The use of imaging systems to monitor shoreline dynamics

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ABSTRACT: The development of imaging systems is nowadays established as one of the most powerful and reliable tools for monitoring beach morphodynamics. Two different techniques for shoreline detection are presented here and, in one case, applied to the study of beach width oscillations on a sandy beach (Pauanui Beach, New Zealand). Results indicate that images can provide datasets whose length and sample interval are accurate enough to resolve inter-annual and seasonal oscillations, and long-term trends. Similarly, imaging systems can be extremely useful in determining the statistics of rip current occurrence. Further improvements in accuracy and reliability are expected with the recent introduction of digital systems.

1 INTRODUCTION

1.1 *Background*

Despite decades of research, the immediate response of a beach to wave attack is still difficult to predict, just as it is difficult to predict the location and movement of dangerous rip currents or the spatial and temporal movements of nearshore sandbars. As a consequence, understanding and hence predicting long-term patterns of erosion and accretion remains a challenging task.

Video-based technology is now becoming an increasingly popular method for monitoring beach change fundamentally because it can be used to build a database of frequent, long-term and spatially-extensive observations of beach behaviour (Holland et al., 1997, Lippmann & Holman 1989, 1990). This can, in turn, promote a better understanding of the hydro- and morpho-dynamics of a specific site, allow real-time monitoring of sites of interest, and provide data to develop and validate models that can be used to predict more general aspects of coastal dynamics (Aarninkhoff et al. 2003, 2005).

Before the advent of video-based techniques, collection of meaningful information on beach dynamics was a prohibitively expensive and time-consuming task. Moreover, a yearly or even twice-yearly surveyed profile of the beach (as typically carried out in many places) is insufficient to capture the natural spatial and temporal variability that occurs. Furthermore, the most significant changes typically occur during and immediately after storms, when it is difficult to mobilise survey teams for the necessary rapid response. Land-based surveying are restricted by runup during wave events (storms or swell) and usually cannot extend much beyond the low-tide waterline, which means that sandbar movements, which are known to be the main driver of shoreline erosion and accretion, are completely missed. In contrast, imaging systems perform satisfactorily under diverse conditions, in storms and fair weather, and capture information along the entire beach including the offshore sandbars.

1.2 *The Cam-Era system*

Coastal changes are being monitored around New Zealand (Figure 1) through images collected using the state-of-the-art automated imaging system "Cam-Era": http://www.niwascience.co.nz/services/cam-era. The Cam-Era stations, which each consist of a video system and computer linked by telephone to a central base station, have been collecting images every hour for a number of years (up to 8 years for some of the sites). Analysis of this information has revealed some interesting phenomena, including linkages between offshore sandbars and shoreline dynamics (Coco et al. 2005), the occurrence of rip currents (Bogle et al. 2000) and the related presence of erosion "hotspots" forming along the shoreline (Figure 2), braided river morphodynamics (Figure 3), and river mouth migration (Paterson et al. 2000) (Figure 4). Recently, a higher-resolution, multi-camera, digital system has been installed as part of a collaboration with the University of East Anglia (UK) to monitor if and how offshore sandbanks affect shoreline behaviour.

The Cam-Era system allows for the collection of different types of images ranging from snapshots to time-averaged (necessary to locate the position of the shoreline and sandbars from wave breaking patterns, see Figure 5 for an example) and time-stacks (necessary to evaluate hydrodynamic characteristics like wave period, angle of approach or even magnitude of the longshore current). In the following, we will present an application of the Cam-Era system to Pauanui Beach (New Zealand) showing long-term monitoring of beach width changes and how these changes can be related to seasonal patterns.

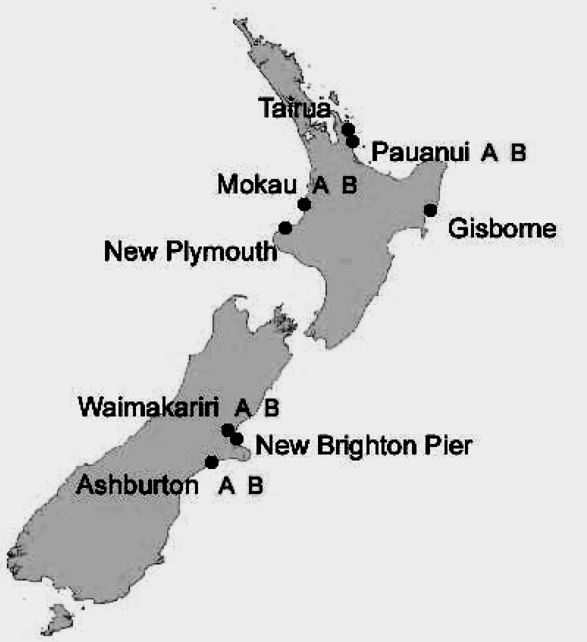

Figure 1. Cam-Era monitoring sites around New Zealand.

