Planning for an Australian National Coastal Observatory: monitoring and forecasting coastal erosion in a changing climate

Ian L. Turner[1], Ian D. Goodwin[2], Mark A. Davidson[3], Andrew D. Short[4], Tim R. Pritchard[5], Chris Lane[4], Daylan W. Cameron[6], Tim MacDonald[7], Jason Middleton[8], Kristen D. Splinter[1]

[1]Water Research Laboratory, School of Civil and Environmental Engineering University of New South Wales, Sydney NSW Australia; *ian.turner@unsw.edu.au*
[2]Marine Climate Risk Group,Environmental Science, Department of Environment and Geography, Macquarie University, Sydney, NSW Australia
[3] School of Marine Science and Engineering, University of Plymouth, Plymouth UK
[4]CoastalComs Pty Ltd, Varsity Lakes, QLDAustralia
[5] NSW Office of Environment and Heritage, Sydney NSW Australia
[6] Warringah Council, Sydney,NSW Australia
[7] Gosford City Council, Gosford,NSW Australia
[8] School of Aviation, University of New South Wales, Sydney,NSW Australia

Abstract
A new, federally-funded research initiative has brought together an international team of researchers, state government, local government and private industry, to establish and rigorously test a practical approach to achieving baseline coastal monitoring at multiple 'coastal reference sites' around the Australian open coastline. Analogous and complementary to existing coastal water-level and ocean wave monitoring programs that already exist around the Australian continent, the purpose of this present effort is to initiate and demonstrate the practical capability and application of sustained, automated and ongoing coastline monitoring in support of coastal research, coastal engineering and coastal management. Initially, ten 'pilot' coastal reference sites in New South Wales have been established, and the immediate use of these data to underpin new developments in modelling and forecasting of seasonal to multi-decadal shoreline variability and change is underway.

Keywords: coastal erosion, climate change, coastal monitoring, coastal modelling

1. Introduction

An international team of researchers, state government, local government and private industry has been brought together by a new, federally-funded research initiative, to establish and rigorously test a practical approach for achieving baseline monitoring at multiple 'coastal reference sites' around the Australian open coastline. Analogous and complementary to existing water-level and ocean wave monitoring programs that already exist around the Australian continent, the goal of this present effort is to initiate and demonstrate the practical capability and application of sustained, automated and ongoing coastline monitoring in support of coastal research, coastal engineering and coastal management.

Outlined here is the initial establishment of 10 'pilot' coastal reference sites in New South Wales, where intensive RTK-GPS beach surveying, image analyses, airborne LiDAR, bathymetric surveying and inshore wave monitoring are now under way. Over the next three years these data streams will be used to rigorously test and evaluate the applicability of existing and new coastal camera infrastructure to autonomously and routinely obtain measurements of local wave climate and shoreline variability and erosion at many sites around our coasts. The application of these data to underpin new developments in the modelling and forecasting of seasonal to multi-decadal shoreline variability and change is outlined.

2. Background - Climate Change and The Coast

In 2011 coastal erosion is front-page news across Australia (Figure 1). Over 80% of the Australian population live in the coastal zone and half of Australia's coastline is sandy beaches[23]. Accelerating coastal erosion, damage to existing coastal infrastructure and loss of coastal amenity, are all identified by the Australian Greenhouse Office [25] as likely detrimental impacts of climate variability and change between now and 2100. But the timing, magnitude and extent of these potential impacts to our sandy coastlines are yet to be established.

Figure 1Coastal erosion is front-page news

2.1 Climate Change Science

In 2007 the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report (AR4) stating that there is now no question that the world's climate system is warming [16]. Global temperatures are projected to increase between 1.1^{o}C and 6.3^{o}C by the end of the present century, depending on future greenhouse gas emissions.

The climate change impacts of likely greatest significance to Australia's sandy coastlines are:
(1) sea-level rise, and
(2) changing regional-scale weather patterns.

Waves are the driving mechanism that shape beaches. At the local scale, changing regional weather trends superimposed on a rising sea-level would result in altered exposure to wave energy at the shoreline, causing the erosion and/or redistribution of unconsolidated sediments within and between coastal embayments around Australia's coastline [21]. Whether wave climate change will exacerbate or partially offset the sea-level rise impacts is presently a key knowledge gap.

