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A statistical-process based approach for modelling beach profile variability

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ABSTRACT

This paper presents a methodology for modelling medium term (annual to decadal) cross shore beach profile change and erosion. The statistical-process based approach (SPA) presented here combines detailed statistical modelling of offshore storm climate with a process based morphodynamic model (XBeach), to assess, and quantify morphodynamic variability of cross shore beach profiles. Until now, the use of process based models has been limited to simulations at storm event timescales. This methodology therefore represents the first application of a fully process based model in longer term simulations, as such, the approach requires simulation of post-storm beach profile recovery as well as individual event impacts. Narrabeen Beach, NSW, Australia was used as a case study for application of the technique due to the availability of an extensive set of storm and beach profile data. The results presented here demonstrate that the methodology produces encouraging results for determining medium term beach profile variability and erosion.

1. Introduction

Increasing awareness of the importance of medium to long term morphological change to coastal sustainability has led to a requirement for methodologies to support predictions over these time scales. Linked to this is the rising prevalence of process based morphodynamic modelling. These two factors have resulted in a requirement for the application of process based models to be extended, to allow the assessment of beach change beyond short term time scales. As this has yet to be achieved, this paper discusses how a statistical framework (Callaghan et al., 2008) can be combined with the process based coastal morphodynamic model XBeach (Roelvink et al., 2009), to form a statistical-process based approach for forecasting cross shore, storm driven, beach change at a medium term time scale.

Quantifying beach morphodynamic variability using a benchmark 1 in N year event has inherent limitations. Hawkes et al. (2002) show that, for a forcing system with multiple variates, such as storm events, the return period of the individual variates does not necessarily match those of the system response. One such reason for the difference is that, during beach erosion, the formation of a new equilibrium profile requires a finite time, meaning erosion is dependent on duration (Kriebel and Dean, 1993). A benchmark event is also unable to account for two (or more) storms occurring in quick succession and effectively merging into one erosive event. Should this occur, there is greater erosive impact on the beach than if separated by a time sufficient enough to allow for natural recovery (accretion). To improve the representation of the forcing conditions, Callaghan et al. (2008) developed a statistical framework for modelling extreme storm climate and beach erosion, known as the Full Temporal Simulation (FTS). This model combines the multivariate statistical modelling of individual storm events with a non homogeneous Poisson process for modelling event spacing which allows for the prediction of a time series of storm (erosion) events and calm (accretion) periods, leading to a more realistic quantification of beach erosion. They combined this model with the empirical storm erosion model of Kriebel and Dean (1993) to determine beach erosion. The usefulness of this model was also demonstrated by Ranasinghe et al. (2011a) who combined it with a simplified empirical model (Larson et al. 2004) to estimate dune erosion at Narrabeen Beach over a 110 year period incorporating sea level rise. Both approaches are limited as the post-storm recovery of the profile was estimated using an empirical technique, as the structural functions used to determine erosion are not capable of predicting post-storm beach recovery.

Process based techniques for the modelling of cross shore beach behaviour have existed for some time with numerous models available (UNIBEST-TC (Reniers et al., 1995), CROSSMOR2000 (van Rijn, 1996) and SBEACH (Larson and Kraus, 1989)). van Rijn et al. (2003) provide a detailed review of the capabilities of these models to predict cross shore profile change. This study involved storm and seasonal time scales with some models shown to produce good representation

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of different profile features at the seasonal timescale. However, the sustainability of process based models for simulating beach change beyond a storm timescale has yet to be demonstrated.

XBeach, as a tool for modelling coastal change, has been extensively validated against numerous flume experiments (1D) and some field case studies (2DH) (Roelvink et al., 2009). The model has then been successfully applied to simulate storm response of sandy beaches at Assateague Island, Maryland (Roelvink et al., 2009), Santa Rosa Island, Florida (McCall et al., 2010) and Ostend Beach, Belgium (Bolle et al., 2010). More recently, the use of XBeach has been extended to the modelling of gravel beach variability (de Alegria-Arzaburu et al., 2010; Jamal et al., 2010; Williams et al., 2012). Until now its use has been curtailed at the storm event timescale (hours to days). Although XBeach has been validated and used extensively for erosive conditions, it has not been successfully validated or used to simulate post-storm beach accretion and recovery.

The aim of this paper is to expand on the studies of Callaghan et al. (2008) and Ranasinghe et al. (2011a), to overcome the limitations of their models as a result of using empirical/data driven approaches to determine storm erosion/post-storm recovery. Here we will attempt to simulate medium term beach change using a fully process based approach, by combining the FTS approach with the XBeach model, hereafter known as the Statistical-Process based Approach (SPA). To the authors' knowledge, this is the first attempt of calibrating XBeach to simulate beach recovery and, use a fully process based model to simulate beach change at medium term timescales. The SPA will provide useful insights into current capabilities of XBeach at medium term beach modelling.

