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Author:
Turner, I.L.

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THE UNIVERSITY OF NEW SOUTH WALES

water research laboratory

Manly Vale N.S.W. Australia

ANALYSIS OF SHORELINE VARIABILITY, SEASONALITY AND EROSION /ACCRETION TRENDS: AUGUST 2005 - JANUARY 2006

REPORT 13
NORTHERN GOLD COAST COASTAL IMAGING SYSTEM

by

I L Turner

Technical Report 2006/01
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Water Research Laboratory
School of Civil and Environmental Engineering
University of New South Wales ABN 57 195 873 179
King Street
Manly Vale NSW 2093 Australia

Telephone: +61 (2) 9949 4488
Facsimile: +61 (2) 9949 4188

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Author(s)	Ian L Turner
Client Name	Gold Coast City Council
Client Address	135 Bundall Road, Surfers Paradise, Queensland 4217
Client Contact	John McGrath – Engineer, Beaches and Waterways
Client Reference	

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1. INTRODUCTION

This report was prepared by Water Research Laboratory (WRL) for Gold Coast City Council. It is the 13th 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 by WRL, with the assistance of WL | Delft Hydraulics (The Netherlands) and the Australian Defence Force Academy. 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 place 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).

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

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

The purpose of this thirteenth report is to present an analysis of shoreline variability, seasonality and erosion-accretion trends for the monitoring period August 2005 to January 2006, and to assess the net changes that have occurred to northern Gold Coast beaches since the commencement of the monitoring program six and a half years ago in August 1999.

1.2 Maintenance & 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.

1.3 What’s New!

This monitoring report is the second 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 is now being used on a routine basis to better monitor and quantify beach changes within the Narrowneck region at the northern Gold Coast.

The 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, through a series of recent journal and conference publications:

- Turner, I.L., Aarninkhof, S.G.J and Holman, R.A. 2006. Coastal imaging research and applications in Australia. Invited submission to Short A.D. and Thom B.G. (eds), Australian Coastal Geomorphology 2004. (Special Issue, Journal of Coastal Research), 22(1), 37-48. (REFER APPENDIX C).

- Turner, I.L., 2005. Engineering assessment of shoreline realignment in the lee of nearshore breakwaters and reefs. Proceedings, 17th Australasian Coastal and Ocean Engineering Conference, 453-458, Institution of Engineers Australia, Adelaide ISBN0-646-45130-8.

- Whyte, D., Turner, I.L., and Ranasinghe, R., 2005. Rip characteristics at the Gold Coast, Australia: an analysis using coastal imaging techniques. Proceedings, 17th Australasian Coastal and Ocean Engineering Conference, 233-238, Institution of Engineers Australia, Adelaide ISBN0-646-45130-8.

- Curtis, W.R., Holman, R.A., and Turner, I.L., 2005. Northern Gold Coast beach topography from imaged shadow observations. Proceedings, 17th Australasian Coastal and Ocean Engineering Conference, 489-492, Institution of Engineers Australia, Adelaide ISBN0-646-45130-8.

- Coco, G., Bryan, K.R., Ruessink, B.G., Turner, I.L., van Enckevort, I.M.J., 2005. Video observations of shoreline and sandbar coupled dynamics. Proceedings, 17th Australasian Coastal and Ocean Engineering Conference, 471-476, Institution of Engineers Australia, Adelaide ISBN0-646-45130-8.

- Ranasinghe, R. and Turner, I.L., 2005. Processes governing shoreline response to submerged breakwaters: multi-function structures – a special case. Coastal Engineering 2004, Proceedings of the 29th International Conference,Vol.2, 1984 - 1996, World Scientific Publishing Co, New Jersey.

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 2005 – January 2006.

The quantitative analysis of shoreline variability for the six month period August 2005 to January 2006 is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total six and a half year monitoring period, August 1999 – January 2006, 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 around 1 – 1.5 m, 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 13^{th} 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.

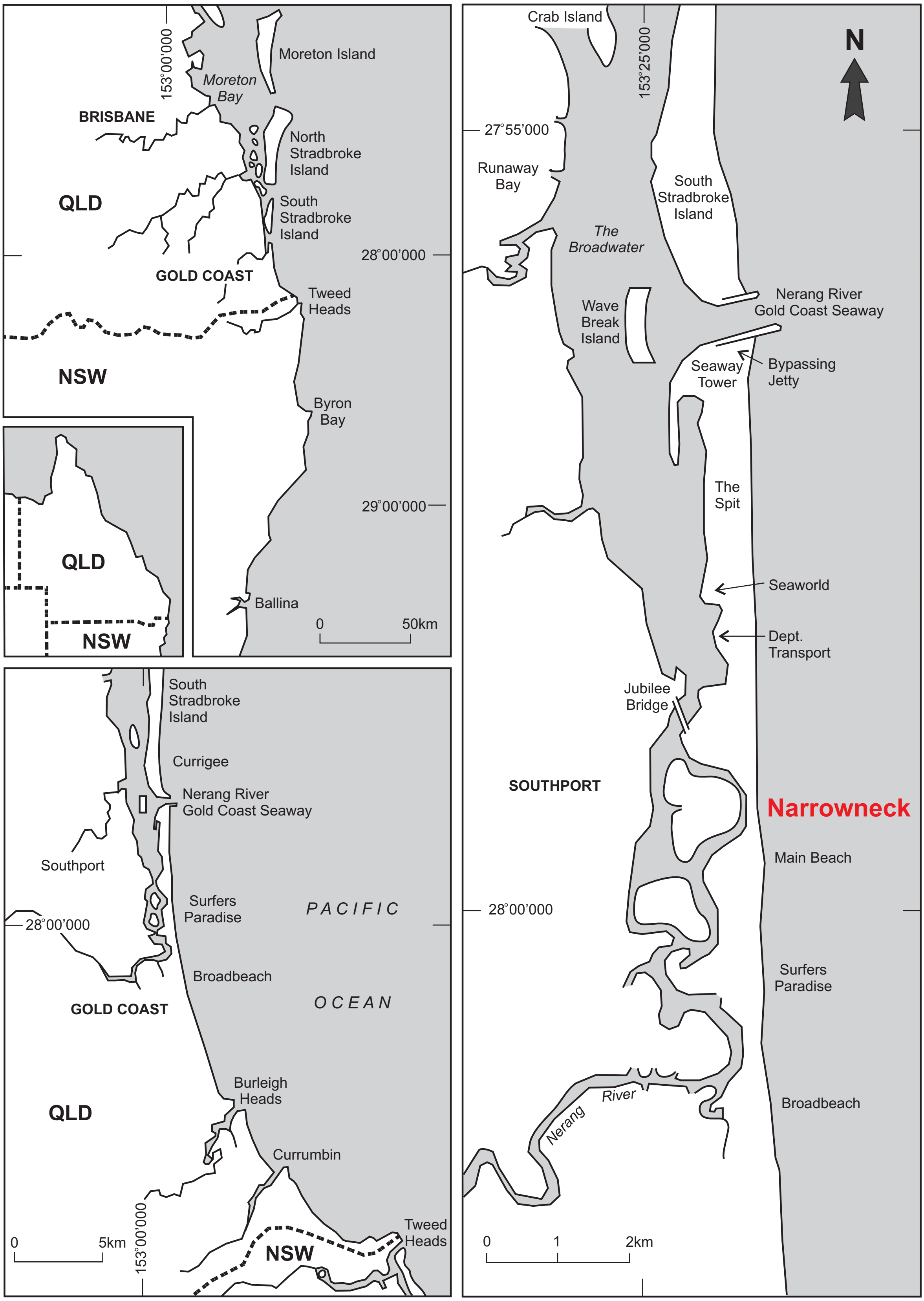
The novel shape of the reef was designed following field investigations and extensive numerical model simulations to determine the optimum reef layout (Black, 1998; Black et al., 1998). The final reef design was further tested by a physical model study (Turner et al., 1998a). Reef construction commenced 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

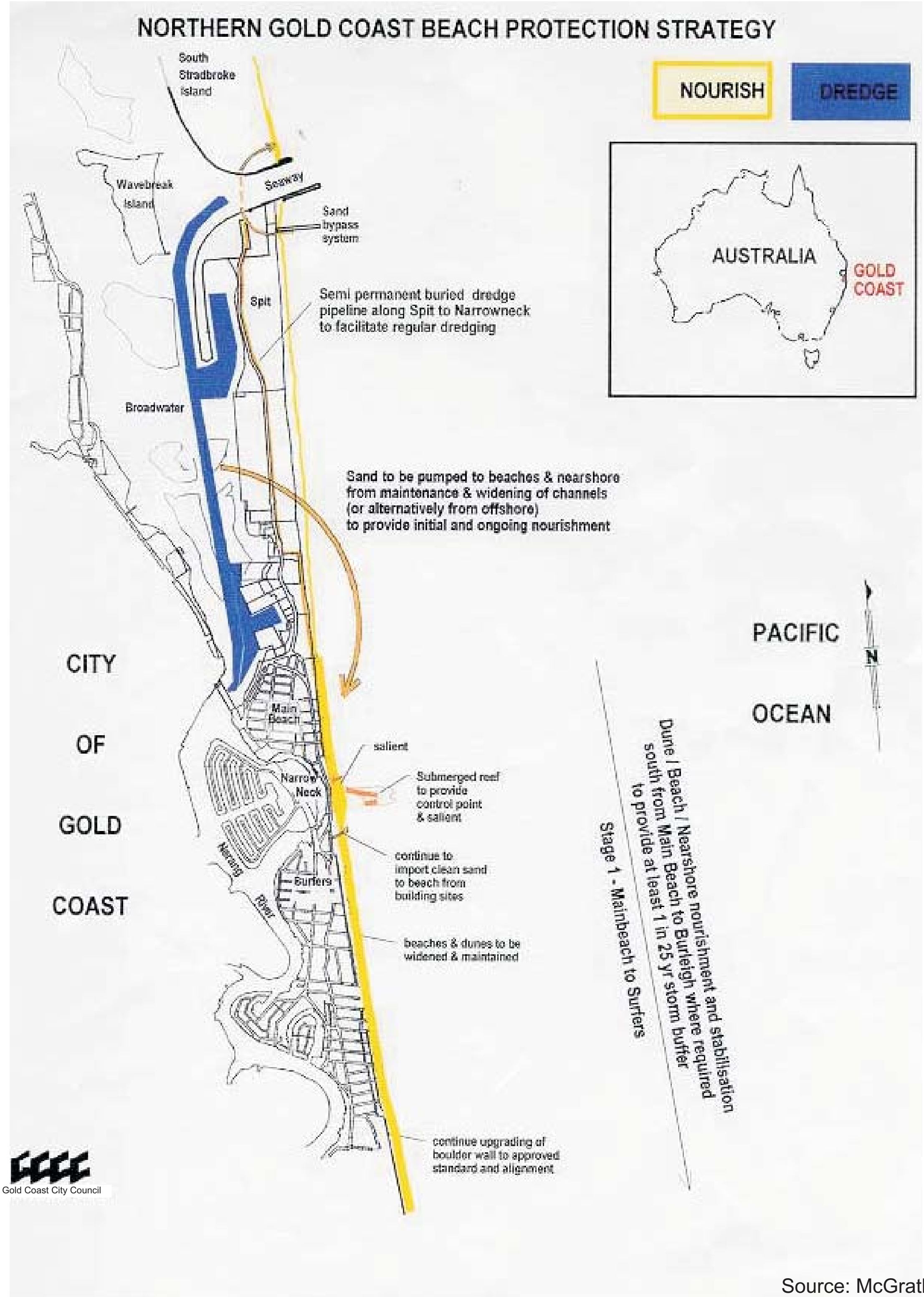
Nourishment of the northern Gold Coast beaches commenced in February 1999, six months prior to reef construction. Cumulative nourishment volumes for the 17 month nourishment period February 1999 to June 2000 are shown in Figure 2.4, at which time this major phase of beach nourishment within the 4,500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

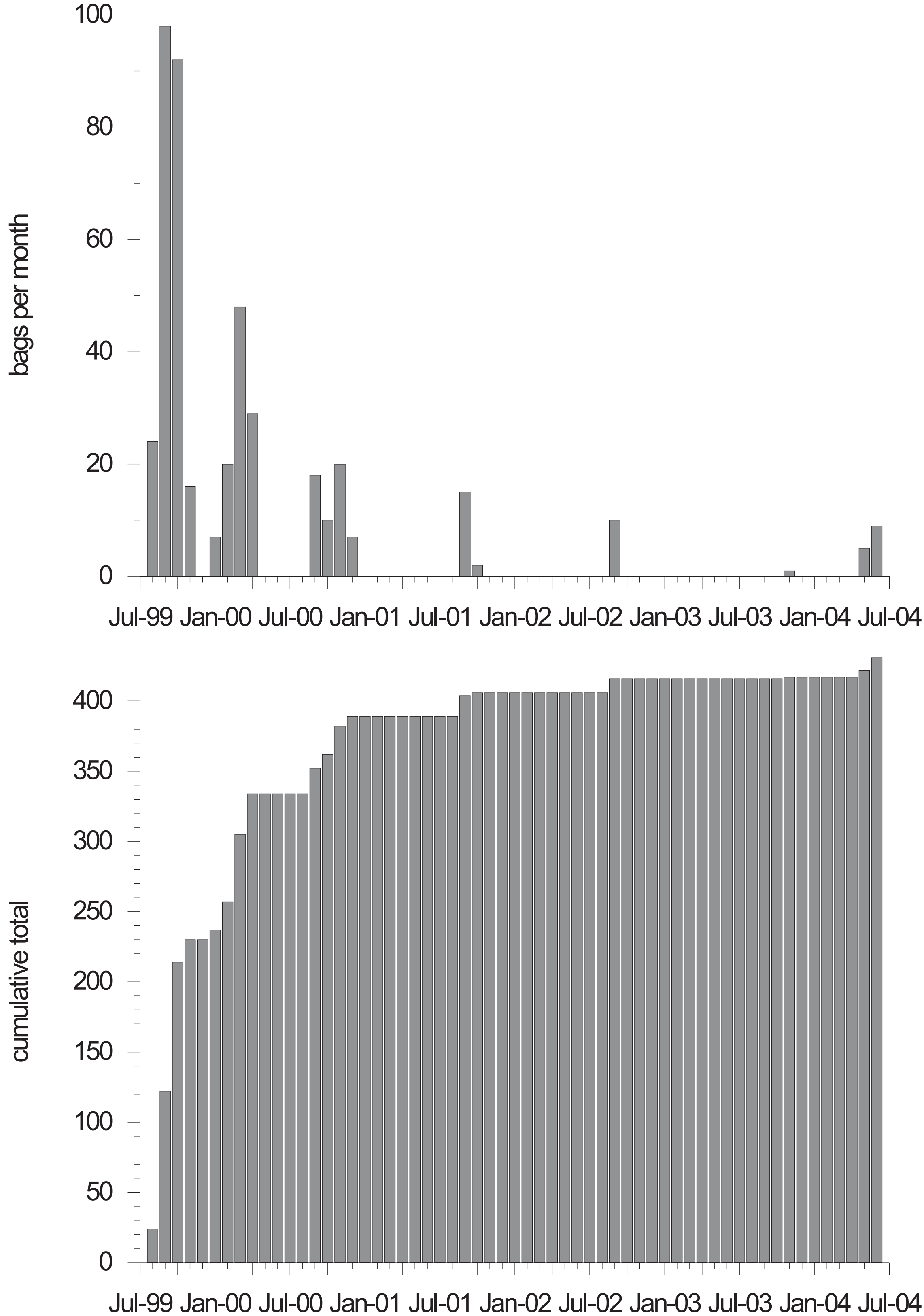


WRL Report No. 2006/01	LOCALITY	Figure 2.1 02074-2-1.cdr

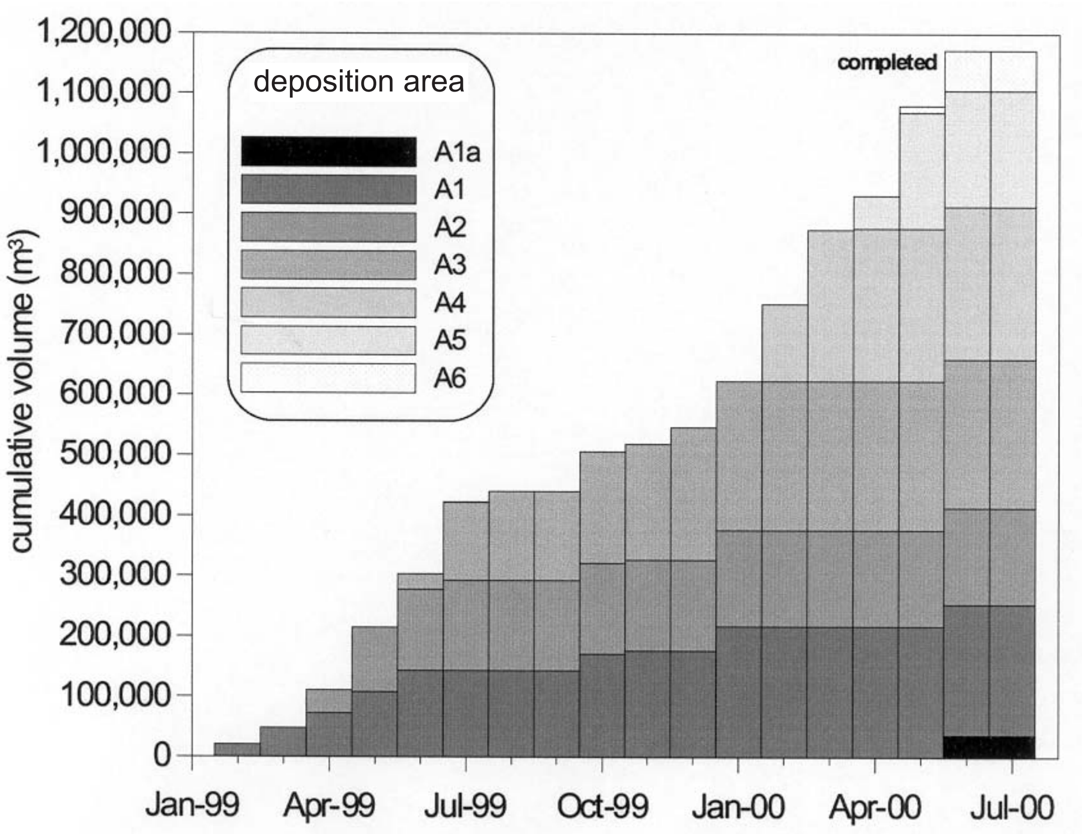


Source: McGrath et al. (2000)

WRL Report No. 2006/01	NGCBPS MASTER PLAN	Figure 2.2 02074-2-2.cdr



WRL Report No. 2006/01	REEF CONSTRUCTION	Figure 2.3 02074-2-3.cdr



WRL Report No. 2006/01	SAND NOURISHMENT (NGCBPS)	Figure 2.4 02074-2-4.cdr

WRL
Report No. 2006/01

SAND NOURISHMENT DEPOSITION AREAS

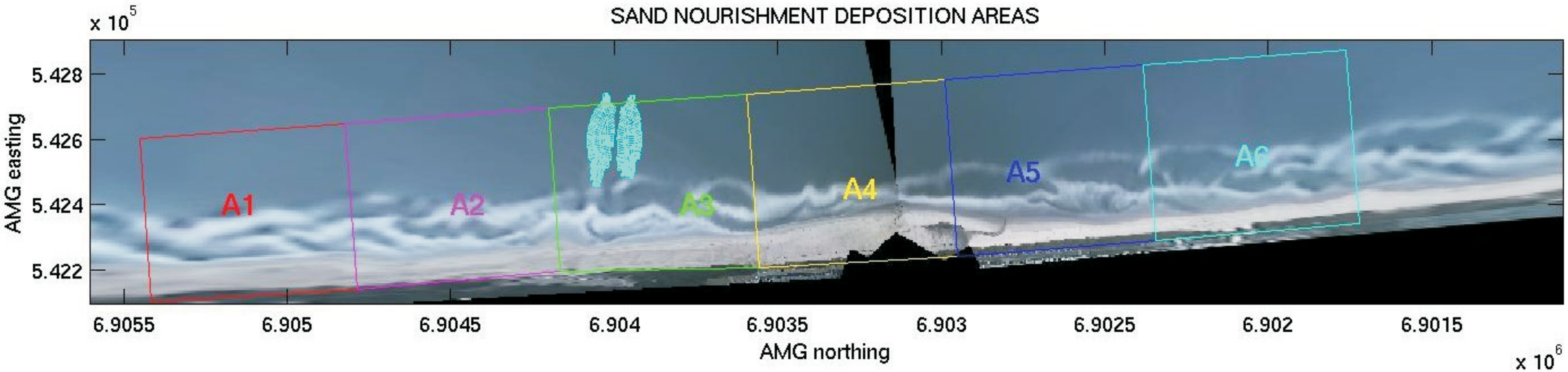


Figure 2.5

02074-2-5.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 fifteen years of ongoing research effort based at 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 2006 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, many ARGUS stations 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 new ‘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.

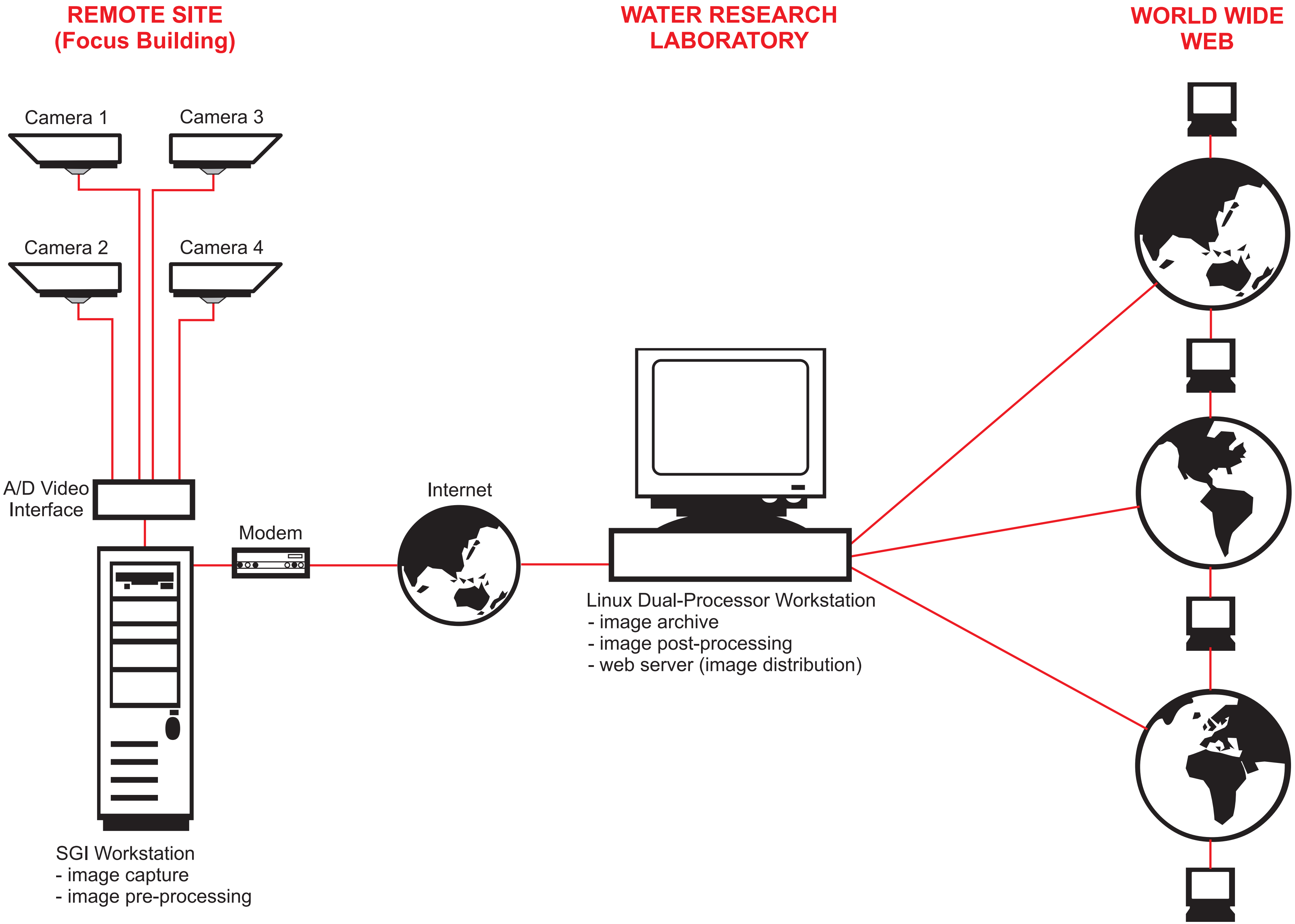
3.8 Standardised Procedure for Shoreline Mapping

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. $H_s \leq \sim 1.4$ 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 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.

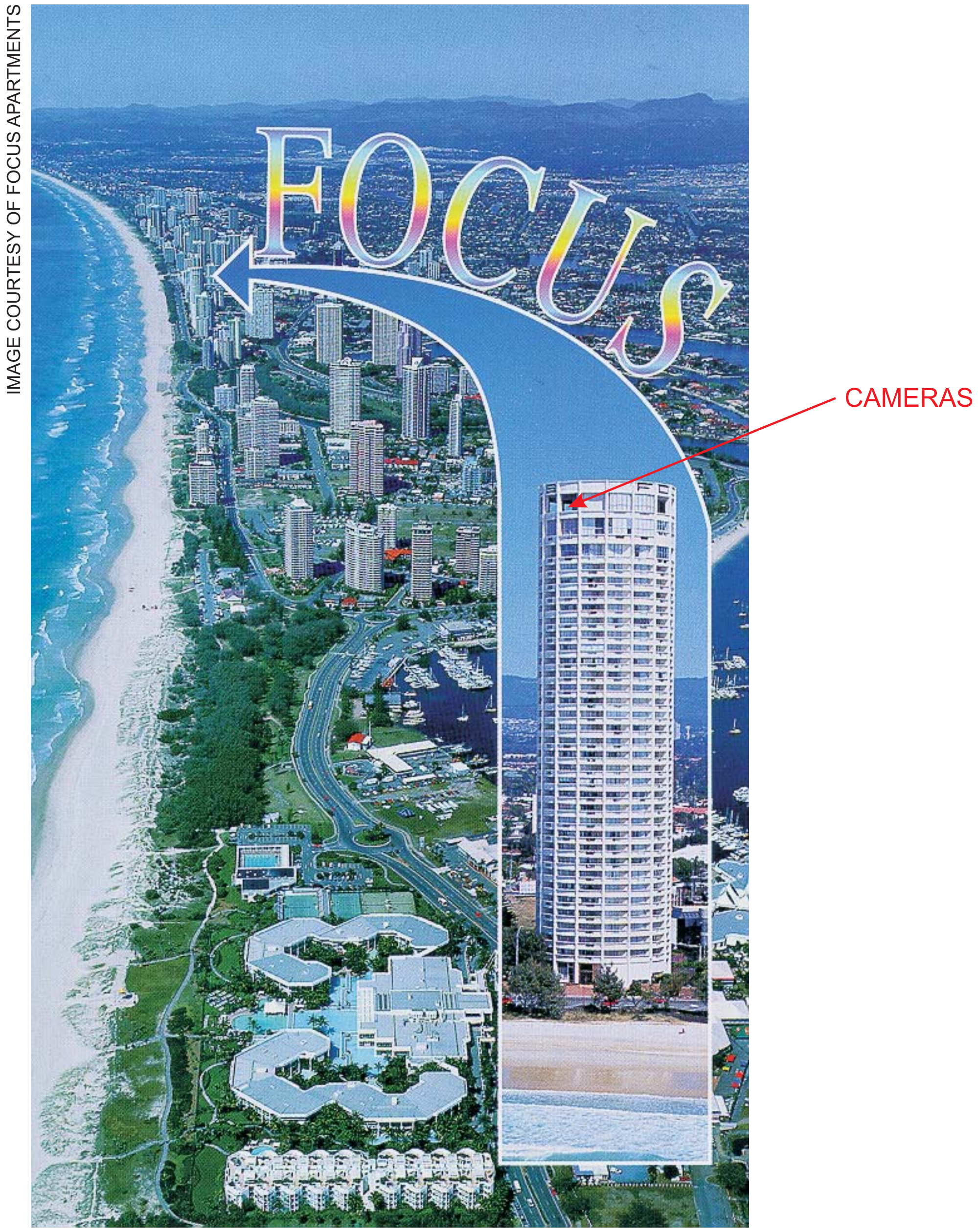


WRL
Report No. 2006/01

SCHEMATIC OF AN ARGUS COASTAL IMAGING SYSTEM

Figure
3.1

02074-3-1.cdr



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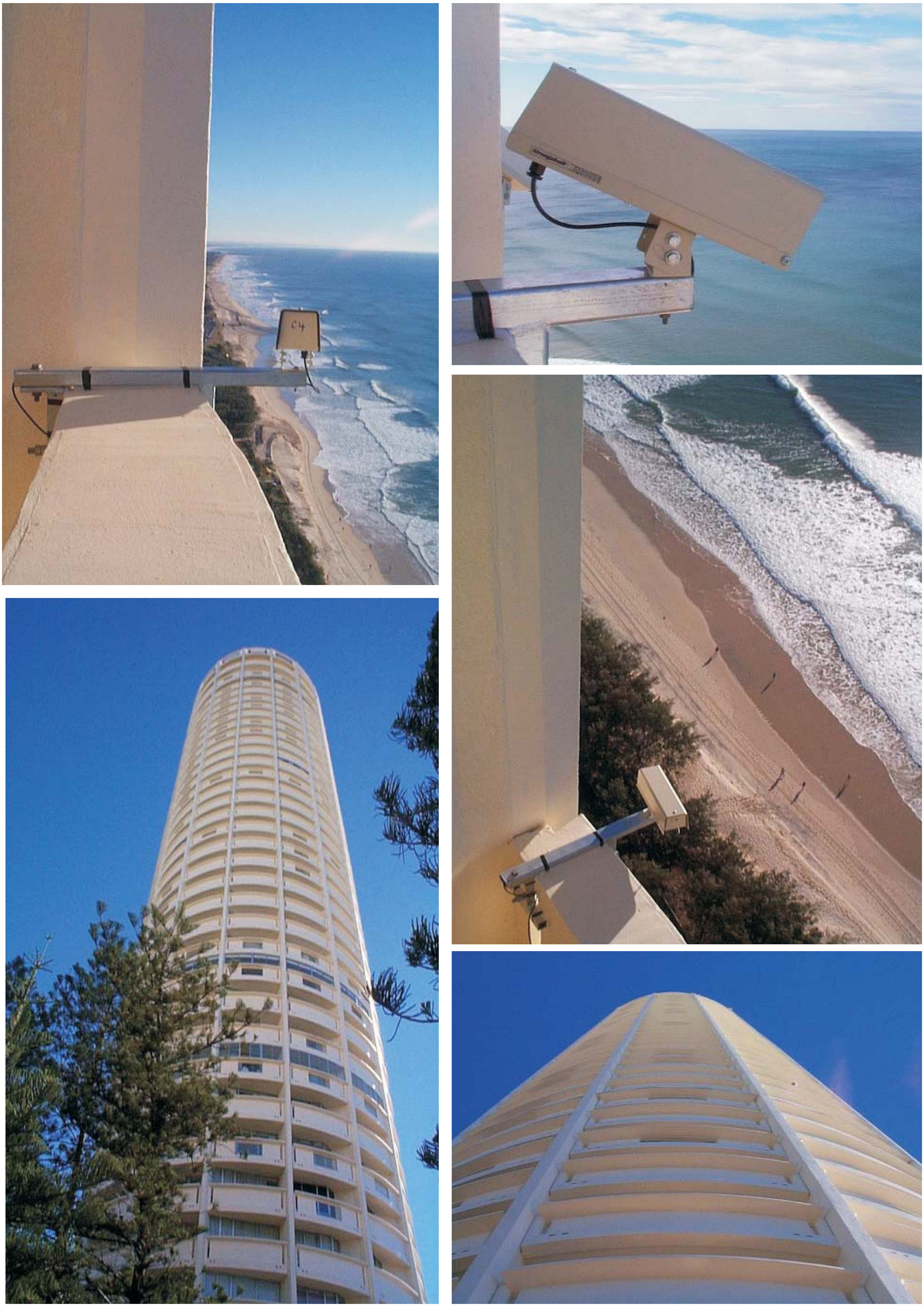
Report No. 2006/01

LOCATION OF ARGUS COASTAL IMAGING SYSTEM
AT THE GOLD COAST

Figure
3.2

02074-3-2.cdr



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Report No. 2006/01

CAMERAS MOUNTED AT AN ELEVATION OF APPROXIMATELY 100m

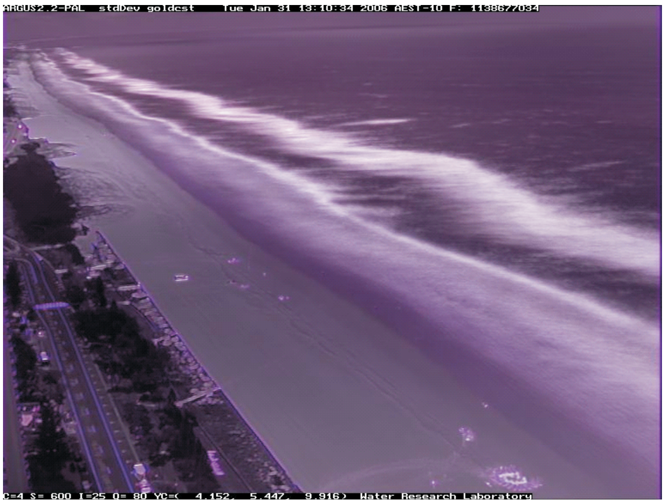
Figure 3.3

02074-3-3.cdr

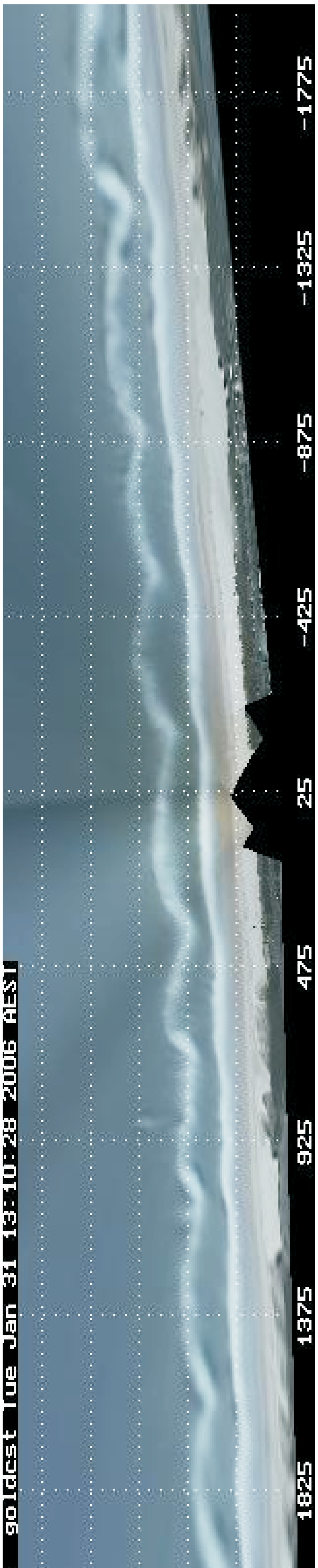
snap

timex

var



WRL Report No. 2006/01	SNAP-SHOT, TIME-EXPOSURE AND VARIANCE IMAGE TYPES (31/01/06)	Figure 3.4 02074-3-4.cdr



