Marine Geology 346 (2013) 153–164

Contents lists available at ScienceDirect

Marine Geology

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

Applicability of parametric beach morphodynamic state classification on embayed beaches

Carlos Loureiro [a,*], Óscar Ferreira [a], J. Andrew G. Cooper [b,c]

[a] CIMA — Centre for Marine and Environmental Research, Universidade do Algarve, Campus de Gambelas, Edifício 7, 8005-139 Faro, Portugal
[b] School of Environmental Sciences, University of Ulster, Coleraine BT52 1SA, Northern Ireland, UK
[c] Geological Sciences, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville Campus, Durban, KwaZulu-Natal 4001, South Africa

ARTICLE INFO

Article history:
Received 11 September 2012
Received in revised form 16 September 2013
Accepted 16 September 2013
Available online 21 September 2013

Communicated by J.T. Wells

Keywords:
Beach state models
Probabilistic statistics
Bayesian networks
Morphodynamic parameters
Geological control
Mesotidal
Wave-dominated beaches

ABSTRACT

Use of parametric classification of beach morphodynamic state has been steadily increasing in coastal research, despite identification of several shortcomings of their representativeness as elementary beach descriptors. In this paper, we analyse the parametric classification of beach morphodynamic state in a set of six embayed beaches in southwestern Portugal, exposed to diverse settings, from high-energy (dissipative to intermediate) to low-energy (intermediate to reflective) conditions. Applicability of parametric approaches considered within the dimensionless space defined by Ω (dimensionless fall velocity) and RTR (relative tidal range) according to averaged wave, tide and sediment characteristics of beaches, was assessed in association with a probabilistic analysis, implemented through a Bayesian network model, that considered the full range of wave, tide and sediment conditions at each site. Both parametric approaches were compared to field-based beach state classification implemented using a novel hierarchical framework for beach state analysis. The classification obtained within a probabilistic framework provided an innovative approach for analysis of beach state and mobility, extending the insights on beach morphodynamic behaviour obtained from averaged environmental parameters. Reflective to lower-intermediate beach conditions showed better agreement with parametric approaches, while poor beach state differentiation was achieved for intermediate beach types. Limitations in the application of beach classification models result from (*i*) an inadequacy of existing beach state types in differentiating beaches, particularly within the intermediate domain and for geologically controlled embayed beaches, and (*ii*) shortcomings involved in the parametric approaches. The beach state models disregard the major role of geological control in embayed beach morphodynamic behaviour (in modulating beach shape and segmentation, influencing sediment size and availability, causing alongshore variations in the wave field and creating topographically induced nearshore circulations). Existing beach state models are unable to adequately represent the widely variable conditions observed in embayed beaches.

1. Introduction

Morphodynamic classification of beach states based on the parameterization defined by the dimensionless fall velocity Ω, given by

$$\Omega = H_b / W_s T \tag{1}$$

where H_b is breaking wave height, W_s is the sediment fall velocity and T is the wave period, according to the beach state model of Wright and Short (1984), afterwards integrated with the relative tidal range RTR, given by

$$\mathrm{RTR} = TR / H_b \tag{2}$$

where TR is the tidal range, proposed in the beach state model of Masselink and Short (1993), has achieved widespread usage (Jackson et al., 2005; Scott et al., 2011). These parameterizations have, generally, been favoured over other parameters frequently employed to differentiate beach states, particularly the surf scaling parameter (Guza and Inman, 1975), given by

$$\varepsilon = \left(a\sigma^2\right) / \left(g\tan^2\beta\right) \tag{3}$$

where a is the incident wave amplitude ($H_b/2$), σ is the incident wave radian frequency ($2\pi/T$), g is the acceleration due to gravity and β is the beach slope. The reason for such preference resides in the documented inability of the surf scaling to differentiate between intermediate beach states (Bauer and Greenwood, 1988). Shortcomings of both the Wright and Short (1984) and Masselink and Short (1993) models have also received increased attention (cf. Anthony, 1998; Masselink and Pattiaratchi, 2001; Jackson et al., 2005), and some have suggested (Scott et al., 2011) that a universal morphodynamic beach classification model may not exist. Nonetheless there has been a steady increase in

* Corresponding author. Tel.: +351 289800900 ext:7885; fax: +351 289800969.
E-mail addresses: cloureiro@ualg.pt (C. Loureiro), oferreir@ualg.pt (Ó. Ferreira), jag.cooper@ulster.ac.uk (J.A.G. Cooper).

0025-3227/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.margeo.2013.09.005

their application in coastal research (Fig. 1), as there is a clear demand to categorize beach states within a common framework for beach behaviour comparisons. Rigid uses of the averaged Ω and RTR values have, however, been progressively discussed, as several factors have been shown to constrain the ability of the parametric approach to characterize beach states, including reduced discriminatory ability (e.g. Wright et al., 1985), geological control (e.g. Jackson et al., 2005), beach variability (e.g. Costas et al., 2005), or local wave climate variability (e.g. Gómez-Pujol et al., 2007).

For any given beach, the modal or mean value of the dimensionless parameter Ω, only indicates the prevailing combination of hydrodynamic and sedimentary conditions and the parametric beach state towards which a beach would eventually change, but it does not necessarily indicate the prevailing beach state (Short, 1987). A similar reasoning can be applied for RTR. Furthermore, the range of temporal variability in state and morphology for any given beach is equally important, and, possibly more informative than the average properties (Wright et al., 1985). Overfocusing on parametric modal beach state implies that other, possibly more important aspects of beach morphology, including parameters that represent beach form, can be overlooked.

