Collaroy-Narrabeen coastal imaging report #3

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COLLAROY-NARRABEEN COASTAL IMAGING SYSTEM
REPORT 3

ANALYSIS OF SHORELINE VARIABILITY AND EROSION/ACCRETION TRENDS: JULY 2006 - JUNE 2007

by

M J Blacka, D J Anderson and I L Turner

Technical Report 2007/30
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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
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1. INTRODUCTION

This report was prepared by the Water Research Laboratory (WRL) of the University of New South Wales for Warringah Council. It is the third in a series of annual data summary reports, to describe, quantify and analyse the regional-scale coastline variability and erosion/accretion trends observed at Collaroy-Narrabeen Beaches. This annual summary supplements the more extensive on-line and 'real-time' monitoring program information that is available to Council and the community via the world-wide web (refer Section 4). It is intended that the growing database described herein, of qualitative and quantitative coastal monitoring information, will inform and enhance the current and future management of the Collaroy-Narrabeen embayment.

1.1 General

In July of 2004, an ARGUS coastal imaging system was installed at the Collaroy-Narrabeen site for an initial period of three years. This leading-edge technology was selected by Warringah Council to provide regional-scale, continuous and long-term monitoring of this 'high value' coastal embayment. It is the ability to provide quantitative as well as qualitative information that distinguishes the ARGUS coastal imaging system from conventional 'webcam' or 'surfcam' technology.

Collaroy-Narrabeen is the first coastal management site in New South Wales that utilises coastal imaging technology and associated digital image techniques to monitor regional-scale coastal response to natural and engineered coastal impacts. Coastal imaging stations have been operating at coastal management sites in Australia since the first site was installed at the northern Gold Coast in 1999, and at the present time there are a total of 8 stations operated by WRL throughout Queensland and New South Wales (Turner *et al.* 2006).

Electronic copies of this and previous monitoring report(s) are made available for public viewing and download in PDF format at:

→ www.wrl.unsw.edu.au/coastalimaging/public/narrabn (link: monitoring reports)

The purpose of this third annual data summary report is to present a summary of the results of shoreline change analysis and erosion/accretion analysis for the twelve-month monitoring period July 2006 – June 2007, and to assess the net changes that have occurred within the Collaroy-Narrabeen embayment since the commencement of the monitoring program 36 months ago in July 2004.

1.2 Maintenance, Upgrades and Operational Issues

During the period July 2006 to June 2007, the ARGUS station operated successfully without the need for significant maintenance or upgrades. Interruptions to communications which occurred for a short duration were corrected by visits to the station, and cleaning of the camera housings and lenses was also undertaken at these times.

1.3 Report Outline

Following this introduction, Section 2 of this report provides a brief description of the Collaroy-Narrabeen embayment, and in particular the 'Precinct 3' study area.

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 Collaroy-Narrabeen Coastal Imaging System entitled *System Description, Analysis of Shoreline Variability and Erosion Accretion Trends: July 2004 – June 2005* (Turner, 2005).

The web site that was established to promote and distribute the images collected by this monitoring program is introduced in Section 4. Description includes the web-based image archive that provides unrestricted public access to all images, weekly-updated quantitative analysis of current coastline conditions, and 'time-lapse' animation files that are updated on a monthly basis.

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 twelve-month period covered by this report, July 2006 – June 2007.

The quantitative analysis of shoreline change for the current monitoring period is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total 36 month period since monitoring began in mid 2004.

The application of an image analysis technique that enables patterns of beach erosion and accretion to be identified and quantified within the Precinct 3 study area on a regular (monthly) basis is presented in Section 8. Section 9 summarises the major findings of this third annual monitoring period at Collaroy-Narrabeen.

2. BACKGROUND

2.1 Environmental Setting

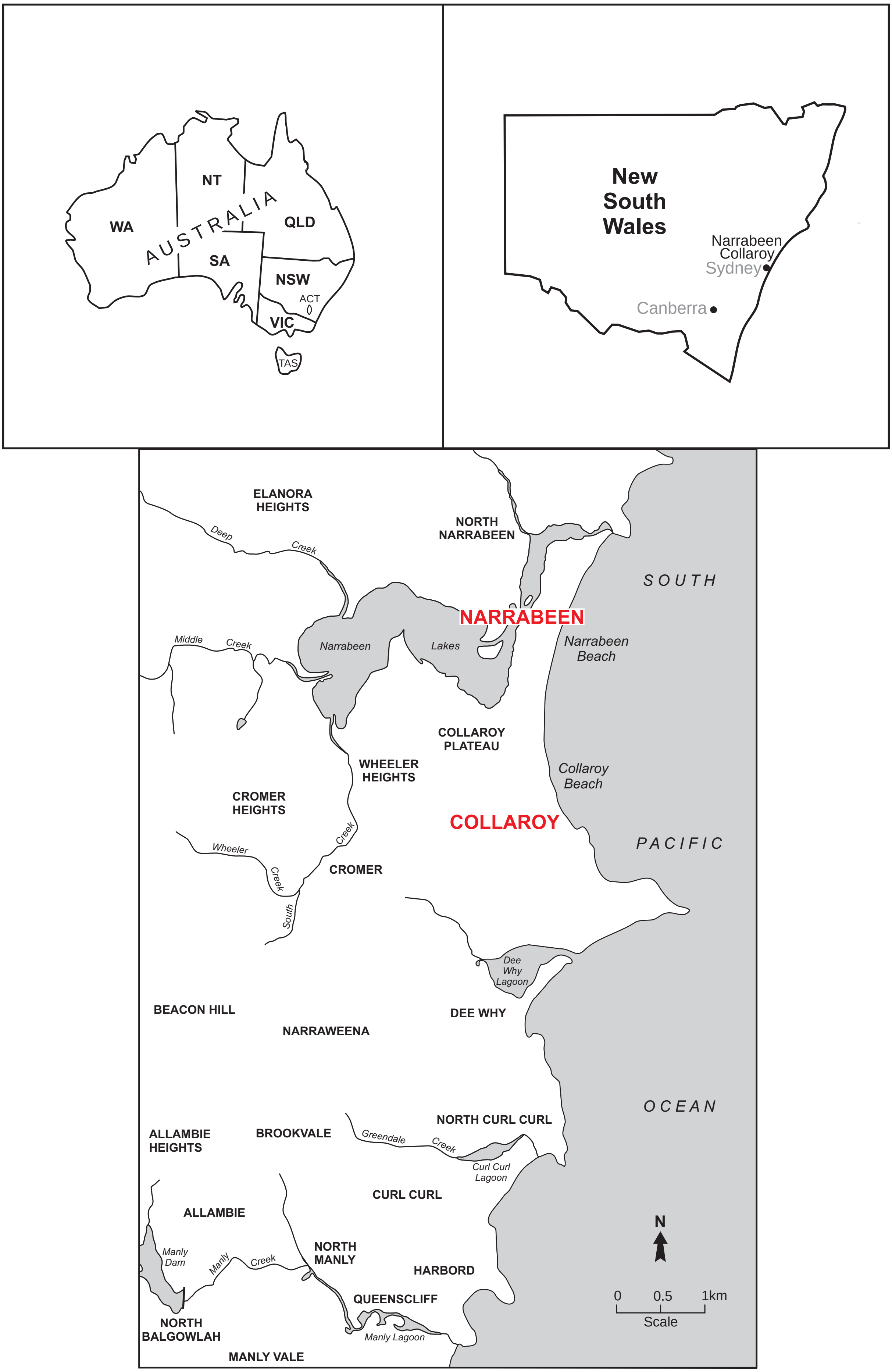
The Collaroy-Narrabeen Embayment is located 16 km north of Sydney's Central Business District, within Warringah Council Local Government Area. The beach is approximately 3.6 km in length from the Collaroy ocean pool in the south to the entrance of Narrabeen Lagoon in the north (Figure 2.1).

The Collaroy-Narrabeen embayment is characterised by having the most intense and highly capitalised shoreline development in Warringah (Figure 2.2). Development along the beach is further characterised as being at risk of impact by coastal processes and coastal erosion.

Several processes cause movement of sand within the Collaroy-Narrabeen Beach system. These include natural processes such as longshore movement of sediment, offshore/onshore movement of sediment to and from deeper water by wave action, and lagoon infilling by wave and tidal action, as well as human activities such as Narrabeen Lagoon Entrance Clearance Works. The only potential natural sources of sediment supply to the beach are the near-shore sand body and biogenic shell production associated with seabed reefs.

2.2 Study Area

The specific study area for the coastline monitoring extends along the embayment with particular focus on Precinct 3 as described in the Collaroy-Narrabeen Coastline Management Plan (1997) and shown in Figures 2.2 and 2.3. It is within this area that existing development encroaches to the greatest degree into the active beach environment. Periodic storm damage to beachfront property has occurred within this area of the Collaroy-Narrabeen embayment since it was first developed (see Tuner, 2005). A boulder wall has been proposed to protect beachfront property, however this option was subsequently rejected by the Warringah community.



WRL

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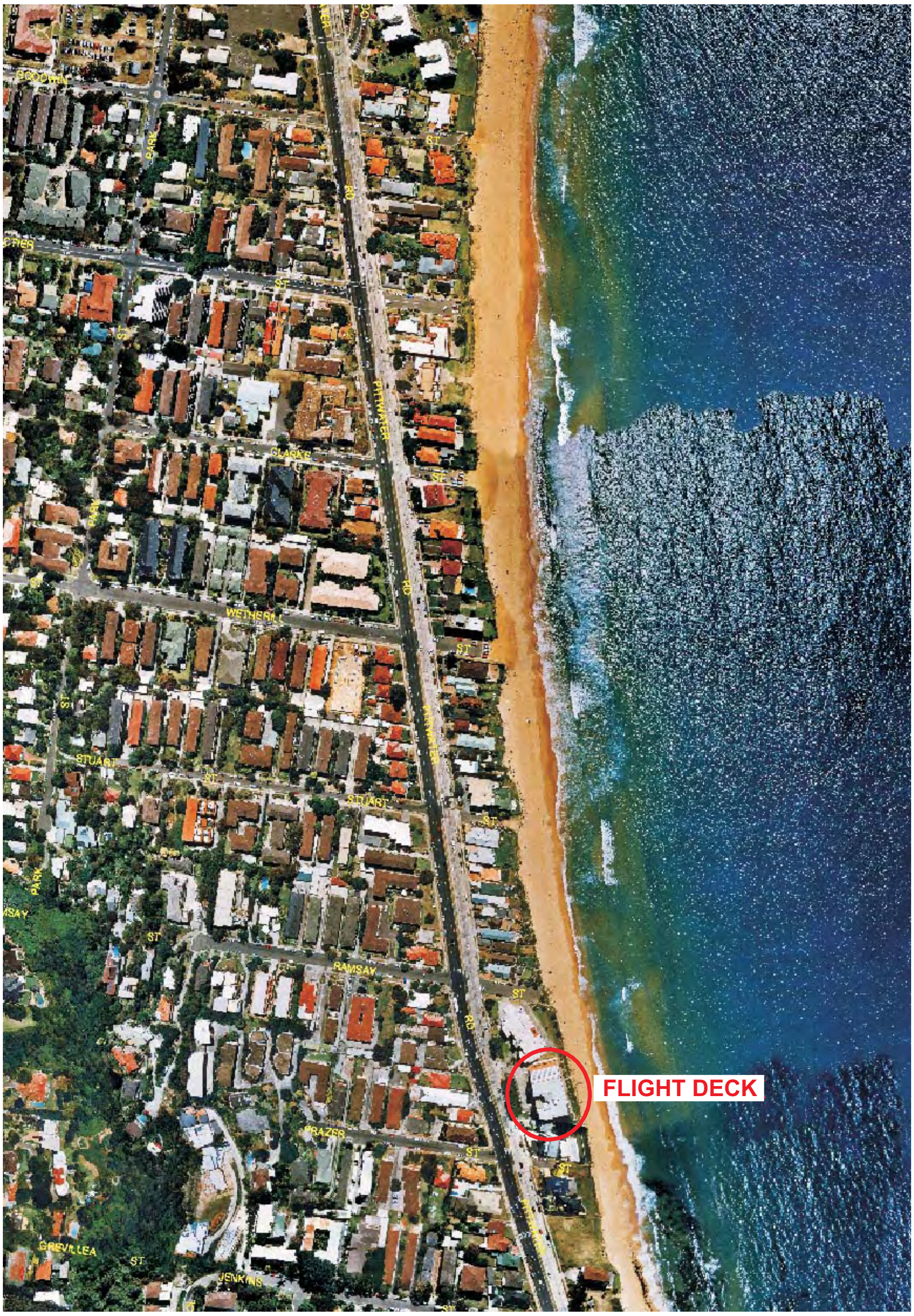
LOCALITY

Figure 2.1

02092-2-1.cdr

WRL Report No. 2007/30	COLLAROY - NARRABEEN EMBAYMENT, NSW	Figure 2.2 02092-2-2.cdr



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Report No. 2007/30

PRECINCT 3

Figure

2.3

02092-2-3.cdr

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

Comprehensive descriptions of the Collaroy-Narrabeen coastal imaging system design, installation, calibration, image types and image processing techniques were detailed in the first Collaroy-Narrabeen coastal imaging report entitled *System Description, Analysis of Shoreline Variability and Erosion/Accretion Trends: July 2004 - June 2005* (Turner, 2005). 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.

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 a tool commonly used by coastal managers to monitor regional-scale coastal behaviour. This is expensive and as a result, coverage is often ‘patchy’ and incomplete. Pictures are only obtained when visibility from the airplane 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 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 months and 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 recorded and available for more detailed analysis as required.

3.2 The Difference between Coastal Imaging and a 'Surfcam'

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 'surfcams' 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 (refer Turner, 2005). Sophisticated digital image processing techniques are then applied to extract and quantify information contained within the images.

3.3 The ARGUS Coastal Imaging System

The ARGUS coastal imaging system has developed out of fifteen years of ongoing research effort originating from Oregon State University, 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 Collaroy-Narrabeen 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 analogue I/O card that enables all images to be captured, stored and distributed in standard JPEG digital image file format.

At WRL, a dedicated 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 Collaroy-Narrabeen 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 Collaroy-Narrabeen

The ARGUS coastal imaging system was installed at Collaroy-Narrabeen in early July 2004. The system is located at an elevation of approximately 50 m above mean sea level, within the roof services area of the Flight Deck building (Figure 3.2). Flight Deck is located approximately 10 m - 20 m landward of the frontal dune, approximately 700 m to the north of the Collaroy ocean pool.

The cameras are mounted externally on a single frame that stands on the roof of the building, and are protected within weatherproof housings (Figure 3.3). The SGI workstation is housed within a pump 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 required.

3.5 Image Types

The ARGUS coastal imaging system installed at Collaroy-Narrabeen 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 June 2007 is shown in Figure 3.4 (upper panel).

3.5.2 Time-Exposure 'timex' Images

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

A lot of quantitative information can be obtained from these images. Time exposures of the shore break and nearshore wave field have the effect of averaging out the natural variations of breaking waves, to reveal smooth areas of white, which has been shown to provide an excellent indication 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 (bright) changing water surface is readily identifiable against the (dark) beach. 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 Narrabeen-Collaroy beaches 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.

3.6 Basic Image Processing – Merge and Rectification

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. As described previously, this is achieved through the solution of the camera model parameters to extract 3-D real-world position from 2-D 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 (lower panel). Also shown in this figure is a ‘pan’ image (upper panel), which provides an alternative wide-angle (but distorted) image of the coastline. The merged and rectified plan image created from five oblique images is analogous to a montage of distortion-corrected photographs taken from an airplane flying directly overhead the Collaroy-Narrabeen embayment. 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 Collaroy-Narrabeen is 2 m; that is, a single pixel represents an area 2 m × 2 m on the ground.

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.

3.7.1 Pixel Intensity Clustering

The shoreline mapping methodology used at the Collaroy-Narrabeen monitoring site utilises the full colour information available from ARGUS images. Called ‘Pixel Intensity Clustering’ or ‘PIC’, 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 3.6).

The filtered histogram is used to define a line to distinguish between Hue-Saturation information used for colour discrimination (Figure 3.6a), or Value information in the case of luminance-based discrimination (Figure 3.6b). 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 3.6). The areas of dry and wet pixels are then mapped, and the boundary between the two regions defines the resulting shoreline feature of interest. Comprehensive description of the PIC shoreline identification technique is provided in Aarninkhof (2003), Aarninkhof and Roelvink (1999) and Aarninkhof *et al*. (2003).

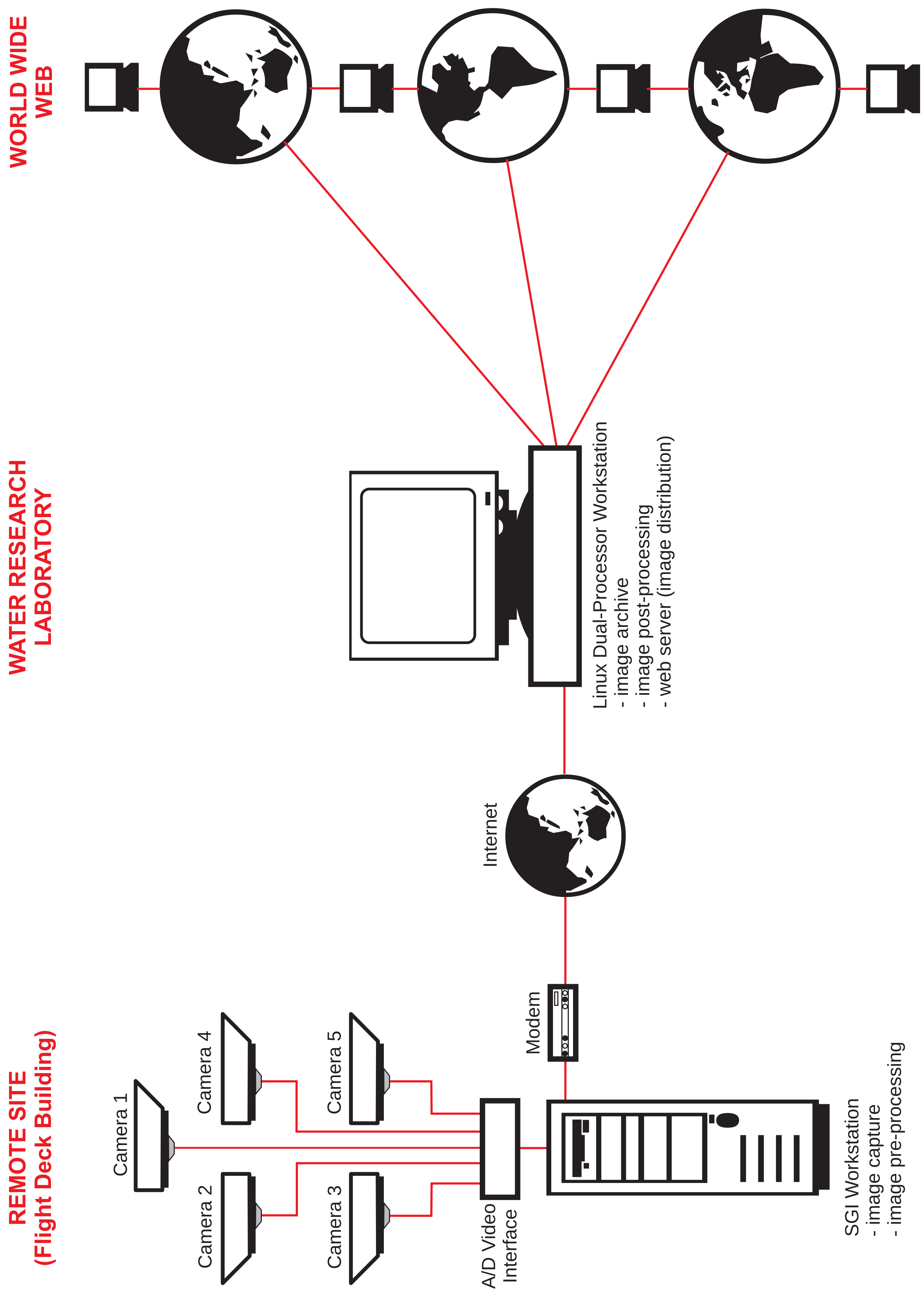
3.7.2 Standardised Procedure for Shoreline Mapping

The procedure used to map the shoreline at Collaroy-Narrabeen is summarised in Figure 3.7. At weekly (nominal seven day) intervals, observed tide information is used to determine the hourly timex images that correspond to mid-tide (0 m AHD). The corresponding merged-rectified 5-camera image is then created. 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 image is checked to confirm that the wave height satisfies the low-pass criteria $H_{rms} \leq 1.0$ m (Hs $\leq \sim$1.4 m). This wave height criteria is used for shoreline mapping as, above this wave height, wave run-up at the beachface increases and the width of the swash zone widens, introducing a corresponding uncertainty in the cross-shore position of the waterline. If the rms wave height is less than 1.0 m, then the shoreline is mapped. If the wave height exceeds the $H_{rms} = 1.0$ m threshold, then the mid-tide image for the preceding day is checked. If this image still does not satisfy the wave height criteria, then the following day's mid-tide image is checked. This process is repeated for up to ± 3 days from the original target weekly image, to locate a mid-tide image for which the rms 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 image to be processed has been identified, the PIC method is applied and the shoreline feature is mapped. Beach width is then calculated relative to the alignment of the existing boulder wall. By repeating this procedure every seven days, a growing database 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.

During the month of June 2007, a series of east coast low pressure cells generated three successive storm events impacting the Sydney coastline, resulting in significant erosion of the Collaroy-Narrabeen beach. Throughout this period, the extreme ongoing wave height meant that there was very little opportunity for shorelines to be mapped, which satisfied the wave height criteria previously discussed. However, to be able to provide some quantification of the erosion caused by this series of events, the wave height criteria was relaxed so that shorelines were mapped up to a H_{rms} of 1.5 m. While this increases the uncertainty associated with the position of these shorelines, it does provide an estimate of the beach erosion, that would otherwise have been unavailable until the month of July.



WRL Report No. 2007/30	SCHEMATIC OF AN ARGUS COASTAL IMAGING SYSTEM	Figure 3.1 02092-3-1.cdr

WRL Report No. 2007/30	LOCATION OF COASTAL IMAGING SYSTEM FLIGHT DECK BUILDING	Figure 3.2 02092-3-2.cdr

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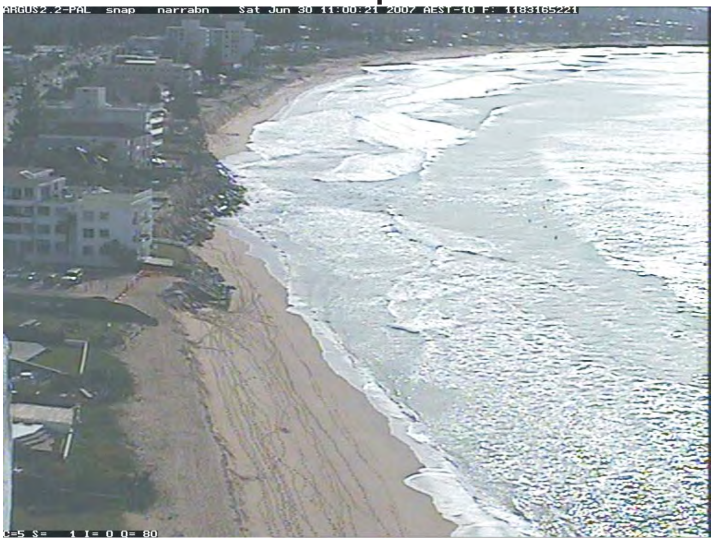
CAMERAS MOUNTED AT AN ELEVATION
OF APPROXIMATELY 50m

Figure

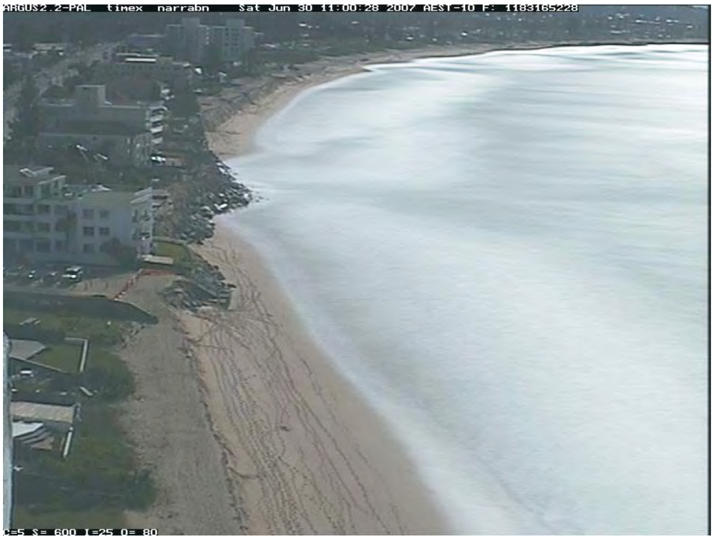
3.3

02092-3-3.cdr

snap

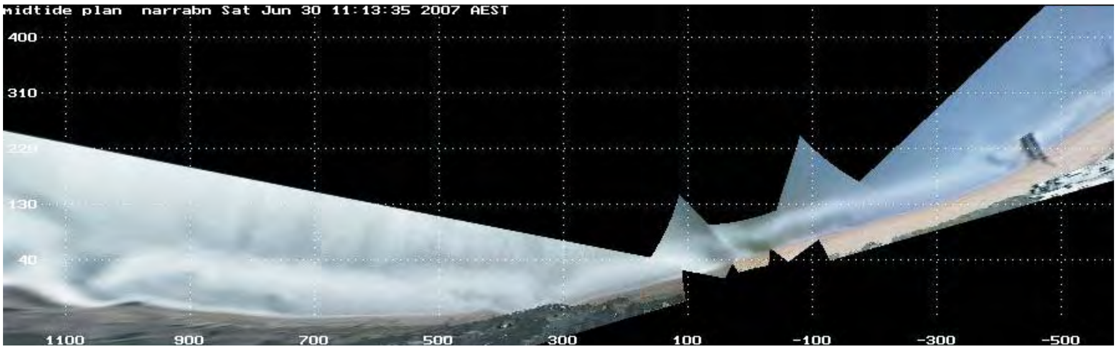


timex



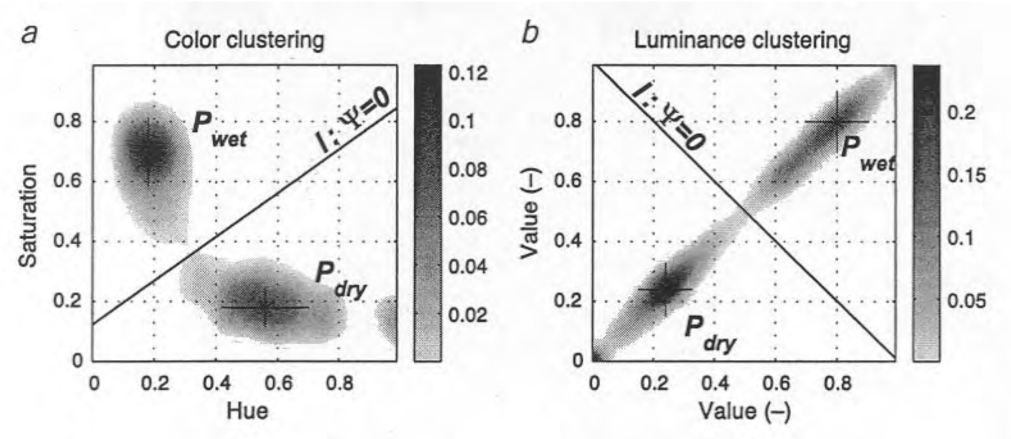
var

WRL Report No. 2007/30	SNAP-SHOT, TIME-EXPOSURE AND VARIANCE IMAGE TYPES (30/06/2007)	Figure 3.4 02092-3-4.cdr

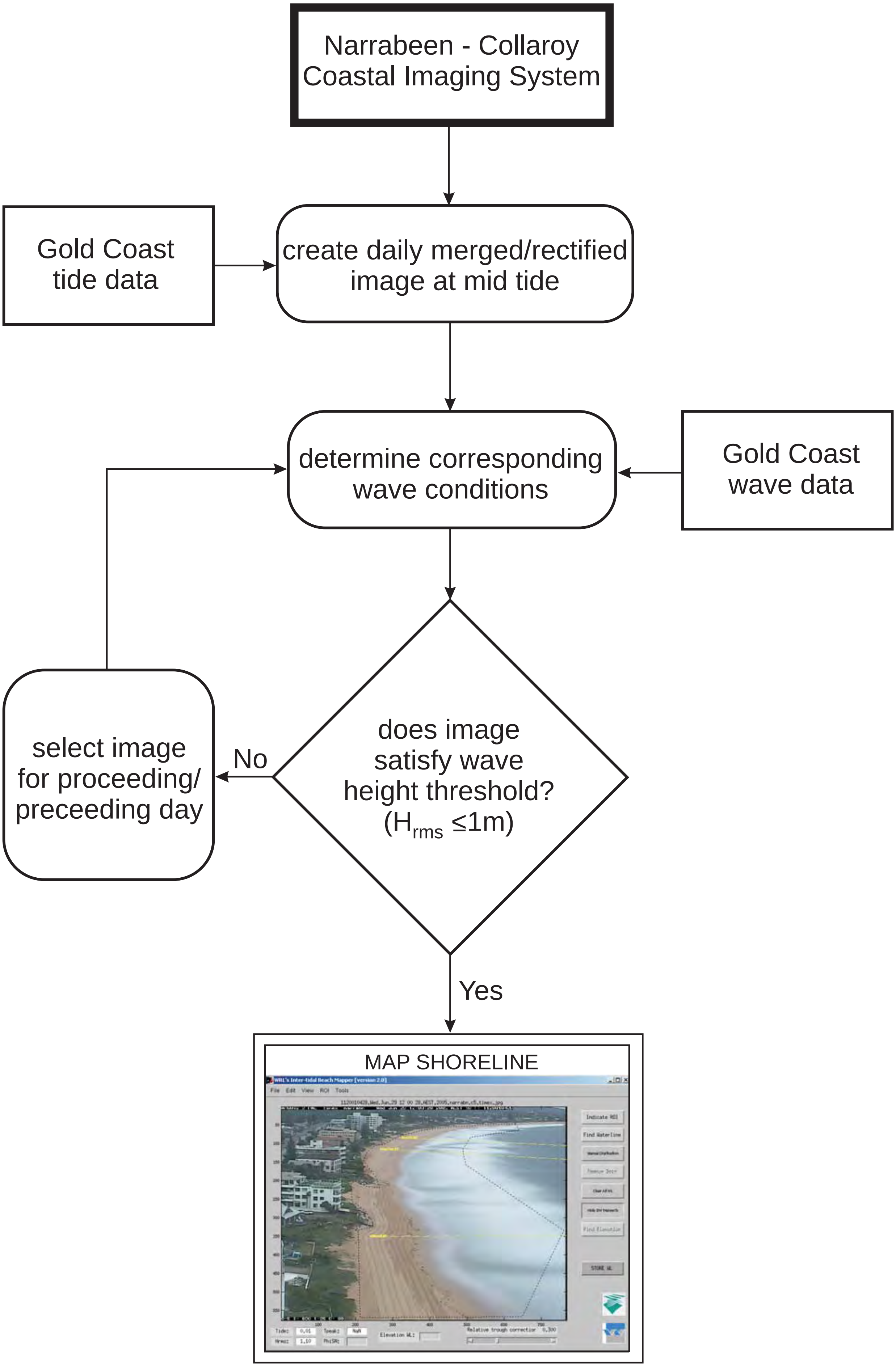


PAN AND PLAN VIEW IMAGES:
FIVE-CAMERA MERGE/RECTIFICATION

Figure 3.5



Source: Aarninkhof (2003)



WRL Report No. 2007/30	STANDARDISED SHORELINE MAPPING PROCEDURE	Figure 3.7 02092-3-7.cdr

4. COASTAL IMAGING WEB SITE

4.1 Coastal Imaging Home Page

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

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

The Collaroy-Narrabeen 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. 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 Warringah Council web site, wave monitoring, local weather conditions, and tide predictions.

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, over 278,000 hits to the main 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, and var images are updated and available at the project web site every hour.

All present and past images can be accessed via the on-line 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.

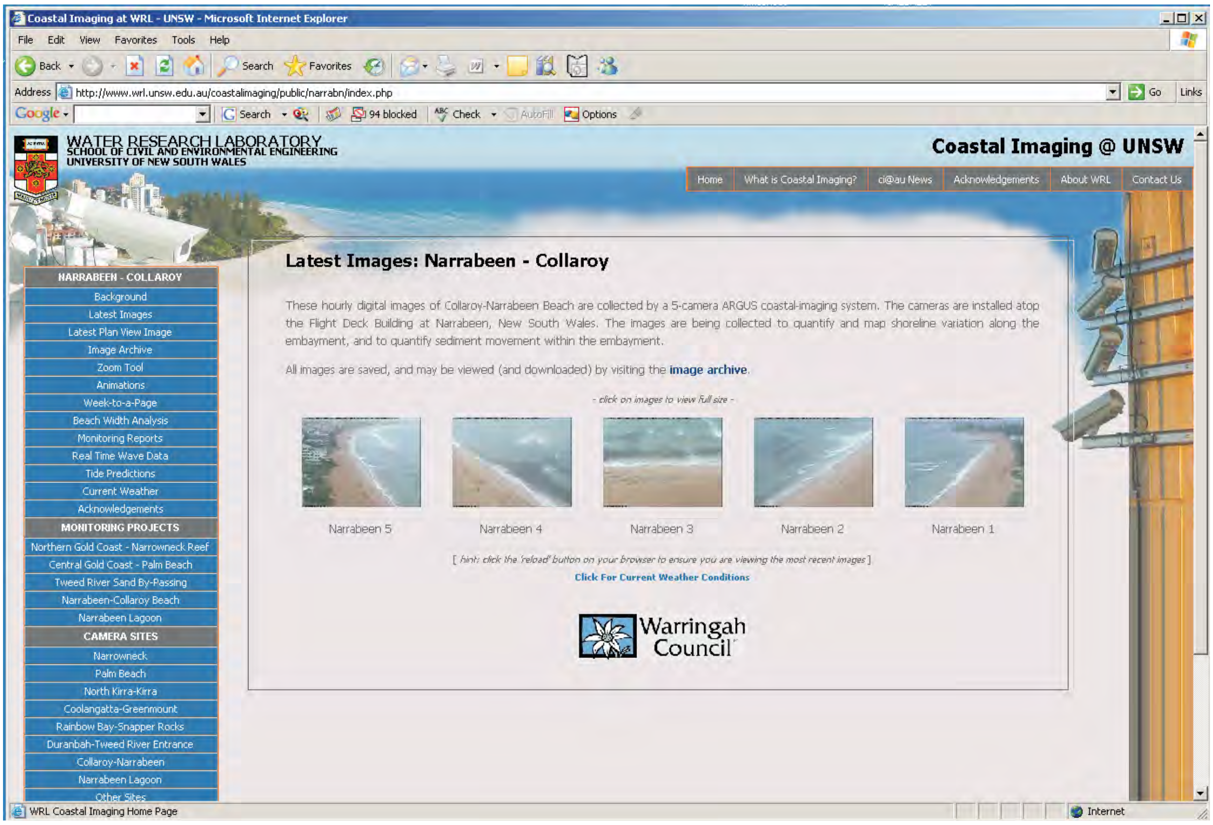
4.3 On-Line 'Beach Analysis System'

On-line access to 'real time' beach monitoring and analysis is made available at the Collaroy-Narrabeen 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 Warringah Council and the general public on a routine basis, via the world wide web.

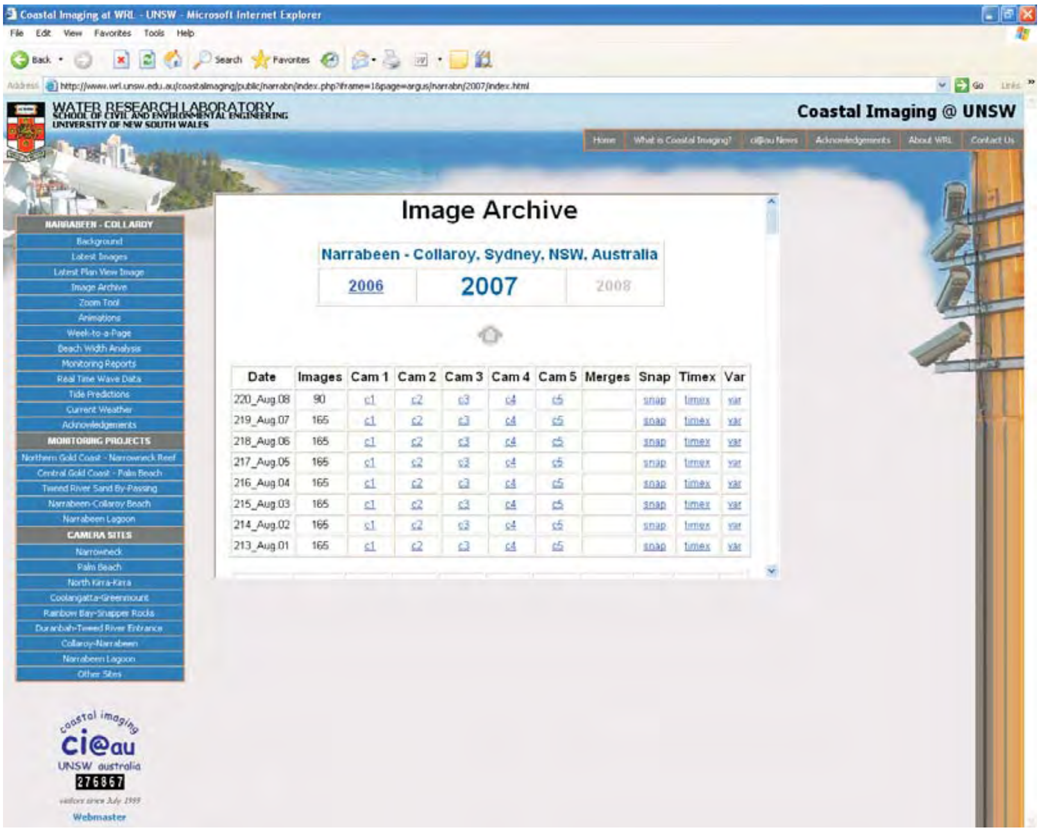
A detailed description of the capabilities of this system was detailed in Turner and Anderson (2007). To summarise, the features available at the project web site include the ability to view the latest mid-tide plan images; access to a zoom tool feature that enables zooming-in and panning through the 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.

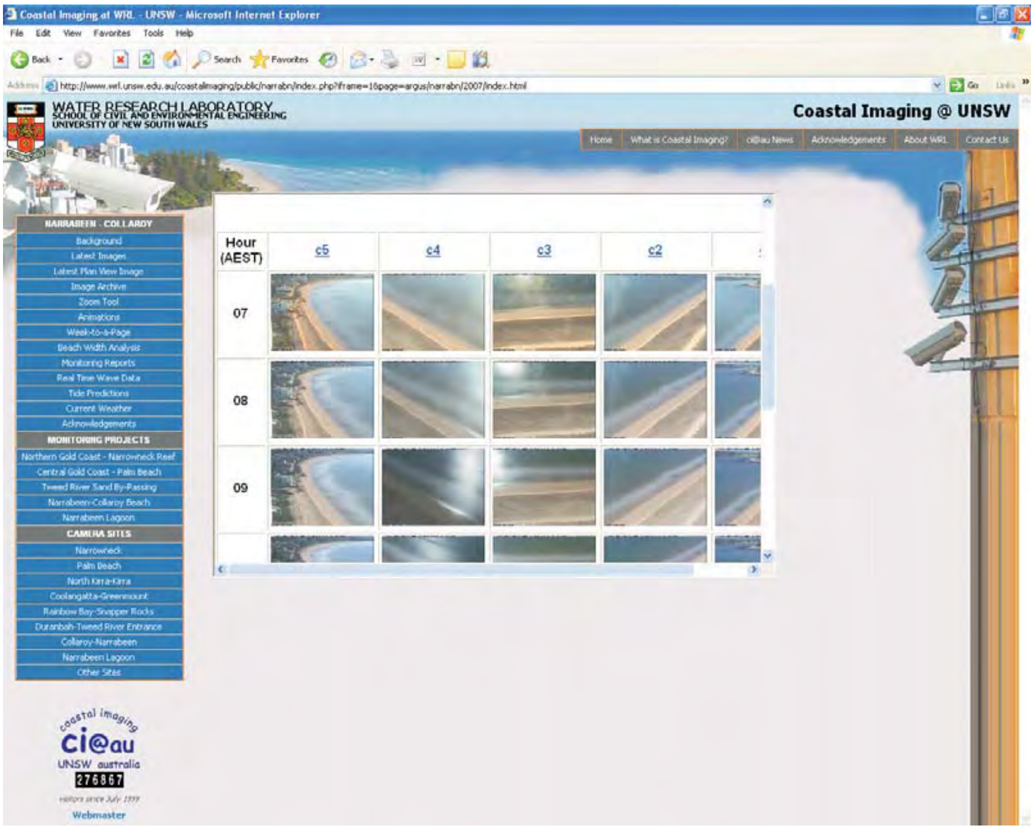
An example of the first of these products called 'week-to-a-page' is illustrated in Figure 4.3. Every Monday morning, this figure is generated and made available for viewing (and download, if required) via the project web site. The figure is pre-formatted to fit on a standard A4 page, to assist reporting. This figure compiles daily mean sea level plan view images of the Collaroy-Narrabeen embayment 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. Appendix A contains a compilation of the 'week-to-a-page' images from the current monitoring period July 2006 to June 2007. An archive of these weekly figures is also maintained and available on-line.

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

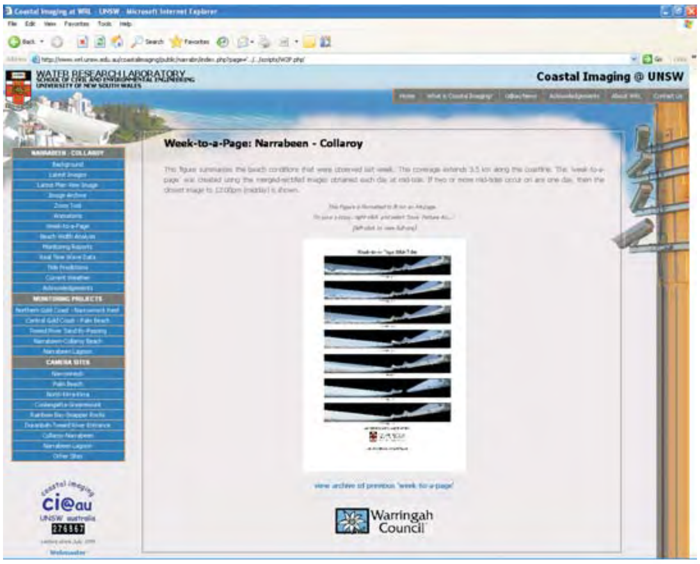


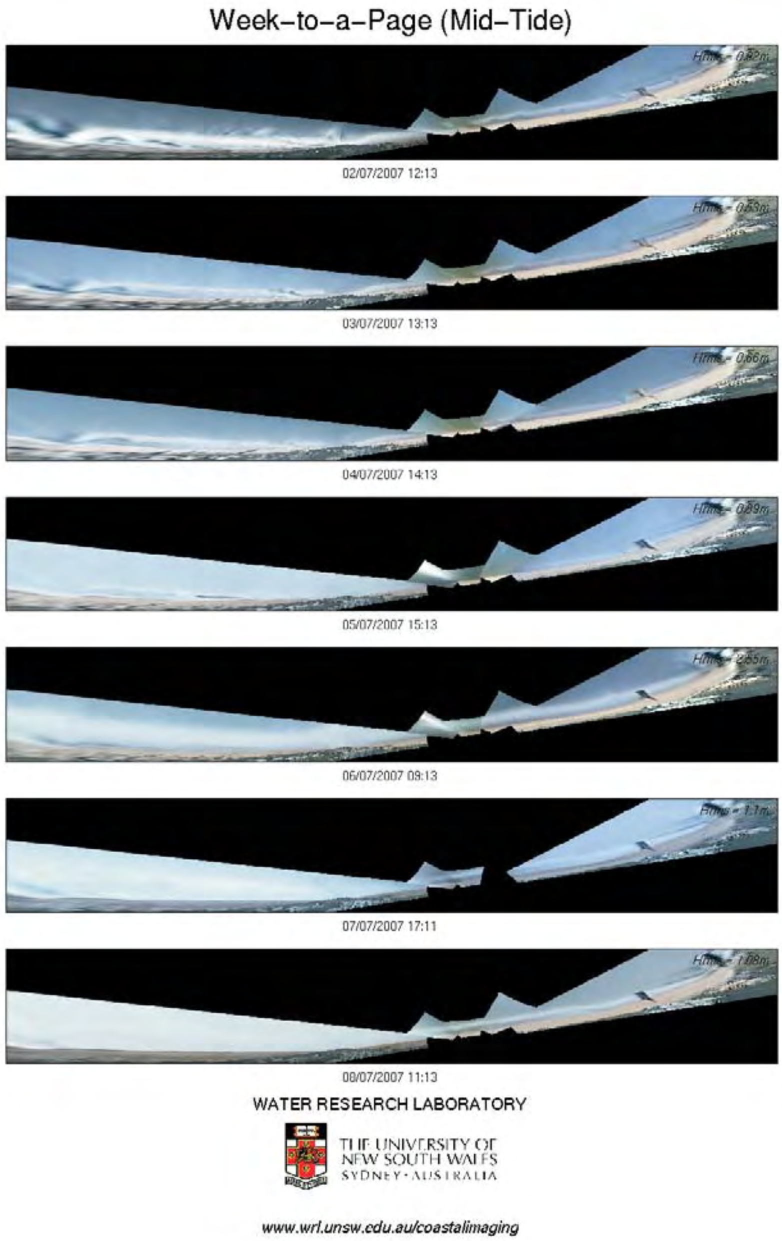
WRL Report No. 2007/30	COASTAL IMAGING WEB SITE - HOME PAGE	Figure 4.1 02092-4-1.cdr



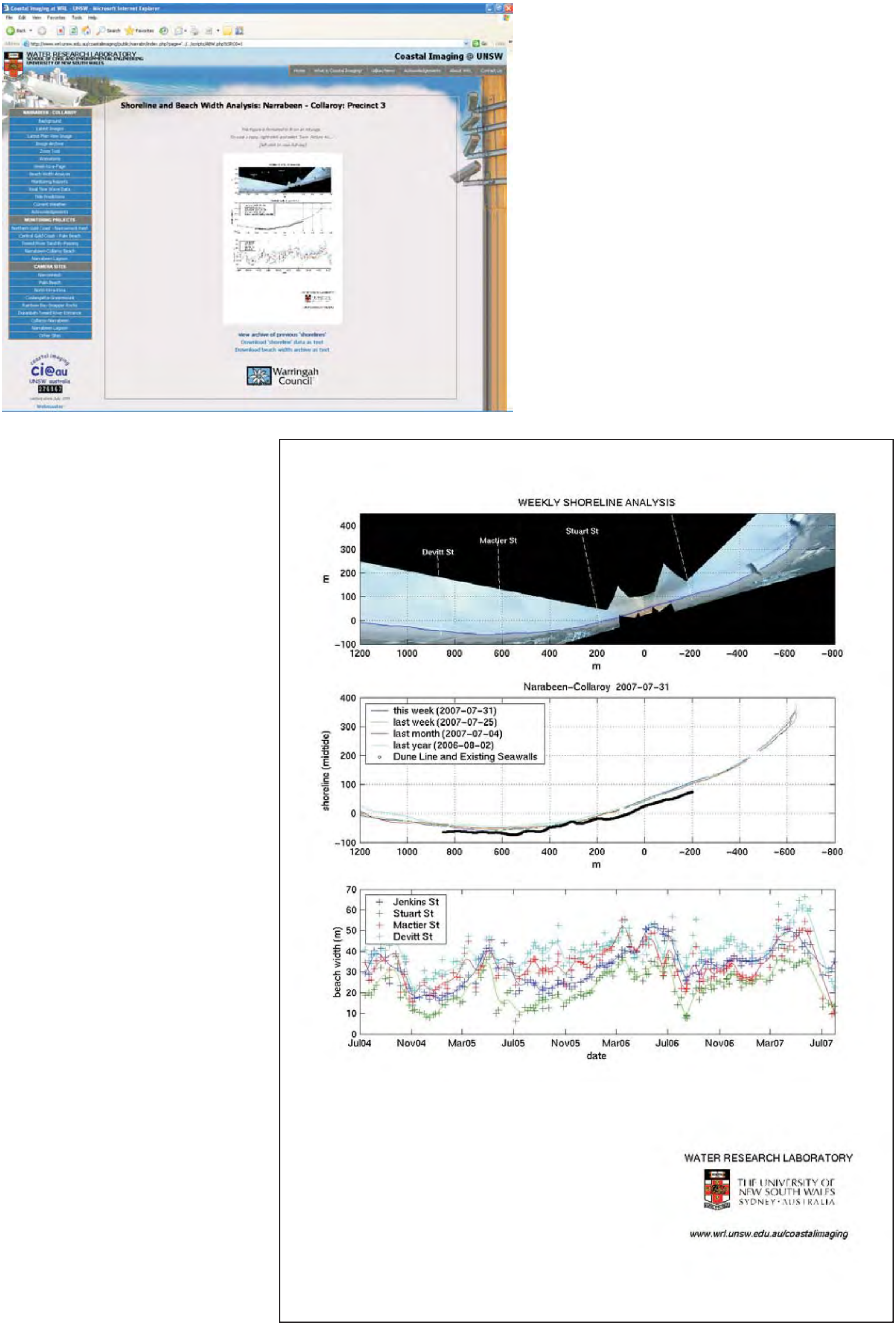


WRL Report No. 2007/30	COASTAL IMAGING SYSTEM WEB SITE - IMAGE ARCHIVE	Figure 4.2 02092-4-2.cdr





WRL Report No. 2007/30	ON-LINE BEACH ANALYSIS SYSTEM 'WEEK-TO-A-PAGE'	Figure 4.3 02092-4-3.cdr



WRL Report No. 2007/30	ON-LINE BEACH ANALYSIS SYSTEM 'BEACH WIDTH ANALYSIS'	Figure 4.4 02092-4-4.cdr

5. MORPHODYNAMIC DESCRIPTION OF COLLAROY-NARRABEEN: JULY 2006 – JUNE 2007

From the daily images obtained by the ARGUS coastal imaging station atop of the Flight Deck building, it is self-evident that Collaroy-Narrabeen beaches 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. This section is included to provide a qualitative description of the observed beach changes during the present twelve-month monitoring period July 2006 to June 2007. The 'week-to-a-page' summary figures that are updated every week and made publicly available for inspection and download via the project web site, are used in this section to illustrate the observed beach changes. The objective is not to describe every characteristic of Collaroy-Narrabeen beaches during this period, but rather 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.

