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Analysis of shoreline variability, seasonality and erosion / accretion trends: August 2006 - January 2007: report 15: Northern Gold Coast coastal imaging system

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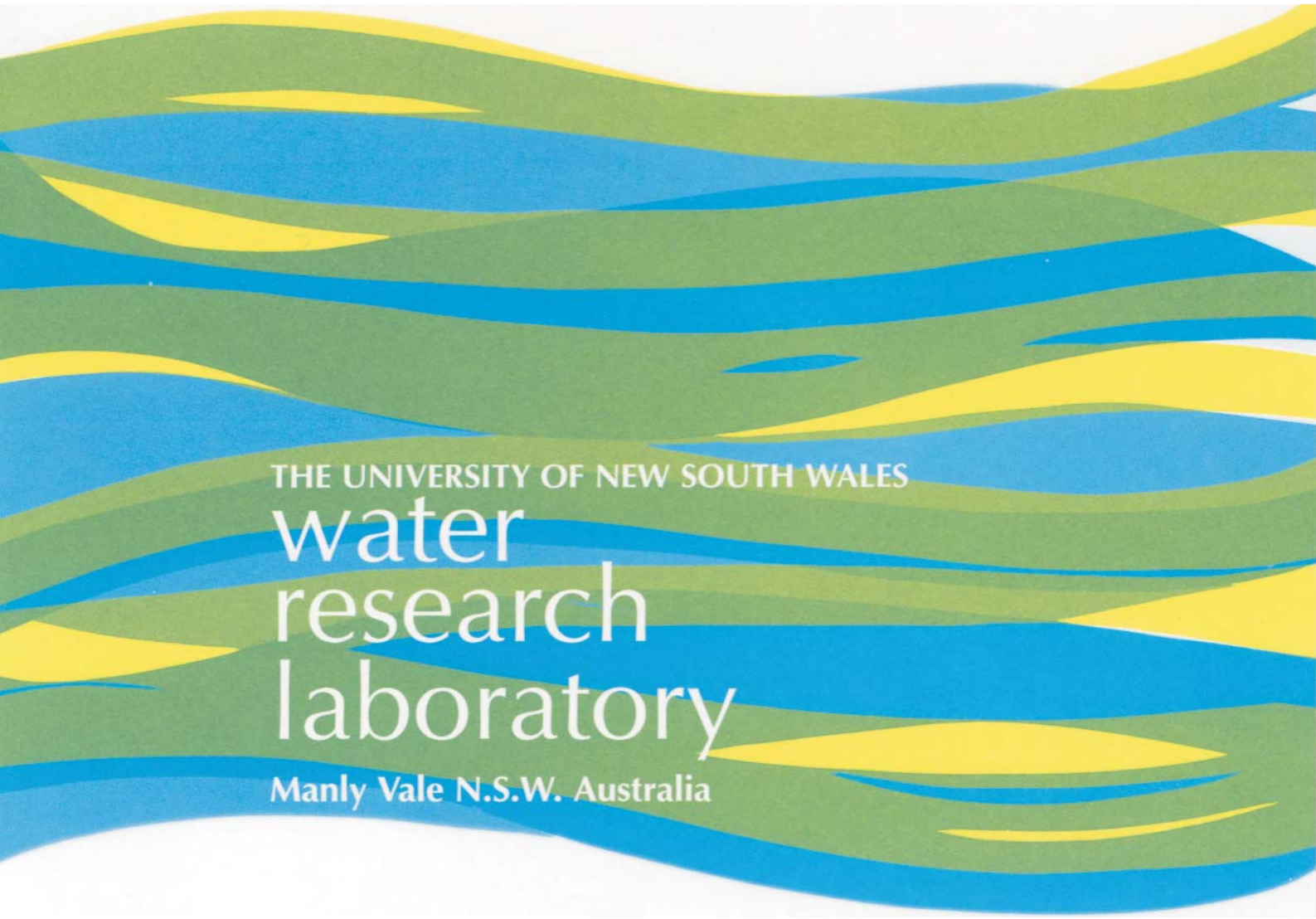
Publication details:
Report No. UNSW Water Research Laboratory Technical Report No. 2007/08

Publication Date:
2007

DOI:
https://doi.org/10.4225/53/58e1b0c0d4483

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ANALYSIS OF SHORELINE VARIABILITY, SEASONALITY AND EROSION /ACCRETION TRENDS: AUGUST 2006 - JANUARY 2007

REPORT 15
NORTHERN GOLD COAST COASTAL IMAGING SYSTEM

by

M J Blacka, D J Anderson and I L Turner

Technical Report 2007/08
April 2007

THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
WATER RESEARCH LABORATORY

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Technical Report No 2007/08
Report Status Final
Date of Issue April 2007

WRL Project No. 06037.01
Project Manager Doug Anderson

Title	Analysis of Shoreline Variability, Seasonality and Erosion/Accretion Trends: August 2006 – January 2007 Report 15: Northern Gold Coast Coastal Imaging System
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The work reported herein was carried out by the Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, acting on behalf of the client.

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1. INTRODUCTION

This report was prepared by Water Research Laboratory (WRL) for Gold Coast City Council. It is the 15th in a series of six-monthly reports, that describe, quantify and analyse the regional-scale coastline changes that have occurred following the implementation of the Northern Gold Coast Beach Protection Strategy (NGCBPS).

1.1 General

In July of 1999, an ARGUS coastal imaging system was installed at the northern Gold Coast. This leading-edge technology was selected by Gold Coast City Council to provide quantitative, continuous and long-term monitoring of coastline changes. It is this ability to provide quantitative information that distinguishes the ARGUS coastal imaging system from conventional 'webcam' technology.

The northern Gold Coast was the first of eight sites in Australia that currently utilise coastal imaging technology and techniques to monitor regional-scale coastal response to proposed, current or completed major coastal engineering works. It is fitting that the first installation in Australia should have occurred in conjunction with the implementation of the innovative NGCBPS coastal management project.

The coastal imaging system installed at the northern Gold Coast became fully operational on 1st August 1999. This timing coincided with the commencement of construction of the Gold Coast Reef. Beach nourishment commenced in February 1999, approximately six months prior to the installation of the coastal imaging system. The NGCBPS Beach nourishment program was completed in June 2000. During January – April 2005, dredging of the Broadwater resulted in a smaller quantity of sand being placed along the Surfers Paradise beachfront. The primary phase of reef construction concluded in December 2000. A second phase of reef construction with the addition of 15 geocontainers to the crest of the reef was completed at the end of 2001, and in November 2002 a further 10 bags were placed. The placement of the additional geocontainers in 2001 and again in 2002 was used to trim the crest level, and to fill the larger void spaces more generally across the reef structure. A further 15 bags were placed during January, July and August 2004, to continue this trimming and maintenance program of the reef structure.

The analysis of beach changes during the preceding six-monthly monitoring periods are detailed in a growing volume of reports:

- WRL Report 00/12: August 1999 to February 2000 (Turner and Leyden, 2000a)
- WRL Report 00/33: March to July 2000 (Turner and Leyden, 2000b)
- WRL Report 01/06: August 2000 to January 2001 (Turner and Adamantidis, 2001)
- WRL Report 01/35: February to July 2001 (Turner, 2001)
- WRL Report 02/08: August 2001 to January 2001 (Turner, 2002a)
- WRL Report 2002/31: February to July 2002 (Turner, 2002b)
- WRL Report 2003/05: August 2002 to January 2003 (Turner, 2003a)
- WRL Report 2003/36: February to July 2003 (Turner, 2003b)
- WRL Report 2004/05: August 2003 to January 2004 (Turner, 2004a)
- WRL Report 2004/25: February 2004 to July 2004 (Turner, 2004b)
- WRL Report 2005/04: August 2004 to January 2005 (Turner, 2005a)
- WRL Report 2005/25: February 2005 to July 2005 (Turner, 2005b)
- WRL Report 2006/01: August 2005 to January 2006 (Turner, 2006a)
- WRL Report 2006/25: February 2006 to July 2006 (Turner, 2006b).

Electronic copies of all these reports are available for public viewing and download in pdf format at:

→ www.wrl.unsw.edu.au/coastalimaging/public/goldcst (monitoring reports)

The purpose of this fifteenth report is to present an analysis of shoreline variability, seasonality and erosion-accretion trends for the monitoring period August 2006 to January 2007, and to assess the net changes that have occurred to northern Gold Coast beaches since the commencement of the monitoring program seven and a half years ago in August 1999.

1.2 Maintenance and Upgrade History

Three years following the installation of the original camera and computer equipment at the northern Gold Coast in July 1999, in October 2002 a major systems hardware and software upgrade was completed (refer Turner, 2002a for details). Since that time the stability of the system and the connectivity between the remote station and the server at WRL has exceeded expectations. Short-lived interruptions (<2 hours) to the power supply at both the remote site and server caused a limited number of automatic system reboots during this period. A UPS backup power supply was installed to the server computer at WRL in March 2003, which has further reduced the requirement for system reboots due to interruptions to the mains power supply.

To bring the northern Gold Coast monitoring project in line with similar projects at other major coastal management and coastal engineering sites in both Australia and overseas, in February 2003 a refined methodology was implemented to map and quantify weekly shoreline variability and change. The software tool called 'WRL Intertidal Beach Mapper' (or 'WIBM') was implemented. Further details are provided in Section 3.7. Coinciding with this upgrade, a new on-line beach monitoring system was progressively implemented during February-March 2003. This system now provides 'real-time' access to the results of the video-based beach monitoring program at the northern Gold Coast via the world-wide-web, and is designed in part to replace the reliance upon (retrospective) six-monthly reporting. Further details of these 'real-time' monitoring capabilities are provided in Section 4.3.

Routine maintenance of computer and camera equipment at the northern Gold Coast site was undertaken in January 2004, including a minor upgrade to the automated image capture software (refer Turner, 2004a). More extensive maintenance of the system was undertaken in November 2004, including the replacement of three of the four cameras installed at the northern Gold Coast ARGUS station. These cameras were beginning to show signs of reduced picture quality due to continuous exposure to the elements. Following extensive testing, in December a new 'remote reboot' device was also installed at the site, that facilitates a reboot of the system via the telephone line, even when communications between the remote and local computer systems have failed. It has been observed that this event occurs several times per year, generally associated with power surges and/or momentary power failures at the remote computer site.

In February 2005 the fourth camera (not replaced in November 2004) developed a power supply fault, and after a period of testing, a new camera was installed in mid March. Routine maintenance of cameras, camera housings and the computer system was completed in December 2005.

Early in 2006 camera 1 (southern camera) failed, and subsequently the camera was replaced on the 16th of March. Later in 2006, a range of new cameras were purchased, and the southern camera was again replaced on 23rd October with one of the new cameras. While the camera had still been operational at that time, the recorded images were showing a green colour tinge compared to images from the other cameras at the site.

1.3 What's New!

This monitoring report is the fourth to present the results of a full six months of monthly mapping and analysis of the three-dimensional intertidal beach profile, and calculation of monthly net changes in sand volumes alongshore. Following the implementation of this new image analysis methodology in November 2004, the technique has been used on a routine basis to better monitor and quantify beach changes within the Narrowneck region at the northern Gold Coast.

The coastal monitoring program underway at the northern Gold Coast continues to attract considerable national and international attention within the coastal engineering, coastal management and coastal scientific professions, via journal and conference publications. In January 2007 a peer-reviewed paper based upon several years of observations from the northern Gold Coast site appeared in the Elsevier Journal Marine Geology:

- Turner, I.L., Whyte, D., Ruessink, B.G., and Ranasinghe, R., 2007. "Observations of Rip Spacing, Persistance and Mobility at a Long Straight Coastline", *Marine Geology*, 236(2007), 209-221. (REFER APPENDIX C).

1.4 Report Outline

Following this introduction, Section 2 of this report provides a brief overview of the Northern Gold Coast Beach Protection Strategy.

Section 3 contains a summary description of the ARGUS coastal imaging system, including the image types that are collected on a routine basis, and an overview of the digital image processing techniques used to analyse the images. The reader requiring more detailed information is referred to Report 1 Northern Gold Coast Coastal Imaging System entitled *System Description and Analysis of Shoreline Change: August 1999 – February 2000* (Turner and Leyden, 2000a).

The web site used to promote and distribute the images collected by the monitoring program is introduced in Section 4. Description includes the web-based image archive that provides unrestricted access to all images, weekly-updated quantitative analysis of current coastline conditions, as well as links to local information such as current weather conditions and wave measurements.

Section 5 introduces the beach morphodynamic classification model of Wright and Short (1983), which is then used to describe in a qualitative manner the beach changes observed

using the time-series of daily images for the period covered by this report, August 2006 – January 2007.

The quantitative analysis of shoreline variability for the six month period August 2006 to January 2007 is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total seven and a half year monitoring period, August 1999 – January 2007, as well as the analysis of cyclic-seasonal versus longer-term erosion-accretion trends observed during this period.

An assessment of shoreline variability and seasonal-cyclic versus net erosion-accretion trends at the reef site at Narrowneck is provided in Section 8. Section 9 contains more detailed analysis of quantitative beachface erosion-accretion trends during the present monitoring period. Section 10 briefly discusses the now ubiquitous occurrence of wave breaking at the reef when wave heights exceed approximately 1m, following the placement of additional geocontainers across the crest of the reef in 2001, 2002, and most recently in 2004. Section 11 summarises the major findings of this 15th six-monthly monitoring period at the northern Gold Coast.

2. BACKGROUND

2.1 Northern Gold Coast Beach Protection Strategy

The Northern Gold Coast Beach Protection Strategy (ICM, 1997; Boak et al, 2000) proposed a long-term, sustainable plan to maintain and enhance the beaches at Surfers Paradise, Gold Coast Queensland, Australia (Figure 2.1). Tourism is the Gold Coast's largest industry, however, the tourist economy is at risk of significant downturn in the event of major storm beach erosion.

Gold Coast beaches are dynamic, and coastal erosion has been an ongoing challenge for coastal managers since development began last century. Early and more recent coastal protection measures have included the construction of timber walls in the 1920s and 1930s, progressive construction of a continuous boulder wall along the entire northern Gold Coast beachfront, construction of the Gold Coast Seaway and sand by-passing system in the mid-1980s, and periodic beach nourishment since the 1970s.

The Northern Gold Coast Beach Protection Strategy (NGCBPS) aims to decrease the risk of economic loss following storm events, by increasing the volume of sand within the storm buffer seaward of the existing oceanfront boulder wall. The NGCBPS has the dual objectives of increasing the sand volume within the dunal buffer and improving surf quality through the implementation of sand nourishment and the construction of an artificial reef (McGrath et al., 2000).

The NGCBPS is specifically concerned with the 1.75 km of beach between Main Beach and Cavill Avenue at Surfers Paradise (refer Figure 2.1). The reef is located at Narrowneck. This section of coastline is part of the Gold Coast coastal compartment between the Gold Coast Seaway 5 km to the north and Burleigh Heads 20 km to the south. The Master Plan for the engineering works now completed at the northern Gold Coast is summarised in Figure 2.2.

2.2 Reef Construction

Construction of the artificial reef at Narrowneck commenced in August 1999, with the major phase of reef building concluded in mid-December 2000. In late 2001, a second phase of construction was completed to raise the crest level of the structure by the placement of a further 15 geocontainers. In November 2002 a further 10 geocontainers

were placed at the site to raise the crest level of the northern reef, and to more generally fill larger void areas across the reef structure.

During 2004 a further 15 bags were placed to trim the crest of the reef, and to partially close the central channel between the northern and southern halves of the reef. One bag was placed in January 2004, a further 5 bags in July, and 9 bags in August of the same year.

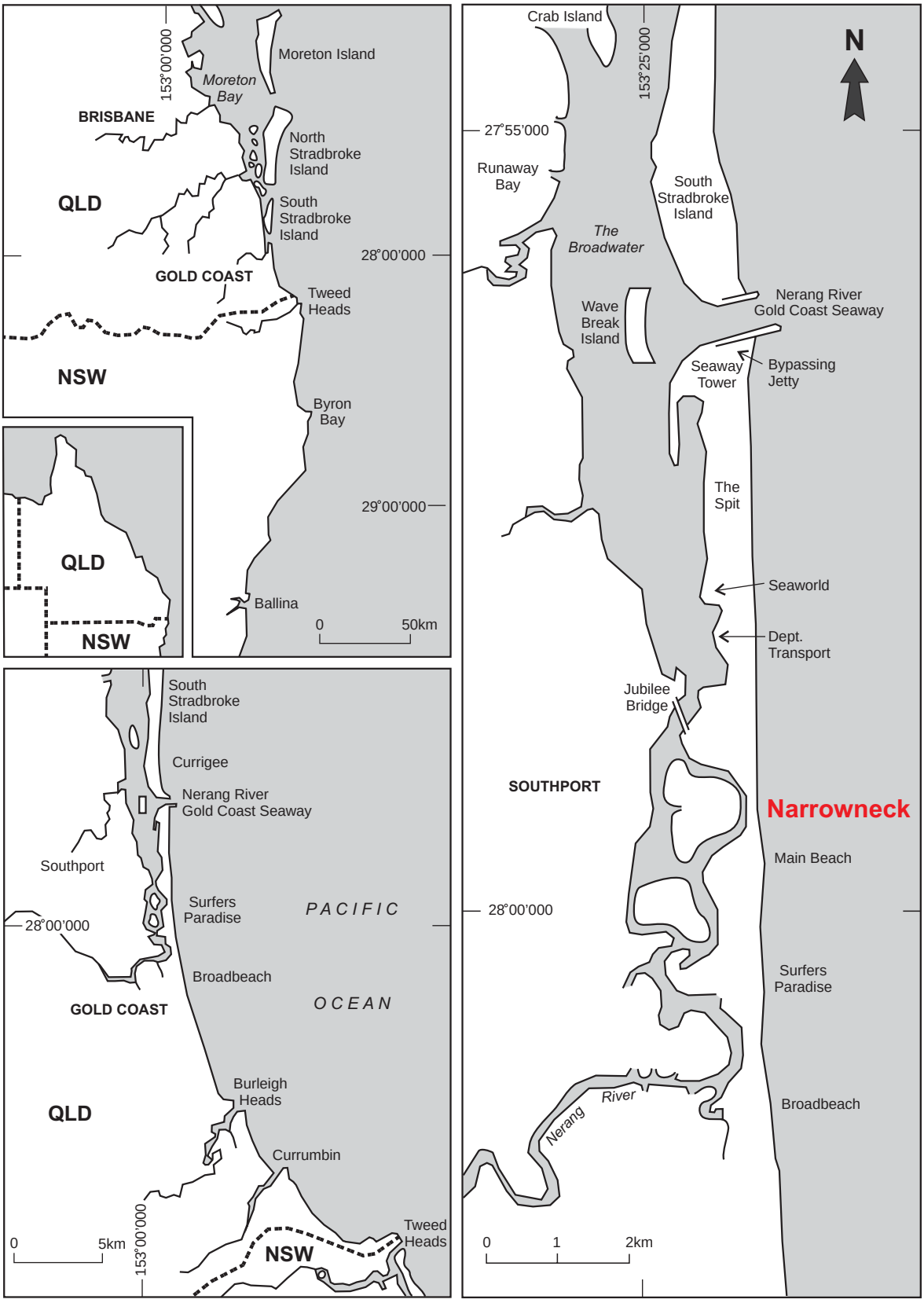
The novel shape of the reef was designed following field investigations and extensive numerical model simulations to determine the optimum reef layout (Black, 1998; Black et al., 1998). The final reef design was further tested by a physical model study (Turner et al., 1998a). Reef construction commenced in August 1999, and to date around 430 sand-filled geocontainers (up to 350 tonnes) have been used to construct the reef. The reef design consists of two primary layers of stacked geocontainer units. Figure 2.3 shows the progress of reef construction up to and including the most recent phase of geocontainer placement.

2.3 Sand Nourishment

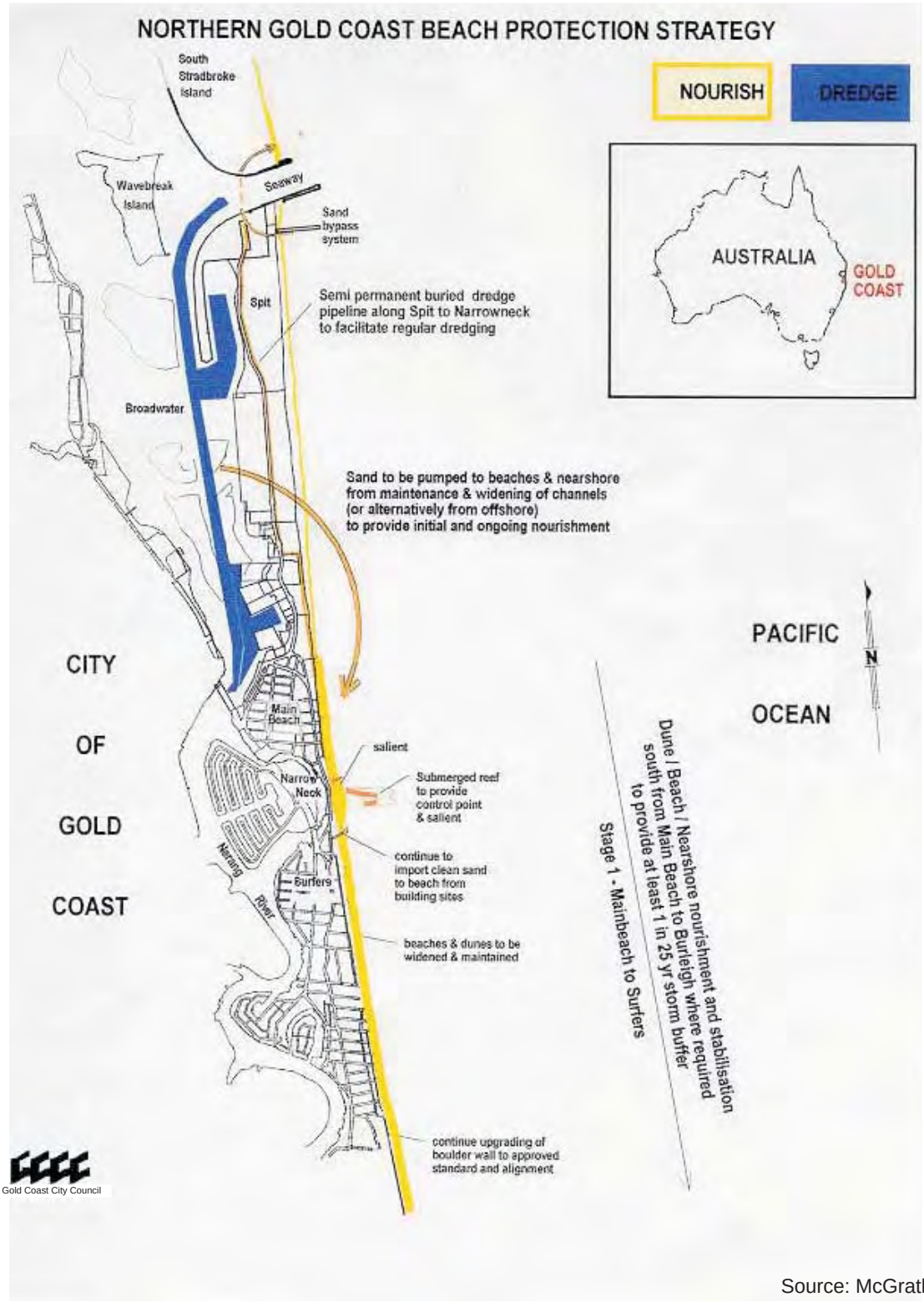
Nourishment of the northern Gold Coast beaches commenced in February 1999, six months prior to reef construction. Cumulative nourishment volumes for the 17 month nourishment period February 1999 to June 2000 are shown in Figure 2.4, at which time this major phase of beach nourishment within the 4,500 m study area was completed.

In summary, during this period approximately 1,170,000 m^3 of sand was placed on the beach and nearshore at the northern Gold Coast. The locations of the six sand nourishment deposition areas are indicated in Figure 2.5. For reference, the location of the reef construction site at Narrowneck is shown in this figure. A small volume of additional sand (~ 37,000 m^3) was also deposited approximately 300 m north of deposition area A1 in June 2000, denoted deposition area A1a in Figure 2.4.

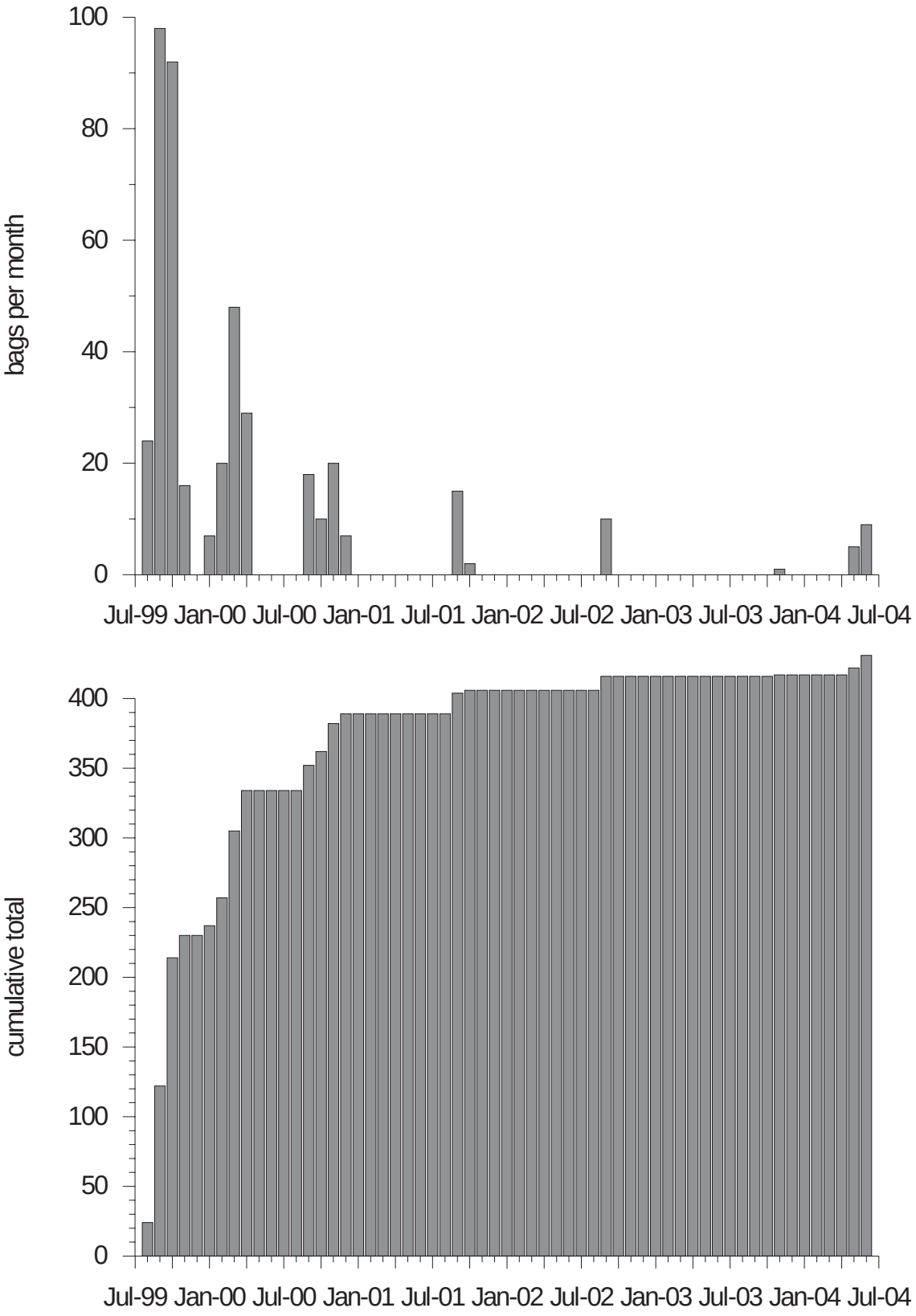
Due to dredging operations in the Broadwater, in January 2005 around 27,000 m^3 of sand was placed in the vicinity of deposition area A5. From February to April 2005, coinciding with this present six-month monitoring period, another 32,000 m^3 of sand was placed within this region, bringing the total nourishment volume during this campaign to 59,000 m^3.



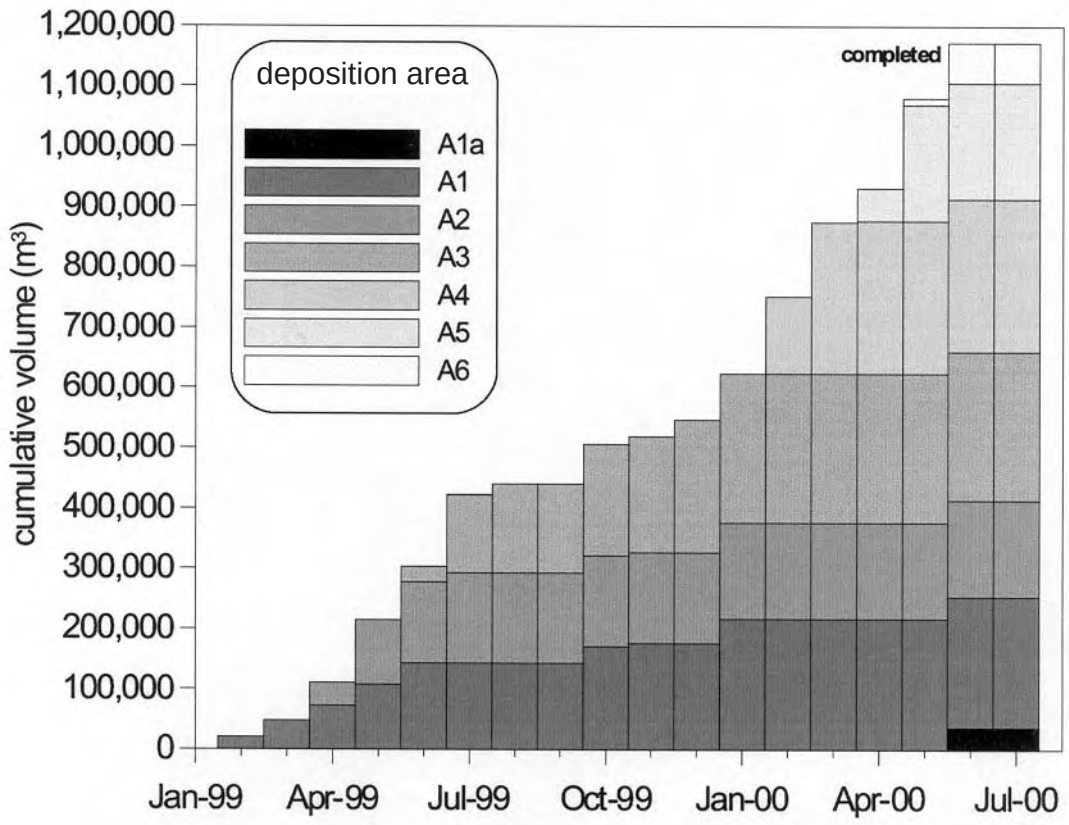
WRL Report No. 2007/08	LOCALITY	Figure 2.1 06037-2-1.cdr



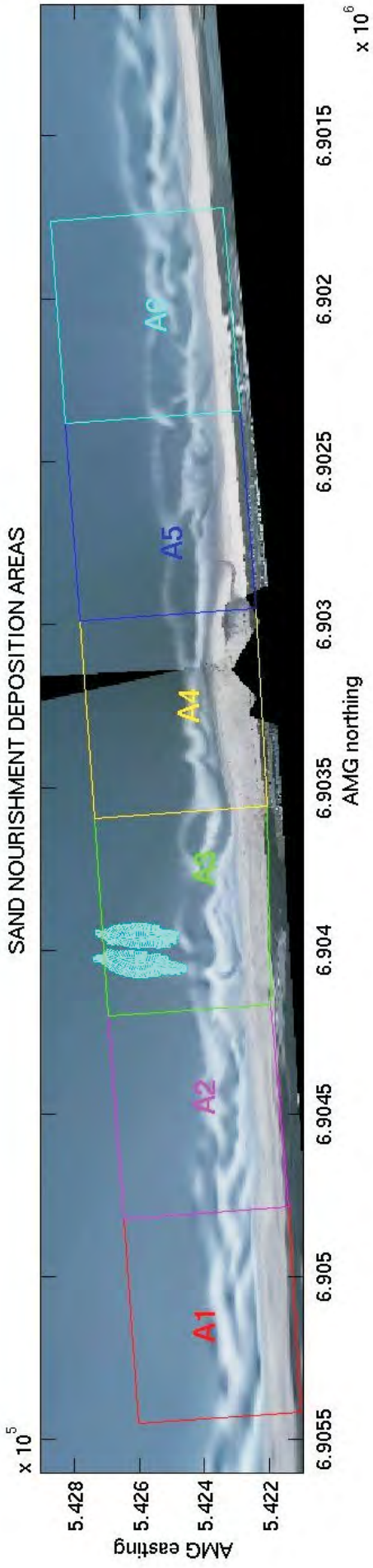
Source: McGrath et al. (2000)



WRL Report No. 2007/08	REEF CONSTRUCTION	Figure 2.3 06037-2-3.cdr



WRL Report No. 2007/08	SAND NOURISHMENT (NGCBPS)	Figure 2.4 06037-2-4.cdr



WRL Report No. 2007/08	SAND NOURISHMENT DEPOSITION AREAS	Figure 2.5 06037-2-5.cdr

3. OVERVIEW OF COASTAL IMAGING, IMAGE TYPES AND IMAGE PROCESSING TECHNIQUES

Comprehensive descriptions of the northern Gold Coast coastal imaging system, image types and imaging processing techniques were detailed in the first NGCBPS coastal imaging report *System Description and Analysis of Shoreline Change: August 1999 – February 2000* (Turner and Leyden, 2000a). For the sake of completeness, the following section provides a brief summary of the system and the image processing techniques being used to quantify beach changes. Also included is a description of the image analysis technique (called WRL Intertidal Beach Mapper or 'WIBM') that was implemented in mid 2003 to bring the northern Gold Coast monitoring project in line with similar projects at other major coastal management and coastal engineering sites in both Australia and overseas.

3.1 What is Coastal Imaging?

'Coastal imaging' simply means the automated collection, analysis and storage of pictures, that are then processed and analysed to observe and quantify coastline variability and change.

Aerial photography has been the tool most commonly used by coastal managers to monitor regional-scale coastal behaviour. This is expensive, and as a result, coverage is often 'patchy' and incomplete. Also of course, pictures are only obtained when the airplane is in the air and visibility is satisfactory, often resulting in a limited number of suitable pictures per year (at most), with no information about the behaviour of the beach between flights.

In contrast, with the recent development of digital imaging and analysis techniques, one or more automated cameras can be installed at a remote site and, via a telephone or internet connection, be programmed to collect and transfer to the laboratory a time-series of images. These images, taken at regular intervals every hour of the day for periods of years, can cover several kilometres of a coastline. Not every image need be subjected to detailed analysis, but by this method the coastal manager can be confident that all 'events' will be documented and available for more detailed analysis as required.

3.2 The Difference between Coastal Imaging and a 'Webcam'

At the core of the coastal imaging technique is the ability to extract quantitative data from a time-series of high quality digital images. In contrast, conventional Webcams are very useful to applications where a series of pictures of the coastline is sufficient, and these types of images can be used to develop a qualitative description of coastal evolution.

The extraction of quantitative information from the coastal imaging system is achieved by careful calibration of the cameras and the derivation of a set of mathematical equations that are used to convert between two-dimensional image coordinates and three-dimensional ground (or 'real world') coordinates. For detailed description and illustration of the methods used to calibrate the lens and cameras installed at the northern Gold Coast, the reader is referred to Turner and Leyden (2000a).

3.3 The ARGUS Coastal Imaging System

The ARGUS coastal imaging system has developed out of almost two decades of ongoing research effort originating from Oregon State University, Oregon USA (Holman et al., 1993). A schematic of a typical ARGUS station is shown in Figure 3.1. The key component of an ARGUS station is one or more cameras pointed obliquely along the coastline. The camera(s) are connected to a small image processing computer (Silicon Graphics SGI workstation), which controls the capture of images, undertakes pre-processing of images, and automatically transfers the images via the internet from the remote site to the laboratory. The cameras installed at the northern Gold Coast are fitted with high quality lenses. A switching interface between the cameras and computer maintains synchronisation of the captured images. The SGI workstation incorporates an internal analog I/O card that enables all images to be captured, stored and distributed in standard jpeg digital image file format.

At WRL a host computer (dual-processor LINUX workstation) stores all images as they are received from the remote site, within a structured archive. This workstation is also integrated to a world-wide-web server, with the images made available to all visitors to the web site to view and download within minutes of their capture and transfer from the northern Gold Coast to WRL. Post-processing of the images is completed using a variety of Linux and PC computer hardware and custom image processing software within the MATLAB programming environment.

3.4 Installation at the Northern Gold Coast

The ARGUS coastal imaging system was installed at the northern Gold Coast in late July 1999. The system is located at an elevation of approximately 100 m above mean sea level, within a roof services area of the Focus Building (Figure 3.2). The Focus Building is located approximately 60 m landward of the dune line, approximately 900 m to the south of Narrowneck.

The cameras are mounted externally to the building, and are protected within weatherproof housings (Figure 3.3). The SGI workstation is housed within an air-conditioning services room, where 240 V power and a dedicated phone line connection to the internet are provided. The system is designed to run autonomously, and is self-recovering should an interruption to the mains power supply occur. Routine maintenance of the system is achieved by connection to the remote system via the internet from WRL. Occasional cleaning of the camera lenses is also required.

3.5 Image Types

The ARGUS coastal imaging system installed at the northern Gold Coast is presently configured to collect three different types of images on a routine hourly basis. A fourth image type is created by automated post-processing at the completion of each day of image collection.

Images are collected every daylight hour. The image collection procedure is fully automated and controlled by the SGI workstation at the remote site. Prior to commencing the hourly image collection routines, a test is undertaken to determine if there is sufficient daylight to proceed with image collection. If the ambient light threshold is exceeded, image collection commences. The reason for first checking for daylight conditions is to avoid unnecessary image collection at night, without excluding image collection earlier in the morning and later in the evening during extended summer daylight hours.

3.5.1 Snap-Shot 'snap' Images

The simplest image type is the snap-shot image. This is the same image obtained if a picture of the beach were taken using a conventional digital camera. Snap-shot images provide simple documentation of the general characteristics of the beach, but they are not so useful for obtaining quantitative information. An example of a snap image obtained in late January 2007 is shown in Figure 3.4 (upper panel).

3.5.2 Time-Exposure 'timex' Images

A much more useful image type is the time-exposure or 'timex' image. Time-exposure images are created by the 'averaging' of 600 individual snap-shot images collected at the rate of one picture every second, for a period of 10 minutes.

A lot of quantitative information can be obtained from these images. Time exposures of the shore break and nearshore wave field have the effect of averaging out the natural variations of breaking waves, to reveal smooth areas of white, which has been shown to provide an excellent indicator of the shoreline and nearshore bars. In this manner, a quantitative 'map' of the underlying beach morphology can be obtained. An example of a timex image is shown in Figure 3.4 (middle panel).

3.5.3 Variance 'var' Images

At the same time that the timex images are being collected, an image type called a variance or 'var' image is also created. Whereas the time-exposure is an 'average' of many individual snap-shot images, the corresponding variance image displays the variance of light intensity during the same 10 minute time period.

Variance images can assist to identify regions which are changing in time, from those which may be bright, but unchanging. For example, a white sandy beach will appear bright on both snap-shot and time-exposure images, but dark in variance images. Because of this, other researchers have found that variance images are useful at some specific coastal sites for analysis techniques such as the identification of the shoreline, as the changing water surface (bright) is readily identifiable against the beach (dark). An example of a var image is shown in Figure 3.4 (lower panel).

3.5.4 Day Time-Exposure 'daytimex' Images

The fourth image type routinely created from the coastal imaging system installed at the northern Gold Coast is referred to as a daytimex image. It is created at the end of each day of image collection, by the averaging of all hourly timex images collected that day. This has the effect of 'smoothing' the influence of tides, and for some conditions may enhance the visibility of the shore break and bar features in the nearshore. In earlier monitoring reports the daily daytimex images provided the basis for the qualitative description of the morphodynamic trends and changes that characterised each six-monthly monitoring period. With the implementation in mid 2003 of the enhanced ‘real-time’ online beach monitoring system at the northern Gold Coast, (refer Section 4.3), the new ‘week-to-a-page’ product

replaced this use of the daytimex images. However, daytimex images continue to be created, and are available for viewing and download at the project web site via the online image archive.

3.6 Basic Image Processing – Merge, Rectification and Reference to Real-World Coordinate System

As noted earlier in Section 3.2, the key feature of coastal imaging technology that distinguishes it from conventional webcam systems is the ability to extract quantitative information from the images. This is achieved through the solution of the camera model parameters (refer Turner and Leyden, 2000a) to extract three-dimensional real-world position from two-dimensional image coordinates, and the application of image processing techniques to identify, enhance and manipulate the image features of interest.

Image merging is achieved by the solution of camera model parameters for individual cameras, then the boundaries of each image are matched to produce a single composite image. Image rectification is then undertaken, whereby the dimensions of the merged image are corrected so that each pixel represents the same area on the ground, irrespective of how close to or how far from the camera position it may be. (In contrast, for an unrectified image the area represented by each pixel increases with increasing distance from the camera.)

Image rectification is achieved by using the calculated camera model parameters to fit an image to a regular grid that defines longshore and cross-shore distance. The rectification of merged images produces a 'plan view' of the area covered by all four cameras. This is illustrated in Figure 3.5. This merged and rectified image created from four oblique images is analogous to a montage of distortion-corrected photographs taken from an airplane flying directly overhead the northern Gold Coast. For convenience, the longshore and cross-shore dimensions of this image are referenced (in metres) to the location of the cameras. The pixel resolution of the merged/rectified images created at the Gold Coast is 5 m; that is, a single pixel represents an area 5 m × 5 m.

The final step in the routine processing of images at the northern Gold Coast is the referencing of merged/rectified images to a convenient map reference system. As the coordinates of the cameras are known, this final step is relatively easy to achieve. In Figure 3.6 an example of a merged and rectified image is shown, referenced to Australian Map Grid (AMG) eastings and northings. The referencing of images to real-world coordinates permits the combination of image information with other cadastral information; in Figure 3.6 a merged and rectified timex image is overlaid by an engineering design

drawing showing the layout of the geotextile bags comprising the bottom layer of the Gold Coast reef. As illustrated in the upper panel of this figure, specific regions of interest within an image can be enlarged to examine in greater detail that region of the beach or nearshore. As also shown in Figure 3.6, this enables the geo-referenced images to be overlaid by other cadastral information (e.g. reef layout).

3.7 Shoreline Detection and Analysis

To map the position of the shoreline and its changing location through time, a rigorous image analysis methodology is required to enable the extraction of this information from the database of hourly ARGUS images.

In earlier reports, a shoreline mapping technique developed specifically for the Gold Coast site was employed, that fully utilised the RGB (Red-Green-Blue) colour information that was newly available at the northern Gold Coast site (prior to 1999, ARGUS stations typically collected grey-scale images only). A comprehensive description of this colour-based shoreline detection technique can be found in Turner and Leyden (2000a), and a summary of the method is contained in all previous reports.

Since that time, the use of full colour information has been adopted more generally by the international ARGUS-user community, which has led to considerable improvements to the range of shoreline detection and mapping techniques that are now more generally available. To ensure that the current and future monitoring program at the northern Gold Coast is in line with these international developments, during 2003 the ‘standardised’ shoreline mapping methodology (called ‘Pixel Intensity Clustering’ or ‘PIC’) that is being used at a number of sites around the world was implemented within the northern Gold Coast image database. For a detailed description of the analysis and image database re-processing that was performed prior to the implementation of this enhanced methodology, the reader is referred to Turner (2003b).

3.7.1 Overview of the ‘PIC’ shoreline identification technique

Comprehensive description of the PIC shoreline identification technique is provided in Aarninkhof (2003), Aarninkhof and Roelvink (1999) and Aarninkhof et al (2003). Briefly, the technique aims to delineate a shoreline feature from 10 minute time exposure images, on the basis of distinctive image intensity characteristics in pixels, sampled across the sub-aqueous and sub-aerial beach. Raw image intensities in Red-Green-Blue (RGB) colour-space, sampled from a region of interest across both the dry and wet beach, are converted to

Hue-Saturation-Value (HSV) colour space, to separate colour (Hue, Saturation) and grey-scale (Value) information. The HSV intensities are filtered to remove outliers and scaled between 0 and 1, to improve the contrast between two clusters of dry and wet pixels. Iterative low-passing filtering of the spiky histogram of scaled intensity data yields a smooth histogram with two well-pronounced peaks P_{dry} and P_{wet}, which mark the locations of the two distinct clusters of dry and wet pixels (Figure 3.7).

The filtered histogram is used to define a line to distinguish between Hue Saturation information used for colour discrimination (Figure 3.7a), or Value information in the case of luminance-based discrimination (Figure 3.7b). For both discriminators, the line defined in this manner crosses the saddle point of the filtered histogram, and thus provides the means to separate objectively the two clusters of dry and wet pixels within the region of interest. With the help of this line, a discriminator function Ψ is defined such that $\Psi = 0$ along this line (see Figure 3.7). The areas of dry and wet pixels are then mapped, and the boundary between the two regions defines the resulting shoreline feature of interest.