Global sea-level rose by approximately 17 cm (the range was 12 – 22 cm) during the 20th Century. In 2007 the IPCC stated that by 2100, sea-level is projected to rise by a further 18 – 59 cm. Significantly, since the AR4 report was released, it is now observed that sea-level is currently rising at a rate close to the upper limit of IPCC projections [2]. In Australia, the adoption of State-based sea-level rise projections for coastal planning to 2100 is presently underway – for example, in November 2009 NSW released a 'Sea-level Rise Policy Statement', which established sea-level rise planning benchmarks along the NSW coastline of up to 40 cm by 2050 and 90 cm by 2100 [22].

Recent studies including those funded by NSW Office of Environment and Heritage[19] (formerly DECCW) and jointly by the federal Department of Climate Change and CSIRO Wealth from Oceans National Research Flagship [12] have begun to consider potential change in regional-scale weather patterns and the resulting changes to waves in the Australian coastal region. Principal conclusions of this emerging body of work include a positive (increasing) trend in the frequency of weather events which lead to large wave (i.e., coastal erosion) events. Wave direction along the western and southern coasts is currently expected to shift from westerly to southerly, suggesting the potential for altered wave exposure within individual coastal embayments. Along Australia's eastern coast a similar rotation of wave direction is observed during EL-Nino, such that wave directions shift from easterly to southerly [12,7,11].

2.2 Baseline and broad-scale coastline monitoring – a National priority

The significance to Australia of enhancing our national coastal monitoring and forecasting capabilities is signalled by the CSIRO Wealth from Oceans National Research Flagship [12] and Australian Greenhouse Office [25]. Both these benchmark reports stress the high priority in Australia for the rapid establishment of a network of long-term coastal observation sites, to be used as a basis for modelling and forecasting the potential coastal impacts of predicted climate variability and trends in coming decades. The Parliament of Australia House of Representatives report 'Managing Our Coastal Zone in a Changing Climate' [15] was released in late 2009, based upon an 18 month inquiry comprising over 100 written submissions and 28 public hearings. Recommendation #5 of this landmark report states the need for further research in Australia to "*establish the wave climate around the coast so as to identify those locations most at risk from wave erosion [and] examine how the wave climate nationally interacts with varying landform types*". Meanwhile, the Australian Government is investing $117 million (2008 to 2012) in climate adaptation policies through the Department of Climate Change, coordinated through the National Climate Change Adaptation Research Facility (www.nccarf.edu.au). Yet in the coastal zone, significant and fundamental knowledge gaps persist.

The high priority internationally that is now being placed on efforts to improve baseline and broad-scale coastal monitoring capabilities, and to improve model forecasting of coastal change, is summed up succinctly in the IPCC AR4 report:

> "*the level of knowledge is not consistent with the potential severity of the problem of climate change and coastal zones… there remains a strong focus on sea-level, which needs to be broadened to include all the climate drivers in the coastal zone… [A key priority is to establish]*

better baselines of actual coastal changes… through additional observations and expanded monitoring. This would help to better establish the causal links between climate and coastal change, which tend to remain inferred rather than observed, and to support model development." [IPCC AR4, pp.345-346]

The above statement places front-and-centre the immediate challenge directed at coastal researchers and practitioners, to now come up with enhanced tools and methods to: (1) expand baseline monitoring of present and future coastline variability and potential change, and (2) use this new information to develop new and better methods for modelling and assessing the present and potential future drivers of coastline variability and trends.

The study outlined here is intended to begin to meet and address these dual objectives.

3. Establishment of Coastal Reference Sites

Commenced in 2011, ten 'pilot' coastal reference sites have been established along the NSW coastline, extending from Lennox Head on the far north coast, to Shoalhaven Heads in south coast New South Wales:

- Lennox Head
- Sawtell (Coffs Harbour)
- Dixon Park (Newcastle)
- Wamberal
- Terrigal
- Narrabeen-Collaroy
- North Steyne (Manly)
- Wanda (Cronulla)
- Thirroul (Wollongong)
- Shoalhaven Heads (Seven-Mile Beach)

In selecting these sites, the objective was to achieve the greatest geographical spread possible, within the present confines that this initial 3-year 'proof of concept' phase is being maintained from a single base in Sydney.