5.1 A Morphodynamic Classification of Beaches

Despite the seemingly endless range of changes observed at any sandy coastline, in fact 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 plan form characteristics of these six beach states are summarised in Figure 5.1. A brief description of each of these states is provided below.

At one extreme is the *dissipative* beach state (Figure 5.1a), which is characterised by a very low profile slope and wide surf zone. 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 beach face 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 July 2006 to June 2007 are presented in Appendix A. Each of these figures shows a week (seven days) of sequential mid-tide plan images, with the date of each indicated. All images are obtained at 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 2000 m alongshore, from Collaroy ocean pool north along North Narrabeen beach.

To assist the interpretation of these images, Appendix B contains monthly summaries of wave height, period, and direction obtained from the Sydney Waverider buoy and supplied to WRL by Manly Hydraulics Laboratory. The Sydney Waverider buoy is located at Latitude 33° 46’ 54’’ S Longitude 151° 25’ 29’’ E in a water depth of approximately 85 m. This buoy was established in 1987, and is considered a good indication of the offshore wave conditions for Sydney.

5.2.1 July 2006

The last half of June 2006 was characterised by mild wave conditions, with the beach having typical RBB-TBR morphology. Wave conditions during July were dominated by a series of southerly swell events, with a peak spectral period of 12 to 15 seconds, and significant wave heights of 3 to 4 m.

The longer period swell events resulted in the surf zone shifting toward a more uniform longshore state, with the rips and transverse bars which developed during June no longer evident. The morphology of the beach was typical of a LBT state for the greater part of the month. For the three days from the 23rd to the 25th of July, a series of transverse bars were seen to develop, due to a short period of milder wave conditions with a more easterly direction, with the more irregular surf zone morphology evident through until the end of July.

5.2.2 August 2006

Throughout the month of August wave conditions were predominantly lower than the previous two months, with significant wave heights of the order of 1.5 m persisting. The wave height was seen to peak at 3.5 m for the week from the 5th to the 11th, and again overnight on the 25th.

The low wave conditions throughout August resulted in the beach continuing to adjust toward a lower energy morphological state. Irregularities in the offshore bar were evident, with transverse bars and cross-shore rips dominating the surf zone for the first half of the month. As the low wave energy conditions persisted, the offshore bar was seen to migrate toward the beach during the last half of the month, with no offshore bar evident at all throughout the last week of August.

5.2.3 September 2006

The low wave conditions experienced during August persisted throughout the month of September, with significant wave heights typically in the range of 1.0 to 1.5 m. The only deviation from the smaller wave conditions was a storm from the 7th to the 12th, with significant wave height peaking at 5 m.

During the initial three days of the moderate 3 m wave conditions (7th – 9th) the surf zone was uniform and wide, with no detached offshore bar present, due to the milder preceding wave conditions. As the moderate wave conditions continued, the surf zone shifted toward a higher energy state, with sand being removed from the beachface, and deposited in detached undular bars. At this point the morphology of the beach was typical of a RBB state. Throughout the remainder of the month, the surf zone and shoreline remained irregular, with transverse bars and rip features present, typical of an intermediate beach state.

5.2.4 October 2006

The morphology of the section of Narrabeen beach north of the ARGUS station remained in a higher energy intermediate beach state throughout most of October. Modal wave conditions were generally slightly larger throughout October than the preceding two months, with ongoing significant wave heights of the order of 2 m, peaking to 4 m on several occasions.

The complex series of transverse bars and rips which developed during late September were present during the first week of October, but migrated to a more uniform longshore bar morphology with the onset of the first 4 m significant wave height event on the 8th. During the period of milder more easterly wave conditions from the 12th to the 21st, the rips again developed at several locations across the beach, extending from the nearshore trough, through the detached offshore bar, to the back of the surf zone. The series of 3 – 4 m significant wave height southerly events which occurred on the 21st, 25th, and 29th, again saw the offshore bar become more uniform, and the surf zone increase in width.

5.2.5 November 2006

The Sydney wave climate during November was dominated by short 8 second period, south easterly wave conditions. During the first half of the month the significant wave height was typically 2 m, peaking to 3.5 m on three occasions. During the second half of the month, the wave height was slightly lower, with significant wave height of the order of 1 – 1.5 m, peaking only on the 30th, to a wave height of 4.5 m.

The wave height peaks dominated the morphology of the Narrabeen-Collaroy embayment during the first half of November, maintaining the beach in a higher energy intermediate state. A detached longshore bar spanned the entire beach length, with several regularly spaced cross shore rip currents evident on several days. During the second half of the month, the typically smaller wave conditions resulted in a narrowing of the surf zone, with the offshore bar inactive, except for the far northern section of the beach.

5.2.6 December 2006

Typical summer wave conditions occurred throughout the month of December, with regularly occurring 6 second wave period sea events, locally generated by the onshore sea breeze. Superimposed on these sea waves were ongoing 1.5 m significant wave height, 14 second wave period, southerly swell waves.

During the periods where the easterly sea waves were dominant, the surf zone was relatively uniform, with the shorter steeper waves typically breaking across the outer bar. This was contrasting to the beach morphology when the sea waves were less significant, and the surf zone was dictated by the southerly swell waves. During these times, the gradient in wave energy along the beach, as a result of the southerly wave direction and refraction/diffraction around long reef, was evident in width and intensity of the surf zone. While the beach was typical of an intermediate state across its entire length, the gradient in energy produced morphology typical of higher energy RBB/TBR conditions in the north ranging to lower energy TBR/LTT conditions in the south.

5.2.7 January 2007

Shorter period easterly sea waves with typical significant wave height of 1.5 m were again persistent during the month of January, interrupted for the week from the 8th to the 15th with a southerly swell wave event, having a significant wave height peaking at almost 4 m. During the last 10 days of January, data from the Sydney waverider buoy was intermittent, with indications of the offshore wave conditions only available for several hours every few days.

During the first week of January, the mild easterly wave conditions resulted in the beach shifting toward a lower energy intermediate state along its entire length. Up until the 5th, the surf zone was seen to narrow, with Narrabeen beach having a typical TBR surf zone, while at Collaroy sand from the bar continued to migrate to the beach face, as the morphology shifted toward a LTT beach state. In contrast to this, during the peak of the southerly swell wave event from the 7th to the 10th, sand was shifted away from the beach face, and again formed a relatively continuous detached offshore bar in response to the higher energy wave conditions. Images captured from the 19th – 21st clearly show this morphological feature.

Directly following the swell wave event, the surf zone was relatively uniform and two dimensional, with the short period easterly wave conditions breaking across the outer bar system. During the final week of January the beach responded to the ongoing lower wave energy conditions, and again began to migrate toward a lower energy intermediate state, with obvious undulations and transverse bar features developing through the surf zone, typical of RBB/TBR conditions.

5.2.8 February 2007

Ongoing lower wave conditions toward the end of summer resulted in the beach having a general accretionary trend, particularly in the south. Throughout February the offshore significant wave height was typically 1 – 1.5 m, peaking at 3 m on the 12th and 13th. The milder wave conditions continuing from the end of January and throughout the start of February resulted in continuing changes to the surf zone toward a lower energy state. This was disrupted by the storm on the 12th and 13th, which resulted in the development of a longshore double bar system at Narrabeen, which became more irregular along the beach toward the south.

In mid February, the surf zone was dominated by the detached offshore bar in the north, a series of transverse bars and large rips in the centre of the mapped section of beach, with fewer rips and again more uniform lower energy conditions at Collaroy. Throughout the last half of the month, the offshore bar at Narrabeen became less regular, and was cut by a series of cross shore rips. Images taken at the end of February show that by the end of the month, the surf zone of the entire Narrabeen-Collaroy embayment was dominated by regularly spaced rips, which were larger across the northern sections of beach and lower in intensity at the south.

5.2.9 March 2007

Throughout March there were very few significant changes to the morphology of the Narrabeen-Collaroy embayment, as the beach continued with an underlying trend toward a lower energy state. By mid March the entire stretch of beach was again uniform and two dimensional, with no significant offshore bar features or rips active in the surf zone.

For two days on the 25th and 26th, the offshore wave conditions were dominated by south easterly swell, which peaked at approximately 4 m significant wave height. The shorter 10 second wave period meant that there was very little impact of this event at Collaroy with most wave energy not refracting/diffracting around Long Reef, while at Narrabeen there was minor movement of sand into a longshore bar, as the surf zone widened in response.

5.2.10 April 2007

Wave conditions throughout April were less dominated by the easterly sea waves which persisted throughout the preceding summer months, and were predominantly south-easterly 12 second period swell waves, with the significant wave height being typically 1.5 m, peaking to 3 m on several occasions. The relatively uniform surf zone which developed during March, was also maintained throughout most of April.

The first peak in wave height from the 6th to the 8th resulted in some movement of sand from the beach face, north of the Argus station. Images taken on the 11th and 12th clearly show the development of a series of regularly spaced cusp features along the entire mapped length of the embayment. These features are typical for a beach in an intermediate energy state, between LTT and RBB. Throughout the remainder of the month, there were few significant changes to the morphology of the beach.

5.2.11 May 2007

While the wave conditions were moderate to low throughout the month of May, it is notable that the predominant wave energy impacting the beach resulted from 10 – 12 second period swell waves, typically approaching from a more easterly direction, than the previous two months. While the significant wave height rarely exceeded 2 m, the more easterly wave direction resulted in changes to the shoreline across the southern half of the embayment, more than the northern half. This was most evident during the period from the 12th to the 18th, when erosion of the beach occurred in the region between the ARGUS station and the Collaroy stormwater pipe.

During the last ten days of May, the cusp features in the shoreline which developed during April, were again evident along the Narrabeen stretch of beach. During this period, there was extremely low wave energy impacting the coastline, with almost no surf zone evident at Collaroy.

5.2.12 June 2007

During the month of June three separate east coast low pressure systems impacted the Sydney coastline, producing extreme wind, wave, and rainfall conditions. Waves generated by the first low pressure cell impacted the coastline on the 8th – 12th of June, with the significant wave height exceeding 6.5 m on several occasions, and persisting at above 4 m for a period of over 60 hours. The second storm impacted the coast on the 16th, with the significant wave height measured by the Sydney waverider buoy again exceeding 6 m. The storm wave conditions generated by the second east coast low pressure cell were ongoing, and impacted the coastline through until the 23rd. On the 29th of June the effects of the third east coast low pressure cell impacted the coast, with the significant wave height peaking at almost 5 m. Ongoing large wave conditions persisted into July.

Kulmar *et al.* (2005) and You (2007) analyse the offshore wave height recurrence interval distribution developed from historical records of wave height data captured by the Sydney waverider buoy. Analysis of June storms with the data presented by Kulmar *et al.* (2005) indicates that the three east coast low pressure cells produced significant wave height events with a 4 year average recurrence interval (ARI), 1.4 year ARI, and 0.4 year ARI respectively. The same analysis undertaken using the wave height frequency distribution published by You suggests that the recurrence intervals were similar, but slightly higher, being 5 year ARI, 2 year ARI, and 0.4 year ARI respectively. This analysis highlights that none of these three storm events, if occurring individually, were of magnitude normally considered for coastal design in NSW. However, the occurrence of the three events within a three week period is somewhat more extreme, and perhaps of greater significance to erosion along the Narrabeen-Collaroy beach.

Throughout the duration of extreme waves generated by the first storm, the images recorded by the ARGUS station show a wide surf zone of broken waves propagating to the shoreline. With the slight decrease in wave height around the 12th to 14th, it can be seen that the large waves of the storm peak caused rapid erosion of the beach, and developed a longshore bar extending the entire length of the embayment, as the morphology of the beach approached a high energy dissipative state. During the slight lull in wave energy between the first and second storm events, a series of rip currents developed and extended through the offshore bar at Collaroy.

With the onset of the second storm from the 16th, the northern section of the embayment maintained its dissipative state, with an outer breaker zone, followed by a trough, then a second breaker zone over a longshore bar, which was separated from the beach by a second trough. The beach remained in this high energy state through the last half of June and into July. The image taken on the 29th of June clearly shows the developed dissipative surf zone across the Narrabeen section of the embayment, and the detached longshore bar and trough system at Collaroy.

It can be seen from the ARGUS images that the three sequential storm events caused widespread and rapid erosion of the Narrabeen-Collaroy beach. At the end of May 2007, the beach was in a relatively accreted state, while at the end of June, the beach was completely eroded back to the rubble seawall at Stuart Street and Wetherill Street. Ongoing erosion of the beach has occurred into July.

5.3 Visual Assessment of Net Beach Width Changes (July 2006 – June 2007)

Beach and nearshore conditions during the present twelve-month monitoring period July 2006 to June 2007 were typically characterised by generally mild wave conditions and growth of the beaches. However, the net change in beach width has been dictated by the three successive storms which occurred at the end of the monitoring period during June 2007. The wave climate during the winter and spring of 2006 was dominated by southerly swell events, with higher energy intermediate morphology across the northern sections of the embayment, ranging to lower energy intermediate morphology at the more sheltered Collaroy section of the beach. During the summer and autumn months the predominant shorter period easterly wave conditions produced less of a gradient in beach morphology along the beach, with the beach generally in a lower energy state. The month of June saw significant erosion of the beach, with the net beach width at the completion of the twelve-month monitoring period narrower than the start of July 2006.

A qualitative visual assessment of the net trends in beach adjustment during this time can be seen by contrasting images of the beach obtained at the start and end of the present twelve month monitoring period. Figure 5.2 shows the snap images obtained at mid-tide from Camera 1 (south) on 1/07/06 and 30/06/07 respectively. The corresponding snap images of the central-northern embayment obtained from Camera 5 are shown in Figure 5.3.

Along both the southern (Figure 5.2) and the central-northern regions of the embayment (Figure 5.3), significant net erosion of the beach has occurred. The most pronounced erosion has been at Stuart and Wetherill Streets, where the beach was tens of metres wide in July 2006, but has been completely eroded back to the boulder wall during the storms of June 2007. A significant near vertical erosion scarp is evident in the images taken on 30th June 2007, and is more predominant extending to the north from the ARGUS station at the Flight Deck building.

5.4 Visual Assessment of Total Beach Width Changes (July 2004 – June 2007)

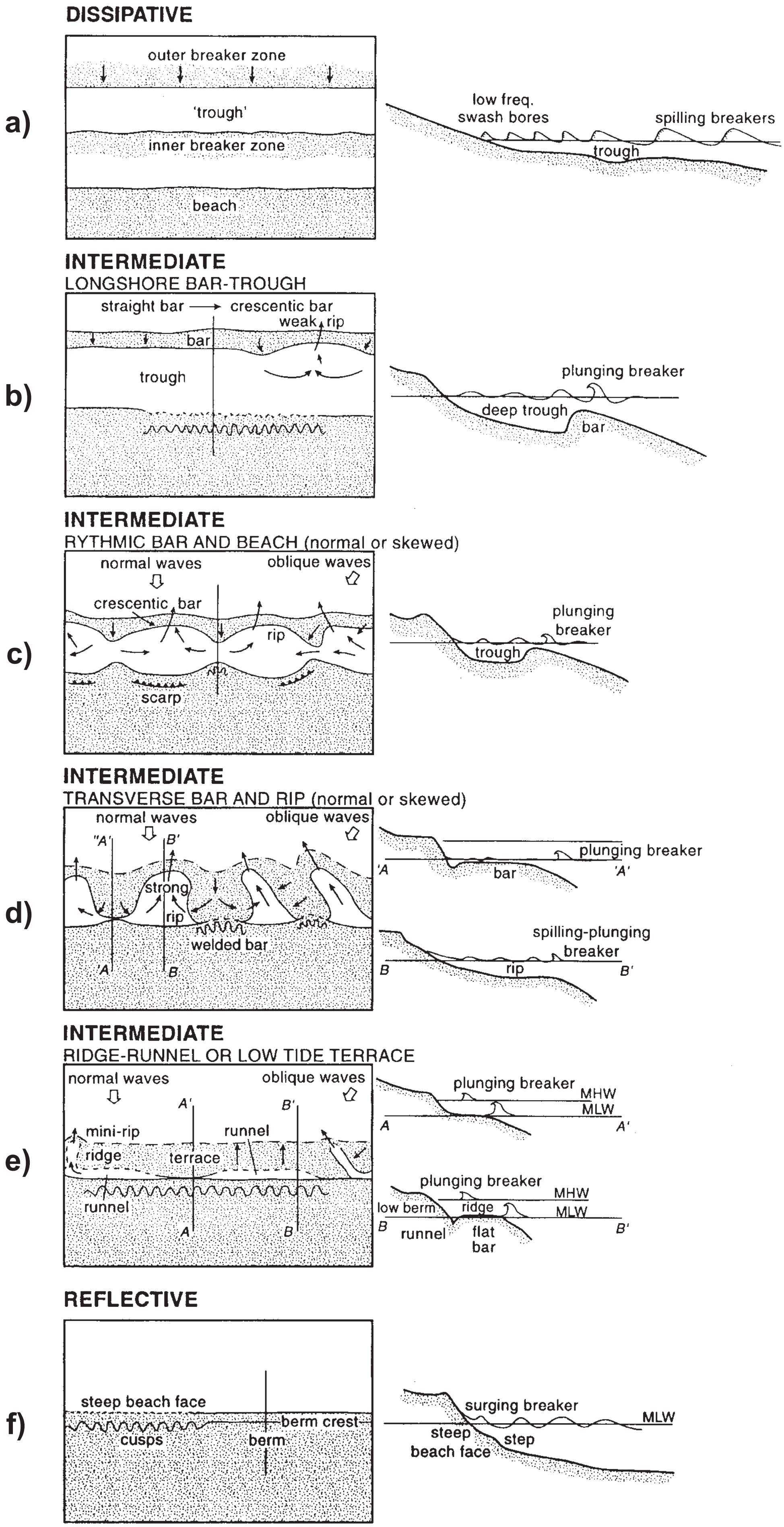
The net changes to date since the commencement of monitoring at Collaroy-Narrabeen three years ago in early July 2004 are seen in Figure 5.4. In this figure, mid-tide timex images of the beach to the south and north of the Flight Deck building are shown at 12-monthly intervals for the entire monitoring period July 2004 – June 2007.

Beach and nearshore conditions during the initial 12 month monitoring period July 2004 to June 2005 were characterised by three distinct stormy periods when the beach was observed to erode, separated by moderate to mild wave conditions, during which times partial beach recovery was observed. The first stormy period commenced with the occurrence of a large storm event in mid July 2004, when offshore significant wave heights rose to 7 m. Moderate wave conditions through the first half of August peaked with the occurrence of a second storm in the middle of the month (offshore significant wave heights up to 5 m). Wave energy then declined, with generally mild conditions through the second half of August, and throughout September. The second stormy period commenced in October, with the occurrence of four storm events in the single month, when offshore significant wave heights up to 6 m were recorded. In contrast, November again saw a return to mild conditions, followed by a series of moderate storms in December, when offshore significant wave heights of 3 – 4 m were observed. Moderate wave conditions prevailed through January 2005, followed by generally milder conditions in February. The third stormy period commenced in the second half of March, when offshore significant wave heights again exceeded 6 m. Mild to moderate wave conditions returned in April and continued through to late June, interrupted in mid May by a period of elevated wave energy.

Beach and nearshore conditions during the monitoring period July 2005 to June 2006 were characterised by generally mild wave conditions and growth of the beaches within the Collaroy-Narrabeen embayment. This general accretionary trend was interrupted on three occasions by the occurrence of storms in October 2005, April and early June 2006, that each resulted in short-term periods of the offshore movement of sand from the beachface and across the surfzone. Along both the southern and central-northern regions of the embayment a distinct trend of net beach widening was monitored. This was most pronounced around the boulder walls around Jenkins and Stuart Streets, which were fully exposed to wave actions at high tide in early July 2005, but by June 2006 were buried again, with a buffer of sand several tens of metres wide between the toe of the walls and the shoreline.

During the present monitoring period, July 2006 to June 2007 beach and nearshore conditions were typically characterised by mild wave conditions and growth of the beaches, however, the net change in beach width has been dominated by the three successive storms which occurred at the end of the monitoring period during June 2007. Slight erosion of the beach was generally observed throughout the winter months from June to August 2006, but was followed by an accretionary period from August to October, where milder wave conditions saw overall increases in beach width. This trend was interrupted from October to December 2006, when the beach was again observed to decrease in width, particularly across the northern section of the embayment. Milder wave conditions dominated the summer and early autumn months of 2007, with the beach again continuing a general trend of widening. There was very little net change to the beach through the months leading into winter, however, during June significant erosion of the beach by three successive storms occurred, and dominated net beach width change for the current monitoring period. The net beach width at the completion of the current twelve-month monitoring period July 2006 to June 2007 was significantly narrower than the start of July 2006.

A quantitative and more detailed assessment of the response of the beach within Precinct 3 for the 12-month period July 2006 to June 2007, is detailed in the following Section 6.



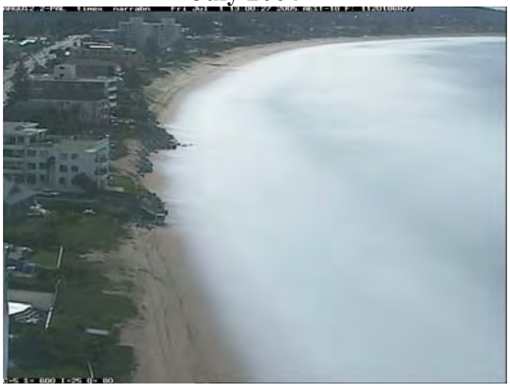
WRL Report No. 2007/30	MORPHODYNAMIC BEACH STATE MODEL (after WRIGHT and SHORT, 1983)	Figure 5.1 02092-5-1.cdr

WRL Report No. 2007/30	SNAP IMAGES FROM CAMERA 1 (SOUTH): 01/07/2006 AND 30/06/2007	Figure 5.2 02092-5-2.cdr

WRL Report No. 2007/30	SNAP IMAGES FROM CAMERA 5 (NORTH): 01/07/2006 AND 30/06/2007	Figure 5.3
		02092-5-3.cdr

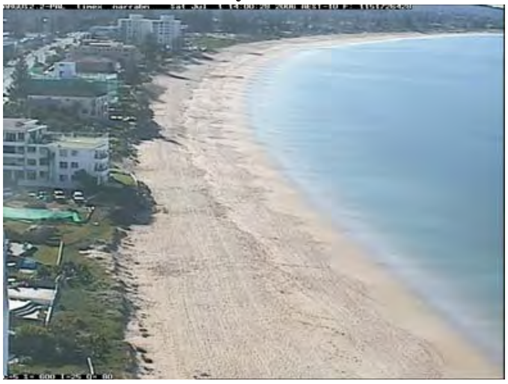
July 2004

July 2004



July 2005

July 2005



July 2006

July 2006

June 30th 2007

June 30th 2007

WRL Report No. 2007/30	ANNUAL BEACH CHANGES C1 (SOUTH) AND C5 (NORTH): JULY 2004 - JUNE 2007	Figure 5.4 02092-5-4.cdr

6. QUANTITATIVE ANALYSIS OF SHORELINE CHANGES: JULY 2006 – JUNE 2007

The primary function of the coastal imaging system installed at the Flight Deck building is to quantify shoreline changes and beach variability within Precinct 3, in order to better understand the behaviour of this most vulnerable section of the Collaroy-Narrabeen embayment. Quantitative analysis of weekly shoreline position and beach width provide an objective measure to assess the beach amenity and storm buffer seawards of the existing property boundaries.

6.1 Weekly Shorelines

All shorelines for the period 01/07/06 to 30/06/07 are shown in Figure 6.1. For reference, these measured shorelines are overlaid onto a representative merged/rectified timex image (image date: 30th June, 2007). The image represents a 2000 m length of the Collaroy-Narrabeen embayment, extending from the Collaroy ocean pool in the south along the Narrabeen beach to the north. The ARGUS station is located at coordinate [0,0], with the black 'shadow' region in this vicinity caused by the region of beach immediately in front of and adjacent to the building being outside the cameras' field of view. For reference, the crest alignment of the back-beach boulder wall (subsequently rejected by the community in 2003 - refer Section 2.2) is here used as the landward reference line for the calculation of beach width, and on Figure 6.1 is also indicated by the landward-most red line.

To see more clearly the range of shoreline positions mapped during this twelve month period, Figure 6.2 shows a plot of the position of the weekly shorelines within Precinct 3, relative to the proposed boulder-wall alignment. The distance of these shorelines from the wall alignment 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 the previous figure is shown for reference. Note that, due to the Flight Deck building being located so close to the beachfront, on a number of occasions the shoreline between approximately ±100 m alongshore could not be mapped, due to it being obscured from the cameras by the edge of the building.

During the present monitoring period 01/07/06 – 30/06/07 it can be seen from Figure 6.2 that the beach along the Precinct 3 oceanfront varied in width (relative to the alignment of the proposed boulder wall) from approximately 65 m toward the northern end, to 0 m at locations 200 m, 300 m, and 400 m north of the Flight Deck building. The envelope of beach width changes across the northern section of the embayment varied from approximately 40 m in the area just north of the Flight Deck building, up to 55 m in the far north of the mapped section of beach. South of the Flight Deck building the envelope of beach widths was less variable, and typically of the order of 30 m.

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

The alongshore variability of the measured shoreline positions within Precinct 3 during the monitoring period 01/07/06 – 30/06/07 is further quantified in Figure 6.3. The upper panel of this figure shows a plot of the mean, maximum and minimum shoreline position at 2 m increments alongshore. For reference, in the lower panel the mean shoreline position during this period is overlaid on to a merged/rectified timex image of the Precinct 3 region (image date = 30th June 2007). Again, data for the region immediately in front of and adjacent to the Flight Deck building is not plotted, as limited shoreline data only was obtained in this location present monitoring period, prior to the adjustment of the positions of cameras C2, C3 and C4 (refer Section 1.2).

Referring to Figure 6.3, the median beach width at mid-tide (relative to the wall alignment) was of the order of 40 m toward the northern end of Precinct 3 and the area 500 – 600 m north of Flight Deck. This reduced to 20 - 30 m along a 200 m length of the beach centred at 300 m north of Flight Deck, then south of this region increased again to around 35 m median beach width. Referring to Figure 6.2, it can be seen that the back-beach alignment from which beach widths are measured tends to project further seaward in the region identified above as corresponding to the region of narrowest beach, due to the presence of existing boulder wall structure(s) in this region of Precinct 3.

The analysis of maximum and minimum beach width for Precinct 3 (upper panel, Figure 6.3) reveals a trend of slightly higher beach width variability in the far north, decreasing in a southward direction alongshore. Throughout Precinct 3 the beach width varied by up to ±20 m from the mean shoreline position at the northern end, and by approximately ±15 m from the mean shoreline position at the southern end. This perhaps highlights the sheltering of the southern stretch of beach from southerly wave attack, that is provided by Long Reef.

The middle panel of Figure 6.3 shows the standard deviation (s.d.) of weekly shorelines from the mean shoreline position during the period 01/07/06 – 30/06/07. The standard deviation of weekly shorelines also shows the slight decreasing trend from north to south alongshore, with the calculated s.d. decreasing in a linear manner from 10 m towards the northern end of Precinct 3, down to 7 m at the southern end.

6.3 Time-Series of Beach Widths at Control Transects (Precinct 3)

The variations in shoreline position measured at four representative transects within Precinct 3 for the twelve month monitoring period July 2006 to June 2007 are shown in Figure 6.4. For convenience, the locations of transects were chosen to coincide with the eastern end of beachfront streets. Figure 6.4 plots the weekly shoreline position at Devitt Street, Mactier Street, Stuart Street and Jenkins Street, with the alongshore position of each of these beach transects shown in the accompanying merged/rectified image. A 3-point running mean has been fitted to the weekly data, to assist interpretation of the predominant trends.

The beach response at all four monitoring transects exhibits a similar underlying accretionary trend throughout the present twelve-month monitoring period up until June 2007. All four transects show rapid decrease in beach width of 20 m to 30 m through July and into August 2006. The beach width then fluctuated with a slight trend of accretion, up until November, when the trend was again interrupted by a period of more erosive wave events. This was particularly evident in the more northern transects at Devitt and Mactier Streets. Throughout the summer months and into autumn, the beach grew rapidly in width, particularly in the north, reaching a maximum width of over 60 m at Devitt Street, 50 m at Mactier and Jenkins Streets, and 40 m at Stuart Street. At this time the beach had accreted to much the same width as at the start of the monitoring period in July 2006, across the entire Precinct 3.

The three storm events which occurred in June 2007 caused rapid erosion of the beach. Within a period of one fortnight, some 40 m to 50 m of beach width was lost at the northern transects at Devitt and Mactier Streets, and 35 m lost at Stuart and Jenkins Streets. At several locations to the north of the ARGUS station, the beach was eroded completely, with wave runup reaching the boulder wall at the back of the beach. North of Devitt Street and south of Jenkins Street, a beach width of 10 m to 20 m remained, at the time the last shoreline was mapped in late June. Ongoing erosion of the beach has occurred since the last shoreline was mapped for June, with the complete analysis of the net erosion from the June and July storms being completed for the next monitoring period report.

6.4 Weekly Shorelines (July 2006 – June 2007) Relative to Mean Shoreline Position of Previous Twelve-Month Monitoring Period

The beach changes observed during the present twelve-month monitoring period July 2006 to June 2007 are presented in Figure 6.5, relative to the mean shoreline alignment calculated for the prior twelve month period July 2005 to June 2006. To summarise, in the upper panel the deviation of weekly shorelines from the prior mean shoreline alignment is plotted. In the lower panel this mean shoreline position for the previous monitoring period July 2005 - June 2006 is shown, along with the mean shoreline calculated for the present monitoring period.

This analysis shows that the majority of the shorelines mapped during the current monitoring period are clustered within ±10 m of the mean shoreline from the previous monitoring period. Most shorelines mapped for Precinct 3 throughout the current monitoring period show a wider beach than the mean width of the previous monitoring period. Between July 2006 and June 2007, the beach reached a maximum width of 25 m to 30 m greater than the mean width calculated for the previous year. The minimum beach width for the current monitoring period (taken from June 2007) is approximately 30 m narrower than the mean beach width from the previous monitoring period.

Analysis of the lower panel of Figure 6.5, which shows the mean shoreline from both the current and previous monitoring periods, indicates that for most of the current monitoring period, the beach was slightly narrower across the northern section of Precinct 3, and slightly wider across the southern stretch of the beach.

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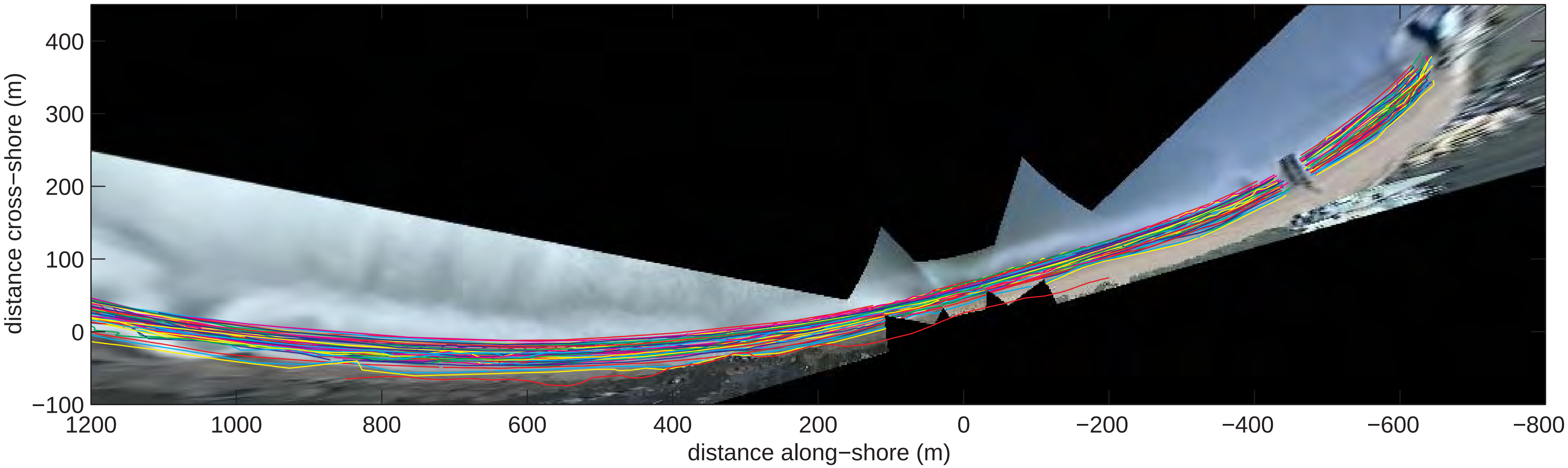
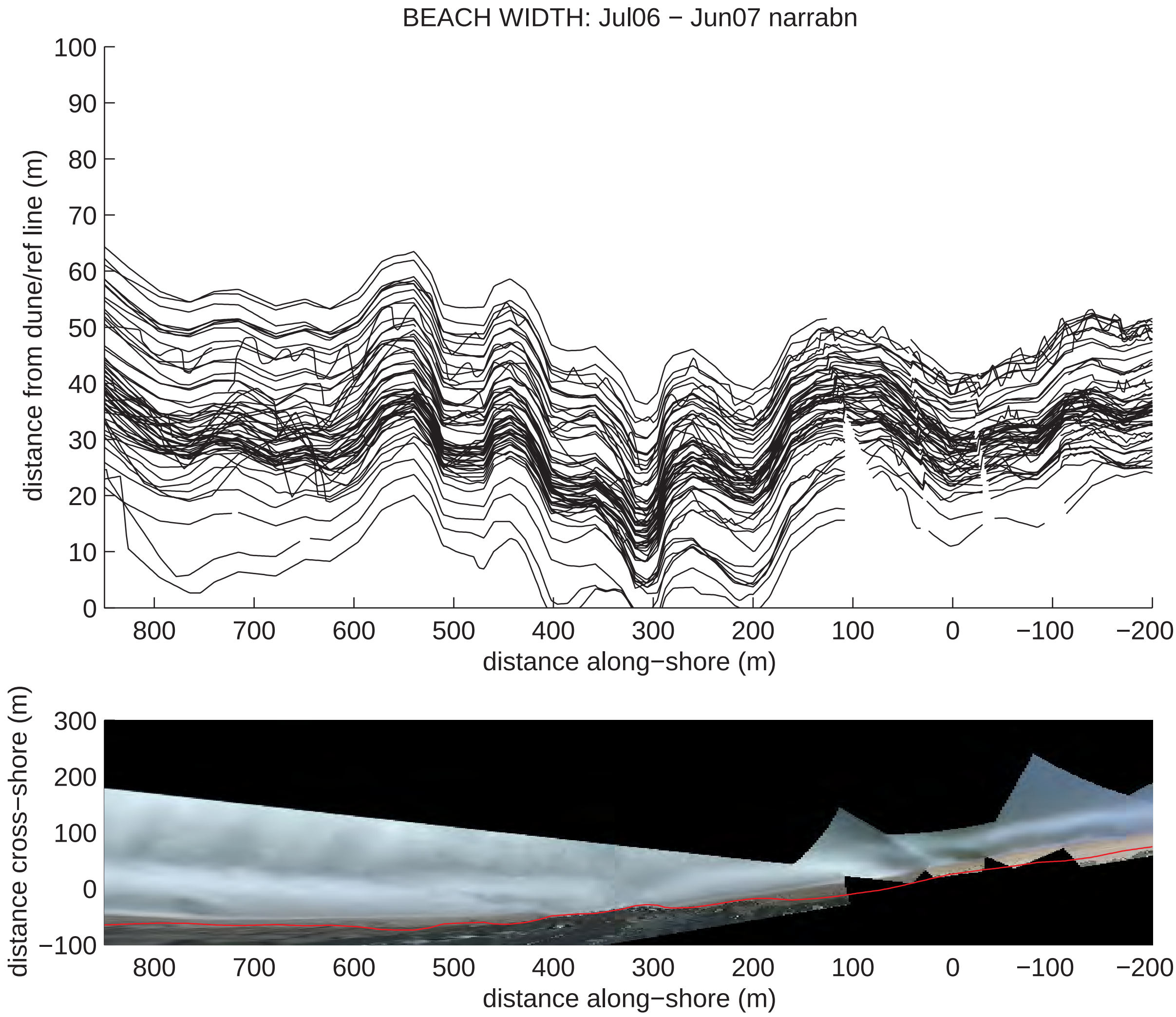
WEEKLY SHORELINES: JULY 2006 - JUNE 2007

Figure 6.1

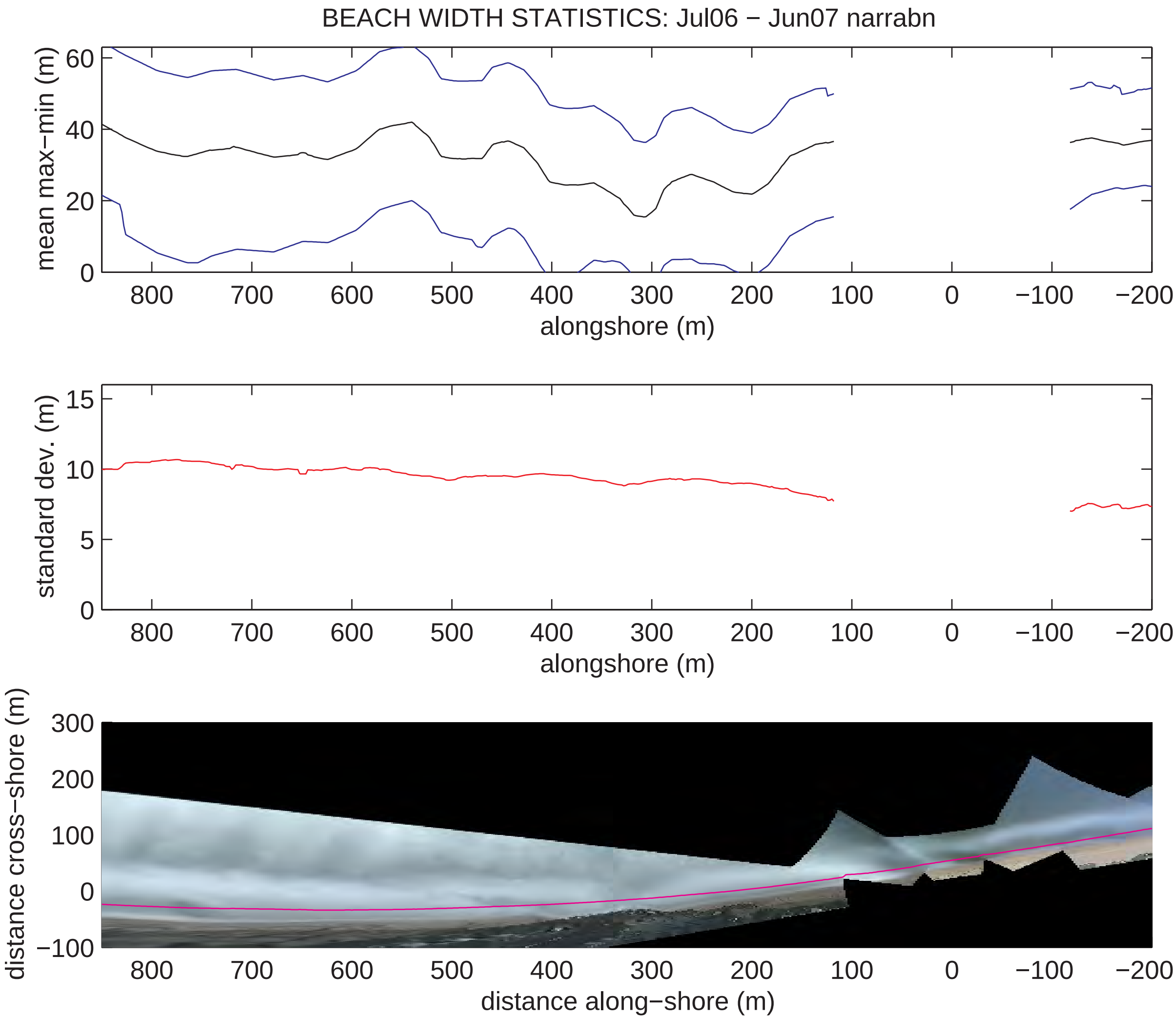
02092-6-1.cdr

WEEKLY SHORELINES: Jul2006 − Jun2007 narrabn

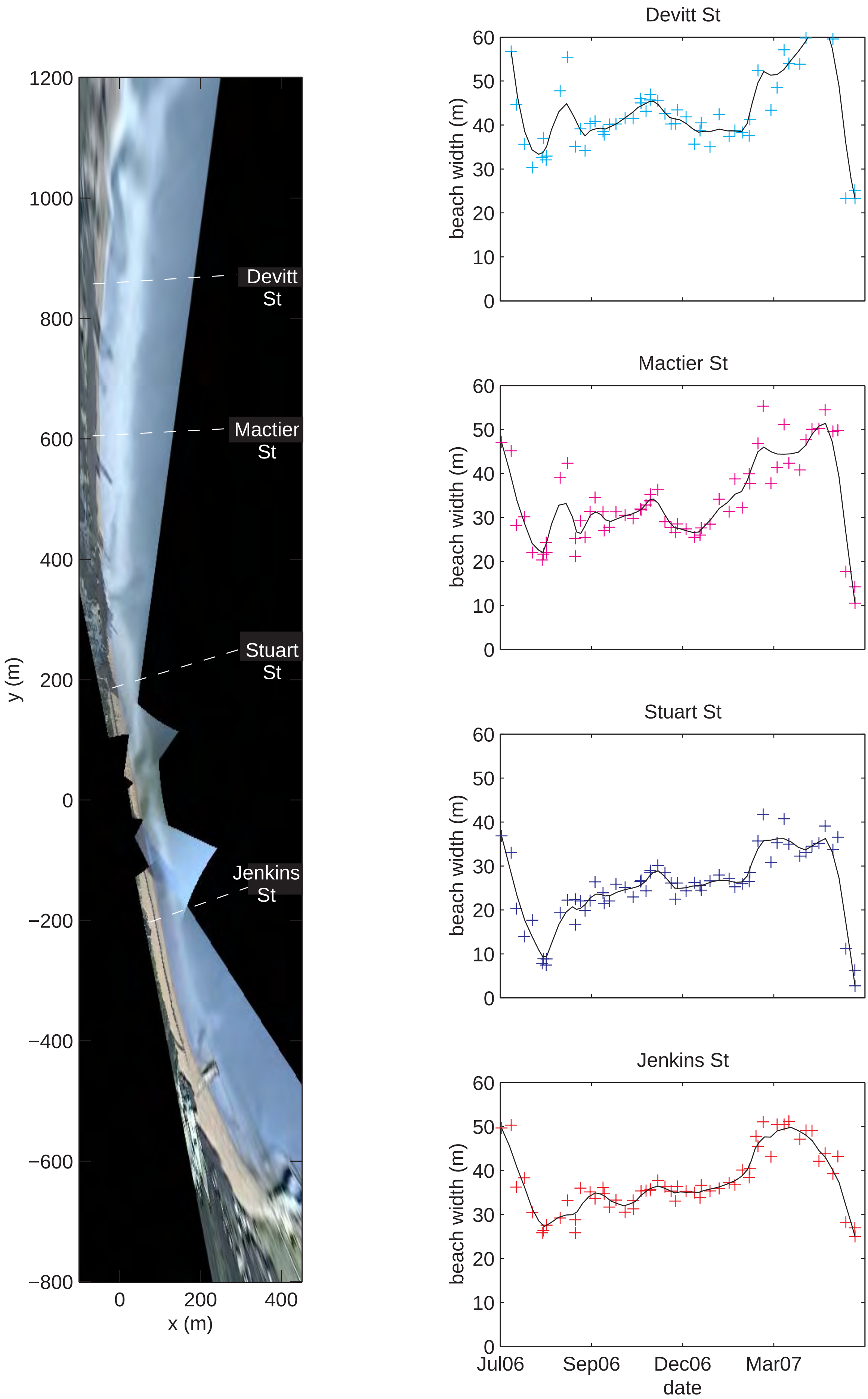




WRL Report No. 2007/30	WEEKLY BEACH WIDTH: JULY 2006 - JUNE 2007	Figure 6.2 02092-6-2.cdr



