Relating Shoreline Behaviour Histories to Wave Climate

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Abstract

This paper describes a study funded by the Commonwealth Department of Climate Change and Energy Efficiency, and undertaken during 2010 – 2011 with the aim of improving capacity to assess coastal vulnerability to sea-level rise by building on existing tools including the Smartline national coastal geomorphic map dataset and the Coastal Vulnerability Index (CVI) previously developed in the USA. We assume that wave climate is most commonly the primary driver determining the physical behaviour of erodible shores, and further assume that past shoreline responses to wave climate will be a useful predictor of future response under conditions of higher mean sea level. We recognise that other factors such as tidal processes and regional and temporal variability in sea-level rise are also important factors governing shoreline response to sea-level rise, and seek to identify coastal environments in which these are equally or more important controls on shoreline response. Seventeen erodible shoreline study sites in both open and sheltered coastal environments were selected in Tasmania, the NSW coast, at Darwin, and in South Australia. Shoreline change histories at each site since the 1940s were mapped and quantified from time series ortho-rectified historic air photos. Swell and local fetch wave climates were modelled for each study site using SWAN and GREMO software respectively. The historic behaviour of each site was compared with wave climate modelling to determine the degree to which wave climate can explain observed shoreline behaviour at each site. The outcomes of this study will contribute to the development of indices of physical coastal sensitivity that are conceptually similar to but more reflective of actual coastal processes than the CVI, and will identify further work needed to understand the behaviour of shores dominated by processes other than wave climate.

Introduction

This paper describes a project undertaken by the University of Tasmania (UTAS) for the Australian Department of Climate Change and Energy Efficiency (DCCEE) with the aim of developing improved capacity to differentiate at regional to national scales those parts of the coasts that are likely to respond to sea-level rise with greater or lesser degrees and rates of change including erosion and recession. The project, which we have termed the 'ShoreWave Project' for simplicity, aims to enable the development of a Coastal Erosion Impact Index (CEII) similar in concept to the Coastal Vulnerability Index (CVI) previously developed in the USA (Gornitz & Kanciruk 1989, Thieler, & Hammar-Klose 1999), but avoiding identified limitations in this earlier concept.

The CVI and its limitations have been recently explored in an Australian context by Abuodha & Woodroffe (2010), who preferred the term Coastal Sensitivity Index (CSI) in recognition that the method assesses only physical shoreline sensitivity to erosion, but not the consequent vulnerability of social or ecological assets. The concept of the CVI (CSI) is based on mapping regional differences in the primary variables considered to determine coastal sensitivity to erosion, namely coastal landform type and coastal slope (indicative of inherent susceptibility to erosion); relative sea-level change, wave climate and tidal range (indicative of the processes driving erosion); and the variation in degree of actual historic shoreline change along the coast. Under the CVI method each of these variables is assigned a numerical weight or ranking (1 to 5) at each defined section of coast, and then a simple equation is used to derive an index of sensitivity to erosion for each section of coast.

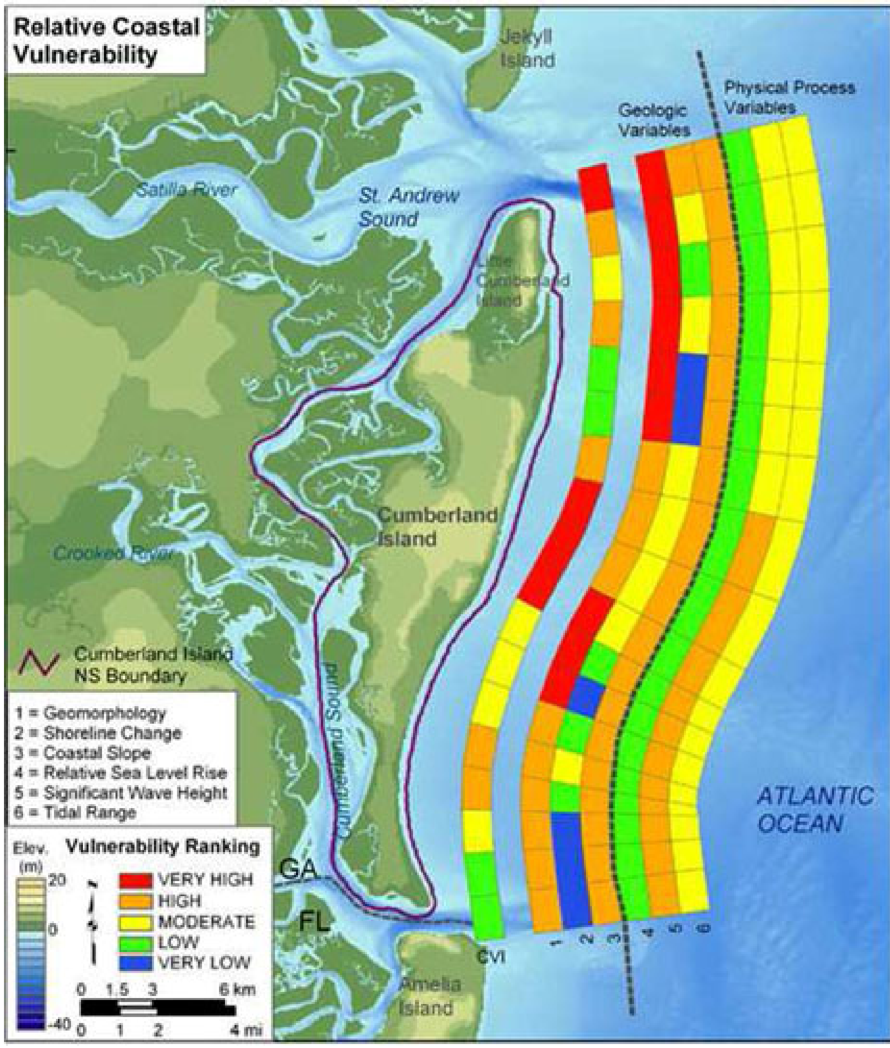

Figure 1: An example of the application of the Coastal Vulnerability Index (from Pendleton *et al.* 2004)