3.8 Standardised Procedure for Shoreline Mapping

The procedure used to map the shoreline at the northern Gold Coast is summarised in Figure 3.8. At weekly (nominal seven day) intervals, predicted tide information is used to determine the hourly timex images that correspond to mid-tide (0 m AHD). The database of wave information is also searched to determine the rms ('root mean square') wave height (H_{rms}) and spectral peak wave period (T_p) that correspond to these daily mid-tide images.

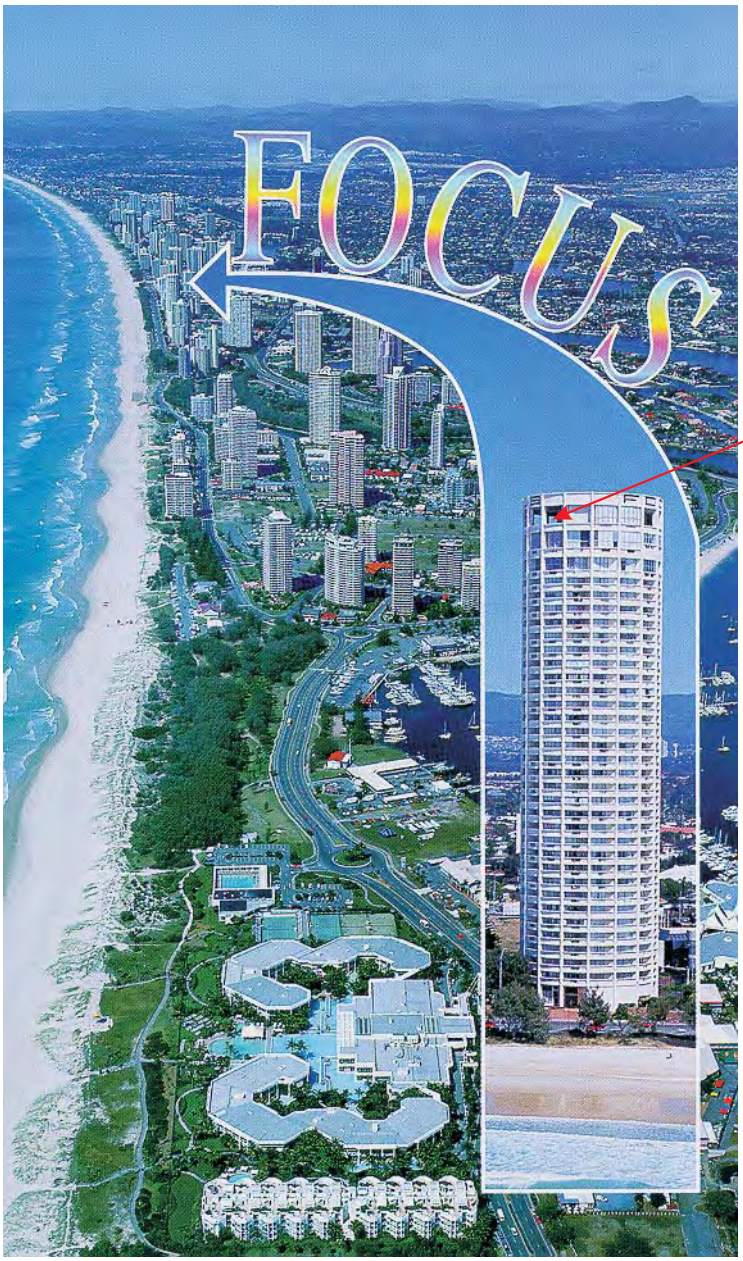
Based on a seven day cycle, the corresponding mid-tide images are checked to confirm that the wave height satisfies the low-pass criteria $H_{rms} \leq 1.0$ m (ie. $H_s \leq$ ~1.4 m). This wave height criteria is used for all shoreline mapping as, above this wave height, wave runup at the beachface increases and the width of the swash zone widens, introducing a degree of uncertainty in the cross-shore position of the waterline. If the Root Mean Square wave height is less than 1.0 m, then the shoreline is mapped. Prior to November 2004 a single merged-rectified image of the entire study area was analysed, but since that time the four (higher resolution) individual oblique images are analysed separately, camera geometries are applied to convert between image and real-world coordinates, and finally the resulting shoreline segments are merged along the length of the study area. The current use of individual-oblique versus merged-rectified images for shoreline mapping enables the full resolution of the individual raw images to be better exploited.

If the wave height exceeds the H_{rms} = 1.0 m threshold, then the mid-tide images for the preceding day are checked. If these images still does not satisfy the wave height criteria, then the following day's images are checked. This process is repeated for up to ± 3 days from the original target weekly image, to locate mid-tide images for which the wave height did not exceed 1.0 m. If no mid-tide images are available in any one seven day cycle that satisfy this criteria, then no shoreline is mapped for that week.

Once the mid-tide images to be processed has been identified, the PIC method is applied and the shoreline feature is mapped. Beach width is then calculated relative to a dune reference line. By repeating this procedure every seven days, a growing data base is developed that contains the time-series of weekly shoreline positions at all positions along the shore. These data are then subjected to a range of analyses as described in the following Sections 6, 7 and 8.

WRL	SCHEMATIC OF AN ARGUS COASTAL IMAGING SYSTEM	Figure 3.1
Report No. 2007/08		06037-3-1.cdr

IMAGE COURTESY OF FOCUS APARTMENTS



WRL Report No. 2007/08	LOCATION OF ARGUS COASTAL IMAGING SYSTEM AT THE GOLD COAST	Figure 3.2 06037-3-2.cdr











WRL Report No. 2007/08	CAMERAS MOUNTED AT AN ELEVATION OF APPROXIMATELY 100m	Figure 3.3 06037-3-3.cdr

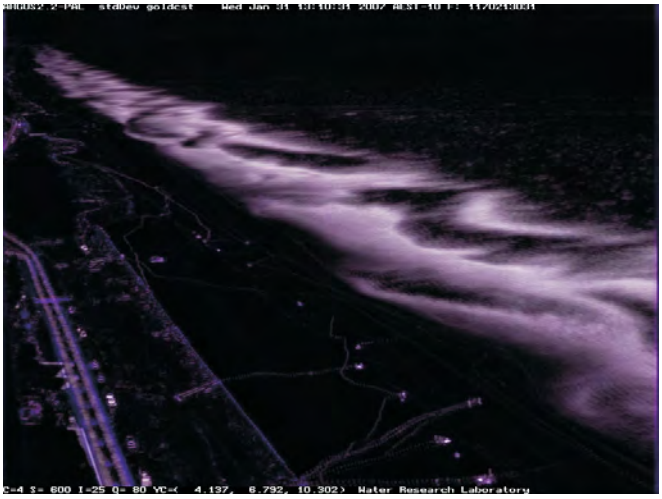
snap



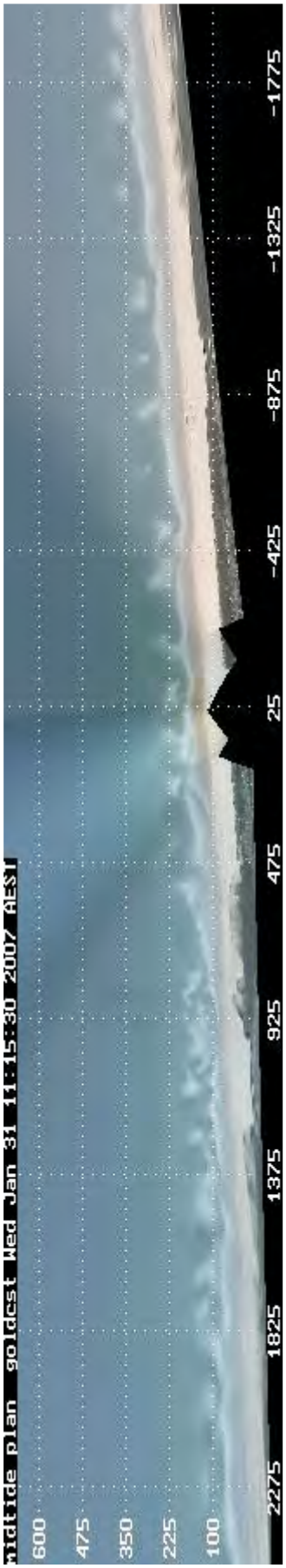
timex



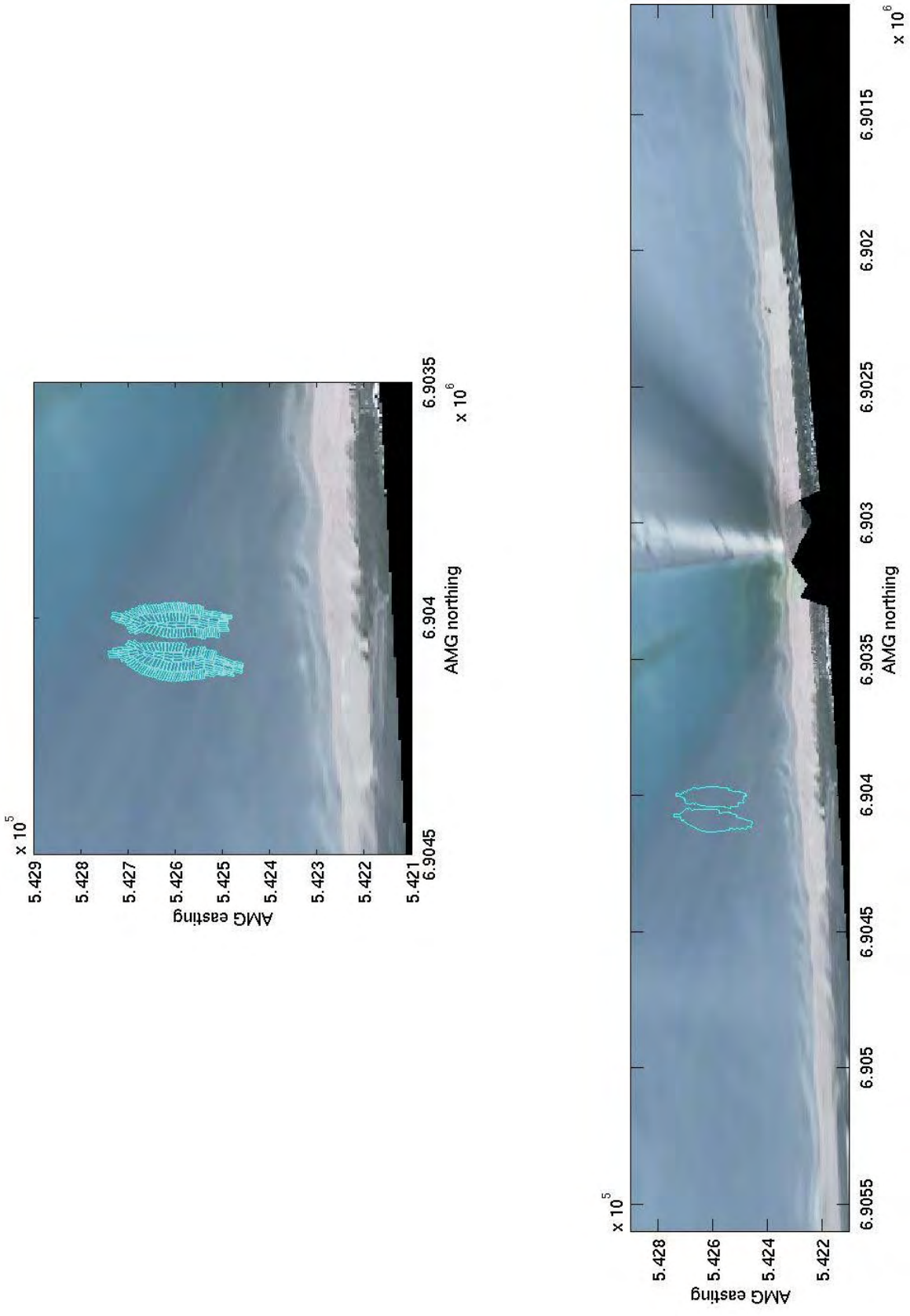
var



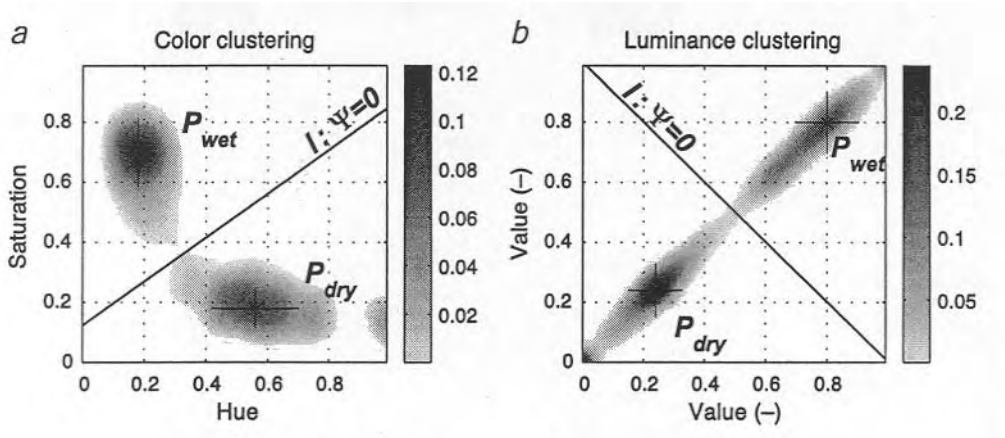
WRL Report No. 2007/08	SNAP-SHOT, TIME-EXPOSURE AND VARIANCE IMAGE TYPES (31/01/07)	Figure 3.4 06037-3-4.cdr



WRL Report No. 2007/08	PLAN VIEW IMAGE 4 CAMERA MERGE/RECTIFICATION (31/01/07)	Figure 3.5 06037-3-5.cdr

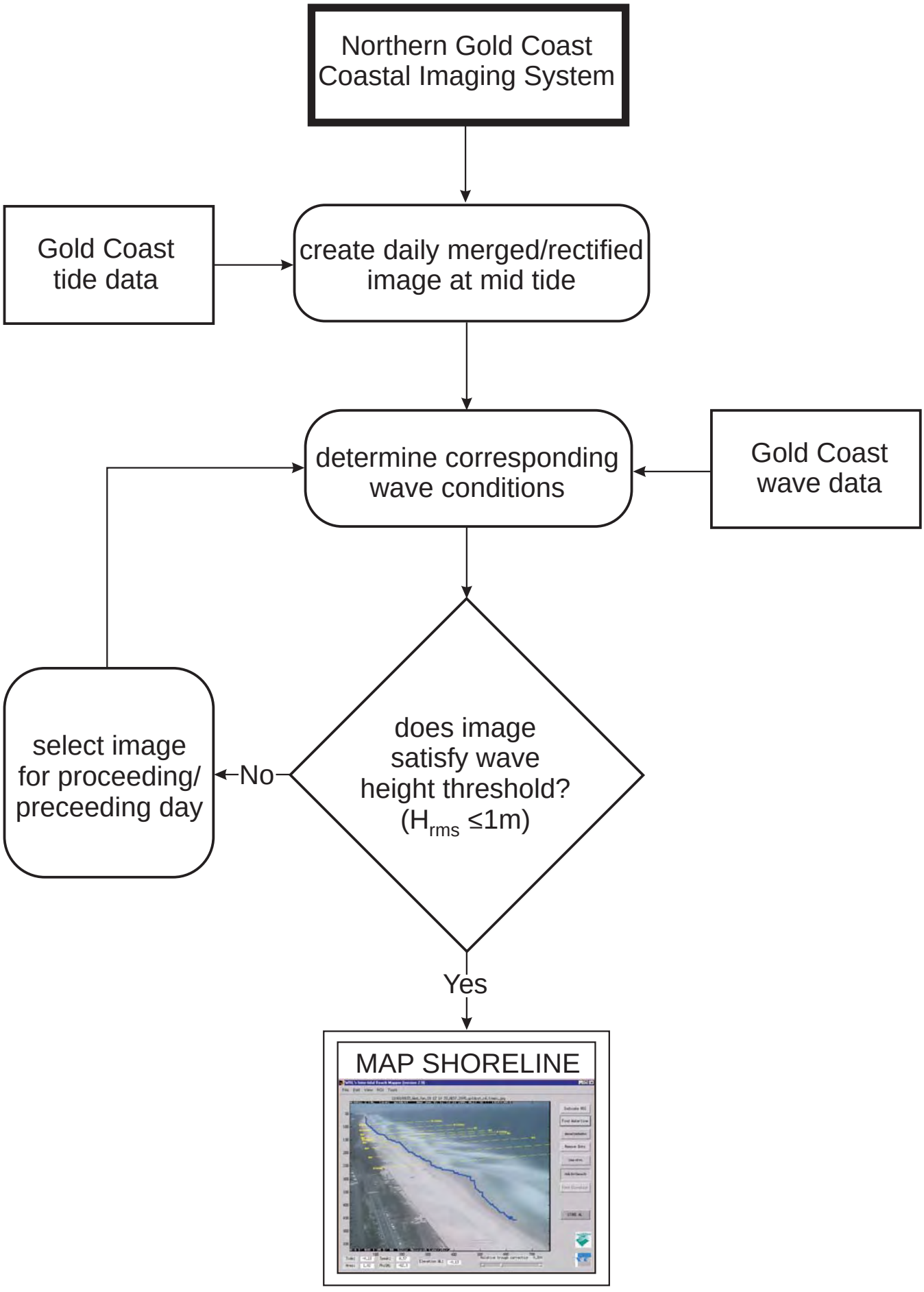


WRL Report No. 2007/08	PLAN VIEW IMAGE REFERENCED TO 'REAL WORLD' AMG COORDINATE SYSTEM	Figure 3.6 06037-3-6.cdr



Source: Aarninkhof (2003)

WRL Report No. 2007/08	IDENTIFICATION OF 'SHORELINE' FEATURE FROM COLOUR IMAGES	Figure 3.7 06037-3-7.cdr



WRL Report No. 2007/08	STANDARDISED SHORELINE MAPPING PROCEDURE	Figure 3.8 06037-3-8.cdr

4. COASTAL IMAGING WEB SITE

4.1 Coastal Imaging Home Page

To promote the dissemination of information about the northern Gold Coast coastal monitoring project, to provide a convenient means to distribute images as they are collected, and to enable 'real-time' access to the regularly-updated results of shoreline monitoring and beach width analysis, a coastal imaging project site was established on the world-wide web at the following address:

→ www.wrl.unsw.edu.au/coastalimaging/public/goldcst

The northern Gold Coast coastal imaging home page is shown in Figure 4.1. The most recent snap images are displayed here and updated every hour, enabling visitors to the site to observe the current beach conditions at the northern Gold Coast. This page also includes a number of links to a variety of background information including a description of the coastal imaging system, image types and image processing techniques. Links are also provided to the Gold Coast City Council web site, the NGCBPS web site maintained by International Coastal Management, the waverider buoy site run by the Queensland Department of Environment, local weather conditions provided by the Bureau of Meteorology, and tidal predictions for the Gold Coast Seaway provided by the National Tidal Facility.

For general interest, a record is maintained of the number of visitors to the WRL coastal imaging web site and the countries they are from. At the time of writing, more than 255,000 hits to WRL coastal imaging web pages have been recorded. Visitors from Australia account for approximately half the total visitors, with the remaining visitors coming from approximately 80 countries world-wide.

4.2 Image Archive

The current snap, timex images and var images are updated and available at the project web site every hour.

All present and past images can be accessed via the image archive. This provides a convenient and readily navigable structure to quickly locate the image(s) of interest. Figure 4.2 shows an example of a daily page contained within the image archive. These

images are provided freely to encourage their use by students, researchers, managers and other non-commercial organisations.

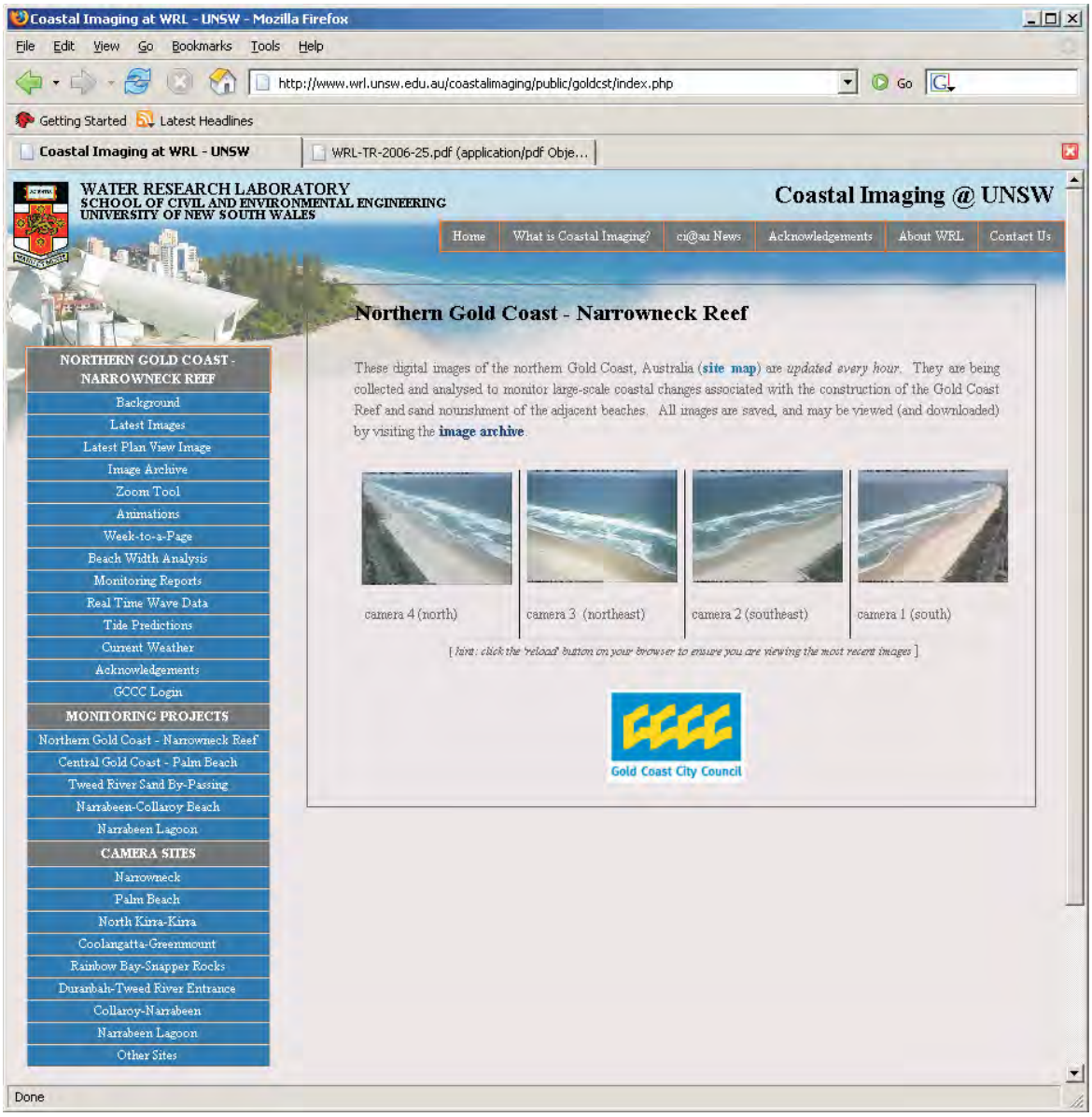
4.3 On-Line 'Beach Analysis System'

Since 2003, on-line access to 'real time' beach monitoring analysis and information (similar to that provided every six months in these NGCBPS reports) has been made available at the northern Gold Coast coastal imaging web site. This capability results from the on-going research and development effort underway by the coastal imaging team at WRL. The purpose of this system is to provide regularly-updated results of the beach monitoring program to Gold Coast Council and the interested general public on a routine basis, via the world wide web.

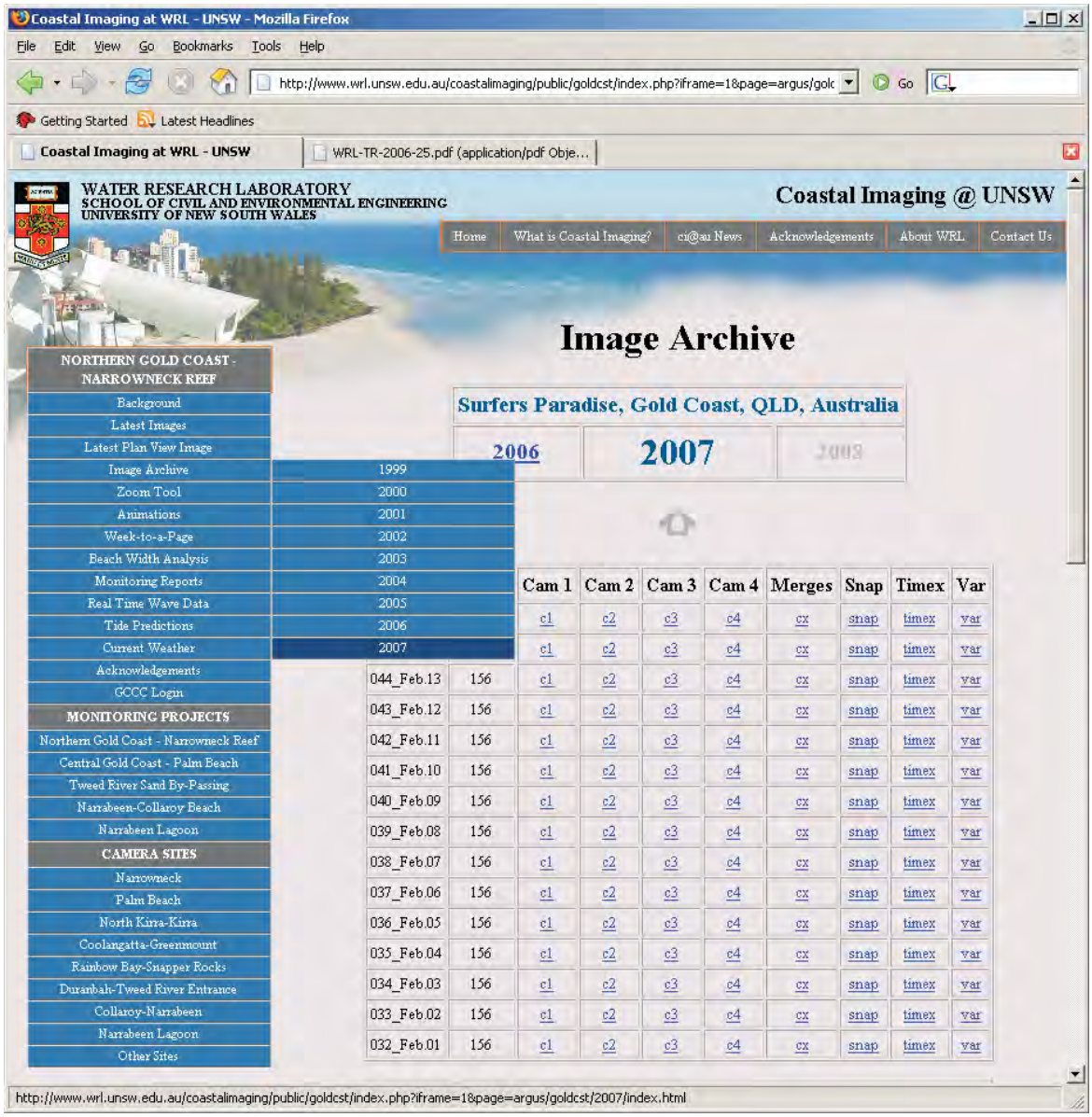
A detailed description of the capabilities of this system is detailed in Anderson et al (2003). To summarise, the features available at the project web site include the ability to view the latest mid-tide plan images; access to a zoom tool feature that enables zooming in and panning through the current oblique and rectified images; full on-line access to all past and present monitoring reports; and two products specifically designed to assist both the qualitative and quantitative interpretation of images, shoreline data and the results of beach width analysis.

An example of the first of these products called 'week-to-a-page' is illustrated in Figure 4.3. Every Monday morning, this figure is generated and made available for viewing (and download if required) via the project web site. The figure is pre-formatted to fit on a standard A4 page, to assist reporting. This figure compiles daily mean sea level plan view images of the entire northern Gold Coast study site for that week, into a compact one-page summary. This product provides coastal managers a means of quickly and efficiently interpreting the daily changes in beach morphology and shoreline position, without continual recourse to the hourly images. An archive of these weekly figures is also maintained and available on-line.

The second product that is also updated each Monday morning and made available via the project web site is 'Beach-Width-Analysis' (Figure 4.4). This figure in graphical format summarises quantitative information of the mean shoreline position for that week; shoreline variability by comparing the current shoreline position with previous weeks and months; beach width along pre-defined monitoring transects; and beach width trends throughout the history of the monitoring project.



WRL Report No. 2007/08	COASTAL IMAGING WEB SITE - HOME PAGE	Figure 4.1 06037-4-1.cdr

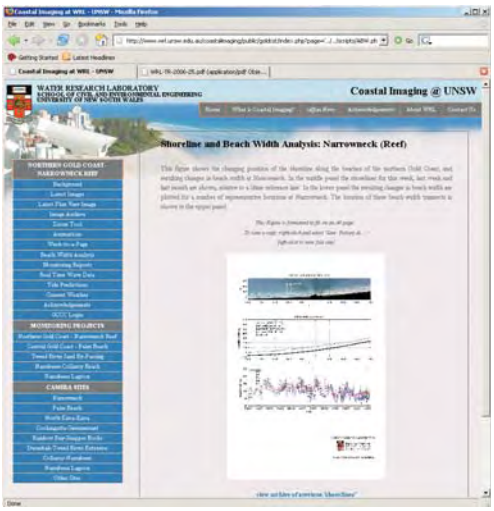


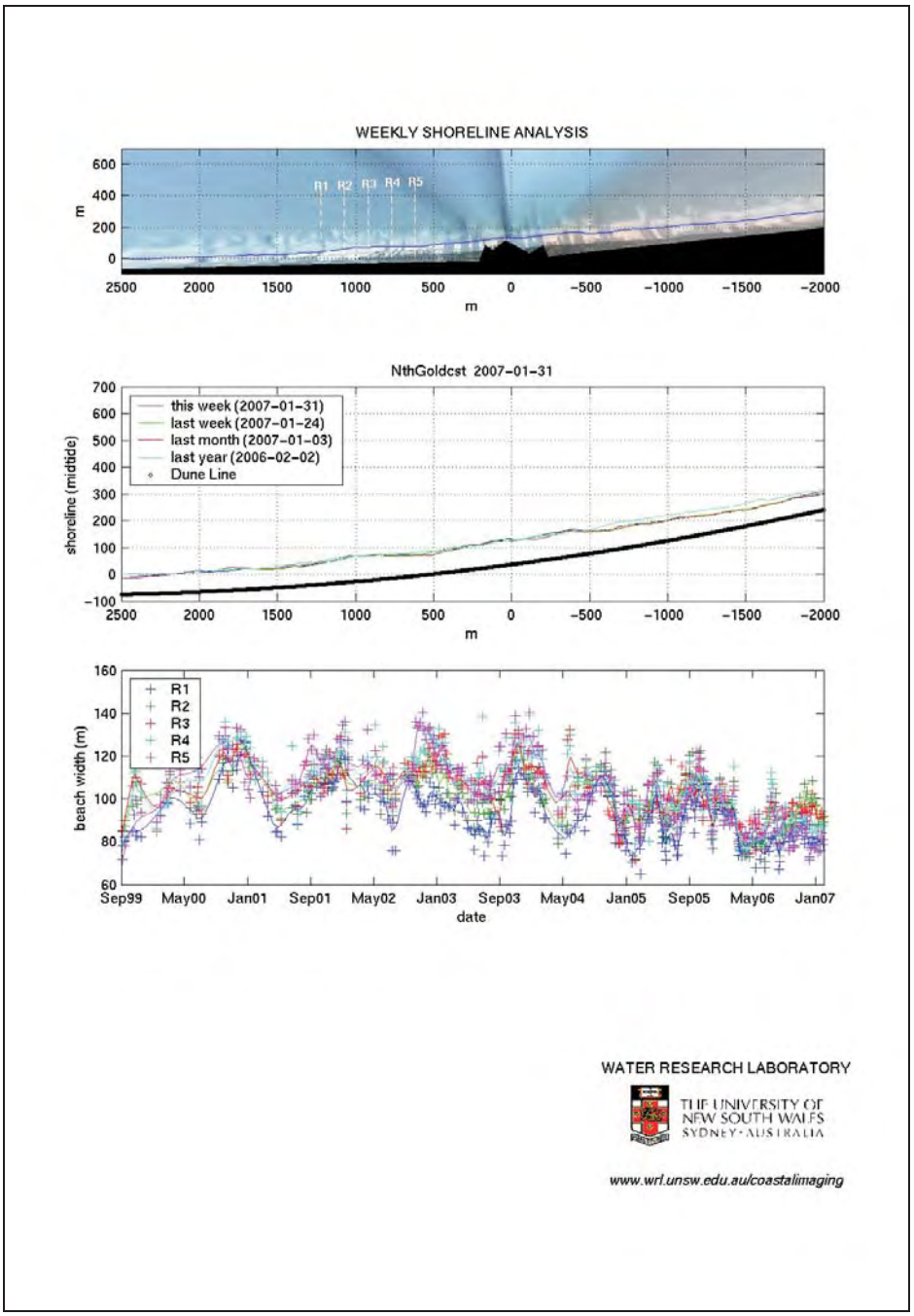
WRL Report No. 2007/08	COASTAL IMAGING SYSTEM WEB SITE - IMAGE ARCHIVE	Figure 4.2 06037-4-2.cdr





WRL Report No. 2007/08	ON-LINE BEACH ANALYSIS SYSTEM - 'WEEK-TO-A-PAGE'	Figure 4.3 06037-4-3.cdr





WRL Report No. 2007/08	ON-LINE BEACH ANALYSIS SYSTEM - 'BEACH WIDTH ANALYSIS'	Figure 4.4 06037-4-4.cdr

5. MORPHODYNAMIC DESCRIPTION OF THE GOLD COAST BEACHES: AUGUST 2006 – JANUARY 2007

From the daily images obtained by the ARGUS coastal imaging station atop the Focus building, it is self-evident that the beaches of the northern Gold Coast are dynamic and continually changing. Bars move onshore and offshore and vary in shape from straight to crescentic, rips emerge and disappear, and the shoreline changes shape and translates landward and seaward in response to varying wave conditions and beach nourishment. As in previous reports, this section is included to provide a qualitative description of the observed beach changes during the present six-month monitoring period August 2006 to January 2007. The 'week-to-a-page' summary figures that are updated every week and made publicly available for inspection and download via the project web site, are used in this section to illustrate the observed beach changes. The objective is not to describe every characteristic of the northern Gold Coast beaches during this period, but rather the aim is to provide an overview of general trends and predominant features that were observed during this time.

To summarise beach changes in some structured manner, it is useful to first outline a systematic beach classification scheme with which to undertake this qualitative analysis. For consistency, this same classification scheme was used in all previous NGCBPS coastal imaging reports, and will continue to be used in future reports to enable inter-comparison as the monitoring program continues.

5.1 A Morphodynamic Classification of Beaches

Despite the seemingly endless range of changes observed at any sandy coastline, it has been shown that beaches tend to exhibit certain characteristics that vary in a systematic and predictable way. One such scheme for describing these changes is the 'Morphodynamic Beach State Model' first outlined by Wright and Short (1983). This beach classification scheme was developed in Australia, and is now the most widely-used descriptive beach model internationally. The term 'morphodynamics' derives from the combination of the words 'morphology' and 'hydrodynamics', emphasising the strong linkage between the shape of a beach and the associated wave and current conditions.

Beaches can be classified as being in one of six beach 'states' at any given point in time. The generalised cross-section and planform characteristics of these six beach states are summarised in Figure 5.1. A brief description of each of these states is provided below.

At one extreme is the *dissipative* beach state (Figure 5.1a), which is characterised by a very low profile slope and wide surfzone. Dissipative beaches are generally composed of fine sand and occur along coastlines exposed to high wave energy. Nearshore bathymetry is usually characterised by one or more straight and shore-parallel bars. The term 'dissipative' is used to describe beaches that exhibit these characteristics because wave energy is essentially dissipated by extensive wave breaking across the surf zone, before it can reach the shoreline.

At the other end of the beach state spectrum, *reflective* beaches (Figure 5.1f) are invariably steep, with no nearshore bars. Waves tend to break close to or right at the shoreline, and hence very little wave energy is dissipated; instead it is reflected by the beachface and propagates offshore. These beaches tend to be composed of coarse sediments and/or are generally located in protected or low wave energy coastal regions.

Between the dissipative and reflective extremes, four *intermediate* beach states can be identified. These incorporate elements of both the reflective and dissipative domains. The four intermediate beach types are referred to as *longshore bar-trough* LBT (Figure 5.1b), *rhythmic bar and beach* RBB (Figure 5.1c), *transverse bar and rip* TBR (Figure 5.1d) and *low tide terrace* LTT (Figure 5.1e). Together, these intermediate beach types form a sequence of characteristic beach states related to the movement of sand onshore (decreasing wave steepness) and offshore (increasing wave steepness). The onshore-offshore movement of sand is most easily recognised by the movement and changing shape of bars within the nearshore zone.

Following the characteristic offshore movement (*i.e.,* erosion) of sediment during a major storm, typical post-storm beach recovery includes the gradual onshore migration of nearshore bars and the development of weak and then stronger rips (LBT → RBB → TBR). If low wave conditions persist, bars ultimately disappear as the bar becomes welded to the beach to form a terrace (LTT). Beaches of the moderately high energy east Australian open coast are typically observed to transfer between these four intermediate morphodynamic beach states, in response to lower wave conditions interspersed by episodic storm events.

5.2 Morphodynamic Interpretation of Daily Images

All week-to-a-page figures for the period August 2006 to January 2007 are presented in Appendix A. Each of these figures shows a week (seven days) of sequential mid-tide plan images, with the date of each indicated. All images are obtained at approximately the same stage of the tide (mean sea level), to enable the direct comparison between different days

and weeks. The region shown in these figures extends 4,500 m alongshore, from approximately 1,500 m north of the reef construction site at Narrowneck, to 3,000 m south along the Surfers Paradise Esplanade.

To assist the interpretation of these images, Appendix B contains monthly summaries of wave height and period, obtained from the Gold Coast Waverider buoy and supplied to WRL by the Queensland Department of Environment. When data from the Gold Coast Waverider buoy has been unavailable, data from the Brisbane buoy has been substituted to fill the gap. The Gold Coast Waverider buoy is located at Latitude 27° 57.84' S Longitude 153° 26.55' E in a water depth of approximately 18 m, while the Brisbane Waverider buoy is located at Latitude 27° 29.75' S Longitude 153° 37.71' E in approximately 73 m water depth. While generally both buoys will measure similar wave conditions, the Gold Coast buoy measures wave heights after wave shoaling has occurred, as it is located in significantly shallower water.

5.2.1 August 2006

At the commencement of the present monitoring period in August 2006, low significant wave heights of approximately 0.5 m were observed. During these first few days, the beach was in a lower energy intermediate state, showing LTT characteristics. Significant wave heights increased rapidly on the 6th to higher than 3 m, and steadily decreased throughout the following week. During this time the beach moved into a LBT state, with a double bar system being established. Wave breaking across the outer and inner bar systems, as well as the Narrowneck reef occurred until the 11th.

Low energy wave conditions with significant wave heights generally in the 0.5 to 0.75 m range, prevailed through until the 22nd, with the detached nearshore bar progressively re-attaching to beach. Weak nearshore rips and troughs were evident throughout this period, along with transverse (shore normal) sections of attached bar. During the last three days of August, the significant wave height steadily increased to greater than 2 m, with waves breaking over an outer bar and on the Narrowneck reef. During the higher wave conditions, the beach again formed a double bar system, typical of LBT characteristics, with the outer bar clearly detached, and separated from the inner surf zone by a trough.

5.2.2 September 2006

Wave conditions steadily decreased throughout the first four days of September from an offshore significant wave height of 2 m, down to approximately 1 m. The wave height was

relatively consistent at about 1 m throughout the remainder of the month, except for a short period from the 11th to the 16th where significant wave heights in the order of 3 m were observed. The wave period was generally in the range of 7 to 10 seconds, peaking twice at approximately 15 seconds, for a period of 2 days on both occasions.

As the wave energy slowly decreased through the first few days of September, the beach could be seen to shift from a LBT system, with straight parallel inner and outer bars, to typical RBB morphology. The outer bar began to show crescentic features, while the inner bar was cut at regular intervals by weak rips and troughs. No significant morphological changes were observed throughout the remainder of September, with the typical beach state showing minor wave breaking on the outer bar, separated from the inner surf zone by a trough.

5.2.3 October 2006

Relatively consistent wave conditions were observed throughout the month of October, with the offshore significant wave height generally around 1 m, peaking occasionally at 1.5 – 2 m. The peak spectral wave period was consistently in the range of 7 to 10 seconds, only rising to 13 seconds during the last three days of the month. The relatively consistent wave conditions were reflected in the relatively consistent morphological conditions which were observed.

The surf zone typically had a shore parallel outer bar, evident throughout the previous months, with a shallow inner surfzone. During the period from the 5th to the 8th, transverse sections of the inner bar began to attach to the beachface, and it appeared to remain that way throughout the remainder of the month. The outer detached bar developed undular characteristics, evident of transverse troughs and rip currents through the surfzone, typical of RBB conditions. During the higher wave conditions, breaking was observed to occur across the Narrowneck reef, most notably around the 29th.

5.2.4 November 2006

Moderate wave conditions were again observed throughout November, with the offshore significant wave height generally being around 1 m, peaking at 2.5 m in the middle of the month. The persisting moderate wave energy resulted in the relatively parallel offshore bar continuing to form transverse sections, which slowly welded to the beach. The beach clearly transitioned from a higher energy RBB/LBT state at the start of the month, to a lower energy TBR by the 20th. This was particularly evident across the section of beach to

the north of the Narrowneck reef, where the double bar system observed throughout September and October completely altered, with a large section of the beach having only a single attached bar by the end of the month.

The transition of the beach toward a lower energy state is evident at the end of the month, with the onshore migration of the bar forming large crescentic terraces, particularly across the southern half of the beach. The surfzone became narrower, with many small rips and troughs evident between sections of attached transverse bar.

5.2.5 December 2006

Moderate wave conditions with heights of 1.5 to 2 m again occurred throughout the month of December. These significant wave conditions allowed the migration of the offshore bar toward the beach to continue. The morphology of the beach stabilised in a relatively low energy TBR state, with sections of attached transverse bar becoming wider, as the beach tended toward a single bar system.

The milder wave conditions and continually changing inner surfzone typical of the TBR beach state caused the alignment of the shoreline to undergo several changes throughout December. During the first week the shoreline alignment was irregular, with several large cusp features along its length. Through the second week, the shoreline became significantly straighter, with the cusp features becoming almost unrecognisable. By the 19th, the irregular shoreline alignment could be seen to emerge again, although to a lesser magnitude than earlier in the month.

5.2.6 January 2007

The wave climate throughout January was generally higher than the previous few months, with offshore significant wave heights consistently of the order of 2 m. Wave data was unavailable from the 19th to the 25th, with 12 second period, 3 m significant wave height conditions recorded throughout the last three days of the month.

During the first 10 days of January the beach could be seen to shift from the lower energy TBR state to become more characteristic of a RBB type. Sand from the inner attached transverse bars and terraces that had formed throughout November and December began to shift seaward to form cusp features on a mostly detached nearshore bar. By the 16th the bar was typically separated from the beach by an irregular longshore channel, with rips cutting through the surfzone at regular intervals along the beach. This morphological state

prevailed throughout the month of January, with relatively consistent and high wave energy. Wave breaking on the Narrowneck reef occurred on several occasions.

5.3 Visual Assessment of Beach Width Changes (August 2006 – January 2007)

Moderate wave conditions occurred across the Gold Coast throughout August and September, with episodic increases in significant wave height up to 2.5 to 3 m. These higher wave conditions saw the formation of a double bar system across the length of recorded beach, which was intermittent throughout August and September. During times of lower energy, transverse bars and rips formed between the inner and outer bars, with sections of the inner bar attaching to the beach, forming low tide terraces.

Lower wave conditions prevailed throughout the remainder of the year, which dictated the morphodynamic changes which occurred during this monitoring period. The lower wave energy allowed the steady migration of the offshore bar toward the beach to occur, through the formation of transverse bars. Eventually the transverse bars welded to the beach, increasing the volume of sand in the terrace formations, and widening the swash zone. The additional volume of sand added to the beach in the terrace formations resulted in slight increases in overall beach width throughout the monitoring period.

A qualitative visual assessment of the net regional trends in beach adjustment during this period can be seen by contrasting images of the beach obtained at the start and end of the present six month monitoring period. Figure 5.2 shows the snap images obtained at mid-tide from Camera 4 (north) on 01/08/06 and 31/01/07, respectively. The corresponding snap images of the southern beaches obtained from Camera 1 are shown in Figure 5.3. Along the southern beach a very subtle increase in beach width is discernable, while to the north this increase in beach width is more pronounced. In the vicinity of the reef site at Narrowneck no similar trend can be seen in Figure 5.2, with the beach width appearing to be similar at the beginning and end of the present six month monitoring period.

5.4 Visual Assessment of Total Beach Width Changes (August 1999 – January 2007)

The visible beach changes to date since the commencement of the NGCBPS coastal imaging monitoring program seven years ago are seen in Figure 5.4 and Figure 5.5. In these figures mid-tide timex images of the beach to the south and north are shown at six-monthly intervals for the entire monitoring period August 1999 to January 2007.