WRL Report No. 2007/30	STATISTICAL SUMMARY OF BEACH WIDTH CHANGES: JULY 2006 - JUNE 2007	Figure 6.3 02092-6-3.cdr



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TIME-SERIES OF BEACH WIDTH:
JULY 2006 - JUNE 2007

Figure
6.4

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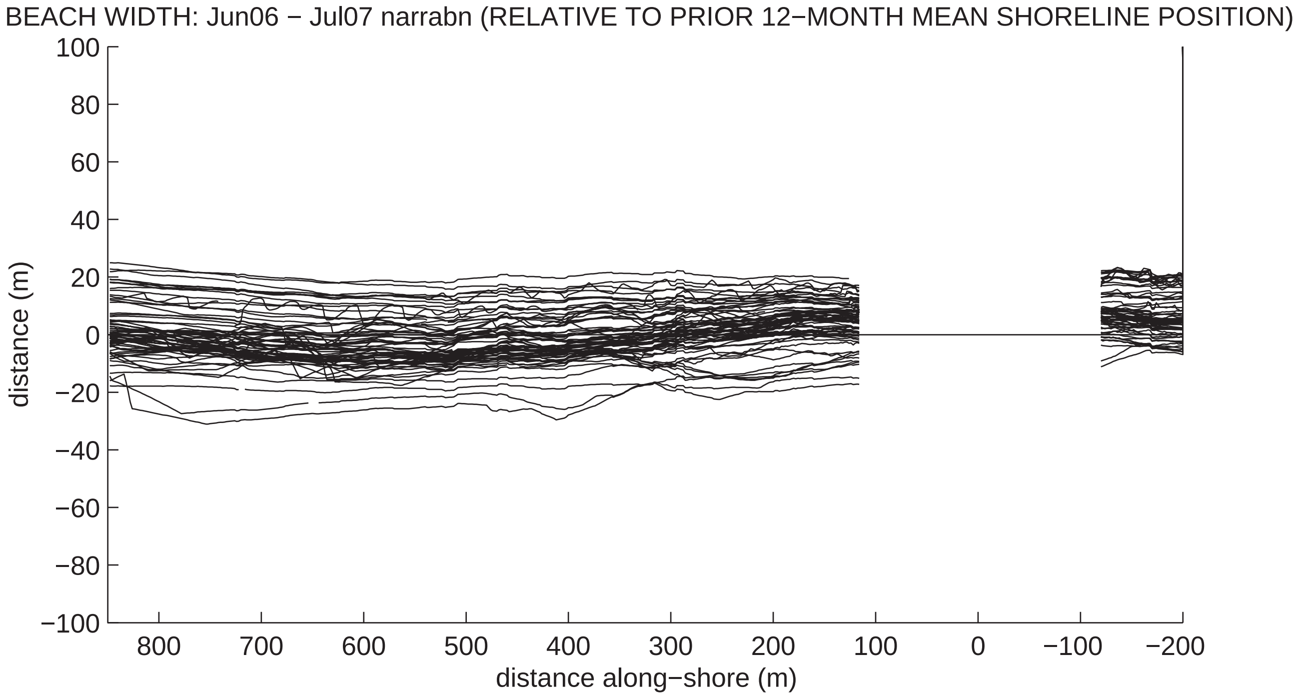
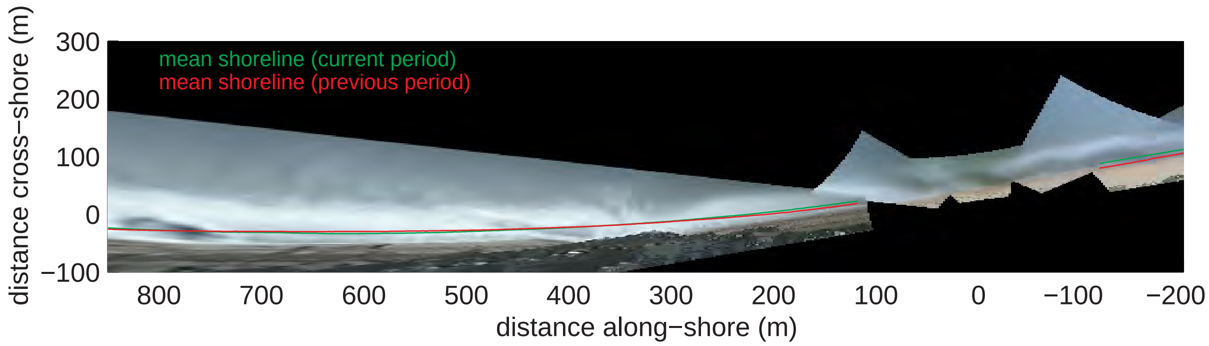




WRL Report No. 2007/30	WEEKLY BEACH WIDTH JULY 2006 - JUNE 2007 RELATIVE TO PRIOR TWELVE-MONTH MEAN SHORELINE POSITION	Figure 6.5 02092-6-5.cdr

7. QUANTITATIVE ANALYSIS OF TOTAL SHORELINE CHANGES: JULY 2004 – JUNE 2007

The completion of a total of 3 years (36 months) of monitoring at Collaroy-Narrabeen beaches provides the opportunity to summarise and analyse longer-term shoreline changes observed to date. As the monitoring program continues in the future, this analysis will extend accordingly, potentially providing valuable new insight to possible seasonal and/or longer-term trends that may emerge, and providing a better understanding of the response of the Collaroy-Narrabeen embayment to varying environmental conditions.

7.1 Weekly Shorelines and Shoreline Variability: July 2004 – June 2007

All weekly beach widths (relative to the alignment of the back-beach boulder wall) for the 156 week period July 2004 to June 2007 are shown in Figure 7.1. As per previous figures, a merged/rectified image is shown in the lower panel for reference (image date: 30th June 2007). Since July 2004 the mid-tide beach width at the northern end of Precinct 3 generally varied in the order of 40 - 50 m, while at the southern end, the variation in beach width has been slightly less, being of the order of 30 – 40 m.

The variations in shoreline position measured at the four monitoring transects (Jenkins Street, Stuart Street, Mactier Street and Devitt Street) for the entire period July 2004 to June 2007 are shown in Figure 7.2. The alongshore position of each of these representative transects is again shown in the accompanying merged/rectified image (image date: 30th June 2007).

The beach response throughout the period July 2004 to June 2005 showed similar trends at all four transects, indicating that the beachfront along Precinct 3 exhibited no distinctive alongshore variability during this first twelve month monitoring period. From July 2004 to September 2004 the beachfront increased in width by 10 m to 20 m, then in response to a succession of storms in October a rapid decline in beach width was recorded, as the shoreline receded by some 30 m.

An early indication of beach recovery in November 2004 was reversed in December 2004, by the occurrence of a further series of moderate storms. Six months after the commencement of the monitoring program in July 2004, by the end of December 2004 the beach along Precinct 3 had eroded back of the order of 20 m. The moderate to mild wave climate through January – February 2005 saw a period of partial beach recovery, with the beach accreting of the order of 10 m during this time. The storm in March again generally cut back the beach by 5 – 10 m, followed by an accretionary period through to mid May, with the beach continuing to accrete up to the conditions that existed 8 months previously at the end of September 2004. Increased wave energy in mid May 2005 caused the beach to again be eroded by some 15 – 20 m at the majority of locations alongshore, with the exception being at Stuart Street, where the beach eroded by around 30 m. In the final month of June 2005 a general trend of beach recovery was recorded. Despite the relatively large magnitude fluctuation of beach width due to erosion-accretion events over the preceding 12 month period, by the end of June 2005 the beach width along Precinct 3 had returned to within 5 m of the conditions that prevailed 12 months previously in July 2004.

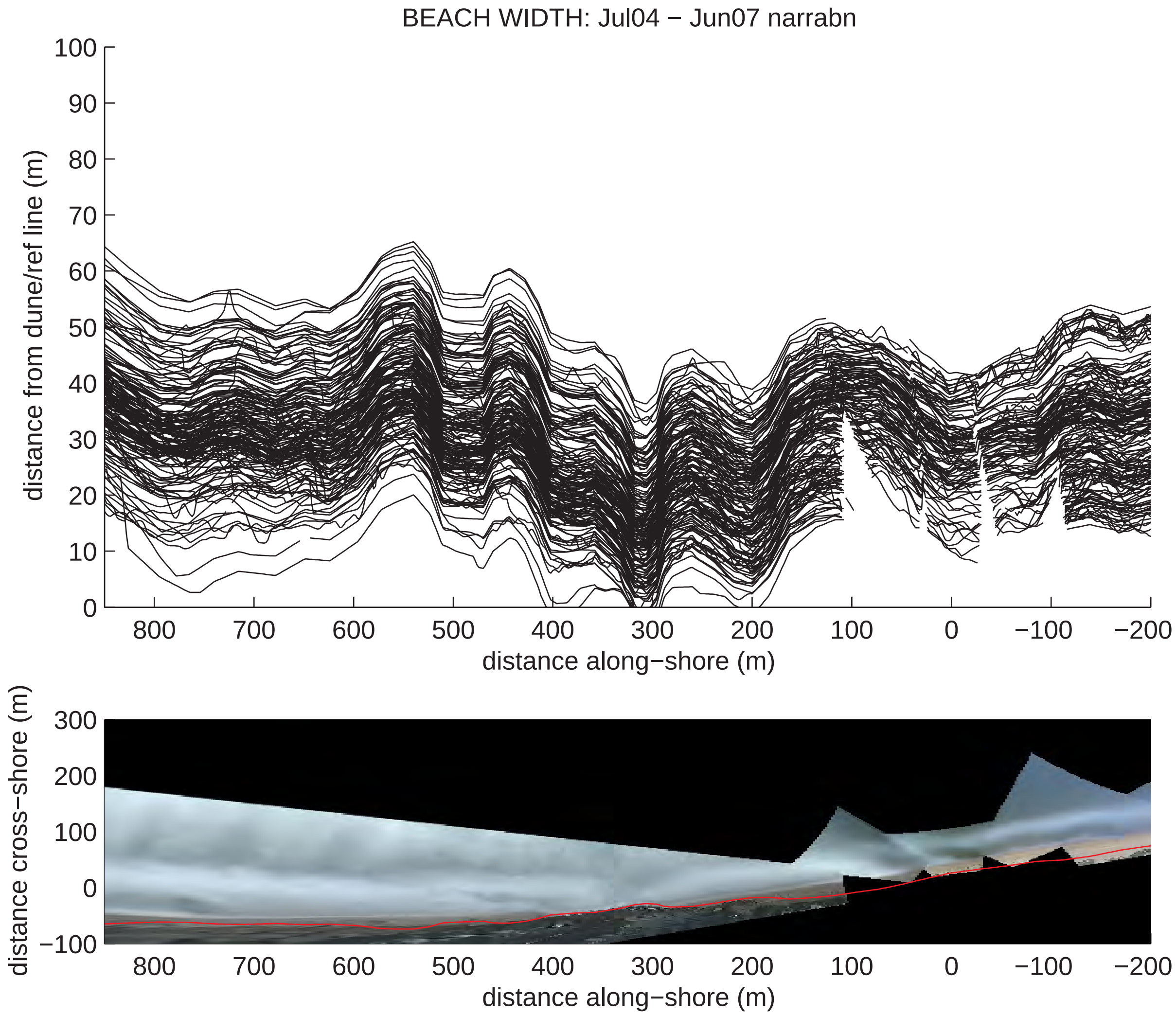
From July 2005 to June 2006 the beach response at all four monitoring transects within Precinct 3 exhibited a similar underlying accretionary trend, however, the shorter-term erosion response to storms in October 2005, April 2006 and June 2006 was more pronounced toward the north. At the southern transects located seawards of Jenkins and Stuart Streets, the beach widened by 30 m during the twelve month period from July 2005 to June 2006. At the more northern transects at Mactier and Devitt Streets, the three storm erosion episodes during this same period resulted in net beach widening from July 2005 to June 2006 of 15 – 20 m. At the completion of the second year of beach monitoring, at the more southern Jenkins and Stuart Streets the sand buffer along the beachfront had widened of the order of 15 – 20m, while at the more northern Mactier and Devitt Street beach widening of 5 – 10 m was observed.

Throughout the majority of the current monitoring period, the general beach width variation trend was again similar at all four of the monitoring cross sections, with the northern cross sections showing slightly more responsiveness to short term fluctuations, and in particular a period of erosion during December 2006. The beach was in a progressively eroding state at the start of the current monitoring period in July 2006, which continued into August. Moderate recovery of beach width occurred from August to December 2006, followed by rapid recovery up until March 2007 at both the Jenkins Street and Stuart Street transects, at the southern end of Precinct 3. The northern transects, however, fluctuated in width with no net accretion up until December 2006, before also experiencing rapid increase in beach width. At the end of May 2007, the beach at the northern end of Precinct 3 was 15 m to 20 m wider, while at the southern end the beach was 10 m wider, than at the start of the monitoring program in July 2004.

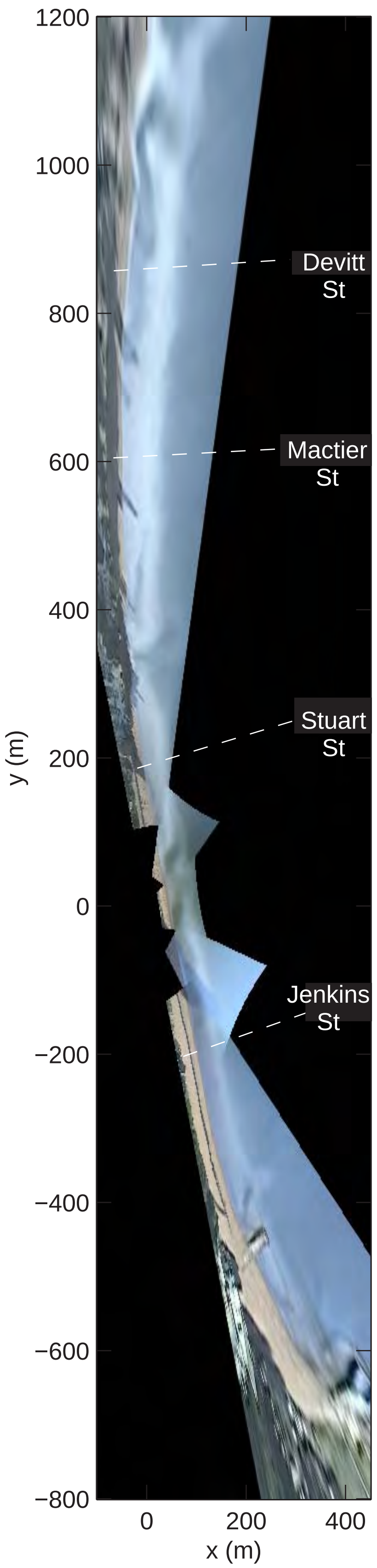
This sand buffer that had accreted throughout the previous 35 months was rapidly eroded with the three storms that occurred in June 2007, with the occurrence of the largest and most rapid decrease in beach observed throughout the monitoring program to date. At the completion of the current monitoring program, the beach was the narrowest it has been throughout the last three years at the Devitt Street, Mactier Street, and Stuart Street monitoring sections. At Jenkins Street the beach remained marginally wider than at the end of the 2004 winter, although with ongoing erosion into July of 2007, this may no longer be the case.

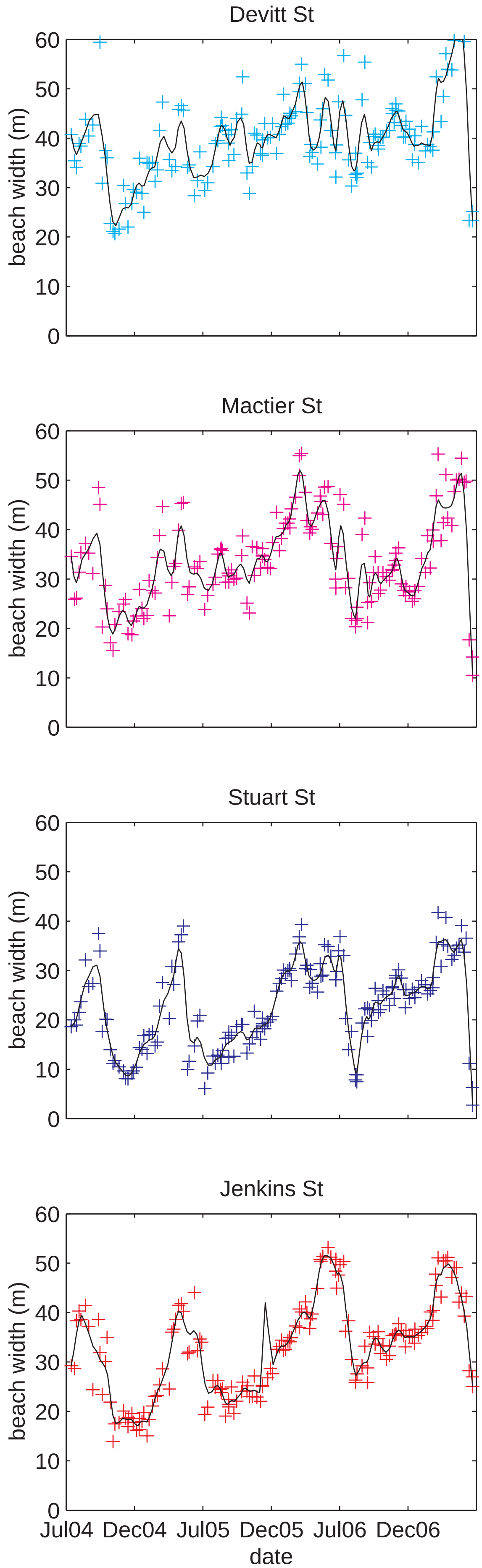
7.2 On-Line Beach Width Analysis

For the sake of completeness Figure 7.3 is also included here, that shows the same data as presented in Figures 7.1 and 7.2, but in the on-line graphical format ('Beach Width Analysis') that is updated each week, and available for public viewing (and download) via the monitoring project web site (refer Section 4.3). The top and bottom panels in these figures are equivalent to the two panels in Figure 7.2, with the additional inclusion of selected shorelines in the middle panel to show the most recent shoreline movements. In addition to the same longer-term trends discussed above, the middle panel of Figure 7.3 provides useful further insight to the degree of variability in the shoreline position over weekly to monthly time-scales. This figure confirms that the shoreline alignment in the vicinity of Precinct 3 is highly dynamic and variable, with beach width variations of the order of tens of metres occurring over time intervals of just a few days to weeks.

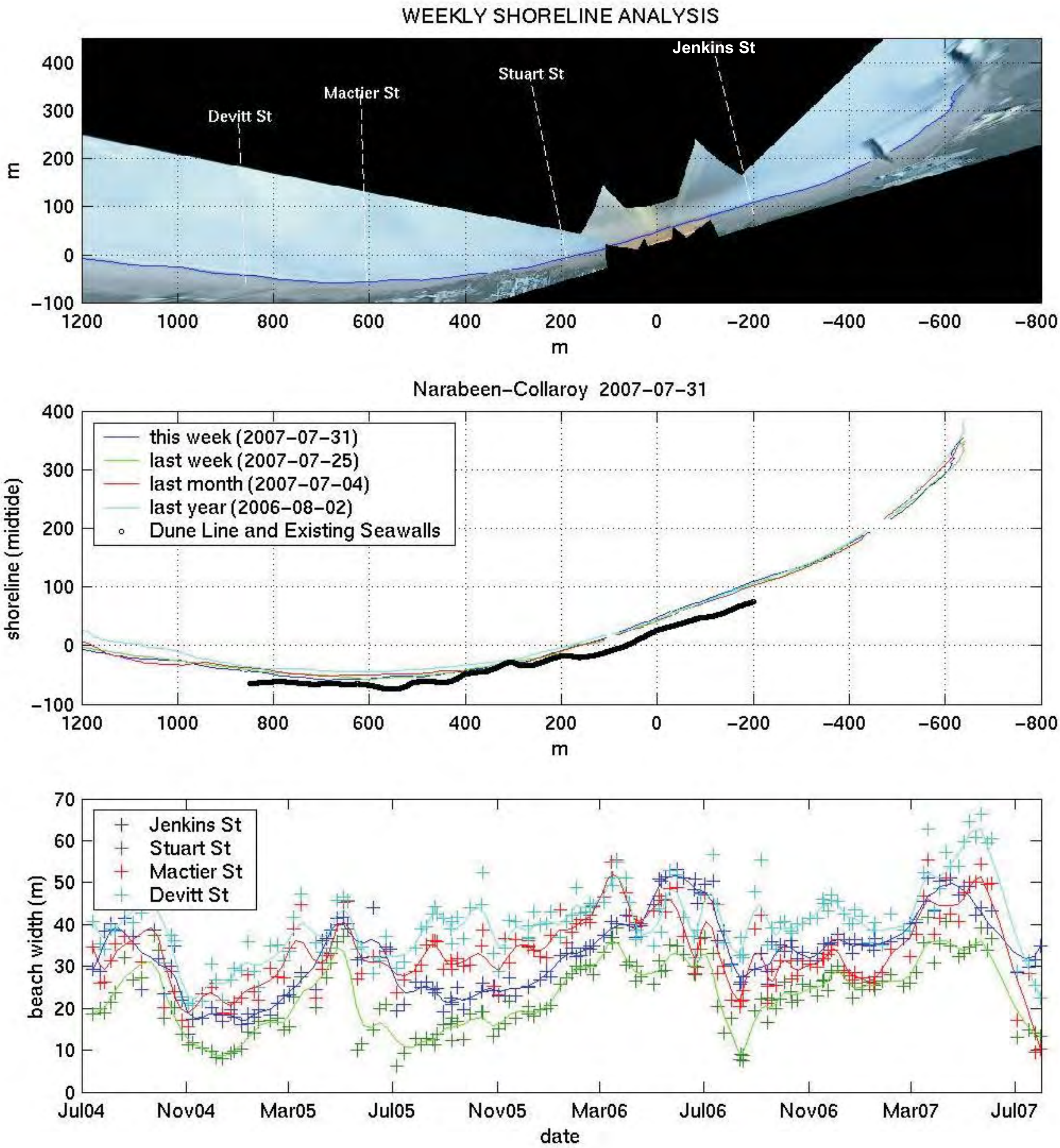


WRL Report No. 2007/30	WEEKLY BEACH WIDTH: JULY 2004 - JUNE 2007	Figure 7.1 02092-7-1.cdr





WRL Report No. 2007/30	TIME-SERIES OF BEACH WIDTH: JULY 2004 - JUNE 2007	Figure 7.2 02092-7-2.cdr



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WRL Report No. 2007/30	ON-LINE BEACH WIDTH ANALYSIS TO JUNE 2007	Figure 7.3 02092-7-3.cdr

8. ANALYSIS OF EROSION-ACCRETION TRENDS

An image analysis technique has been implemented at Collaroy-Narrabeen that enables patterns of beach erosion and accretion to be clearly identified and quantified. On a monthly basis, hourly images throughout a single spring tide are analysed and a 3-D bathymetry of the beach face extending from the low tide waterline to the high tide waterline is derived. These data are further analysed to assess regions of beachface erosion and deposition within Precinct 3.

8.1 Methodology

A detailed description of the analysis techniques used to derive three-dimensional beachface bathymetry from two-dimensional image analysis was included in the first Collaroy-Narrabeen monitoring report (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 8.1, 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 analysis is undertaken during the monthly spring tide cycle, so as to maximise the area of beachface covered by the analysis. 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.

8.2 Monthly Beachface Bathymetric Mapping

The main application to coastal management of monthly intertidal bathymetries derived from image analysis, is the ability to compare successive months in order to identify and quantify areas of erosion and accretion. However, the monthly beachface bathymetries used to achieve this, do provide a degree of interest in their own right. The bathymetries derived at monthly intervals along Precinct 3 are shown in Figure 8.2 (June-July 2006), Figure 8.3 (August-September 2006), Figure 8.4 (October-November 2006), Figure 8.5 (December 2006-January 2007), Figure 8.6 (February-March 2007), Figure 8.7 (April-May 2007) and Figure 8.8 (June 2007). In accordance with observations from the previous monitoring period, these data reveal two distinct ‘modes’ in the bathymetry of the intertidal region along the Precinct 3 beachfront. Following periods of higher wave energy (e.g. July 2006 – Figure 8.2 and June 2007 – Figure 8.8), the beach exhibits a uniform and lower gradient profile alongshore, indicative of the movement of sediment offshore and the development of LBT (Longshore Bar Trough refer Section 5) dissipative beach conditions. In contrast, following periods of relatively mild incident wave energy (e.g. January 2007 – Figure 8.5 and April 2007 – Figure 8.7) a narrower and steeper beachface morphology prevails, indicative of sand accretion and lower energy wave conditions.

The beachface contour map images also provide other indicative pieces of information about the beach. Firstly, the beachface images clearly identify the gradient in wave energy along the Collaroy-Narrabeen embayment, with the southern end of the Precinct 3 study area typically having a narrower and steeper beachface (associated with lower wave energy), while at the northern end the beachface is typically shallower in gradient and wider (associated with higher wave energy). Secondly, when lower energy intermediate wave conditions prevail, and the surf zone is a complex area of transverse bars and rip currents, the beachface maps can identify the effect of these conditions on the beachface morphology. Examples of this are the images for August 2006 (Figure 8.3) and February 2007 (Figure 8.6).

8.3 Monthly Erosion-Accretion Trends

As noted above, by further processing of the monthly bathymetries shown in Figures 8.2 - 8.8, a quantitative measure of the net change in sand volumes across the beachface throughout Precinct 3 can be obtained. Figures 8.9 to 8.12 show the results of these calculations to determine the net change per month in bed elevation between June 2006 and June 2007.

Figure 8.9 (Top) shows that between June and July 2006, most of the beach within the Precinct 3 study area eroded slightly, with the exception of the far northern end. Typically the vertical beachface erosion was of the order 0.6 m. Continuing into August 2006 (Figure 8.9 Mid) a general trend of further erosion occurred, although not as uniform as the previous month. Looking at the beachface map from August shows that most of the erosion occurred in the development of irregular crescentic features along the beachface, which is highlighted by the irregular erosion/accretion zones. By mid September 2006, the beach had again become more uniform, with erosion and accretion occurring in converse locations to the previous months, smoothing the crescentic features that developed in August.

From mid September to mid October 2006 (Figure 8.10 Top) uniform accretion occurred along the entire study area, with the beachface accreting by 0.4 m in vertical elevation along the entire beach, and up to 0.8 m in the far north. This trend of accretion continued into November (Figure 8.10 Mid), although to a lesser extent, with some areas of the beach experiencing little net change. The trend reversed between November and December 2006, with slight erosion occurring across the entire study area. In most places, lowering of the beachface by at least 0.2 m in vertical elevation, and up to 0.6 m, was experienced.

From December through to February 2007 (Figure 8.11), a general trend of accretion occurred, with the prevailing lower energy summer wave conditions. Most of the accretion occurred irregularly through the formation of crescentic features along the beachface. In some locations the intertidal beachface accreted by up to 1 m of vertical elevation during this time period. The rate of accretion of the beachface increased significantly between February and mid March (Figure 8.11 Bottom), with a widening of the beach, and the onshore migration of sand from the nearshore bar. During this one month period, the beachface accreted by 1 m vertical elevation across the entire Precinct 3 study area.

Figure 8.12 (Top) shows that between March and April 2007, a significant portion of the material that had accreted during the previous summer, was again eroded across the northern area of the beach, with the onset of more dominant southerly swell wave conditions. There was little net erosion/accretion across the southern end of the study area. This trend was reversed between April and May (Figure 8.12 Mid), with the eroded material returning to the beachface across the northern section of the study area, and erosion along the southern stretch of the beach.

The most dramatic short term change in beachface bathymetry experienced to date in the three years of monitoring at Narrabeen/Collaroy, occurred in June 2007. As previously discussed, three successive east coast low pressure cells generated ongoing storm wave conditions for most of the month, which resulted in significant erosion of the beach along its entire length. Figure 8.12 (Bottom) shows that by 21st June, the beachface had migrated landward by 50 m in the north of the study area, and by 20 m in the south. The limit of the analysis technique used in the beachface mapping (only considering beach elevations above -0.5 m AHD and below 0.7 m AHD) means that the depth of erosion is shown as a 1 m drop in vertical beachface elevation, however, field observations and quad bike surveys covering a greater range in beachface elevation, indicated the beach erosion scarp which occurred further landward of this region was of the order of 2 m.

Table 8.1
Total and Net Intertidal Sand Volumes Changes: June 2006 – July 2007

	NET CHANGE INTERTIDAL (+0.7 to -0.5 m AHD) SAND VOLUME – PRECINCT 3	
period	**cubic m (total)**	**cubic m per m shoreline**
June – July 2006	-6,115	-5.8
July – August	-5,410	-5.1
August – September	-470	-0.4
September - October	+8,060	+7.6
October – November	+3,600	+3.4
November – December	-6,270	-5.9
December – January 2007	+4,070	+3.8
January – February	+2,100	+2.0
February – March	+17,840	+16.8
March – April	-6,370	-6.0
April – May	+3,610	+3.4
May – June 2007	-39,980	-37.7

Referring to Table 8.1 above, the typical monthly fluctuations of erosion and accretion volumes from the beach were in the range of 3,000 – 8,000 m^3, which equates to approximately 3 – 8 m^3 per metre of beach length. The minimum monthly change observed was between August and September 2006, with a net loss of only 470 m^3 total along the entire beachface within the Precinct 3 study area. It is interesting to note that the maximum accretion in any one month period during the current monitoring period occurred between February and March, with almost 18,000 m^3 of sand accreting on the beachface. The maximum monthly accretion in the previous monitoring period, July 2005 to June 2006, also occurred between February and March, and was of the order of 13,000 m^3.

As previously discussed, the most dramatic monthly erosion event recorded in the beach monitoring program to date, occurred in June 2007. It is important to note that the extent of the erosion/accretion analysis completed with the ARGUS images is limited to elevations between -0.5 and +0.7 m AHD, and therefore the estimated erosion volumes for the June event do not consider the beach material that was initially located outside of this range. From the coastal image analysis, it is estimated that at least 40,000 m^3 of sand was eroded from the beach during June, which equates to almost 40 m^3 per metre of shoreline. Quad bike surveys also undertaken during and after June confirm that this is a reasonable estimate of the amount of material eroded from the beach between -0.5 and +0.7 m AHD, but the erosion from across the whole beach profile was of the order of 80 m^3/m.

This degree of erosion is almost double the previous maximum monthly erosion loss derived from the coastal imaging analysis, in September to October 2005, of 25,000 m^3. This also highlights that erosion of the beach can occur at rates significantly higher than the subsequent beach recovery, with the maximum monthly accretion recorded during the monitoring program to date of 18,000 m^3 in February to March 2007.

8.4 Annual Net Erosion-Accretion Trends

The net change in beachface bathymetry that has been measured through the present and past twelve month monitoring periods are summarised in Figure 8.13. Despite the occurrence of a number of large storm events and resulting fluctuations of the shoreline during the first monitoring period, July 2004 to June 2005 (Figure 8.12 Top Panel), beach conditions in June 2005 were similar to the conditions that prevailed 12 months earlier in July 2004. From the more detailed analysis presented in Figures 8.13 and 8.14, it is apparent that the majority of Precinct 3 experienced a slight net erosional trend (-3,446 m^3 total or -3.2 m^3 per m shoreline) during this period, with the beachface elevation lowering in the vertical range of 0 m to -0.4 m during this time. The exception to this trend was at a very localised region located approximately 650 m north of Flight Deck, where up to +0.6 m vertical beach accretion was observed.

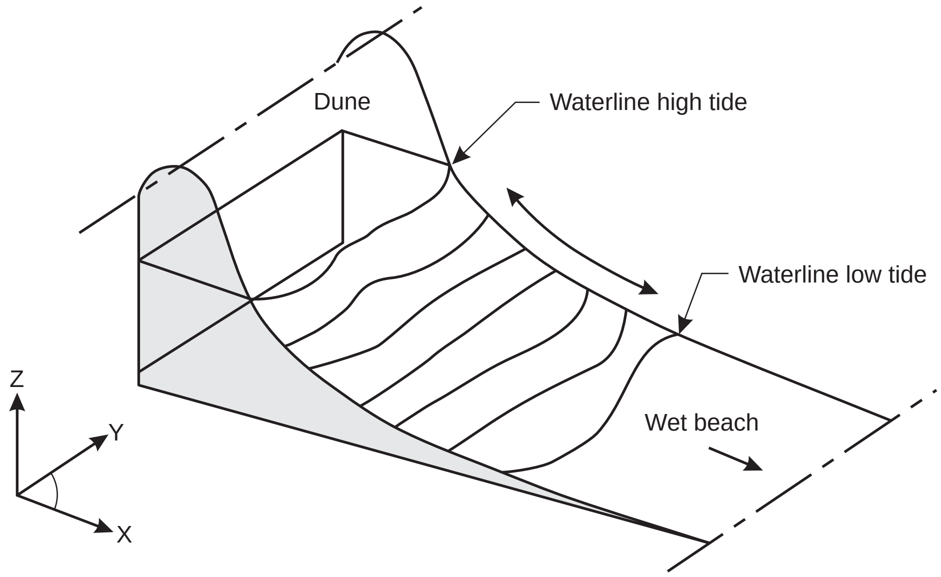
In contrast, the analysis for the monitoring period July 2005 to June 2006 (Figure 8.13, Middle Panel) reveals a distinct trend of net beach accretion (+8,300 m^3 or +7.8 m^3 per m shoreline). Vertical beachface accretion in excess of 1 m occurred at all but the most northern end of Precinct 3, where vertical accretion up to +0.6 m was more typical. A localised area of less than 100 m length around 700 m north of Flight Deck exhibited a slight reduction in beachface elevation during this same twelve month period.

The net volume change in the beachface for the current monitoring period, July 2006 to June 2007 (Figure 8.13 Bottom Panel), was dominated by the extensive erosion caused by the June 2007 storms. For the first 11 months of the monitoring period, the beach was generally in an accretionary trend, with a total of some 15,000 m^3 of sand accreting between June 2006 and May 2007. However, the storms of June resulted in approximately 40,000 m^3 of beach erosion, with the net erosion for the June 2006 to June 2007 period being 25,000 m^3, equating to approximately 24 m^3 per m shoreline. Between June 2006 and June 2007, a reduction of over 1.0 m in vertical elevation was experienced across the entire Precinct 3 study area.

8.5 Total Erosion-Accretion Trends: July 2004 – June 2007

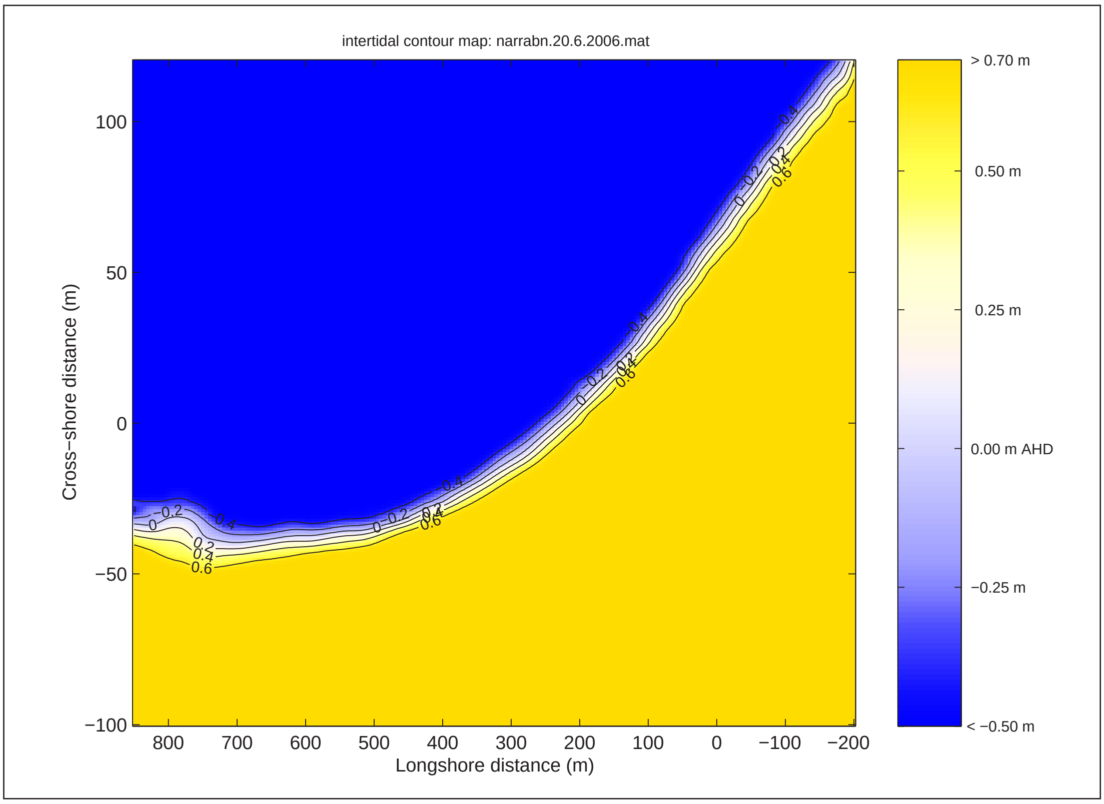
The final Figure 8.15 shows the total net change in beachface bathymetry for the entire two year monitoring period July 2004 to June 2007. Figure 8.14 also shows the cumulative monthly erosion/accretion during this time period. Over this period the beach within Precinct 3 experienced net erosion of -20,500 m^3 (-19.3 m^3 per m) within the intertidal profile (+0.7 to -0.5 m AHD).

It can be seen in Figure 8.15, that the net erosion has occurred almost uniformly across the entire study area. If the plot of net change for the entire monitoring period July 2004 to June 2007, is compared to that for the current monitoring period, it can be seen that most of the net erosion has occurred in the past 12 months. Figure 8.14 clearly shows that in fact, this erosion can be attributed wholly to the storms of June 2007. From this analysis, it can be concluded that these storms have dominated the net erosion/accretion processes for the Precinct 3 study area to date, and it is anticipated will continue to dominate for some time to come.