However whilst we consider the concept underlying this method likely to be valid in principle, and its application is relatively simple to achieve, we perceive important limitations in the CVI (CSI) method as used previously, namely:

- Some of the variables are too simplistic to properly represent the relevant processes. In particular wave climate is represented as simple mean wave height (equivalent to wave energy); however we consider a range of other wave climate parameters - particularly alongshore wave-driven sediment transport and variability in both cross-shore and alongshore wave action - are likely to be at least if not more important determinants of shoreline behaviour; and
- The simple numerical method of ranking and combining the variables into an index is unlikely to accurately reflect real coastal processes; and
- The inclusion of historic (measured) shoreline change as a variable makes the index tautological since this is actually what we are aiming at gaining some predictive ability for. The inclusion of this variable also makes the CVI impractical to implement unless comprehensive historic shoreline change data

is already available, which for most Australian coasts is not the case. Instead, the aim of the ShoreWave project is to develop a method to integrate mapped data on shoreline type and driving processes (especially wave climate in the first instance) so as to yield some capacity to predict likely shoreline behaviour where actual data on historic shoreline change is not available.

A previous project undertaken by the authors for Geoscience Australia and the Department of Climate Change combined a wide range of previous coastal landform maps for the entire Australian coast into a single nationally-consistent coastal landform map of Australia which we dubbed the 'Smartline' map (Sharples *et al.* 2009). This map provides comprehensive data for Australia on two of the key CVI (CSI) variables, namely shoreline geomorphic type and coastal slope. As such the Smartline maps out shorelines with greater and lesser inherent susceptibility to erosion, as well as identifying shores with differing styles of response to coastal erosion processes (for example the Smartline map differentiates 'soft rock' and clayey-gravel shores which are readily erodible but cannot rebuild after erosion events, from open coast sandy shores which may naturally recover from erosion events as the swell moves sand back onto the beach). However we regard this as only a 'First Pass' stage in building the capacity to better identify relative shoreline erosion risks at regional to national scales, since it does not incorporate any measures of regional or local variation in the processes driving the erosion that may occur, and therefore does not allow identification of which parts of a given shoreline type (e.g., sandy beaches, soft rock shores) are likely to erode more or less than other shores of the same physical type.

The ShoreWave project aims to build on the Smartline map by developing a 'Second Pass' method for integrating other key variables such as wave climate with the existing landform type mapping so as to produce a 'Coastal Erosion Impact Index' (CEII) which is conceptually similar to the CVI (CSI), but incorporates data on the processes driving coastal erosion in a way that is more reflective of actual coastal processes, and which has some explanatory – and therefore predictive – power.

Patterns and rates of erosion in any given coastal landform type may be governed by a wide range of processes including but not limited to wave climate (including alongshore sediment transport currents), tidal range and currents, river discharge currents, regional variations in sea-level rise, local hard bedrock topography, other local processes affecting sediment budgets, artificial disturbances, and a wide range of other locally variable processes and conditions. Many of these governing variables can only be identified, mapped and their influence on erosion patterns assessed at local scales and so require detailed site-specific investigations of the sort referred to by Sharples (2008) as a 'Third Pass' assessment.

Notwithstanding this, the ShoreWave Project is based on the assumption that of all the processes driving coastal erosion, wave climate will be a dominating driver in a large proportion of coastal locations. Therefore – whilst fully recognising that many other processes are involved in coastal erosion and may be significant or even dominate in certain locations – we consider that the most effective approach to developing a CEII is to first focus on investigating wave climate as a control on erosion in those locations where it is dominant, with a view to subsequently extending similar work to incorporate other regionally-identifiable drivers such as tidal range and currents in places where they are significant or dominant. The aim is to develop improved capacity to predict likely regional variations in coastal erosion sensitivity whilst recognising that there will always be a proportion of coastal locations where some factor that is not incorporated into regional 'Second Pass' analyses may confound the predictions and result in locally-distinctive shoreline behaviour which can only be properly assessed at a 'Third Pass' level of detailed site-specific investigation.

A further assumption underlying the ShoreWave Project is that historic shoreline behaviour is likely to be a useful predictor of future shoreline behaviour under conditions of accelerating sea-level rise. The basis of this assumption is that it is not sea-level rise *per se* which will cause accelerated shoreline erosion; rather it is that sea-level rise will allow erosive waves to impact on shorelines at a higher level and further to landwards than previously. We therefore assume that shorelines which have been exposed to more erosive wave climates in the past will respond to sea-level rise by eroding and receding at a greater rate or degree in future than shorelines that have been exposed to less erosive wave climates. Note that it is not necessary to assume unchanging future wave climates accompanying sea-level rise for this assumption to remain valuable, since an understanding of how erosion sensitivity varies with different wave climates will allow the same indices to be applied in relevant locations even if changes to the wave climates on particular coasts do occur.

Method

The method adopted for the ShoreWave Project tests the capacity of a range of modelled wave climate variables to explain observed and quantified historic shoreline behaviour at a suite of representative study sites, with the aim of being able to predict the likely behaviour of other similar coasts where information on the basic wave climate and geomorphic type variables is available but actual shoreline behaviour data is not.

