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The effects of storm clustering on beach profile variability

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ABSTRACT

Impacts of storms in reshaping coastlines are well known. Also, the far greater impact of clusters of storms, where storms occur at close succession, has been noted in a number of previous studies. In this paper, we analyse and discuss the storm wave climate and the beach profile response to clusters of storms at Narrabeen Beach, New South Wales, Australia. Narrabeen Beach is subjected to frequent storms all year round and the beach undergoes substantial variability as a result. The impact of storm clusters with closely spaced individual storms reaching the beach is investigated by combining historic measurements of beach profile surveys and numerical modelling of storm induced beach change. Our analysis of storm power index of storm clusters and its correlation with the change in beach width reveals that the strengths of single storms in a storm cluster alone are not the reason for beach change, but time interval between successive storms and the post-storm recovery speed of the beach concerned also play important roles. We have quantified and compared beach erosion return levels resulting from single storms and storm clusters. It was found that beach erosion volumes resulting from storm clusters with two or more storms resemble potential beach erosion volumes induced by single storms of far higher return periods.

1. Introduction

Beaches undergo continuous and on-going morphodynamic changes as a result of waves, tides and wind, at a range of time scales. However, episodic major high wave events generated by storms, hurricanes and tropical cyclones impose huge morphodynamic stresses on beaches over short time scales thereby triggering potentially rapid morphological changes. This may lead to severe erosion, wave overtopping and instability of beach systems that lead to devastating consequences (Berkemeier, 1979; Dolan and Davis, 1994; Lee et al., 1998; Forbes et al., 2004).

The extent of storm-induced beach erosion depends on a range of phenomena. In general, while storms with larger wave height can cause relatively more damage, other storm characteristics such as storm duration, direction, peak wave period and water levels (tide and surge) also play a significant role (Cox and Pirrello, 2001). Apart from these storm characteristics, the occurrence of multiple storms may also have a major impact on beach erosion, exceeding that of a single storm with similar wave/surge characteristics. Analyses of storm clusters as a beach erosion multiplier have been done by Ferreira (2005), Callaghan et al. (2008) and Vousdoukas et al. (2012).

Even though beaches erode and become unstable during a storm event, they undergo natural post-storm recovery as a result of onshore sediment transport during calmer weather conditions. However, if the interval between two consecutive storms is less than the recovery period needed to replenish the beach then, the next and subsequent storms can potentially impose a greater damage on the beach. As a result, the sequencing or chronology of storm events and the recovery period in between them can play an important role in determining coastal profile dynamics (Morton, 2002). Dong and Chen (1999, 2001) concluded, as part of an analytical and numerical study, that both the distribution and variability of wave conditions had significant influence on the statistics of shoreline erosion. Using a long term wave record from northwest Portuguese coast, Ferreira (2005) found that storm clusters with relatively small return periods induce average erosion volumes as significant as a single storm with a much larger return period. Callaghan et al. (2008) demonstrated that beach profile change is sensitive to storm clustering, using Botany Bay wave measurements and beach profiles at Narrabeen Beach, New South Wales (NSW), Australia. Vousdoukas et al. (2012) state that if a beach profile achieves equilibrium after the first storm then, additional erosion only occurs when the storm intensity and/or water levels exceed precedent conditions. Splinter et al. (2014) investigated cumulative impact of storm clusters on beach erosion of Gold Coast, Queensland Australia using XBeach model. The comparison of the model simulated results with measured profiles showed that the model is capable of simulating

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storm induced beach erosion with good accuracy. They also concluded that the total erosion volume for the entire storm cluster is not significantly impacted by the storm sequencing but, is a function of antecedent beach state. However, it should be noted that they did not consider beach recovery between two successive storms and that the number of storm clusters they used is limited to arrive at generalised conclusions. Coco et al. (2013) investigated the impacts of storm clusters on a highly dynamic beach system in Bordeaux, France using field measurements of beach profiles measured during the occurrence of one storm cluster. They concluded that occurrence of a storm cluster did not enhance beach erosion in this particular situation. However, they also concluded that it is not possible to generalise or upscale their findings, as a result of complex interplay between a range of governing parameters and the limited storm clusters they used for their study.

Despite numerous suggestions of the higher potential for coastal erosion due to storm clusters, the relative erosion potential of single storms versus storm clusters has not been quantified comprehensively to date. The present study aims to investigate this phenomenon via a combination of detailed analysis of 20 years of monthly measured cross-shore profiles at Narrabeen Beach, New South Wales, Australia and a strategic numerical modelling of beach erosion from storm clusters, using the process based model XBeach.

