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RIP CURRENT DYNAMICS ON AN EMBAYED BEACH

A thesis submitted in partial fulfilment

of the requirements for the Degree

of

Master of Science

in Earth and Ocean Sciences

by

SHARI L. GALLOP

THE UNIVERSITY OF

WAIKATO

Te Whare Wānanga o Waikato

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Abstract

Rip currents are fast, narrow currents which traverse the surf-zone in the seaward direction. The most important effect of rip currents is that they can pose a deadly hazard to beach-users. Rip currents and their interaction with waves and underwater morphology are still poorly understood. This is often attributed to a lack of high quality long-term datasets. This shortcoming is due to the difficulty of sampling in the turbulent surf-zone. Past attempts to compare rip current behaviour (e.g. alongshore spacing) to waves have failed to show that they interact.

In this thesis, an improved technique of locating rip channels in video imagery is presented. Previous studies to create computer algorithms to locate rips in video imagery have only looked at one alongshore transect which is averaged in the cross-shore direction, and there have been issues making the algorithms work in complicated cases. The method created in this thesis uses computer algorithms to locate light intensity minima across the entire expanse of the surf-zone in video imagery. This was applied to a dataset from Tairua Beach. The light intensity minima are sorted into distinct rip channels to create a dataset spanning 3.3 years from 1999 until April 2002. Using the high quality rip data output from the algorithms, rip channel morphological reconfiguration events were defined using a measure of change. Wave climate was compared to the timing of these reconfiguration events. It was found that mean wave energy averaged over ten days and wave event duration showed a better relationship to the reconfiguration events than immediate, instantaneous measures of significant wave height.

Rip channel spatial scale (i.e. cross-shore extent) was found to be critical in determining how rip channels behave during high wave events. At Tairua Beach, it was not uncommon for the surf-zone to be wide on one half of the beach and narrow on the other. This ‘dual’ surf-zone can be attributed to wave shadowing by offshore islands under certain wave directions. Smaller rip channels on the narrow half of the beach changed rapidly whereas larger rips were stable during the same period. This situation shows the importance of both hydrodynamic-control and topographic-control of rips, where rips may respond directly to changes in the wave conditions or be stabilised by the pre-existing morphology respectively. There was also a tendency for rips to form and persist at the headlands of the beach.

A conceptual model was created to demonstrate how rip channels of different spatial scales respond to changes in the wave conditions. Small rips relative to the wave energy are more likely than larger rips to evolve, and vice versa.

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My biggest thank you is to my supervisor Dr. Karin Bryan. She has been amazing. She gave constant encouragement, laboriously helped me develop my computer programming skills (answering all my millions of questions!) and was always sure to make time to give assistance with a smile. She is inspirational and always full of brilliant ideas.

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Chapter One: Introduction

1.1 Introduction

Rip currents are fast, concentrated currents which flow seaward in the surf-zone. Rip currents are a visible feature of beaches all over the world. Rip currents are a critical link in the energy balance of the surf-zone. Energy enters the surf-zone with the incoming waves and is transferred upward and forward in the spectrum to higher order waves, turbulent eddies, and to infragravity waves and mean currents. The energy in currents, where rip currents are an example, is ultimately dissipated by turbulence and bed friction.

Rip currents are central to nearshore circulation (Turner et al., 2007) and thus can cause the mixing and dilution of pollutants (Bohem, 2003). Rip currents can also have significant ecological implications, for example Talbot and Bate (1987) showed that rip currents have an effect on surf-zone diatom concentrations. It has long been recognised that rip channels can carry sediment offshore from the surf-zone (Short, 1985) and can cause changes to bar and shoreline morphology (Turner et al., 2007). Perhaps the most critical effect of rip currents is the danger they pose to beach swimmers and other recreational beach-users (e.g. most energetic beaches have signage warning users of the dangers (Figure 1.1). Rip currents in the surf-zone are a significant natural hazard because of their fast current velocities and often inconspicuous nature. For example, in the state of Florida, U.S.A., rip currents are responsible for 80% of lifeguard rescue efforts, and are the dominant natural hazard (MacMahan et al., 2006). Understanding rip current systems is central to developing forecasts for predicting rip current events that pose a hazard to swimmers and other beach-users.

Much effort has gone into trying to predict when and where they will occur and how intense they will be. However, at present, rip currents are still poorly documented and understood. There are great difficulties sampling in the turbulent surf-zone and hence there are few high quality, long-term data-sets of rip currents. As highlighted by Ranasinghe et al. (1999), qualitative and theoretical attempts to explain rip characteristics such as their generation, spacing and persistence are abundant in the scientific literature. Short-term (i.e. hours to a few days) process studies of rip currents and their associated morphology have significantly advanced knowledge of short term rip current morphodynamics (Turner et al., 2007). However, longitudinal studies of fundamental rip current characteristics such as spacing, persistence and mobility have been limited by the low availability of high quality data-sets (Turner et al., 2007).

Video imagery as a technique for making measurements in the surf-zone has been shown to be appropriate for measuring rip currents. Video imagery is still under-utilised in measuring rips. The general aim of this thesis is to take a step further in solving the enigma that is rip currents.

Figure 1.1. Examples of signage warning beach-users of the danger of rip currents.

1.2 Study Sites

This thesis examines two study sites where video cameras overlooked the surf-zone: Tairua Beach and Muriwai Beach. Cam-Era is project involving the camera at Tairua

Beach and the camera at Muriwai Beach is part of the Argus Programme (see Section 3.4). The main focus of this study is on Tairua Beach, however Muriwai Beach is briefly included. The computer algorithms created in this study to locate rip channels in video imagery (see Chapter Four) were tested with video images from both Tairua and Muriwai Beach.

1.2.1 Tairua Beach

Tairua Beach is located on the Coromandel Peninsula on the north east coast of the North Island of New Zealand (Figures 1.2 and 1.3).

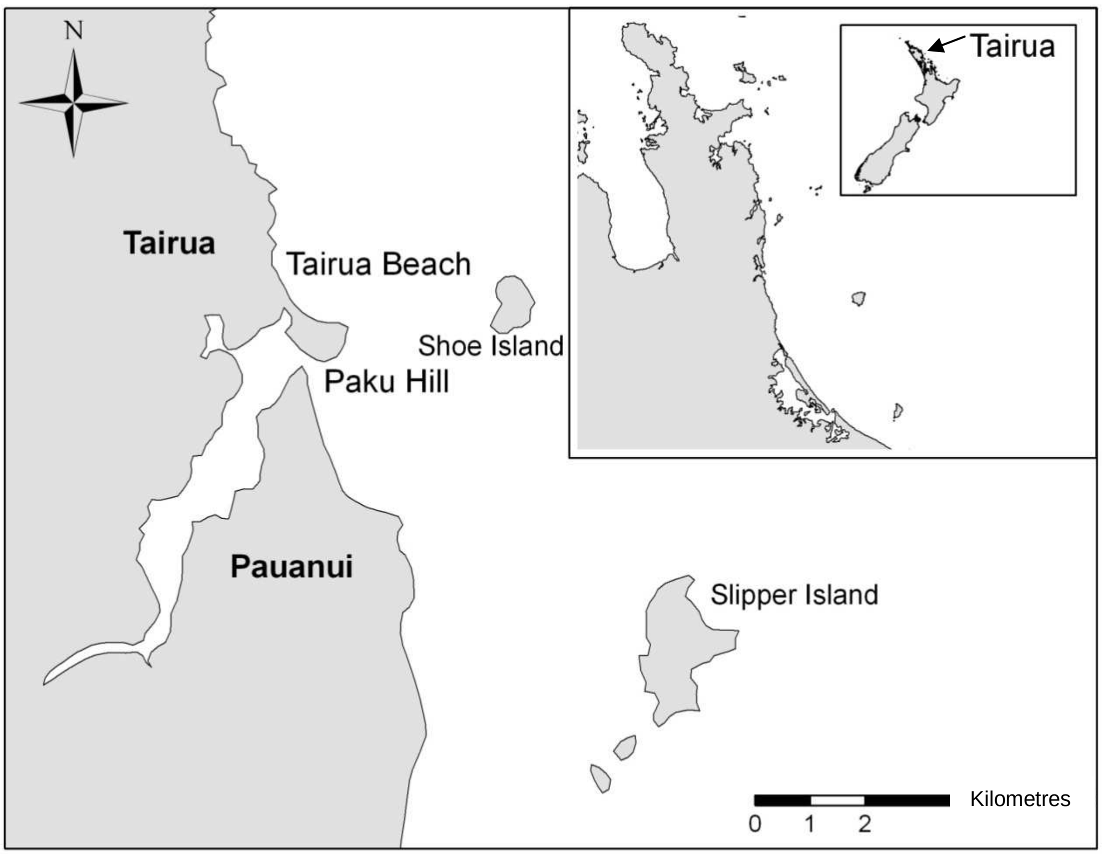


Figure 1.2. Map of New Zealand showing the location of Tairua Beach.

Tairua Beach is an embayed beach that is about 1.6 km long, and is in front of a Holocene barrier (Trembanis et al., 2004) with headlands at both ends. The beach is steep and is composed of medium-coarse sands. The beach state can change often, varying between rhythmic longshore bar pattern and a transverse bar and rip pattern

(Bogle et al., 2000; Almar et al., 2008). The wave climate at Tairua Beach primarily consists of storm and swell waves from the north and east and Shoe Island is thought to partially shelter the beach (Trembanis et al., 2004) (Figure 1.2). Mean significant wave height (H_s) and period (T) were 0.56 m and 5.8 s respectively, which were derived using a WAM hindcast (Gorman, 2005). Significant wave height can exceed 6 m during cyclone events. The tide at Tairua Beach is diurnal with a range of 1.2 m and has little spring-neap variation (Salmon et al., 2007). Note that in un-rectified camera images of Tairua Beach (such as Figure 1.3), north to south is from top to bottom.

Figure 1.3. Cam-Era video image of Tairua Beach study site taken on Julian Day 56 at 1100 hours in 2008. The camera faces north.

1.2.2 Muriwai Beach

Muriwai Beach is located on the west coast of New Zealand's North Island about 3 km west of Auckland (Figures 1.4 and 1.5). Muriwai Beach lies at the southern end of an extensive Holocene beach and dune barrier system that extends northward to the

Kaipara Harbour (Brander and Short, 2000). Over the last few decades, there has been an overall trend of erosion along Muriwai beach, and net sediment transport is usually considered to be northward (Brander and Short, 2000).

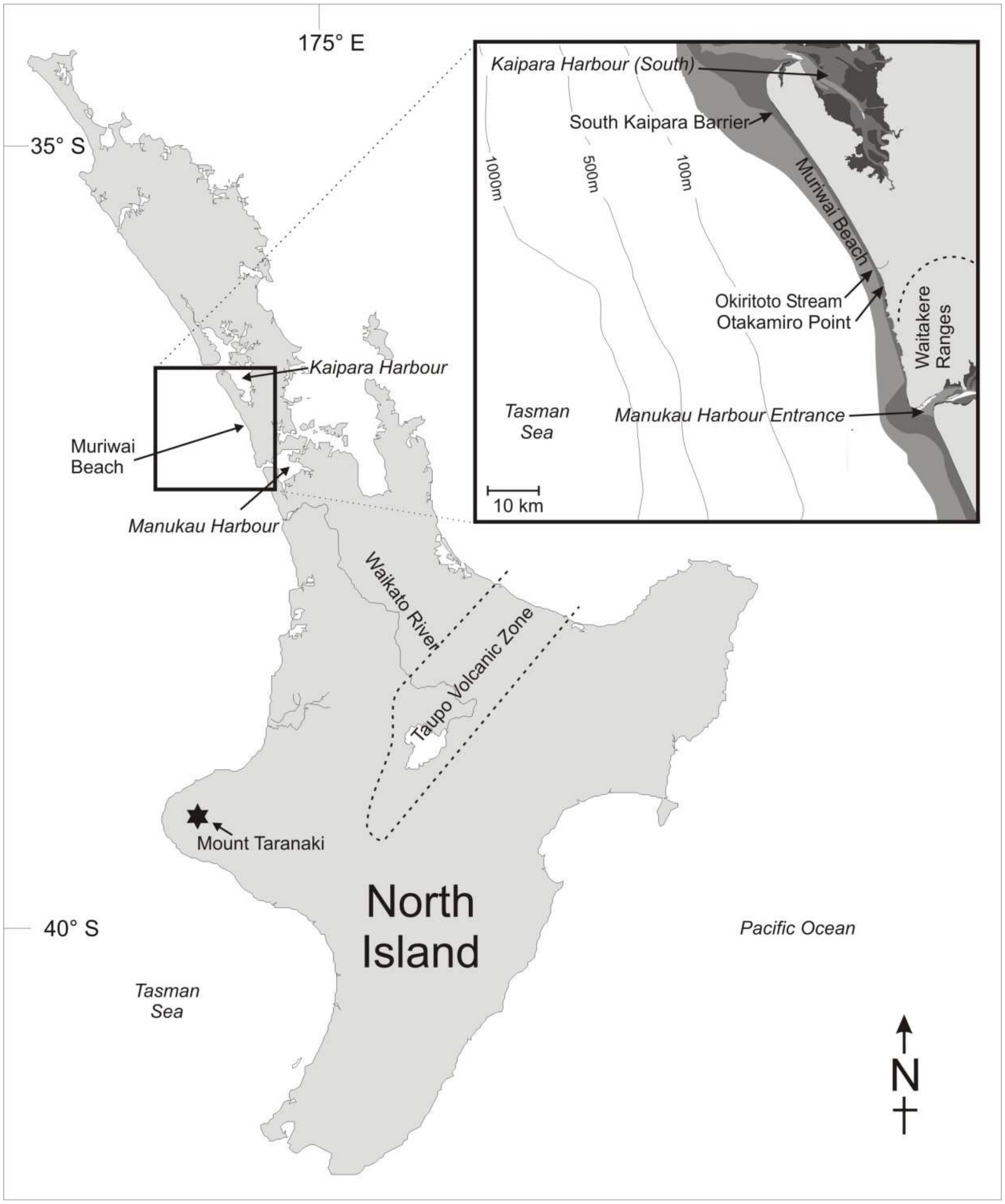


Figure 1.4. Map of New Zealand showing the location of Muriwai Beach (modified from Bryan et al., 2007).

Muriwai Beach is a high-energy, mesotidal beach, exposed to constant high energy wave conditions from the Tasman Sea and the Southern Ocean. The west coast of

New Zealand typically has H_s of 1–3 m, and mean wave periods that range from 6–8 s (Gorman et al., 2003). During storms, swell heights on the west coast can exceed 6 m (Gorman et al., 2003). The mean spring tidal range at Muriwai beach is 3 m (Bryan et al., 2007). Muriwai beach is characterised by a double-barred beach, with an outer dissipative bar and an inner intermediate state bar with a gently sloping beach face (Brander and Short, 2000). The surf-zone at Muriwai Beach is generally 400–500 m wide, and may reach over 800 m during storms. Sediments on the beach and in the surf-zone at Muriwai are predominantly fine (<0.25 mm), comprised of quartz, augite and feldspar (Bryan et al., 2007).

Figure 1.5. Argus image of Muriwai Beach study site on Julian Day 56 at 1200 hours in 2008.

1.3 Thesis Objectives

The general objective of this thesis was to uncover the processes responsible for the spatial and temporal variation of rip currents. To achieve this goal, there were several sub-objectives that had to be fulfilled:

1. Develop a suite of computer algorithms to quantify the spatial and temporal variability of the orientation, occurrence, and spacing of local light intensity lows (corresponding to rip channels) in time-averaged video imagery of the surf-zone. Test the algorithms with a wide variety of images to ensure their applicability;

2. Use the algorithms to extract long-term measurements of rip channels from a sequence of images from Tairua Beach. Use these measurements to study the natural variability of rip current spacing, occurrence, migration, and persistence.

3. Using rip channel data from the algorithms, compare rip channel spacing behaviour during storm events and calm periods to the wave conditions. Use different ways of comparing the wave climate to rip channel behaviour such as by averaging wave energy over different periods of time and by creating wave duration time series (duration of wave height above certain thresholds). Use these measurements to see if and how wave conditions relate to rip channel behaviour;

4. Develop a conceptual model for the response of rip channels of different sizes to changes in wave conditions (i.e. a change in wave energy) using observations made of rip channel and wave behaviour.

1.4 Thesis Outline

Following this chapter, the thesis will be organised into seven subsequent chapters:

Chapter Two: Rip Current Review

Chapter Two gives a brief overview of the theory behind rip currents and previous studies that have been undertaken. Rip currents are defined and reasons why they are important are given. A brief summary is given of rip morphology, different models of rip generation, rip velocities and alongshore rip spacing. Beach states and their relationship to rip currents are discussed as they are inherently linked.

Chapter Three: Video Imaging and Data Collection

Chapter Three contains a brief summary of the advantages of video imaging in the coastal zone. This is followed by an explanation of how time-averaged video images can be used to locate rip channels. There is a section explaining the lack of an automated method to locate rip channels in video images, followed by a description of image sources for this thesis. The image rectification process is briefly summarised.

Chapter Four: Algorithms to Locate Rip Currents

In Chapter Four, the suite of computer algorithms created to locate rip channels in time-averaged video images of the surf-zone are introduced and explained. The algorithms to locate the barline and shoreline are first discussed. The algorithms created to locate and refine local maxima (corresponding to sand-bar crests) and minima (corresponding to rip channels and alongshore troughs) in light intensity in video images are presented, followed by the algorithms to define rip channels from these minima and refine the resulting rip channel time-series. This is followed by giving the specific definition of a rip channel used in this thesis. Finally preliminary results of using the computer algorithms on Muriwai Beach are presented.

Chapter Five: Rip Current Behaviour

Chapter Five presents the resulting rip channel observations from 1999 until April 2002 and gives a summary of the rip behaviour and wave conditions for each year. This is followed by a discussion of key aspects of the rip channel behaviour and a comparison to the findings of past studies.

Chapter Six: Relation of Rip Currents to Waves

Chapter Six presents an analysis of how rip channels behave during storm events, with a focus on change in alongshore rip locations. Rip channel reconfiguration events, defined using an objective measure of change, are introduced. These reconfiguration events are compared to wave conditions in different ways, including to wave energy averaged over different periods of time to take into account the previous wave conditions, and the duration over which wave conditions exceed a threshold. The main objective of this Chapter is to define the relationship between rip channels and waves that might cause rip channels to reconfigure.

Chapter Seven: Conceptual Model

Chapter Seven summarises the major findings of this thesis into a conceptual model of how rip channels of different spatial scales (i.e. cross-shore extents) might respond to changes in the wave conditions (i.e. a change in the wave energy).

Chapter Eight: Conclusions and Recommendations

Chapter Eight gives a brief summary of the research undertaken for this thesis and lists the key findings. Recommendations for further research are given.

Chapter Two: Rip Current Review

2.1 Introduction

The purpose of this chapter is to define rip currents, where they form, and overview their general characteristics. The relationship of rips to waves is briefly discussed with some case studies presented of attempts to relate rip channel spacing to the wave conditions. The beach state model of Wright and Short (1984) is discussed, as rip currents are inherently related to beach state.

2.2 Definition and Location of Rip Currents

Rip currents are the most visible feature of nearshore circulation systems (Ranasinghe et al., 1999). Rip currents are fast, concentrated currents which flow seaward in the surf-zone. They can often contain sediment and debris which makes them a different colour to the rest of the surf (Komar, 1998). Rips are absent on reflective beaches which are dominated by shore-normal swash oscillations (Short, 1985) and are rare on completely dissipative beaches where the surf-zone is controlled by low frequency surf beat and where circulation is not segregated horizontally but vertically (Wright et al., 1982). Rip currents are an integral part of all beach systems in an intermediate beach state and hence are a major feature of sandy beaches from all over the world (Short and Brander, 1999). Rip currents can be present on a variety of intermediate beaches but tend to be a major feature on those with pronounced bar and trough morphology (Wright and Short, 1984). It is important to note that for this thesis there was a specific set of conditions that had to be met for an area to be considered as a rip channel, these conditions are listed in Section 4.6.

2.3 Rip Current Morphology

Rip currents generally consist of three main components: (1) a feeder channel parallel to the shoreline that carries water into (2) a narrow rip neck with a deeper channel approximately perpendicular to the shore, through which water flows seaward through the surf-zone, eventually decelerating and expanding into (3) a rip-head seaward of the breaking waves (Brander and Short, 2000) (Figure 2.1). Rip channels consist of incised channels with shore-connected shoals (transverse bar) or cut through an alongshore bar (MacMahan et al., 2006).

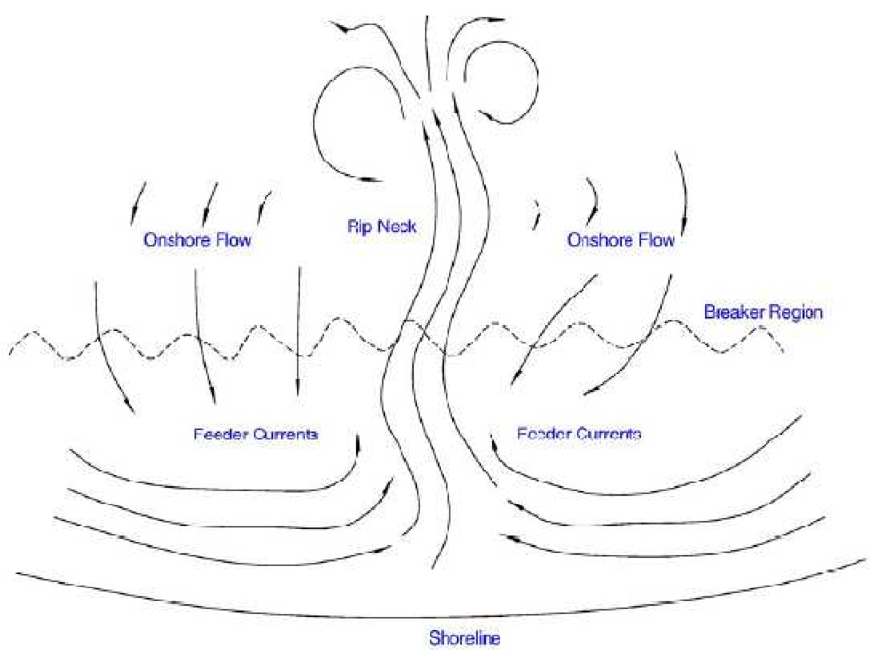


Figure 2.1. Schematic of a rip current (similar to the classic definition of Shepard et al. (1941)), as presented by MacMahan et al., (2006).

For all analyses undertaken in this thesis, all rip currents were assumed to be associated with rip channels and vice versa. However, rip currents can in fact occur in the absence of bathymetric features such as rip channels on alongshore-uniform beaches (Murray et al., 2003). These apparently non-bathymetrically driven rip currents are sometimes called ‘flash rips’ by lifeguards and transient rips by scientists (Johnson and Pattiaratchi, 2004). In cases of ‘flash rips’, hydrodynamic interactions form narrow, widely spaced or isolated jet-like rip currents. There are various theories and models for the formation of flash rips, none of which is generally accepted yet.

2.4 Rip Current Generation Models

2.4.1 Model Types

Rip currents are thought to arise from alongshore gradients in wave height and the associated variations in the mean water surface elevation (Long and Ozkan-Haller, 2005). It is generally understood that the gradients in water surface elevation that drive flow could arise from several individual mechanisms which may also work in combination (Long and Ozkan-Haller, 2005). Munk (1949) gave the first attempt to explain rip currents by suggesting that when water piles up at the shore, the resulting pressure gradient forces the water to exit as a rip current. Since the first scientific discussions on rip currents by Shepard et al. (1941) and McKenzie (1958), various researchers have suggested a range of different rip generation mechanisms (Ranasinghe et al. 1999).

There are two main types of models for the generation of crescentic sand-bars and associated rip channels (van Enckevort et al., 2004). These two models are: (1) template models (edgewave models); and (2) self-organisation models. Table 2.1 shows some of the studies that have been undertaken on template and self-organisation models for crescentic sand-bar development. In template models, the 'template' refers to the three dimensional pattern in the hydrodynamics which forces the generation of a three-dimensional crescentic pattern in the bar morphology. In template models, it is assumed that there is no feedback between the hydrodynamics and morphology. Self-organisation models are based on the idea that crescentic sand-bar features form through positive feedback between the hydrodynamics and the morphology.

Table 2.1. Examples of references for studies of difference types of rip current/ crescentic sand-bar generation models.

Template Models	Self-organisation Models	
	Linear	**Non Linear**
Bowen, 1969		
Bowen and Inman, 1969	Hino, 1974	Caballeria et al., 2002
Bowen and Inman, 1971	Christensen et al., 1994	Coco et al., 2002
Dalrymple, 1975	Deigaard et al., 1999	
Holman and Bowen, 1982	Vittori et al., 1999	
Holman and Sallenger, 1993	Falques et al., 2000	
Bryan and Bowen, 1998	Calvete et al., 2002	
	Klein et al., 2002	
	Damgaard et al., 2002	
	Caballeria et al., 2003	

2.4.2 Template Models

The template in template models is the pattern of near-shore residual velocities of low-mode monochromatic alongshore standing edge waves that are typically at infragravity frequencies (van Enckevort et al., 2004). Edge waves refer to waves that are bound to the coast by reflection and refraction. Bowen (1969) and Bowen and Inman (1969) used a wave tank to show that incident waves can generate synchronis edge waves which interact with incident waves to produce a pattern of regular high and low wave heights alongshore. This variation in wave height alongshore was proposed to cause a longshore gradient in wave set-up, causing a regular pattern of cell circulation with rip currents present at each antinode (Ranasinghe et al., 1999). It is thought that the pattern of the edge waves might rearrange the sediment that is suspended by short waves into a crescentic bar with an alongshore wavelength that is half the edge wave wavelength (van Enckevort et al., 2004).

An issue with template models is that they do not consider feedback between crescentic sand-bars as they emerge and the edge waves. Also, in many template models (such as Bowen, 1969 and Dalrymple, 1975), the wave conditions are assumed to be monochromatic and sometimes mono-directional which is different from the stochastic forcing that occurs on natural beaches (Turner et al., 2007). There have been many papers written about template models and rip currents including: Bowen, 1969; Bowen and Inman, 1969; Bowen and Inman, 1971; Holman and Bowen, 1982; and Dalrymple, 1975. Template models for the generation of patterns on beaches (such as rip channels) assume that the wave forcing has the same physical scales as the resulting morphology. Template models are no longer thought to be responsible for crescentic bar formation by some such as Holman (2000) who noted that recent tests of a number of these models found no evidence that scales of morphological patterns are being forced by fluid motions (e.g. Masselink et al., 2004). Despite this evidence against template models, in many well-known text books such as Komar (1998) and Woodroffe (2003) template models are still given as the only suggestion on how crescentic sand-bars might form.

2.4.3 Self-organisation Models

Self-organisation models assume the formation of morphological patterns that do not directly correspond to the hydrodynamics. The concept of self-organisation of crescentic sand-bars and rip channels has been explored through linear and nonlinear models. Linear models can only predict alongshore regular and temporally constant alongshore length scales whereas nonlinear models can produce spatial as well as temporal variability. In general, the equations used for hydrodynamics and sediment transport are similar for linear stability models and nonlinear models. In linear stability models the flow is described using depth-integrated equations for mass and momentum conservation. The first linear stability model for crescentic bar development was introduced by Hino (1974) who suggested that even if the longshore wave set-up was uniform, a small disturbance to the set-up could eventuate in regularly spaced rip currents. Hino (1974) hypothesised that the variable alongshore bathymetry and hydrodynamics could evolve as a result of an instability of the coupled hydrodynamic-morphodynamic system (Long & Ozkan-Haller, 2005).

2.4.4 Testing of Rip Generation Models

There has been testing of some rip generation models such as by Ranasinghe et al. (1999) and Turner et al. (2007). Ranasinghe et al. (1999) used data from a quantitative analysis of time exposure video images from Palm Beach, Sydney, Australia spanning almost two years. Data from Palm Beach indicated that rip current generation could not be directly attributed to any one of the rip generation models that had so far been proposed.

According to Ranasinghe et al. (1999) the mostly irregularly spaced (alongshore) rip currents at Palm Beach implied that none of the proposed template models and instability mechanisms for rip generation could govern rip generation. This finding is in contrast to findings of Holman and Bowen (1984) who found that template models could predict rip channels with irregular alongshore spacing. Rips generated at Palm Beach after high energy wave events which reworked the nearshore morphology did not form at the same location as before the wave event. According to Ranasinghe et al. (1999) this also indicated that the observed rip generation could not be attributed to wave-boundary interaction mechanisms. Ranasinghe et al. (1999) thought it most likely that rip currents are generated through a combination of generation mechanisms.

Turner et al. (2007) used three years of daily observations at a long straight beach to determine the temporal trends and variability of the location, spacing, persistence and mobility of rips. This data-set could not be reconciled with the majority of existing template and instability models for rip formation that predict a relationship between incident wave conditions and regular spacing of rips alongshore (Turner et al., 2007). In contrast, observations tend to support emerging theories of rip current generation that predict irregular spacing of rip channels alongshore (Turner et al., 2007). More testing is required of rip current generation models. However to do so highlights the need for quantitative, long-term data-sets of rip current and sand-bar behaviour.

2.5 Rip Current Velocities

The mean velocities of rip currents are often relatively low and yet the maximum values can be rather high. RIPEX (RIP current EXperiment) was performed in conjunction with a steep beach experiment during the months of April and May 2001 at the southern end of Monterey Bay in Sand City, California (MacMahan et al., 2005). The mean rip current velocity was found to be 0.3 ms^{-1} for a wide range of wave conditions, with maximum hourly averaged velocities approaching 1 ms^{-1} during extreme storms (MacMahan et al., 2006). One-minute averaged velocities were found to be approximately twice that of maximum hourly velocities at 2 ms^{-1} (MacMahan et al., 2006). Rip current velocities are affected by both tidal elevation and wave forcing. With increasing wave heights rip current velocities increase, if this occurs during high tide this can offset the effect of tidal modulation (MacMahan et al., 2005).

2.6 Rip Channel Spacing

Rip currents are a dominant component of the cellular surf-zone circulation of intermediate beaches (Wright and Short, 1984) and are often the dominant mechanism for offshore transport of sediment and water. The dimensions and spacing of rip currents is thought to be an indicator of the general surf-zone circulation and sediment transport, as well as indicative of the environmental forcing parameters of spacing (Short and Brander, 1999), although this has yet to be proven. Rip spacing is also a vital aspect of the recreational hazard potential of beaches (Short and Brander, 1999). There is much debate over whether rip channels are regularly or irregularly spaced alongshore. Huntley and Short (1992), Short and Brander (1999) and MacMahan et al. (2005) found that rips were relatively regularly spaced alongshore. On the contrary, Holman et al. (2006) and Turner et al. (2007) both found that rip currents were irregularly spaced alongshore. Symonds et al. (1997) noted periods of quasi-regular rip channel spacing and periods of irregular spacing. Eliot (1973) found that there were places where rip currents tended to occur frequently and that these locations were regularly spaced. While there have been many studies of rip currents, there are few long term studies where rip current characteristics such as spacing have been examined. Table 2.2 shows a list of the long-term rip current studies that have been undertaken to date and where appropriate, conclusions on whether rip spacing was regular or irregular alongshore. Note that there is some overlap in the data-sets. The only sites where long-term rip current behaviour has been studied are Tairua Beach (New Zealand), Palm Beach, the Gold Coast and Narrabeen Beach in Australia, and Duck in the U.S.A. Short-term rip channel studies are not included in Table 2.2.

There have been many attempts to find a good relationship between wave conditions such as wave height, and rip channel characteristics, particularly rip spacing. There is a general assumption that larger inputs of energy into the surf-zone will result in the development of morphologies with larger spacing. Several rip current studies have indicated the relationship between rips and waves. McKenzie (1958) found that under increasing wave conditions rips become less numerous but larger in size (i.e. spacing increased). Eliot (1973) found that under low wave conditions there were more rips present and strangely a wider surf-zone. Short (1985) proposed that when wave heights are increasing there will be an increase in rip channel spacing and a decrease in the number of rips and vice versa during decreasing wave heights. Huntley and Short (1992) showed quantitatively (although rip channels were located visually which means results are subjective) using regression analysis that rip channel spacing mostly depends on the breaker height and sediment fall velocity, and that it increases with increasing wave height and surf-zone width, and decreasing sediment size. They found that rip spacing was not sensitive to wave period, although there was a weak trend for increased spacing with increasing wave period. Huntley and Short (1992) found that rip channel spacing was better predicted by simulations of surf-zone width based on observed wave height using a model for the beach profile rather than the visually estimated surf-zone width. This relationship was used to create a predictive equation for rip spacing which is proportional to $H^{3/2}/w^2$, where H is the breaker height and *w* the sediment fall velocity. The ratio of rip spacing to surf-zone width appeared to be relatively insensitive to incident wave period, although there is slight evidence that it increases with increasing period. Short and Brander (1999) suggested that rip density (number of rips per kilometre of beach) decreases with wave height and period, surf-zone width, wave energy and wave power however they did not successfully correlate rip channel spacing to wave characteristics. Short and Brander (1999) noted that with large waves, only a few rips were produced and when waves were smaller, rips were also smaller in size but were more numerous.

More recent work with more substantiated data-sets has also failed to show the relationship between rip currents and waves. This failure to find a relationship between rip channel spacing and growth time, and distance between the shoreline and sandbar crest, was at first thought to be due to difficulties in locating sand-bar crests (Calvete et al., 2007). However, more recent studies using more accurate estimates of the sand-bar crest from video images such as by van Enckevort et al. (2004) and Holman et al. (2006) have also failed to explain variations in rip channel spacing (Calvete et al., 2007). Topographically-controlled rips are those controlled by the pre-existing rip channel morphology while hydrodynamically-controlled rips are those responding directly to changes in the wave conditions. Ranasinghe et al. (2000) and Whyte et al. (2005) found that rip spacing did not increase or decrease with increases or decreases in wave height, suggesting that once rips are formed they are topographically-controlled. Calvete et al. (2007) stated that rip channel spacing does not appear to respond to hydrodynamic forcing alone (i.e. hydrodynamically-controlled), but to a more complex function linked to the pre-existing morphology. Results of Calvete et al. (2007) show that there is a relationship between wave height and rip spacing (where alongshore rip channel spacing increases with increasing wave height) but also suggested that the pre-existing morphology was essential and that the sensitivity of the rip channel system to initial conditions is as important as hydrodynamic forcing. Turner et al. (2007) found no clear relationship between the number of rips/ mean rip channel spacing and the offshore wave conditions (wave

Table 2.2. Long-term, quantitative studies undertaken of rip currents. Method refers to how data-set was collected, rips and waves refers to if there was a relationship found between rips and wave conditions, and rip spacing refers to if rip channel spacing was regular or irregular alongshore. QL represents a qualitative data analysis and QT a quantitative analysis.

Reference	Beach Type	Site	Method	Duration (Months)	Rips & waves Relationship?	Rip Spacing	Analysis
Short, 1985	Straight	Narrabeen Beach (AU)	Visual	19	Yes	Not reported	QL and QT
Lippmann and Holman, 1990	Straight	Duck, N.C.(USA)	Video	24	Not tested	Not reported	Not tested
Huntley and Short, 1992	Straight	Narrabeen Beach (AU)	Visual	19	Poor	Not reported	QT
Symonds et al., 1997	Embayed	Palm Beach (AU)	Video	12	Not tested	Mixed	Not tested
Bogle et al., 1999	Embayed	Tairua Beach (NZ)	Video	14	None	Not reported	QT
Ranasinghe et al., 1999	Embayed	Palm Beach (AU)	Video	24	None	Not reported	QT
Bogle et al., 2000	Embayed	Tairua Beach (NZ)	Video	11	Not tested	Not reported	Not tested
Ranasinghe et al., 2000	Embayed	Palm Beach (AU)	Video	24	None	Not reported	QT
Ranasinghe et al., 2004	Embayed	Palm Beach (AU)	Video	48	Not tested	Not reported	Not tested
Whyte et al., 2005	Straight	Gold Coast (AU)	Video	36	None	Irregular	QT
Holman et al., 2006	Embayed	Palm Beach (AU)	Video	26	None	Irregular	QT
Turner et al., 2007	Straight	Gold Coast (AU)	Video	32	None	Irregular	QT

** Study undertaken focused on sand-bars not rip currents.*

height, peak wave period and incident wave power). This is consistent with the idea of topographic-control of rips by the underlying shoals and channels once the rips are formed, hindering their ability to respond to wave forcing (Turner et al., 2007). It appears that the traditional time-series approach to comparing rip channel and wave data is not appropriate to show how they interact. For example, qualitative analyses of rip currents and waves appear to be more likely to show that there is a relationship rather than purely quantitative analyses.

In general, numerical models predict an increase in alongshore rip channel spacing with increasing wave height or surf-zone width (Calvete et al., 2007). More recently, changes in mean rip channel spacing have been linked to the directional spreading of short waves such as by Reniers et al. (2004) where it was suggested that increased directional spreading of waves caused an increase in rip channel spacing. Numerical models of rip currents could be very useful to generate hypotheses to test. However, the current lack of high quality rip current data means that there is a large gap in the research of rip currents.

Template models have also suggested that rip channel spacing may not be at all sensitive to the height and mean period of incident waves but is dependent on the alongshore length scale of the wave group energy and the direction of the incident waves (MacMahan et al., 2006). An added complication into the search for a relationship between rip currents and wave conditions is that rip currents don’t always develop under the same wave conditions (Calvete et al., 2007). Calvete et al. (2007) stated that the search for a rip channel predictor will need to fully account for the shape of the pre-existing underlying bathymetry.

2.7 Beach States

2.7.1 Beach State Morphodynamics and Hydrodynamics

Wright and Short (1984) used the concept of morphodynamic beach states to define beaches with coupled morphology and hydrodynamics. The two most extreme states are (1) fully dissipative; and (2) highly reflective. Fully dissipative beaches tend to have flat, shallow beach morphology (Figure 2.2a) with relatively large subaqueous sand storage. Fully reflective beaches tend to have steep morphology with small subaqueous sand storage (Wright and Short, 1984). In between the two extreme beach states of dissipative and reflective, Wright and Short (1984) recognised four different intermediate beach states with a combination of dissipative and reflective characteristics.

The six beach states identified by Wright and Short (1984) are presented in Figure 2.2. Figure 2.2 clearly shows the morphological differences between the six beach states but not the associated differences in the means of sediment transport (Wright and Short, 1984). According to Wright and Short (1984), depending on the beach state, near bottom currents show variations in the relative dominance of motions due to incident waves, sub-harmonic oscillations, infragravity oscillations, mean longshore currents and rip currents.

2.7.2 Surf Scaling Parameter

With regard to morphology, the two beach state extremes (dissipative and reflective) are distinguished using the surf-scaling parameter (Guza and Inman, 1975):

$$\varepsilon = a_b \omega^2 / g \tan^2 \beta \qquad (1)$$

where a_b is breaker amplitude, ω is incident wave radian frequency ($2\pi / T$, where T is wave period), g is acceleration due to gravity and β is the beach/ surf-zone gradient. According to Wright and Short (1984), the following will occur with changing ε: If ε is less than 1.0, complete reflection of waves will occur at the beach of interest. If ε is greater than 2.5, waves will start to plunge causing energy dissipation to occur. If ε is greater than 20, waves will become spilling breakers causing the surf-zone to increase in width.

2.7.3 Dissipative Beach States

The following descriptions of the three major beach states are as described in Wright and Short (1984). Dissipative beach states are often described as a ‘storm’ or ‘winter’ beach profile (Figure 2.2a). Dissipative beaches tend to be wide with a low gradient and a large amount of subaqueous sand. Dissipative beaches also tend to be uniform alongshore with no rhythmic morphologies. Dissipative beaches are associated with high energy spilling breakers that dissipate energy as they head in to shore. Hence dissipative beaches persist under constant high wave energy, combined with large amounts of (fine) sediment. Rip currents are unlikely to be present on fully dissipative beaches.

2.7.4 Reflective Beach States

Reflective beach states occur when breakers are surging to collapsing. These waves tend to focus their energy on the upper part of the beach face and a steep beach develops (Figure 2.2f) with a step beneath it. Below this step (i.e. seaward), reflective beaches have a lower gradient. In contrast to dissipative beaches, reflective beaches tend to have little subaqueous sand. Reflective beaches are often associated with rhythmic beach cusps and sub-harmonic edge-waves are common. The reflective beach state is likely to be dominant on beaches with coarse-grained sediment when waves are of a low steepness for an extended period of time. Rip currents are generally not found on beaches in a reflective beach state.

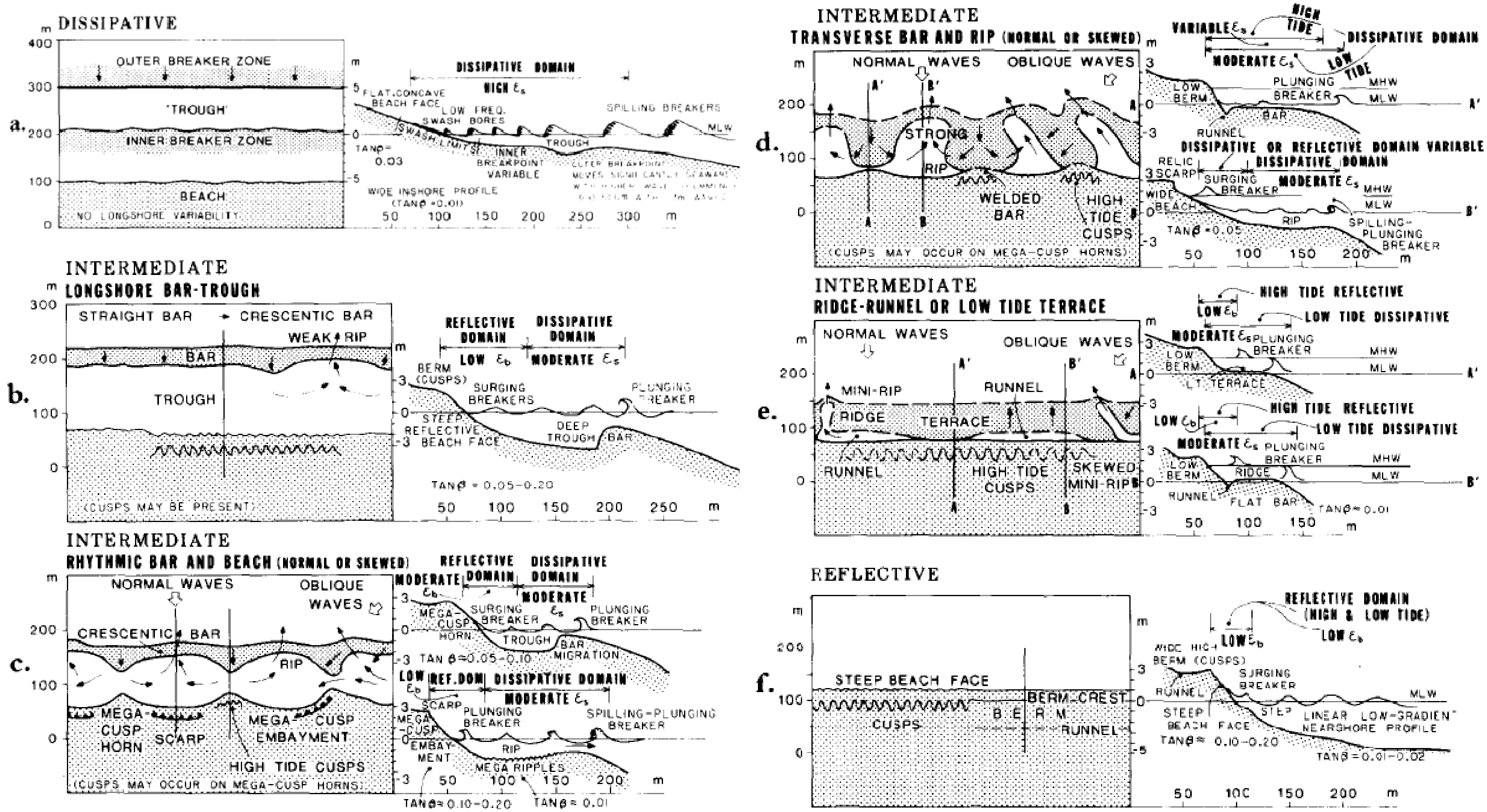


Figure 2.2. Plan and profile configurations of the six major beach states (Wright and Short, 1984).

2.7.5 Intermediate Beach States

In between completely dissipative and reflective beach states are the intermediate beach states. Beaches in an intermediate beach state have a mix of characteristics of both dissipative and reflective beaches. Intermediate beach states tend to occur when there is medium-grained sediment with a small to moderate supply, and under intermediate (but variable) waves. Beaches in an intermediate state tend to have pronounced bar-trough and rhythmic morphologies. There are four main intermediate beach types according to Wright and Short (1984), summarised below:

a) Longshore Bar-Trough State

Beaches in a longshore bar-trough state (Figure 2.2b) generally develop from a beach in a dissipative state. Longshore bar-trough beaches tend to be steeper than dissipative beaches. Sand-bars and channels are well developed on longshore bar-trough beaches. On longshore bar-trough beaches, the waves first break over the sand-bar and reform in the troughs, rather than dissipate energy as they come into shore such as occurs on dissipative beaches. Cusps are often present in the swash zone of longshore bar-trough beach states.

b) Rhythmic Bar and Beach State

As is the case with longshore bar-trough beach states (Figure 2.2c), rhythmic bar and beach states develop from beaches in a dissipative state and tend to have a steeper slope. Beaches in the rhythmic bar and beach state are different to beaches in the longshore bar-trough state as they have pronounced rhythmic patterns of the sand-bar and sub-aerial beach. Rip currents are common in rhythmic bar and beach states and tend to have weak to moderate circulation with semi-permanent alongshore locations.

c) Transverse Bar and Rip State

Beaches tend to develop into a transverse bar and rip state (Figure 2.2d) by accretion where crescentic sand-bar horns join to the beach. This welding of sand-bars to the beach causes the development of ‘transverse bars’ with channels containing strong rip channels in between the bars. Rip currents are most pronounced and have the fastest velocities on beaches in a transverse bar and rip state.

d) Ridge and Runnel/ Low Tide Terrace State

Beaches in the ridge and runnel/ low tide terrace state (Figure 2.2e) are characterised by a dissipative, low gradient area of sand at/ below the low tide mark with a steeper beach face above it (reflective at high tide). Therefore, ridge and runnel beaches are generally dissipative at low tide and reflective at high tide. Rip currents are common on ridge and runnel beaches but they tend to be small, slow-flowing and irregularly spaced alongshore.

The morphodynamic beach state models of Wright and Short (1984) identifies the occurrence of rip channels and channel morphology as an integral feature of intermediate state beaches. Rip channels are often observed to emerge then disappear again as a beach progresses from a higher energy dissipative to a lower energy reflective state (Turner et al., 2007) (Figure 2.2).

2.8 Summary

Rip currents are fast, narrow currents that traverse the surf-zone and are a crucial consideration in beach safety. There are two main types of models that have been proposed for rip current generation: (1) template models; and (2) self-organisation models. There is still much debate over what mechanism or combination of mechanisms causes rip currents to form. Rip currents typically flow at speeds of ~1ms^{-1}. There is an ongoing debate over whether rip currents are regularly or irregularly spaced alongshore. This debate is interesting because the spatial configuration of rip currents alongshore will relate to hypotheses of rip channel formation and ideas of what might control their morphology. There is also much debate over if and how rip currents are related to changing wave conditions. Rip currents are inherently related to beach state, they are central to intermediate beach states and in distinguishing the four intermediate states.

Rip current studies where qualitative analysis techniques have been used appear to generally indicate that there is a relationship between rip currents and waves. In contrast, studies with purely quantitative analysis techniques such as time-series techniques and other methods developed for waves generally appear to show that there is no relationship between rips and waves. In this thesis, it will be attempted to bridge this gap between qualitative and quantitative analysis methods to show that there is a relationship between rips and waves. It will be attempted to indicate why traditional quantitative techniques to compare rips to waves have failed.

