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ABSTRACT

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The exchange of material between the surf zone and continental shelf can be driven by pulsations in rip current velocities. However, there is a poor understanding of the relationship of these pulsations to surf zone morphology and material exchange. Moreover, understanding of rip current dynamics has focused mainly on single-barred beaches in an intermediate state, and there have been few studies on high energy beaches. Therefore, this paper undertakes preliminary research on surf zone current velocity pulsations, on a high energy beach in New Zealand. This initial analysis presents results from two days of measurements using Acoustic Doppler Velocimeters and Lagrangian GPS drifters. Drifters revealed pulsations in current velocities on the order of ~0.5–2 m s^{-1} throughout the surf zone, whether inside a rip current circulation cell or not. More infragravity wave energy was associated with constant pulsations in current velocity, and lower infragravity energy with pulsation bursts, lasting 5–10 minutes, interspersed with periods of relatively constant velocity lasting 15–25 minutes. However, higher wave conditions also reduced the exit rate from the surf zone.

ADDITIONAL INDEX WORDS: *rip channels, surf zone, beach morphodynamics, Raglan, infragravity.*

INTRODUCTION

Rip currents are jet-like flows in the surf zone that generally head in an offshore direction (Aagaard *et al.*, 1997). They are often present on beaches in an intermediate morphodynamic beach state (Wright and Short, 1984), and adjacent to structures such as headlands and groynes (Gallop *et al.*, 2011; McCarroll *et al.*, 2014; Short, 1985). It is important to understand the variability and drivers of rip current flows because: (1) globally, they are the leading cause of rescues and fatalities on beaches (Short, 1999; Woodward *et al.*, 2015); and (2) they are a key mechanism transporting material between the surf zone and continental shelf, such as larvae (Fujimura *et al.*, 2014), diatoms (Talbot and Bate, 1987), and sediments (Aagaard *et al.*, 1997). Therefore, they are an important sediment transport conduit contributing to coastal sediment budgets (Goodwin *et al.*, 2013; Wright, 1987). Recent research suggests that the exit rate of material from the surf zone to offshore is an important control of: (1) hazard to beach users (Scott *et al.*, 2013); (2) the best escape strategy for people caught in a rip (McCarroll *et al.*, 2013); and (3) rates of cross- shore exchange of water (Smith and Largier, 1995), and materials (Loureiro *et al.*, 2013; Thorpe *et al.*, 2013).
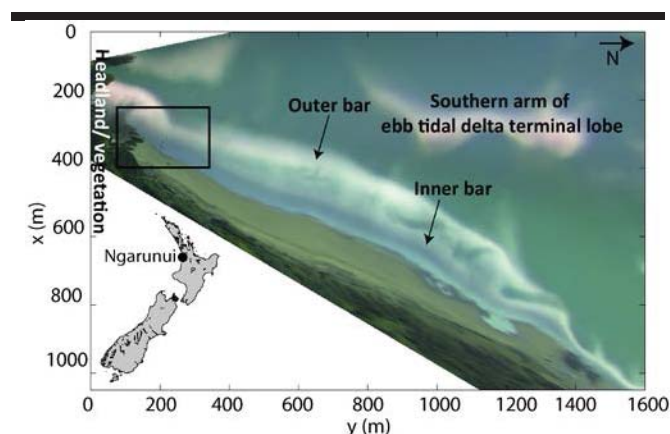

Figure 1. Study area at Ngarunui Beach, Raglan, New Zealand. Photo is a rectified, 10-minute average image from the Cam-Era video monitoring system. The box shows the area where ADVs and GPS drifters were deployed on 10 and 11 February 2015. White areas show breaking waves over shallow bathymetry. The dark area at the top of the beach is a shadow from the headland.