Seventeen erodible shoreline study sites in both open coast and 'sheltered' (local fetch-dominated) coastal environments were selected in south-east Tasmania, the NSW coast, at Darwin, and at Yorke Peninsula (South Australia). A representative range of shoreline types were selected including 'two-way' sandy shores capable of accretion and recovery after erosion, and 'one-way' erodible 'soft rock' shores which cannot naturally rebuild after erosion. Shoreline change histories at each site since the 1940s were mapped and quantified from time series ortho-rectified historic air photos. Swell and local fetch wave climates were modelled for each study site using SWAN and GREMO software respectively. The historic behaviour of each site was compared with wave climate modelling to determine the degree to which modelled wave climate can explain observed shoreline behaviour at each site. Each component of this method is described further in the following sections.

Shoreline history data

Study area shorelines were of necessity selected where a good time series of historical air photographs was available with photo scales of at least 1:30,000 or better. For the selected shorelines we endeavoured to obtain aerial photography coverage at good scales at roughly decadal intervals from the 1940s onwards, although the realities of air photo quality and availability meant this was rarely achieved perfectly. Nonetheless for most sites air photographs from at least four and usually more dates from the 1940s or 1950s onwards were obtained. Where not already ortho-rectified, scanned air photos were ortho-rectified by Matt Dell and Kan Otera using Landscape Mapper™ software, with estimated ground surface feature location accuracies of the order of ± 3 metres or better being obtained in most cases.

For each site, shoreline positions were digitised for each air photo date based on the seawards vegetation limit, which may correspond to an erosion scarp on receding shores and an incipient foredune front on accreting shores. Shoreline positions were meticulously digitised by Sarah Harries using Landscape Mapper™ software and saved as shapefiles in ArcMap™ software.

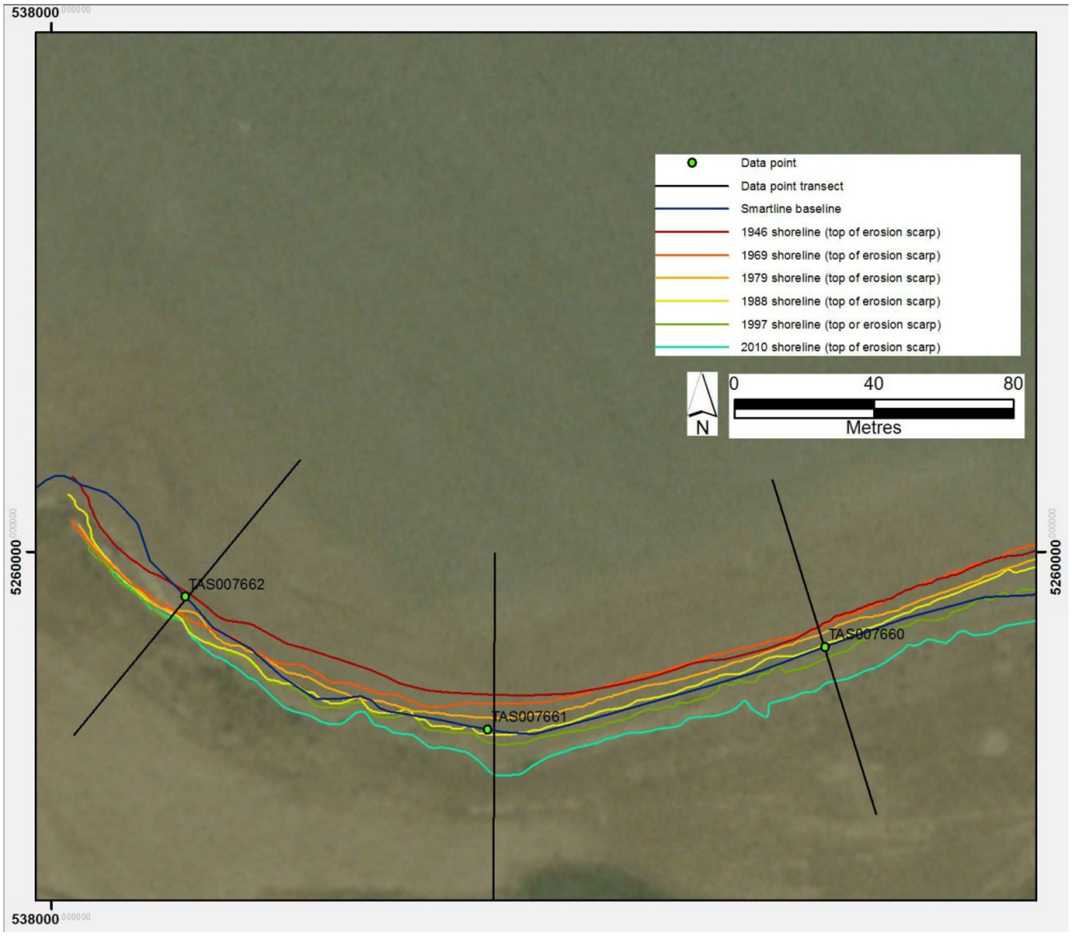

Figure 2: Example of a study site shoreline (Barilla Bay, south-east Tasmania) showing digitised historic shoreline positions, shoreline measurement points and digital transects. Photo is the 2010 image.

The time-series of digitised shorelines obtained in this way were converted to numerical measures and indices of shoreline change by first digitally generating measurement points regularly spaced 100 metres apart along each study shoreline, and then creating transect lines normal to the shoreline at each measurement point (using scripts prepared for ArcMap™ software by Michael Lacey). An automated script was then used to measure the position of each dated shoreline along each transect, and the resulting numerical data was compiled into an Excel™ spread sheet. The movement of the shoreline (landwards or seawards) at each shoreline measurement point was then charted by Sarah Harries as shoreline movement plots zeroed on the median shoreline position along each transect as a form of normalisation. When used in conjunction with a map of shoreline measurement point positions, this representation was found to be an effective way of visualising shoreline changes over time and detecting variations in change along a given shoreline (see Figure 3).