Chapter Three: Video Imagery and Data Collection

3.1 Introduction

The purpose of this chapter is to describe the sources of data used in this thesis. The advantages of video imaging are briefly introduced following by a description of how video images can be used to measure rip currents. Image sources for this thesis are described, as is the image processing prior to images being used for analysis Deploying instruments in the high energy surf-zone can often result in damage and/ or loss to expensive equipment. Obtaining sufficient spatial coverage can also mean that large numbers of instruments are required (Bogle et al., 1999), which can be logistically difficult and expensive. Coastal imaging overcomes many of the shortcomings of traditional in situ deployments in the harsh marine environment, and especially in the turbulent surf-zone. Remote measurement of the surf-zone via video cameras allows measurements to be taken of the surf-zone while equipment is not hindered by the high energy surf-zone conditions. Cameras can be used to survey the surf-zone at any location where there is a suitable vantage point (Lippmann and Holman, 1989). Remote measurement also overcomes issues of flow disturbance and bio-fouling (Holland et al., 1997).

Optical signatures from video images are able to provide a huge source of data at a low-cost and with a temporal and spatial dynamic range appropriate to various sampling needs (Holman & Stanley, 2007). Coastal imaging allows extensive spatial coverage of a high resolution (Lippmann and Holman, 1989) and reduces the cost of instrumentation (Bogle et al., 1999). Cameras can be left in position over longer periods of time, sampling on demand and therefore increasing temporal coverage (Bogle et al., 1999). Surf-zone morphology can change rapidly during events such as storms. Due to fast rates of change, it is crucial to have a sampling interval that is less than the time scales of sand-bar movement (Sallenger et al., 1985; Lippmann and

Holman, 1989), a problem which is overcome by video imaging. Another advantage of using remote measurement is that post-design of sampling arrays can be carried out relatively easily after an experiment, allowing new ideas to be tested (Holland et al., 1997). The logistics and cost of sampling near-shore processes via video are generally less than traditional solutions involving the deployment of large arrays of instrumentation at a discrete number of positions (Holland et al., 1997).

3.2 Background to Video Techniques

Lippmann and Holman (1989) were the first to demonstrate and model the relationship between the bands of white in video time-exposure images and the position of the crests of submerged sand-bars (Holman and Stanley, 2007). The patterns of light intensity that are recorded in time exposure images are the result of the bubbles and foam of breaking waves (Lippmann and Holman, 1989). To relate this signal to fluid motions (and hence to underlying morphology), some assumptions must be made on the mechanism of bubble formation (Lippmann and Holman, 1989). Lippmann and Holman (1989) hypothesised that the light intensity recorded in video images is proportional to the local incident wave energy dissipation (for equations relating light intensity to local incident wave energy dissipation see Lippmann and Holman (1989)). This relationship of light intensity to wave dissipation is based on the premise that more waves break over the shallow areas of the bar than the surrounding, deeper areas. The majority of rip currents are linked to seabed depressions called rip channels (Calvete et al., 2007), which is assumed to always be the case for this thesis. Due to their greater depth, there tends to be little wave breaking in the rip channels and hence low light intensities in video images. The low light intensities in video images can be used to locate rip channels and the high light intensities to locate sand-bar crests. Instead of using just one instantaneous video ‘snapshot’ from one instant in time (Figure 3.1) to locate sand-bar crests and rip channels, it is common practice to use time-averaged images (Figure 3.2). Averaging images over a period of time (in this thesis, 15 minutes for Tairua Beach) averages out fluctuations due to incident wave modulations and gives a statistically stable image of the wave breaking pattern (Lippmann and Holman, 1989).

Lippmann and Holman (1989) carried out ground-truthing to test the applicability of using light intensity minima in time-averaged video images as a proxy to locate rip channels. This ground-truthing was carried out during SUPERDUCK, a near-shore processes experiment carried out at Duck in North Carolina, U.S.A. SUPERDUCK was carried out during September and October 1986 and was hosted by the U.S. Army Engineer Waterways Experiment Station's Coastal Engineering Research Centre (CERC). During SUPERDUCK it was found that there was excellent agreement between the locations of light intensity maxima and sand-bar crests. It was also found that time-averaged images were appropriate for detecting longshore variability and rhythmicity and for quantifying length scales, supporting the validity of the model and the potential of the technique for imaging morphology (Lippmann and Holman, 1989).

Although video imaging of the surf-zone is a useful technique, there are still issues that users need to be aware of. The method of using light intensity values in video camera images of the surf-zone yields a map of morphology but not actual bathymetry (Holman and Stanley, 2007). There are certain wave conditions under which video images may not be such a good proxy for rip channel bathymetry. For example, during RIPEX (RIP current EXperiment) MacMahan et al. (2005) found that when wave heights exceeded 2 m rip channels were obscured by wave breaking, although flow measurements indicated that strong (~1 ms^{-1}) rip currents were still present (MacMahan et al., 2005). This makes studying rip currents by video challenging as high wave events are generally associated with the disappearance of rip currents. Lippmann and Holman (1989) found that during high wave events, persistent surface foam obscured the relationship of image intensity to local dissipation. Conversely when wave conditions are too low, rip channels are often not visible in video images as there is not enough wave breaking to distinguish channels from sand-bar crests. Generally when wave conditions are low,

Figure 3.1. Un-rectified image (snapshot) of Tairua Beach on Julian Day 179 at 0800 hours in 2000.

Figure 3.2. Un-rectified, time-averaged image (over a 15 minute duration) of Tairua Beach on Julian Day 179 at 0800 hours in 2000.

the surf-zone morphology hardly changes. Another issue with using video imagery to locate rip currents is that sometimes rips can form in the absence of rip channels (referred to as transient or ‘flash rips’).

3.3 Automated Image Analysis

There have been attempts to create a method to automatically locate rip channels from video images. Ranasinghe et al. (1999) created an automated method which identified rip channels as local minima in image light intensity in alongshore profiles of pixel intensity transects, taken at approximately mid surf-zone. While adequate for simple cases, this automated approach was found to be sensitive to parameter choices in the analysis and often gave results in disagreement with visual assessment (Holman et al., 2006). Ranasinghe et al. (2000) integrated image pixel intensities along a number of equally-spaced cross-shore positions and combined these to represent the mean longshore variation in pixel intensity across the surf-zone. These integrated profiles were used to identify rip channel locations in each image. The locations of rip channels were determined using a zero downcross-upcross analysis of the filtered alongshore intensity profiles. Ranasinghe et al. (2000) identified rip channels as corresponding to the location of the minimum light intensity between adjacent pairs of zero down-crossings and up-crossings. Some trough locations were found to be too small to correspond to rip channels. These locations were removed by visually comparing the channel locations predicted by the analysis to the image.

A similar method to Ranasinghe et al. (2000) to locate rip channels from video images was used by Bogle et al. (2000) to define alongshore rip currents locations. Bogle et al. (2000) used light intensities of time-averaged, rectified images which were averaged in the cross-shore direction. This averaging reduced the light intensities to a single variable as a function of alongshore position, from which rip positions were visually identified as minima in light intensity. However, this averaging obscures rip feeder channels and rip current orientation.

While there have been some attempts to automatically analyse video images of the surf-zone to locate rip channels such as by Ranasinghe et al. (2000) and Bogle et al. (2000), these methods have tended to look at just one or an averaged alongshore transect rather than look at the entire cross-shore extent of the surf-zone. There have also been issues with parameter choices (i.e. thresholds) to locate rip channels, adding to the difficulty in creating an automated method to locate rips in video imagery. When creating algorithms to locate rips in video imagery, it is inevitable that some thresholds in light intensity are going to be needed, for example to distinguish what light intensity corresponds to a rip current. Recent researchers on rip currents using video images have continued to use the somewhat subjective, labour intensive methods of locating rip channels in the surf-zone. For example, Holman et al. (2006) and Turner et al. (2007) both manually located rip currents using light intensity minima in alongshore light intensity transects. Holman et al. (2006) stated "…after considerable experimentation it became clear that no simple algorithm provided robust location of rip locations under the range of conditions exhibited at this site" (Holman et al., 2006, p. 3). While the methods of Ranasinghe et al. (1999) and Bogle (2000) are automated, they only examine at averaged cross-shore locations of rip currents, not the entire surf-zone.

3.4 Image Sources

Images used in this thesis were from two different locations. The main focus of this thesis was Tairua Beach however an additional test of the computer algorithms was undertaken on an image from Muriwai Beach. Images from Tairua Beach were from a video camera installed as part of the Cam-Era programme set up and co-coordinated by the National Institute of Water and Atmospheric Research Limited (NIWA) and Environment Waikato (Waikato Regional Council) in New Zealand. A video camera overlooked Tairua Beach from Paku Hill on the southern end of the beach at 70.5 m above chart datum. Images from Muriwai Beach were from a video camera set up and developed by the Coastal Imaging Lab (CIL) at Oregon State University in the United

States for the Argus programme. These cameras are set up to take a snapshot every 1.57 s. Images used in this project were averaged over a fifteen minute duration for Tairua Beach and a ten minute duration for Muriwai Beach. The purpose of this averaging was to remove the high degree of variability in wave breaking and to allow better contrast between rip channels and bar crests. Both video camera systems consisted of a camera and a computer that were set to automatically collect images at regular intervals during daylight hours. Camera images were collected by a CCD chip inside the camera and made into a video by a time grabber. These videos were then turned into RGB (red, green, blue) matrices which could be manipulated in Matlab.

3.5 Image Rectification

3.5.1 Rectification Process

The raw camera images of the beaches were not a plan-view (i.e. ‘birds eye view’) of the beach, as the angle of the camera was oblique to the beach (Figure 3.3).

Figure 3.3. Un-rectified, time averaged image of Tairua Beach from Julian Day 318 at 1000 hours in 1998.

The location of objects in an image is a function of the spatial orientation of the camera relative to ground topography (Lippmann and Holman, 1989). Therefore, each image was transformed through mathematical projection onto a horizontal plane located at mean sea level (Figure 3.4) (found for each image using tide information, Figure 3.5). Details of the method used for image rectification can be found in Heikkilla and Silven (1997) and details of the rectification algorithms used can be found in Appendix 1 and Figure A1.1. Measurements of mean sea level at Tairua Beach for image rectification were obtained by NIWA. To gain a measure of mean sea level for image rectification of the Muriwai Beach images, a pressure sensor was deployed at the southern end of the beach (Figures 3.5a and 3.5b) for half of one tidal cycle (from one low tide to another) on November 17 2008 (Appendix 4).

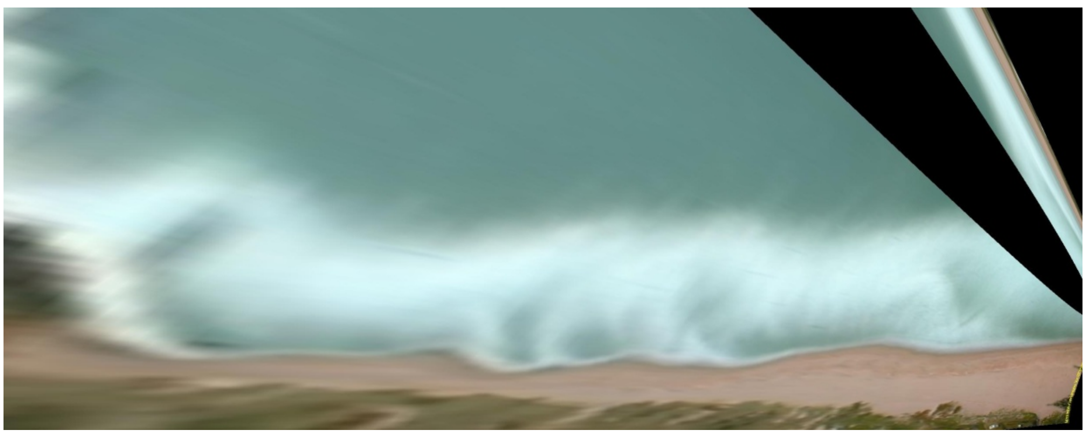


Figure 3.4. Rectified, time-averaged image of Tairua Beach from Julian Day 318 at 1000 hours in 1998.

Figure 3.5. Location of the pressure sensor deployment at the southern end of Muriwai Beach (indicated by arrows) to measure mean sea level for image rectification.

3.5.2 Image Quality

Not all video images were of a suitable quality to analyse for the location of rip channels. Only high quality images were chosen for rectification. There tends to be more wave breaking at low tide (i.e. when the water depth is at its shallowest). More wave breaking tends to produce the best colour intensity distinction of sand-bars and rip channels. Therefore, an algorithm was created to find all low tide images (‘*Imagechoose*’, see Appendix 1 and Figure A1.1). Only the highest quality images were selected for rectification and analysis to aid in achieving a high quality data-set. Some images were obscured due to low amounts of sunlight, sun-glare, shadow, rain (Figure 3.6) and/or condensation on the camera lens. These issues led to a low degree of contrast between sand-bar crests and rip channels, making them difficult to distinguish. Sometimes there were gaps in the data-set for which no quality low-tide images were available, hence images from other stages in the tidal cycle were used.

Figure 3.6. Un-rectified image of Tairua Beach from Julian Day 171 at 0400 hours in 2000. Image is obscured by rain and/or condensation on the camera lens

3.5.3 Ground Control Points

For the image rectification process, there must be at least 3–4 locations that are known in real-world coordinates with a high degree of accuracy. These locations are referred to as ‘ground control points’ or GCPs. These points had already been obtained for Tairua Beach by NIWA, therefore GCPs only needed to be obtained for the Muriwai Beach site. 13 GCPs were located using RTK-GPS. The RTK-GPS base station is shown in Figure 3.7a. These GCPs were taken using both more-or-less permanent landmarks such as the Muriwai Beach Surf Club (Figure 3.7b) and temporary locations by holding up a sign which was visible in images from the camera. GCPs were taken both near to the camera, and far away, in a scatter of locations on the beach and on land within the field of view of the cameras. For each GCP, the location was found using the RTK-GPS, and at the same time a snapshot was taken with both cameras of the landmark. A table of RTK-GPS locations and snapshots taken at Muriwai Beach with the cameras of the landmarks can be found in Appendix 4.

a. **b.**

Figure 3.7. Panel a. shows the RTK-GPS base station on hill overlooking Muriwai Beach. b. Shows taking location of the corner of the Muriwai Beach Surf Club using RTK-GPS.

3.6 Wave Data

Wave data used for this thesis are described in Gorman (2005). The wave data were modelled using the wave evolution model WAM (WAve Model). WAM was used to simulate wave generation and propagation of deep-water waves around New Zealand. Input winds for the model were from the United States National Centre for Environment Prediction (NCEP). A forecast was run daily to predict waves at three hour intervals and was run on a global domain with a resolution of 3.75º longitude by 3º latitude. Wave forecasts were validated by comparing the output to wave recorders off the New Zealand coastline. Wave data for nearshore locations such as Tairua were obtained by interpolation of directional spectra from nearshore grid cells, using a technique that considers limited fetch in the nearshore (Gorman, 2005). In the interpolation to the Tairua Beach site, there was a "parallel coast" approximation for refection used (R. Gorman, pers. comm., 29 January 2009). Wave data used was for a location on the 20 m depth contour off Tairua Beach (latitude and longitude -36.985, 175.878).

3.7 Summary

Video imaging of the coastal zone has many advantages over traditional in situ techniques of making measurements in the turbulent surf-zone. Time-averaged video images can be used to locate rip channels as corresponding to light intensity minima (dark areas) in images. Thus far, there is no method available to automatically locate light intensity minima for the entire cross-shore extent of the surf-zone or that is suitable for complicated surf-zone morphologies. Before video images can be used to locate rip channels they need to be rectified into real-world coordinates using several locations in the images for which the real-world coordinates are known with a high degree of accuracy. Wave data used in this thesis were from the WAM wave evolution model (Gorman, 2005; Gorman et al., 2003).

Chapter Four: Algorithms to Locate Rip Currents

4.1 Introduction

This chapter presents the suite of computer algorithms (programmes) created to locate rip channels in time-averaged video images of the surf-zone. The algorithms worked by locating local maxima and minima in light intensity. The algorithms created to define and refine distinct rip channels are also described. Each group of algorithms is presented as a schematic to show the linkages between the programmes with an explanation in Appendix 1. Throughout this chapter, examples of images and graphs are given to help show the principles and processes used in the algorithms.

4.2 Locate the Shoreline

The computer algorithms detect rip channels as minima in light intensity in the surf-zone (wave-breaking) area in the field of view of the camera. The problem is that lighting variations and variations in the surf-zone extent mean that false points were detected. Therefore it was necessary to find the shoreline and the barline so that only the points between these lines were included as rip currents.

An algorithm to automatically locate the shoreline in each image was adapted from Salmon at al. (2007) and Salmon (2008) (see Figure A1.2). To locate the position of the shoreline, two limits were delineated between which the algorithm would look for the shoreline, rather than searching the entire image (see '*makedcutfiles*' Appendix 1 and Figure A1.2). These limits were manually digitised to make two representative lines each for both Tairua, and Muriwai Beach. One limit was digitised along the seaward limit of the vegetation line (referred to as the seaward limit or *dcut2*), and one limit well seaward from the shoreline, roughly following the line of vegetation (referred to as the landward limit or *dcut1*) (Figure 4.1). These representative limit files were used for all images. Note that in time-averaged, rectified images of Tairua Beach such as is shown in Figure 4.1, zero in the alongshore and cross-shore directions corresponds to the location of the camera.

The difference between the beach sand and surf-zone colours in the images was used to locate the shoreline in each image. Salmon (2008) created a computer algorithm to locate the shoreline, which was also used in this thesis. The shoreline-finding routine worked by searching images for gradients in colour intensity, following Smith and Bryan (2007). The ratio of red light to green light was used to locate the shoreline between *dcut1* and *dcut2*, based on the premise that the beach sand would have a higher proportion of red colour due to higher shell content, and the ocean a greater proportion of green light. Colour intensities in the images changed due to factors such as weather conditions and light intensity which changed at different times of the day and of the year. Therefore, for each image, the threshold for the difference between the beach and surf-zone colours was found by manually selecting two boxes of colour: one on the beach and one in the surf-zone. This value was assumed to be representative of the ratio for the entire image. A threshold was chosen to differentiate beach and surf areas (for details see Salmon, 2008).

For the purpose of locating rip channels, the shoreline was made to be 10 m seaward of the shoreline located by the algorithm. This was because there tended to be an area of noticeably high light intensity in the images along the shoreline due to the high intensity of breaking waves along the shore. Since the shoreline was simply used to discard false points from the rip current finder, it was better to remove all local light intensity maxima associated with the shoreline. Also, the barline locating algorithm discussed below worked by finding areas of high light intensity, and if the light band of foam following the shoreline was included in the analysis this region could be found as a sand-bar when obviously it is not.

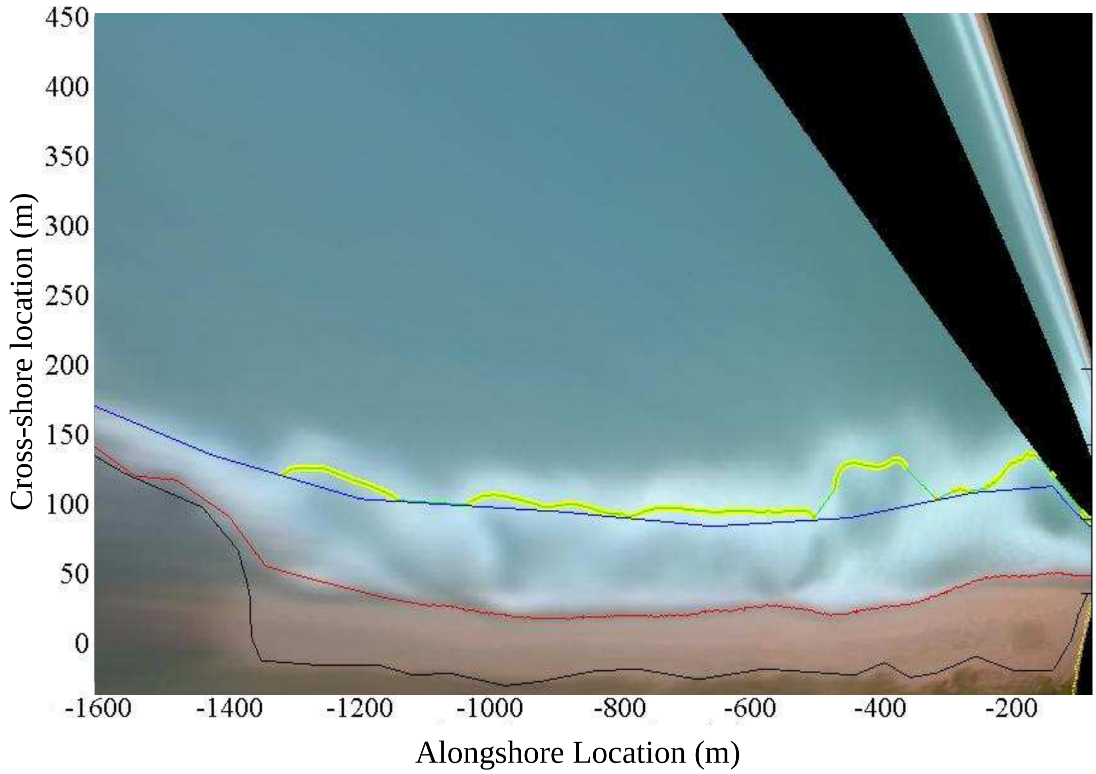


Figure 4.1. Rectified, time-averaged image of Tairua Beach from Julian Day 147 at 0800 hours in 2000. Yellow dots are light intensity maxima found corresponding to the barline and the green line joining the dots is the interpolated barline. The black line at the bottom shows the location of *dcut1* (landward limit), and the dark blue line under the barline shows the location of *dcut2* (seaward limit). The red line between *dcut1* and *2* shows the shore-line found by '*shoreline*'.

4.3 Locate the Barline

4.3.1 Distinctiveness of the Barline

An algorithm called '*barline'* was created to locate the position of the bar for each image (see Appendix 1 and Figure A1.2). Before locating the position of the barline, '*barline'* was written so that first each image was visually checked to see if the wave breaking was sufficient to a sand-bar at all. Waves break when their height is some constant function of the depth, so if the waves are insufficiently high, there is no way of detecting the bar in the video image. If there was no sand-bar in the surf-zone, it was assumed that there would be no rip current generation. This is because when waves are low, there is little breaking so there is no strong radiation stress gradients i.e. the shallow sand-bars don't push the water up (i.e. cause a set-up) and make gradients in water level, decreasing to the channels. This means there are no gradients to drive the rip currents when waves are low. If there was no visible bar present at all for a particular image, or perhaps there were small sand-bar crests visible (probably too small to cause rip currents) this image was not analysed to find rip channels (e.g. it was assumed there were no rip currents present). Images were treated differently depending on if there was a distinct bar present (i.e. with sharp light intensity maxima) or a diffuse, indistinct bar. If a bar was not particularly distinct, the algorithm written to locate the barline did not work particularly well. For these images with an indistinct barline, the barline was manually digitised into the image (the entire length or just sections of it).

4.3.2 Locate Local Light Intensity Maxima

For images in which there were distinct sand-bars present, the main principle of the barline finding algorithm was that, in general, the barline corresponded to the maximum light intensity in each image. Therefore, to locate the barline the image was searched in cross-shore transects for each alongshore location. The algorithm '*barline*' was written to look seaward of *dcut1* (the same 'seaward limit' used to locate the shoreline) for the highest local light intensity maximum of blue light for each transect. Originally, the barline locating algorithm was created to look seaward of the shoreline. Although this worked well for most images, for some images the maximum local cross-shore light intensity was found to be close to the shoreline when the barline was obviously further seaward. This was the case because in some cases, pushing the shoreline found with the algorithms seaward by 10 m was not sufficient to stop the brightest light intensities to be found at the shore rather than the barline. The algorithm to locate rip channels only looked between the shoreline and the barline, therefore some rip channels were not located by the algorithms when the barline found was too close to shore. *Dcut2* was tested and found to work well as a minimum distance from the shore between which rip currents may form (Figure 4.1). In some cases parts of or the entire barline were seaward of *dcut2* so it was not found by the algorithm. This was not an issue as there was a routine built into the algorithm allowing corrections to be made to the barline if need be (see Section 4.3.3).

For each cross-shore transect of light intensity, a polynomial with seven orders was fitted (Figure 4.2). This purpose of this polynomial was to remove some of the small-scale variation in light intensity which may have caused light intensity maxima to be found that in fact did not correspond to the actual barline. An order of seven was used because after comparing maxima found on the polynomial with the position of the barline in the image, an order of seven was best for locating the barline accurately.

4.3.3 Define the Barline

Local light intensity maxima possibly corresponding to the location of the barline in each image were defined as at location between *dcut2* and the seaward limit of the rectified images where a particular location had a local maximum in light intensity (where maxima were defined using a threshold). Of the local maxima found for each transect, some of these maxima were too small to correspond to a sand-bar crest (by visually comparing positions of maxima found to locations of sand-bar crests in images). Small local maxima were removed using a threshold of standard deviation (1.5 times) for each cross-shore transect. Also, a final check was used to remove maxima (using a threshold) from areas simply too dark to be a sand-bar.

For many cross-shore transects, more than one light intensity local maximum was found, in which case the position of the barline was taken as the furthest seaward maximum. By visual comparison to images, the seaward maximum almost always corresponded to the true barline position. Using the furthest seaward maximum was also done to ensure that the barline found was not located too close to the shore, in which case some rip channels were not detected in later parts of the analysis as rip channels were defined as being between the shoreline and barline (see Section 4.6). A local light intensity maximum above the necessary threshold was not always found for every cross-shore transect. If no maximum was found for any cross-shore location, the maxima that were found for surrounding alongshore locations were interpolated to fill in the missing barline (Figure 4.1). A routine was created so that before the position of the barline found was used for further analyses, the barline was visually checked. The barline correcting routine allowed parts of the barline to be corrected as many times as needed, although corrections were only ever required one or two times, if at all for any one barline.

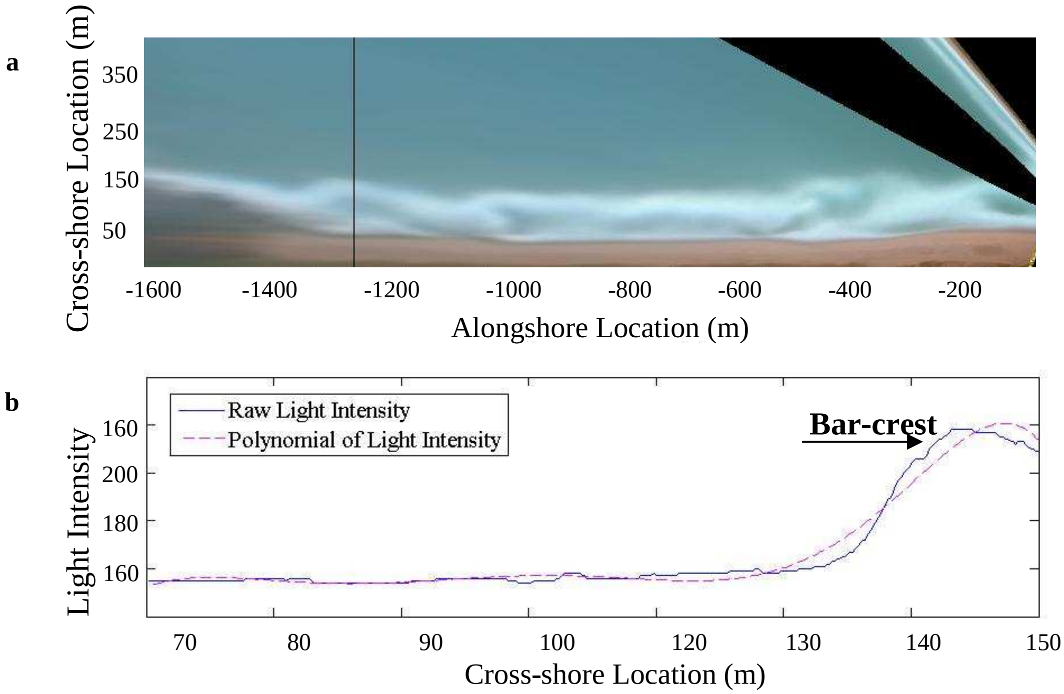


Figure 4.2. Panel a. shows a rectified, time-averaged image of Tairua Beach from Julian Day 147 at 0800 hours in 2000. Line shows one cross-shore transect in the barline locating algorithm from which the intensity of blue light is shown in b. b. Shows the 'raw' blue light intensity (solid blue line) and the polynomial fitted (dashed magenta line), with the sand-bar crest indicated by the arrow.

4.4 Locate Maxima and Minima

The next step was to detect local maxima and minima between the shoreline and barline, needed to find the rip channels. Images were searched both in the alongshore and cross-shore directions for local maxima and minima in light intensity to get the best spatial coverage possible. Below it is discussed how rip channels were located using alongshore transects for each cross-shore location, this method was the same when using cross-shore transects. The algorithms '*loadimages*' and '*findrips*', see

Appendix 1 and Figure A1.2 were used to locate maxima and minima. The steps carried out with the computer algorithms are summarised below (see schematic in Figure 4.3):

Step 1: Search Light Intensity Transects

To locate rip channels and sand-bar crests in each image that had a sand-bar present (and hence possible rip channels), transects of light intensity were extracted from the image and searched to find local maxima and minima in the alongshore and cross-shore directions. Figure 4.4 (and Figure 4.3, step 1) shows an alongshore transect that was searched to find the alongshore position of local maxima and minima.

Step 2: Smooth Light Intensity

Before searching for local extremes (maxima and minima) in light intensity, the light intensity was first fitted with a spline (Figure 4.3, step 2). The spline removed some of the high frequency variability in light intensity which may have caused maxima and minima to be found that were too small to correspond to rip channels and/ or sand-bar crests.

Step 3: Locate Local Maxima and Minima

The slope of the spline was calculated. The locations where the spline slope crossed zero (e.g. went from positive to negative and vice versa) were then detected by the algorithm. Where the spline crossed zero, this corresponded to a possible local extreme. Once the local extremes had been found for a transect, these extremes needed to be sorted into maxima and minima of light intensity. Local maxima were sorted from minima using the second derivative of the slope (i.e. ‘slope of the slope’) of the spline. Maxima were associated with a negative second derivative and minima with a positive second derivative. As a check to make sure there were no false maxima and minima, if only one extreme was found for a particular transect, this extreme was discarded as in general there cannot be a rip channel present without a sand-bar next to it and vice versa (as required by the definition of a rip channel in Section 4.6).

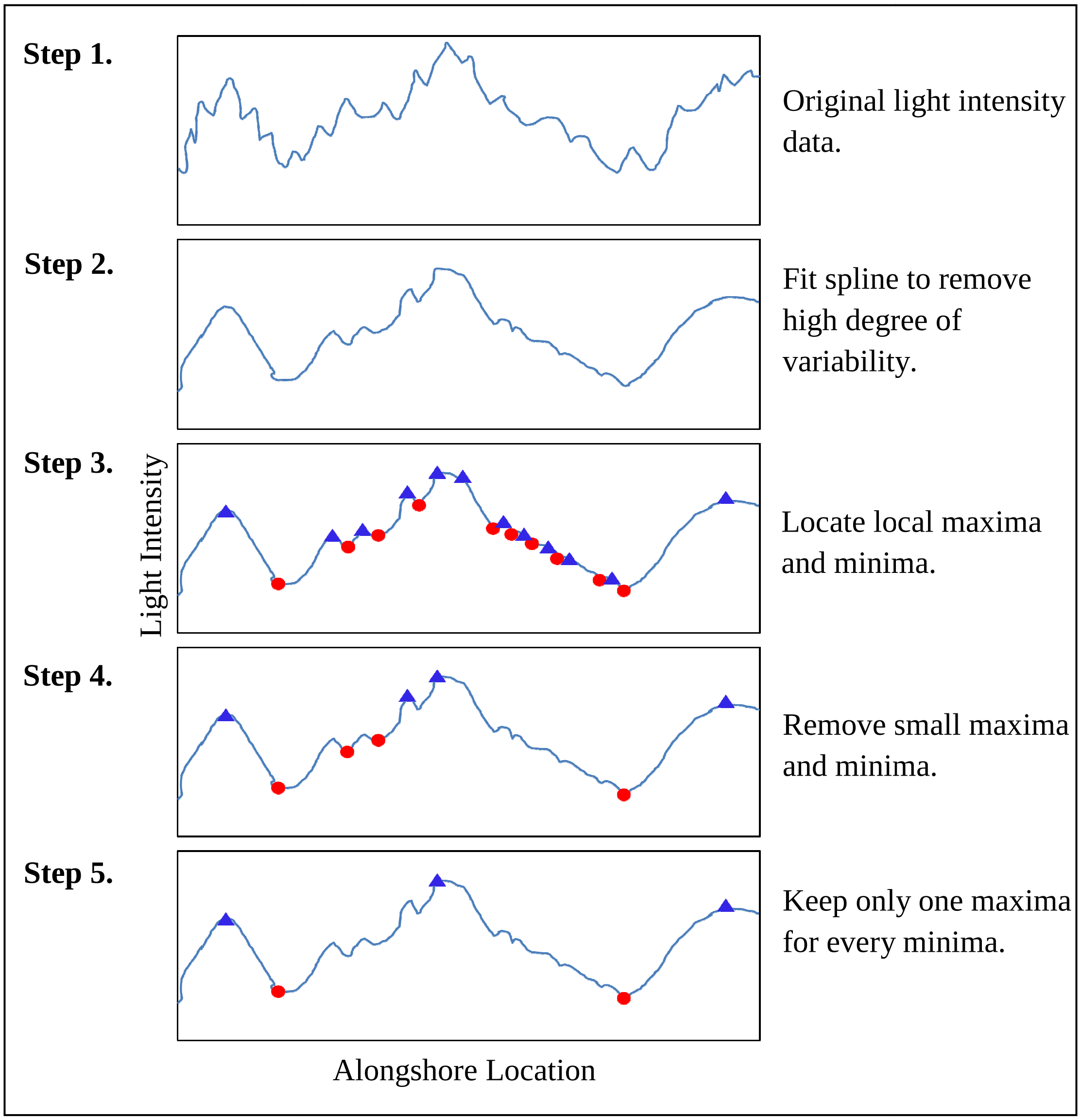


Figure 4.3. Schematic showing how computer algorithms located local maxima and minima in light intensity. Triangles indicate local maxima and red circles local minima.

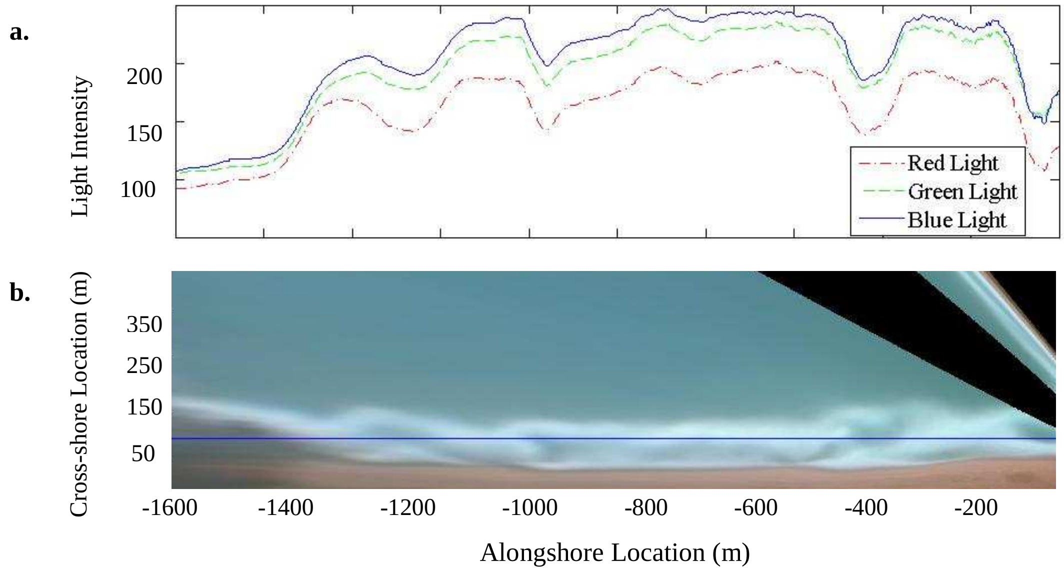


Figure 4.4. Panel a. shows light intensities for red (small dashed line), green (large dashed line) and blue light (solid line) at one alongshore transect. b. Shows the alongshore transect of interest (blue line) on a rectified, time-averaged image of Tairua Beach from Julian Day 147 at 0800 hours in 2000.

Step 4: Remove Small Local Maxima and Minima

At this point in programming after locating maxima and minima, observations showed that local maxima and minima had been found where there were in fact no rip channels or sand-bar crests visible in the corresponding images. This discrepancy was due to maxima and minima that were too small being found. To overcome this issue, maxima and minima that were 'too small' were removed (Figure 4.3, step 4). The algorithm was written so that maxima and minima that had relatively small changes in light intensity on both sides of the extreme were removed. A threshold of the difference in light intensity was chosen through testing with various images, where the locations of maxima and minima found were compared to the locations of rip channels and bar crests in the images. Although this threshold was subjective, the results were only weakly dependent upon it. For the series of maxima and minima found, the algorithm calculated how big the change in light intensity was to the next maximum or minimum on both sides alongshore. If this change in light intensity was below the threshold, the offending two extremes were removed (one maximum and one minimum). Two extremes were removed as opposed to one because as mentioned in Section 4.6, a rip channel must be associated with a bar crest. If only one extreme was removed, then there would be two consecutive maxima or minima. This routine was repeated but this time, maxima and minima with differences in light intensity that were less than the threshold on only one side of the extreme (as opposed to two) were removed.

Step 5: Remove Multiple Maxima and/ or Minima

Occasionally, there were consecutive local maxima or minima, in which case all but one were removed (Figure 4.3, step 5). In the case of multiple maxima and minima, the largest extreme was retained as these were most likely to correspond to a real rip channel or sand-bar crest.

Step 6: Remove Minima Not Between Shoreline and Barline

In the final step, maxima and minima corresponding to sand-bar crests and rip channels may only be in the surf-zone, i.e. between the shoreline and the outer barline (as required for the definition of a rip channel in Section 4.6). Some minima were found seaward of the barline due to the relatively dark colour of the water outside of the surf-zone. This dark colour was due the lack of wave breaking in deeper water and not due to the presence of rip channels. There were also maxima and minima found landward of the shoreline on the dry sand of the beach. These maxima and minima outside of the surf-zone were removed using an algorithm called '*cleanup*' (see Appendix 1 and Figure A1.2). Maxima and minima landward of the shoreline were found by subtracting the cross-shore position of the extremes from the cross-shore position of the shoreline for every alongshore position. If this value was negative it meant that the maximum or minimum of interest was landward of the shoreline and was hence removed from the data-set. Likewise, maxima and minima seaward of the barline were removed by subtracting the cross-shore position of the extremes from the cross-shore position of the barline for each alongshore location. If this value was positive it meant that the maximum or minimum of interest was seaward of the barline and hence it was discarded. After being 'cleaned up', the maxima and minima found by searching the image along all possible transects extracted in alongshore and cross-shore directions, were merged into one set of data. The result of this merging was a cluster of points associated with sand-bar crests (maxima) and rip channels/alongshore troughs (minima) and another cluster associated with (Figure 4.5).

4.5 Define Rip Channels

Now that there had been a cluster of minima produced, these minima needed to be defined into distinct rip channels. At this stage in programming, the computer only knows that there is a cluster of separate minima but does not know which ones are part of the same rip channel. An algorithm was developed to define a rip current as a cluster of local minima that were connected. Since the local maxima were scattered with unknown separation, a two-dimensional histogram with coarser and consistent resolution was used as the basis for the connectivity algorithm. Once connectivity was established, the original cluster was divided into individual rips. The result was sets of points, with each set defining a rip. The steps undertaken to define distinct rip channels are summarised below.

Step 1: Create a Grid

An algorithm was written called '*gridrip*' (see Appendix 1 and Figure A1.3) that for each image first created a 7.5 m by 7.5 m grid to cover the region of rip currents. (Figure 4.5). Extra cells were added on the outside of the grid to ensure that all cells containing minima were completely surrounded by more cells i.e. (by 8 cells) (Figure 4.6) as was required by the algorithm. Note that 'surrounding cells' refers to the 8 cells surrounding one centre cell (Figure 4.6). This grid was used as the basis for a two-dimensional histogram of rip-current minima (Figure 4.7).

Step 2: Define Rips with Connectivity Algorithm

An algorithm called '*locaterips*' (see Appendix 1 and Figure A1.3) was designed to locate and define distinct clusters of minima (possible rip channels) which were associated with maxima in the two-dimensional histogram (Figure 4.7). A connectivity algorithm was created using the two-dimensional histogram. The first step for each rip was to find the cell containing the most minima as a starting point. The algorithm then found how many minima were contained in each of the 8 surrounding cells. The rip current was then marked as being in the surrounding call with the most minima. Thus the computer found the most probable location of the rip current by moving between connected minima in the two-dimensional histogram non-zero cells.

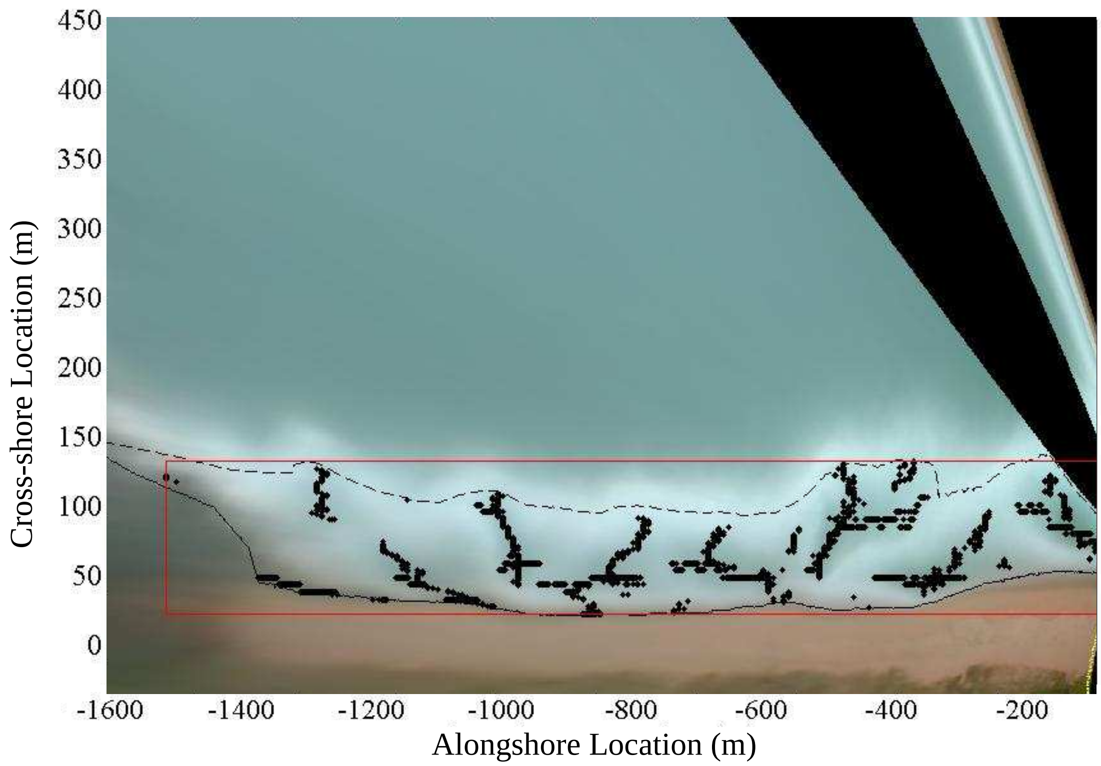


Figure 4.5. Rectified, time-averaged image of Tairua Beach from Julian Day 149 at 0800 hours in 2000. Black dots show minima found corresponding to light intensity lows (channels). Solid black line indicates shoreline and the dashed black line the barline located by algorithms. Red box shows the outer limits of the grid created for '*gridrip*'.

Before each cluster of minima was considered complete, the algorithm would go back and check every cell to see if there were any 'connected' cells containing minima that had not yet been counted. Connected cells might not yet have been counted because each time the rip-definer moved to a new cell, it went to the closest cell containing the most minima. Therefore cells containing a lower number of minima may not have been counted. A cluster of minima was completely defined when all the connected non-zero cells in the two-dimensional histogram were found. Then the routine would move on to the next cluster of uncounted minima, until all clusters of minima had been found for that image. Figure 4.7 shows an example of an image showing the 'cells' that contain minima, with a cross plotted on the corner of each cell to indicate the cells that had been counted as part of a cluster of minima i.e. a possible rip current. Some of these defined clusters of minima corresponded to real rip currents and some did not. Any clusters consisting of less than five grid cells were discarded. The local minima contained in the 7.5 m by 7.5 m grid cells defining cluster of minima, were then stored in a separate variable name associated with that cluster (i.e. possible rip current). These clusters of points are plotted in Figure 4.8, where each cluster represents a possible rip current.

1	2	3
4	centre cell	5
6	7	8

Figure 4.6. Schematic of a 'centre (grid) cell' and the 8 'surrounding' cells.

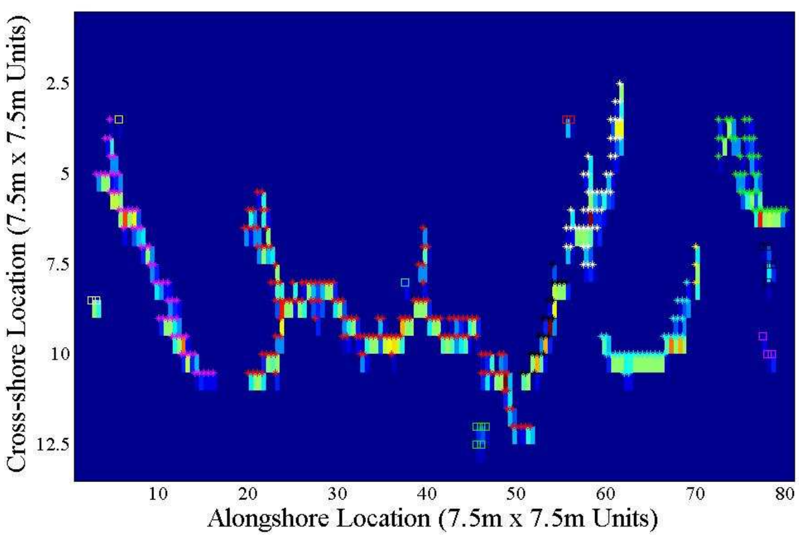


Figure 4.7. Two-dimensional histogram of number of minima in a 7.5m by 7.5 m grid (from Julian Day 147 at 0800 hours from 2000), which covers the area in the grid limits shown in Figure 4.5. Brighter colour intensities indicate that there were lots of minima in a cell, and vice versa.

Step 3: Merge Clusters of Minima

In some cases clusters of minima had ends that were close together and therefore should be merged into one cluster (Figure 4.8). A routine called '*endpoints*' (see Appendix 1 and Figure A1.4) was created to find the locations of the endpoints of each cluster. The minima in each cluster were sorted and ranked to define the ends points of the possible rips. The next step was to calculate the absolute distance between each endpoint and every other endpoint. End points that were closer than a threshold apart were merged together. Although clusters were automatically merged, the threshold used was rather conservative to allow for the high degree of variability between the images. Therefore, there were sometimes still clusters remaining that obviously needed to be merged. The algorithm '*manualmerge*' (see Appendix 1 and Figure A1.4) was created to allow the user to simply select clusters, which would then be merged. Clusters were merged if it appeared that any were more-or-less in the same cross-shore location and close together where one was accompanied by a perturbation in the shoreline or barline.