Surf zone exits may be driven by pulsations in rip current velocity. Pulsation of surf zone currents can occur at infragravity (IG) frequencies (25–250 s) due to standing IG waves (MacMahan *et al.*, 2004a; Sonu, 1972) or wave groups (Munk, 1949; Reniers *et al.*, 2010; Shephard and Inman, 1950). In addition, recent research has revealed the presence of vortical motions at Very Low Frequency (VLF) (4–10 min) motions (Castelle *et al.*, 2013; MacMahan *et al.*, 2004b; Reniers *et al.*, 2010). A range of generation mechanisms for VLF motions have been suggested. The dominant mechanism appears to be surf zone eddies due to wave groups (MacMahan *et al.*, 2004b; Peregrine, 1998; Reniers *et al.*, 2007).

There is a lack of measurements (MacMahan *et al.*, 2004a) to understand the relationship of current pulsations to rip current generation, surf zone morphology, material exchange, and hazard. Therefore, the aim of this paper is to undertake preliminary research on the influence of IG wave energy on rip current flows on a high energy beach.

METHODS

This section introduces the study site, field experiment, and data analysis methods.

Study site

Ngarunui Beach on the west coast of New Zealand (Figure 1) has fine-medium iron sand (Sherwood and Nelson, 1979). The tide is semidiurnal, with neap and spring ranges of ~1.8 and 2.8 m (Walters *et al.*, 2001). Offshore mean significant wave height is 2 m, with a period of 7 s (Gorman *et al.*, 2003). The southern arm of the ebb tidal delta, terminal lobe to Whaingaroa Harbor acts as the outer bar during large swell events. Further inshore, there are inner (high tide) and outer (low tide) bars which are often cut by rip channels (Figure 1).
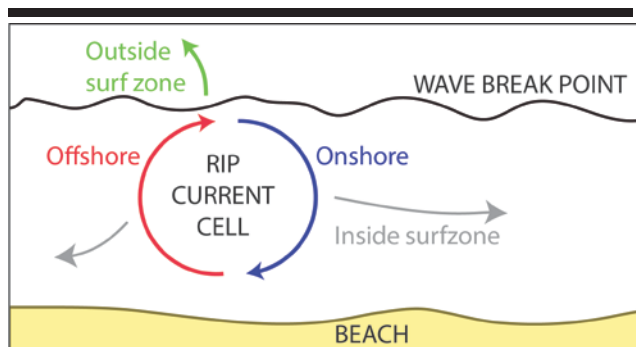

Figure 2. Generalized rip current circulation cell from box in Figure 1. Color coded arrows show the locations for which drifters are classified in Figures 3c and 4c.

Field experiment

A field experiment was undertaken between 9 and 11 February 2015 and included the deployment of three Triton Sontek Acoustic Doppler Velocimeters (ADVs), and ten GPS drifters. This paper focuses on data collected on February 10 and 11 collected in the rip current cell at the south end (Figure 1).

ADVs were deployed upward-facing within the rip current, and were set to the maximum sampling rate of 4 Hz for 4086 samples. GPS drifters were based on the design of Schmidt *et al.*

(2003) and MacMahan *et al.* (2009). The GPS logger was the QStarz BT-Q100eX, which has a velocity accuracy of ±0.05 m s^{-1} (Thomson, 2012). One drifter was left in a static position on a benchmark to estimate the mean horizontal error and standard deviation of 3.78 ± 1.20 m. Drifters were deployed by wading out to waist-depth. They were retrieved using a combination of shore-retrieval, and a jetski when they: (1) washed onshore and dragging on the bed; (2) travelled alongshore outside of the study area; (3) exited the surf zone; and (4) entered busy surfing/ swimming areas. All times are given in New Zealand Standard Time (NZST).