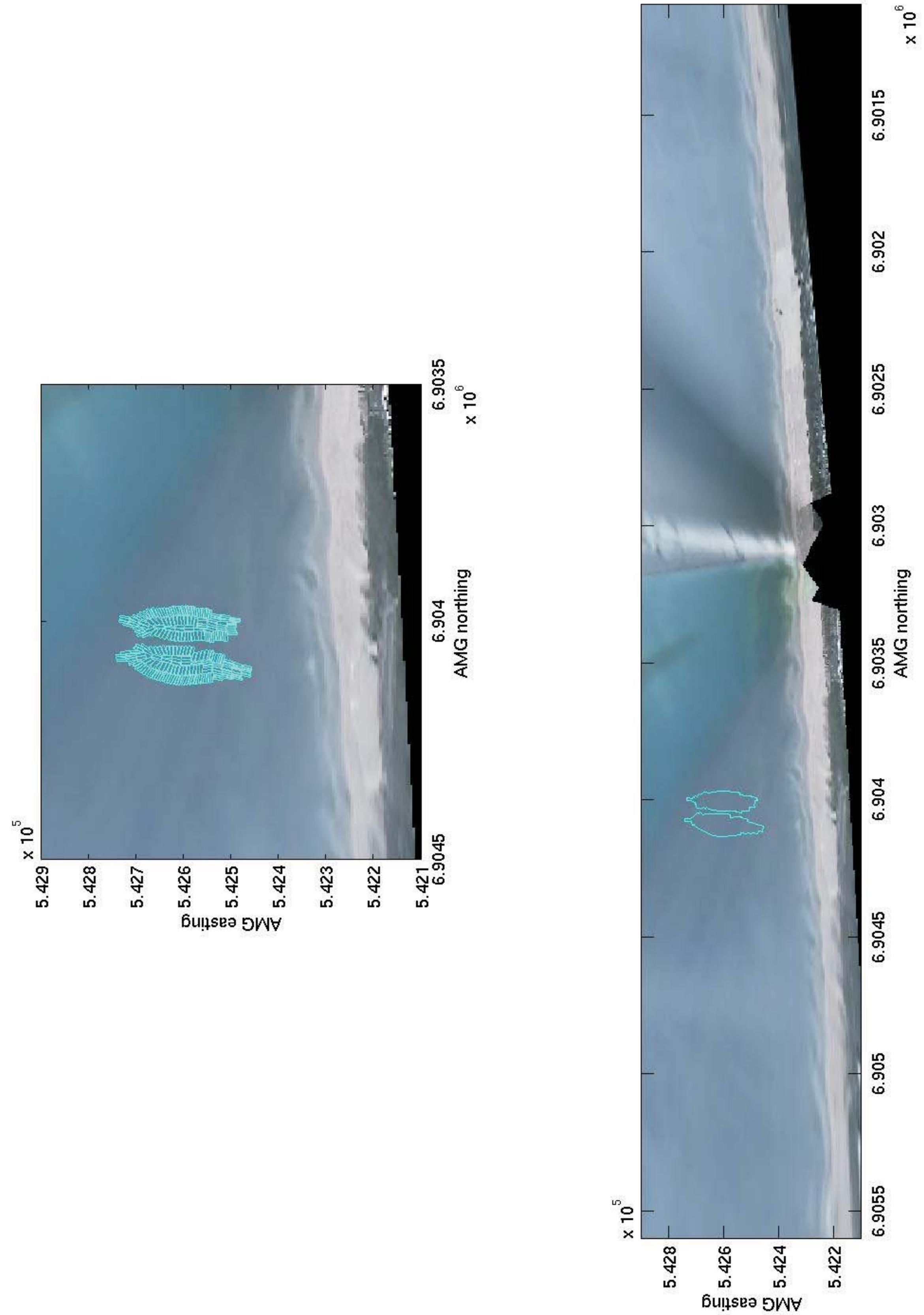
WRL

Report No. 2006/01

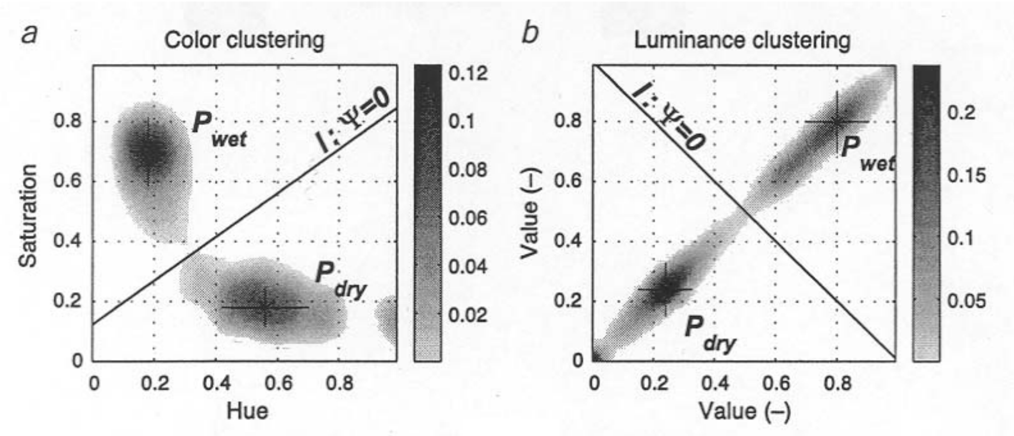
PLAN VIEW IMAGE
4 CAMERA MERGE/RECTIFICATION (31/01/06)

Figure 3.5

02074-3-5.cdr

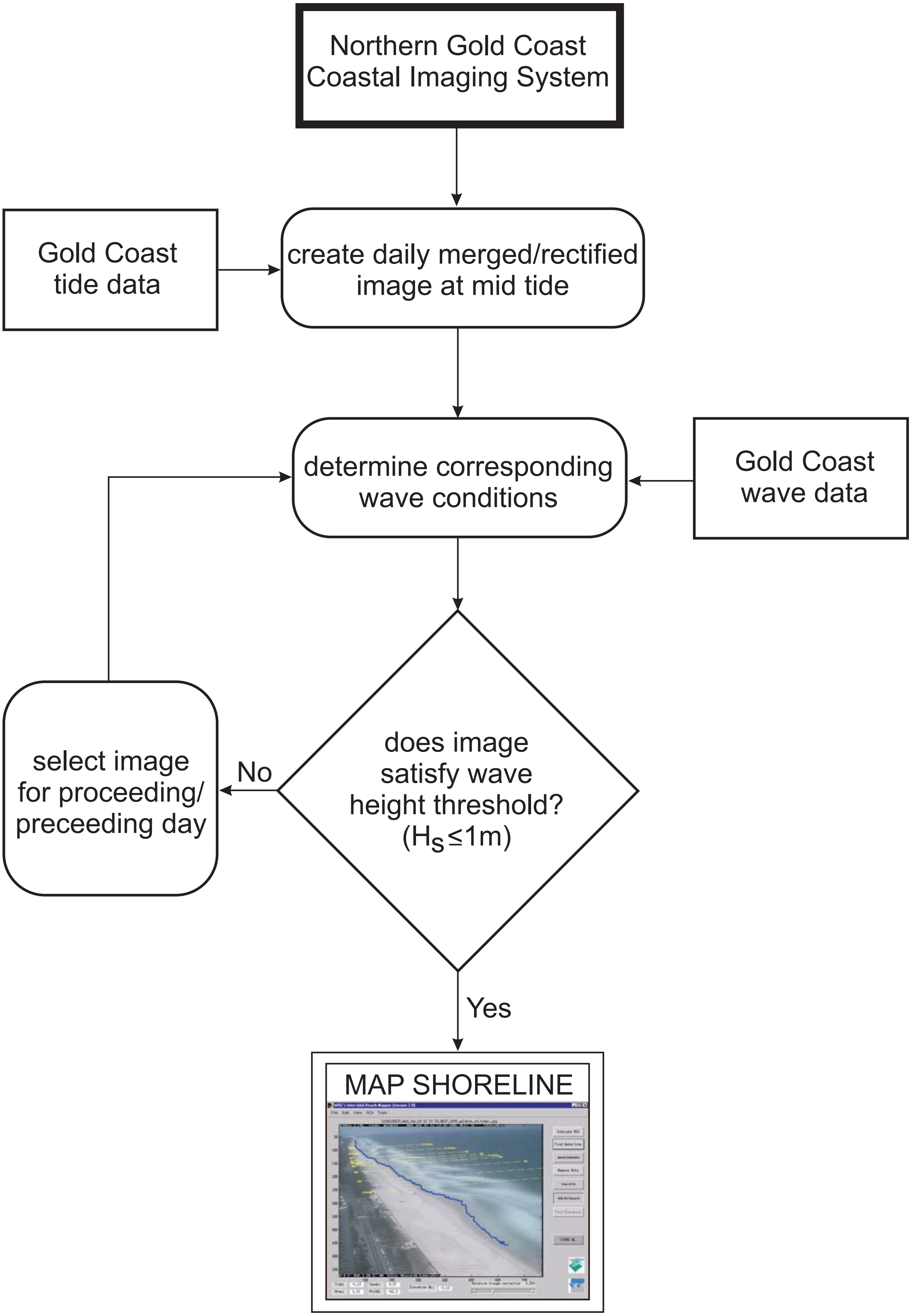


WRL Report No. 2006/01	PLAN VIEW IMAGE REFERENCED TO 'REAL WORLD' AMG COORDINATE SYSTEM	Figure 3.6 02074-3-6.cdr



Source: Aarninkhof (2003)

WRL Report No. 2006/01	IDENTIFICATION OF 'SHORELINE' FEATURE FROM COLOUR IMAGES	Figure 3.7 02074-3-7.cdr



WRL

Report No. 2006/01

STANDARDISED SHORELINE MAPPING PROCEDURE

Figure 3.8

02074-3-8.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/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 172,000 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.

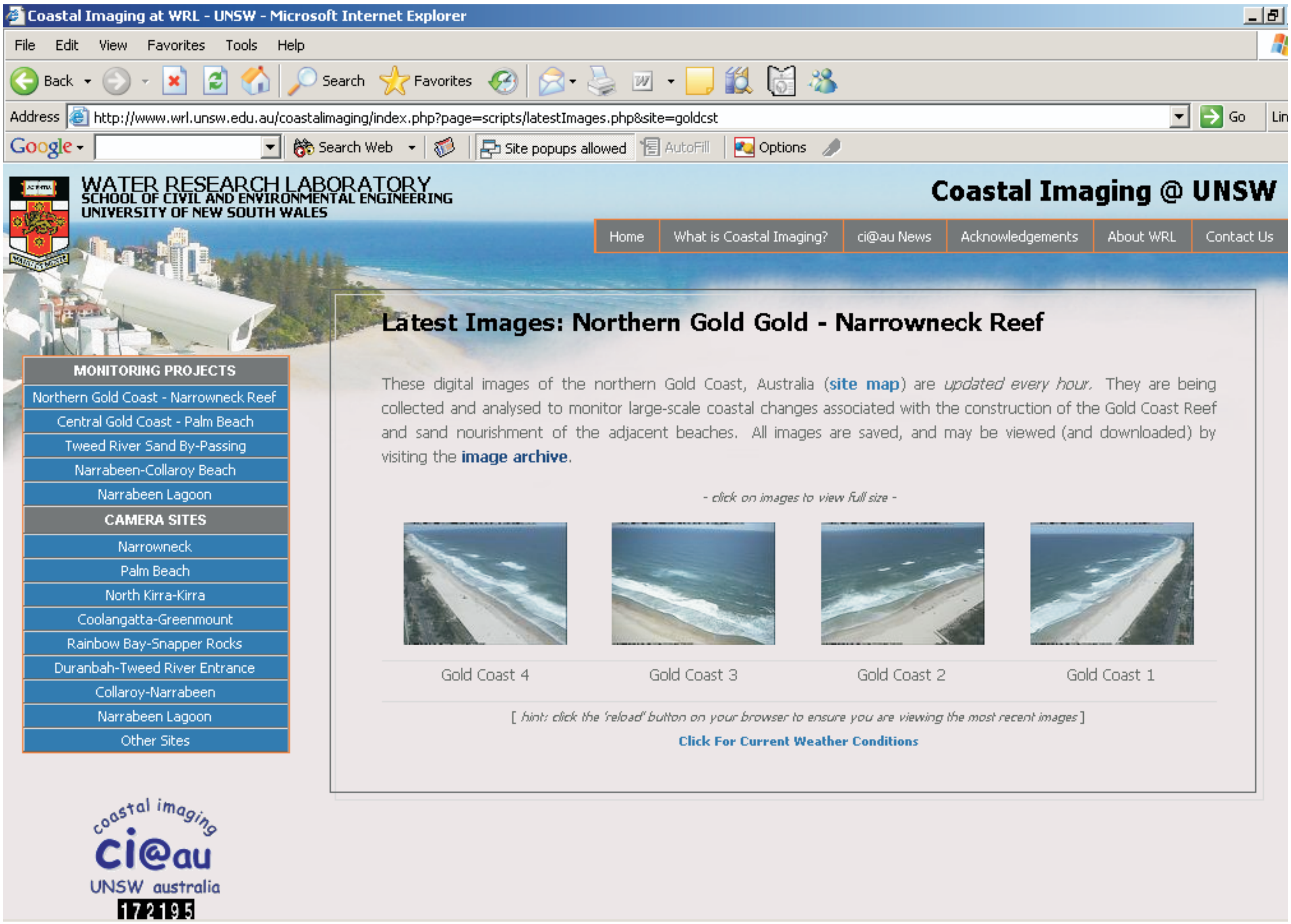
4.3 On-Line ‘Beach Analysis System’

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.

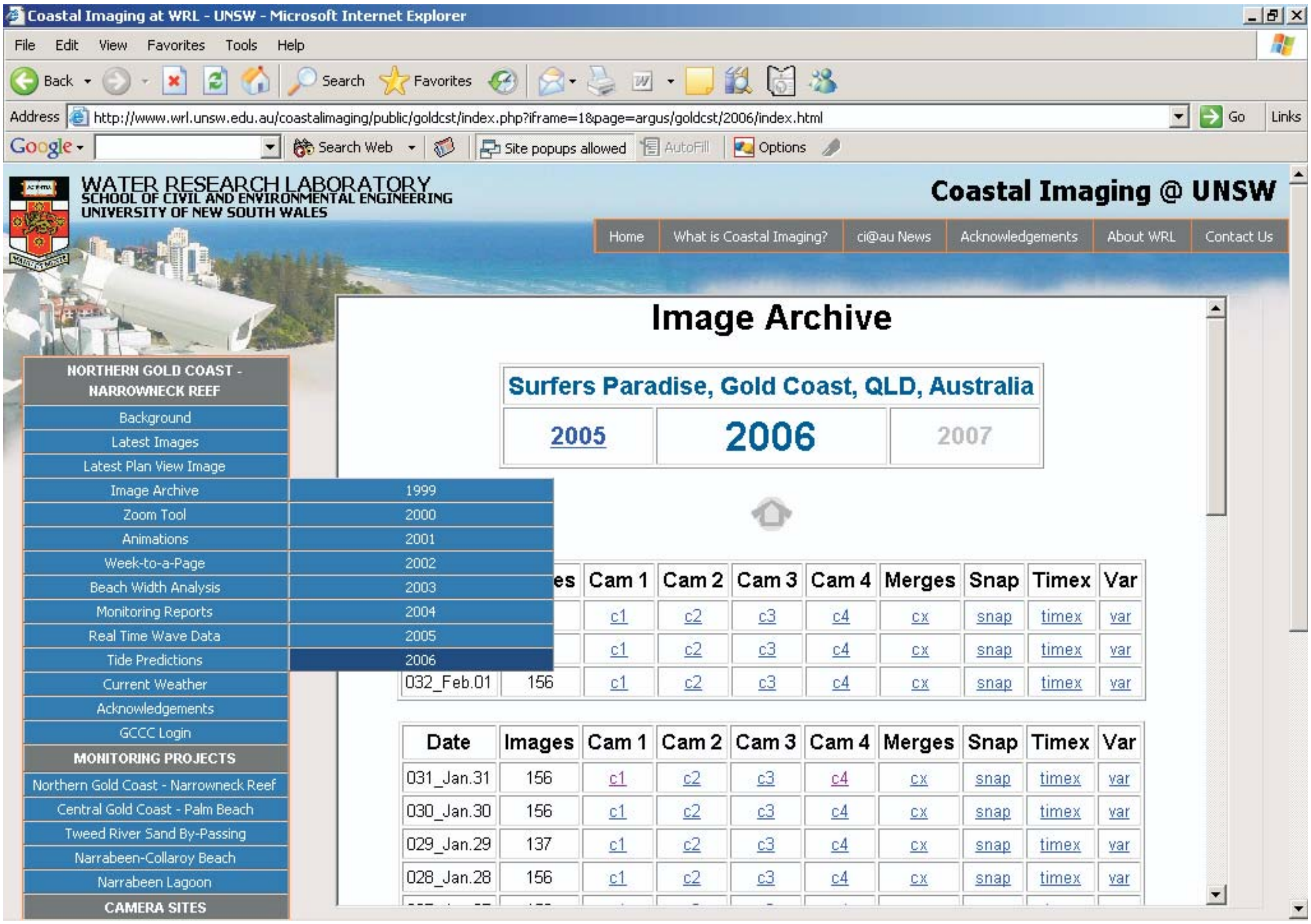
A detailed description of the capabilities of this system is detailed in Anderson et al (2003). To summarise, the features available at the project web site include the ability to view the latest mid-tide plan images; access to a zoom tool feature that enables zooming in and panning through the current 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.

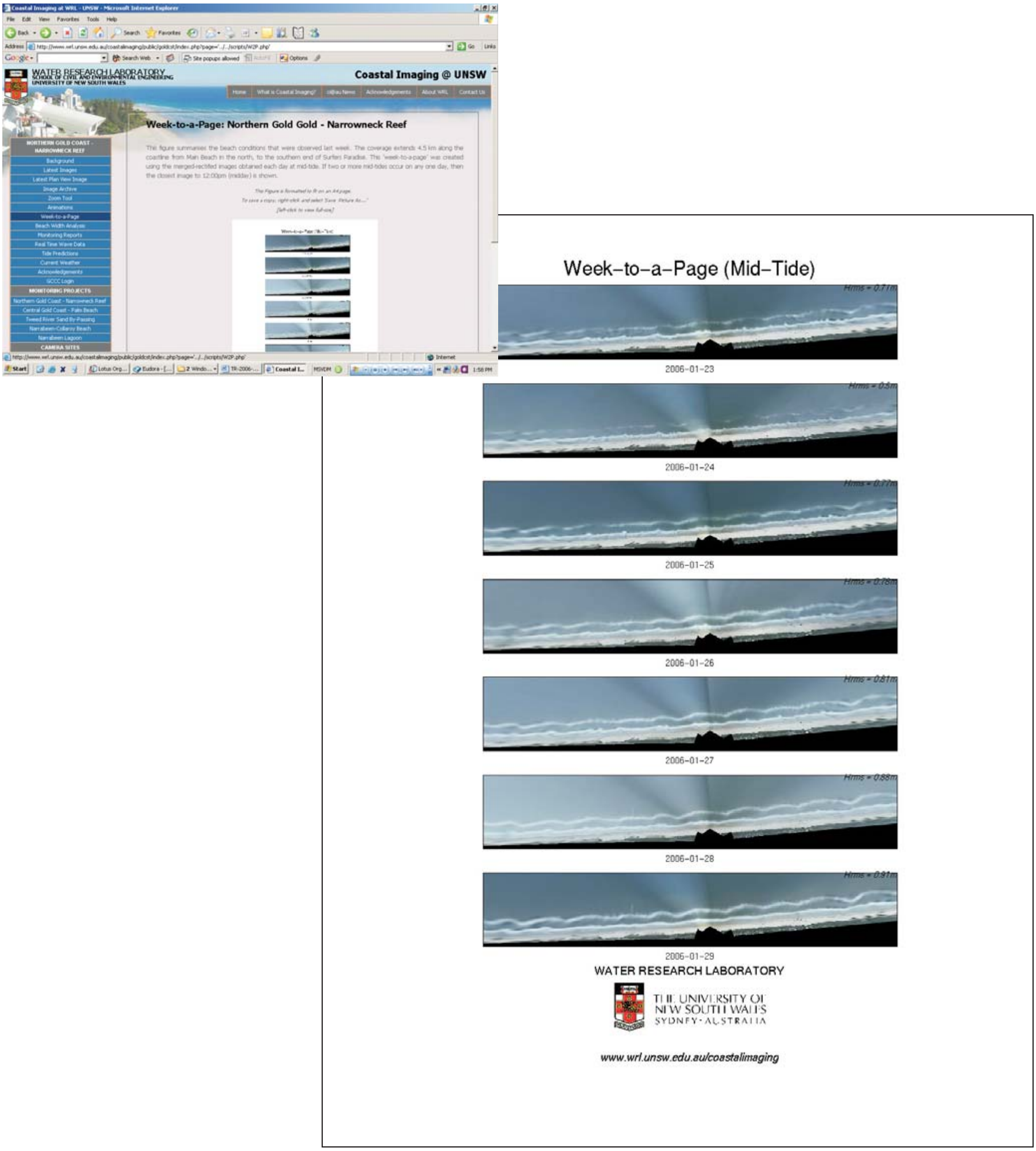
The second product that is also updated each Monday morning and made available via the project web site is ‘Beach-Width-Analysis’ (Figure 4.4). This figure in graphical format summarises quantitative information of the mean shoreline position for that week; shoreline variability by comparing the current 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.



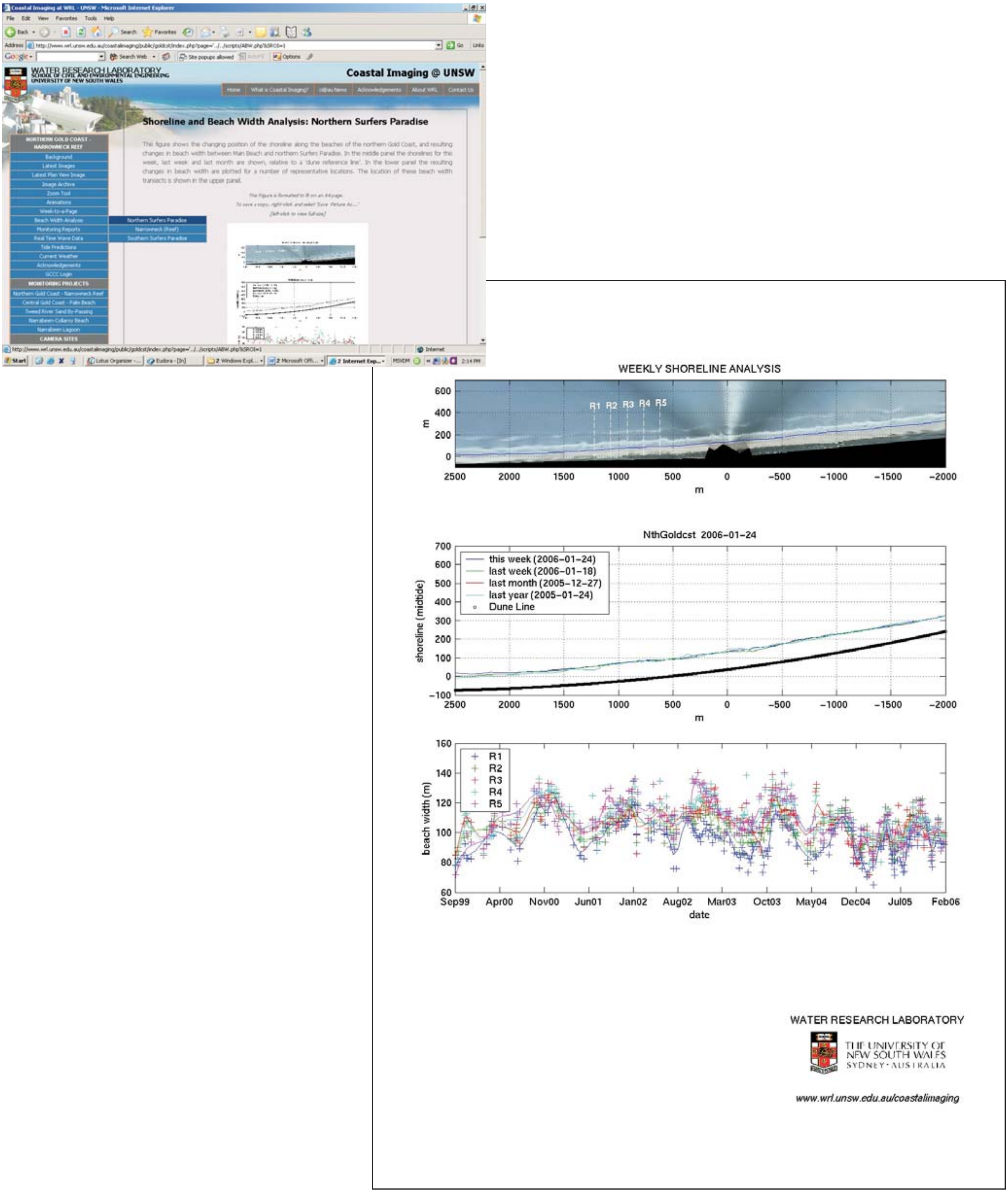
WRL Report No. 2006/01	COASTAL IMAGING WEB SITE - HOME PAGE	Figure 4.1 02074-4-1.cdr



WRL Report No. 2006/01	COASTAL IMAGING SYSTEM WEB SITE - IMAGE ARCHIVE	Figure 4.2 02074-4-2.cdr



WRL Report No. 2006/01	ON-LINE BEACH ANALYSIS SYSTEM - 'WEEK-TO-A-PAGE'	Figure 4.3 02074-4-3.cdr



WRL Report No. 2006/01	ON-LINE BEACH ANALYSIS SYSTEM - 'BEACH WIDTH ANALYSIS'	Figure 4.4 02074-4-4.cdr

5. MORPHODYNAMIC DESCRIPTION OF THE GOLD COAST BEACHES: AUGUST 2005 – JANUARY 2006

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 2005 to January 2006. 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 <u>Figure 5.1</u>. 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 2005 to January 2006 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 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.

5.2.1 August 2005

The month of August was characterised by generally mild wave conditions right up to the last few days of the month. Offshore significant wave heights were steady at around 1 m for most of the month, rising to 2 m for a few hours late on the 13th, and then rapidly declining again. From the 23rd onwards, significant wave heights rose to around 1.5 m, and on the 27th - 28th climbed steadily to peak at around 2 m. Wave energy then declined again to around H_s = 1 m by the end of the month.

At the start of August the inner bar was adjacent to the beachface, with smaller rips cutting across the low tide terrace, resulting in the beach exhibiting the lower-energy LTT morphology. The outer bar remained linear (LBT) due to insufficient wave energy to cause significant mobilisation of sand within the surfzone and nearshore. As these conditions continued into mid August, the rip channels infilled, and the inner bar fully welded to the beachface. The increase in wave energy in the last few days of August caused the re-mobilisation of sand at the outer bar, which rapidly developed crescentic (RBB) features as sand lobes began to migrate onshore.

5.2.2 September 2005

Offshore significant wave heights remained at or below around 1 m for the entire month of September, with the exception of a peak at around 2 m for the afternoon and evening of the 16th.

The prevailing beach morphology was in equilibrium with these mild wave conditions, resulting in the LTT inner bar remaining fully welded to the beachface and the absence of rip channels. Some continued movement of the now crescentic outer bar inshore was discernable, however, for much of the month, due to the mild wave conditions, wave breaking across the outer bar was largely absent.

5.2.3 October 2005

Wave data was not available from the Gold Coast wave-rider buoy up to the 10th of October, but checking against the Tweed wave-rider located ~40 km to the south, confirmed that significant wave heights remained at or below around 1 m up to the 19th of September. From the 19th to the 22nd, and again from the 25th – 26th significant wave heights rose to around 1.5 m, then declined to 1 m to the end of the month.

During the first half of September the mild wave energy conditions resulted in continued movement onshore of the outer bar, as sand lobes began to attach to the beachface, and the outer bar began to transition from RBB to TBR morphology. In response to the increase in wave energy commencing around the 19th and continuing through to the 26th, the outer bar straightened again and the trough became continuous alongshore, as the outer bar reverted to LBT morphology. However, compared to two months previously, the outer bar was now located closer to the shore and hence in shallower water. As wave energy declined again in the last few days of October, rhythmic features began to re-emerge alongshore, as the outer bar developed toward RBB morphology again.

5.2.4 November 2005

Offshore significant wave heights remained steady at around 1 m during the first half of November, then began to increase on the 16th, peaking at 2 - 2.5 m on the 17th – 18th. Wave data was again not available from the Gold Coast wave-rider buoy for the period 21st – 28th, however, checking against the adjacent Tweed site confirmed that mild (generally less than 1 m significant wave height) conditions prevailed during this period. On the 29th wave energy began to increase again, rising to 1.5 m significant wave height by the end of the month.

The rhythmic outer bar that began to emerge at the end of October continued to develop up to the 16th of November, as the bar moved onshore in lobes, and fully developed TBR morphology emerged. The period of higher wave energy from the 17th to the 18th then caused the bar to rapidly straighten again, and for the alongshore trough to re-develop. This higher energy LBT morphology then persisted for the next week, due to the rapid decline in wave height, with insufficient wave energy prevailing to cause the movement of sand back towards the shore. As wave heights then began to rise again in the last few days of the month, the movement of sand within the nearshore was re-activated, and by the end of November crescentic features were beginning to reappear across the outer bar.

5.2.5 December 2005

In the first few days of December the offshore significant wave height decreased from 1.5 m to less that 1 m, and for the remainder of the month remained in the range of 0.5 – 1 m.

The mild conditions that prevailed throughout December resulted in very limited wave breaking across the outer bar, while the inner bar remained fully welded to the beachface and there was an absence of rips. As the month progressed the outer bar slowly moved onshore, as lobes of sediment began to approach the shore, resulting in the development of distinctive and irregularly-space rhythmic features alongshore. By the end of the month the outer bar had transitioned from a linear bar-trough LBT beach state, through RBB to TBR, as the inshore lobes of sediment attached to the beachface.

5.2.6 January 2006

Mild wave conditions of less than 1 m offshore significant wave height continued into January 2006, but were interrupted around the 8th by the passage of a storm. Offshore significant wave heights rose up to 3 m, and maximum offshore wave heights up to 6 m were recorded. These high wave energy conditions persisted for two days, followed by a further period of 3 days when significant wave heights remained in the range of 1 – 2 m. From the 13th – 20th significant wave heights decreased to below 1 m, rapidly rising to 2 m again during the 20th – 21st. Significant wave heights then decreased again to around 0.5 m on the 25th, at which time they began to steadily increase again, up to 1.5 m on the 31st.

The passage of the storm commencing on the 8th January caused the rapid straightening and seaward movement of the outer bar, as the beach reverted to LBT morphology. The inner bar partially detached from the beachface, resulting in the formation of inshore gutters and channels alongshore. The subsequent general decline in wave energy to the end of the month resulted in the reappearance of crescentic features across the outer bar, and the gradual infilling of the inshore gutters between the beachface and the inner bar. The transition in January 2006 of the outer bar from higher energy LBT morphology to lower energy RBB morphology matched the observed behaviour of the beach six months previously, at the commencement of the present monitoring period in August 2005.

5.3 Visual Assessment of Beach Width Changes (August 2005 – January 2006)

Beach and nearshore conditions during the present monitoring period August 2005 to January 2006 were characterised by persistently mild wave energy conditions, with offshore significant wave heights exceeding 3 m on one occasion only, and just six short-duration events when offshore significant wave heights exceeded 2 m. The outer bar moved onshore and offshore in response to varying incident wave energy, straightening (TBT morphology) as it moved offshore in response to increased wave energy, then developing more crescentic features and moving inshore (RBB – TBR morphology) in response to the mild wave conditions that were more typical of this period. The inner bar remained welded to the beachface (LTT) though most of this same six month period, only partially detaching once from the shore in January 2006, in response to elevated wave energy conditions. 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 1 (south) on 01/08/05 and 31/01/06 respectively. The corresponding snap images of the northern beaches obtained from Camera 4 are shown in Figure 5.3. As per the previous six month monitoring period (Turner, 2005b), along the southern beach no net change in the visible (subaerial) beach is discernable, with similar conditions also observed along the northern beach. The exception to generally similar conditions at the beginning and end of the present six month monitoring period was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed along the Gold Coast beachfront.

5.4 Visual Assessment of Total Beach Width Changes (August 1999 – January 2006)

The visible beach changes to date since the commencement of the NGCBPS coastal imaging monitoring program six and a half years ago are seen in Figures 5.4 and 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 July 2005.

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.