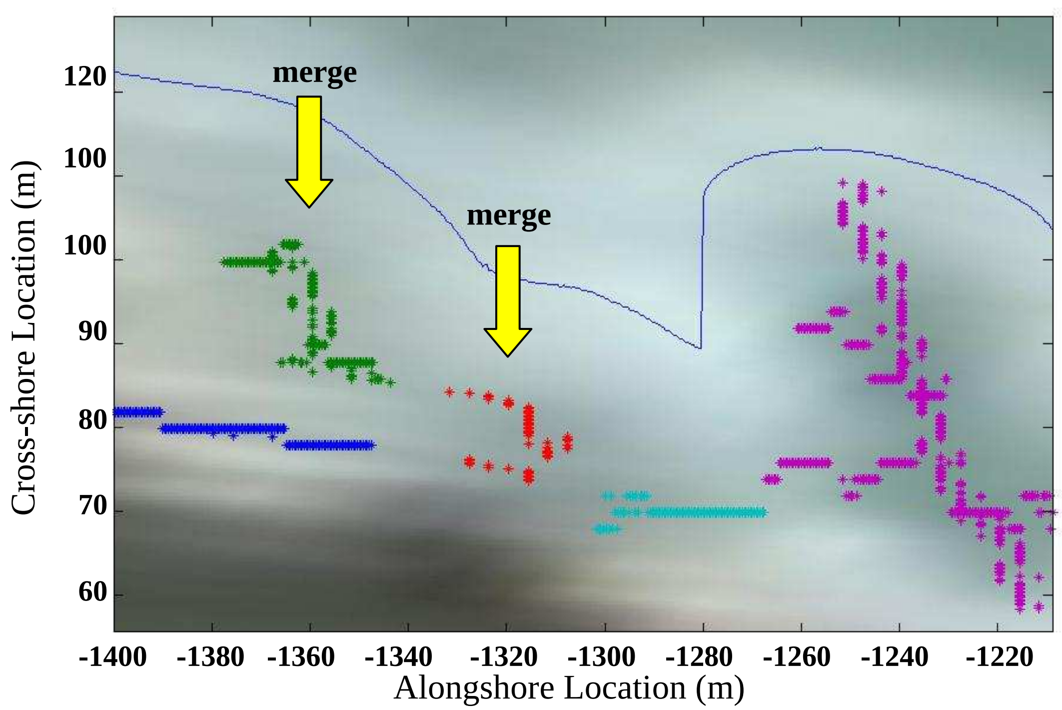


Figure 4.8. Rectified, time-averaged image of Tairua Beach from Julian Day 194 at 0900 hours in 2000. The blue line shows the barline found by 'barline' and the different coloured dots show the clusters of minima before being refined. The yellow arrows are pointing to two clusters that need to be merged.

Step 4: Split Clusters of Minima

In some cases, clusters of minima needed to be split. The definition of a rip current in this thesis is that it must not the parallel to the shore and must have a corresponding perturbation in the corresponding part of the barline or shoreline (see Section 4.6). Therefore, any clusters of minima found that were near to parallel to the shore were removed. However, in some cases, clusters found had both areas that were near to perpendicular to the shore and areas parallel to the shore. In such cases it was important to keep the perpendicular areas and remove the parallel areas to comply with the definition of a rip channel for this thesis.

In an attempt to create an automatic method to split clusters, a routine was created to go through each cluster defined and see if it needed splitting based on the orientation of that cluster segment. First, the '*ripsplit*' routine found and removed minima where there was no cross-shore difference to the next minima. The absolute distance was then calculated between each of the remaining minima. Where the distance from one minimum to another was greater than 6 m, these minima were removed. The absolute distance between each of the remaining minima was calculated. It was then found where this distance was greater than 100 m. Where this distance between minima was greater than 100 m, the cluster was split in these areas to create a group of separate rip channels normal to the shore. The algorithm '*ripsplit*' worked extremely well in many cases. However, for other cases, although the main principles of the algorithm seemed to work fairly well to split up clusters, there were issues with thresholds. There were no thresholds found that appeared to work for all cases due to the extreme variability in rip current patterns. Therefore, it was decided to use a manual method of splitting up rip currents based on local cluster orientation.

A routine called '*manualsplit*' (see Appendix 1 and Figure A1.4) was created which allowed the user decide for each image if there were any clusters that appeared to need splitting in each image. Entire clusters could be split by the user simply selecting a location where a cluster required splitting. Although somewhat subjective, some conditions were created to decide whether or not clusters should be split to keep subjectivity to a minimum. Clusters were split where they were near to parallel to the shoreline (Figure 4.9). Another condition for splitting was that according to the rip current definition (Section 4.6) rip currents needed to correspond to one and only one visible perturbation in the barline directly seaward of rip current, or in the shoreline directly landward. Therefore, if a rip had two areas perpendicular to the shoreline (Figure 4.9) then this cluster needed to be split to only keep the part(s) of the cluster corresponding to a perturbation in the barline or shoreline. Likewise, if a cluster had an area perpendicular to the shoreline and an adjoining area near to parallel to the shoreline, the cluster needed to be split to remove the parallel area but to keep the perpendicular area, such was the case in Figure 4.9.

Step 5: Remove Clusters of Minima

There was a routine created to automatically remove clusters of minima that were too small to correspond to rip channels. In most cases there were clusters found that were small and appeared to not actually correspond to real rip channels in the images. Therefore, any clusters that contained less than 10 minima (a conservative threshold) were automatically removed using '*removerips*' (see Appendix 1 and Figure A1.4). '*Manualremove*' (see Appendix 1 and Figure A1.4) was created to allow the user to manually remove clusters by simply selecting which ones to remove (Figure 4.11). After clusters had been merged, split and removed, what remained was a high quality, comprehensive data-set of rip currents. An example of a refined image showing only defined and refined rip channels is shown in Figure 4.12.

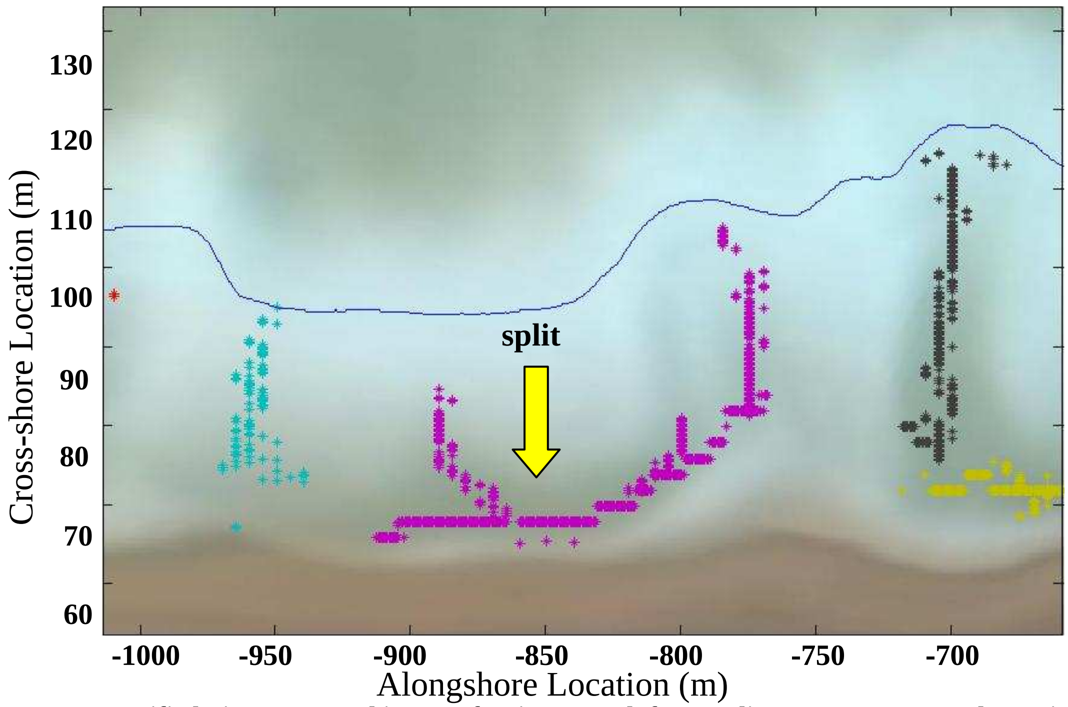


Figure 4.9. Rectified, time-averaged image of Tairua Beach from Julian Day 178 at 0800 hours in 2000. The blue line shows the barline found by '*barline*' and the different coloured dots show the clusters of minima before being refined. The yellow arrow is pointing to a cluster that needs to be split up at the location indicated.

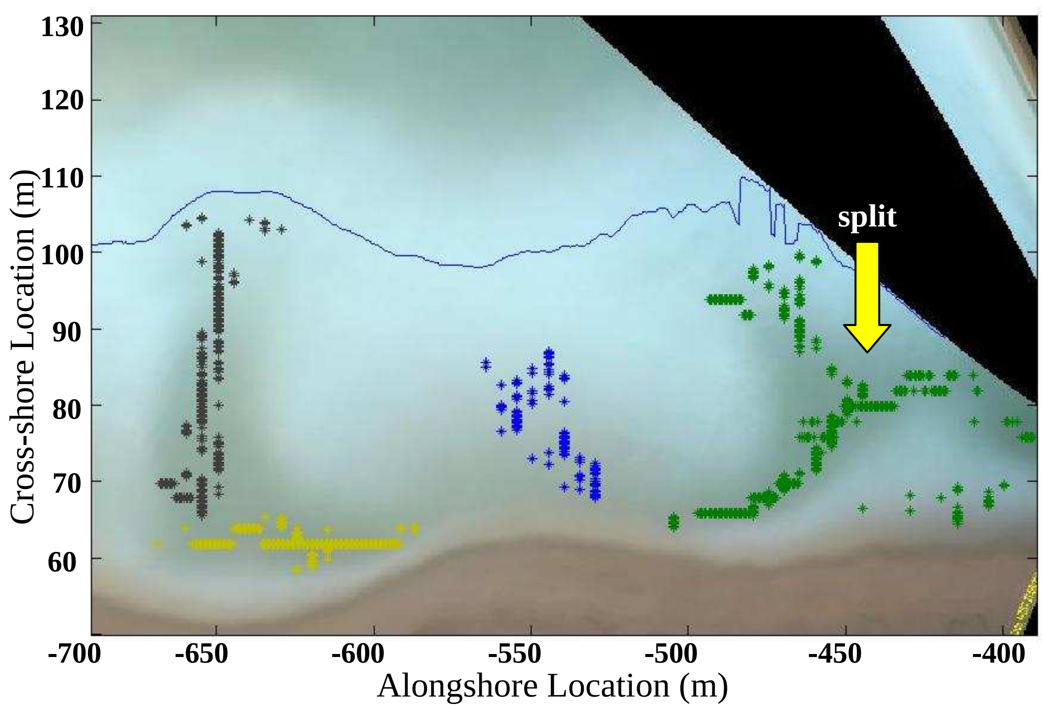


Figure 4.10. Rectified, time-averaged image of Tairua Beach from Julian Day 178 at 0800 hours from 2000. Blue line shows the barline found by '*barline*' and the different coloured dots show the clusters before being refined. Yellow arrow is pointing to a cluster that needs to be split up at the location indicated.

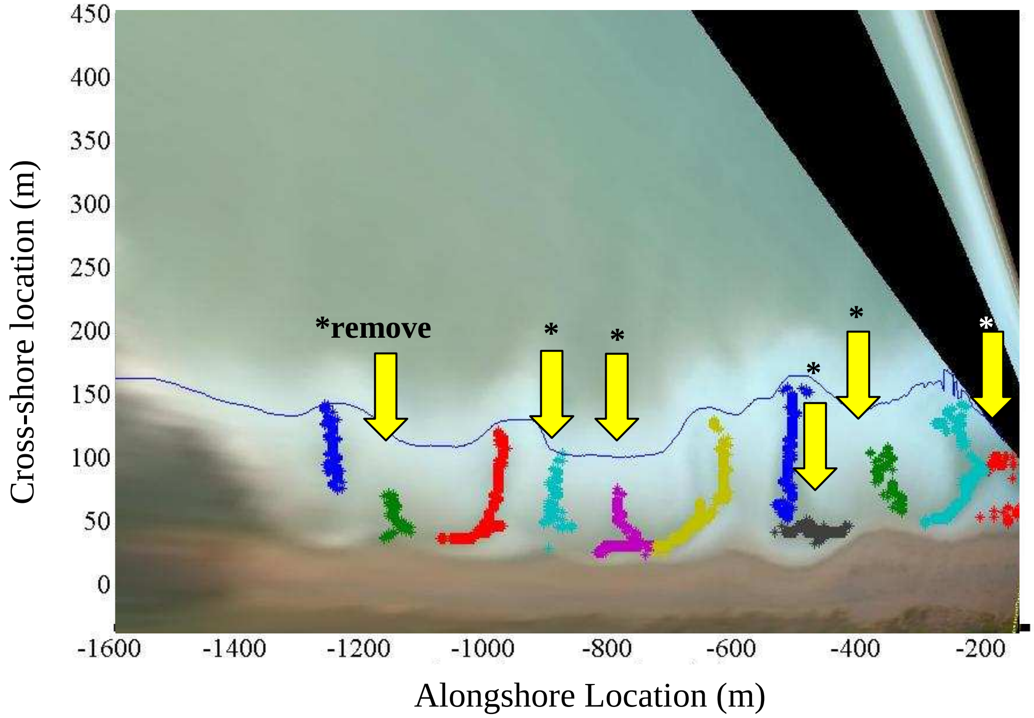


Figure 4.11. Rectified, time-averaged image of Tairua Beach from Julian Day 178 at 800 hours in 2000. Blue line shows the barline found by '*barline*' and different coloured dots show the clusters of minima after splitting and merging. Yellow arrows indicate clusters that were manually removed.

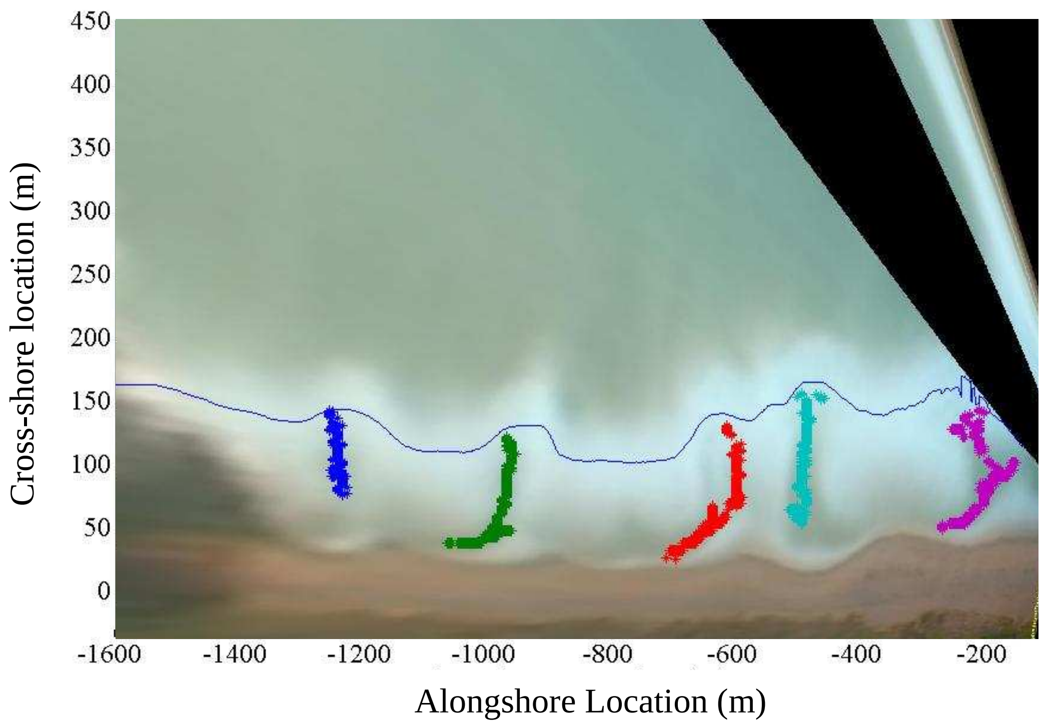


Figure 4.12. Rectified, time-averaged image of Tairua Beach from Julian Day 178 at 0800 hours in 2000. The blue line shows the barline found by '*barline*' and different coloured dots show the separate rip channels after being refined.

Step 6: Measure Rip Channel Parameters

For each refined rip current, a line was fitted. Line fit yielded two numbers, the slope and the intercept (with alongshore position). This angle was assumed to be the angle representative for each rip i.e. rip orientation relative to shore-normal (0 degrees). The mean alongshore rip channel spacing for each image was also found. For calculating mean rip spacing, alongshore rip channel locations were taken as the alongshore location of the most seaward endpoint of each rip channel (the location of the rip current head). This method is consistent with that used by Short (1985) who took rip locations as the point where the rip current and/ or head left the surf-zone. When the alongshore position of each rip channel was averaged for each rip channel, there were only minor differences compared to when the seaward endpoints were used. The mean rip channel spacing for each image was taken as the mean difference between the alongshore spacing for each rip. For the rip channel data found using the computer algorithms see Appendix 5.

4.6 Rules for Defining a Rip Channel

In summary, the rules for defining a rip channel were as follows:

(1) Minima in light intensity associated with rip channels must have a maximum on at least one side;

(2) The difference light intensity between maxima and minima in each transect must be above a threshold (see Section 4.4, Step 4);

(3) Rip channels may only be located between the shoreline and the barline (see Section 4.4, Step 6);

(4) There must be a minimum number of 5 connecting grid cells in the two-dimensional histogram (see Section 4.6, Step 5);

(5) Rip channels must be accompanied by a visible perturbation in the shoreline or the barline. This definition is supported by Ranasinghe et al. (2004), Whyte et al. (2005) and Turner et al. 2007 who noted that crescentic features at the seaward extend of the breaker zone can be an

indicator of the presence of rip channels. This definition means that any clusters of minima and/or alongshore troughs near to parallel to the shore were removed, as were any other clusters that were perpendicular to the shore yet were not accompanied by a perturbation in the barline or shoreline;

4.7 Preliminary Muriwai Beach Results

The algorithms to locate local maxima and minima in light intensity were tested on Muriwai Beach. Figure 4.13 shows that the algorithms also seem to work very well on Muriwai Beach.

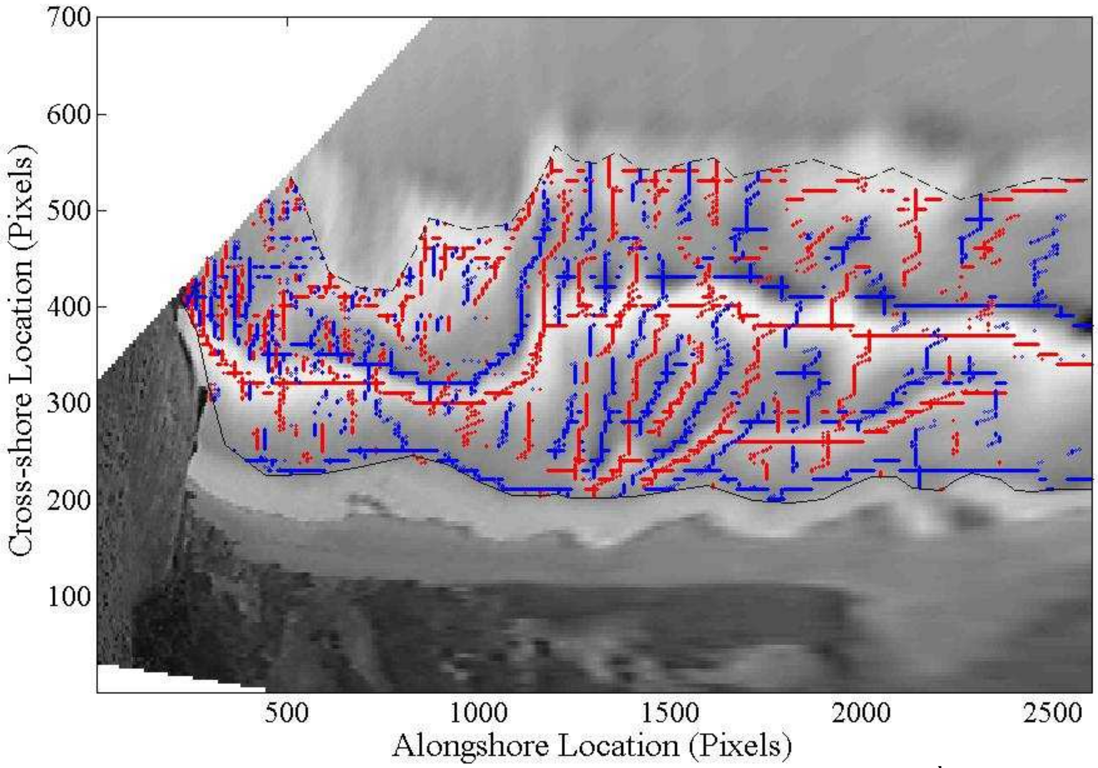


Figure 4.13. Rectified, time-averaged image of Muriwai Beach from February 15th 2003 at 1500 hours. Blue dots show local light intensity minima and red dots show local light intensity maxima. Black line shows shoreline and dashed black line shows barline.

4.8 Summary

A suite of computer algorithms was created to locate rip channels as light intensity minima between the shoreline and the barline in rectified, time-averaged video images of the surf-zone. The resulting cluster of minima found for each image was then defined into separate clusters of minima for each image. Clusters were refined by removing those that were too small, merging those that appeared to be the same one and splitting clusters based on the orientation. Attempts were made to automate the rip-refining process however the large amount of variability in rip channels with time did not allow thresholds that were appropriate to all situations. The result of the application of the computer algorithms was a data-set of rip channels spanning the entire alongshore and cross-shore extent of the surf-zone at Tairua Beach spanning from 1999 until April 2002.

Chapter Five: Rip Current Behaviour

5.1 Introduction

This chapter presents rip channel and wave data for each year for which Cam-Era video images of Tairua Beach were analysed (1999–April 2002). Rip channel behaviour and how it changed throughout each year is discussed. Data are presented of each rip channel parameter found using the computer algorithms, including alongshore rip channel locations, mean rip channel angle, mean alongshore rip channel spacing, spacing standard deviation, number of rip channels, and mean surf-zone width. Significant wave height, mean wave angle and mean wave period data for each year are also presented and discussed. There are two main purposes of this chapter: (1) to show the potential and type of data that can be obtained using the suite of computer algorithms created to locate rip channels in time–averaged video images; and (2) to give an overview of annual rip channel behaviour at Tairua Beach, for example what kinds of behaviours occur and how might different rip channel parameters be related to each other.

The majority of rip channel locations were found using the computer algorithms. However, note that for periods of time when there were no rip channels present which fitted the specific rip channel definition (see Section 4.6), it was still possible to manually detect the relic rip channels in some cases. These cases generally corresponded to images in which the rip channel was visible, but the wave energy too low to have the associated signal in the wave breaking pattern and hence light intensity values (see Section 4.6, rule number two). The locations of relic rips were manually digitised. These were included to provide continuity in figures. Since rip channels did not change significantly during the calm periods, the inclusion of relic rips did not affect any interpretations/ conclusions. Note that no other rip channel parameters (such as angle, spacing, etc) included this relic rip information except for calculations carried out in Section 6.2.

5.2 Wave Climate

During 1999 at Tairua Beach, H_s varied between ~0.5 and ~4 m (Figure 5.1b). There appeared to be four short-lived events when H_s reached greater than 3 m. The highest H_s occurred at day ~90 reaching a magnitude of 4 m. Mean wave period (T) varied between ~4 and 13 s, although the majority of the time it was 8 s or less (Figure 5.1c). Wave period appeared to be more stable at the beginning and the end of the year, being the most variable between days ~100 to 250 during the autumn and winter periods when there was generally more storm activity. During each year, the wave angle (mean wave incident angle, direction heading to) varied between ~200 and ~280 degrees relative to true north (from southerly to north-westerly, Figure 5.1b). At the beginning of 1999 up until day ~100 the wave direction was mostly from 220–260 degrees (south-westerly to westerly). From day 100 wave direction was more variable and, towards the end of 1999, it was towards a more southerly direction than at the beginning of the year.

During 2000, overall H_s appeared to be lower than in 1999. The maximum H_s was 5 m, and the minimum was ~0.2 m. In 2000, H_s was relatively stable at the beginning of the year until day ~125, and at the end of the year from day ~250 (Figure 5.2b). There was an extremely high wave event that occurred between days ~170 to ~200. During this high wave event H_s reached a maximum of 5 m, and the event lasted for about one month. The only other time during the period of study when H_s reached a maximum of 5 m was at day ~120 in 2001 (Figure 5.2b), however this event was short lived compared to the one in 2000. During 2000, T was more stable compared to 1999. Mean wave period in 2000 was generally between 6 and 9 s with three instances when it reached greater than 10 s (days ~150, ~275 and ~320, Figure 5.2c). Wave direction was more stable from the beginning of 2000 until day ~150. From day 150 wave direction was highly variable. Between days 0 to ~40 wave angle was towards a fairly southerly direction, after which it became more westerly and was fairly stable heading westerly until day ~140. For the remainder of 2000 wave direction was highly variable.

During 2001, H_s reached a maximum of almost 5 m, and a minimum of ~0.5 m. At the beginning of 2001 until day ~100, H_s was fairly constant at 1.5–2 m. Between days ~100–130, there was a high wave event when H_s reached a maximum of almost 5 m. From day ~150 until day ~350 there was an increasing trend in H_s to reach ~4 m (Figure 5.3b). From day ~250 until the end of 2001 H_s appeared to be decreasing. During 2001, T varied between 5 and 11 s. Wave period was fairly stable throughout 2001, but was more variable between days 150–250 (the autumn and winter months) (Figure 5.3c). At the beginning of 2001 until day ~140, wave direction was coming from an increasingly northerly direction (Figure 5.3d). From day ~140 wave direction was towards an increasingly more westerly direction until day ~250 when it began to head more towards the south.

For the period of 2002 studied in this thesis (until day 107), H_s was generally lower than 2 m. On day 70, H_s reached a maximum of 2.5 m (Figure 5.4b). Wave period was relatively stable varying between 6 and 10 s (Figure 5.4c). Up until day ~30 in 2002, the waves were heading towards an increasingly more westerly direction, after which the direction became more southerly until day ~60, then there appeared to be a trend towards a more westerly direction (Figure 5.4d).

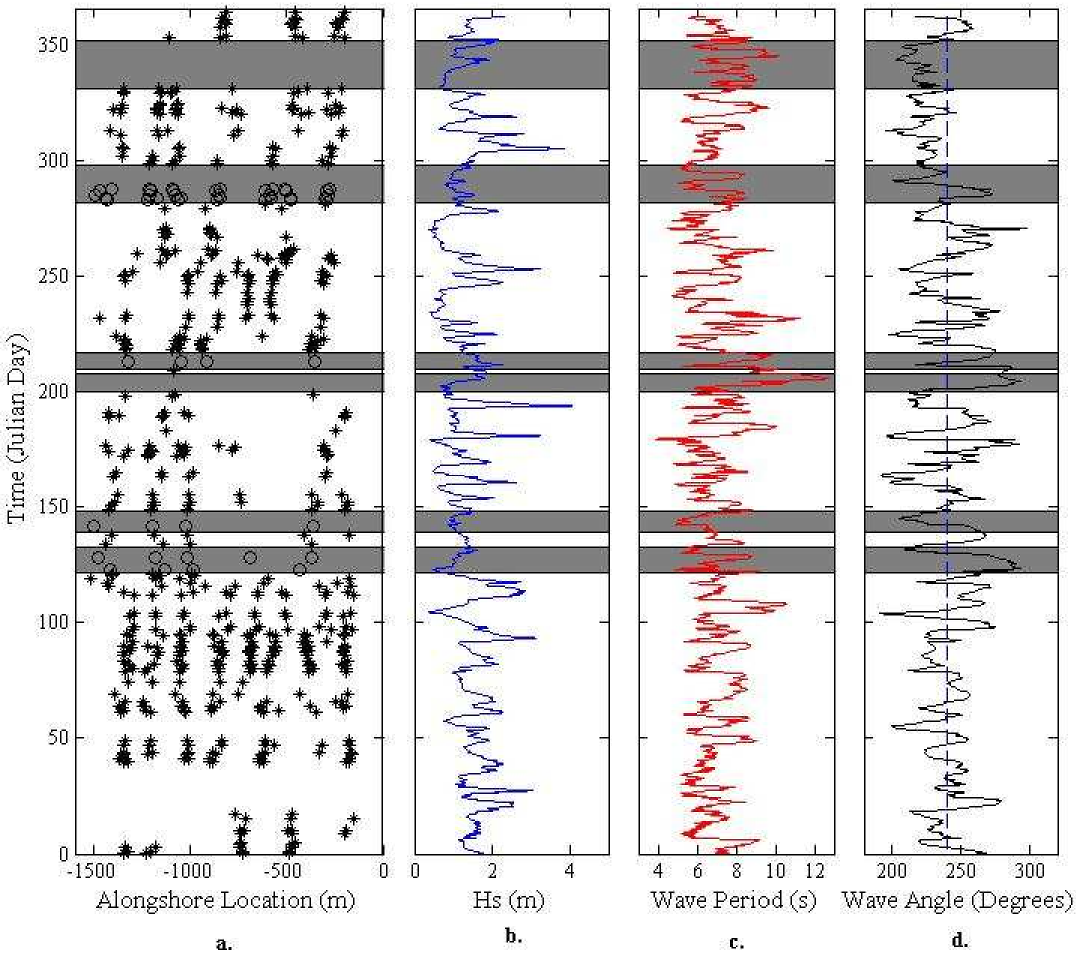


Figure 5.1. This figure shows rip channel and wave data from 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low to make rip channels detectable by automatic algorithms. b. Shows significant wave height, c. The mean wave period, and d. The mean wave direction (to), where blue dashed line indicates shore-normal.

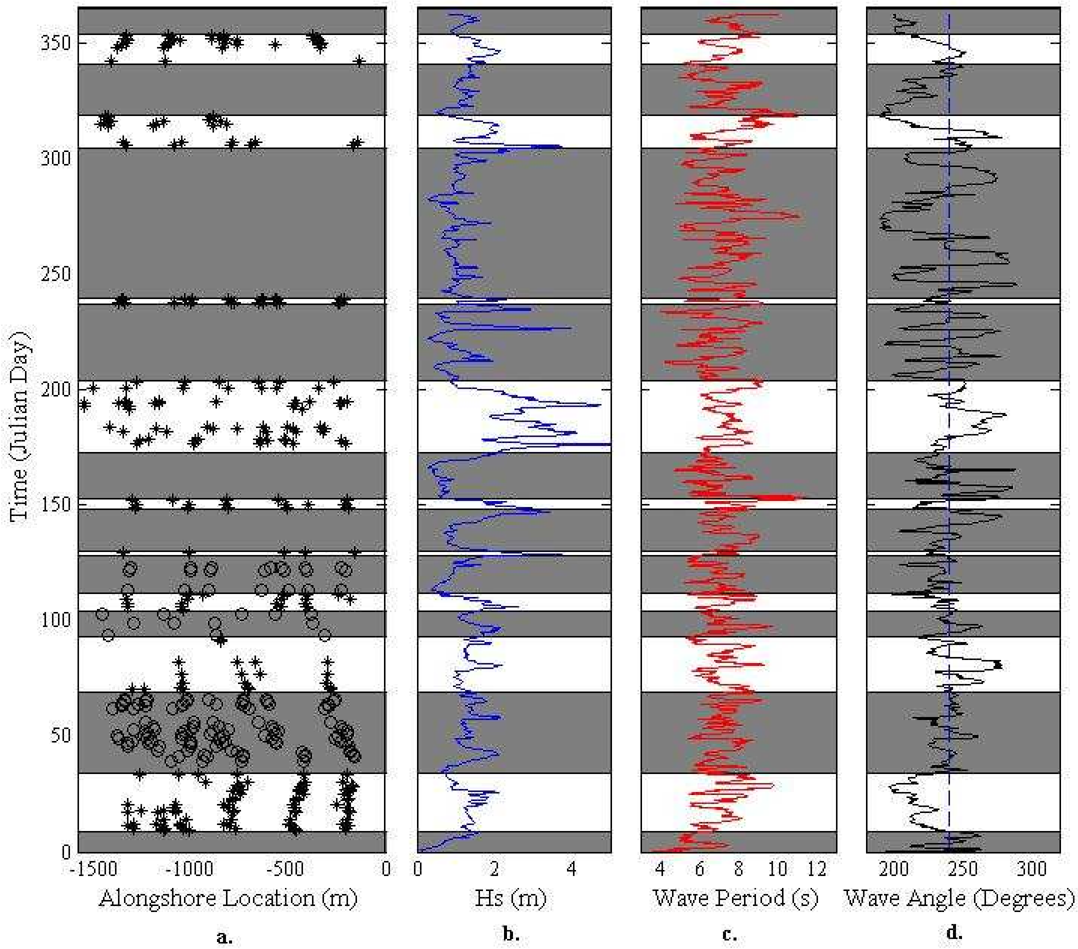


Figure 5.2. This figure shows rip channel and wave data from 2000. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low to make rip channels detectable by automatic algorithms. b. Shows significant wave height, c. The mean wave period, and d. The mean wave direction (to), where blue dashed line indicates shore-normal.

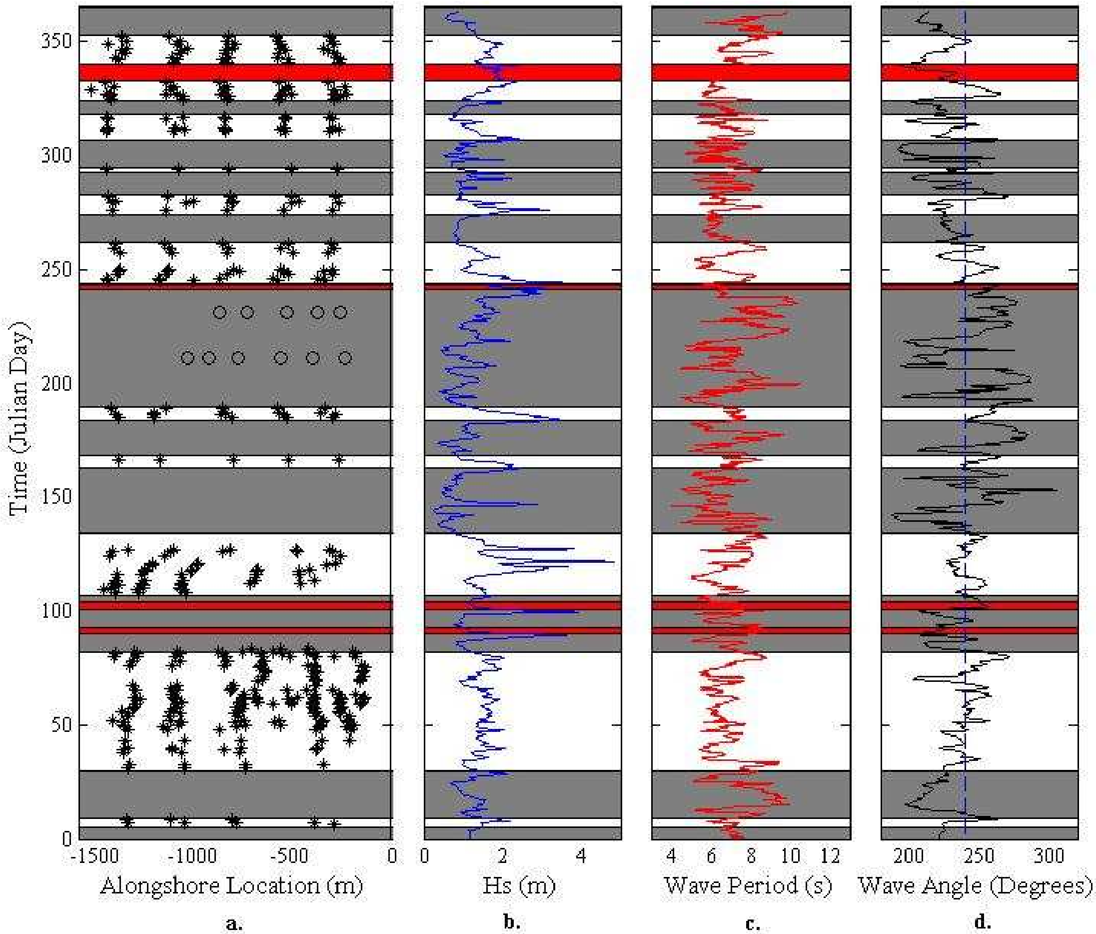


Figure 5.3. This figure shows rip channel and wave data from 2001. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low and red areas when wave energy was too high to make rip channels detectable by automatic algorithms. b. Shows significant wave height, c. The mean wave period, and d. The mean wave direction (to), where blue dashed line indicates shore-normal.

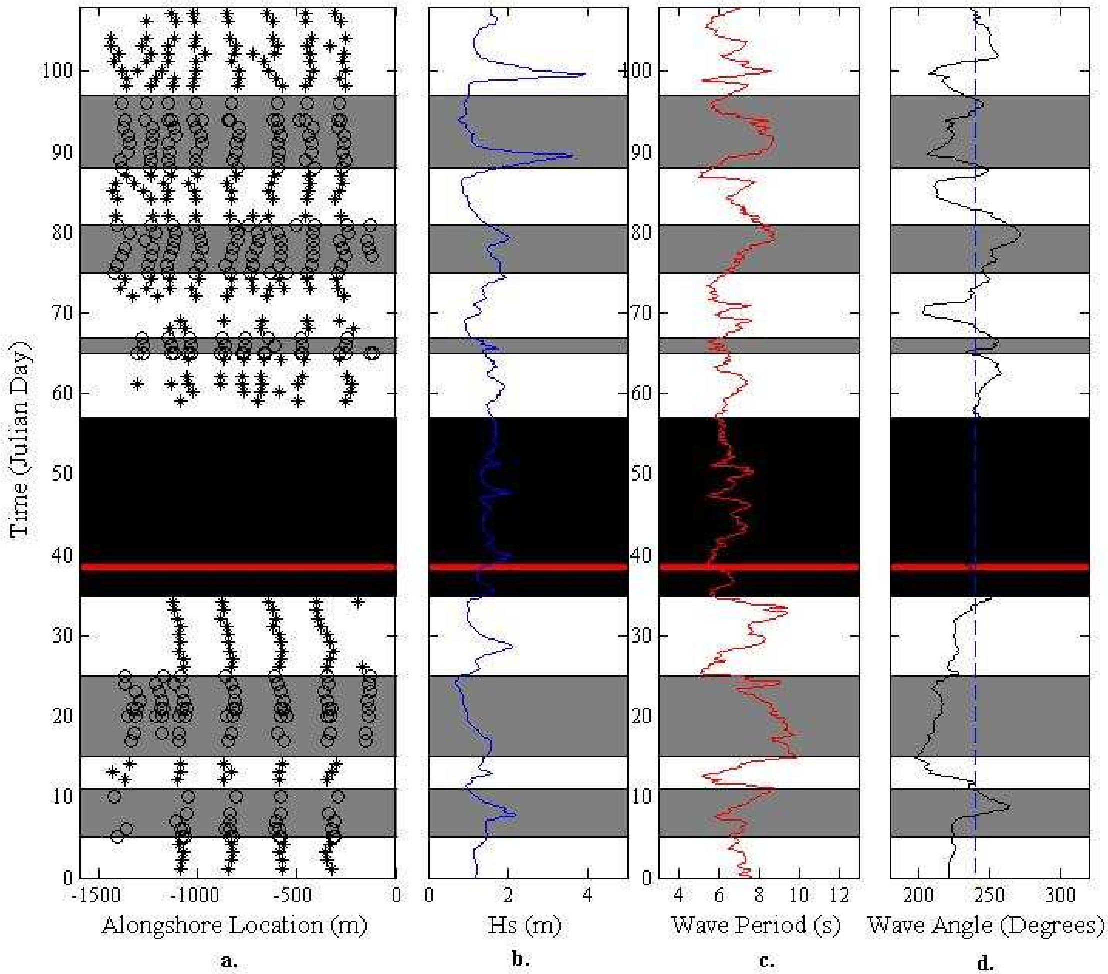


Figure 5.4. This figure shows rip channel and wave data from 2002. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low and red areas when wave energy was too high to make rip channels detectable by automatic algorithms. Black areas indicate when there were no images available due to malfunction. b. Shows significant wave height, c. The mean wave period, and d. The mean wave direction (to), where blue dashed line indicates shore-normal. Note the shortened time scale compared to others years.

5.3 Rip Current Behaviour in 1999

During 1999, the rip channel record was of a high quality with only a few relatively short periods of low wave energy when rip channels could not be seen in the images (Figure 5.6a). There was just one relatively short period when there was too much camera movement to use the images without correcting for the errors, hence these images were not included in the analysis. The mean surf-zone width for 1999 appeared to be much more stable and was less variable (Figure 5.6f) than in other years studied (see below). The surf-zone width seemed to oscillate around ~75 m reaching a maximum of ~115 m and a minimum of ~100 m. Rip migration is when rip currents move alongshore. For the first 100 days, rip channel behaviour was moderately stable with a small amount of rip migration occurring. At the beginning of 1999 there were 3–4 rip channels present (Figure 5.6e). This number increased to 6–7 starting from day ~50 until day 120. During this period when the number of rips increased to an unusually high number, although there were times when H_s was greater than 2 m (Figure 5.1b), these events were short-lived and overall wave conditions were fairly low. It is interesting to note that when the highest number of rip channels were present this corresponded to a relatively narrow surf-zone width. From the beginning of 1999 up until day 170, mean rip channel spacing was fairly stable at around 300 m (Figure 5.6c). From the beginning of 1999 up until day ~125, alongshore rip channel spacing standard deviation (std) was low at around 75 m (Figure 5.6d). This low standard deviation during this period is to be expected when comparing to Figure 5.6a which shows alongshore rip channel locations were regular and stable with time. Rip channel angle is defined as the orientation of the rip currents relative to shore-normal. The mean rip channel angle from the beginning of 1999 up until around day 100 was near to zero (or at least oscillated around zero) (Figure 5.6b) i.e. normal to the shore. During this period, little rip migration occurred.

From around day 100, the rip channel pattern appeared to change fairly abruptly to become less regular, with rip channels changing much more with time. This led to a rapid decrease in the number of rip channels (Figure 5.6d). From about day 120 the number of rips oscillated around 2–5, and when compared to Figure 5.6b appeared to correspond to a high wave energy event at day ~100. It appeared that this high wave energy event caused the rips from alongshore locations -1000–-500 to disappear, while rips at the sides (i.e. at the headlands) of the beach remained (also causing an increase in mean rip channel spacing). This alludes to the role of the headlands, to be explained in further detail further in the text. From day 100 up until day 200, rip channel angle went sharply negative, likely due to the dominant role of the northern headland rips during this period when there were less rips in the middle of the beach (explored further later in the text). Rip angle then trended upward until new rip currents appeared in the centre of the beach around day 200, when the mean rip channel angle went back to shore-normal (zero). Between days 125 and 200, spacing std rapidly increased to a maximum of greater than 375 m, this was consistent with an increase in the mean rip spacing (Figure 5.6c), irregular/ unstable alongshore rip channel locations (Figure 5.6a), an increase in mean rip channel angle (Figure 5.6h) and in H_s (Figure 5.1b).

For the remainder of 1999, the number of rip channels present was highly variable. From day 200 up until the end of 1999, mean rip channel angle appeared to oscillate around zero. From approximately day 220, two new rips formed in the space (alongshore trough) created by the high energy event. Figure 5.6a shows that between days 200 and 280 the six rip channels migrated towards the south (i.e. heading towards a more positive alongshore location), which was not reflected well in the mean rip channel angle as the mean rip channel angle was more southerly than northerly (Figure 5.6b). From day 200 until the end of the year, mean rip channel spacing oscillated around 300 m like it did at the beginning of the year. However, this time the spacing was more variable. After day 200 spacing std varied with a maximum of ~188 m. Figure 5.6a shows that this was a time when rip channel behaviour and spacing was irregular and changed rapidly with time. Rip channels were constantly splitting and merging.

From around day 300, the rip channel pattern became more stable. It appeared that the beach behaved as two separate systems, where there were three relatively small, closely spaced rip channels at the northern end of the beach and three relatively large, widely spaced rip channels at the southern end (Figure 5.5). Note that the two rip channels at alongshore locations -800 and -400 (Figure 5.5) were fed by very significant feeder channels.

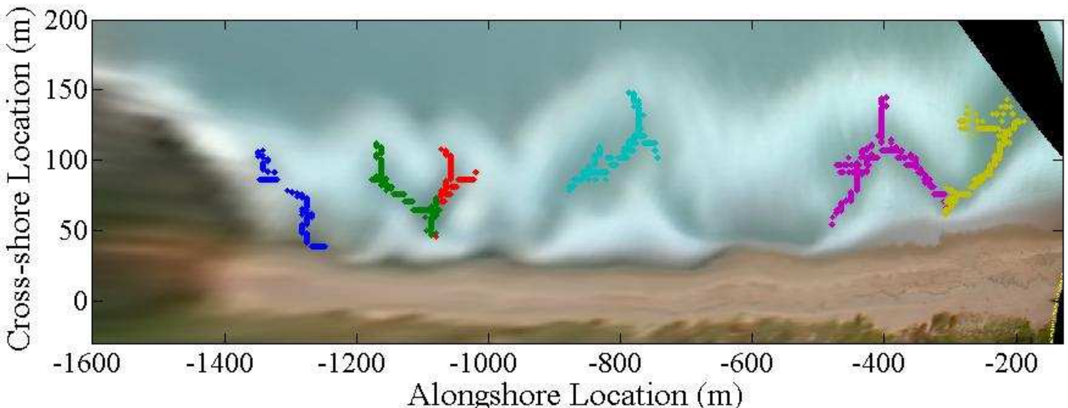


Figure 5.5. Rectified, time-averaged image of Tairua Beach from Julian Day 331 at 1601 hours in 1999. Different coloured dots show separate rip channels.

In summary, 1999 was a period of high variability with the alongshore rip channel configuration varying greatly. The beginning of 1999 was a fairly stable period of time, where from day 100 rip channel behaviour became unstable. There was a substantial amount of short, sharp wave events (Figure 5.1b) which were not detected in surf-zone width data.

5.4 Rip Current Behaviour in 2000

The rip channel record for the year 2000 was patchy with long periods of no data (Figure 5.7a) which does not allow a good record of rip channel parameters. This lack of data was mostly due to unusually long and frequent periods of low wave energy which meant that rip channels were not visible in the video images due to a lack of breaking waves. Spacing std and mean rip channel angle cannot be commented on with certainty due to the patchy rip channel record (Figure 5.7b and 5.7h).

In the beginning of year 2000 it appeared that the northern system of rip channels that were evident during much of 1999, containing three rip channels, had disappeared, while the southern system remained. The presence of the three rips on the southern half of the beach was associated with more a more positive mean rip channel angle. Mean rip channel spacing appeared to vary around ~300 m (Figure 5.7c). It appeared that from approximately day 40 (using relic rip information), the rip channels migrated towards the north. From around day 70 there was a poor record, although it appeared that the rip channel locations, spacing and behaviour were relatively unstable. For the first half of 2000, mean surf-zone width was narrow at ~50 m up until day 100 when it began to increase to a maximum width of approximately 150 m on day 200 (Figure 5.7d). For the remainder of 2000 mean surf-zone width was fairly stable at around 125 m. The time of maximum surf-zone width occurred near the end of a high energy wave event (Figure 5.2b) which was also reflected in a wide surf-zone (Figure 5.7f). From day 165 when there was a good record until just after day 100, it is clear that rip channel behaviour was erratic, with a constantly changing, irregular alongshore spacing. This period of irregular, rapidly changing rip channels was also marked by consistently higher than usual H_s (Figure 5.2b). In particular, days 170–200 had sustained unusually high wave heights. The record for the remainder of the year was almost non-existent up until day 300 when it appeared that there were three evenly spaced rip channels at the northern end of the beach. The presence of three rip channels on the northern half of the beach (opposite to the beginning of 2002) corresponded to a more negative mean rip channel angle.

In summary, the 2000 rip channel record was of a poor quality due to an unusual amount of low wave energy. Rip channel behaviour appeared to be quite variable in 2000, with one very large storm event where H_s reached almost 5 m that caused a large amount of change in rip channel configurations.

5.5 Rip Current Behaviour in 2001

The rip channel record for 2001 was of a relatively high quality, however, there was a fairly long gap during the middle of the year when there was little data due to low wave conditions. For the beginning of 2001 up until day ~125, the number of rip channels present was variable reaching a maximum of 8 rip channels at any one time (Figure 5.8e). The maximum number of rip channels for 2001 occurred after a period of low wave energy at the beginning of the year (Figure 5.8g) when there was stable rip channel spacing (Figure 5.8c and 5.8d). Until day ~90 rip channel behaviour was moderately stable with 5–6 channels present and a small amount of rip migration occurring (Figure 5.8a). From the beginning of 2001 up until day 110, the mean surf-zone width varied around 100 m. From days 60 to 90 small amounts of rip channel migration occurred in different directions (Figure 5.8a). This migration appeared to be reflected in the mean rip channel angle which oscillated in different directions (Figure 5.8b). However, on day 120 when there was also significant rip channel migration, there appeared to be no signature in the mean rip channel angle. From the beginning of 2001 until approximately day 130, mean rip channel spacing was variable with a large spike present at day ~115 (Figure 5.8c). This spike was consistent with observations from Figure 5.8a when it appeared that 2–3 rip channels disappeared sometime after day 80. This loss of rip channels caused the mean rip spacing to increase. Spacing std during 2001 varied between ~75 and ~150 m until day ~125.

