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Drivers of alongshore variable dune erosion during a storm event: Observations and modelling

Kristen D. Splinter *, Edward T. Kearney, Ian L. Turner

Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Sydney, Sydney, Australia

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ABSTRACT

The ability to understand and predict alongshore-variable sand dune erosion is key to better coastal management. This study utilizes detailed observations (immediately pre, during and post-storm topography, waves and water levels) collected over a 6-day period at the 3.6 km long Narrabeen-Collaroy beach in south-east Australia, to identify and explore drivers of the highly variable alongshore dune erosion caused by an East Coast Low storm in June 2011. Key characteristics of the immediately pre-storm subaerial morphology obtained by airborne Lidar (beach slope, dune toe elevation, dune height) varied considerably alongshore. Daily airborne Lidar surveys conducted at low tide indicated considerable temporal variability in the evolution of the subaerial beach profile. Despite considerable alongshore variability in the magnitude of modelled inshore wave heights during the storm, it was instead observed that the predominant determinant of maximum dune erosion was the pre-storm dune toe elevation. A simple dune impact model forced with local alongshore-variable inshore wave modelling was found to successfully predict up to 85% of the observed alongshore variability in dune erosion at this site, with this erosion tidally modulated over the 6 days to time periods when the waves were directly impacting the dune. Importantly, alongshore variation in wave height is shown to account for just 10% of the alongshore variability in dune erosion during this storm. These results reconfirm that knowledge of the pre-storm subaerial morphology, in particular the elevation of the dune toe with respect to time-varying water levels during a storm, is a key driver of alongshore variability in the erosion response along dune-backed sandy coastlines.

1. Introduction

Along sandy coasts it is generally accepted that beaches will accrete during less energetic wave conditions, and erode during more energetic wave conditions (Aubrey, 1979; Wright and Short, 1984; Stive et al., 2002; Quartel et al., 2008). The most energetic wave conditions that occur in the coastal environment are coastal storms; events which can potentially cause considerable beach erosion and dominate the short-term erosion history of the coastline (Russell, 1993; Frazer et al., 2009). The risk posed by coastal erosion is recognised as considerable and potentially increasing as a result of elevated sea levels, changing regional weather patterns, and growing populations and infrastructure located in the coastal zone (IPCC et al., 2007; Callaghan et al., 2009; Ruggiero et al., 2013; Anderson et al., 2015; Barnard et al., 2015).

The destructive potential of storms due to large waves and/or elevated water levels is not a new phenomenon. For example, Australia's east coast was battered by a series of large storms in 1967 and then again by storms in 1974 (McGrath, 1968; Foster et al., 1975; McLean and Thom, 1975; Bryant and Kidd, 1975; Splinter et al., 2014). Most recently, an East Coast Low storm event in June 2016 stripped 11.5 M m^3 of subaerial sediment from 177 km of surveyed sandy coastline in New South Wales (Australia) (Harley et al., 2017). In the past decade devastating hurricanes have caused billions of dollars of damage and widespread erosion along the eastern USA (Stockdon et al., 2007; van Verseveld et al., 2015), while strong El-Nino/La Nina events are linked to large erosion on the west coast of the USA (Allan and Komar, 2006; Barnard et al., 2011) as well as more generally across the Pacific basin (Barnard et al., 2015). In the winter of 2013/2014 Europe was impacted by a series of large extra-tropical wave events that caused significant and widespread coastal erosion (Castelle et al., 2015; Masselink et al., 2016a, 2016b). Within these studies, it is frequently observed that there is considerable variability in storm-induced dune erosion in the alongshore direction at scales of 10s–1000s of meters, which may be due to the presence of offshore sand bars, localized rip currents, and alongshore gradients in wave height (Castelle et al., 2015; Loureiro et al., 2012; Coco et al., 2014; Senechal et al., 2015; Harley et al., 2015), as well as

* Corresponding author.
E-mail address: k.splinter@unsw.edu.au (K.D. Splinter).

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morphological characteristics of the subaerial beach such as the elevation of the dune toe, dune height and beach slope (Overton and Fisher, 1988, 1994; Larson et al., 2004; Palmsten and Holman, 2012; Plant and Stockdon, 2012; Splinter and Palmsten, 2012; Palmsten et al., 2014; Palmsten and Splinter, 2016; Houser, 2013; Sallenger, 2000; Houser et al., 2008).

Previous studies that use numerical models to compute design coastal erosion volumes and engineering setbacks are typically hampered by a general lack of immediately pre- and post-storm beach profile data (Roelvink et al., 2009; Mariani et al., 2012; Ranasinghe et al., 2013). Roelvink et al. (2009). used predominantly laboratory scale experiments for the development of the 2DH process model XBEACH, whilst the field-scale dataset of storm erosion that was included had a 4-month lag between the available pre-storm survey and the onset of the storm event, introducing uncertainty regarding the true pre-storm condition of the beach. Similarly the study by McCall et al. (2010). utilised pre-storm data that preceded the storm event by 4 months. Due to lack of available data, Splinter and Palmsten (2012) were likewise limited to using pre-storm data that preceded the storm event by between 6 and 9 months. And again, Stockdon et al. (2007). estimated the impact of hurricane landfall using pre-storm survey data obtained 12 months prior. In all cases, the lack of immediate pre-storm data is implicitly brought into the calibration process via tuning of model free parameters, which inevitably can lead to highly storm- and/or site-specific calibration. In order to minimise errors in modelling and truly understand the drivers of the erosion response, the pre and post-storm surveys need to be as recent to an event as possible (Morton et al., 1993).