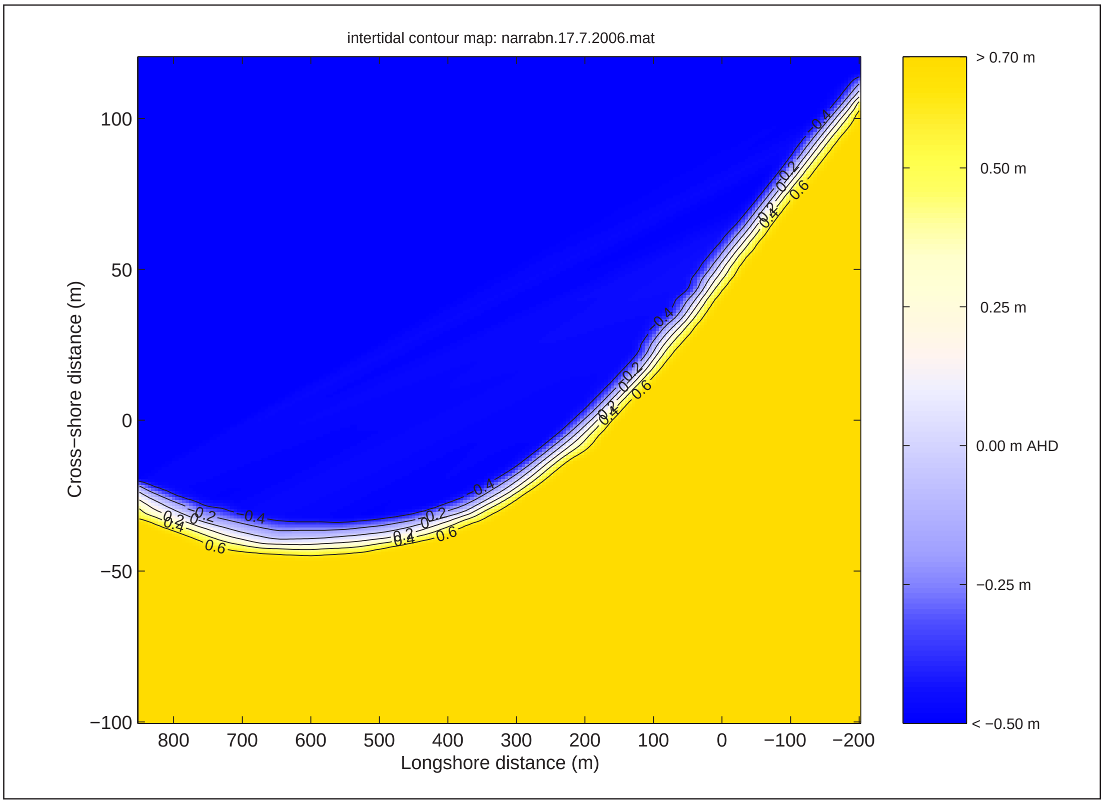


WRL Report No. 2007/30	DEFINITION SKETCH INTERTIDAL BATHYMETRY FROM HOURLY WATERLINES	Figure 8.1 02092-8-1.cdr

JUNE 2006



JULY 2006



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BEACHFACE MAPPING - JUNE, JULY 2006

Figure 8.2

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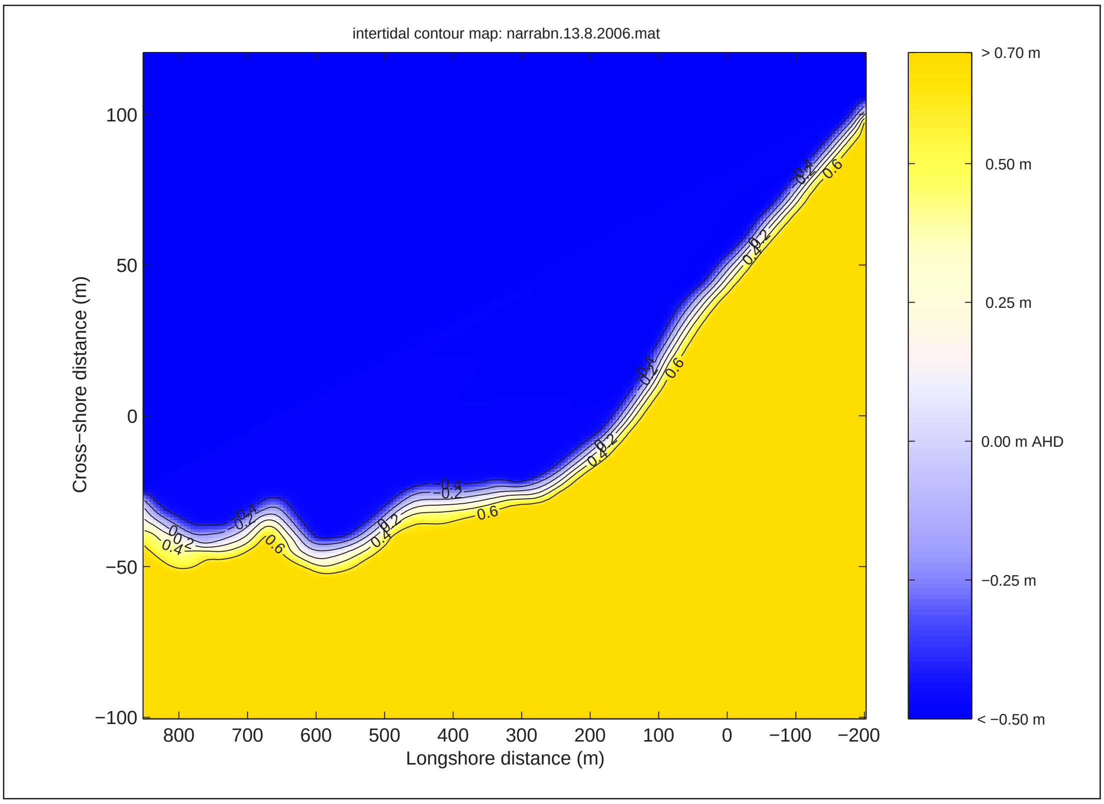
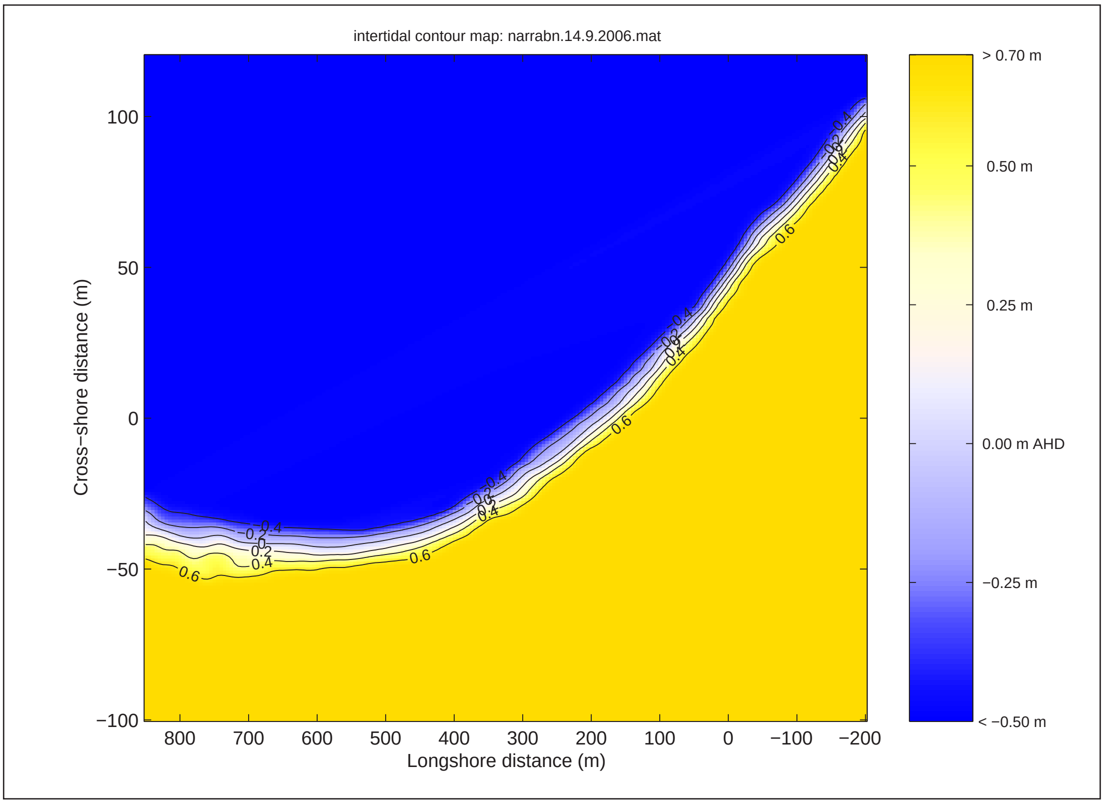
AUGUST 2006

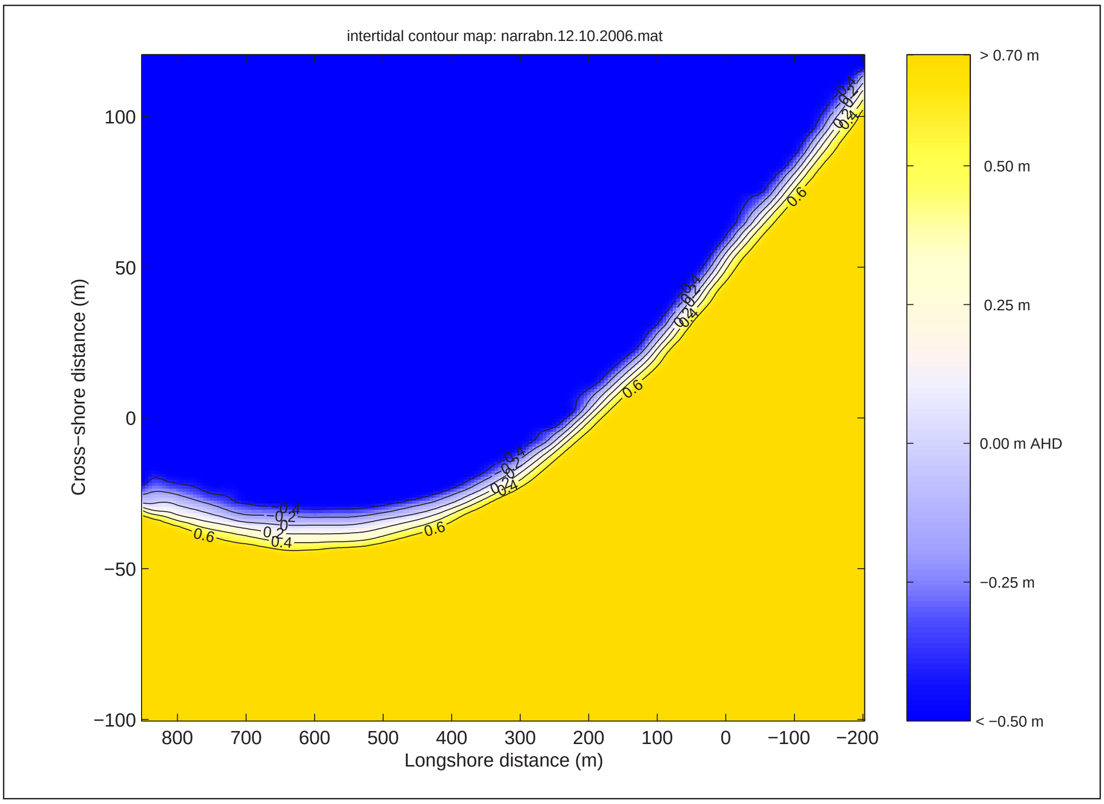


SEPTEMBER 2006

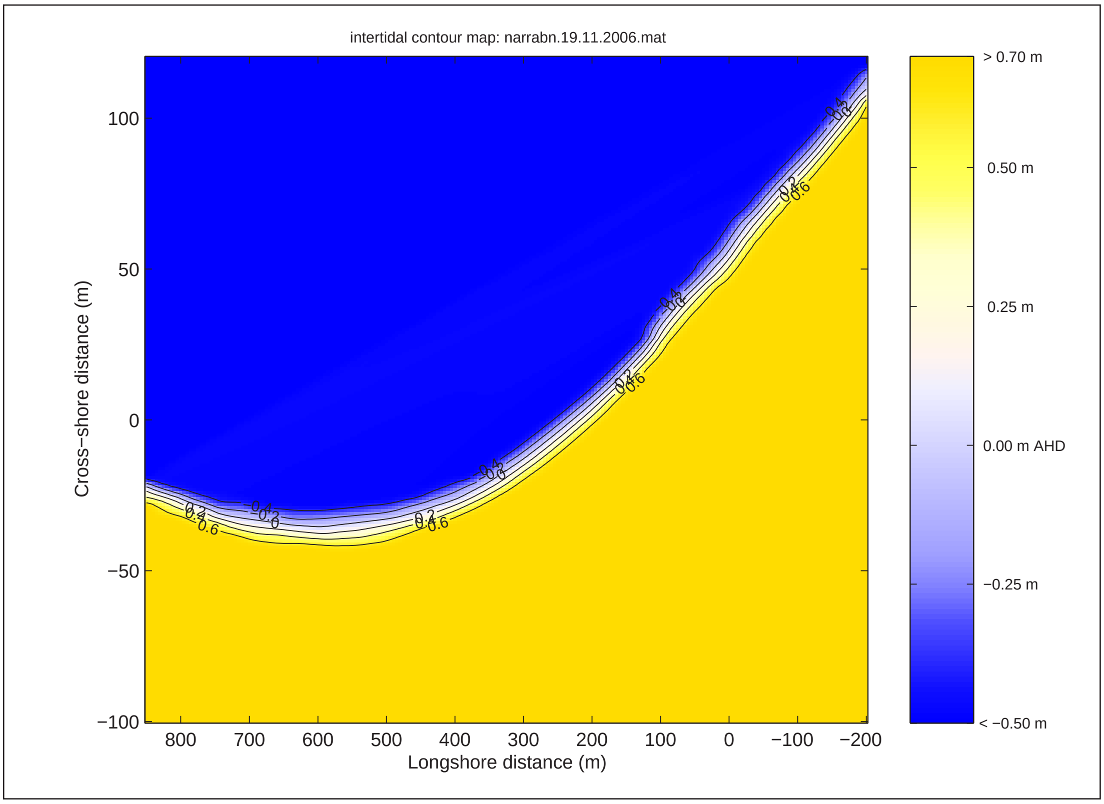


WRL Report No. 2007/30	BEACHFACE MAPPING - AUGUST, SEPTEMBER 2006	Figure 8.3
		02092-8-3.cdr

OCTOBER 2006



NOVEMBER 2006



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BEACHFACE MAPPING - OCTOBER, NOVEMBER 2006

Figure
8.4

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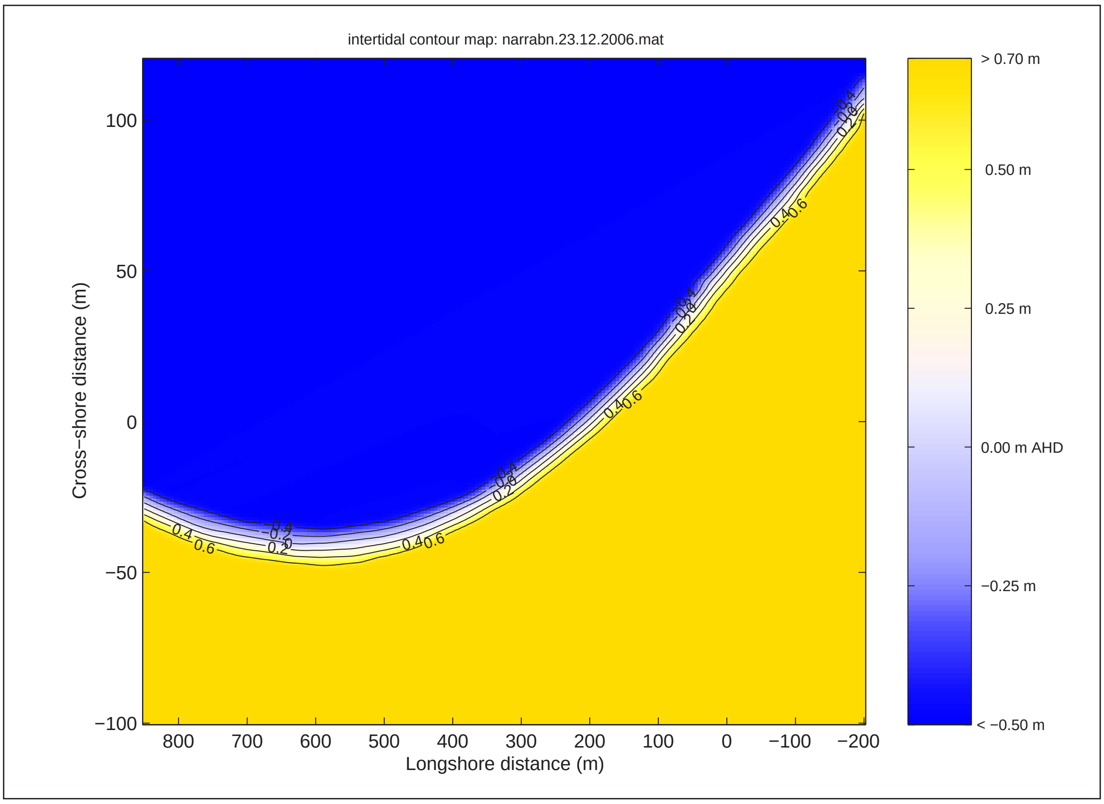
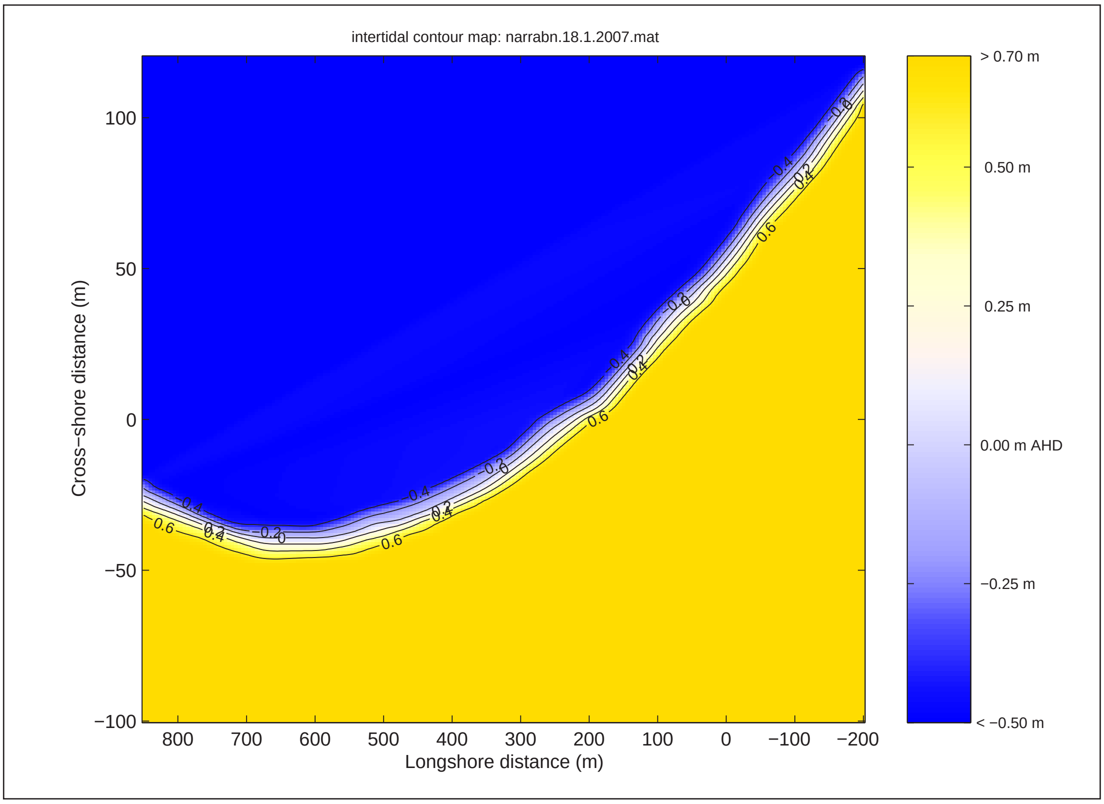
DECEMBER 2006

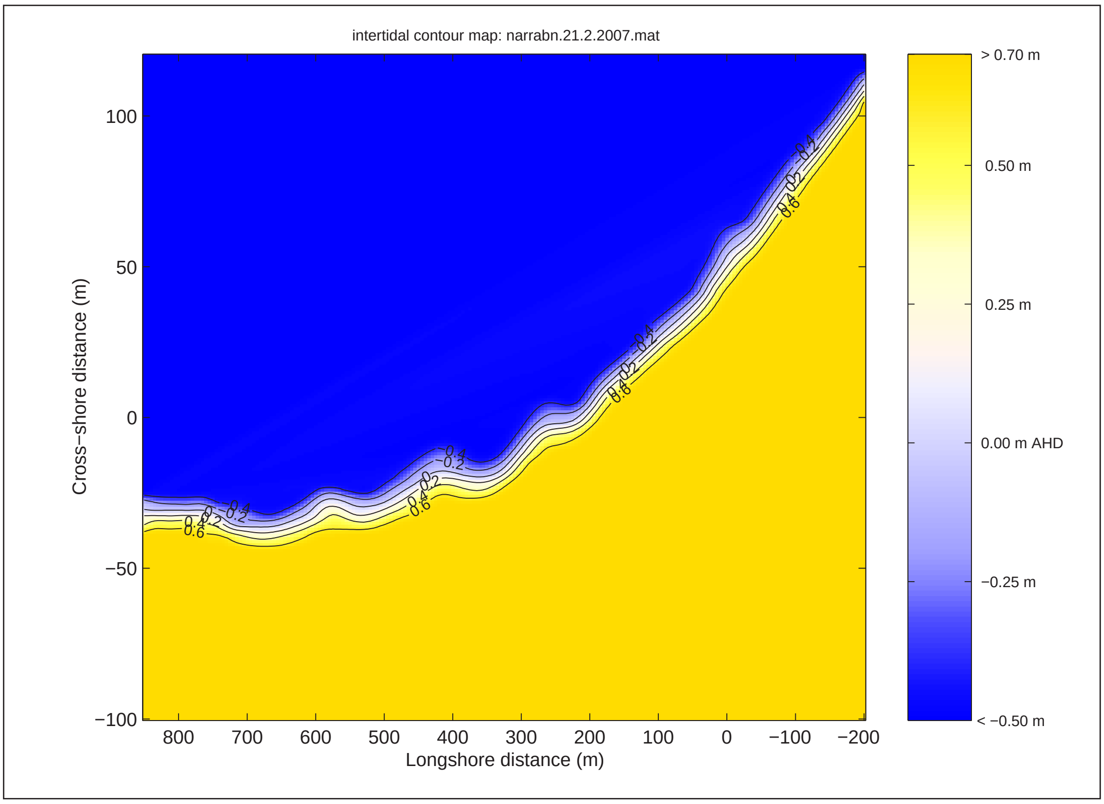


JANUARY 2007

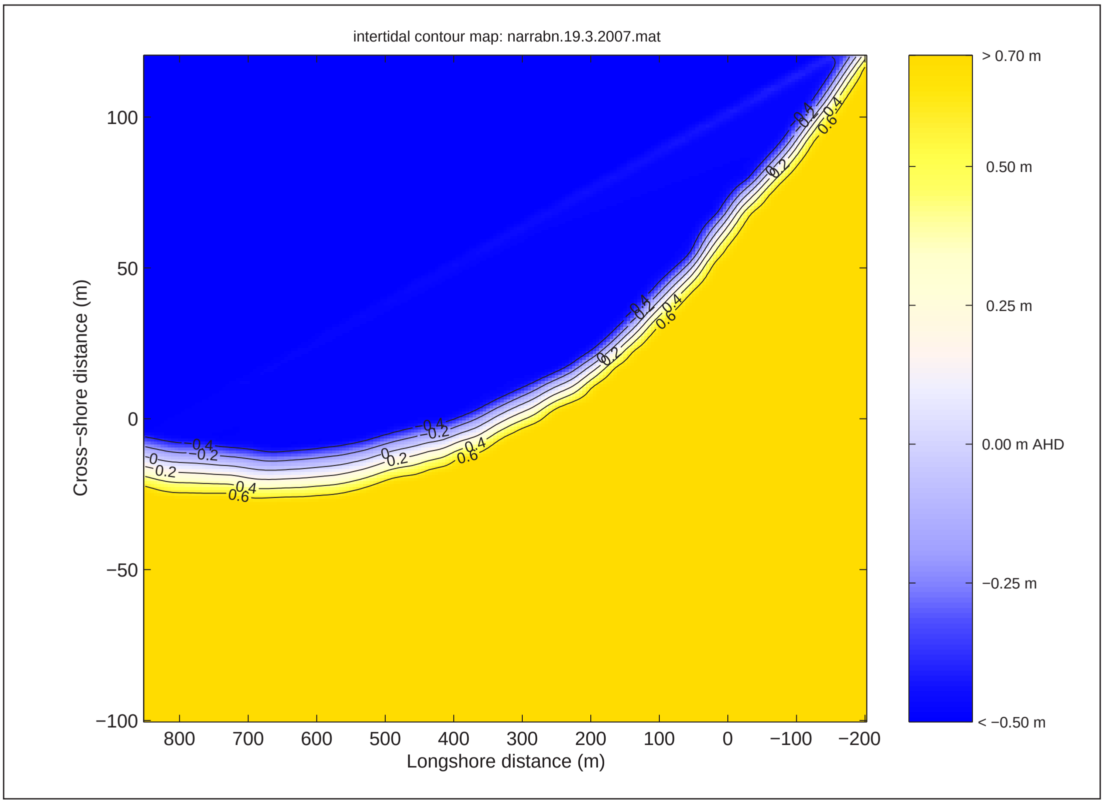


WRL Report No. 2007/30	BEACHFACE MAPPING - DECEMBER 2006, JANUARY 2007	Figure 8.5
		02092-8-5.cdr

FEBRUARY 2007

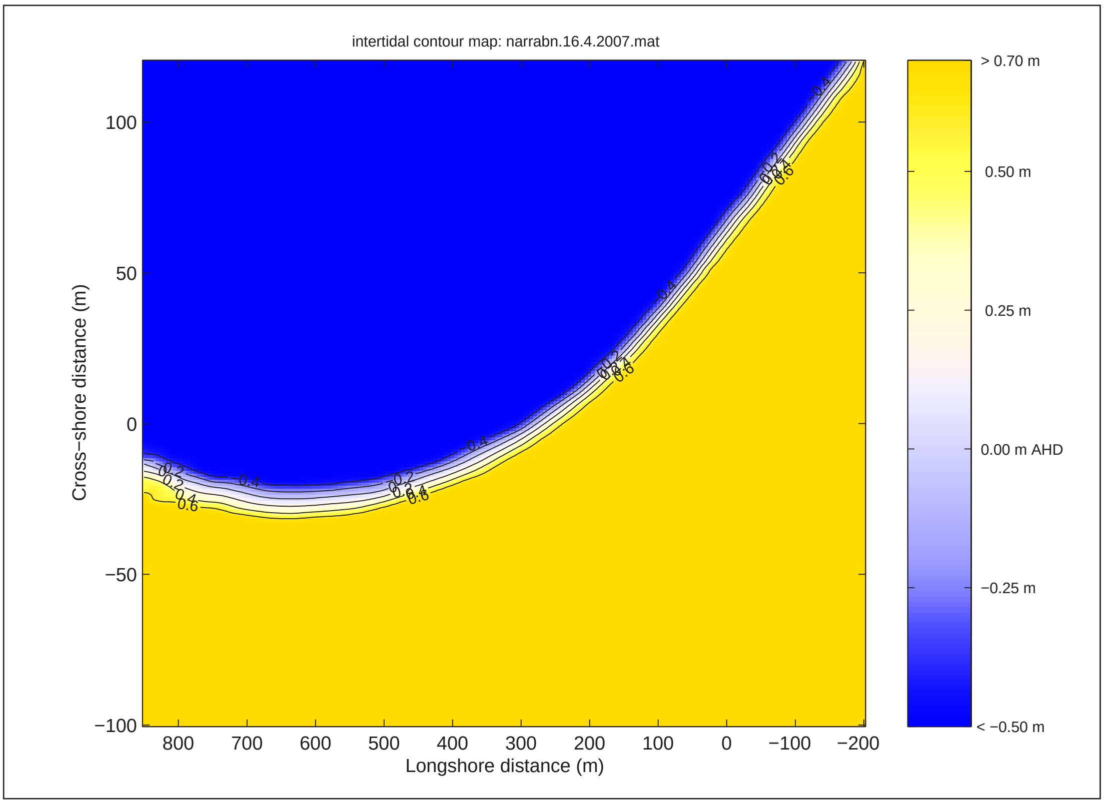


MARCH 2007



WRL Report No. 2007/30	BEACHFACE MAPPING - FEBRUARY, MARCH 2007	Figure 8.6 02092-8-6.cdr

APRIL 2007



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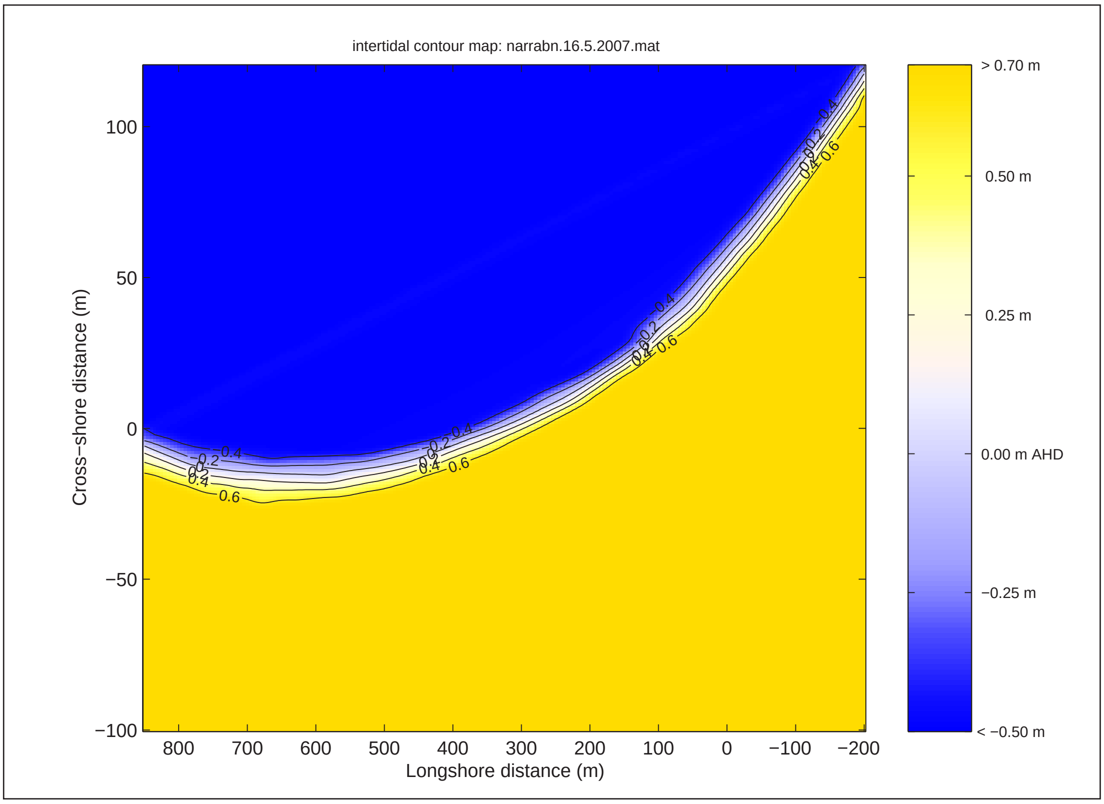
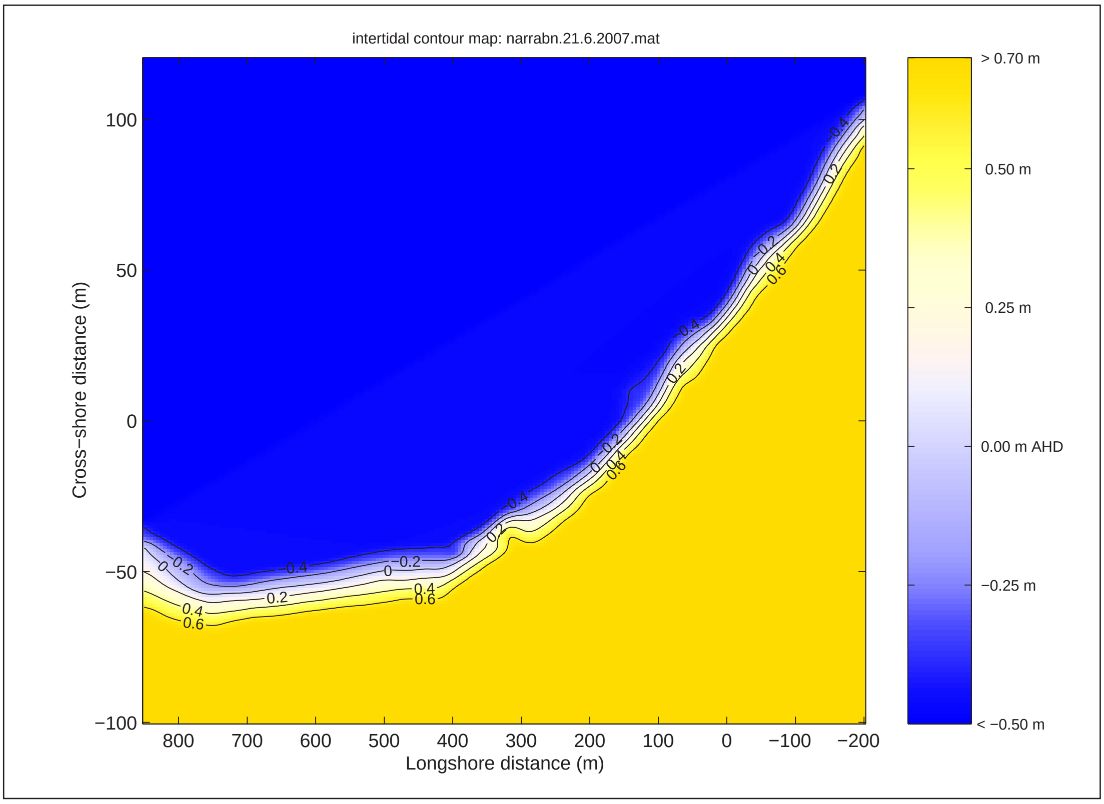


WRL Report No. 2007/30	BEACHFACE MAPPING - APRIL, MAY 2007	Figure 8.7

02092-8-7.cdr

JUNE 2007



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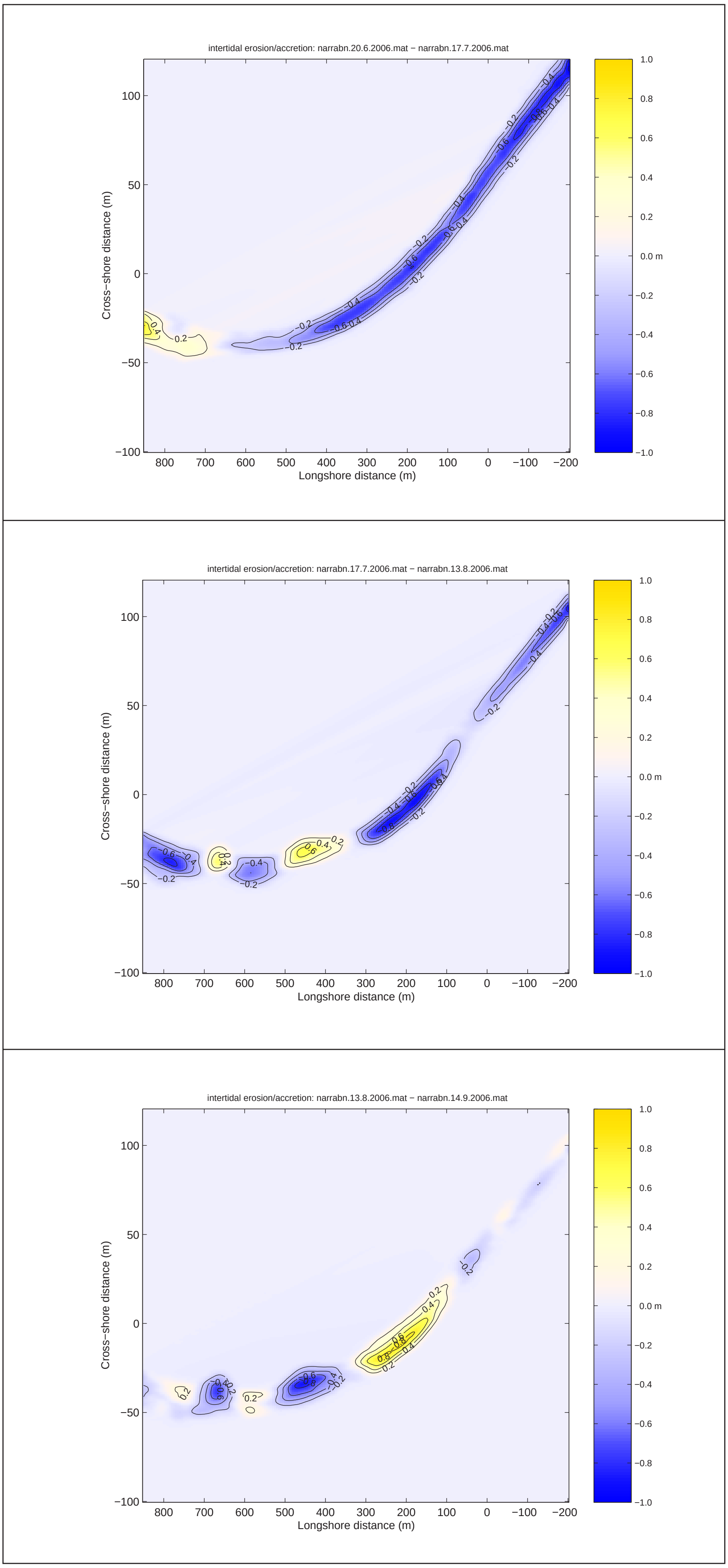