Data analysis

As in other studies of surf zone currents using GPS drifters (e.g., Johnson and Pattiaratchi, 2004; McCarroll *et al.*, 2014), velocity data were low-pass filtered using a Butterworth filter with a low-pass cutoff of 0.05 Hz, to average wave motion and other noise.; including an algorithm to reduce end effects. For this preliminary investigation, results are presented of individual drifter velocities and their location within the surf zone circulation system, and compared with IG wave energy. Drifter velocities are color coded by location: (1) offshore- and (2) onshore-directed flow in the rip current circulation cell; (4) elsewhere inside the surf zone (Figure 2); or (3) offshore.

Offshore wave conditions were obtained from the nzwave_12 wave forecast which used WAVEWATCHv3.14, and was run by NIWA. Drifter velocities were compared to the energy in the IG band of: pressure (water level); x (cross-shore); and y (longshore) currents recorded by ADVs in the surf zone. These were obtained by calculating wave power spectra on the detrended time-series, which were then smoothed using a Hanning window of 4096 data points. The total IG energy was summed for each window, within the frequency band of 0.0033–0.05 Hz (20–300 s); suggested infragravity wave frequency cutoffs vary but generally range within this window (e.g. Holman, 1981; MacMahan *et al.*, 2004a). Periods of pulsations in surf zone current velocities were identified by calculating the standard deviation of the low pass-filtered velocity in 2 minute windows. Pulsations were defined as occurring when the standard deviation was greater than the 50th percentile standard deviation of filtered drifter velocities.

RESULTS

Here, results are summarized for 10 and 11 February.

10 February

On 10 February, mean offshore significant wave height was 1.4 m, and period was 8.7 s. There was significantly more IG energy in cross-shore currents compared to sea level and long-shore currents (Figure 3a). IG energy gradually increased during late morning, with energy in cross-shore currents increasing from ~10 m^2/Hz, to peak at 15 m^2/Hz after 13:00 h (Figure 3a). Pulsation bursts of drifter velocity were identified by periods of high standard deviation (Figure 3b). During these pulsations, the drifters reached velocities on the order of ~0.5–2 m s^{-1} (Figure 3c). Drifter velocities alternated between pulsation bursts lasting around 5–10 minutes (Figure 3c), interspersed with periods of relatively constant, lower velocity of <0.5 m s^{-1}. Pulsations were not associated with the position within the surf zone, as this occurred at all locations sampled, *i.e.* in the offshore and onshore
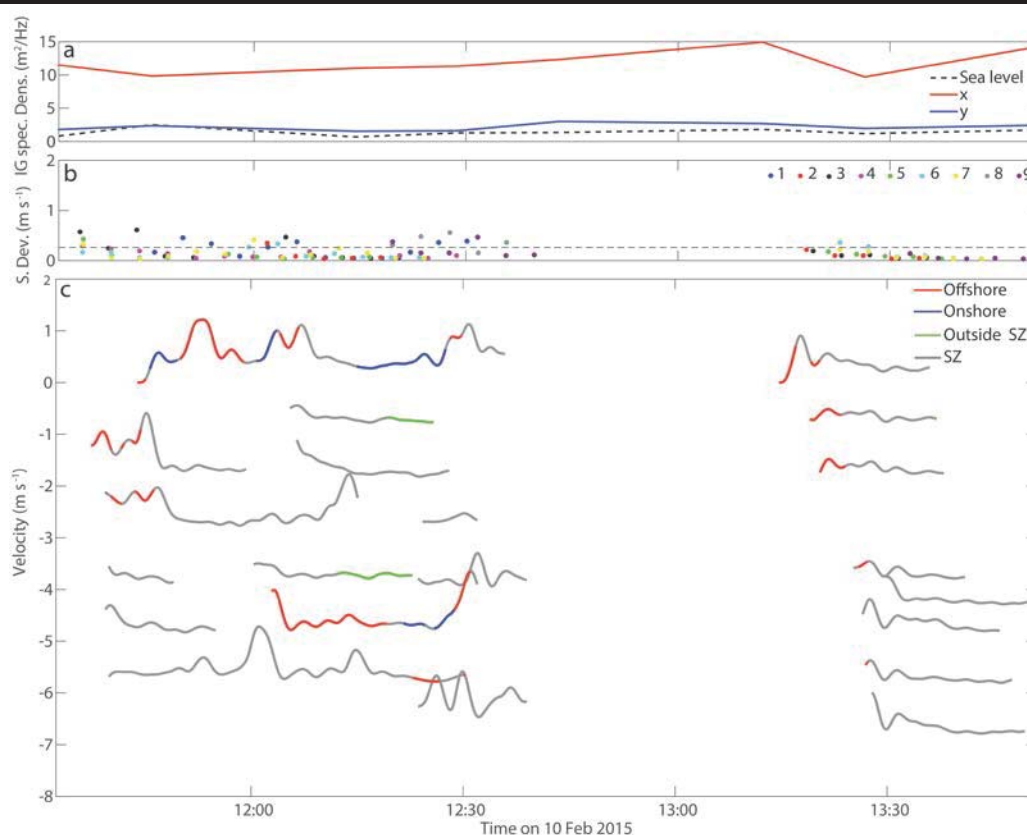
Figure 3. (a) On 10 February 2015, energy in the infragravity (IG) band (0.0033–0.05 Hz) for sea level, *x*, and *y* currents measured with an ADV; (b) standard deviation in drifter velocity for drifters 1 to 9, for 2 minute windows where the dashed line shows the 50th percentile; and (c) filtered GPS drifter velocity for 1 (top) to 9 (bottom), with plotting successively offset by -1 m s^{-1}. Color code corresponds to the areas shown in Figure 2.

