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Regional scale sandbar variability: Observations from the U.S. Pacific Northwest

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ABSTRACT

Understanding sandbar dynamics and variability is integral to developing a predictive capacity for nearshore flows, sediment transport, morphological change, and ultimately for determining coastline exposure to damaging storm waves. Here we report on a nearshore bathymetric data set from the U.S. Pacific Northwest (PNW) that stretches from Point Grenville, Washington to Cascade Head, Oregon, over approximately 260 km in the alongshore and includes 8 distinct littoral cells. We describe and quantify the morphological variability of sandbars on a regional scale, using 560 individual cross-shore transects, as well as attempt to explain the inter-littoral cell variability via relationships to various environmental parameters. The cross-shore extent of the bar zone extends over 1 km from the shoreline in the northern part of the study area, but only to about 600 m from the shoreline in the southern part. Maximum bar crest depths are typically 7 m below MLLW. Bar heights range from a step in the cross-shore profile to over 3 m from crest to trough. The northernmost littoral cells typically have two or more subtidal sandbars per cross-shore profile whereas the littoral cells in the southern part of our study area have only one bar. The mean depths of the bars, however, are much more consistent across littoral cells even while the upper shoreface slope significantly increases from north to south, requiring that the maximum bar distance from the shoreline decreases from north to south. Results from a limited study of the temporal variability suggest that while data collected over large spatial scales captures significant amounts of overall sandbar variability, it does not completely characterize the variability over the entirety of the net offshore migration cycle.

1. Introduction

Nearshore sandbars are found in the active zone of sandy coastlines worldwide, often contain substantial volumes of sand, and are important expressions of nearshore sediment transport. An understanding of sandbar dynamics is important for coastal hazard and change prediction. Because these features can often dominate nearshore morphological variability, taking a large scale approach, by examining long duration and large-scale bathymetric data sets, can yield important insight into their characteristics and behavior (*eg.*, Birkemeier, 1984; Lippmann et al., 1993; List and Terwindt, 1995; Grunnet and Hoekstra, 2004). Unfortunately, *in-situ* measurements of nearshore bars have historically been relatively scarce due to the difficulty and expense of collecting such measurements. Few studies are continued over long time scales and even fewer encompass large spatial scales (*e.g.* Plant et al., 1999; Wijnberg and Terwindt, 1995; Ruessink et al., 2003; Grunnet and Hoekstra, 2004; Pape et al., 2010).

Given the difficulties of collecting this type of data, it is not surprising that large scale spatial and temporal sandbar variability is still relatively poorly understood. Previous efforts have, in general, focused either on the net offshore migration (NOM) of sandbars or on classification systems for spatio-temporal variability. NOM has particularly intrigued the coastal community (Lippmann and Holman, 1990; Plant et al., 1999; Ruessink and Terwindt, 2000; Ruessink et al., 2003; Grunnet and Hoekstra, 2004; Ruessink et al., 2007; Pape et al., 2010; Kuriyama, 2012; Walstra et al., 2012; Wijnberg, 2002); studies have described and characterized the cycle of bar generation near the shoreline, offshore migration, and bar degeneration well seaward of the shoreline. Timescales and patterns of NOM have been documented at several coasts worldwide (*e.g.* Lippmann et al., 1993; Grunnet and Hoekstra, 2004; Ruessink et al., 2003). Recent efforts have focused on modeling the processes responsible for interannual to decadal-scale bar behavior (*e.g.* Ruessink et al., 2007; Pape et al., 2010; Kuriyama, 2012; Walstra et al., 2012). Larger scale studies have documented alongshore differences in the NOM behavior of

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bar systems along different coastlines and have attempted to correlate the variability to environmental variables (Wijnberg and Terwindt, 1995; Wijnberg, 2002; Ruessink et al., 2003). However, truly satisfactory explanations of the underlying causes of differing bar behavior are still lacking.

Studies focused on spatial variability have used classification systems to characterize the longshore variability of sandbar planforms, typically using categories such as linear, rhythmic, and non rhythmic (Wright and Short, 1984; Lippmann and Holman, 1990; van Enckevort and Ruessink, 2003,). These efforts have primarily focused on the variability of a continuous outer or inner bar as a response to varying hydrodynamic conditions, over scales on the order of a kilometer (Lippmann and Holman, 1990; van Enckevort and Ruessink, 2003). Sandbar behavior at this scale is influenced by both wave conditions and self organization (Coco and Murray, 2007).

Here we report on over 260 km of nearshore bathymetry data measured between 2010 and 2012 in the U.S. Pacific Northwest (PNW). Sandbars dominate the variance of the nearshore active zone of the PNW coast (Ruggiero et al., 2005), and this data provides an opportunity for characterizing the variability of sandbars on a regional scale. The PNW region broadly shares the same Quaternary geologic history and present-day environmental forcing. However, smaller scale, local variations in the geologic and depositional history dictate the location of headlands and barrier spits as well as the amount and type of sediment available in the nearshore. The geology of the region organizes the coast into littoral cells which share sediment sources and depositional history. Likewise, while the large-scale wave climate varies little at the regional scale, within the region there will be local alongshore variability in wave shoaling, refraction, and diffraction patterns over a heterogeneous bathymetry (Garcia-Medina et al., 2012, García-Medina et al., 2014). Here we investigate whether the alongshore variability of underlying geology and environmental forcing is expressed as differences in nearshore bar morphology at the regional scale.