Despite wide recognition that geological inheritance and control have a major impact in beach morphodynamics (Muñoz-Pérez et al., 1999; Short and Masselink, 1999; Klein and Menezes, 2001; Benedet et al., 2004; Jackson et al., 2005; Short, 2006; Jackson and Cooper, 2009; Short, 2010; Scott et al., 2011), affecting beach morphodynamic classification (cf. Jackson et al., 2005), parametric approaches to beach morphodynamic state are largely insensitive to geological control yet often applied in geologically constrained settings without further discussion. For an embayed coast, variables such as headland spacing, bay shape, wave obliquity, indentation ratio, nearshore morphology and substrate control are of primary importance in determining beach morphodynamic type and behaviour (Roy and Stephens, 1981; Klein and Menezes, 2001), yet these remain absent from most beach morphodynamic classification studies and their influence is often disregarded.

Naturally, parameterization is important if one wishes to depart from a purely descriptive framework to analyse beach state. Empirical models have been shown to have some predictive skill (e.g. Plant et al., 2006), offering a pragmatic alternative to limitations of process-based morphodynamic models (Cooper and Pilkey, 2004, 2007; Pilkey and Cooper, 2007; Cooper and Pilkey, 2008). So far no other empirical approach to beach morphodynamic state classification has achieved wider applicability than the use of Ω. Acknowledging that there is uncertainty in the calculation of any parameter, and that a single value for any parameter is not a universal descriptor of beach characteristics (Bauer and Greenwood, 1988; Anthony, 1998), we explore and analyse the parametric classification of beach morphodynamic state defined by Ω and RTR in embayed beaches. Here, we take a probabilistic approach to beach morphodynamics that, although suggested initially by Wright and Short (1984) with the use of beach state histograms, has rarely been incorporated in the morphodynamic classification of beaches. A notable exception is the work of Gómez-Pujol et al. (2007) and further exploration by Jiménez et al. (2008).

Considering the full range of wave, tide and sediment conditions observed and modelled from a set of embayed beaches exposed to diverse settings, from high-energy dissipative to intermediate conditions and low-energy intermediate to reflective conditions, we implement a probabilistic model to perform an assessment of beach morphodynamic state and mobility within the dimensionless space determined by Ω and RTR. The probabilistic distribution is then compared to the observed beach states and the single averaged parametric modal state. The overall aim is to explore the influence of joint probability of beach states as opposed to the classical use of modal beach state, and to assess the applicability of parametric classification of morphodynamic state in geologically controlled embayed beaches exposed to contrasting environmental conditions.

2. Study sites

The present assessment is performed with data from six embayments located along the rocky coastline of the southwestern coast of Portugal (Fig. 2), where topographic and sedimentary beach monitoring was performed over a period of two years from September 2007. The beaches are located in two clusters; the western one includes intermediate to dissipative beaches, while the southern cluster includes intermediate to reflective beaches. Western facing beaches (Amoreira, Mt. Clérigo and Arrifana) are fully exposed to the North Atlantic swell and storms and therefore experience a high energy wave climate, with a marked oceanographic seasonality. Mean significant wave height ranges between 1.5 and 2 m and average peak period between 9 and 13 s for summer and winter periods, respectively. Waves reach this section of the coastline mostly from the north-westerly quadrant (Costa and Esteves, 2010) (Fig. 2); yet nearly complete refraction of ocean swell renders most of these embayed beaches swash aligned. Southern facing beaches (Salema, Boca do Rio and Cabanas Velhas) are relatively sheltered from the full impact of the North Atlantic, experiencing attenuated swell waves combined with waves generated from SE winds across the Gulf of Cadiz. Offshore wave conditions are moderate, with mean wave heights around 0.9 m and peak periods of 8 s, experiencing only slight variations between summer and winter conditions. Dominant waves reach this southern coast from the south-westerly quadrant, yet shorter period south-easterly waves account for roughly a quarter of

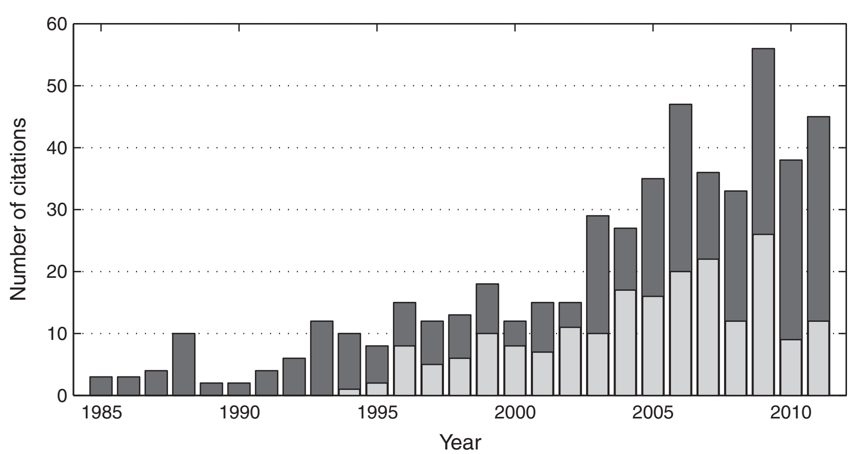

Fig. 1. Yearly citations for Wright and Short (1984) (dark grey) and Masselink and Short (1993) (light grey) morphodynamic beach classification models based on Thomson Reuters ISI Web of Knowledge (V5.5) checked on 23/02/2012.