flows within the rip current circulation cell, and others areas of the surf zone. Due to a lack of temporal drifter coverage, it is also not clear if more pulsing occurred as IG energy increased on this day.

11 February
On 11 February, mean offshore significant wave height increased to 1.9 m, and mean period to 11.7 s. This higher wave energy was reflected in cross-shore IG energy that was an order of magnitude greater than the day before, reaching 130 m^2/Hz (Figure 4a) compared to 13 m^2/Hz on 10 February (Figure 3a). Total IG energy was variable. For cross-shore currents, it reached local maxima in spectral density of ~80, 100, and 130 m^2/Hz at 12:30, 13:10, and 14:20 respectively; and local minima of ~50 m^2/Hz at 12:45 and 14:10. Unlike on the previous day, there were almost constant pulsations in GPS drifter velocities (Figure 4b). During these pulsations, drifters reached velocities on the order of 0.5–2 m s^{-1} (Figure 4c). These oscillations occurred regardless of location within the surf zone.

DISCUSSION
IG frequency energy was an order of magnitude greater on 11 February compared to 10 February. If rip current pulsations are driven by IG waves (MacMahan *et al.*, 2004a; Reniers *et al.*,

2010), then it is expected that more IG wave energy would lead to more pulsations in rip current velocity. This relationship is confirmed by differences between the two days, where pulsations in rip current velocities were constant on 11 February (Figure 4c), when IG wave energy was much greater (Figure 4a). Conversely, on 10 February when IG wave energy was relatively lower (Figure 3a), surf zone current pulsations were