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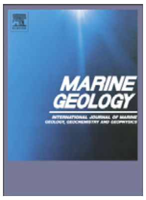

Modeling dune response to an East Coast Low

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ABSTRACT

Coastal dunes can act as a method of soft coastal protection against inundation and direct impact of waves during storms if they are substantially large enough in volume to withstand erosion without breaching. However, the time evolution of sand dunes under direct wave impact is not well understood and many available models require site specific calibration and have had limited verification at field scales. Here we test three models of varying complexity in their ability to predict both dry beach erosion volumes and dune to a retreat for an East Coast Low storm event that occurred on the Gold Coast, Australia. The process-based model, XBeach, which models the entire profile was able to reproduce both dune toe retreat and dry beach volume, however, was sensitive to calibration parameters. The two parametric models that only modeled erosion above the initial dune toe position were capable of accurately predicting dune toe retreat, however, under-estimated dry beach erosion volumes. With no calibration, the parametric model proposed by Palmsten and Holman (2012) produced the smallest errors of dune toe retreat with mean error in final dune position of 6.6 m, or 18% of the total measured dune retreat. With minimal calibration estimated absolute error in average dune toe retreat was less than 13% of observed retreat for all three models.

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1. Introduction

Coastlines and in particular sandy dune systems evolve over timescales of individual storms to decades in response to processes of wave action and wind (e.g. Morton et al., 1995; Hesp, 2002). Sandy dunes build up primarily through aeolian processes and erode due to wave action and are a well-documented source of sediment to the littoral drift system (Aubrey, 1979). Recently, coastal dune systems have also been acknowledged in their capacity to provide a natural buffer against the impacts of the sea on adjacent low-lying areas (Martinez and Psuty, 2004) provided dunes are both tall and wide enough to prevent storm surge and waves from impacting the back areas during a storm event. However, when they fail or breach, the consequences can be rapid and catastrophic. Therefore, it is of key importance to understand how resilient coastal dunes are to individual or a sequence of storm events in order to assess the vulnerability of adjacent human population and infrastructure.

Sallenger (2000) proposed a *Storm Impact Scale* for barrier islands that classified the relationship between external forcing and foreshore topography resilience into four distinct regimes: swash, collision, overwash, and inundation. External forcing was parameterized as the total water level, defined as the sum of the 2% exceedence of wave runup, tides, and non-tidal residual. The collision regime (when the total water level exceeds the toe of the dune but is below the dune crest), and the overwash/innundation regimes (when the total water level exceeds the dune crest) are of particular importance to coastal engineers, scientists, and managers when assessing the vulnerability of adjacent property. Using the 2% exceedence of wave runup parameterization of Stockdon et al. (2006, 2007) successfully used the *Storm Impact Scale* model to hindcast the potential impact of two hurricanes that made landfall on the Outer Banks, NC, USA. This methodology has since been adopted within the United States Geological Survey (USGS) to forecast storm response and alert the public prior to major storms (http://coastal.er.usgs.gov/hurricanes/) about the probability of extreme coastal change in low lying communities. Although it is assumed that erosion capacity is related to regime (with swash having the lowest erosion potential and overwash having the greatest), this approach is limited in its ability to predict possible breaching or total erosion of a dune system due to its lack of time dependence, therefore storms in a collision regime may require additional modeling to assess the true vulnerability of the adjacent coastal communities.

Vellinga (1986) used extensive lab data to derive an equation for total dune erosion based on surge, wave height, and sediment characteristics. However, no feedbacks between the changing morphology and forcing were included due to the lack of time dependence. A number of time dependent dune erosion models have also been developed. These include cross-shore sediment transport models such as EDune (Kriebel and Dean, 1985), SBeach (Larson and Kraus, 1989), CROSMOR

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(van Rijn, 2009), and XBeach (Roelvink et al., 2009) that model the evolution of the entire cross-shore profile. The cross-shore sediment transport models require knowledge of offshore wave parameters, sediment properties, nearshore bathymetry, and although they explicitly model subaqueous sediment transport, rely on parameterizations to quantify dune erosion. For instance, XBeach, invokes a user defined critical wet and dry slope to erode the upper beach profile. This volume of material is subsequently placed at the dune toe where it is mobilized and carried offshore by swash zone processes. Additionally, because of the large number of free parameters and high level of detailed physics, these models are sensitive to errors in the input variables and may require extensive calibration(and therefore data) to produce reliable results (Splinter et al., 2011a).

Alternatively, more simplified physics-based models explicitly account for dune erosion but don't account for the transport of sand seaward after it has eroded from the dune face. These include wave impact models (Overton and Fisher, 1988; Overton et al., 1994; Larson et al., 2004; Palmsten and Holman, 2012) that relate the volumetric erosion rate of a dune to the momentum flux impacting the dune, and more recently, dune instability models (Erikson et al., 2007; Palmsten and Holman, 2011) that relate dune slumping to forces acting on internal failure planes. Similar to the *Storm Impact Scale*, a key benefit of these models is their reliance solely on information such as wave runup derived from offshore wave properties and subaerial beach profiles, all of which can be easily measured or parameterized.