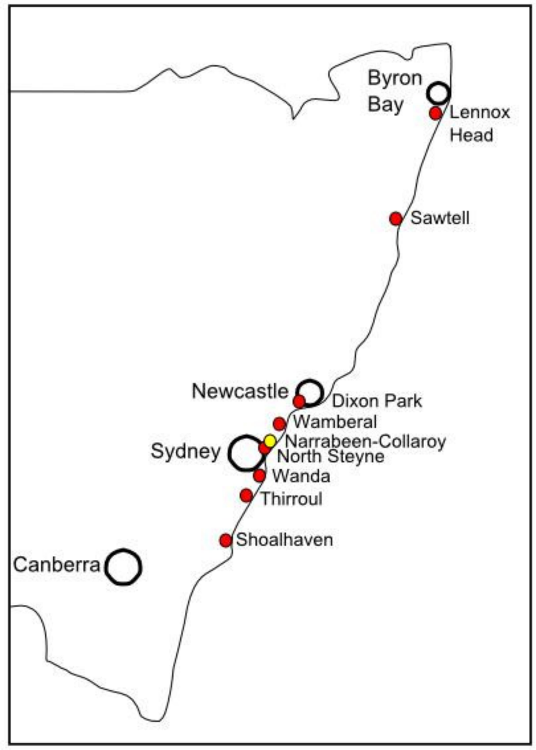

Figure 2 Location of the ten 'proof-of-concept 'NSW coastal references sites, extending from Lennox Head on the far north coast, to Shoalhaven Heads (Seven Mile Beach) in the south.

In addition to achieving regional variation, these ten coastal reference sites span broad parameter space in the key variables of embayment size and embayment orientation (wave exposure). On a practical level, at eight of the ten sites, existing coastal camera infrastructure was already in place, while at the Narrabeen-Collaroy and Wamberal-Terrigal embayments, new cameras were installed to support this study (refer Section 4.1).

Of particular note is the monitoring site at Narrabeen-Collaroy, which was chosen to coincide with the location of the existing *SE Australia Climate Change Coastal Reference Station (CC-CRS)*, that has been in continuous operation since 1976 [9]. Over the past 5 years this site has been the focus of intensive investigation to link observed erosion-accretion processes and embayment rotation trends to storm wave energy [8,17] and a range of regional-scale climatic indices [10].

4. Coastal Monitoring

4.1 Imaging (cameras)

There are well-proven, autonomous, camera-based systems for quantitative monitoring in the coastal zone – two front-runners being Argus Coastal Imaging [13] and CamEra[1]. At the present time there are on the order of 30 Argus stations and 10 CamEra sites worldwide. Despite the significant and extensive body of research that has emerged over the past two decades from the use of these (and similar) systems, the coverage of these present coastal monitoring networks remains limited, camera deployment has tended to be site and research-project specific, and to our knowledge there are no plans or funding models in place for major expansion of this coastal monitoring infrastructure in the foreseeable future.

More recently, with the fast development and wider commercial availability of sophisticated imaging technology, the use of video-based 'surfcam' systems has rapidly expanded around many of the world's coastlines. Project Partner CoastalComs maintains what is presently the most extensive national network of coastal cameras in Australia. Initially established for the surfing community, more recently CoastalComs has invested significantly to expand the capabilities of its systems beyond that of merely providing qualitative observations of surf conditions, to include the regular quantification of shoreline position (beach width) and inshore wave parameters, including wave height and period.[18].

To facilitate the wide coverage of the Australian coastline now provided by its existing camera network, CoastalComs has partnered with Surf Life Saving Australia, resulting in the great majority of their existing camera stations being situated atop beachfront surf clubs. Whilst there has been past concern about the low height and angle of these cameras, as a component of recently-completed study by UNSW researchers using an Argus station elevated just 15 m above sea-level, extensive testing demonstrated that low-level camera deployments can provide the same level of shoreline measurement accuracy that are obtained by more traditional high-elevation cameras, albeit along a shorter length of beach [9]. A comparable assessment of the CoastalComs camera network across a broad range of coastal sites now needs to be rigorously and objectively completed, to test their utility to accurately monitor and quantify shorelines and inshore wave conditions.

In addition, there is existing historical photogrammetric analyses available at a number of the coastal reference sites, and at the CC-CRS at Narrabeen-Collaroy a high elevation (45 m) Argus coastal imaging station owned and maintained by the University of New South Wales has been in continuous operation since 2004. The precision and practical utility of these data has been extensively investigated [9]. For the next three years this site will provide the ability to directly compare the capabilities of this more established coastal measurement technology, with the emerging capabilities of a commercial coastal-camera network.

4.2 RTK-GPS Beach Surveys

Monthly RTK-GPS beach surveys (Figure 3) are underway and will continue for the next three years at all coastal reference sites. These on-ground surveys provide a rigorous control dataset with which to objectively and independently evaluate the accuracy and practical use of image-derived shoreline and intertidal profile information that is being extracted on a daily basis from the cameras across all 10 sites.