intermittent (Figure 3c) and occurred in bursts lasting for 5–10 minutes, interspersed by periods of relatively constant velocity, lasting 15–25 minutes. The magnitude of the velocity pulsations was similar between the two days, on the order of 0.5–2 m s^{-1}. If IG pulsations in rip current velocity are the main driver of surf zone exits, then more exits should have occurred on 11 February. However, there were significantly less exits on 11 February (6 %) compared to 10 February (71 %) (Gallop *et al.*, 2015). Offshore significant wave height was higher on the second day, at 1.9 m compared to 1.4 m on the first day. This relationship is consistent with findings elsewhere that more drifter exits occur during lower wave conditions (MacMahan *et al.*, 2010; Scott *et al.*, 2014).
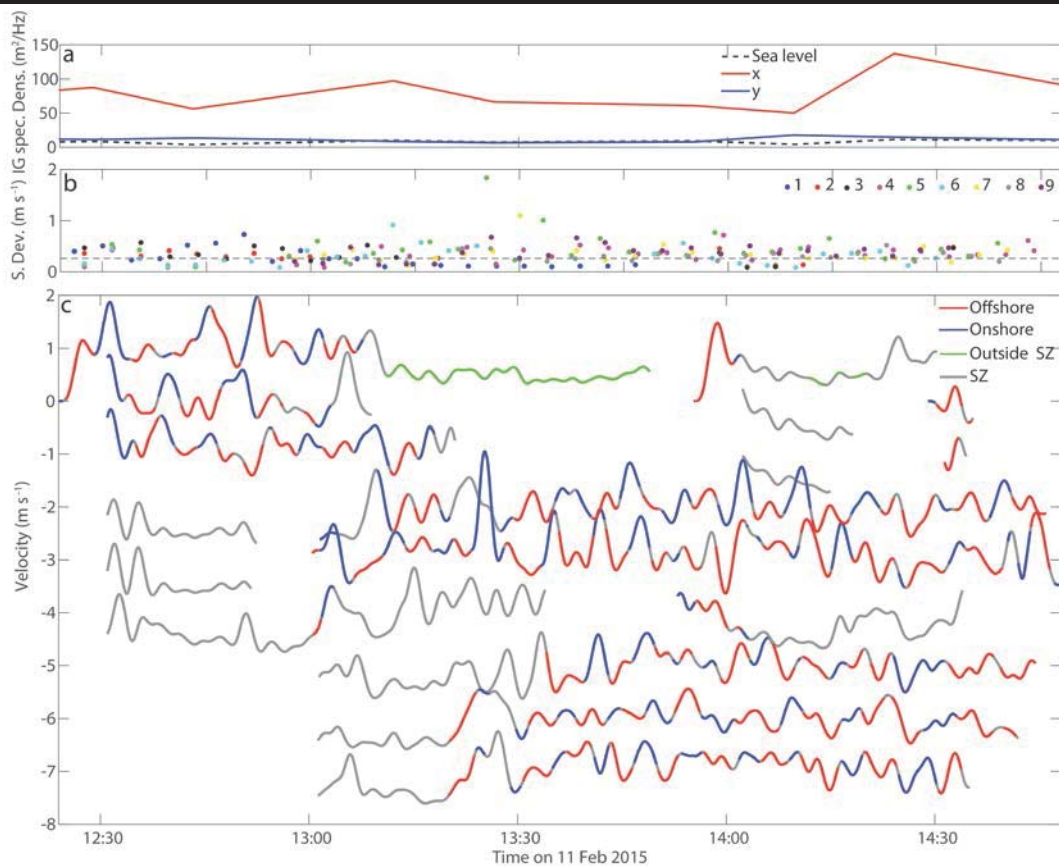
Figure 4. (a) On 11 February 2015, energy in the infragravity band (IG) (0.0033–0.05 Hz) for sea level, x, and y currents measured with an ADV; (b) standard deviation in drifter velocity for drifters 1 to 9, for 2 minute windows where the dashed line shows the 50th percentile; and (c) filtered GPS drifter velocity for 1 (top) to 9 (bottom), with plotting successively offset by -1 m s^{-1}. Color code corresponds to the areas shown in Figure 2.

This may be caused by larger waves breaking further offshore which induce current vortices that are coupled to the surf zone morphology, and encourage material retention (MacMahan *et al.*, 2010). Further research is required to understand the effect of rip current pulsations and incident wave conditions on rip current flows, particularly on high energy beaches.