Along wave exposed coasts, the impacts of storms are likely to be more important in long-term coastal evolution than the impacts of sea level rise (Ruggiero, 2008; Brunel and Sabatier, 2009). Parametric models such as Larson et al. (2004) and Palmsten and Holman (2012) are favored for multi-year coastal evolution scenarios because they are less sensitive to numerical instabilities, calibration parameters and require no information about offshore bathymetry that hinder process-based models such as XBeach to be used inlong-term simulations. Recently, Ranasinghe et al. (2012) proposed a probabilistic model to predict coastal recession over multiple decades using the dune erosion model of Larson et al. (2004) and an assumed recovery rate between storms. Using 30+ years of roughly monthly survey data, Ranasinghe et al. (2012) calibrated both the erosion and recovery rates. However, the best-fit calibration coefficient in the dune erosion model was found to be an order of magnitude greater than that reported by Larson et al. (2004) for their field data set and therefore suggests a certain level of uncertainty in using these models without an appropriate calibration data set.

Although both process-based profile models and the parametric dune erosion models described above have shown potential to be used as predictive tools to estimate dune erosion and coastal vulnerability during lab experiments for individual storm events, very little work has focused on quantitative field scale comparison. Therefore, the objective of this work was to compare three models of varying complexity against field observations obtained during an East Coast Low storm off the coast of South East Queensland, Australia in May 2009 to assess their capability to accurately estimate dune erosion. From least to most complex, the models tested were: that proposed by Larson et al. (2004), herein LEH04; the expanded model with the changes described by Palmsten and Holman (2012), herein PH12; and XBeach (Roelvink et al., 2009). In the following section we summarize the study site and field conditions followed by Section 3 were we describe each of the models in more detail and the calibration procedure. Results for both the uncalibrated and calibrated models are presented in Section 4 followed by discussion in Section 5 and concluding remarks in Section 6.

2. Data

The Gold Coast, Queensland, Australia, is located along the east coast of Australia near the Queensland–New South Wales border (Fig. 1). This east-facing 35-km stretch of highly developed sandy coastline is exposed to year-round south-southeast swell, as well as infrequent tropical cyclones and East Coast Low storm events. East Coast Lows, ECLs, commonly form over the Tasman Sea and are driven by temperature gradients between air masses at sea level and the upper atmosphere (Callaghan, 1986). ECLs are usually short-lived (lasting several days) but may also intensify quite rapidly, generating gale force winds and storm surge along the coast. Shoreline variability along the Gold Coast displays an annual cyclic pattern related to changes in seasonal mean wave height (Davidson and Turner, 2009; Splinter et al., 2011b). During the Australian summer — fall months (Dec–June), the coast is exposed to larger waves and more frequent storms, resulting in shoreline retreat, while shoreline recovery usually occurs during the milder winter and spring months. A primary dune system exists along the majority of the coast and is vegetated by low lying dune grasses and coastal bushes depending on the location. Dune height varies from upwards of 10 m above mean sea level (measured as the Australian Height Datum (AHD) = 0 m) at the northern end to 5 m AHD at the southern end. Dune erosion is typically isolated to larger storm events where combined high waves and surge directly impact the primary dune system. Dune erosion may also occur during King Tide (highest spring tide of the year) events, but this is minor in comparison to storm-induced erosion. In most instances, the primary dune system covers a landward buried sea wall (elevation of roughly 5 m AHD) that acts as a last line of defense to storm induced damage to adjacent infrastructure.

As part of an ongoing coastal monitoring effort, select transects (referred to as ETA lines) are surveyed using standard survey methods. Profiles along the select transects are measured on average 1–2 times per year. This study focused on the northern end of the coast (Fig. 1) due to the proximity of the offshore wave measurement buoy and tidal gauge. Unlike the southern end of the Gold Coast, the northern Gold Coast is more exposed to wave action from all directions and does not experience large spatial gradients in longshore transport. While the southern end can experience erosional problems and the boulder wall may become exposed during large erosion events, the four northern Gold Coast sites chosen represent natural dune erosion. The four sites used were Mermaid Beach (ETA 52), Broadbeach (ETA 58), Surfers Paradise (ETA 63) and Narrowneck (ETA 67) and are shown in Fig. 1. Pre-storm surveys were completed between October and December 2008 and post-storm profiles were completed within one week of the storm impact in June 2009 prior to mechanical beach reprofiling that moved sand to reduce large and dangerous scarps.

In 1987 a non-directional wave buoy was installed offshore of Narrowneck (ETA 67) in 18 m of water. The buoy is operated in conjunction with Gold Coast City Council and the Queensland Department of Environment and Resource Management (DERM) and was upgraded to include direction in 2007. The buoy provides statistical measurements of significant wave height, H_s (m), maximum wave height, H_{max} (m), peak wave period, T_p (s), and peak wave direction, θ_p (°N) at 30 minute intervals. Water levels are recorded every 10 min and include both tides and surge. The tide gauge is operated by Maritime Safety Queensland and is situated within the Gold Coast Seaway located at the northern end of the Gold Coast.

In May 2009, an ECL storm event impacted the south-eastern Queensland and north-eastern New South Wales coast. The intense low pressure system brought heavy rains, high winds, large waves and storm surge over a week-long period, resulting in significant damage to the beaches. The Gold Coast waverider recorded the second largest significant wave height ($H_s = 6.1$ m) and fourth largest maximum wave height ($H_{max} = 10.6$ m) since monitoring began. Wave periods peaked at ~14 s and wave direction was ~90° N (directly onshore). Maximum recorded surge was 0.5 m and the highest recorded water level (surge + tides) was 1.2 m AHD and exceeded the highest astronomical tide. Conditions for the event are summarized in Fig. 2.

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