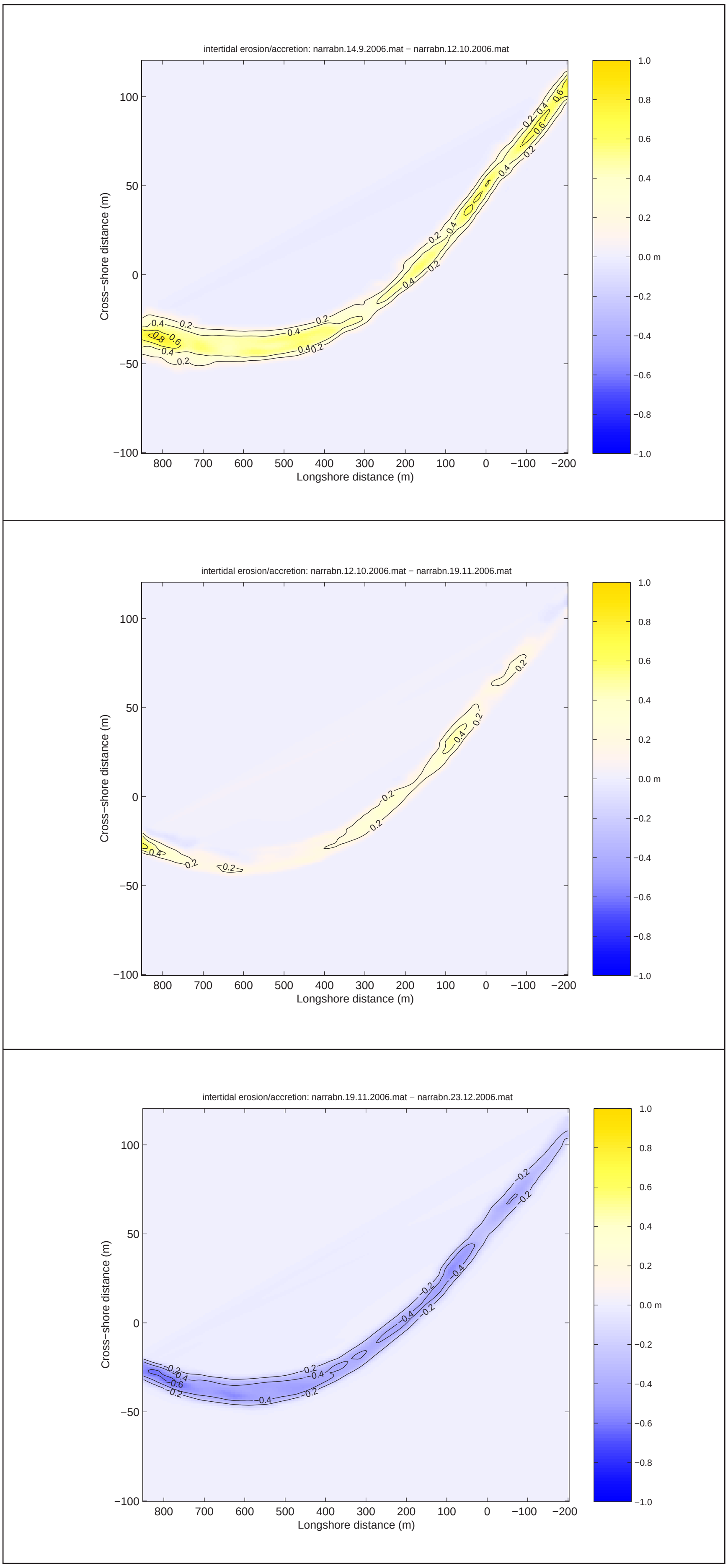
WRL

Report No. 2007/30

MONTHLY EROSION/ACCRETION:
JUNE - SEPTEMBER 2006

Figure
8.9

02092-8-9.cdr



WRL

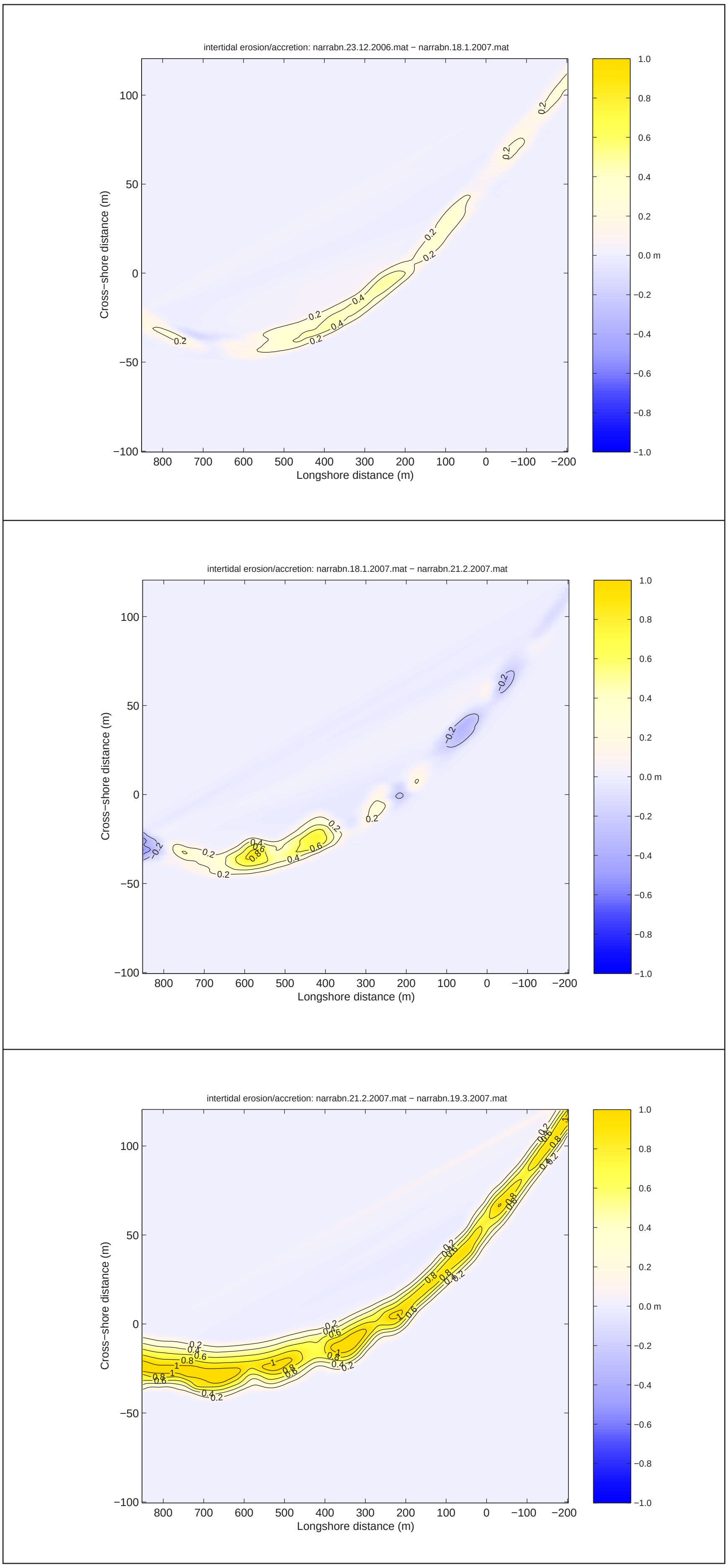
Report No. 2007/30

MONTHLY EROSION/ACCRETION:
SEPTEMBER - DECEMBER 2006

Figure

8.10

02092-8-10.cdr



WRL

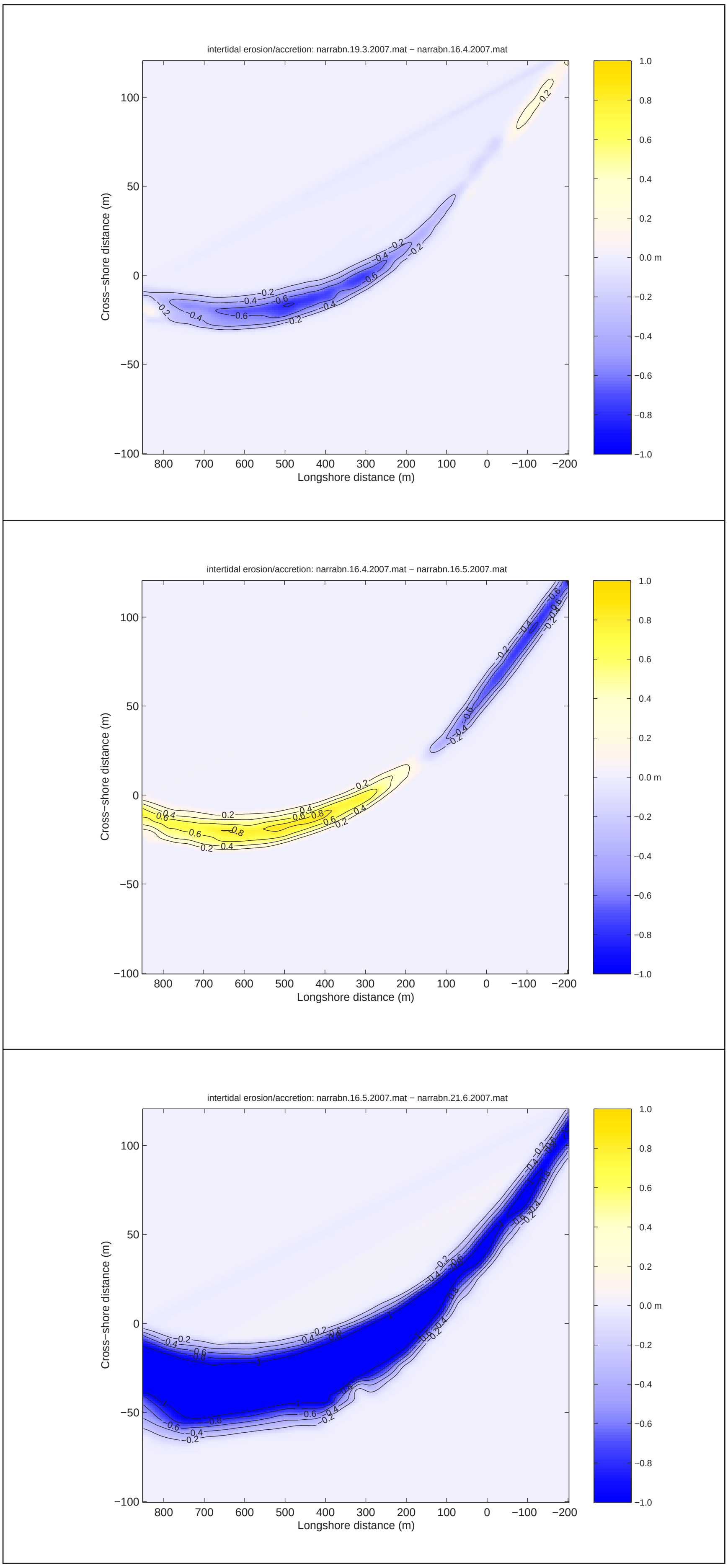
Report No. 2007/30

MONTHLY EROSION/ACCRETION:
DECEMBER 2006 - MARCH 2007

Figure

8.11

02092-8-11.cdr



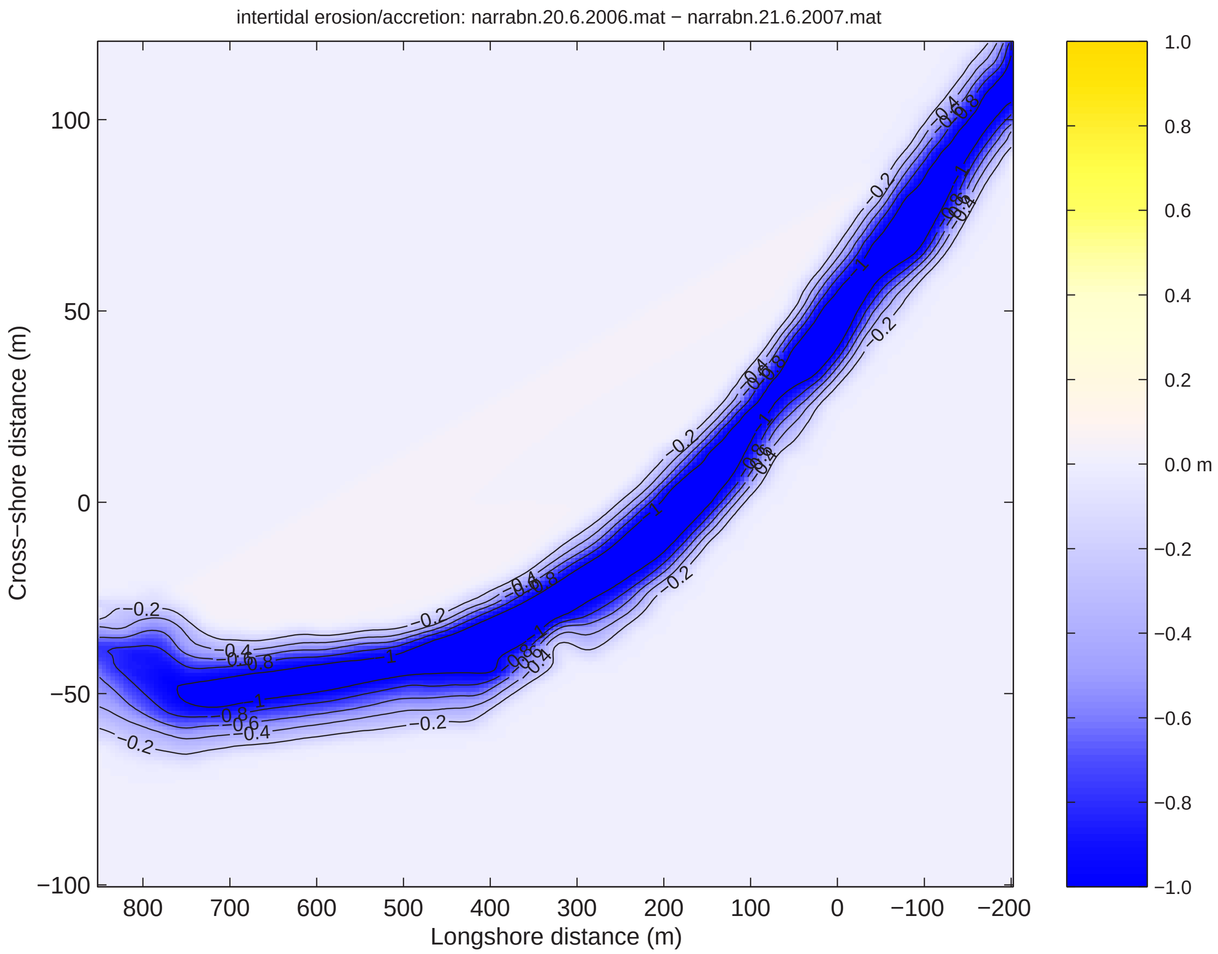
WRL

Report No. 2007/30

MONTHLY EROSION/ACCRETION:
MARCH - JUNE 2007

Figure
8.12

02092-8-12.cdr



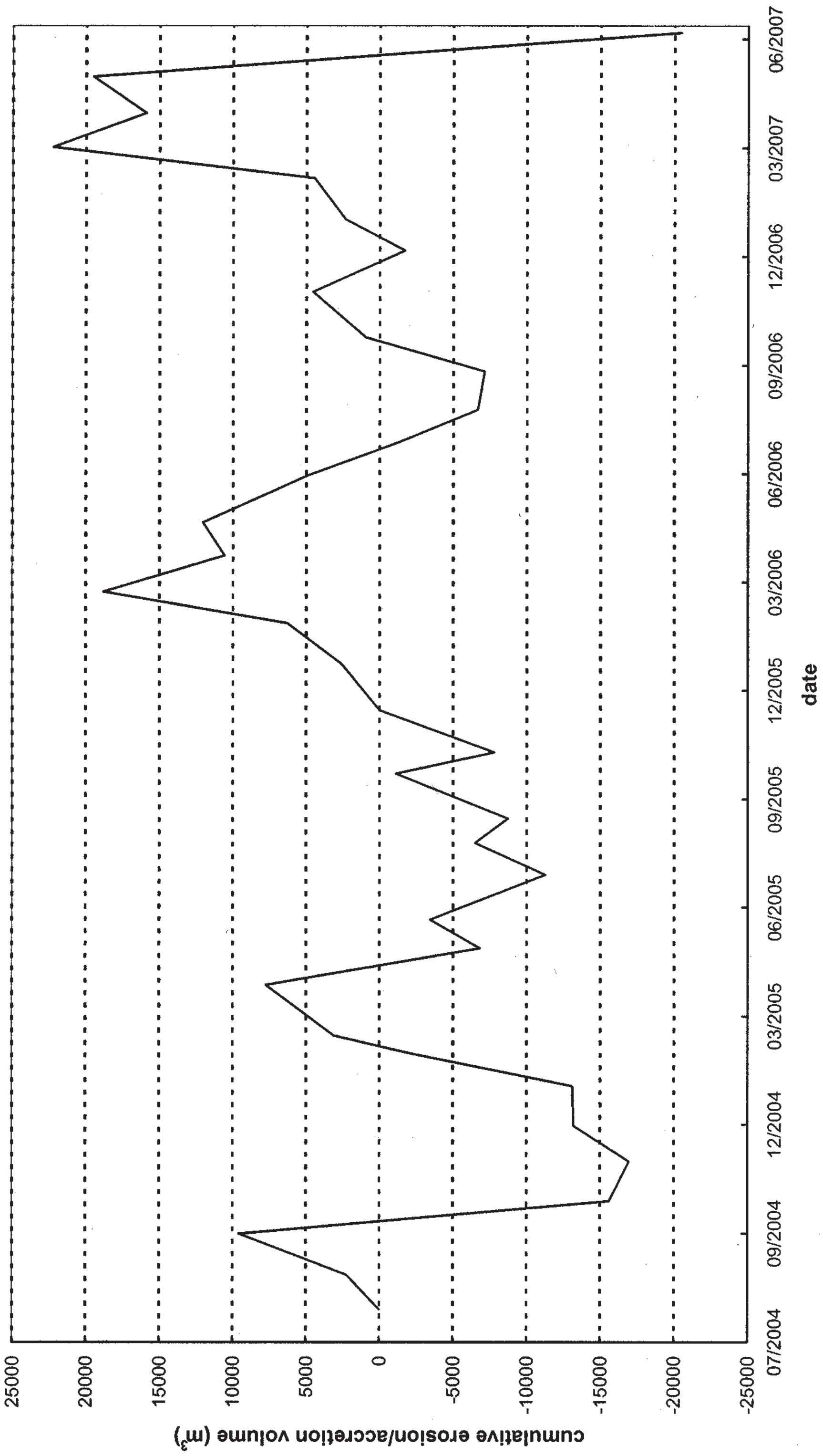
WRL

Report No. 2007/30

EROSION/ACCRETION
PER TWELVE MONTH MONITORING PERIOD

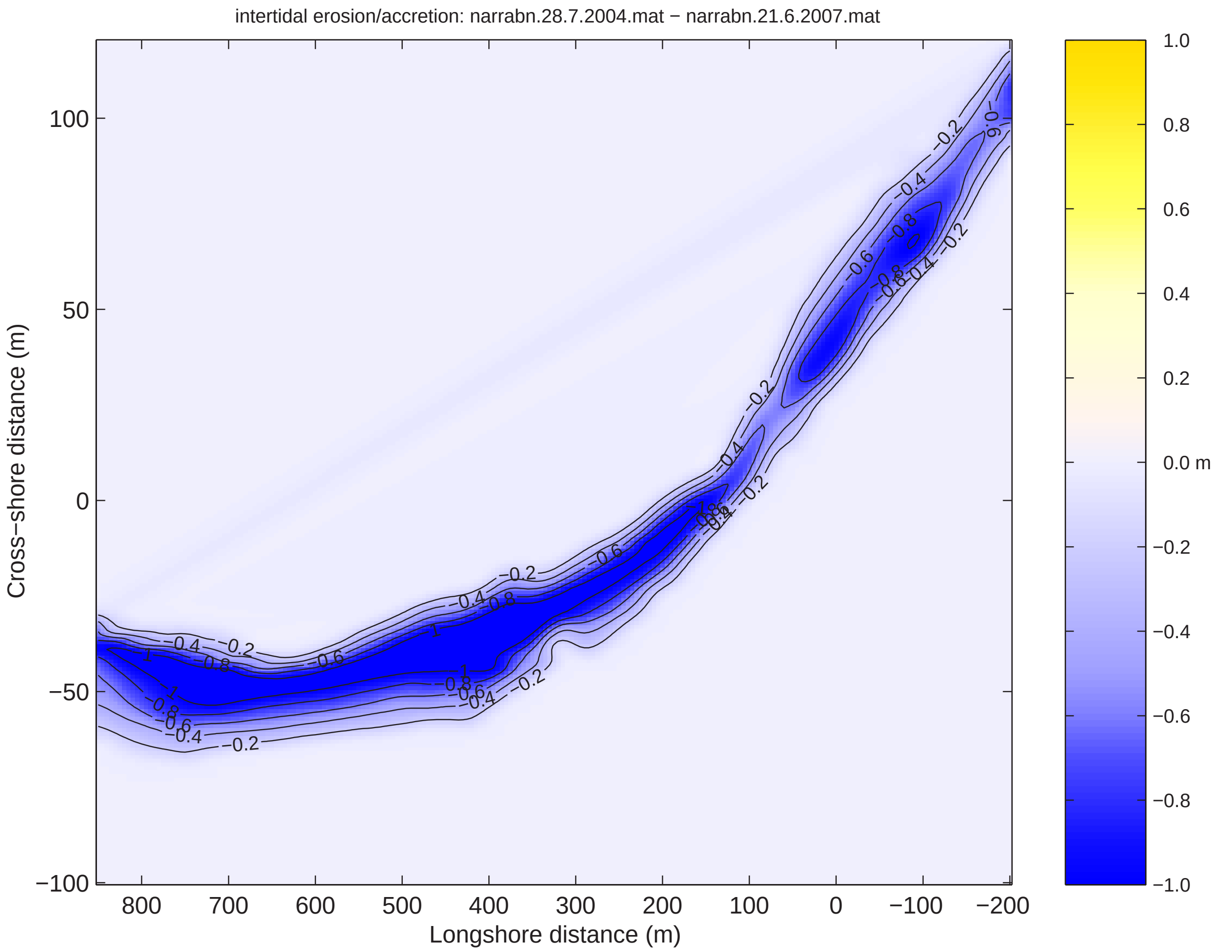
Figure
8.13

02092-8-13.cdr



WRL Report No. 2007/30	CUMULATIVE BEACHFACE EROSION/ACCRETION JULY 2004 TO JUNE 2007	Figure 8.14 02092-8-14.cdr

NET CHANGE: JULY 2004 - JUNE 2007



WRL Report No. 2007/30	TOTAL NET EROSION/ACCRETION TO JUNE 2007	Figure 8.15 02092-8-15.cdr

9. SUMMARY AND CONCLUSIONS

This summary data report for the twelve month monitoring period July 2006 to June 2007 is the third in a series of annual reports for the Collaroy-Narrabeen embayment, with particular focus on Precinct 3.

9.1 Qualitative Visual Assessment

Beach and nearshore conditions during the present twelve-month monitoring period July 2006 to June 2007 were typically characterised by generally mild wave conditions and growth of the beaches, however, the net change in beach width has been dictated by the three successive storms which occurred at the end of the monitoring period during June 2007. The wave climate during the winter and spring of 2006 was dominated by southerly swell events, with higher energy intermediate morphology across the northern sections of the embayment, ranging to lower energy intermediate morphology at the more sheltered Collaroy section of the beach. During the summer and autumn months the predominant shorter period easterly wave conditions produced less of a gradient in beach morphology along the beach, with the beach generally in a lower energy state. The month of June saw significant erosion of the beach, with the net beach width at the completion of the twelve-month monitoring period significantly narrower than the start of July 2006.

A qualitative visual assessment of the net trends in beach adjustment during this time can be seen by contrasting images of the beach obtained at the start and end of the present twelve month monitoring period. Along both the southern (Figure 5.2) and the central-northern regions of the embayment (Figure 5.3), significant net erosion of the beach has occurred. The most pronounced erosion has been at Stuart and Wetherill Streets, where the beach was tens of metres wide in July 2006, but has been completely eroded back to the boulder wall during the storms of June 2007. A significant near vertical erosion scarp is evident in the images taken on 30th June 2007, and is more predominant extending to the north from the ARGUS station at the Flight Deck building.

Extending this qualitative visual assessment of images to include the entire 3 year monitoring period (Figure 5.4), the initial 12 month monitoring period July 2004 to June 2005 was characterised by three distinct stormy periods when the beach was observed to erode, separated by moderate to mild wave conditions, during which times partial beach recovery was observed. The first stormy period commenced with the occurrence of a large storm event in mid July 2004, when offshore significant wave heights rose to 7 m. Moderate wave conditions through the first half of August peaked with the occurrence of a second storm in the middle of the month (offshore significant wave heights up to 5 m). Wave energy then declined, with generally mild conditions through the second half of August, and throughout September. The second stormy period commenced in October, with the occurrence of four storm events in the single month, when offshore significant wave heights up to 6 m were recorded. In contrast, November again saw a return to mild conditions, followed by a series of moderate storms in December, when offshore significant wave heights of 3 – 4 m were observed. Moderate wave conditions prevailed through January 2005, followed by generally milder conditions in February. The third stormy period commenced in the second half of March, when offshore significant wave heights again exceeded 6 m. Mild to moderate wave conditions return in April and continued through to late June, interrupted in mid May by a period of elevated wave energy.

Beach and nearshore conditions during the second monitoring period July 2005 to June 2006 were characterised by generally mild wave conditions and growth of the beaches within the Collaroy-Narrabeen embayment. This general accretionary trend was interrupted on three occasions by the occurrence of storms in October 2005, April and early June 2006, that each resulted in short-term periods of the offshore movement of sand from the beachface and across the surfzone. Along both the southern and central-northern regions of the embayment a distinct trend of net beach widening was monitored. This was most pronounced adjacent to the boulder walls around Jenkins and Stuart Streets, which were fully exposed to wave actions at high tide in early July 2005, but by June 2006 were buried again, with a buffer of sand several tens of metres wide between the toe of the walls and the shoreline.

During the present monitoring period, July 2006 to June 2007 beach and nearshore conditions were typically characterised by generally mild wave conditions and growth of the beaches, however, the net change in beach width has been dominated by the three successive storms which occurred at the end of the monitoring period during June 2007. Slight erosion of the beach was generally observed throughout the winter months from June to August 2006, but was followed by an accretionary period from August to October, where milder wave conditions saw overall increases in beach width. This trend was interrupted from October to December 2006, when the beach was again observed to decrease in width, particularly across the northern section of the embayment. Milder wave conditions dominated the summer and early autumn months of 2007, with the beach again continuing a general trend of widening. There was very little net change to the beach through the months leading into winter, however, during June significant erosion of the beach by three successive storms occurred, and dominated the current monitoring period net beach width change. The net beach width at the completion of the current twelve-month monitoring period July 2006 to June 2007 was significantly narrower than the start of July 2006.

9.2 Shoreline Variability and Beach Width Analysis

Based upon the qualitative analysis of weekly shoreline positions within Precinct 3 during the present monitoring period 01/07/06 - 30/06/07 (Figure 6.2), the beach along the Precinct 3 oceanfront varied in width (relative to the alignment of the proposed boulder wall) from approximately 65 m toward the northern end, to 0 m at locations 200 m, 300 m, and 400 m north of the Flight Deck building. The envelope of beach width changes across the northern section of the embayment varied from roughly 40 m in the area just north of the Flight Deck building, up to 55 m in the far north of the mapped section of beach. South of the Flight Deck building the envelope of beach widths was less variable, and typically of the order of 30 m.

The analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals a trend of slightly higher beach width variability in the far north, decreasing in a southward direction alongshore. Throughout Precinct 3 the beach width varied by up to ±20 m from the mean shoreline position at the northern end, and by approximately ±15 m from the mean shoreline position at the southern end. This is consistent with the sheltering of the southern stretch of beach from southerly wave attack, that is provided by Long Reef. The standard deviation of weekly shorelines (middle panel, Figure 6.3) shows the slight decreasing trend from north to south alongshore, with the calculated s.d. decreasing in a linear manner from 10 m towards the northern end of Precinct 3, down to 7 m at the southern end.

The variations in shoreline position measured at four representative transects within Precinct 3 for the twelve month monitoring period July 2006 to June 2007 (Figure 6.4) exhibit a similar underlying accretionary trend up until June 2007. All four transects show rapid decrease in beach width of 20 m to 30 m through July and into August 2006. The beach width then fluctuated with a slight trend of accretion, up until November, when the trend was again interrupted by a period of more erosive wave events. This was particularly evident in the more northern transects at Devitt and Mactier streets. Throughout the summer months and into autumn, the beach grew rapidly in width, particularly in the north, reaching a maximum width of over 60 m at Devitt Street, 50 m at Mactier and Jenkins Streets, and 40 m at Stuart Street. At this time the beach had accreted to much the same width as at the start of the monitoring period in July 2006, across the entire Precinct 3.

The three storm events which occurred in June 2007 caused rapid erosion of the beach. Within a period of one fortnight, some 40 m to 50 m of beach width was lost at the northern transects at Devitt and Mactier Streets, and 35 m lost at Stuart and Jenkins Streets. At several locations to the north of the ARGUS station, the beach was eroded completely, with wave runup reaching the boulder wall at the back of the beach. North of Devitt Street and south of Jenkins Street, a beach width of 10 m to 20 m remained, at the time the last shoreline was mapped in late June. Ongoing erosion of the beach has occurred since the last shoreline was mapped for June, with the complete analysis of the net erosion from the June and July storms being completed for the next monitoring period report.

When the weekly shoreline data for the period July 2006 – June 2007 were re-analysed to assess beach width changes relative to the mean shoreline position for the preceding twelve-month period (Figure 6.5), the analysis showed that the majority of the shorelines mapped during the current monitoring period were clustered within ±10 m of the mean shoreline from the previous monitoring period. Most shorelines mapped for Precinct 3 throughout the current monitoring period indicated a wider beach than the mean width of the previous monitoring period. Between July 2006 and June 2007, the beach reached a maximum width of 25 m to 30 m greater than the mean width calculated for the previous year. The minimum beach width for the current monitoring period (taken from June 2007) is approximately 30 m narrower than the mean beach width from the previous monitoring period. For most of the current monitoring period, the beach was slightly narrower across the northern section of Precinct 3 than the previous monitoring period, and slightly wider across the southern stretch of the beach.

9.3 Erosion/Accretion Trends

Based upon the analysis of monthly intertidal bathymetries (Figures 8.2 – 8.8) to derive monthly net erosion-accretion trends (Figures 8.9 – 8.12), between June and July 2006, most of the beach within the Precinct 3 study area eroded slightly, with the exception of the far northern end. Continuing into August a general trend of further erosion occurred, with most of the erosion occurring in the development of irregular crescentic features along the beachface. By mid September 2006, the beach had again become more uniform, with erosion and accretion occurring in converse locations to the previous months, smoothing the crescentic features that had previously developed. From September to October uniform accretion occurred along the entire study area, with the beachface accreting by 0.4 m in vertical elevation along the entire beach, and up to 0.8 m in the far north. This trend of accretion continued into November, although to a lesser extent. The trend reversed between November and December 2006, with slight erosion occurring across the entire study area. In most places, lowering of the beachface by at least 0.2 m in vertical elevation, and up to 0.6 m, was experienced.

From December through to February 2007 a general trend of accretion occurred, with the prevailing lower energy summer wave conditions. Most of the accretion occurred irregularly through the formation of crescentic features along the beachface, with some locations accreting by up to 1 m in vertical elevation. The rate of accretion of the beachface increased significantly between February and March, with a widening of the beach, and the onshore migration of sand from the nearshore bar. During this one month period, the beachface accreted by a further 1 m in vertical elevation across the entire Precinct 3 study area. Between March and April 2007, a significant portion of the material that had accreted during the previous summer, was again eroded across the northern area of the beach, with the onset of more dominant southerly swell wave conditions. There was little net erosion/accretion across the southern end of the study area. This trend was reversed between April and May, with the eroded material returning to the beachface across the northern section of the study area, and erosion along the southern stretch of the beach.

The most dramatic short term change in beachface bathymetry experienced to date in the three years of monitoring at Narrabeen/Collaroy, occurred in June 2007. Figure 8.12 (Bottom) shows that by 21st June, the beachface had migrated landward by 50 m in the north of the study area, and by 20 m in the south. The limit of the analysis technique used in the beachface mapping (only considering beach elevations above -0.5 m AHD) means that the depth of erosion is shown as a 1 m drop in vertical beachface elevation. However, field observations and quad bike surveys covering a greater range in beachface elevation indicated that landward of this region the beach erosion scarp was of the order of 2 m.

The net change in beachface bathymetry for the current monitoring period, July 2006 to June 2007, was dominated by the extensive erosion caused by the June 2007 storms. For the first 11 months of the monitoring period, the beach was generally in an accretionary trend, with a total of some 15,000 m^3 of sand accreting between June 2006 and May 2007. However, the storms of June resulted in approximately 40,000 m^3 of beach erosion, with the net erosion for the June 2006 to June 2007 period being 25,000 m^3, equating to approximately 24 m^3 per m shoreline. Between June 2006 and June 2007, a reduction of over 1.0 m in vertical elevation was experienced across the entire Precinct 3 study area.

Based upon the analysis of monthly intertidal bathymetries, calculations of the monthly net changes in intertidal (+0.7 to -0.5 m AHD) sand volumes within Precinct 3 are tabulated below.

Total and Net Intertidal Sand Volumes Changes: June 2006 – June 2007

	NET CHANGE INTERTIDAL (+0.7 to -0.5 m AHD) SAND VOLUME – PRECINCT 3	
Period	**Cubic m (total)**	**Cubic m per m shoreline**
June – July 2006	-6,115	-5.8
July – August	-5,410	-5.1
August – September	-470	-0.4
September - October	+8,060	+7.6
October – November	+3,600	+3.4
November – December	-6,270	-5.9
December – January 2007	+4,070	+3.8
January – February	+2,100	+2.0
February – March	+17,840	+16.8
March – April	-6,370	-6.0
April – May	+3,610	+3.4
May – June 2007	-39,980	-37.7

The typical monthly fluctuations of erosion and accretion volumes from the beach have been in the range of 3,000 – 8,000 m^3, which equates to approximately 3 – 8 m^3 per metre of beach length. The minimum monthly change observed was between August and September 2006, with a net loss of only 470 m^3 total along the entire beachface within the Precinct 3 study area. It is interesting to note that the maximum accretion in any one month period during the current monitoring period occurred between February and March, with almost 18,000 m^3 of sand accreting on the beachface. The maximum monthly accretion in the previous monitoring period, July 2005 to June 2006, also occurred between February and March, and was of the order of 13,000 m^3.

The most dramatic monthly erosion event recorded in the beach monitoring program to date, occurred in June 2007. It is important to note that the extent of the erosion/accretion analysis completed with the ARGUS images is limited to elevations between -0.5 and +0.7 m AHD, and therefore the estimated erosion volumes for the June event do not consider the beach material that was initially located outside of this range. From the coastal image analysis, it is estimated that at least 40,000 m^3 of sand was eroded from the beach during June, which equates to almost 40 m^3 per metre of shoreline. Quad bike surveys also undertaken during and after June confirm that this is a reasonable estimate of the amount of material eroded from the beach between -0.5 and +0.7 m AHD, but the erosion from the whole beach profile was of the order of 80 m^3/m.

This level of erosion is almost double the previous maximum monthly erosion loss predicted from the coastal imaging analysis, in September to October 2005, of 25,000 m^3. This also highlights that erosion of the beach can occur at rates significantly higher than the subsequent beach recovery, with the maximum monthly accretion recorded during the monitoring program to date of 18,000 m^3 in February to March 2007.

10. ACKNOWLEDGEMENTS

This project was commissioned and funded by Warringah Council.

The Body Corporate of Flight Deck is thanked for permitting the ARGUS system to reside on the roof of the building.

Manly Hydraulics Laboratory is acknowledged for the ongoing provision of wave and tide data.

Doug Anderson of WRL continues to manage the wave and tide data processing, computer operations for remote communications, image storage, off-line image archiving and web serving at WRL. Ian Cunningham of WRL completed the weekly analysis and updating of monitoring program information via the project web site.

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 providing practical tools for coastal monitoring and management.

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Appendix A

Week-to-a-Page: July 2006 to June 2007

(no images for weeks 25/09/2006 - 01/10/2006 and 16/10/2006 - 22/10/2006)

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

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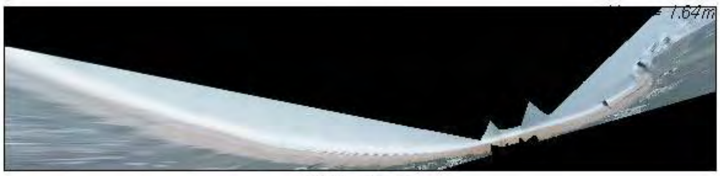

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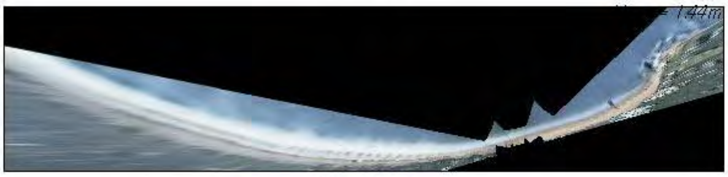

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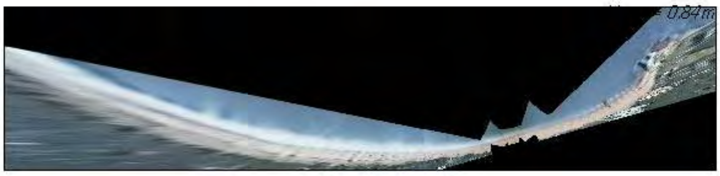

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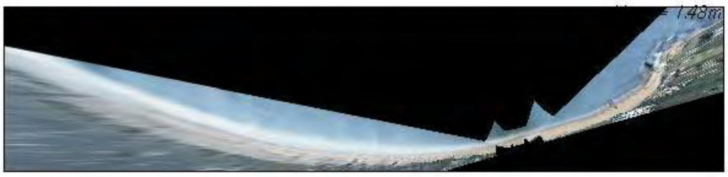

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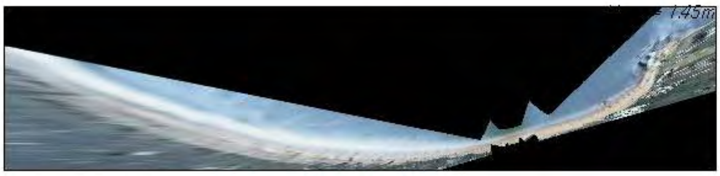

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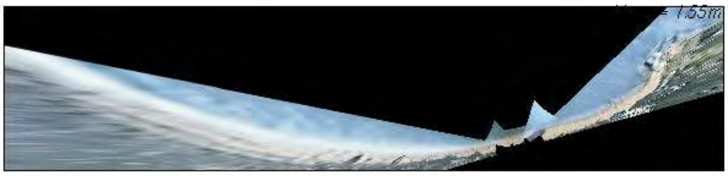

2006-07-09

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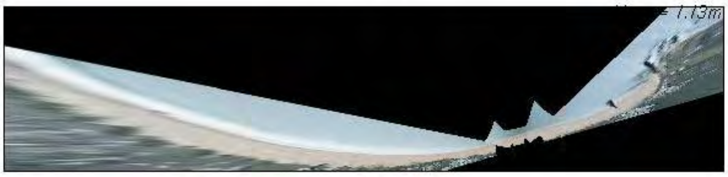
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 03/07/2006 - 09/07/2006	Figure A1 02092-A01.cdr

Week–to–a–Page (Mid–Tide)

2006–07–10

2006–07–11



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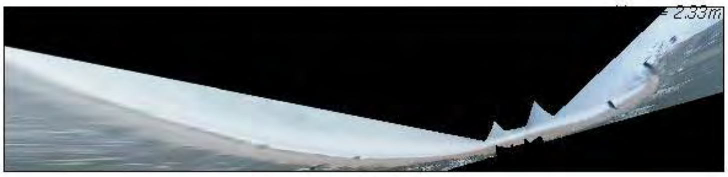
2006–07–13



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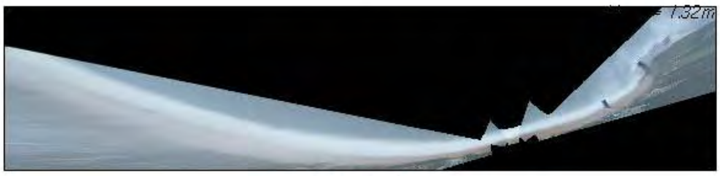

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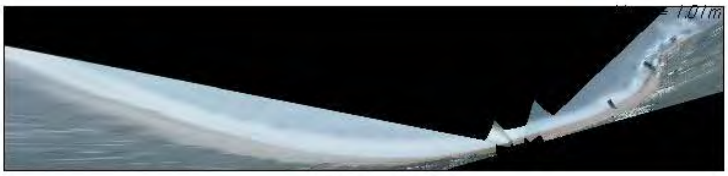

2006–07–16

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 10/07/2006 - 16/07/2006	Figure A2 02092-A02.cdr

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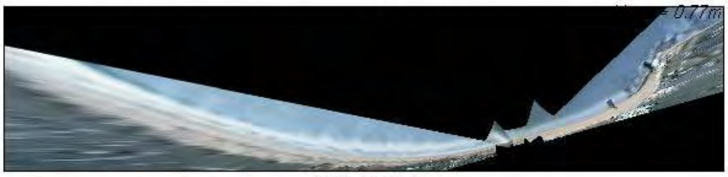

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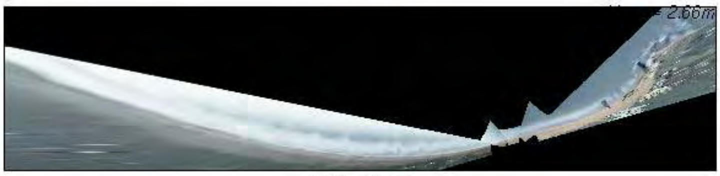

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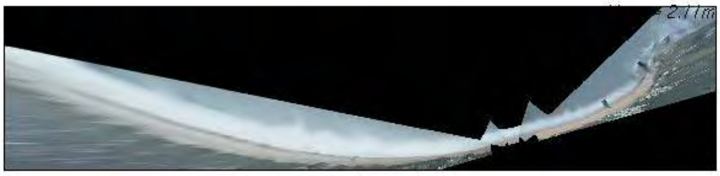

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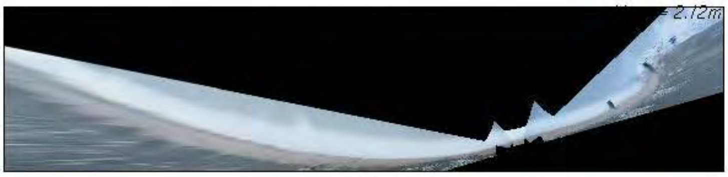

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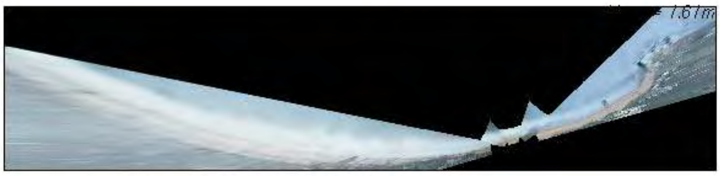

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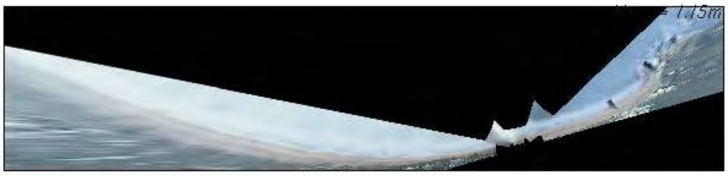

2006-07-23

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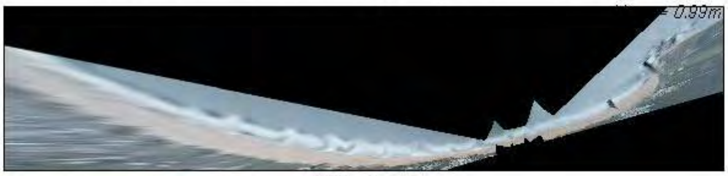
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 17/07/2006 - 23/07/2006	Figure A3 02092-A03.cdr

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



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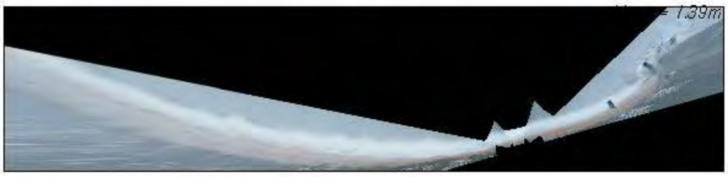

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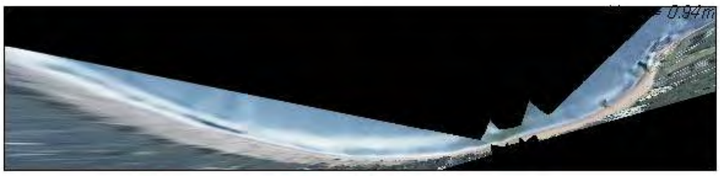
2006-07-27

2006-07-28



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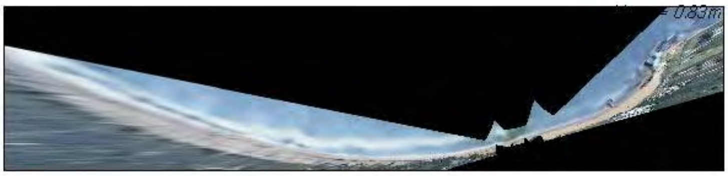

2006-07-30

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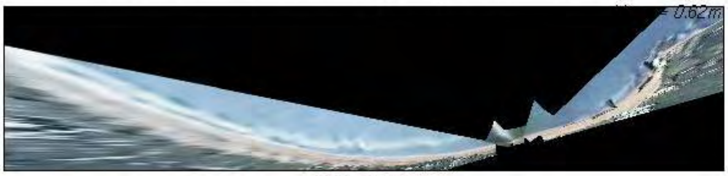
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 24/07/2006 - 30/07/2006	Figure A4 02092-A04.cdr

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



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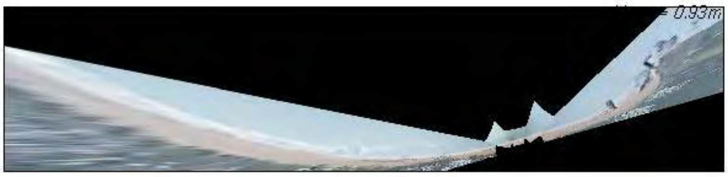
2006-08-01

2006-08-02

image not available
2006-08-03



2006-08-04

2006-08-05

image not available
2006-08-06

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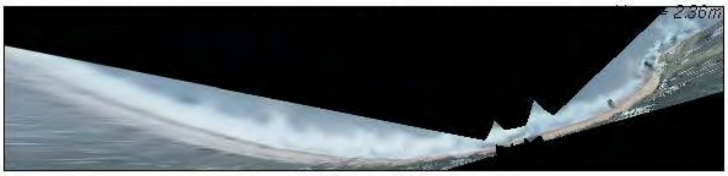
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 31/07/2006 - 06/08/2006	Figure A5
		02092-A05.cdr

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



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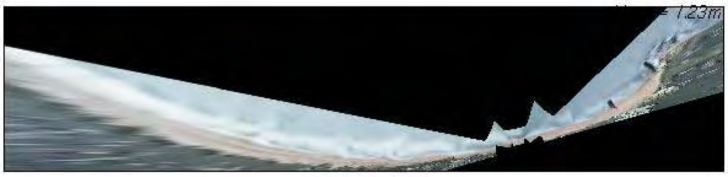

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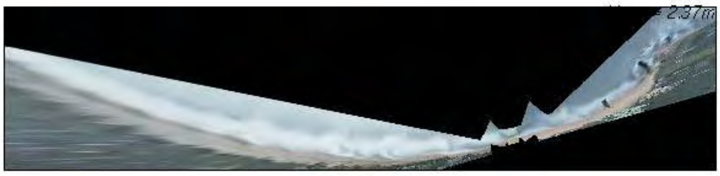

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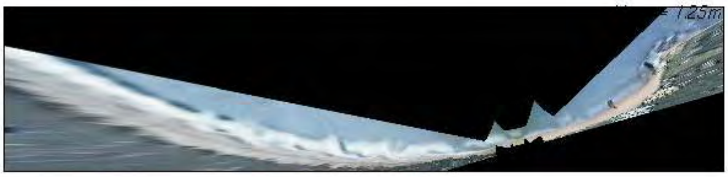

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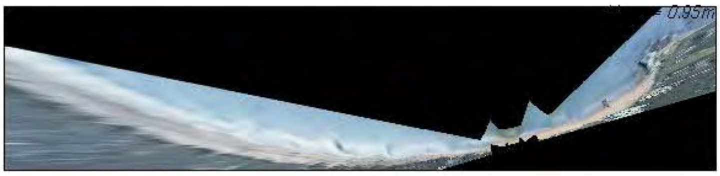

2006-08-12

image not available
2006-08-13

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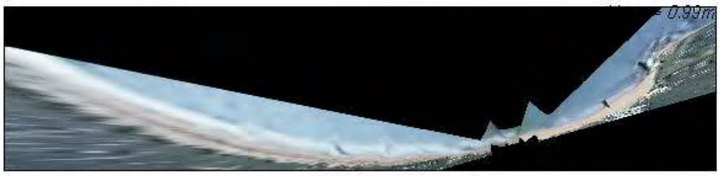
Week-to-a-Page (Mid-Tide)

2006-08-14



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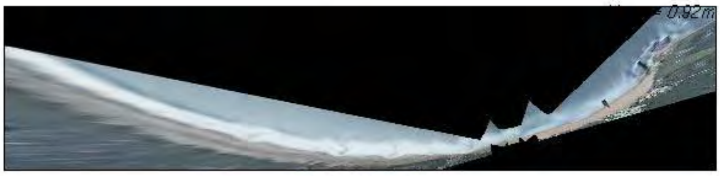
2006-08-16



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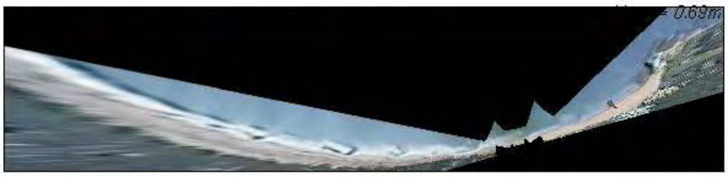

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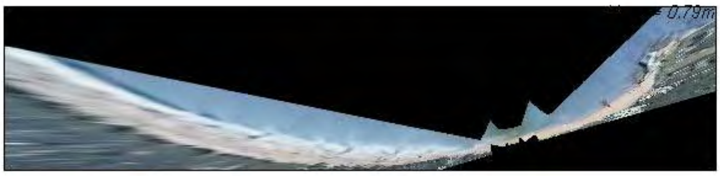

2006-08-19

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2006-08-20

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 14/08/2006 - 20/08/2006	Figure A7 02092-A07.cdr

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

2006-08-21

2006-08-22

2006-08-23

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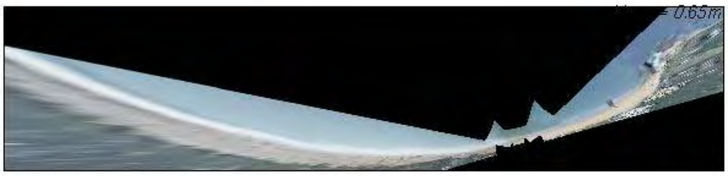
2006-08-24

2006-08-25

2006-08-26



2006-08-27

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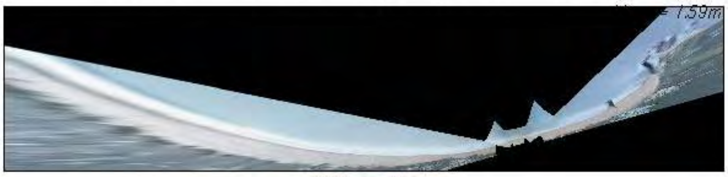
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 21/08/2006 - 27/08/2006	Figure A8 02092-A08.cdr

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



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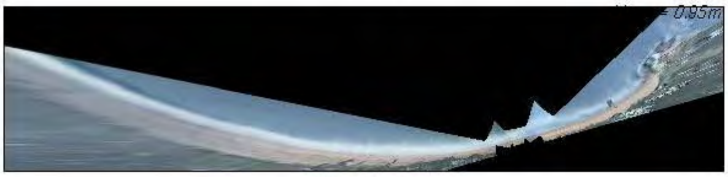

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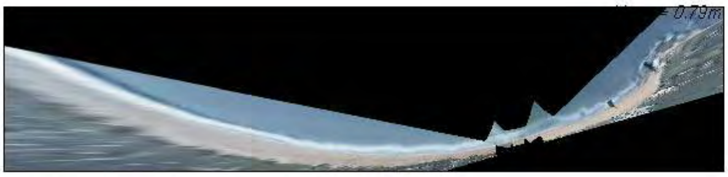

2006-09-01

2006-09-02

image not available

2006-09-03

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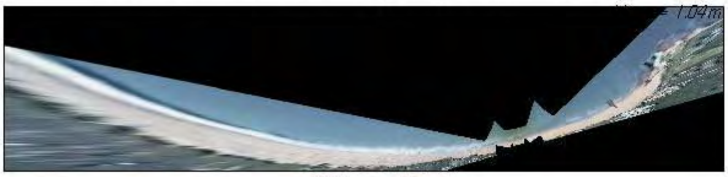
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 28/08/2006 - 03/09/2006	Figure A9 02092-A09.cdr

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



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2006-09-05

2006-09-06

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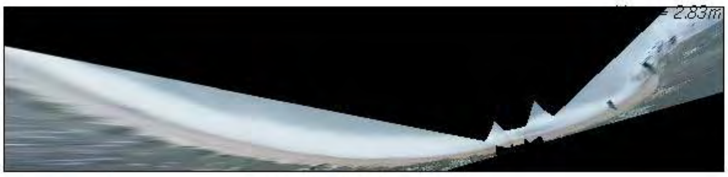
2006-09-07



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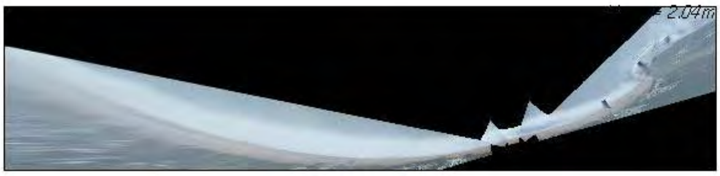

2006-09-09

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2006-09-10

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 04/09/2006 - 10/09/2006	Figure A10 02092-A10.cdr

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

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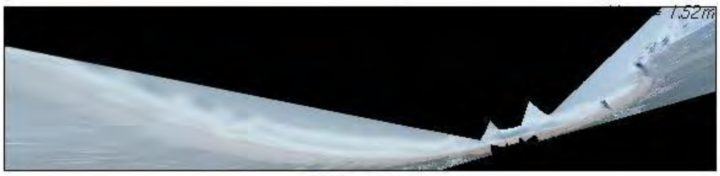

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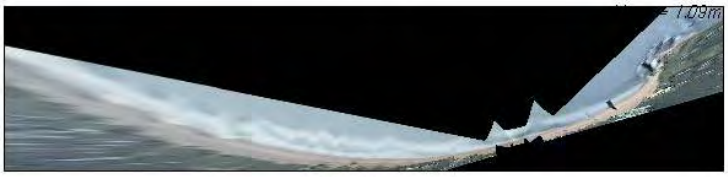

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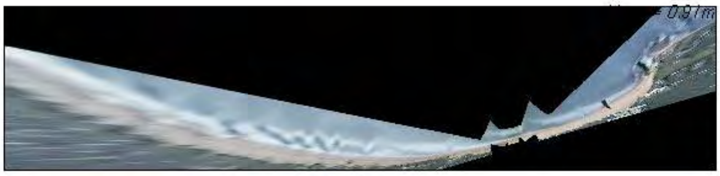

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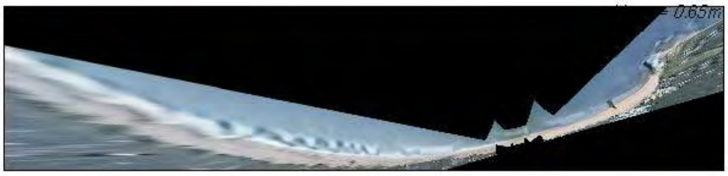

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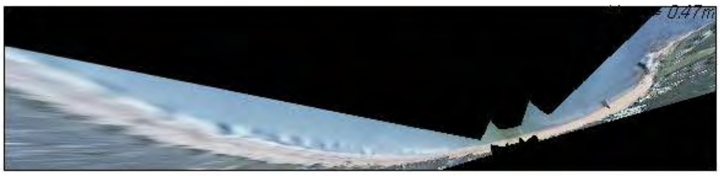

2006-09-16

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2006-09-17

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 11/09/2006 - 17/09/2006	Figure A11 02092-A11.cdr

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

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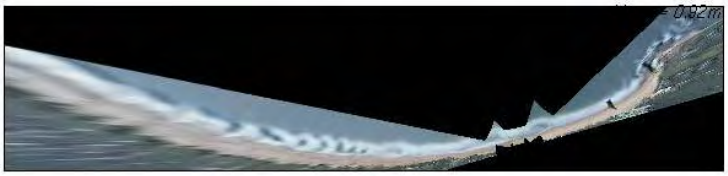
2006-09-19



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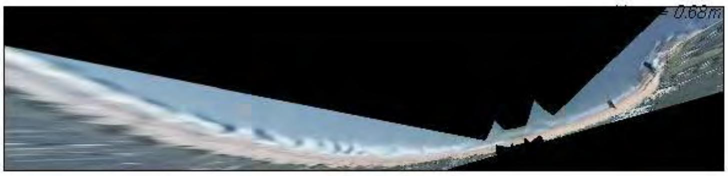

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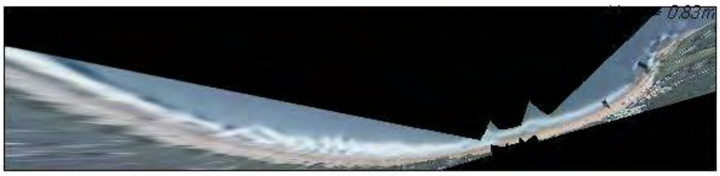

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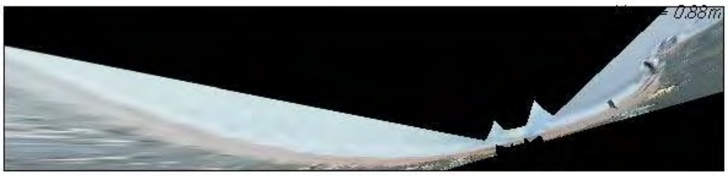

2006-09-24

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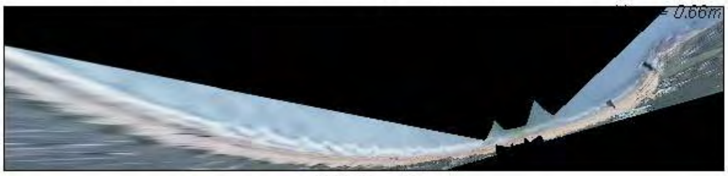
Week-to-a-Page (Mid-Tide)



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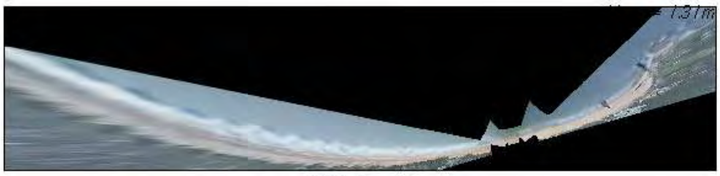

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2006-10-04

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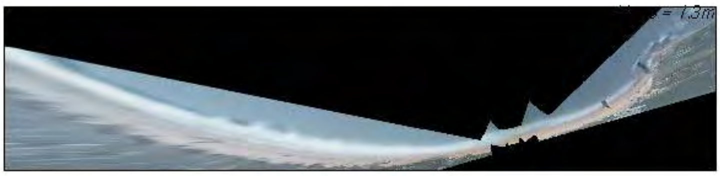
2006-10-05

2006-10-06



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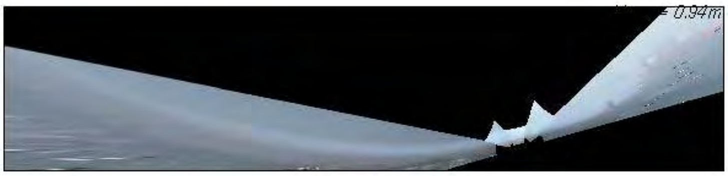