2 SHORELINE DETECTION

One of the most challenging and fruitful applications of imaging-systems is monitoring shoreline dynamics (Aarninkhof et al. 2003). From a conceptual point of view the first task is to determine “what” the shoreline is. Coastal scientists and engineers have proposed a variety of different definitions (reviewed in detail by Boak & Turner 2005) and in a number of cases these definitions do not always relate to physical processes that can be clearly defined or cannot be associated to objective and repeatable detection techniques. For practical purposes, when dealing with images, it might be convenient to use different algorithms as the final aim is to develop a “detector” that is objective, robust, and that allows for unsupervised, repeatable measurements (Boak & Turner 2005). In the following, two different techniques for shoreline detection using time-averaged images will be presented.

2.1 *Difference between “wet” and “dry” sand as a shoreline indicator*

This study utilised images from Tairua and Pauanui Beach (Figure 2). We defined the shoreline as the intersection of “wet” and “dry” parts of the beach on time-averaged images. We have developed a technique to detect the edge between “wet” and “dry” beach and used it to monitor beach width change (with beach width being defined as the distance between the dune edge and the shoreline). The technique, probably similar to the one presented in Aarninkhof et al. (2003), involves tracking the variation of the three colour components - red, green, and blue (RGB) - along cross-shore transects taken from colour images of the beach. Pixels from each transect are analysed to detect the minimum in the gradient between the ratio of the blue and red components which corresponds to the waterline. This allows for detailed monitoring of the intertidal area (Figure 6) and allows variability in the alongshore position of the shoreline to be quantified. Volumetric change within the beachface can be evaluated by coupling the shoreline detection algorithm with a limited number of beach surveys (Smith & Bryan 2005).

Figure 2. Time-averaged image of Pauanui Beach (North Island, New Zealand) showing large breaking areas (brighter colour) and rip currents (areas where wave breaking does not occur). Localized shoreline erosion is associated with rip currents.

Figure 3. Snapshot image collected at Waimakariri (South Island, New Zealand) showing braided-river morphology.