2. Study area and field data

Narrabeen Beach is a wave-dominated embayment located 20 km north of Sydney, NSW, Australia (Fig. 1). The beach facing east into the Tasman Sea is 3.6 km long and is bounded by two headlands, Narrabeen Head to the north and Long Reef Point to the south (Short and Wright, 1981). The beach is composed of medium to fine quartz and carbonate sands with $D_{50} = 0.3$–0.4 mm and has a relatively steep upper beach and a gentler lower beach in the sub-tidal region (Ranasinghe et al., 2004).

Narrabeen Beach is exposed to a highly variable, moderate- to high-energy wind wave climate superimposed on long period, moderate- to high-energy south-easterly swell waves (Short and Wright, 1981). Waves are originated from multiple cyclonic sources: mid-latitude

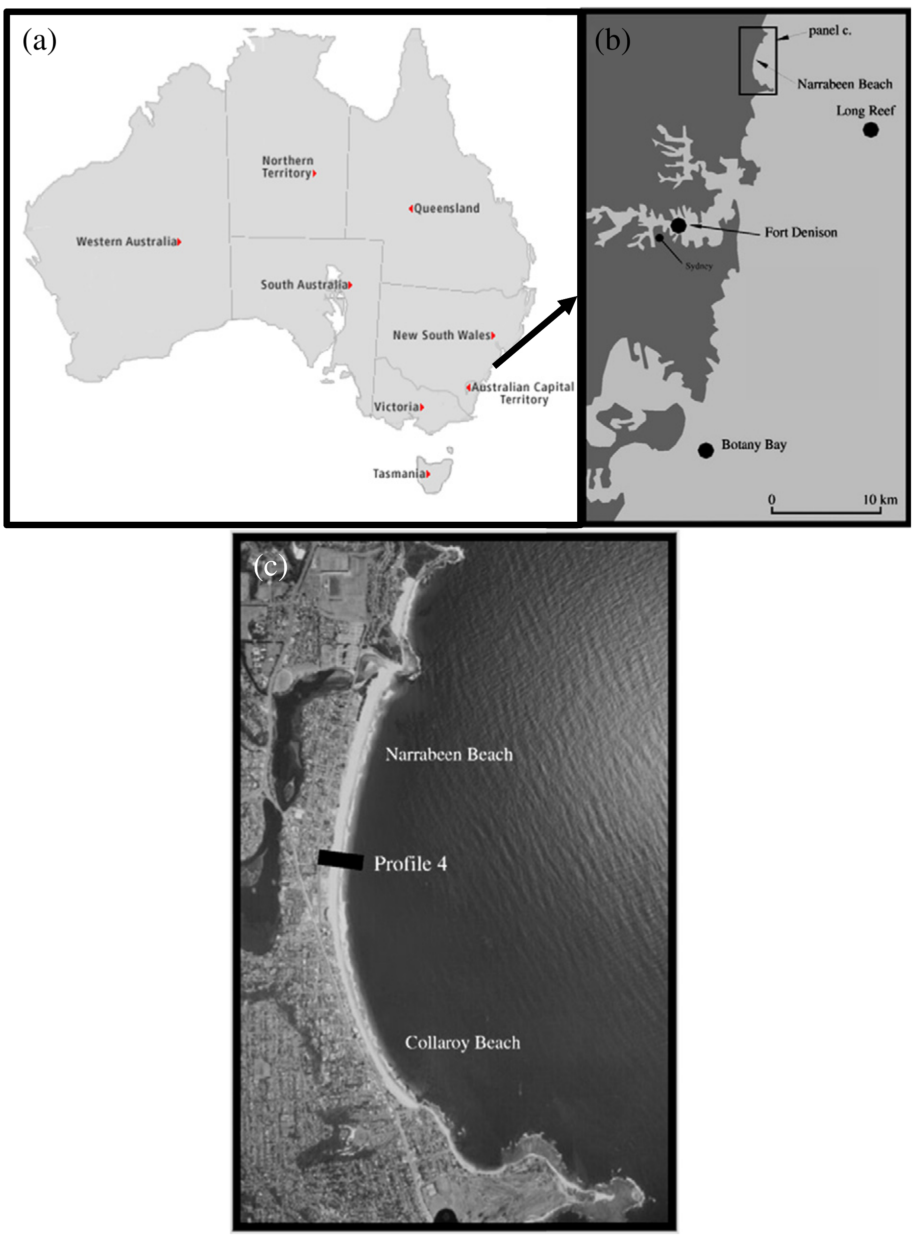

Fig. 1. (a) A map of Australia and NSW; (b) location of Narrabeen Beach and wave measuring points Long Reef and Botany Bay; (c) view of Narrabeen Beach, location of Profile 4.