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Detecting ebb-tidal delta migration using Landsat imagery

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ABSTRACT

Ebb-tidal deltas are important coastal sedimentary features that influence broad-scale coastal system behaviour. However, sediment transport within and around tidal deltas is complex, making it very difficult to understand the role they play within coastal sedimentary systems. Here we present details of a new method to examine ebb-tidal delta processes using long records of cloud-masked Landsat 7 and 8 satellite imagery. Our approach is similar to that adopted in nearshore process studies, in which time-averaged collections of digital photographs from terrestrial cameras are used to differentiate between broken and unbroken water based on image tone. Using the Google Earth Engine we are able to rapidly segment 100s of Landsat images into broken and unbroken water classes based on a threshold value. By then calculating the frequency of wave breaking at the Manukau ebb-tidal delta (METD) near Auckland, New Zealand, we can repeatedly map geomorphic features such as channels, linear bar formation, channel margin linear bars, swash bars, and the terminal lobe that marks the outer limit of wave breaking. Using a ~17-year long record of observations we observe > 2 km of northward alongshore channel migration and the potential emergence of a new channel to the south. The approach is simple, quick and with the growing constellations of earth observation satellites, has easy application to a range of other coastal systems.

1. Introduction

Ebb-tidal deltas (ETD) are sedimentary deposits often fronting tidal inlets, formed by the interaction of tidal and wave-generated flows (FitzGerald, 1984). They are important morphological features within coastal systems because: (1) they represent huge sand reservoirs, (2) sand shoals associated with ebb-tidal deltas reduce wave energy on landward beaches, (3) they affect the bypass process towards downdrift shorelines, thereby influencing coastal change, and (4) due to shallow water and dynamic sandbars they pose a key hazard to shipping. Ebb-tidal deltas are characterised by a seaward protrusion of typically sand-sized material, intersected by the main channel (FitzGerald et al., 2000). A number of other features, such as highly migratory sand bars and secondary and often ephemeral channels are commonly found within the systems (Harrison et al., 2017). The morphology of ebb-tidal deltas is strongly controlled by the tidal prism, which has been shown to correlate with the volume of sediment contained within the delta (Walton Jr and Adams, 1976; Hicks and Hume, 1996). Other factors including wave and tidal flows, sediment supply, local geology and anthropogenic modifications, either through engineering of harbour mouths, or as a result of interruption of sediment supplies, exert a control on ETD morphology and dynamics (FitzGerald et al., 2000).

In places, ETD act as stores of massive quantities of sand. For instance, the ETD at the Kaipara Harbour on the west coast of New Zealand are estimated to contain > 12 km^3 of sediment (Hicks and Hume, 1996). Sediment contained within ETD systems can continuously bypass the deltas or be cyclically or episodically released, thereby modulating coastal change along downdrift beaches (FitzGerald, 1984). Variability in sediment supply to coastal areas represents a key control on coastal change. Coastal evolution studies have demonstrated the importance of sediment supply for millennial-scale coastal change (Carter and Woodroffe, 1997), and modelling studies have revealed how human engineering (dams on rivers, groynes, and seawalls on beaches) has profoundly influenced sediment supply and sediment transport over decadal time-scales, with far-reaching impacts on coastal erosion and coastal flooding (Dickson et al., 2007; Dawson et al., 2009). In contrast, much less is known about natural drivers of multi-decadal variability in sediment supply to coastal areas and the impacts on coastal change. While it has been widely recognised that ETD play a key role in coastal sedimentary systems, linking the dynamic behaviour of deltas and the resultant effects on nearby coastlines remain challenging. For example, in a recent analysis of multi-decadal coastal change of several high-energy dissipative beaches north of the Manukau Harbour, New Zealand, Blue and Kench (2017) documented

