40 YEARS AND STILL GOING STRONG: THE PAST, PRESENT AND FUTURE OF COASTAL MONITORING AT NARRABEEN-COLLAROY BEACH

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Abstract

Long-term high-resolution measurements of coastal variability are extremely rare and provide unique insight to beach fluctuations and change at a variety of different scales. Crucially, they also provide an invaluable dataset that coastal practitioners can use to test and develop new coastal modelling tools and coastal management techniques. This paper describes one such coastal monitoring program that has been continuously underway at Narrabeen-Collaroy Beach at monthly or greater survey frequencies for the past 39 years. The history of this unique program can be divided into two periods: (1) the initial three decades (1976-2006) characterised by the use of traditional survey methods; and (2) the past decade during which the monitoring program has been expanded and modernised using new survey technologies such as RTK-GPS, coastal imaging, LiDAR and UAV technology. A summary and timeline as to the introduction of the various technologies is presented, followed by some standard data products (e.g. the Subaerial Volume and Beach Orientation Indices) produced from the raw historical data to facilitate easy data interpretation. With the forty-year anniversary of this dataset approaching in April 2016, efforts are being made to make this dataset openly accessible for download via a public web interface, thereby extending the reach of this valuable dataset to coastal researchers and practitioners both in Australia and worldwide.

Introduction

In April 1976, a beach monitoring program was initiated on the 3.6-km long Narrabeen-Collaroy Beach (within the Warringah LGA) by Professor Andrew Short and members of the University of Sydney Coastal Studies Unit. Established as a means of quantifying short to longer-term beach profile variability within beach compartments, the original monitoring program consisted of a series of cross-shore profile lines surveyed using traditional survey techniques. Thirty-nine years later this beach monitoring program is still continuing, making it one of the longest on-going records of beach variability and change at any single coastal location worldwide (Harley et al., 2011a). The data collected by this program has served as the basis for many significant studies that have increased our understanding of coastal processes, as well as provided a core dataset to test new coastal modelling tools. Examples of internationally significant work that has to a large part been founded on this growing record of observations from Narrabeen-Collaroy Beach include the establishment of the morphological beach state model in the late 1970s/early 1980s (Wright and Short, 1984), research into medium-term beach rotation and its links to the El Niño/Southern Oscillation (Ranasinghe et al., 2004; Harley et al., 2011b; Barnard et al., 2015), frameworks for probabilistic coastal risk assessments (Callaghan et al., 2008; Pender and Karunarathna, 2013) and recent work on equilibrium shoreline models for forecasting future coastal change (Davidson et al., 2013; Splinter et al., 2014).

Over the last decade the coastal monitoring program at Narrabeen-Collaroy has been under the custodianship of the Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Australia. During this time the program has undergone a period of considerable expansion and enhancement in terms of survey frequency, spatial resolution and survey accuracy. This expansion has coincided with the emergence of new technologies in the field of coastal surveying, which include Real-Time Kinematic GPS (RTK-GPS), Argus coastal imaging, fixed and airborne Light Detection and Ranging (LiDAR) and, most recently, the emergence of sophisticated structure-from-motion (SfM) photogrammetric techniques supported by the deployment of Unmanned Aerial Vehicles (UAVs). Combined with the historical data, these new survey technologies have provided a greater understanding of beach processes at a wide range of spatial and temporal resolutions.

With the forty-year anniversary of coastal monitoring at Narrabeen-Collaroy approaching in early 2016, efforts are being made to make the historical profile dataset open-access for wider use both in Australia and internationally by coastal researchers, managers and practitioners, and as an educational resource to the general public. This paper therefore provides a timely overview of the Narrabeen-Collaroy coastal monitoring program, from its inception and operation over the past four decades, to current practice and future directions. An overview of some standard data products produced from the raw profile line data is also presented.

Monitoring program history

The history of the monitoring program at Narrabeen-Collaroy can be divided into two distinct periods: (1) the first three decades (1976-2006) characterised by a uniform approach using traditional survey techniques; and (2) the past decade during which the monitoring program has been significantly expanded by the use of modern survey technologies. These two periods are discussed below.

