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Dynamic equilibrium of sandbar position and height along a low wave energy micro-tidal coast

Jun Cheng*, Ping Wang

School of Geosciences, University of South Florida, Tampa, FL 33620, USA

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ABSTRACT

Nearshore sandbars play an essential role in dissipating incident wave energy and protecting the beach landward. Thus, understanding the dynamic equilibrium of nearshore bars is valuable to beach management and shore protection. This study examines the sandbar equilibrium in terms of bar height and cross-shore bar location, in order to assess how the dynamic equilibrium is maintained and influenced by storms along a low wave energy micro-tidal coast. The bar height and bar position were extracted from 51 beach profiles surveyed every two months, spaced at 300 m along a 15-km stretch of beach from October 2010 to August 2014. For the studied coast, alongshore variation in equilibrium bar position measured from the shoreline ranges between 40 and 80 m and equilibrium bar height between 0.20 and 0.70 m. Greater equilibrium sandbar height tends to occur around a headland, where waves are higher. Alongshore variations of bar behavior were observed during storms, with both onshore and offshore bar migration observed during one storm. Water depth over the pre-storm sandbar crest is a major factor controlling the storm-induced onshore or offshore bar migration. On average, the depth over the onshore migrating sandbar is found to be 0.20 m deeper than that over the offshore migrating bar during both summer and winter storms. There is no significant correlation between incident wave angle and sandbar height changes, while significant correlation exists between wave angle and sandbar movement under certain wave conditions, with more oblique waves being associated with further offshore movement of the sandbar. Energetic storm conditions tend to make the bar higher than the equilibrium height, while post-storm adjustment would restore the equilibrium height within 4–6 months. Although the exact values may vary at different locations, the concept of dynamic equilibrium of bar height and distance to shoreline could apply at many locations.

1. Introduction

The sandbar and trough features are important parts of a nearshore equilibrium profile (Wang and Davis, 1998), and they have important implications on the performance of beach and nearshore nourishments (Kroon et al., 1994; Van Duin et al., 2004; Roberts and Wang, 2012; Brutsché et al., 2014). By inducing wave breaking, the nearshore bars reduce the incident wave energy arriving at the shoreline and therefore provide protection against beach erosion. Due to their control on wave breaking, sandbars influence the spatial distribution of turbulent kinetic energy generated by breaking waves as they propagate onshore (Longo et al., 2002; Cheng and Wang, 2015a). Nearshore water quality can also be influenced by the existence of sandbars (Feng et al., 2013). Thus, understanding and quantifying the sandbar behavior play an important role in coastal management and shore protection. Sandbar morphodynamics remains a challenging research topic due to complicated interaction between breaking waves and sediment transport in the energetic surf zone (Voulgaris and Collins, 2000; Ruessink and Kuriyama, 2008).

Time-series of beach profile surveys along a significant stretch of coast, e.g., on the order of tens of kilometers, are essential to quantifying the temporal and spatial behavior of beach-sandbar system (Browder and Dean, 2000; Roberts and Wang, 2012). However, long-term field measurements of sandbar configurations (e.g. bar height and bar location) and their response to incident wave conditions are limited to a few locations (Ruggiero et al., 2009). Well known examples include Duck, North Carolina, USA (Holman and Sallenger, 1993; Larson et al., 2000; Plant et al., 2001), Egmond, Netherlands (Ruessink et al., 2000; Pape et al., 2010), Hasaki, Kashima Coast, Japan (Kuriyama et al., 2008), and Gold Coast, Australia (Castelle et al., 2007). Most of these well studied coasts have multiple nearshore sandbars in the surf zone and cyclic cross-shore bar migration occurs. Such a cycle is typically characterized by a net offshore bar migration (NOM) comprising sandbar generation near the shoreline by a storm, followed by a period of offshore bar migration, and eventual bar decay at the seaward edge

* Corresponding author.
E-mail address: jun@mail.usf.edu (J. Cheng).

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of the breaker zone (Kuriyama et al., 2008; Ruessink et al., 2000). Field studies on nearshore sandbar behavior along low-energy coasts are scarce and the applicability of findings from multibarred and high-energy coasts along low-energy micro-tidal coasts is not clear. A few existing examples include research conducted at the fetch limited Mediterranean Sea (Guillén and Palanques, 1993; Certain and Barusseau, 2005; Ojeda et al., 2011). General cyclic morphological behavior with interruption from severe storm events was documented along those coasts. Compared to previous studies at high-energy coasts, the morphological response of low-energy micro-tidal coasts is more sensitive to changing wave conditions (Aleman et al., 2015).

Several numerical modeling studies have revealed some insights on the mechanisms of sandbar height change and its cross-shore movement (Hoefel and Elgar, 2003; Almar et al., 2010; Splinter et al., 2011; Walstra et al., 2012; Dubarbier et al., 2015; Fernández-Mora et al., 2015). Both Walstra et al. (2012) and Dubarbier et al. (2015) concluded that more oblique incident waves tend to cause increased offshore sandbar migration under certain wave climates. Regarding the effect of wave angle on bar height changes, Walstra et al. (2012) also found that the oblique incident waves induce bar growth, whereas shore-normal waves tend to cause bar decay. On the other hand, Dubarbier et al. (2015) did not find any significant correlation between wave angle and bar height changes. All the existing beach profile models are site specific and are controlled by a number of calibration parameters that vary from one site to another (Fernández-Mora et al., 2015). These considerable variations in the empirical parameters from one site to another may indicate an attempt of applying constraining parameters to compensate model limitations that primarily arise from simplifications of the physics (Walstra et al., 2012; Dubarbier et al., 2015). Systematic field measurements of sandbar characteristics at a regional scale are therefore crucial to improve our modeling capability.