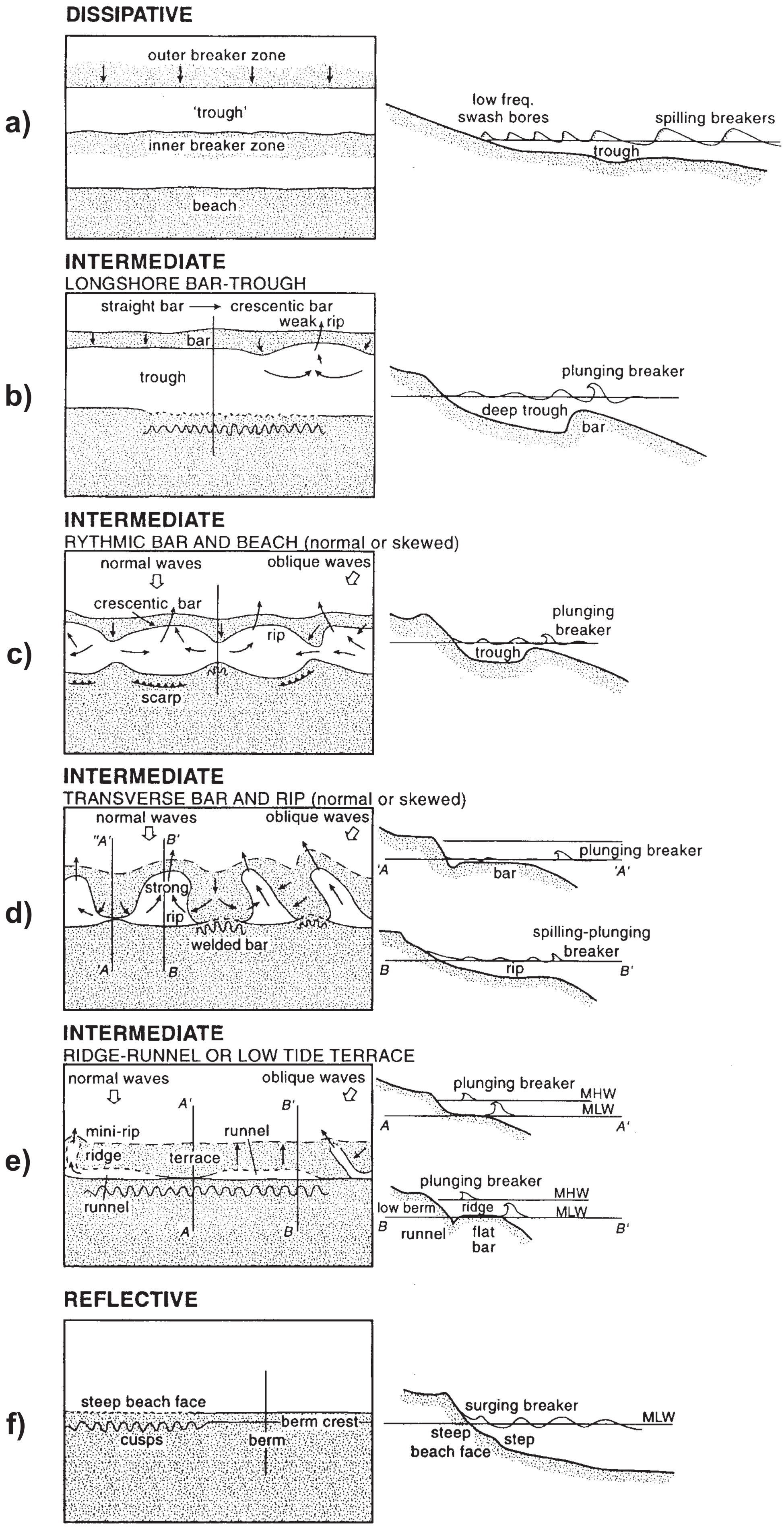
From January 2002 – August 2002 the beach of the northern Gold Coast were moderately depleted, with the beach at the end of this period intermediate to the eroded state that prevailed in August 2001, and the most accreted state that was recorded at the end of January 2002. By January 2003 the beaches 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 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.

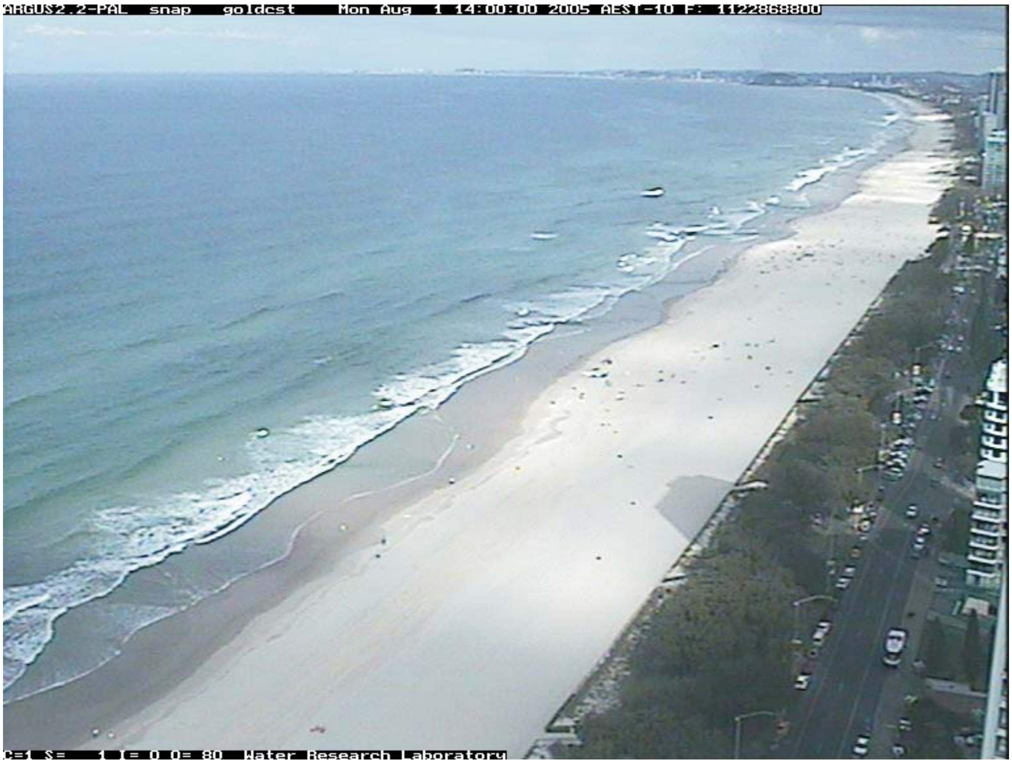
From August 2003 to January 2004 minimal storm wave activity was observed, and the beaches of the Northern Gold Coast generally accreted. During February 2004 to July 2004 large wave events occurred in March, and the beaches were observed to be cut back during that time. However, by the end of July 2004, 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.

In February 2005 and six months later in 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. Again, during the current monitoring period August 2005 to January 2006 (Figures 5.4 and 5.5), 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 generally similar conditions at the beginning and end of the present six-month monitoring period was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed.

A more quantitative assessment of the response of the northern Gold Coast beaches for the period August 2005 to January 2006 is detailed in Section 6.



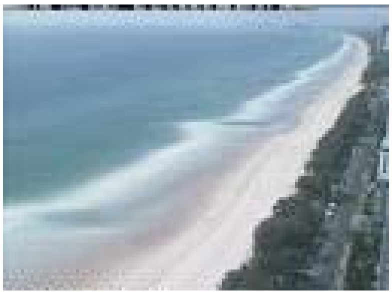
WRL Report No. 2006/01	MORPHODYNAMIC BEACH STATE MODEL (after WRIGHT and SHORT, 1983)	Figure 5.1 02074-5-1.cdr



WRL Report No. 2006/01	SNAP IMAGES FROM CAMERA 1 (SOUTH): 01/08/2005 AND 31/01/2006	Figure 5.2 02074-5-2.cdr

WRL Report No. 2006/01	SNAP IMAGES FROM CAMERA 4 (NORTH): 01/08/2005 AND 31/01/2006	Figure 5.3 02074-5-3.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

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SIX-MONTHLY BEACH CHANGES (CAMERA 1-SOUTH):
AUGUST 1999 - JANUARY 2006

Figure
5.4

02074-5-4.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

WRL Report No. 2006/01	SIX-MONTHLY BEACH CHANGES (CAMERA 4-NORTH): AUGUST 1999 - JANUARY 2006	Figure 5.5 02074-5-5.cdr

6. QUANTITATIVE ANALYSIS OF SIX-MONTH SHORELINE CHANGES: AUGUST 2005 – JANUARY 2006

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 01/08/05 to 31/01/06 are shown in Figure 6.1. For reference, these measured shorelines are overlaid onto a representative merged/rectified timex image (image date: 31/01/06). 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 01/08/05 – 31/01/06 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 70 m to 120 m. The envelope of beach width changes is relatively uniform alongshore, generally varying in width along the 4,500 m study region by approximately 30 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 01/08/05 – 31/01/06 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: 31/01/2006) 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 01/02/05 – 31/07/05 was in the range of 90 – 100 m, but can be seen to have varied by approximately 30 m, from 80 m to 110 m. As was discernible from Figure 6.2, relative to the dune reference line the mean beach width was greatest in the central 1,000 m region of the 4,500 m monitoring area, averaging approximately 100 m.

The analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals an alongshore-uniform range of beach variations along the 4,500 m study area. Both north and south of the camera, beach widths generally varied by ~20 m from the mean shoreline position.

The middle panel of Figure 6.3 shows the standard deviation of weekly shorelines from the mean shoreline position during the period 01/08/05 – 31/01/06. The standard deviation of weekly shorelines was generally in the range of ± 5 - 10 m. During the preceding 12 months of monitoring at the northern Gold Coast (Turner 2005a; Turner 2005b) it was noted that the standard deviation of weekly shorelines was higher in the northern half of the study region, however, this trend was not observed during the present six-month monitoring period.

6.3 Weekly Shorelines (August 2005 – January 2006) Relative to Mean Shoreline Position of Previous Monitoring Period (February 2005 – July 2005)

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 01/08/05 – 31/01/06 have been re-analysed and plotted relative to the mean shoreline position calculated for the previous six month monitoring period February 2005 – July 2005 (refer Turner, 2005b). 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 2005 – July 2006 is shown, along with the mean shoreline calculated for the present monitoring period.

This analysis shows that during the present monitoring period the beaches of the northern Gold Coast simply oscillated around the mean shoreline position for the preceding six month period. As per the previous six-month monitoring period (Turner, 2005b), and in contrast to more complex changes observed twelve months previously during August 2004 to January 2005 (Turner, 2005a), from August 2005 to January 2006 no discernable net beach width trends were observed.

The observation from the present monitoring period of relatively uniform beach changes alongshore is more typical of the general trend observed throughout the total six and a half year monitoring program. The rather atypical observation 12 months ago (refer Turner, 2005a) of a distinct alongshore variability in beach width, did not continue through 2005.

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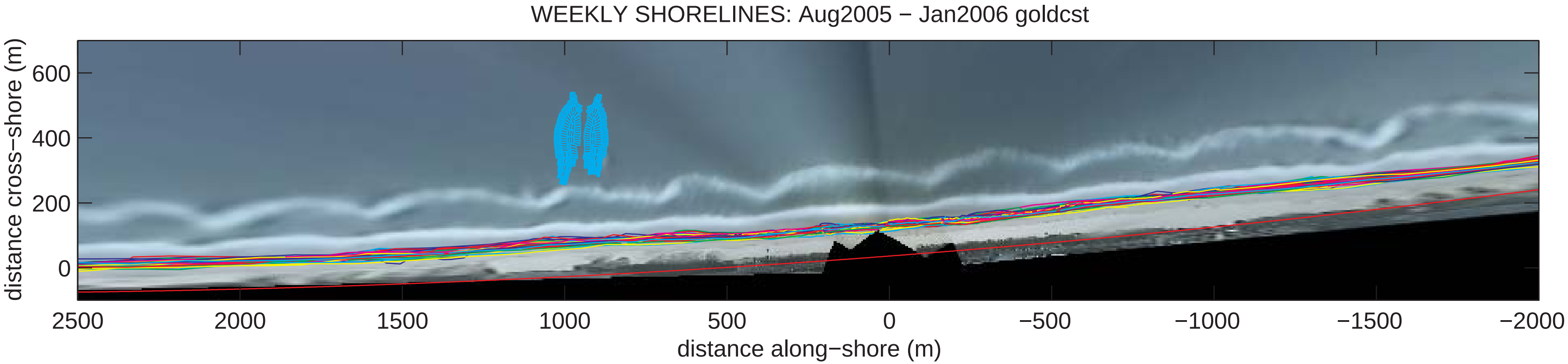
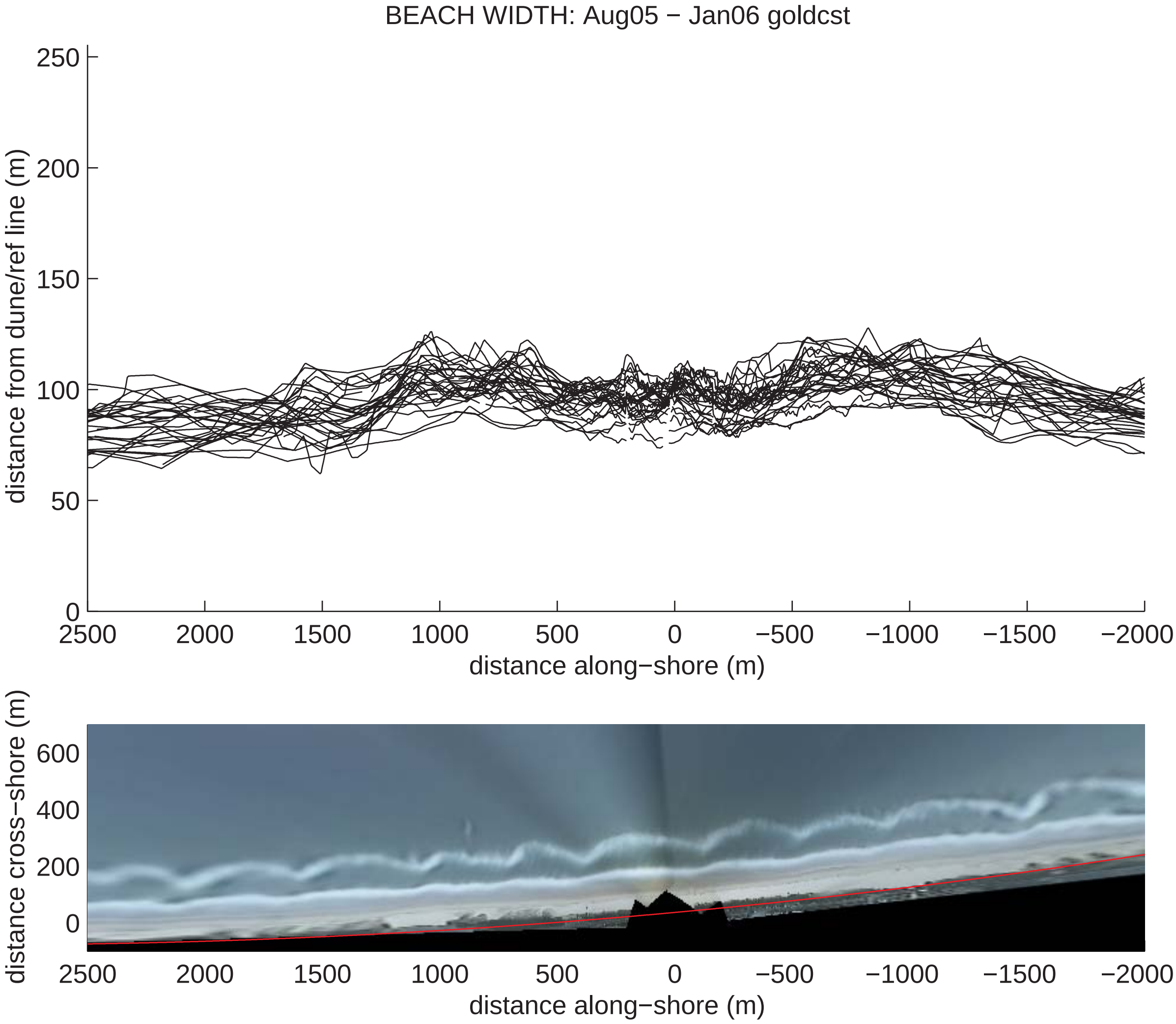
WEEKLY SHORELINES: AUGUST 2005 - JANUARY 2006

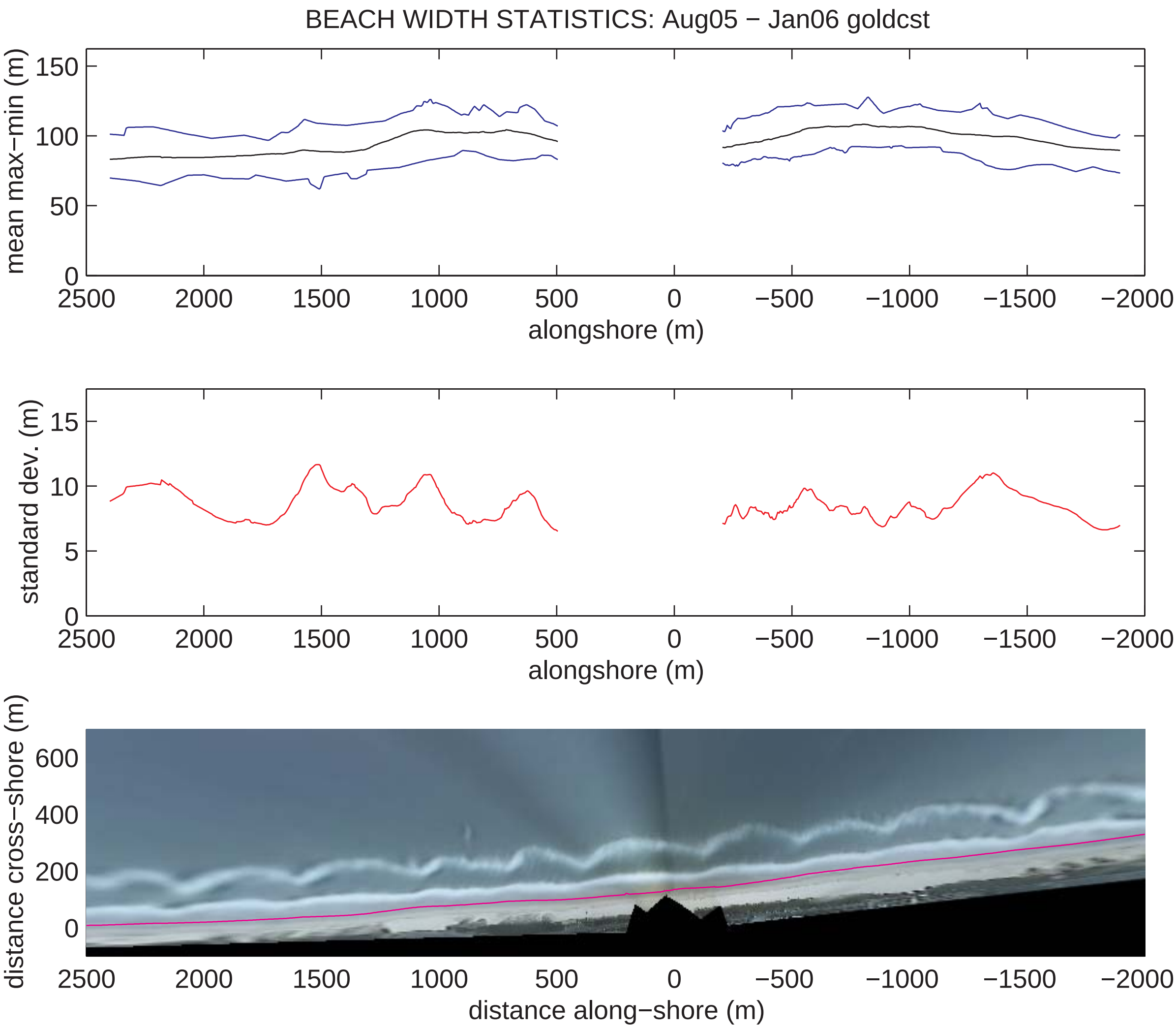
Figure 6.1

02074-6-1.cdr





WRL Report No. 2006/01	WEEKLY BEACH WIDTH: AUGUST 2005 - JANUARY 2006	Figure 6.2 02074-6-2.cdr

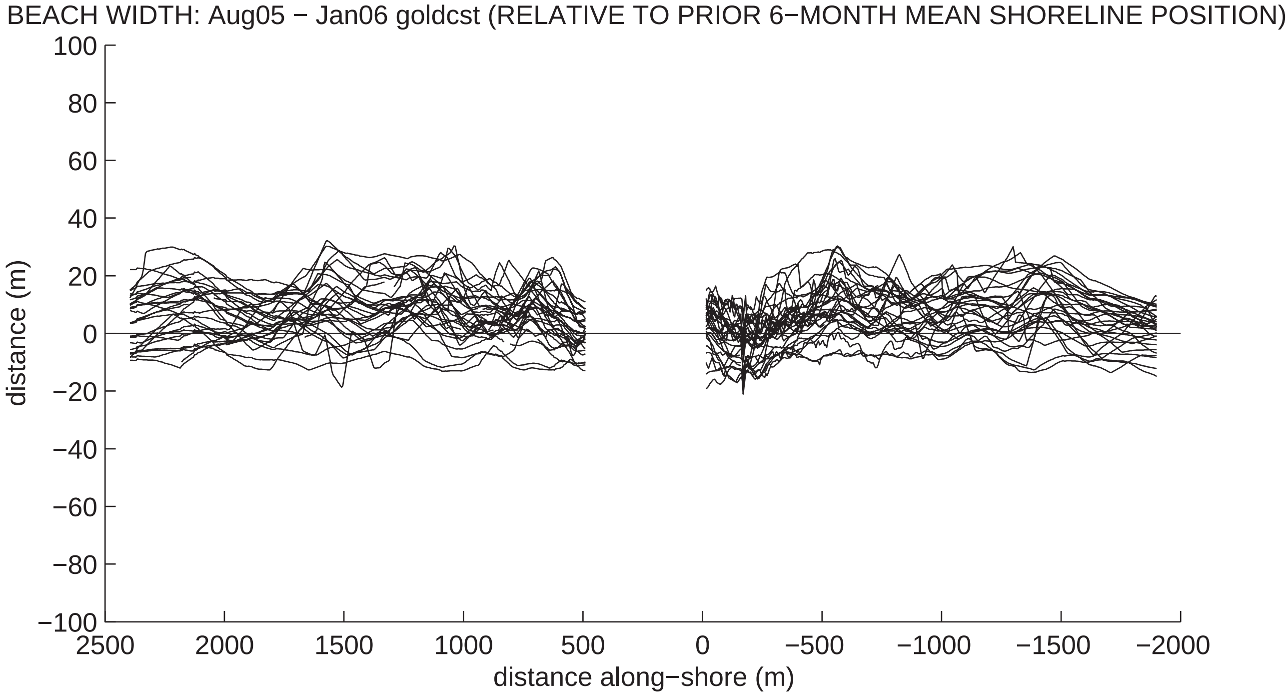


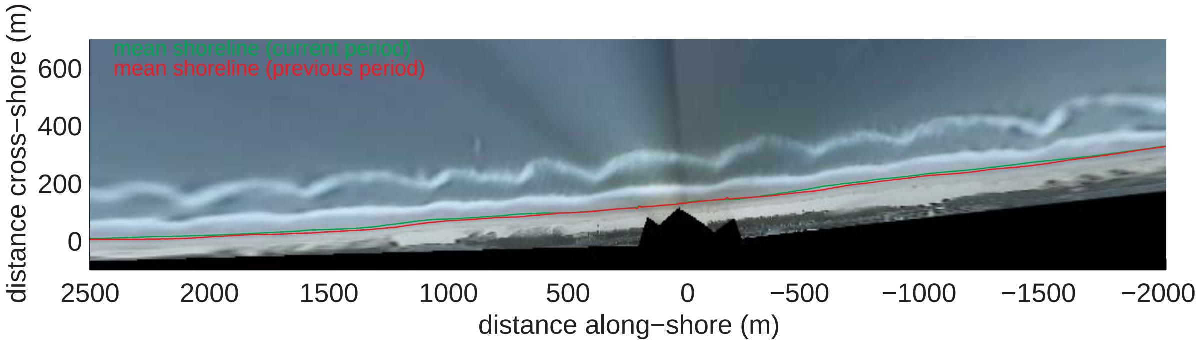
WRL
Report No. 2006/01

STATISTICAL SUMMARY OF BEACH WIDTH CHANGES:
AUGUST 2005 - JANUARY 2006

Figure
6.3

02074-6-3.cdr





WRL Report No. 2006/01	WEEKLY BEACH WIDTH CHANGES AUGUST 2005 - JANUARY 2006 RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION	Figure 6.4 02074-6-4.cdr

7. QUANTITATIVE ANALYSIS OF SHORELINE VARIABILITY, SEASONALITY AND LONGER-TERM EROSION/ACCRETION TRENDS: AUGUST 1999 – JANUARY 2006

The completion of a total of six 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.

7.1 Weekly Shorelines and Shoreline Variability: August 1999 – January 2006

All weekly shorelines for the 338 week period August 1999 to January 2006 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 2006). 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 78 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 six and a half year period August 1999 – January 2006 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: 31/01/2006).

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 present 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 the single storm wave event in January caused the beaches to narrow again.

Referring to Figures 7.2 and 7.3, at the completion of six and a half years of monitoring and around five 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. 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.

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 July 2005 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 also show the general accretion-erosion trends that were measured through the present monitoring period.

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 existing 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 over the past several years 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 4,500 m 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.

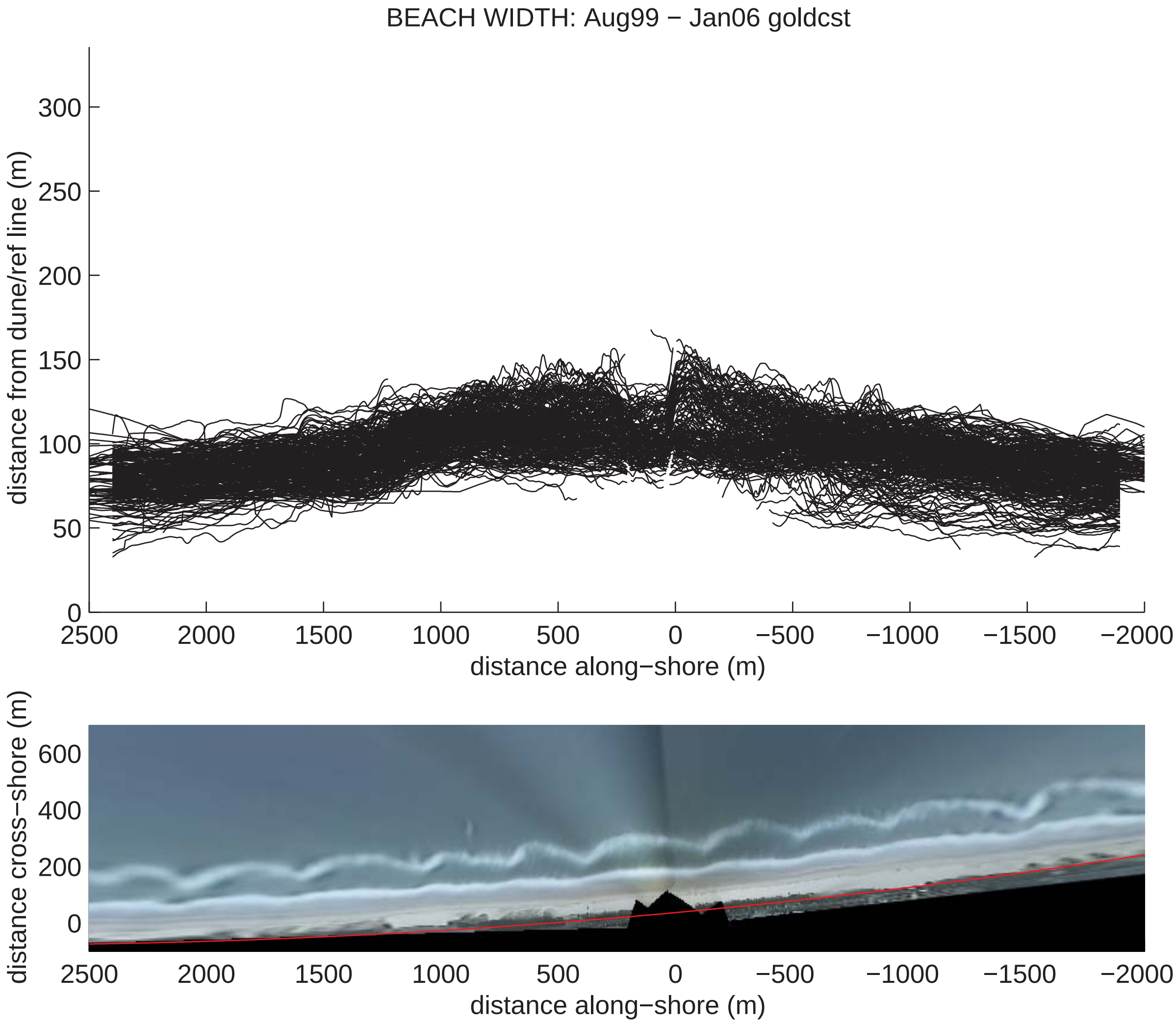
7.2.3 Results

The results of auto-correlation analysis for the five year period January 2001 to January 2006, 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 diminishes. The further breaking down of this previously dominant seasonal-cyclic trend continued in 2005, as is 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. During the latter half of 2005, the six month monitoring period covered by this report, again no clear trend is evident.

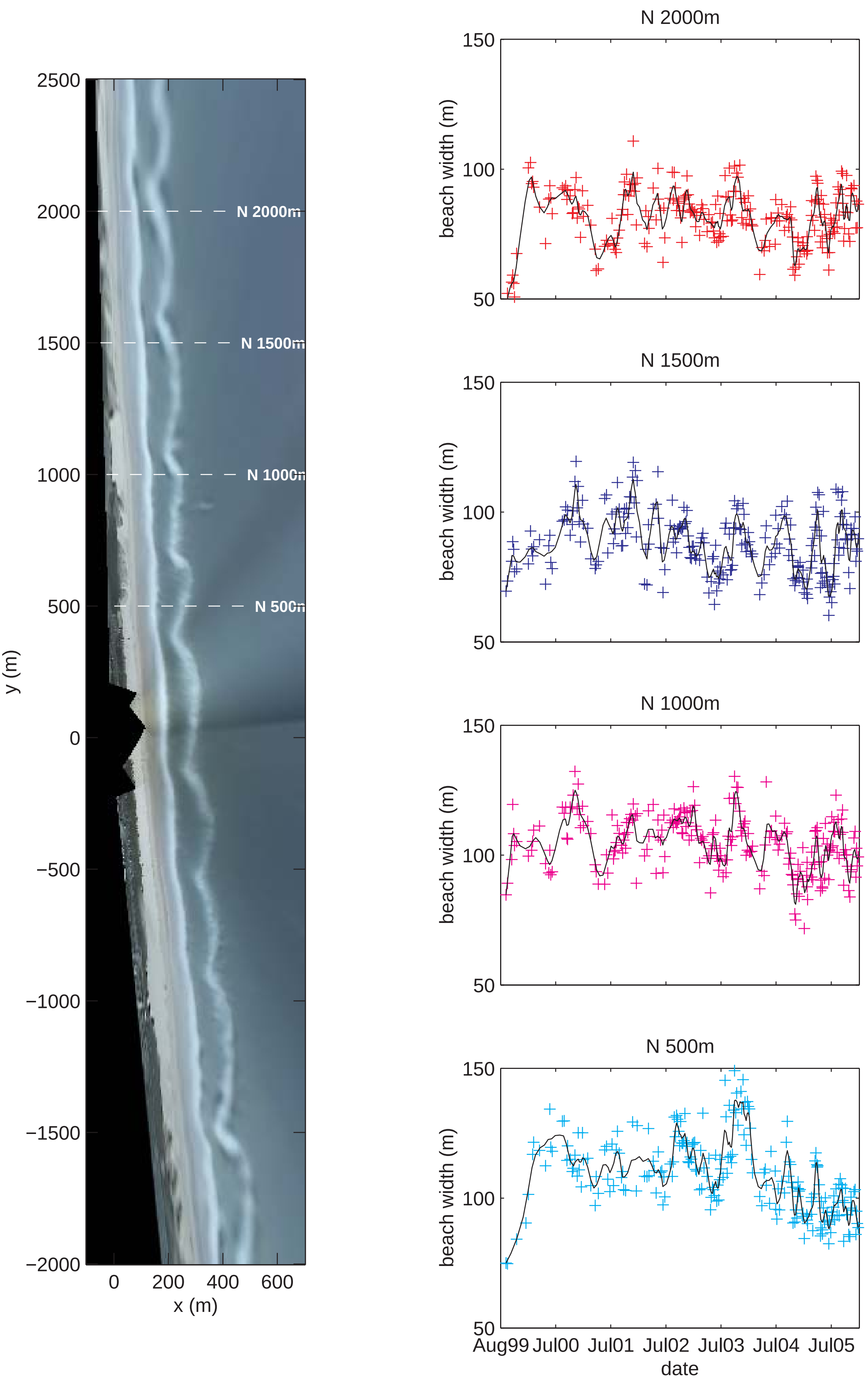
In the upper panel of both these figures the best-fit linear trend to the full 5 years of post-nourishment data is also shown, and along with the detrended data in the middle panel, can be used to estimate the relative magnitude of the diminishing cyclic-seasonal beach changes, relative to longer-term beach 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 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 both figures, the underlying trend at both sites is of a significantly lower magnitude.

To the end of January 2006, at the southern section the net accretionary trend is of the order of 4.2 m/year, while along the northern section, the underlying trend is of the order of -0.2 m/year, that is, a marginal erosional trend. Compared to this same analysis completed six months ago to the end of July 2005, the longer-term accretion trend at the southern beach appears to be increasing, while the corresponding erosion trend observed at the northern beach is diminishing.