In order to enable statistical analysis of shoreline changes against modelled wave climate, the extracted numerical shoreline change data was used to construct a series of quantified measures or indices of shoreline change. A variety of measures have been experimented with, however the most useful shoreline change indices identified in this work to date include:

- Net and gross (cumulative) landwards or seawards movement per year (net and gross shoreline movements over the time series period divided by the duration of the period to give a comparable annual rate).

- Detrended cut-and-fill range (range of first order and second order cut and fill movements on a beach with any evident underlying long term accretion or erosion trend removed). This index was selected as a measure of beach erosional (and recovery) response to wave climate that should be a useful indicator of potential erosional response to sea-level rise even on beaches which have shown no underlying recession or accretion trend to date

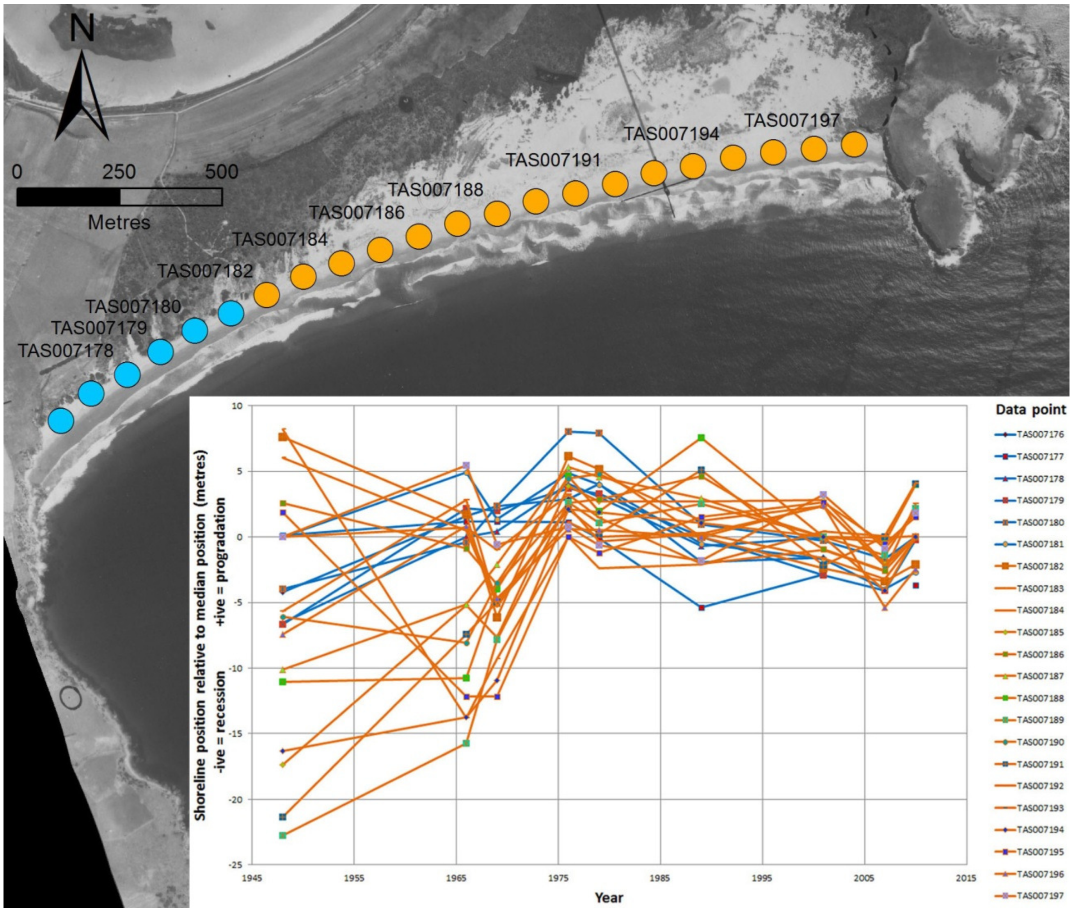

Figure 3: Historic shoreline behaviour plot for Clifton Beach (Tasmania) derived from air photo time series analysis, with transect locations indicated over the 1948 air photo. Shoreline movement over time at each transect is plotted as a separate line. Inspection reveals spatial clusters (colour-coded) of transects with differing shoreline behaviour over time. At this beach, stabilisation of mobile dunes and dune front accretion was most pronounced but also variable in the central – eastern part of the beach until the 1970's, since when the whole beach has been stable or slightly receding. Note that the obvious spatial clustering of the early phase of beach behaviour also corresponds to visible differences in mobile dune activity and wave behaviour in the air photo.

Wave Climate modelling

Swell modelling

Swell wave modelling was undertaken by Mark Hemer (CSIRO) using the method proposed by Hemer (2009) to identify shoreline segments susceptible to wave climate variability. The widely-used SWAN numerical wave model (Booij *et al.* 1999) was used to model swell wave climates for the Tasmanian, NSW and South Australian study sites forced with wave data for 1998-2007 from the US National Oceanic and Atmospheric Administration (NOAA) WaveWatch III (NWW3) operational wave model archives (Tolman 2002). Verification of the method used has previously been provided for the South Australian study region domain by Hemer (2009). The use of wave data for the 1998 – 2007 period was considered adequately representative of southern Australian swell wave climate variability since no significant long term changes in the wave climates for the region have as yet been detected from wave rider buoy data (Lord & Kulmar 2000, Hemer *et al.* 2008, Hemer 2010).