During the first six months (August 1999 to January 2000) the on-going nourishment of the northern beach is visible, with no change to the southern beach as this area was yet to be nourished at that time. A dramatic change in the width of the beach occurred between January 2000 and August 2000, when nourishment of the entire stretch of coastline from Narrowneck to Cavill Avenue was completed, with the result that the mid-tide beach can be seen to have nearly doubled in width during this period.

During the next six months to January 2001 the beach alignment became more uniform alongshore, as the coastline re-adjusted to the new sand volume available within the beach system.

The following six-month period of February 2001 – July 2001 saw a general erosional trend along the northern Gold Coast beaches in response to a succession of storms. This contrasted to the following six months (August 2001 to January 2002) during which the beaches recovered, returning to a similar state as was seen 12 months previously in January 2001. As was first noted in a previous six-monthly report (Turner, 2002), a return to prior conditions following a period of storm erosion suggested that the beaches of the northern Gold Coast at that time were close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000.

From January 2002 – August 2002 the beaches of the northern Gold Coast were moderately depleted, with the beaches at the end of this period intermediate to the eroded state that prevailed in August 2001, and the most accreted state that was recorded at the end of January 2002. By January 2003 the beaches had returned to their more accreted state, similar to beach conditions observed 24 and 12 months previously in January 2001 and January 2002.

During February 2003 to August 2003, the beaches again experienced a period of modest erosion. Both to the north and south, the beach at the beginning of August 2003 appeared very similar to the conditions that prevailed 12 months previously in August 2002. Moderately depleted conditions prevailed, that were intermediate to the more accreted states observed in January 2002 and January 2003, and the more eroded state that prevailed two years previously in August 2001. From this now recurring pattern, it was concluded at that time (Turner, 2003b) that the beaches of the northern Gold Coast were fully adjusted to the sand nourishment that was placed three years previously, and the morphodynamic changes that were being observed were predominantly the result of seasonal variation in the frequency of storm events.

From August 2003 to January 2004 minimal storm wave activity was observed, and the beaches of the Northern Gold Coast generally accreted. During February 2004 to July 2004 large wave events occurred in March, and the beaches were observed to be cut back during that time. However, by the end of July 2004, both the northern and southern beaches had recovered. From August 2004 to January 2005, storms in October 2004 and again in January 2005 caused a general movement of sand offshore, with the visible width of the subaerial beach decreasing during this time, and the widening of the surf zone as the outer bar translated further seaward.

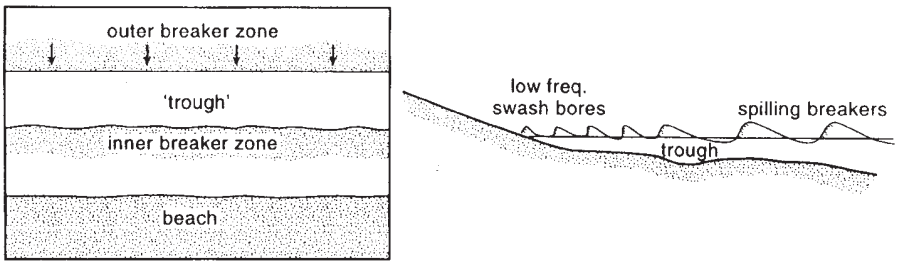
During February 2005 to July 2005 both the northern and southern beaches exhibited similar beach width and shoreline alignment, with the exception of the region in the immediate vicinity of Narrowneck, where a modest trend of net beach widening was discernable. From August 2005 to January 2006, along the southern beach no net change in the visible (subaerial) beach was discernable, with similar conditions also observed along the northern beach. The exception to this observation of similar conditions was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed.

During the period from February 2006 to July 2006 a subtle trend of a narrower beach was observed to the south, with a more pronounced decrease in beach width to the north of Narrowneck. In contrast, in the vicinity of the reef site at Narrowneck the visible beach was similar at the beginning and end of this six month period.

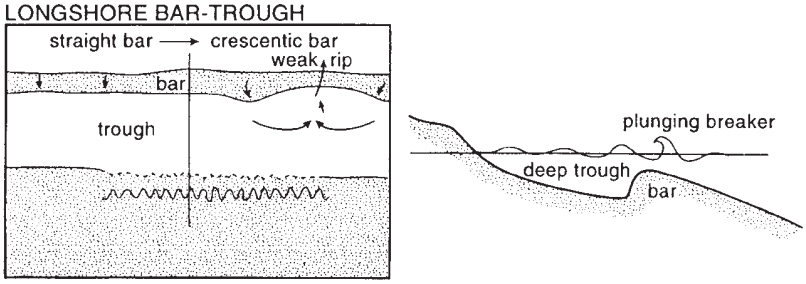
During the current monitoring period from August 2006 to January 2007, the wave climate was predominantly moderate to low, with very few storm wave occurrences. This resulted in a general widening in both the northern and southern beaches. The beach width and alignment at the end of January 2007 is comparable to that at the end of January 2006, with the beaches recovering from the higher energy period observed in the early parts of 2006.

A more quantitative assessment of the response of the northern Gold Coast beaches for the period August 2006 to January 2007 is detailed in Section 6.

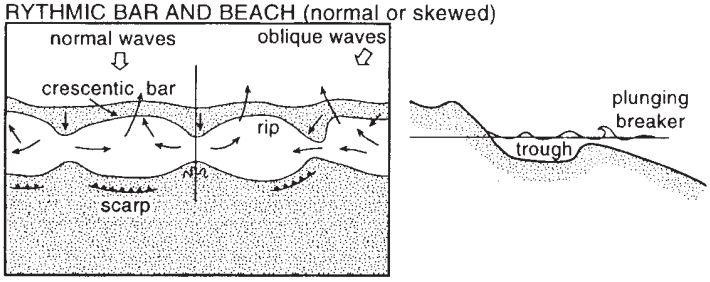
a) DISSIPATIVE



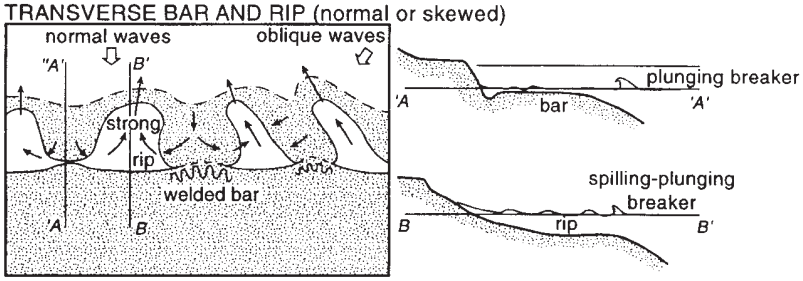
b) INTERMEDIATE
LONGSHORE BAR-TROUGH



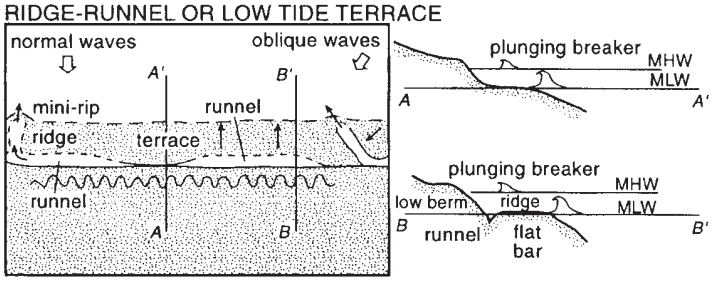
c) INTERMEDIATE
RYTHMIC BAR AND BEACH (normal or skewed)



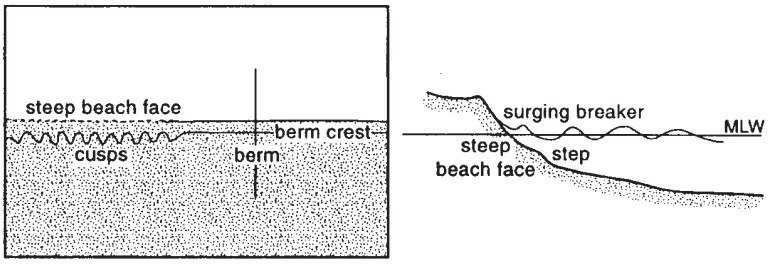
d) INTERMEDIATE
TRANSVERSE BAR AND RIP (normal or skewed)



e) INTERMEDIATE
RIDGE-RUNNEL OR LOW TIDE TERRACE



f) REFLECTIVE



WRL Report No. 2007/08	MORPHODYNAMIC BEACH STATE MODEL (after WRIGHT and SHORT, 1983)	Figure 5.1 06037-5-1.cdr





WRL Report No. 2007/08	SNAP IMAGES FROM CAMERA 1 (SOUTH): 01/08/2006 AND 31/01/2007	Figure 5.2 06037-5-2.cdr



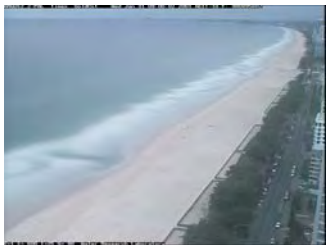


WRL Report No. 2007/08	SNAP IMAGES FROM CAMERA 4 (NORTH): 01/08/2006 AND 31/01/2007	Figure 5.3 06037-5-3.cdr


August 1999


January 2000

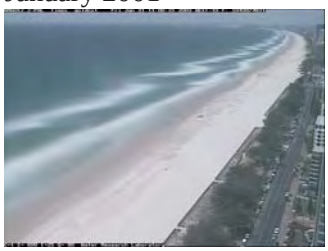

August 2000

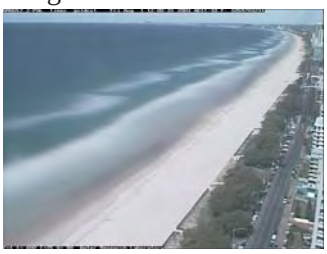

January 2001


August 2001

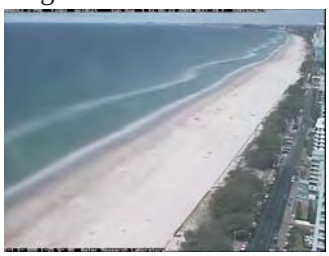

January 2002

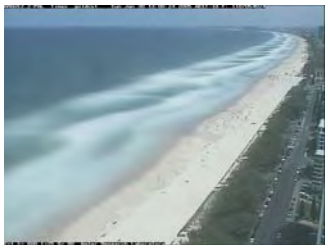

August 2002


January 2003


August 2003


January 2004

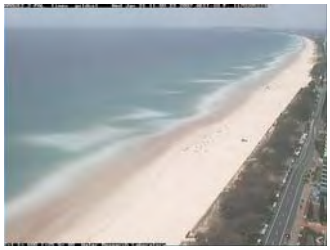

August 2004


January 2005


August 2005


January 2006


August 2006


January 2007

WRL Report No. 2007/08	SIX-MONTHLY BEACH CHANGES (CAMERA 1-SOUTH): AUGUST 1999 - JANUARY 2007	Figure 5.4 06037-5-4.cdr


August 1999


January 2000


August 2000


January 2001


August 2001


January 2002


August 2002


January 2003


August 2003


January 2004


August 2004


January 2005


August 2005


January 2006


August 2006


January 2007

WRL Report No. 2007/08	SIX-MONTHLY BEACH CHANGES (CAMERA 4-NORTH): AUGUST 1999 - JANUARY 2007	Figure 5.5 06037-5-5.cdr

6. QUANTITATIVE ANALYSIS OF SIX-MONTH SHORELINE CHANGES: AUGUST 2006 – JANUARY 2007

A primary function of the coastal imaging system installed at the northern Gold Coast is to quantify shoreline variability and changes during and post beach nourishment and construction of the Gold Coast Reef. Quantitative analysis of shoreline position and beach width provide an objective measure to assess the success of the NGCBPS in meeting the aims of enhanced beach amenity and the increased availability of an adequate storm buffer.

6.1 Weekly Shorelines

All weekly shorelines that are available for the period 01/08/06 to 31/01/07 are shown in Figure 6.1. For reference, these measured shorelines are overlaid onto a representative merged/rectified timex image (image date: 31/01/07). The image represents a 4,500 m length of the beach, extending approximately 3,000 m to the south of Narrowneck and approximately 1,500 m to the north. The Gold Coast Reef at Narrowneck is centred around x = 900 m in this image (relative to the ARGUS station centered at coordinate [0,0]). The landward dune reference line used to calculate beach width is also indicated (red line). The location of the cameras can be identified by the region of beach immediately in front of the Focus Building, that is outside (ie., in front of, and below) the cameras' fields of view.

To see more clearly the range of shoreline positions mapped during this six month period, Figure 6.2 shows a plot of the position of the weekly shorelines relative to the dune reference line. The distance of these shorelines from the dune reference line is plotted in the upper panel, and for convenience the alongshore position in this figure is relative to the location of the ARGUS station (0 m). In the lower panel of this figure the same mid-tide timex image used in Figure 6.1 is shown for reference.

Note that, due to sun glint off the surface of the ocean in cameras 2 and 3, the mapped shorelines between approximately -100 m and 500 m alongshore are regarded as lower accuracy, and are therefore excluded from the following discussion and analysis.

During the present monitoring period 01/08/06 – 31/01/07 it can be seen from Figure 6.2 that the beach along the 4,500 m study region varied in width (relative to the dune reference line) from approximately 50 m to 100 m. The envelope of beach width changes is relatively uniform alongshore, generally varying in width along the 4,500 m study region by approximately 25 - 35 m during this period.

It is important to note here that, although it may appear that the beach alignment widens in the centre of the 4,500 m study region, in fact this is not the case, but rather the wider beach in this central region is due to the curvature of the dune reference line used to calculate beach width. In reality, the position of this reference line is somewhat arbitrary, and was selected so as to generally indicate the seaward edge of the vegetated dune between the beach and The Esplanade.

6.2 Shoreline Variability – Mean, Maximum, Minimum, Standard Deviation

The alongshore variability of the measured shoreline positions during the monitoring period 01/08/06 – 31/01/07 is further quantified in Figure 6.3. The upper panel of this figure shows a plot of the mean, maximum and minimum shoreline position at all locations alongshore. For reference, in the lower panel the mean shoreline position during this period is overlaid on to a merged/rectified timex image (image date: 31/01/2007) of the northern Gold Coast.

Referring to Figure 6.3, the median beach width at mid-tide (relative to the dune reference line) along the 4,500 m stretch of coastline during the period 01/08/06 – 31/01/07 was in the range of 65 – 95 m. As was discernible from Figure 6.2, relative to the dune reference line the mean beach width was greatest at approximately 1000 m alongshore (to the north of the ARGUS station), with a width of approximately 90 – 95 m.

The analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals a relatively uniform range of beach variations along the 4,500 m study area. Both north and south of the cameras, the minimum beach width generally deviated from the mean by approximately 20 – 25 m, while the maximum beach width deviated by only 15 m. This would suggest that the beach was generally wider throughout the current monitoring period than the mean shoreline indicates.

The middle panel of Figure 6.3 shows the standard deviation of weekly shorelines from the mean shoreline position during the period 01/08/06 – 31/01/07. The standard deviation of weekly shorelines varied along the length of the beach, but was clearly a minimum over the stretch of beach from 500 to 1000 m north of the cameras.

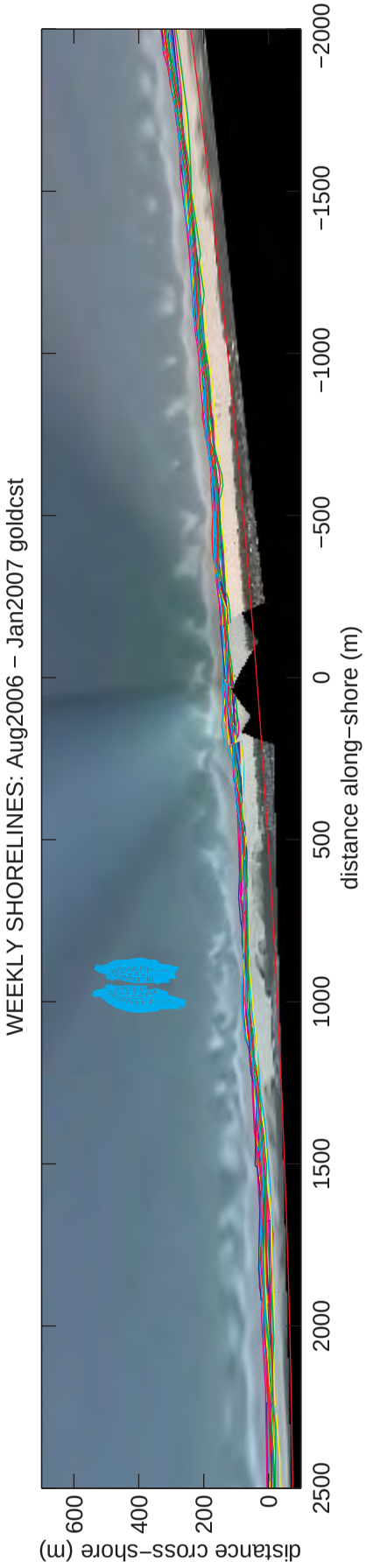
It is worth noting that the section of beach which was generally the widest coincided with the stretch that showed the least variability during the current monitoring period, and was the area in the lee of the Gold Coast Reef at Narrowneck, approximately 900 m to the north of the cameras.

6.3 Weekly Shorelines (August 2006 – January 2007) Relative to Mean Shoreline Position of Previous Monitoring Period (February 2006 – July 2006)

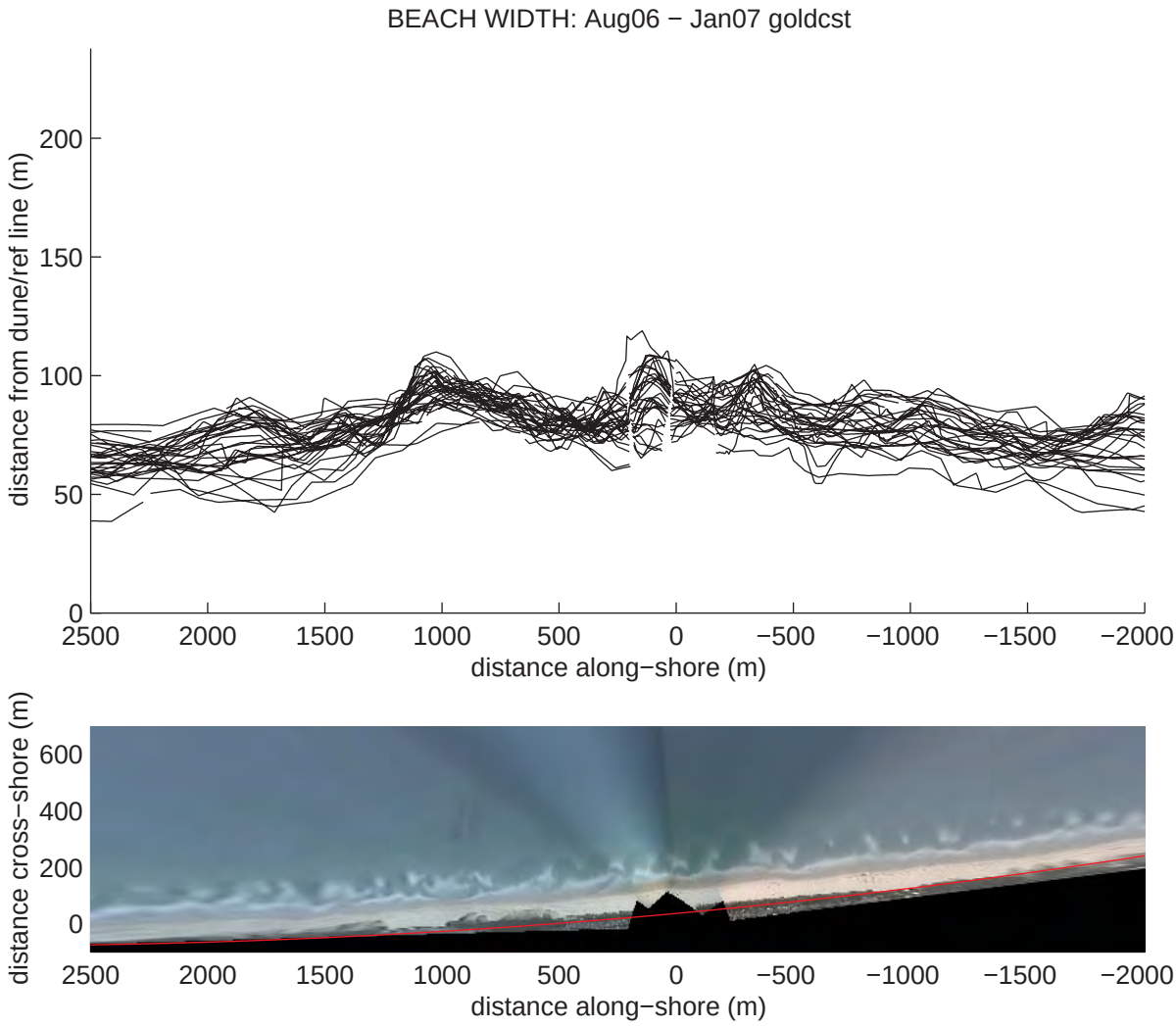
To remove the effect of the arbitrary dune reference line appearing to indicate a change in beach alignment in the centre of the 4,500 m study region, in Figure 6.4 weekly shorelines for the period 01/08/06−31/01/07 have been re-analysed and plotted relative to the mean shoreline position calculated for the previous six month monitoring period February – July 2006 (refer Turner, 2006b). In the upper panel the deviation of weekly shorelines from this earlier mean shoreline is plotted. In the lower panel the mean shoreline position for the previous monitoring period February – August 2006 is shown, along with the mean shoreline calculated for the present monitoring period.

Figure 6.4 top panel shows that during the present monitoring period the beaches of the northern Gold Coast varied both narrower and wider than the mean shoreline from the previous monitoring period. However, it can also be seen that there were a greater number of occasions during this monitoring period, where the beaches were wider than the previous mean beach width. Figure 6.4 bottom panel also shows that the mean beach width is very slightly wider throughout the current monitoring period than the previous period, over some sections of the beach.

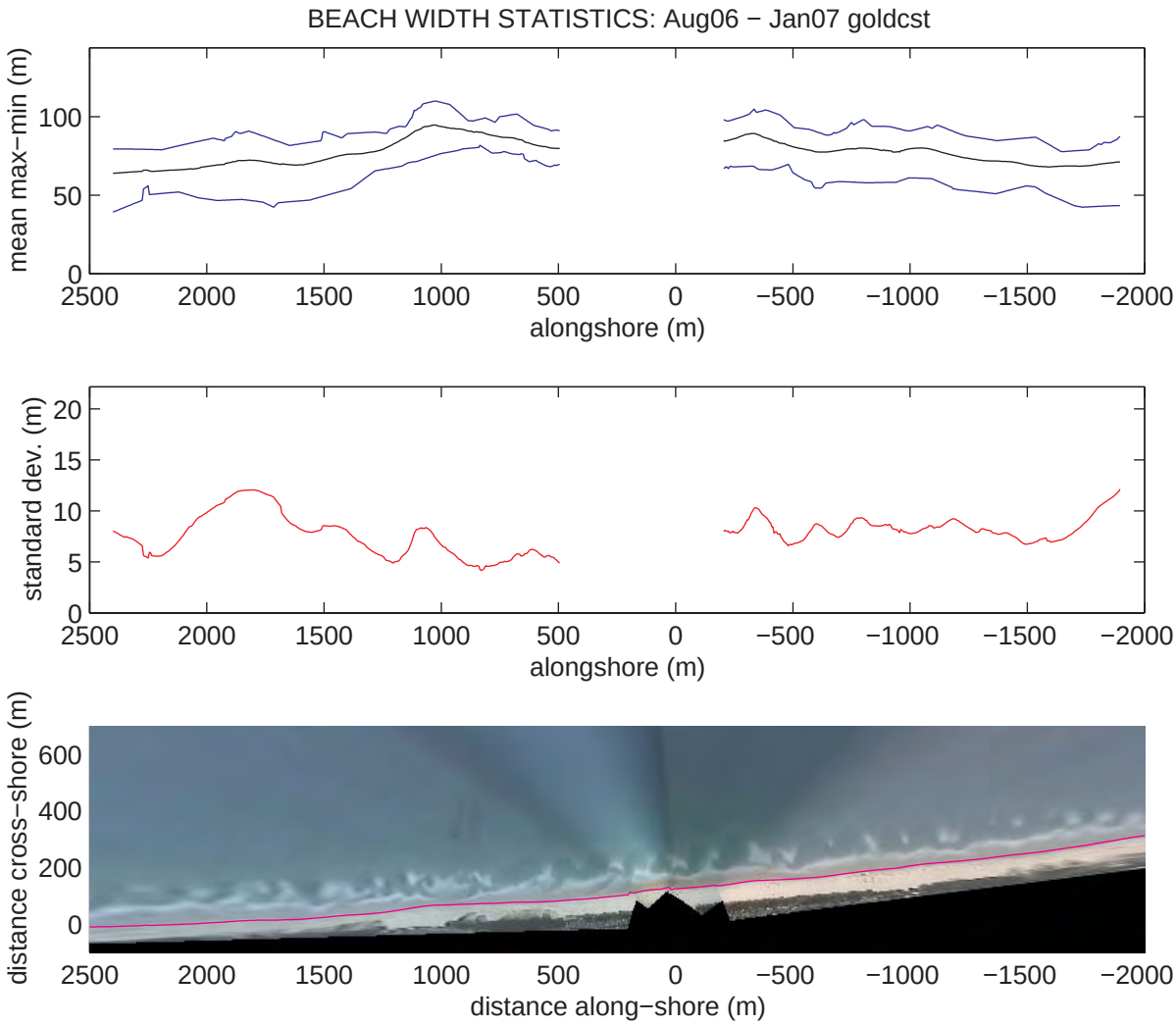
The observation from the present monitoring period of relatively uniform beach changes alongshore is more typical of the general trend observed throughout the total seven and a half year monitoring program. The rather atypical observation 2 years ago (refer Turner, 2005a) of a distinct alongshore variability in beach width, did not continue through 2005 and 2006.



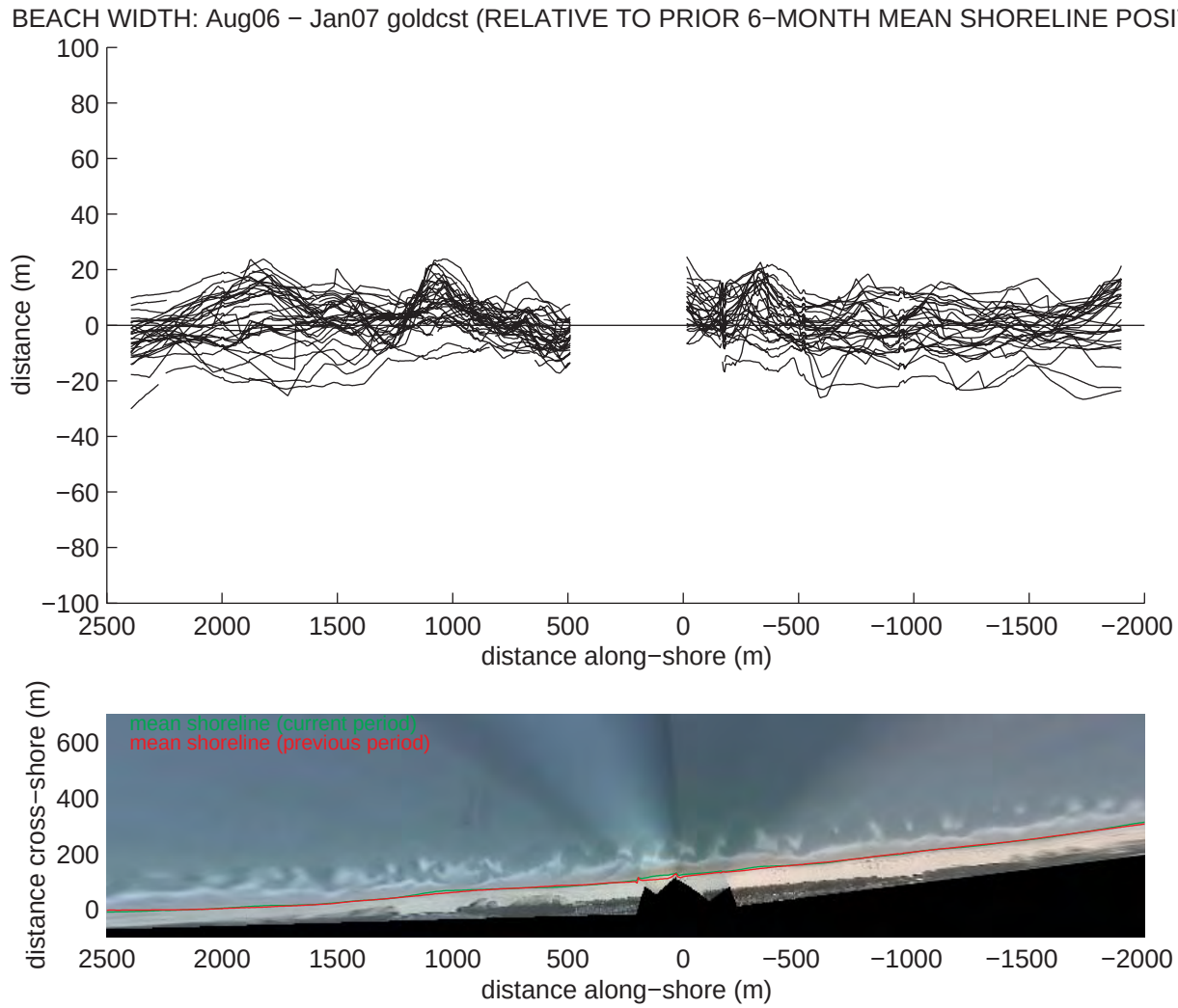
WRL Report No. 2007/08	WEEKLY SHORELINES: AUGUST 2006 - JANUARY 2007	Figure 6.1 06037-6-1.cdr



WRL Report No. 2007/08	WEEKLY BEACH WIDTH: AUGUST 2006 - JANUARY 2007	Figure 6.2 06037-6-2.cdr



WRL Report No. 2007/08	STATISTICAL SUMMARY OF BEACH WIDTH CHANGES: AUGUST 2006 - JANUARY 2007	Figure 6.3 06037-6-3.cdr



WRL Report No. 2007/08	WEEKLY BEACH WIDTH CHANGES AUGUST 2006 - JANUARY 2007 RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION	Figure 6.4 06037-6-4.cdr

7. QUANTITATIVE ANALYSIS OF SHORELINE VARIABILITY, SEASONALITY AND LONGER-TERM EROSION/ACCRETION TRENDS: AUGUST 1999 – JANUARY 2007

The completion of a total of seven and a half years of monitoring at the northern Gold Coast beaches provides the opportunity to summarise and analyse longer-term shoreline changes observed to date. With sand nourishment completed in mid 2000, and significant erosion-recovery of the beach observed during the twelve months that followed in 2001, since that time it is now apparent that the new equilibrium alignment of the northern Gold Coast coastline has developed, upon which cyclic-seasonal beach changes and longer-term erosion/accretion trends can be observed and quantified.

7.1 Weekly Shorelines and Shoreline Variability: August 1999 – January 2007

All weekly shorelines for the 390 week period August 1999 to January 2007 are shown in Figure 7.1. As per previous figures, a merged/rectified image is shown in the lower panel for reference (image date: 31 January 2007). Again, due to sun glint these data between –100 m and 500 m alongshore are less reliable, and are excluded from the following analysis and discussion. Over the entire 90 month monitoring period mid-tide beach width (relative to the dune reference line) along the full 4,500 m study region can be seen to have varied in the order of 100 m. Beach width changes of typically up to 50 m have been recorded at all positions alongshore, which highlights the highly dynamic nature of the beaches of the northern Gold Coast.

The variations in shoreline position measured at eight representative survey transects alongshore for the entire seven and a half year period August 1999 – January 2007 are shown in Figures 7.2 and 7.3. Figure 7.2 plots the weekly shoreline position at transects spaced at regular 500 m intervals north of the camera location, and Figure 7.3 plots the weekly shoreline position at transects spaced at 500 m intervals south of the cameras. The alongshore position of each of these representative beach transects is shown in the accompanying merged/rectified image (image date: 31/01/2007).

A general trend of increasing beach width is apparent along both the northern and southern beaches during the initial 18 months of monitoring. The rapid growth of the beach at each of the nourishment areas (refer Figure 2.5) can be seen. As previously noted in preceding monitoring reports, the lag in beach response at each of these locations matches the progression southward of the beach nourishment program (see Figure 2.4). The effects of nourishment clearly dominate beach changes during the initial 18 month period.

During the period February – July 2001, a general erosion trend was evident. This six month period was characterised by a series of storms that resulted in the net recession of northern Gold Coast beaches. Examining this trend in more detail, Figures 7.2 and 7.3 show that the beaches eroded rapidly during the first months of 2001, followed by partial recovery, then eroded again towards the end of this six month period. The degree of recovery is variable, but at all locations alongshore, by the end of July 2001 the recovered beach width had again been lost.

This period of beach erosion was then followed during the 24 – 30 month period (August 2001 – January 2002) by a distinct trend of beach recovery at all locations. Most notably, by January 2002 Figures 7.2 and 7.3 show that the beach had recovered to the extent that beach widths were sufficiently regained to match the conditions that were measured 12 months previously in January 2001. At the central nourished regions of the beach it is concluded that the storms of early to mid 2001 resulted in the offshore movement of sediment, but that during the six month period that followed this, sand returned to the subaerial beach, rather than being lost from the beach system.

During the next six month monitoring period February 2002 to July 2002, in general a modest net erosional trend is seen in Figures 7.2 and 7.3. Erosion of the shoreline during February to April was then followed by a 1 – 2 month period of partial recovery, followed by stabilisation or minor erosion again up to the end of July. As a generalisation, the beach at the end of the 36 month period to July 2002 was intermediate between the initial (un-nourished) condition in August 1999, and the most accreted states as observed in January 2001 and January 2002.

From August 2002 to January 2003 the beach at all locations alongshore exhibited marked recovery, returning to and more typically exceeding (especially at the more southern transects) the accreted conditions that prevailed 12 and 24 months previously in January 2002 and January 2001. During the period February 2003 to July 2003 an erosional trend was again evident in Figures 7.2 and 7.3 for all transects alongshore. The beach receded, in response to the occurrence of a greater frequency of storm events during this time.

Net accretion at all locations alongshore was observed during the period August 2003 to January 2004. A very similar trend was measured at all locations. From August to December 2003 the beach accreted, this accretionary trend was interrupted once in late November when a brief period of higher wave activity caused the offshore bar to migrate seaward, and the inner bar to detach for a period of 1 – 2 weeks only from the shoreface. Following re-attachment of the inner bar, the beach continued to increase in width at all

locations alongshore through to the beginning of January 2004, when two periods of higher waves caused the offshore movement of sand and detachment of the inner bar. From February 2004 to July 2004, two large storm events in March, followed by continued moderate wave activity in April, caused the beach at all locations to initially continue this erosion trend. However, by the end of July 2004 the beach had generally recovered to the conditions that prevailed at the end of January. The exception to this was in the region between Narrowneck and the cameras, where more limited recovery was observed.

This general accretionary trend initially continued during the period August 2004 to January 2005. However, due to a large storm wave event in the second half of October 2004, beach recession was then observed at all locations alongshore, being most pronounced in the north. Following a subsequent two month period of partial beach recovery, two more storms occurred in January 2005, resulting in further beach recession. In the northern region of the study area the beach had returned to the beach conditions that prevailed some 10 months prior following the major storms of March 2004. To the south, this cycle of accretion, erosion, partial recovery and subsequent erosion, was less pronounced.

From February 2005 to July 2005, the beaches of the northern Gold Coast initially accreted due to generally mild wave conditions, then receded again to the end of July 2005, following the occurrence of a series of moderate storm wave events. During the monitoring period of August 2005 to January 2006, the beaches oscillated around the same position, largely in response to the movement of the inner bar. As this feature initially became fully welded to the beachface, the beaches of the northern Gold Coast generally increased in width accordingly. As the mild wave conditions persisted through the second half of 2005, this resulted in the continued landward movement of a portion of the inner bar sand volume, resulting in a narrowing of the low tide terrace, and subsequent narrowing of the total beach width.

At the end of 2005, periods of slightly elevated wave energy caused the removal of this newly accreted sand from the beachface back to the low-tide terrace, causing re-widening of the beaches at this time. The partial separation of the inner bar from the beachface in response to a single storm wave event in January 2006 caused the beaches to narrow again. A major east coast low pressure weather system in early March 2006 caused the beaches of the northern Gold Coast to transition to a lower gradient and dissipative beach state, characterised by the removal of sand from the beachface and formation of a distinctive inner bar and outer storm bar system. A marked narrowing of the beach was observed at all locations alongshore. By May 2006 the inner bar had temporarily re-attached to the

beachface to form a low tide terrace, but in June this detached again as the sand moved back into the inner surfzone, in response to a general increase in the incident wave energy. By the end of July 2006 the beach was continuing to recover from the significant erosion event of five months previous, as sand slowly moved back onshore.

Early in the current monitoring period, August and September 2006, relatively consistent moderate wave conditions prevailed at the Gold Coast. During this time, the beach width fluctuated, and the double bar system established in March of 2006 was still evident for short durations during larger wave conditions. The beaches generally continued to increase in width throughout the last months of 2006, and by the end of the year, were almost completely recovered from the large east coast low pressure storm system which occurred in March. During this period, the beaches were predominantly in an intermediate state, fluctuating between RBB characteristics during moderate energy times, and transverse semi-attached bar systems during lower energy periods. By January, an intermittent low tide terrace had developed along the beach, with the inner bar attaching to the beach face. Persistent moderate wave conditions throughout January 2007 again resulted in minor narrowing of the beach, as the inner bar system was again developed.

Referring to Figures 7.2 and 7.3, at the completion of seven and a half years of monitoring and around six and a half years since the completion of the major phase of sand nourishment of northern Gold Coast beaches, at all southern monitoring sites the beaches have experienced a net accretionary trend up to the beginning of 2006, that was interrupted in early March by the occurrence of high waves associated with the relatively slow passage of an east coast low pressure weather system. In contrast, to the north, following the initial phase of beach widening in response to nourishment, Figure 7.2 indicates that a net erosional trend has prevailed. Since March 2006, both southern and northern beaches have begun to recover. Further analysis and quantification of these longer-term trends is detailed in the following Section 7.2.

Since the implementation in 2003 of the web-based on-line ‘Beach Analysis System’ at the northern Gold Coast (refer Section 4.3), these shoreline and beach width data are now updated each week and available for public viewing at the project web site, extending back to the commencement of monitoring in August 1999. For completeness, the presentation of these same data in the on-line graphical format (‘Beach Width Analysis’) for the period to January 2007 is shown in Figures 7.4 and 7.5. The top and bottom panels in these figures are equivalent to the two panels in Figures 7.2 and 7.3, with the additional inclusion of selected shorelines to show the most recent shoreline movements. As has already been

discussed, these summary Figures 7.4 and 7.5 show the same general accretion-erosion trends as summarised in report Figures 7.2 and 7.3.

7.2 Analysis of Cyclic-Seasonal versus Longer-Term Trends

It was noted in previous monitoring reports that for the period 2001 to mid 2004 a general cyclic pattern of beach variability had become evident. During this post-nourishment period, erosion was a characteristic of the first half of the calendar year, followed by accretion in the second half of the year. This cycle was interrupted during 2004, due to a large storm event that occurred in October 2004. This general cyclic trend matches the prevailing wave climate of the south east Queensland coast, whereby larger storm wave events are more frequent in the later summer and autumn months. Having observed this cyclic trend for a period of some three years, it was concluded in a prior monitoring report (Turner, 2004a) that the re-emergence of an annual erosion-recovery cycle is further indication that the beaches of the northern Gold Coast at that time had reached a dynamic state of equilibrium with the sand nourishment that was placed on the beach during 1999-2000.

The weekly shoreline data that continues to be obtained on a routine basis provides the opportunity to continue to assess and analyse the emergence of longer-term versus seasonal-cyclic trends at the northern Gold Coast. Of particular interest is to identify any underlying beach erosion or accretion, to assess whether this is uniform or variable within different areas of the study region, and to quantify the magnitude of any identified underlying trend(s), relative to the observed seasonal beach fluctuations. This information is of particular importance to the future planning for additional sand nourishment that may be required to maintain the acceptable beach conditions.

7.2.1 Auto-correlation Methodology

The auto-correlation method is used to identify and quantify the cyclic-seasonal regional-scale beach changes that have been monitored to date at the northern Gold Coast. Auto-correlation is a mathematical technique that seeks to identify repetitions of behaviour, in this case being the analysis of time-series of beach width, measured at discrete locations within the 4,500m long study area. Repetitions, or cyclic behaviour, in data of this type can be found by computing a measure of the self-similarity of the sequence. That is, the sequence can be compared to itself at successive positions and the degree of similarity between the corresponding intervals computed. If every point (here the measured beach width on a specific day) is compared successively to every other point (ie., all other weekly

beach widths measured at that same location), the positions within the sequence of good correspondence will be detected, and also the degree of dissimilarity of other positions will be determined. The separation between two points is called the 'lag', which for the existing database of measured beach width at the northern Gold Coast corresponds to the weekly interval at which the shoreline is mapped.

In order to perform auto-correlation of any dataset, certain criteria must be met. The data sequence (ie., weekly measures of the beach width) must be uniformly separated (in time), and the data must be stationary, or in other words exhibit no net increasing or decreasing trend through time. By careful pre-processing of the weekly shoreline data, it is this second criteria which can be exploited here to separate and compare seasonal-cyclic versus measured longer-term erosion-accretion trends at the northern Gold Coast.

7.2.2 Data Pre-processing

The dataset of shorelines obtained along the 4,500 m study area at the northern Gold Coast is obtained at nominal weekly intervals. Due to the maximum wave height criterion that is applied for the selection of images used for this analysis (see Section 3.8), the actual time interval (ie., 'lag') between successive mapped shorelines may in reality vary between approximately 5 and 8 days. On a limited number of occasions, no shoreline is mapped for an entire weekly period. In order to perform auto-correlation analysis, the time-series of beach widths at each 5 m location alongshore within the 4,500 m study region was first interpolated at exact seven day intervals. The data prior to August 2000 was then removed, so that only the period post sand nourishment is included in the analysis.

In order that regional-scale variations can be identified, the alongshore-average shoreline position was then calculated for each week along three representative 500 m sections of the coastline. These comprised a northern section (centred at 2,000 m alongshore), a southern section (centred at –1,000 m alongshore) and at the site of the reef at Narrowneck (centred at 900 m alongshore). The resulting weekly time-series of alongshore-averaged beach width at the three representative sites was finally detrended (best-fit linear filter), to remove any non-stationarity prior to auto-correlation analysis.

7.2.3 Results

The results of auto-correlation analysis for the six year period August 2000 to January 2007 inclusive, to identify and quantify cyclic-seasonal versus longer-term erosion-accretion trends at the northern and southern sections, are summarised in Figures 7.6 and 7.7

respectively. The corresponding results in the vicinity of the reef are presented in Section 8. The upper panel in these figures shows the interpolated 7-day time-series of alongshore-averaged beach width, the middle panel shows the corresponding detrended data, and the bottom panel shows the resulting auto-correlation function.

In both Figure 7.6 and 7.7 a strong annual cycle is evident during the first three years, but commencing with a storm in October 2004 (during what in preceding years was previously an accretionary period), this cyclic trend weakened. In prior monitoring reports it was observed that the further breaking down of this previously dominant seasonal-cyclic trend continued in 2005, as was evident by the diminishing auto-correlation function after January 2004 (3 years) for both northern and southern sites (bottom panels, Figures 7.6 and 7.7). In the first half of 2005 a net trend of accretion occurred along the northern beaches (Figure 7.6), during what in previous years has been a period of net erosion. Along southern beaches (Figure 7.7), no clear cyclic trend (as was observed in previous years) was evident.

It is of particular interest to note that the occurrence of significant beach erosion in March 2006 has had the effect of 'resetting' the cyclic erosion-accretion trends that dominated the Northern Gold Coast during the years 2000 to 2003. Referring to both Figures 7.6 and 7.7, in 2006 this dominant cyclic behaviour has now re-emerged, characterised by erosion in the first half of the calendar year, followed by accretion throughout the last half of the year (current monitoring period).

In the upper panel of both these figures the best-fit linear trend to the full 6.5 years of post-nourishment data is also shown, and along with the detrended data in the middle panel, can be used to estimate the relative magnitude of the re-emerged cyclic-seasonal beach changes, relative to longer-term beach erosion-accretion trends. Referring to the de-trended data first, at both the northern (Figure 7.6) and southern (Figure 7.7) sections, the beach width at these sites has varied cyclically and seasonally by +/- 20 m, indicating a range of approximately 40 m annual variability in beach width that can be attributed to the seasonal wave climate. In contrast, referring to the upper panel in both figures, the underlying trend at both sites is of a significantly lower magnitude.