From days ~100–125 the ~6 rip channels present appeared to migrate relatively rapidly toward the south. This migration was possibly due to a high energy event as indicated by Figure 5.3b, however wave angle during this period was almost shore-normal (Figure 5.3d). Rip channel spacing spiked on day 125 when it rapidly increased to more ~600 m (Figure 5.8d). This spike in spacing std was consistent with an increase in H_s (Figure 5.3b), mean rip channel spacing (Figure 5.8c) and mean surf-zone width (Figure 5.8f).

The rip channel record was poor from days 130 to 250. However, during this period it appeared that the five rip channels present prior to this gap in the record did not change much in their alongshore positions, as we would expect during low wave conditions. From day ~150 the rip channels were extremely stable with little or no migration occurring. Mean rip channel spacing was remarkably stable at ~300 m for the remainder of 2001 (Figure 5.8d) as was spacing std at just ~75 m (Figure 5.8e). Mean surf-zone width increased to a maximum of ~150 m on day 180 (Figure 5.8f). This peak in mean surf-zone width occurred after a series of events when H_s was greater than 3 m (Figure 5.3b). After the peak in surf-zone width, mean surf-zone width slowly decreased to just below 100 m by the end of 2001 (Figure 5.8f). This decrease in surf-zone width was consistent with Figure 5.3b which shows there was no H_s greater than ~3 m during this period.

On days ~240–250 it appeared that there was an event when the five rip channels present migrated towards the south. During this short period of migration waves were heading towards shore-normal, and more towards the north with time. From day 250 until the end of the year, rip channel behaviour was extremely stable with regular spacing and little/ no migration. During this stable period mean rip channel angle oscillated around zero as expected.

In summary, rip channel behaviour in 2001 was relatively stable compared to other years. Rip channels were relatively regularly spaced alongshore and stable in their alongshore locations. This stability was reflected in stable mean rip angle, spacing, spacing std, number of rips and surf-zone width.

5.6 Rip Current Behaviour in 2002

For the period of 2002 analysed (up until day 107), the rip channel record was of a high quality, with a gap of about 20 days when no video images were available, and several short periods when there was low wave energy. It was largely possible to fill in the low wave energy periods with relic rip information (Figure 5.9a). In the beginning of 2002 it appeared that the northern-most rip channel that was present at the end of 2001 had disappeared (Figure 5.9a).

Four evenly spaced channels remained with little rip migration occurring up until at least day 36 (after which there was no rip channel data until day 57). During 2002, there appeared to be two modes of mean rip channel spacing. From the beginning of the year until at least day 36 rip channel spacing appeared to be regular alongshore (Figure 5.9a). This regular rip spacing was reflected in Figure 5.9c which shows that mean rip channel spacing was fairly constant at ~300 m. From the beginning of 2002 until at least day 36, mean rip channel spacing std was low at ~38 m (Figure 5.9d) and mean rip channel angle was generally negative reaching a maximum of ~25 degrees (Figure 5.9b). At the beginning of 2002, the mean surf-zone width was approximately 75 m (Figure 5.9f), after which it decreased to a minimum of 50 m on day 60.

From approximately day 60 there was a shift in the rip channel behaviour (Figure 5.9a), including a shift in the mode of mean rip channel spacing and a change in angle from negative to almost 50 degrees (easterly). From day 60, the number of rips was variable and appeared to gradually increase. Figure 5.9a shows that rip channels were substantially more closely spaced than at the beginning of the year. Figure 5.9d shows that mean rip channel spacing was relatively variable from days 60–75. On day 60 spacing std increased to almost 150 m. Spacing std reached a maximum and was most variable at the time when there appeared to be a shift in the mean rip channel spacing (Figure 5.9c) (between days 60–70). Figure 5.9a also shows that rip channel spacing and behaviour were variable between days 60–70, and became fairly stable at ~180 m after day ~70. Rip channels appeared to become more regularly spaced alongshore from approximately day 75. Rip channel angle decreased to almost zero at day 70, where it remained until the end of the period analysed for 2002 (day 107). From day 75, there appeared to be 8 stable rip channels with stable rip channel spacing (180 m) and spacing std (Figure 5.9c and 5.9d).

Mean surf-zone width increased (from day 60) to a maximum of ~90 m just before day 100. The number of rips was fairly stable at approximately 7 rips from day 75 to 107 (the end of the period analysed). From about day 100 it appeared that there was an unusually high amount of rip channel splitting occurring. However, from close examination of the original video imagery there was no evidence of splitting occurring. The ends of the rips were moving around substantially during this period to give the appearance of splitting. This shows how critical it was to compare algorithm rip channel location results to video imagery before drawing final conclusions about rip channel behaviour that appears to be unusual.

In summary, rip channel behaviour in 2002 was fairly stable, as was observed in 2001. However, there appeared to be a shift in the overall behaviour of the system, where mean rip channel spacing decreased and there was an increase in the number of rip channels. This shift appeared to occur during relatively low (<2 m) H_s.

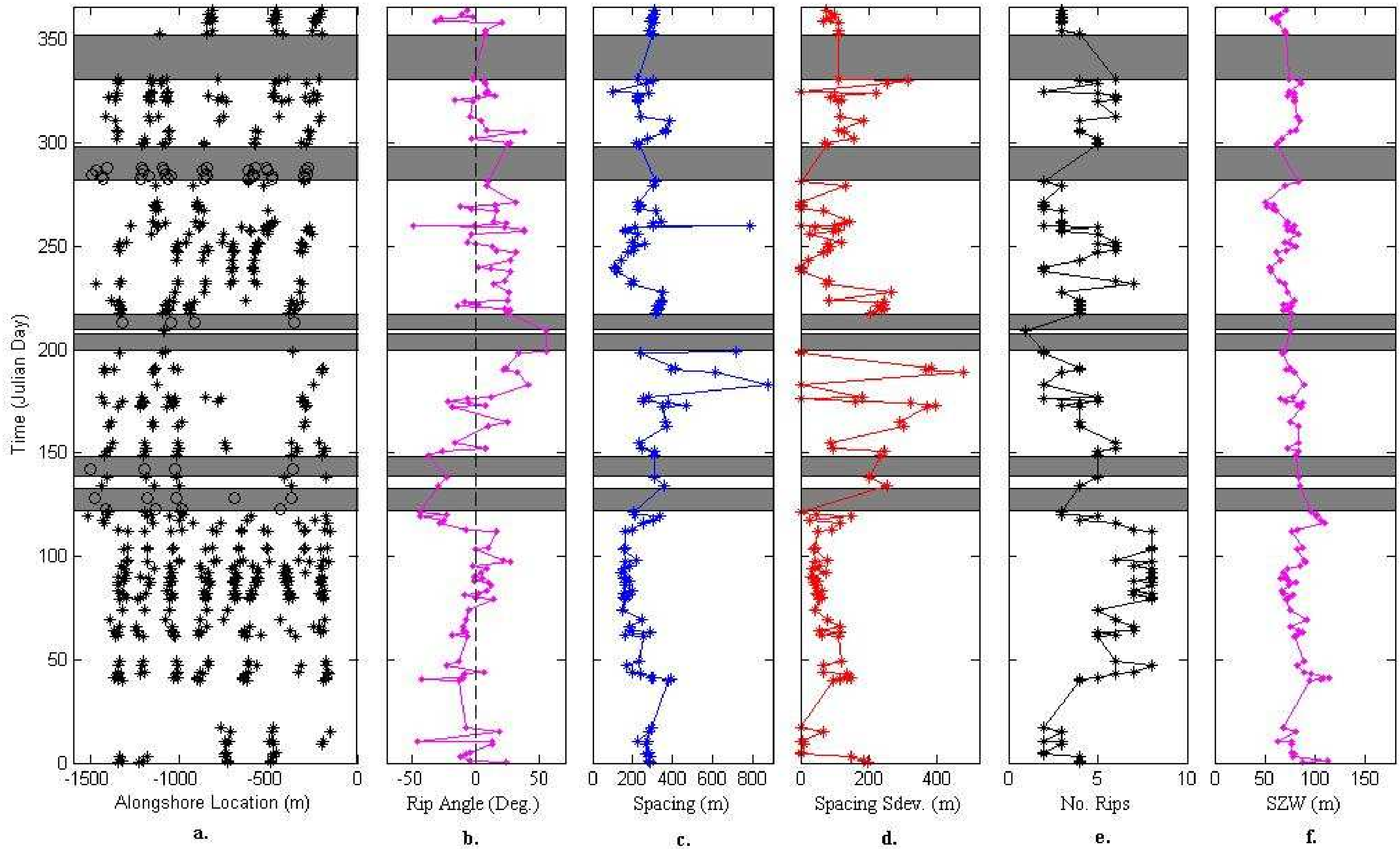


Figure 5.6. This figure shows rip channel and wave data for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms. b. Shows the mean rip channel angle where dashed line indicate shore-normal, c. The mean rip channel spacing, d. Rip channel spacing standard deviation, e. The number of rips per image, and f. The mean surf-zone width.

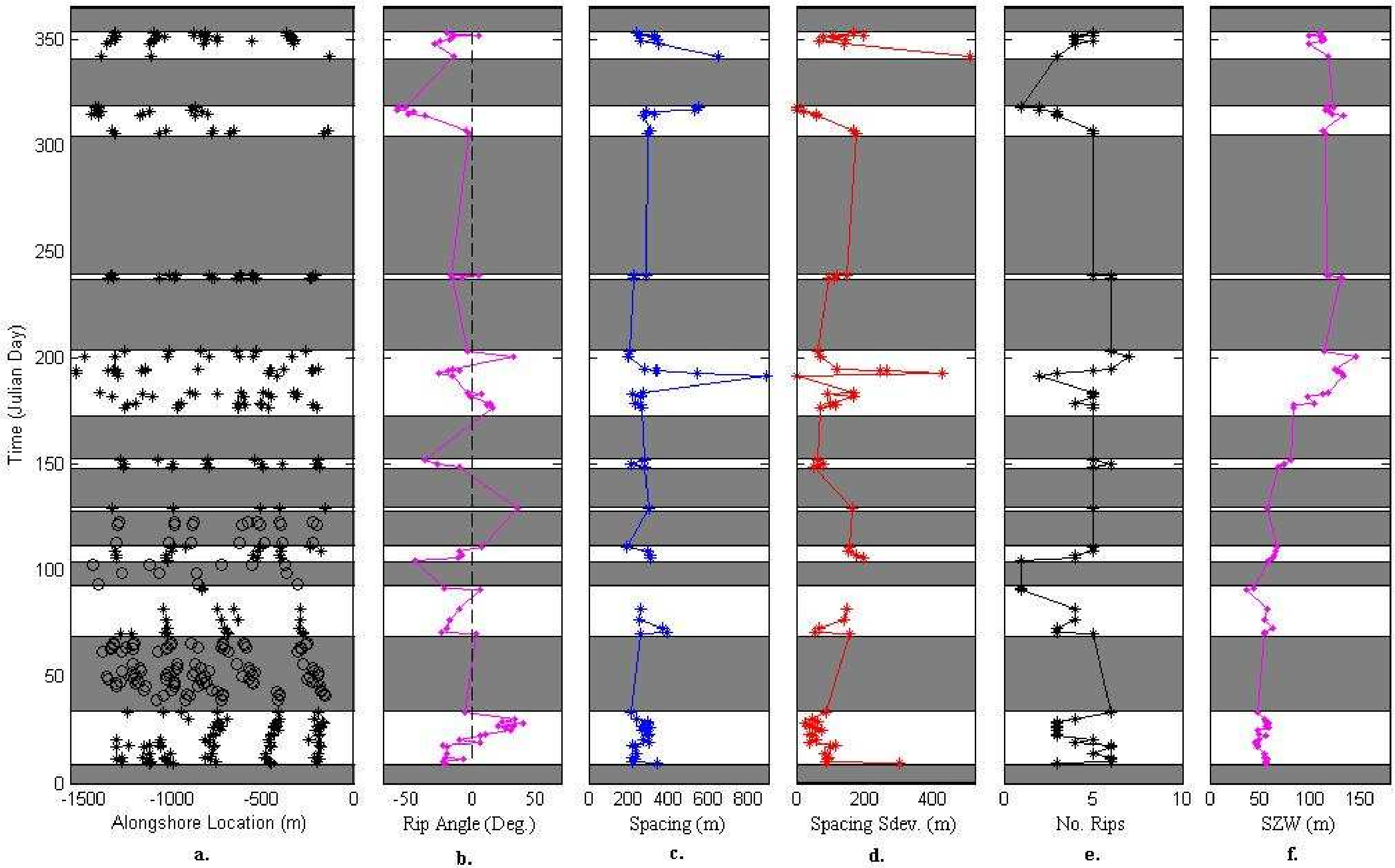


Figure 5.7. This figure shows rip channel and wave data for 2000. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms. b. Shows the mean rip channel angle where dashed line indicate shore-normal, c. The mean rip channel spacing, d. Rip channel spacing standard deviation, e. The number of rips per image, and f. The mean surf-zone width.

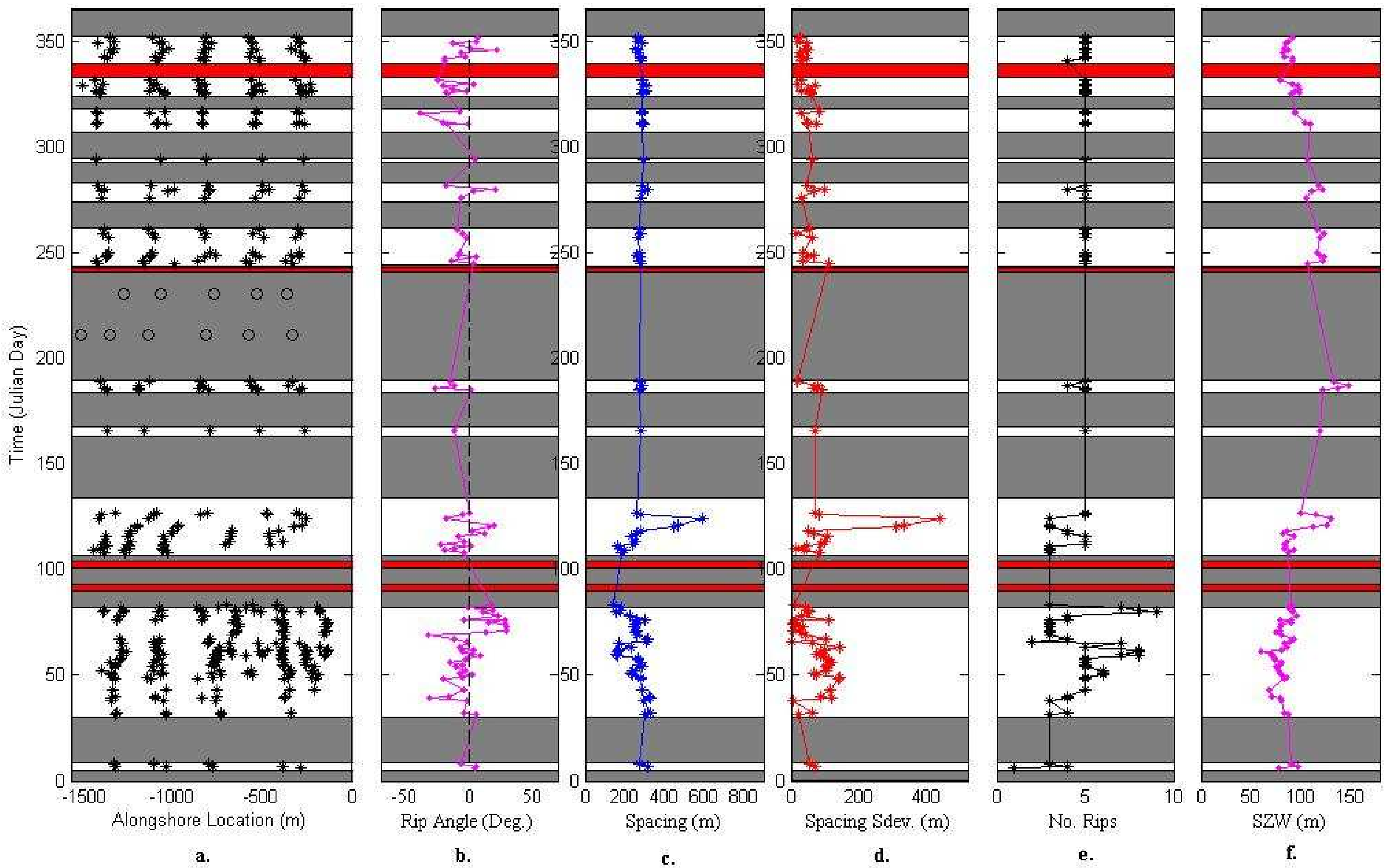


Figure 5.8. This figure shows rip channel and wave data for 2001. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and red areas when wave energy was too high to make rip channels to be detectable by automatic algorithms. b. Shows the mean rip channel angle where dashed line indicate shore-normal, c. The mean rip channel spacing, d. Rip channel spacing standard deviation, e. The number of rips per image, and f. The mean surf-zone width.

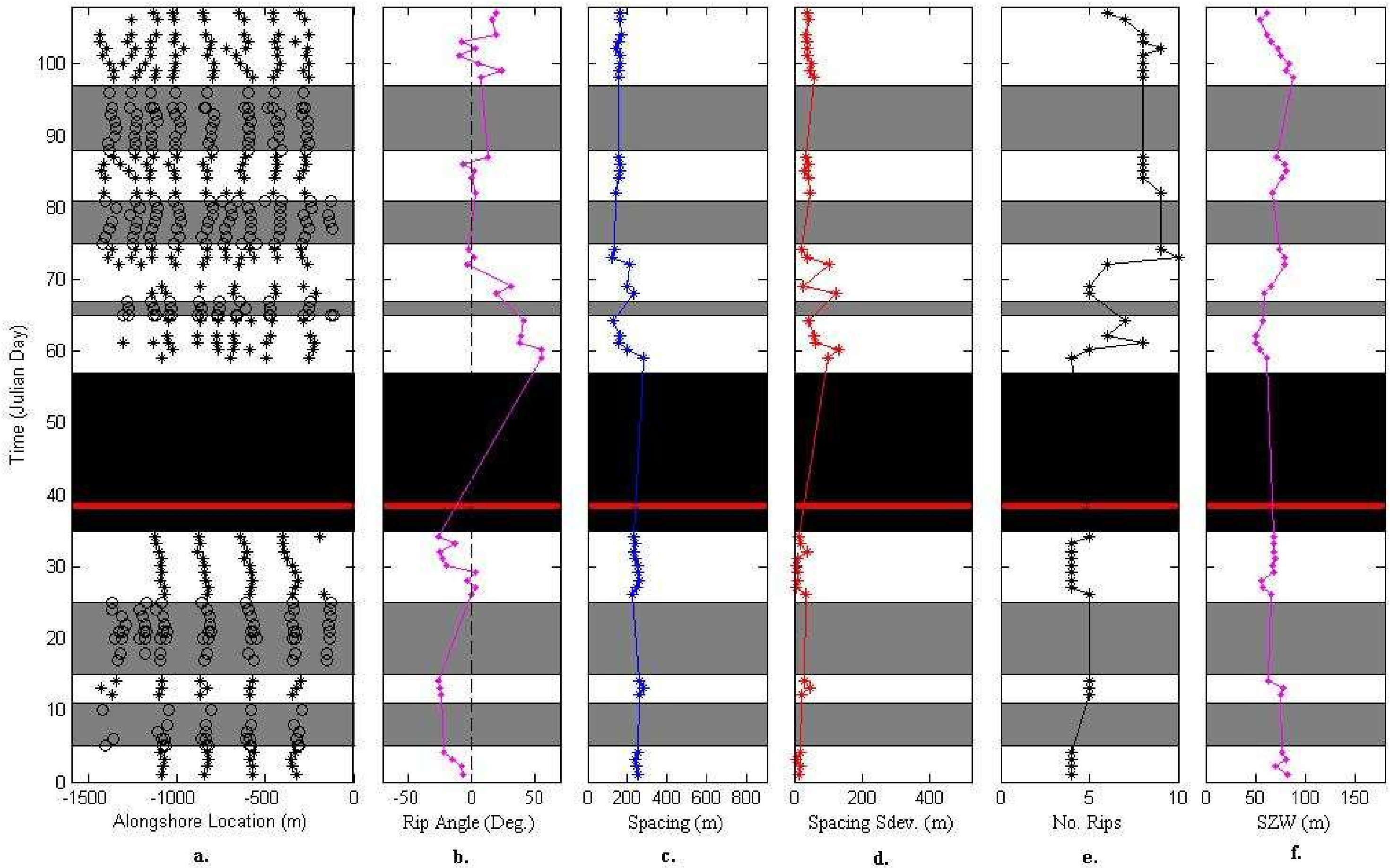


Figure 5.9. This figure shows rip channel and wave data for 2002. Stars in panel a. show the alongshore location of rip channels found by the algorithms while circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and red areas when wave energy was too high to allow rip channels to be detectable by automatic algorithms. Black areas indicate camera malfunction. b. Shows the mean rip channel angle where dashed line indicate shore-normal, c. The mean rip channel spacing, d. Rip channel spacing standard deviation, e. The number of rips per image, and f. The mean surf-zone width.

5.7 Rip Current Parameter Correlations

Past attempts to compare rip channel parameters to immediate/instantaneous measures of the wave conditions have resulted in poor correlations (Ranasinghe et al., 2000; Holman et al., 2006; Turner et al., 2007), with the same results found in this thesis. Many different correlations were attempted, pairing various rip channel parameters to each other and to the wave conditions. Figure 5.10 shows a selection several different correlations undertaken in this analysis. Note that in Figure 5.10e, rip spacing factor was used in an attempt to isolate rip channels as separate groups. Somewhat obviously, the number of rip channels present correlates well to mean rip channel spacing (Figure 5.10a). This good correlation is to be expected as when rip spacing is wider there is less room for rips so there will be fewer. Figure 5.10b shows that there was a poor correlation between the number of rips present and H_s. However, it appeared that when Hs was low, the number of rips was highly variable and vice versa. Figure 5.10c shows that there was also a poor correlation between H_s and mean rip channel spacing. However, it can be seen that mean rip channel spacing was almost always between 300–600 m. Figure 5.10b shows that the number of rips and the mean surf-zone width were poorly correlated, although it appears that there are perhaps two groups. These two groups may be simply due to sampling a period of time that was too short to include the full range of wave and rip conditions, particularly since small waves hampered rip detection. Also, if rip channels extend far offshore, and the alongshore bar is far offshore, lots of rips will be detected for the same wave conditions than if the bar is closer, because offshore bars tend to be deeper. Figure 5.10e shows that there was a poor correlation between mean rip channel spacing and mean surf-zone width, although fairly distinct groups of each year can be seen. Figure 5.10f shows that mean surf-zone width and mean rip channel spacing show a similar relationship to as shown in Figure 5.10c, as is to be expected.

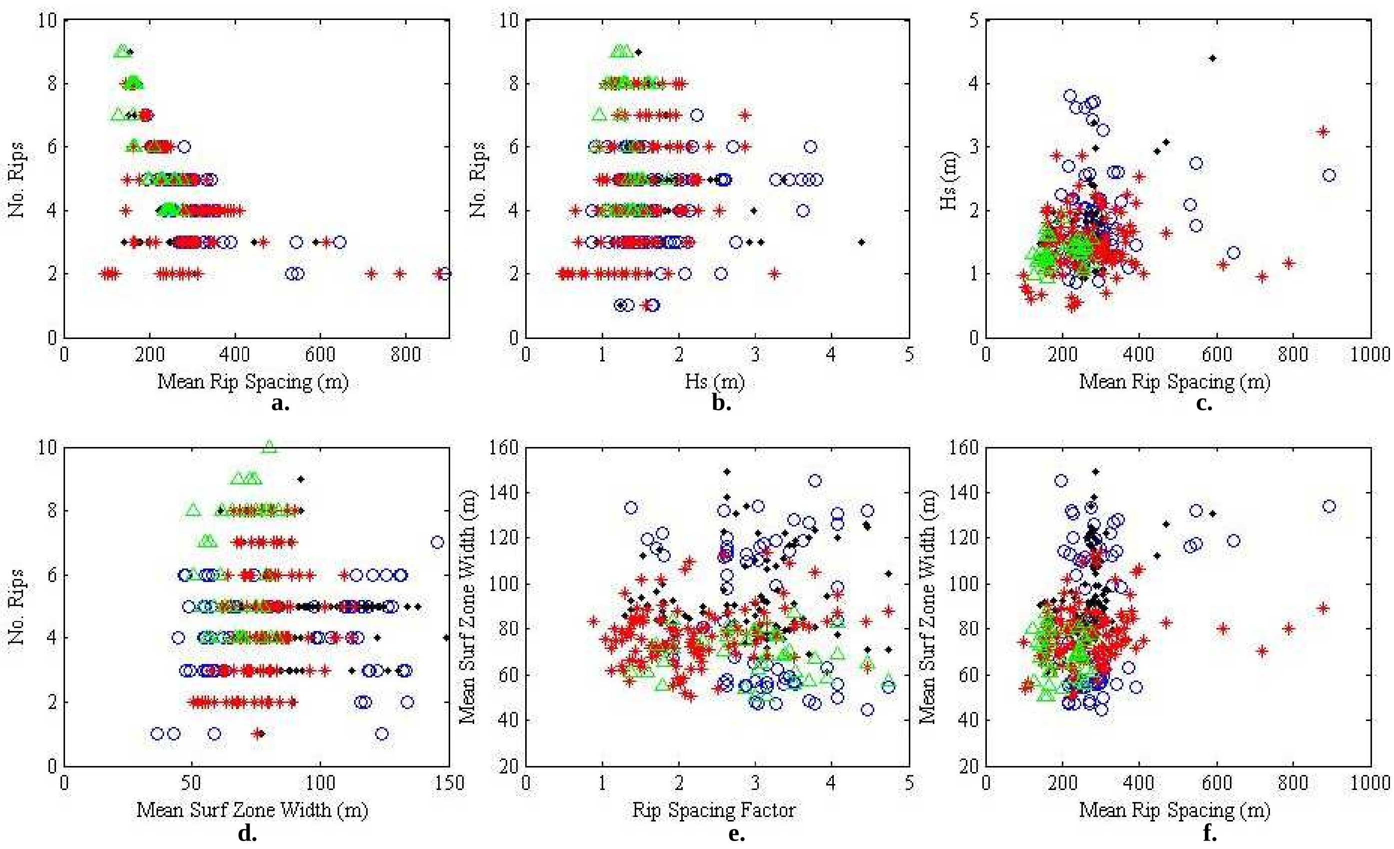


Figure 5.10. This figure shows rip and wave data from the entire period studied: 1999–April 2002. Red stars indicate data from 1999, blue circles from 2000, black dots from 2001 and green triangles from 2002. Panel a. shows a scatter plot of the number of rips and mean rip channel spacing, b. The number of rips and significant wave height, c. Significant wave height and mean rip channel spacing, d. Mean surf-zone width and number of rips, e. Rip spacing factor (mean alongshore rip spacing divided by mean surf-zone width) and mean surf-zone width, and f. Mean surf-zone width and mean rip channel spacing.

5.8 Headland Rip Currents

There has been suggestion in literature (e.g. Short, 1985) that rip channels can be persistent near headlands. Observations of video imagery of Tairua Beach appeared to show that there are often rips at the headlands that are persistent and resilient to changes in the wave conditions. Often these headland rips were larger than other rips along the beach. In an attempt to show the persistence, and perhaps to give an indication of the cause of these headlands rips, Figures 5.11 to 5.13 were created. Figure 5.11 shows that for alongshore rip channel locations between ~-1600 to ~-1200 m (near the northern headland), rip channel angles tended to be highly negative (i.e. orientated more northerly). Figure 5.11 also shows that for alongshore rip channel locations of near to 0 m (near the southern headland), the rips tended to have a positive angle (orientated more easterly) than rips at the northern end of the beach. The clustering of angles at the southern end of the beach may not be as distinctive as at the northern end because this is where the camera is located. The area directly below the camera (near the southern headland) is outside of the field of view. During the creation of the rip channel data-set, it appeared that there were often rip channels present at the southern-most end of the beach but they could not be included in the data-set as the corresponding perturbation in the barline (and/ or shoreline) was outside the field of view of the camera (section 4.6, rule 5).

In order to better understand preferred location of rip currents, a histogram was created using 200 m alongshore bins (Figure 5.12). It appears that there is a preference for rips to form with mean alongshore locations of approximately -900 (A), -750 (B) and -550 (C) m alongshore, while the remainder of the surf-zone (D) (the more southerly end) did not appear to have any alongshore locations preferred by rips (keeping in mind that the southern-most rips were often outside the field of view of the camera). Figure 5.12 indicates that areas A, B and C appear to be separated by approximately 200 m in the alongshore. Therefore, bins to create a Tukey plot (Figure 5.13) were chosen to be 200 m wide alongshore. Figure 5.13 supports observations made of Figure 5.11 indicating that rip channels at the northern end of the beach tend to have a more northerly angle and the rips at the southern end a more easterly angle.

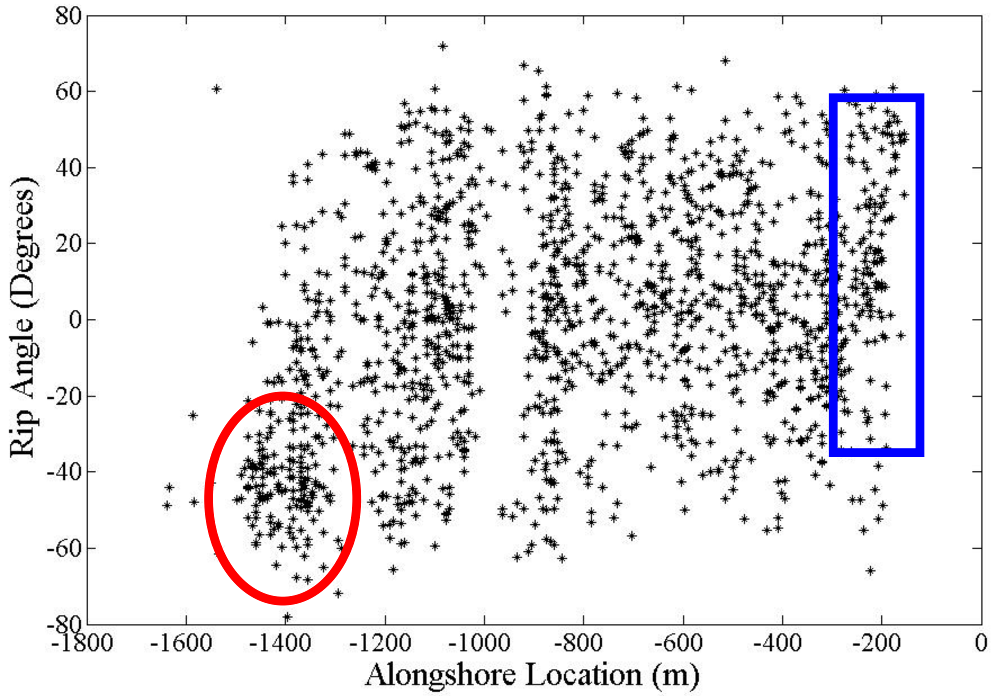


Figure 5.11. Alongshore rip channel locations and rip channel angle for every rip channel located (i.e. not mean values) from 1999–April 2002. Rips enclosed by the red circle are those that appear to correspond to northern headland rips and rips enclosed by the blue square appear to correspond to southern headland rip(s).

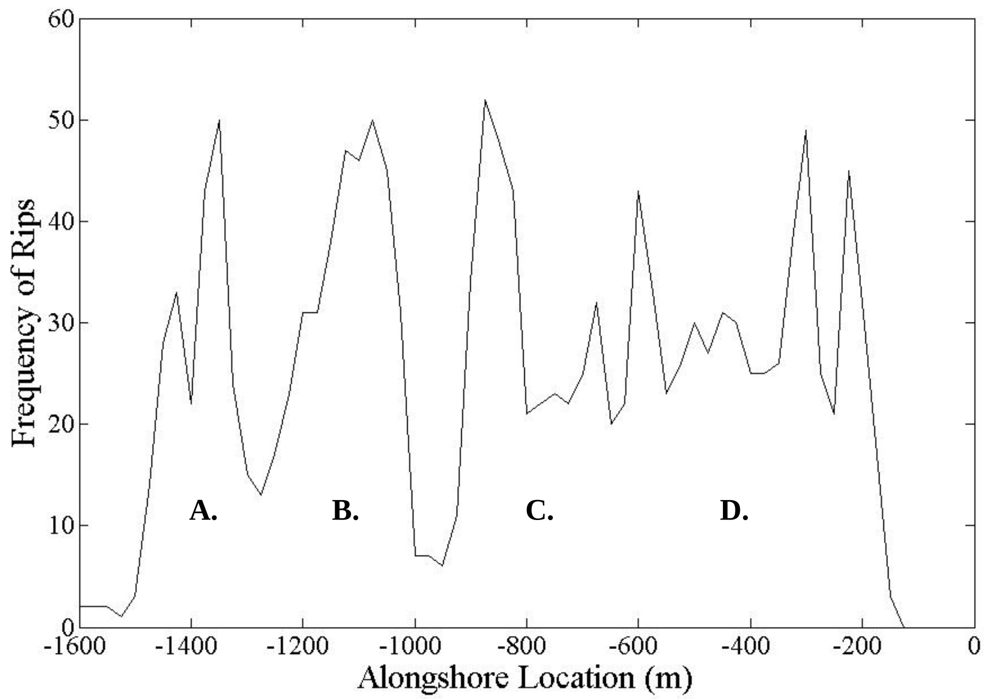


Figure 5.12. Alongshore rip channel locations and rip channel angle for every rip channel located (i.e. not mean values) from 1999–April 2002. A, B, C and D indicate separate rip channel areas referred to in the text above.

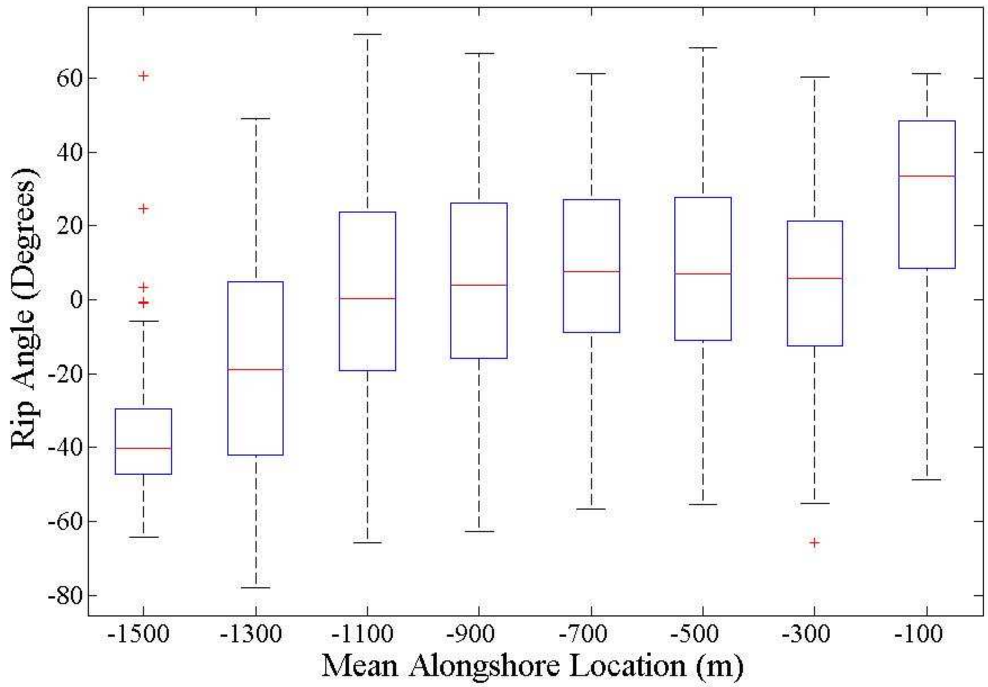


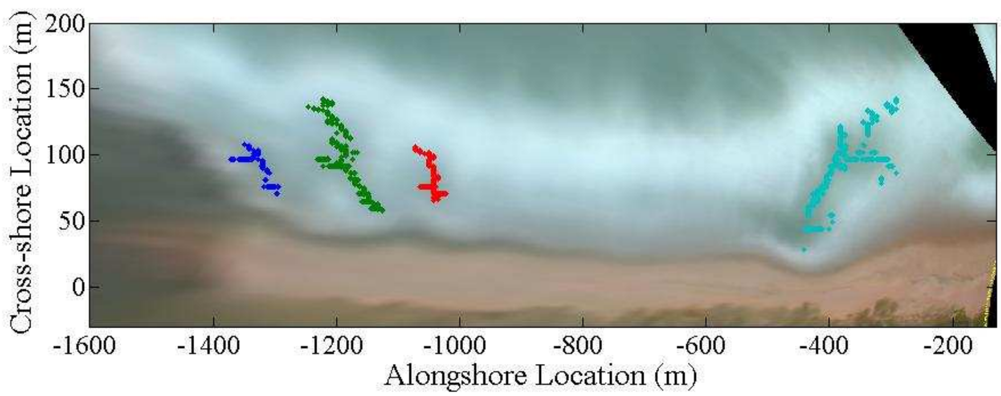
Figure 5.13. Tukey plot of alongshore rip channel locations and rip channel angle for every rip channel located (i.e. not mean values) from 1999–April 2002.

5.9 Discussion of Key Points

5.9.1 Rip Current Angle and Headlands

Sometimes mean rip channel angle was not consistent with the direction of rip migration shown in Figures 5.6a–5.9a. The mean rip channel angle appeared to change more over time when rip channel spacing in Figures 5.6a–5.9a appeared to be irregular alongshore and with time, which was generally during storm events. Overall rip channel angle appeared to reach a minimum angle of ~50 degrees and a maximum of ~50 degrees (where zero degrees was normal to the beach). There were times when the mean rip channel angle did and did not appear to reflect the direction of channel migration suggested in Figures 5.6a–5.9a. For example, in the beginning of 1999 when there appeared to be almost no rip channel migration occurring, the mean rip channel angle was consistent at ~0 degrees. Between days 200 and 280 in 1999, rip channels were migrating towards the south, while mean rip channel angle oscillated between ± 20 degrees. We might have expected the mean rip channel angle to become more positive (between 0 and perhaps 45 degrees) if the rip channels were migrating towards the south. During 2001 from days ~105 to ~125 rips were strongly migrating towards the south. During this period mean rip channel angle oscillated from ~-40 degrees to ~25 degrees. From observing how strongly the migration was towards the south, we might have expected that rip channel angle to have been more strongly positive.

The apparent poor relationship between mean rip channel angle and the direction of rip channel migration does not necessarily mean that there is no good relationship present. As mentioned earlier in Section 4.5, step 6, mean rip channel angle for each image was found by fitting a line to each rip channel and then taking the mean of the line slopes for all the rips in each image. This gave a single value for mean rip channel angle per image. Rip channel angle is extremely variable in each image. First of all, the use of a line to approximate rip channel angle introduces an error. Also, in many images, rip channels at the northern end of the beach were orientated more towards the north east while channels at the southern end of the beach were orientated more towards the south east, for example as shown in Figure 5.14.



5.14. Rectified, time-averaged image of Tairua Beach from Julian Day 172 at 0800 hours in 1999. Different coloured dots show separate rip channels.

When the beach was dominated by headland rips, the mean rip channel angle was also dominated by the direction of these rips. For example, in 1999 and 2002, when the northern headland rips dominated the system, the mean rip channel angle was strongly negative. Conversely in 2002, when southern headland rips dominated the system, the mean rip channel angle became strongly positive. The high amount of variability in the orientation of individual rip channels and the effect of headland rips on mean rip channel angle means that mean rip channel angle does not appear to be an appropriate way to summarise rip channel angle.

Further research is required to study rip channel angle and how it relates to other rip channel parameters such as direction of migration and migration rate.

5.9.2 Rip Current Migration

Short (1985) mentioned that migration of rips can occur from two different processes: (1) from shore-normal waves; and (2) from oblique waves. During oblique waves, the directionality of the waves can force the rip channels to move, where generally the rip channels along the beach will all move in the same direction. During shore-normal waves, rip migration can occur if rip spacing increases where rips may shift away from each other with no direction preferred. As mentioned previously, sometimes mean rip channel angle did not appear to correlate well with the direction of rip channel migration. For example, during 2001 there were two events when rip channels appeared to migrate towards the south (between days 100–125 and days 240–250, as indicated in Figure 5.8a). Figure 5.8a shows that during these migration periods, mean rip angle still oscillated around zero. During these migration events there was high H_s (Figure 5.3b) and the waves appeared to be predominantly heading towards westerly/south-westerly directions. These waves could be expected to force the rip channels southwards, as was observed. In the cases of rip channel migration mentioned, all rip channels were more-or-less moving in the same direction, hence it is likely that the migration is due to the angle of wave incidence not spreading occurring during oblique waves. During the 1999 migration event that occurred between days ~230–270, the rips appeared to be migrating southwards while the mean rip channel angle oscillated between ~-20 to 20 degrees which is not as we would expect. The maximum rate of rip migration occurred between days ~250–270 which also corresponded to the maximum H_s (~4 m) during the migration period. Wave angle during the 1999 migration event changed from south westerly to more westerly with time, which could be expected to force the rips southwards. It is important to remember, when comparing mean rip channel angle to the direction of rip channel migration, that the mean rip angle appears to be too dominated by headland effects to be an appropriate parameter.

5.9.3 Wave Height and Rip Current Behaviour

In general, when rip channel spacing changed from being regular alongshore and stable with time to irregular alongshore and unstable with time, this tended to correspond to periods of relatively high H_s. However, there were times when H_s reached relatively high magnitudes and there was no change visible in rip behaviour from regular to irregular alongshore spacing alongshore and with time. For example, near days 25 and 190 in 1999 (Figures 5.1a and 5.1b), and 170 and 240 in 2001 (Figures 5.3a and 5.3b). There were also times when there was an event of low H_s that lasted for a relatively long period of time that appeared to cause rip channels to behave irregularly, such as occurred between days 50–70 in 2001 (Figures 5.3a and 5.3b). Results suggest that there is some sort of relationship between H_s and rip channel behaviour, however comparing rip channels to instantaneous measures of H_s as is the tradition, may not be the most appropriate way to look for this relationship. Figure 5.10 shows results similar to those gained in the past when attempts have been made to correlate rip channel parameters to the wave conditions. For example, Turner et al. (2007), Ranasinghe et al. (2000) and Whyte et al. (2005) found a poor correlation between mean rip channel spacing and H_s. Ranasinghe et al. (1999) found a poor correlation between surf-zone width and rip channel spacing

Comparing instantaneous, immediate measures of H_s to rip channel measurements does not take into account the previous wave conditions. Rip channels are likely to take some time to adjust to the wave conditions (i.e. there is a lag time) and not respond instantaneously. Due to this lag time in rip channel response to waves, comparing rips to immediate, instantaneous wave conditions is not likely to give a good relationship. This comparison also does not take into account the duration of H_s over different thresholds. Significant wave height may only have an effect on rip channels if the height is great enough for a sufficient period of time. Comparing rip channel behaviour to waves may need a different approach to the traditional time-series techniques used in the past. The following Chapter (Chapter Six) explores different ways of comparing the wave climate to rip channel behaviour.

Over the period of study, there were periods when rips appeared to be spaced regularly alongshore for long periods of time, and there were also long periods of time when the spacing was irregular alongshore. As mentioned earlier, several studies have found rip spacing to be regular alongshore (Huntley and Short, 1992; Short and Brander, 1999; MacMahan et al., 2005) while others have found rip spacing to be irregular alongshore (Holman et al., 2006; Turner, 2007). In this study, it was found that rip channels can be both regularly and irregularly spaced alongshore, such as was also found by Symonds et al. (1997). It appears that the regularity of the alongshore spacing is related to the wave conditions, but it is unclear how by simply comparing immediate, instantaneous H_s to rip channel behaviour.

By comparing mean rip channel spacing to H_s for 1999, 2001 and 2002, it appeared that when there was a rapid increase in mean alongshore rip channel spacing there was also a similar increase in the rip channel spacing standard deviation. In general, increases in mean rip channel spacing appeared to correspond to increases in H_s, however the relationship does not appear to be strong. Observations by Holman et al. (2006) and Turner et al. (2007) that mean rip channel spacing showed no relationship to offshore wave conditions supports the hypothesis that after a storm reset event (i.e. the longshore-bar trough state in Wright and Short (1984)), rips may become rapidly topographically-controlled rather than the hydrodynamically-controlled.

5.9.4 Rip Current System Behaviour

Although at times it is difficult to tell with certainty, all indications are that during 1999, 2000 and 2001 rip channel systems were generally behaving in a similar manner with around 5 regularly spaced rip channels of a similar size present when the system was stable (Figures 5.6a–5.9a). In 2002 at day ~ 60 it appeared that there was a large change in the behaviour of the rip channel system (Figure 5.9a). Up until day 35 in 2002, the rip channel system appeared to be similar to most of 1999 and 2001 with four evenly spaced alongshore rip channels present (hereby referred to as a ‘widely spaced’ system) that were stable with time (Figure 5.15). From day 60 in 2002, it is apparent that the system was behaving differently.

There was twice the number of rip channels present (~8) than is usual at Tairua Beach (referred to as a ‘narrowly spaced’ system) (Figure 5.16). These rip channels were evenly spaced alongshore. It appears that in the beginning of 1999 the rip current system may also have been behaving as a narrowly spaced system, as there appeared to be ~8 rips relatively narrowly spaced rips present. When the rip channel system shifted from a narrowly spaced to a widely spaced system (or vice versa), these shifts were also associated with substantial changes in mean rip channel angle, number of rip channels, mean surf-zone width and spacing standard deviation.

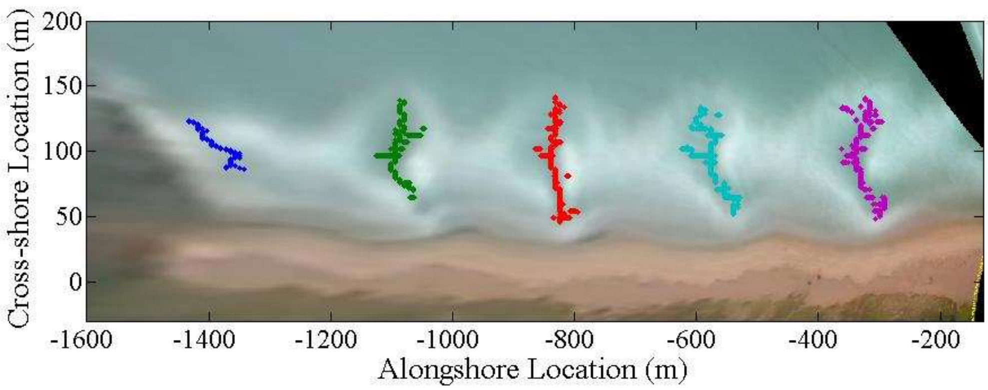


Figure 5.15. Rectified, time-averaged image of Tairua Beach from Julian Day 013 at 1300 hours in 2002. Different coloured dots show separate rip channels.