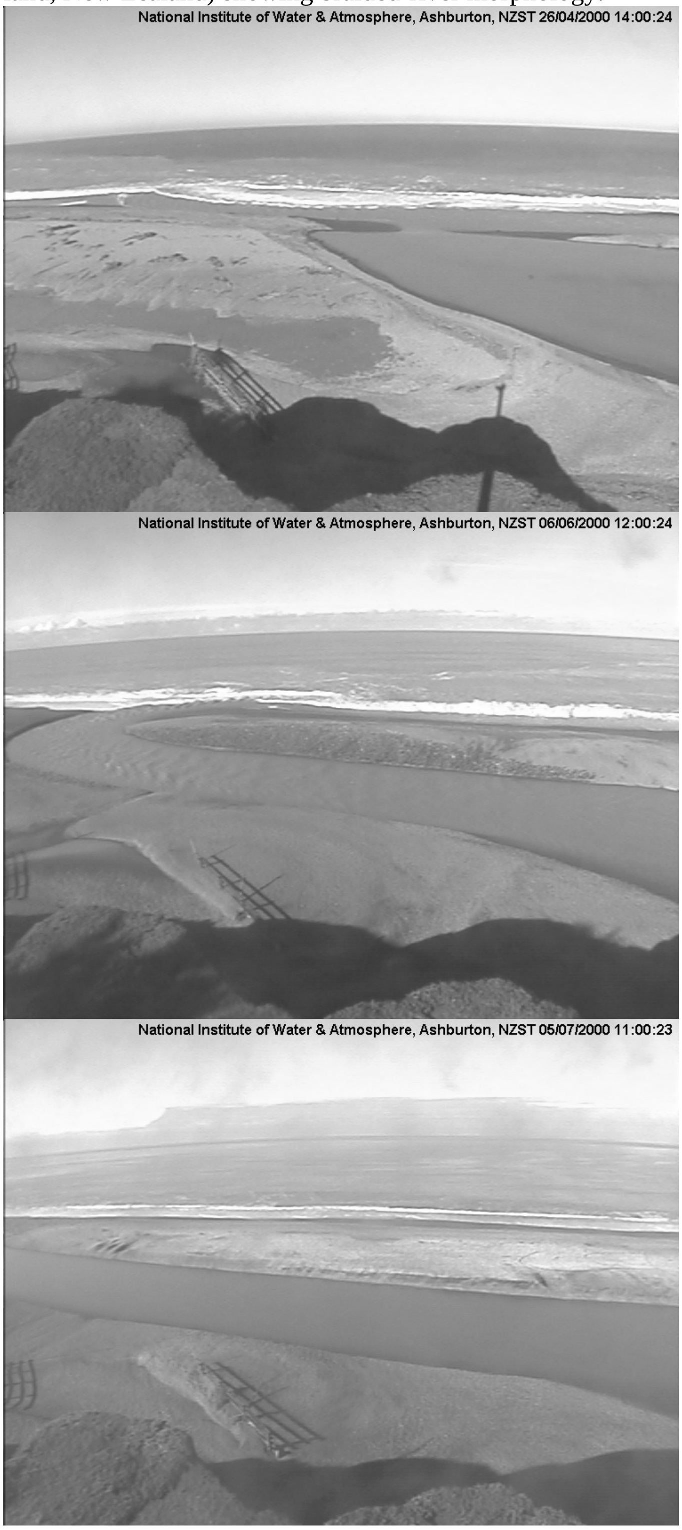

Figure 4. Snapshot images from the Ashburton river mouth (South Island, New Zealand) showing the rapid migration of the main channel.

The same shoreline-detection technique has been applied to time-averaged images collected at Pauanui Beach (Figure 7). For this beach, using the same detection algorithm, it was possible to also detect the edge of the dune at the back of the shoreface and so to analyze temporal changes in beach width (defined as the distance between the edge of the dune and the shoreline at a specified tidal level) at two different alongshore locations (Figure 7).

Figure 5. Snapshot (top panel) and time-averaged image (bottom panel) at Tairua Beach (North Island, New Zealand). Time-averaged images are the result of averaging ten minutes of images collected every second (for a total of 600 images). Notice how the shoreline is difficult to characterize on snapshots (top panel) patterns related to individual wave and run-up are discernable. On time-averages (bottom panel) individual run-ups are merged into a shore-break while individual breaking waves are merged around the position of the submerged sandbar.

Figure 6. Shoreline detection at Tairua Beach (North Island, New Zealand) using a “wet” and “dry” shoreline-detection algorithm. Shoreline has been detected at different tidal stages resulting in a detailed intertidal bathymetry map.

Tidal levels have been calculated using a numerical model that forecasts tides on open coasts and ocean waters around New Zealand (forecasts are available at: www.niwascience.co.nz/services/tides).

Figure 7. Shoreline and dune detection using a “wet” and “dry” shoreline-detection algorithm. Dark symbols indicate the shoreline, light symbols indicate the edge of the dune. Dark and light filled circles (and arrows) indicate the two locations where beach width was measured.

Data analysis spanned three years of time-averaged images, although not all of the images could be used (for example due to the presence of raindrops on the camera lenses). This type of analysis provides a reasonable estimate of shoreline dynamics even though non-tidal changes in water level (for example due to wave set-up) have been neglected. Results, shown in Figure 8, show a clear seasonal pattern with accretion usually beginning around July. In contrast erosion, which is primarily driven by ex-tropical cyclones and other low pressure systems, occurs between December and June.