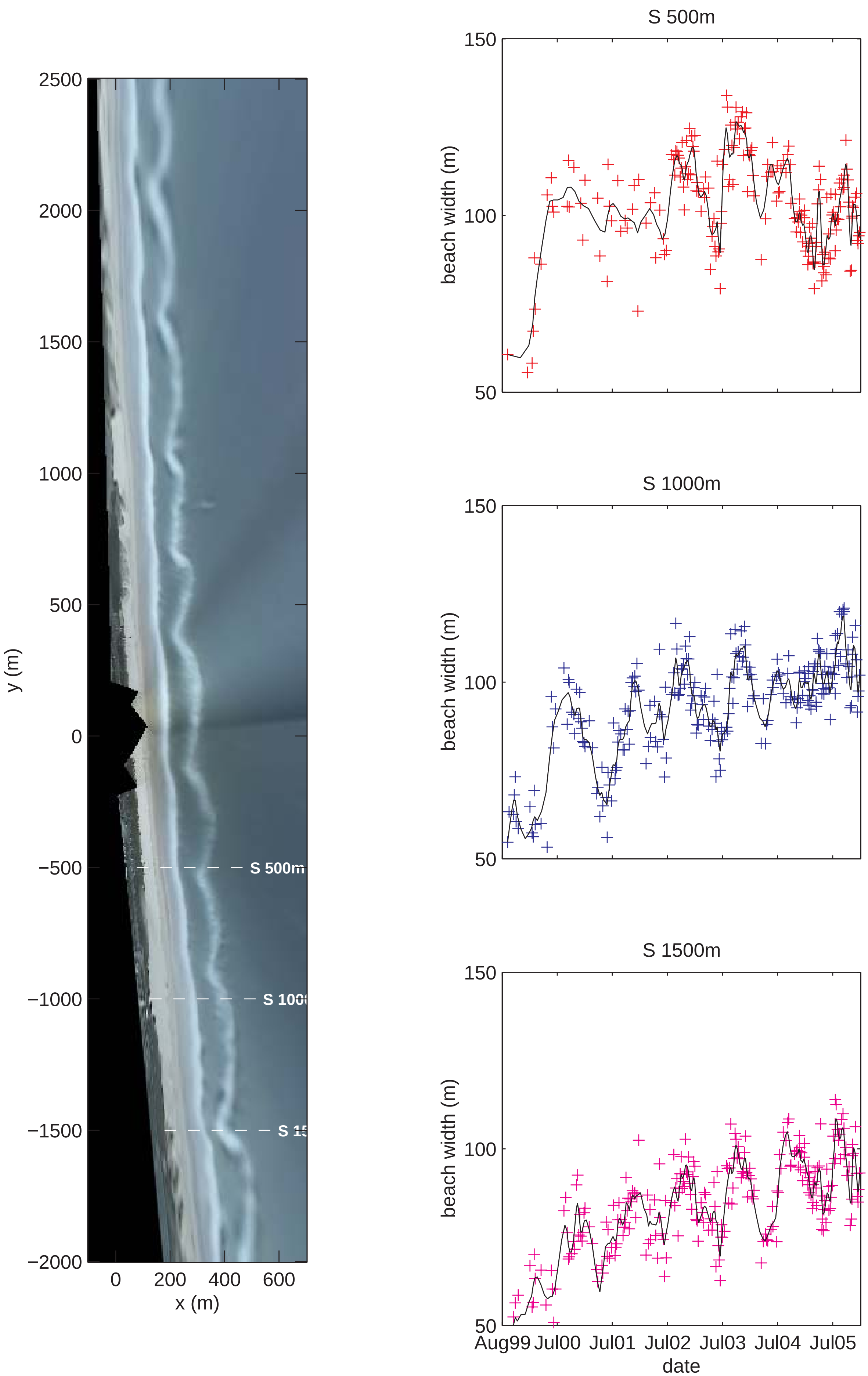
The five years of data upon which these longer-term trends has been inferred is sufficiently long to permit these trends to be used for future forecasting with reasonable degree of confidence, and to draw two important conclusions. The first is that the underlying regional-scale trend at the northern Gold Coast since the completion of sand nourishment in mid 2000 has been net beach accretion in the south of the order 20 m (4.2 m/yr), and marginal erosion in the north of the order of -1 m (-0.2 m/yr). The second conclusion is that, during the three year period from the beginning of 2001 to the end of 2003, 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. Since early 2004, this seasonality appears to have declined.



WRL Report No. 2006/01	WEEKLY BEACH WIDTH: AUGUST 1999 - JANUARY 2006	Figure 7.1 02074-7-1.cdr



WRL Report No. 2006/01	TIME-SERIES OF BEACH WIDTH (NORTH): AUGUST 1999 - JANUARY 2006	Figure 7.2 02074-7-2.cdr



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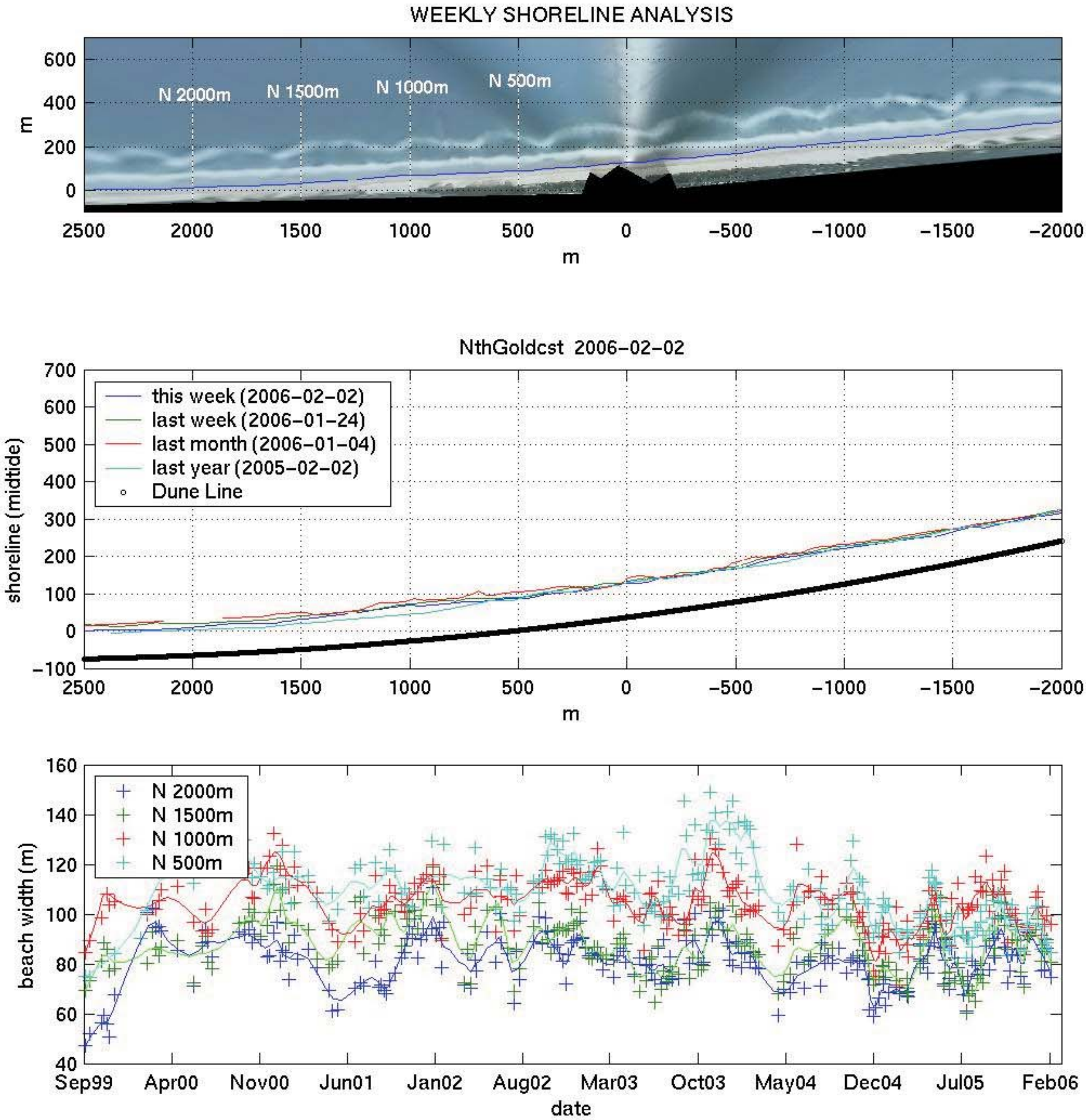
TIME-SERIES OF BEACH WIDTH (SOUTH): AUGUST 1999 - JANUARY 2006

Figure 7.3

02074-7-3.cdr



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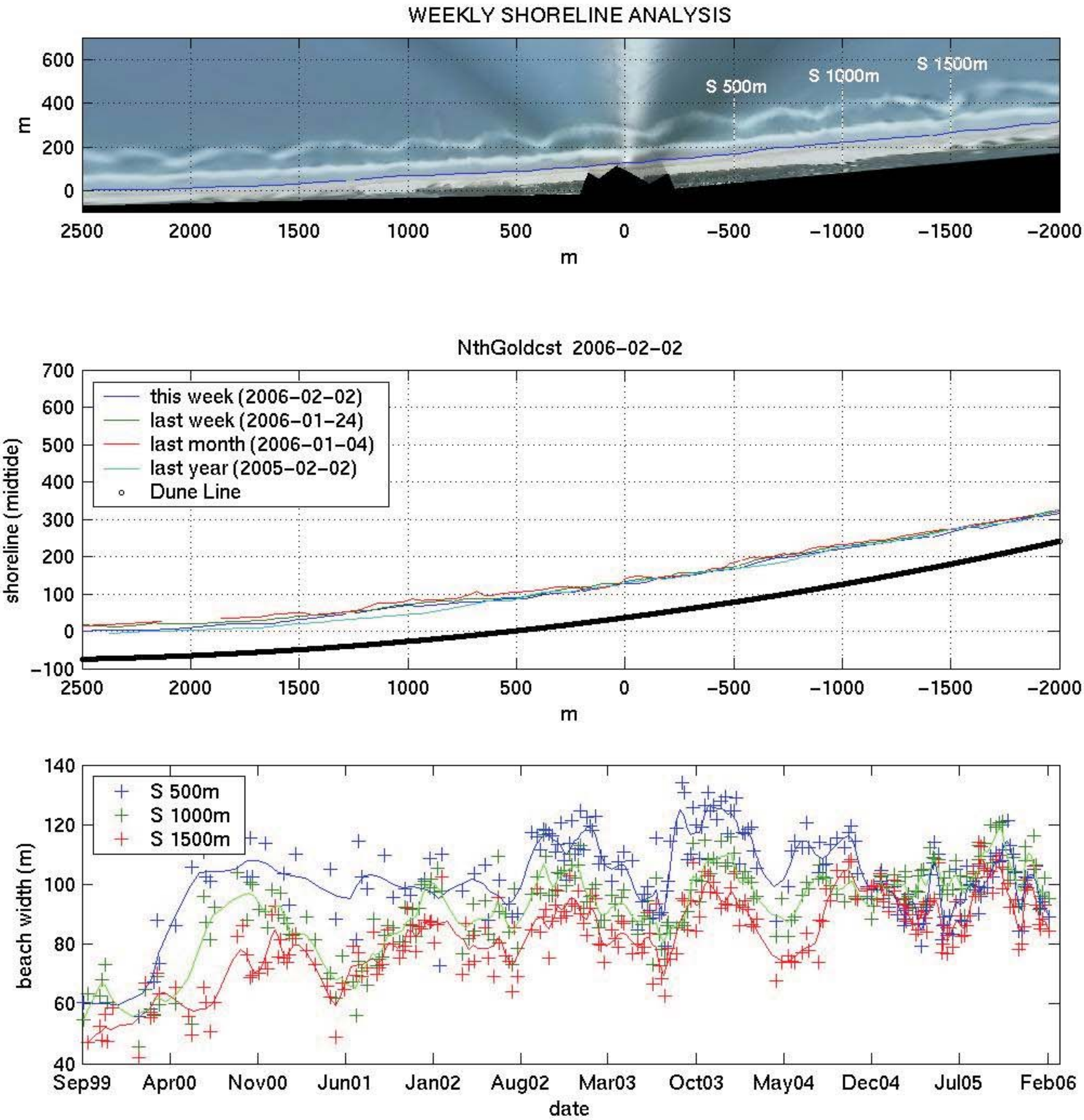
WRL Report No. 2006/01	ON-LINE BEACH WIDTH ANALYSIS: JANUARY 2006 (NORTH)	Figure 7.4

02074-7-4.cdr



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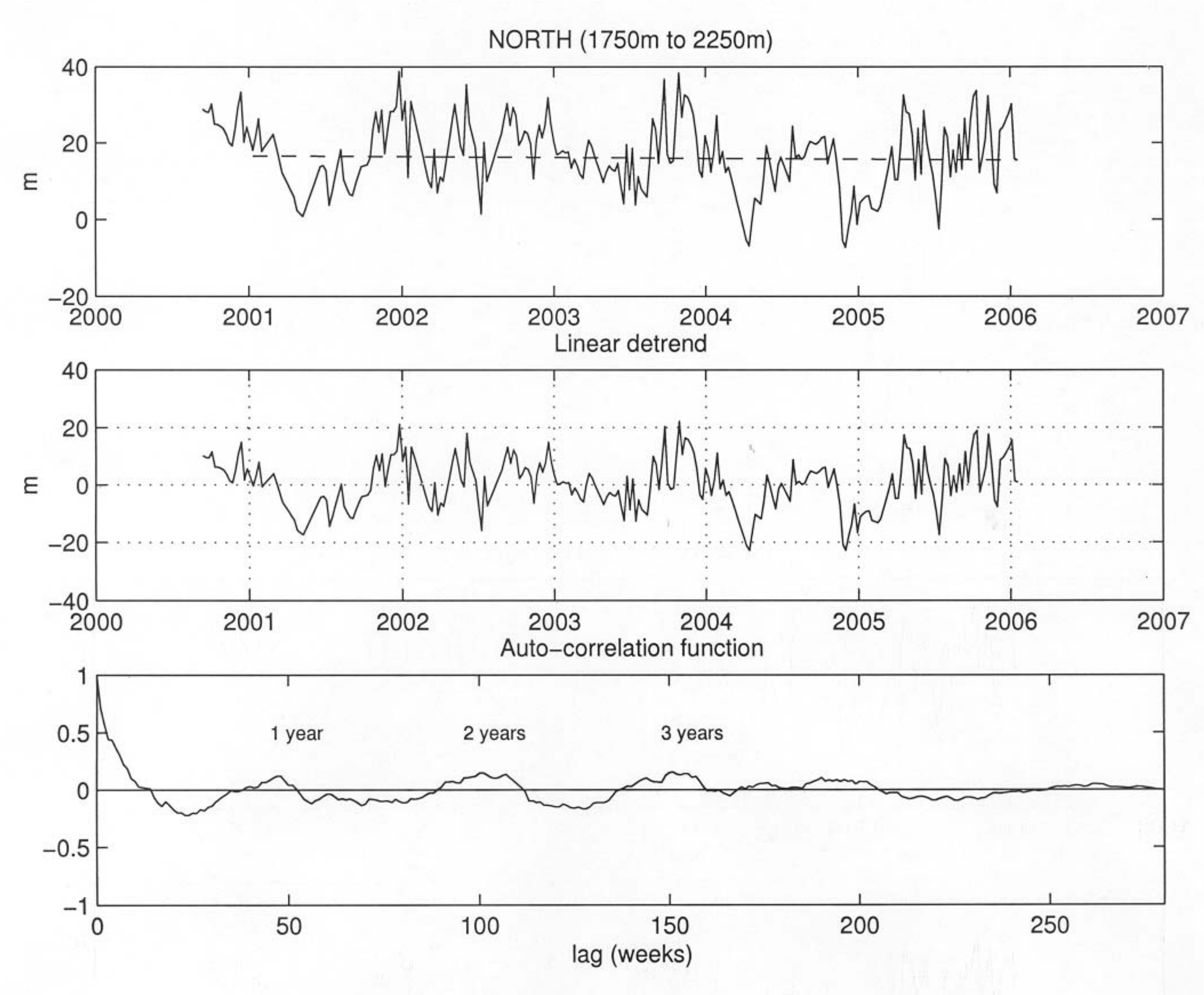
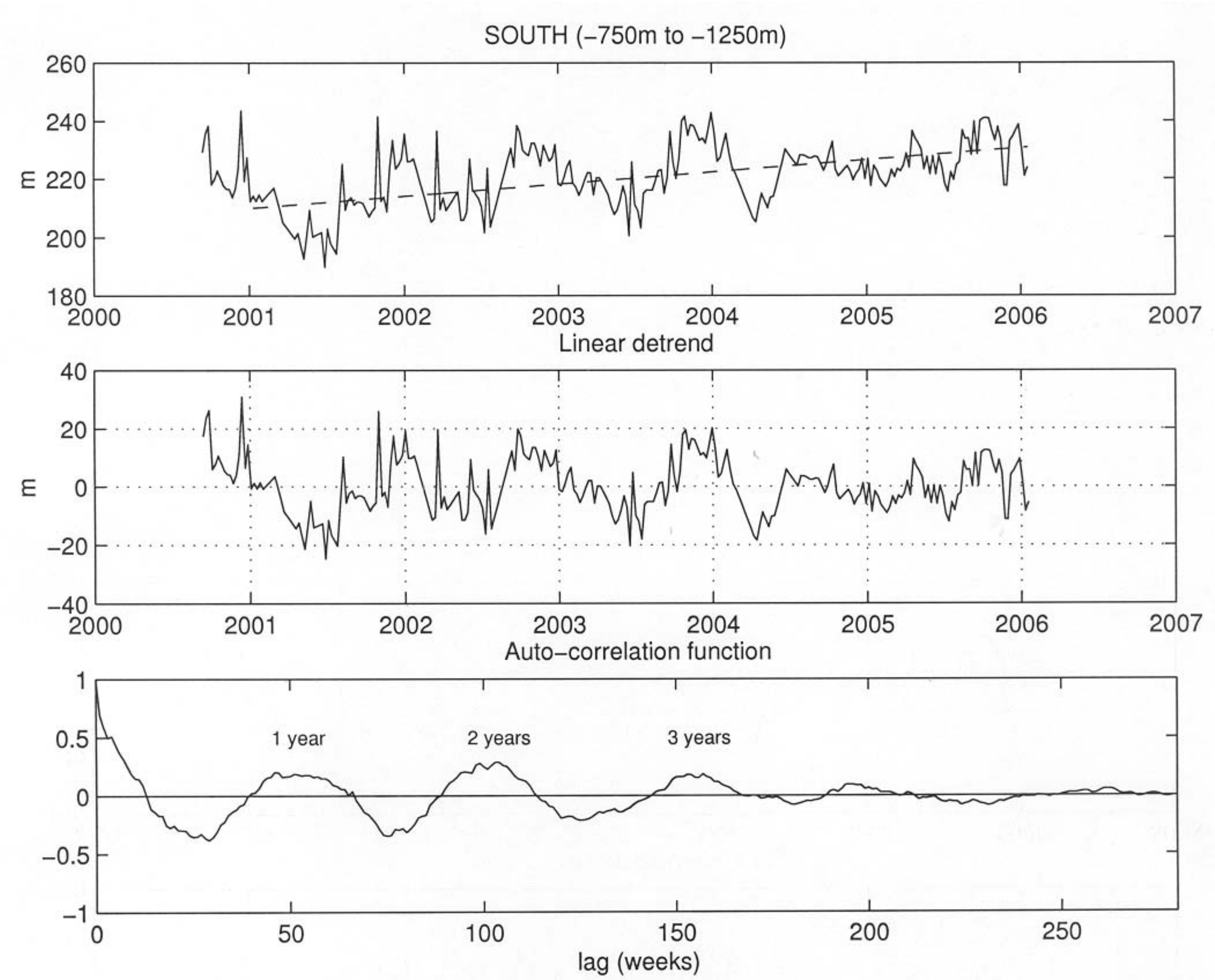
WRL Report No. 2006/01	ON-LINE BEACH WIDTH ANALYSIS: JANUARY 2005 (SOUTH)	Figure 7.5

02074-7-5.cdr



WRL Report No. 2006/01	CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS NORTHERN STUDY SECTION	Figure 7.6 02074-7-6.cdr



CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS
SOUTHERN STUDY SECTION

Figure
7.7

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 2005 – January 2006

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 01/08/05 – 31/02/06 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 2005 to January 2006. 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 30 - 40 m. Figure 8.3 (upper panel) confirms that the maximum and minimum shoreline varied from the mean in a generally uniform manner throughout Narrowneck. 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 20% reduced shoreline variability, relative to the regions immediate north and south.

Figure 8.4 shows the weekly shorelines for the present monitoring period August 2005 – January 2006, relative to the mean shoreline position for the preceding monitoring period February 2005 – July 2005. The shoreline alignment at Narrowneck through the present monitoring period exhibits a general trend of accretion to the north and in the lee of the reef, while to the south the beach generally oscillated around the position of the prior six month average shoreline.

Fluctuations of the shoreline position during the present monitoring period August 2005 – January 2006, 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 & R3) and south (R1 & 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 same general trends are evident: a generally stable beach August – October, slightly decreasing beach width October – November, followed by a period of recovery in December. As noted in previous Section 7, the slight decrease in beach width in the latter part of 2005 during mild wave conditions is interpreted to have resulted from the onshore movement of sand within the adjacent low-tide terrace. Mild erosion and the commencement of recovery was observed in January 2006, in response to the single storm event during this time. At the end of January 2006, the beach widths in the vicinity of Narrowneck were typically within 5 m of the conditions that prevailed six month previously at the end of July 2005.

8.2 Total Monitoring Period: August 1999 – January 2006

Figure 8.6 shows the changing shoreline position for the entire 78 month monitoring period August 1999 to January 2006 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.

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 the present monitoring period August 2005 to January 2006 resulted in little net change to beach width during this time.

By the end of the present six month monitoring period the beach width immediately north of the Narrowneck reef (R1 and R2) was approximately 20 m wider than was recorded at the commencement of monitoring six 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 this figure is a low estimate of the net increase in beach width since August 1999, that has occurred at this location since implementation of the NGCBPS.

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, the generally mild wave conditions that prevailed through the present monitoring period August 2005 to January 2006 resulted in little net change to beach width during this time.

By the end of January 2006 the beach to the south (up-drift) of the reef was of the order of 25 m wider than at the commencement of monitoring. In the lee of the reef, an additional 20 m had been maintained.

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 2006 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 five year period January 2001 to January 2006 is of the order of ± 20 m annually. Again, commencing mid 2004, the strongly seasonal- cyclic trend of the preceding 3 year period appears to have diminished, though not to the degree observed at the northern and southern beaches. 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 five year period to January 2006 is estimated to be of the order of -2.3 m per year (erosion). This 5-year erosion trend is decreasing, relative to the 4.5 year trend last reported at the end of July 2005 (refer Turner, 2005b).

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Report No. 2006/01

WEEKLY SHORELINES AT NARROWNECK:
AUGUST 2005 - JANUARY 2006

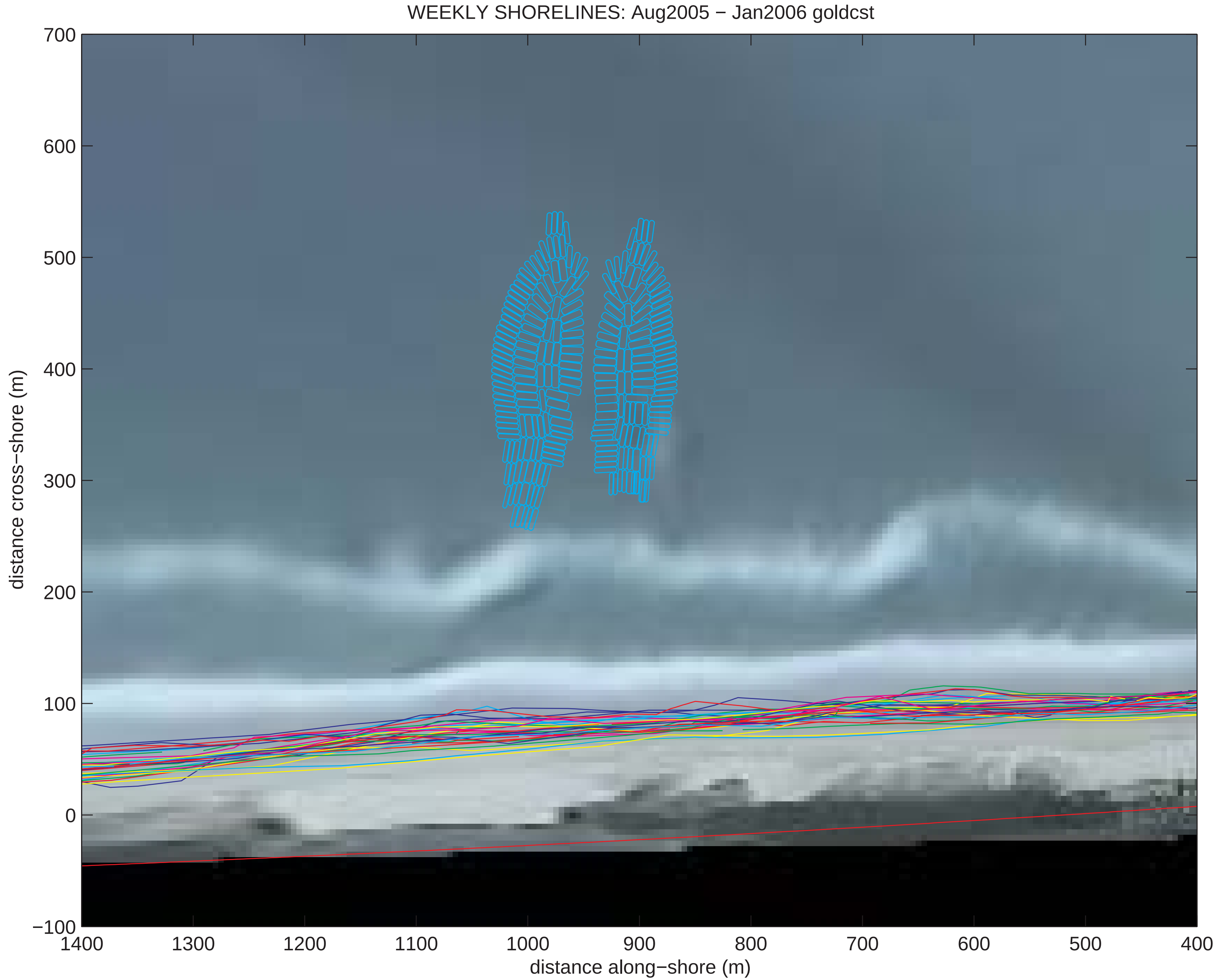
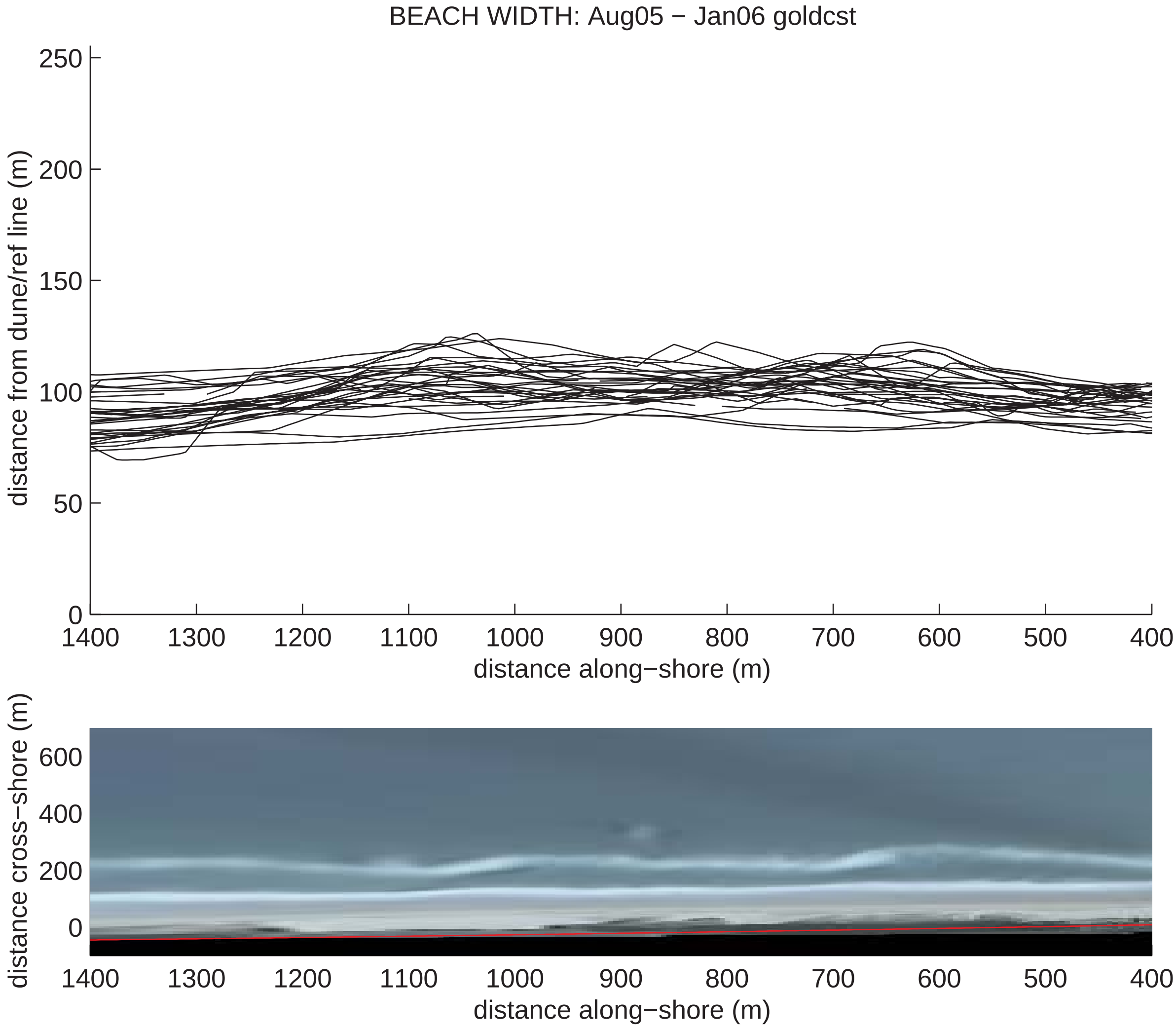
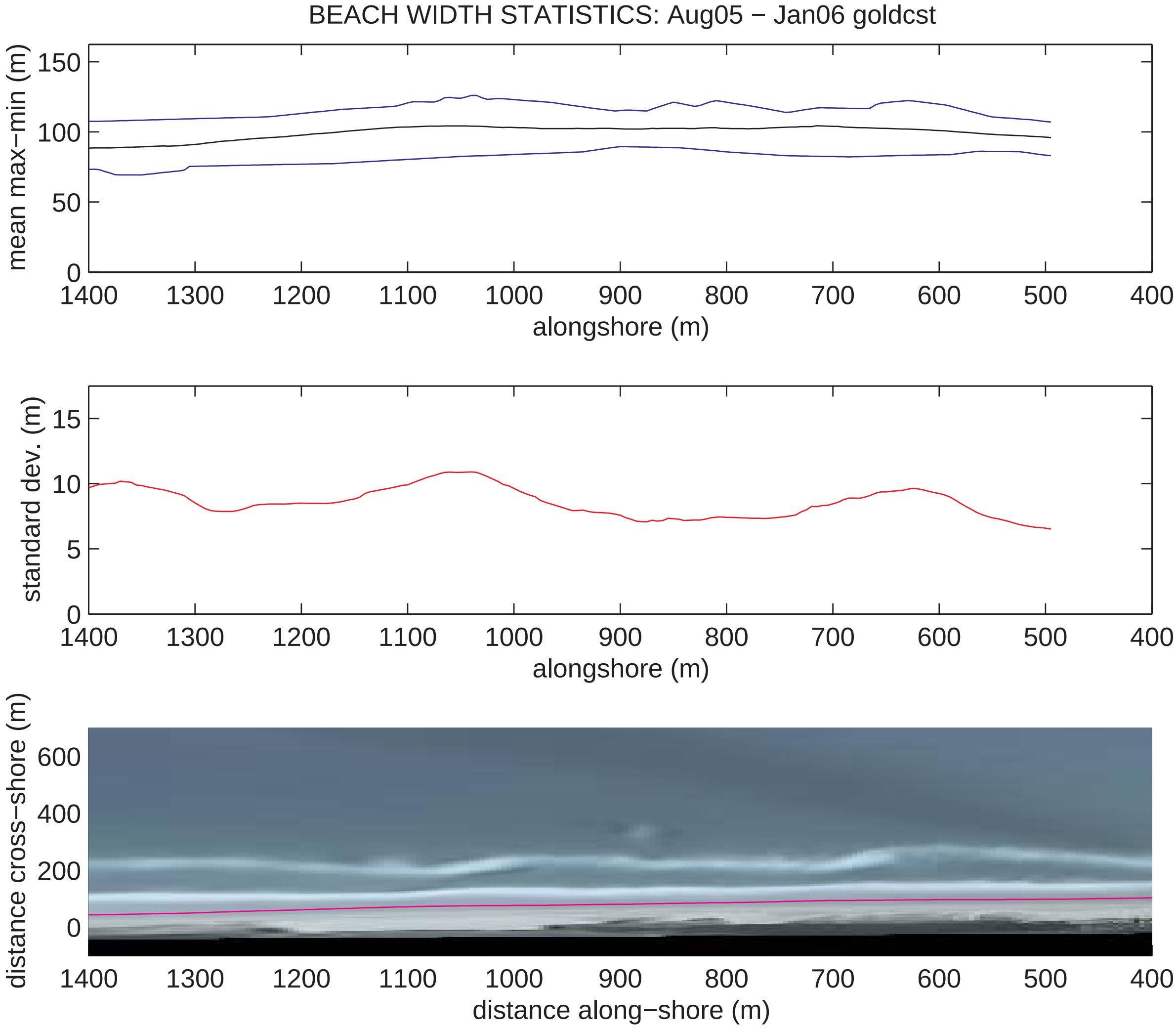