2. Field site

2.1. Narrabeen Beach

Narrabeen Beach is located approximately 20 km north of Sydney, NSW, Australia (Fig. 1). It is a 3.6 km long embayed beach that experiences semi diurnal, microtidal conditions with a mean spring tidal range of 1.25 m (Short, 1984). The region is subjected to highly variable, moderate to high energy incoming wave conditions as the wave climate is driven by a number of cyclonic sources, with storms reaching the beach throughout the year (Short, 2006; Short and Trenaman, 1992). The beach predominantly exhibits an intermediate state, but has been shown to frequently change between all states (Wright and Short, 1984).

The beach sediments are quartz and carbonate sands with median diameter (D_{50}) ranging from 0.25 to 0.50 mm (Wright and Short, 1984). The morphodynamic variability has been regularly and extensively monitored during the last few decades with beach profiles being surveyed at 5 locations (Fig. 1) along the beach by the Coastal Studies Unit, University of Sydney (Short and Trembanis, 2004). The beach profiles surveyed at profile 4, where long term longshore transport effects are minimal (Harley et al., 2011a; Ranasinghe et al., 2004), are used in the present study. Fig. 2 highlights the variability in profile 4 during the recording period.

2.2. Offshore wave data

Wave data collected between 1981 and 2005, offshore of Botany Bay (Fig. 1) at a water depth of 85 m, using a waverider buoy have

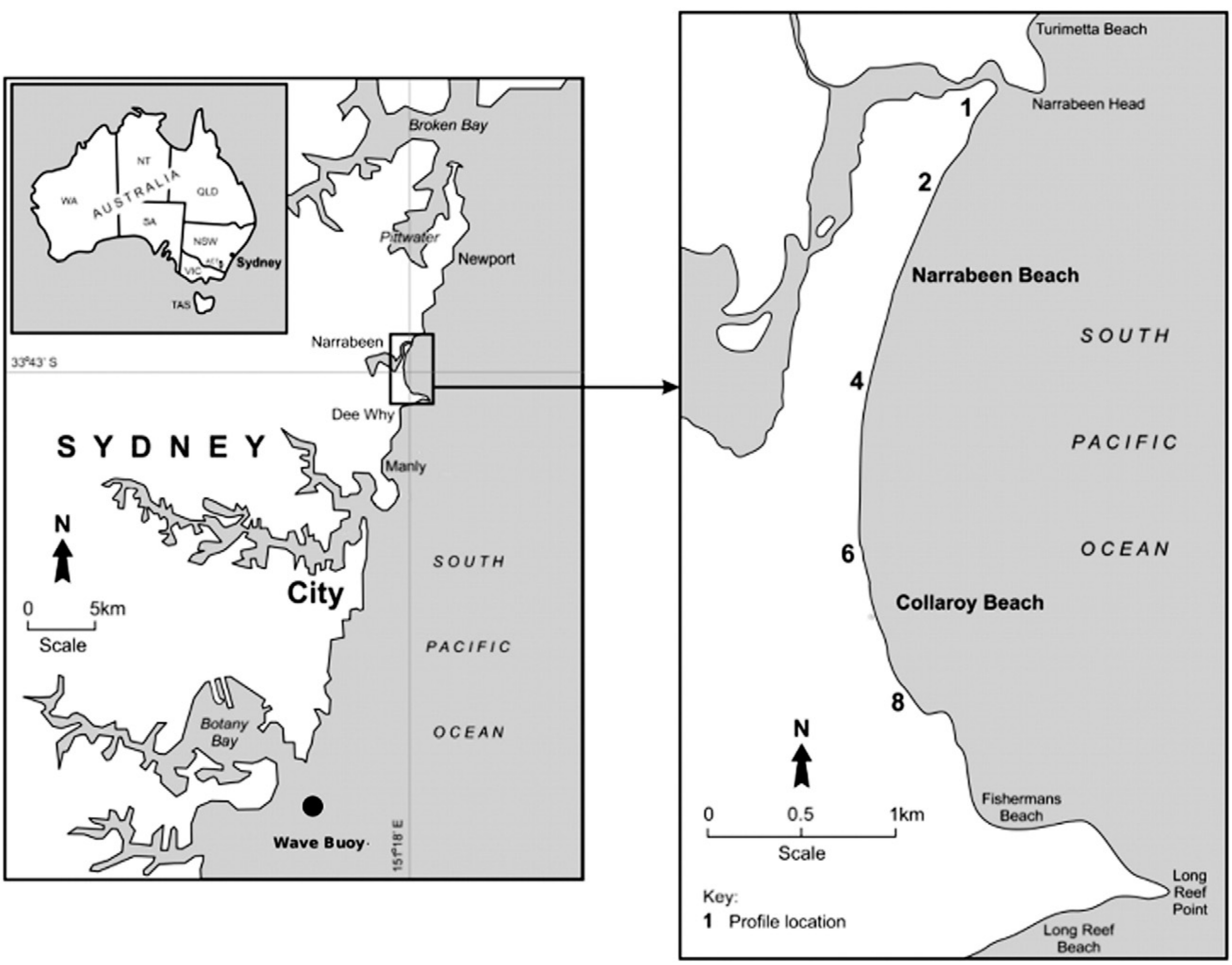

Fig. 1. Location of Narrabeen Beach, waverider buoy and measured profiles. Modified after Harley et al. (2011b).