1976 – 2006: Historical profile surveys

The years between 1976 and 2006 constitute the period of conventional profile line surveys undertaken wholly by Professor Short and volunteers of the Coastal Studies Unit, University of Sydney using a survey technique known as the Emery method (Emery, 1961). The Emery method is a low-cost technique whereby vertical elevation changes along the profile are measured using line-of-sight between two grade rods and the horizon. Horizontal (i.e., cross-shore) changes between the two rods are then measured using a measuring tape and this process is repeated sequentially along the profile line.

Figure 1 Location of the five representative profile lines (profile numbers 1, 2, 4, 6 and 8) that have been surveyed monthly since April 1976 along Narrabeen-Collaroy Beach. Also indicated is the location of the Narrabeen-Collaroy Argus and Fixed Lidar station

Following several years of these fortnightly surveys of fourteen profile lines, a pragmatic decision was made to cease profile measurements at Fishermans Beach (owing to the lack of significant profile variability observed there) and focus on monthly surveys of five representative profile lines along Narrabeen-Collaroy Beach. These five profiles are identified by the numbers 1, 2, 4, 6 and 8 and are indicated in Figure 1. The lower survey limit for each of these five profiles was also changed from the original limit well into the surf zone to a limit that satisfied profile intersection with mean sea level (i.e., approximately wading depths). These early and pragmatic decisions to limit the number and cross-shore extent of each profile line are undoubtedly the key reasons why monthly surveys were subsequently achieved by the same personnel for the three decades that followed.

2004 – present: new survey technologies

Recognising the uniqueness and value of this dataset worldwide, beginning in 2004 efforts were made by the UNSW Australia Water Research Laboratory to improve and expand the monitoring program into the future through the use of new survey technologies. This commenced in July 2004, when an Argus coastal imaging station was installed on top of the 44 m-high Flight Deck building at South Narrabeen (see Figure 1 for its location). Since this time, this station has continuously collected hourly daylight images of the southern sector of the beach from five separate cameras (the field of view encompassing historical profiles lines Profiles 6 and 8) and uses automated algorithms to measure high-frequency shoreline variability (Harley et al, 2011a).

At the same time the decision was also made to transition the historical profile line surveys from the Emery method to the use of high-accuracy RTK-GPS technology (vertical accuracy ≈ ± 0.03 cm). Following an 18-month validation period during which surveys were undertaken concurrently using the Emery method and RTK-GPS (see Harley et al., 2011 for the results of this validation), the use of RTK-GPS as the standard survey method for the five profile lines was adopted in August 2006. The cross-shore resolution of each profile survey was also increased at this time from the original 10 m measurement spacing to near-continuous (i.e., approximately every 0.10 m cross-shore). From 2005 onwards a number of other different survey techniques were also added to complement the historical profile line surveys and to gain greater understanding of beach morphodynamics at higher spatial and temporal resolutions. These techniques include:

(1) Monthly three-dimensional RTK-GPS surveys of the entire subaerial beach using an all-terrain vehicle (quad bike).
(2) A second Argus coastal imaging station installed at the northern end of the beach
(3) Pre- and post-storm three-dimensional Airborne Lidar surveys of the entire beach and dune systems
(4) A permanent fixed Lidar system scanning a single profile line day and night at a frequency of 5 Hz
(5) Pre- and post-storm three-dimensional surveys of the entire beach and dune systems using an Unmanned Aerial Vehicle
(6) Single and multi-beam bathymetric surveys of the surf zone and offshore bathymetry

A summary of the survey periods, frequency and spatial coverage of each survey technique is presented in Table 1. Figure 2 shows the evolution of survey equipment used to continue the Narrabeen-Collaroy beach monitoring program.

