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Rip current circulation and surf zone retention on a double barred beach

Shari L. Gallop[a,*], Karin R. Bryan[b], Sebastian J. Pitman[c], Roshanka Ranasinghe[d,e,f], Dean R. Sandwell[b], Shawn R. Harrison[g]

[a] Department of Environmental Sciences & Macquarie University Marine Research Centre, 12 Wally's Walk, Macquarie University, NSW 2109, Australia
[b] School of Science, University of Waikato, Private Bag 3105, Hamilton, New Zealand
[c] Department of Geography, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand
[d] Department of Water Science and Engineering, IHE Delft Institute for Water Education, PO Box 3015, 2601 DA, Delft, the Netherlands
[e] Water Engineering and Management, Faculty of Engineering Technology, University of Twente, PO Box 217, 7500 AE, Enschede, the Netherlands
[f] Harbour, Coastal and Ocean Engineering, Deltares, PO Box 177, 2600 MH Delft, the Netherlands
[g] Pacific Coastal and Marine Science Center, U.S. Geological Survey, 2885 Mission Street, Santa Cruz, CA 95060, USA

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ABSTRACT

Rip currents have an important control on the exchange of water and advected materials such as sediment and pollutants, between the surf zone and inner shelf. Concurrent in situ Eulerian and Lagrangian (GPS drifter) data of surf zone waves and currents were combined with video data on wave breaking patterns over the inner and outer bars on a high energy, double-barred beach. The data collectively show how the occurrence of wave breaking over the outer bar changes the behavior of a channel rip current, and the exchange process. On both days, there was a prominent clockwise eddy in the surf zone, for which the seaward-heading portion formed a rip current in a well-defined channel rip, incised into the inner bar. Exit rate (measured with drifters) from the surf zone to inner shelf decreased significantly with increased wave breaking over the outer bar, from 71% exits to 6% over the two days. Exit rate appears to be driven by the balance between wave breaking over the inner and outer bars and pulsing of currents within the surf zone. Under higher wave conditions, there were stronger pulsations in surf zone currents and more surf zone exits. However, higher wave conditions caused wave breaking over the outer bar. This breaking increases vorticity around the outside of the surf zone eddy, which increases surf zone retention. This is in contrast to previous studies showing that vorticity is highest at the center of surf zone eddies. Under such conditions, drifter exits were rare, and occurred due to vortex shedding. During lower incident wave conditions, eddy vorticity was lower, and drifters could relatively freely exit the surf zone. This is one of the few studies that investigate surf zone circulation on a high energy, double-barred beach.

1. Introduction

On surf beaches, water is exchanged between the surf zone and inner continental shelf (Smith and Largier, 1995; Brown et al., 2009; Spydell et al., 2014; Hally-Rosendahl et al., 2015; Suanda and Feddersen, 2015), and also transports sediment (Holman et al., 2006; Loureiro et al., 2012; Thorpe et al., 2013; Spydell, 2016), nutrients (Castelle et al., 2010a), diatoms (Talbot and Bate, 1987), larvae (Defeo and McLachlan, 2005; Fujimura et al., 2014; Spydell, 2016), pathogens (Feng et al., 2013; Hally-Rosendahl et al., 2015) and other pollutants (Spydell et al., 2007, Spydell and Feddersen, 2012, Spydell, 2016) in nearshore and shelf waters (Kumar and Feddersen, 2016a, 2016b). However, the exchange process is highly variable in space and time (Suanda and Feddersen, 2015), and understanding the mechanisms remains a challenge.

Surf zone exchange occurs on all types of wave-dominated beaches (e.g., Spydell et al., 2007, 2014; Spydell and Feddersen, 2009, 2012; Feddersen et al., 2011; Suanda and Feddersen, 2015). On beaches with sand bars, a key conduit for this exchange is rip currents (rips) (Kumar and Feddersen, 2016a, 2016b). Rips are narrow, seaward-directed flows that extend from close to the shoreline, through the surf zone and sometimes beyond (Short, 1985; Aagaard et al., 1997; Castelle et al., 2016a, 2016b). There are three broad categories of rip currents, which can be subdivided into six fundamental types (Castelle et al., 2016a, 2016b). *Hydrodynamically-controlled rips* (sometimes called *transient rips*) occur on beaches that have uniform bathymetry alongshore and are transient in space and time (Johnson and Pattiaratchi, 2004, 2006; Castelle et al., 2014a; Feddersen, 2014; Suanda and Feddersen, 2015).

* Corresponding author.
E-mail address: shari.gallop@mq.edu.au (S.L. Gallop).