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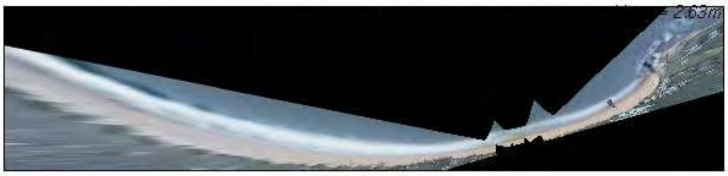
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 02/10/2006 - 08/10/2006	Figure A13 02092-A13.cdr

Week–to–a–Page (Mid–Tide)



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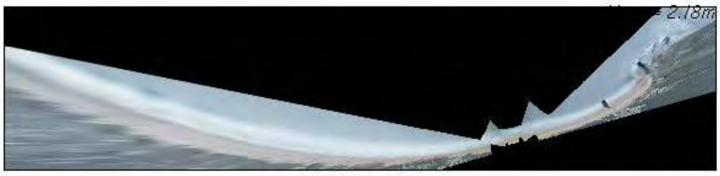

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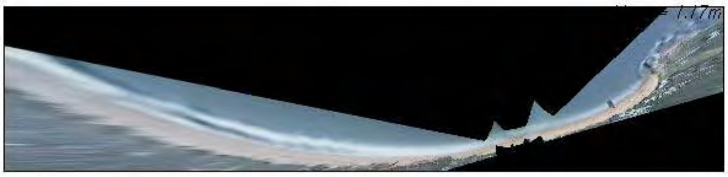

2006–10–11

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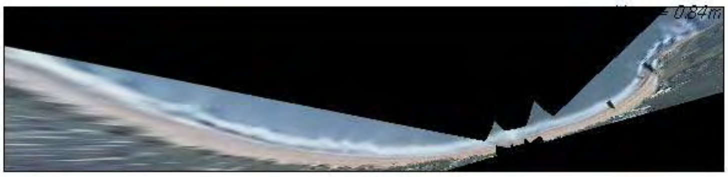
2006-10-12



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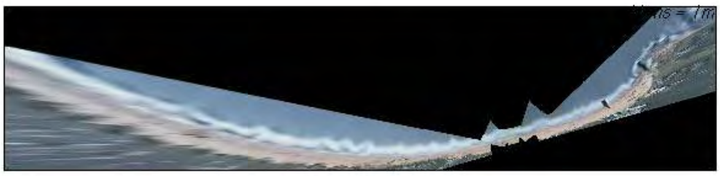

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image not available

2006-10-15

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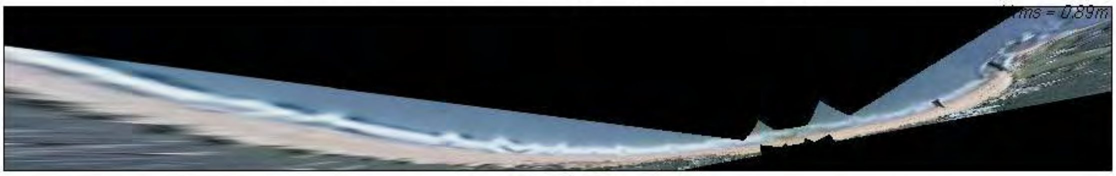
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 09/10/2006 - 15/10/2006	Figure A14 02092-A14.cdr

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



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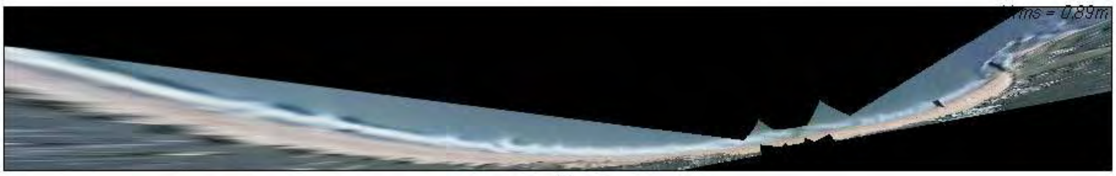

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2006-10-25

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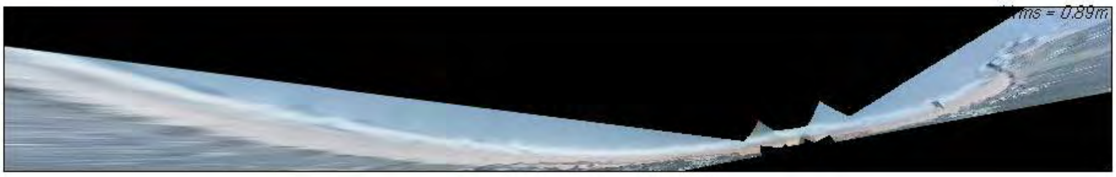
2006-10-26



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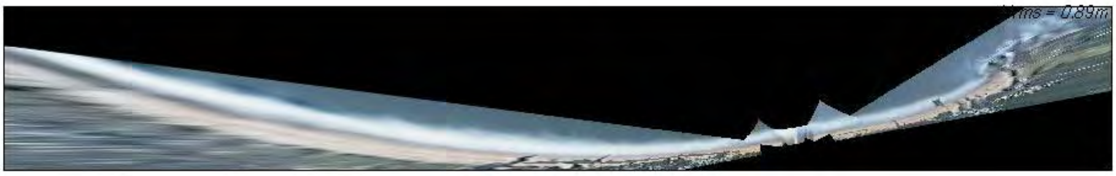

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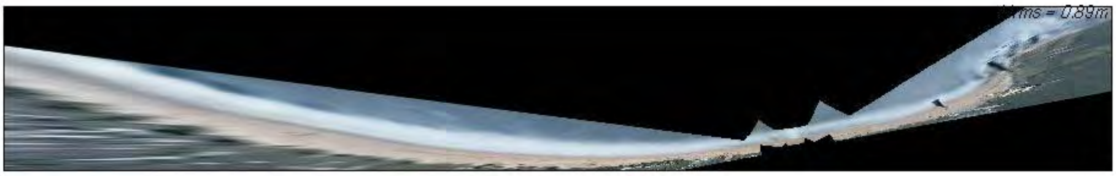

2006-10-29

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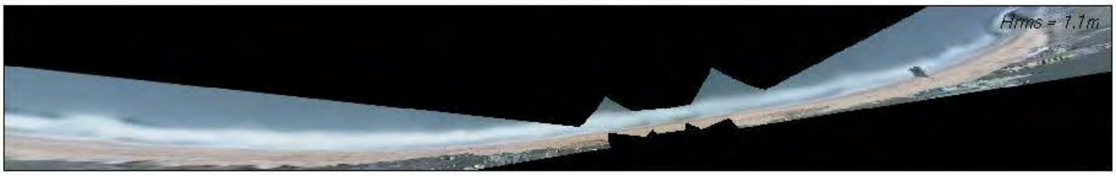
Week-to-a-Page (Mid-Tide)

30/10/2006 10:13

31/10/2006 12:13



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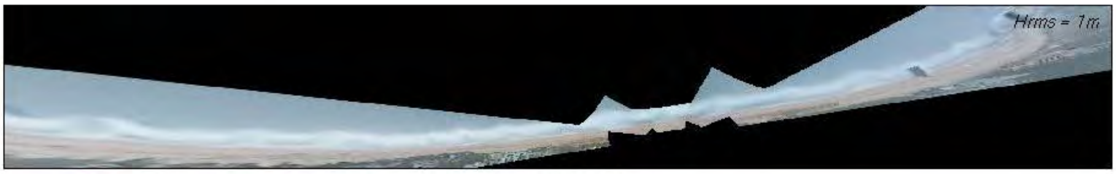

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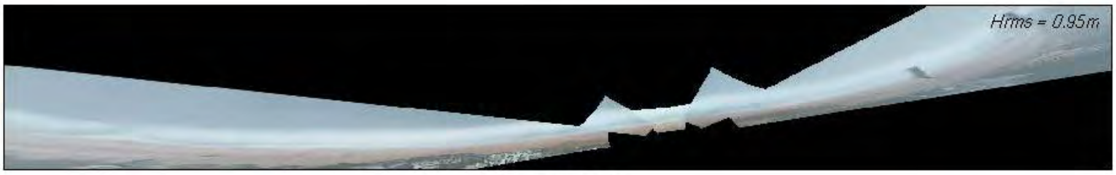

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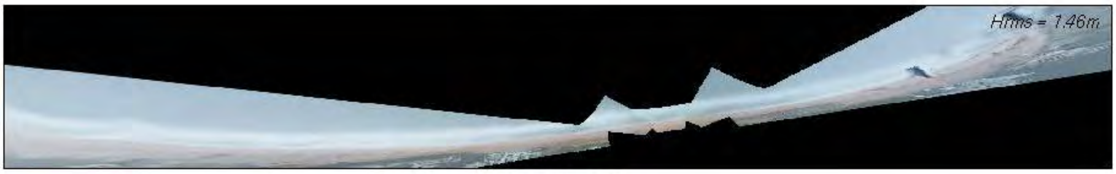

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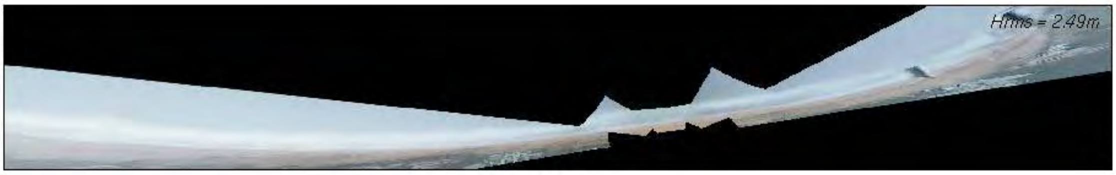

05/11/2006 11:13

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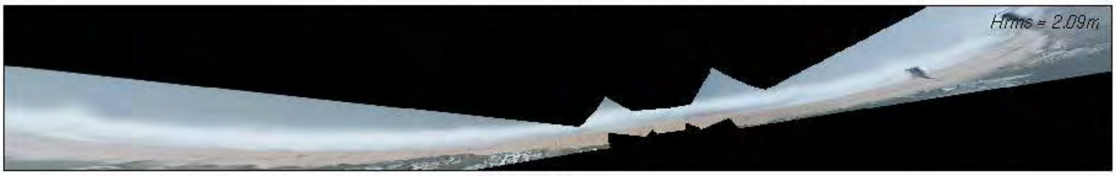
Week-to-a-Page (Mid-Tide)



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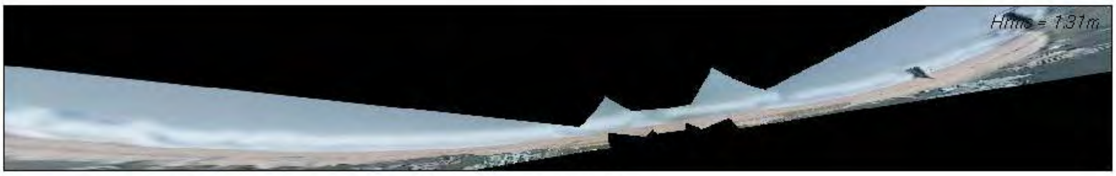
07/11/2006 12:13



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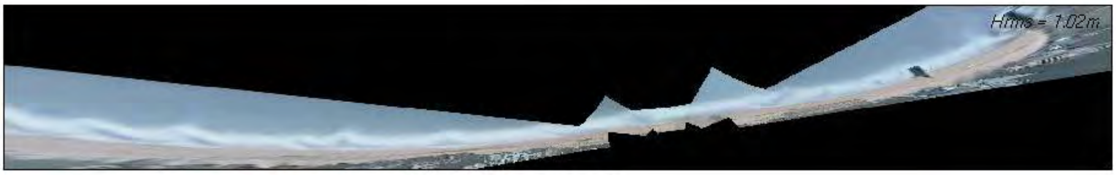

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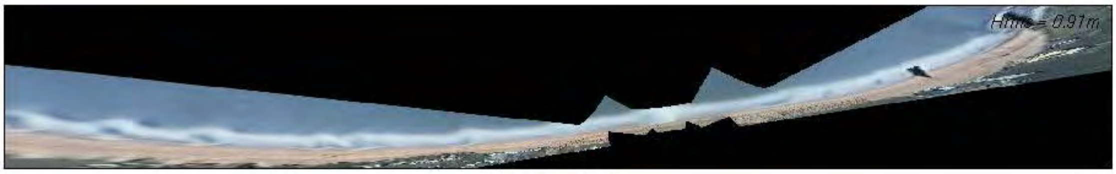

11/11/2006 08:13

12/11/2006 09:13

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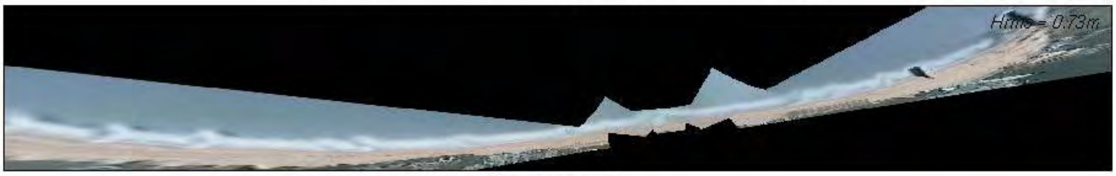
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 06/11/2006 - 12/11/2006	Figure A17 02092-A17.cdr

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



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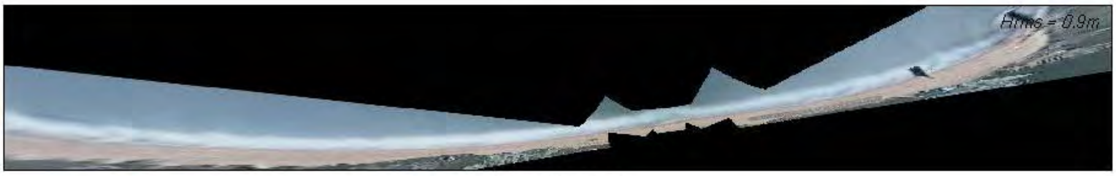
14/11/2006 11:13



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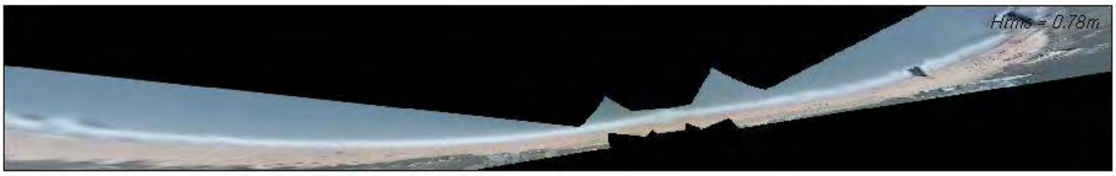
16/11/2006 14:13

17/11/2006 09:13

18/11/2006 09:13



19/11/2006 10:13

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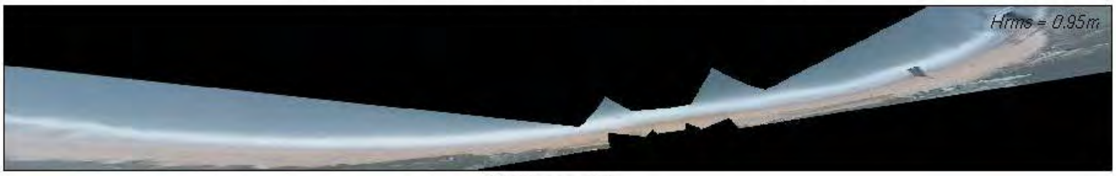
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 13/11/2006 - 19/11/2006	Figure A18 02092-A18.cdr

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



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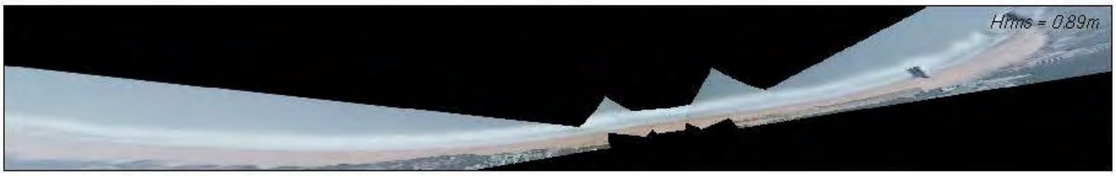
21/11/2006 11:13



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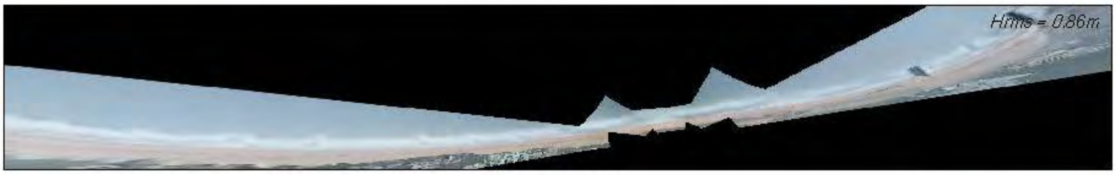
23/11/2006 13:13



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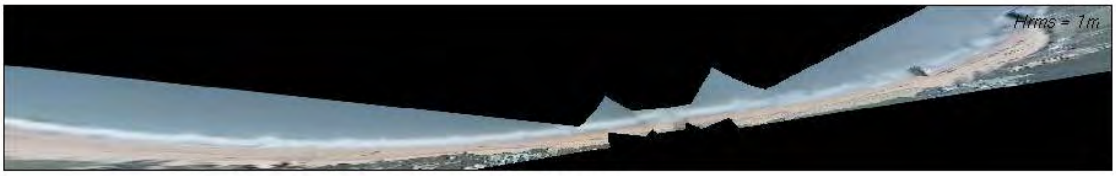
25/11/2006 14:13



26/11/2006 15:13

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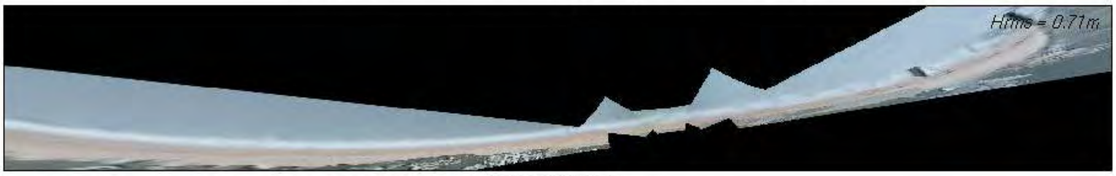
Week-to-a-Page (Mid-Tide)



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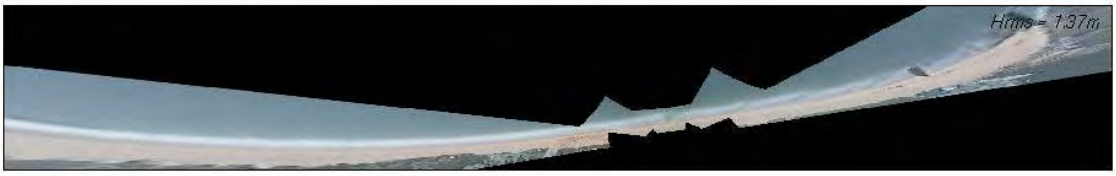
28/11/2006 10:13



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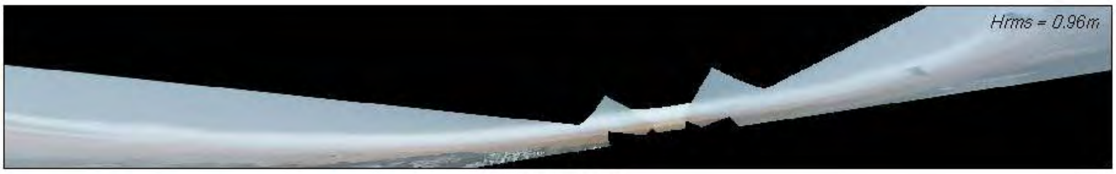
30/11/2006 12:13

01/12/2006 14:13



02/12/2006 09:13

03/12/2006 10:13

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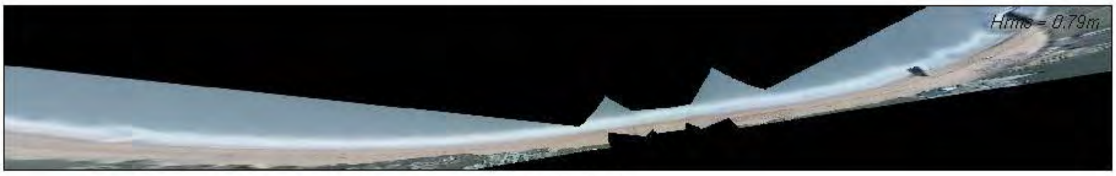
Week-to-a-Page (Mid-Tide)

04/12/2006 11:13

05/12/2006 11:13



06/12/2006 12:13

07/12/2006 13:13

08/12/2006 14:13

09/12/2006 15:13

10/12/2006 15:13

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

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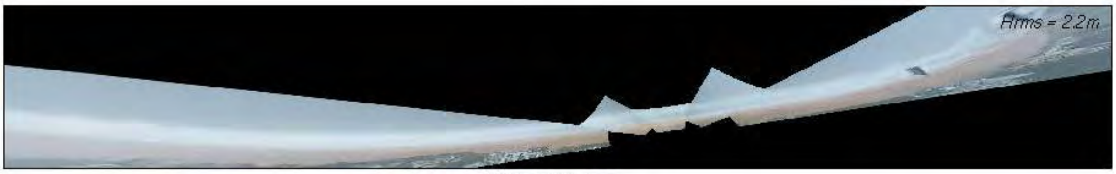

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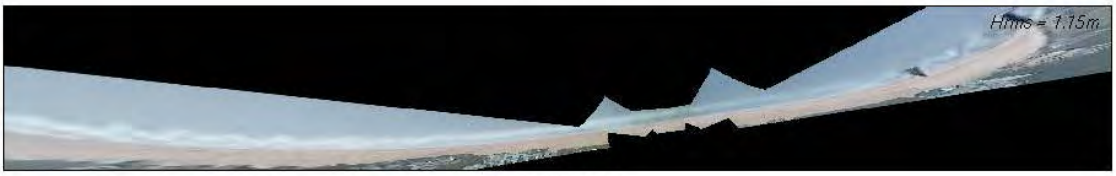

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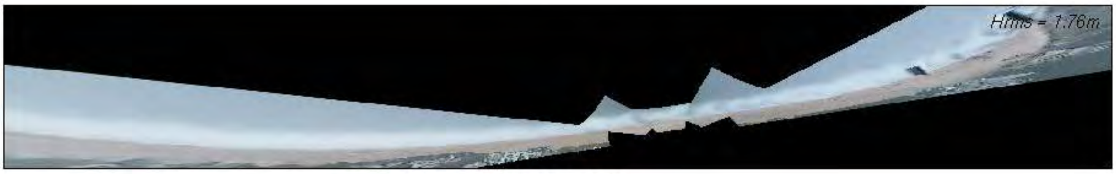
14/12/2006 11:13

15/12/2006 14:13



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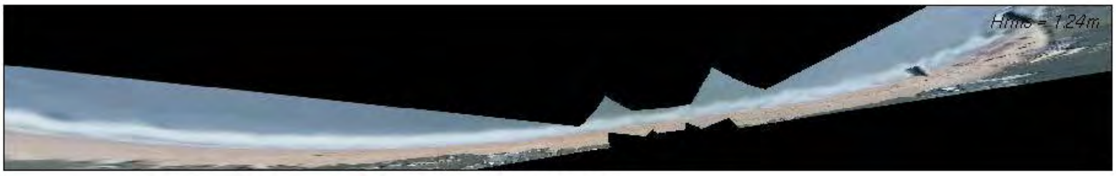

17/12/2006 09:13

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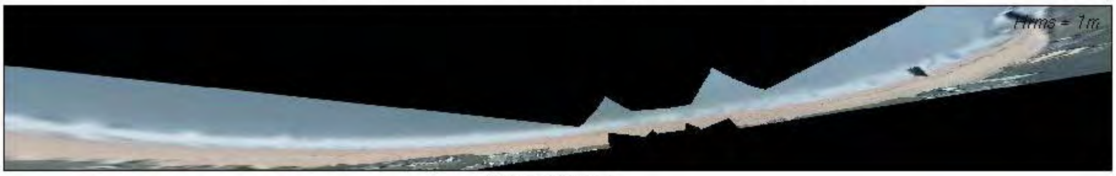
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 11/12/2006 - 17/12/2006	Figure A22

02092-A22.cdr

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



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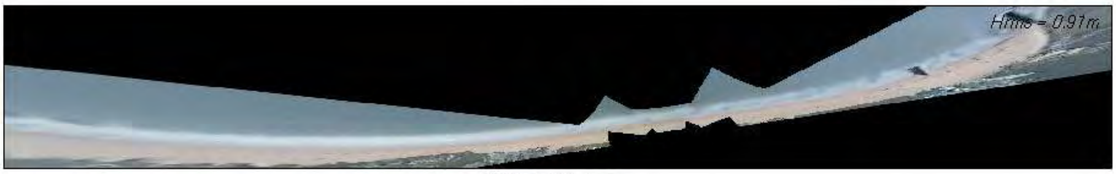

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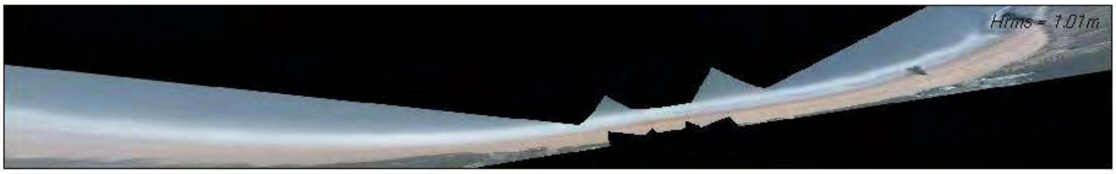
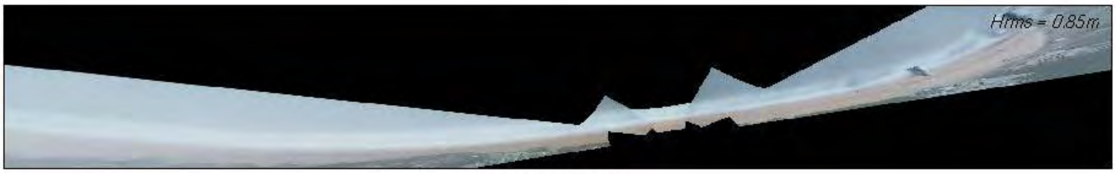
20/12/2006 11:13



21/12/2006 12:13

22/12/2006 12:13



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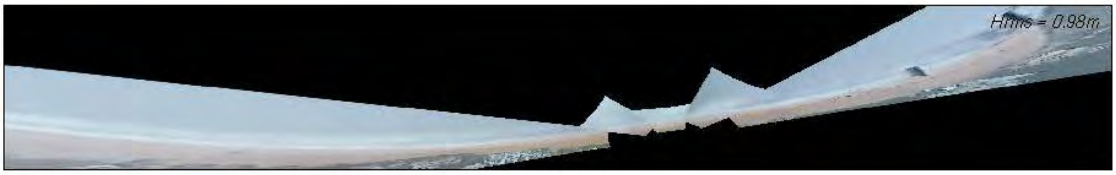

24/12/2006 14:13

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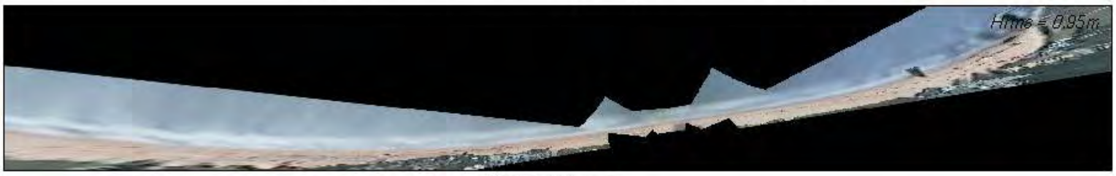
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 18/12/2006 - 24/12/2006	Figure A23 02092-A23.cdr

Week–to–a–Page (Mid–Tide)



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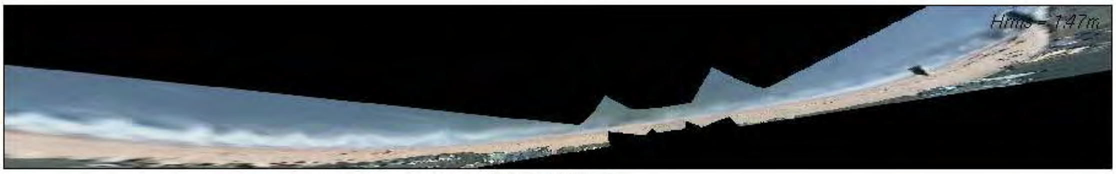
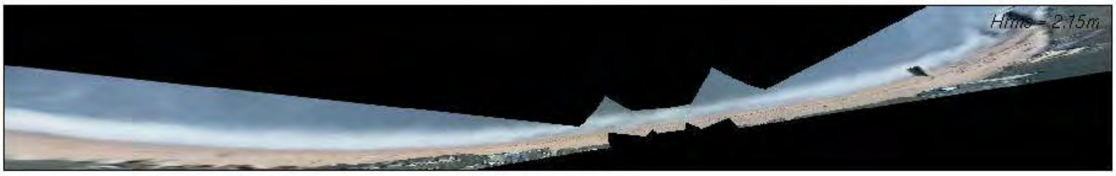


26/12/2006 09:13



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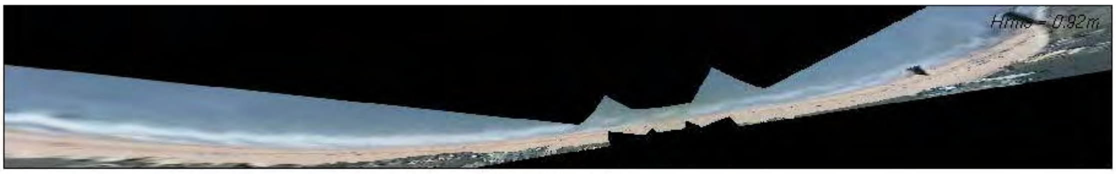
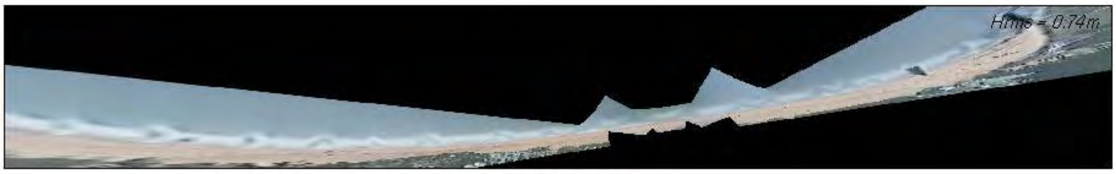


28/12/2006 10:13

29/12/2006 13:13



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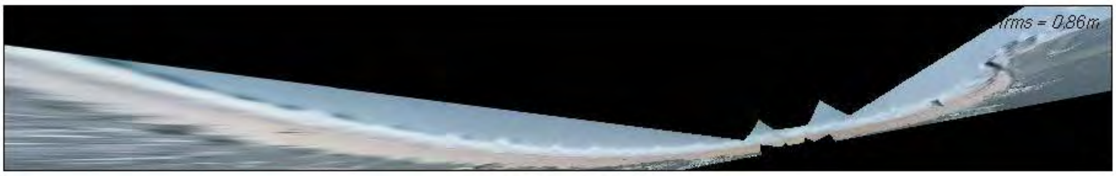

31/12/2006 09:13

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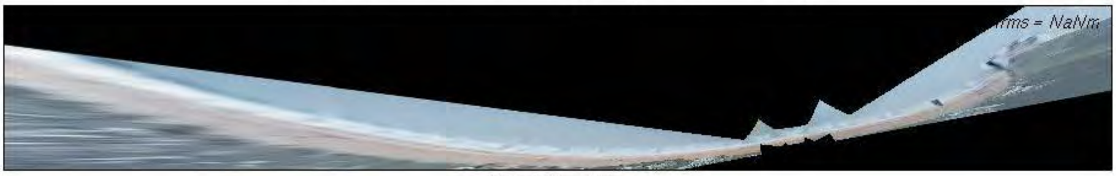
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 25/12/2006 - 31/12/2006	Figure A24 02092-A24.cdr

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



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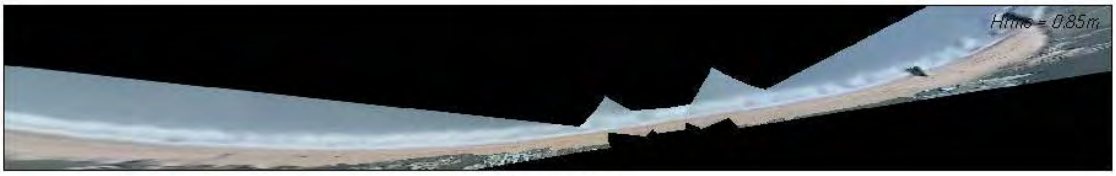

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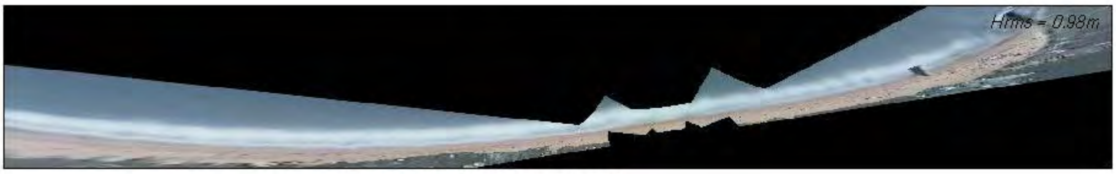
05/01/2007 12:13



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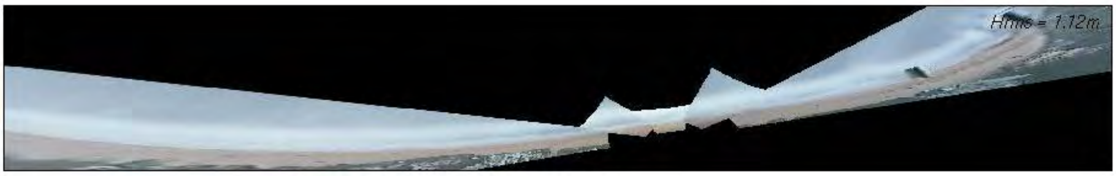

07/01/2007 14:13

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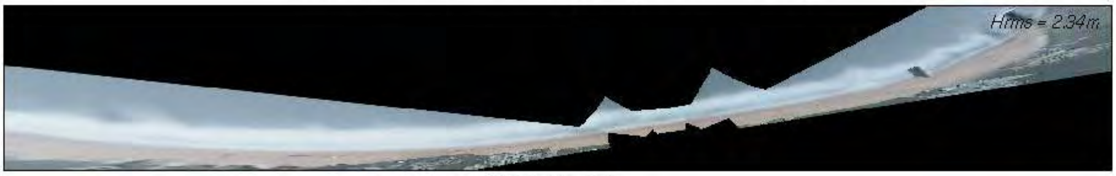
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 01/01/2007 - 07/01/2007	Figure A25 02092-A25.cdr

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



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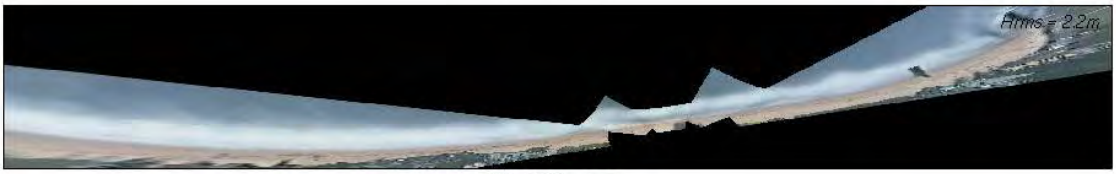

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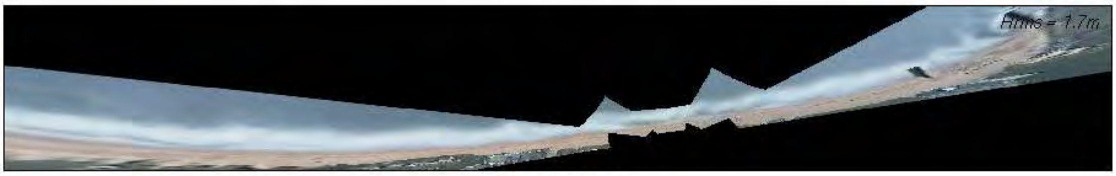
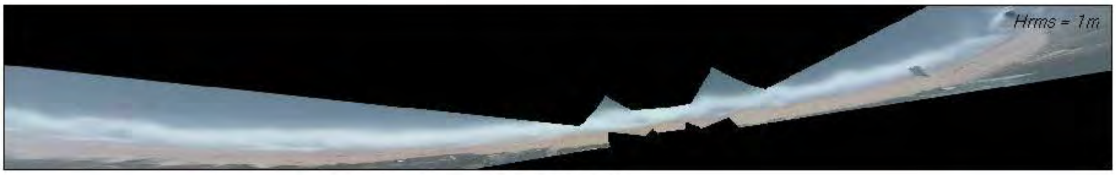


10/01/2007 09:13

11/01/2007 09:13



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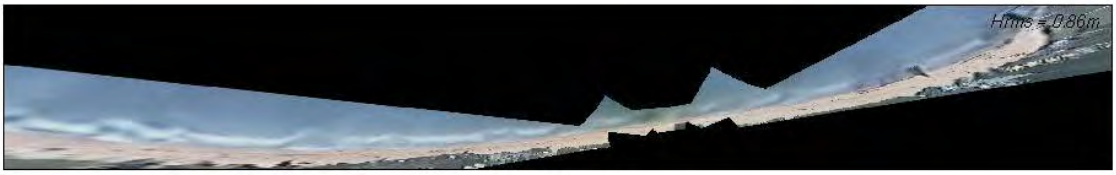
13/01/2007 13:13



14/01/2007 15:13

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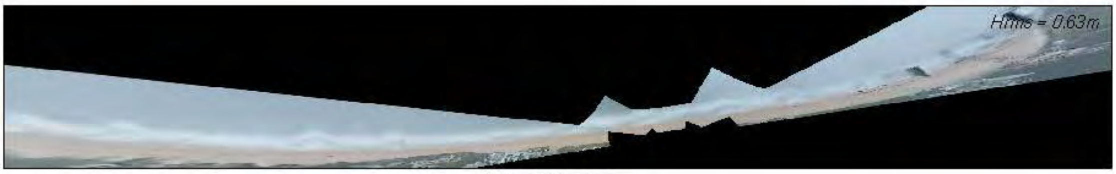
Week-to-a-Page (Mid-Tide)

15/01/2007 09:13



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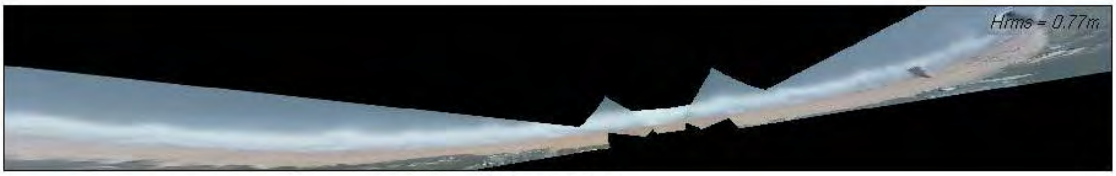
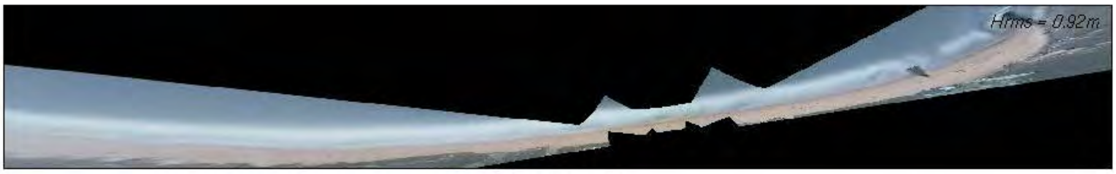


17/01/2007 10:13



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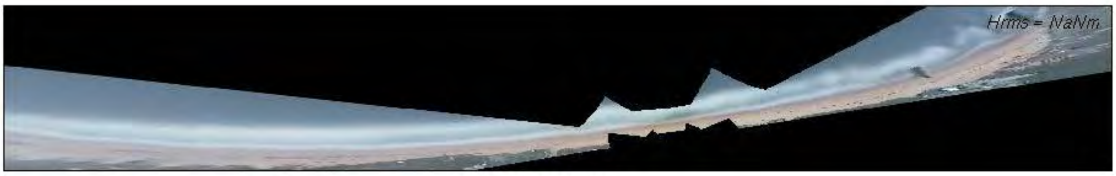
20/01/2007 12:13



21/01/2007 13:13

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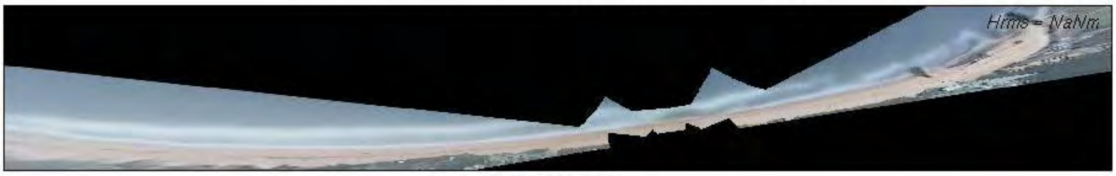
Week-to-a-Page (Mid-Tide)



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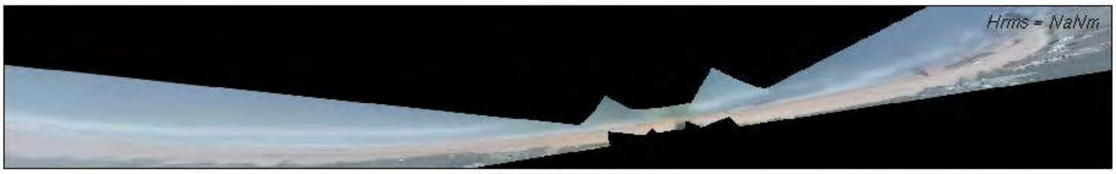

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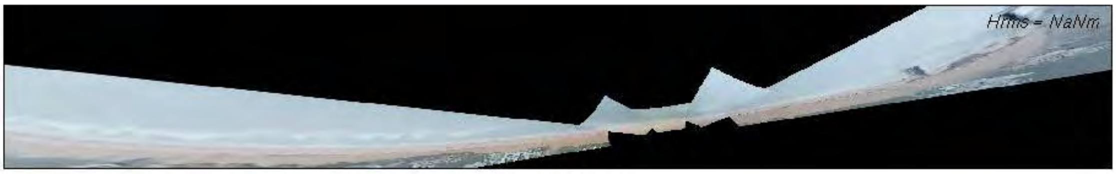
24/01/2007 15:13



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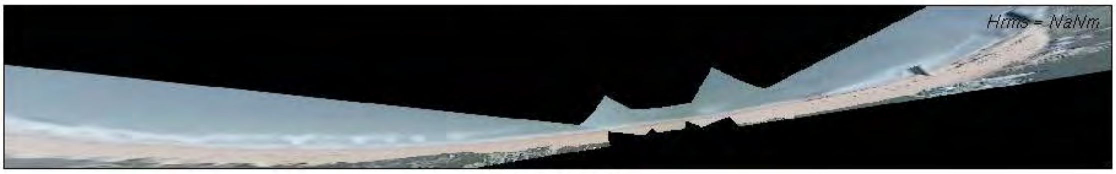
26/01/2007 11:13



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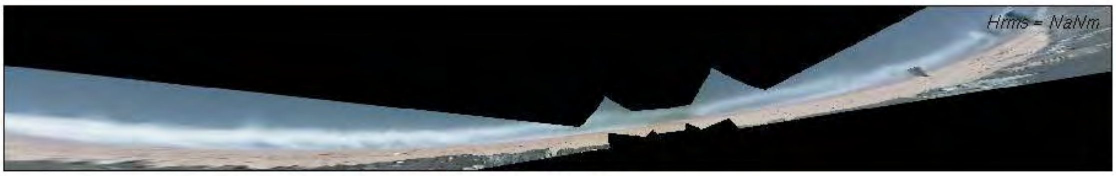

28/01/2007 13:13

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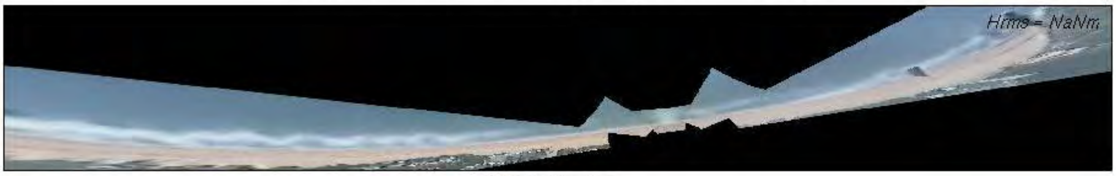
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 22/01/2007 - 28/01/2007	Figure A28 02092-A28.cdr

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



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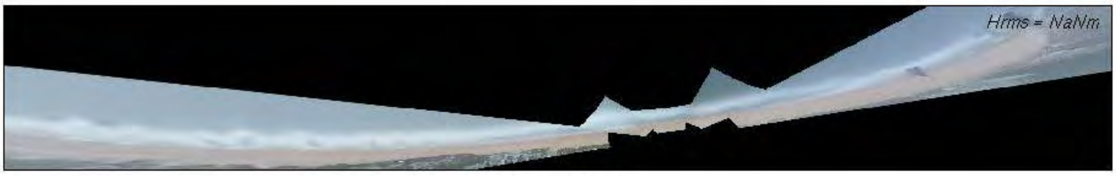
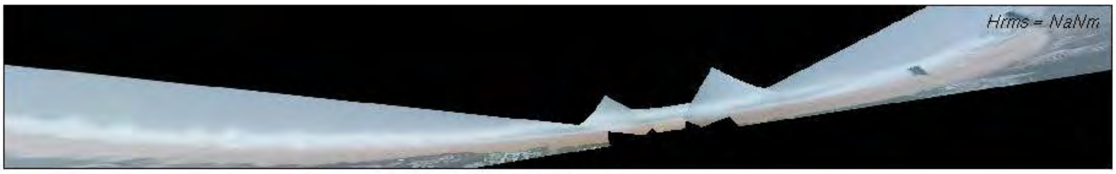
30/01/2007 10:13