Table 1 Summary of different survey techniques used in the Narrabeen-Collaroy coastal monitoring program

Survey technique	Survey period	Survey frequency	Spatial coverage
Historical profile line surveys (Emery method)	April 1976 – August 2006	Monthly	Five representative profile lines (subaerial beach)
Historical profile line surveys (RTK-GPS)	May 2005 - present	Monthly	Five representative profile lines (subaerial beach)
Argus coastal imaging (Narrabeen – Collaroy)	July 2004 - present	Hourly (daylight hours only)	Southern half of beach (shoreline mapping)
Argus coastal imaging (Nth Narrabeen/Narrabeen Lagoon)	July 2005 - August 2008	Hourly (daylight hours only)	Northernmost 500 m of beach/ Narrabeen Lagoon (shoreline mapping)
RTK-GPS mounted on an All-Terrain-Vehicle	July 2005 - present	Monthly	Entire 3.6 km long subaerial beach
Airborne LiDAR surveys	July 2011 – present	Pre/post major storm events	Entire 3.6 km long subaerial beach and dunes
Permanent fixed LiDAR	May 2014 - present	5 Hz (day and night)	One profile line
Unmanned Aerial Vehicle Structure-from-Motion surveys	June 2014 - present	Pre/post major storm events	Entire 3.6 km long subaerial beach and dunes
Single/multi-beam bathymetric surveys (courtesy of NSW Office of Environment and Heritage)	April 2011 - present	Sporadic	Entire 3.6 km long beach in the surf zone and offshore

Figure 2 Evolution of coastal monitoring program technology at Narrabeen-Collaroy, from the Emery method using grade rods and a measuring tape (left) through to RTK-GPS and an all-terrain vehicle (centre) and, more-recently, the use of UAV technology (right)

Standard data products from historical survey dataset

In addition to the profile survey, 3-D surface, and image data that continue to be collected, a number of standard data products are produced to facilitate easy analysis and understanding of several key beach processes observed at Narrabeen-Collaroy. These data products include:

1) ***Beach Width (W)***

Time-series of beach width are extracted from the data as defined by the cross-shore distance from a fixed landward benchmark to the 0.7 m AHD contour line (approx. mean high water). This width provides a measure of the available ‘dry beach’ amenity between the dunes and the high water mark, distributed along the length of the 3.6km beach at the site of each representative profile line. Figure 3 indicates the 39-year time-series (1976-2015) of beach width at each of these profile lines. Figure 4 meanwhile shows a more-detailed ten-year time-series (2005-2015) of both the daily Argus-derived beach width at Profile 6 as well as the monthly RTK-GPS measurements. This latter figure highlights the match between the remotely-sensed high-frequency Argus data and the *in situ* monthly RTK-GPS data.

2) ***Subaerial Beach Volume (V)***

Time-series of subaerial beach volume is extracted for each profile line as the total volume above 0 m AHD. This volume therefore provides a measure of the available sand storage above mean sea level for each profile, as well as the sand volume that is removed during storm events (i.e., the storm demand).

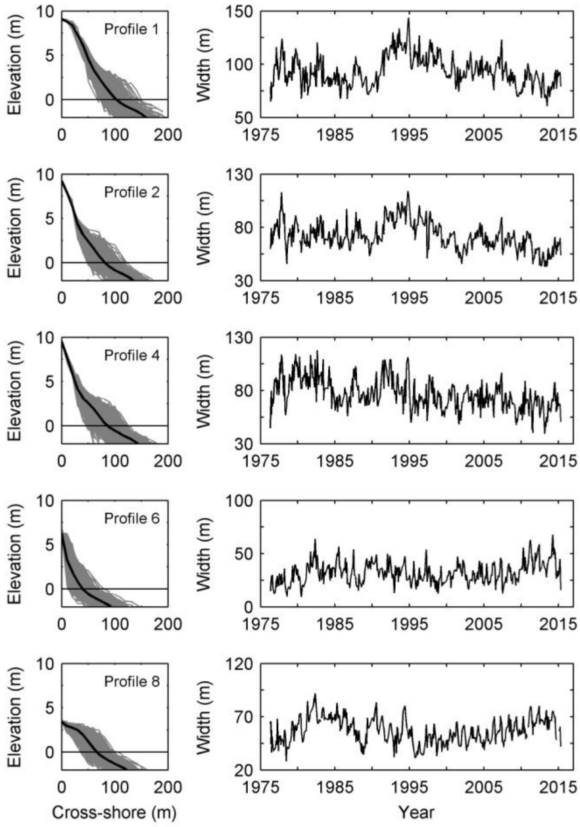

Figure 3 Dataset of the five profile lines surveyed at Narrabeen-Collaroy Beach (1976 – 2015). Left panels indicate beach profiles (mean profile in bold) while right panels present time-series of beach width