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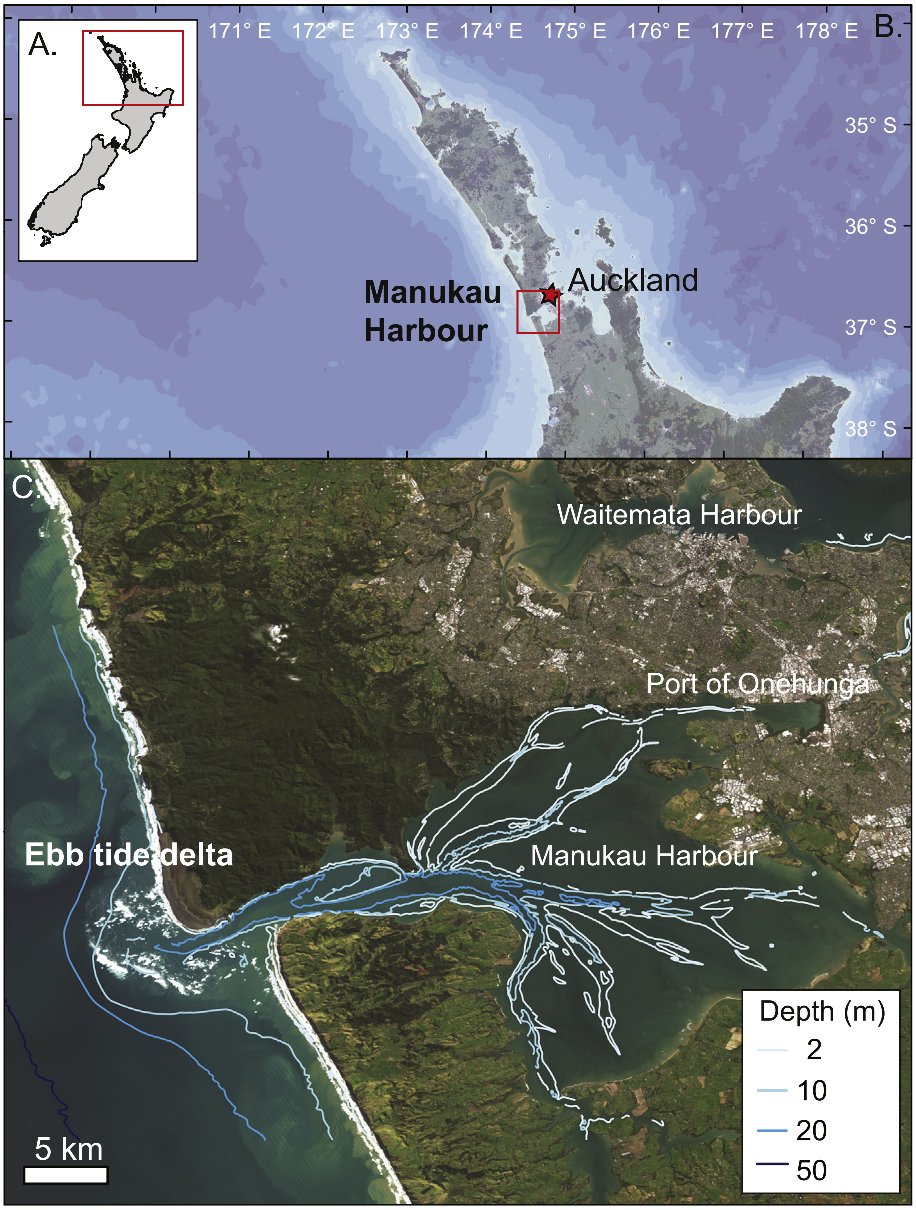

Fig. 1. A & B) Manukau Harbour on the west coast of the North Island of New Zealand. C) Ebb-tidal delta at the entrance to the Manukau Harbour, depth contours from NZ4314 chart.

asynchronous erosion and accretion patterns that could not be explained by human activity, nor wave-climate drivers (e.g. variation in wave height, storminess, and sea level). In this work Blue and Kench (2017) joined King et al. (2006) and Hart and Bryan (2008) in speculating that pulsing sediment supply associated with massive ETD may be the primary driving factor of coastal change at this location; however, there has been no systematic analysis of this hypothesis.

Various approaches have been employed to study ETD dynamics, including remote and field observations and hydrographic surveys, along with numerical models (Van Leeuwen et al., 2003). In many instances, field surveys of large ETD are technically difficult and often prohibitively expensive. Remote sensing data have been applied to map delta migration using imagery from a range of terrestrial (Balouin et al., 2004; Harrison et al., 2017) and airborne platforms (Hicks and Hume, 1997; Garel et al., 2014). Recently, time-averaged imagery from fixed, terrestrial cameras has been used to examine the morphological characteristics and behaviour of ETD (Balouin et al., 2004; Siegle et al., 2007; Pianca et al., 2014; Harrison et al., 2017).

Digital images captured from terrestrial cameras have been extensively used to study beach processes including: wave runup (Ruggiero et al., 2004), rips (Gallop et al., 2009) and nearshore bar morphology (Lippmann and Holman, 1989). Images are typically captured continuously at intervals ranging seconds to minutes. Collections of images provide temporally-rich visual records of nearshore conditions. Underpinning the approach is the stark contrast between broken (i.e. white in a grayscale image) and unbroken waves, which are darker in tone. When time-averaged and rectified, these collections of images reveal areas where wave breaking frequently occurs relative to areas of unbroken water. Such an approach is widely used to isolate rips, which are characterised by largely unbroken waves, and sand bars where waves break frequently.

In this paper we present details of a new approach developed using Landsat imagery to reveal decadal and inter-annular scale dynamics of the Manukau Harbour ebb-tidal delta (METD) system on the west coast of Auckland, New Zealand (Fig. 1). Our focus is on developing a technique to map ETD morphological features (e.g. migratory sand bars, primary and secondary channels and ephemeral channels) through time. The increasing availability of satellite imagery, coupled with