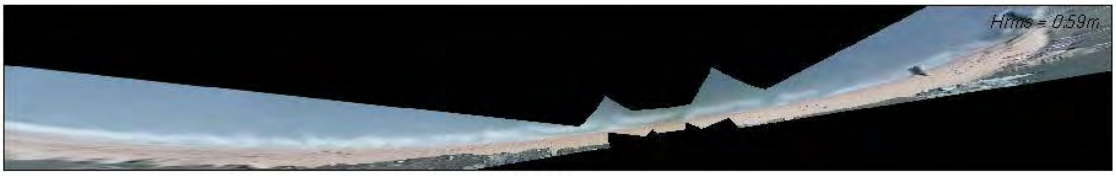
31/01/2007 11:13



01/02/2007 11:13

02/02/2007 12:13

03/02/2007 12:13



04/02/2007 12:13

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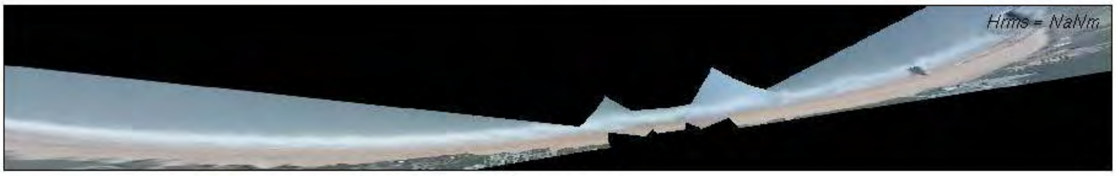
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 29/01/2007 - 04/02/2007	Figure A29 02092-A29.cdr

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

05/02/2007 13:13

06/02/2007 14:13



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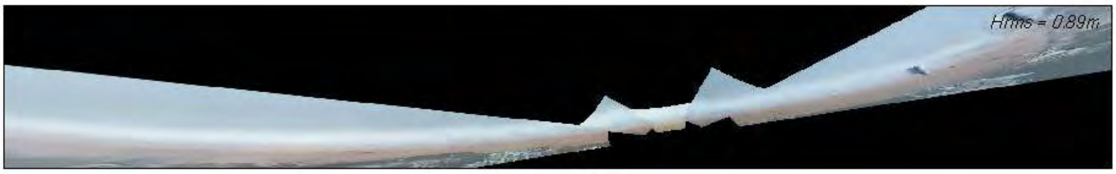
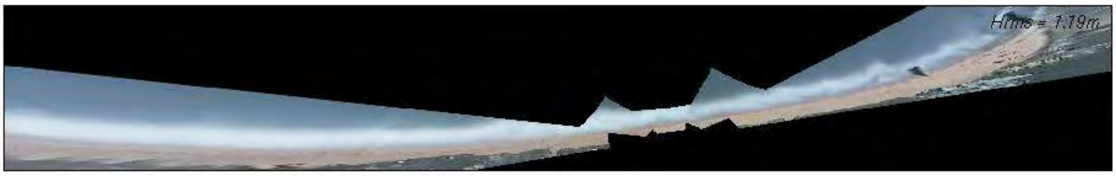
08/02/2007 15:13

09/02/2007 10:13



10/02/2007 10:13



11/02/2007 13:13

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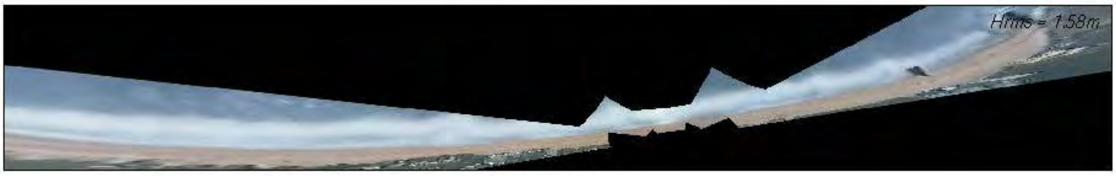
		02092-A30.cdr

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

12/02/2007 15:13

13/02/2007 08:13



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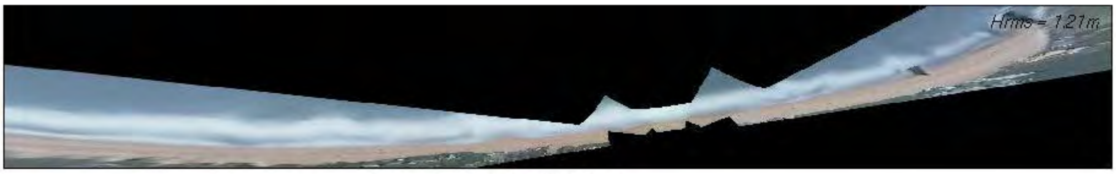

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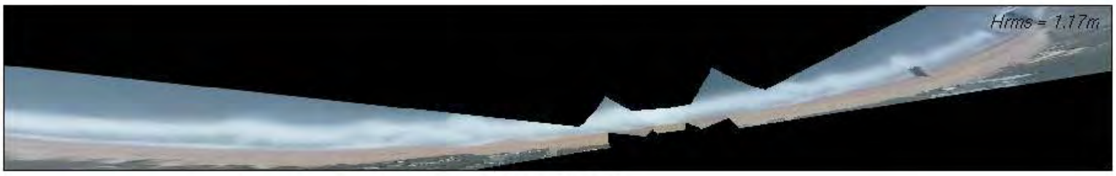

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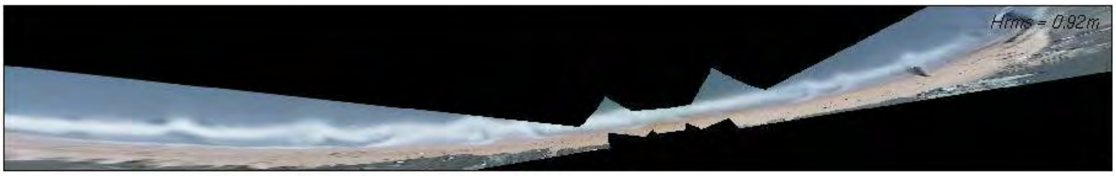

18/02/2007 12:13

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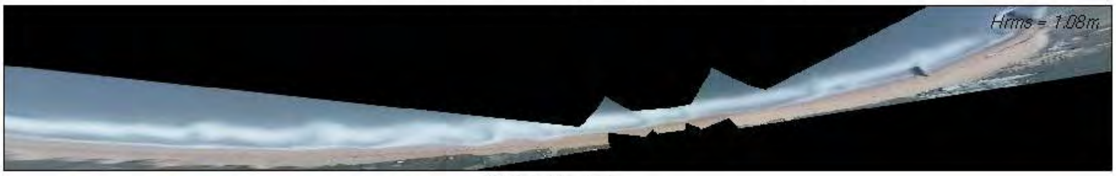
Week-to-a-Page (Mid-Tide)



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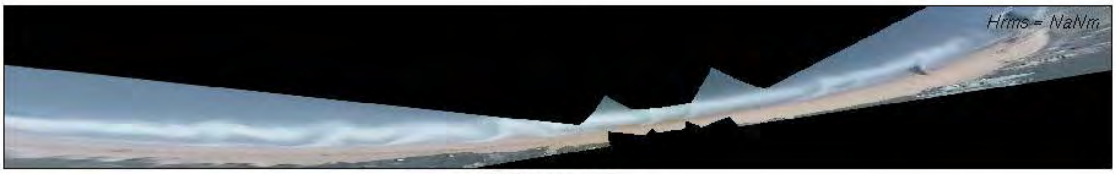

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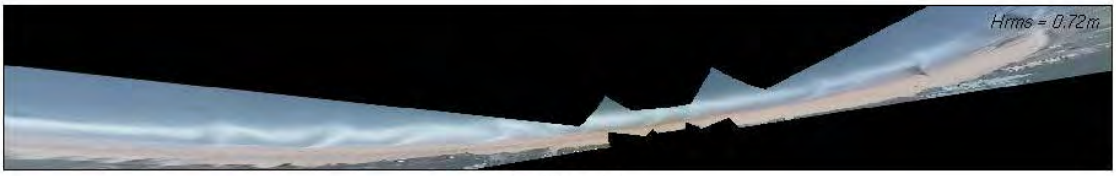

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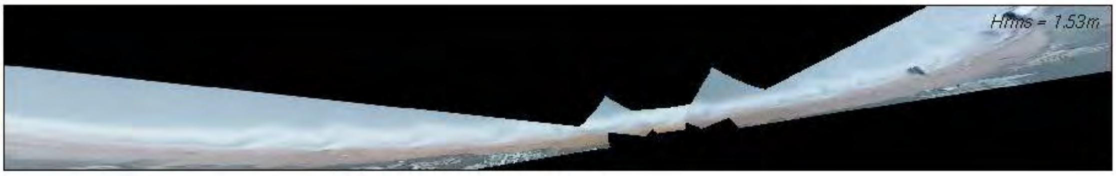

25/02/2007 14:13

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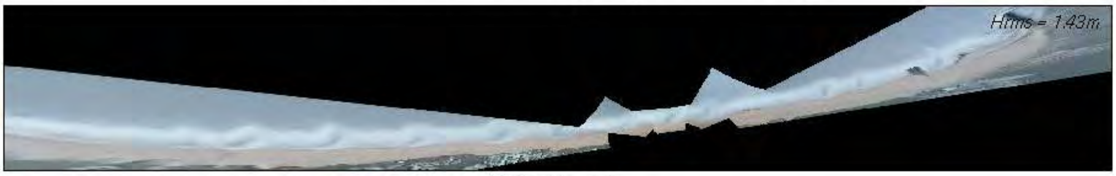
Week-to-a-Page (Mid-Tide)



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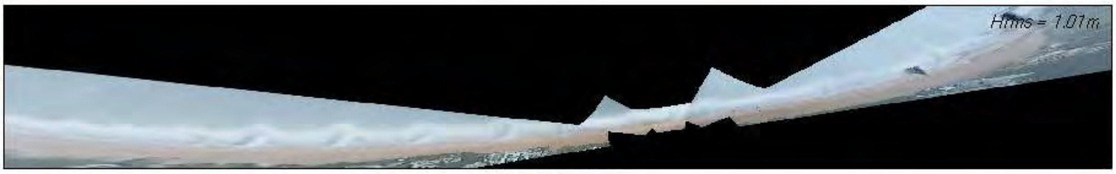

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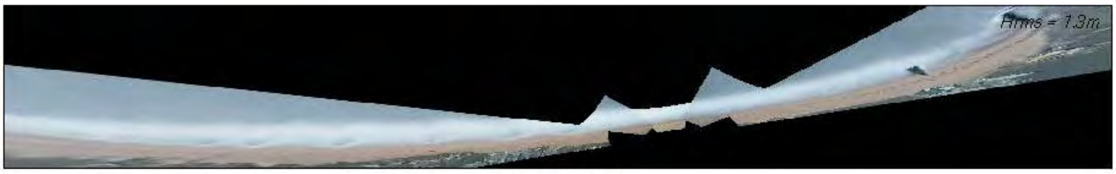

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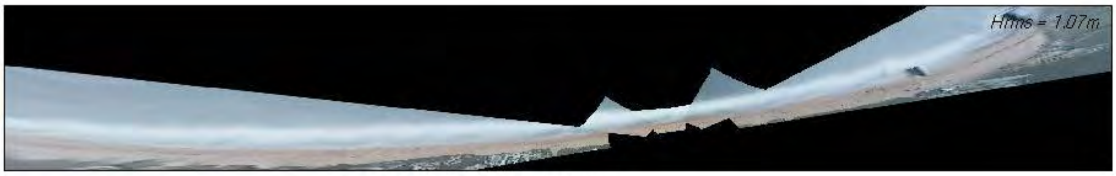

04/03/2007 12:13

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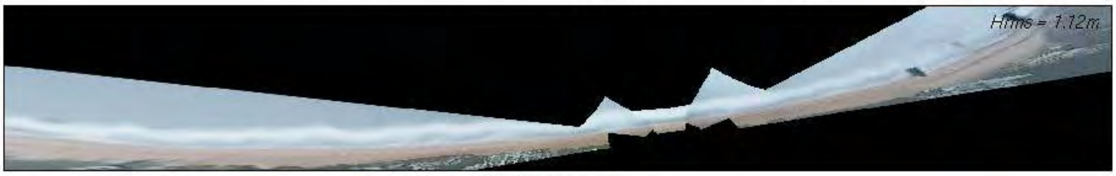
DAILY MID-TIDE IMAGES
26/02/2007 - 04/03/2007

Figure A33

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



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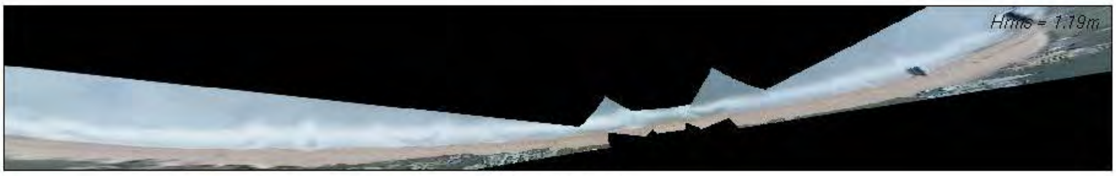

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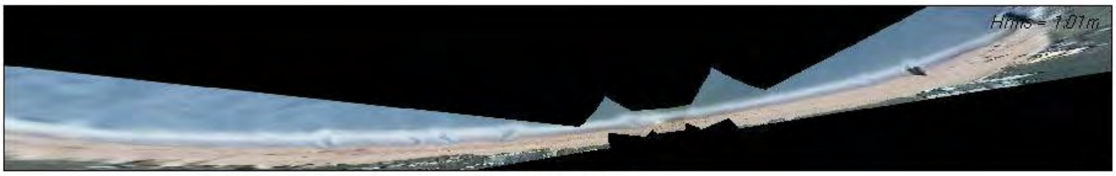
10/03/2007 15:13



11/03/2007 09:13

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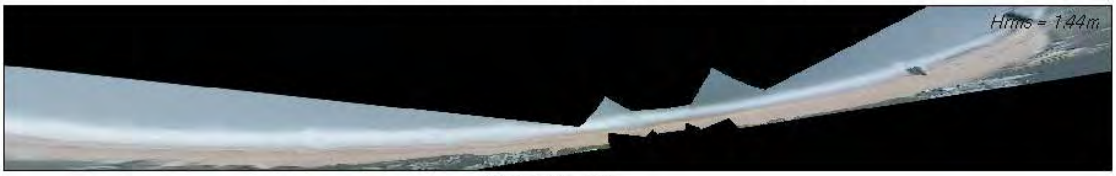
Week-to-a-Page (Mid-Tide)



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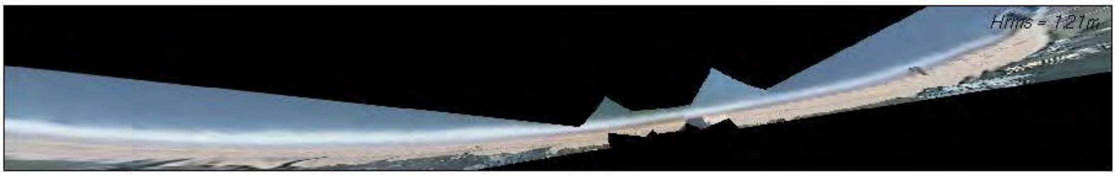

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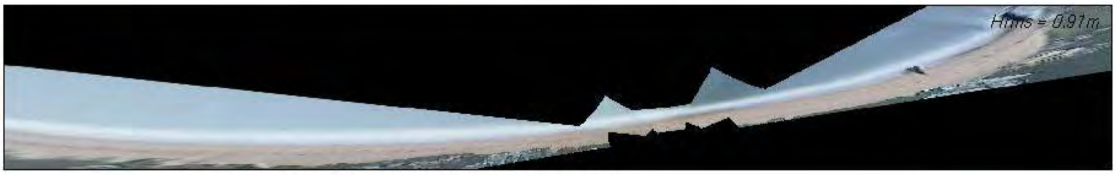
15/03/2007 15:13



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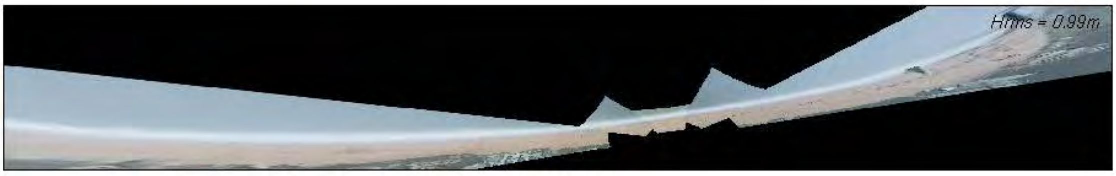
17/03/2007 10:13



18/03/2007 11:13

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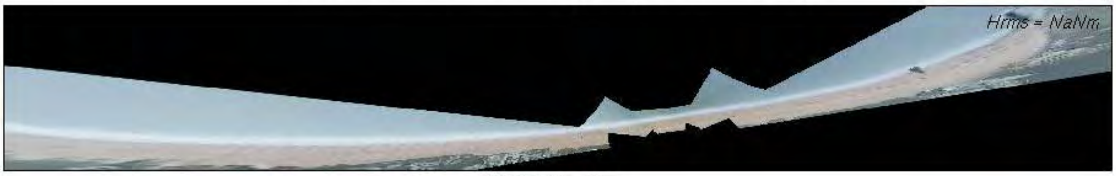
		02092-A35.cdr

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



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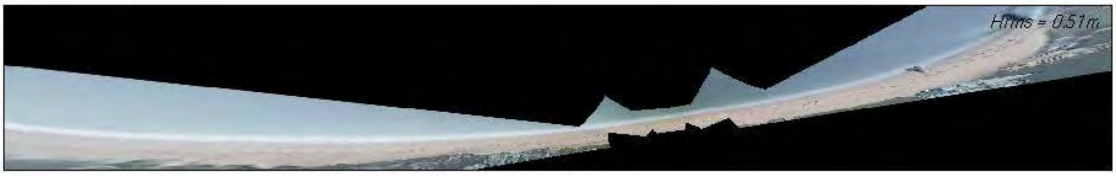
20/03/2007 12:13



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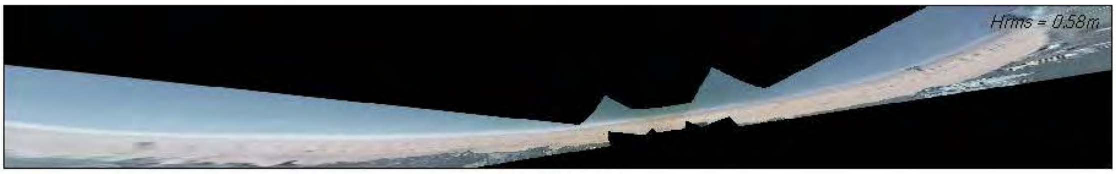

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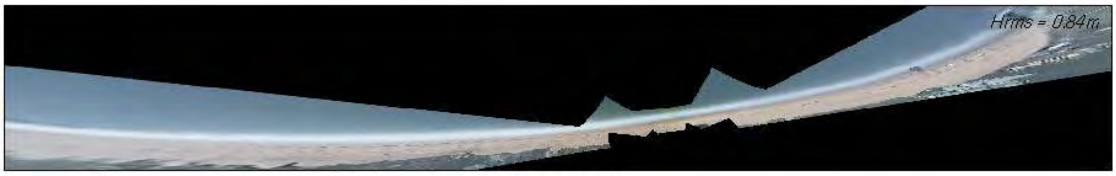

23/03/2007 14:13

24/03/2007 10:13

25/03/2007 11:13

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

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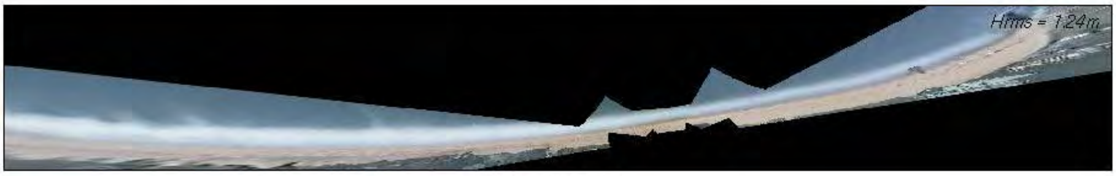
27/03/2007 14:13



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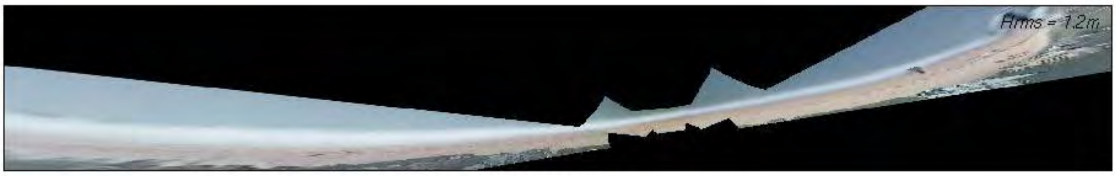
31/03/2007 11:13



01/04/2007 12:13

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 26/03/2007 - 01/04/2007	Figure A37 02092-A37.cdr

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

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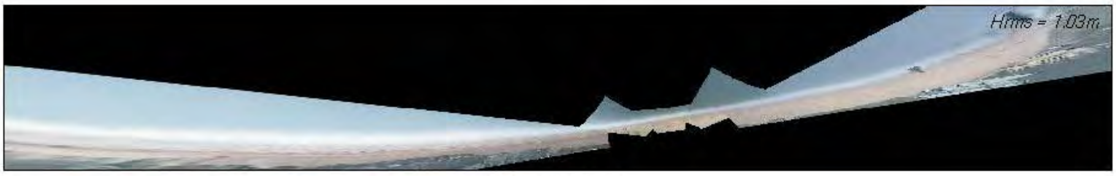
03/04/2007 12:13



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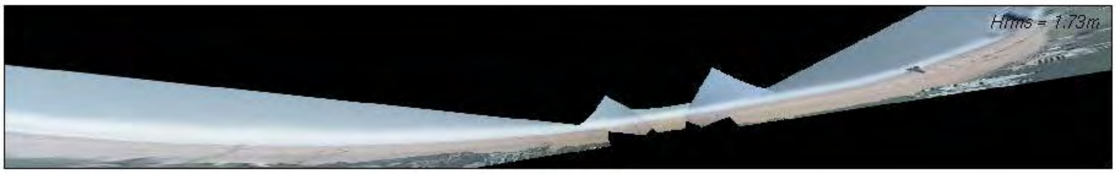
06/04/2007 13:13



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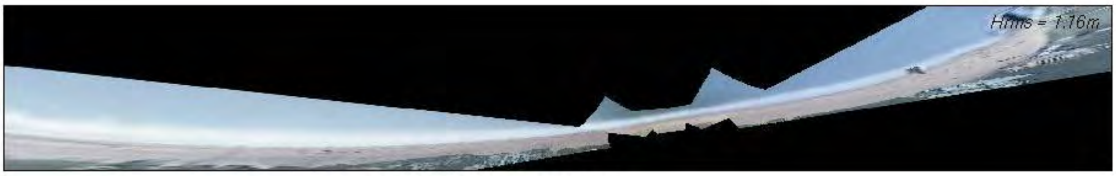

08/04/2007 14:13

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WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 02/04/2007 - 08/04/2007	Figure A38

02092-A38.cdr

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

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image not available

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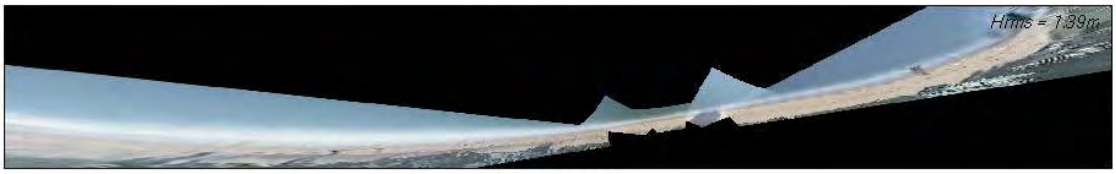
12/04/2007 15:13

13/04/2007 15:13



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15/04/2007 09:13

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

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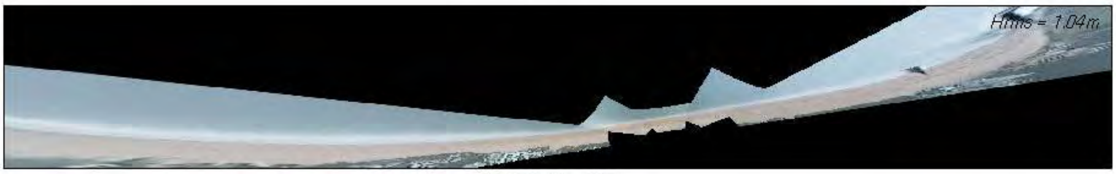

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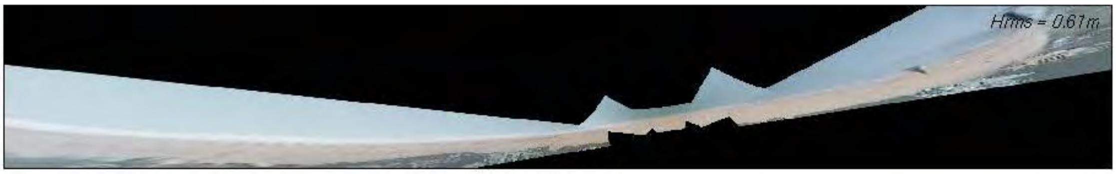

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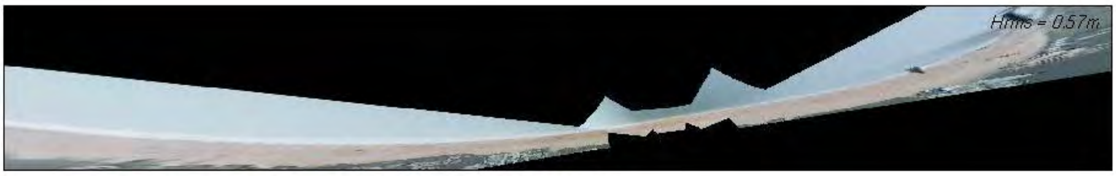

22/04/2007 10:13

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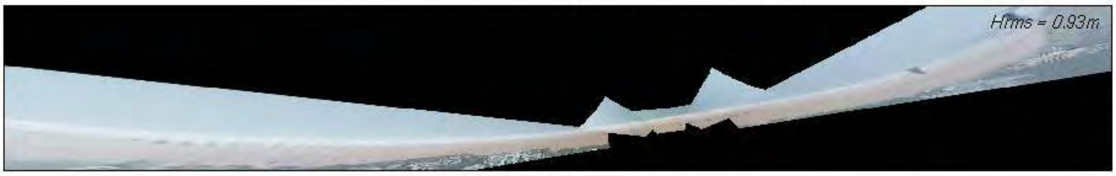
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 16/04/2007 - 22/04/2007	Figure A40 02092-A40.cdr

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



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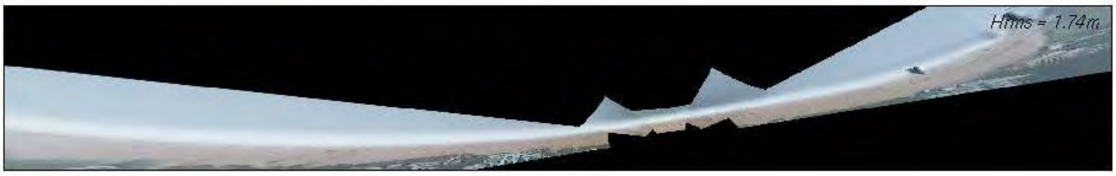

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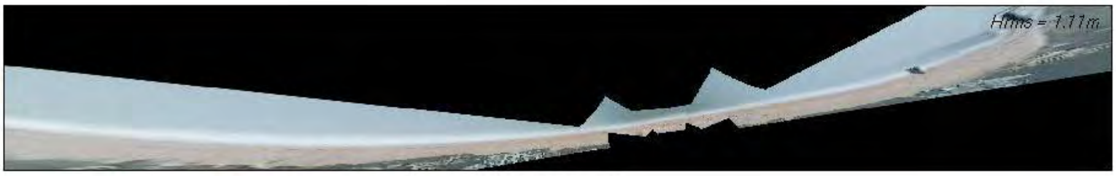
26/04/2007 14:13



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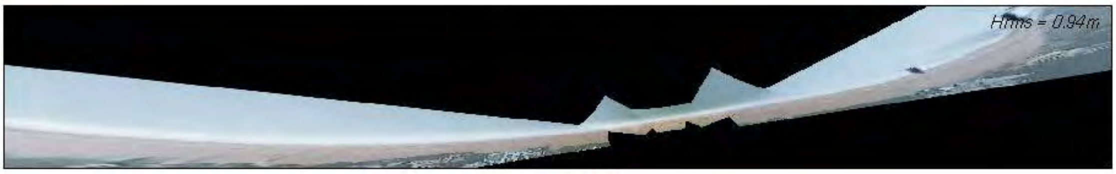

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29/04/2007 10:13

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

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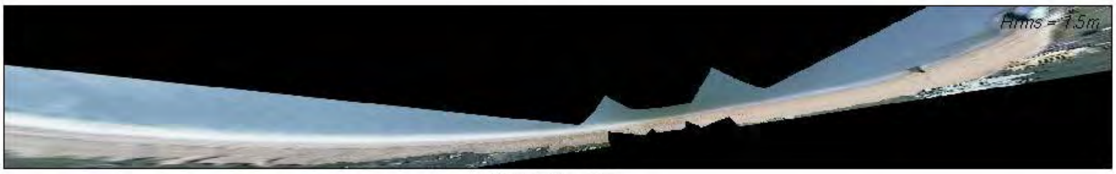

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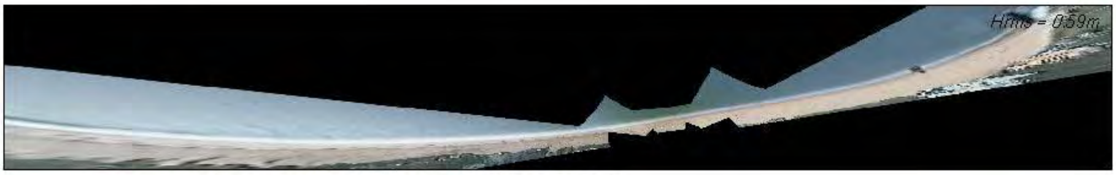
02/05/2007 11:13

03/05/2007 12:13



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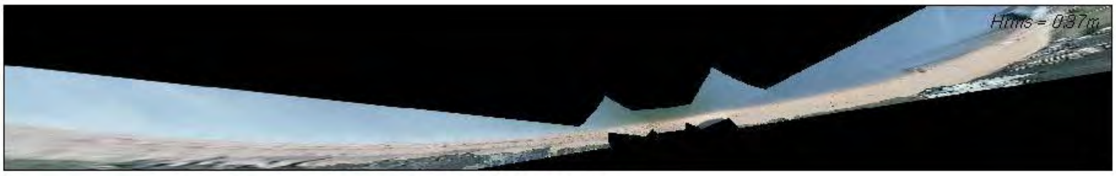

06/05/2007 14:13

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

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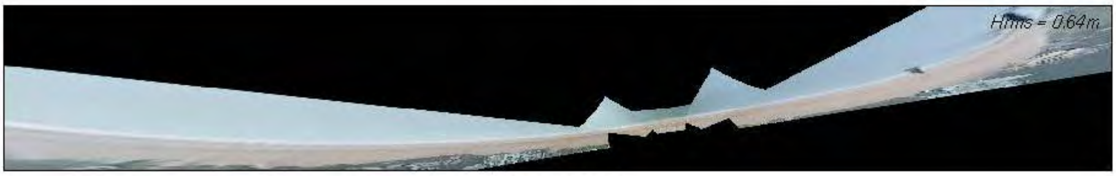
08/05/2007 09:13



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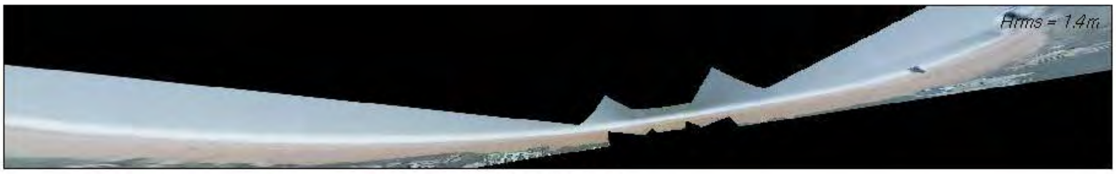

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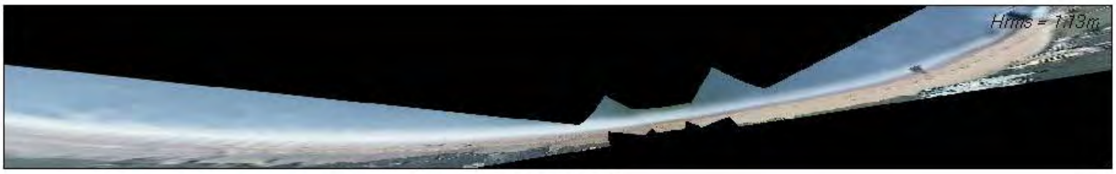
11/05/2007 13:13



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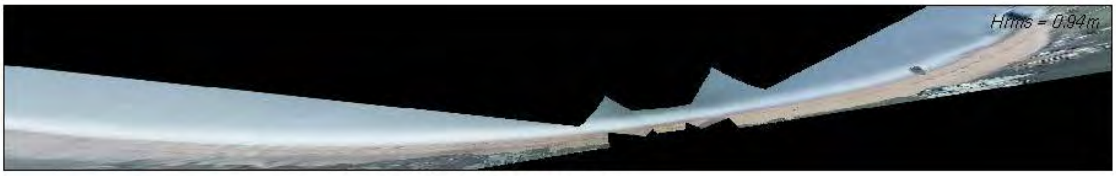

13/05/2007 14:13

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

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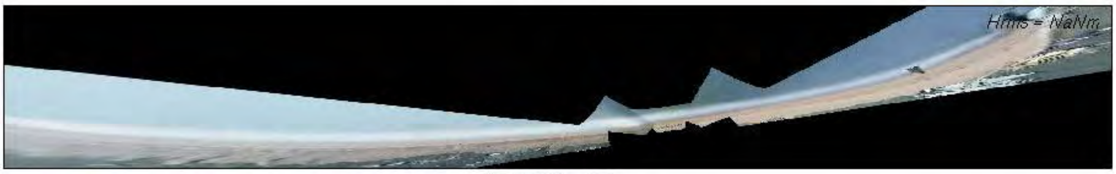

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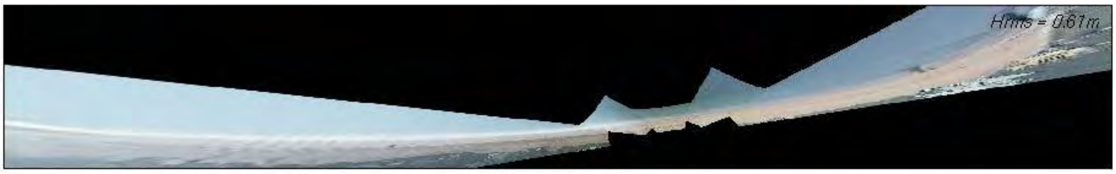
16/05/2007 10:13



17/05/2007 11:13

18/05/2007 12:13

19/05/2007 13:13

20/05/2007 14:13

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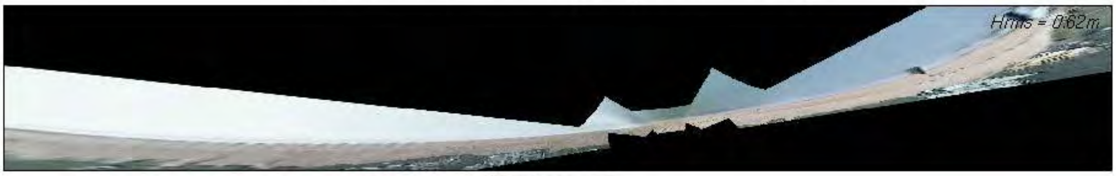
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 14/05/2007 - 20/05/2007	Figure A44

02092-A44.cdr

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



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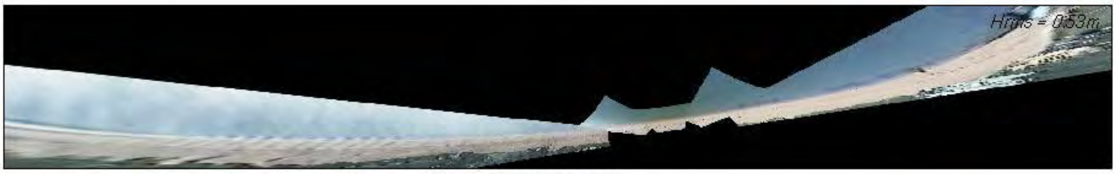

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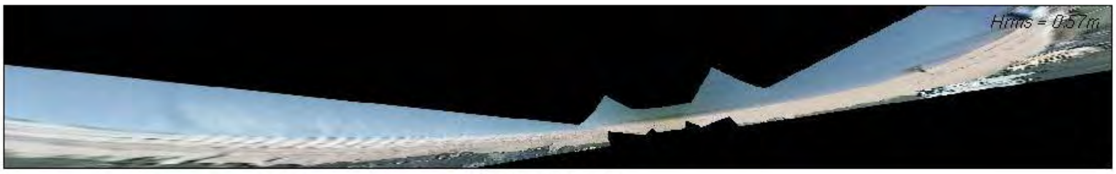

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25/05/2007 13:13

26/05/2007 14:13

27/05/2007 14:13

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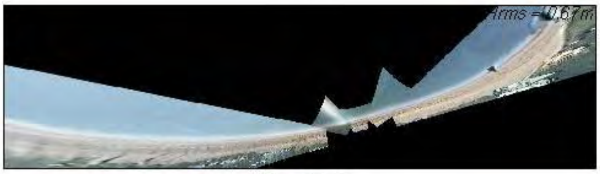
02092-A45.cdr

Week-to-a-Page

2007-05-28



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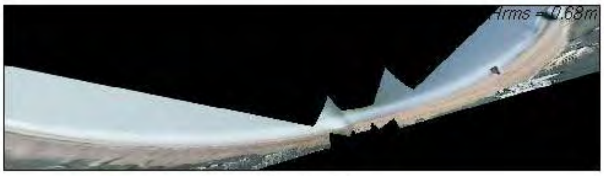

2007-05-30

2007-05-31

2007-06-01

2007-06-02

2007-06-03

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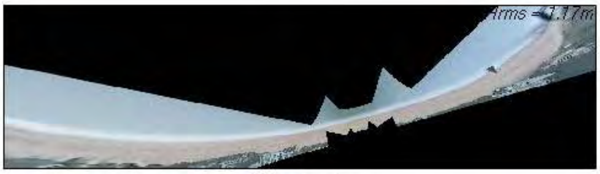
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 28/05/2007 - 03/06/2007	Figure A46 02092-A46.cdr

Week-to-a-Page

2007-06-04



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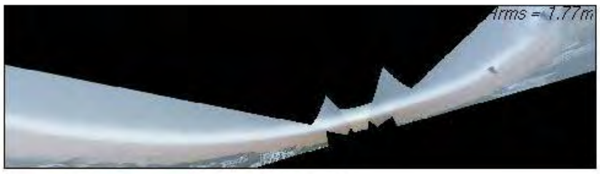

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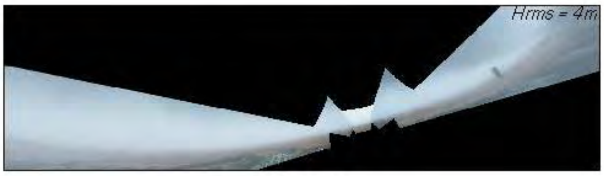

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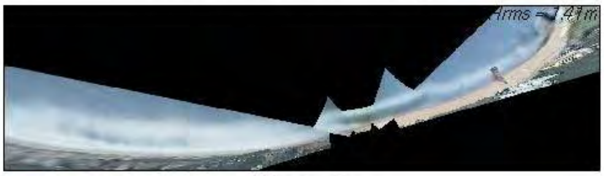
Week-to-a-Page



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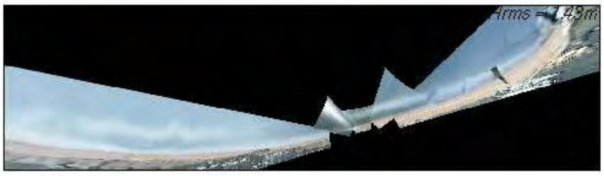

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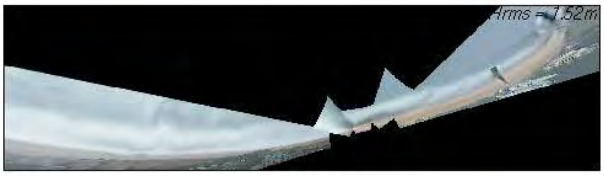

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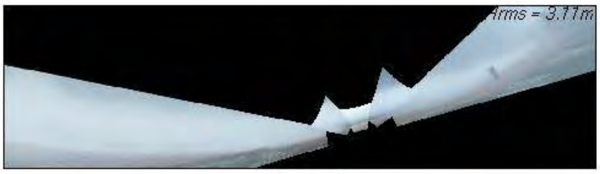

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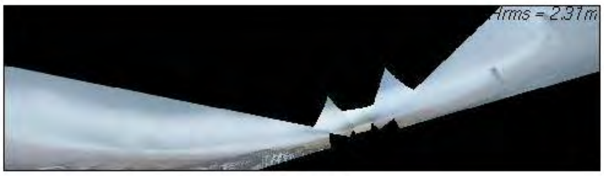

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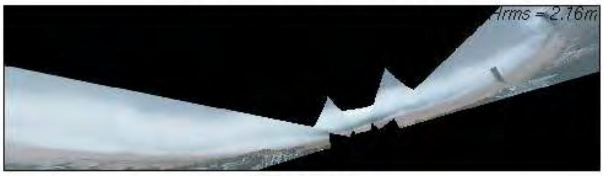
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 11/06/2007 - 17/06/2007	Figure A48 02092-A48.cdr

Week-to-a-Page



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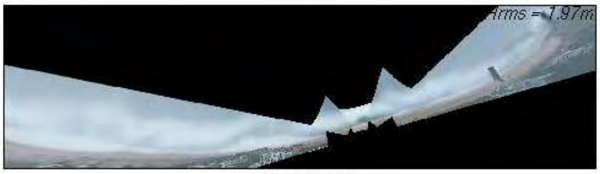

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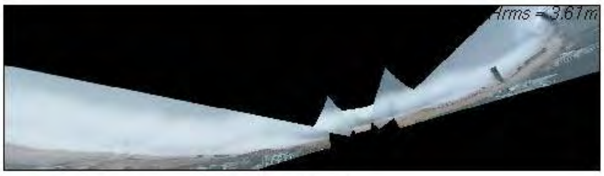

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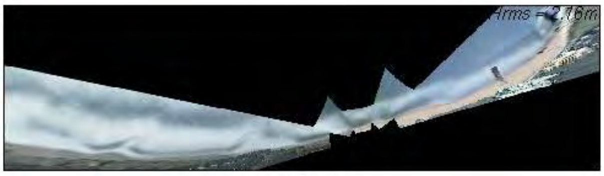

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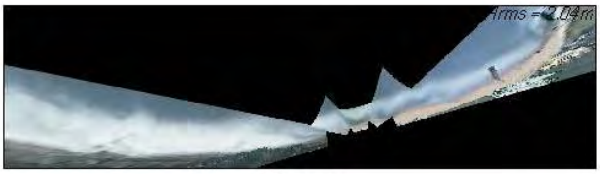

2007-06-23

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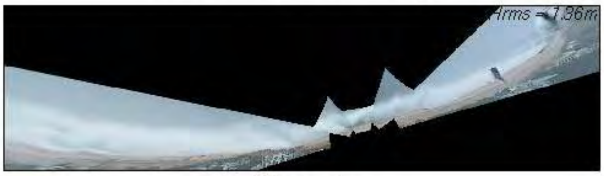
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 18/06/2007 - 24/06/2007	Figure A49 02092-A49.cdr

Week-to-a-Page



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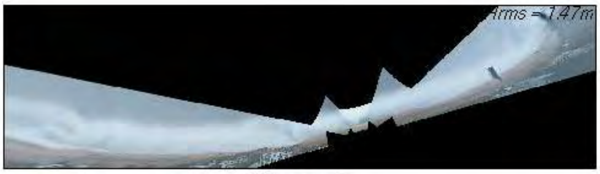

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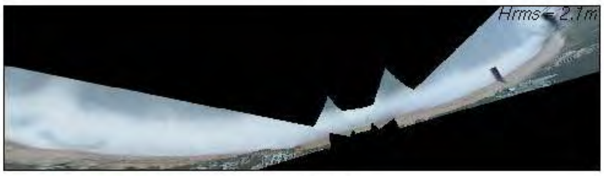

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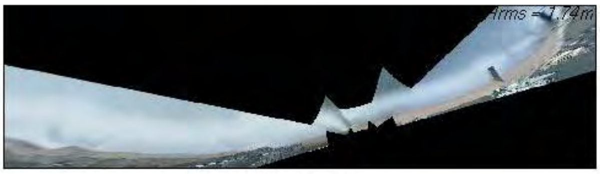

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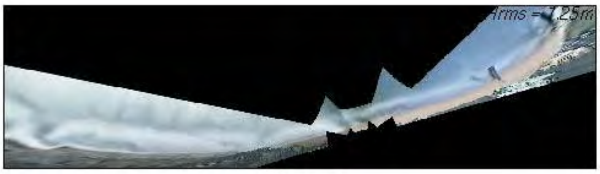

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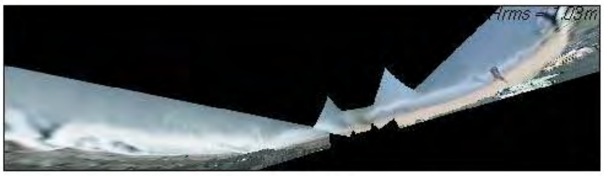