Here we present daily observations of alongshore-variable dune erosion obtained by rapid-response airborne Lidar deployed within a single 3.6 km long embayment during a 6-day storm wave event. Utilizing a simple model framework (Palmsten and Holman, 2012; Splinter and Palmsten, 2012), we explore the key drivers with respect to hydrodynamic (tides and runup) and morphological (beach slope and dune toe elevation) drivers that account for our observations. In the next section the study site and data (airborne Lidar surveys, waves and water levels) are described. This is followed by a presentation of the observed alongshore-variable erosion response in Section 3. A simple empirical dune erosion model is used to interpret the observed alongshore-variable response in Section 4, which is followed by a synthesis (Section 5) and summary of the key findings in Section 6.

2. Background

2.1. Study site

Narrabeen-Collaroy embayment is located approximately 20 km north of the city of Sydney on the southeast coastline of Australia (Fig. 1). The embayment is bounded to the south by the prominent Long Reef Point and at its northern end by Narrabeen Head. The enclosed sandy beach is 3.6 km in length and is composed of fine to medium quartz sand underlain by sandstone bedrock, with a median sand grain size $D_{50} \approx 0.3$ mm, exhibiting typical gradients for the nearshore and intertidal of 0.02 and 0.12 respectively. The site experiences a micro-tidal semi-diurnal tide with a mean spring tidal range of 1.6 m.

Due to the prevalence of moderate to high wave energy conditions and the exposed orientation of the central and northern end of the beach

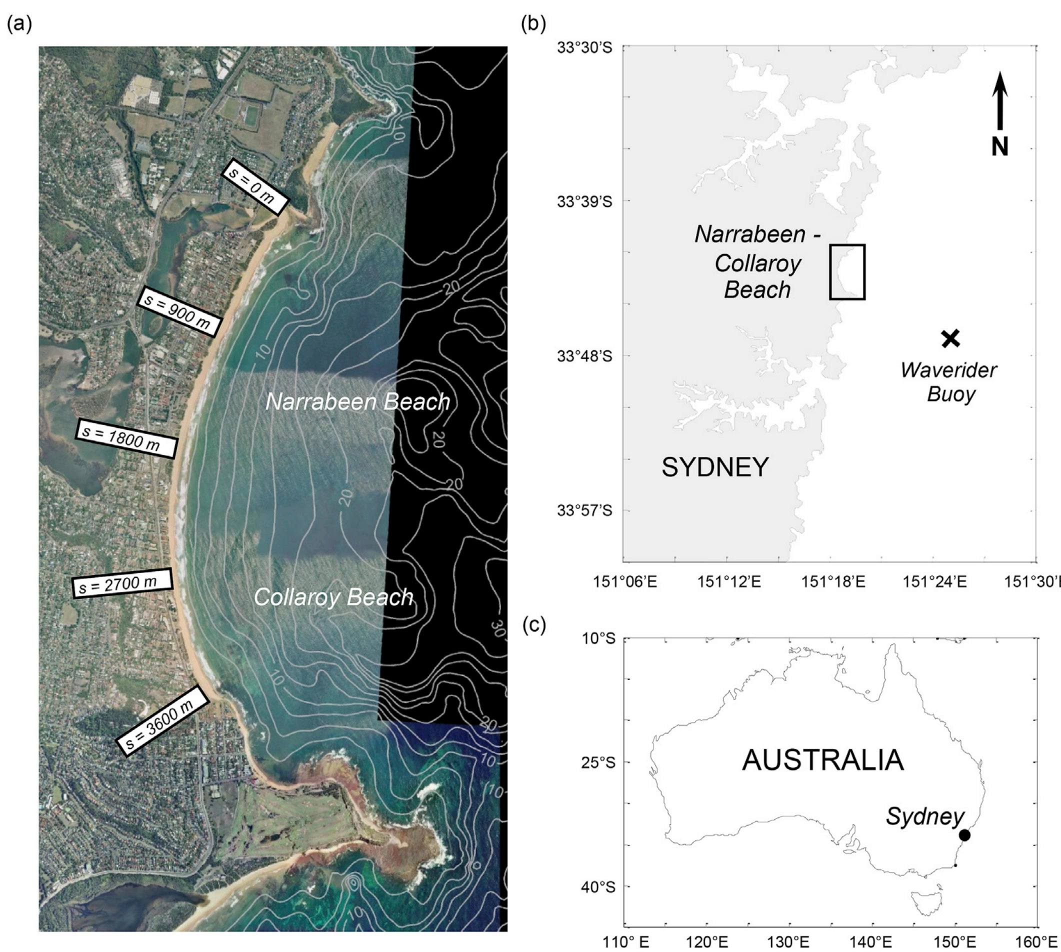

Fig. 1. (a) Map of the Narrabeen Embayment on the south east Australian coastline with superimposed log spiral alongshore positions as per Harley and Turner (Harley and Turner, 2008). (b) Regional map of Sydney with location of wave buoy. (c) Map of Australia with location of Sydney.