From August 2000 to the end of July 2006, at the southern section the net accretionary trend was of the order of 1.8 m/year, while over the northern section the underlying trend was erosion at a rate of -1.3 m/year. However, when the current monitoring period is included in the data set, so that the data spans from August 2000 until January 2007, there is almost no net accretion or erosion trend evident over the southern section (0.2 m

accretion per year), and the erosion rate trend over the northern section increases to -1.8 m/year. This significant change in erosion/accretion trend, is due to the erosion observed throughout the first half of 2006, and the subsequent slow period of beach recovery during the following six months (current monitoring period), throughout which the beach width has remained narrower than the mean beach width recorded over the last 6.5 years. This significant increase in long term erosion trend for the beaches, from the previous monitoring period (Turner, 2006b) to the current monitoring period, shows the sensitivity of the predicted long term erosion/accretion rates to significant storm erosion events and the subsequent period of beach recovery. It also identifies that the time scale for natural cycles/events effecting beach width is large, relative even to the 6.5 year data set recorded, and shows the importance of long term data sets in identifying the long term beach erosion/accretion trend.

The analysis of cyclic-seasonal versus net erosion-accretion trends at the northern Gold Coast post sand nourishment (i.e. mid 2000) has been updated every six months monitoring period commencing in early in 2004. Table 7.1 summarises the six monthly results obtained to date. A net accretionary trend has persisted along the southern beaches within the 4,500 m study area, though a decrease in the rate of beach growth has emerged. Along the northern beaches a more constant erosion trend has occurred.

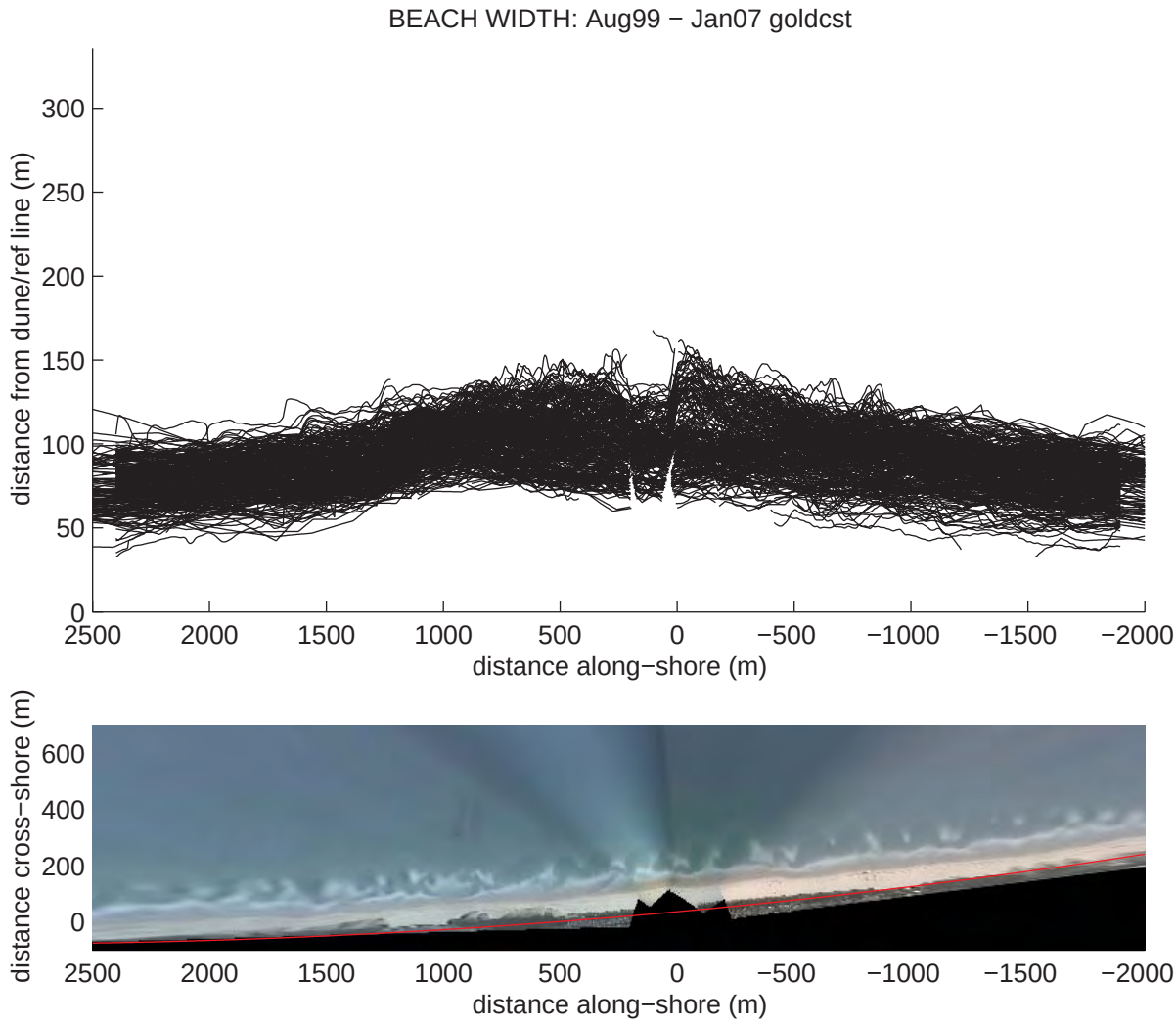
Table 7.1
Summary of Cyclic-Seasonal Variability versus Net Erosion-Accretion Trends

Post-nourishment monitoring period	Years	Cyclic-seasonal variability (m)	Net erosion-accretion trend (m per year)	
			North	South
August 2000 – January 2004	3.5	±20	+1.1	+7.4
August 2000 – July 2004	4	±20	-0.6	+5.2
August 2000 – January 2005	4.5	±20	-1.8	+3.1
August 2000 – July 2005	5	±20	-1.1	+3.8
August 2000 – January 2006	5.5	±20	-0.2	+4.2
August 2000 – July 2006	6	±20	-1.3	+1.8
August 2000 – January 2006	6.5	±10	-1.8	+0.2

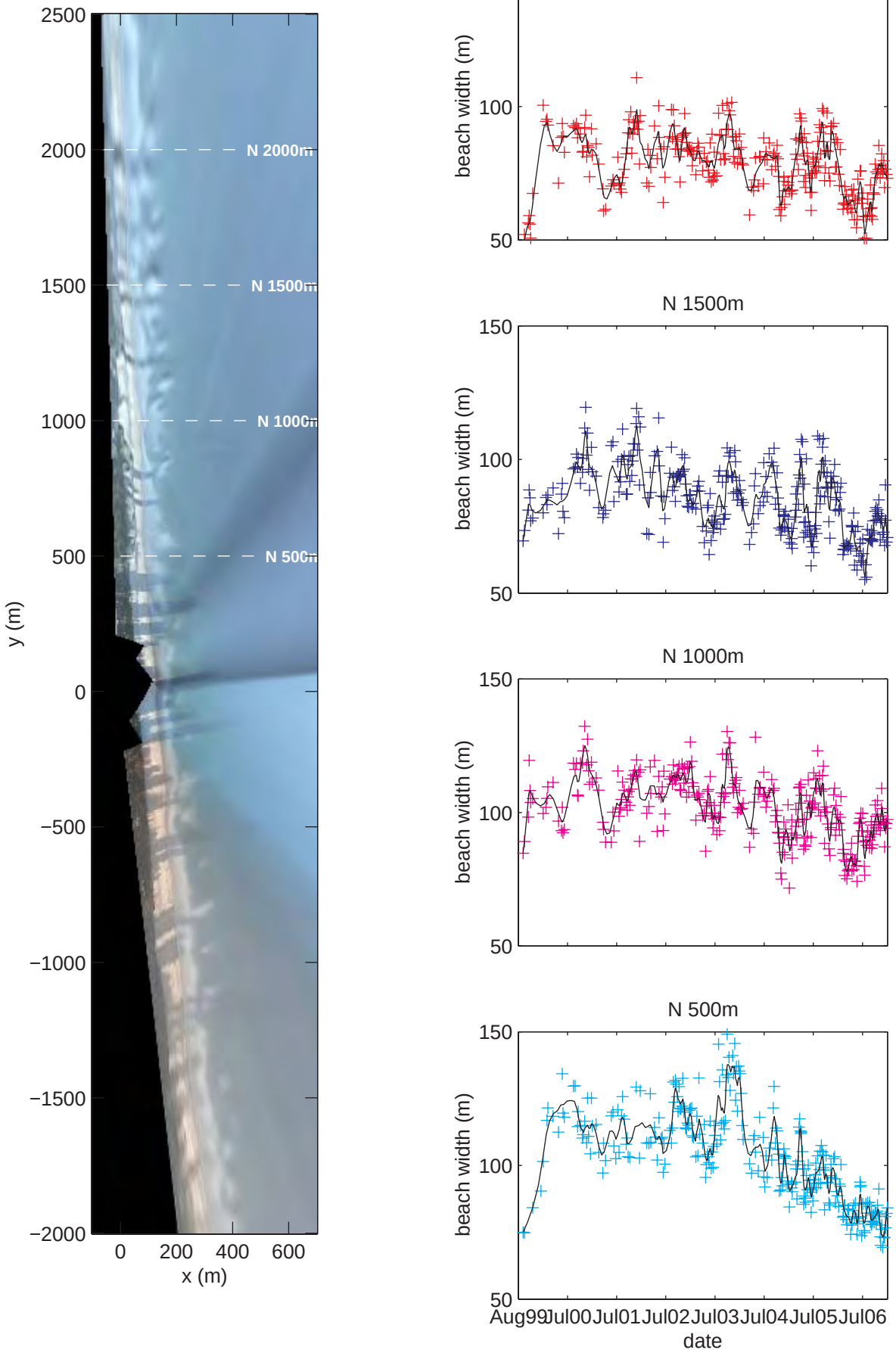
The six and a half years of data upon which these longer-term trends are inferred is now sufficiently long to permit the results of this analysis to be used for future forecasting with a reasonable degree of confidence, and to draw two important conclusions. The first is that the underlying regional-scale trend at the northern Gold Coast since the completion of sand nourishment in mid 2000 has been net minor beach accretion in the south of the order 1 m

(+0.2 m/yr), and net erosion in the north of the order of -12 m (-1.8 m/yr). The second conclusion is that the cyclic annual variability of beach width due to the seasonally varying wave climate was an order of magnitude greater than the underlying beach width trends.

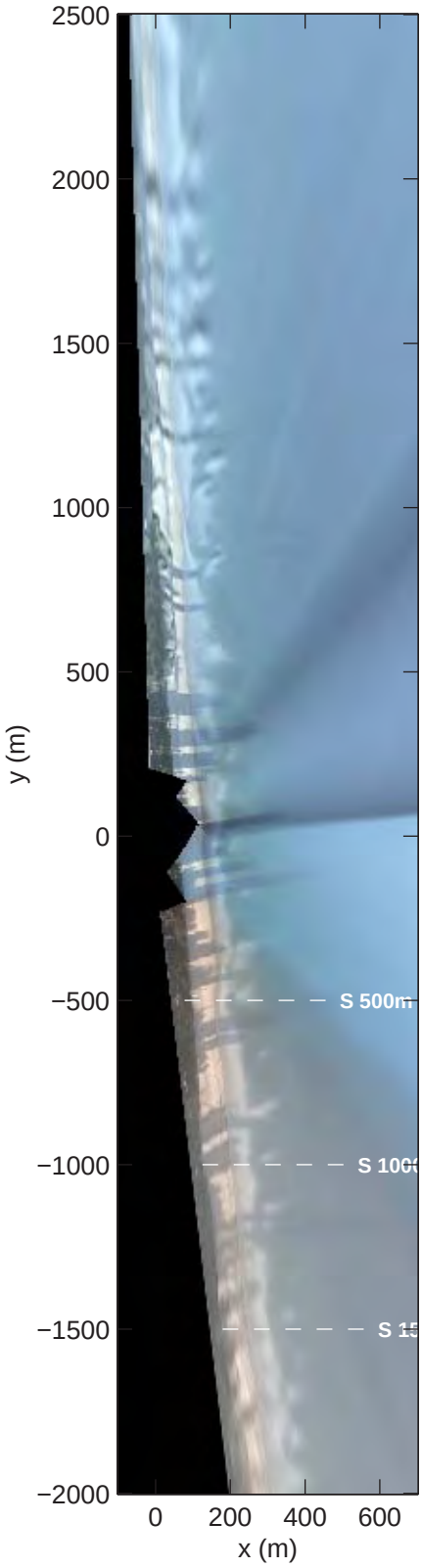
With the beaches of the northern Gold Coast presently in a relatively healthy state, it is shorter-term storm erosion rather than the underlying but much longer-term erosion-accretion trends, which at the present time are of primary importance to the ongoing planning and management of northern Gold Coast beaches.

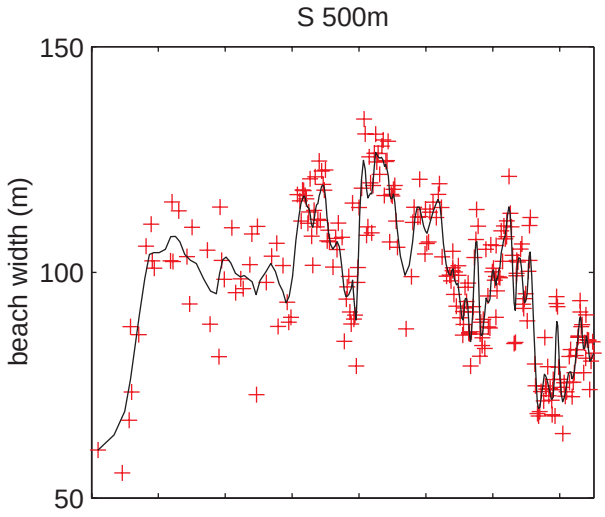


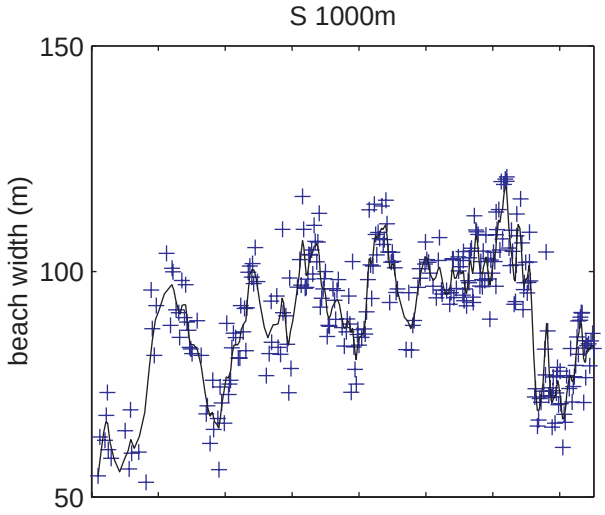
WRL Report No. 2007/08	WEEKLY BEACH WIDTH: AUGUST 1999 - JANUARY 2007	Figure 7.1 06037-7-1.cdr

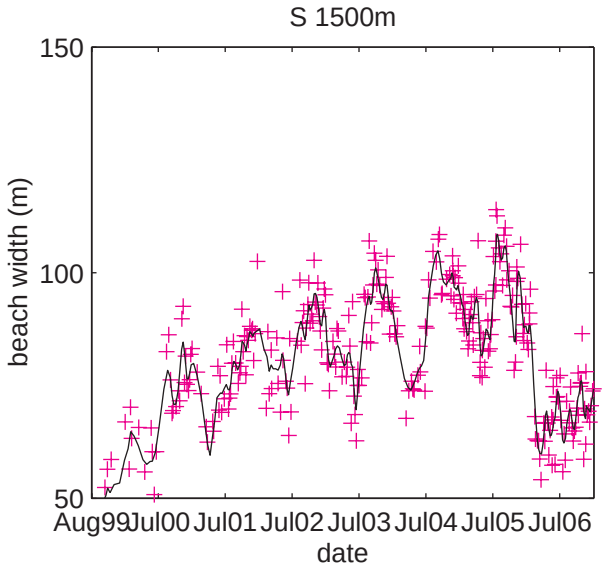


WRL Report No. 2007/08	TIME-SERIES OF BEACH WIDTH (NORTH): AUGUST 1999 - JANUARY 2007	Figure 7.2 06037-7-2.cdr

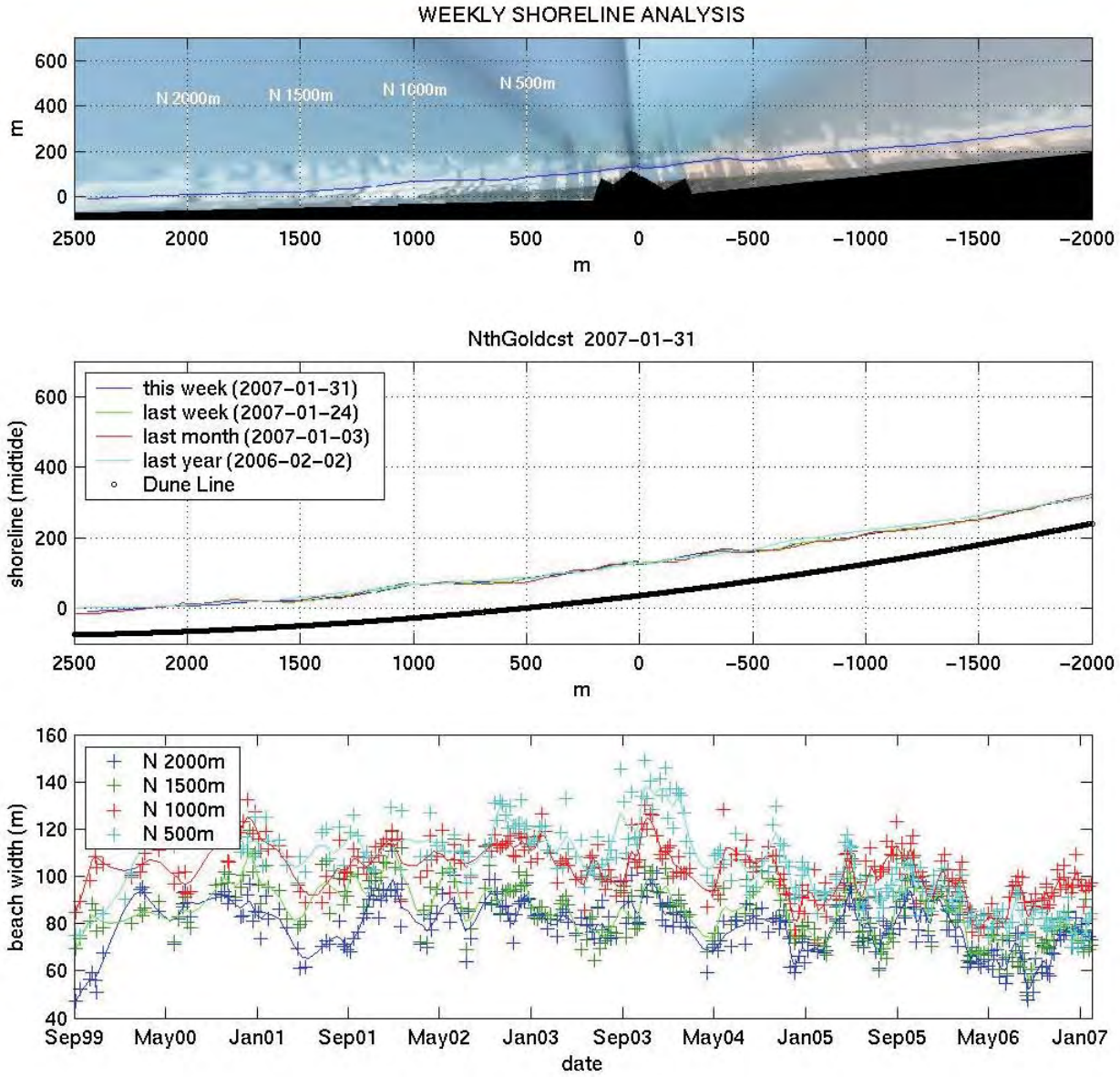








WRL Report No. 2007/08	TIME-SERIES OF BEACH WIDTH (SOUTH): AUGUST 1999 - JANUARY 2007	Figure 7.3 06037-7-3.cdr

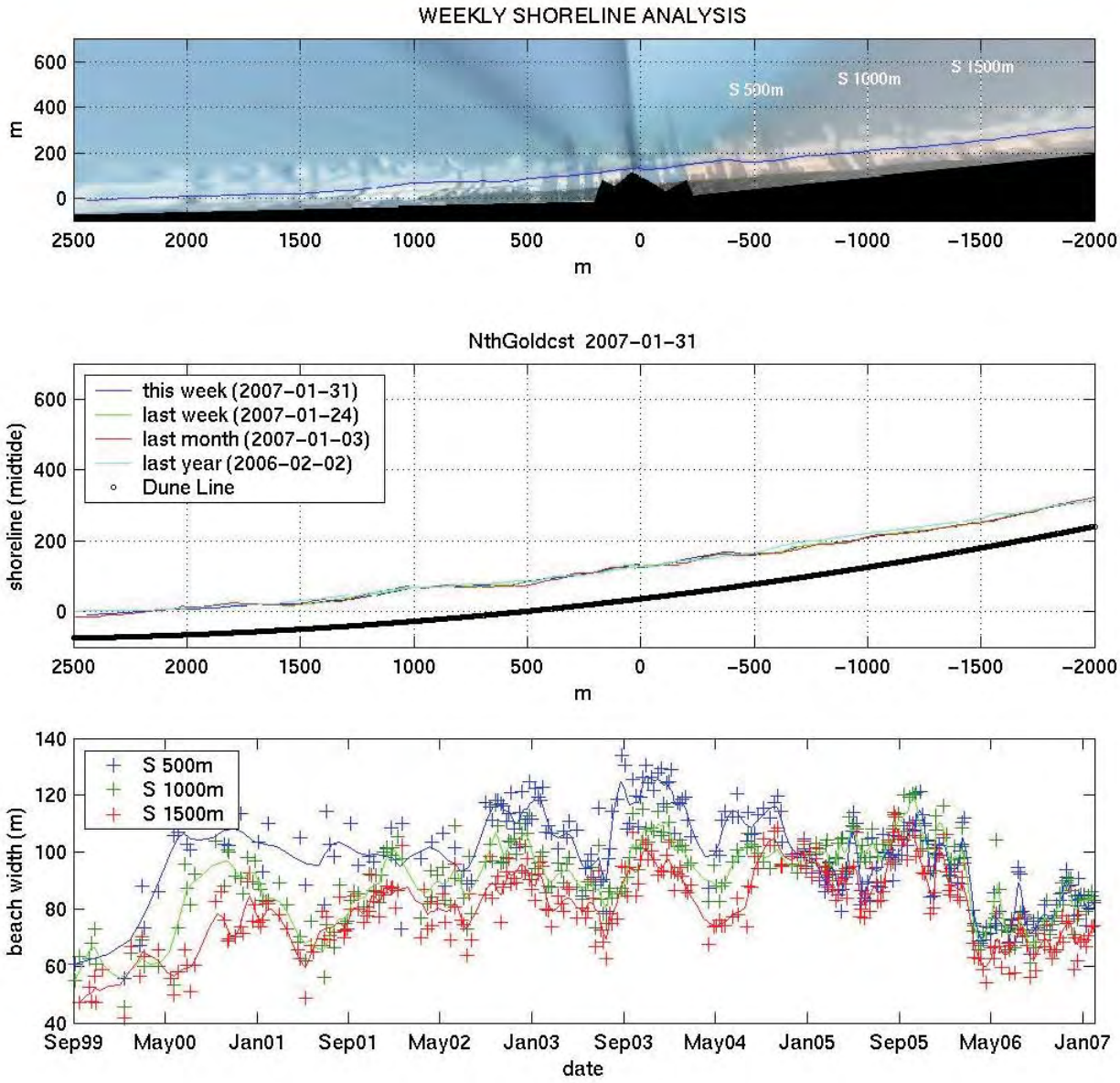


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WRL Report No. 2007/08	ON-LINE BEACH WIDTH ANALYSIS: JANUARY 2007 (NORTH)	Figure 7.4 06037-7-4.cdr

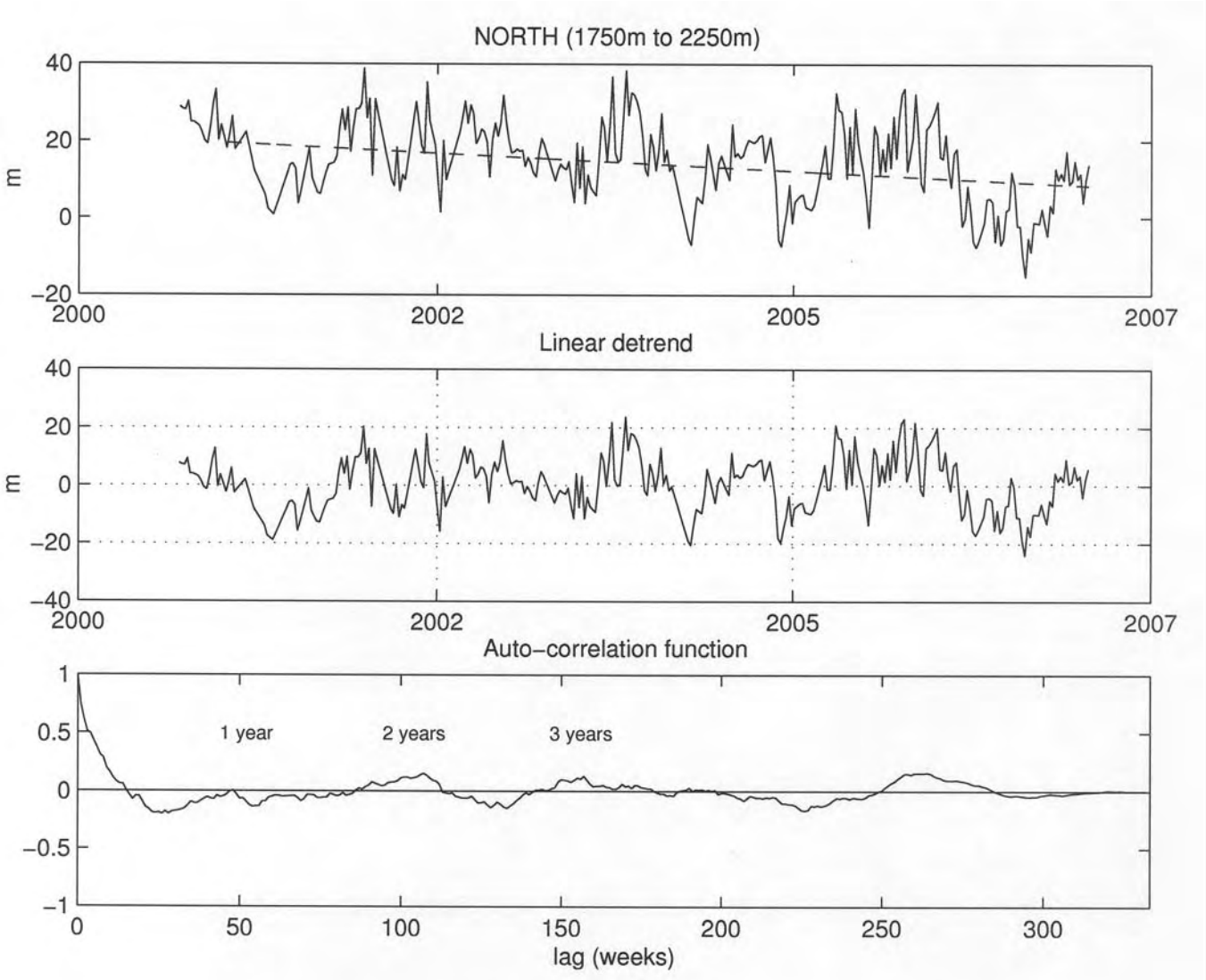


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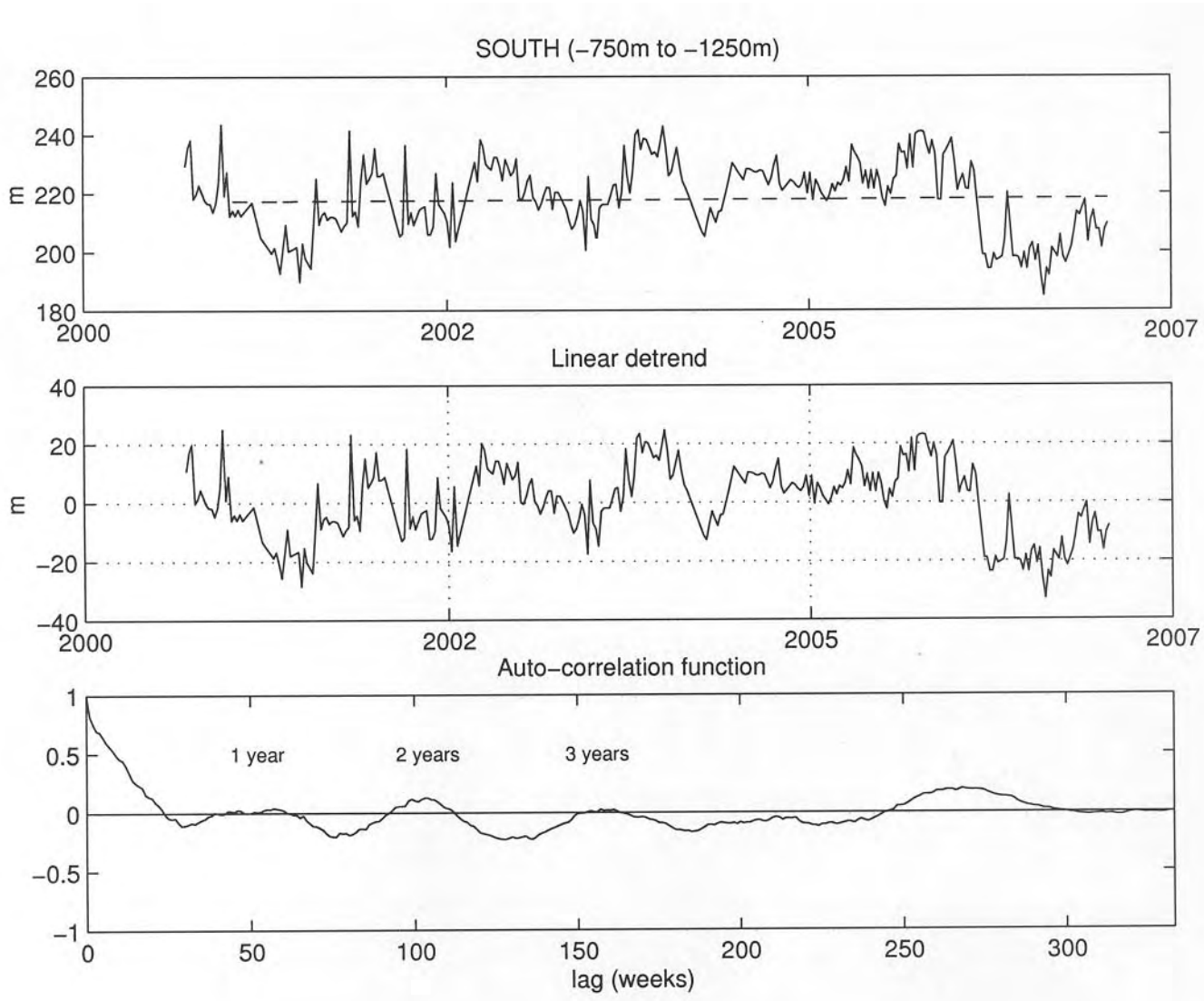
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WRL Report No. 2007/08	ON-LINE BEACH WIDTH ANALYSIS: JANUARY 2007 (SOUTH)	Figure 7.5 06037-7-5.cdr



WRL Report No. 2007/08	CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS NORTHERN STUDY SECTION	Figure 7.6 06037-7-6.cdr



WRL Report No. 2007/08	CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS SOUTHERN STUDY SECTION	Figure 7.7 06037-7-7.cdr

8. ASSESSMENT OF SHORELINE TRENDS IN THE LEE OF THE REEF

A primary objective of the Gold Coast Reef is to promote beach widening and stabilisation at Narrowneck by the development of a shoreline salient (ICM, 1997). The natural processes of wave dissipation, wave diffraction and wave refraction were predicted to result in a general widening of the beach, initially in the lee of the reef, then extending progressively southwards as the salient begins to act as a partially bypassing 'headland' (Black, 1998; Turner et al., 1998a). However, super-imposed on these anticipated changes at Narrowneck are the impacts of storms and re-adjustment of the beach following sand nourishment. It is therefore of interest to look more specifically at the shoreline trends within the region of beach in the immediate vicinity of Narrowneck.

8.1 Present Monitoring Period: August 2006 – January 2007

Figure 8.1 depicts a detailed view of a 1,000 m long region of the beach, centred at Narrowneck at the site of the reef. The weekly shorelines for the period 01/08/06 – 31/01/07 are shown. The dune reference line (solid red line) and a schematic of the reef are also shown in this figure for reference.

A relatively uniform alongshore envelope of weekly shorelines at Narrowneck is apparent in this figure during the period August 2006 to January 2007. In Figure 8.2 the weekly beach widths (relative to the dune reference line) for the same period are plotted at an exaggerated cross-shore scale. Beach width can be seen to have varied by approximately 20 - 40 m alongshore, with the minimum variability being at a distance of 850 m north of the cameras. Figure 8.3 (upper panel) confirms that the maximum and minimum shoreline varied from the mean in a generally uniform manner throughout Narrowneck. As per the prior six month monitoring period, the standard deviation of weekly shorelines (Figure 8.3, middle panel) exhibit a slight decreasing trend to the south, with the region immediately behind the reef (900 m alongshore) showing of the order of 30-40% reduced shoreline variability, relative to the regions immediately north and south.

Figure 8.4 shows the weekly shorelines for the present monitoring period August 2006 – January 2007, relative to the mean shoreline position for the preceding monitoring period February 2006 – July 2006. The shoreline alignment at Narrowneck through the present monitoring period showed very little change, with only very slight accretion observable to the north of the Gold Coast Reef.

Fluctuations of the shoreline position during the present monitoring period August 2006 – January 2007, located at five cross-shore transects within the immediate vicinity of the reef, are shown in Figure 8.5. Four of the transects are located 150 m and 300 m north (R2 and R3) and south (R1 and R2) of the reef site respectively, while the fifth and central transect (R3) is aligned with the centre of the reef. Moving-average curve fitting was applied to these data to help clarify the general erosion/accretion patterns.

At all locations, the variation in beach width throughout the current monitoring period is significantly less than observed in earlier monitoring periods. As discussed above, there was only very minor accretion just to the north of the reef (R2) throughout the six months. The only significant change in beach width detectable was an initial period of erosion in August, where the beach width was observed to decrease by approximately 10 m.

8.2 Total Monitoring Period: August 1999 – January 2007

Figure 8.6 shows the changing shoreline position for the entire 90 month monitoring period August 1999 to January 2007 at the same five representative cross-shore transects in the immediate vicinity of Narrowneck. Again, the locations of the transects are shown in the panel on the left, and the onshore–offshore movement of the shoreline at each transect is shown in the five panels on the right.

8.2.1 Down-Drift of Reef

North of the reef construction site (located in deposition area A2 – refer Figure 2.5), the beach in the vicinity of Narrowneck can be seen to have widened by 20–25 m through the latter part of 1999, stabilised in the first months of 2000, and then evolved to a generally erosional state from April to August 2000. Accretion then occurred up to December 2000, followed by modest erosion again in January 2001. The net result by this time had been an increase in beach width of the order of 40–50 m. The beach then eroded though the first half of 2001, resulting in a net gain in beach width since the start of monitoring period of approximately 10 – 20 m. During the six month period August 2001 to January 2002 the beach recovered fully, regaining some 30 – 40 m beach width, of which some 20 – 30 m was removed again during February 2002 – July 2002. From August 2002 the beach again recovered some 40 – 50 m, then receded again during the period February 2003 to July 2003, followed again by a general trend of beach recovery during August 2003 to January 2004. From February 2004 to July 2004, a distinct erosion trend was measured, followed by recovery to the conditions that prevailed at the end of January 2004.

The period August 2004 to January 2005 was dominated by storm events in October and again in January 2005, resulting in a net erosion at Narrowneck. From February to July 2005 mild conditions through the first 3 months resulted in accretion and beach widening at Narrowneck, then the onset of a series of moderate storms through to July caused the partial removal of this accreted sand volume. The generally mild wave conditions that prevailed through August 2005 to January 2006 resulted in little net change to beach width during this time. In March 2006, a significant east coast low pressure system produced larger wave conditions and resulted in rapid erosion of the beach by 20 to 30 m. Throughout the remainder of 2006, the beach fluctuated in width by approximately 5 - 10 m, and at the end of the current monitoring period, remains 10 – 20 m narrower than the mean beach width observed throughout the previous 7.5 years of monitoring.

By the end of the present six month monitoring period the beach width immediately north of the Narrowneck reef (R1 and R2) was approximately the same as was recorded at the commencement of monitoring seven and a half years earlier in August 1999. It should be noted, however, that extensive sand nourishment was underway in this area prior to the commencement of the ARGUS monitoring program (refer Section 2.3). Therefore, it is believed that there is still a net increase in beach width since August 1999, that has occurred at this location since implementation of the NGCBPS.

8.2.2 Lee and Up-drift of Reef

At the centre of the reef construction site and the two transects to the south (R3, R4 and R5 - all located in deposition area A3), beach widening of 50–60 m was observed through to early 2000 in response to ongoing nourishment during this time. At the centre of the reef construction site and 150 m south, this was followed by a period of erosion through to March then accretion to May, after which time a general accretionary trend persisted. At the transect 300 m south the beach continued to increase in width at a generally steady rate through 2000. Again, the net result had been an increase in beach width of the order of 50 – 60 m. Storms in March, April and July 2001 resulted in recession of the shoreline, with the beach in mid 2001 approximately 30 m wider than at the commencement of the monitoring program.

Through August 2001 to January 2002 the beach in the lee of the reef and to the south recovered to the conditions of January 2001. During the period February 2002 to July 2002 the beach width decreased by 20 – 30 m, then recovered through to the end of 2002 and continue to accrete some 30 – 40 m, mirroring the shoreline erosion–accretion changes observed north of the reef. Through to July 2003 recession again occurred, followed by

accretion to January 2004. As was observed to the north of the reef, a period of erosion followed by recovery was measured from February 2004 to July 2004, followed by further erosion through to January 2005. From February 2005 to July 2005 a similar pattern to that on the northern side of Narrowneck was observed: mild conditions through the first 3 months resulted in accretion and beach widening at Narrowneck, then the onset of a series of moderate storms through to July 2005 caused the partial removal of this accreted sand volume. As per the northern beach, through August 2005 to January 2006 the generally mild wave conditions resulted in little net change to beach width, until March 2006, when significant erosion occurred as a result of an east coast low pressure system. From March through to July 2006 the beach width fluctuated, with a general trend of slow accretion.

Throughout the current monitoring period of August 2006 to January 2007, minor fluctuations in beach width have occurred, but generally this has been the most stable period for beach width recorded throughout the previous 7.5 years.

By the end of January 2007 the beach to the south (up-drift) and in the lee of the reef was of the order of 10 m wider than at the commencement of monitoring. Again, this is likely to represent a conservative (lower) estimate of beach widening, due to the extensive sand nourishment that was underway in this area prior to the commencement of the ARGUS monitoring program.

Since the implementation of the new web-based 'Beach Analysis System', these weekly beach width data in the vicinity of the reef are now available on-line and updated each week. Again for the sake of completeness, these data in the on-line graphical format ('Beach Width Analysis') for the period to the end of January 2007 are shown in Figure 8.7, along with a selection of recent shorelines.

8.3 Analysis of Cyclic-Seasonal versus Longer-Term Trends

The results of auto-correlation analysis for the 500 m section of beach centred at the site of the reef are summarised in Figure 8.8. Refer to Section 7.2 for details of the methodology used to complete this analysis.

As per the northern and southern sections, the cyclic variation in beach width observed at Narrowneck (middle panel) for the six and a half year period August 2000 to January 2007 is of the order of ± 20 m annually. Again, the occurrence of the east coast low and associated beach erosion in early March had the effect of 're-setting' this dominant seasonal-cyclic trend, although the associated beach recovery occurred to a reduced extent

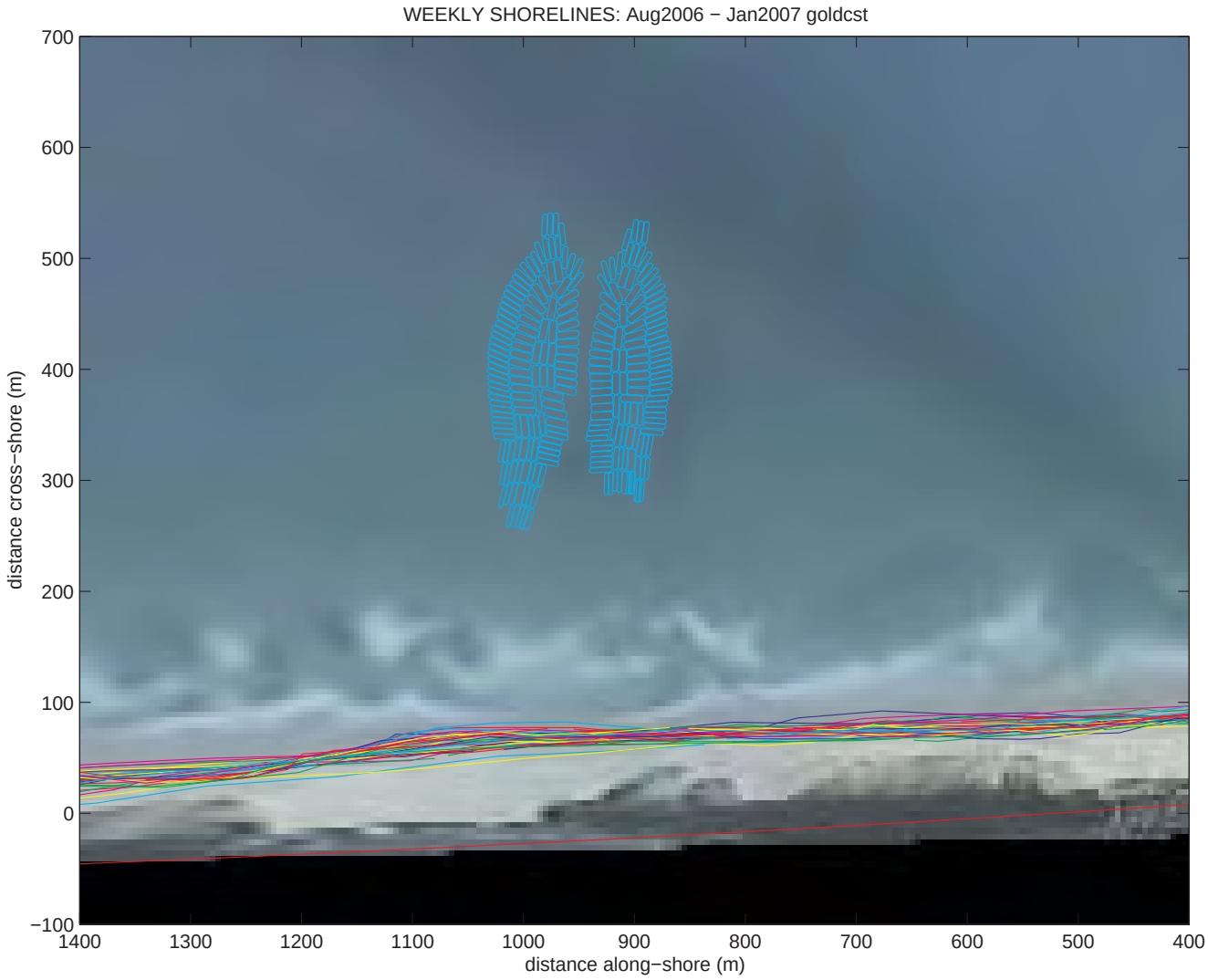
throughout the remainder of 2006. Referring to the best-fit linear trend to these data as shown in the upper panel of Figure 8.8, the underlying trend at this site for the six and a half year period to January 2007 is estimated to be of the order of -4 m per year (erosion).

The analysis of cyclic-seasonal versus net erosion-accretion trends at Narrowneck post sand nourishment (i.e. mid 2000) has been updated every six months monitoring period commencing in early in 2004. Table 8.1 summarises the six monthly results obtained to date. A modest net erosion trend has emerged at Narrowneck, with this exhibiting the subtle trend of increasing with time.