Figure 3 RTK-GPS beach survey and Jetski bathymetric surveying underway at Narrabeen-Collaroy.

4.3 Bathymetric Surveys

The hydrographic survey team of the NSW Office of Environment and Heritage are undertaking detailed bathymetric surveys of all ten study embayments to support this new work. These surveys at each site extend from the high tide shoreline contour out to a shelf depth of 30 m. Inshore surveys are being conducted using a jetski (Figure 3), with the 10 m to 30 m soundings being completed by boat-based equipment. At all sites, inshore survey lines (0 – 12 m water depths) are being obtained at 50 m spacing alongshore within the field of view of each camera. Survey tracks extending from 0 – 30 m water depths are being conducted at 250 m intervals alongshore across a larger aerial extent (Figure 4).

The detailed bathymetry at each site is being used for detailed deepwater-to-surfzone modelling of the inshore wave climate, and in the case of distinctly embayed monitoring sites, the alongshore gradients in wave energy reaching the shore is also being assessed and quantified.

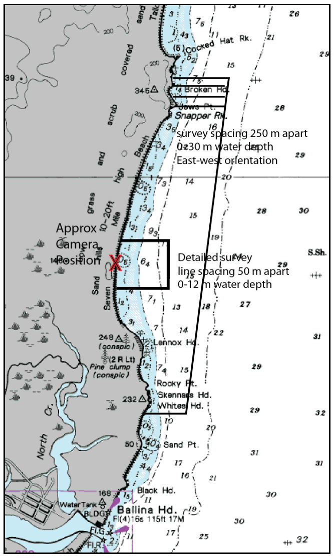

Figure 4 Example from Lennox Heads of the extent of inshore (0 – 12m) and broader scale (0 – 30m) bathymetric surveys being conducted at all ten coastal references sites (chart depth in fathoms).

4.4 Inshore Wave Monitoring

The Narrabeen-Collaroy and Wamberal-Terrigal embayments represent urban and regional locations respectively, where existing shoreline variability has historically impacted upon beach front property. Both sites are distinctly embayed, and have been chosen for detailed wave monitoring and modelling. The purpose is to examine alongshore gradients in wave energy as a function of offshore wave direction, and to rigorously test the wave measurement capabilities of the cameras at both sites. Spanning the winter and spring of 2011, two wave-rider buoys were deployed at ~10m water depth (approximately 350m offshore) directly in front of the cameras at each site, to simultaneously record the inshore wave climate at these locations, synchronous to the camera measurements. At the Narrabeen site a third wave-rider buoy was located further offshore at a depth of 20m, to provide intermediate wave measurements between the inshore wave-rider and Sydney deepwater wave-rider located at 60m water depth. The in-situ data at both sites will be used to calibrate and validate the ability of existing wave modelling packages (SWAN and MIKE21) to provide reliable nearshore wave climatology and variability across the coastal reference station network. This capability is required for the modelling and forecasting study objectives outlined in Section 5.

4.5 Airborne LiDAR

Within the context of this new project the UNSW School of Aviation is utilising low-level (500 ft) airborne LiDAR to test the use of this well established coastal monitoring technology to examine and quantify detailed storm response. Immediately prior to, at every low tide during, and for the initial days following a significant storm wave event, the full Wamberal-Terrigal and Narrabeen-Collaroy embayment - each extending more than 3 km in length - will be mapped in detail. It is anticipated that such frequent and repeat LiDAR over-flights will provide valuable new insight to the magnitude, rate of progression and alongshore variability in storm erosion-recovery. These data are a key requirement for the erosion modelling detailed below.

5. Shoreline Modelling and Forecasting

Despite the considerable research effort that has sought to model past (hindcast) and predict future (forecast) shoreline variability and change, little consensus has yet emerged as to the best or preferred methodology [14]. Complex coastal models that attempt to fully describe the physics of waves, currents, sediment transport and resulting morphological response across a two- or three-dimensional numerical grid, presently require excessive computational effort to be of any real practical value for the purpose of longer-term shoreline prediction. [24]. In addition, the numerous complex and non-linear feedback mechanisms inherent within this type of model framework promote instabilities, which when combined with the aggregation of small-scale errors, produce unreliable predictions. In the absence of any real alternative, longer-term trends (>years) in shoreline evolution have most commonly been 'predicted' by some form of simple regression analysis derived from past shoreline trends [6].The inadequacy of this 'extrapolate from the past' approach is obvious, in the context of the potential for unprecedented climatic change in coming decades.