In this study, beach profiles surveyed every two months along a 15-km stretch of west-central Florida coast over a 4-year period are analyzed to answer the following questions. What are the morphodynamic characteristics of nearshore bars under low wave energy and micro-tidal conditions? More specifically, what is the morphodynamic equilibrium of the sandbar height and cross-shore bar location? How do storm events impact such sandbar equilibrium? The studied coast extends around a broad headland with a shoreline orientation change of 65 degrees. The curved shoreline provides an opportunity to investigate the longshore variations of sandbar responses to incident wave conditions. The sandbar morphodynamics are examined under various incident wave climates including calm summer seasons, relative energetic winter seasons, and tropical storms. Fifty-one beach profiles surveyed every two months along the coast of Sand Key barrier island over a 4-year period from October 2010 to August 2014 are obtained. Data from two of the 4 years, October 2010 to August 2011 and October 2013 to August 2014 are analyzed to investigate equilibrium bar morphology, represented here by sandbar height and cross-shore bar location. Deviations from the sandbar equilibrium state induced by energetic storms, exemplified by a series of strong winter storms in early 2011 and the Tropical Storm (TS) Debby in June 2012, are subsequently studied. The study area is described in Section 2. The methodologies applied in the study are discussed in Section 3. The results are presented in Section 4 and discussed in Section 5, respectively, and conclusions are given in Section 6.

2. Study area

The west-central Florida coast is composed of a chain of barriers islands (Davis and Barnard, 2003). Sand Key, the longest barrier island along this coast, is bounded to the north by Clearwater Pass inlet and to the south by John's Pass. Both inlets are of mixed-energy type with large ebb-tidal deltas (Gibeaut and Davis, 1993). Complex tidal inlet processes have significant influences on beach morphodynamics at the two ends of the barrier island (Roberts and Wang, 2012). The Sand Key

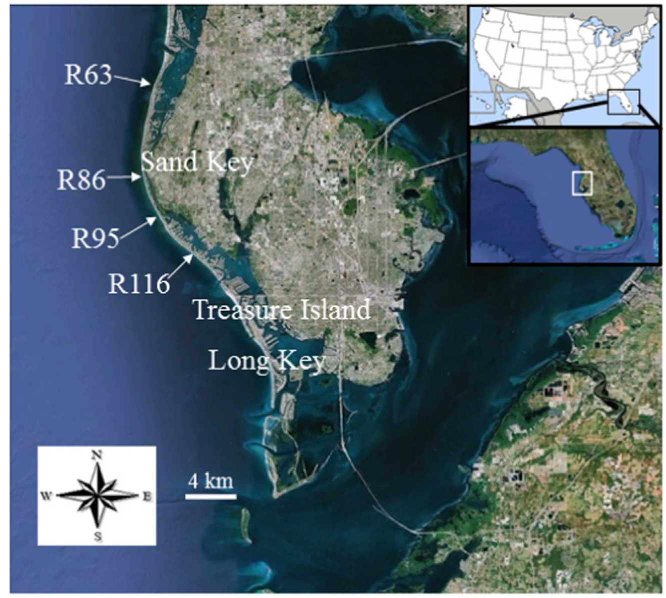

Fig. 1. Study Area: the studied section of beach extends 15 km around a broad headland from R63 to R116 (map source is from Google Earth).

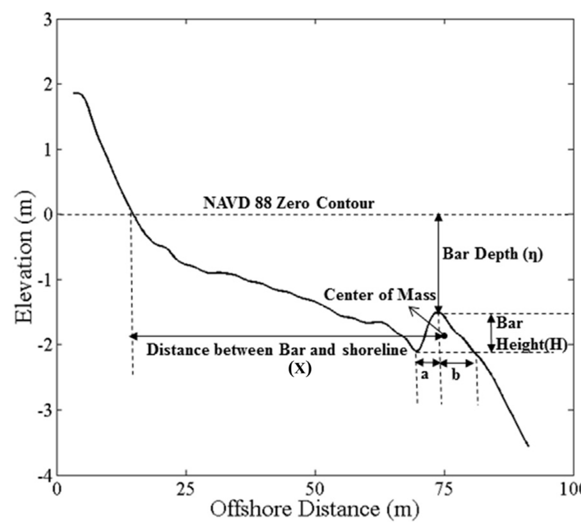

Fig. 2. Definition sketch of bar morphological parameters.

barrier island, extending around a broad headland, has an overall shoreline orientation change of 65° from northwest-facing to southwest-facing beaches, controlled by the antecedent geology (Fig. 1). A large portion of Sand Key has been identified as critically eroding (Florida Department of Environmental Protection, 2011). In order to mitigate the erosion, a long stretch of the beach has been regularly nourished every 6–8 years, the most recent ones being in 2006 and 2012. Sediments along the west-central Florida coast are bimodal composed of siliciclastic and carbonate fractions. The siliciclastic component is primarily fine quartz sand with a mean grain size of roughly 0.16 mm. The carbonate fraction is mostly shell debris of various sizes. Mean grain size in the study area varies typically from 0.15 mm to 1.0 mm, controlled by the varying amounts of shell debris.

The west-central Florida coast has a mixed tide regime, with spring tides being typically diurnal with a roughly 1.0 m range and neap tides being semi-diurnal with a range of about 0.4 m. The wave energy is generally small along the west-central Florida coast, with an averaged nearshore significant wave height of about 0.3 m (Wang and Beck, 2012). Waves are typically sea type generated by local winds. Higher