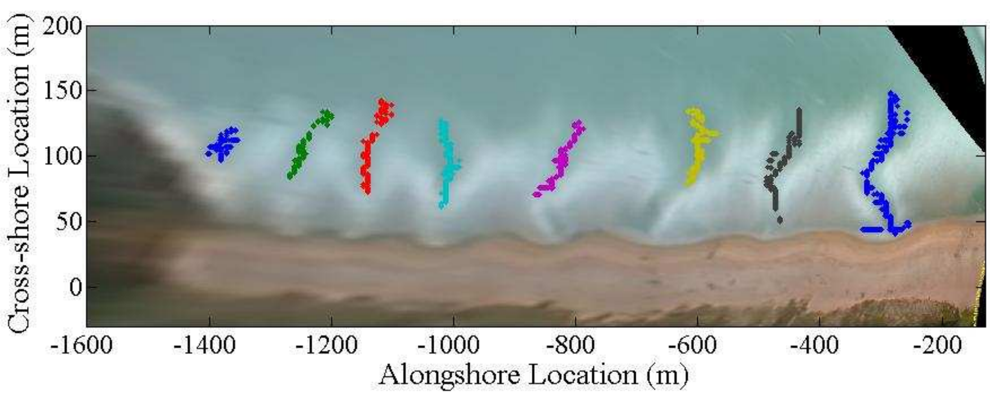


Figure 5.16. Rectified, time-averaged image of Tairua Beach from Julian Day 099 at 1100 hours in 2002. Different coloured dots show separate rip channels.

During 2002 the shift occurred on day ~60. Mean rip channel angle (Figure 5.9b) appeared to change from between 0 and -25 degrees, to between 0 and 50 degrees. Mean rip channel spacing (Figure 5.9c) was ~300 m until day 60 when it decreased to stabilise at ~150 m. Spacing standard deviation (Figure 5.9d) was between zero and 75 m until day 60 when it was ~75 m and then stabilised at about 45 m. The number of rips at any one time (Figure 5.9e) increased from ~4–5 to ~8 after day 60. The mean surf-zone width (Figure 5.9f) prior to day 60 was decreasing from 112 m at the beginning of 2002, when from day 60 it appeared to increase.

The rip channel system appeared to be narrowly spaced both at the beginning of 1999 and near the end of the 2002 period of study. However, the 1999 system did not appear to be as stable at the 2002 system. In both the 1999 and 2002 narrowly spaced systems, there were 7–8 rip channels present. Figure 5.6f shows that there was no significant change in mean surf-zone width or spacing standard deviation between the narrowly spaced and the widely spaced system in 1999, as opposed to in 2002 when the mean surf-zone width was wider during the narrowly spaced system, contrary to expectations.

In summary, at Tairua Beach there appeared to be two main types of rip channel systems: (1) a narrowly spaced system consisting of many (8) closely spaced (~200 m) rip channels; and (2) a widely spaced system consisting of fewer (~5) widely spaced (~260 m in 2000 and ~300 m in 1999) rip channels. The period prior to the 1999 narrowly spaced system is outside the scope of this thesis so it is unclear what might have caused the system to begin to behave in this manner, although this could be a topic for further research. The period in 2002 when the rip system appeared to shift from widely spaced to narrow shows that H_s was fairly stable near 2 m for 60–70 days (depending on when, during the period where no video images were available, the change occurred).

5.9.5 Dual Surf-zone

Throughout 1999, 2000 and 2001 there appeared to be periods of time when rip channels were persistent. For example, in 1999 between days ~125 and 175 the ~2–3 rips channels that were present in the middle of the beach disappeared whereas the rip channels and the ends of the beach remained (Figure 5.6a). Prior to the disappearance of these rip channels in the middle of the beach, the rips all along the beach appeared to be approximately the same size i.e. have the same seaward extent. It could have been expected that the rip channels at the ends of the beach were bigger i.e. extended further seaward so that higher energy wave conditions were required to remove the bigger rip channels at the ends of the beach. Since the rip channels appear to be of a similar size along the beach prior to the storm, perhaps the wave energy reaching the middle section of the beach was higher than the wave energy reaching the ends of the beach. Short (1985) also noted that there seemed to be a preference for rips to form adjacent to the headlands at the embayed Narrabeen Beach near Sydney, Australia while there was no preference along the rest of the beach.

At the beginning of 2001, it appeared that there were two separate surf-zones: (1) a stable system of three rips on the northern half of the beach; and (2) a smaller, rapidly evolving system at the southern end of the beach (Figure 5.17). It appeared that the rip channels in the northern system were persistent with time and did not change much. On the contrary, the southern system changed rapidly with time with rips migrating and new rips forming (Figure 5.17). In the situation shown in Figure 5.17, the wave conditions were large enough to break over the smaller southern surf-zone, but not big enough to break over the deeper, northern part of the surf-zone. This situation also occurred near the end of 1999 until the beginning of 2000, however the southern half of the beach had bigger rips than the northern half, the opposite to what occurred during 2001.

Examining wave direction during the period when the dual surf-zone appeared to have a bigger half and a smaller half appears to show some clues as to why the surf-zone at Tairua Beach may sometimes separate into two halves. A hypothesis is that large waves may arrive at such an angle that Shoe Island protects half of the surf-zone from being rearranged and then only half of the beach is affected. During the large storm event that occurred in 2000 between days ~170 and ~200, there was change in the orientation of the bar that occurred rapidly. This change in bar orientation occurred between days 184–191 (the exact date cannot be isolated due to discontinuity in the data-set). The mean wave direction was from the east between days 183–192, and H_s during this period was up to 3 m (Figure 5.18).

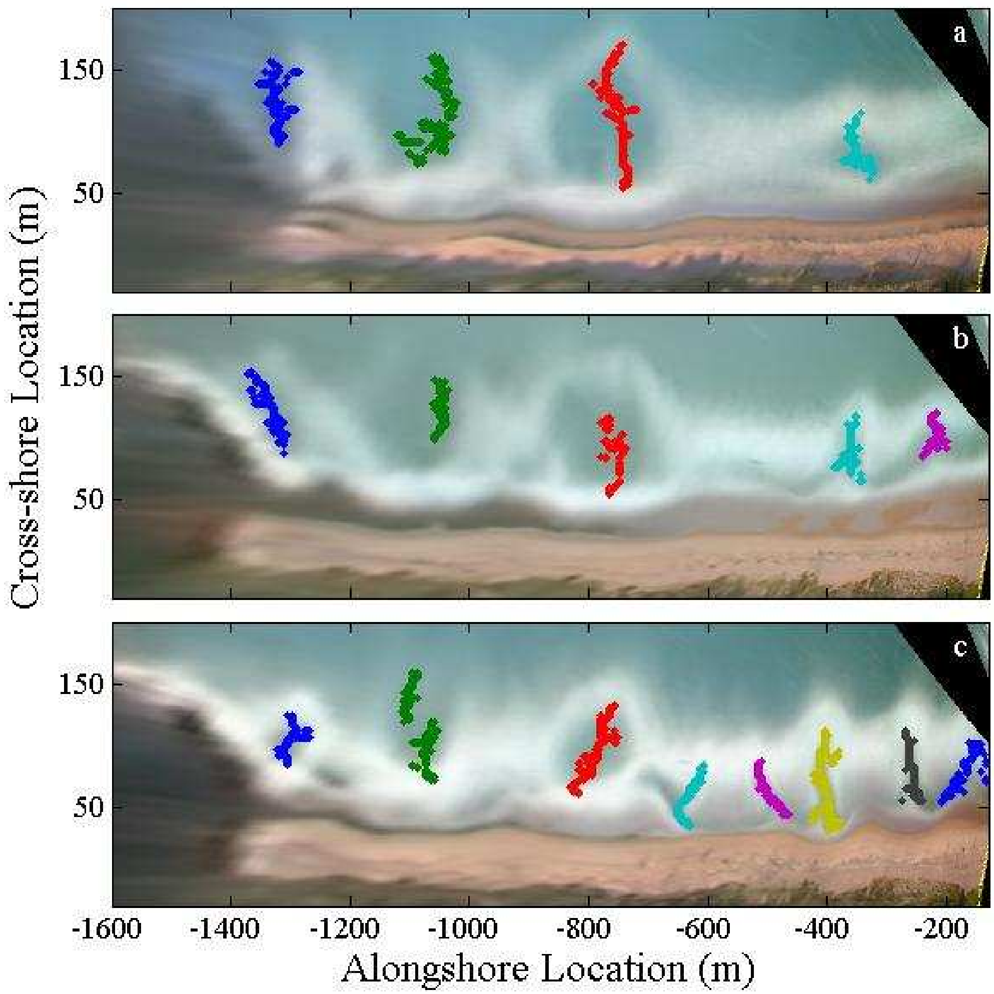


Figure 5.17. Rectified, time-averaged video images of Tairua Beach from 2001 where different coloured dots show distinct rip channels found with the computer algorithms. Panel a. shows Julian Day 32 at 1800 hours, b. Julian Day 43 at 1600 hours, and d. Julian Day 59 at 1600 hours.

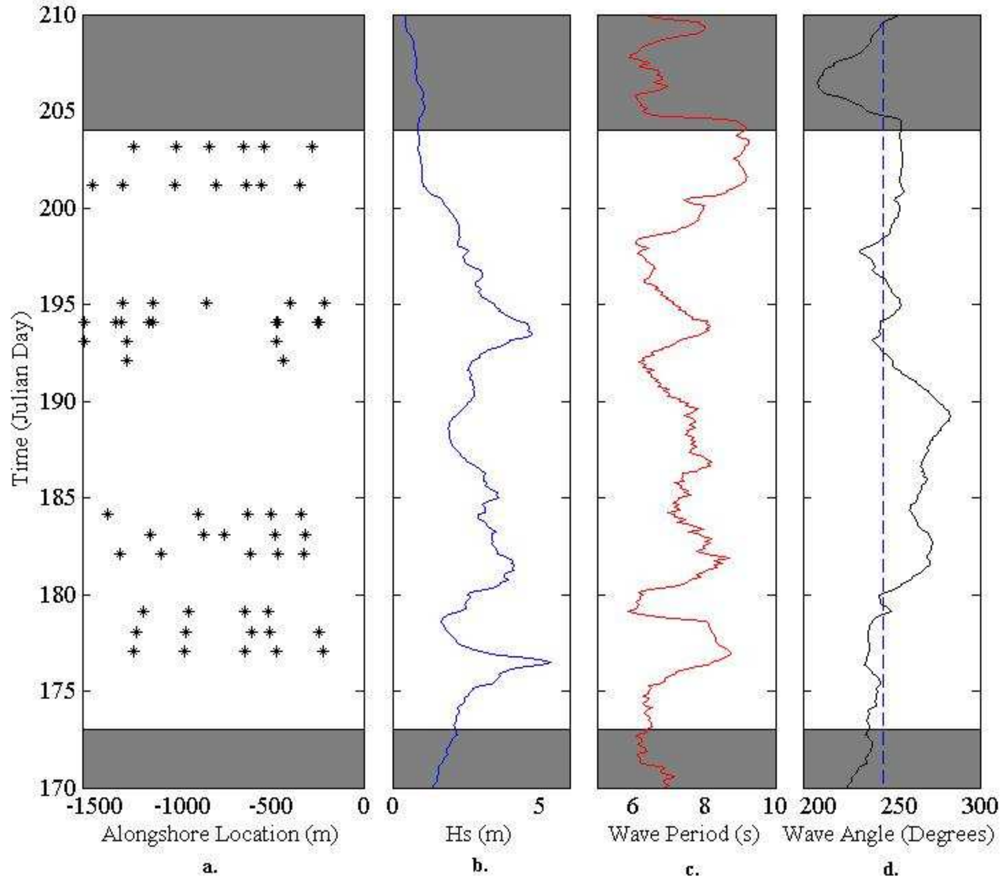


Figure 5.18. Rip channel and wave data from 2000 between Julian days 170 and 210. Stars in panel a. show the alongshore location of rip channels found by the algorithms. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms. b. Shows significant wave height, c Mean wave period, and d. Mean wave direction (to) where blue dashed line indicated shore-normal.

It appeared that perhaps the combination of a westerly wave angle and high H_s caused the bar orientation to change. Figures 5.19 and 5.20 show that when waves are coming from the west, the northern half of the beach receives much more wave energy than the southern half. Waves on the southern half of the beach are shadowed by Shoe Island. The higher amount of wave energy on the northern half of the beach caused the rip channels to grow large, while the rips on the southern half remained relatively small (Figure 5.17).

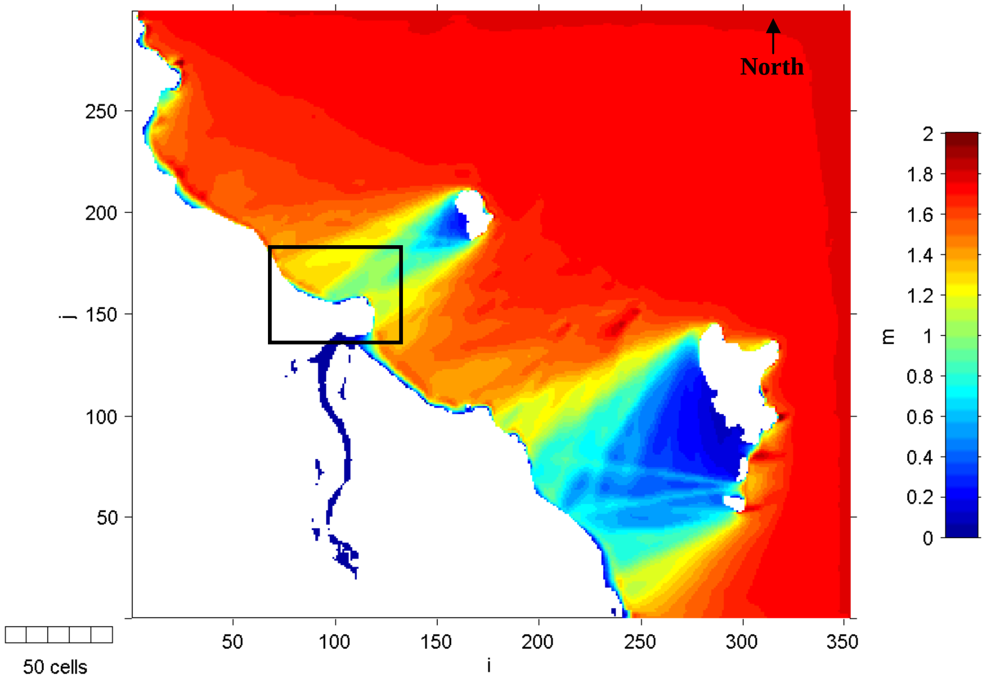


Figure 5.19. Significant wave heights along the east coast of the Coromandel. Modelled by S. Stephens (NIWA, NZ) using SWAN for waves with a significant wave height of 2 m, a period of 8 s, travelling west. Box indicates location of Tairua Beach.

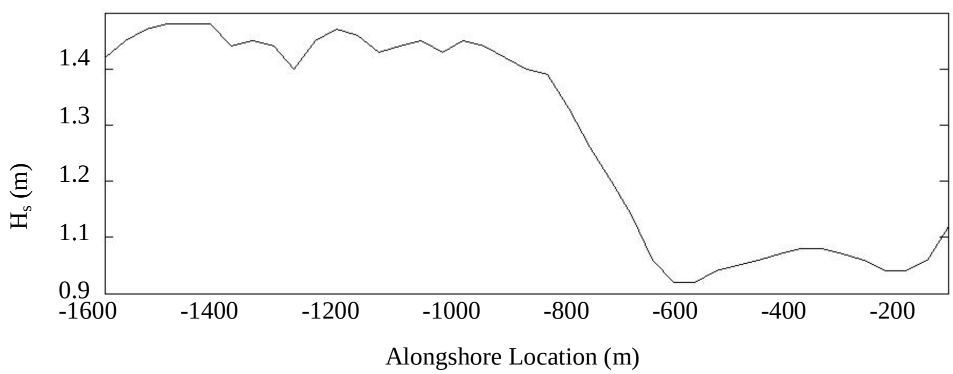


Figure 5.20. Significant wave heights on Tairua Beach. Modelled by S. Stephens (NIWA, NZ) using SWAN for waves with a significant wave height of 2 m, a period of 8 s, travelling west.

5.9.6 Hydrodynamic- vs. Topographic Rip Current Control

There is a hypothesis that once rip channels have formed under certain wave conditions, when the wave energy decreases the rips become dominantly topographically-controlled as opposed to hydrographically controlled (Short, 1985; Turner et al., 2007). Eliot (1973) noted that some rips persisted for days, while for the same time others were short-lived. Eliot suggested that rip locations that were more permanent were those that were created during high energy events when deep channels were cut through the outer bar. It was also noted that during low wave conditions these rips could remain until ephemeral low energy patterns became established or there was high wave conditions. Short (1985) proposed that when rip currents are topographically-controlled, they can persist in that location for days or weeks depending on how long the wave conditions remain constant. Short (1985), like Eliot (1973), noted that topographically-controlled rips could persist until enough time had elapsed for them to be modified by lower energy waves or until high energy conditions occurred.

In the case shown in Figure 5.17, it appeared that the rips in the northern system were formed during higher energy conditions, consistent with the idea of Eliot (1973) and were topographically-controlled and therefore were persistent. The rips in the southern system appeared to be hydrodynamically-controlled as they were rapidly changing in response to the wave conditions. Thus far there has been little research into topographic-control of rip currents, which may be due to the difficulty of getting topographic information in the high energy surf-zone (Brander and Short, 2001). The rips in the southern system remained in place for at least 400 days, when they were reworked in 2002 between days 35 and 57 (for when there were no video images available) after a long period of low H_s. Significant wave height data for 2002 showed that during the period when the northern rip channels began to be reworked, there were no high energy wave events as we might expect. A high wave event of a sufficient magnitude could be expected to rework the rips that were previously topographically-controlled and “reset” the system. A “reset” event caused by a high wave energy event does not appear to have occurred in this case. Significant wave height in 2002 during the period when the system behaviour appears to have changed significantly was less than 2 m and was fairly steady. The reworking of these rips may be explained by the ideas of Eliot (1973) and Short (1985) presented above, where they noted that topographically-controlled rips could be modified by lower energy waves that have been present for a sufficient duration.

5.10 Summary

Throughout the 3.3 year period studied (1999–April 2002), there were periods when the alongshore rip channel spacing appeared to be regular with persistent locations. There were also periods when alongshore rip channel spacing was irregular alongshore and the alongshore rip locations changed rapidly with time. It appeared that when rip channel spacing became irregular and rip locations variable alongshore, this generally corresponded to periods when H_s was high. However, there does not appear to be a strong relationship (e.g. there were times when H_s was high and there was no change from regular to irregular spacing). Scatter plots of various rip channel parameters to wave conditions showed no strong relationship, as has been found in many past studies. Wave conditions need to be compared to rip channel behaviour while taking into account previous wave conditions and duration of wave events over different thresholds. Studying mean rip channel angle may not be an appropriate way to examine rip angles. Mean rip channel angle appears to be too dominated by the effects of headlands. However, this parameter appears to compare reasonably well to the direction of rip channel migration most of the time. It appeared that there may be two types of rip channel systems at Tairua Beach: (1) a widely spaced system where there are 4–5 evenly spacing rip channels with a wide surf-zone; and (2) a narrowly spaced system where there are ~8 evenly spacing rip channels with a narrow surf-zone. Tairua Beach can develop a ‘dual’ surf-zone due to wave shadowing by offshore islands, where half of the surf-zone is wide and the other half narrow. During these periods there can be rips present that are hydrodynamically- controlled and rips that are topographically-controlled present at the same time. This idea of topographically-controlled rips may help explain why this study, as well as past studies, have shown that rips show a poor relationship to the current wave conditions when using traditional correlation methods.

Chapter Six: Relation of Rip Currents to Waves

6.1 Introduction

Past attempts to compare wave conditions to rip current behaviour have used immediate, instantaneous indexes of wave behaviour to quantify definitions of beach changes. Instantaneous indexes refer to the wave height averaged over a short time frame such as 10–20 minutes. In general, comparisons of these immediate measures of wave behaviour have shown a poor, if any relationship, to rip current behaviour (Holman et al., 2006; Turner et al., 2007). Here it is suggested that these past attempts to compare waves to rips do not indicate that there is no/ a poor relationship, but that wave conditions need to be compared to rips in a different way than straight-forward time-series analysis methods such as direct correlation. Rip currents are not likely to respond instantaneously to changes in wave conditions. There is likely a lag time between changes in wave conditions and rip current/channel response, which is likely to depend on the spatial scale (seaward extent) of the rip channel. Therefore, perhaps rip channels are more likely to show a relationship to the previous wave conditions rather than the immediate wave conditions. Also, rip channels may only respond to certain wave conditions if the waves are greater than a threshold for a sufficient period of time. The purpose of this chapter is to explore different ways of comparing wave climate to rip currents to find out how rips and waves are related.

6.2 Reconfiguration Events

Over the three years and four months of video images analysed (1999–April 2002), there appeared to be two main rip current behaviours (*event types*, defined using a measure of change) with regard to alongshore rip channel spacing and stability of alongshore locations:

(1) *Steady Events:* Periods of time when rip channel spacing was relatively regular alongshore and stable with time; and

(2) *Reconfiguration* (*Unsteady) Events:* Periods of time when rip channel spacing was irregular alongshore and changing rapidly with time.

Many different possibilities for defining reconfiguration events were explored, including changes in H_s, alongshore rip channel migration rates, mean rip channel spacing standard deviation, wave energy (see Section 6.3.1), and the duration of wave events (see Section 6.3.2). Each of these definitions appeared to show where reconfiguration events might have occurred in some instances, but did not appear to work well for the entire period of study. Therefore, a new measure of change was created to indicate consistently when rip reconfiguration events occurred. The histogram of the distance between every combination of rip channels at two consecutive time periods (for which rip channel data were available) was calculated (Figure 6.1). The number of rip current pairs in the 7.5 and 15 m bin was used as a measure of change. This measure did not require identifying the same rip currents at two different times, but assumed that a distance change of less than 15 m was an indication that the same rip current was being measured. There was some subjectivity in the development of the measure of change. For example, in choosing the histogram ranges and which bin made the best parameter.

Comparing the frequency of 7.5–15 m movement of rip channels with time to plots of alongshore rip locations with time, appeared to show when reconfiguration events occurred fairly well. This appeared to accurately indicate when the rip currents were reconfiguring to a new state. However, there were issues that arose with the 2002 period. There appeared to be maxima in the measure of change when reconfiguration events were not occurring, the rip channels were simply being ‘re-organised’(see section 5.6) where the seaward endpoints moved substantially, but the number of rips did not change. Therefore, the number of rip channels present was also taken into account to define reconfiguration events. Note that the measure of change and the number of rips are correlated, although sometimes the increases and decreases did not correlate exactly (i.e. there was sometimes a lag-time). A reconfiguration event was defined as a period of time when there was a prominent increase in the measure of change, and the number of rip channels present was changing with time.

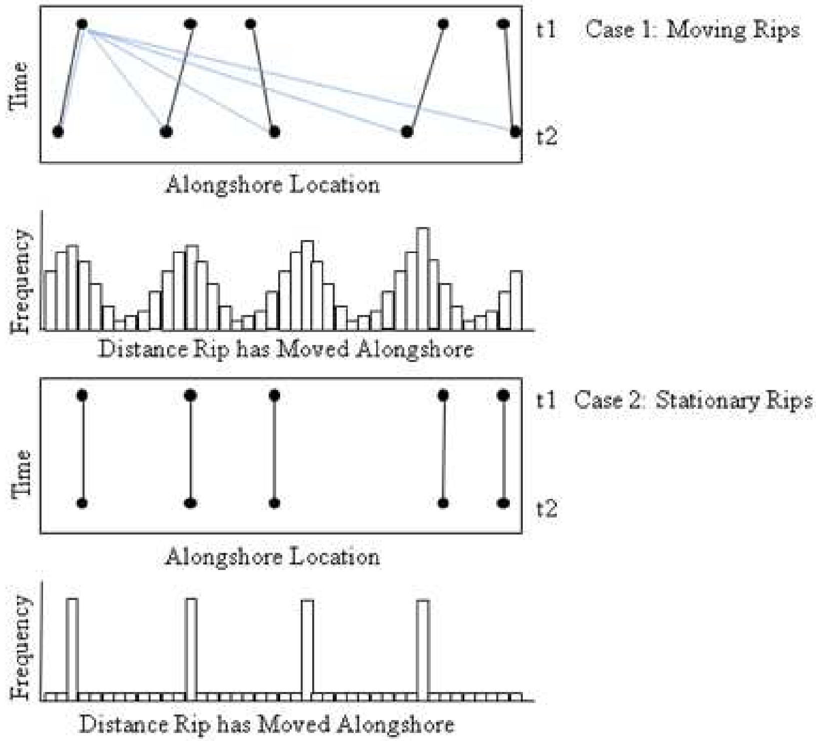


Figure 6.1 Schematic diagram showing how the measure of change was calculated. Top two panels shows a case where rip channels have moved alongshore with time. Blue lines show an example of how distance between the rip of interest and rips at the next time step was measured. Bottom two panels show a case when the rip channels have not moved alongshore with time.

The start and end times of reconfiguration events were defined from, until when the alongshore rip locations appeared to be changing substantially with time (visually). Periods of time not defined as reconfigurations were assumed to be 'steady' events/ periods. Figures 6.2–6.5 show how reconfiguration events were defined. Over the period of study (not including 2000 which is lacking data), there were six reconfiguration events in total: three in 1999, two in 2001 and one in 2002. These reconfiguration events are referred to by number in order of their occurrence: the three reconfiguration events that occurred in 1999 are events one–three, the two reconfiguration events in 2001 are events four and five, and the reconfiguration event that occurred in 2002 is event six. Figure 6.3 shows that during 2000 there appeared to be a large reconfiguration event between days 170 to 200. However, Figure 6.3b gives no evidence for this reset. This lack of evidence is likely due to the discontinuous rip channel data record of 2000 (the time interval between days 170 and 200 had no rip data) and the fact that rip currents shifted around more than 5–10 m.

The purpose of this ‘reconfiguration event’ classification was (1) to see what type of wave conditions caused the rip current behaviour to change from steady to unsteady; and (2) too see how rip channel morphology and the magnitude of the wave conditions affected how rip channels respond. There was a hypothesis created to explain this behaviour proposing that rip channel spacing tends to be regular and stable with time (steady) until there is a wave event of a sufficient magnitude to change the rip channels. In this case magnitude may refer not just to H_s alone, but also to the period of time for which a particular wave condition was present for. Note that ‘reset’ events occur when the bar straightens and hence rip channels disappear. Also note that all reconfiguration events during 1999, 2001 and 2002 do not appear to have been reset events. There appears to have been only one complete reset event during the period studied which occurred during 2000. This complete reset event in 2000 is discussed in Section 6.8. The following section contains an analysis of rip and wave data from 1999, 2001 and part of 2002. 2000 was not examined in this section due to the poor record with a lack of continuity due to long periods of low energy.

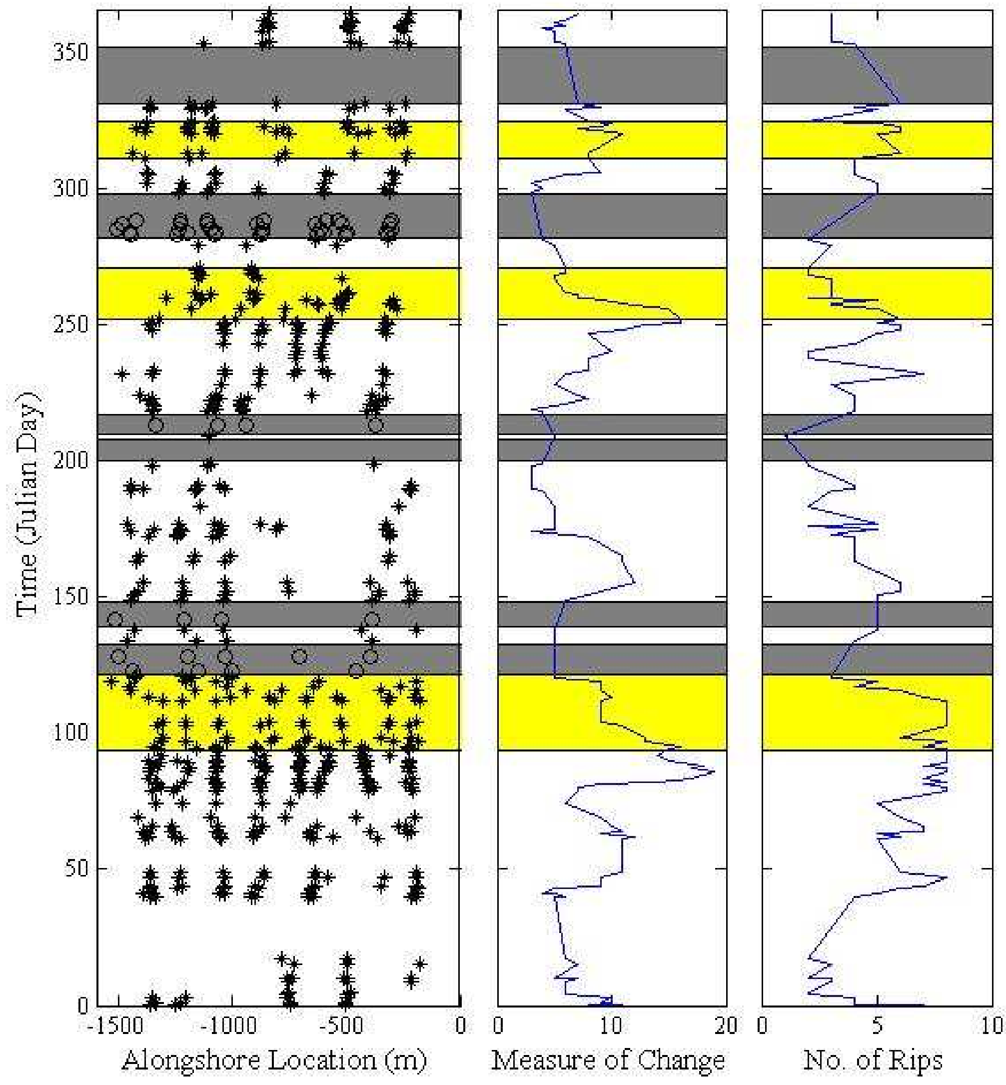


Figure 6.2. Shows rip channel data for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b. Shows the number of rip channels between 7.5 and 15 m apart between consecutive times of data availability, and c. The number of rip channels. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

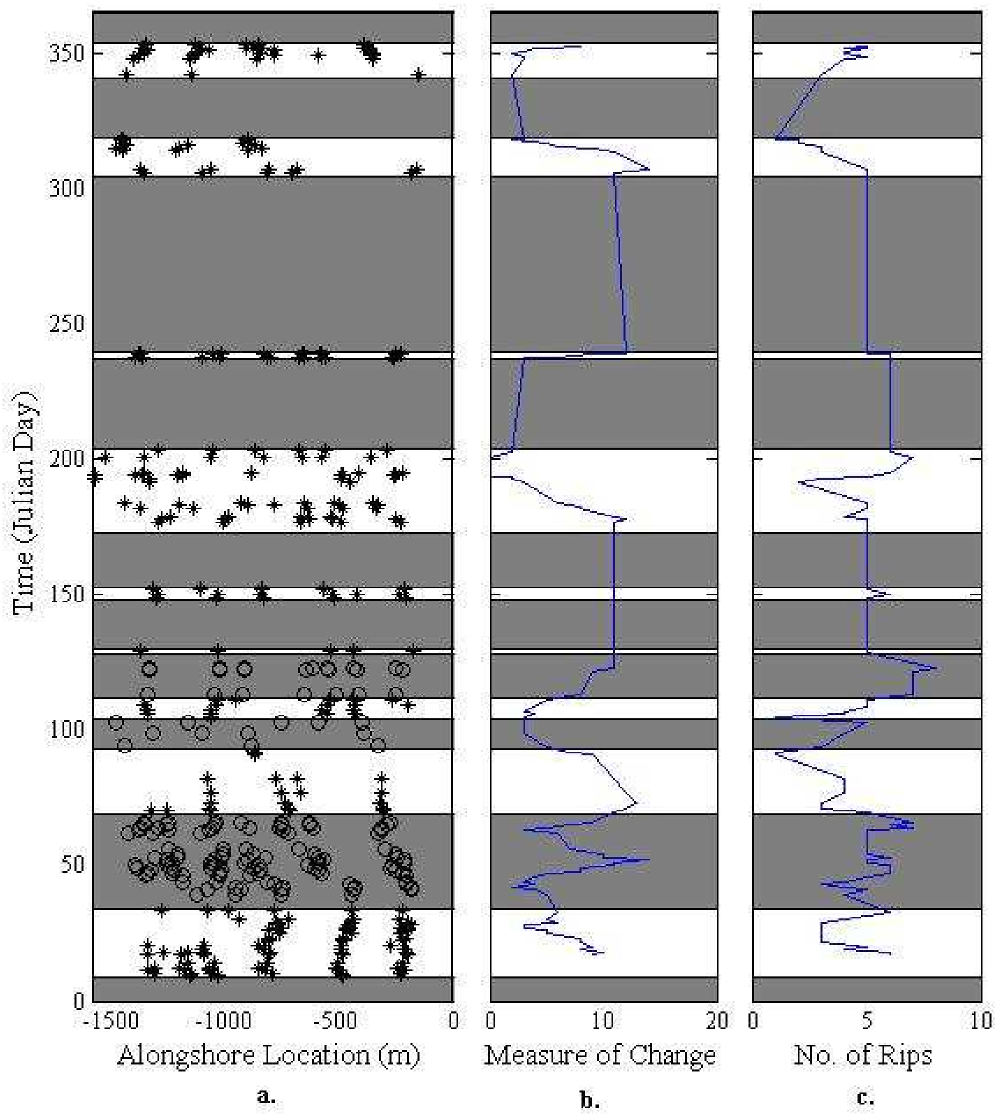


Figure 6.3. Shows rip channel data for 2000. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b. Shows the number of rip channels between 7.5 and 15 m apart between consecutive times of data availability, and c. The number of rip channels. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

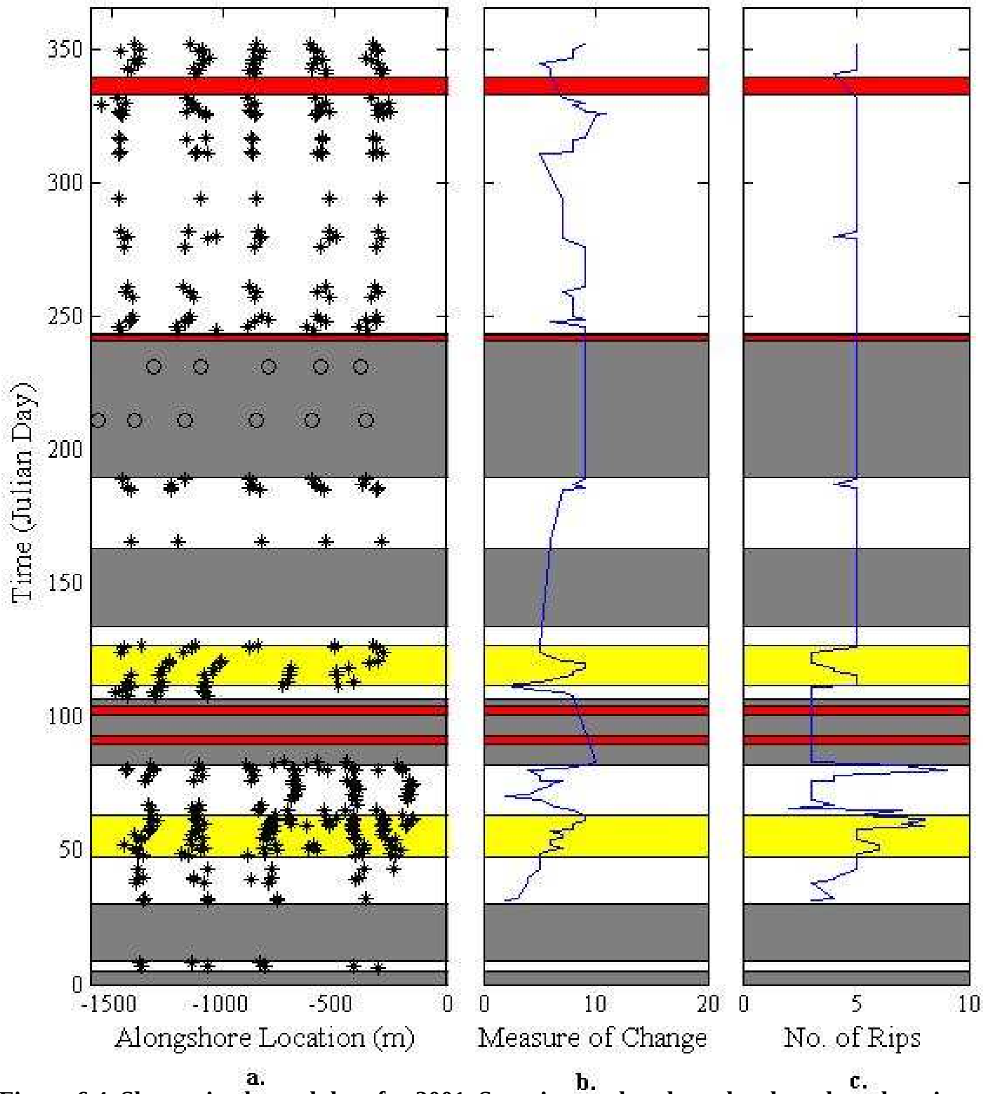


Figure 6.4. Shows rip channel data for 2001. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b. Shows the number of rip channels between 7.5 and 15 m apart between consecutive times of data availability, and c. The number of rip channels. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

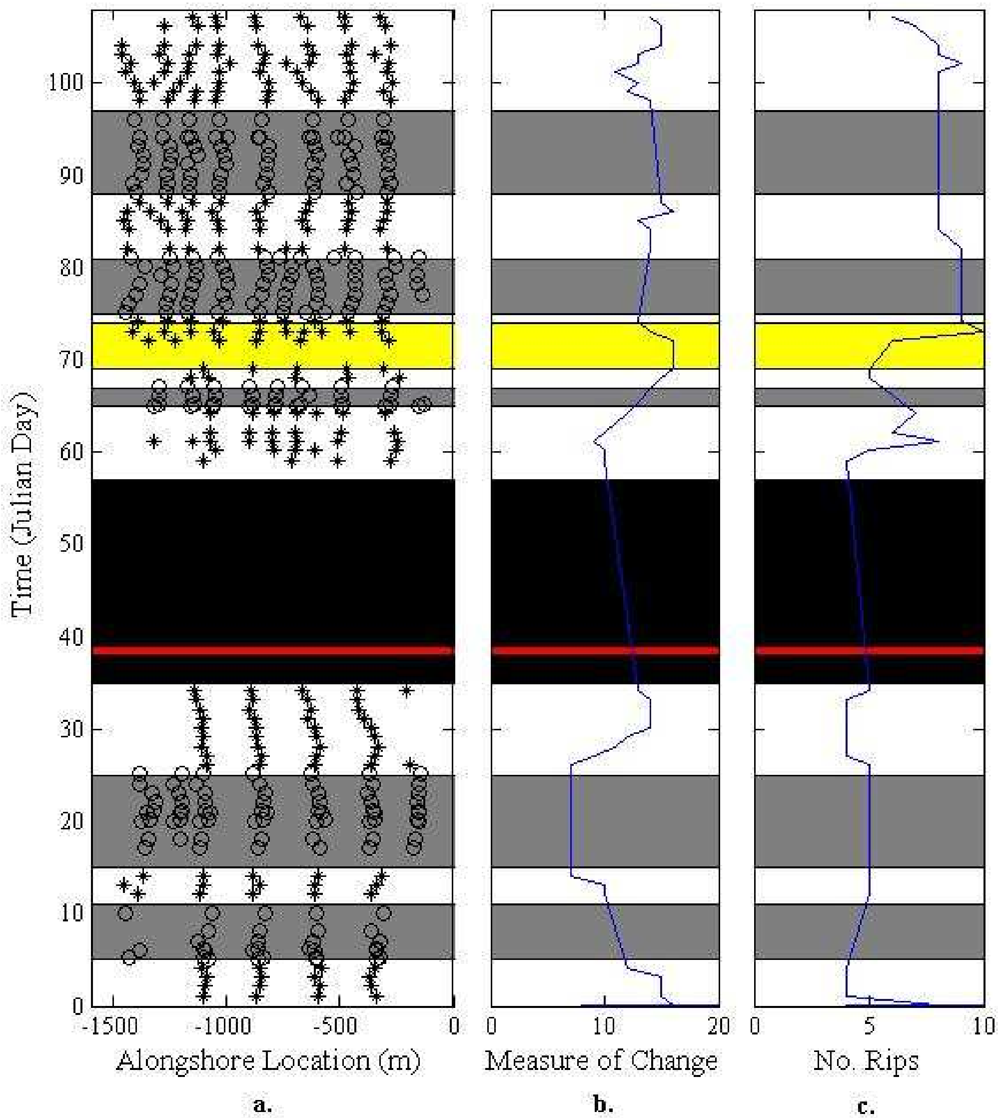


Figure 6.5. Shows channel data for 2002. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b. Shows the number of rip channels between 7.5 and 15 m apart between consecutive times of data availability, and c. The number of rip channels. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

6.3 Representing Wave Climate

6.3.1 Wave Energy

Wave energy was defined as $1/8\rho g H_s^2$, where ρ is the density of seawater (1025 kgm^{-3}), g is acceleration due to gravity (9.81 ms^{-1}) and H is significant wave height. Significant wave height was averaged over different durations. Durations used over which to average H_s were 3, 6 and 12 hours, and 1, 2, 5, 7.5 and 10 days. Significant wave height was averaged over the period of time up to and including each time H_s was output from the WAM model (every three hours). It is essential to note that mean H_s was not centre–averaged because waves occurring after rip channels were measured will not be able to affect the current rip channel morphology.

6.3.2 Wave Duration

Duration time series were created for each point in time (e.g. each H_s modelled) (Figure 6.6). The duration consisted of the length of time over which H_s or the wave energy was greater than a threshold.

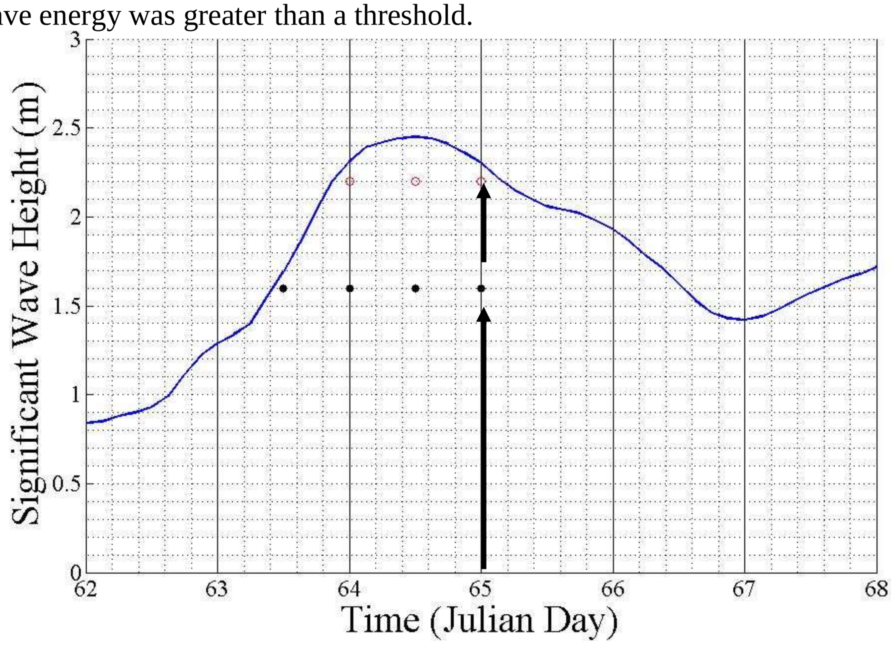


Figure 6.6. Schematic diagram showing how a duration of significant wave height was calculated for 1999. Arrows point at the Julian Day for which a duration calculation was being made. Black and red dots indicate Julian Days when H_s was greater than 1.6 m and 2.1 m respectively. In this case the duration greater than 1.6 m was 1.5 days and the duration greater than 2.2 m was 1 day.

A duration time series was created for H_s greater than 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 m and for wave energy (averaged over 10 days) greater than 1.3, 2.5, 3.8 and 5 Mgs^{-2} (corresponding to H_s greater than 1, 2, 3 and 4 m^2).

6.4 1999 Reconfiguration Events

6.4.1 Significant Wave Height

During 1999 there were three reconfiguration events. When these events were compared to H_s, it appeared that there was some relationship between H_s and whether a period of time was classed as steady or unsteady. Figure 6.7 shows that the highest H_s appear to have been associated with reconfiguration events, however there were still times when high wave heights occurred during periods that were not classed as reconfiguration such as between days 170 and 200.

6.4.2 Wave Energy

Wave energy (Figure 6.8) appeared to show a much better relationship to rip channel spacing regularity and stability than H_s (Figure 6.7). Wave energy averaged over longer periods such as 5 and 10 days as opposed to shorter periods of 1 day or less appeared to show the best relationship to rip channel regularity for 1999. During reconfiguration events the average wave energy was much higher than during steady events.

6.4.3 Wave Duration

6.4.3.1 Duration of Significant Wave Height

For 1999 using a threshold H_s of 1.5 m or less to create a duration time series did not show a particularly good relationship to rip channels (Figure 6.9). Using H_s greater than 2 m appeared to best show the relationship. For example, for H_s greater than 2.5 m, in general there were only times when H_s was greater than 2.5 m during the reconfiguration events (Figure 6.9). For the irregular events, when the wave duration greater than 2.5 m was used, it appeared that for reconfiguration events to occur an H_s of greater than 2.5 m for ~40–50 hours was necessary.

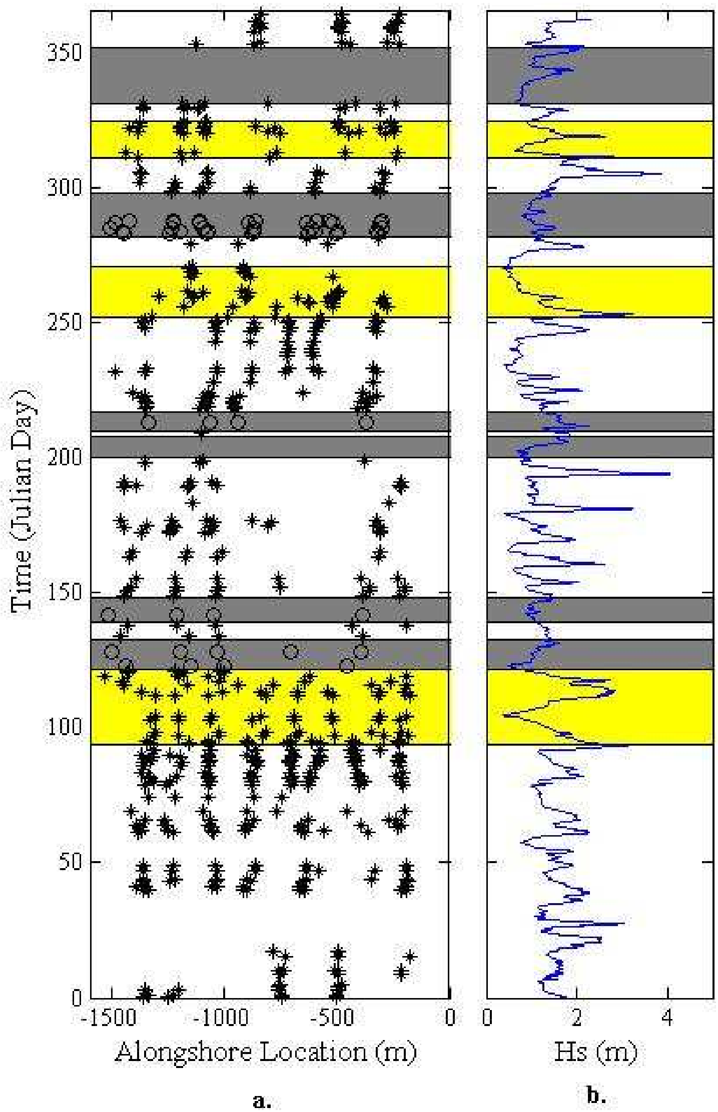


Figure 6.7. a. Shows alongshore rip channel locations for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b. Shows significant wave height. Grey areas indicate periods when wave energy wave too low to make rip channels detectable by automatic algorithms, and yellow areas are reconfiguration events.