The primary goal of this work is to describe and understand spatial sandbar morphological variability at the regional scale. More specifically, our objectives are to (1) quantify the spatial variation of sandbars over approximately 260 km of the southwest Washington and northwest Oregon coastline, (2) consider environmental variables that might cause or contribute to the variation observed in (1), and (3) contextualize the observed spatial variability in terms of temporal bar variation. We concentrate on large, inter-littoral scale variability and trends.

Below, we first describe the study area and data set in detail. Next we elaborate on the methods used to extract sandbar morphometrics from cross-shore beach profiles. The remainder of the paper describes how the observed variability in nearshore morphology links to variability in a suite of environmental parameters.

2. Study area and data set

2.1. Study area

Data collection for this research was conducted along a 260 km long section of the U.S. PNW coast in southwest Washington and northwest Oregon (Fig. 1). The southwest Washington coast is characterized by broad, low-lying accreted barrier beach plains (Peterson et al., 2010b; Vanderburgh et al., 2010), while much of the northern Oregon coast is characterized by pocket beaches separated by more erosion resistant headlands. Our study area encompasses 9 littoral cells, including the four sub-cells of the Columbia River littoral cell (CRLC) as well as the Cannon Beach, Rockaway, Netarts, Neskowin, and Sand Lake littoral cells in

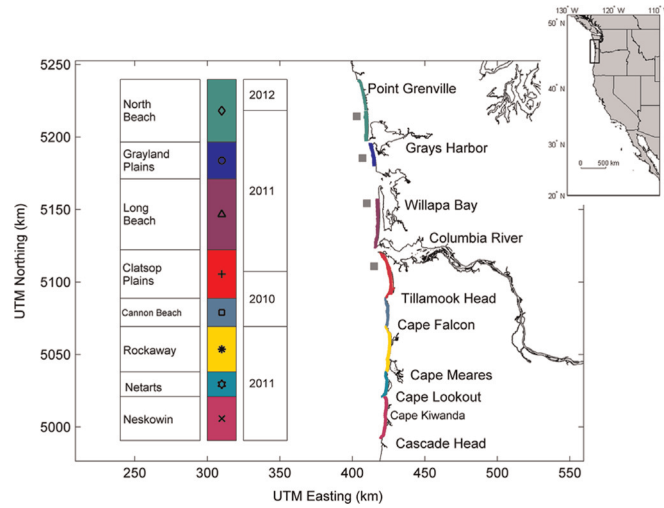

Fig. 1. Map of the study area. Vertical bars show the year of data collection for each area, color and symbol assigned to each littoral cell, and name of each littoral cell. Each cross-shore transect is plotted along the coast using the respective color of each littoral cell. Gray squares represent the location of the transects used for the temporal study.

northern Oregon (Fig. 1). These littoral cells are delineated by natural features such as headlands and estuary mouths, and the sediment within them has been isolated from neighboring littoral cells within the late Holocene (Clemens and Komar, 1988). The lack of bypassing of beach sands between littoral cells results in distinct characteristics of the individual pocket beaches. For these reasons littoral cells serve as a natural spatial scale in this study for assessing sandbar variability. The CRLC is the largest littoral cell in the study region and spans approximately 165 km from Point Grenville, WA to Tillamook Head, OR. The CRLC is divided into the sub-cells of North Beach, Grayland Plains, Long Beach, and Clatsop Plains by large estuary mouths at the Columbia River, Willapa Bay, and Grays Harbor (Fig. 1). Each of the sub-cells shares the Columbia River as their sediment source. During the late Holocene, Long Beach and Clatsop Plains received large amounts of Columbia River sediment beginning 4.7–5 ka. After more than 50 km of longshore transport, Columbia River sediment reached Grayland Plains (2.5–2.8 ka) and North Beach (2.8–3.2 ka) (Peterson et al., 2010a). Gelfenbaum et al. (1999) and Kaminsky et al. (2010) document a significant reduction of Columbia River sediment supply over the 20^{th} century due to anthropogenic influences such as flood control and hydropower.

Five additional littoral cells are examined in northwest Oregon: Cannon Beach, Rockaway, Netarts, Neskowin, and Sand Lake (Fig. 1). Many of the large Oregon headlands are highly effective at restricting sediment transport along the shoreline and so delineate these littoral cells. The Cannon Beach cell extends ~20 km south from Tillamook Head, Oregon to Cape Falcon, Oregon. The Rockaway cell starts south of Cape Falcon and stretches 32 km to Cape Mears. The Netarts cell is the smallest littoral cell in our study area (~17 km), and is located between Cape Mears and Cape Lookout. The Sand Lake and Neskowin littoral cells are separated by Cape Kiwanda, a relatively minor headland that is substantially smaller than either Cape Lookout to the north or Cascade Head to the south and does not necessarily restrict sediment transport. We therefore combine these two small littoral cells (~15 km each) into a single analysis region, the coastline between Cape Lookout and Cascade Head, referred to hereafter as the Neskowin cell.

Sediments in the PNW overlie an erosional, geomorphic ravinement surface created by wave action during Holocene sea level transgression (Peterson et al., 2010a; Vanderburgh et al., 2010). This surface slopes shallowly seaward (Vanderburgh et al., 2010);