3) Subaerial Volume Index (SVI)

The Subaerial Volume Index (SVI) is a simple measure of the overall eroded/accreted state of the beach relative to the historical (pre-2006) survey period and is first defined by the average V for all five profiles:

$$V_a(t) = \frac{1}{5}\sum\nolimits_{i=1}^{5} V_i(t) \qquad (1)$$

V_a is then normalised for the period 1976-2006 and, for ease of interpretation multiplied by a factor of 10. This is given by:

$$SVI(t) = 10\frac{(V_a(t) - \overline{V_a(t)})}{std(V_a(t))} \qquad (2)$$

The full SVI time-series spanning the period 1976 to present is presented in Figure 5 (upper panel). As an example, the SVI at the time of writing (May 2015) has a value of -27, which indicates the beach is in a highly eroded state (minimum SVI = -30, July 1978; maximum SVI = +29, June 1991). This low SVI value is a consequence of a major east coast low that impacted the SE Australian coastline in April 2015. Figure 5 also indicates considerable variability in the SVI as the embayment fluctuates between an overall eroded and overall accreted state. Of particular note is a period of prolonged

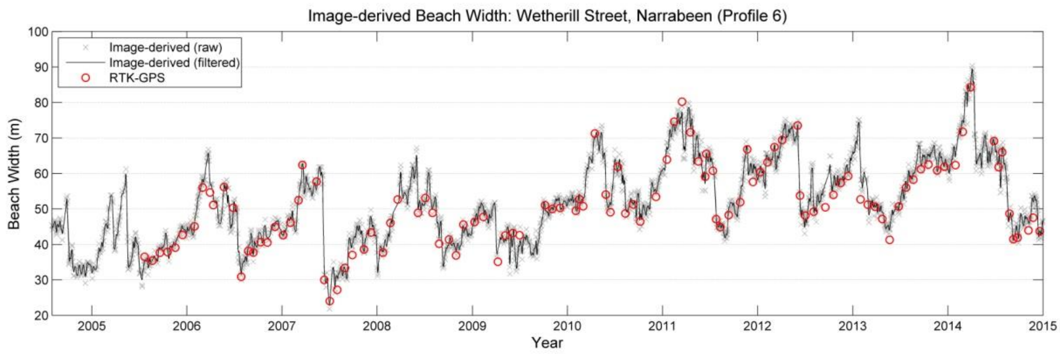

Figure 4 Time-series of daily image-derived beach width obtained from the Argus coastal imaging station and monthly *in situ* RTK-GPS measurements at Profile 6.

accretion throughout the early 1990s, which can be attributed to low storm activity associated with El Niño conditions during this period (Harley et al., 2010).

4) Beach Orientation Index (BOI)

While the SVI provides an indication of the overall eroded/accreted state of the beach, a second index known as the Beach Orientation Index (BOI) provides a measure of whether the beach orientation is more clockwise or anticlockwise with respect to the long-term average. This measure is important for considering how beaches rotate with respect to changes in the wave climate (Ranasinghe et al, 2004,Harley et al., 2011b; Harley et al., 2015)

Similar to other studies of embayed beaches (Ojeda and Guillen, 2008; Bryan et al., 201; Harley et al, 2013), the beach orientation is calculated as follows: first, the 30-year (1976-2006) average beach width is removed from the individual beach width time-series; a linear-regression fit is then applied to these de-meaned values and the associated alongshore locations; and as the final step, the orientation *O(t)* is calculated as the slope of this linear fit.

As with the SVI described previously, O(t) is normalised for the period 1976-2006 and multiplied by a factor of -10. This is given by:

$$BOI(t) = -10\frac{(O(t) - \overline{O(t)})}{std(O(t))} \tag{3}$$

By this definition a positive/negative BOI conveniently represents a clockwise/anti-clockwise beach orientation with respect to the long-term average.