For each study site region, archived Significant Wave Height (Hs), Peak Wave Period (Tp) and Peak Wave Direction (Dir) data from the NWW3 archives was used to force the ocean boundaries of a coarse resolution (approx. 5km grid) model domain, with finer resolution (approx. 1 km grid) domains being nested within the larger domain for the specific study sites. This resolves waves to a position approximately 1 km offshore, which is still too coarse to fully resolve wave conditions at the shoreline itself. However the rationale behind using this approach is that it resolves the transformations in wave conditions that takes place between the continental shelf edge and ~1km offshore, and locations with less wave variability ~1km offshore should have less variability at the coast that locations with more variability ~1km offshore. Achieving higher wave condition resolution closer to the shoreline would require much greater computational resources and finer bathymetric data than are practical – especially if applied to the entire Australian coast – hence an aim of the ShoreWave project is to determine whether the degree of wave climate resolution achieved is sufficient to provide a model with some useful (albeit not perfect) explanatory power at the shoreline.

The wave conditions modelled to ~1km offshore were defined at 1 km spaced coastal grid points taken from the NOAA NGDC GSHHS dataset (http://ngdc. noaa.gov/mgg/shorelines/gshhs.html), and then attached to the same 100m spaced shoreline measurement points as used to calculate shoreline change indices (above) on a nearest neighbour basis. Directional wave data were then transformed into longshore and cross-shore components of energy at each shoreline point depending on shoreline orientation at that point.

Twenty three indices of wave climate were generated at each shoreline measurement point. These included mean significant wave height (mean Hs), mean longshore transport magnitude (mean Qs, positive and negative values indicating transport direction), mean wave energy flux (including mean cross shore and longshore components of wave energy flux), variability of these and of wave direction, variability of the magnitude of longshore transport (Tr), and indices of storm wave energy, duration and number of storms for Hs>1, 2 and 3 metre storms.

All of these indices have been used in analysing shoreline change during the ShoreWave project, however it is of note that Hemer (2009) proposed that the variability of the magnitude of longshore transport index (Tr) should have a significant relationship to shoreline behaviour since there is a strong relationship between regions with diverging longshore transports and shoreline erosion, and similarly between converging longshore transports and accreting shorelines. The index Tr is expected to represent how variable longshore transport is at a shoreline location, with high values indicating a shoreline at which the shoreline position is unlikely to be in a stable equilibrium, and thus potentially subject to greater changes in shoreline position.

Fetch modelling

Local wind-wave climates for the Tasmanian, South Australian and Darwin study sites were modelled by Marji Puotinen (University of Wollongong and University of Ohio) using GREMO™, a cartographic fetch modelling software tool developed by Pepper & Puotinen (2009) which is a faster and considerably less computer-intensive than alternative numerical modelling methods and was considered appropriate to the purposes of the ShoreWave Project.

Using this approach, simple fetch openness (distance across water to the first wave obstacle, e.g., islands or opposite shorelines in fetch-limited coastal environments) was first measured at 16 compass directions around each of the same 100 metre-spaced shoreline measurement points that were used to calculate shoreline change indices (above). Wind records from the nearest available Bureau of Meteorology weather stations were then used to weight the openness measures in each direction according to the frequency and intensity of winds from that direction. The basic indices produced in this way for each shoreline measurement point were:

- Openness (simple fetch distance in each direction)
- Dominant direction fetch (openness weighted according to the dominant wind direction)
- Wind-rose weighted fetch (openness weighted according to wind frequency and intensity from each compass direction)

These basic indices were calculated using all available wind records, which differed between sites but ranged between 15 years (Stenhouse Bay, Yorke Peninsula) and over 50 years (Hobart airport and Darwin airport). A range of additional indices were experimented with, including indices calculated using only wind-data from a standard 10 year period (1997-2007), indices weighted according to shallow bathymetry (using bathymetric digital elevation models), and storm-weighted indices calculated using 75th and 95th percentile or greater wind speeds. In practice we have found that most of these alternative indices yield results little different from the basic fetch indices, and the latter appear to give the best correlations with shoreline change indices.

In the course of analysis we have found each of the three basic indices to be most useful in differing situations, for example simple openness works well where there is no significantly dominating wind direction, whereas wind-rose weighted fetch indices are most useful where there are one or more significantly dominating onshore wind directions. Dominant direction fetch must be used with care since if there is a dominant wind direction but it is offshore rather than onshore, then the resulting fetch indices can be misleading for interpreting coastal change processes.

Analysis

The method used to compare and analyse the shoreline change and modelled wave climate indices for explanatory inter-relationships comprises three concurrent approaches, namely:

- Visual clustering and pattern analysis of charted shoreline change data (as illustrated in Figure 3 above) in order to identify spatial and temporal patterns in shoreline change at each study site.
- Use of such patterns to inform visual comparison of mapped shoreline change and wave climate indices in ArcMap™ software so as to identify any apparent spatial correlations.
- Statistical testing for correlations between the quantified shoreline change and wave climate indices, in particular by using scatterplot matrices generated with JMP™ statistical analysis software to identify any significant correlations between indices.

Each of these three approaches informs the others, leading to identification of any statistically significant and physically meaningful correlations between shoreline change history variations and wave climate variability across a site. Where significant correlations of this sort are found within a site, the final stage is to statistically compare wave and shoreline behaviour indices across sites of similar type, to see if the correlations found within sites can be applied more broadly at regional or national scales.

Analysis of the shoreline change and modelled wave climate indices for the study sites is ongoing at the time of writing, however results to date have demonstrated statistically significant relationships between wave climate and shoreline behaviour in some cases but not in others (as may be expected). The historic behaviour of some study site beaches, including Rokeby, Clifton and Roches beaches in south-eastern Tasmania show significant relationships between some aspects of their historic behaviour and both swell and fetch wave indices, whereas some others do not receive swell and so are dominated by local wind waves only.