Figure
8.1

02074-8-1.cdr

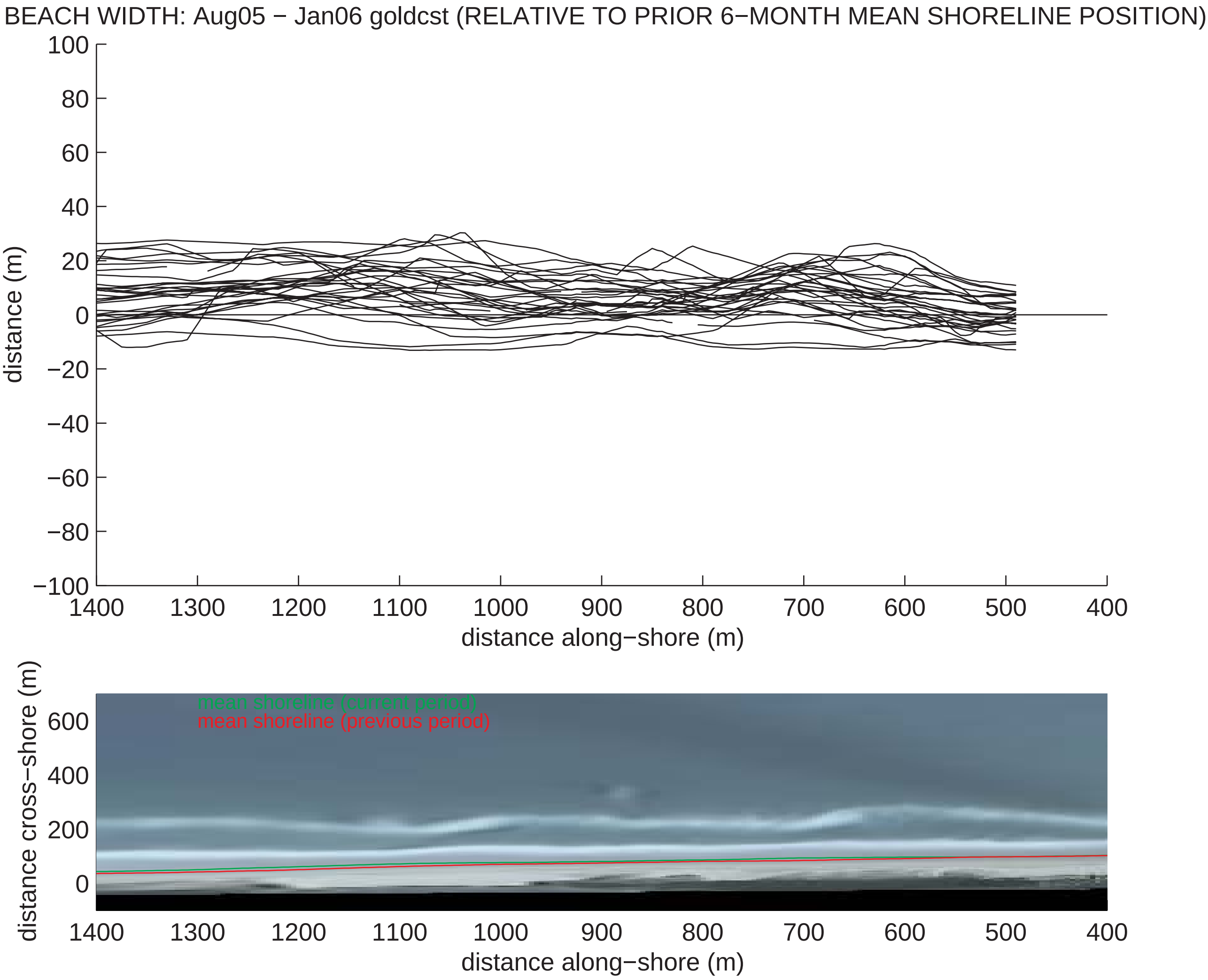


WRL Report No. 2006/01	BEACH WIDTH AT NARROWNECK: AUGUST 2005 - JANUARY 2006	Figure 8.2 02074-8-2.cdr



WRL Report No. 2006/01	STATISTICAL SUMMARY OF BEACH WIDTH CHANGES AT NARROWNECK: AUGUST 2005 - JANUARY 2006	Figure 8.3

02074-8-3.cdr



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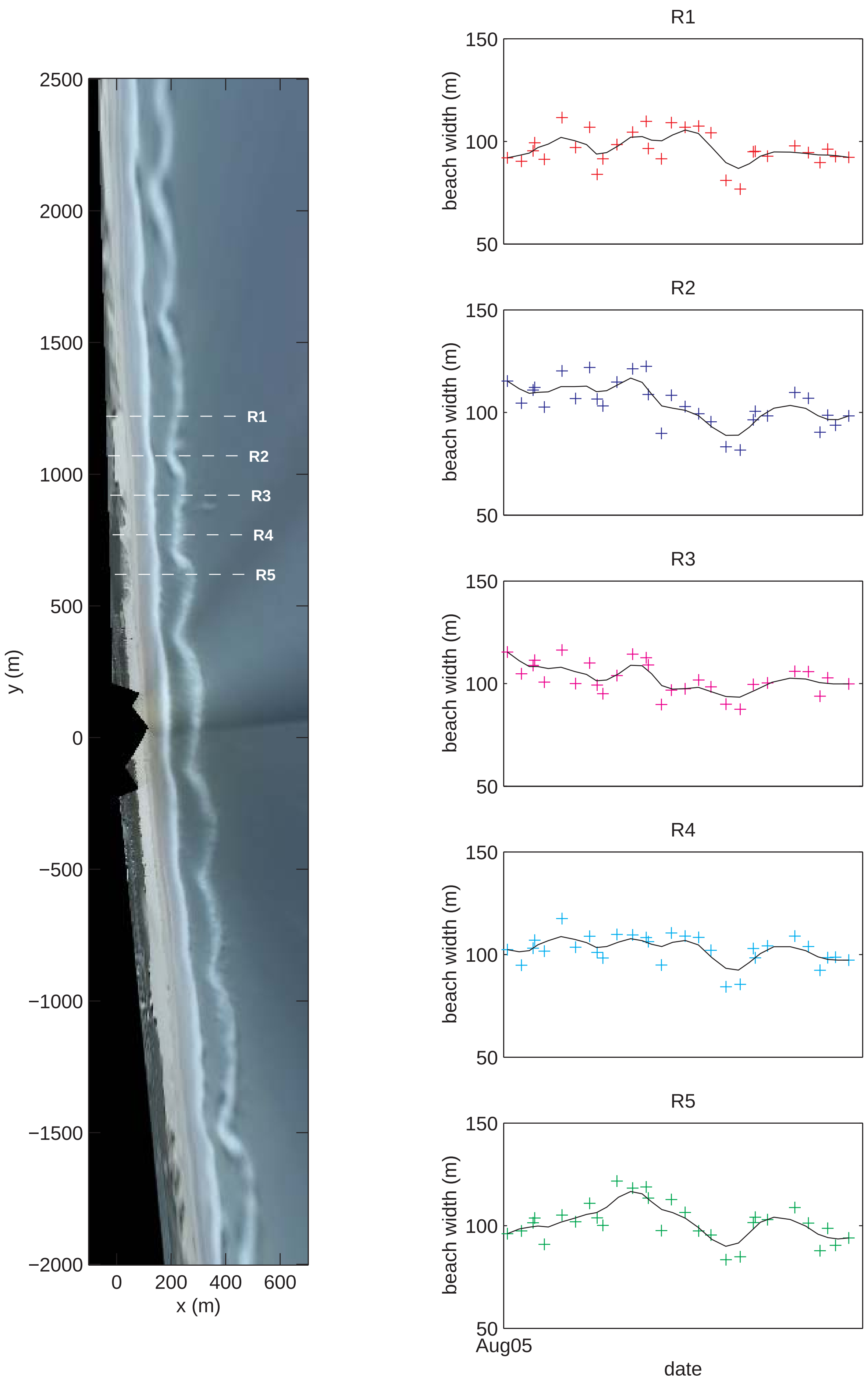
Report No. 2006/01

WEEKLY BEACH WIDTH CHANGES AT NARROWNECK
AUGUST 2005 - JANUARY 2006
RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION

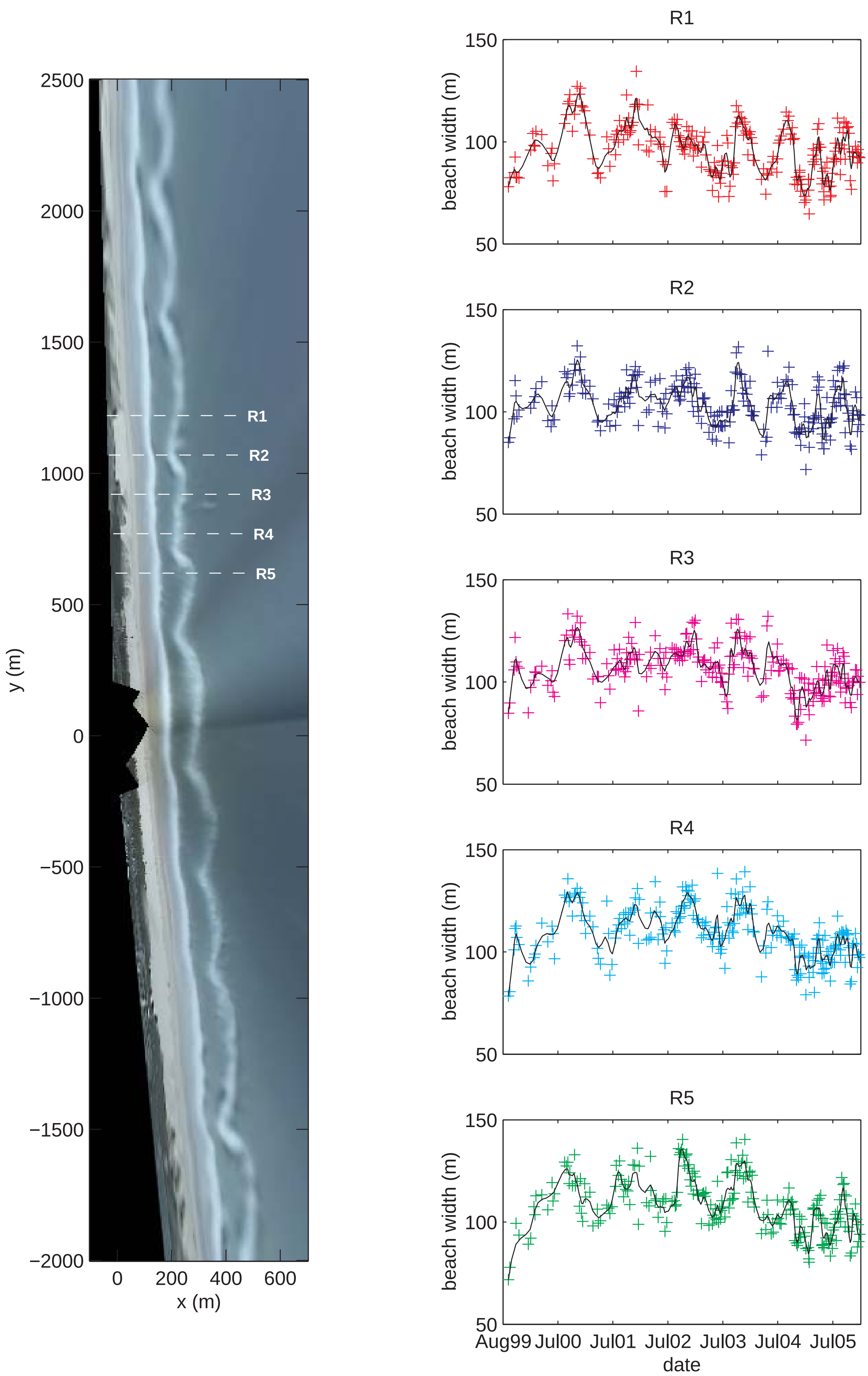
Figure 8.4

02074-8-4.cdr

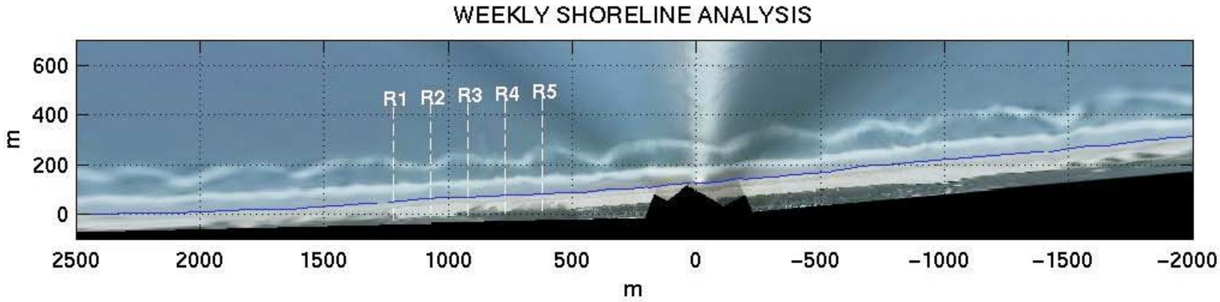


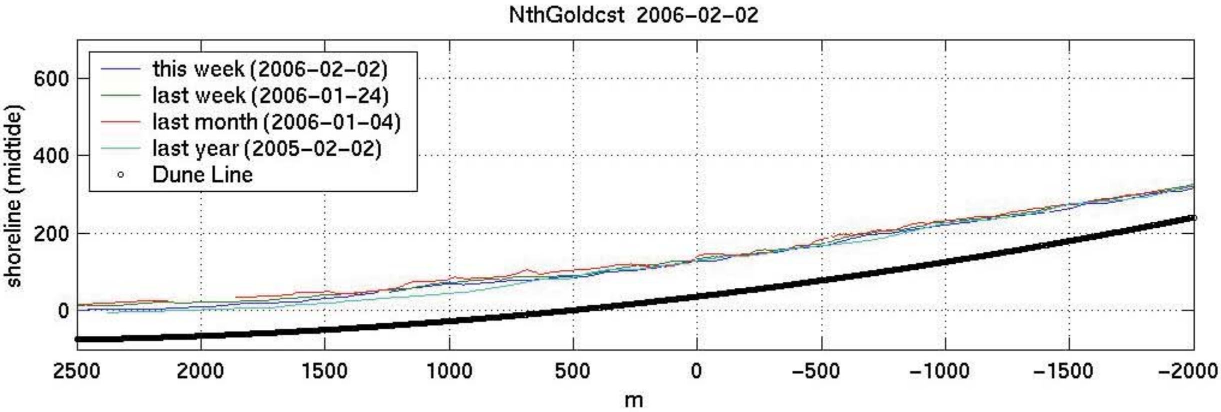
WRL Report No. 2006/01	TIME-SERIES OF BEACH WIDTH AT NARROWNECK: AUGUST 2005 - JANUARY 2006	Figure 8.5

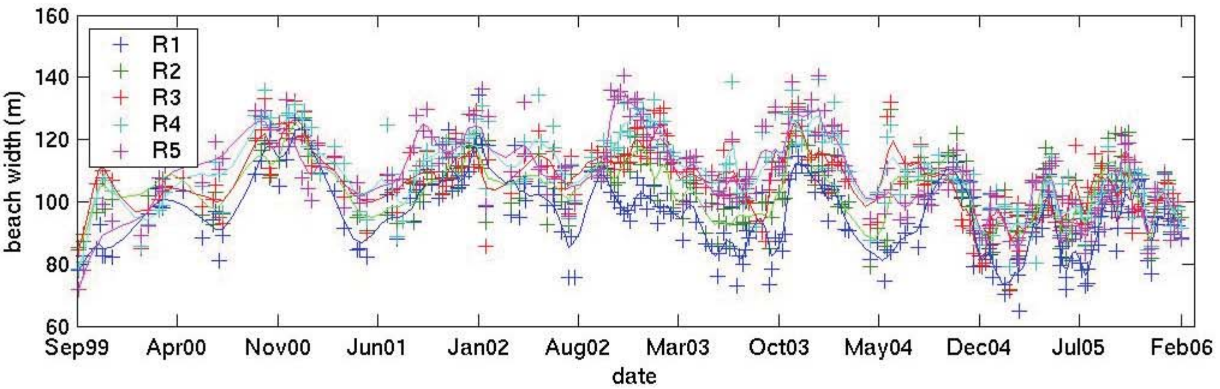
02074-8-5.cdr



WRL Report No. 2006/01	TIME-SERIES OF BEACH WIDTH AT NARROWNECK: AUGUST 1999 - JANUARY 2006	Figure 8.6 02074-8-6.cdr







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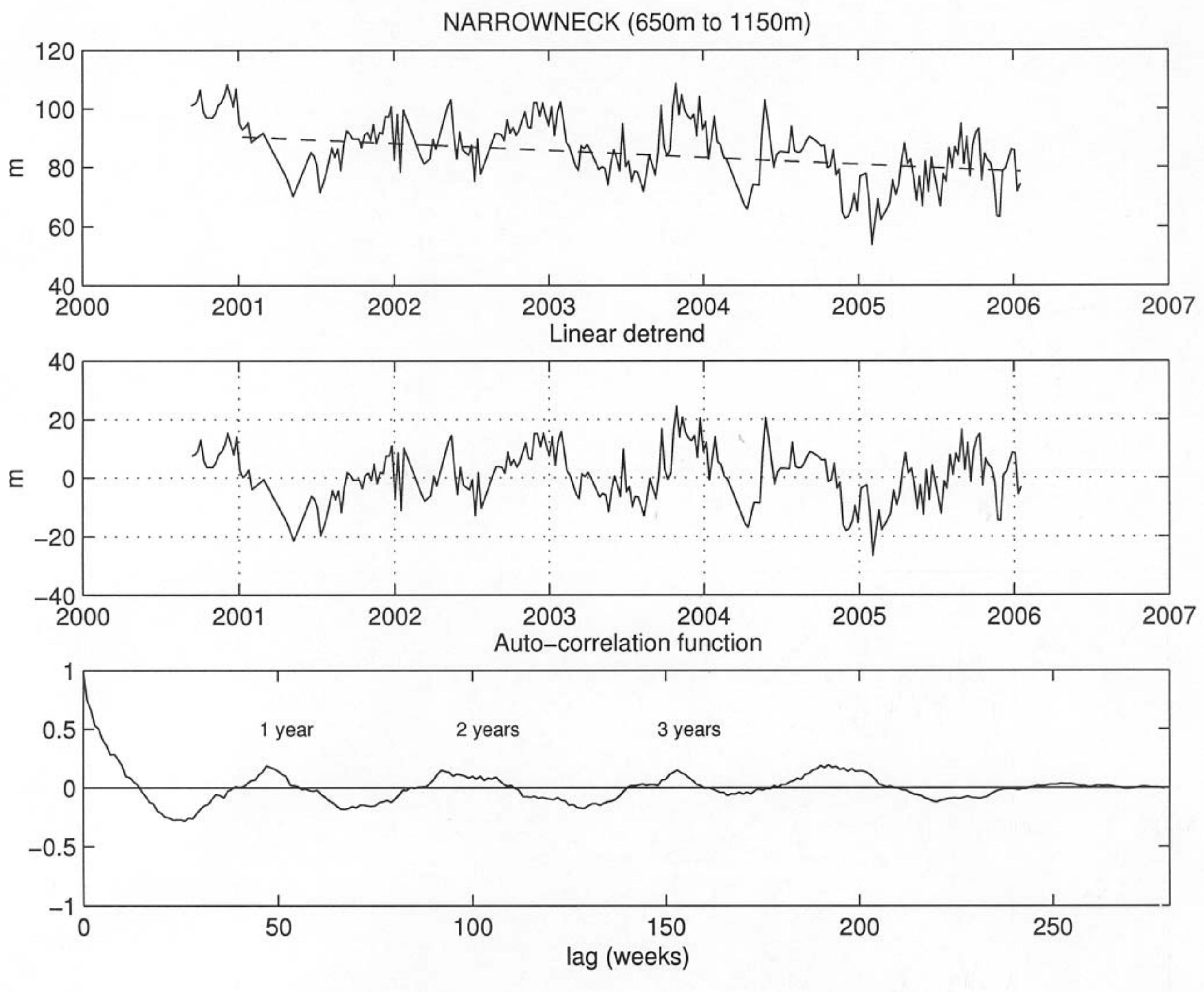
ON-LINE BEACH WIDTH ANALYSIS:
JANUARY 2006 (REEF)

Figure 8.7



CYCLIC SEASONAL VERSUS LONGER-TERM TRENDS
NARROWNECK

Figure
8.8

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 (2005). 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 16th August 2005 and 18th September 2005 are shown in Figure 9.2, 14th October 2005 and 9th November in Figure 9.3, 8th December 2005 and 14th January 2006 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.

From August to September (Figure 9.2) the shoreline developed lower energy crescentic features, which then became more subdued in October and November (Figure 9.3), evident by the more linear beachface morphology at this time. The beachface was also observed to steepen, consistent with previous observations that sand within the low tide terrace moved onshore in the latter part of 2005. In December 2005 the low tide terrace widened again, with the crescentic features complete removed in January 2006 (Figure 9.4), following the onset of a single higher energy storm wave event.

9.3 Monthly Erosion-Accretion Trends

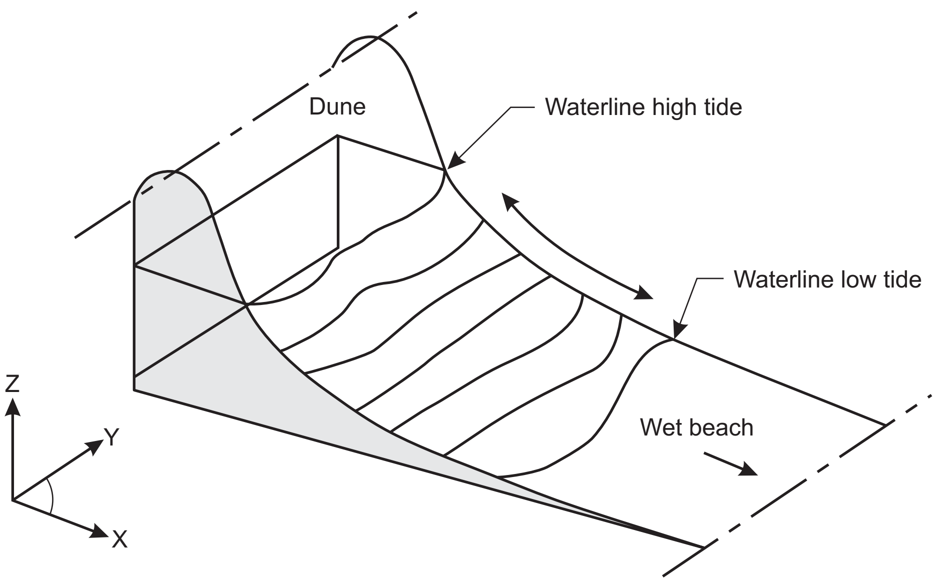
By further processing of the monthly bathymetries shown in Figures 9.2 - 9.4, a quantitative measure of the net change in sand volumes across the beachface (between -0.5 and + 0.7 m AHD) around Narrowneck can be obtained. Figure 9.5 shows the results of these calculations to determine the monthly net change in beachface elevation between August and November 2005, and Figure 9.6 summarises the monthly beachface changes between November 2005 and January 2006.

The top panel of Figure 9.5 reveals that in August-September 2005 net beachface accretion occurred at Narrowneck, with over half a metre of sand deposited in regions to the north and south of the reef. During the period 16th August to 18th September the net beachface accretion along this 1000 m of beach was around +14,194 m^3 (+14.1 m^3 per metre shoreline, between -0.5 and + 0.7 m AHD).

From September 18th to October 14th more limited accretion across the upper beachface continued, however, the lower beachface decreased in elevation by 0.2 – 0.4 m, resulting in the net loss of around -618 m^3 of sand, or -0.6 m^3 per metre shoreline, between -0.5 and + 0.7 m AHD. This subtle erosion trend continued from October 14th to November 9th (-3,797 m^3, or -3.6 m^3 per metre shoreline), November 9th to December 8th (-1,198 m^3, or -1.2 m^3 per metre shoreline), and again from December 8th 2005 to January 14th 2006 (-5,362 m^3, or -5.3 m^3 per metre shoreline).

9.4 Net Erosion-Accretion Trends: August 2005 - January 2006

Despite one month of net accretion followed by five straight months of net erosion as described above, the net trend for the entire six-month period August 2005 to January 2006 was beachface accretion at Narrowneck. Referring to Figure 9.7, from 18th August 2005 to 14th January 2006 the 1000 m length of beach at Narrowneck accreted by +3,219 m^3, or +3.2 m^3 per metre shoreline (between -0.5 and + 0.7 m AHD). The area of greatest accretion occurred to the north of the reef, with only minor net change in sand volumes in the lee of the reef and to the south. In contrast to the two proceeding six month monitoring periods, any impacts of the reef on observed erosion-accretion trends at Narrowneck were not discernable during the present period.



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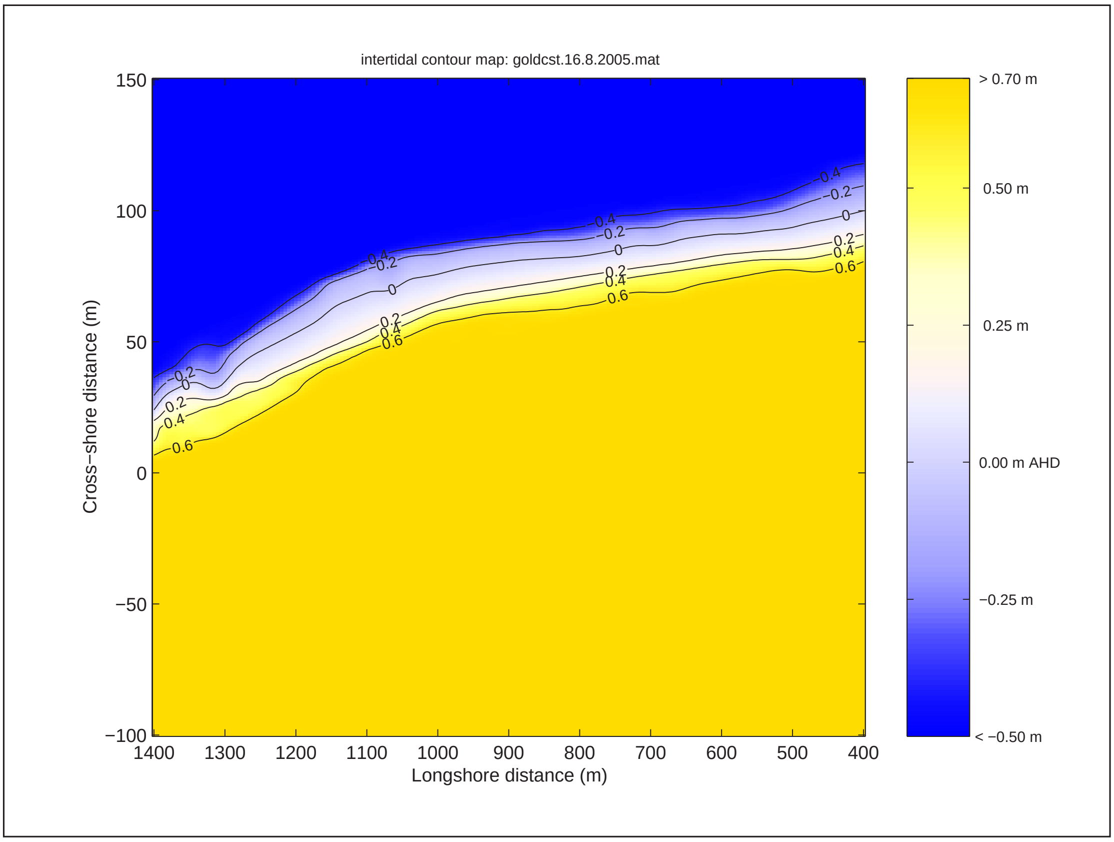
DEFINITION SKETCH
INTERTIDAL BATHYMETRY FROM HOURLY WATERLINES

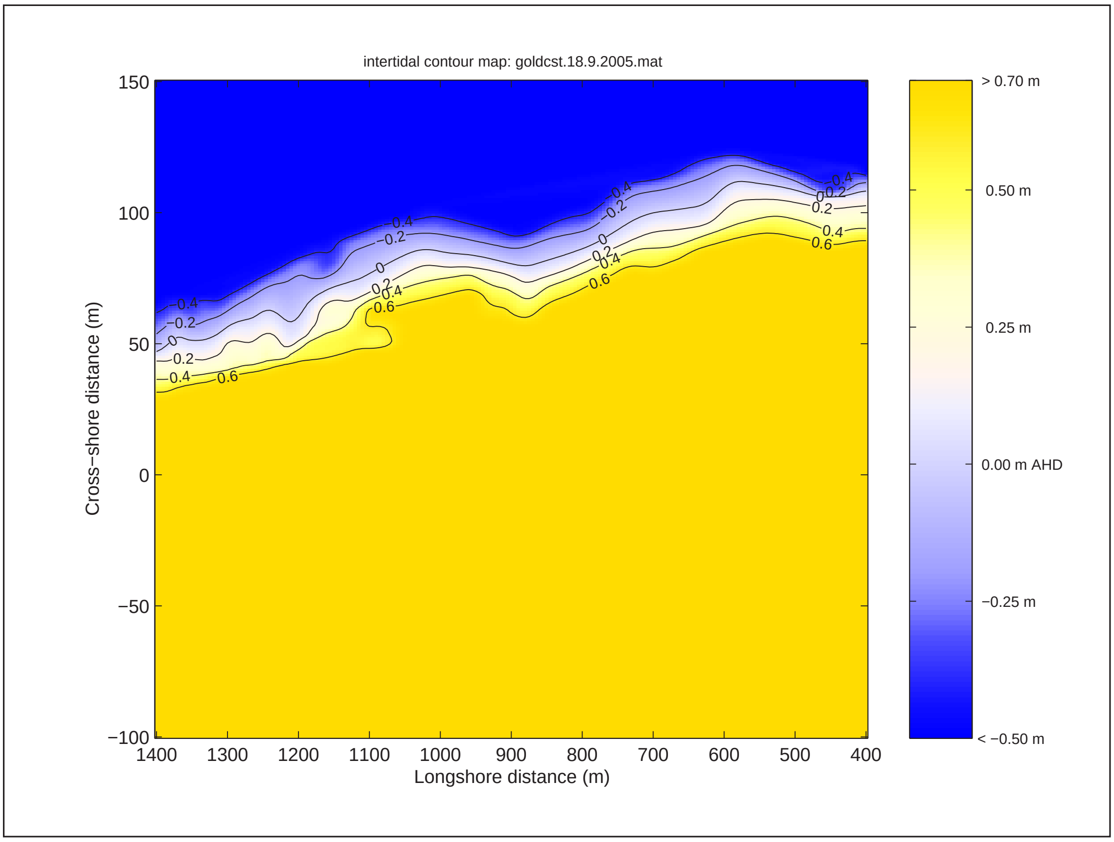
Figure
9.1

02074-9-1.cdr

AUGUST 2005

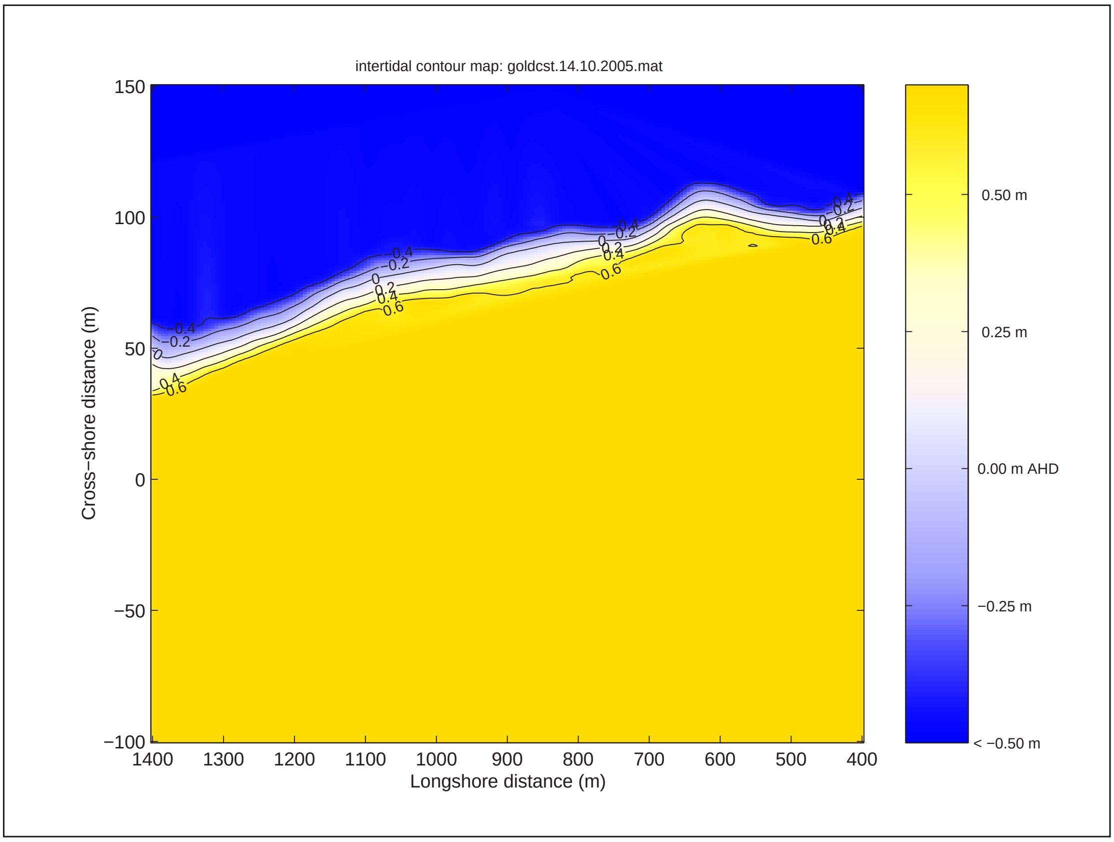


SEPTEMBER 2005

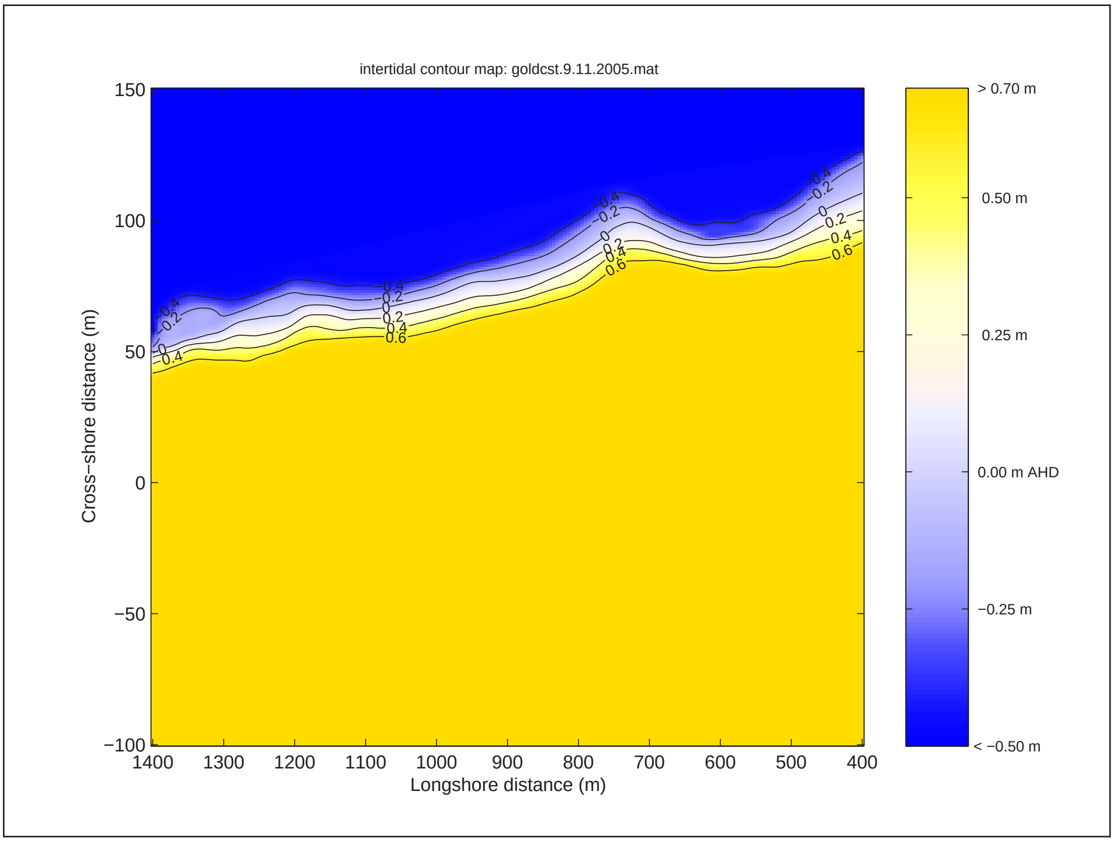


WRL Report No. 2006/01	BEACHFACE MAPPING AUGUST, SEPTEMBER 2005	Figure 9.2 02074-9-2.cdr