As an example of this index, the latest BOI (May 2015) has a value of -3, which indicates that the embayment has a slight anti-clockwise orientation with respect to the long-term average. To place this in perspective, the minimum BOI over the entire record since 1976 (i.e., the most anti-clockwise beach orientation) has a value of -25 and occurred in May 2013, whereas the BOI reached a maximum value of +29 (i.e., most clockwise beach orientation) in November 1994.

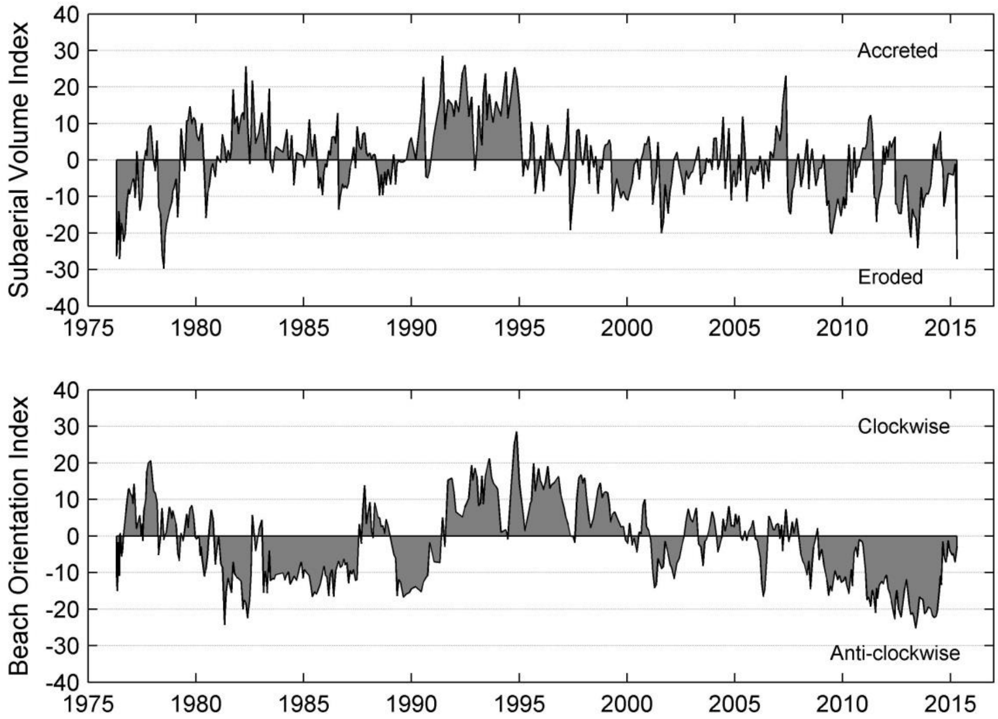

Figure 5 Time-series of the Subaerial Volume Index (SVI, upper panel) and the Beach Orientation Index (BOI, lower panel).

The full 1976 to present BOI time-series is shown in Figure 5 (lower panel). This figure indicates that the embayment has undergone prolonged phases whereby its orientation has been more clockwise than average (e.g. 1992-2000) and more anti-clockwise than average (e.g. 1980-1988, 1989-2002, 2008-present). Recent research investigating the causes of these rotations in embayment orientation suggest that they are caused primarily by variability in cross-shore sediment fluxes alongshore (Harley et al., 2011a; Harley et al., 2015).

Summary

Coastal monitoring at Narrabeen-Collaroy Beach has evolved significantly over time, from an initial exploration of beach profile variability to one of the longest and most comprehensive records of coastal variability and change at any coastal site worldwide. In addition to the five historical profile lines that have been surveyed monthly for the past 39 years, new beach survey technologies have progressively been added to the monitoring program to provide greater knowledge of beach variability at a wide range of spatial and temporal scales. With the forty year anniversary of the dataset approaching in early 2016, efforts are currently underway to make the dataset openly accessible for download via a public web interface. This will include both the quality-controlled profile survey data, as well as a number of standard data products outlined here.

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