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Sediment transport processes and morphodynamics on a reflective beach under storm and non-storm conditions

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ABSTRACT

New field experiments of sediment transport on the shoreface of a reflective beach ($R = 0.4–0.6$) during pre-storm, storm and post-storm conditions are reported. Data were collected outside the breakpoint and include water surface elevations, cross-shore and long-shore flow velocity, suspended sediment concentrations, bedform dimensions and the morphological response. Instruments included two pulse-coherent ADPs, an ADV, multiple OBS and a pencil-beam sonar. The depth-averaged mean velocity was always offshore and increased by a factor five during the storm, and this increase is attributed to undertow being enhanced by strong backwash plumes from cusp bays. Estimates of cross-shore suspended sediment transport are landward during the pre- and post-storm phases, consistent with the morphological response. During the storm, the shoreface quickly appeared to reach equilibrium, despite energy levels being maintained, with sediment transport rates reducing rapidly after the initial phase of the storm. Streaming in the wave boundary layer was observed and strongest during the pre-storm phase, consistent with the observed shoreward transport. During the storm the near-bed streaming was too small to reverse the increased offshore current, consistent with the observed net offshore transport. The generally small orbital velocity skewness observed on this steep reflective beach suggests that wave reflection may reduce the overall skewness of the velocity, in turn contributing to the stability of reflective beach types.

1. Introduction

Reflective beaches are the low-energy end-member of the beach type continuum laid out by Wright and Short (1984). They are unbarred and consist of a steeply sloping beach face, a narrow or absent breaker/surf zone at the toe of the beach face, and a lower shoreface where waves are shoaling. Reflective beaches are often semi-enclosed, swash-aligned beaches and the shoreline typically exhibits small-scale alongshore perturbations in the form of beach cusps. Because sediment is stored mainly on the subaerial beach rather than in nearshore bars, reflective beaches respond rapidly to changes in wave energy and since longshore directed currents and sediment transport are generally weak due to the swash-alignment, changes in beach morphology are predominantly a response to cross-shore processes (Dall et al., 2000).

Field investigations of morphodynamics and sediment transport on reflective beaches are rare. Swash zone processes and sediment transport were examined on gravel beaches in England (Austin and Masselink, 2006; Masselink et al., 2010) and New Zealand (Ivamy and Kench, 2006) but nearshore processes have rarely been investigated. Reflective beaches provide a convenient opportunity for detailed field study of sediment transport processes under natural shoaling and non-breaking waves and the exchange of sediment between the lower shoreface and the beach, because the proximity of the lower shoreface to the shoreline allows for easy installation of field instrumentation.

With respect to areal extent, the lower shoreface constitutes the major part of reflective beaches and the seabed is commonly covered by wave ripples which introduce complexities to the transport of suspended sediment. It has been known for a long time (Inman and Bowen, 1963) that when steep vortex ripples are present, the effects of wave shoaling and the consequent orbital asymmetry can result in the direction of net oscillatory sediment transport being opposite to the wave direction and this was later confirmed by field measurements (Osborne and Greenwood, 1992). Vincent et al. (1991) demonstrated that suspended sediment transport over vortex ripples is vertically stratified due to the ejection of sediment clouds from ripples at times of velocity reversal. From the bed upward, progressively larger phase lags are introduced between wave orbital fluid velocity and sediment concentration because of the time it takes for the sediment clouds to be lifted to higher elevations in the water

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column. This results in variable transport rates and directions at different elevations and consequently, conventional discrete-point sensors for measurement of sediment concentration such as OBS-sensors coupled with fluid velocity measurements from one, or a few current meters are in most cases inadequate to resolve the complex vertical transport structure over ripples. Moreover, vertical mixing lengths are relatively small under non-breaking waves compared to situations when waves are breaking (Masselink and Pattiaratchi, 2000) and the high-concentration near-bed layer may be difficult to resolve due to sensor intrusion. Another disadvantage with conventional instrumentation is that transport magnitude is highly dependent on measurement position relative to a bedform, i.e. whether measurements are made in a ripple trough or at a ripple crest (Chang and Hanes, 2004; van der Werf et al., 2007). Hence, acoustic instruments that can remotely monitor fluid velocity and sediment concentration at identical positions relative to the bed with high vertical resolution within the wave boundary layer are best suited for quantifying transport under non-breaking waves over wave ripples in the field.

This paper reports on results from field measurements of suspended sediment transport and morphological change during storm and fairweather conditions on a reflective beach. The aims of the paper are: i) to examine the morphologic response of a reflective beach to storm and post-storm wave conditions, ii) to quantify the sediment exchange between the beach and the lower shoreface under these wave conditions using Pulse-Coherent Acoustic Doppler Profilers (PC-ADP's) and iii) to examine the detailed vertical structure of fluid flows and suspended sediment transport under natural non-breaking waves over a rippled seabed.

