissanayake et al., 2014; Souza et al., 2013; Williams et al., 2011). Both Souza et al. (2013) and Williams et al. (2011) have focused on the storm driven dune erosion and potential hinterland flooding of the Sefton coast. They adopted a 1D XBeach numerical model imposing event-scale wave boundary conditions (i.e. single event) over a few tidal cycles. Dissanayake et al. (2014) used a 2D XBeach model to investigate event-scale morphodynamic response of Sefton beach/dune system to isolated storms, as in the previous two studies. However, none of the studies investigated storm clustering effects on this beach/dune system. The present research therefore investigates storm clustering effects on beach/dune morphodynamics, using the 2013/2014 winter storms and the 2D XBeach model. This includes the alongshore transport contribution and provides alongshore variation of the cluster impacted erosion/accretion patterns. The model setup of Dissanayake et al. (2014) was used in this study to identify the difference between storm clusters vs isolated events impacts.

Results of the clustering effects on beach/dune erosion, will be useful to interpret observed evolutions supplementing shoreline monitoring with detailed information between surveys. This information will also provide guidance for local coastal managers when reviewing the shoreline management plans and be of interest more widely when developing management strategies for the highly dynamic Sefton beach/dune system as more frequent storm clustering during winter months can be generally anticipated in future as a result of global climate change. Though this study focuses on a selected beach, the research findings are transferable to any beach/dune system with similar characteristics worldwide.

This paper is organized as follows. Section 2 and 3 describe the study area and the storm cluster that occurred in winter 2013/2014 respectively. Section 4 describes the modelling approach used to assess the morphodynamic impact of the storm cluster. A discussion is given in Section 5 while Section 6 provides conclusions.

2. Study area

The Sefton coast has a convex shape and stretches about 36 km from the Mersey (in the south) to the Ribble (in the north) estuaries in the Liverpool Bay (Fig. 1) (Williams et al., 2011). The Sefton coastal system consists of natural beaches/dunes of high recreational and conservation value, engineered beaches protected by seawalls, groynes, rock armour and revetments and, a man-made rubble beach. The dune system extends about 4 km inland, reaches about 30 m in height at some locations (Esteves et al., 2012) and represents the UK's largest dune complex (Holden et al., 2011). These dunes form an effective natural coastal flood defence for the local urban areas, high grade agricultural lands and a significant number of conservational areas of national and international interest, which consist of extremely high biodiversity, forming the habitat of a number of rare animals and plants (Edmondson, 2010).

The semi-diurnal hyper-tide in Liverpool Bay propagates alongshore with a mean spring tidal range reaching about 8.2 m at Liverpool Gladstone Dock (see location TG in Fig. 1) (Brown et al., 2010a; Palmer, 2010). Long-term wave measurements from 2002 to 2013 are available at the WaveNet buoy at 0.5 hourly intervals (see location WAV in Fig. 1). Using this information, Brown et al. (2010b) simulated an 11-year wave hindcast which suggests a mean annual significant wave height (H_{m0}) of 0.5 m, with extremes reaching 5.6 m. The mean annual peak wave period (T_p) is 5 s while extremes are about 22 s. Positive surge in the area is often less than

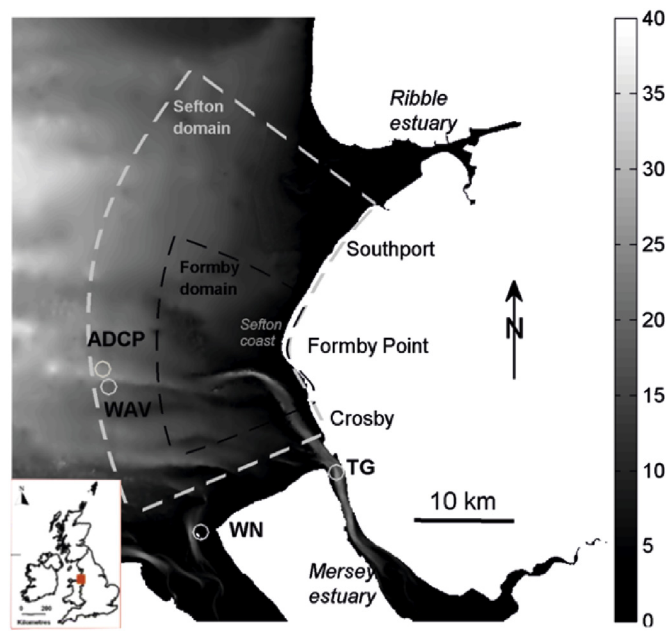

Fig. 1. Location of the Sefton coast and the monitoring locations; Acoustic Doppler Current Profiler (ADCP), WaveNet buoy (WAV), Wind station (WN) and tide gauge (TG), within the Sefton and Formby model domains. The bathymetry is shown relative to Ordnance Datum (ODN) (see colour bar). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)