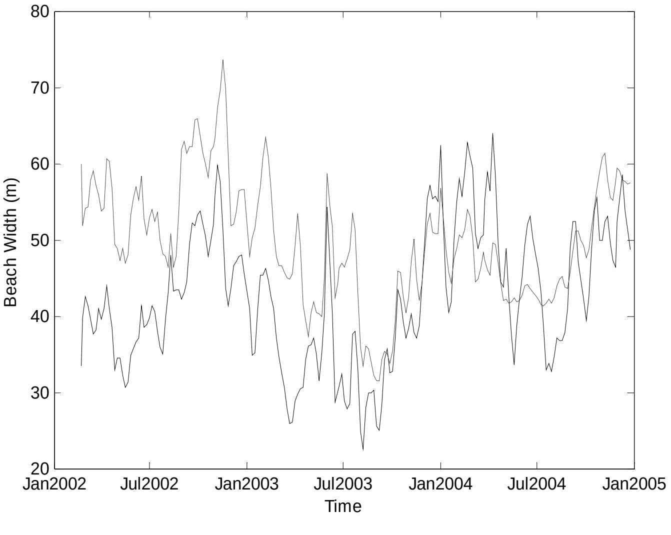

Figure 8. Time series of beach width evolution for two distinct alongshore locations at Pauanui Beach (New Zealand). The dark and light lines refer respectively to the dark-circle and light-circle locations shown in Figure 7.

Figure 8 is a valuable tool for coastal managers as trends in beach erosion or accretion can be clearly visualized as well as seasonal patterns or long-term oscillations. This type of analysis also allows understanding of the type of oscillations a beach might undergo during a single year. For example, for the case of Pauanui Beach, oscillations larger than 30 m can be observed without any overall, long-term, trend in erosion or accretion.

2.2 *Intensity maxima as a shoreline indicator*

A different technique, focusing on the detection of maxima in cross-shore transects of pixel intensity of time-averaged images, can be used to locate the area(s) where strongest shore-break occurs (Plant & Holman 1997). A similar technique has also been used to locate surfzone sandbars (Lippmann & Holman 1990). This technique appears particularly valuable at sites where color gradients are less significant. This technique is robust too but it does not provide the same estimate of shoreline position as the “wet’ (submerged) and “dry” (emerged) technique. As recently pointed out (Plant et al. in press) these two techniques are characterized by some sort of correlation as they represent different physical aspects of runup properties. As for the previous technique, wave-driven set-up can affect the location of the shore-break. The “intensity maxima” appears to be particularly suitable on beaches characterized by a shore-break whose extent is spatially limited in the cross-shore direction. For this reason we have applied this technique to the detection of shoreline at a site, Lowestoft (UK), where a multiple-digital camera unit has recently been installed. Results (Figure 9) clearly show the validity of the technique and how accurately the shoreward edge of the shore-break can be detected.

3 RIP CURRENTS

Imaging systems are also extremely useful to detect the appearance, location, and persistence of dangerous rip currents. Although many mechanisms have been suggested (see Van Enckevort et al., 2003 for a review), understanding of rip current dynamics is still limited and more observations are needed to unravel the complexity of this phenomenon. Imaging systems provide long-term datasets and rip currents are easily identifiable on time-averaged images (Figure 2). Several authors, worldwide, have recently adopted this approach (Holman et al. 2006) and provided reliable indications of the frequency of occurrence of rip currents. We have undertaken a similar effort for Tairua and Pauanui Beach, as both locations are popular beaches that appear to be particularly prone to the occurrence of rip currents. Results are shown in Figure 10 and clearly indicate the presence and strong persistence of rip currents.

Figure 9. Shoreline detection at Lowestoft (U.K.) using the “intensity maxima” detection algorithm. Each circle represents the maximum of a cross-shore intensity profile.

Pauanui Beach in particular seems to be characterized by a nearly continuous presence of rip currents while at Tairua Beach, especially in the (southern hemisphere) winter months, occurrence of rip currents is lower. Another feature of interest (not shown) is that a higher number of rips is observed along Tairua Beach in the summer months than in the winter ones. Also, at both Tairua and Pauanui beach, rip currents do seem to appear at preferred alongshore locations. This result is particularly relevant as it might help to develop specific hazard warnings for certain parts of a beach. We are now in the process of extending this analysis in an attempt to relate the appearance (and disappearance) of rip currents to offshore wave conditions (wave height, period, and angle of approach) as the ultimate scope of this work is the development of a fully integrated rip current warning system.