The emerging development of an alternative and promising approach to shoreline modelling and forecasting at time scales ranging from seasonal to multi-year is presented in a series of recent publications [3,4,5].The computational efficiency of this approach now enables shoreline variability and evolution spanning from a succession of individual storms to potentially several decades to be hindcast/forecast, it is inherently stable, and by its formulation requires no numerical diffusion or smoothing.

Extensive new work is under way to further test and refine this new approach to the modelling of shoreline variability and potential longer-term trends. The three year project described here will provide a diverse range of inshore wave climate and corresponding shoreline datasets obtained from across the 10 coastal reference stations, with which to now undertake extensive model testing, calibration and validation, and significant new model development. For example, current work that for the first time is utilising the existing shoreline dataset at the Narrabeen-Collaroy site, has already led to improved generic model performance as detailed in [5]. Illustrated in Figure 5, the ability of the newly-refined modelling approach (termed 'DMT11') to predict weekly, seasonal and multi-year shoreline is evident. For further explanation and details of this current area of work, the reader is referred to [20]. The end goal of this work is to make available a practical modelling tool that can incorporate future predictions of evolving regional wave climates and sea-level to produce forecasts of future shoreline variability and trends.

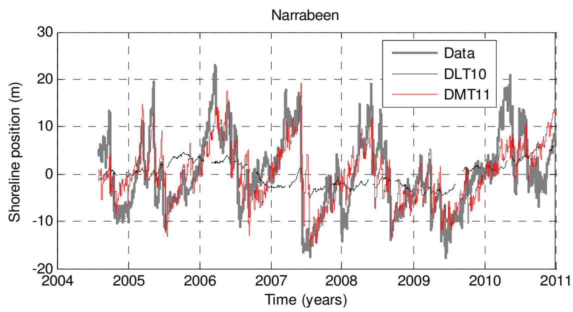

Figure 5 Measured and modelled shorelinetime-series – Narrabeen-Collaroy (source: [20])

A second and parallel effort that is underway is to use the emerging datasets from across the network of ten Coastal Reference Stations to quantify and model storm erosion on an event-by-event basis. As the starting point to this work, the generic applicability of an existing energy-based empirical approach to predicting shoreline retreat as a function of cumulative storm wave energy [8] is being examined. For further explanation and details of this current area of work, the reader is referred to [17].

6. Concluding Remarks

This new initiative is a proactive response to the October 2009 House of Representatives Standing Committee on Climate Change report 'Managing our Coastal Zone in a Changing Climate', that identified the immediate need to better understand the present and potential future risks of coastal erosion, through monitoring and modelling. The study is addressing the knowledge gap between advancing Climate Change science, and the lagging development of our ability to quantify, assess and forecast coastal variability and change.

The outcomes of this three-year project are anticipated to be two-fold:

(1) fast-track the testing of a new capability within Australia to provide automated, sustained and ongoing measurement of inshore wave climate and coastal erosion at many sites around our sandy coastlines, that if successful can circumvent the need for major investment in new monitoring infrastructure; and

(2) use this capability to test and significantly advance a new methodologies for forecasting storm, seasonal and multi-year shoreline variability and change.

As the most developed and populous stretch of beaches around the Australian continent, this 'proof of concept' study is initially focussed on the state of New South Wales, providing a test-bed and template for a national-scale roll-out of coastal monitoring and coastal-change forecasting, utilising existing infrastructurearound Australia.

7. Acknowledgements

This project is funded by the Australian Research Council Linkage Program, project number LP100200348.

8. References

[1] Almar, R, Coco, G, Bryan, KR, Huntley, DA, Short, A.D. and Senchal, N, (2008). Video observations of beach cusp morphodynamics. Marine Geology, 254, 216-223.

[2] Church, JA, White, NJ, Hunter, JR and Lambeck, K, (2008). Briefing: a post-IPCC AR4 update on sea-level rise. Antarctic Climate &Ecosystems Cooperative Research Centre, 11pp.

[3] Davidson, MA and Turner, IL, (2009). A behavioural-template beach profile model for predicting seasonal to interannual shoreline evolution. Journal of Geophysical Research - Earth Surface, 114, F01020, doi:10.1029/2007JF000888.

[4] Davidson, MA, Lewis, RP and Turner, IL,(2010). Forecasting seasonal to multi-year shoreline change. Coastal Engineering, 57, 620-629.