2. Field site and wave conditions

Data were collected at Pearl Beach on the northwest shore of Broken Bay, New South Wales, Australia (Fig. 1) during the period June 12–24, 2011. Pearl Beach is modally reflective and maintains this beach state virtually year round (Hughes and Cowell, 1987). The beach has a 960 m long zeta-shaped shoreline facing the incoming ocean swell, which has a modal deep-water significant wave height of 1.5 m and wave periods typically ranging from 8 to 14 s. The mean sediment grain size on the foreshore of Pearl Beach is 0.35–0.45 mm and the sand becomes finer on the lower shoreface where the mean grain size was 0.25–0.30 mm at the instrument deployment positions.

Deep-water wave height and period measured off Sydney Harbour, approximately 25 km south of the field site are shown in Fig. 2 and the time series can be separated into three distinct periods. First is a pre-storm phase with significant offshore wave heights $H_s = 2–3$ m and significant wave periods of about 8 s. Second is a storm phase beginning on June 14, when an East Coast Low passed the coastline of New South Wales and generated offshore waves exceeding $H_s =$ 4.5 m. Third is a post-storm phase associated with increasing wave periods to $T = 9–11$ s and a decrease in wave height to about $H_s = 2$ m on June 17, a return to $H_s = 3$ m and finally a steady drop in wave height to about $H_s = 1$ m on June 21.

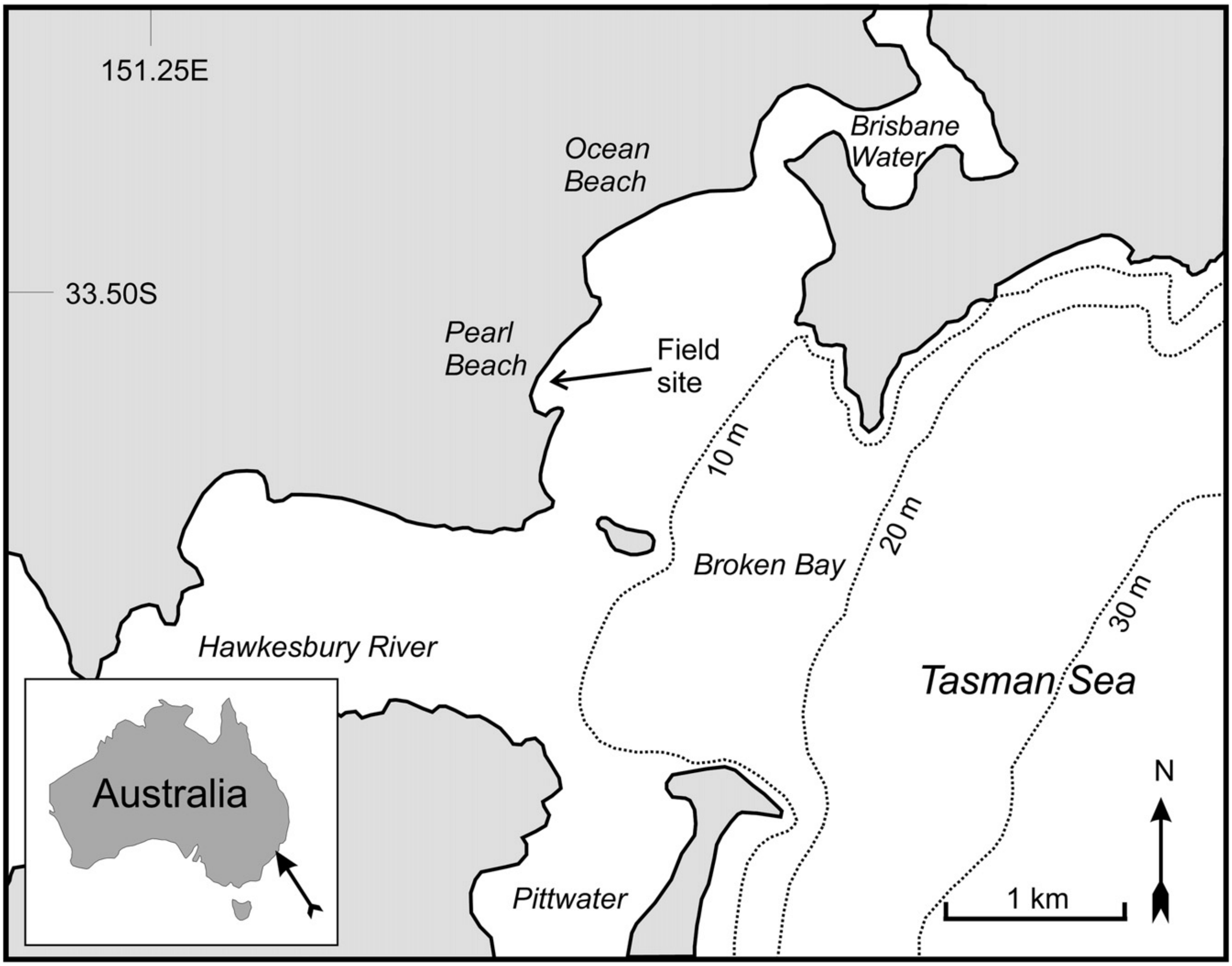

Fig. 1. Map of the location of Pearl Beach in Broken Bay, NSW, Australia.