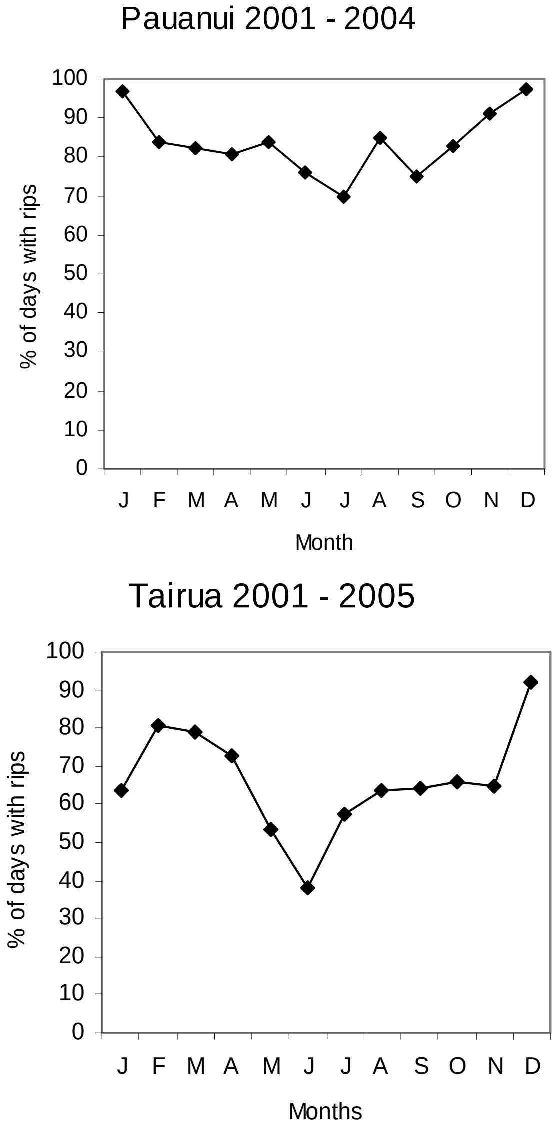

Figure 10. Rip occurrence at Pauanui (top panel) and Tairua (bottom panel) beach. Each point represents the average of observations collected over 4 (Pauanui) and 5 (Tairua) years.

4 DIGITAL SYSTEMS

With recent advances in digital camera systems it is now possible to use high speed, high resolution digital still cameras rather than standard video cameras. The digital cameras are available in various resolutions and the Lowestoft (UK) installation (Figure 9) used 3.2 megapixel cameras connected to 3 GHz Pentium computers via USB. These are capable of streaming 6-7 frames per second to the computer screen and to capture and save to disk at 2 frames per second. The major advantage of these high resolution digital systems is the increased ability to discern features. Typical standard video systems using frame grabbers produce a 0.43 megapixel image whereas digital systems used at Lowestoft produce 3.2 megapixel images and 4 megapixel cameras are now becoming available. The use of digital systems has also a couple of disadvantages. Firstly, the use of 3.2 megapixel images implies larger storage capacity on computer hard disks (although this is offset by the fact that modern computer hard disk size and cost is minimal), as well as requiring high speed processors to deal with the large image size. Secondly, because they connect to the computer using USB2 this requires the computer and the camera to be in close proximity with less than 30 metres of cabling between them. The latest digital cameras on the market use Ethernet connections as opposed to USB2 between the computer and camera which overcomes this problem. Overall it appears that digital cameras are the way forward as the technical difficulties can already be dealt with and the images obtained are characterized by a substantial increase in resolution.

5 CONCLUSIONS

Imaging systems appear to be an appropriate tool to study and monitor beach morphodynamics and shoreline evolution. Two different techniques to detect shoreline position have been presented: one assumes that the shoreline is the boundary between “wet” and “dry” areas; the other assumes the shoreline position corresponds to the location of the most intense shore-break. Although the two techniques define the shoreline differently, they both appear to be useful tools to study the long-term evolution of beach width (as shown for Pauanui Beach, New Zealand) or to provide detailed intertidal mapping (as shown for Tairua Beach, New Zealand). We have also used video images to analyze rip currents at two New Zealand beaches. At both sites the probability and frequency of rip currents occurrence is high. This type of analysis, conducted using several years of video images, could only be performed thanks to the daily acquisition of images by the Cam-Era remote sensing technique. Further improvements are expected with the recent introduction of digital systems

6 ACKNOWLEDGMENTS

Giovanni Coco, George Payne, Darcel Rickard and Doug Ramsay were funded by the (New Zealand) Foundation for Research, Science and Technology (Contract C01X0401). The Natural Environment Reseach Council (contract NE/B503917/1) funded TD and the Cam-Era deployment at Lowestoft.

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