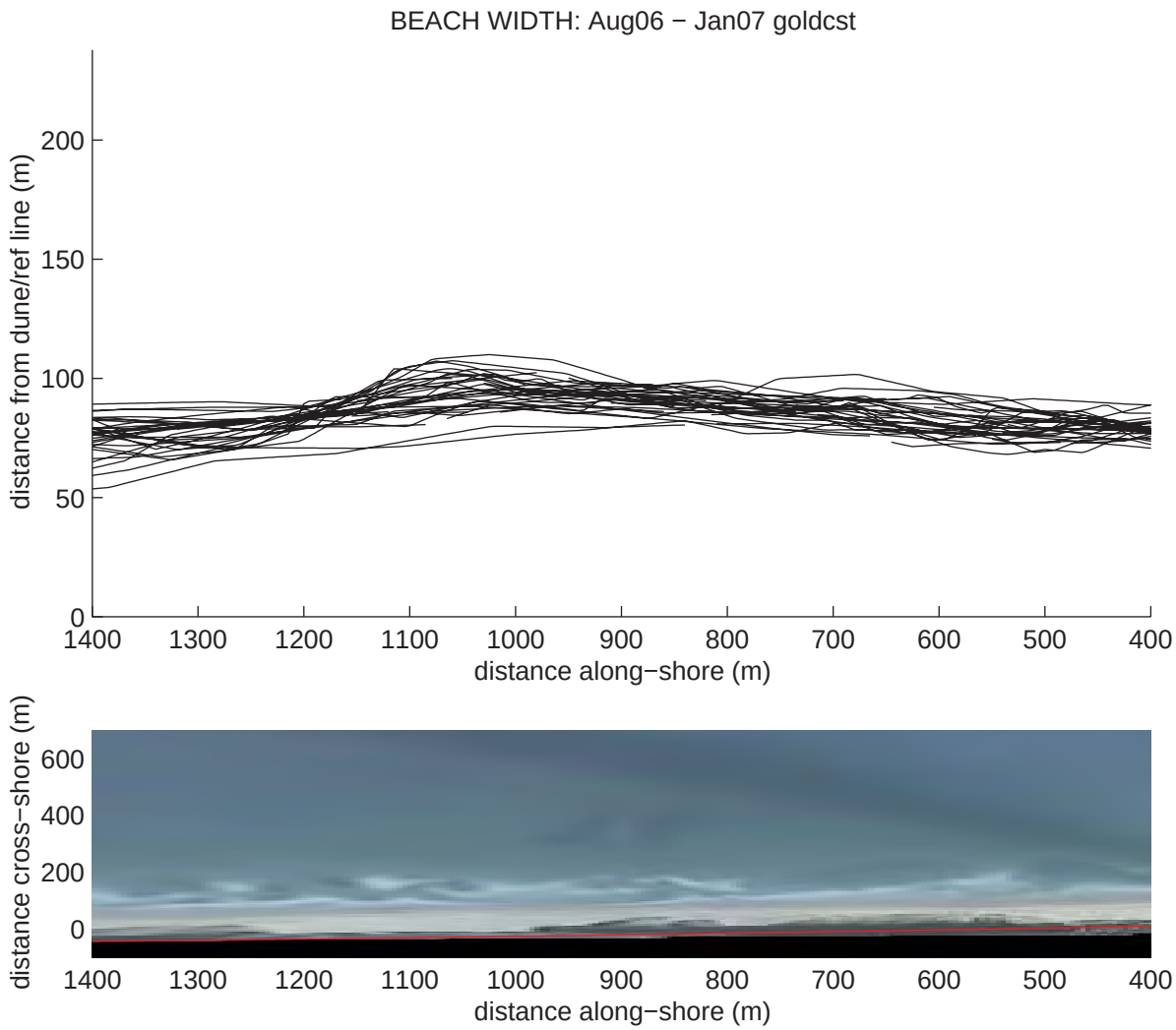
Table 8.1
Summary of Cyclic-Seasonal Variability versus
Net Erosion-Accretion Trends (Narrowneck)

Post-nourishment monitoring period	Years	Cyclic-seasonal variability (m)	Net erosion-accretion trend (m per year) Narrowneck
August 2000 – January 2004	3.5	±20	+1.6
August 2000 – July 2004	4	±20	-0.6
August 2000 – January 2005	4.5	±20	-1.4
August 2000 – July 2005	5	±20	-2.8
August 2000 – January 2006	5.5	±20	-2.3
August 2000 – July 2006	6	±20	-3.5
August 2000 – January 2007	6.5	±10	-3.8

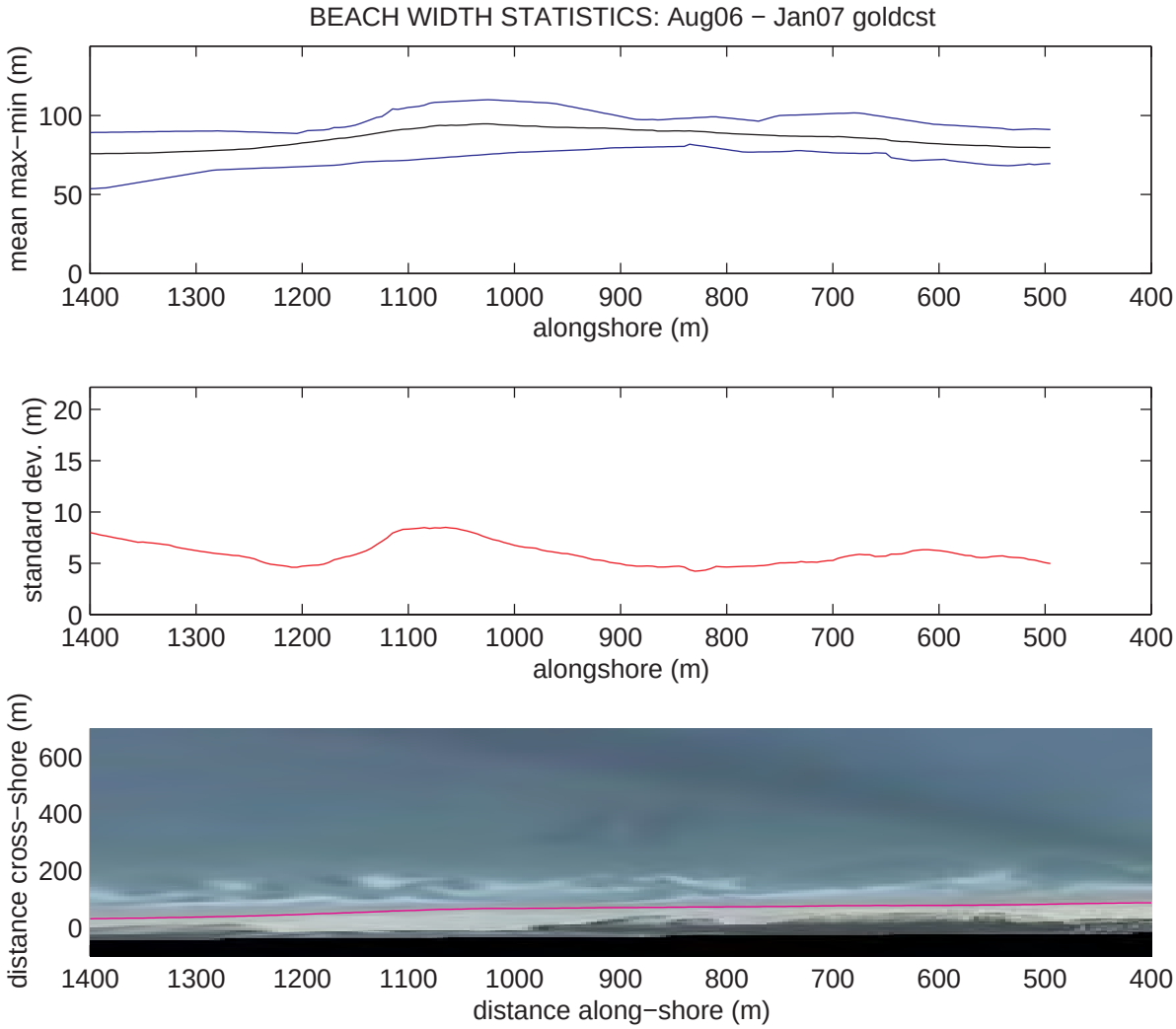
From the results presented in Table 8.1 it is concluded that at Narrowneck the underlying local beach width trend to date, since the completion of sand nourishment in mid 2000, has been modest net erosion of the order 25 m (-3.8 m/yr). More significant to the future management of this region, is the observation (as per the northern and southern beaches) that the cyclic annual variability of beach width at Narrowneck due to the seasonally varying wave climate, was an order of magnitude greater than the underlying slightly erosional beach width trend.



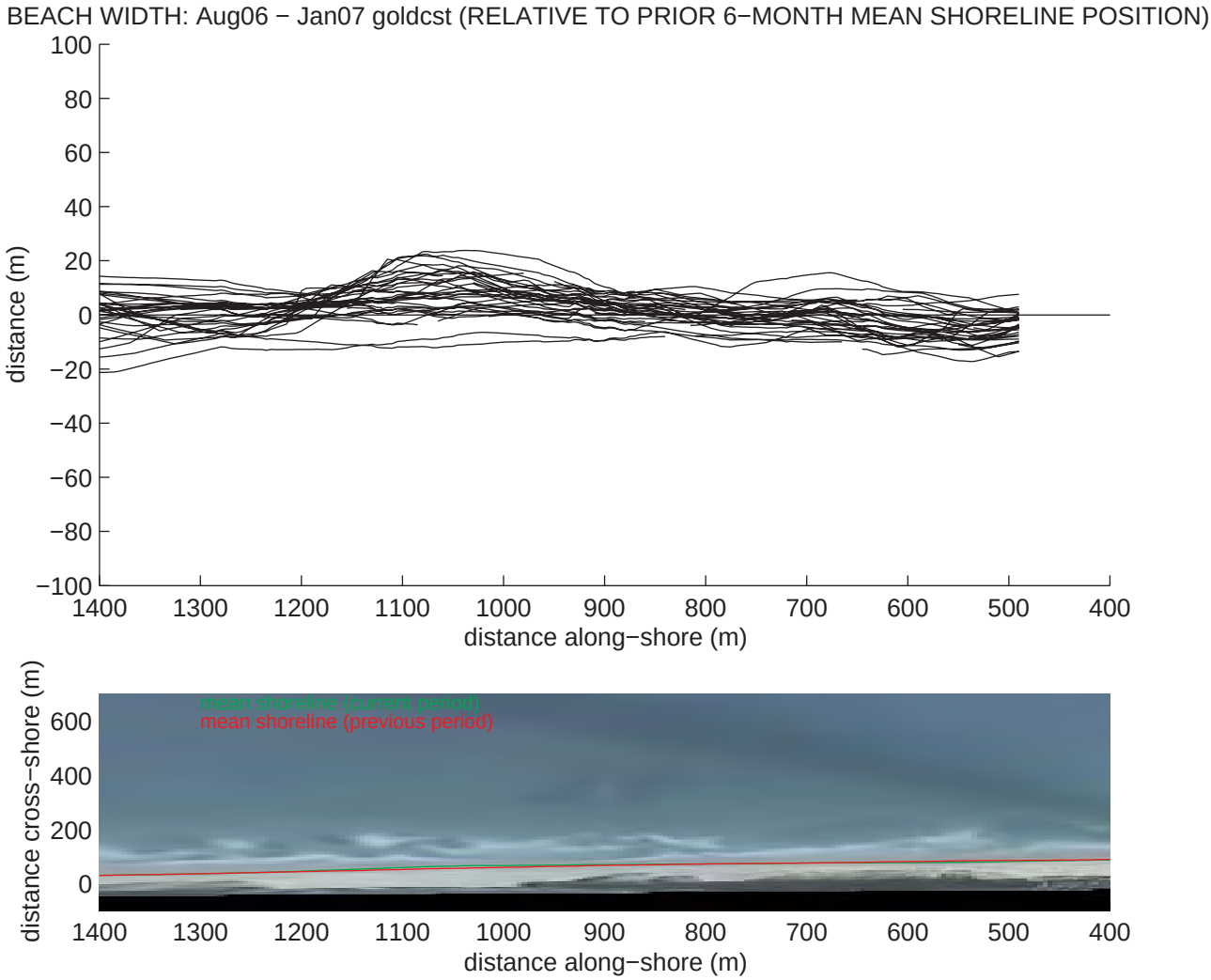
WRL Report No. 2007/08	WEEKLY SHORELINES AT NARROWNECK: AUGUST 2006 - JANUARY 2007	Figure 8.1 06037-8-1.cdr



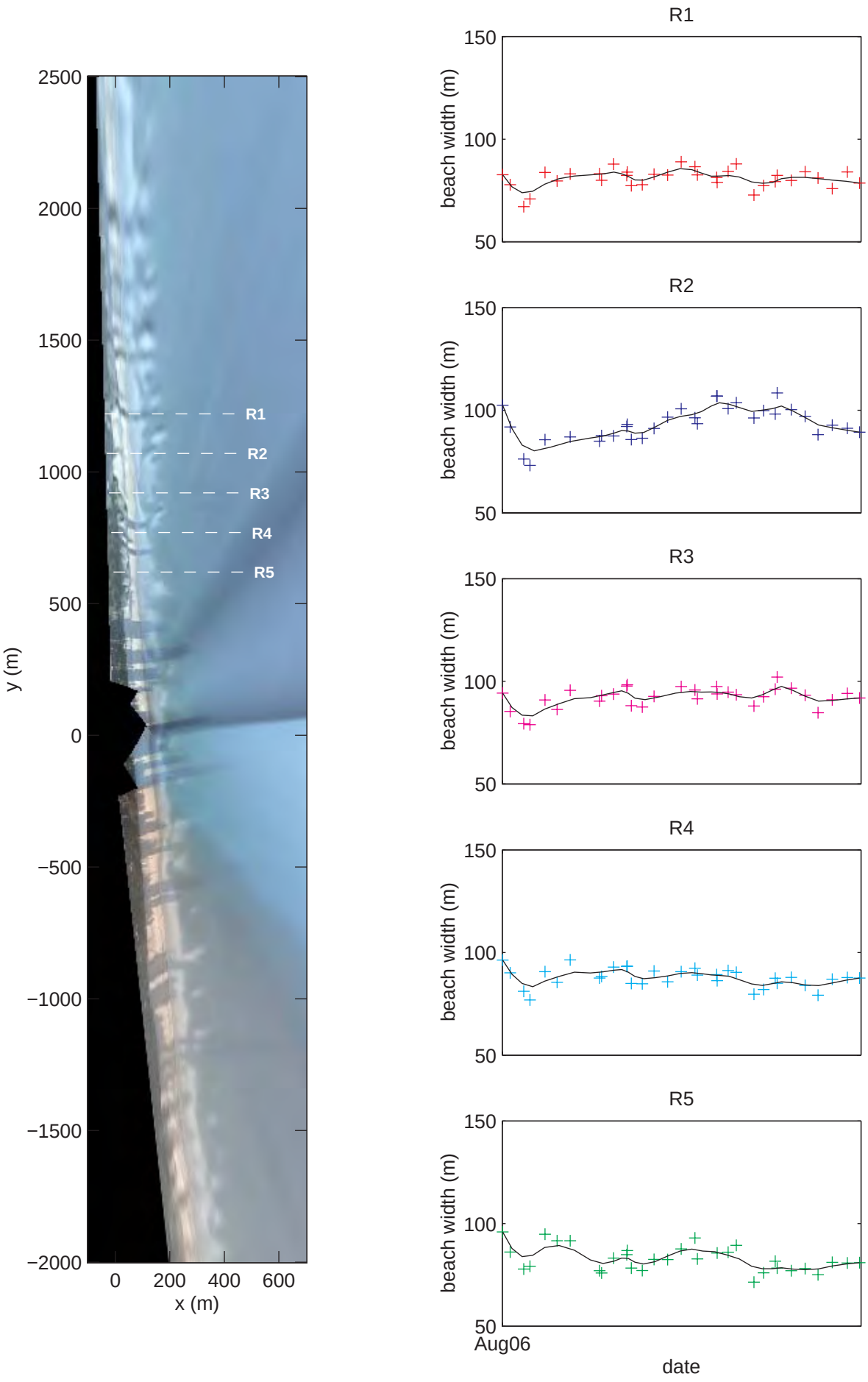
WRL Report No. 2007/08	BEACH WIDTH AT NARROWNECK: AUGUST 2006 - JANUARY 2007	Figure 8.2 06037-8-2.cdr



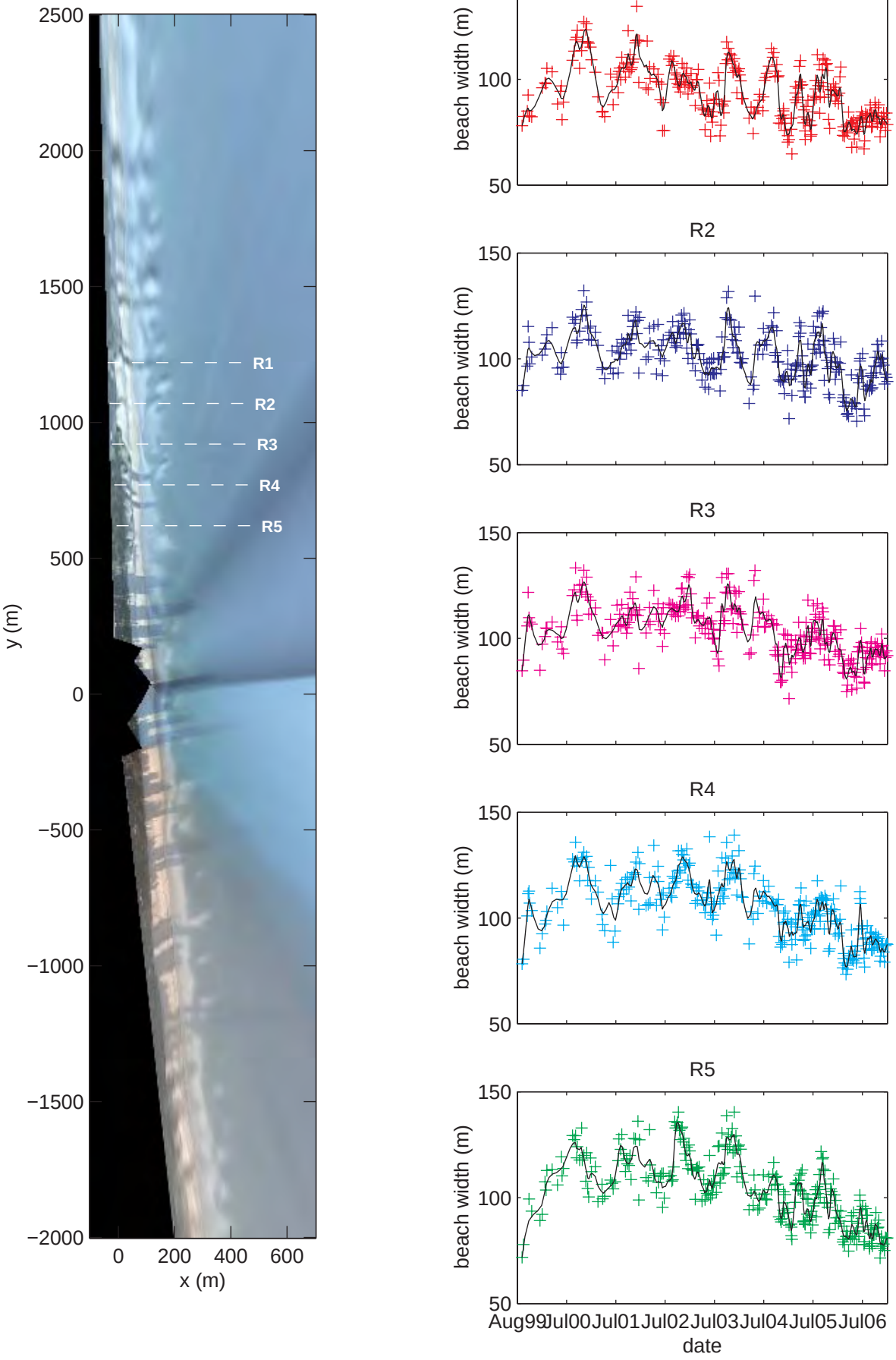
WRL Report No. 2007/08	STATISTICAL SUMMARY OF BEACH WIDTH CHANGES AT NARROWNECK: AUGUST 2006 - JANUARY 2007	Figure 8.3 06037-8-3.cdr



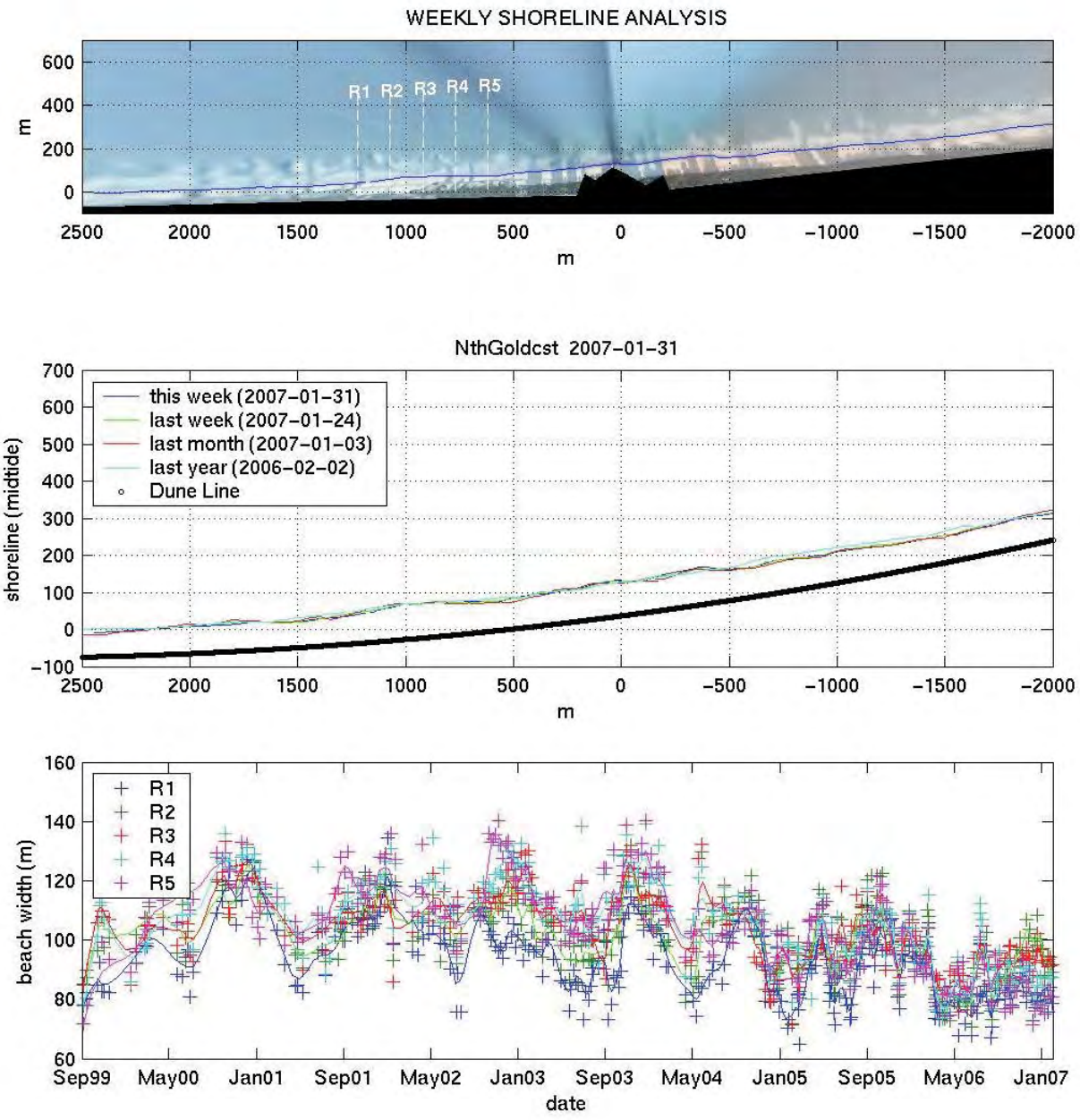
WRL Report No. 2007/08	WEEKLY BEACH WIDTH CHANGES AT NARROWNECK AUGUST 2006 - JANUARY 2007 RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION	Figure 8.4 06037-8-4.cdr



WRL Report No. 2007/08	TIME-SERIES OF BEACH WIDTH AT NARROWNECK: AUGUST 2006 - JANUARY 2007	Figure 8.5 06037-8-5.cdr



WRL Report No. 2007/08	TIME-SERIES OF BEACH WIDTH AT NARROWNECK: AUGUST 1999 - JANUARY 2007	Figure 8.6 06037-8-6.cdr

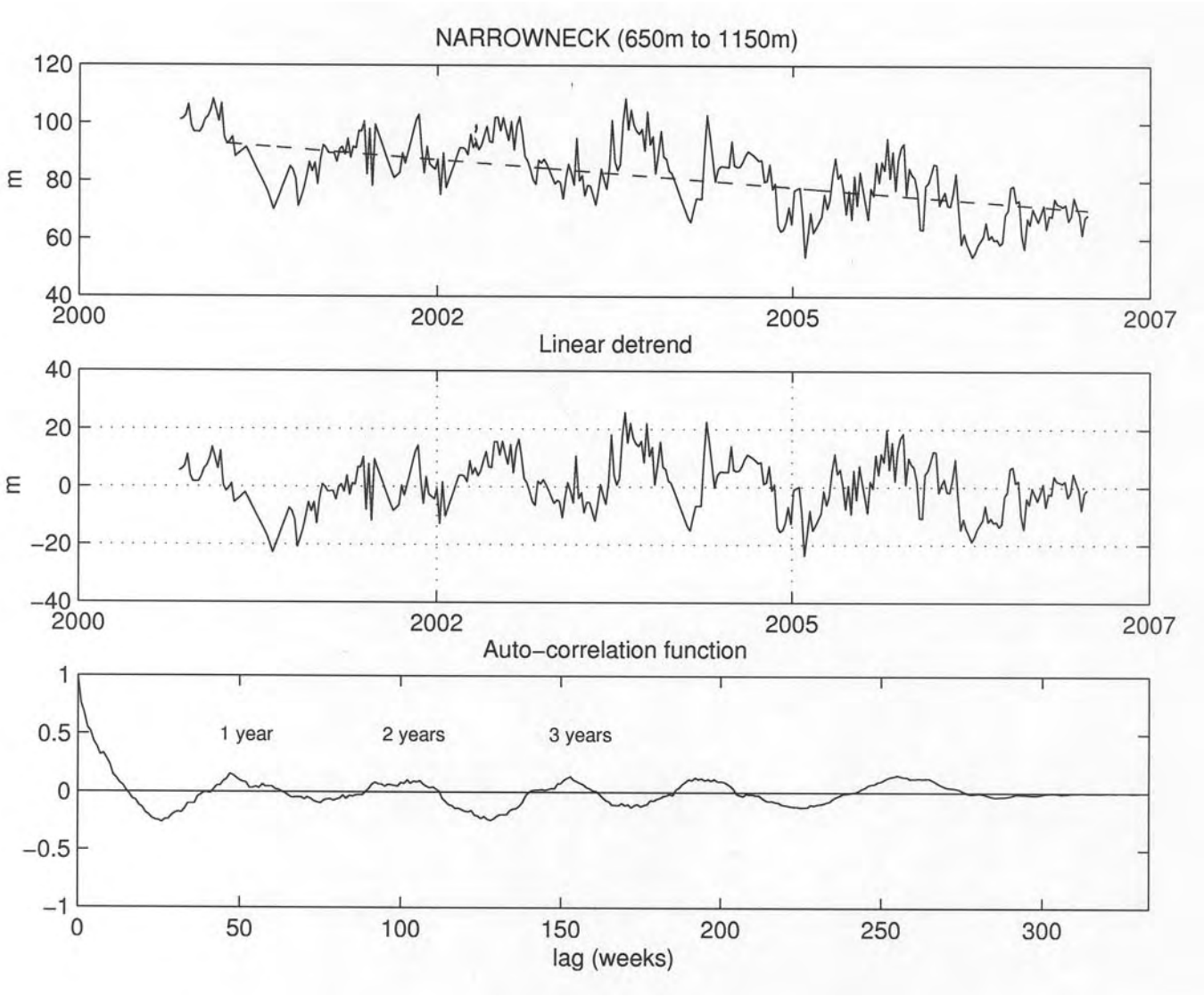


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WRL Report No. 2007/08	ON-LINE BEACH WIDTH ANALYSIS: JANUARY 2007 (REEF)	Figure 8.7 06037-8-7.cdr



WRL Report No. 2007/08	CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS NARROWNECK	Figure 8.8 06037-8-8.cdr

9. ANALYSIS OF EROSION-ACCRETION TRENDS

On a monthly basis, hourly images throughout a single spring tide are analysed and a 3-D bathymetry of the beachface extending from the low tide waterline to the high tide waterline is derived. These data are then analysed to better assess regions of beachface erosion and deposition up-drift and down-drift of the artificial reef site at Narrowneck.

9.1 Methodology

A detailed description of the analysis techniques used to derive three-dimensional beachface bathymetry from two-dimensional image analysis was provided in Turner (2005a). In summary, throughout a single spring tide cycle, the shoreline mapping technique is applied to locate the waterline in successive hourly images. The elevation corresponding to the detected waterlines is calculated on the basis of concurrent tide and wave information, which is incorporated in a model that combines the effects of wave setup and swash, at both incident and infragravity frequencies. As illustrated in Figure 9.1, if this process is repeated at all points alongshore throughout a complete tide cycle, a three-dimensional bathymetry of the beachface, between the high tide and low tide waterlines, can be derived. The beachface is the most dynamic region of sediment movement within the coastal system, and sand changes observed in this area are indicative of the total profile.

9.2 Monthly Beachface Bathymetric Mapping

Beachface bathymetry maps for 12th August 2006 and 21st September 2006 are shown in Figure 9.2, 8th October 2006 and 19th November 2006 in Figure 9.3, 20th December 2006 and 17th January 2007 in Figure 9.4. In all these figures, the centre-line of the Gold Coast Reef structure at Narrowneck is located at the longshore coordinate x = 900 m, and the landward edge of the structure is located offshore at around y = 250 m.

The section of beachface mapped in August (Figure 9.2) was uniform in gradient and alignment over the entire 1 km stretch. Consistent moderate wave conditions throughout September and October resulted in a general seaward migration of the beach face by 20 m in the north (0.5 km north of Narrowneck) and 10 m in front of the reef. The beachface to the south of the reef also became less uniform in alongshore alignment as the inner bar began to attach to the beachface in places. In November a significant salient developed downdrift of the reef, with a beach widening of almost 15 m in this location occurring in only a one month period. The growth of the salient decreased in December, and general straightening of the beach occurred. To the north of the salient, the beach was observed to

flatten in gradient and migrate slightly landward. Higher wave conditions in January resulted in further straightening of the beach, with the salient being almost completely removed, and the eroded sand forming a complex inner bar system.

Overall throughout the current six month monitoring period from August 2006 to January 2007, the shoreline (location of MSL) was observed to migrate seaward by approximately 15 m updrift and in the lee of the reef, and 25 m downdrift of the reef.

9.3 Monthly Erosion-Accretion Trends

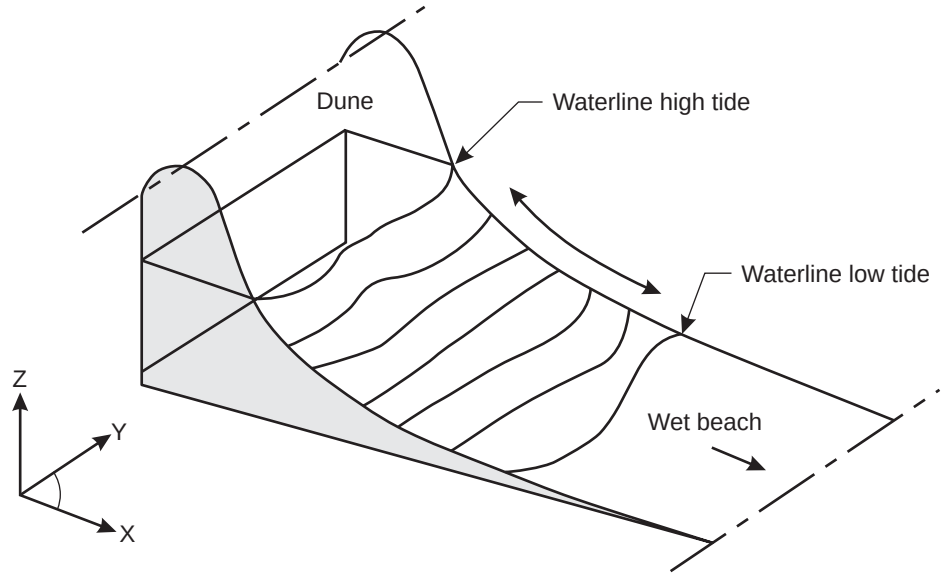
By further processing of the monthly bathymetries shown in Figures 9.2 - 9.4, a quantitative measure of the net change in sand volumes across the beachface (between -0.5 and + 0.7 m AHD) around Narrowneck can be obtained. Figure 9.5 shows the results of these calculations to determine the monthly net change in beachface elevation between August and November 2006, and Figure 9.6 summarises the monthly beachface changes between November 2006 and January 2007.

The top and mid panels of Figure 9.5 show the slow general accretion that occurred through the months of August – October 2006, particularly in the lee of the reef and further to the north. During this period, a total sand volume of approximately 10 000 m^3 accreted in the study zone, which equates to approximately 10 m^3 per metre of shoreline. The most dramatic change, however, occurred early in November, when a reasonably large volume of sand accreted in a salient just north of the reef location. During the period between 8/10/06 and 19/11/06 (Figure 9.5 bottom panel), a net accretion of approximately 6000 m^3 of sand occurred within the intertidal zone. From the figure, the distribution of this accretion can be seen to have mostly occurred in a large salient, just downdrift of the reef location. Significant accretion in this salient stretched a distance of approximately 30 – 40 m seaward. Throughout the remainder of November and during December, the salient continued to grow slightly in the lee of the reef, while the areas to the south and north of the reef underwent minor erosion. There was negligible net change in sand volume within the intertidal zone, with this period.

During January 2007, the salient that had developed throughout the previous months was eroded, as larger wave conditions prevailed. The higher wave energy acted to straighten the shoreline, moving some of the sand volume from the salient to an inner bar, while the remainder of the sand was pushed to the north, filling the area that had eroded in December. Again, the result of this erosion/accretion was negligible net change in sand volumes within the intertidal zone of the 1 km stretch of beach analysed.

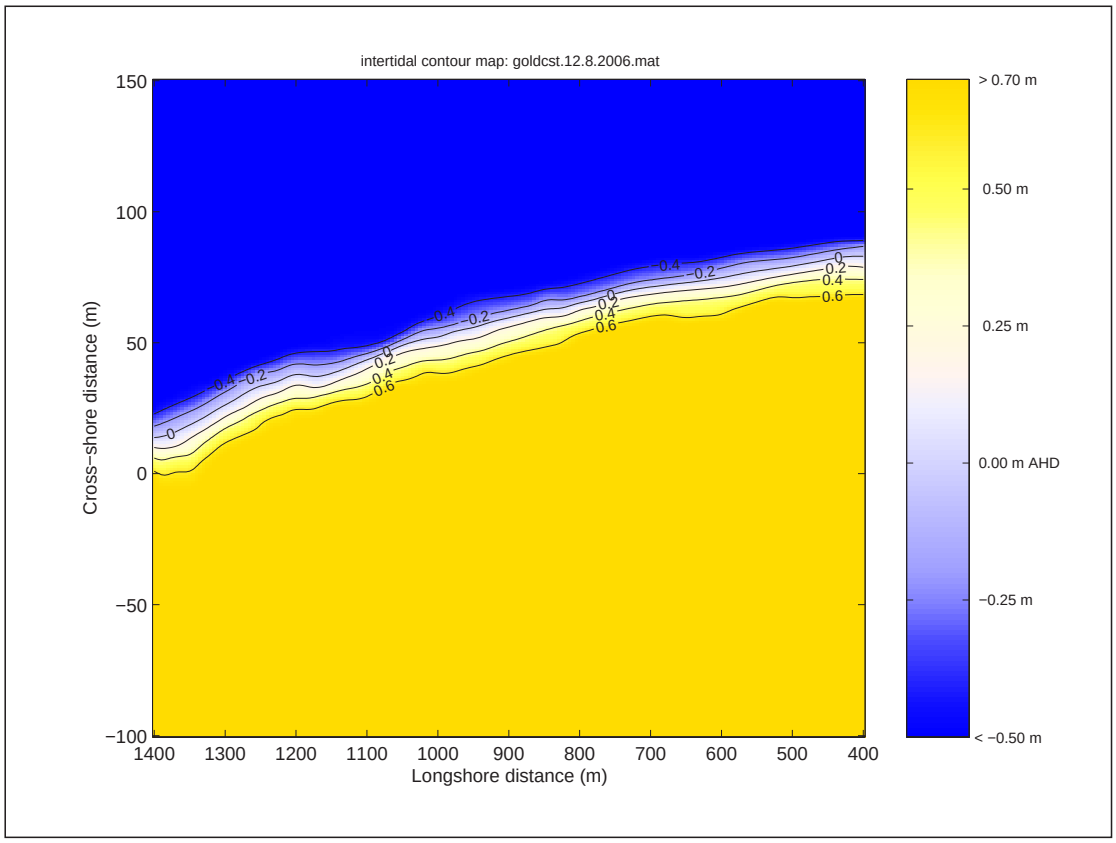
9.4 Net Erosion-Accretion Trends: August 2006 - January 2007

The net trend for the entire six-month period August 2006 to January 2007 was modest accretion across the entire 1 km stretch of beach. Referring to Figure 9.7, from 12th August 2006 to 17th January 2007, the 1000 m length of beach at Narrowneck accreted a net volume of approximately 16 000 m^3, between -0.5 and +0.7 m AHD. It can be seen from Figure 9.7, that the majority of this accretion occurred in the lee of the reef, and further to the north, with localised vertical accretion of the order of 0.8 – 1.0 m occurring in this area. Further to the south of the reef, minor vertical accretion up to 0.4 m was recorded. The higher levels of accretion in the lee of the reef are expected to be a result of the decreased wave energy in this zone, caused by wave breaking and dissipation across the submerged reef structure.

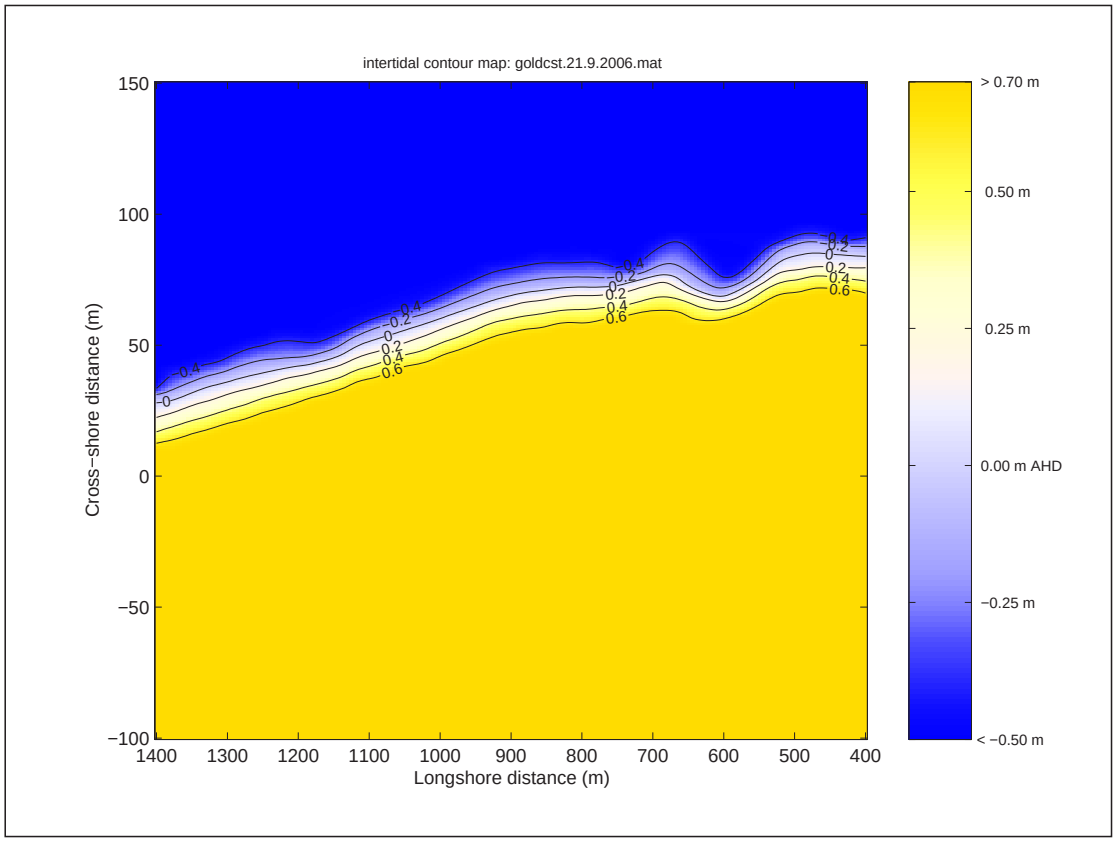


WRL Report No. 2007/08	DEFINITION SKETCH INTERTIDAL BATHYMETRY FROM HOURLY WATERLINES	Figure 9.1 06037-9-1.cdr

AUGUST 2006

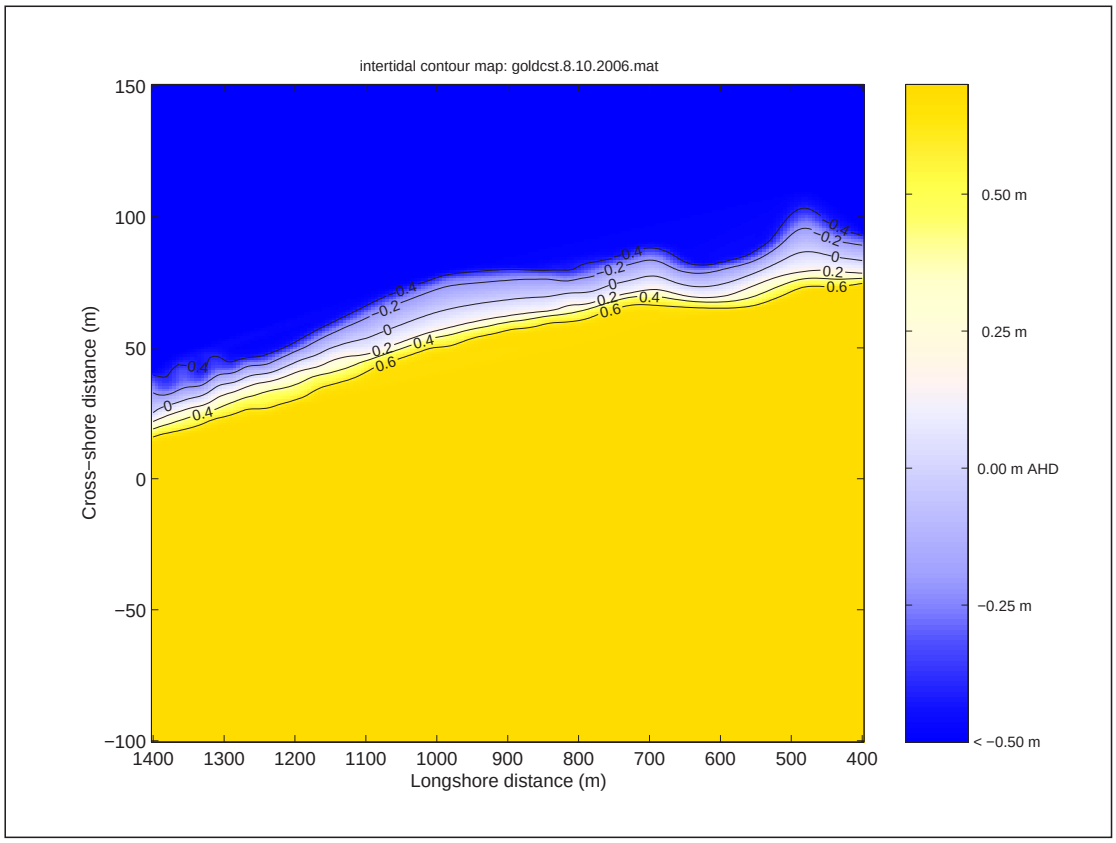


SEPTEMBER 2006

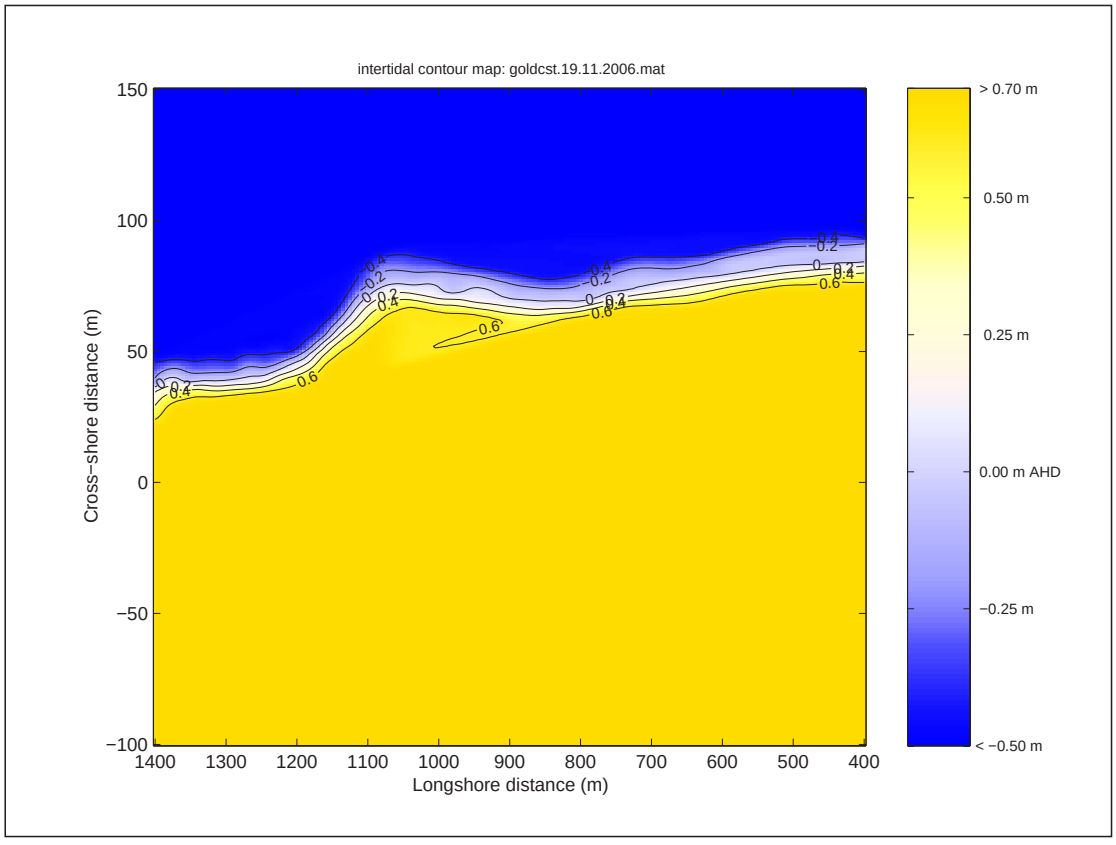


WRL Report No. 2007/08	BEACHFACE MAPPING AUGUST, SEPTEMBER 2006	Figure 9.2 06037-9-2.cdr