Several examples follow:

Barilla Bay (south-east Tasmania)

Barilla Bay is in many ways one of the simplest ShoreWave Project study sites, and exhibits a clear statistically-significant relationship between shoreline change and modelled fetch. The study site shoreline is located within a swell-sheltered estuary, distant from river discharge and tidal channels, where locally-generated wind waves are the only significant identified mechanism of shoreline erosion. The shoreline is a clayey-gravel 'soft-rock' scarp of Tertiary-age sediments which is a 'one-way' shoreline type with no capacity to naturally rebuild following erosion. The air photo time series analysis indicates this shore has been actively eroding at a relatively constant – but spatially variable - rate since at least 1946. Wind data from Hobart Airport (only a few kilometres from the site) demonstrate a strongly dominant wind direction from the northwest, towards which parts of the study shore face directly across several kilometres fetch, whilst other parts are oriented obliquely to the dominant direction. A scatterplot matrix identified a number of significant correlations between the shoreline change indices and modelled fetch indices (swell being absent here). The best correlation was identified between gross landwards shoreline movement per year and wind rose-weighted fetch, with a bivariate fit of these indices yielding a statistically significant correlation coefficient of $r^2 = 0.3255$.

The physical significance of this correlation can be appreciated by mapping these indices: as Figure 4 demonstrates, greater gross landwards movement per year (i.e., faster shoreline recession) is reasonably well-correlated with increased exposure towards the northwest fetch, over which wind waves are generated by the dominant winds. This relationship provides a clear explanatory relationship between shoreline behaviour and wave climate, in this simple case at least.

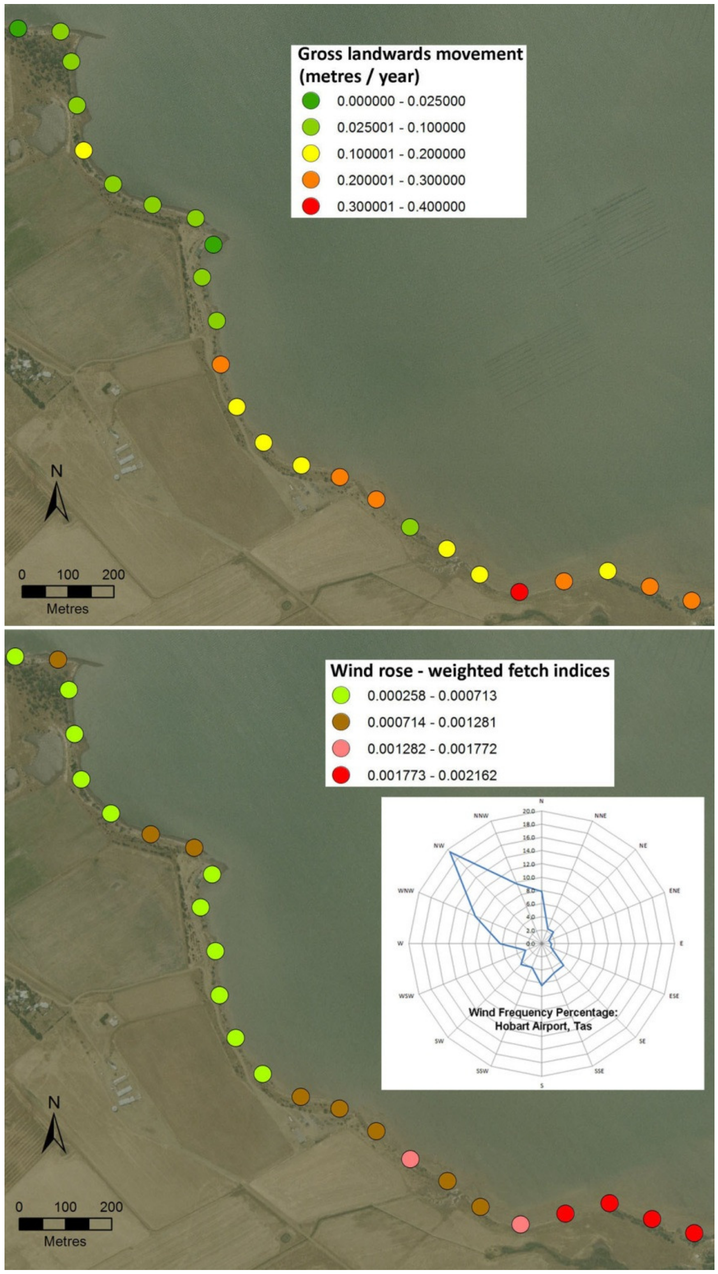

Figure 4: Mapped comparison of gross landwards movement per year index (shoreline recession rate) and wind rose –weighted fetch index (with wind rose for the site shown for comparison). A significant correlation between greater erosion rates and greater wind rose – weighted fetch exposure is apparent from visual inspection of these mapped indices.

Palm Beach (NSW)

Shoreline behaviour for the swell-exposed Palm Beach (NSW) was analysed using an air photo time series for eight dates from 1941 to 2008. The air photo intervals used (mostly 10 to 14 years apart) are too coarse to reveal beach state changes on inter-annual and shorter time scales, such as those identified at Palm Beach by Ranasinghe *et al.* (2004), and indeed the data does not reveal the first-order storm erosion events of 1974 (the first photo used following the storms was 1979). However a number of apparently-systematic spatial and temporal trends are evident in the plotted shoreline history data (see Figure 5) and we interpret these to be at least in part significant underlying shoreline behaviour trends at Palm Beach.