OCTOBER 2005

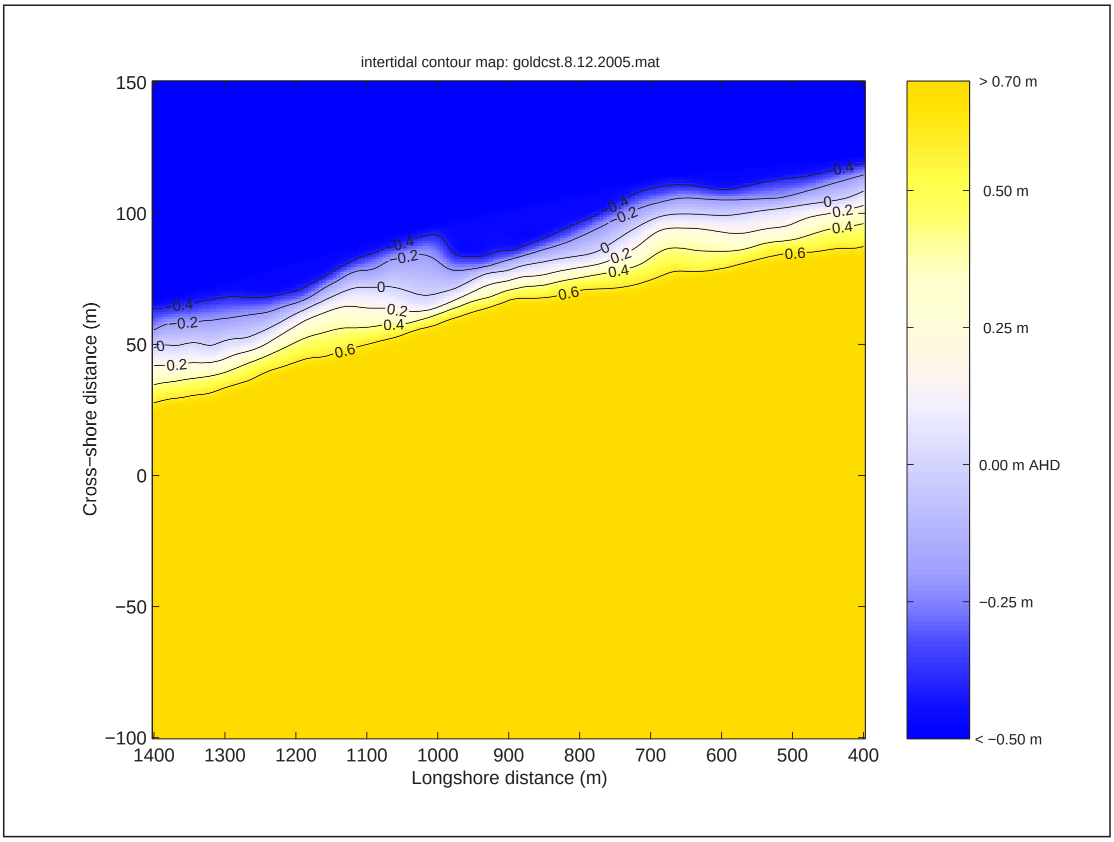


NOVEMBER 2005

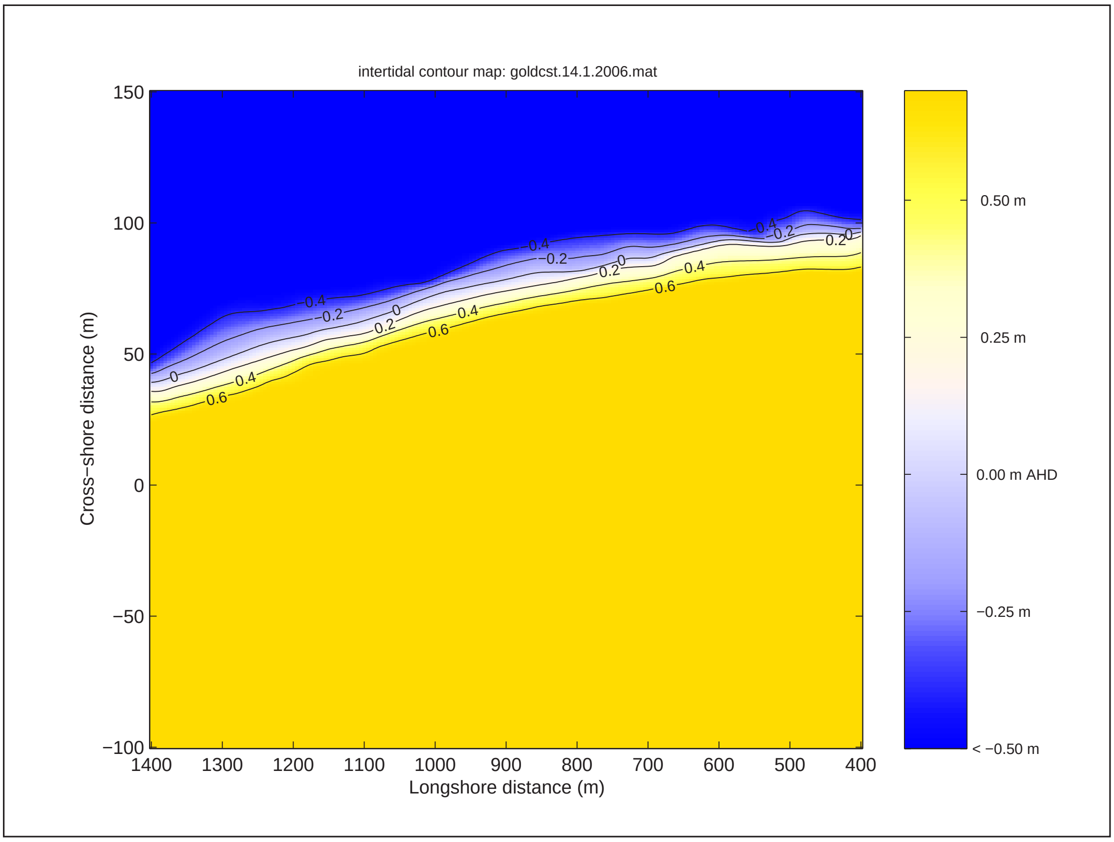


WRL Report No. 2006/01	BEACHFACE MAPPING OCTOBER, NOVEMBER 2005	Figure 9.3 02074-9-3.cdr

DECEMBER 2005



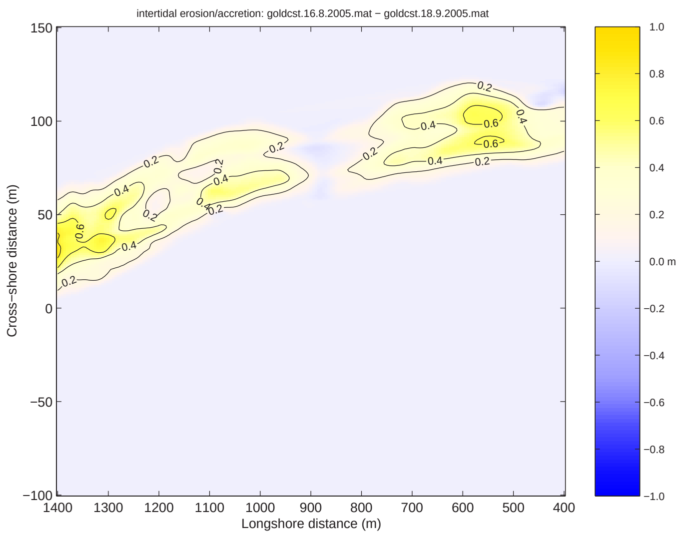
JANUARY 2006



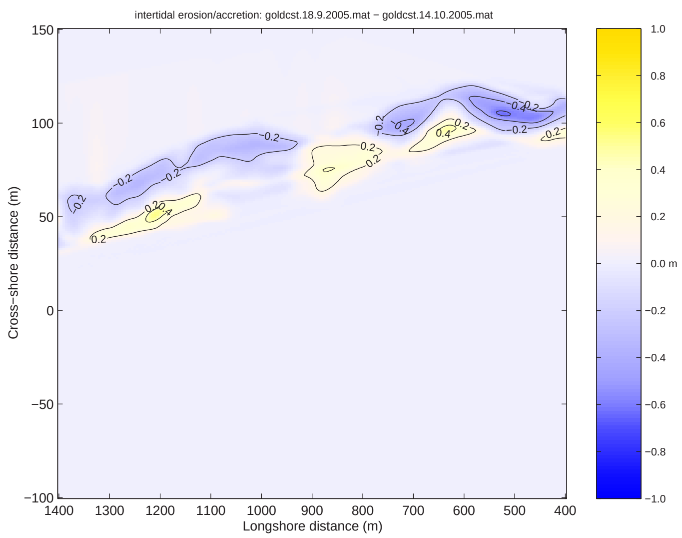
WRL Report No. 2006/01	BEACHFACE MAPPING DECEMBER 2005, JANUARY 2006	Figure 9.4

02074-9-4.cdr

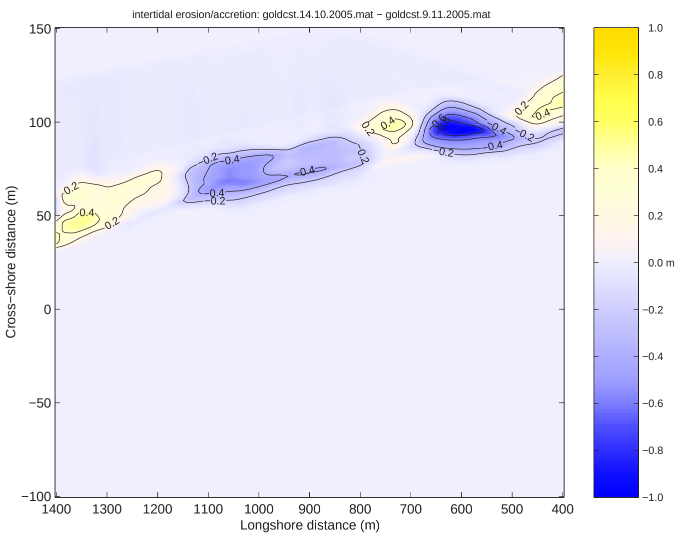
AUGUST - SEPTEMBER 2005



SEPTEMBER - OCTOBER 2005



OCTOBER - NOVEMBER 2005



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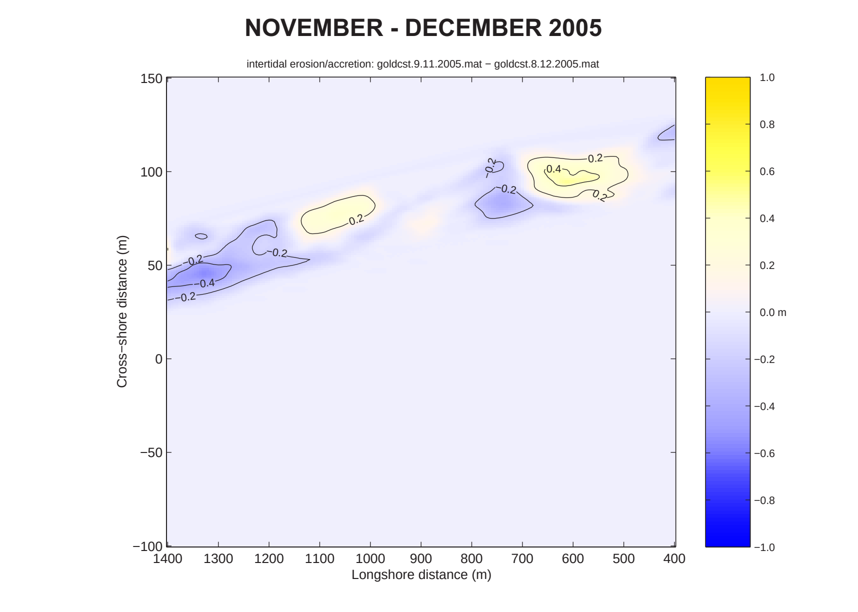
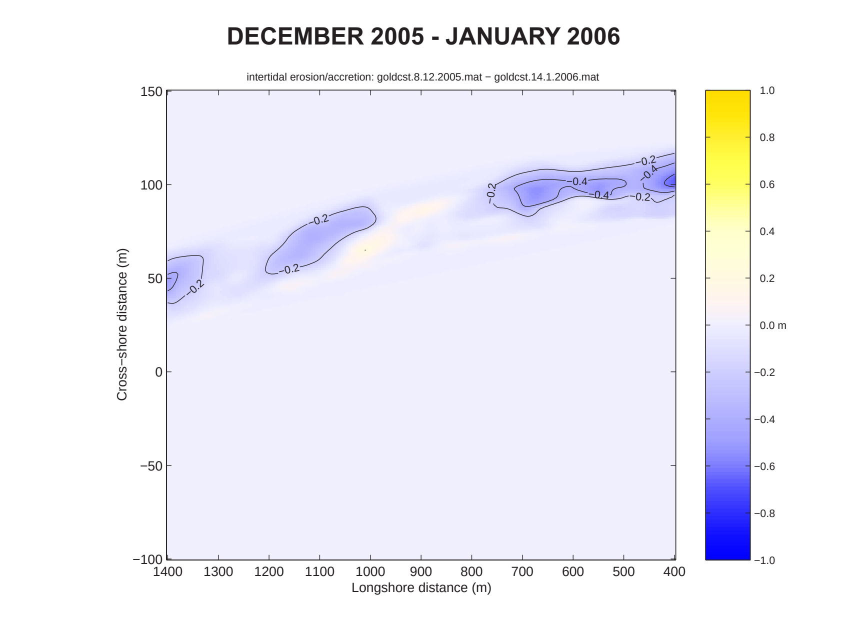
Report No. 2006/01

MONTHLY EROSION/ACCRETION:
AUGUST - OCTOBER 2005

Figure 9.5

02074-9-5.cdr





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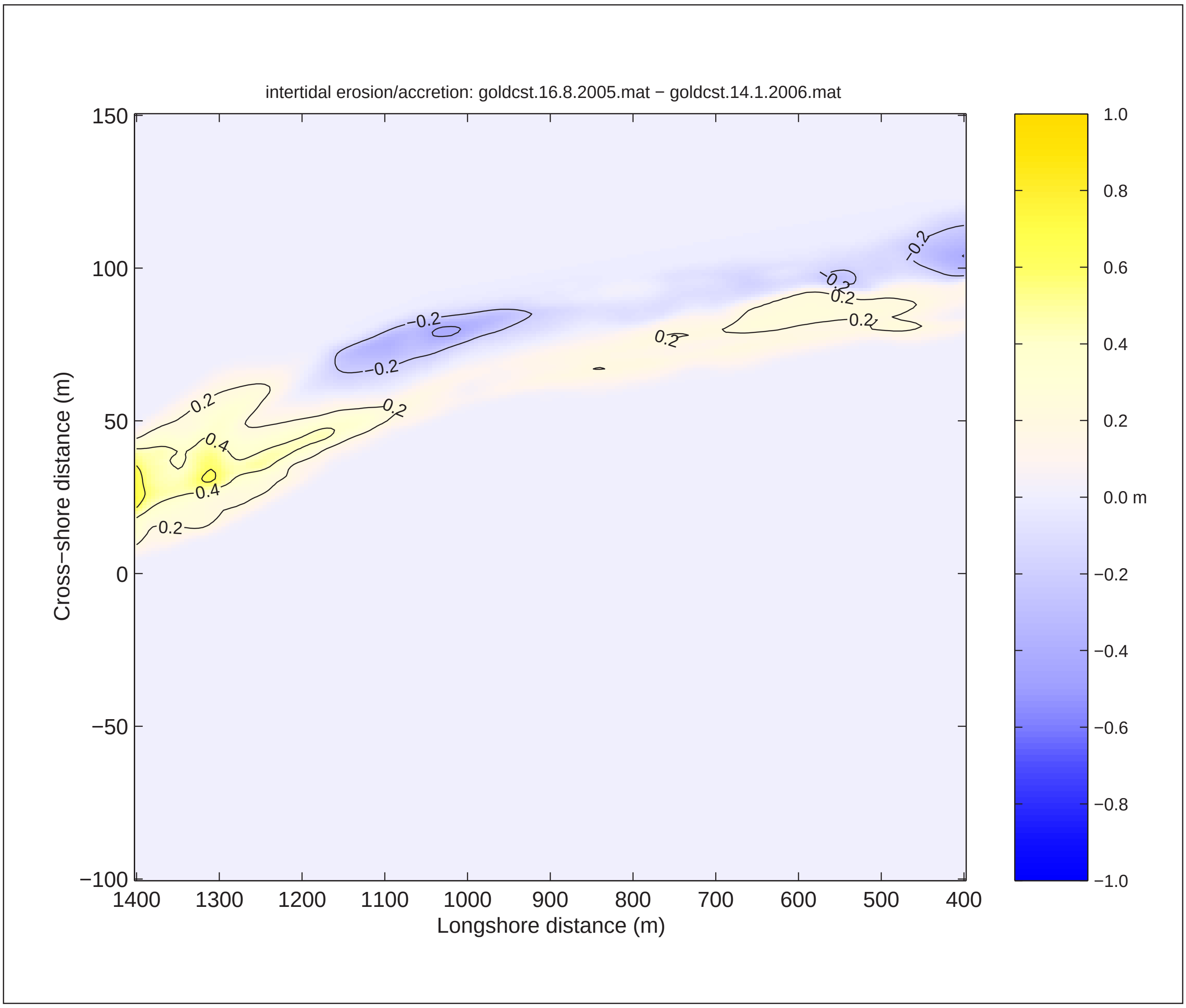
Report No. 2006/01

MONTHLY EROSION/ACCRETION:
NOVEMBER 2005 - JANUARY 2006

Figure
9.6

02074-9-.cdr

NET CHANGE: AUGUST 2005 - JANUARY 2006



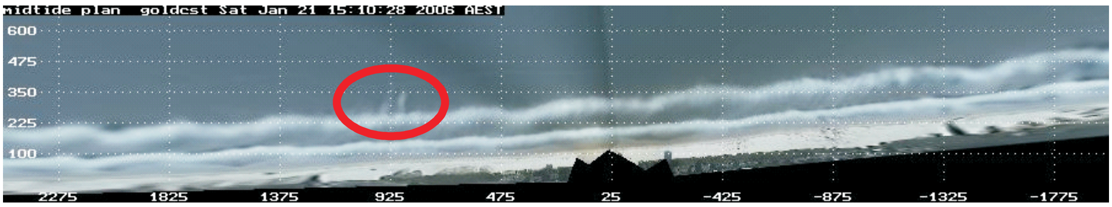
WRL Report No. 2006/01	NET EROSION/ACCRETION: AUGUST 2005 - JANUARY 2006	Figure 9.7 02074-9-7.cdr

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 21st January 2006).

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. 2006/01	VISIBLE WAVE BREAKING ON REEF (21st JANUARY 2006)	Figure 10.1 02074-10-1.cdr

11. CONCLUSIONS

The present six month monitoring period to January 2006 marks five and a half years since the completion of beach nourishment in June 2000 at the northern Gold Coast, and five 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

Beach and nearshore conditions during the present monitoring period August 2005 to January 2006 were characterised by persistently mild wave energy conditions, with offshore significant wave heights exceeding 3 m on one occasion only, and just six short-duration events when offshore significant wave heights exceeded 2 m. The outer bar moved onshore and offshore in response to varying incident wave energy, straightening (TBT morphology) as it moved offshore in response to increased wave energy, then developing more crescentic features and moving inshore (RBB – TBR morphology) in response to the mild wave conditions that were more typical of this period. The inner bar remained welded to the beachface (LTT) though most of this same six month period, only partially detaching once from the shore in January 2006, in response to elevated wave energy conditions.

A visual assessment of resulting beach changes during August 2005 to January 2006 (Figure 5.2 and Figure 5.3) reveals that, as per the previous six-month monitoring period, along the southern beach no net change in the visible (subaerial) beach is discernable, with similar conditions also observed along the northern beach. The exception to generally similar conditions at the beginning and end of the present six-month monitoring period was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed.

Extending this qualitative visual assessment of images to include the entire six 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 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.

In February 2005 and six months later in 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. Again, during the current monitoring period August 2005 to January 2006 (Figures 5.4 and 5.5), 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 generally similar conditions at the beginning and end of the present six-month monitoring period was along the northern beach north of Narrowneck, where a general straightening of the beach within this region was observed.

Based upon the quantitative analysis of weekly shorelines during the present monitoring period 01/08/05 – 31/01/06, that the beach along the 4,500 m study region varied in width (relative to the dune reference line) from approximately 70 m to 120 m (Figure 6.2). The envelope of beach width changes is relatively uniform alongshore, generally varying in width along the 4,500 m study region by approximately 30 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 01/08/05 – 31/01/06 was in the range of 90 – 100 m, but can be seen to have varied by approximately 30 m from 80 m to 110 m (Figure 6.3). As was discernible from Figure 6.2, relative to the dune reference line the mean beach width was greatest in the central 1,000 m region of the 4,500 m monitoring area, averaging approximately 100 m. The standard deviation of weekly shorelines from the mean shoreline position during the period 01/08/05 – 31/01/06 was generally in the range of ± 5 - 10 m. During the preceding 12 months of monitoring at the northern Gold Coast (Turner 2005a; Turner 2005b) it was noted that the standard deviation of weekly shorelines was higher in the northern half of the study region, however, trend this was not observed during the present six-month monitoring period.

When the weekly shoreline data for the period August 2005 to January 2006 were re-analysed to assess beach width changes relative to the mean shoreline position for the preceding six month period (Figure 6.4), this analysis shows that during the present monitoring period the beaches of the northern Gold Coast simply oscillated around the mean shoreline position for the preceding six month period. As per the previous six-month monitoring period, and in contrast to more complex changes observed twelve months previously, from August 2005 to January 2006 no discernable net beach width trends were observed. The observation from the present monitoring period of relatively uniform beach changes alongshore is more typical of the general trend observed throughout the total six and a half year monitoring program. The rather atypical observation 12 months ago of a distinct alongshore variability in beach width, did not continue through 2005.

Over the entire 78 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 (Figure 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 through 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 the present 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. 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 the single storm wave event in January caused the beaches to narrow again.

At the completion of six and a half years of monitoring and around five years since the completion of the major phase of beach nourishment of northern Gold Coast beaches, at all southern monitoring sites (Figure 7.3) the beaches have experienced a net accretionary trend. 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.

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 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.

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 2006 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. To the end of January 2006, at the southern section the net accretionary trend is of the order of 4.2 m/year, while along the northern section, the underlying trend is of the order of -0.2 m/year, that is, a marginal erosional trend. Compared to this same analysis completed 6 months ago to the end of July 2005, the longer-term accretion trend at the southern beach appears to be increasing, while the corresponding erosion trend observed at the northern beach is diminishing.

The five years of data upon which these longer-term trends has been inferred is sufficiently long to permit these trends to be used for future forecasting with 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 beach accretion in the south of the order 20 m (4.2 m/yr), and marginal erosion in the north of the order of 1 m (-0.2 m/yr). The second conclusion is that, during the three year period from the beginning of 2001 to the end of 2003, 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. Since early 2004, this seasonality appears to have declined.

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 (Figure 8.8) for the five year period January 2001 to January 2006 is of the order of ± 20 m annually. Again, commencing mid 2004, the strongly seasonal-cyclic trend of the preceding 3 year period appears to have diminished, though not to the degree observed at the northern and southern beaches. The underlying trend at this site for the five year period to January 2006 is estimated to be of the order of -2.3 m per year (erosion). This 5-year erosion trend is decreasing, relative to the 4.5 year trend last reported six months previously at the end of July 2005.

11.4 Erosion-Accretion Trends

In August-September 2005 net beachface accretion occurred at Narrowneck, with over half a metre of sand deposited in regions to the north and south of the reef. During the period 16th August to 18th September the net beachface accretion along this 1,000 m of beach was around +14,194 m^3 (+14.1 m^3 per metre shoreline, between -0.5 and + 0.7 m AHD).

From September 18th to October 14th more limited accretion across the upper beachface continued, however the lower beachface decreased in elevation by 0.2 – 0.4 m, resulting in the net loss of around -618 m^3 of sand, or -0.6 m^3 per metre shoreline, between -0.5 and + 0.7 m AHD. This subtle erosion trend continued from October 14th to November 9th (-3,797 m^3 , or -3.6 m^3 per metre shoreline), November 9th to December 8th (-1,198 m^3 , or -1.2 m^3 per metre shoreline), and again from December 8th 2005 to January 14th 2006 (-5,362 m^3 , or -5.3 m^3 per metre shoreline).

Despite the period August 2005 to January 2006 experiencing just one month of net beachface accretion followed by five straight months of net erosion as described above, the net trend for the entire six-month monitoring period was beachface accretion at Narrowneck (Figure 9.7). From 18th August 2005 to 14th January 2006 the 1,000 m length of beach at Narrowneck accreted by +3,219 m^3, or +3.2 m^3 per metre shoreline, between -0.5 and + 0.7 m AHD). The area of greatest accretion occurred to the north of the reef, with only minor net change in sand volumes in the lee of the reef and to the south. In contrast to the two proceeding six month monitoring periods, any impacts of the reef on observed erosion-accretion trends at Narrowneck were not discernable during the present period.

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.

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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 2005 to January 2006

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

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2006-01-17

2006-01-18

2006-01-19

2006-01-20

2006-01-21

2006-01-22

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WRL Report No. 2006/01	DAILY MID-TIDE IMAGES 16/01/2006 - 22/01/2006	Figure A25 02074-A25.cdr

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

2006-01-23

2006-01-24

2006-01-25

2006-01-26

2006-01-27

2006-01-28

2006-01-29

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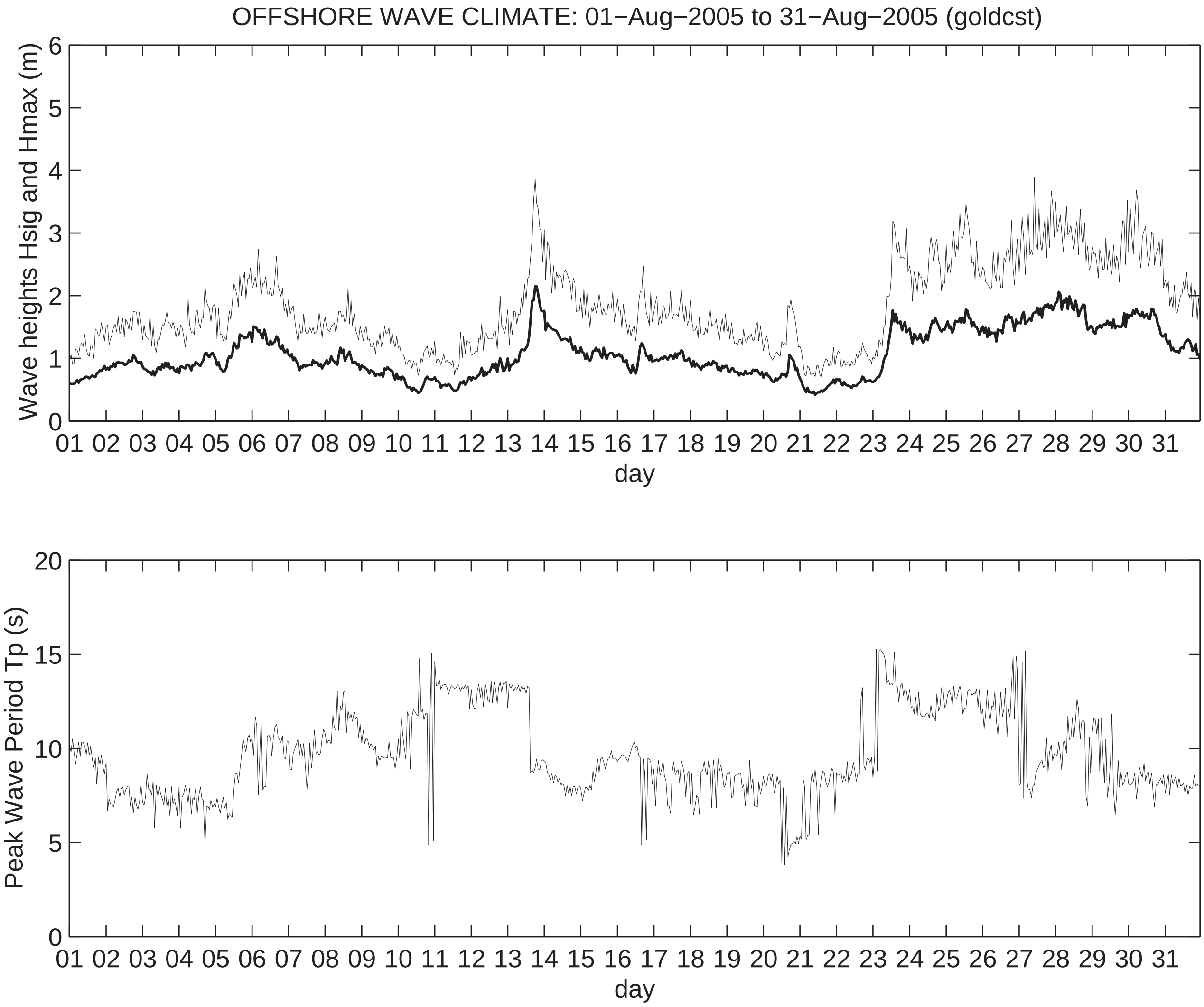
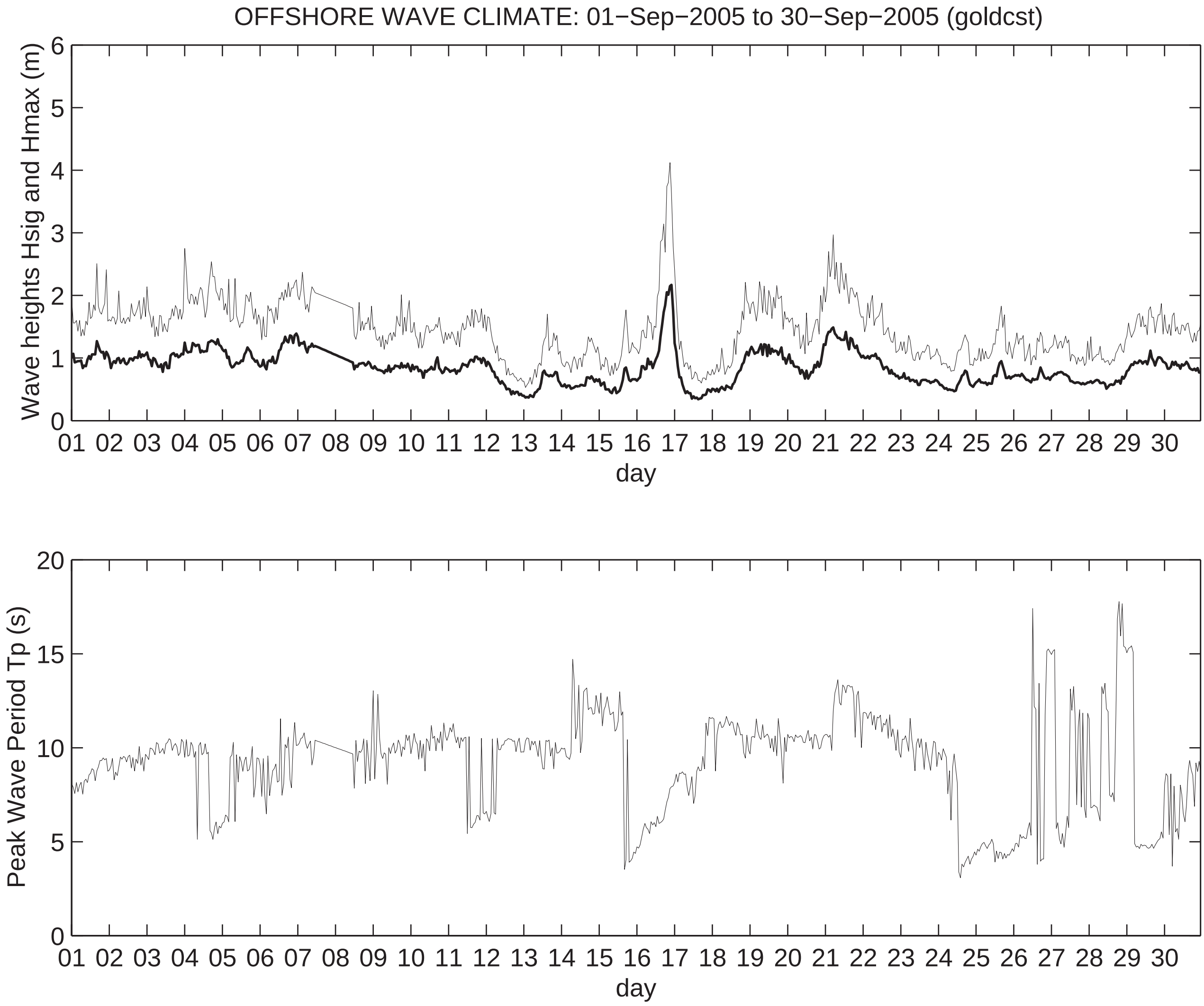
WRL Report No. 2006/01	DAILY MID-TIDE IMAGES 23/01/2006 - 29/01/2006	Figure A26 02074-A26.cdr