OCTOBER 2006

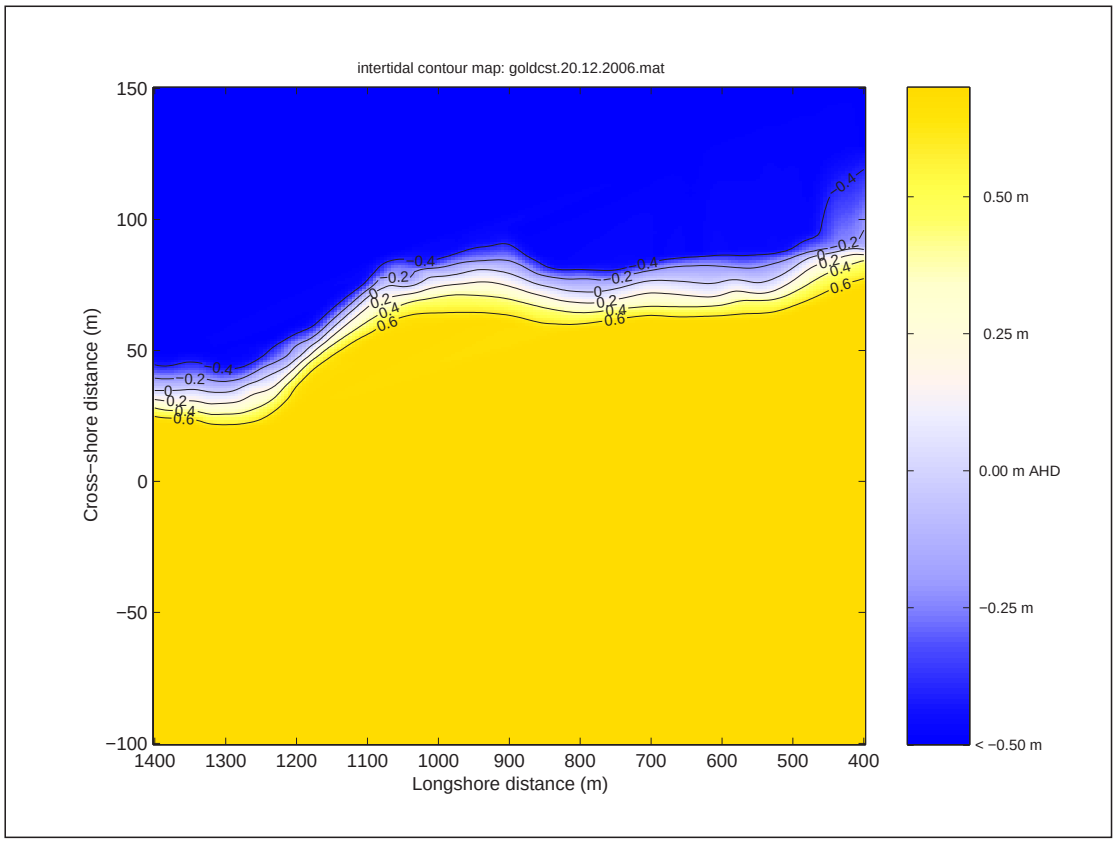


NOVEMBER 2006

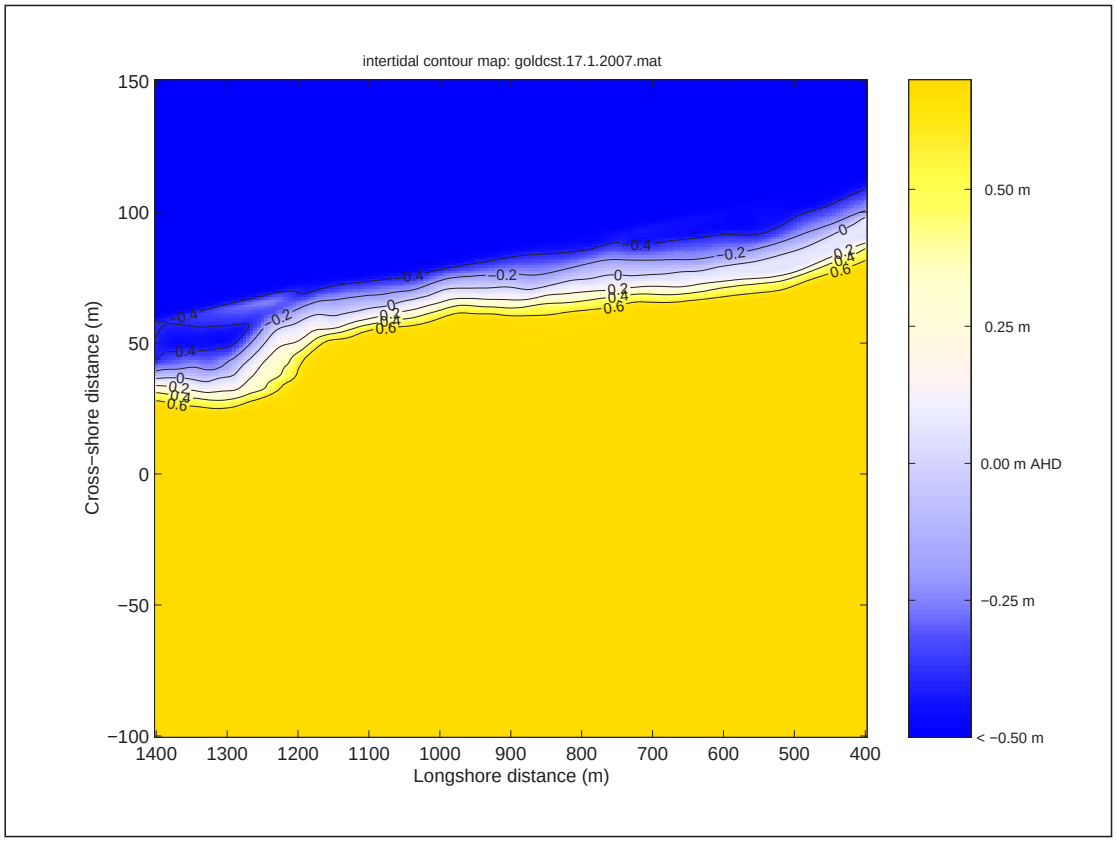


WRL Report No. 2007/08	BEACHFACE MAPPING OCTOBER, NOVEMBER 2006	Figure 9.3 06037-9-3.cdr

DECEMBER 2006

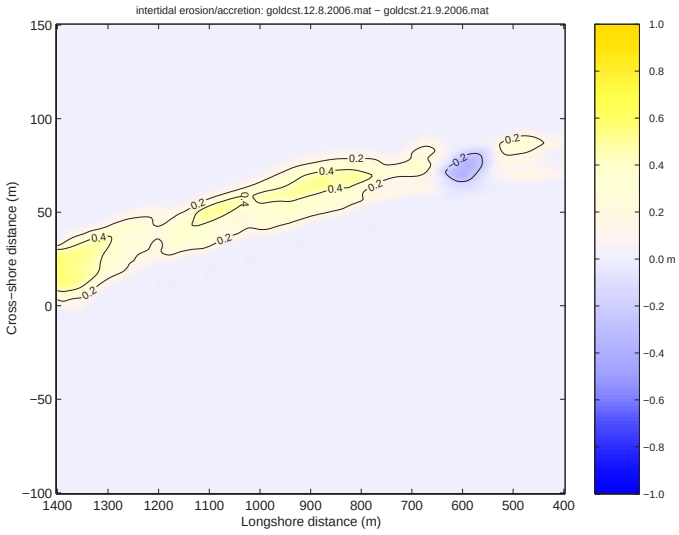


JANUARY 2007

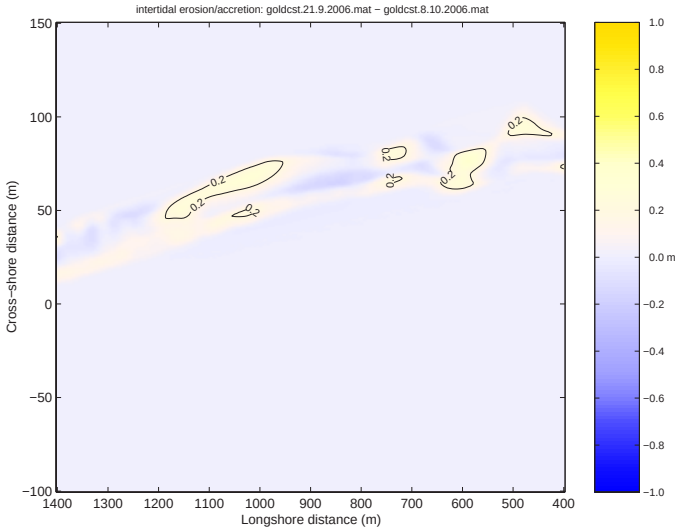


WRL Report No. 2007/08	BEACHFACE MAPPING DECEMBER 2006, JANUARY 2007	Figure 9.4 06037-9-4.cdr

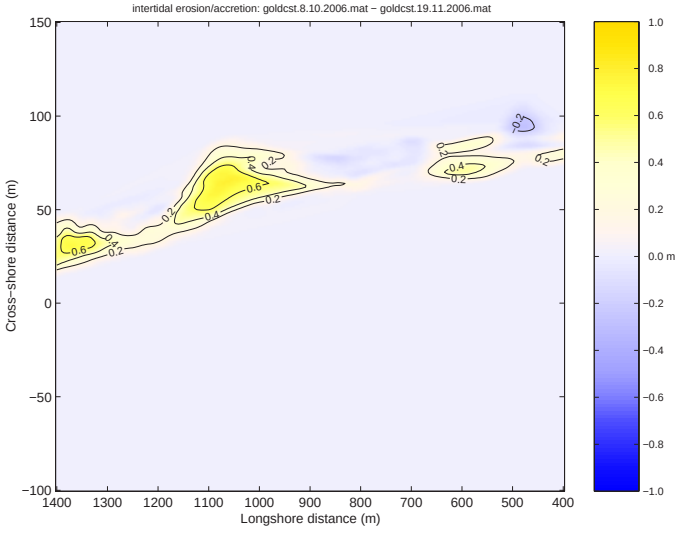
AUGUST - SEPTEMBER 2006



SEPTEMBER - OCTOBER 2006

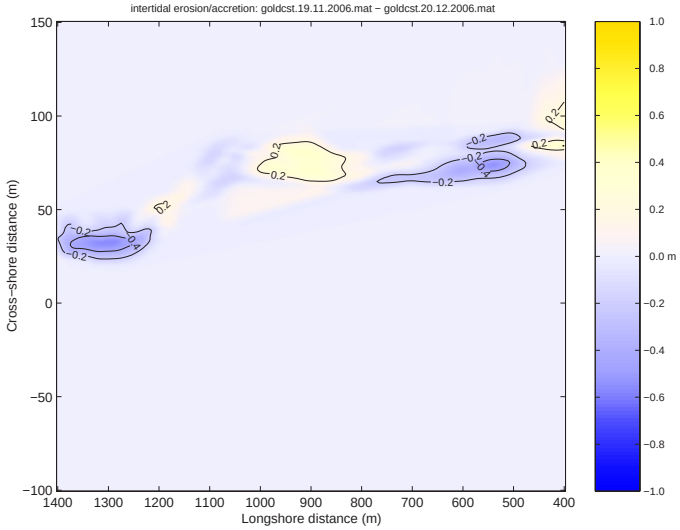


OCTOBER - NOVEMBER 2006

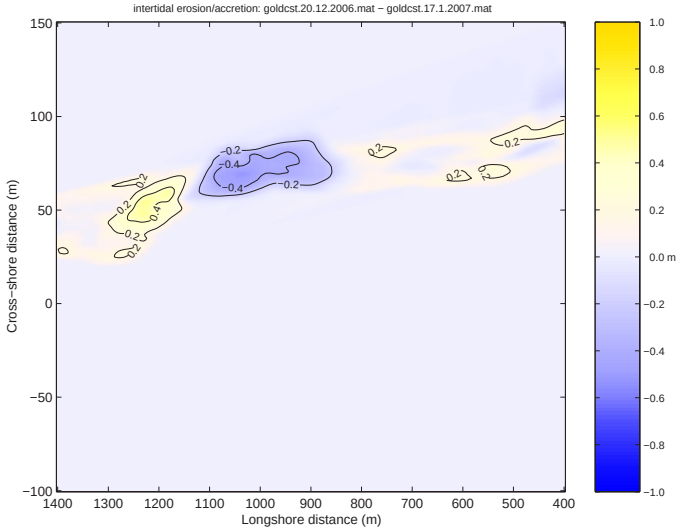


WRL Report No. 2007/08	MONTHLY EROSION/ACCRETION: AUGUST - NOVEMBER 2006	Figure 9.5 06037-9-5.cdr

NOVEMBER - DECEMBER 2006

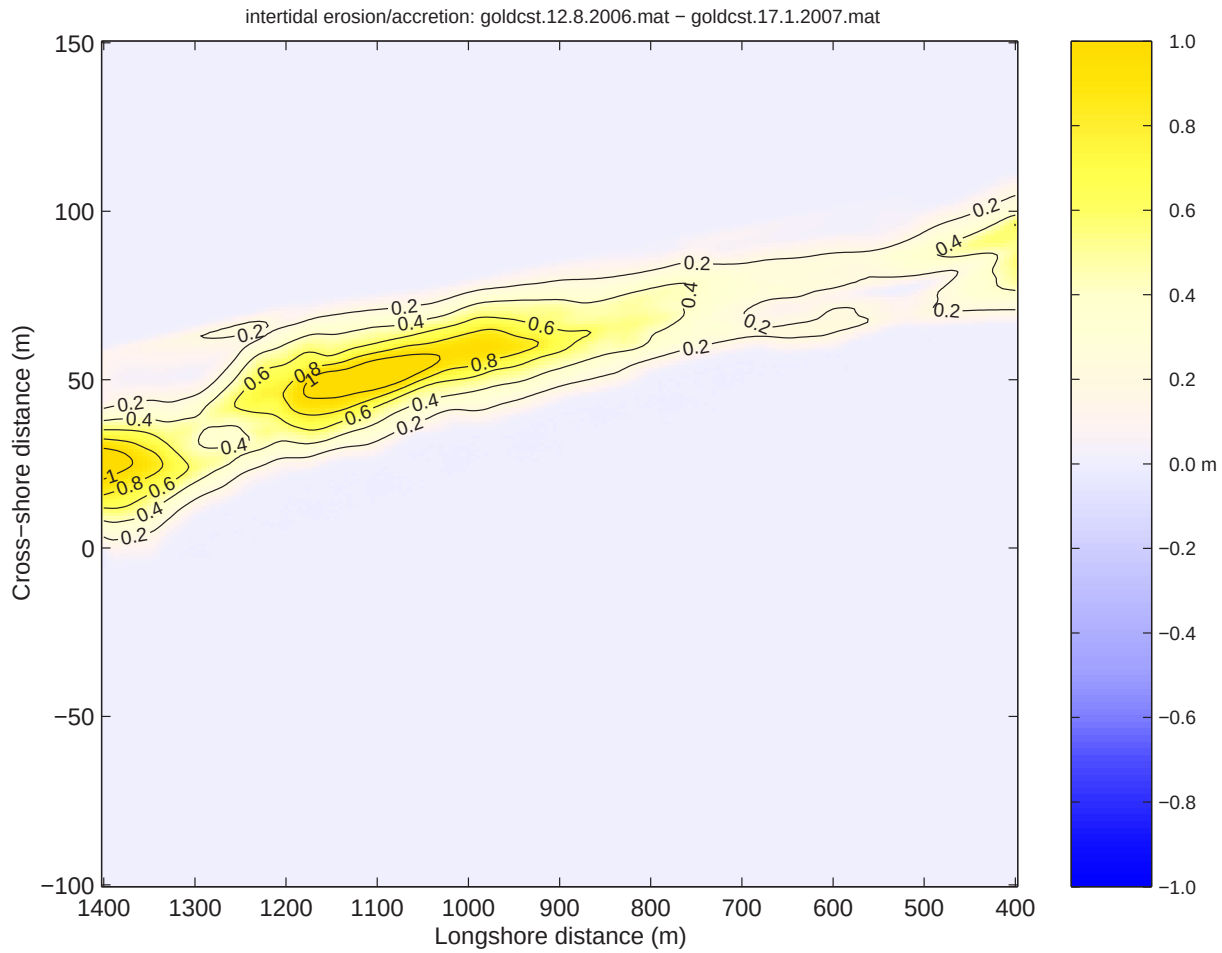


DECEMBER 2006 - JANUARY 2007



WRL Report No. 2007/08	MONTHLY EROSION/ACCRETION: NOVEMBER 2006 - JANUARY 2007	Figure 9.6 06037-9-.cdr

NET CHANGE: AUGUST 2006 - JANUARY 2007



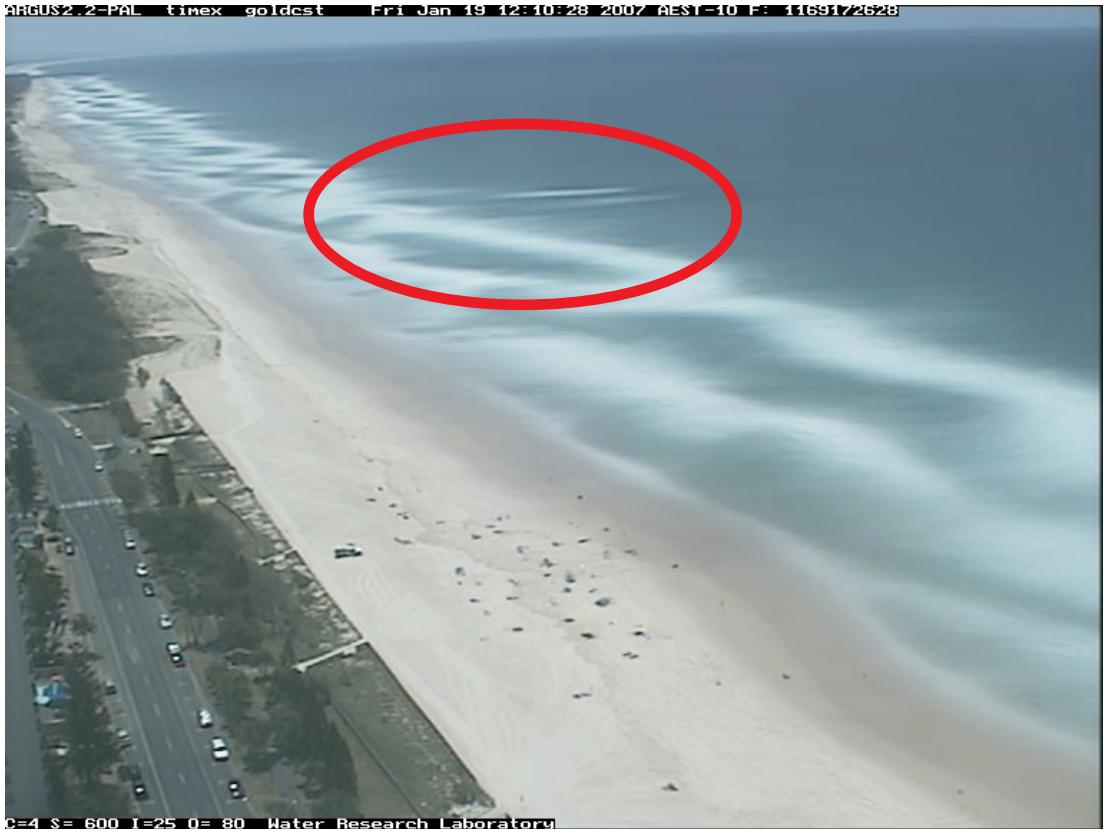
WRL Report No. 2007/08	NET EROSION/ACCRETION: AUGUST 2006 - JANUARY 2007	Figure 9.7 06037-9-7.cdr

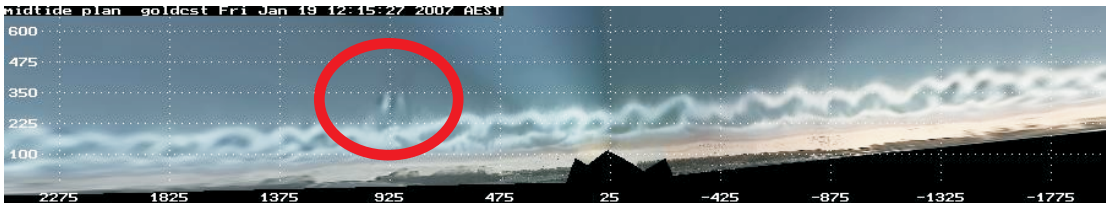
10. ASSESSMENT OF WAVE BREAKING AT THE REEF

It was noted in Section 2.1 that the Gold Coast Reef was designed to serve two functions. The dual purpose of the structure is to: (1) act as a 'control point' at Narrowneck to promote beach widening and extend the design life of the sand nourishment, and (2) to improve the surfing conditions at Narrowneck (McGrath et al., 2000).

The regional-scale focus of this monitoring program does not permit the use of the video system to assess the surf 'quality' (ie., wave shape, peel angle, etc) at the reef. Current examples of an oblique (single camera) image and corresponding merged-rectified (four camera) image that clearly show wave breaking across the northern and southern halves of the reef, are shown in Figure 10.1 (image date 19th January 2007).

In earlier monitoring reports completed during the construction of the reef, the progressive increase in the occurrence of wave breaking was documented and quantified as additional geocontainers were added. Further geocontainers were placed on the reef crest in late 2001, November 2002 and again in January, July and August 2004 (refer Section 2.2). Since 2003, it has been observed that waves now break across the reef structure once the incident significant wave height exceeds around 1 m.





WRL Report No. 2007/08	VISIBLE WAVE BREAKING ON REEF (19 JANUARY 2007)	Figure 10.1 06037-10-1.cdr

11. CONCLUSIONS

The present six month monitoring period to January 2007 marks six and a half years since the completion of beach nourishment in mid 2000 at the northern Gold Coast, and six years since the major phase of reef construction was completed in December 2000. A limited number of additional geocontainers were placed across the crest of the Gold Coast Reef in November – December 2001 (17 bags), November 2002 (10 bags) and January - August 2004 (15 bags). During the period January – April 2005 approximately 59,000 m^3 of additional sand dredged from the Broadwater was placed along the northern Gold Coast beachfront.

11.1 Beach Width

Moderate wave conditions occurred across the Gold Coast throughout August and September of 2006, with episodic increases in wave height up to 2.5 to 3 m (offshore significant wave height). These higher wave conditions resulted in the formation of a double bar system across the length of recorded beach, which was intermittent throughout August and September. During times of lower energy, transverse bars and rips formed between the inner and outer bars, with sections of the inner bar attaching to the beach, forming low tide terraces.

Lower wave conditions prevailed throughout the remainder of the year, which dictated the morphodynamic changes which occurred during this monitoring period. The lower wave energy allowed the steady migration of the offshore bar toward the beach to occur, through the formation of transverse bars. Eventually the transverse bars welded to the beach, increasing the volume of sand in the terrace formations, and widening the intertidal zone. The additional volume of sand added to the beach in the terrace formations resulted in slight increases in overall beach width throughout the monitoring period.

A visual assessment of resulting beach changes during August 2006 to January 2007 (Figure 5.2 and Figure 5.3) reveals that along the southern beach a very subtle increase in beach width is discernable, while to the north this increase in beach width is more pronounced. In the vicinity of the reef site at Narrowneck no similar trend can be seen in Figure 5.2, with the beach width appearing to be similar at the beginning and end of the present six month monitoring period.

Extending this qualitative visual assessment of images to include the entire seven and a half year monitoring period (Figures 5.4 and 5.5), it is observed that during the first six months

(August 1999 to January 2000) the on-going nourishment of the northern beach was visible, with no change to the southern beach as this area was yet to be nourished at that time. A dramatic change in the width of the beach occurred between January 2000 and August 2000, when nourishment of the entire stretch of coastline from Narrowneck to Cavill Avenue was completed, with the result that the mid-tide beach can be seen to have nearly doubled in width during this period. During the next six months to January 2001 the beach alignment became more uniform alongshore, as the coastline re-adjusted to the new sand volume available within the beach system. February 2001 to July 2001 saw a general erosional trend along the northern Gold Coast beaches, in response to a succession of storms. This contrasted to the following six months (August 2001 to January 2002) during which the beaches recovered, returning to a similar state as was seen 12 months previously in January 2001. A return to prior conditions following a period of storm erosion indicates that the beaches of the northern Gold Coast at that time were close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000.

From January 2002 to August 2002 the beach of the northern Gold Coast were moderately depleted, with the beach at the end of this period intermediate to the eroded state that prevailed in August 2001, and the most accreted state that was recorded at the end of January 2002. By January 2003 the beaches had returned to their more accreted state, similar to beach conditions observed 24 and 12 months previously in January 2001 and January 2002. During February 2003 to August 2003, the beaches again experienced a period of modest erosion. Both to the north and south, the beach at the beginning of August 2003 appeared very similar to the conditions that prevailed 12 months previously in August 2002. Moderately depleted conditions prevailed, that were intermediate to the more accreted states observed in January 2002 and January 2003, and the more eroded state that prevailed two years previously in August 2001. From August 2003 to January 2004 minimal storm wave activity was observed, and the beaches of the Northern Gold Coast generally accreted. During February 2004 to July 2004 large wave events occurred in March, and the beaches were observed to be cut back during that time. However, by the end of July 2004, both the northern and southern beaches had recovered. From August 2004 to January 2005, storms in October and again in January caused a general movement of sand offshore, with the visible width of the subaerial beach decreasing during this time, and the widening of the surf zone as the outer bar translated further seaward.

During February 2005 to July 2005 both the northern and southern beaches exhibited similar beach width and shoreline alignment, with the exception of the region in the immediate vicinity of Narrowneck, where a modest trend of net beach widening was discernable. From August 2005 to January 2006, along the southern beach no net change in

the visible (subaerial) beach was discernable, with similar conditions also observed along the northern beach. The exception to this observation of similar conditions was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed.

During the period from February 2006 to July 2006 a subtle trend of a narrower beach was observed to the south, with a more pronounced decrease in beach width to the north of Narrowneck. In contrast, in the vicinity of the reef site at Narrowneck the visible beach was similar at the beginning and end of this six month period. During the current monitoring period from August 2006 to January 2007, the wave climate was predominantly moderate to low, with no storm wave occurrences. This resulted in a general widening in both the northern and southern beaches. The beach width and alignment at the end of January 2007 is comparable to that at the end of January 2006, with the beaches recovering from the higher energy period observed in the early period of 2006.

Based upon the quantitative analysis of weekly shorelines during the present monitoring period 01/08/06–31/01/07, the beach along the 4,500 m study region varied in width (relative to the dune reference line) from approximately 50 m to 100 m (Figure 6.2). The envelope of beach width changes was relatively uniform alongshore, generally varying in width along the 4,500 m study region by approximately 25 - 35 m during this period.

Median beach width at mid-tide (relative to the dune reference line) along the 4,500 m stretch of coastline during the period 01/08/06–31/01/07 was in the range of 65 – 95 m (Figure 6.3). As was discernible from Figure 6.2, relative to the dune reference line the mean beach width was greatest at approximately 1000 m alongshore (to the north of the ARGUS station), with a width of approximately 90 – 95 m. The standard deviation of weekly shorelines from the mean shoreline position varied along the length of the beach, but was clearly a minimum over the stretch of beach from 500 to 1000 m north of the cameras. It is worth noting that the section of beach which was generally the widest coincided with the stretch that showed the least variability during the current monitoring period, and was the area in the lee of the Gold Coast Reef at Narrowneck, approximately 900 m to the north of the cameras.

The weekly shoreline data for the current monitoring period was re-analysed to assess beach width changes relative to the mean shoreline position for the preceding six month period (Figure 6.4). The analysis showed that during the present monitoring period, the beaches of the northern Gold Coast varied both narrower and wider than the mean shoreline from the previous monitoring period. However, it could also be seen that there was a

significantly larger number of occasions during this monitoring period, where the beaches were wider than the previous mean beach width. Figure 6.4 bottom panel also showed that the mean beach width was very slightly wider throughout the current monitoring period than the previous period, over some sections of the beach.

The observation from the present monitoring period of relatively uniform beach changes alongshore is more typical of the general trend observed throughout the total seven year monitoring program. The rather atypical observation 2 years ago (refer Turner, 2005a) of a distinct alongshore variability in beach width, did not continue through 2005 and 2006.

Over the entire 90 month monitoring period, mid-tide beach width (relative to the dune reference line) along the full 4,500 m study region has varied in the order of 100 m (Figures 7.2 and 7.3). Beach width changes of typically 50+ m have been recorded at all positions alongshore. A general trend of increasing beach width was apparent during the initial 18 months of monitoring, clearly indicating the dominant effect of nourishment during this period. In contrast, during the period 18 – 24 months, a general erosion trend occurred. The monitoring period February – July 2001 was characterised by a series of storms that resulted in the net recession of northern Gold Coast beaches. From August 2001 to January 2002 a distinct trend of beach recovery at all locations alongshore was observed. By January 2002 the beach had recovered to the extent that beach widths were sufficiently regained to match the conditions that were measured 12 months previously in January 2001. From February 2002 to July 2002 a modest net erosional trend was recorded, which again reversed though to January 2003, at which time the beach at all locations alongshore exhibited marked recovery, returning to the accreted conditions that prevailed 12 and 24 months previously in January 2002 and January 2001. During February 2003 to July 2003 an erosion trend was again evident. The beach receded, in response to the occurrence of the greater frequency of storm events during this time.

Net accretion at all locations alongshore was observed during the period August 2003 to December 2003, followed by the commencement of erosion in January 2004, in response to two periods of higher waves (> 2m significant wave height). From February 2004 to July 2004, two large storm events in March, followed by continued moderate wave activity in April, caused the beach at all locations to initially continue this erosion trend. However, by the end of July 2004 the beach had generally recovered to the conditions that prevailed at the end of January. The exception to this was in the region between Narrowneck and the cameras, where more limited recovery was observed. From August 2004 to January 2005 this general accretionary trend initially continued. However, due to the large storm wave event in the second half of October 2004 beach recession was then observed at all locations

alongshore. A two month period of beach recovery followed, when beach width temporarily increased, but was again removed by two storms in January 2005.

From February 2005 to July 2005, the beaches of the northern Gold Coast initially accreted due to generally mild wave conditions, then receded again to the end of July 2005, following the occurrence of a series of moderate storm wave events. During August 2005 to January 2006, the beaches oscillated around the same position, largely in response to the movement of the inner bar. As this feature initially became fully welded to the beachface, the beaches of the northern Gold coast generally increased in width accordingly. But as the mild wave conditions persisted through the second half of 2005, this resulted in the continued landward movement of a portion of the inner bar sand volume, resulting in a narrowing of the low tide terrace, and subsequent narrowing of the total beach width. At the end of 2005, periods of slightly elevated wave energy caused the removal of this newly accreted sand from the beachface back to the low-tide terrace, causing re-widening of the beaches at this time. The partial separation of the inner bar from the beachface in response to a single storm wave event in January 2006 caused the beaches to narrow again. A major east coast low pressure weather system in early March 2006 caused the beaches of the northern Gold Coast to transition to a lower gradient and dissipative beach state, characterised by the removal of sand from the beachface and formation of a distinctive inner bar and outer storm bar system. A marked narrowing of the beach was observed at all locations alongshore. By May 2006 the inner bar had temporarily re-attached to the beachface to form a low tide terrace, but in June this detached again as the sand moved back into the inner surfzone, in response to a general increase in the incident wave energy. By the end of July 2006 the beach was continuing to recover from the significant erosion event of five months previously, as sand slowly moved back onshore.

At the completion of seven and a half years of monitoring and around six and a half years since the completion of the major phase of sand nourishment of northern Gold Coast beaches, at all southern monitoring sites (Figure 7.3) the beaches have experienced a net accretionary trend up to the beginning of 2006. This was interrupted at the beginning of March 2006 by the occurrence of high waves associated with the relatively slow passage of an east coast low pressure weather system. In contrast, to the north (Figure 7.2), following the initial phase of beach widening in response to nourishment, a net erosional trend has prevailed. Since March 2006, both southern and northern beaches have recovered slightly, although the underlying trend of long term erosion across the northern sections of beach has increased, and there is now almost no net erosion or accretion trend over the southern beaches.

11.2 Cyclic-Seasonal versus Longer-term Erosion-Accretion Trends

It was noted in previous monitoring reports that for the period 2001 to mid 2004 a general cyclic pattern of beach variability had become evident. During this post-nourishment period, erosion was a characteristic of the first half of the calendar year, followed by accretion in the second half of the year. This general cyclic trend matches the prevailing wave climate of the south-east Queensland coast, whereby larger storm wave events are more frequent in the later summer and autumn months. This cycle was interrupted during 2004 due to a large storm event that occurred in October 2004, and the further breaking down of this previously dominant seasonal-cyclic trend was noted in to the first half of 2005. Significant erosion during early 2006, followed by minor beach recovery during this monitoring period, appears to show that the cycle has been somewhat restored, although to lesser magnitude than previous.

Application of the statistical auto-correlation method provides objective confirmation that the cyclic behaviour of beach changes at the northern Gold Coast has decreased since mid 2004. The results of this analysis up to and including January 2007 are summarised in Figures 7.6 and 7.7. In the northern (Figure 7.6) and southern (Figure 7.7) sections of the 4,500 m study region, the beach width at these sites previously varied cyclically by up to +/- 20 m, indicating a range of approximately 40 m annual variability in beach width that could be attributed to the seasonal wave climate. In contrast, referring to the upper panel in these figures, the underlying trend at these three sites is of a significantly lower magnitude.

Post-nourishment monitoring period	**Years**	**Cyclic-seasonal variability (m)**	**Net erosion-accretion trend (m per year)**	
			North	**South**
August 2000 – January 2004	3.5	±20	+1.1	+7.4
August 2000 – July 2004	4	±20	-0.6	+5.2
August 2000 – January 2005	4.5	±20	-1.8	+3.1
August 2000 – July 2005	5	±20	-1.1	+3.8
August 2000 – January 2006	5.5	±20	-0.2	+4.2
August 2000 – July 2006	6	±20	-1.3	+1.8
August 2000 – January 2006	6.5	±10	-1.8	+0.2

The table above summarises the six monthly results obtained to date. To the end of January 2007, at the southern section the net accretionary trend has decreased to0.2 m/year, while along the northern section, the underlying trend is of the order of -1.8 m/year, that is, a marginal erosional trend.

The six and a half years of data upon which these longer-term trends are inferred is now sufficiently long to permit the results of this analysis to be used for future forecasting with a reasonable degree of confidence, and to draw two important conclusions. The first is that the underlying regional-scale trend at the northern Gold Coast since the completion of sand nourishment in mid 2000 has been net marginal beach accretion in the south of the order 1 m (+0.2 m/yr), and net marginal erosion in the north of the order of -12 m (-1.8 m/yr). The second conclusion is that the cyclic annual variability of beach width due to the seasonally varying wave climate was an order of magnitude greater than the underlying beach width trends.

With the beaches of the northern Gold Coast presently in a relatively healthy state, it is shorter-term storm erosion rather than the underlying but much longer-term erosion-accretion trends, which at the present time are of primary importance to the ongoing planning and management of northern Gold Coast beaches.

11.3 Shoreline Trends in the Vicinity of the Reef Structure

As per the northern and southern sections, the cyclic variation in beach width observed at Narrowneck (middle panel) for the six and a half year period August 2000 to January 2007 is of the order of ± 20 m annually. Again, the occurrence of the east coast low pressure system and associated beach erosion in early March had the effect of 're-setting' this dominant seasonal-cyclic trend. The underlying trend at this site for the six and a half year period to January 2007 is estimated to be of the order of -3.8 m per year erosion.

The table below summaries the six monthly seasonal-cyclic versus longer-term erosion-accretion trends observed at Narrowneck.

Post-nourishment monitoring period	**Years**	**Cyclic-seasonal variability (m)**	**Net erosion-accretion trend (m per year)** **Narrowneck**
August 2000 – January 2004	3.5	±20	+1.6
August 2000 – July 2004	4	±20	-0.6
August 2000 – January 2005	4.5	±20	-1.4
August 2000 – July 2005	5	±20	-2.8
August 2000 – January 2006	5.5	±20	-2.3
August 2000 – July 2006	6	±20	-3.5
August 2000 – January 2007	6.5	±10	-3.8

It is concluded that at Narrowneck the underlying local beach width trend to date, since the completion of sand nourishment in mid 2000, has been modest net erosion of the order 25 m (-3.8 m/yr). More significant to the future management of this region, is the observation (as per the northern and southern beaches) that the cyclic annual variability of beach width at Narrowneck due to the seasonally varying wave climate, was an order of magnitude greater than the underlying slightly erosional beach width trend.

11.4 Erosion-Accretion Trends in the Vicinity of the Reef Structure

General accretion occurred through the months of August – October 2006, particularly in the lee of the reef and further to the north. During this period, a total sand volume of approximately 10 000 m^3 accreted in the study zone, which equates to approximately 10 m^3 per metre of shoreline. The most dramatic change, however, occurred early in November, when a reasonably large volume of sand accreted in a salient just north of the reef location. During the period between 8/10/06 and 19/11/06 (Figure 9.5 bottom panel), a net accretion of approximately 6000 m^3 of sand occurred within the intertidal zone. From the figure, the distribution of this accretion can be seen to have mostly occurred in the salient, which stretched 30 – 40 m seaward. Throughout the remainder of November and during December, the salient continued to grow slightly in the lee of the reef, while the areas to the south and north of the reef underwent minor erosion. There was negligible net change in sand volume within the intertidal zone with this period.

During January 2007, the salient that had developed throughout the previous months was eroded, as larger wave conditions prevailed. The higher wave energy acted to straighten the shoreline, moving some of the sand volume from the salient to an inner bar, while the remainder of the sand was pushed to the north, filling the area that had eroded in December. Again, the result of this erosion/accretion was negligible net change in sand volumes within the intertidal zone of the 1 km stretch of beach analysed.

The net trend for the entire six-month period August 2006 to January 2007 was modest accretion across the entire 1 km stretch of beach. Referring to Figure 9.7, from 12th August 2006 to 17th January 2007, the 1000 m length of beach at Narrowneck accreted a net volume of approximately 16 000 m^3, between -0.5 and +0.7 m AHD. It can be seen from Figure 9.7, that the majority of this accretion occurred in the lee of the reef, and further to the north, with localised vertical accretion of the order of 0.8 – 1.0 m occurring in this area. Further to the south of the reef, minor vertical accretion up to 0.4 m was recorded. The higher levels of accretion in the lee of the reef are expected to be a result of the decreased

wave energy in this zone, caused by wave breaking and dissipation across the submerged reef structure.

11.5 Wave Breaking at Reef

Wave breaking on the reef at Narrowneck continues to be commonly visible in images obtained by the coastal imaging system (Figure 10.1). In previous monitoring reports completed during the initial construction phase of the reef, the progressive increase in the occurrence of wave breaking was documented and quantified as additional geocontainers were added. Further geocontainers were placed on the reef crest in late 2001 and again in November 2002 (refer Section 2.2). Since that time it has been observed that waves break across the reef structure once the incident significant wave height exceeds around 1 m.

It is concluded that the reef continues to achieve the objective of enhancing potential surfing opportunities at Narrowneck.

12. ACKNOWLEDGEMENTS

This project was commissioned and funded by the Gold Coast City Council as a component of the *Northern Gold Coast Beach Protection Strategy* monitoring program.

Technical support for the original design and installation in 1999 of the ARGUS coastal imaging system was provided by Irv Elshoff and Stefan Aarninkhof of WL|delft Hydraulics (Netherlands) and Graham Symonds of the Australian Defence Force Academy (Canberra).

The owners of the Focus Apartments are thanked for continuing to permit the ARGUS system to reside within the roof of the Focus Building. Also we thank the building manager and caretaker for their support during routine maintenance visits to the site.

The Queensland Department of Environment is acknowledged for the ongoing provision of deepwater wave data from the Gold Coast Waverider buoy.

Doug Anderson of WRL continues to assist with wave and tide data processing, computer operations for remote communications, image storage, off-line image archiving and web serving at WRL. Since June 2002 Doug Anderson has taken over the day-to-day management of the Gold Coast Argus system. From mid 2004 to mid 2005 Ainslie Frazer of WRL was responsible for the weekly analysis and updating of monitoring program information via the project web site, and since mid 2005 this task is now undertaken by Ian Cunningham.

Finally, Professor Rob Holman of Oregon State University and the growing world-wide team of ARGUS users are acknowledged for continuing system development. These research efforts are assisting to provide the continued development of practical tools for coastal monitoring and management.