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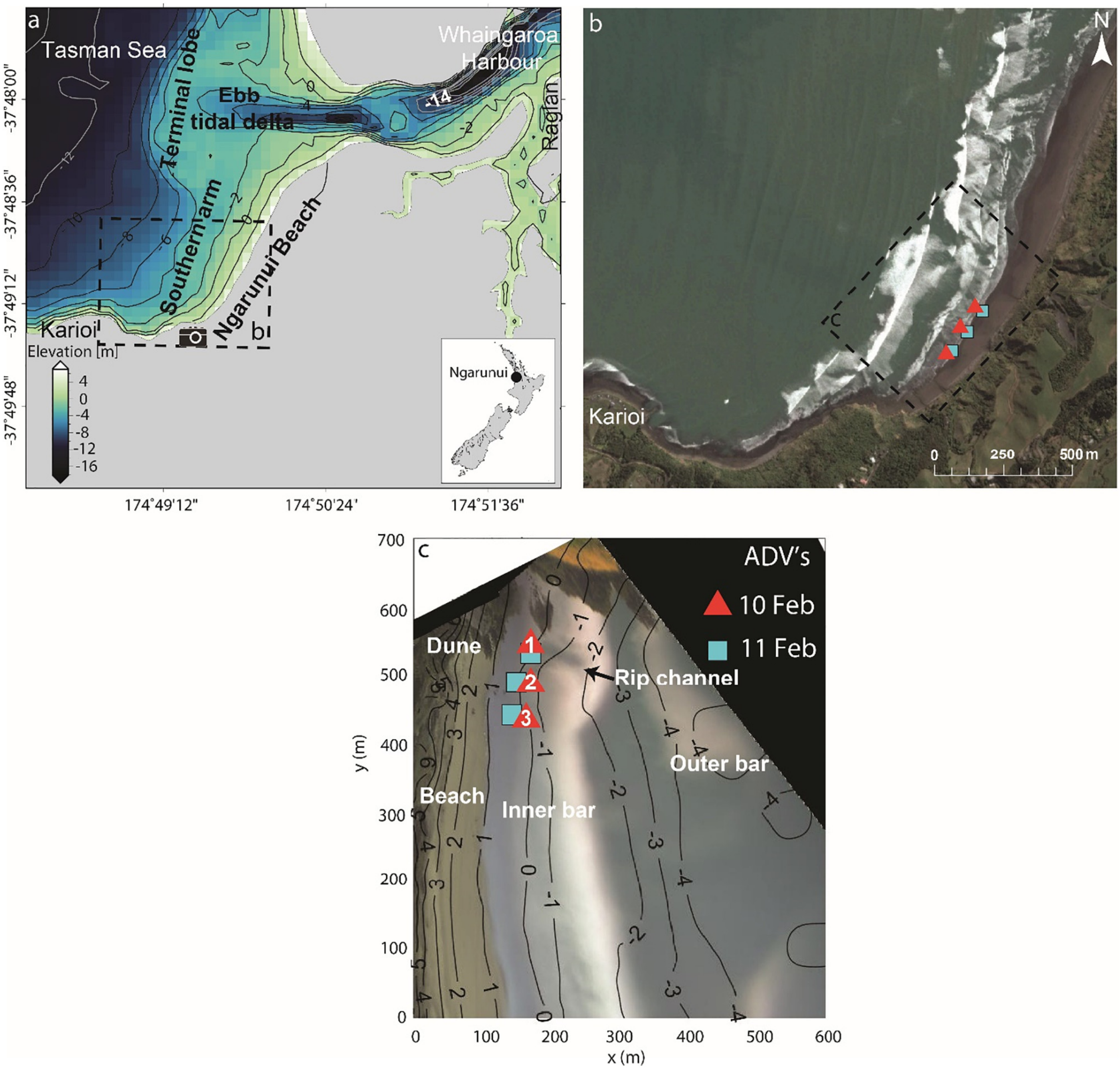

Fig. 1. (a) Study site location and bathymetry (compiled by Harrison and Hunt, 2014, with data sources detailed in Harrison, 2015), indicating the location of the Cam-Era camera (camera symbol). (b) Google Earth image from 22/07/2015 of the study area in the box indicated in (a). (c) timex Cam-Era image of the focus area on 11/02/2015 at 09:30 shown in (b), where black areas are outside the camera field of view. Bathymetry contours in (b) were collected on 5 February 2015 with RTK GPS down to low tide level and merged with bathymetry from Harrison and Hunt (2014), with a vertical datum of mean sea level. Coordinates in (c) and throughout the rest of the paper are local and in m, with an arbitrary zero, and rotated 153° relative to true north to align with the shoreline. Locations of the Acoustic Doppler Velocimeters (ADVs) on each day are indicated by the numbered symbols, also shown in (b) for reference.

The two types of *hydrodynamically-controlled rips* are *shear instability rips* which can form due to shear instabilities of longshore currents (Özkan-Haller and Kirby, 1999; Spydell et al., 2009; Castelle et al., 2014a; Feddersen, 2014), and *flash rips*, which are episodic bursts of water that jets offshore, due to transient surf zone eddies (Spydell and Feddersen, 2009; Feddersen, 2014). *Bathymetrically-controlled rips* are forced by alongshore variability in hydrodynamics, driven by bathymetric variations. These rips can be subdivided into *channel rips*, which occupy channels in between sand bars (Holman et al., 2006; Gallop et al., 2009; Dalrymple et al., 2011), and *focused rips* which form due to variations in offshore bathymetry (Long and Özkan-Haller, 2005, 2016). *Boundary-controlled rips* occur along lateral boundaries such as headlands (Gallop et al., 2011; McCarroll et al., 2014), piers and groynes (Pattiaratchi et al., 2009; Scott et al., 2016), and can be divided into *shadow rips*, which form against a boundary in the area shadowed from incident waves (Gourlay, 1974; Castelle and Coco, 2012), and *deflection rips* which form due to strong alongshore currents generated by incoming waves, that are deflected against a lateral boundary (Dalrymple et al., 2011; Scott et al., 2016). This paper focuses on surf zone exchange on a beach with *channel rips*, that is, rip currents located within channels in between sand bars, driven by alongshore variation in breaking wave energy dissipation, due to the alongshore variability in water depth (Bowen et al., 1968).

Surf zone exchange can be measured in terms of retention and exit rate of material from the surf zone (MacMahan et al., 2010; Reniers et al., 2010; Castelle et al., 2014b; Suanda and Feddersen, 2015). An exit occurs when currents move water and material seaward of the wave breaker zone onto the inner shelf, as opposed to retention by