Appendix B

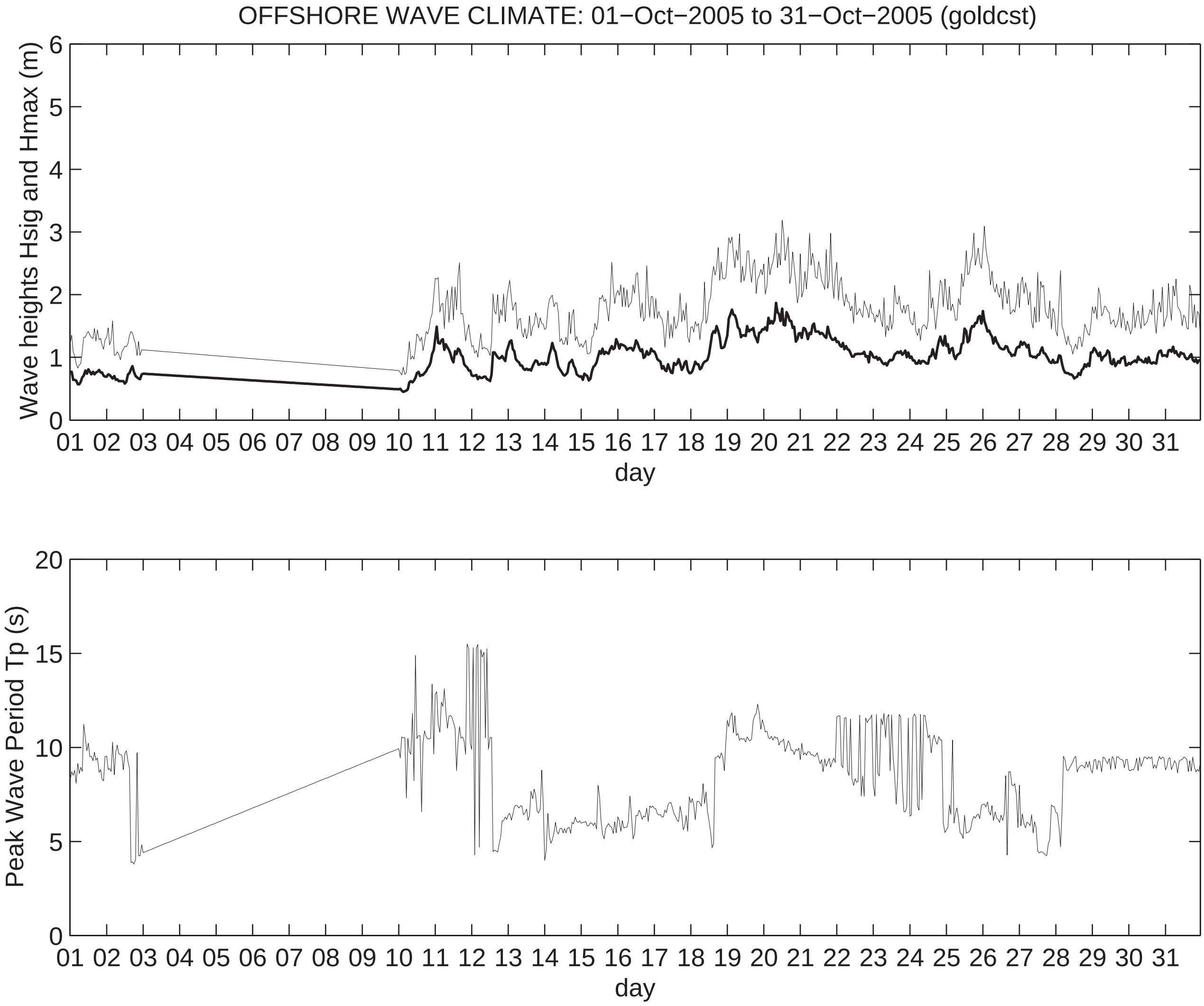
Monthly Wave Climate Summaries: August 2005 to January 2006



WRL Report No. 2006/01	MONTHLY WAVE SUMMARY AUGUST 2005	Figure B1 02074-B01.cdr

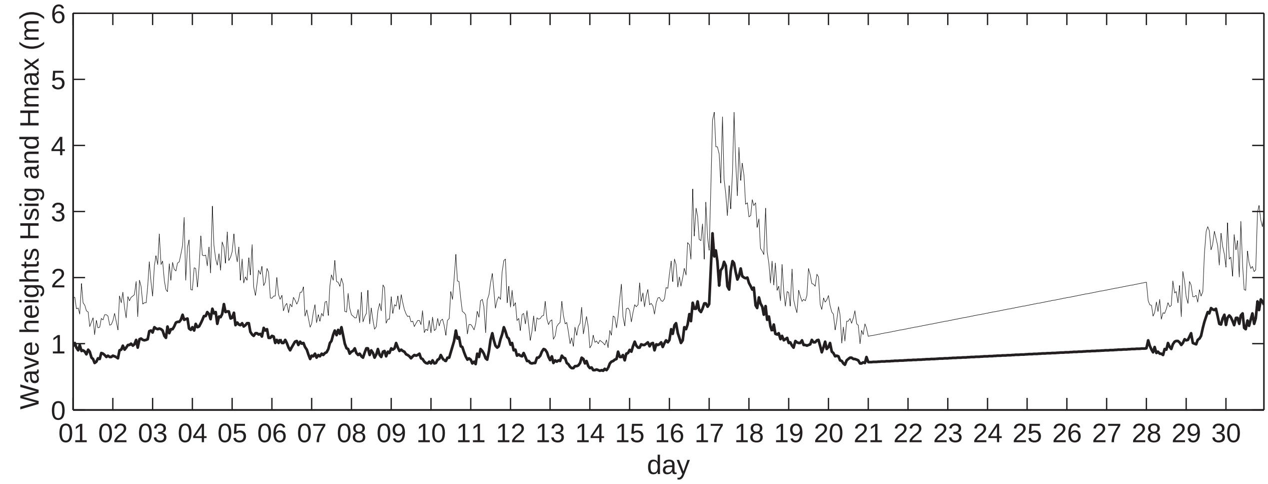


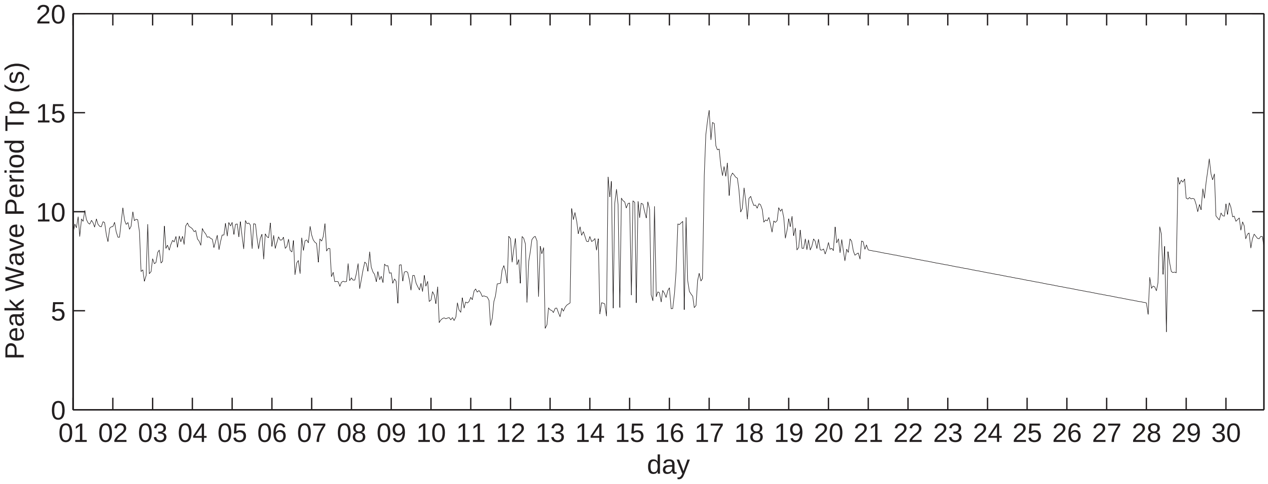
WRL Report No. 2006/01	MONTHLY WAVE SUMMARY SEPTEMBER 2005	Figure B2 02074-B02.cdr



WRL Report No. 2006/01	MONTHLY WAVE SUMMARY OCTOBER 2005	Figure B3 02074-B03.cdr

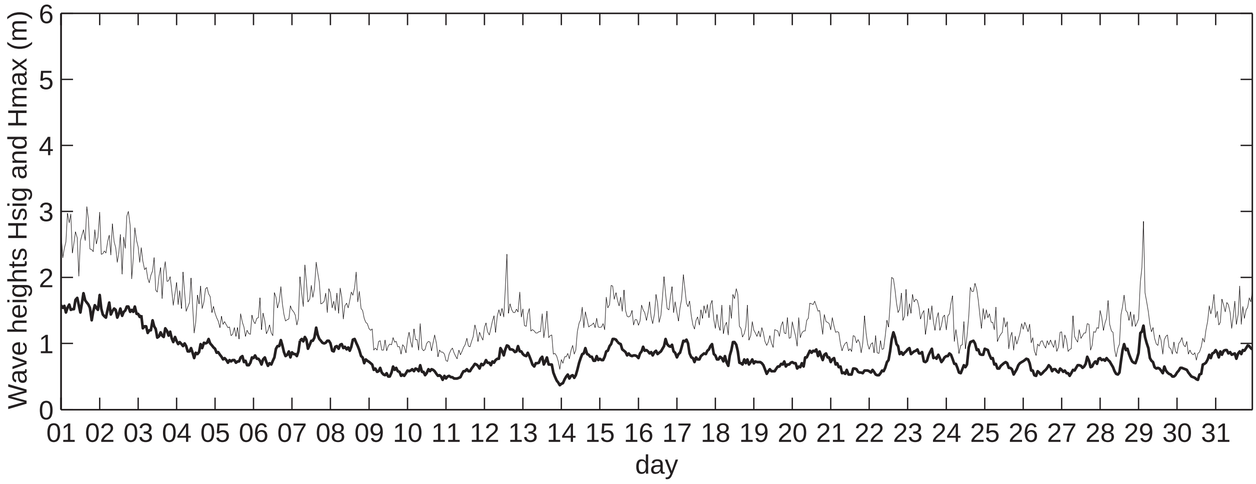
OFFSHORE WAVE CLIMATE: 01−Nov−2005 to 30−Nov−2005 (goldcst)

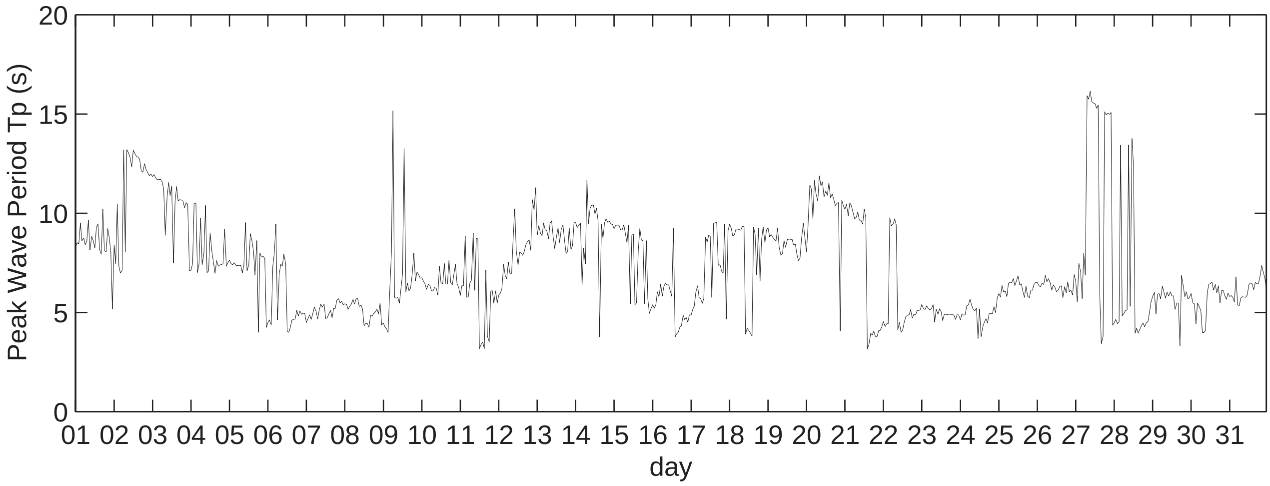




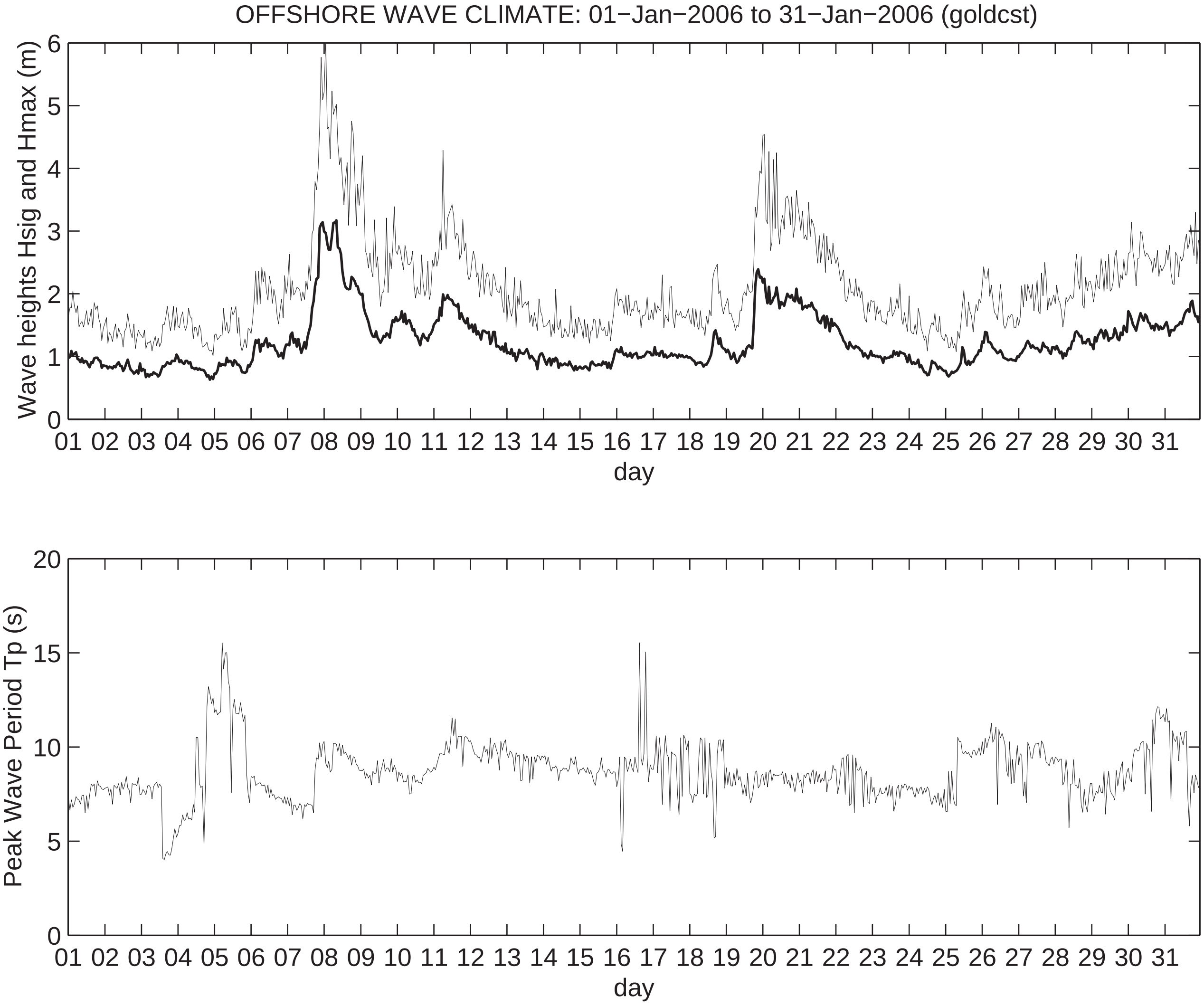
WRL Report No. 2006/01	MONTHLY WAVE SUMMARY NOVEMBER 2005	Figure B4 02074-B04.cdr

OFFSHORE WAVE CLIMATE: 01−Dec−2005 to 31−Dec−2005 (goldcst)





WRL Report No. 2006/01	MONTHLY WAVE SUMMARY DECEMBER 2005	Figure B5 02074-B05.cdr



WRL Report No. 2006/01	MONTHLY WAVE SUMMARY JANUARY 2006	Figure B6 02074-B06.cdr

Appendix C

Turner et al., 2006.
JCR Special Issue
(‘Coastal Imaging Applications and Research in Australia’)

Journal of Coastal Research	22	1	37–48	West Palm Beach, Florida	January 2006

Coastal Imaging Applications and Research in Australia

Ian L. Turner[†], **Stefan G.J. Aarninkhof**[‡], **Rob A. Holman**[§]

[†]Water Research Laboratory
School of Civil and Environmental Engineering
University of New South Wales
King Street, Manly Vale
Sydney, NSW 2093, Australia
ian.turner@unsw.edu.au

[‡]Marine and Coastal Management
WL | Delft Hydraulics
Delft, The Netherlands

[§]College of Ocean and Atmospheric Sciences
Oregon State University
Corvallis, OR U.S.A.

ABSTRACT

TURNER, I.L.; AARNINKHOF, S.G.J., and HOLMAN, R.A., 2006. Coastal imaging applications and research in Australia. *Journal of Coastal Research,* 22(1), 37–48. West Palm Beach (Florida), ISSN 0749-0208.

Remote sensing methods are increasingly being deployed to measure and investigate morphology and hydrodynamics in the littoral zone, across spatial scales ranging from centimetres to kilometres, and at time-scales ranging from seconds to years. In the past 5 years in Australia, the deployment of video-based coastal imaging systems has grown rapidly, and by 2004, some 32 cameras were operating at eight sites along the coasts of New South Wales and Queensland. Coastal imaging techniques are being applied to a range of coastline monitoring programs. Projects include large- and small-scale sand nourishment works, the construction of a nearshore artificial reef structure, and the ongoing management of sand bypassing operations. At the same time, the growing image databases are underpinning more fundamental coastal research. The focus of recent and current research includes rip current behaviour, climate impacts, nearshore bar dynamics, and the development of new image analysis methods to support future research.

ADDITIONAL INDEX WORDS: *Remote sensing, nearshore research, coastal management, coastal engineering, coastal monitoring.*

INTRODUCTION

Remote sensing methods are increasingly being deployed to measure and investigate morphology and hydrodynamics in the littoral zone, across spatial scales ranging from centimetres to kilometres and time-scales ranging from seconds to years. Since the early 1990s, nearshore research originating from Oregon State University in the U.S.A. and now including international user groups in Europe and Australasia, has focused on the development of low-cost video monitoring techniques and methods to observe and measure a broad range of coastal phenomena.

The advent of digital imaging technology now enables near-continuous analysis of coastal geomorphology and nearshore processes at any target site of interest. The key feature of coastal imaging systems that distinguishes them from conventional 'surfcams' is the ability to extract quantitative information from a time-series of digital images. This core capability is achieved through the solution of a set of camera model parameters (Holland *et al.*, 1997) that enable the determination of three-dimensional real-world (x, y, z) position from two-dimensional (U, V) image coordinates (Figure 1). These geo-referenced images are then subjected to a growing range of digital image analysis techniques to identify, enhance, and quantify the particular coastal processes or features of interest.

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The use of a network of video-based and automated monitoring stations was originally conceived of primarily as a research tool. More recently, the application of coastal imaging technology to a growing range of coastal engineering and management applications has been recognised. The ARGUS coastal imaging system (Aarninkhof and Holman, 1999; Holman *et al.*, 1993) is being used at all the Australian coastal sites described here. The eight Australian sites form part of a network of over 30 ARGUS stations currently operating across four continents.

This review provides a compilation and overview of existing coastal imaging capabilities, illustrated by some of the fundamental and applied research programs underway around the Australian coastline. Following a brief summary of the key concepts that underpin ARGUS-based image analysis methods, the sites in Australia are described where automated coastal imaging systems are currently operating. The practical application of the ARGUS coastal imaging system to coastal geomorphology, engineering, and management is described at four project sites in Australia. At these sites, image-derived data are being used to fulfill and extend a broad range of engineering and management objectives. Several examples of more fundamental research-focused work that has utilised image data collection from across the Australian coastal sites are also described. The reader is introduced to key findings of this current research, with reference to where more detailed published accounts of this work can

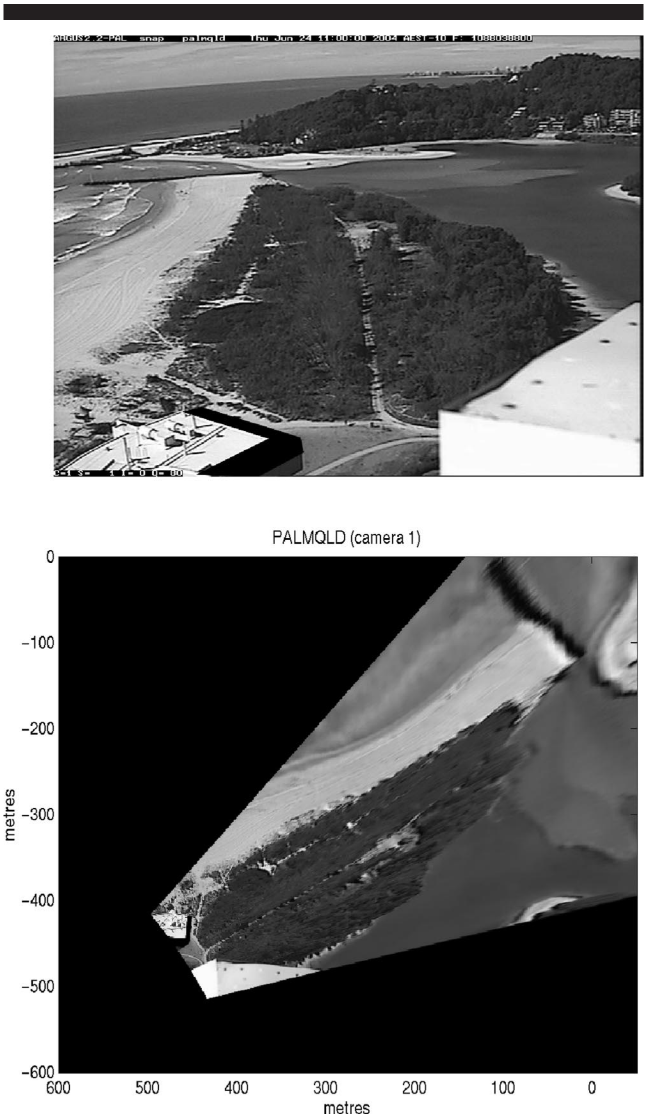

Figure 1. Image rectification that enables the conversion between (U, V) oblique image coordinates (upper panel) and (x, y, z) real-world coordinates (lower panel) is achieved through the solution of a set of camera model parameters. The oblique and rectified image shown is from Palm Beach, QLD (camera 1—looking south), overlooking the adjacent sand spit and entrance to Currumbin Creek.

be found. Finally, some concluding comments are presented to suggest that coastal imaging techniques offer new opportunities for coastal researchers to further contribute to the understanding and better management of the coastal environment.

SYSTEM OVERVIEW

A typical ARGUS coastal imaging station consists of four or five cameras installed at an elevated location that provides a 180° view of the coastline. Fundamentally, data acquisition consists of the automated and routine collection (typically hourly, but for some applications, sampling frequencies of 10 Hz or greater are required) of either full images covering the entire field of view or a time-series of any subset of pixels. In this manner, phenomena that vary both spatially and/or temporally can be identified and measured. Not every image or pixel array that is captured need be subjected to detailed analysis. Rather—and much in the manner of more familiar long-term tide- and wave-monitoring programs that operate around the world—the coastal researcher/engineer/manager can be confident that all 'events' will be recorded and available for future detailed analysis as required. Within the ARGUS system, images are archived within a database structure that facilitates searching and retrieval.

As was noted in the introduction, the ARGUS coastal imaging system has been developed through more than 10 years of ongoing research effort centred at the Coastal Imaging Laboratory at Oregon State University (OSU). The continuing development of the system, with the primary emphasis on new image capture and analysis techniques to support nearshore research, has expanded to include an international user group. A partial selection of past and present image analysis techniques that have been developed within this group includes measurement of incident wave parameters, including breaking height, peak period, direction, celerity dissipation, and spectral characteristics (*e.g.,* LIPPMANN and HOLMAN, 1991); measurement of water depth and nearshore bathymetry (*e.g.,* AARNINKHOF *et al.*, 2003; STOCKDON and HOLMAN, 2000); the use of particle image velocimetry (PIV) applied to the swash zone (*e.g.,* PULEO *et al.*, 2000); nearshore bar position (*e.g.,* VAN ENCKEVORT and RUESSINK, 2001) and morphology (*e.g.,* LIPPMAN and HOLMAN, 1990); dynamics of estuary shoals (*e.g.,* MORRIS *et al.*, 2001); swash dynamics (*e.g.,* HOLLAND *et al.*, 1995); mapping of rip position and spacing (*e.g.,* RANASINGHE *et al.*, 1999a); measurement of rip current position and longshore current velocity (*e.g.,* CHICKADEL, 2001); and the synthesis of many of these phenomena to objectively classify beach morphodynamic variability (*e.g.,* ALEXANDER and HOLMAN, 2001). New image or pixel-based analysis techniques are continuing to be developed and are made available to the wider coastal imaging community through publication in a range of coastal research journals.

ARGUS SITES IN AUSTRALIA

The first installation of an ARGUS coastal imaging station in Australia was undertaken in 1996 by the Coastal Imaging Laboratory at OSU, supported by the Australian Defense Force Academy in Canberra. This was part of an international network of approximately 10 stations that were operating at that time across a range of coastal environments in the U.S.A., The Netherlands, the UK, Australia, and New Zealand. Palm Beach in Sydney, New South Wales (NSW), was selected because of the usual presence of multiple rip currents at this site. Commencing in 1999, a further seven ARGUS stations have been progressively installed in Australia by the Water Research Laboratory, University of New South Wales (WRL), in cooperation with WL Delft Hydraulics in The Netherlands.

The location of all ARGUS sites currently operating in Australia in 2004 are shown in Figure 2. The technology (and data) is shared, but the motivation for site selection between

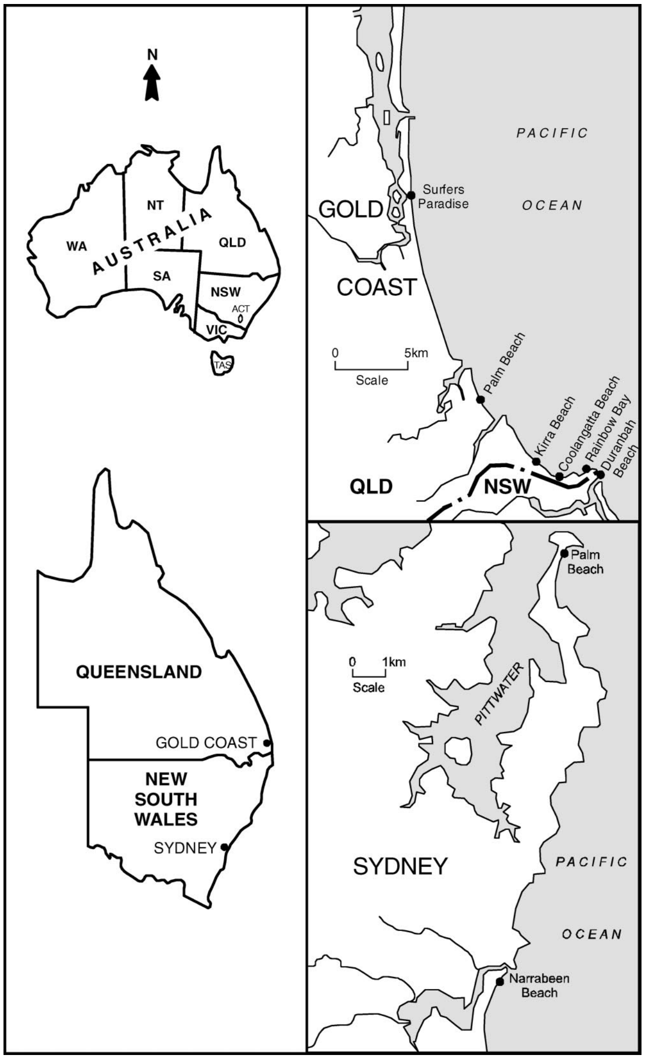

Figure 2. Location of all ARGUS sites currently operating in Australia in 2004.

the world-wide network of ARGUS stations maintained by OSU (including Palm Beach, Sydney) and the WRL sites in NSW and Queensland (QLD) is different. The latter locations were selected specifically to monitor coastal environments dominated by major engineering works and/or significant encroachment of human development within the active beach zone. In contrast, the monitoring stations operated by OSU have been sited to minimize the impact of human activities on beach processes.

The key attributes of all ARGUS sites currently operating in Australia in 2004 are summarised in Table 1, including age of each installation. A brief overview and illustration of each of these locations is provided below.

Palm Beach—NSW

Palm Beach in NSW is located at Sydney's Northern Beaches (Figure 2). The 2-km–long embayment is classic

Table 1. *Australian ARGUS sites in 2004.*

Location*	Site Selection	Embayment Size (km)	Sediment D50 (mm)	Deepwater Wave Climate (m) H_s (H_{max})	Nearshore Refraction-Diffraction	Tide Range (mean spring)	Number of Cameras	Camera Elevation (m)	Year of Installation
Palm Beach NSW	High occurrence of multiple rips	2	0.2	1.5 (12+)	Distinct alongshore gradient	1.3 (semidiurnal)	2	79	1996
Surfers Paradise QLD	Site of world-first hybrid protection-surfing reef and sand nourishment	18+	0.2	0.7 (12+)	Minimal	1.3 (semidiurnal)	4	102	1999
Palm Beach QLD	Site of proposed submerged reef construction and sand nourishment	4.5	0.2	0.7 (12+)	Moderate alongshore gradient	1.3 (semidiurnal)	5	79	2004
Kirra Beach QLD	Sand nourishment	5+	0.2	0.7 (12+)	Moderate	1.3 (semidiurnal)	4	47	2002
Coolangatta Beach QLD	Sand nourishment	0.9	0.2	0.7 (12+)	High	1.3 (semidiurnal)	4	75	2002
Rainbow Bay QLD	Sand nourishment	0.4	0.2	0.7 (12+)	High	1.3 (semidiurnal)	4	58	2002
Duranbah Beach QLD	Sand nourishment	0.5	0.2	0.7 (12+)	Minimal	1.3 (semidiurnal)	4	48	2002
Narrabeen-Collaroy Beaches NSW	Erosion 'hot spot' + site of existing multidecade survey data set	3.5	0.45	1.5 (12+)	Distinct alongshore gradient	1.3 (semidiurnal)	5	45	2004

* NSW = New South Wales, QLD = Queensland.

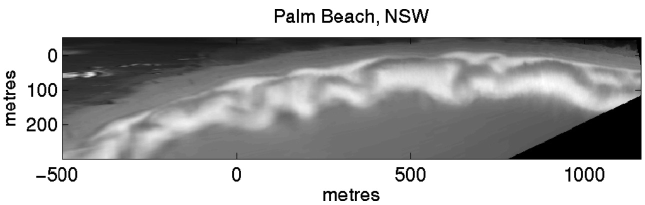

Figure 3. Example of single-camera merged-rectified image at Palm Beach, NSW (north is to the right in figure).

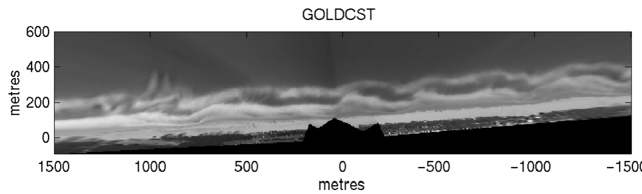

Figure 4. Example of four-camera merged-rectified image at Surfers Paradise, QLD (north is to the left).

zeta-spiral in shape (Figure 3), with a pronounced increasing energy gradient from south to north as a result of increasing exposure to the predominant southeasterly winds and swells of the Tasman Sea. There is little to no net alongshore movement of sand into or out of the embayment, which is contained between rock headlands at the northern and southern end. The beach typically exhibits the full range of intermediate beach states, and multiple rips at quasi-regular spacing alongshore are a characteristic feature of the nearshore (BRANDER, 1999). Despite its location within Australia's largest metropolitan area, coastal engineering structures are absent, and apart from passive dune stabilisation in recent years at the northern end, the beach is largely unaltered from its natural state.