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Appendix A

Week-to-a-Page: August 2006 - January 2007

Week-to-a-Page (Mid-Tide)



31/07/2006 15:10



01/08/2006 10:10



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04/08/2006 12:10



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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 31/07/2006 - 06/08/2006	Figure A1 06037-A01.cdr

Week-to-a-Page (Mid-Tide)



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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 07/08/2006 - 13/08/2006	Figure A2 06037-A02.cdr

Week-to-a-Page (Mid-Tide)



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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 14/08/2006 - 20/08/2006	Figure A3 06037-A03.cdr

Week-to-a-Page (Mid-Tide)



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22/08/2006 09:10



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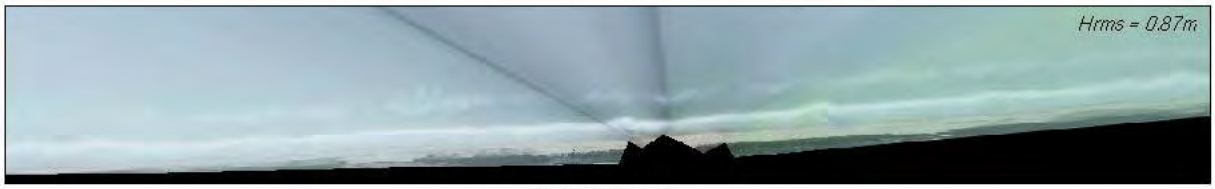
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Week-to-a-Page (Mid-Tide)



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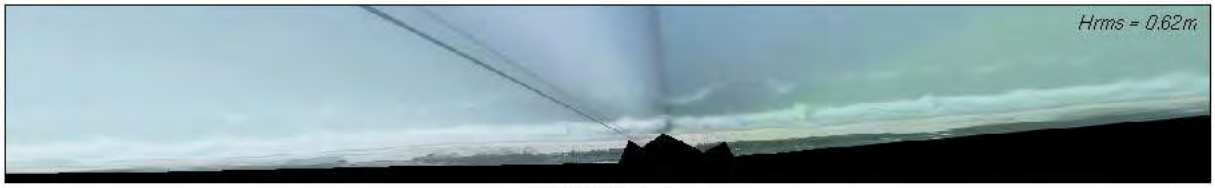
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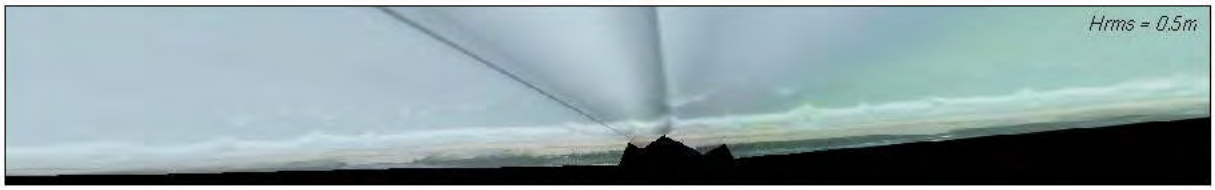
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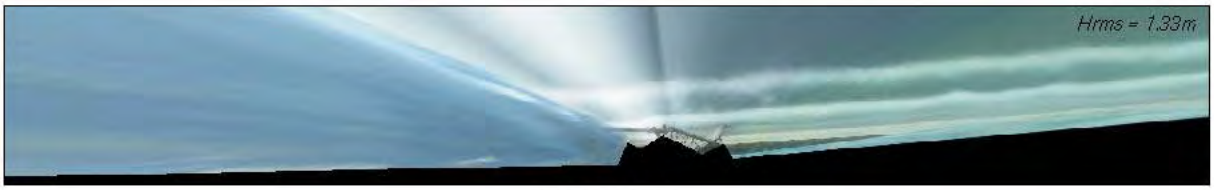
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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 11/09/2006 - 17/09/2006	Figure A7 06037-A07.cdr

Week-to-a-Page (Mid-Tide)



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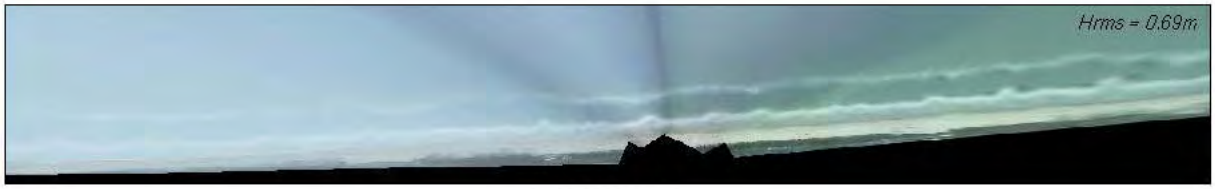
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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 25/09/2006 - 01/10/2006	Figure A9 06037-A09.cdr

Week–to–a–Page (Mid–Tide)



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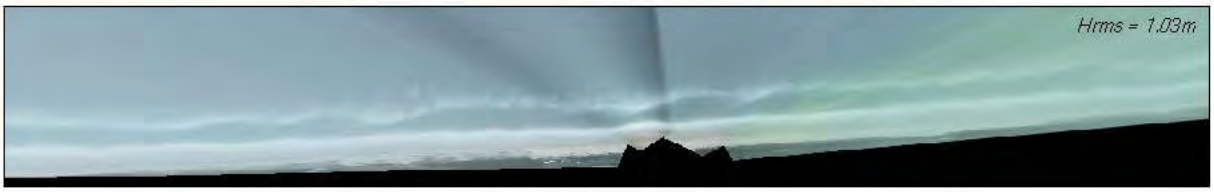
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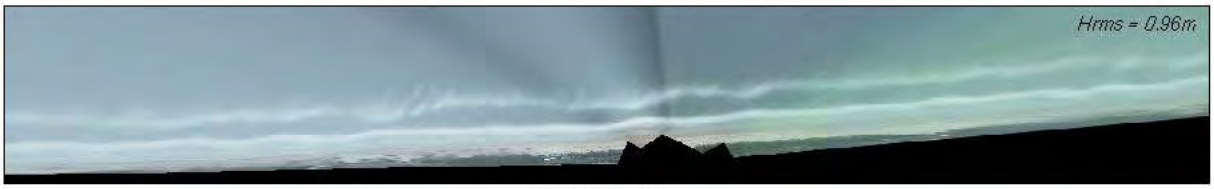
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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 09/10/2006 - 15/10/2006	Figure A11 06037-A11.cdr

Week-to-a-Page (Mid-Tide)



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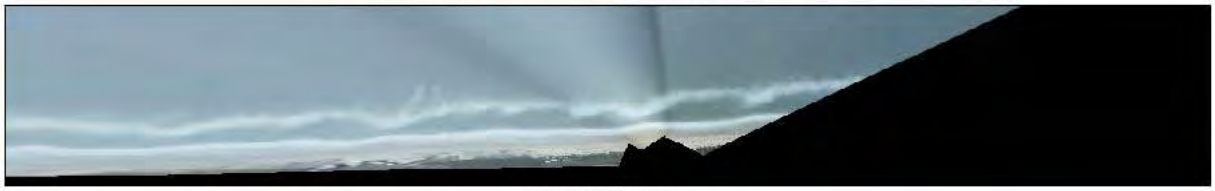
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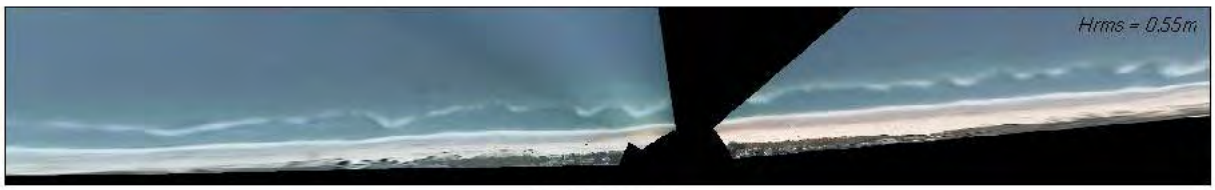
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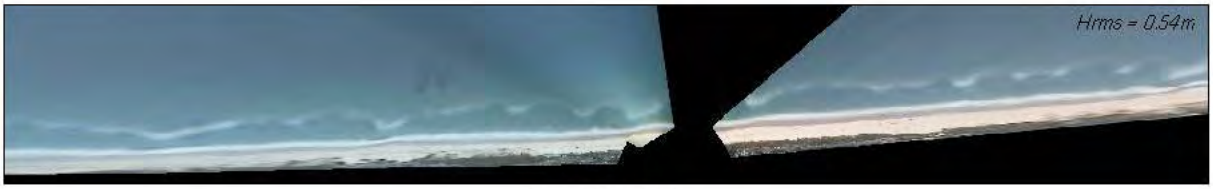
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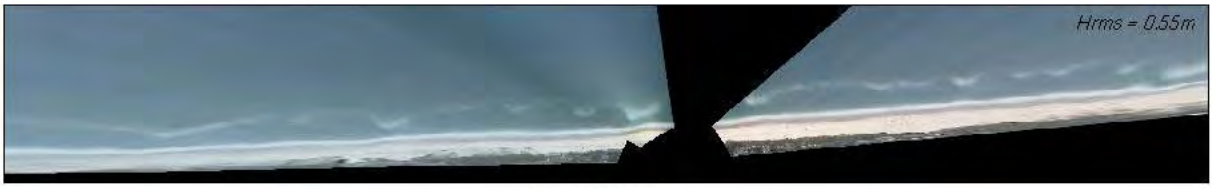
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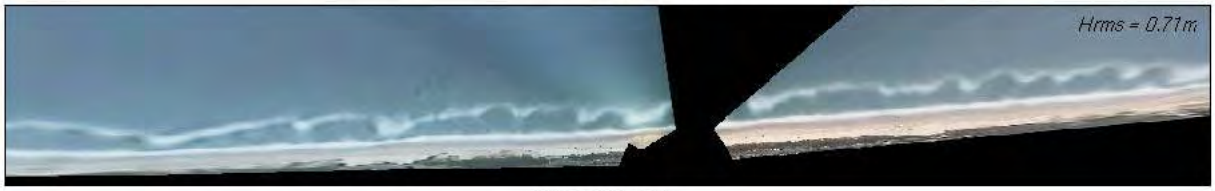
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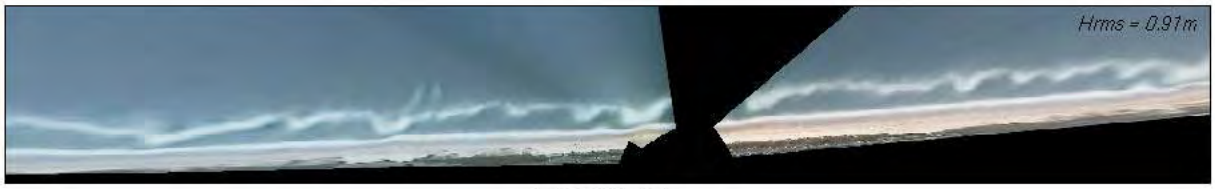
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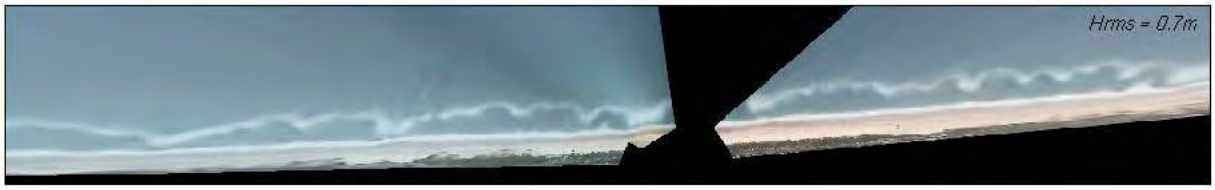
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10/11/2006 15:15



11/11/2006 08:15



12/11/2006 09:15

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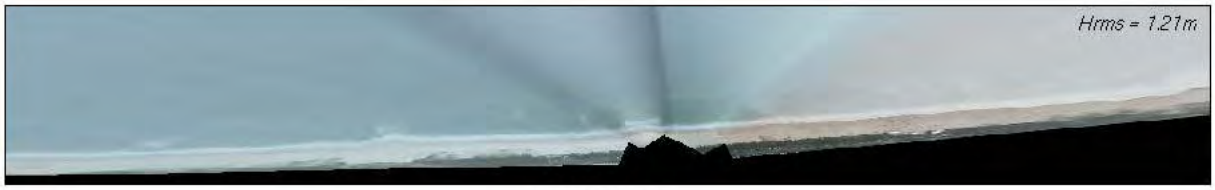
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18/11/2006 09:15



19/11/2006 10:15

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Week–to–a–Page (Mid–Tide)



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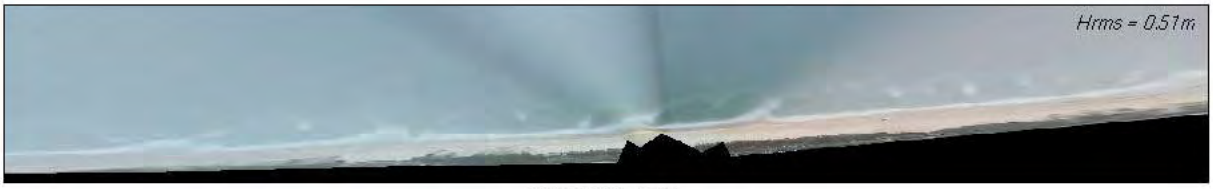
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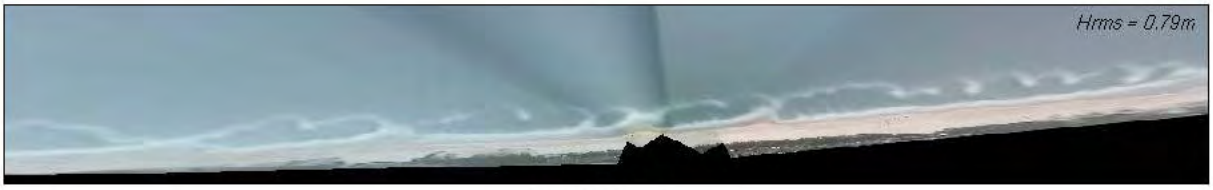
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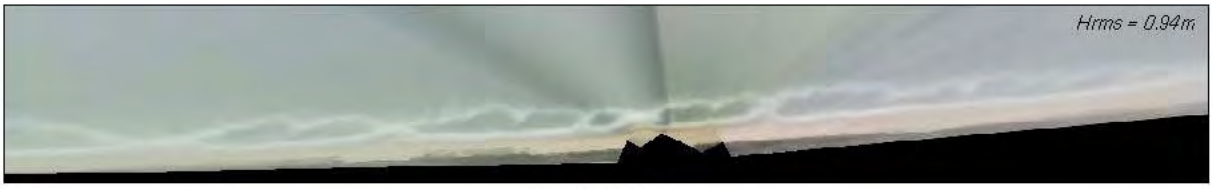
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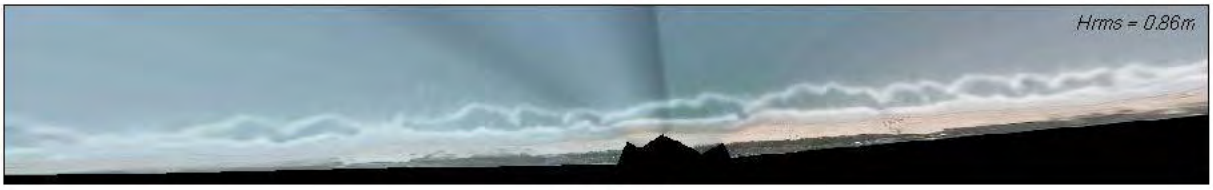
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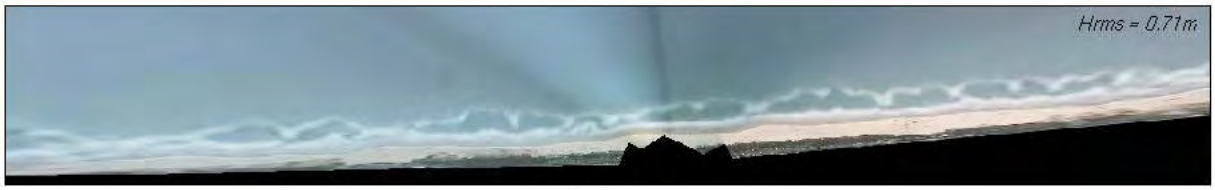
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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 11/12/2006 - 17/12/2006	Figure A20 06037-A20.cdr

Week-to-a-Page (Mid-Tide)



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21/12/2006 12:15



22/12/2006 13:15



23/12/2006 13:15



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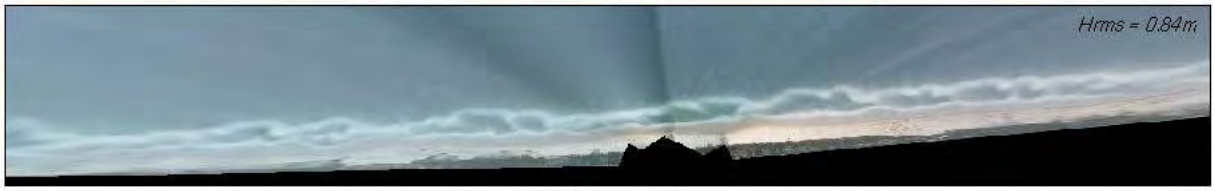
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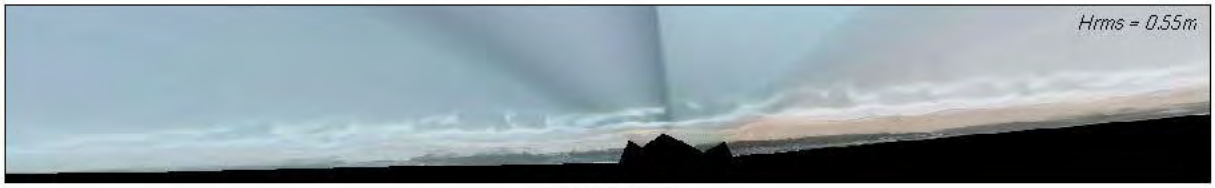
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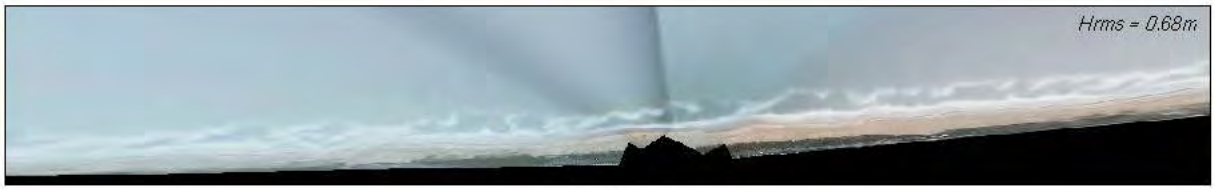
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29/12/2006 12:15



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31/12/2006 09:15

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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 25/12/2006 - 31/12/2006	Figure A22 06037-A22.cdr

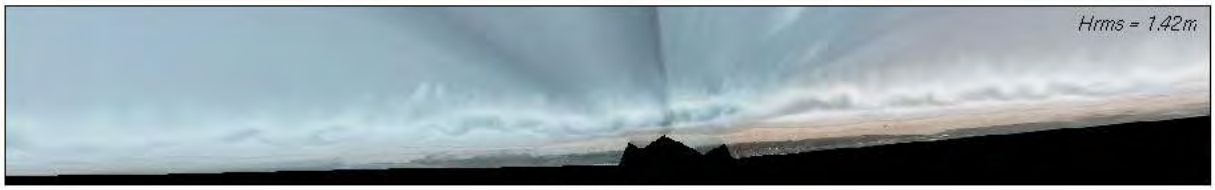
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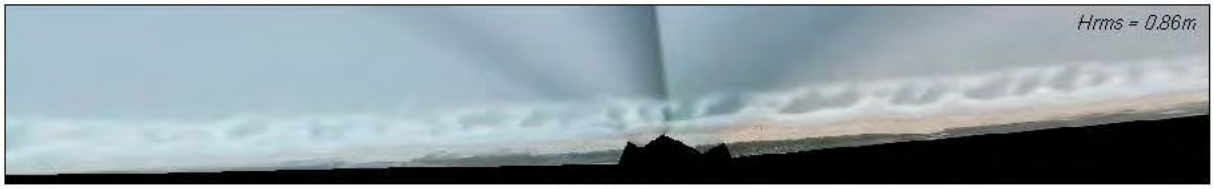
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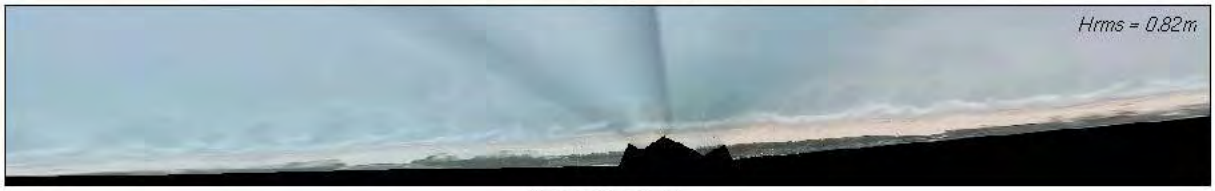
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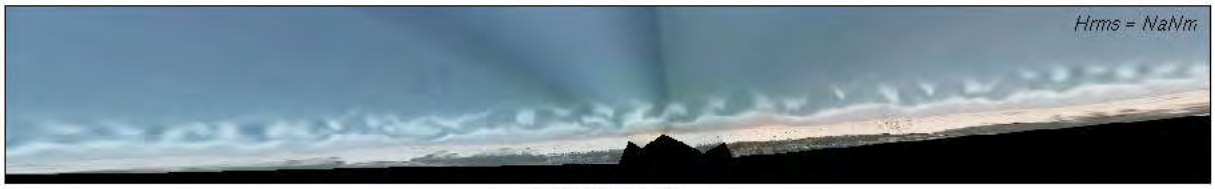
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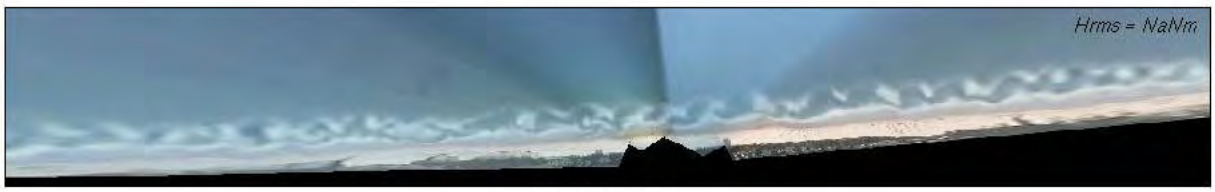
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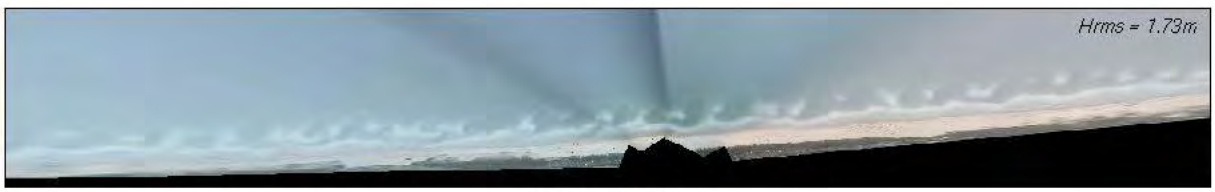
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WRL Report No. 2007/08	DAILY MID-TIDE IMAGES 22/01/2007 - 28/01/2007	Figure A26 06037-A26.cdr

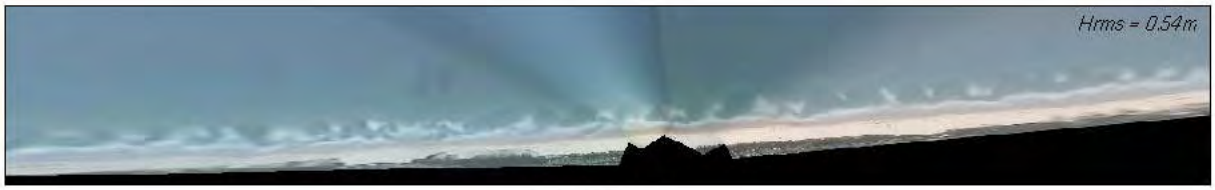
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02/02/2007 12:15



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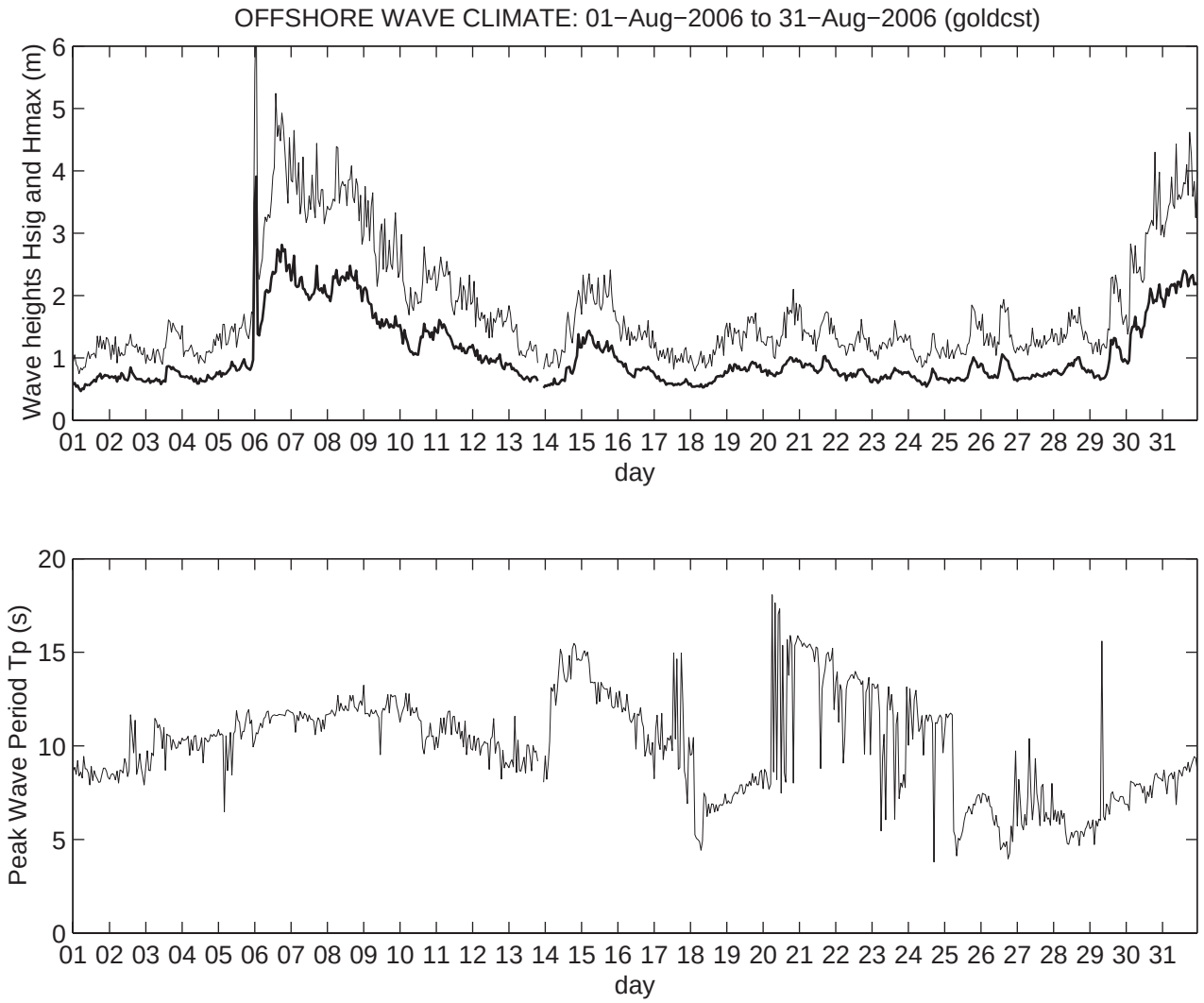
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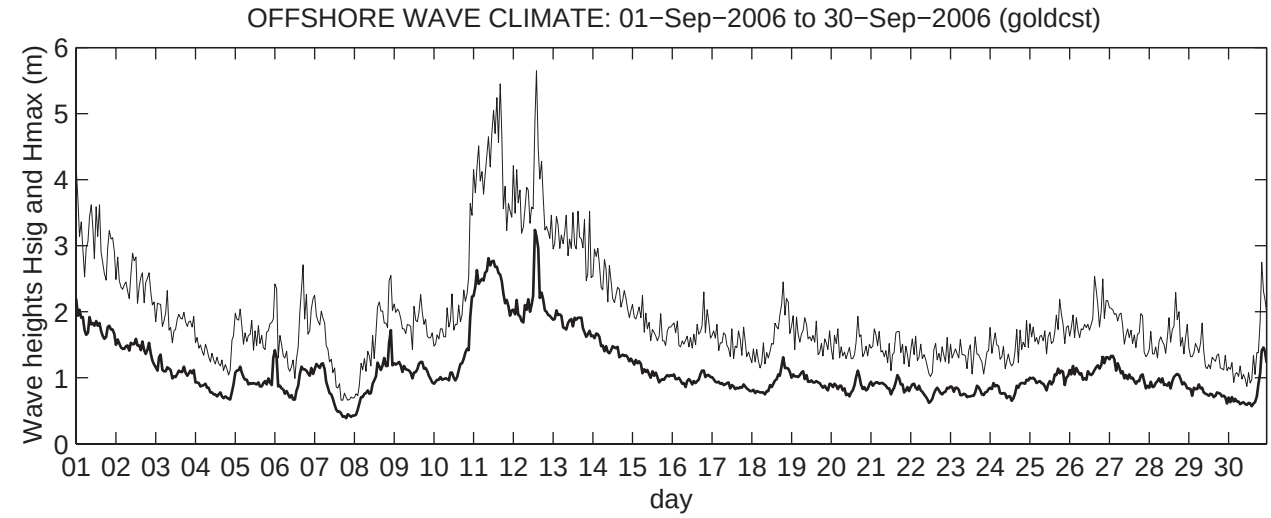
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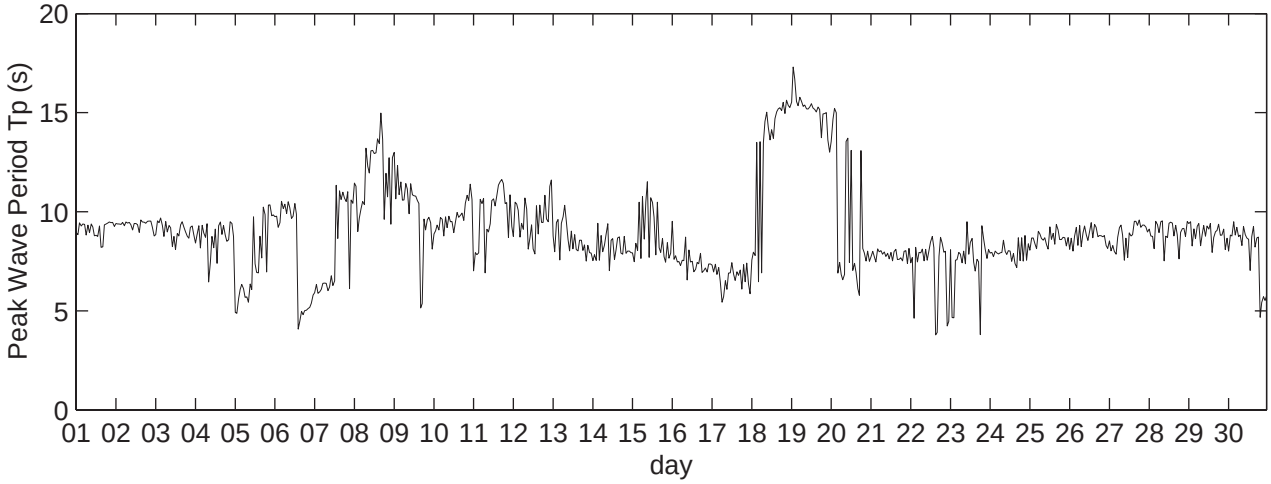
Appendix B

Monthly Wave Climate Summaries: August 2006 - January 2007

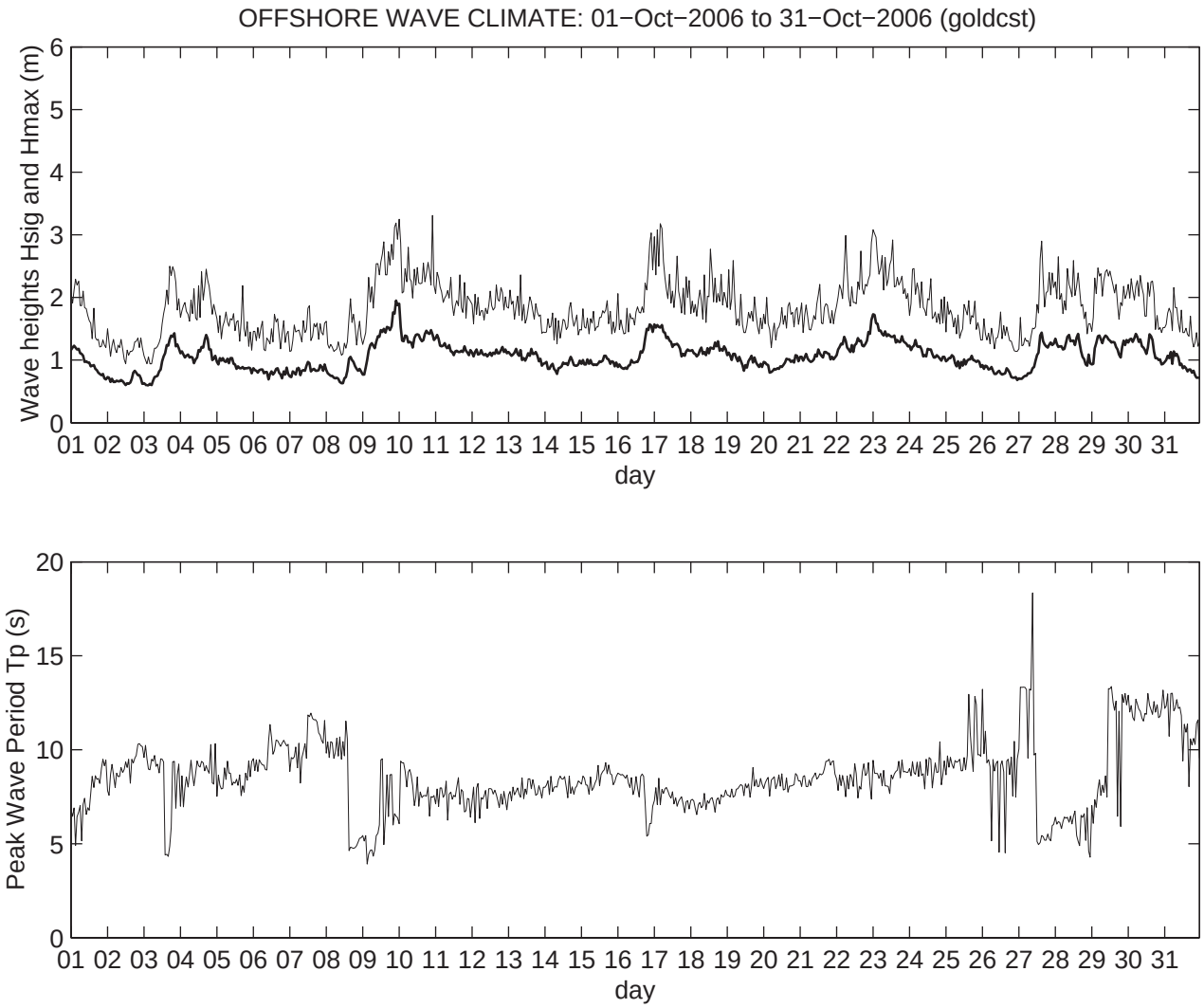


WRL Report No. 2007/08	MONTHLY WAVE SUMMARY AUGUST 2006	Figure B1 06037-B01.cdr

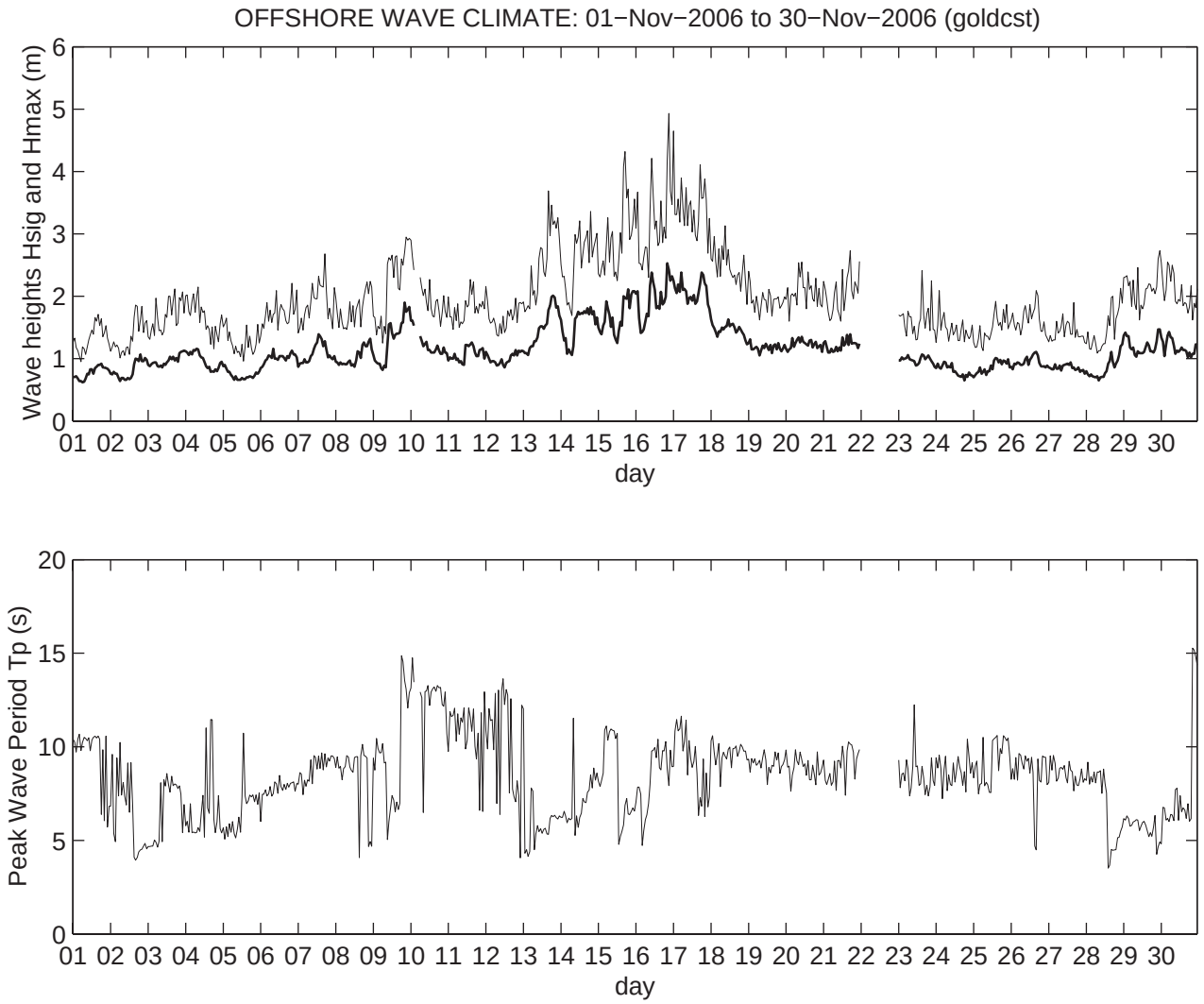




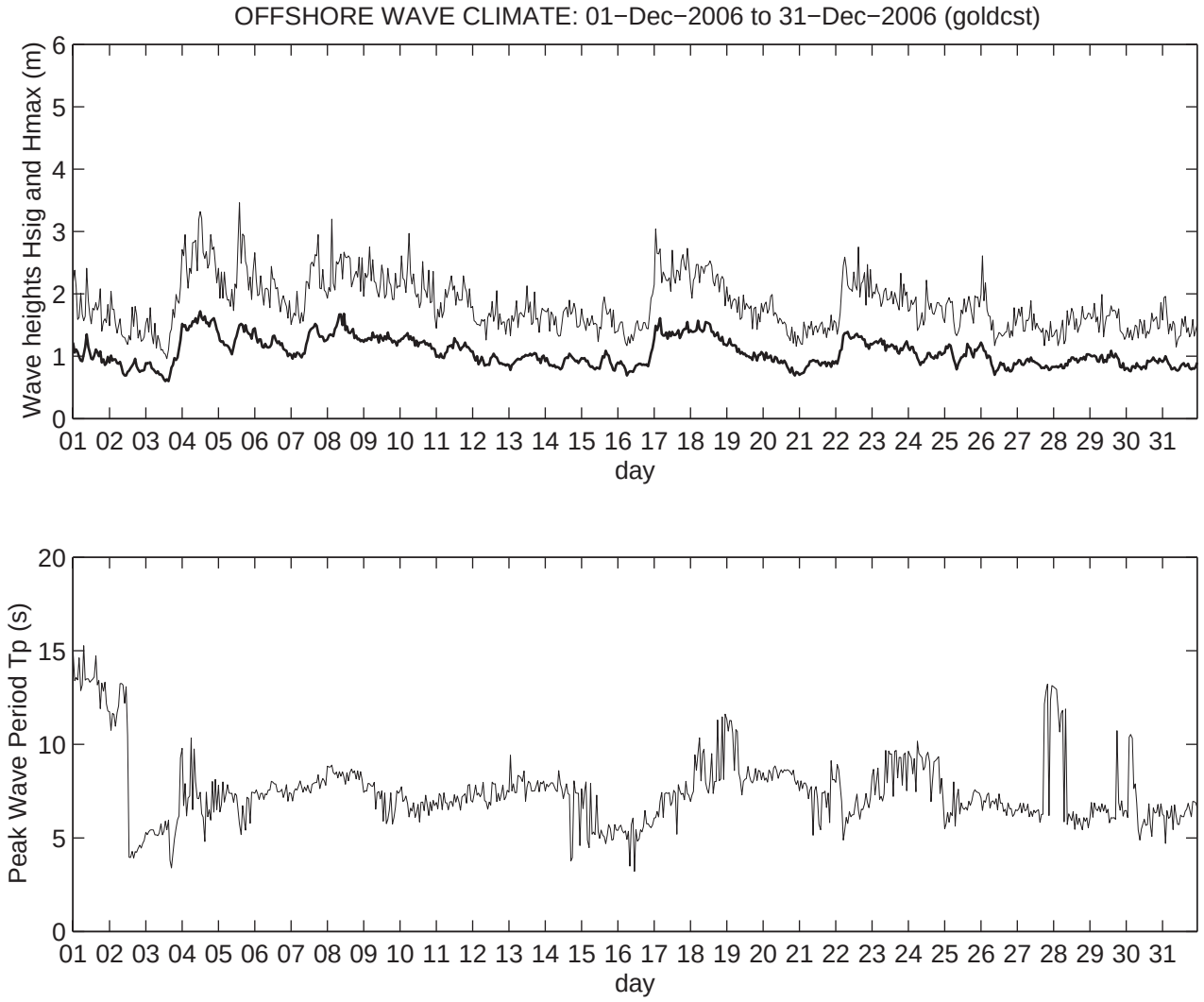
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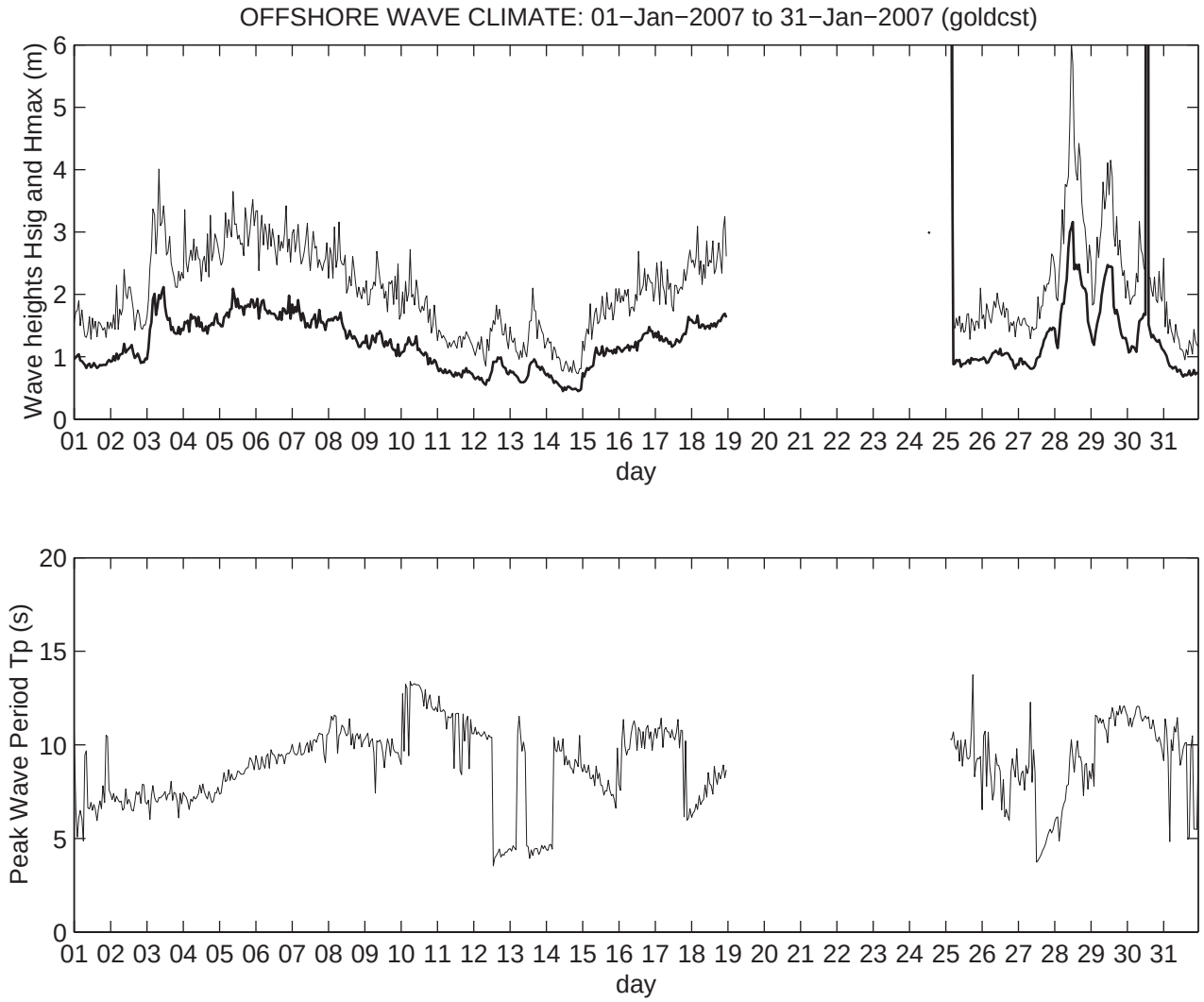
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WRL Report No. 2007/08	MONTHLY WAVE SUMMARY NOVEMBER 2006	Figure B4 06037-B04.cdr



WRL Report No. 2007/08	MONTHLY WAVE SUMMARY DECEMBER 2006	Figure B5 06037-B05.cdr



WRL Report No. 2007/08	MONTHLY WAVE SUMMARY JANUARY 2007	Figure B6 06037-B06.cdr

Appendix C

Marine Geology 236 (2007) 209 - 221

"Observations of rip spacing, persistence and mobility at a long, straight coastline"

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Marine Geology 236 (2007) 209 – 221

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

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Observations of rip spacing, persistence and mobility at a long, straight coastline

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[b] *Department of Physical Geography, Faculty of Geosciences, Institute for Marine and Atmospheric Research, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands*

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Received 14 September 2006; accepted 22 October 2006

Abstract

Three years of daily video observations at a long, straight beach were analysed to determine the temporal trends and variability of the location, spacing, persistence and mobility of rips. Rips were identified at this site on 684 days of the total 947 days (72% occurrence) when suitable images were available. A median number of 7 rips were observed within the total 2 km study area, on days when rips were present. No tendency was identified for rips to reoccur in preferred locations alongshore following storm reset events. The average alongshore distance between all rips observed was 209 m, but with a high standard deviation of 98 m or approximately 47% of the mean rip spacing, there was no evidence at this site that rips tended to be regularly spaced alongshore. No clear relationship was identified between the number of rips and the prevailing offshore wave conditions, including significant wave height, peak wave period and incident wave power. The majority of rips persisted for 5 or fewer days, with an average of 8 days and standard deviation of 9 days. Rips were stationary 33% of days, with migration rates of less than 5 m/day observed on 47% of days when rips were present. Maximum migrations rates of up to 50 m/day were observed, and generally though not always occurred in the direction consistent with the prevailing offshore swell direction and resulting alongshore current. The occurrence of inshore sea breezes may have accounted for the less frequent observations of rip migration against the opposing regional swell direction.