CONCLUSIONS

This paper presented a preliminary study on rip current velocity pulsations, on a high energy, mesotidal beach in New Zealand. There were strong pulsations in surf zone current velocity on the order of ~0.5–2 m s^{-1}. These pulsations occurred in 5-10 minute bursts interspersed with 15-20 minute periods of relatively constant velocity, during lower total wave energy, and lower IG energy conditions. Conversely, during higher wave energy conditions, and when there was more IG wave energy present, the pulsations were constant. More pulsations did not lead to increased surf zone exits, possibly because the higher incident wave conditions encouraged the retention of material in the surf zone. Further research is planned to understand the balance of rip current velocity pulsations and incident wave

conditions on rip current flows and surf zone exits on high energy beaches

LITERATURE CITED

Aagaard, T.; Greenwood, B., and Nelson, J., 1997. Mean currents and sediment transport in a rip channel. *Marine Geology*, 140, 25-45.

Castelle, B.; Reniers, A., and MacMahan, J., 2013. Numerical modelling of surfzone retention in rip current systems: On the impact of the surfzone sandbar morphology. *Proceedings of Coastal Dynamics 2013* (24-28 June, Arcachon).

Fujimura, A.G.; Reniers, A.J.H.M.; Paris, C.B.; Shanks, A.L.; MacMahan, J.H., and Morgan, S.G., 2014. Numerical

simulations of larval transport into a rip-channeled surf zone. *Limnology and Oceanography*, 59(4), 1434-1447.

Gallop, S.L.; Bryan, K.R.; Coco, G., and Stephens, S.A., 2011. Storm-driven changes in rip channel patterns on an embayed beach. *Geomorphology, 127*(3–4), 179-188.

Gallop, S.L.; Bryan, K.R.; Pitman, S.; Ranasinghe, R., and Sandwell, D., 2015. Rip current observations on a low-sloping dissipative beach. *Proceedings of Coasts and Ports* (15-18 September, Auckland).

Goodwin, I.D.; Freeman, R., and Blackmore, 2013. An insight into headland sand bypassing and wave climate variability from shoreface bathymetric change at Byron Bay, New South Wales, Australia. *Marine Geology*, 341, 29-45.

Gorman, R.; Bryan, K.R., and Laing, A.K., 2003. Wave hindcast for the New Zealand region: Nearshore validation and coastal wave climate. *New Zealand Journal of Marine and Freshwater Research*, 27, 567-588.

Holman, R.A., 1981. Infragravity energy in the surf zone. *Journal of Geophysical Research* 86(C7), 6442-6450.

Johnson, D. and Pattiaratchi, C., 2004. Transient rip currents and nearshore circulation on a swell-dominated beach. *Journal of Geophysical Research*, 109, C02026.

Loureiro, C.; Ferreira, Ó., and Cooper J.A.G., 2012. Extreme erosion on high-energy embayed beaches: Influence of megarips and storm grouping. *Geomorphology,* 139–140, 155–171.

MacMahan, J.; Reniers, A.J.H.M.; Thornton, E.B., and Stanton, T., 2004a. Infragravity rip current pulsations. *Journal of Geophysical Research*, 109, C01033.

MacMahan, J.H.; Reniers, A.J.H.M.; Thornton, E.B., and Stanton, T.P., 2004b. Surf zone edits coupled with rip current morphology. *Journal of Geophysical Research*, 109, C07004.

MacMahan, J.; Brown, J., and Thornton, E., 2009. Low-cost handheld global positioning system for measuring surf-zone currents. *Journal of Coastal Research*, 25(3), 744-754.

MacMahan, J.; Brown, J.; Brown, J.; Thornton, E.; Reniers, A.; Stanton, T.; Henriquez, M.; Gallager, E.; Morrison, J.; Austin, M.J.; Scott, T.M., and Senechal, N., 2010. Mean Lagrangian flow behaviour on an open coast rip-channeled beach: A new perspective. *Marine Geology,* 268(1-4): 1-15.