Surfers Paradise—QLD

Surfers Paradise is located at the northern end of the Gold Coast (Figure 2) in southeast QLD. The coastline is essentially linear and extends uninterrupted some 18+ km alongshore. The nearshore morphology typically exhibits a double-bar system, with the highly three-dimensional and complex inner bar system ever changing in response to varying wave climate, whereas the outer storm bar alternates on a more seasonal basis between linear and crescentic states (Figure 4). The net alongshore movement of sand is estimated to be on the order of 500,000 m^3/y, comprising a gross transport of 650,000 m^3/y to the north and 150,000 m^3/y southward (*e.g.,* DELFT, 1970). A boulder wall revetment backs the entire length of beach, and extensive sand nourishment has been undertaken in recent years to maintain and enhance the subaerial beach width. A hybrid coastal protection-surfing reef structure is located 900 m north of the camera site at Narrowneck.

Palm Beach—QLD

Palm Beach in QLD is located in the central region of the Gold Coast, approximately 10 km north of the Tweed River and 15 km south of Surfers Paradise (Figure 2). The 4.5-km embayment is contained by the trained entrance to Currumbin Creek to the south and the similarly trained Tallubudgera Creek to the north (Figure 5). As is the case for all Gold Coast beaches, the estimated net rate of northward littoral sand transport is on the order of 500,000 m^3/y. The beach and nearshore exhibits the full range of intermediate states in response to the varying incident wave climate, ranging from a shore-welded low tide terrace through to crescentic and more linear offshore bars. In addition to the trained creek entrances, a buried rubble-mound revetment runs near continuously along the dune line, and two rubble mound groynes are located within the central region of the embayment.

Kirra, Coolangatta, Rainbow Bay, Point Danger—QLD/NSW

Four ARGUS coastal imaging stations are located at sites along the southern end of the Gold Coast, straddling the state border between NSW (to the south) and QLD (Figure 2). Together these stations provide near-continuous coverage of approximately 7 km of coastline, comprising five distinct embayments and the entrance to the Tweed River (Figure 6). The beaches are typically of intermediate beach state, with differing degrees of exposure to the incident wave climate. Like the northern Gold Coast, the estimated net rate of littoral sand transport is 500,000 m^3/y toward the north. The entrance to the Tweed River is fully trained by rubble mound breakwaters. Historically, these entrance training structures have resulted in the buildup of sand to the south (Letetia Spit) and a corresponding sand deficit at all beaches to the north (including Duranbah, Rainbow, Coolangatta, and Kirra). A sand bypassing plant now delivers sand around the Tweed River entrance via an under-river pipeline to outlets along the down-drift, northern beaches.

Collaroy-Narrabeen Beach—NSW

Collaroy-Narrabeen Beaches are located on Sydney's northern beaches, approximately 12 km south of the ARGUS site at Palm Beach, NSW (Figure 2). The 3.5-km–long embayment is contained by the rock headlands of Long Reef to the south and Narrabeen Headland to the north (Figure 7). Adjacent to the northern headland, the Narrabeen tidal lake system enters the ocean via a partially engineered entrance. These beaches were made famous in the coastal geomorphol-

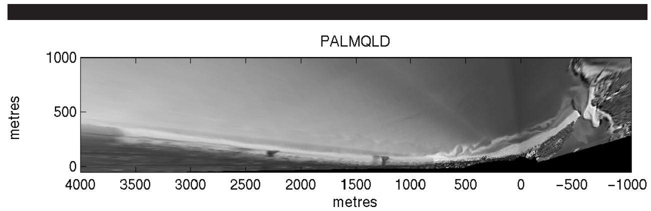

Figure 5. Example of five-camera merged-rectified image at Palm Beach, QLD (north is to the left).

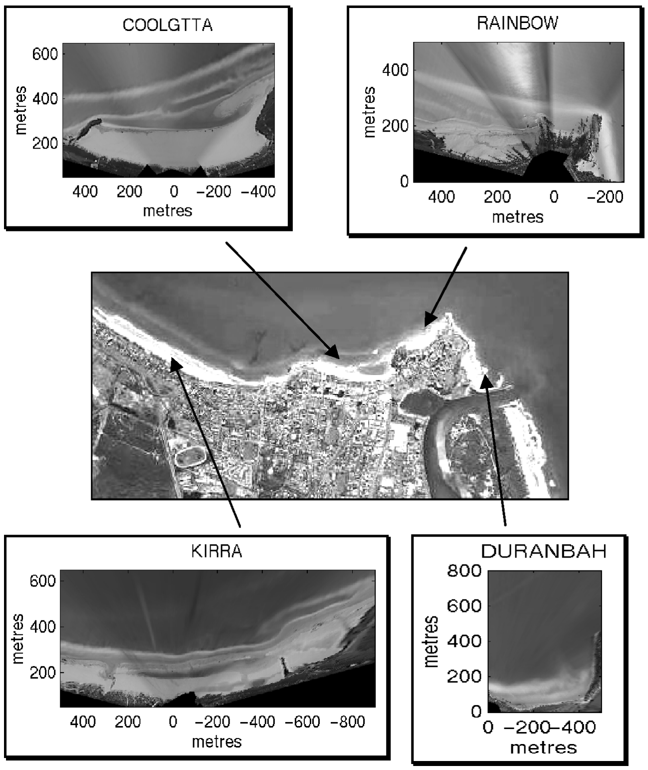

Figure 6. Examples of four-camera merged-rectified images at Kirra, Coolangatta, Rainbow, and Duranbah Beaches.

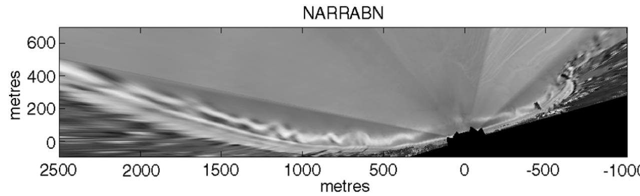

Figure 7. Example of five-camera merged-rectified image at Narrabeen Beach, NSW (north is to the left).

ogy literature in the late 1970s and 1980s because of the pioneering work undertaken at this site by Don Wright, Andy Short, and colleagues at Sydney University's Coastal Studies Unit, to develop their 'beach state' morphodynamic model of microtidal beaches (*e.g.,* Wright and Short, 1984). As is the case at the Palm Beach (NSW) site to the north, a distinct alongshore gradient in wave energy is observed at this site, with the northern end increasingly exposed to the incident wave climate. For 30 years, monthly profiling along the length of the embayment (*e.g.,* Short *et al.*, 1996) has revealed the site to be highly dynamic, exhibiting the full range of low- to high-energy, intermediate beach states in response to the varying incident wave climate. Nonengineered revetments structures (ranging from rubble mound walls to broken concrete) are in place in front of a limited number of individual beachfront properties. The beachfront development consists primarily of private residential housing that encroaches onto the frontal dune area well within the active beach zone.

ENGINEERING AND MANAGEMENT APPLICATIONS

The growth of coastal imaging research in Australia is to a large part due to the relatively rapid acceptance by state and local governments of new engineering and management applications of the technology (Turner, 2003a, 2003b). To date, coastal imaging–based monitoring programs are sponsored at three sites by local government authorities in QLD and NSW and at a further four sites through joint cooperation between the QLD and NSW State governments. Links to all these sites can be found at the project web site. Presented below is an overview of four engineering/management programs that utilise coastal imaging capabilities.

Northern Gold Coast Beach Protection Strategy—Surfers Paradise

Episodic storm erosion is an ever-present threat to the intensely developed Gold Coast region. Early mitigation measures including timber (and later boulder) revetments date back to the 1920s, and extensive sand nourishment campaigns commenced in the 1970s. In 1997, the 'Northern Gold Coast Beach Protection Strategy' was implemented by Gold Coast City Council to maintain and enhance the beaches of Surfers Paradise (Boak *et al.*, 2000). The aim of the strategy was to decrease the risk of potential economic loss following storm erosion by increasing the volume of sand within the storm buffer seaward of the existing oceanfront boulder wall. The major components of the engineering works included an initial 1.2 Mm^3 of beachface sand nourishment along 2 km of beach front and the construction at Narrowneck of a submerged artificial reef structure to provide a coastal 'control point.' The latter also aims to enhance surfing opportunities at the northern Gold Coast. Sand nourishment was completed in mid-2000, and the major construction phases of the reef were completed at the end of 2001.

Since 1999, the Surfers Paradise ARGUS coastal imaging station has been a core component of the construction and post-construction monitoring effort to document and quantify the success of the Protection Strategy. The primary aim of investigation is to monitor and quantify changing shoreline amenity (*i.e.,* dry beach width) along a 4.5-km length of the coastline (Turner *et al.*, 2001, 2004). This region incorporates the nourishment area including the reef site, as well as control regions to the north and south. The shoreline is mapped each week, and the resulting database of shorelines is then subjected to a range of analyses. A second focus of this work has been to quantify the more localised response of the coastline in the vicinity of submerged reef structure (Jackson *et al.*, 2002; Turner *et al.*, 2000).

The frequency of shoreline mapping (weekly), and the now-several years length of this record, have provided the opportunity to gain new insight into the regional-scale behaviour of the dynamic northern Gold Coast beaches. The response

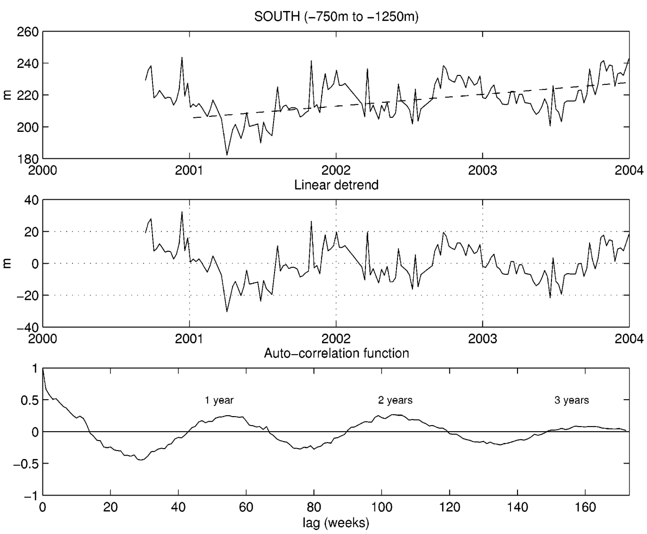

Figure 8. Results of auto-correlation analysis to assess the relative magnitudes of cyclic-seasonal variability *vs.* longer-term erosion/accretion trends at Surfers Paradise, QLD. (Upper panel) Spatially averaged (500 m) beach width for 3.5-year period, 2001–2004, with underlying accretionary trend approximated by linear best fit (~7–8 m/y). (Middle panel) Detrended beach width data, showing ±0.20 m variability with linear trend removed. (Bottom panel) Auto-correlation function calculated from detrended beach width data, revealing the dominance of an annual (52-wk) cyclic erosion/accretion trend.

time of the coastal system to placement of 1.2 Mm^3 of sand nourishment can be measured using this system. Figure 8 summarises the result of an auto-correlation analysis to assess the relative magnitudes of cyclic-seasonal variability *vs.* longer-term erosion/accretion trends. The upper panel shows the raw data of weekly beach width (post–sand nourishment), spatially averaged over a 500-m length of beach within the nourishment area. The middle panel shows the corresponding detrended data, while the lower panel shows the results of auto-correlation performed on this 3.5-year detrended data set. These results reveal the dominance over this period of an annual cycle of erosion (late summer and autumn) and accretion (winter and spring). The magnitude of cyclic beach width changes were on the order of ±20 m (Figure 8, middle panel), compared to an underlying accretionary trend during this same period of the order of 7–8 m/y (upper panel).

Tweed River Sandy Bypassing Project

The ocean entrance to the Tweed River coincides with the border between the states of NSW and QLD. Since the late 1800s, entrance-training works and dredging have been undertaken in an attempt to improve navigability. In the mid-1960s these efforts culminated in the further extension of the entrance breakwalls, which was observed to improve navigation for a period, but in recent years, the entrance bar had reformed and again created navigation difficulties. The northward littoral drift of sediment from NSW to QLD beaches was also interrupted, resulting in the accumulation of sand in NSW against the southern (up-drift) training wall and major erosion along down-drift beaches of the southern Gold Coast in QLD (Dyson *et al.*, 2001). In 2001, a fixed sand bypassing system was commissioned by the joint NSW-QLD state governments. Sand is pumped from the NSW side of the entrance, through a 400-mm–diameter polyurethane-lined steel pipeline that runs beneath the Tweed River to four outlet points along the down-drift beaches (Dyson *et al.*, 2002).

The four ARGUS coastal imaging stations at Duranbah, Rainbow, Coolangatta, and Kirra Beaches are used to assess the beach conditions at each of the outlet points, and this information is in turn fed back into the operational management to determine the rate and location of monthly sand delivery. The use of image-derived information to support ongoing system operations has required the development of new methods for the timely delivery of the required information to the project management team. Every week, a range of analysis techniques are applied to the growing hourly image archive to assist the project management team to observe, quantify, and interpret coastal processes and changing beach conditions at all the sand delivery points. Analyses are updated weekly, and a web-based information delivery system has been developed that provides the necessary information in summary format directly to the project managers' desks (Anderson *et al.*, 2003).

The range of 'real-time' information and data that is available to the managers of the sand bypassing project includes the following:

- access to the full archive of current and past hourly images;
- the use of a zoom applet that enables smaller-scale features to be inspected in greater detail;
- plan view (multi-camera and merged-rectified) images of the beaches and river entrance at all high, mid, and low stages of the tide;
- a web-based interface that enables project managers to create and view an animation of daily images and concurrent wave information for any current or past period of interest;
- 'week-to-a-page' weekly summaries to highlight trends in subaerial and nearshore morphology; and
- weekly quantitative analysis of shoreline position and beach width.

This last feature is used to highlight current beach conditions relative to 1 week, 1 month, and 1 year prior, as well as long-term temporal trends. Figure 9 shows examples of a 'week-to-a-page' image summary from Coolangatta Beach and the weekly summary of shoreline and beach width analysis for this same site. These data summaries are updated each week, preformatted for easy inclusion in reports, and are available for viewing and download by the NSW and QLD project management teams.

Figure 10 illustrates the value of these data to assess the impacts of the bypassing plant and to inform the monthly decision as to the choice of the location(s) for sandy delivery. The upper panel shows the location of one of the project control survey transects (DMB2) within the central region of Duranbah Beach. The middle panel shows the monthly sand

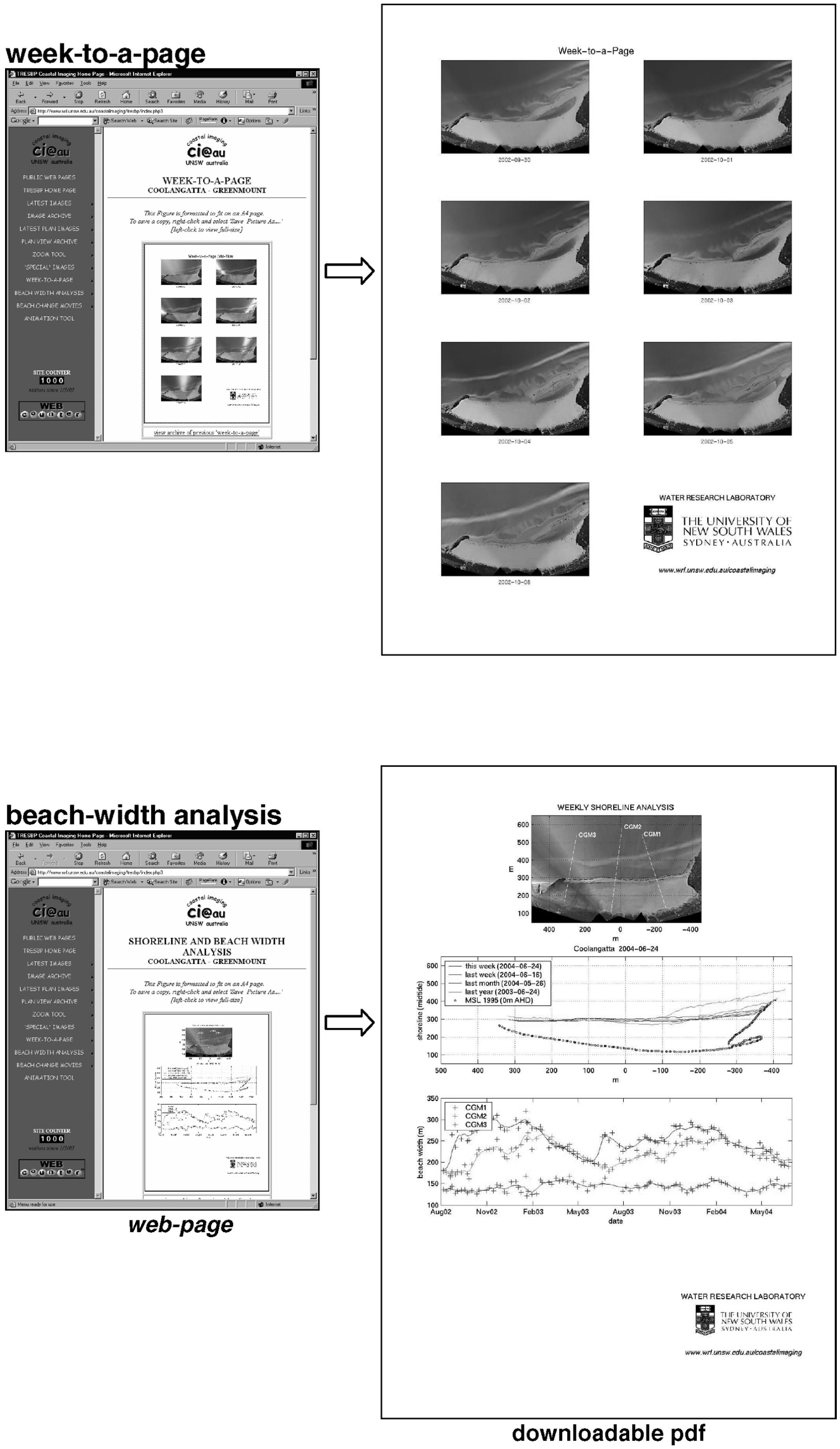

Figure 9. Examples of the range of weekly updated information made available to the Tweed River Entrance Sandy Bypassing Project (TRESBP) management team via the project web site, including 'week-to-a-page' image data summaries and analyses of beach width changes. Examples shown are from Coolangatta Beach, QLD.

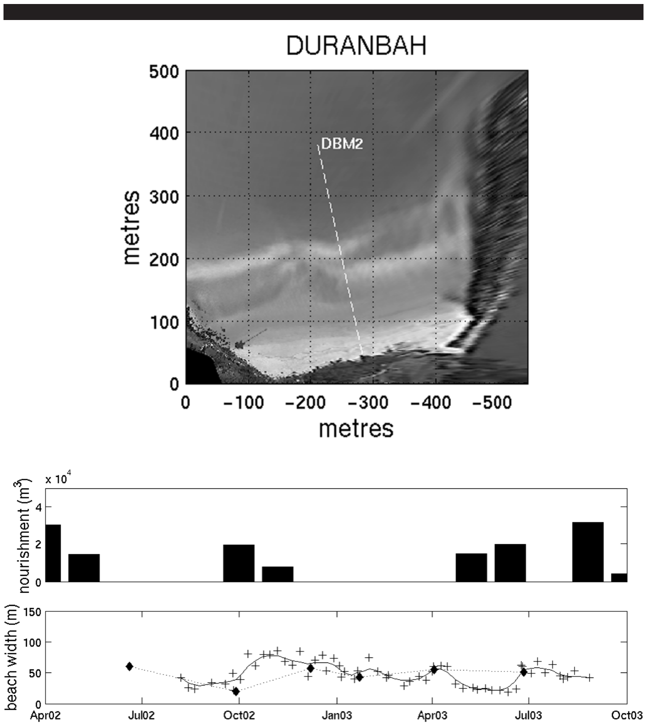

Figure 10. (Upper panel) Location of a control survey line (DMB2) at Duranbah Beach, QLD. (Middle panel) History of monthly sand delivery to the Durnbah embayment for the period April 2002 to October 2003. (Lower panel) Comparison at DMB2 of quarterly conventional surveys of beach width (♦) and weekly image-derived calculations of beach width (+).

delivery to Duranbah Beach by the bypassing plant for a 12-month period in 2002–03, and the lower panel shows the surveyed beach response to this nourishment, based upon conventional (total station) and image-derived techniques. The imaging system first became operational at this site in August 2002. The existence of quarterly survey data is relatively frequent for this type of project; however, the information that is lost when compared to the weekly image-derived surveys is readily apparent in this figure. For example, the rate of beach recovery in response to the nourishment effort undertaken in October–November 2002 was shown from the results of the image-derived data to be much more rapid than what the quarterly surveys indicated. Similarly, from April to July 2003, the erosion–recovery cycle detected and quantified by the imaging system was entirely missed by the quarterly survey effort. For operational applications, the dependence upon imaging methods removes the risk to managers that key behaviour within the coastal system may be missed.

Palm Beach (QLD) Beach Protection Strategy

Coastal storms (cyclones) in 1967, 1972, and again in 1974 caused severe structural damage to properties along the beach front at Palm Beach, QLD. Over the ensuing three decades, a number of protection works have been implemented (Tomlinson *et al.*, 2003). These works include construction of an (almost) continuous seawall, two short rubble-mound groynes, beach nourishment in excess of 1 Mm^3, Tallebugera Creek breakwall, and Currumbin Creek breakwall.

In Figure 6 the creek entrance training works and groynes are evident. Despite these structures and the buried back-beach revetment, storms in May 1996 again highlighted the vulnerability of the central section of Palm Beach. To address these concerns, the 'Palm Beach Beach Protection Strategy' was developed (Tomlinson *et al.*, 2003). A staged construction approach was adopted in 2003. Immediate works comprise the upgrade of the existing (but substandard) public and private back-beach revetment, construction of a series of (up to three) offshore submerged reef structures, and sand nourishment. However, immediately prior to the commencement of these works in late 2003, protest by the local surfing community and others raised public concerns as to the impact to existing surf conditions of the proposed reef structures. The construction of the proposed reef structures was halted, and the Palm Beach ARGUS station was installed to monitor the existing beach and nearshore conditions at the site.

Figure 11 shows the results of erosion/accretion analysis that is now reported on a routine basis for Palm Beach, using an image analysis technique that enables three-dimensional 'survey' information to be extracted from two-dimensional images (*e.g.,* Aarninkhof and Roelvink, 1999). Briefly, the waterline is mapped every hour through a spring tide cycle. 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 11 (upper panel), if this process is repeated at all points alongshore throughout a complete tide cycle, a three-dimensional bathymetry of the beachface—extending from spring high to low tide—is obtained. The derived net change in beachface bathymetry that was measured through the initial 6-month monitoring period at Palm Beach is illustrated in Figure 11 (lower panel). This analysis revealed a distinct trend of beach accretion in the southern third of the beach, in contrast to a more general trend of beach erosion along the northern two-thirds of the embayment. The site of this beachface accretion occurred in the vicinity of sand nourishment of the offshore bar that was completed by contractors during this same period and indicates a landward migration of a portion of this nourishment volume and/or the early development of a shoreline salient in response to the placement of a sand mound in the nearshore zone.

Narrabeen-Collaroy Coastline Monitoring Project

The 3.5-km embayment on Sydney's northern coastline that comprises Narrabeen and Collaroy Beaches exhibits a chronic erosion problem. Historically, between 1944 and 1986 a number of houses were lost, and many others were severely damaged as a result of major storms. More than $100,000,000 of public and private beachfront property, second only to the Gold Coast in terms of the economic value of infrastructure, is currently at risk. The NSW Coastal Council, a peak advisory body to the NSW government, identified Narrabeen–Collaroy as one of beaches of greatest risk amongst the state's

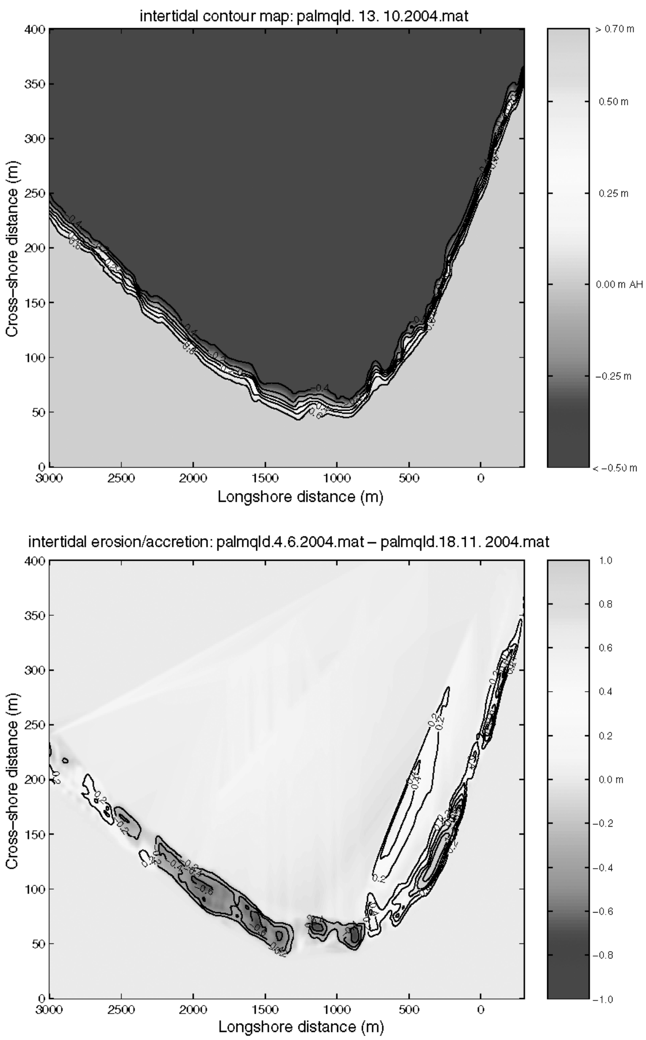

Figure 11. (Upper panel) Intertidal bathymetry along 3.5 km of the Palm Beach embayment, derived from image analysis (13 June 2004). (Lower panel) Estimate of net change in beachface elevation, again derived from image analysis (June–November 2004).

721 beaches and 1590 km of coastline. In 1997, the 'Collaroy–Narrabeen Coastline Management Plan' prepared for Warringah Council–identified upgrading of an existing nonengineered seawall (Figure 12) as one possible option for managing the risk to property at the site. A preliminary design and statement of environmental effects were prepared in 2002. In 2003, following a period of public exhibition, the Council resolved not to proceed with the proposed seawall upgrade at that time, given significant community opposition to the proposal. It was resolved to undertake further investigation into alternate options for management of coastal erosion within the Collaroy–Narrabeen embayment, including the sourcing of offshore sand supplies for beach nourishment.

The ARGUS station installed at Narrabeen–Collaroy in July 2004 is the latest site chosen for this monitoring technology. As per the Palm Beach site in QLD, the initiation of this coastal monitoring program prior to the commencement of possible future engineering works provides the all-too-rare opportunity to first document and quantify the existing conditions. The analysis of these data is affording greater insight to the location, extent, and alongshore variability of the existing erosion hazard. In the future, this same data will enable the impacts and intended improvements of any engineering/management works that may be undertake at the site to be objectively assessed and evaluated.

PRESENT RESEARCH

With the exception of Palm Beach NSW, all the Australian ARGUS sites to date have been installed for primarily engineering and coastal management applications. The wider value of the image databases that continue to grow with the progress of these monitoring programs is well recognised within both the Australian and international research community. A broad range of more fundamental coastal research is now utilising this resource. Space limitations here do no permit a full description of the work underway. Instead, summarised below is a brief description of several examples of this research, with cited references indicating where more detailed published accounts of this work can be found.

Rip Current Behaviour

Investigation of the behaviour of rips currents using image-derived data from Palm Beach NSW was underway prior to the advent of engineering or management ARGUS applications in Australia. This work was undertaken by researchers at the Australian Defense Force Academy in Canberra, in collaboration with OSU. Time-series of daily images comprising several years were analyzed to demonstrate that the location of rip channels within the 2-km Palm Beach embayment do not exhibit any preferred locations along the beach. Rip spacing was not observed to change in response to varying incident wave height, but once formed, rips were observed to migrate alongshore under oblique incident waves. It was concluded from this novel work that gradients in oblique waves causing longshore currents and resulting alongshore sediment transport governed the alongshore migration of rip channels (Ranasinghe *et al.*, 1999b, 2000). Work completed more recently utilising 3 years of image data obtained at the contrasting nonembayed (*i.e.,* long, straight) Surfers Paradise site matched the earlier studies at Palm Beach NSW (Whyte *et al.*, in press). These new results from a rather different setting further supported the original work of Ranasinghe *et al.* (1999b) that once formed, the position of rips appears to be strongly topographically controlled and does not adjust markedly to varying incident wave height, but instead migrates as a result of oblique wave incidence.

Shoreline Detection and Definition

At the core of many coastal monitoring programs is the identification of the shoreline for the purpose of quantifying the available beach amenity and to assess impacts of new or existing engineering works. The location of the shoreline, and the changing position of this boundary through time, are of

1967 1978

Figure 12. Present condition of the nonengineered revetment that is in place to protect beachfront property at the site of the newly installed ARGUS station at Narrabeen Beach, NSW (Source: Warringah Council).

elemental importance to coastal scientists, engineers, and managers (NRC, 1990).

A range of methods have been developed to identify and map the shoreline from time-series maps, aerial photography, and digital images (BOAK and TURNER, 2005). A recent study was completed at four contrasting ARGUS sites around the world, including the Surfers Paradise site, to test and compare four different image analysis techniques for shoreline detection (PLANT *et al.,* 2006). Absolute errors of the four shoreline mapping methods were estimated by comparison with direct topographic surveys. It was determined that the differences between image-derived *vs.* directly surveyed shorelines depended on differences in the four different mapping methods and the prevailing hydrodynamic conditions. Before accounting for these differences, rms errors ranged from 0.3 to 0.8 m. An empirical correction model that computed local estimates of setup, swash, and surf beat amplitudes reduced errors by about 50%. It was concluded from this study that available remote-sensing methodology can be applied to the shoreline mapping problem in an interchangeable and intercomparable manner across diverse nearshore environments. Current research is underway to gain a better physical understanding of the 'shoreline' feature that is detected by the various ARGUS-based image analysis techniques that are currently available (BOAK and TURNER, 2003).

An extension of this research has been to map the shoreline feature through all stages of the tide, to produce a three-dimensional surface of the intertidal region of the beach (*e.g.,* AARNINKHOF and ROELVINK, 1999). In Australia, this method has been successfully applied at the Surfers Paradise, Palm Beach (QLD), and Tweed sites to help elucidate the fate of sand nourishment (*e.g.,* AANRNIKHOF *et al.*, 2003; Turner *et al.,* 2004) and to examine whether specific elevation contours within the intertidal zone provide a useful proxy for sand volume changes within the wider beach system.

Climate Control of Regional-Scale Coastal Behaviour

The central and southern coastline of NSW is characterised by relatively short (<3 km in length) beaches bounded on either extremity by headlands (SHORT, 1993). Over the last decade, many of these beaches have experienced severe erosion at their southern end, which is normally protected from the dominant southeasterly waves. This erosion does not appear to be associated with severe storm events nor with any long-term recession trend. Rather, it appears to be related to a medium-term (period of 2–8 years) and cyclic process of beach rotation, possibly caused by variations in wave climate associated with phase shifts in the Southern Oscillation Index (SOI) (RANASINGHE *et al.*, 2004; SHORT and TREMBANIS, 2004; SHORT *et al.,* 1996, 2000). Given the Pacific-wide impact of the SOI (El Niño/La Niña) and the documented inverse impact at northwest Pacific beaches (*e.g.,* DINGLER and REISS, 2002; KOMAR *et al.*, 2001; SEYMOUR, 1998), it is likely that similar longer-term cycles of beach erosion/accretion and rotation are a widespread phenomenon on beaches along both Pacific coastal belts.

A new research effort commenced in 2004 based around the Narrabeen–Collaroy ARGUS site, which is working to integrate coastal imaging-derived data with a multidecadal conventional survey data set (believed to be one of the longest beach survey records of any site in the world) to investigate the regional-scale climatic control of coastal erosion and coastline variability over time-scales of months to decades. This collaborative effort brings together researchers from Australian universities, as well as partners in local and state government, and WL Delft Hydraulics in The Netherlands. Following a 3-year period of initial comparison and analysis, it is the intention that the ARGUS techniques may supercede and extend this important survey effort into the foreseeable future.

Other Areas of Active Research

In addition to the research highlighted above, image data obtained across the network of ARGUS sites in Australia are being utilised by researchers both in Australia and internationally to support a range of investigations. These include the analysis of temporal and spatial variability of crescentic sand bars (VAN ENCKEVORT *et al.*, 2004) and the cyclic transition between differing intermediate morphodynamic beach states in response to varying wave climate (RANASINGHE *et al.*, 2004a). Other areas of current investigation that are utilising this resource include the derivation of subaerial beach profiling through the analysis of shadow casting (CURTIS and HOLMAN, 1998; Curtis *et al.,* in press) and the analysis of varying modes of beach response to offshore-detached structures in the nearshore zone (TURNER, in press).

CONCLUSIONS

Applications of coastal imaging technology in Australia and internationally are providing increased opportunities for coastal researchers in the fields of both science and engineering to contribute to the present and future management of the coastline. More fundamentally, existing and emerging imaging capabilities will continue to complement and extend the progress of nearshore research.

From the perspective of practical management applications, in addition to meeting technical monitoring requirements, the use of automated image collection is also providing new opportunities for coastal professionals to meet increased community expectations. By providing public access (via the world-wide web) to regularly updated monitoring program data, and through the opportunity to link this more technical information to educational and other project-specific information, an integrated approach to coastal measurement, monitoring, and dissemination is being implemented. From the research perspective, data collection across a wide range of coastal processes and phenomena can now be obtained, across spatial and temporal scales that are simply unachievable using *in situ* instrumentation.

One of the more wide-reaching challenges for researchers in this field is the better integration of image-derived data with state-of-the-art numerical nearshore models. Within the next few years, better solutions will emerge to enable researchers to fully assimilate the spatial and temporal capabilities of image-derived data with the predictive capability of numerical simulation.

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