The results presented at this site complement a recent four year study at a contrasting short and embayed beach, detailed in Holman et al. [Holman, R.A., Symonds, G., Thornton, E.B. and Ransinghe, R., 2006. Rip spacing on an embayed beach. Journal of Geophysical Research, 111, C01006. doi:10.1029/2005/JC002965 (17p)]. The specific mechanism(s) of rip channel infilling at the long, straight and littoral-drift dominated coastline may have contributed to the observation of shorter rip persistence relative to the embayed site. Mean rip spacing was observed at both sites to be highly variable, irregular, and exhibited no identifiable trend associated with the offshore wave conditions. This latter observation supports the notion that rips may become rapidly topographically controlled soon after a storm reset event, and their location is then primarily determined by the evolving nearshore morphology, rather than hydrodynamic forcing.

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doi:10.1016/j.margeo.2006.10.029

This new dataset of daily, multi-year observations at an open coast site cannot 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. Rather, these observations tend to support emerging theories of rip genesis that predict the irregular and random spacing of rip channels alongshore.
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Keywords: rip currents; surfzone morphology; coastal imaging

1. Introduction

Rips are strong, narrow currents that flow seaward through the surfzone and are commonly observed on ocean beaches. They play an important role in nearshore circulation, sediment transport, bar and shoreline morphology, and recreation safety. Rip currents have long been of particular interest to coastal geologists and geomorphologists because of their association with spatially and temporally variable rip channels, oriented in the general cross-shore direction, and separated in the alongshore by shallower nearshore bars (e.g. Shepard et al., 1941; Short, 1985; Brander, 1999a). It is common that this morphological succession of channels and bars along the shoreline is visually relatively easy to identify, and to the casual observer, the rip channels often appear to be regularly spaced along the beach. Indeed, a prevalent feature of many theoretical studies of rip current genesis defines an alongshore length scale, corresponding to the locations of alternating channels and bars, associated with regularly-spaced patterns of net onshore and offshore (rip current) flows.

The emergence over the last decade of coastal imaging monitoring techniques is providing coastal researchers new opportunities to examine the temporal variability of surfzone and nearshore morphology and hydrodynamics (Holman and Stanley, in press). Ranasinghe et al. (1999) and Holman et al. (2006) used daily time exposure images (of two and four years duration, respectively) to document rip channel characteristics at Palm Beach, in southeastern Australia. Palm Beach is a short (2 km long) and embayed sandy beach, situated between prominent sandstone rocky headlands and with minimal or no exchange of sediment alongshore. In contrast to many of the existing models for rip genesis, both these multi-year studies at the swash-dominated Palm Beach site found that rips were observed to be predominantly irregularly spaced alongshore. The mean rip spacing was observed to be an order of magnitude greater than that predicted by most theoretical models, while no preferred locations for rip occurrence were found. The necessary conclusion from this work at the embayed Palm Beach site is that the rip generation models predicting regularly spaced rips appear to be of limited general applicability to natural beaches.

The principal objective of the present study is to characterise the statistics of daily rip observations at a contrasting long, straight, littoral-drift beach, based upon a three year dataset of daily time exposure images. A comparison of temporal rip characteristics at an embayed versus open coastline has not been previously reported, and the significance of this fundamental difference in geological setting is not known. The embayed beach is a closed coastal compartment with minimal littoral-drift while the open coast beach exhibits a strong net littoral-drift, and any potential end effects caused by adjacent headlands at the embayed site are absent at the long, straight, open coast beach.

It is intended that the data presented here will inform present and future modelling studies, to investigate and understand the physical mechanism(s) that underlie rip current genesis and rip channel evolution on natural beaches. The specific aims of this study are: (a) to characterise and quantify the temporal trends and variability of daily rip observations over a three year period at a long, straight beach; and (b) to compare these findings with the multi-year rip study recently reported at the embayed Palm Beach site. Modelling implications are noted.

2. Background

The morphodynamic beach stage model of Wright and Short (1984) identifies the occurrence of rip currents and channel morphology as characteristic of intermediate beach states. Conceptually, rip currents and associated rip channel morphology are often observed to emerge then disappear again as a beach progresses from a higher energy dissipative to a lower energy reflective state. Following a storm reset event the nearshore morphology is typically characterised by one or more shore-parallel bars separated from the shoreline by an alongshore-continuous trough, with no rip circulation present. With declining wave energy the beach is described by these authors to progress through a series of intermediate beach states whereby the alongshore bar is observed to become more crescentic

then non-continuous alongshore, as offshore-directed rip currents incise the surfzone. Further decline in incident wave energy results in the disappearance of these rip current features, as a low tide terrace and finally a non-barred reflective beach face emerges.

Short-term (i.e. hours to a few days) process studies of rips and their associated morphology have significantly advanced our knowledge of short term rip current morphodynamics. For example, Brander (1999a,b) and Brander and Short (2001) describe field studies completed at the embayed Palm Beach site discussed herein. MacMahan et al. (2006) provide a comprehensive list of short-term field studies that range from the fortuitous location of nearshore instrumentation, to more comprehensive efforts to specifically instrument a rip current system.

Longitudinal studies of fundamental rip characteristics such as their spacing, persistence and mobility have been limited by the availability of suitable temporal datasets. Short (1985) presented the results of 19 months of daily visual observations of surfzone morphology obtained from ground level at Narrabeen Beach, Australia, providing the first longer-term and semi-quantitative observations of rip spacing and persistence. Short and Brander (1999) present a valuable and extensive data collation of rip density (defined as the number of rips per kilometre of beach) obtained primarily from aerial photographs at a number of sites around the world. By applying a classification scheme comprising five regional wave climate environments (represented by continental-scale coastline orientation and a single wave height and period), it was shown that rip density exhibited a consistent dependency on each of these differing wave environments. These authors also concluded that their results show rip density was inversely related to wave height, wave period, surfzone width, wave energy and wave power. Appropriately, the difficulties in representing each of these parameters by a single and regional-scale measure are acknowledged, as was the uncertainty in applying these to rip observations that were generally obtained at a single moment in time. Importantly, implicit within the analysis presented by these authors was that rips exhibit "relatively regular spacing" in the longshore direction, though their results do not necessarily support this conclusion. Re-analysing the data presented in their Table 3, the ratio of the standard deviation of rip spacing to mean rip spacing ranged from 0.1 to 1.0 (median value of 0.4) for each of the 38 sites where both statistics are reported. Because the analysis presented by Short and Brander (1999) was (by necessity) primarily based upon aerial photographs, the temporal variability of rip spacing at individual sites could not be examined.

Existing theoretical models for the generation of regularly-spaced rips can be generally classified as either 'hydrodynamic template' or 'instability' models (Holman, 1995). Template models are those where the rip length-scales (and of particular interest here is the alongshore rip spacing) are derived from the hydrodynamic forcing terms alone. Bowen (1969) and Dalrymple (1975) presented what are probably the best known of the hydrodynamic template models, both of which predict regularly-spaced rips alongshore. However, the stochastic forcing observed on natural beaches is difficult to reconcile with the monochromatic and/or mono-directional forcing wave field imposed by these (and similar) template models. For this reason, it is now generally accepted that this approach may be of more limited applicability.

As described by Holman et al. (2006), more contemporary instability models suggest that rips result from instabilities in nearshore circulation and/or bathymetry (e.g. Hino, 1974; Dalrymple and Lozano, 1978; Deigaard et al., 1999; Falques et al., 2000; Damgaard et al., 2002). By this approach, the spacing of individual rip cells along the beach is associated with the unstable mode that grows most rapidly. Since the pioneering observations reported by Shepard et al. (1941), it has been widely suggested that rip spacing is anticipated to be related to the incident wave height.

Although rip spacing is one of the most widely used diagnostic features to assess the validity of rip generation models, few long-term datasets present temporal observations of rip spacing along natural beaches. As was noted above, Short (1985) reported nineteen months of daily visual observations of rip locations at Narrabeen Beach, Australia, with these same data being subsequently re-examined by Huntley and Short (1992). As reported by Holman et al. (2006), both of these studies found surprisingly poor correlations between rip spacing and a range of incident wave and nearshore morphology features, including wave height, wave period and surfzone width. This observation is contrary to the predictions of the prevailing rip generation models described above.

There remains considerable uncertainty as to the time-varying distribution and movement of rips along natural beaches. Contradictory evidence suggests rips may be regularly or irregularly spaced alongshore, and suitable datasets that describe and quantify the temporal trends and variability of rips are lacking. It is anticipated that the observational data and analyses presented herein can assist with the formulation of future efforts that aim to better simulate and predict rip currents and their associated surf zone morphodynamics.

3. Study area

Surfers Paradise, located at the northern Gold Coast in southeast Queensland (Australia) was selected as the site for this study (Fig. 1). The specific study area comprises a 2 km long, straight stretch of beach toward the northern end of the continuous 20 km of coastline, that extends essentially uninterrupted from Burleigh Heads in the south to the trained Nerang River entrance 5 km further north. The coastline is aligned north–south and fronts the Pacific Ocean, and due to the straight and parallel bathymetric contours offshore, is unaffected by any alongshore variation in local wave refraction and diffraction. The mean offshore significant wave height is around 1–1.5 m, increasing to 2.0–3.5 m during regular storm wave events, and maximum wave heights can exceed 10 m several times per year during larger storms. The predominant offshore wave direction is south-easterly, with less frequent east to north-easterly swells associated with the passage of mid-tropical cyclones. As a result, the net annual littoral-drift along this stretch of coastline is of the order of 500,000 m^3/yr to the north (comprising ~650,000 m^3/yr north, and ~150,000 m^3/yr south). Gold Coast beaches exhibit dynamic and complex morphology, where a double barred system often exists (e.g. van Enckevort et al., 2004) with rips appearing most often through the inner bar. The spring tide range is around 1.5 m, and the beach is composed of predominantly quartz sand of mean grain size ~0.3 mm.

4. Methods

4.1. Argus video images

An Argus coastal imaging station has been operating at the study site since August 1999, at an elevation of approximately 100 m atop a beachfront apartment building. This system is being used to support a range of research and management objectives (e.g. Aarninkhof

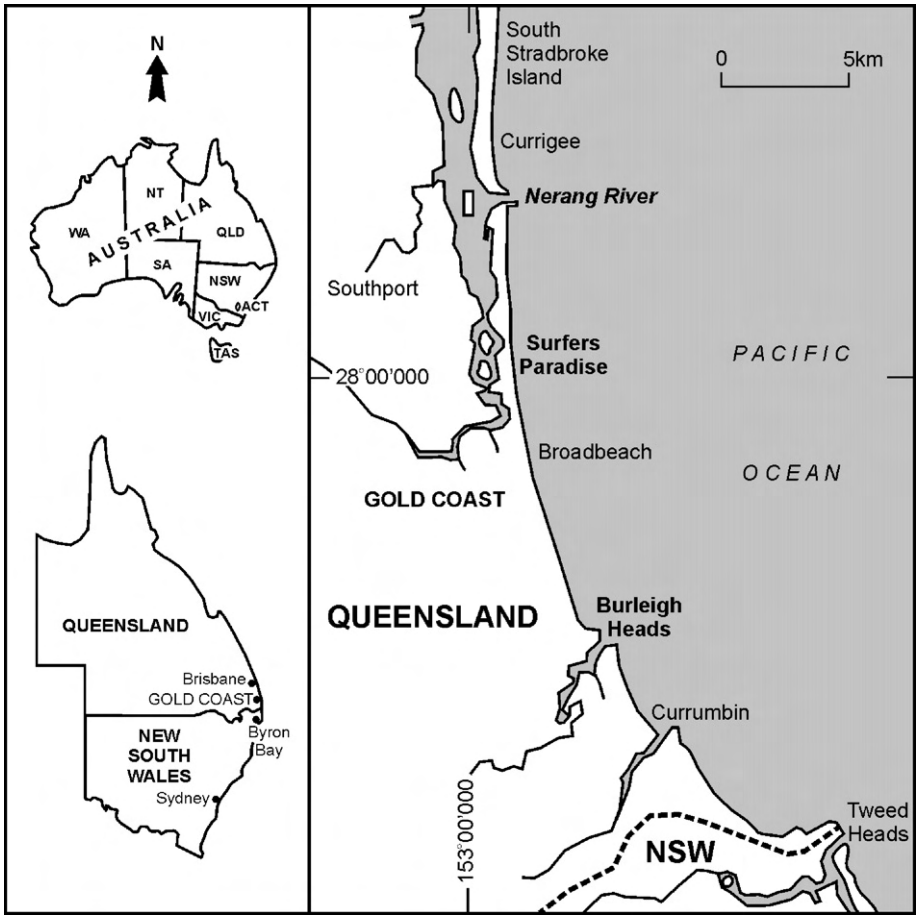


Fig. 1. Northern Gold Coast study site.

et al., 2003; Turner et al., 2004, 2006). The station consists of four cameras pointed obliquely along the beach, providing 180° uninterrupted coverage of the northern Gold Coast region. Images of the 2 km study area used here were obtained from cameras 1 and 2, which both face the southern sector of the beach. The location of the cameras and a number of clearly visible ground control points (GCPs) were surveyed at the time of station installation. The image to real-world photogrammetric transformation was computed using the standard technique presented in Holland et al. (1997). The accuracy of this transformation process is typically one image pixel. In the mid study area, one pixel equates to a ground accuracy of approximately 0.5 m and 5 m in the cross-shore and alongshore directions, respectively. At the far extreme (south) of the 2 km study area the alongshore accuracy decreases to around 16 m.

Every daylight hour, the cameras acquire a time-exposure image, created by the averaging of 600 individual images acquired at 1 Hz (i.e. one image per second during a ten minute period). On each day, all hourly time exposure (timex) images were combined to create a composite daily time exposure (daytimex) image, thereby eliminating tidal variations. The daytimex images from both cameras were then merged into one image and rectified to real world coordinates. The result is a dataset comprising daily rectified plan view images of the 2 km study area. This dataset is used to identify both the spatial and temporal characteristics of a range of morphological features, such as rip channels and submerged sand bars, based on the variations in pixel intensity within each image (e.g. Lippman and Holman, 1989). Fundamentally, wave breaking in the nearshore region is evident by high-intensity bands (Fig. 2), which reveal the submerged shoals and channels associated with sandbars and rips.

Using the above techniques, daily rectified daytimex images of the study area were created for the present study over a three year period spanning from the 1st January 2000 to 31st December 2002. Of the total 1096 days, 947 suitable images were utlised. Short duration gaps in the data set resulted from fog, sun glint off the ocean surface, temporary down-time of the Argus station and occasional periods of very low wave heights (resulting in the absence of any breaking wave signatures in the nearshore).

4.2. Wave data

Hourly significant wave height (H_s) and peak wave period (T_p) were obtained from the Gold Coast waverider buoy, located approximately 2 km offshore of the study area, in 16 m water depth. As the Gold Coast waverider buoy is non-directional, directional (Dir) wave data from the Byron Bay waverider buoy located 10 km offshore in 71 m water depth,

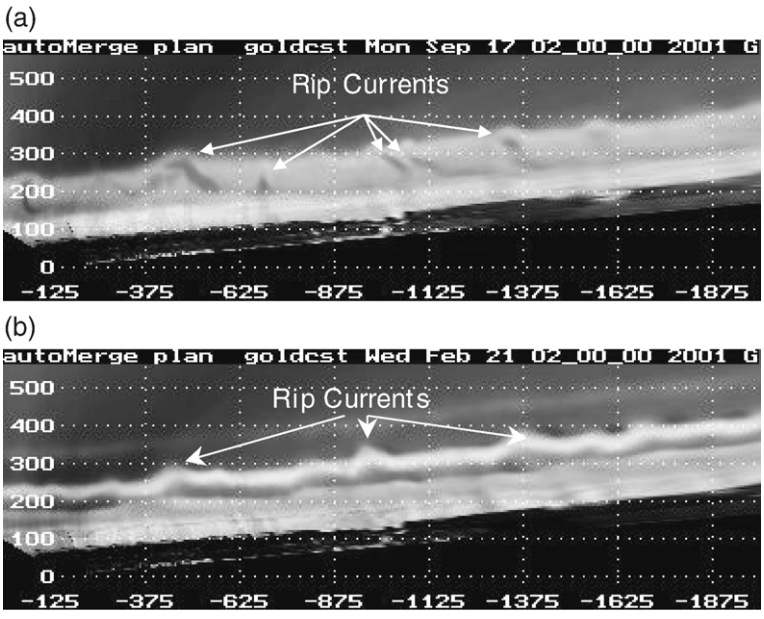


Fig. 2. Rectified daytimex image of the 2 km study area with rips identified by two image 'signatures': (upper panel) alternating transverse channel/bar morphology, and (lower panel) crescentic features in the longshore sand bar.

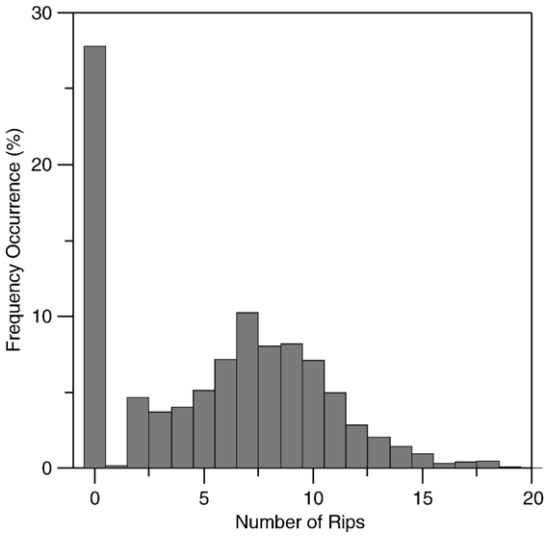


Fig. 3. Frequency histogram of number of rips per day within 2 km study area, for the three year study period.

approximately 100 km south of the study area (see Fig. 1), was used to infer the regional offshore wave direction.

4.3. Rip channel locations

Previous research (e.g. Lippman and Holman, 1989; van Enckevort and Ruessink, 2001) has shown that the locations of bright bands of wave breaking in time-exposure images correspond to the locations of submerged sand bars in the nearshore. Similarly, gaps in breaking wave patterns within the surfzone correspond to topographic rip channels that incise a surrounding sand bar (e.g. Ranasinghe et al., 1999).

Crescentic features at the seaward extent of the breaker zone are also an indicator of the development of rip currents (Ranasinghe et al., 2004). Examples of rips identified in the study area using these two criteria are illustrated in Fig. 2. It should be noted that although a double-barred system was typically present within the study area, rips predominantly appear across the inner bar. For consistency, the analysis presented here is limited to rips that were observed across the inner bar.

The prior work of Ranasinghe et al. (1999) identified rip channels by locating local minima in alongshore profiles of pixel intensity transects, taken approximately at mid surfzone. This fully-automated approach to rip identification was observed to perform well for simple cases. However, the methodology was also found to be sensitive to the (subjective) choice of various automation parameters and often gave results in disagreement with visual assessment (Holman et al., 2006). For this reason, and after much testing of alternative methods, Holman et al. (2006) opted for a manual rip selection method. For consistency, in the present study a manual selection procedure was similarly used to identify rip channel locations within daytimex images. Successive daily images were analysed within a guided interface that incorporated several image processing tools to assist the user to locate and map rip current features. In this manner the mobility and temporal persistence of individual rip features could be tracked and measured.

4.4. Temporal persistence of rips

In this study rip locations are considered to be coherent features with trajectories of alongshore location versus time (as opposed to independent daily events), enabling their statistics to be analysed. This approach was adopted to maintain consistency and enable the direct comparison with the results reported by Holman et al. (2006). The transform of individual daily rip locations to alongshore trajectories was achieved by a nearest neighbour analysis between rip locations for successive days. Automated rip location matching was then completed to obtain individual rip trajectories, spanning over breaks of up to but not exceeding 4 days, to account for occasional short-term gaps in the daily dataset.

4.5. Rip channel mobility

Using the rip trajectory data described above, rip migration was quantified by calculating the daily change

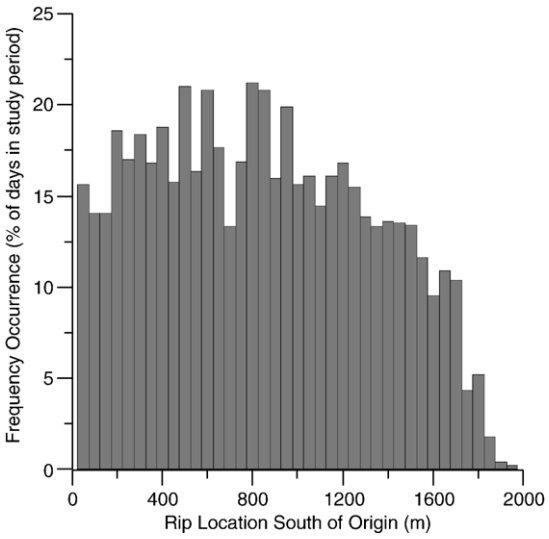


Fig. 4. Frequency histogram of rip location (50 m alongshore bins) within 2 km study area, for the three year study period.

in the longshore location of individual rips. Daily average rip migration was estimated by calculating the average of the change in location for every rip present on a given day.

5. Results

5.1. Rip channel locations

The frequency occurrence of the total number of rips observed each day within the 2 km study area over the entire three year period of this study is shown in Fig. 3. Rips were observed a total of 684 days of the 947 days when suitable images were available (72% occurrence). A median occurrence of 7 rips along the 2 km study area was observed, when rips were present.

Previous studies have discussed the existence or absence of preferred locations along the beach where rips are observed to recur (e.g. Eliot, 1973; Short, 1985). The frequency occurrence of rip locations at the Gold Coast study site, assigned to 50 m longshore bins, is shown in Fig. 4. This dataset exhibits no tendency for preferred rip locations. A general decline in the number of rips toward the south suggested by these data is most likely due to the increase in pixel footprint at larger distances from the camera (refer Section 4.1) and is currently the focus of further investigation.

The frequency of occurrence data presented above is based upon the analysis of the entire three year dataset. To examine whether any preference in rip locations occurred immediately following storm resets of the nearshore morphology, all reset events at the Gold Coast

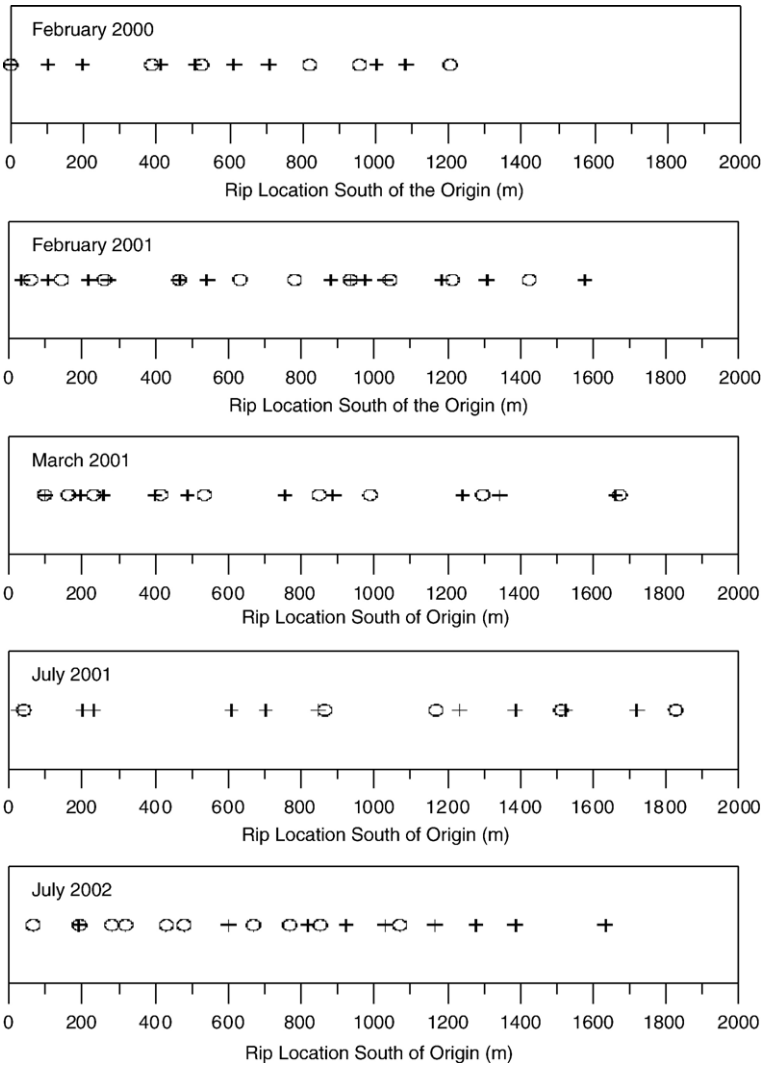


Fig. 5. Rip locations before and after 5 example 'system reset' events. (+ denotes pre-storm locations, o denotes post-storm locations).

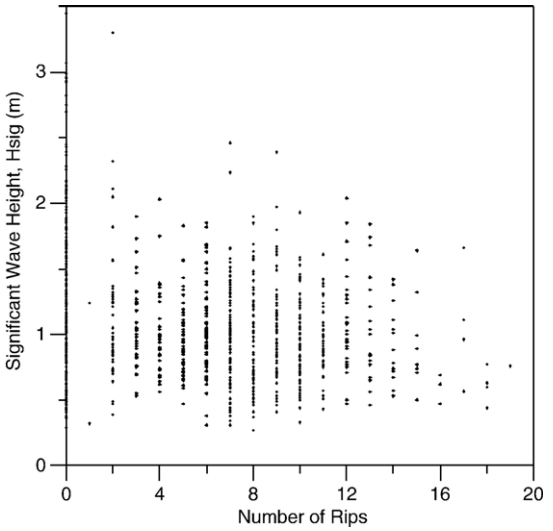


Fig. 6. Number of observed rips within the 2 km study area vs. significant wave height.

during the three year study period were first identified from the wave data, and confirmed by visual examination of the daily timex images. To illustrate, the locations of rips before and after five selected system reset events are shown in Fig. 5. This subset of the data again shows the lack of any preference for rips to reform in particular locations alongshore.

It is commonly held that the number of rips is related to the incident or antecedent wave height (e.g. Short, 1985; Short and Brander, 1999). Referring to Fig. 6, the three year dataset obtained at the Gold Coast site appears to contradict this notion. In this figure the total number of rips per day observed within the 2 km study area shows no correlation to the daily significant wave height. Similar analysis undertaken of the number of rips observed versus wave period (T_p) and wave power also indicated no correlation to incident wave parameters.

5.2. Rip channel spacing

Fig. 7 summarises the frequency occurrence of mean rip spacing (MRS) along the 2 km study area during the three year study period, calculated on days when two or more rips were present. The average MRS during the study period was 209 m, with a large standard deviation of 98 m, representing around 47% of the 'average' alongshore length-scale. It should be noted that large MRSs were associated with very high standard deviations, and corresponded to time periods when only two to four rips were observed within the 2 km study area.

Previous studies have commonly asserted that rip spacing mirrors changes in offshore wave height, increasing and decreasing with likewise variation in the incident wave climate (e.g. Mckenzie, 1958; Short, 1985). In contrast, the results of the present study summarised in Fig. 8 (same data as Fig. 6) indicate no observable relationship between MRS and offshore wave height. This is consistent with topographic control of rips by the underlying shoals and channels once the rips are formed, retarding their ability to respond to variable wave forcing.

5.3. Temporal persistence of rips

The temporal persistence of rips observed over the total three year period at the Gold Coast site is shown in Fig. 9. As was observed by Holman et al. (2006), rip persistence can be quite variable, and indeed a limited number of rip trajectories lasted for periods of up to one month. Referring to Fig. 9, the majority of observed rips persisted for 5 or less days, but with the strongly skewed distribution resulting in an average of 8 days and a standard deviation of 9 days.

5.4. Rip channel mobility

The frequency occurrence of observed rip migration (metres per day) in the alongshore direction is shown in Fig. 10. In this figure positive values indicate northward migration, i.e. towards the left in Fig. 2. Rips were observed to be stationary 33% of the time during the total three year study period. Migration rates of less than

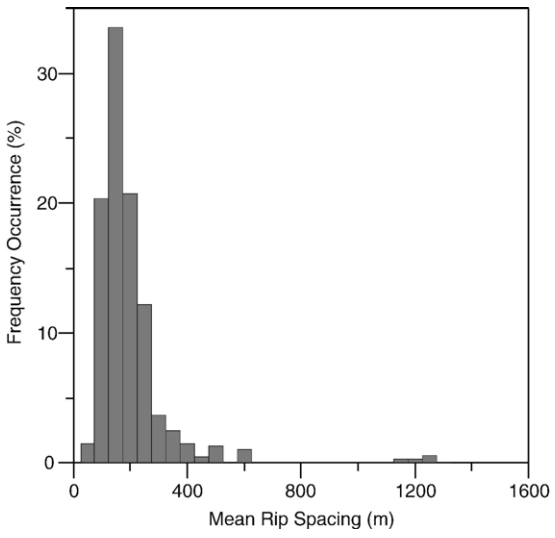


Fig. 7. Frequency histogram of mean rip spacing (MRS).

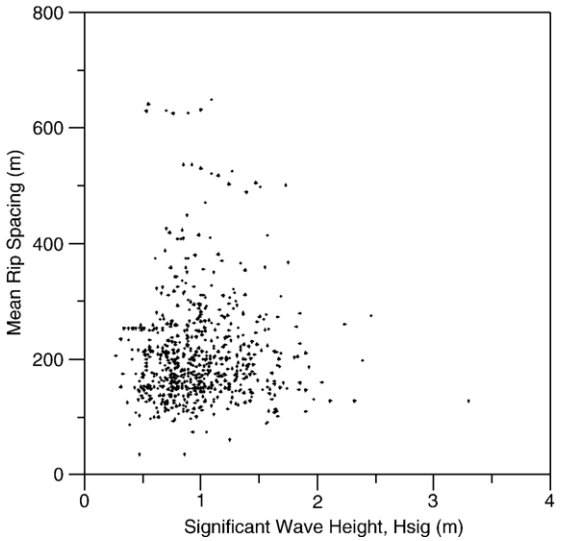


Fig. 8. Mean rip spacing (MRS) vs. significant wave height.

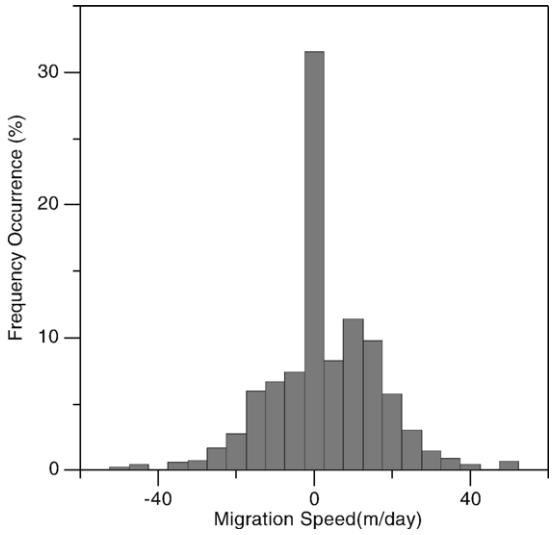


Fig. 10. Frequency histogram of all migration events observed over the three year study period.

5 m/day were observed 47% of days when rips were observed. Rips were observed to migrate alongshore for the remaining 53% of the time at rates of up to 50 m per day. Over the entire three year period when rips were present, northward migration occurred 41% of days, with southward migration occurring on 26% of days.

In the absence of locally-measured wave direction information for the Gold Coast site, a time-series of the alongshore component of wave power is not available. Instead, the concurrent deepwater wave angle measured at Byron Bay some 100 km to the south is used here as a first-order proxy for the relative strength of the northerly or southerly longshore current. The correlation between rip migration speeds for all rip migrations observed and the concurrent deepwater wave angle was poor, with a marginally positive regression value of $R^2=0.17$. Further analysis was undertaken of observed rip migration speeds (to partially account for the dependence of longshore current speed on wave power) by subdividing the wave direction data by wave height (H_s greater or less than 1.5 m) and also by peak wave period (T_p greater or less than 10 s). Again, no clear relationship between rip migration speed and wave

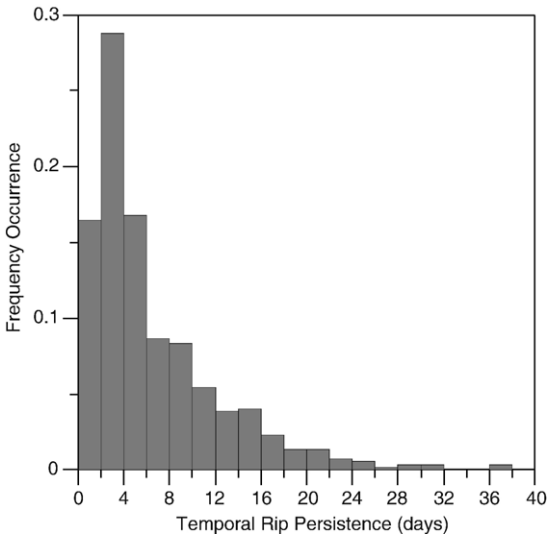


Fig. 9. Frequency histogram of temporal rip persistence.

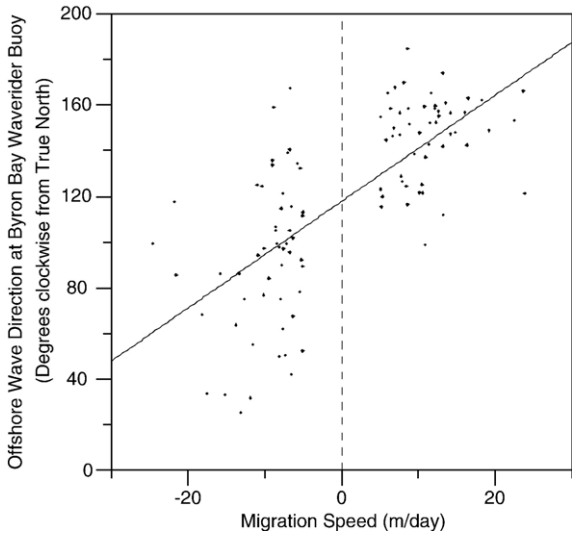


Fig. 11. Average daily rip migration vs. offshore wave direction for the special cases of $H_s<1.5$ m, $T_p<10$ s and observed migration speeds greater than 5 m/day.

Table 1
Seasonal correlation between rip migration speeds and incident wave direction

Season	R^2		
	H_s<1.5 m	T_p<10 s	H_s<1.5 m T_p<10 s
Summer	0.30	0.43	0.42
Autumn	0.06	0.11	0.17
Winter	0.25	0.28	0.35
Spring	0.09	0.14	0.06

direction was obtained. The 'best' correlation between wave direction and rip migration speeds occurred for wave heights of less than 1.5 m, concurrent with wave periods less than 10 s ($R^2=0.23$).

This analysis was refined still further by excluding all cases where observed rip migration was less than 5 m/day. For these special cases, the correlation between rip migration speeds and incident wave angles improved somewhat, with $R^2=0.50$. The results of this analysis are shown in Fig. 11. Unsurprisingly, the general trend was for northward migration when offshore wave directions were generally from the south, and vice-versa. Perhaps more surprising is the number of negative (southward) migration events which occurred against an opposing southerly wave direction (refer Fig. 11). At the Gold Coast a so-called 'sea breeze' is common at the coast, due to the differential warming during the day of the land relative to the ocean. The occurrence of inshore sea breezes from the north-east resulting in locally-generated seas may account in part for the observed southward migration of rips into the opposing regional (measured 10 km offshore) southerly wave direction.

To assess the potential influence of seasonality on rip migration, correlations by season were undertaken for the sub-set of wave heights and periods determined previously to be associated with the greatest degree of correlation to all rip migration events (Table 1). The strongest seasonal correlations are observed during summer and winter, with little or no correlation evident during spring and autumn. From the rip migration results presented earlier, this suggests that rip channel development may be less pronounced at the Gold Coast site in the summer and winter months.

6. Discussion

The northern Gold Coast study site is representative of a long, straight beach that is uninterrupted by headlands for many kilometres to the north and south, while the Palm Beach study site recently reported by Holman et al. (2006) located around 1000 km to the south, is an example of a short and embayed beach, bound at both ends by prominent rocky headlands. Conveniently, the two study sites exhibit very similar sediment size and composition, and over 25 yr of continuous wave recording at multiple sites along the south-east Australian coast shows that the wave climates of southern Queensland (Gold Coast) and central New South Wales (Palm Beach) are equivalent (Lord and Kulmar, 2000). A comparison of rip characteristics observed at these two sites provides useful insight to the potential similarities and differences between rip characteristics at embayed versus non-embayed beaches. In total, over seven years of daily rip observations are available to complete this comparison.

Referring to the new results presented above and those obtained by comparable methods at the embayed Palm Beach (refer Holman et al., 2006), the similarities between the two data sets include the lack of any preferred rip locations alongshore in general, and more significantly, immediately after system resets by storms. Also, the results from the two sites both lack any clear correlation between the number of rips and offshore wave conditions, including significant wave height, peak wave period and incident wave power. Related to this, mean rip spacing was observed at both sites to be highly variable, irregular, and exhibiting no trend associated with the offshore wave conditions. This latter observation is consistent with the concept that rips at both embayed and non-embayed beaches may become rapidly topographically controlled after a system reset event (i.e. a storm), and their location is then primarily determined by the evolving nearshore morphology, rather than the prevailing hydrodynamic conditions. In this regard, simple template and instability models that predict regular rip spacing as some function of incident (and monochromatic) wave conditions appear to be irreconcilable with the multi-year observations reported here. The new model of Reniers et al. (2004) appears more promising, with low frequency surfzone vortices (forced by directionally-spread wave groups) perturbing the initial uniform nearshore bathymetry. Through positive feedback between hydrodynamics and morphology, this was found to result in the prediction of rip channels that are spaced irregularly and randomly alongshore.

The observed differences between the long-straight Gold Coast and short-embayed Palm Beach sites include mean rip spacing, temporal persistence of rips and rip mobility. Comparison of results between these two sites only suggest that rips at long-straight beaches may be fewer in number per km length of beach. The mean rip spacing of 209 m at the Gold Coast site was significantly different (*t*-test, 99% confidence level) and of the order

of 20% larger than the 178 m mean rip spacing observed at Palm Beach. But of likely greater importance, when considering the concept of a 'mean' rip spacing at both the embayed and non-embayed beaches, it is observed that the standard deviations associated with rip spacing at both sites were of the order of ~100 m. With this representing around half the 'mean' rip spacing at both sites, it is the natural conclusion that rips were irregularly spaced at both the embayed and non-embayed sites.

Holman et al. (2006) concluded that many of the existing models for rip generation do not appear to be valid at short, embayed beaches. The new results reported here from the non-embayed Gold Coast study site extend this conclusion to also include long, straight, littoral-drift dominated beaches. The mean rip spacing of 209 m observed at the Gold Coast is an order of magnitude longer than that predicted by the 'hydrodynamic template' models of Bowen (1969) and Bowen and Inman (1969), that are based on synchronous edge waves. Dalrymple's (1975) model can produce longer rip spacing, but requires a phase-locked bi-directional wave field, which is now widely regarded as an elegant rather than realistic representation of waves on natural beaches.

Mean duration of rip channels at the Gold Coast study site during the three year observation period was just 8 days (standard deviation of 9 days), contrasting to a much longer mean duration of 46 days reported for Palm Beach over the four year observation period at that site (Holman et al., 2006). This difference may be due to several phenomena. First, during the Gold Coast observation period 2000 to 2002 an average of six wave events per year exceeded 2.5 m significant wave height. This compared to four per year similar wave events during the non-concurrent 1996 to 1999 study period at Palm Beach. This difference may suggest a greater degree of 'reworking' of the nearshore morphology at the Gold Coast site during the particular three year period of study. However, the observed five-fold difference in the duration of individual rips is hard to account for by this degree of difference in the relative storminess through the two study periods. Secondly, and likely of greater significance, in contrast to the single-barred system at Palm Beach, the more complex interactions between the inner and outer bars at the frequently double-barred Gold Coast site may result in the more rapid 'filling-up' of rip channels. From earlier work at the Gold Coast site that examined the evolution of crescentic bar patterns (van Enckevort et al., 2004), it was observed that these features are relatively short-lived and, as per the single bar conceptual model of Wright and Short (1984), rip channel morphology at the double-bar Gold Coast was confirmed to represent an intermediate accretionary stage in surfzone morphology. Due to wave breaking on the outer bar, the inner bar at the Gold Coast will receive less wave energy than the Palm Beach site for the same offshore wave height. Consequently, it may be argued that the inner Gold Coast bar experiences more reflective conditions, and once undergoing a reset, will tend to transition to the reflective conditions more rapidly. Though the precise mechanism(s) are presently unclear, the results presented here may suggest that rips can be expected to be relatively short-lived at long, straight, double-barred beaches, compared to rips at short, embayed, single-bar beaches. Indeed, it was observed in this three year study that the great majority of rip channels at the double-bar Gold Coast ended by the process of infilling to form low-tide terraces, rather than the occurrence of a new storm reset event.

In addition to these differences in rip duration, the new rip mobility statistics from the long-straight Gold Coast site also differ to those for the embayed Palm Beach over the two year observation period detailed in Ranasinghe et al. (2000). When rip migration was observed, the rips at Palm Beach migrated alongshore with speeds ranging from 2 m/day up to 20 m/day. In contrast, rip migration speeds of 5 m/day to 50 m/day were markedly greater at the Gold Coast. Also, the dominant northerly direction of rip migration at the drift-aligned Gold Coast (net longshore transport of 500,000 m^3/yr) contrasts to the equally distributed migration along the swash-aligned Palm Beach embayment (zero net longshore transport). Though the correlation was found to be not so strong for the present Gold Coast study, this observation further supports previous conclusions (e.g. Ruessink et al., 2000; Holman et al., 2006) that rip migration may be closely related to the direction and magnitude of the prevailing longshore currents.

7. Conclusions

Rips at the long, straight northern Gold Coast study site were observed 72% of days with a median number of 7 rips within the total 2 km study area, on days when rips were present. No tendency was identified for rips to reoccur in preferred locations alongshore. The mean spacing of rips was 209 m, but with a high standard deviation of 98 m, and no evidence that rips tend to be regularly spaced alongshore. No clear relationship was identified between the number of rips and offshore wave conditions, including significant wave height, peak wave period and incident

wave power. The majority of rips persisted for no more than 5 days, with an average of 8 days and standard deviation of 9 days. Rips were stationary 33% of days, with migration rates of less than 5 m/day observed 47% of days when rips were present. Maximum migration rates of up to 50 m/day were observed.

Results presented are consistent with those recently obtained at a site of contrasting geological setting (Holman et al., 2006). The similarities between the two datasets include the lack of any preferred rip locations alongshore in general, and more significantly, immediately after system resets by storms. Also, the results from both the non-embayed (Gold Coast) and embayed (Palm Beach) sites lack any clear correlation between the number of rips and offshore wave conditions, including significant wave height, peak wave period and incident wave power. Related to this, mean rip spacing was observed at both sites to be highly variable, irregular, and exhibiting no trend associated with the offshore wave conditions.

The observed differences between the long-straight Gold Coast and short-embayed Palm Beach sites include mean rip spacing, temporal persistence of rips and rip mobility. Comparison of results at these two sites only suggests that rips at long-straight beaches may be fewer in number (per km length of beach). The mean rip spacing observed at the Gold Coast site was significantly different (*t*-test, 99% confidence level) and of the order of 20% larger than the embayed Palm Beach. At both sites, it is of particular note that the standard deviations associated with rip spacing statistics were of the order of ~100 m. With this representing around half of the 'mean' spacing at both sites, it is concluded that rips were irregularly spaced at both the embayed and non-embayed sites.

Mean duration of rip channels at the Gold Coast study site during the three year observation period was just 8 days (standard deviation of 9 days), contrasting to a much longer mean duration of 46 days reported for Palm Beach over the four year observation period at that site. This may have been the result of a slightly different degree of 'storminess' over the two non-concurrent observation periods. But likely to be of greater significance, in contrast to the single-barred system at Palm Beach, the more complex interactions between the inner and outer bars at the frequently double-barred Gold Coast site may result in the more rapid 'filling-up' of rip channels.

Daily, multi-year observations are consistent with rips at both non-embayed beaches (present study) and embayed beaches (Holman et al., 2006) becoming rapidly topographically controlled following a storm reset event, and their location is then primarily determined by the evolving nearshore morphology, rather than prevailing hydrodynamic conditions. In this regard, simple template and instability models that predict regular rips spacing as some function of incident (and monochromatic) wave conditions appear to be of limited applicability to natural beaches. Recent modelling approaches that predict the irregular and random spacing of rips are more consistent with the observations presented herein.

Acknowledgements

This study was originally completed by DW as a Masters research project under the supervision of ILT, with significant input and guidance from RR. Doug Anderson of the Water Research Laboratory, UNSW is thanked for providing DW assistance with the adaptation of RR's guided rip-picking software and maintenance of the network of Argus stations operated by UNSW. The funding support of Gold Coast City Council to operate the Surfers Paradise Argus station is gratefully acknowledged. BGR was funded by the Netherlands Organization for Scientific Research (NWO) under contract 864.04.007. The comments of two anonymous reviewers to an earlier version of this manuscript are gratefully acknowledged.

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