2007-07-01

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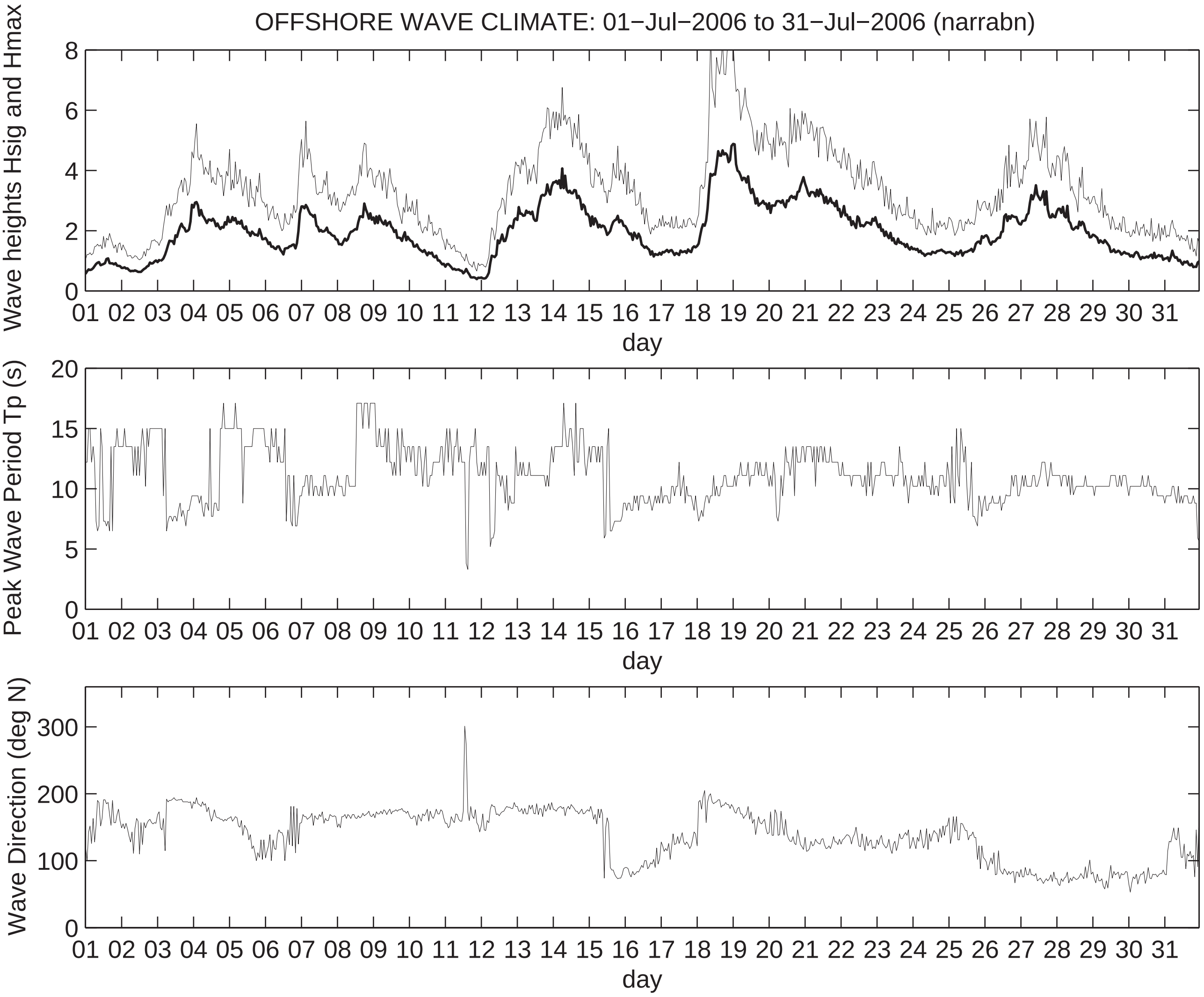
WRL Report No. 2007/30	DAILY MID-TIDE IMAGES 25/06/2007 - 01/07/2007	Figure A50 02092-A50.cdr

Appendix B

Monthly Wave Climate Summaries: July 2006 to June 2007



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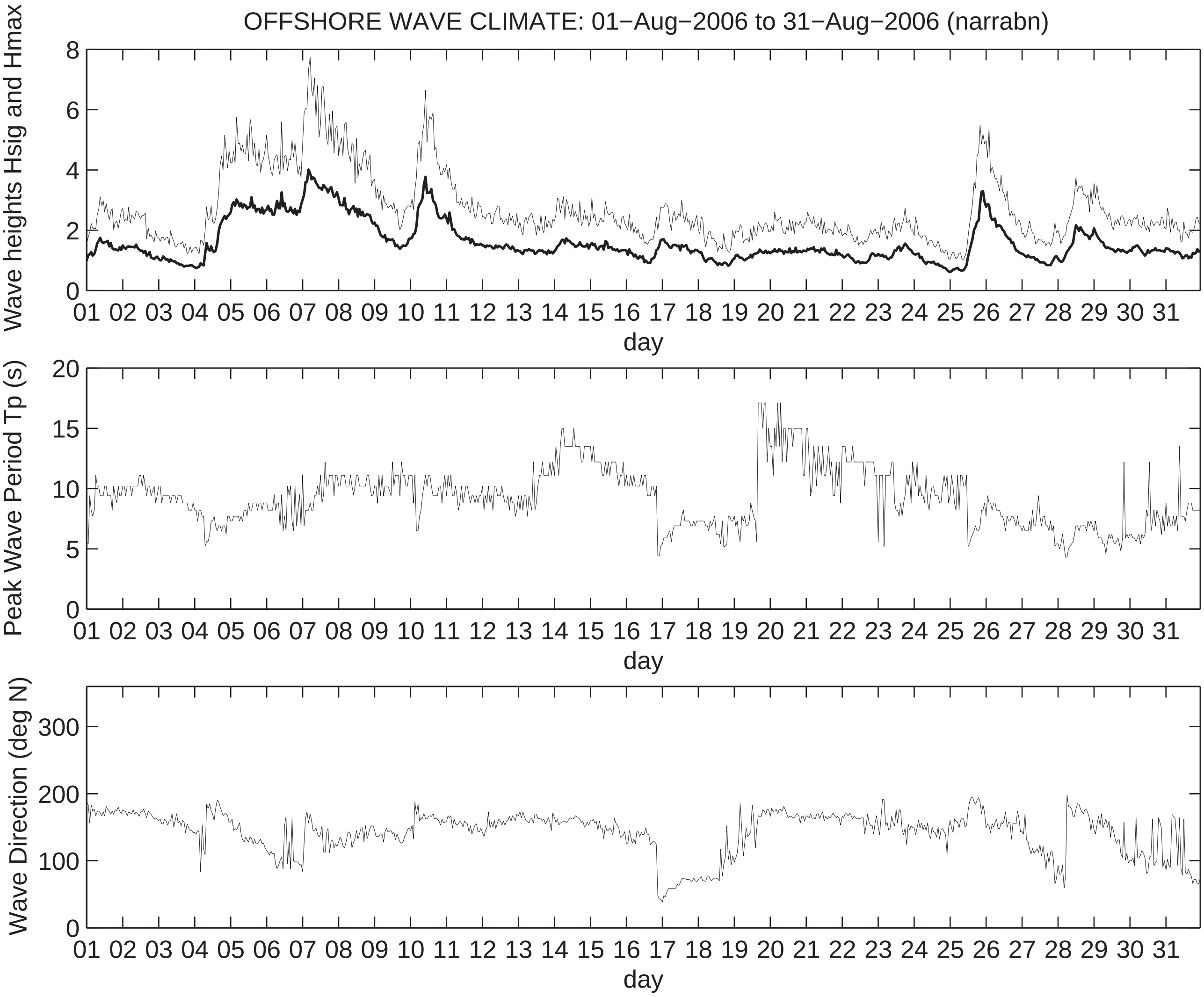
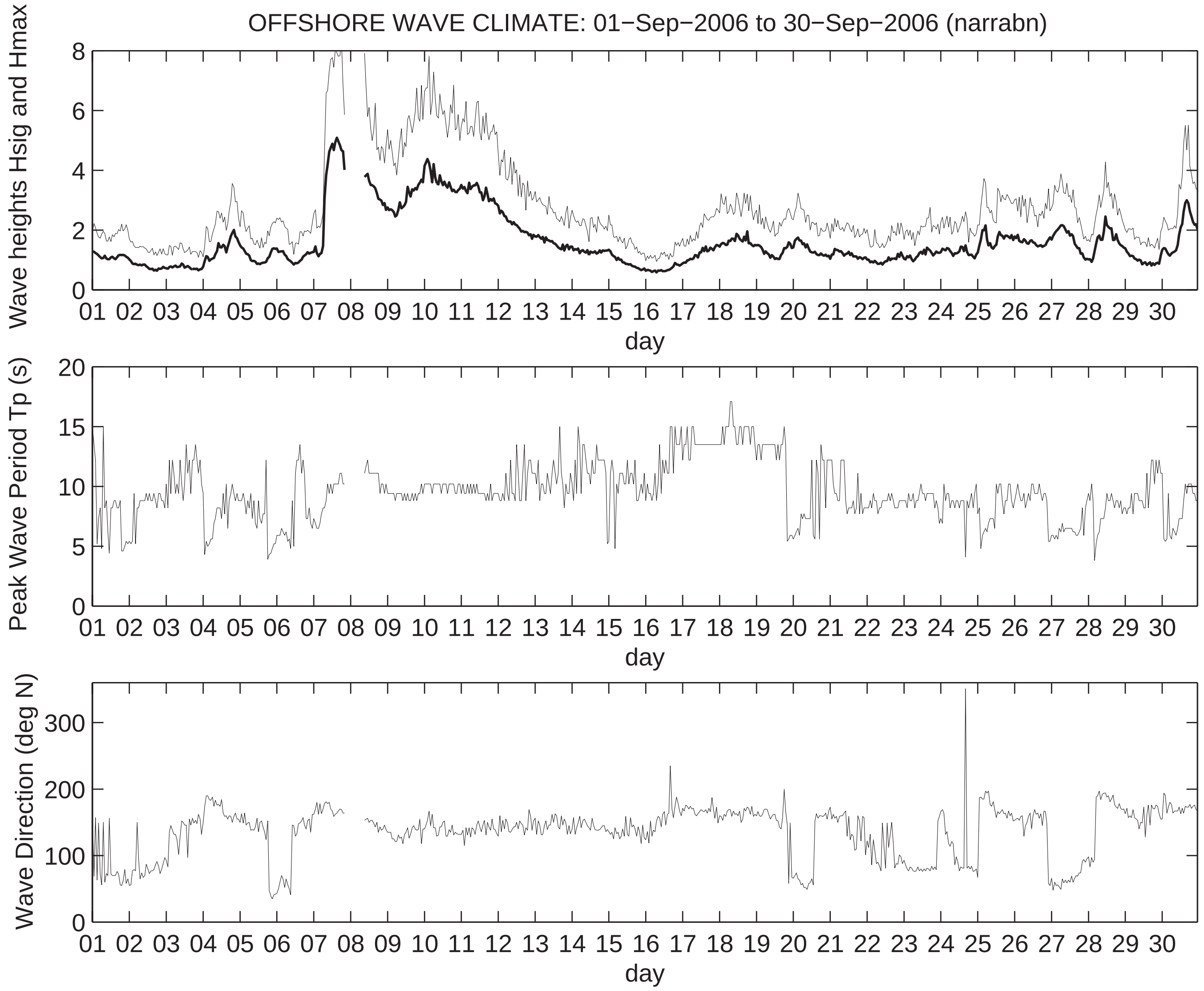
MONTHLY WAVE SUMMARY
JULY 2006

Figure
B1

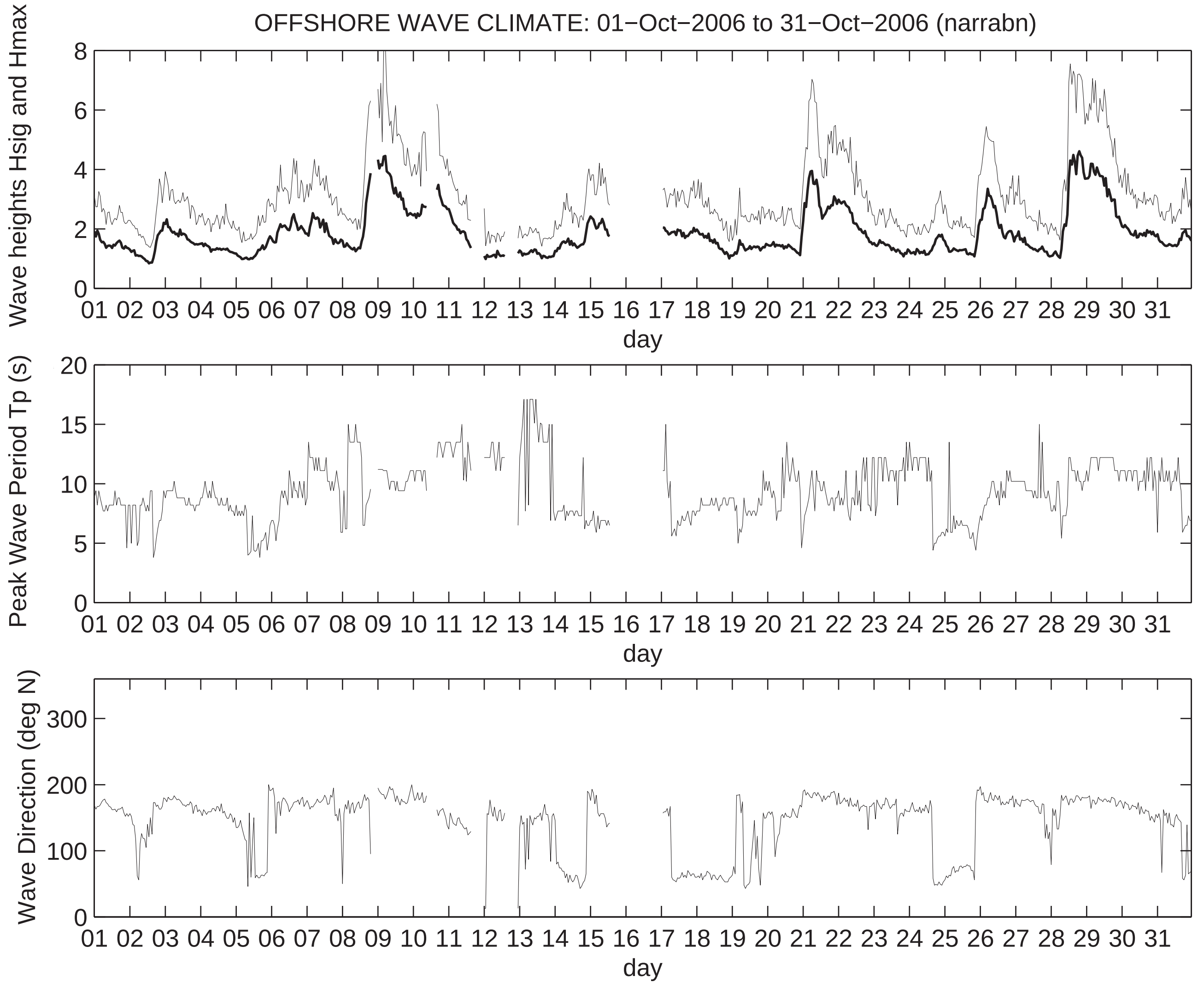
02092-B01.cdr



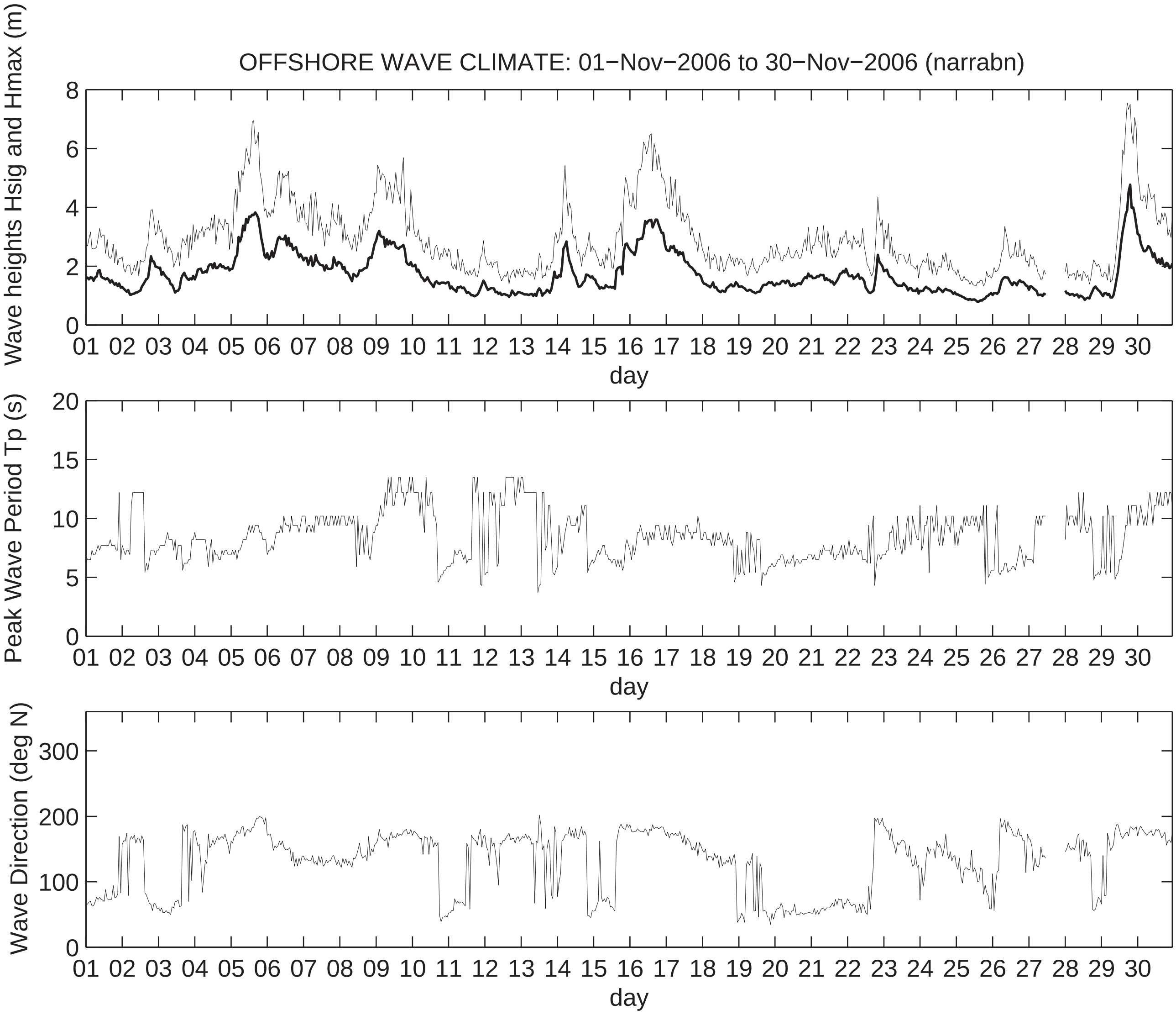
WRL Report No. 2007/30	MONTHLY WAVE SUMMARY AUGUST 2006	Figure B2 02092-B02.cdr



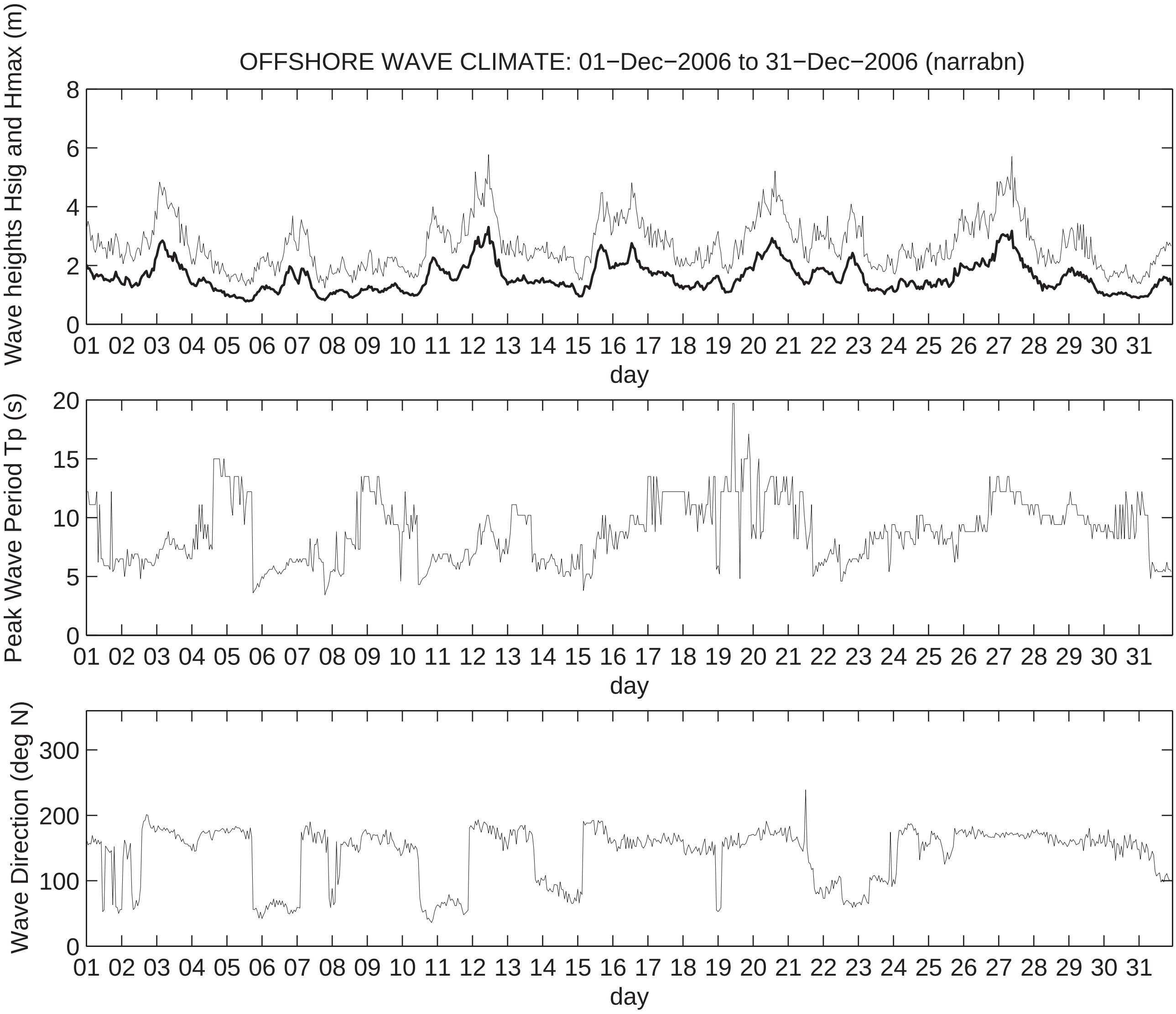
WRL Report No. 2007/30	MONTHLY WAVE SUMMARY SEPTEMBER 2006	Figure B3 02092-B03.cdr



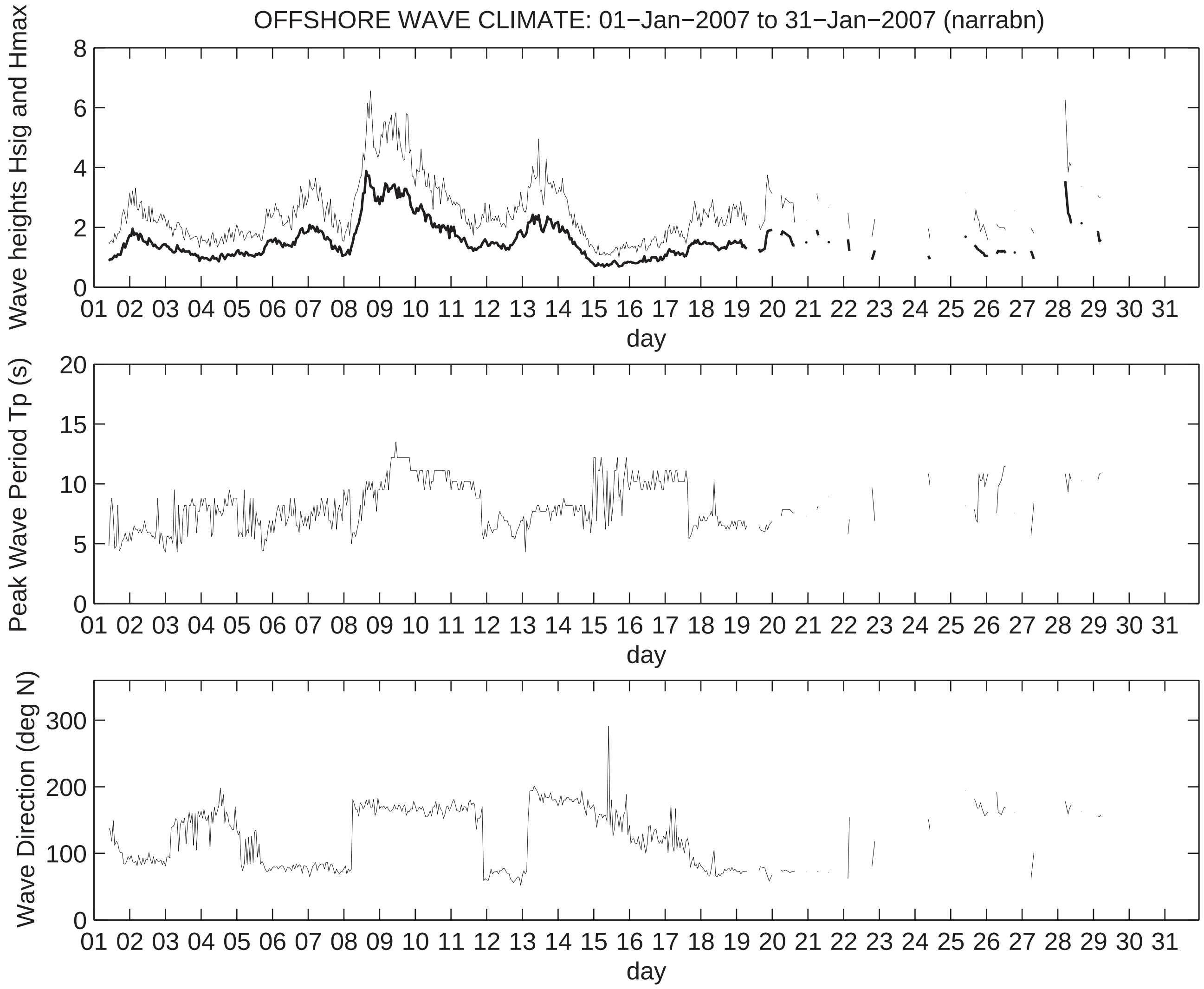
WRL Report No. 2007/30	MONTHLY WAVE SUMMARY OCTOBER 2006	Figure B4 02092-B04.cdr



WRL Report No. 2007/30	MONTHLY WAVE SUMMARY NOVEMBER 2006	Figure B5 02092-B05.cdr



WRL Report No. 2007/30	MONTHLY WAVE SUMMARY DECEMBER 2006	Figure B6 02092-B06.cdr



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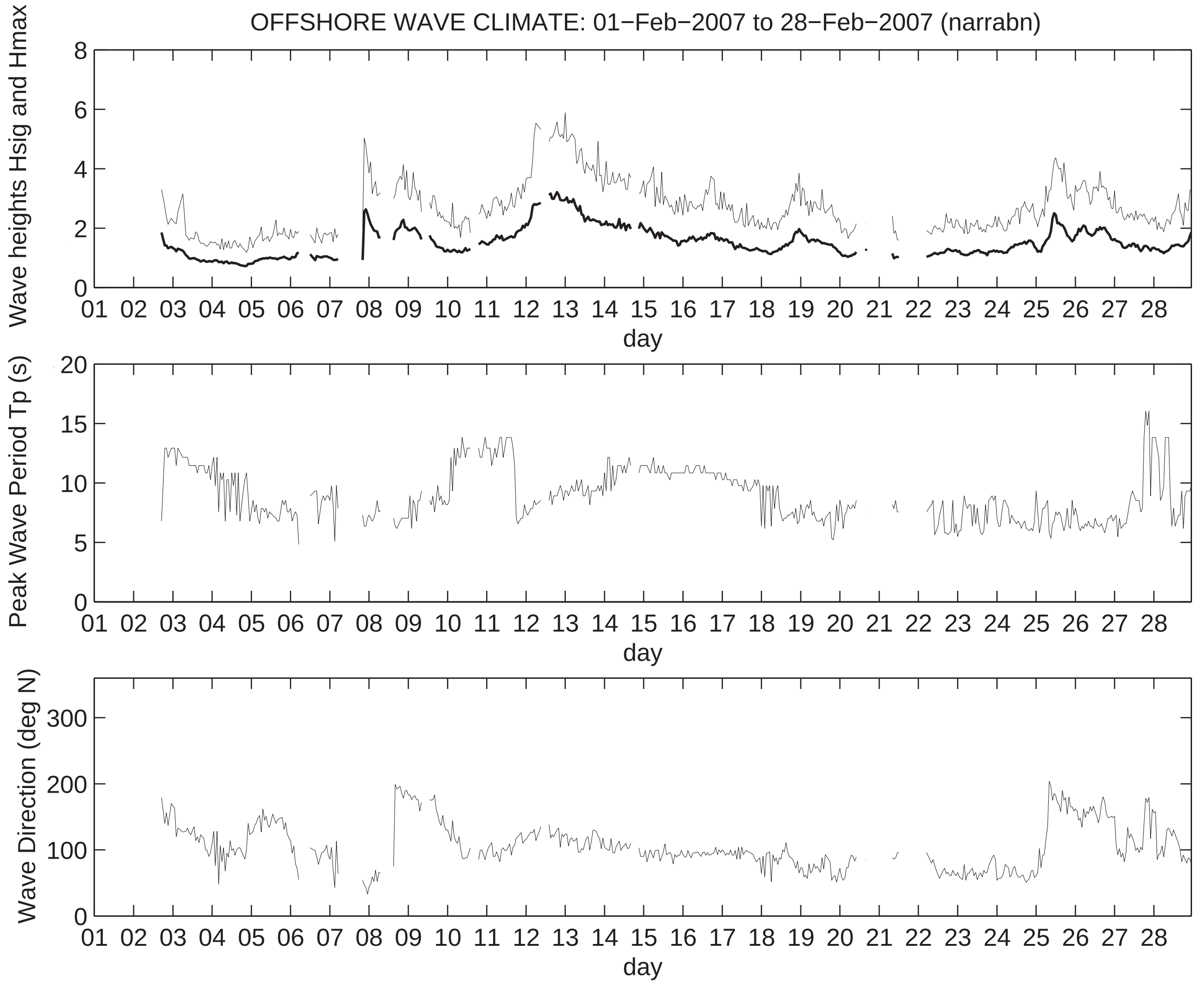
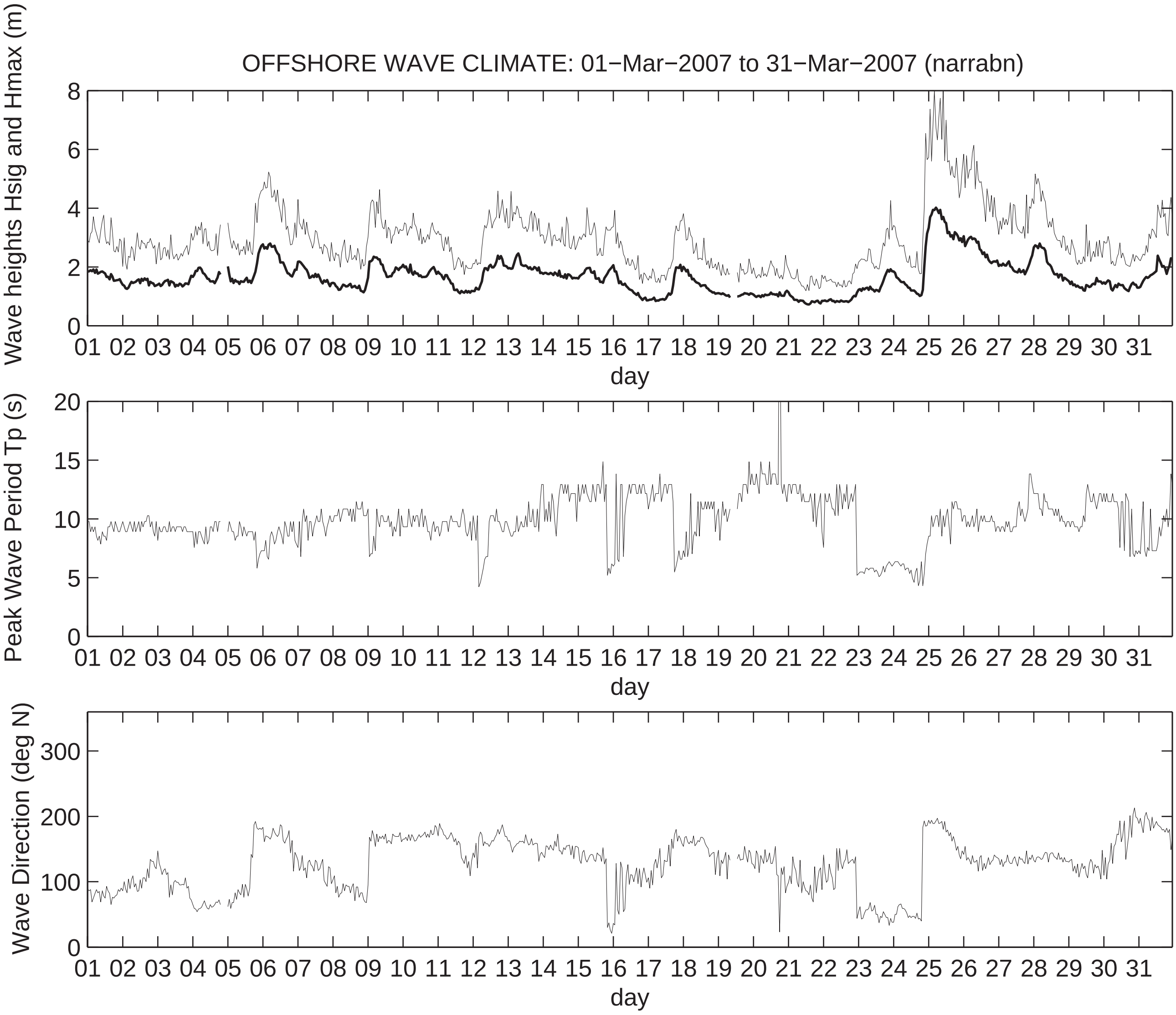
MONTHLY WAVE SUMMARY
JANUARY 2007

Figure
B7

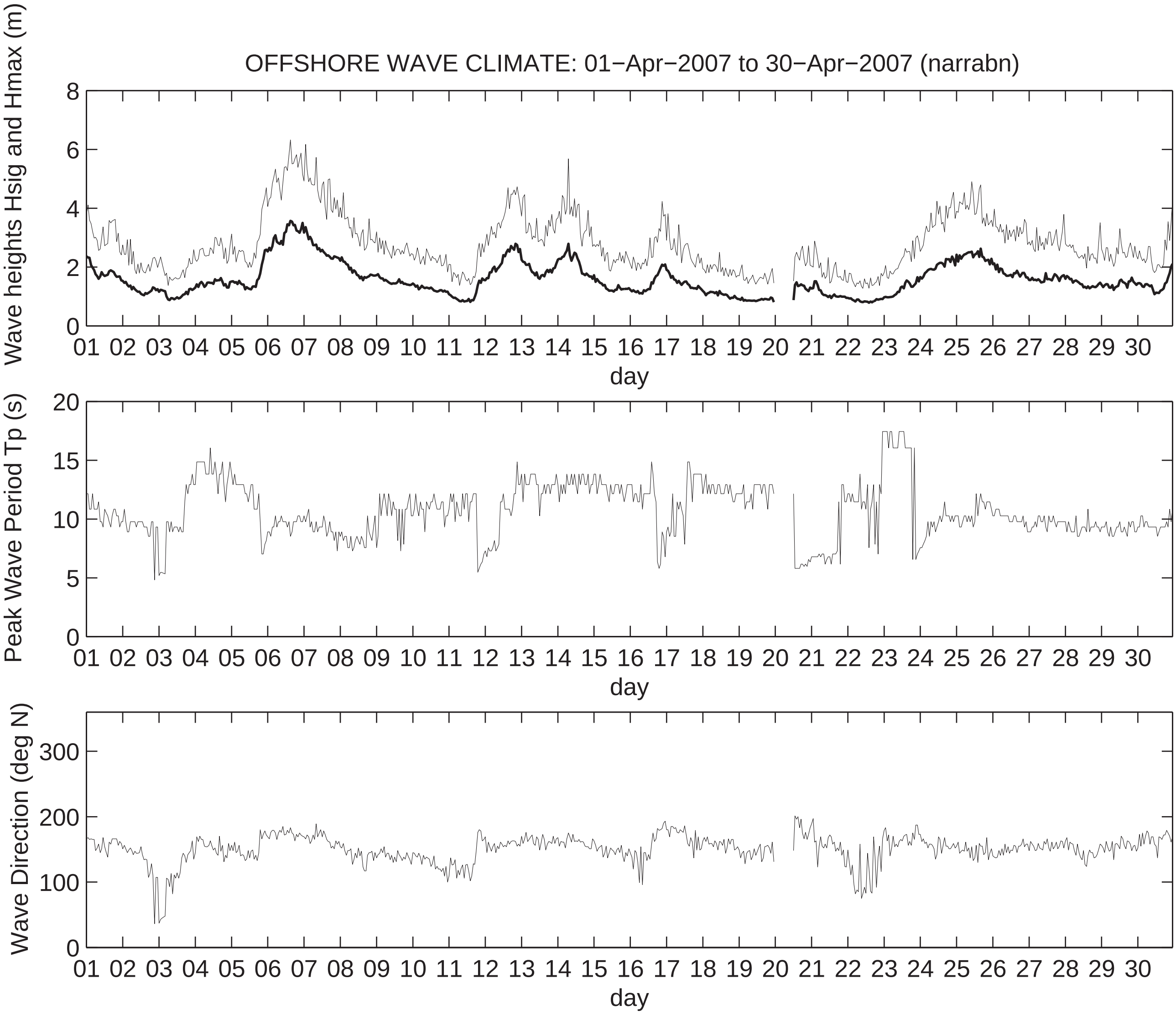
02092-B07.cdr



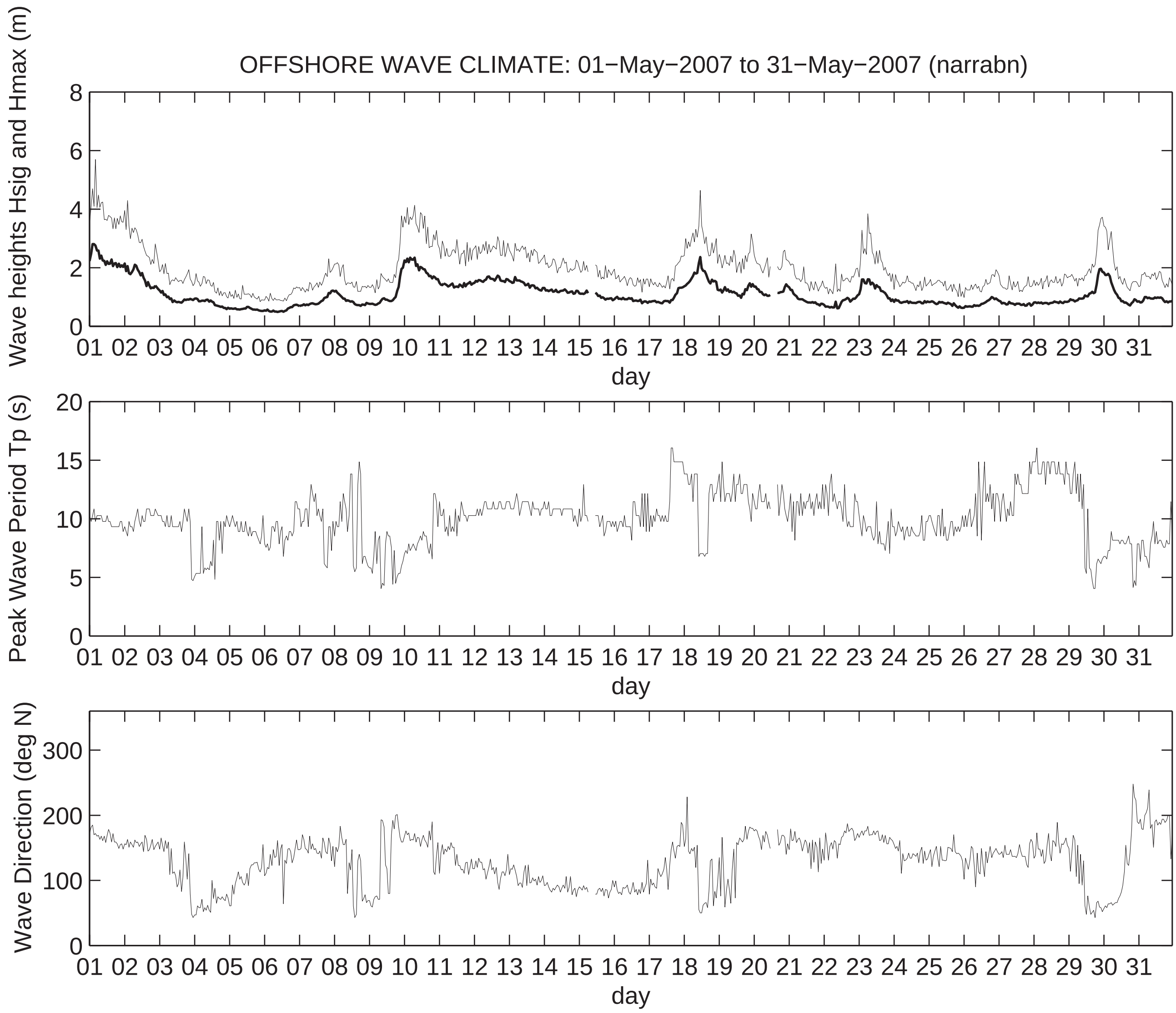
WRL Report No. 2007/30	MONTHLY WAVE SUMMARY FEBRUARY 2007	Figure B8 02092-B08.cdr



WRL Report No. 2007/30	MONTHLY WAVE SUMMARY MARCH 2007	Figure B9 02092-B09.cdr



WRL Report No. 2007/30	MONTHLY WAVE SUMMARY APRIL 2007	Figure B10 02092-B10.cdr



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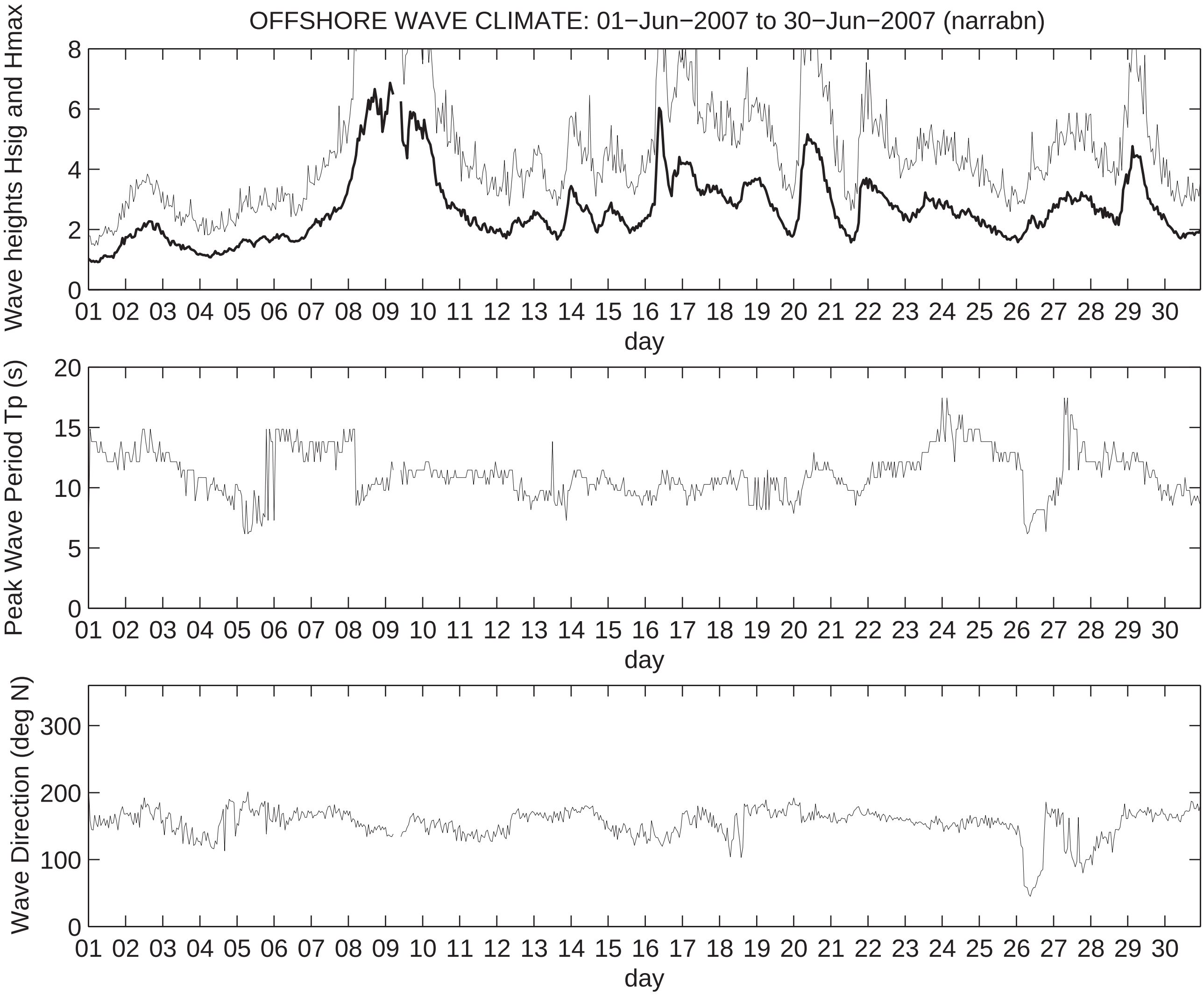
MONTHLY WAVE SUMMARY
MAY 2007

Figure
B11

02092-B11.cdr



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MONTHLY WAVE SUMMARY
JUNE 2007

Figure
B12

02092-B12.cdr