6.4.3.2 Duration of Wave Energy

Duration time series were also created using wave energy averaged over different durations. Using wave energy averaged over 10 days to create a duration time series (Figure 6.10) yielded a similar result to using raw wave H_s (Figure 6.7). However, perhaps using the wave energy average over 10 days is too-long-a period to average over as there werre peaks in wave duration in periods not classed as reconfigurations (Figure 6.10a). Figure 6.10e shows that for the duration of wave energy greater than 2.5 Mgs^{-2}, although there were peaks in the magnitude during reconfiguration events, there were also peaks during steady events.

Wave energy averaged over two days was also used to create a wave duration time series. This appeared to produce results even better than using wave energy averaged over 10 days. Figure 6.11 shows that when using duration greater than 3.8 and 5 Mgs^{-2} there was fairly good agreement between when the peaks are located and when reconfiguration events occurred. There were still small peaks present during periods when rip spacing was thought to be regular. However, it appears that when these peaks occurred there was slight irregularity occurring with the rip channel spacing.

Wave energy averaged over a period of six hours was also used to create a duration time series. This appeared to use a period that was too small to average over as when plotting a graph like Figure 6.11, there were peaks in wave duration present of a similar size for both steady and unsteady periods. Finally, wave energy averaged over 5 days was also used to create a wave duration time series. This yielded results similar to those when using wave energy averaged over 10 days (Figure 6.8).

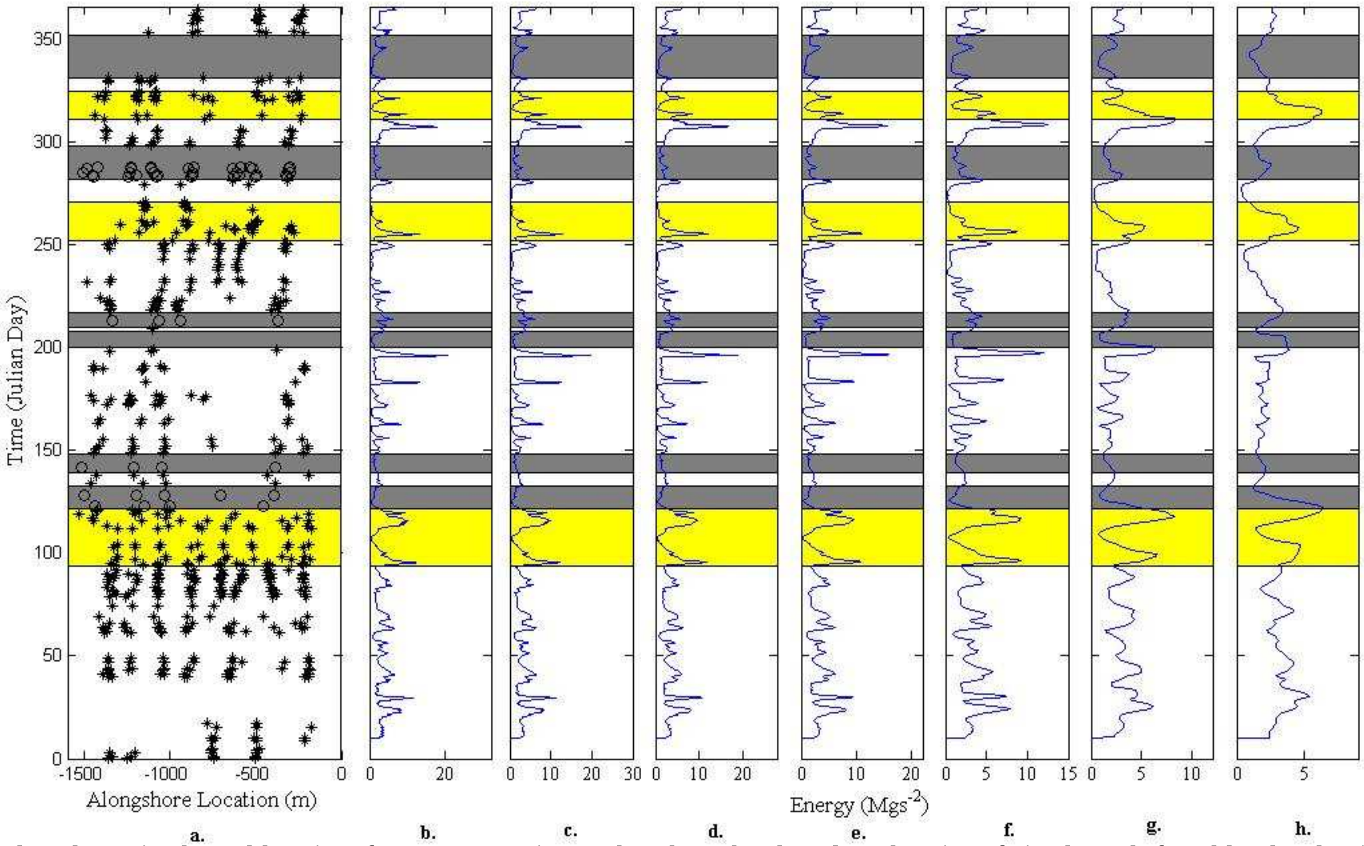


Figure 6.8. a. shows alongshore rip channel locations for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels that where the locations were manually digitised. b. Shows wave energy averaged over 3 hours, c. Wave energy averaged over 6 hours, d. Wave energy averaged over 12 hours, e. Wave energy averaged over 1 day, f. Wave energy averaged over 2 days, g. Wave energy averaged over 5 days, and h. Wave energy averaged over 10 days. Grey areas indicates periods when wave energy wave too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

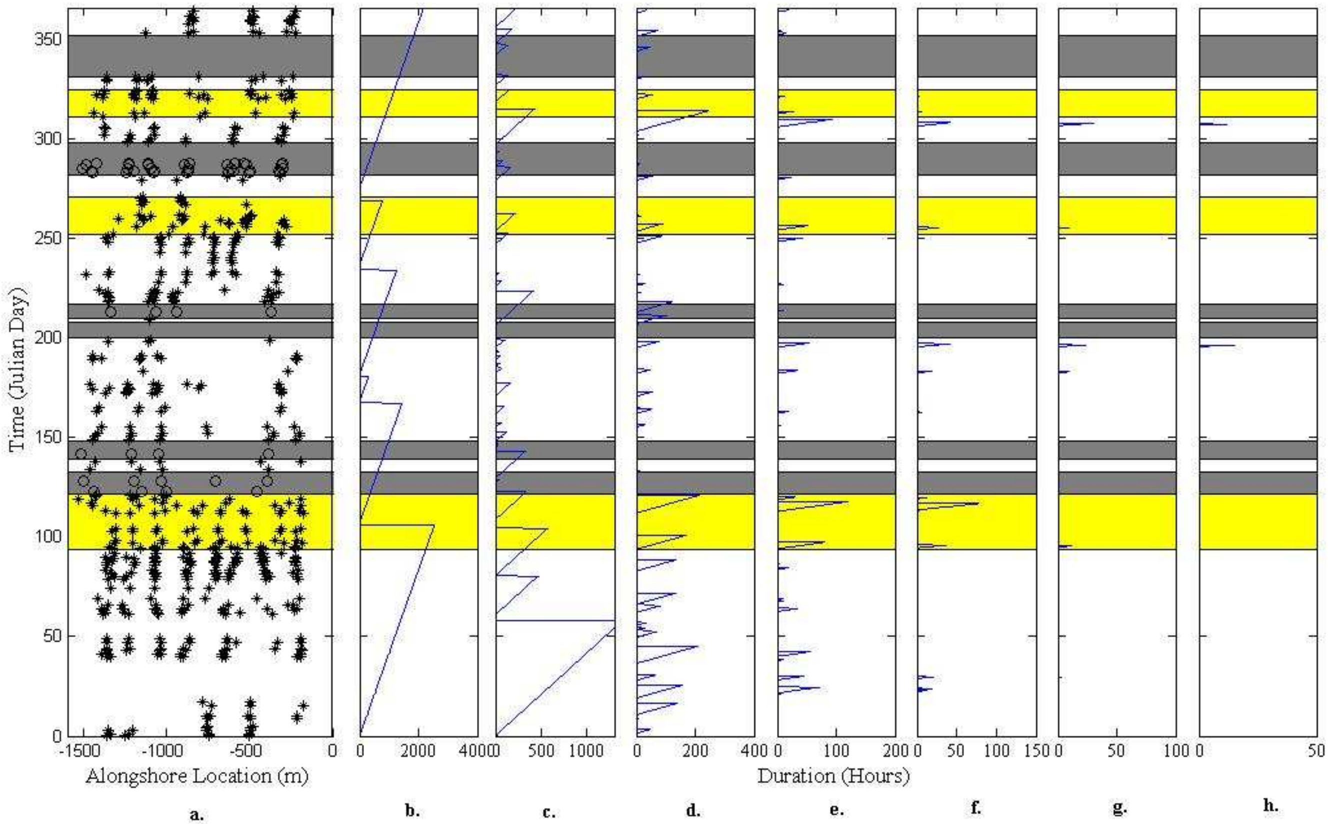


Figure 6.9. a. shows alongshore rip channel locations for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels that where the locations were manually digitised. b. Shows the duration of wave heights greater than 0.5 m, c. Duration of wave heights greater than 1 m, d. Duration of wave heights greater than 1.5 m, e. Duration of wave heights greater than 2 m, f. Duration of wave height greater than 2.5 m, g. Duration of wave heights greater than 3 m, and h. Duration of wave heights greater than 3.5 m where all durations are in hours. Grey areas indicates periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

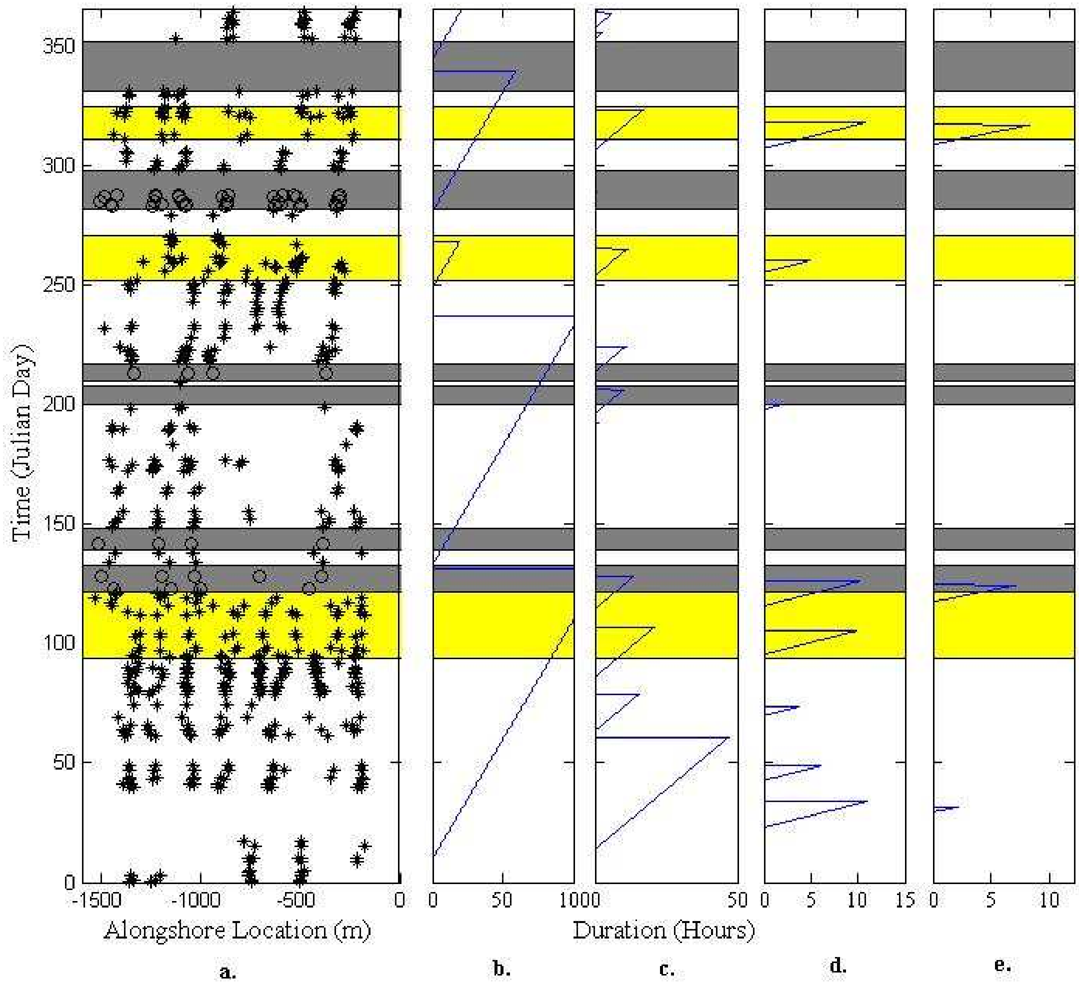


Figure 6.10. a. shows alongshore rip locations for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels that where the locations were manually digitised. b–e. Show the duration of wave energy squared averaged over 10 days where b. Shows duration of wave energy greater than 1.3 Mgs^{-2}, c. Duration of wave energy greater than 2.5 Mgs^{-2}, d. Duration of wave energy greater than 3.8 Mgs^{-2}, and e. Duration of wave energy greater than 5 Mgs^{-2}. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

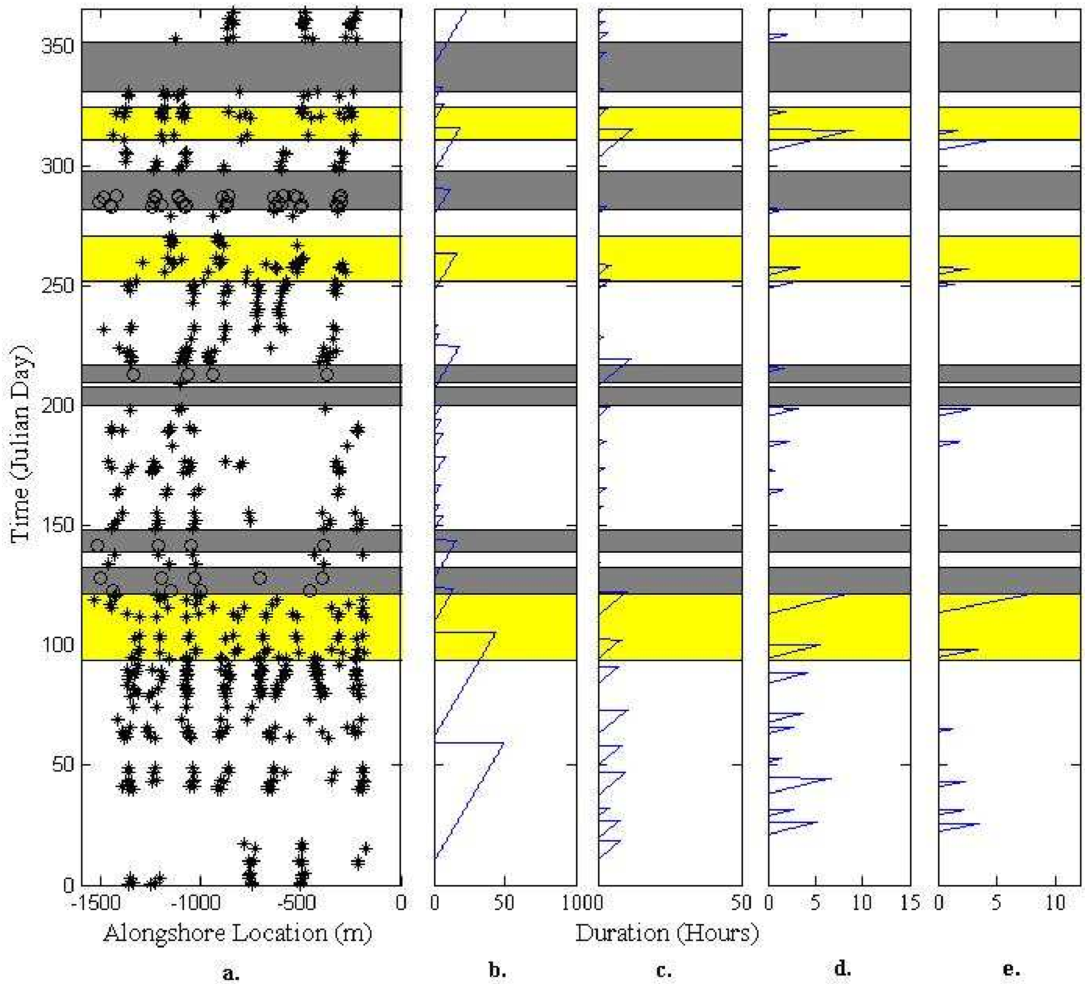


Figure 6.11. Panel a. shows alongshore rip locations for 1999. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels that where the locations were manually digitised. b–e. shows duration of wave energy averaged over 2 days where b. Shows duration of wave energy greater than 1.3 Mgs^{-2}, c. Duration of wave energy greater than 2.5 Mgs^{-2}, d. Duration of wave energy greater than 3.8 Mgs^{-2}, and e. Duration of wave energy greater than 5 Mgs^{-2}. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms and yellow areas are reconfiguration events.

6.5 2001 Reconfiguration Events

During 2001, the rip channel behaviour was remarkably regular alongshore throughout the entire year, however there appeared to be much more regular, stable rip channel spacing over the second half of the year (Figure 6.4). Comparing rip channel regularity and stability to H_s in 2001 did not give a good indication of any relationship present, although it does appear that the highest H_s occurred during the reconfiguration events (see Appendix 3 and Figure A3.1).

As was the case for 1999, wave energy appears to show a better relationship to rip channel regularity and stability than H_s during 2001 (see Appendix 2 and Figure A2.2). Wave energy averaged over longer periods such as 5 and 10 days appeared to show the best relationship to alongshore rip spacing regularity, as was the case in 1999. During periods when rip channel spacing appeared to be irregular, the mean wave energy was much higher than when rip channel spacing was regular.

Results for a comparison between rip channel regularity and stability and H_s durations show a similar trend to that observed for 1999. Significant wave height of 1.5 m or less did not show the relationship to rip channels particularly well (see Appendix 2 and Figure A2.3). Using H_s greater than 2, 2.5 and 3 m appeared to show the relationship to rip spacing behaviour with the greatest clarity. For example, Figure A2.3f shows that during the reconfiguration events, the duration of H_s greater than 2.5 m was for at least ~50 hours. For a duration of wave energy greater than a magnitude of 2.5, 3.8 and 5 Mgs^{-2}, although there were peaks in the magnitude during periods when the rip channel spacing was regular, the biggest peaks in general tended to be when there were periods with irregular, unstable rip channel behaviour (see Appendix 2 and Figure A2.4).

6.6 2002 Reconfiguration Events

2002 shows different behaviour again from previous years. The rip spacing was regular alongshore for at least the first month (Figure 6.5). Around March it became more erratic, from then on the spacing still appeared to be fairly even but with rips much more closely spaced than seen previously. Comparing H_s to rip channel spacing regularity and stability in 2002 appeared to show that relatively high H_s tended to occur during the irregular periods (see Appendix 2 and Figure A2.5). However, fairly high H_s also occurred during the regular periods which was not to be expected. As was the case for 1999 and 2001, during 2002 wave energy appeared to show a better relationship to rip channel regularity and stability (see Appendix 2 and Figure A2.6) than to H_s. Wave energy averaged over 1–5 days appeared to show the best relationship to rip channel regularity and stability. During reconfiguration events the average wave energy was higher than when rip channel spacing was regular.

A comparison between rip channel regularity and stability and H_s durations shows a relationship (see Appendix 2 and Figure A2.7). The duration of H_s greater than 1 m shows a good relationship to rip spacing behaviour. There were peaks in the duration for the irregular periods but only small ones for the regular periods. For the duration of wave energy (averaged over two days) greater than 1.3 Mgs^{-2}, there were peaks present during the periods when rip channel spacing was irregular alongshore and unstable with time (see Appendix 2 and Figure A2.8). For greater magnitudes there were peaks during only 1–2 of the periods with irregular, unstable channel behaviour. For the year 2002 this plot is different to those for previous years (1999 and 2001) where magnitudes of 2.5, 3.8 and 5 Mgs^{-2} appeared to show the relationship to channel behaviour better than 1.3 Mgs^{-2}.

6.7 Rip Behaviour During Reconfiguration Events

This section describes what occurred during each reconfiguration event. The main purpose of exploring these reconfiguration events is to identify what are the main drivers of changes in rip behaviour during the events. Images of the beach with the rip channels that were present from before and after each reconfiguration event are shown in Figure 6.12. See Table 7.1 for a summary of wave and rip channel characteristics during reconfiguration events.

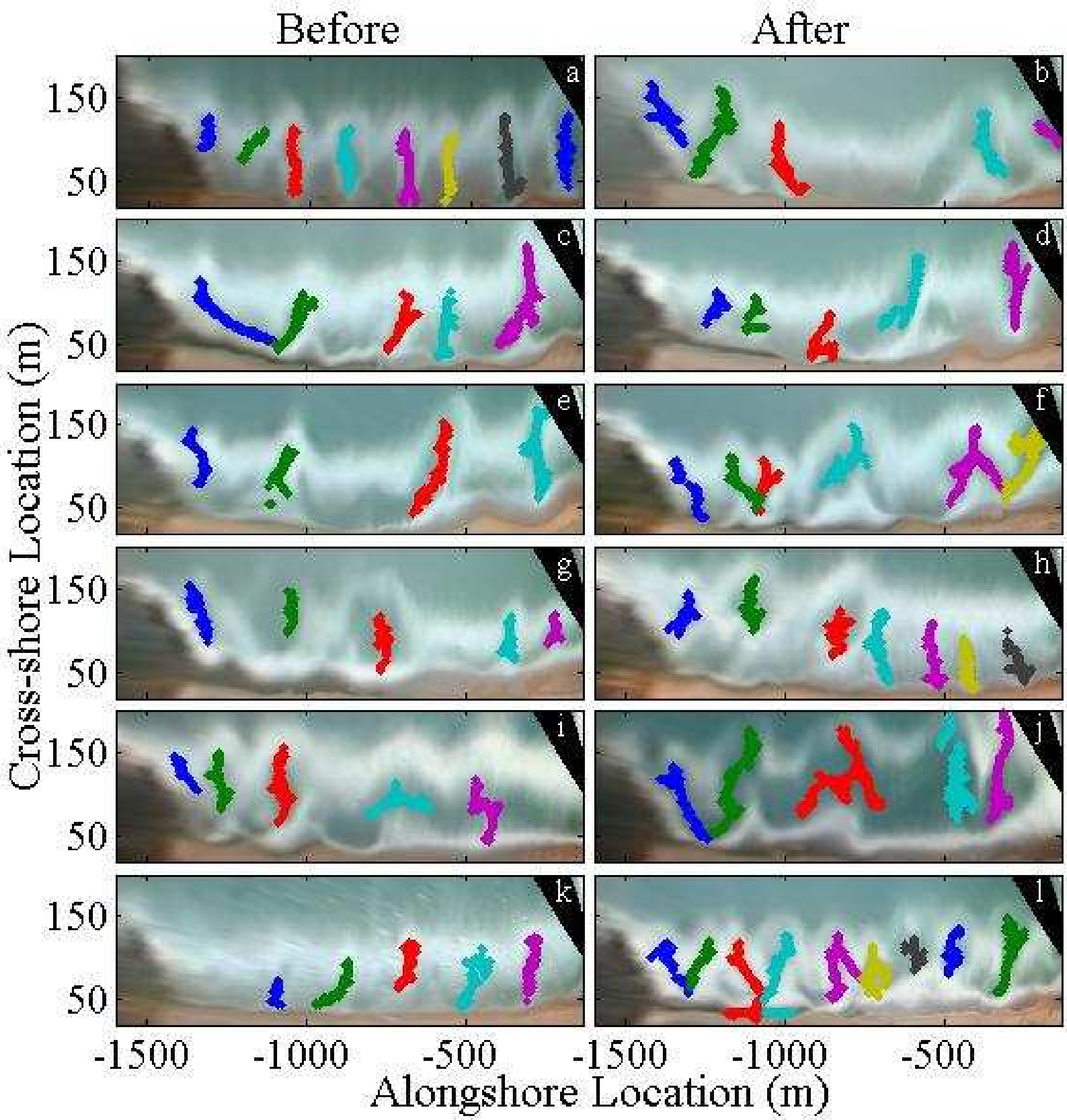


Figure 6.12. Rectified, time-averaged video images of Tairua Beach prior to and after each reconfiguration event. Coloured dots show separate rip channels found with the computer algorithms. The left hand column shows the beach before each reconfiguration event and the right hand column shows the beach after each reconfiguration event (1-6).

6.7.1 Reconfiguration Event One

Prior to reconfiguration Event One, H_s oscillated between ~1 and ~2.5 m while during the event it reached a maximum of ~3.5 m. Wave energy averaged over 10 days increased to ~6.3 Mgs^{-2} during the event. The duration of H_s greater than 2.5 m was ~70 hours at the beginning of the event, ~40 hours towards the end and 10 hours at the end. The total duration of H_s greater than 2.5 m was ~120 hours. There was no H_s greater than 3 m during Event One. During the event, wave energy was greater than 5 Mgs^{-2} for ~3 hours at the beginning of the event and ~7 hours near the end of the event. An alongshore trough (longshore bar–trough state) developed on the southern half of the beach. The three northern rips remained as did 1–2 reworked rips at the southern end. The number of rips decreased from 8 to 5, and spacing changed from regular and irregular alongshore. Prior to the event it appeared that the rip channel system was the same along the entire beach (Figure 6.12a). After the event however there appeared to be two systems: a northern system with three rips, and an alongshore trough and two rips at the southern end. Figure 6.12a and 6.12b shows that the three northern rips had moved, two towards the north and one towards the south. Figure 6.12b also shows that the rips at the southern end hardly moved. The sequence of images during this event appeared to show that these rips at the southern end after the event were the same rips that were present prior to the event, they had just been reworked.

6.7.2 Reconfiguration Event Two

Prior to Event Two, H_s reached a maximum of ~3 m during the steady period. During the event H_s reached a maximum of ~3.5 m, as was the case during Event One. Wave energy averaged over 10 days prior to Event Two was low at ~2.5 Mgs^{-2}, while during it reached a maximum of 5 Mgs^{-2}. During the event, H_s was greater than 2.5 m for ~40 hours, greater than 3 m for ~10 hours, while there were no H_s greater than 3.5 m. The duration of wave energy averaged over two days was greater than 5 Mgs^{-2} for ~4 hours during Event Two. Prior to the event, there were five irregularly spaced rips spread along the beach (Figure 6.12c). The rips at the ends of the beach where slightly larger than the others, with the largest rip located at the southern end. These two rips at the northern appeared to have been re-developed. From observation of the images, on day 281 there was a large surf-zone, after which two large rips remained at the southern end and three small rips at the northern end of the beach (Figure 6.12d). Images show that the rip furthest northward was a new rip, and the other two were the original two rips. Figure 6.12d shows that the two rips at the southern end of the beach stayed near the same location. The two rips at the northern end moved towards the south. Rip channel spacing remained irregular after the event.

6.7.3 Reconfiguration Event Three

Prior to Event Three, H_s was relatively low at ~2 m. During the event, H_s increased rapidly to a maximum of 3 m then decreased rapidly. Wave energy averaged over 10 days was low prior to the event at ~2.5 Mgs^{-2}, and increased to a maximum of ~6.3 Mgs^{-2} during. Significant wave height was greater than 2.5 m for ~40 hours just prior to the event and ~10 hours during, while there were no H_s greater than 3 m. Wave energy averaged over two days was greater than 5 Mgs^{-2} for ~5 hours at the beginning of the event and ~2.5 hours during. Prior to the event there were four rips present (Figure 6.12e). Two rips were at the northern end of the beach with a trough in between, and two larger rips were present at the southern end. During the event a new rip developed in the middle of the trough, and then another at the southern side of the northern rips (Figure 6.12f). The trough had an unusual shape. After the event there was a smaller system of three rip channels to the north and a larger system of three rip channels to the south. Figure 6.12f shows that there were two rip channels to the north that were in the same location as prior to the event with a new rip in the middle. The northern rip was the same one as before, however due to gaps in data it is not clear if the other rip channel is the same one as prior to the event. Figure 6.12f also shows the development of a new rip in the middle of the beach, and that the two southern rips moved further south.

6.7.4 Reconfiguration Event Four

Prior to and during Event Four, H_s remained stable at ~2m. During the event there was no signature in the wave energy averaged from three hours to 10 days. Prior to, during and after Event Four, wave energy averaged over 10 days was ~3.8 Mgs^{-2}. During the event there was however a signature in the duration of H_s greater than 0.5–1.5 m. For example, H_s was greater than 1.5 m for ~180 hours. There was also a signature in the duration of wave energy averaged over two days greater than 1.3 and 2.5 $Mgs^{-2.}$ Wave energy averaged over two days was greater than 1.3 Mgs^{-2} for ~30 hours just before the event, and greater than 2.5 Mgs^{-2} for ~18 hours just after. Prior to the event there were 5 rip channels present (Figure 6.12g). There were three large rip channels on the northern half of the beach and two smaller ones on the southern half (perhaps with another smaller rip beginning to form) (Figure 6.12g). During the event it appeared that the three larger rips became reworked, ~2 more smaller rips developed and the smaller rips extended further seaward (Figure 6.12h).

6.7.5 Reconfiguration Event Five

During Event Five, H_s reached a maximum of 5 m and wave energy averaged over 10 days reached a maximum of ~9.4 Mgs^{-2}. During the event, H_s was greater than 2.5 m for ~100 hours. The duration of wave energy averaged over two days greater than 3.8 and 5 Mgs^{-2} was for ~7.5 hours. Prior to the event there were 5 rip channel present where three were well-defined at the northern end of the beach (Figure 6.12i). From the most southern end of the beach to half way, there were two small rips present prior to the event. The dominant beach state at the southern half appeared to be rhythmic bar and beach (i.e. a pronounced alongshore trough was present). There was one poorly developed rip present in the trough. During the event a fifth rip developed in the southern half and the surf developed more towards a transverse bar and rip state (Figure 6.12j). The rips appeared to have migrated southwards. After the event there were five rips present with a wide trough. Again the two rips at the northern end were most developed.

6.7.6 Reconfiguration Event Six

Prior to Event Six, H_s was low at ~2 m. During the event H_s reached a maximum of just ~2.5 m, which was much lower than during other reconfiguration events. Wave energy averaged over 10 days showed no increase in energy during the event. Wave energy averaged over four days showed a small peak to indicate the presence of the event, however this peak was more pronounced when wave energy was averaged over shorter periods of time (Figure A2.6). Wave energy averaged over two days was ~2.5 Mgs^{-2} prior to the event and during increased to a maximum of ~7.5 Mgs^{-2}. During the event, there were no H_s greater than 2.5 m. Significant wave height exceeded 2 m during the event for ~40 hours. Wave energy averaged over two days was greater than 5 Mgs^{-2} for ~2 hours during the event. Prior to the event there were five rips present along the beach that were fairly evenly spaced alongshore (Figure 6.12k). There were no rips present at the northern-most end of the beach. During the event, the rips extended further seaward and two rips developed at the northern end in the space (Figure 6.12j). After the event there were nine evenly spaced rips present. Figure 6.12j shows that there was little rip migration during Event Six.

6.8 Storm Event in 2000

As mentioned earlier, it appeared that the only complete reset event to the rip channel system that occurred during the period of study was in 2000 between days 170 and 200. During this reset event, the barline straightened and a pronounced alongshore trough developed. After the reset event, the rip channel configuration had no resemblance to the configuration prior to the reset. There was a clear signature in the wave duration (regardless of thresholds of H_s tested, from 0.5 to 3.5 m) time series when the storm event occurred in 2000 that caused the reset. Significant wave height exceeded the thresholds tested for longer periods during the 2000 reset event than in other years.

Figure 6.13 shows the rip channel configurations prior, during and after (once the channel configurations appeared to have become stabilised) the large storm event in 2000. Note the tilt of the alongshore bar and the increasing width of the surf-zone throughout the event (Figure 6.13). Prior to the large storm event in 2000, on day 150 there were six rip channels present that were relatively regularly spaced alongshore. Between days 150–174 there was low wave energy so no rip channels were discernable.

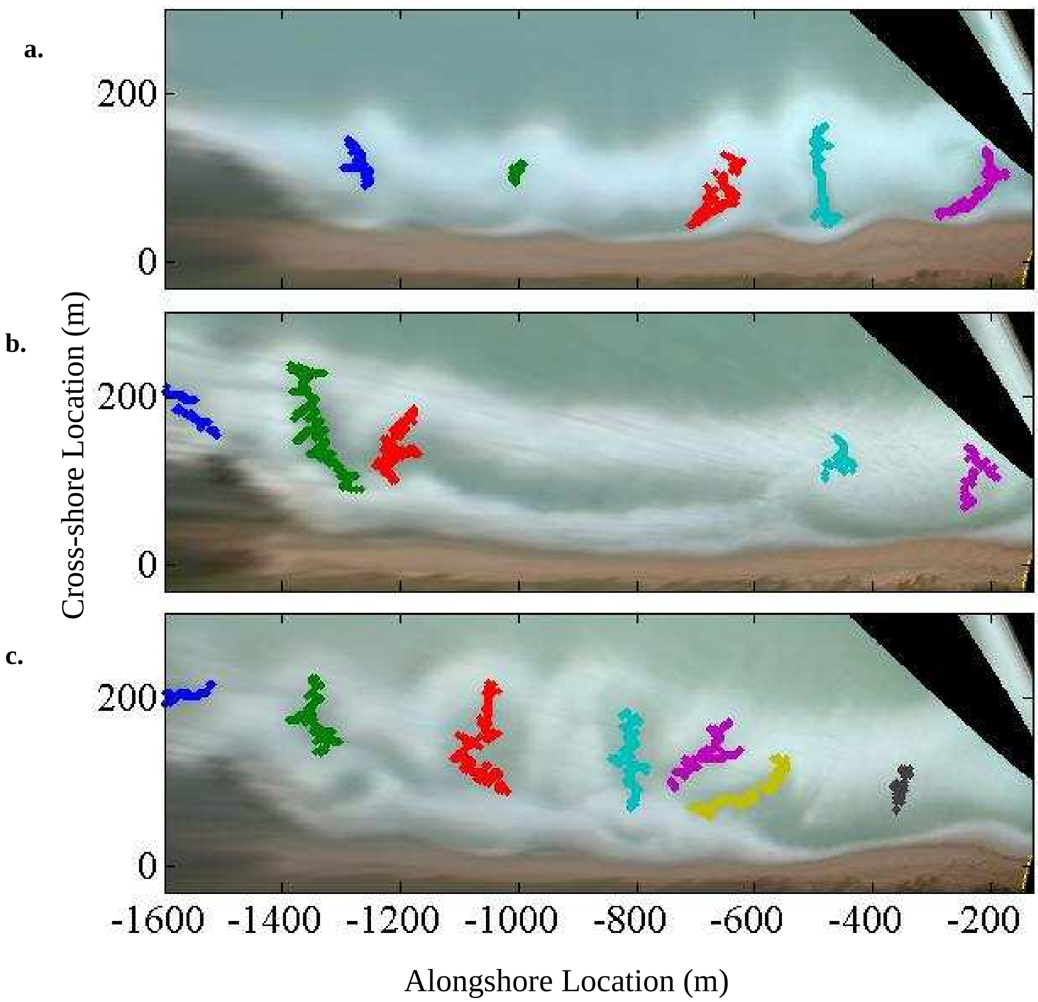


Figure 6.13. Rectified, time-averaged video images of Tairua Beach where different coloured dots show distinct rip channels found with the computer algorithms. Panel a. Shows prior to the reset event in 2000 (Julian Day 177 at 0800 hours), b. During the reset in 2000 (Julian Day 194 at 1000 hours), and c. After the reset in 2000 (Julian Day 201 at 1400 hours).

On day 174, the 5 rips present appeared to be more regularly spaced alongshore than prior to the storm (Figure 6.13a). Between days 170-182 it appeared that rip channels on each half of the beach moved away from each other to form an alongshore trough in the middle of the beach. On day 182, there was an increase in the magnitude of the wave conditions and on day 191 there were three huge rips present at the southern end of the beach extending ~400 m, with a trough in the middle of the beach and two smaller rips at the southern end (Figure 6.13b). A fourth rip developed in the trough southward of the most southern rip on the northern half of the beach which is apparent on day 195. Between days 197–199 there was high wave conditions and the rips appeared to move southward. Nearing the end of the storm on day 201, there were four large rips present covering most of the beach, with some smaller ones at the most southern end (Figure 6.13c). The wave conditions for this event are plotting in detail on Figure 5.18.

6.9 Discussion

6.9.1 Wave Climate Comparisons

From comparisons of H_s to rip channel behaviour (in particular to whether periods of time were steady or unsteady (i.e. a reconfiguration event) in regard to alongshore rip channel movement), it appeared that in general H_s reached maximum magnitudes during reconfiguration events. The relationship between instantaneous H_s and rip channels does not appear to be a strong one. There are discrepancies when H_s appeared to reach relatively high magnitudes during steady periods. This type of discrepancy suggests that it is not just H_s that forces the rip channel system, but perhaps a combination of factors such as previous wave conditions and the duration for which H_s exceeds a threshold.

For all three years of data presented in this Chapter (1999, 2001, 2002), it appeared that wave energy (mean H_s averaged over time) and wave duration (duration for which waves were greater than a threshold) showed a much better relationship to rip channel behaviour than immediate, instantaneous H_s. In particular, wave energy and duration were different depending on whether rip channel behaviour during a period of time was steady or unsteady. In general, wave energy was greater during reconfiguration events compared to steady events. For 1999 and 2001, wave energy averaged over 5–10 days showed the best relationship to event type. For 2002, wave energy averaged over 1–5 days appeared to show the best relationship to rip channel behaviour. This gives an indication that rip channel systems with smaller spatial scales, such as was seen in 2002, change more quickly in relation to changes in the wave conditions than systems with larger scales.

Ortega-Sánchez et al. (2008) carried out a study on the relationship between beach-face morphology (particularly beach cusps) and wave conditions. Results of this study indicated that the wave energy and duration for which certain wave conditions are maintained are vital in determining whether beach morphology will respond and the response time. The analysis showed that the evolution time of the beach depended on the energy of the waves. It seemed that H_s was the determining factor in how fast the beach changed from one morphological state to another. Ortega-Sánchez et al. (2008) found that for higher energy waves, the changes could be produced in a much shorter time that for lower energy waves. Due to this need for wave conditions to be maintained for a period of time, there were times when the wave conditions changed but there was no change in the morphology.

From comparisons of the duration of wave events to rip channel behaviour for 1999–April 2002, wave duration is obviously critical however it does not appear that there is a ‘magic number’ that defines the threshold for the duration that H_s or energy must exceed to cause a change in the rip behaviour. For example, for a duration time series of H_s greater than 2.5 m for 1999, the duration to cause a reconfiguration event was variable at 120, 40 and 10 hours for the three reconfigurations. For 2001, the duration of H_s greater than 2.5 m during reconfiguration events were for zero and 100 hours and for 2002 zero hours, meaning the beach responded in less than three hours (although the resolution of the video data is rarely less than one day). These differences could relate to the magnitude of the reconfiguration event, e.g. how much of a new rip channel configuration the system acquired, perhaps the previous wave conditions, and almost certainly the scale of the rip channels. As mentioned earlier, bigger rip channels (i.e. those that extend far seaward) will require higher wave conditions to be reworked than smaller scale rips. In order to begin to understand the complex set of conditions that affect rip channel behaviour, a first step is to engineer a conceptual model.

For 1999 and 2001 wave duration time series using H_s of 2–3 m appeared to show the best relationship to rip channel behaviour. For 1999 and 2001 it appeared that H_s had to be greater than 2.5 m for ~40–50 hours for a reconfiguration event to occur. For 2002, a duration time series with H_s greater than 1 m appeared to show the best control over rip channel behaviour. In general, it appeared that the duration of wave energy instead of H_s gave the best relationship to event type with peaks occurring only during reconfiguration events. A wave event lasting for only a short period of time may not have any effect on rip channel configuration whereas a longer event of the same magnitude might. Figure 6.10e shows that for the duration of wave energy greater than 2.5 Mgs^{-2}, although there were peaks in the magnitude during reconfiguration events, there were also peaks during steady events. This suggests that it is not just the duration of a wave event that is the key in causing reconfiguration events.

6.9.2 Rip Channel Scale

A key observation suggesting that rip channel scale plays a vital role in determining rip channel behaviour was seen in 2001. During 2001 there were two reconfiguration events found using the measure of change (Figure 6.4) (Event Four and Event Five). However, Figure A2.2 shows that there were two other instances when wave energy (averaged over 10 days) reached considerably high magnitudes. At day 190 in 2001 wave energy reached 6.3 Mgs^{-2} and on day 250 reached 7.5 Mgs^{-2}. During the two reconfiguration events in 2001, wave energy reached maxima of 3.8 and 7.5 Mgs^{-2}. This would suggest that perhaps the latter two high energy events should also have caused rip channel reconfiguration events. However, comparing rip channel scales between these high energy events gives an indication of what may cause the differences in rip channel behaviour under high wave energy conditions.

During the third and fourth high wave energy events in 2001 when they were not classed as reconfiguration events, the mean surf-zone width was much wider than the prior two events, at ~120 m or more as opposed to ~80 m. This means that the bar at the seaward ends of these rips was deeper than during the previous two high wave events. Therefore, larger waves were needed to break over the bar and cause rip channels to reconfigure. In this case rips extending ~120 m cross-shore at Tairua Beach appear to need wave energy (averaged over 10 days) greater than 7.5 Mgs^{-2} to reconfigure.

6.9.3 Rip Scale, Wave Intensity and Duration

Results suggest that rip channel scale, intensity of wave event (i.e. wave energy) and wave event duration are three key factors that interact and determine how rip channels behave in response to waves. Results also suggest that rip channels do not respond instantaneously to changes in the wave conditions, but that there is a lag-time which depends on the combination of rip spatial scale, wave event intensity and duration. This complicated relationship between rip channel spatial scale, wave event intensity and duration together with its relationship to lag-time in rip channel response to changes in waves shows why past attempts to correlate rip channel behaviour (e.g. alongshore spacing) to immediate, instantaneous measures of the wave conditions have yielded poor relationships.

Jiménez et al. (2008) commented that beaches do not respond instantaneously to wave forcing and that an instantaneous morphodynamic state parameter ($\Omega = H_b/(w_s T)$) alone does not accurately predict beach state statistics, as was also observed by Wright et al. (1985). Smit et al. (2008) hypothesised that spatial scales of morphology observed in the surf-zone are seldom in equilibrium with the instantaneous wave conditions due to the slow response of sand-bars/ rips. Wright and Short (1984) noted that during low intensity (i.e. low energy) events, surf-zone morphology will take longer to respond than during high intensity events. This concept of a lag-time in rip channel response to changes in wave conditions is crucial when attempting to relate rip channel behaviour to wave conditions.

Jiménez et al. (2008) also found that wave forcing intensity (i.e. wave energy level) and the duration of wave events are also key factors in determining the morphology of the nearshore. It was also noted that the time it takes for a beach to reach equilibrium morphology depends on the previous morphological configuration. This observation is the same as found in this thesis: rip channel morphology (spatial scale) prior to a reconfiguration event and the wave energy (intensity) and duration determines if and how rip channels will respond.

Jiménez et al. (2008) and Wright et al. (1985) recommended averaging Ω-values for a period of time prior to observation to increase the accuracy of prediction of beach-state. Results found by Jiménez et al. (2008) suggest that the period of time over which to average Ω-values depends on the wave energy, e.g. for lower energy wave conditions the averaging period should be longer. This idea could be used for rip current behaviour. For example, perhaps for lower energy wave conditions, wave energy could be averaged over a longer period of time than during higher energy wave conditions.

Due to lag-time in response of surf-zone morphology to changes in wave conditions, the relatively fast-changing wave conditions may hence prevent the beach evolving to a state to match the conditions (Smit et al., 2008). Therefore, any beach state is likely correlated to the sequence of past conditions rather than to the actual conditions (Smit et al., 2008). This relationship of morphology to past conditions is a function of the intensity and duration of wave events and the time required for a particular morphology to evolve, which is proportional to the volume of sand to be redistributed (Wright and Short, 1984).

Smit et al. (2008) stated that to understand why surf-zone bathymetry has a certain morphology there are three questions, which also relate to understanding rip channel morphology:

(1) What is the intention of the system, e.g. if wave conditions were infinitely constant how would the morphology respond?
(2) How long does it take for the morphological response to develop?
(3) How does the antecedent morphology affect the morphological evolution?

There is a similar suite of questions to ask when trying to understand why rip channel morphology has a certain configuration at any one time. These questions are explored in the following chapter.

6.10 Summary

Rip channel behaviour in regard to change in alongshore location with time was defined as steady or unsteady (i.e. a reconfiguration event) using a measure of change. Significant wave height appeared to show some relationship to rip channel behaviour, where generally higher H_s appeared to correspond to reconfiguration events. Using measures of wave energy to take into account the previous wave conditions showed a much better relationship to rip behaviour, as did the duration of wave events. There did not appear to be one threshold of wave magnitude for which the duration determined when reconfiguration events occurred. This is likely due to factors such as rip channel spatial scale, magnitude of the reconfiguration event and the previous wave conditions. There were no ‘magic numbers’ found to show if, for example, rip channels of a particular spatial scale will respond to a wave event of a certain magnitude and or duration. However, the significance of the interaction between rip channel spatial scales, previous wave conditions and the duration of wave events is demonstrated. The next step to understand how wave climate affects rip channels was to develop a conceptual model for how rip channels respond to changes in the wave conditions. This conceptual model is presented in the following Chapter Seven.

Chapter Seven: Conceptual Model

7.1 Introduction

Chapter Five showed that rip currents changed significantly and experienced reconfiguration and partial reset events. In one case even a total reset of the system. Chapter Six went some way toward characterising the rip channel and wave conditions leading to reset events. The purpose of this chapter is to summarise these findings into a conceptual model for how rip channels respond to changes in the wave conditions. This conceptual model summarises the results and observations made in Chapters Five and Six.

7.2 Key Observations

From observations of rip channel behaviour presented in Chapters Five and Six, there are several key observations that appear to be critical in determining whether or not a particular rip channel with a certain spatial scale (i.e. morphology) will respond to a change in the wave conditions, and how the rip channels may respond. Rip channel spatial scale (i.e. cross-shore extent) appears to have at least as much influence as the wave conditions in determining how rips will behave. Below is a summary of key observations made during Chapters Five and Six that appear to be key factors in determining rip channel behaviour during wave events.

Whether or not a rip channel will respond to a change in the wave conditions appears to depend on the following:

i) If the waves are of a sufficient magnitude to affect the rip (which is dependent on rip spatial scale, where bigger rip channels require bigger waves) and are above a threshold for a sufficient period of time.

This threshold is likely to depend on how big the wave conditions are, e.g. a longer duration is required for rips to respond to lower magnitude wave conditions.

ii) If relatively low wave conditions remain constant for a long enough period of time (which is again dependent on rip spatial scale, where bigger rips require a longer period of time).

The duration for which wave conditions were greater than a threshold affects how rips will respond to changes in wave conditions. For example, the duration of H_s greater than 2–3 m and wave energy averaged over two days showed the best relationship to rip channel behaviour. The duration required to cause changes in rip channel behaviour is dependent on rip spatial scale where bigger rips require a longer duration. Previous wave conditions appear to be vital, e.g. in general, wave energy averaged over 5–10 days to take into account the previous wave conditions showed the best relationship to rip channel behaviour (where behaviour refers to the alongshore rip location stability with time). The lag time in rip channel response to waves depends on the spatial scale of the rip channel compared to the magnitude of the wave condition (for example, relatively large rips take longer to respond to changes in wave conditions).

It appeared that at Tairua Beach there are two main types of rip channel systems: (1) a narrowly spaced system (small scale) consisting of many (~8) closely spacing rips; and (2) a widely spaced system (large scale) consisting of fewer (5) relatively widely spaced rips. It appears that when the system is narrowly spaced, different ways of presenting wave energy and duration compared to during a widely spaced system show the best relationship to rip behaviour. During the narrowly spaced system, wave energy averaged over 1–5 days and the duration of H_s greater than 1 m showed the best relationship to rip behaviour. Conversely, during the widely spaced system wave energy averaged over 5–10 days and the duration of H_s greater than 2–3 m showed the best relationship to rip behaviour. This difference in relationship suggests that the narrowly spaced system responded more easily (e.g. does not require wave conditions as large) and faster (e.g. less of a lag time due to smaller rips) to changes in wave conditions.