Inspection of the shoreline history plot for Palm Beach against the spatial distribution of the plotted transects (Figure 5) reveals a systematic pattern. A major erosion event evidently affected much of the beach between 1941 and 1951, however the southernmost three transects on the beach (sheltered in the lee of Little Head, red points and transects in Figure 5) have shown little shoreline position change throughout the time series period from 1941 to 2008. In contrast the large moderately swell-exposed middle section of the beach (orange points and transects in Figure 5) has shown a slow underlying accretion trend with a moderate cut-and-fill range (10-15m), whereas the most exposed northern end of the beach (blue points and transects) has since at least 1979 shown a distinctly faster underlying accretion trend with a larger cut-and-fill range of about 15 – 20 m super-imposed (note shoreline position data from 1951 to 1970 could not be obtained for the northern transects due to extensive unvegetated mobile dunes in that area with insufficient photo contrast to define a shoreline indicator feature).

In general terms the larger cut-and-fill range and faster underlying accretion rate at the northern end of the beach both seem explainable as the result of greater exposure to (less refracted) south-south-easterly swell waves at the north end of the beach, together with a net long-term northerly longshore drift of sand along the beach.

Comparison of shoreline change indices quantified from the plotted shoreline history data with modelled swell wave indices for Palm Beach revealed several significant correlations which appear explanatory of such underlying spatial and temporal trends. In particular, modelled significant wave height (Hs) is greater at the northern end of the beach, and mean variability of the magnitude of longshore transport index (mean Tr) and mean longshore wave energy flux (EFLS) both show statistically significant correlations with alongshore variation in detrended cut-and-fill range, net shoreline change per year and gross seawards movement per year (the best bivariate fit between these indices is a very good correlation co-efficient of r^2=0.769457 between mean Tr and net change per year).

Given the relative coarseness of both the swell modelling and of the shoreline behaviour time series data used in this study, we assume correlations of this sort are reflecting long term underlying beach behaviour trends, not inter-annual or finer resolution behaviour, and we further consider the coarser underlying shoreline behaviour trends to represent the level of shoreline behaviour that it would be most useful to be able to predict in a regional scale assessment of likely relative differences in shoreline responses to accelerating sea-level rise. On the basis of the observed long term shoreline change trends at Palm Beach, it might be expected that the greater exposure and larger cut-and-fill range at the northern end of the beach would result in a more rapid recessional response to sea-level rise at that end of the beach after sea-level has continued to rise sufficiently as to overwhelm the current underlying accretionary behaviour of the beach. If this interpretation is valid, the fact that several modelled wave climate indices are correlated with and may be predictive of the observed variation in beach behaviour implies that those indices may have the potential to be predictive of shoreline response to sea-level rise, at least on shoreline types and under wave climates comparable to that of Palm Beach.