McCarroll, R.J.; Brander, R.W.; MacMahan, J.H.; Turner, I.L.; Reniers, A.J.H.M.; Brown, J.A., and Bradstreet, A., 2013. Assessing the effectiveness of rip current swimmer strategies, Shelly Beach, NSW, Australia. *Journal of Coastal Research*, Special Issue 65, 784-789.

McCarroll, R.J.; Brander, R.W.; Turner, I.L.; Power, H.E., and Mortlock, T.R., 2014. Lagrangian observations of circulation on an embayed beach with headland rip currents. *Marine Geology, 355*, 173-188.

Munk, W.H., 1949. Surf beats. *EOS Transactions*, AGU. 30(6), 849-854.

Peregrine, D.H., 1998. Surf zone currents. *Theoretical and Computational fluid dynamics*, 10, 295-309.

Reniers, A.J.H.M.; MacMahan, J.H.; Beron-Vera, F.J., and Olascoaga, M.J., 2010. Rip-current pulses tied to Lagrangian coherent structures. *Geophysical Research Letters*, 37, L05605.

Reniers, A.J.H.M.; MacMahan, J.H.; Thornton, E.B., and Stanton, T.P., 2007. Modeling of very low frequency motions

during RIPEX. *Journal of Geophysical Research* 112, C07013.

Schmidt, E.W.; Woodward, B.T.; Millikan, K.S.; Guza, R.T.; Raubenheimer, B., and Elgar, S., 2003. A GPS-tracked surf zone drifter. *Journal of Atmospheric and Oceanic Technology*, 20(7), 1069-1075.

Shepard, F.P. and Inman, D.L., 1950. Nearshore water circulation related to bottom topography and wave refraction. *EOS Transactions*, AGU, 31(1), 196-212.

Sherwood, A.M. and Nelson, C.S., 1979. Surficial sediments of Raglan Harbour, N.Z. *Journal of Marine and Freshwater Research*, 15(4), 475-496.

Short, A.D., 1985. Rip current type, spacing and persistence, Narrabeen beach, Australia. *Marine Geology*, 65(1-2), 47-71.

Short, A.D., 1999. Beach hazards and safety. In: Short, A.D. (ed.). *Beach and shoreface morphodynamics.* Chichester: John Wiley and Sons, pp. 292-304.

Scott, T.; Masselink, G.; Austin, M.J., and Russell P., 2014. Controls on macrotidal rip current circulation and hazard. *Geomorphology,* 214, 198–215.

Smith, J.A. and Largier, J.L., 1995. Observations of nearshore circulation: Rip currents. *Journal of Geophysical Research-Oceans,* 100(C6), 10967–10975.

Sonu, C.J., 1972. Field observation of nearshore circulation and meandering currents. *Journal of Geophysical Research*, 79, 3065-3071.

Talbot, M.M.B. and Bate, G.C., 1987. Rip current characteristics and their role in the exchange of water and surf diatoms between the surf zone and nearshore. *Estuarine, Coastal and Shelf Science*, 25(6), 707-720.

Thomson, J., 2012. Wave breaking dissipation and 'SWIFT' drifters. *Journal of Atmospheric and Oceanic Technology*, 29, 1866-1882.

Thorpe, A.; Miles, J.; Masselink, G.; Russell, P.; Scott, T., and Austin, M., 2013. Suspended sediment transport in rip currents on a macrotidal beach. *Journal of Coastal Research,* Special Issue 65, 1880–1885.

Walters, R.A.; Goring, D.G., and Bell, R.G., 2001. Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 35(3), 567-580.

Woodward, E.; Beaumont, E., and Russell, P., 2015. Public understanding and knowledge of rip currents and beach safety in the UK. *International Journal of Aquatic Research*, 9, 49-69.

Wright, L.D., 1987. Shelf-surfzone coupling: Diabathic shoreface transport. *Proceedings of Coastal Sediments 1987* (12-14 May, New Orleans).

Wright, L.D. and Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: A synthesis. *Marine Geology*, 56, 93-118.