From the above observations, a list of factors that are likely to be critical in a conceptual model of rip channel response to changes in wave conditions include:

(1) Rip channel spatial scale (morphology);
(2) Magnitude of the wave conditions (wave energy);
(3) Duration of wave event (greater than an threshold);
(4) Previous wave conditions;
(5) Lag time of rip response to change in wave conditions.

Note that these factors do not act independently of each other but are inherently linked.

7.3 Reconfiguration Events

Below a summary is presented of the six reconfiguration events found with the associated measure of change. A summary of rip channel and wave characteristics prior to, during and after each event is shown in Table 7.1.

Reconfiguration Event One: Prior to Event One, the mean surf-zone width was 69 m. During the event, H_s reached a maximum of 3.5 m. Wave energy reached a maximum of 6300 kgs^{-2}. Significant wave height was greater than 2.5 m for ~120 hours and wave energy was greater than 5000 kgs^{-2} for 11 hours, both of which were long periods compared to the other reconfiguration events. From observations of imagery, the biggest change to the surf-zone occurred during this event. During Event One, half of the rips disappeared (the spacing increased) and the bar straightened with a longshore trough developing in the centre of the beach (Figures 6.12a and 6.12b), i.e. an upstate transition. Mean rip channel spacing and spacing standard deviation changed the most of all the events (Table 7.1).

Reconfiguration Event Two: Prior to Event Two the mean surf-zone width was 82 m. During the event H_s reached a maximum of 3.5 m and wave energy reached a maximum of 5000 kgs^{-2}. Significant wave height was greater than 2.5 m for ~30 hours and wave energy was greater than 5000 kgs^{-2}for ~4 hours. Observations of imagery indicated that during Event Two there appeared to be little change to the surf-zone morphology (e.g. although rip currents experienced alongshore movement during the event, the number of rips and beach state did not change) (Figure 6.12c and 6.12d).

Reconfiguration Event Three: Prior to Event Three the mean surf-zone width was 83 m. Significant wave height reached a maximum of 3 m during the event and wave energy reached a maximum of 6300 kgs^{-2}. Significant wave height was greater than 2.5 m for ~40 hours and wave energy was greater than 5000 kgs^{-2} for ~7.5 hours. Observations of imagery indicate that during Event Three there was little change to the surf-zone morphology (Figures 6.12e and 6.12f).

Reconfiguration Event Four: Mean surf-zone width prior to Event Four was 69 m. During Event Four, H_s reached a maximum of only 2 m and the maximum wave energy was just 3800 kgs^{-2}. Significant wave height was never greater than 2.5 m or wave energy greater than 5000 kgs^{-2}. The mean surf-zone width prior to Event Four was relatively small, however it is important to note that there appeared to be two different morphologies present: a wide, stable surf-zone to the north and a narrow, rapidly changing surf-zone to the south. From observations of imagery during Event Four, the large surf-zone hardly changed whereas the smaller southern half became wider and more rips developed (Figures 6.12g and 6.12h).

Reconfiguration Event Five: Prior to Event Five the mean surf-zone width was 85 m. Significant wave height reached a maximum of 5 m and wave energy reached a maximum of 8800 kgs^{-2}. Significant wave height was greater than 2.5 m for ~100 hours and wave energy was greater than 5000 kgs^{-2} for ~7.5 hours. Observations of imagery indicate that during the event there was little change to the surf-zone.

Table 7.1. Wave and rip channel characteristics for each reconfiguration event. *SZW* is mean surf-zone width and *T* is mean wave period.

Reconfiguration Event number	1	2	3	4	5	6
Year	1999	1999	1999	2001	2001	2002
Julian Days (from-until)	94-122	252-271	311-325	48-63	112-127	69-74
Duration (Days)	29	20	15	15	16	6
Duration H_s >2.5 m (Hours)	120	40	10	0	100	0
Duration Energy> 5000 kgs^{-2} (Hours)	11	4	7.5	0	7.5	2
$Energy_{max}$ (kgs^{-2})	6300	5000	6300	3800	8800	2500
$H_{s\ max}$ (m)	3.5	3.5	3	2	5	2.5
Wave T_{max} (s)	11	10	10	8	8	8
Mean *SZW* (before/after) (m)	69/86	82/70	83/89	69/87	85/121	59/69
Difference (m)	17	8	6	18	36	10
No. rips (before/after)	8/5	5/5	4/6	5/7	5/5	5/9
Rip spacing (before/after) (m)	144/366	256/320	360/264	286/168	238/280	216/144
Difference (m)	222	64	- 96	-118	42	-72
Rip spacing std (before/after) (m)	72/253	81/110	110/255	114/63	88/70	126/46
Difference (m)	181	29	145	-51	-18	-80

morphology (Figures 6.12i and 6.12j).

Reconfiguration Event Six: The mean surf-zone width prior to Event Six was 59 m. The maximum H_s was just 2.5 m and the maximum wave energy was only 2500 kgs^{-2}. Event Six had no H_s greater than 2.5 m. The duration of wave energy greater than 5000 kgs^{-2} was just two hours. From observations of imagery there was a small amount of change to the surf-zone morphology with four more rips developing (Figures 6.12k and 6.12i). There was little change to the mean surf-zone width, while mean rip channel spacing and spacing standard deviation decreased (Table 7.1).

7.4 Upstate and Downstate Transitions

Figures 7.1 and 7.2 show that some of the reconfiguration events were upstate transitions and some were downstate transitions (see Wright and Short, 1984). Figure 7.1 shows that with regard to mean rip channel spacing, there were three downstate transitions and three upstate transitions. Shorter durations of high H_s were associated with a decrease in mean rip channel spacing (alongshore) and hence downstate transitions. Longer durations of high H_s were associated with increases in mean rip channel spacing and hence upstate transitions.

Figure 7.2 shows that with regard to the number of rip channels, there were three downstate transitions, one upstate transition and two cases when the beach state did not appear to change. As was shown in Figure 7.1, upstate transitions appear to be associated with longer durations of high waves (i.e. energy) and downstate transitions with shorter durations of high waves.

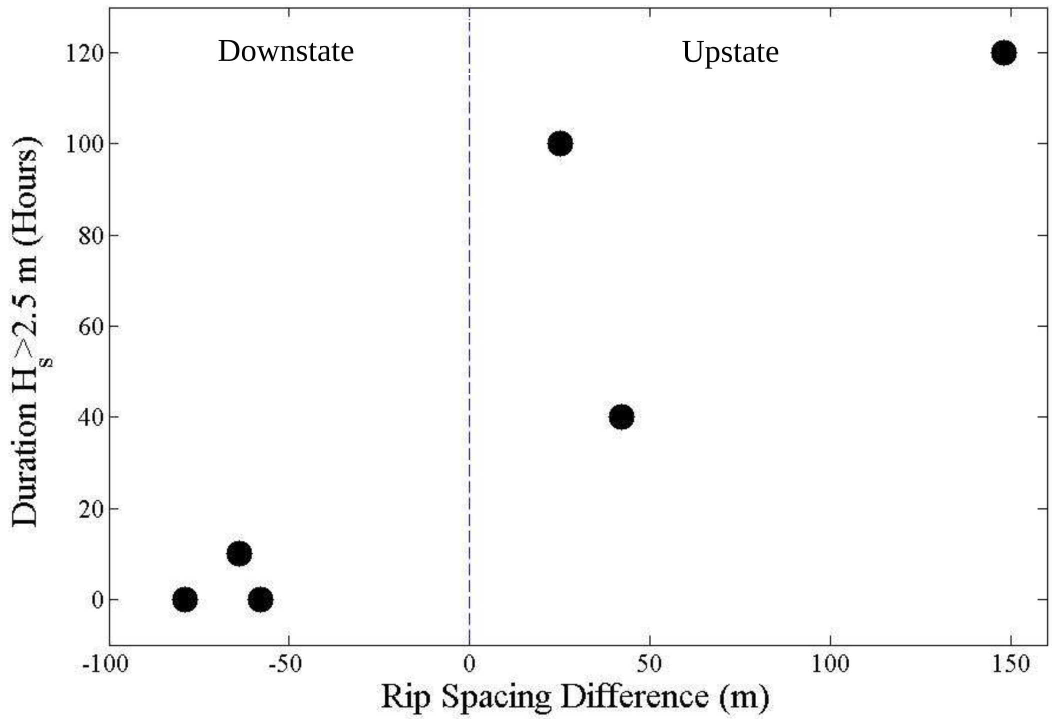


Figure 7.1. Mean rip channel spacing difference between before and after reconfiguration events 1-6 and duration of Hs greater than 2.5 m during each event. Dashed line indicates the boundary between a downstate and upstate transition.

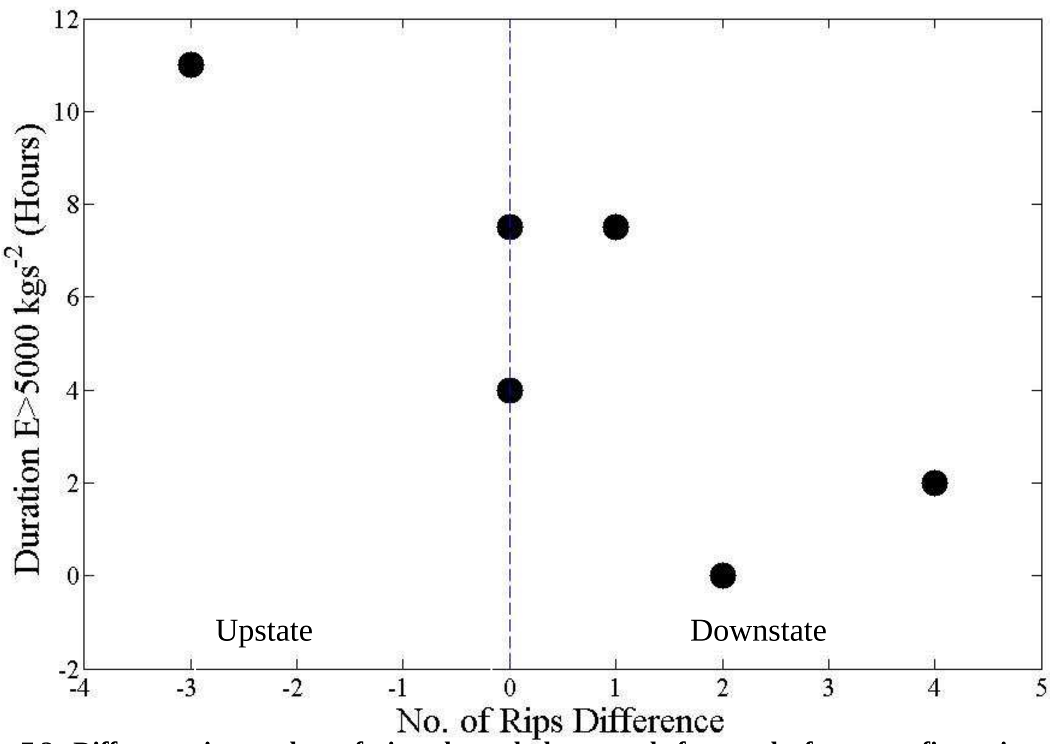


Figure 7.2. Difference in number of rips channels between before and after reconfiguration events 1-6 and duration of Hs greater than 2.5 m during each event. Dashed line indicates the boundary between an upstate and downstate transition.

7.5 Rip and Wave Scales

A conceptual model was created to demonstrate how rip channels appear to respond to changes in wave conditions. There are four main combinations of rip channel spatial scale and wave magnitude. These combinations were found by comparing the maximum wave energy (averaged over 10 days) during each reconfiguration event and the mean surf-zone width (to represent rip channel cross-shore extent) prior to each event. Small rips refers to rip channels that had relatively small spatial scales in relation to the wave energy that was usual at Tairua and vice versa for large rips. Figure 7.3 illustrates a flow diagram of the conceptual model. Table 7.2 shows a summary of the different combinations of rip channel scale and wave event magnitudes.

The wave conditions prior to any reconfiguration event are essential as they will determine the surf-zone morphology. The previous wave conditions can also affect what type of rip channel system is present, fewer (5 at Tairua) widely spaced rip channels or more (~8 at Tairua) narrowly spaced rip channels (both regularly spaced alongshore). There are four basic combinations of rip and wave scale summarised below.

(1) Same Rip and Wave Scale

Event Six had relatively small rip channel morphology and small waves. Events Two, Three and Five had relatively large rip channel morphology and large waves. When the magnitude of the wave energy is a similar scale to the rip channel morphology (e.g. the small spacing configuration observed in this study combined with smaller than average waves, or rip channels with larger spatial scales with larger than average waves) the rip channel may respond if the wave conditions are constant for a sufficient duration. The time required (the threshold) for conditions to remain constant to cause a rip channel response will be longer for rips of a larger scale and vice versa for smaller-scale rip channels. There is likely to be a medium lag-time for the response of the rip channel to the change in the wave conditions and a medium changes to the rip/ surf-zone morphology. The same argument applies to the conditions described at the top left of Table 7.2 which corresponds to observations related to Event Four (Table 7.1).

(2) Small Rip Scale with Large Waves

Event One had relatively small rip channel morphology when large waves occurred. When the scale of the rip channel morphology is small relative to the magnitude of the new wave energy the rip channel will likely respond to the change quickly (i.e. short lag-time). Further study is required, but it appeared that when wave energy was large relative to the scale of the rip, the rip channel disappeared, the bar straightened and the beach began a complete reset (i.e. a large change to the surf-zone morphology). The beach may only reach a total reset if wave energy is large enough relative to the scale of the rip channel and/ or they last for a sufficient duration.

(3) Large Rip Scale with Small Waves

Event Four had relatively large rip channel morphology and small waves. When the scale of the rip channel is large relative to the magnitude of the wave energy, it is not likely that the rip channel will respond to the change in the wave conditions. The rip channel may only respond if the wave conditions remain constant for a long duration. The lag-time of rip channel response to a change in the wave conditions for large rips with small waves is likely to be long. There will be a small change in the surf-zone morphology where it will likely move towards a smaller scale system i.e. smaller, more closely spaced rip channels.

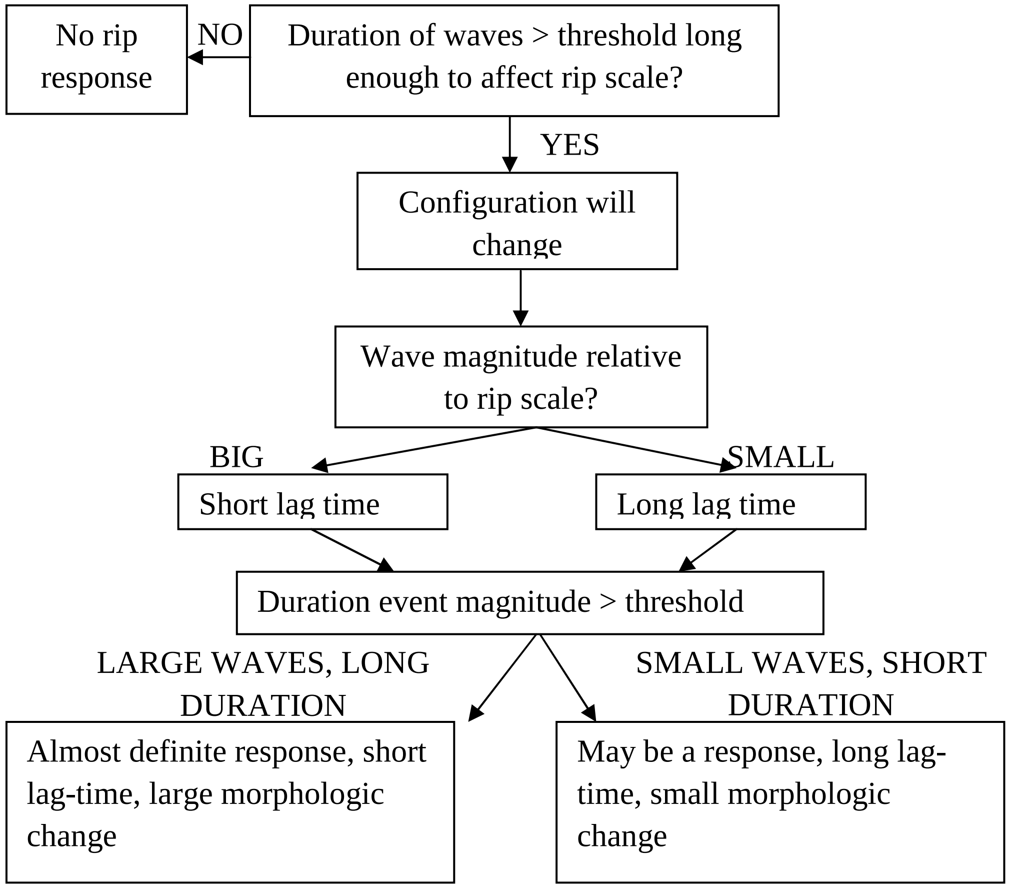


Figure 7.3. Conceptual model diagram of how a single rip channel with a particular cross-shore extent may respond to changes in wave conditions. Thresholds vary and are greater for larger rip channels.

Table 7.2. Summary of conceptual model for response of rip channels with different scales to wave energy of different magnitudes. The scale of the rip morphology refers to the mean surf-zone width prior to each event.

Magnitude of Wave Energy (↑)

SMALL RIPS, LARGE WAVES Event One, 2000 Reset ▪ Will almost definitely respond to waves. ▪ Short lag-time. ▪ Large change in morphology: rip channel disappears; bar will straighten heading towards a total reset.	**LARGE RIPS, LARGE WAVES** Events Two, Three and Five ▪ May respond if waves are constant for a long duration. ▪ Medium lag-time. ▪ Medium change in morphology.
SMALL RIPS, SMALL WAVES Event Six ▪ May respond if waves are constant for a long duration. ▪ Medium lag-time. ▪ Medium change in morphology: wider trough develops.	**LARGE RIPS, SMALL WAVES** Event Four ▪ May respond if waves are constant for a long duration. ▪ Long lag-time. ▪ Small change in morphology: head towards smaller scale system.

Scale of Rip Morphology (seaward extent) (→)

7.6 Summary

A conceptual model for the response (or lack of-response) of rip channels to changes in the wave conditions was created. This conceptual model was based on the assumption that the morphology (e.g. spatial scale) of a rip channel is at least as essential as the wave conditions in determining if and how rip channel will respond to a change in the wave conditions. The conceptual model also noted how central the previous wave conditions are (which in turn creates the scale of rip morphology) to rip channel behaviour. The spatial scale of a rip channel relative to the magnitude of the wave conditions will determine whether or not a rip channel will respond to a change in the wave conditions (e.g. when wave conditions are small relative to the size of the rip current, the rip may not respond unless the conditions are constant for a sufficient period of time). When the wave conditions are large relative to the spatial scale of the rip channel, a response of the rip channel to a change in the wave conditions will likely occur quickly and there will likely be large changes to the rip morphology.

Chapter Eight: Conclusions

8.1 Introduction

Rip currents and what drives them are still a very poorly understood phenomenon. The lack of understanding is often attributed to a lack of quality long-term data-sets. Past attempts to relate rip currents to waves have generally resulted in poor relationships. For this thesis, the general objective was to uncover the processes responsible for the spatial and temporal variation and morphology of rip currents. To achieve this goal, an improved technique was created that consisted of a suite of computer algorithms to locate rip channels as light intensity minima in rectified, time-averaged video images of the surf-zone. The 3.3 year data-set of Tairua Beach created with these algorithms was used to study rip channel behaviour at Tairua Beach. Rip channel behaviour was compared to waves focusing on the shifts in rips and waves. Rip channel reconfiguration events were defined using a measure of change. These events were compared to wave energy and the duration of wave events. Below a summary of the main findings of these thesis is given.

8.2 Rip-Locating Algorithms

An improved method to locate rip channels in video imagery of the surf-zone was created. Past methods to locate rips in video imagery such as Ranasinghe et al., 1999 and Bogle et al., 1999 have searched just one alongshore transect or a transect which represents an average of the cross-shore light intensity distribution. Moreover, the thresholds they employed did not work universally and so these methods have not been widely implemented. An improved technique was created in this thesis where computer algorithms searched the entire alongshore and cross-shore expanse of the surf-zone for minima corresponding to rip channels. The shoreline and barline were also located using computer algorithms and rips were assumed to exist only between these limits. The light intensity minima were then sorted into distinct rip channels based on connectivity of minima. Some of these separate rips were merged if they were close enough together to be the same rip, removed if they were too small to be a rip, and rips/parts of rips were removed that did not correspond to a perturbation in the barline or shoreline, as was required by the rip channel definition for this thesis. The algorithms were tested with a wide variety of video images (e.g. with a wide variety of surf-zone morphology) and they were found to work well in most cases. The algorithms were used on three years and four months of time-averaged video images from Tairua Beach, spanning from 1999 to April 2002. The algorithms to locate local maxima and minima were also tested on Muriwai Beach and appeared to work well.

8.3 Rip Currents at Tairua Beach

Over the period of study it was found that at Tairua Beach there were periods of time when rip channel spacing appeared to be relatively regular alongshore and stable with time (steady), and other times when rip channel spacing was irregular alongshore and unstable with time (unsteady\reconfiguration events). There is much debate over whether rip channels are regularly or irregularly spaced alongshore. This study shows that rip channels can be both regularly (such as found by Huntley and Short (1992), Short and Brander (1999) and MacMahan et al. (2005)) and irregularly spaced alongshore (such as found by Holman et al. (2006) and Turner et al. (2007)). Results found in this study appear to be similar to those found by Symonds et al. (1997) who found that rip currents could change from being regularly to irregularly spaced alongshore.

There also appeared to be two main types of stable rip system behaviour: there were periods of time when there were ~8 rips relatively closely (and regularly) spaced alongshore at ~200 m (narrowly spaced system), and periods of time when there were ~5 rips relatively widely (and regularly) spaced alongshore (a widely spaced system) at ~300 m. It is unclear what caused the system to have these two different stable patterns. However, during one of the two narrowly spaced events which were stable during 2002, the wave conditions were unusually low over the period of time when the narrowly spaced system developed. In summary, there is some evidence for down-state transitions associated with less energetic wave events although more data is needed to provide the mechanism for the switch between a narrowly-spaced and a widely spaced rip channel system and vice versa.

The presence and importance of headland rips was demonstrated at Tairua Beach. It was found that rip channels had a tendency to form and persist at the headlands (Figure 5.13). Headland rips were also noted as important by Short (1985). It appears that headlands rips are dominantly topographically-controlled as opposed to hydrodynamically-controlled. The headland rips can dominate average signals (such as the mean rip current angle), and make relationships to waves difficult to quantify.

Another observation at Tairua Beach relating to the presence of the headlands was the development of a ‘dual surf-zone’. The offshore islands could shadow part of the beach during certain wave angles, allowing rip channels on half of the beach to grow large while rips on the other half remained small. The presence of this dual surf-zone showed the how central rip channel scale (i.e. cross-shore extent) is in determining how rip channels behave. During the presence of the dual surf-zone, the smaller rips were observed to change rapidly while the larger rips were very stable. This shows the presence and importance of hydrodynamic-control and topographic-control of rip channels. Topographically-controlled rip channels will show a poor, if any relationship to the current wave conditions which gives an indication of why previous attempts to compare rips and waves have failed. Short (1985) and Turner et al. (2007) both noted that after rips form they become rapidly topographically controlled. This appears to be the case at Tairua Beach, when rips are formed/ reworked during relatively high wave conditions then the wave conditions become lower. This is consistent with the suggestion by Eliot (1973) that only some rips persist for long periods of time and that persistent rip channels are created during high energy events. During 2002, some rips persisted for ~400 days and were reworked after a long period of low wave energy. This is consistent with the ideas of Eliot (1973) and Short

(1985) who suggested that topographically controlled rips could be reworked by low energy waves when the waves were constant for a sufficient duration.

8.4 Reconfiguration Events

Past attempts to compare rip channel behaviour to wave conditions have consisted of the traditional time-series approach to correlate rip channels to waves. For this thesis it was decided to focus on periods of large changes in rip channel behaviour in order to understand how they might relate to the wave conditions. A measure of change was used to define ‘reconfiguration events’ by measuring how much rip channels moved alongshore with time. Over the 3.3 year periods of study, the measure of change indicated that there were six reconfiguration events. There was also an additional period when there was a large amount of change to the rip channel configuration that occurred in 2000 but which was no indicated by the measure of change. This was likely due to missing data before and after the event as opposed to problems with the measure of change. ‘Reset events’ are often referred to in studies of rip currents and sand-bars, referring to when rip currents disappear and the barline straightens (i.e. the longshore bar-trough beach state as defined by Wright and Short (1984)). At Tairua Beach, the only time when the surf-zone appeared to reach a complete (or nearly complete) reset was during the large storm event in 2000. This lack of reset events shows that Tairua behaves differently from other beaches, perhaps because it is such a small embayed beach. The headland might cause a degree of persistence of rips hot shown in rip currents on longer beaches. For example, Holman et al. (2006) found that reset events occurred on averaged four times per year at the 2km long, embayed Palm Beach in Australia.

8.5 Rips and Waves

Past attempts to compare rip current behaviour to waves have resulted in poor relationships. These studies have tended to correlate rip channel characteristics with immediate, instantaneous measures of the current wave conditions (e.g. Holman et al.

(2006) and Turner et al. (2007)). When rip channel characteristics were compared to instantaneous H_s in this thesis, a poor correlation between rips and waves was also found.

In order to uncover how rips and waves interact, different measures of the wave conditions were compared to rip channel reconfiguration events. It was found that although there was some relationship between H_s and when the reconfiguration events occurred, this relationship was complicated by the presence of high magnitudes of H_s during periods of time when rip channel behaviour was not defined as a reconfiguration event (i.e. during steady periods). It was found that wave energy averaged over 2-10 days and the duration of high wave events showed a much better relationship to rip channel reconfiguration events than H_s. The importance of wave energy and duration was also noted by Ortega-Sánchez et al. (2008) and Jiménez et al. (2008). It appeared that for rip channel systems of a smaller spatial scale (such as in 2002) wave energy averaged over shorter periods (1–5 days as opposed to 5–10 days) showed a better relationship to rip reconfiguration events. This shows how essential the interaction between rip channel spatial scale and how long rip channels take to respond to changes in the wave conditions is. Rip channel spatial scale was found to be critical in determining how rip channels respond to changes in the wave conditions. For example, in 2001 it was found that wave energy that was greater than during the two reconfiguration events in 2001 did not cause rip channel to reconfigure as the mean surf-zone width was ~40 m greater.

A conceptual model was created to summarise how rips and waves of different scales might interact. The model focused on how a particular rip with a particular cross-shore extent might respond to a change in the wave conditions. The conceptual model indicated that when the rip spatial scale is relatively small (i.e. smaller than the average at Tairua) in comparison to the wave energy, these rips respond easily and rapidly and generally result in a large amount of morphological change to the surf-zone. Conversely, when the spatial scale of rips is large (i.e. larger than the average observed at Tairua) relative to the wave energy, these rips are not likely to respond unless the conditions remain constant for a sufficient period of time. The conceptual model provides the building blocks for beginning to understand how rip currents are related to waves, however more data and further analysis is required to quantify this relationship.

8.6 Embayed vs. Straight Beaches

It is important to remember in discussions of rip channel behaviour in this thesis that the study site was a relatively small (~1.6 km long) embayed beach with headlands at each end. This means that various factors that are central at Tairua Beach may not be as prominent at straight beaches. For example, headland rips played a very important role in the rip channel behaviour at Tairua, but on a straight beach they would be irrelevant and on a longer embayed beach have less influence on the overall behaviour of the system. Likewise a dual surf-zone due to wave shadowing is less likely to occur on a straight beach and would be less important on a longer embayed beach.

Turner et al. (2007) compared results from a long, straight beach (Surfers Paradise, Australia) to results from a 2km long embayed beach (Palm Beach, Australia) by Holman et al. (2006). Turner et al. (2007) noted that similarities in rip currents between the two sites included a lack of preferred alongshore rip channel locations in general and immediately after reset events, no clear correlations between the number of rips/mean rip channel spacing alongshore and offshore wave conditions, and alongshore rip channel spacing was highly variable and irregular. Differences found between the sites by Turner et al. (2007) included that it appeared that per km of beach there were less rips on the long, straight beach with mean rip channel spacing 20 percent larger. The mean duration of rip channel was much longer at the embayed beach (46 days as opposed to 8 days) thought to be due to more complex interactions between the inner and outer bars at the often double-barred long, straight beach. While there are differences in rip channel behaviour between long, straight beaches and embayed beaches, results from this thesis regarding the interaction between rip channel scale, wave energy and duration are still likely to be just as relevant and significant.

8.7 Recommendations for Further Research

While yielding some very useful results to indicate how rip channels and waves may interact, this study is by no means exhaustive and is only a step on the way to uncover how rips and waves relate. The following are recommendations for further research following on from this thesis:

i) It could be possible to refine the computer algorithms created to automatically only keep rip channels accompanied by a visible perturbation in the barline or shoreline. For this thesis rip channels were manually removed if they did not have a perturbation in the corresponding barline or shoreline. An algorithm could be created to locate perturbations in the barline and shoreline and only keep rip channels associated with these perturbations.

ii) In Chapter Five it was mentioned the possibility of two types of rip channel systems at Tairua Beach: (1) a narrowly spaced system contains many closely spacing rip channels with perhaps a wider surf-zone; and (2) a widely spaced system consisting of fewer widely spaced rip channels with a narrower surf-zone. It could be useful to analyse more years of images at Tairua Beach to see if there are other cases where the two types of systems are observed and then see what type of wave conditions caused the different systems.

iii) Development of a larger data-set and the finding of more reconfiguration events would be useful to begin to develop thresholds for how rips of certain scales (cross-shore extents) and waves of different magnitudes and durations related to each other. More data could help to locate thresholds of rip channel scale vs. wave energy and duration to indicate when rips may reconfigure. This could then be fed into the conceptual model. More data will also be useful to find out exactly how rip channel characteristics change during reconfiguration events such as spacing and numbers of rips.

iv) The conceptual model that has been created in this thesis was based on data from an embayed beach. It could be useful to also incorporate data from more embayed beaches and long, straight beaches to see how the beach configuration affects how rip channels respond to changes in the wave conditions.

v) Further research is required of how rip channel parameters besides rip channel spacing change with changes in the wave conditions. To do this it may be required to find a better way to represent each of these parameters for example, mean rip channel angle appears to be inappropriate due to the high level of rip channel angle variability alongshore.

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Appendix 1: Computer Algorithm Structure

Appendix 1 has a brief summary and flow diagrams with a description of the algorithms created to locate rip channels in time-averaged video images of the surf-zone.

Programme Structure for Image Rectification

The algorithms created for the rectification process and the links between them are shown in Figure A1.1. '*Imagechoose*' was used to select high quality images to rectify and analyse. '*Fullrectification*' was used to run '*Unrectify*' and rectify images, then to run '*Blackout*' to refine colour intensities in rectified images.

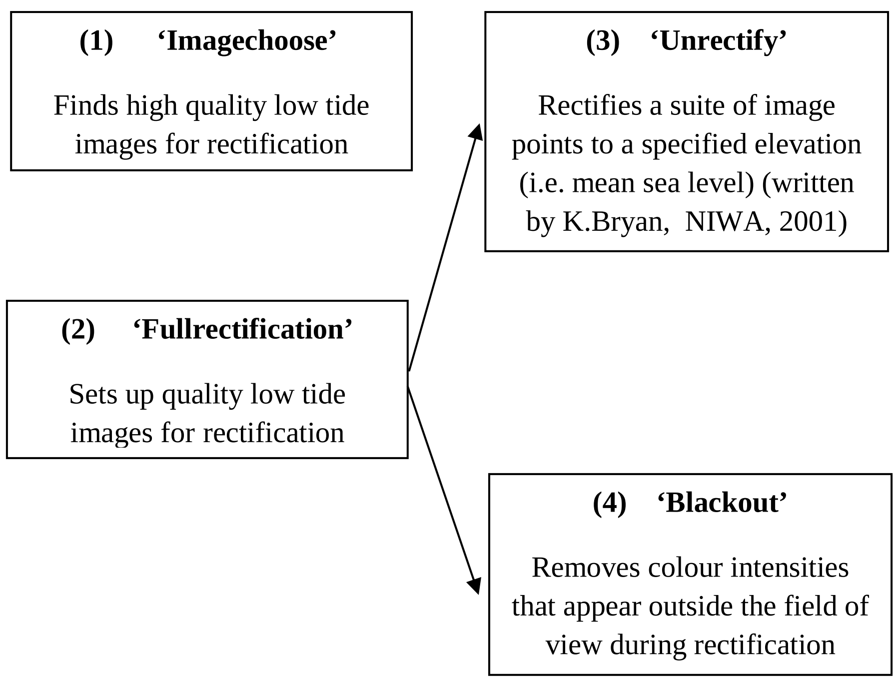

Figure A1.1. Schematic diagram of rectification programme structure. Arrows indicate that the algorithms were linked to each other. Numbers indicate the order the programmes were run in. Note that all algorithms unless otherwise specified were written by the author.

Programme Structure to Locate Minima

The algorithms created for the process to locate maxima and minima and the linkages between them are shown in Figure A1.2. '*Loadimages*' was designed to run the '*Barline'* and '*Shoreline*' algorithms before locating rip channels. A separate programme called '*Findrips*' was used to locate rip currents, with another programme called '*Cleanup'* to remove bar and rip channel points found that did not correspond to rips or bars.

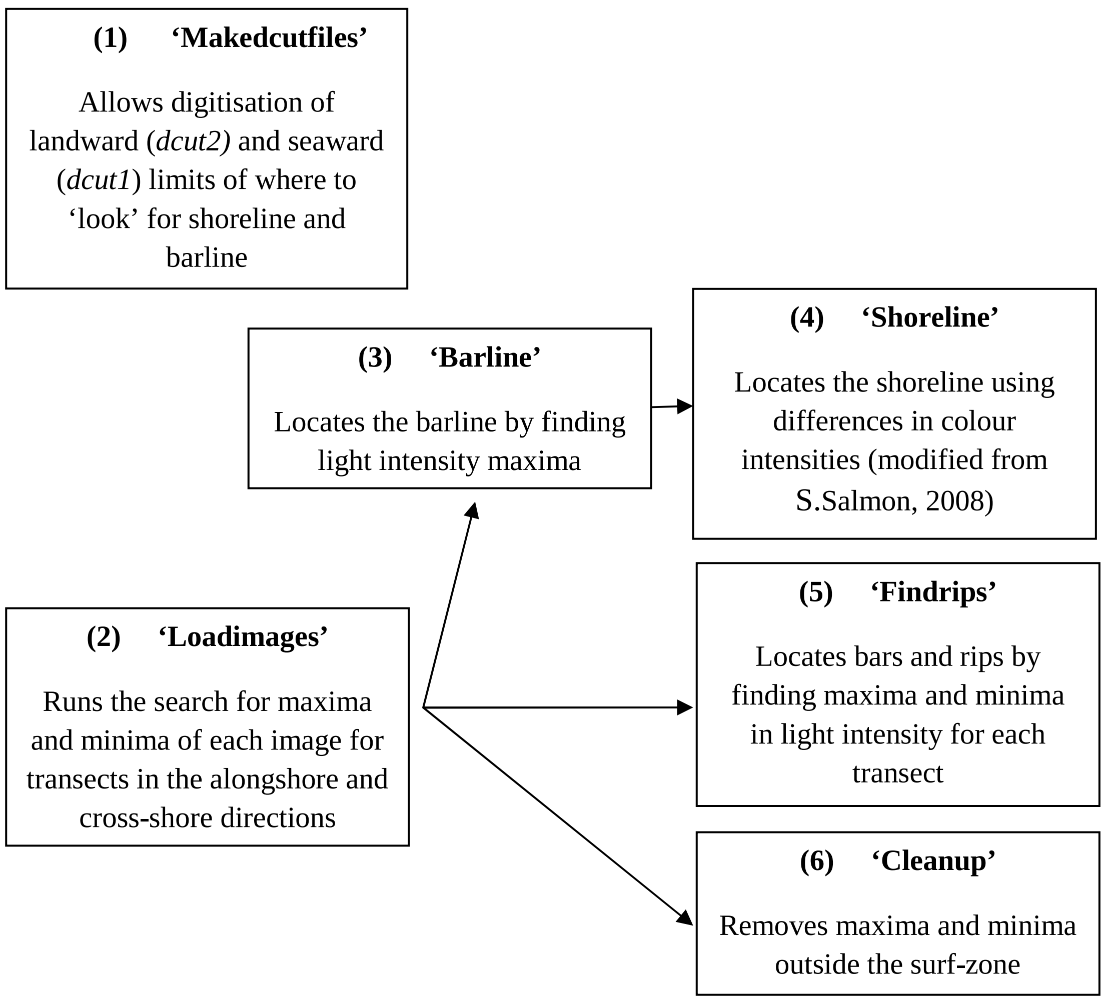

Figure A1.2. Schematic diagram of rip locating programme structure. Arrows indicate linkages between algorithms. Numbers indicate the order the programmes were run in. Note that all algorithms unless otherwise specified were written by the author.

Programme Structure for Defining and Refining Rips

The algorithms created for the process to define and refine the minima located into distinct rip channels and the linkages between them are shown in Figures A1.3 and A1.4. An algorithm called '*Gridrip*' was created to run '*Locaterips*' which put minima into separate rip channels.

Once '*Gridrip*' and '*Locaterips*' were finished, a algorithm called '*Ripedit*' was responsible for co-coordinating a set of algorithm to refine the rip currents found (Figure A1.4). '*Ripedit*' first ran '*Endpoints*' to merge rips, followed by '*removerips*' to remove rips that were too small, followed by '*manualsplit*' to manually split rip currents where required. The next step was to manually merge rips using '*Manualmerge*', after which '*Removerips*' was run again to remove rips that were too small. Next '*Manualremove*' was used to manually remove any remaining rips that appeared to not correspond to rip channels, followed by '*Poly*' which fitted polynomials to each rip channel, calculated the error and found the rip endpoints. The final algorithms '*Spacing*' and '*Meanblue*' found the mean rip channel spacing for each image and the mean intensity of blue light at each rip channel.

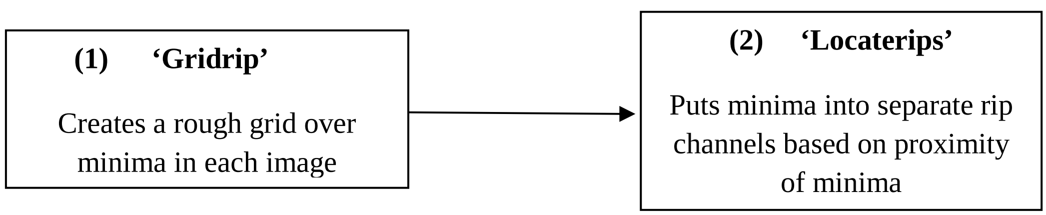

Figure A1.3. Schematic diagram of first part of rip defining algorithm structure. Arrows indicate linkages between algorithms and numbers indicate the order in which algorithms were run. Note that all algorithms unless otherwise specified were written by the author.

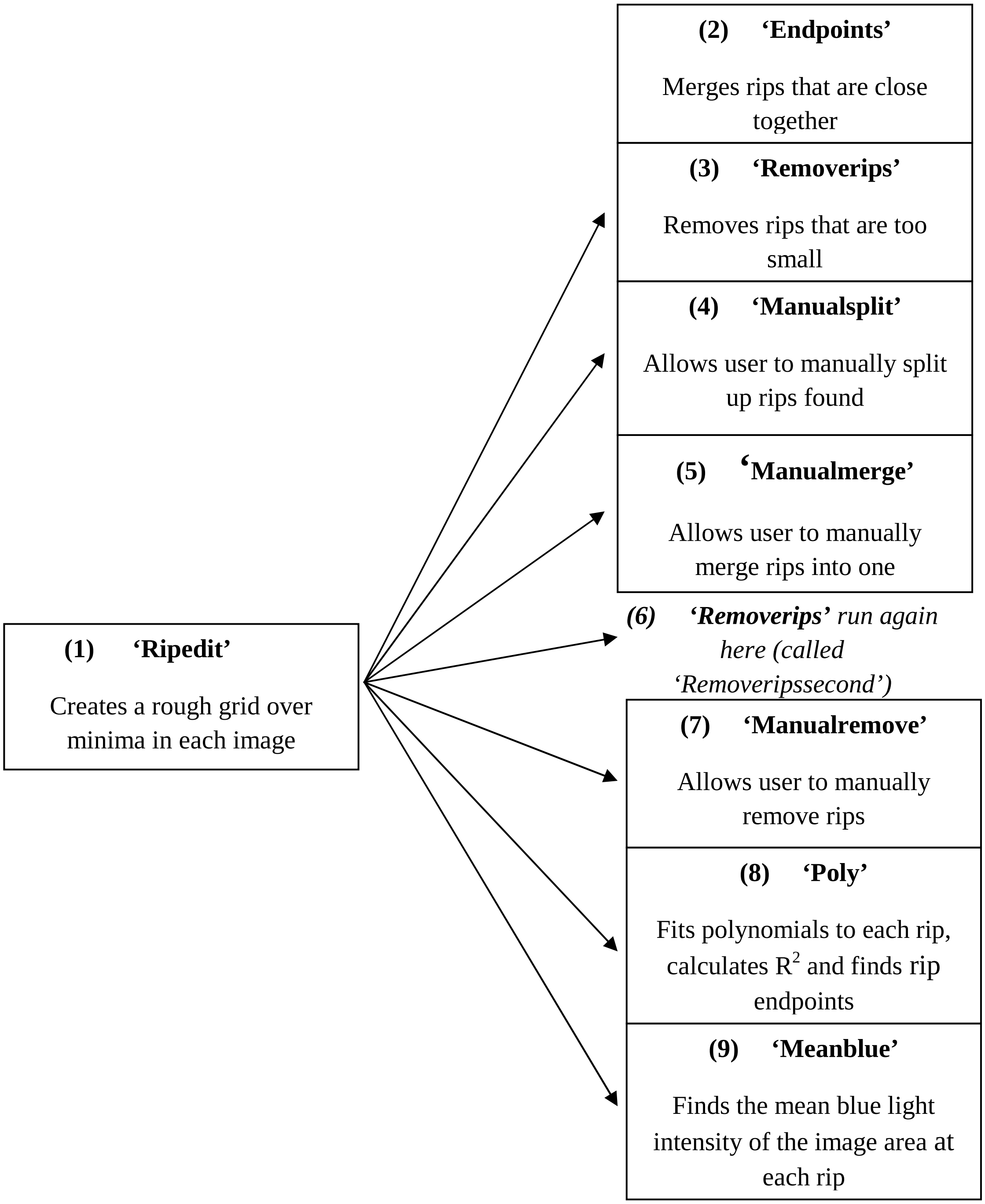

Figure A1.4. Schematic diagram of second part of rip defining algorithm structure. Arrows indicate linkages between algorithms and numbers indicate the order in which the algorithms were run. Note that all algorithms unless otherwise specified were written by the author.

Appendix 2: Figures and Tables

Appendix two has figures for the years 2001 and 2002. Each group of figures for each year show different ways of comparing waves to rip currents during reconfiguration events.

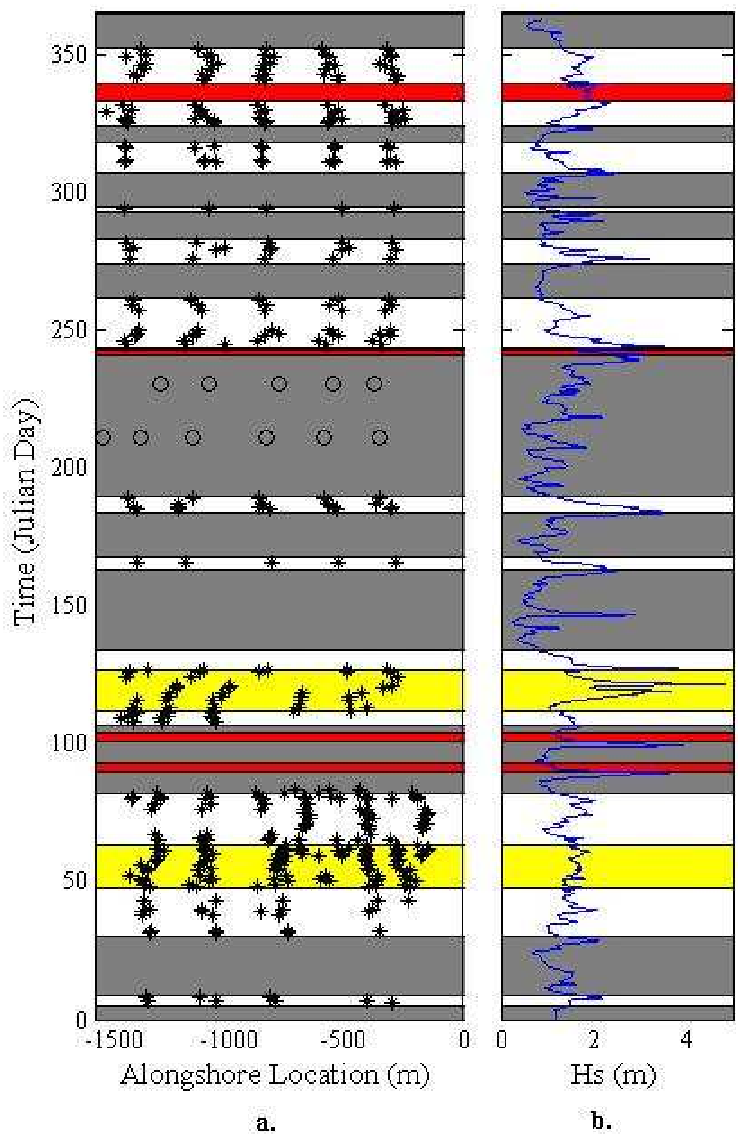

Figure A2.1. This figure shows rip channel and wave data from the year 2001. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low to make rip channels detectable by automatic algorithms, red areas indicate periods when wave energy was too high to make rip channels detectable by automatic algorithms and yellow areas indicate reconfiguration events. b. Shows significant wave height.