[5] Davidson, MA, Mole, MA and Turner, IL, (2011). The importance of hydro/morpho-dynamic feedback in equilibrium shoreline prediction models Geophysical Research Letters (in review)

[6] Douglas, BC and Crowell, M, (2000). Long-term shoreline position prediction and error propagation. Journal of Coastal Research, 16(1), 145-152.

[7] Goodwin, IG, (2005). A mid-shelf, mean wave direction climatology for southeastern Australia, and its relationship to the El Nino – Southern Oscillation since 1878 A.D. International Journal of Climatology, 25, 1715-1729

[8] Harley, MD, Turner, IL, Short, AD andRanasinghe, R, (2009). An Empirical model of beach response to storms – SE Australia. 19th Australasian Conference on Coastal and Ocean Engineering, Engineers Australia, Wellington NZ.

[9] Harley, MD, Turner, IL, Short, AD, Ranasinghe, R(2011). Assessment of conventional, RTK-GPS and image-derived beach survey methods for daily to decadal coastal monitoring. Coastal Engineering, 58(2), 194-205.

[10] Harley, MD, Turner, IL, Short, AD, Ranasinghe, R., (2011). A re-evaluation of coastal embayment rotation in SE Australia: the dominance of cross-shore versus alongshore processes? Journal of Geophysical Research – Earth Surface (in press).

[11] Harley, MD, Turner IL, Short, AD &Ranasinghe, R, (2009). Interannual variability and controls of the Sydney wave climate. International Journal of Climatology, DOI: 10.1002/joc.1962

[12] Hemer, MA, McInnes K, Church JA, O'Grady J, Hunter JR, (2008). Variability and trends in the Australian wave climate and consequent coastal

vulnerability. Report to Department Climate Change Surface Ocean Wave Variability Project, CSIRO.

[13] Holman, RA and Stanley, J, (2007). The history and technical capabilities of Argus. Coastal Engineering, 54, 477-491.

[14] Honeycutt, MG, Crowell, M and Douglas, BC, Shoreline-position forecasting: Impacts of storms, rate-calculation methodologies, and temporal scales. Journal of Coastal Research, 17(3), 721-730.

[15] House of Representatives, (2009). Managing our coastline in a changing climate. Report by Standing Committee on Climate Change, Water, Environment and The Arts, Canberra, 368 pp.

[16] IPCC, (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds, S. Solomon, et al). Intergovernmental Panel on Climate Change, Cambridge University Press.

[17] Kearney, ET, Harley, MD, Turner, IL, Wyeth, B, Goodwin, .D., (2011). An energy-based empirical model of storm-induced shoreline erosion, Gold Coast, Australia. Coasts and Ports 2011, Engineers Australia, Perth WA (this volume).

[18] Lane, C, Gal, Y, Browne, M, Short, AD, Strauss, D, Tomlinson, R, Jackson, K, Tan, C and Blumenstein, M, (2011). New technique for measuring breaking wave dynamics, height and periods. Australasian Coasts and Ports 2011, Engineers Australia, Perth WA (this volume).

[19] McInnes KL, Abbbs DJ, O'Farrell SP, Macadam I, O'Grady J and Ranasinghe R, (2007). Projected changes in climatological forcing for coastal erosion in NSW. Report to NSW Department of Environment and Climate Change, CSIRO.

[20] Mole, MA., Davidson, MA., Turner, IL., Goodwin, ID, (2011). forecasting seasonal to multi-year shoreline change on the east Australian coast. Coasts and Ports 2011, Engineers Australia, Perth WA (this volume).

[21] NCCOE, (2004). Guidelines for responding to the effects of climate change in coastal and ocean engineering. National Committee on Coastal and Ocean Engineering, Engineers Australia, EA Books. 27p.

[22] NSW Government, (2009). 'Sea-level Rise Policy Statement'. NSW DECCW, 9 pp

[23] Short, AD and Woodroffe, CD, (2009). The Coast of Australia. Cambridge University Press, Melbourne, 288 pp.

[24] Van Rijn, L.C., Walstra, D.J.R., Grasmeijer, B., Sutherland, J., Pan, S., Sierra, J.P., (2003). The Predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based Profile models. Coastal Engineering 47, 295-325.

[25] Voice, M, Harvey N and Walsh K, (2006). Vulnerability to climate change of Australia's coastal zone: analysis of gaps I methods, data and system thresholds. Report to Australian Greenhouse Office, Department of Environment and Heritage.