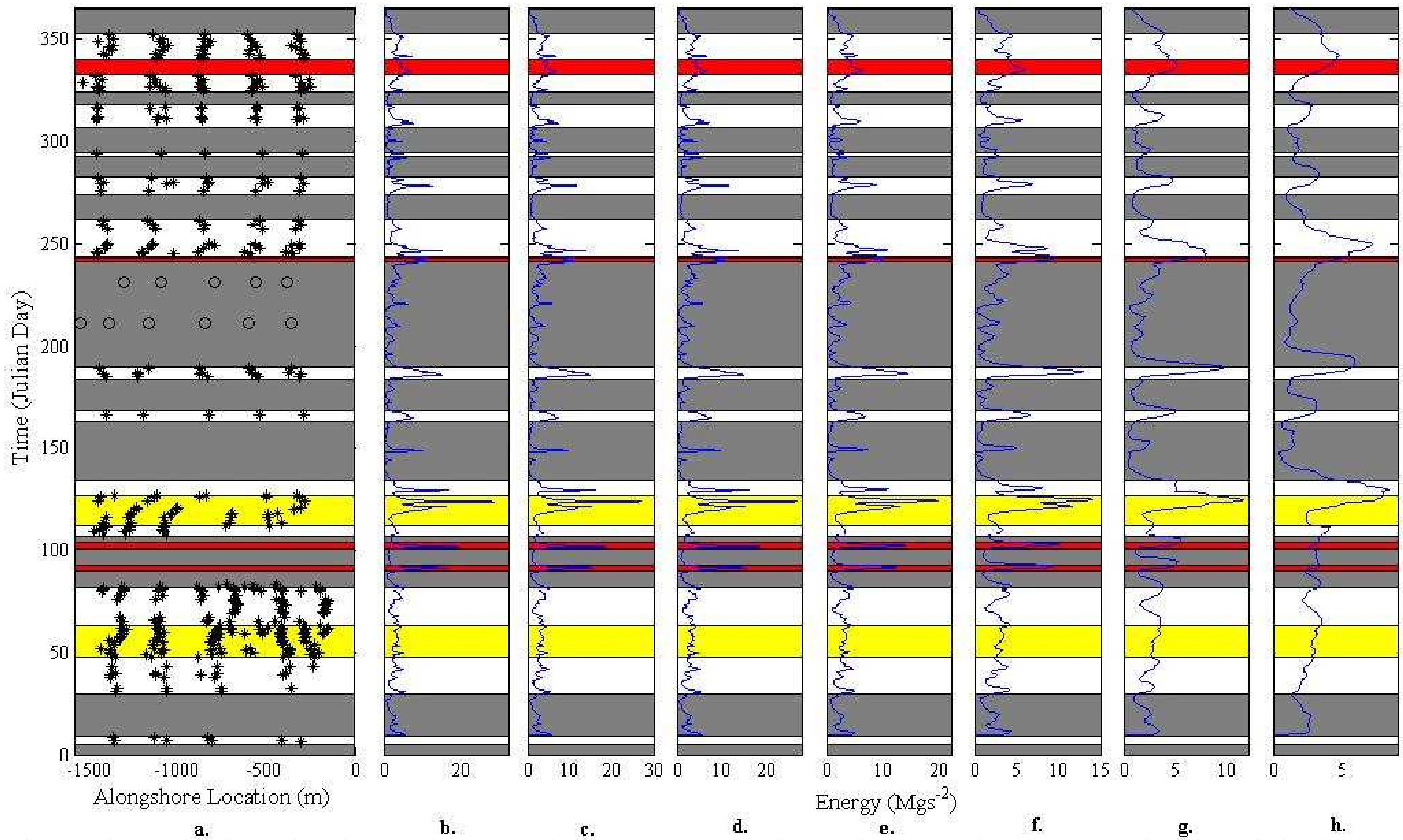

Figure A2.2 This figure shows rip channel and wave data from the year 2001. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. Grey and red areas indicate periods of time when wave energy was too low or too high (respectively) to make rip channels detectable by automatic algorithms, black areas indicate periods when no data wave available due to camera malfunction and yellow areas indicate reconfiguration events b. Shows wave energy averaged over 3 hours, c. Wave energy averaged over 6 hours, d. Wave energy averaged over 12 hours, e. Wave energy averaged over 1 day, f. Wave energy averaged over 2 days, g. Wave energy averaged over 5 days, and h. Wave energy averaged over 10 days.

.

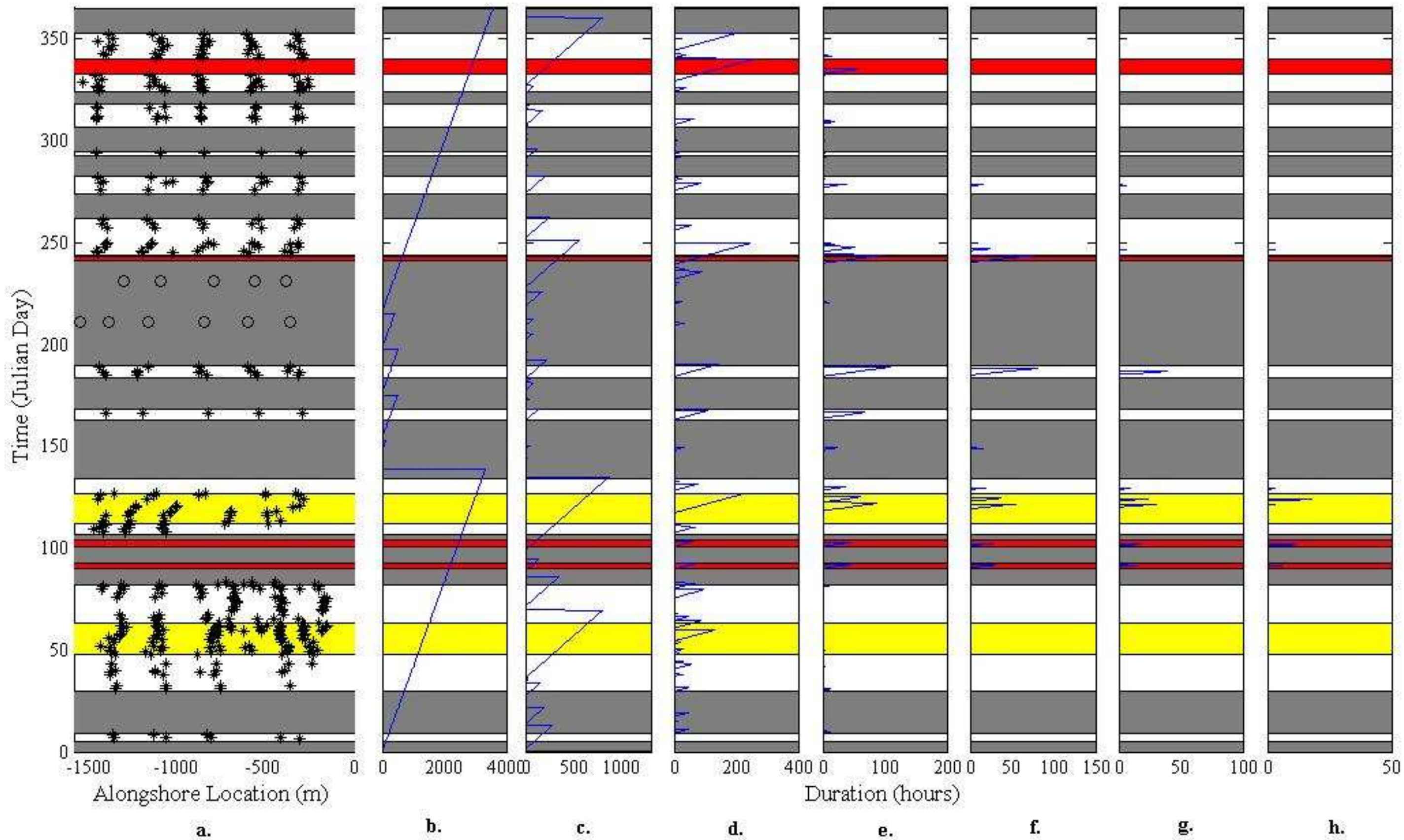

Figure A2.3 This figure shows rip channel and wave data from the year 2001. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels that where the locations were manually digitised. Grey and red areas indicate periods of time when wave energy was too low or too high (respectively) to make rip channels detectable by automatic algorithms, black areas indicate periods when no data wave available due to camera malfunction and yellow areas indicate reconfiguration events. b. Shows the duration of wave heights greater than 0.5 m, c. Duration of wave heights greater than 1 m, d. Duration of wave heights greater than 1.5 m, e. Duration of wave heights greater than 2 m, f. Duration of wave heights greater than 2.5 m, g. Duration of wave heights greater than 3 m, and h. Duration of wave heights greater than 3.5 m where all durations are in hours.

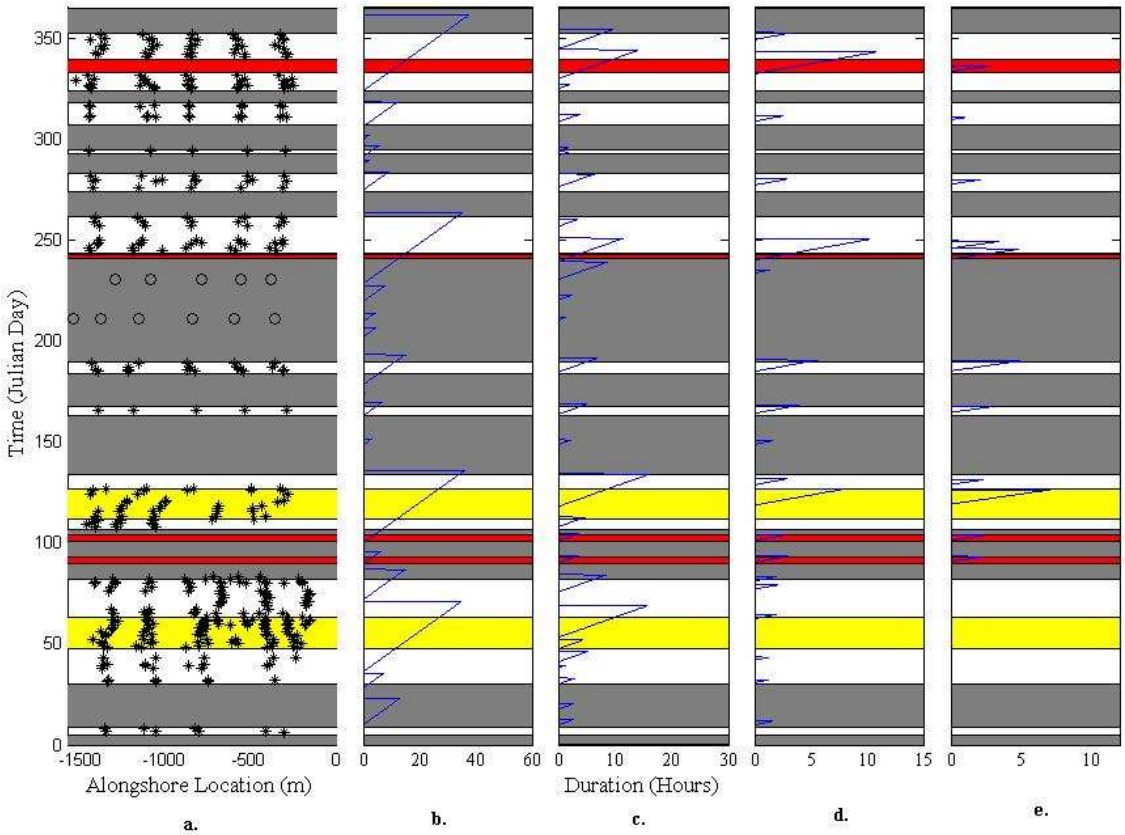

Figure A2.4. This figure shows rip channel and wave data from the year 2001. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b–e. Show duration of wave energy squared averaged over 10 days where b. Shows duration of wave energy greater than 1.3 Mgs-2, c. Duration of wave energy greater than 2.5 Mgs-2, d. Duration of wave energy greater than 3.8 Mgs-2, and e. Duration of wave energy greater than 5 Mgs-2. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms, and yellow areas are reconfiguration events.

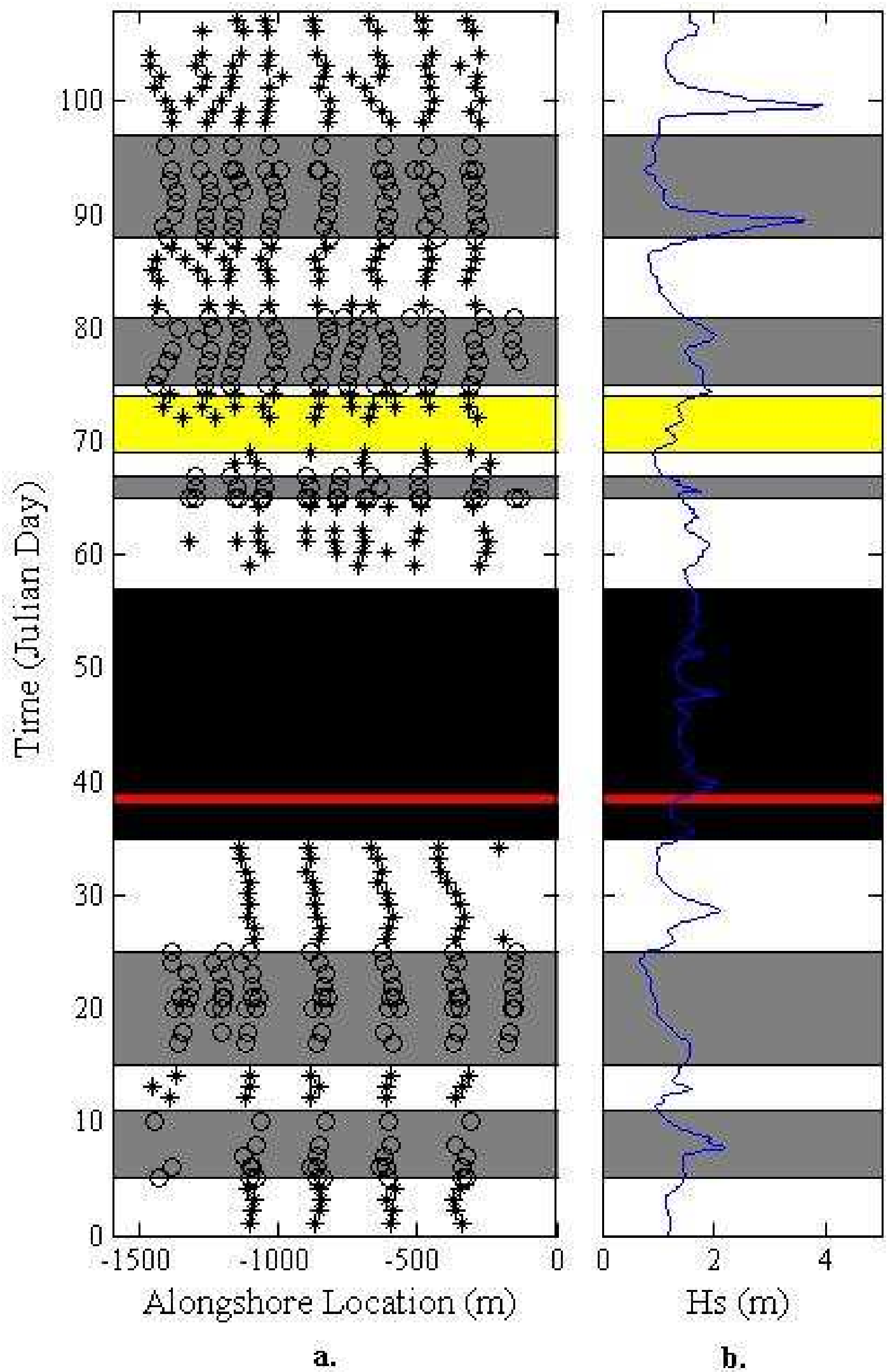

Figure A2.5. This figure shows rip channel and wave data from the year 2002. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low or too high to make rip channels detectable by automatic algorithms, black areas indicate periods when no data wave available due to camera malfunction and yellow areas indicate reconfiguration events. b. Shows significant wave height.

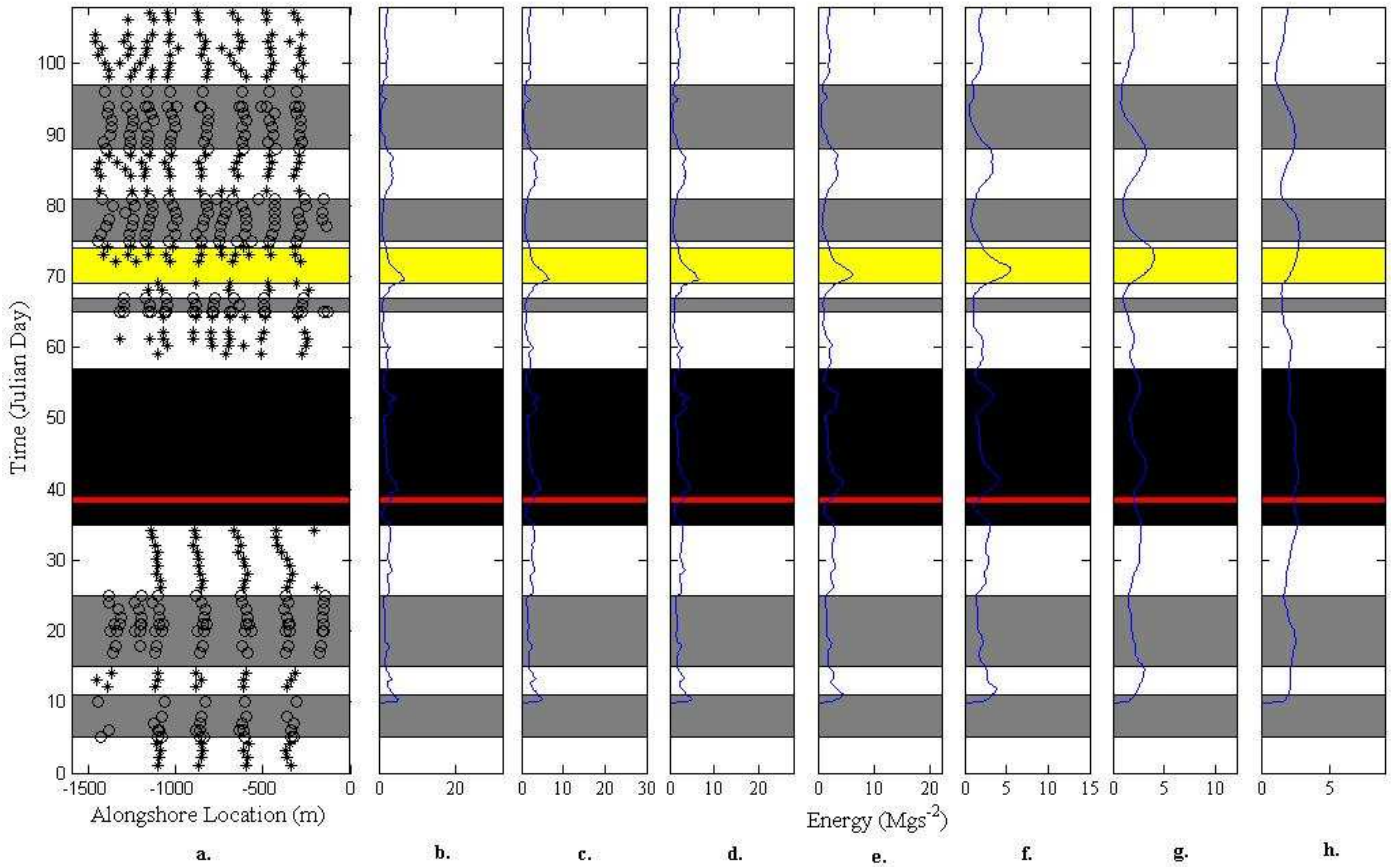

Figure A2.6. This figure shows rip channel and wave data from the year 2002. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low or too high to make rip channels detectable by automatic algorithms, black areas indicate periods when no data wave available due to camera malfunction and yellow areas indicate reconfiguration events b. Shows wave energy averaged greater than 3 hours, c. Wave energy averaged greater than 6 hours, d. Wave energy averaged greater than 12 hours, e. Wave energy averaged greater than 1 day, f. Wave energy averaged greater than 2 days, g. Wave energy averaged greater than 5 days, and h. Wave energy averaged greater than 10 days.

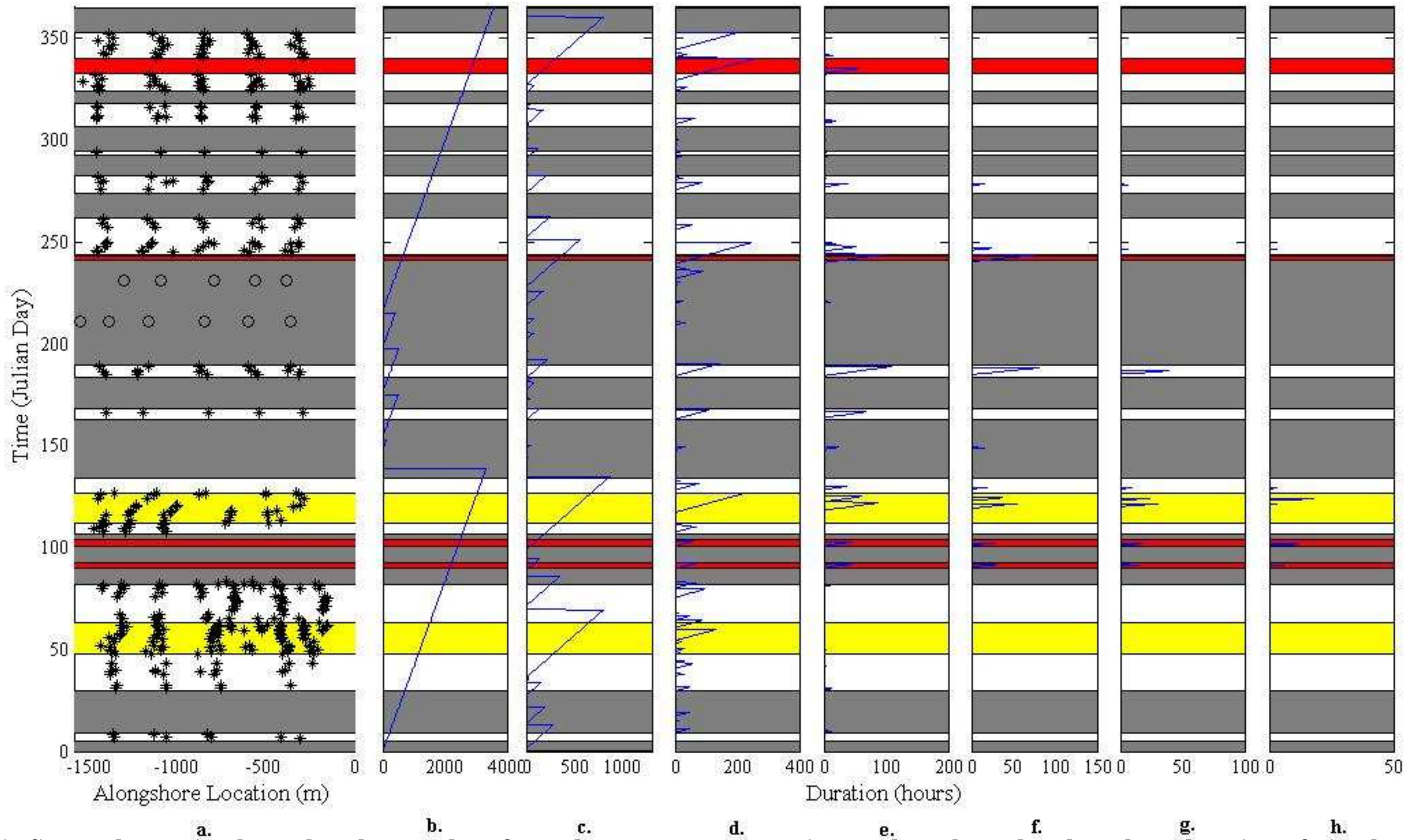

Figure A2.7. This figure shows rip channel and wave data from the year 2002. Stars in panel a. Show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. Grey areas indicate periods of time when wave energy was too low or too high to make rip channels detectable by automatic algorithms, black areas indicate periods when no data wave available due to camera malfunction and yellow areas indicate reconfiguration events. b. Shows duration of wave heights greater than 0.5 m, c. Duration of wave heights greater than 1 m, d. Duration of wave heights greater than 1.5 m, e. Duration of wave heights greater than 2 m, f. Duration of wave heights greater than 2.5 m, g. Duration of wave heights greater than 3 m, and h. Duration of wave heights greater than 3.5 m where all durations are in hours.

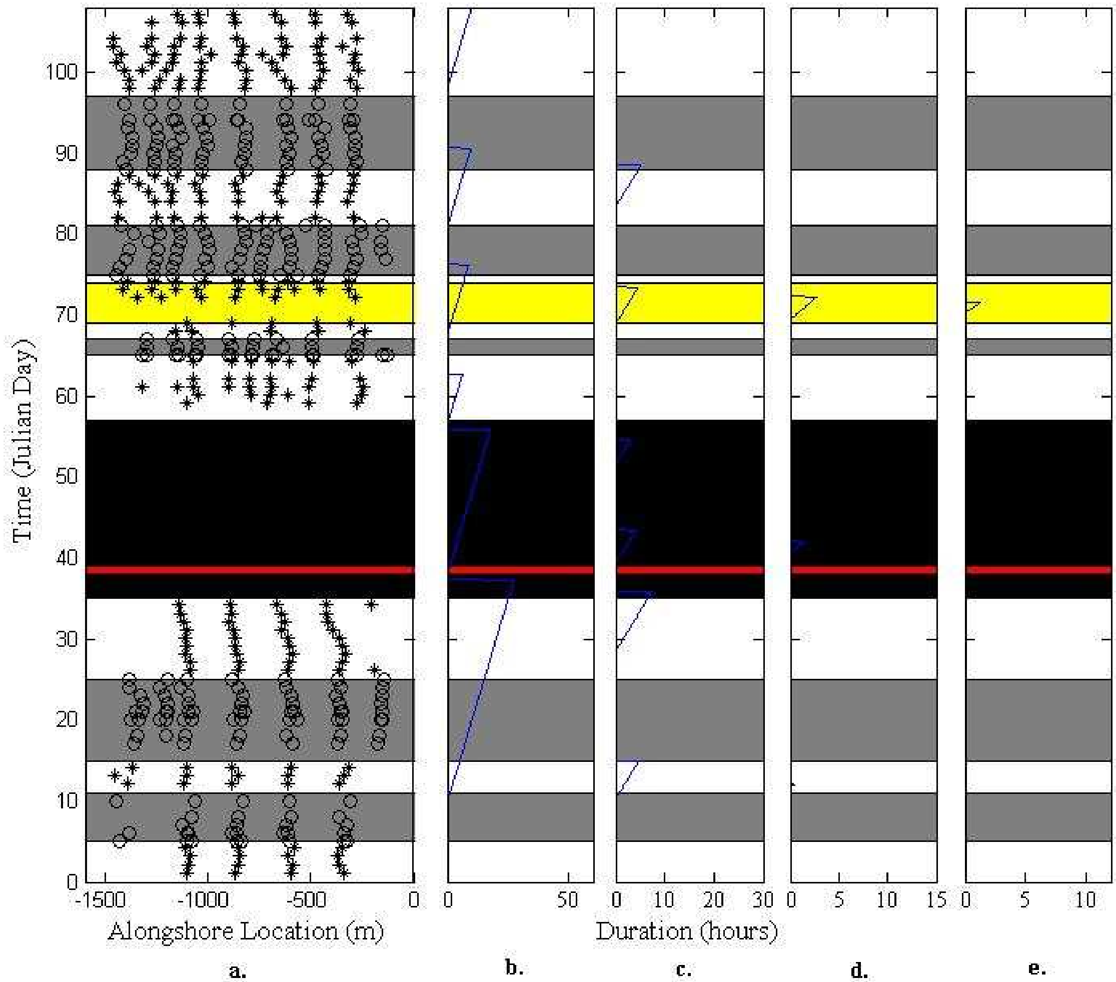

Figure A2.8. This figure shows rip channel and wave data from the year 2002. Stars in panel a. show the alongshore location of rip channels found by the algorithms while the circles indicate rip channels for which the locations were manually digitised. b–e. show duration of wave energy squared averaged over 10 days where b. shows duration of wave energy greater than 1.3 Mgs^{-2}, c. Duration of wave energy greater than 2.5 Mgs^{-2}, d. Duration of wave energy greater than 3.8 Mgs^{-2}, and e. Duration of wave energy greater than 5 Mgs^{-2}. Grey areas indicate periods when wave energy was too low to make rip channels detectable by automatic algorithms, and yellow areas are reconfiguration events.

Appendix 3: Paper in Press

At the date of thesis publication, this paper was in press to be published in a Special Issue of the Journal of Coastal Research for the International Coastal Symposium 2009 to be held in Portugal.

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Video Observations of Rip Currents on an Embayed Beach

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ABSTRACT

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Rip currents and their interaction with waves and underwater morphology are still poorly understood. This study presents a conceptual model demonstrating how rip channels respond to changes in wave conditions, focusing on wave energy and wave event duration. Past attempts to relate rip channels to wave conditions have not resulted in good relationships between rip characteristics (e.g. rip spacing) and waves. In order to address this problem, a 3.3 year rip channel data set was obtained using an improved computer-based technique to locate rips from video imagery. In this study we show how the scale of rip channels (i.e. cross-shore extent), previous wave conditions and the duration of high wave events determine how rip channels will evolve. Observations of six events when rip channels changed their spatial configuration are used to create a conceptual model for how rip channels respond to changes in the wave conditions. When rip channels are small in relation to the wave energy, these rips are more likely than larger rips (extending less than ~70 m cross-shore) to evolve. Conversely when rip channels are large in relation to the wave energy, these rips are less likely to evolve than smaller rips (extending more than ~80 m cross-shore).

ADDITIONAL INDEX WORDS: *video imagery, rip channels, Tairua, surf-zone*

INTRODUCTION

Rip currents are fast, narrow currents that traverse the surf-zone. There have been many attempts to determine how rip channels relate to wave climate. Several studies have indicated that there is a relationship between rip channel spacing and waves (e.g. MCKENZIE (1958); SHORT (1985); and HUNTLEY and SHORT (1992)). However, there have also been studies indicating that there is a poor relationship between rip spacing and waves (e.g. VAN ENCKEVORT et al. (2004); HOLMAN et al. (2006); and RANASINGHE et al. (2000)). There is a general consensus that once rip channels form, they become rapidly topographically-controlled as opposed to hydrodynamically-controlled (SHORT 1985; ELIOT 1973). Hydrodynamically-controlled rips respond directly to changes in the wave conditions while topographically-controlled rips are held in place by the pre-existing morphology. For example, CALVETE et al. (2007) noted that rip channel spacing does not appear to respond to hydrodynamic forcing alone, but to a more complex function linked to the pre-existing morphology. In general, factors that have largely been ignored in these studies examining the relation of rips to waves include the lag-time in rip response to waves, the role of rip channel scale, previous wave conditions and the duration of high wave events.

The objectives of this paper are (1) to define rip channel reconfiguration events and compare rip channel scales and wave conditions between these events; and (2) to develop a conceptual model for how rip channels respond to changes in wave conditions. The rip channel data used in this study were derived from time-averaged video images of the surf-zone, collected on a daily basis were possible. The data cover a 3.3 year period at the embayed Tairua Beach in New Zealand (Figures 1a and 1b). This work introduces an improved method created to locate rip channels in video imagery, which builds on techniques developed by LIPPMANN and HOLMAN (1989); RANASINGHE et al., 1999; and BOGLE et al., 2000. The technique was used to extract rip channel locations, from which rip reconfiguration events were defined and categorised to provide a basi for a conceptual model. A major finding of this study is that rip channel scale contributes to determining how rip channels respond to changes in wave conditions, where the previous wave energy and the duration of wave events are more important than instantaneous wave energy in determining rip channel response. Rips characterised by a smaller than average cross-shore extent than generally observed at Tairua, are more likely respond (and to respond immediately) to changes in wave conditions than larger rips. Conversely, large rips have a much longer lag-time in their response to a change in wave conditions.

FIELD SITE

Rip channel behaviour covering the entire alongshore and cross-shore extent of the surf-zone was investigated using video imagery from Tairua Beach (Figures 1a and 1b). Tairua Beach is an embayed, steep beach composed of medium-coarse sands. The beach state can change often, varying between rhythmic longshore bar pattern and a transverse bar a rip pattern

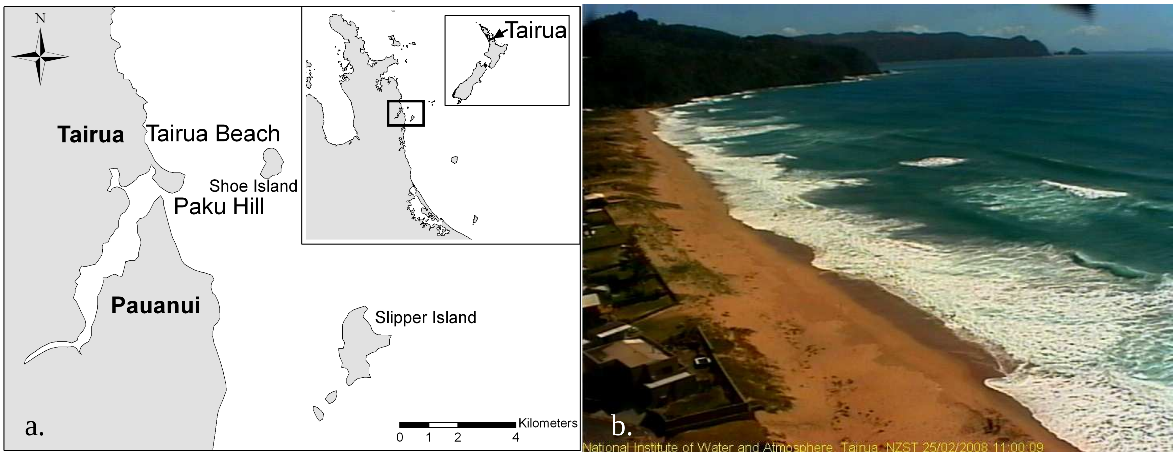

Figure 1. a. Map of New Zealand showing the location of Tairua Beach. b. Cam-Era video image of Tairua Beach study site on Julian day 56 at 1100 hours in 2008.

(BOGLE et al., 2000). Shoe Island is thought to partially shelter Tairua Beach (TREMBANIS et al., 2004). The wave climate at Tairua Beach primarily consists of storm and swell waves from the north and east (TREMBANIS et al., 2004). Mean significant wave height (H_s) and period at Tairua Beach were 0.56 m and 5.8 s respectively, which were derived using a 20-year WAM hindcast (GORMAN et al. 2003). The tide at Tairua Beach is diurnal with a range of 1.2 m with little spring-neap variation.

DATA SET

Video images used to construct the rip channel dataset were from a video camera installed as part of the Cam-Era programme, set up and co-coordinated by the National Institute of Water and Atmospheric Research Limited (NIWA), and Environment Waikato (Waikato Regional Council) in New Zealand. A video camera overlooked Tairua Beach from Paku Hill on the southern end of the beach at 70.5 m above chart datum. The camera was set up to take a snapshot of the surf-zone every 1.57 s. Images used in this study were averaged over fifteen minutes to remove the high degree of variability caused by wave breaking and to allow better contrast between rip channels and sand-bar crests. Images were ortho-rectified using the method of HEIKILLA and SILVEN (1997) where rectified images covered an area approximately 1.6 km alongshore and almost 500 m cross-shore. The dataset spanned from January 1999 until April 2002. Note that the 2000 data were mostly omitted from this paper due to discontinuity arising from low wave conditions which meant that rip channels could not be detected due to a lack of breaking waves (see below).

LIPPMANN and HOLMAN (1989) were the first to demonstrate and model the relationship between the bands of white light (due ot high amounts of wave breaking) in video time-exposure images and the position of the crests of submerged sand bars. In general, rip currents are linked to seabed depressions called rip channels (CALVETE et al., 2007), associated with small amounts of wave breaking and hence low light intensities.

A suite of computer algorithms was created to locate light intensity maxima (sand-bar crests) and minima (rip channels) in rectified, time-averaged images of the surf-zone. In the past there have been attempts to create automated methods to locate rips in video imagery (RANASINGHE et al., 1999; and BOGLE et al., 2000), however these methods generally located rips on one alongshore transect only, and difficulties were encountered in making the algorithms suitable for all cases. For example, the automated method of RANASINGHE et al. (1999) was found to work well in simple cases but was sensitive to choice of parameters for more complicated bathymetric configurations (HOLMAN et al., 2006).

To simplify the rip current algorithm, rip currents were assumed to lie between the shoreline and the barline only. In this study, the shoreline in each image was found using a method by SALMON et al. (2007), following the work of SMITH and BRYAN (2007) that used gradients in the ratio between red and green light (Figure 3). The barline was located by finding the furthest seaward maximum in a polynomial that was fitted to the cross-shore variation of light intensity (Figure 3). To locate rip channels, local maxima and minima in light intensity were found by searching images in which there was a sand-bar present in alongshore and cross-shore transects. Minima that were connected by no more than 7.5 m were sorted into distinct rip channels (Figure 3). Some post-processing occured including removing rips or sections of rips that were parallel to the shoreline, and requiring that each rip current be associated with seaward local maximum in the shoreline or barline, a definition supported by RANASINGHE et al. (2004); WHYTE et al (2005); and TURNER et al., 2007.

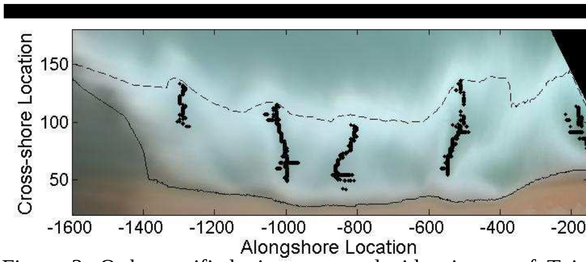

Figure 3. Ortho-rectified, time-averaged video image of Tairua Beach from Julian Day 099 at 1100 hours in 2002. Black dots show distinct rip channels located by the computer algorithms. Lower (solid) line indicates the shoreline and the upper (dashed) line the barline, both located with computer algorithms.

RIP RECONFIGURATION EVENTS

Rip channel reconfiguration events were defined by calculating the histogram of the alongshore distance between every combination of rip channels at two consective times (for which rip channel data were available). The number of rip channel pairs in the 7.5 and 15 m bin was used as a measure of change. This number indicated when rip channels had changed considerably in alongshore location which generally during high wave events. Over the period of study (1999, 2001 and 2002 until Julian Day 107) there were six reconfiguration events. Each of these events were characterised by different rip channel scales (i.e. cross-shore extent), wave event magnitudes and durations (Table 1).

Each reconfiguration event resulted in a different type and amount of morphological change to sand-bars and rip channels in the surf-zone. Surf-zone morphological change was quantified by comparing numbers of rip channels, mean surf-zone widths, and by visual observation of sand bar and rip channel configuration prior to and after the events in video imagery. Table 1 shows a summary of the wave conditions and surf-zone morphology changes during each reconfiguration event. Note that wave energy was calculated using mean H_s over ten days. Below a summary is given of rip and wave characteristics prior, during and after each reconfiguration event. A short description of each reconfiguration event is provided.

Reconfiguration Event One: Prior to Event One the mean surf-zone width was 69 m. During Event One H_s reached a maximum of 3.5 m. Wave energy reached a maximum of 6300 kgs^{-2}. H_s was greater than 2.5 m for ~120 hours and wave energy was greater than 5000 kgs^{-2} for 11 hours, both of which were long periods compared to the other reconfiguration events. From observations of imagery, the biggest change to the surf-zone occurred during this event. During Event One half of the rips disappeared (the spacing increased) and the bar straightened with a longshore trough developing in the centre of the beach. Mean rip channel spacing and spacing standard deviation changed the most of all the events.

Reconfiguration Event Two: Prior to Event Two the mean surf-zone width was 82 m. During the event H_s reached a maximum of 3.5 m and wave energy reached a m**a**ximum of 5000 kgs^{-2}. H_s was greater than 2.5 m for ~30 hours and wave energy was greater than 5000 $kgs^{-2}$for ~4 hours. Observations of imagery indicated that during Event Two there appeared to be little change to the surf-zone morphology (e.g. although rip currents experienced alongshore movement during the event, the number of rips and beach state did not change).

Table 1. Wave and rip channel characteristics for each reconfiguration event. SZW is mean surf-zone width and T is mean wave period.

Reconfiguration Event number	1	2	3	4	5	6
Year	1999	1999	1999	2001	2001	2002
Julian Days (from-until)	94-122	252-271	311-325	48-63	112-127	69-74
Duration (Days)	29	20	15	15	16	6
Duration H_s>2.5 m (Hours)	120	40	10	0	100	0
Duration Energy> 5000 kgs^{-2} (Hours)	11	4	7.5	0	7.5	2
$Energy_{max}$ (kgs^{-2})	6300	5000	6300	3800	8800	2500
$H_{s\ max}$ (m)	3.5	3.5	3	2	5	2.5
Wave T_{max} (s)	11	10	10	8	8	8
Mean SZW (before/after) (m)	69/86	82/70	83/89	69/87	85/121	59/69
Difference (m)	17	8	6	18	36	10
No. rips (before/after)	8/5	5/5	4/6	5/7	5/5	5/9
Rip spacing (before/after) (m)	144/366	256/320	360/264	286/168	238/280	216/144
Difference (m)	222	64	- 96	-118	42	-72
Rip spacing std (before/after) (m)	72/253	81/110	110/255	114/63	88/70	126/46
Difference (m)	181	29	145	-51	-18	-80

Table 2. Summary of conceptual model for response of rip channels with different scales to wave energy of different magnitudes. The scale of the rip morphology refers to the mean surf-zone width prior to each event.

Magnitude of Wave Energy

SMALL RIPS, LARGE WAVES Event One ▪ Will almost definitely respond to waves. ▪ Short lag-time. ▪ Large change in morphology: rip channel disappears; bar will straighten heading towards a total reset.	**LARGE RIPS, LARGE WAVES** Events Two, Three and Five ▪ May respond if waves are constant for a long duration. ▪ Medium lag-time. ▪ Medium change in morphology.
SMALL RIPS, SMALL WAVES Event Six ▪ May respond if waves are constant for a long duration. ▪ Medium lag-time. ▪ Medium change in morphology: wider trough develops.	**LARGE RIPS, SMALL WAVES** Event Four ▪ May respond if waves are constant for a long duration. ▪ Long lag-time. ▪ Small change in morphology: head towards smaller scale system.

Scale of Rip Morphology (seaward extent)

Reconfiguration Event Three: Prior to Event Three the mean surf-zone width was 83 m. H_s reached a maximum of 3 m during the event and wave energy reached a maximum of 6300 kgs^{-2}. H_s was greater than 2.5 m for ~40 hours and wave energy was greater than 5000 kgs^{-2} for ~7.5 hours. Observations of imagery indicate that during Event Three there was little change to the surf-zone morphology.

Reconfiguration Event Four: Mean surf-zone width prior to Event Four was 69 m. During Event Four, H_s reached a maximum of only 2 m and the maximum wave energy was just 3800 kgs^{-2}. H_s was never greater than 2.5 m nor wave energy greater than 5000 kgs^{-2}. The mean surf-zone width prior to Event Four was relatively small, however it is important to note that there appeared to be two different morphologies present: a wide, stable surf-zone to the north and a narrow, rapidly changing surf-zone to the south. From observations of imagery during Event Four, the large surf-zone hardly changed whereas the smaller southern half became wider and more rips developed.

Reconfiguration Event Five: Prior to Event Five the mean surf-zone width was 85 m. H_s reached a maximum of 5 m and wave energy reached a maximum of 8800 kgs^{-2}. H_s was greater than 2.5 m for ~100 hours and wave energy was greater than 5000 kgs^{-2} for ~7.5 hours. Observations of imagery indicate the number of rips stayed the same, with one dissapearing and another developing. The rips present also moved slightly alongshore.

Reconfiguration Event Six: The mean surf-zone width prior to Event Six was 59 m. The maximum H_s was just 2.5 m and the maximum wave energy was only 2500 kgs^{-2}. Event Six had no H_s greater than 2.5 m. The duration of wave energy greater than 5000 kgs^{-2} was just two hours. From observations of imagery there was a small amount of change to the surf-zone morphology with four more rips developing. There was little change to the mean surf-zone width, while mean rip channel spacing and spacing standard deviation decreased.

CONCEPTUAL MODEL

Rip and Wave Scales

A conceptual model was created to demonstrate how rip channels appear to respond to changes in wave conditions. There are four main combinations of rip channel spatial scale and wave magnitude. These combinations were found by comparing maximum wave energy (running mean over 10 days) during each reconfiguration event and the mean surf-zone width (to represent rip channel cross-shore extent) prior to each event. The notation 'small rips' refers to rip channels that had relatively small spatial scales in relation to the wave energy that was usual at Tairua and vice versa for large rips. Figure 3 illustrates a flow diagram of the conceptual model. Table 2 shows a summary of the different combinations of rip channel scale and wave event magnitudes.

The wave conditions prior to any reconfiguration event are important as they will determine the surf-zone morphology. The previous wave conditions can also affect what type of rip channel system is present, fewer (5 at Tairua) widely spaced rip channels or more (~8 at Tairua) narrowly spaced rip channels (both regularly spaced alongshore). There are four basic combinations of rip and wave scale summarised below.

(1) Same Rip and Wave Scale

Event Six had relatively small rip channel morphology and small waves. Events Two, Three and Five had relatively large rip channel morphology and large waves. When the magnitude of the wave energy is a similar scale to the rip channel morphology (i.e. the small spacing configuration observed in this study combined with smaller than average waves, or rip channels with larger spatial scales with larger than average waves) the rip channel may respond if the wave conditions are constant for a sufficient duration. The time required (the threshold) for conditions to remain constant to cause a rip channel response will be longer for rips of a larger scale and vice versa for smaller-scale rip channels. There is likely to be a medium lag-time for the response of the rip channel to the change in the wave conditions and a medium changes to the rip/ surf-zone morphology. The same argument applies to the conditions described at the top left of Table 2 which corresponds to observations related to Event Four (Table 1).

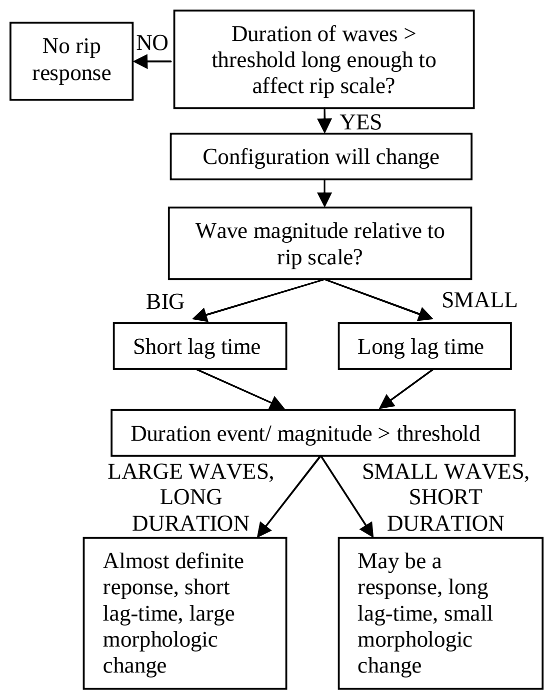

Figure 3. Conceptual model diagram of how a single rip channel with a paticular cross-shore extent may respond to changes in wave conditions. Thresholds vary and are greater for larger rip channels.

(2) Small Rip Scale with Large Waves

Event One had relatively small rip channel morphology when large waves occurred. When the scale of the rip channel morphology is small relative to the magnitude of the new wave energy the rip channel will likely respond to the change quickly (i.e. short lag-time). There was insufficient data to define a reset that occurred in 2000 but it appeared that when wave energy was large relative to the scale of the rip, the rip channel disappeared, the bar straightened and the beach began a complete reset (i.e. a large change to the surf-zone morphology). The beach may only reach a total reset if wave energy is large enough relative to the scale of the rip channel and/ or they last for a sufficient duration.

(3) Large Rip Scale with Small Waves

Event Four had relatively large rip channel morphology and small waves. When the scale of the rip channel is large relative to the magnitude of the wave energy, it is not likely that the rip channel will respond to the change in the wave conditions. The rip channel may only respond if the wave conditions remain constant for a long duration. The lag-time of rip channel response to a change in the wave conditions for large rips with small waves is likely to be long. There will be a small change in the surf-zone morphology where it will likely move towards a smaller scale system i.e. smaller, more closely spaced rip channels.

CONCLUSION

In this study an improved method of locating rip channels in time-averaged video images of the surf-zone using computer algorithms was used to create a 3.3 year dataset (1999-April 2002, excluding 2000). Rip channel reconfiguration events were identified using a measure of change. These reconfiguration events were used to create a conceptual model of how rip channels of different spatial scales might respond to changes in wave conditions.

Pre-existing rip channel scale (i.e. cross-shore extent) is extremely important in determining how rip channels behave during certain wave conditions. With large scale rip channels (relative to wave energy), it is not likely that the rip channel will respond to the change in the wave energy unless the waves are constant for a long period of time. Small rip channels respond much more easily to changes in the wave conditions and there is more likely to be a large change to the surf-zone morphology. Smaller rips tend to be hydrodynamically-controlled (i.e. respond directly to changes in the wave conditions) while larger rips tend to be topographically-controlled (i.e. are predominantly controlled by the pre-existing rip channel morphology). The duration for which particular wave conditions are greater than a threshold will determine how much the rip channel changes i.e. do they extend further seaward or retract? Do they become narrower or get wider? Do they disappear altogether?

This study indicates that the traditional time-series approach for comparing rips and waves (e.g. HOLMAN et al., 2006; and TURNER et al., 2007) appears to be inappropriate. To begin to uncover the complicated relationship between rip currents and waves, focusing on the shifts (reconfigurations) in rip channel configuration may be more appropriate to reveal the relationships. The conceptual model resulting from this study could be used to test and advance the capability of rip channel numerical models. Further research is required to begin to quantify the interaction of rip channel scale and magnitude of wave conditions.

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