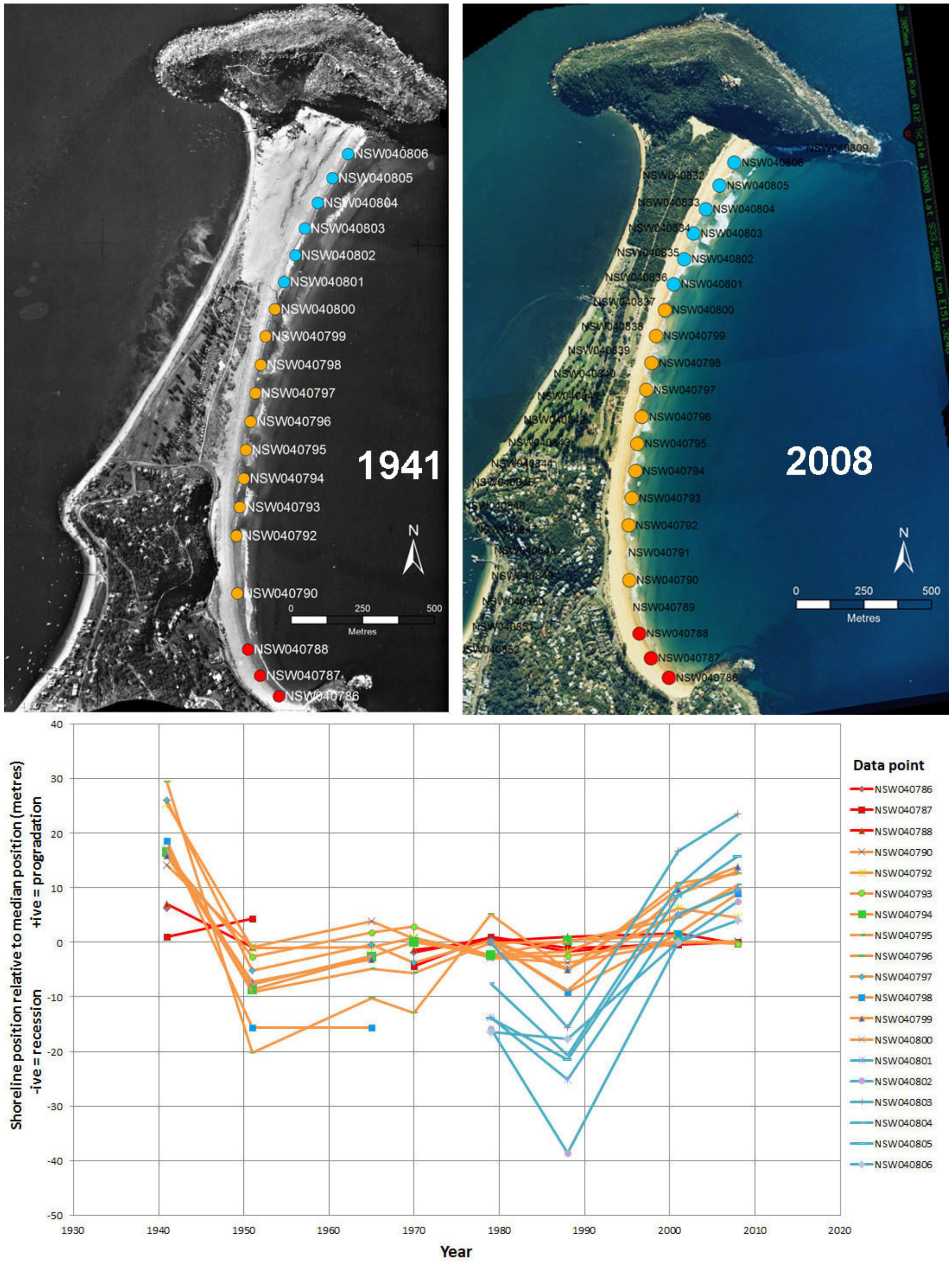

Figure 5: Historic shoreline change plot for Palm Beach, NSW, with colour-coded transect clusters for ease of comparison with the mapped location of each shoreline measurement point (transect). See text for discussion.

Marion and Foul Bays, Yorke Peninsula, South Australia

In contrast, Marion and Foul Bays (Yorke Peninsula) provide an example of study areas where no explanatory relationships have been found between historic shoreline changes and modelled fetch and swell wave climates. Each of these (adjacent) bays has shown a significant underlying shoreline accretion (progradation) trend along their (more swell-exposed) central and eastern parts between 1956 and 2006, with a net recession trend only in their (more swell-sheltered) western parts. With only relatively minor differences in the wind rose-weighted fetch indices for onshore wind directions, statistical analysis of shoreline change and both swell and fetch wave indices failed to identify any statistically-significant correlations or explanatory relationships between these.

The reason for this surprising result is presently unclear, however a possible explanation may lie at least partly in one of the most distinctive features of both beaches (and the reason for Foul Bays name), which is their rich subtidal seagrass beds that produce seasonal accumulations of seagrass wrack that can be seen to thickly mantle the beaches on historic air photo images. Given that thick wrack – which is mainly deposited onshore during storms - could both protect beaches from wave erosion and act as a sand-trapping mechanism, this may partly explain the historic behaviour of these shorelines although the observed distribution of wrack does not appear to explain the erosion at the west end of both beaches.

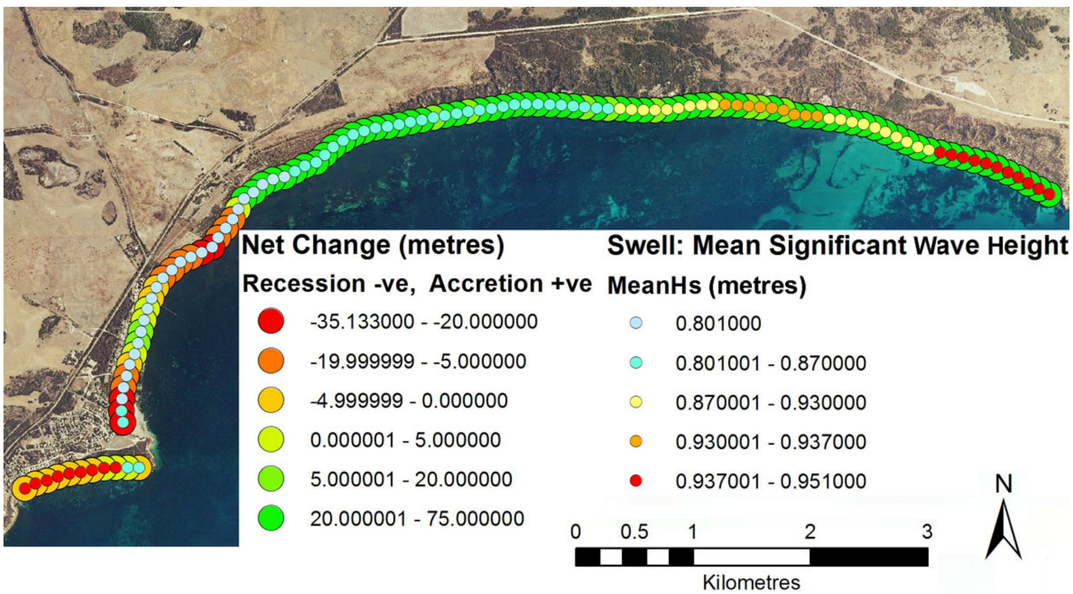

Figure 6: Example shoreline change and swell wave climate indices mapped at shoreline measurement points for Marion Bay, SA. No clear explanatory relationship between these or other shoreline change and wave climate indices is apparent, however a confounding factor here may be the rich seagrass beds (dark subtidal patches in the air photo) which result in seasonally thick accumulations of wrack on the beach.

Conclusions: Application and further development

The results to date from analysis of shoreline change data against modelled wave climate indices – whilst still in progress – indicate that meaningful correlations between modelled wave climate and historic shoreline behaviour can be found in at least a proportion of coastal situations where waves are the dominant process governing shoreline change. This supports the ShoreWave project aim of enabling at least some combinations of shoreline type (represented as Smartline landform erosion susceptibility classes) and modelled wave climate to be identified which can be mapped out at regional or even national scales as an improved 'CVI / CSI' type of predictive Coastal Erosion Impact Index (CEII) capable of broadly predicting likely shoreline behaviour (with and without sea-level rise) for a sufficient proportion of the shoreline as to be of value in regional – scale coastal vulnerability assessments.

We propose that such an index should not be produced as a simple numerical index (as is the CVI), given the limitations of such indices. Rather we propose that a CEII would better take the form of an attribute-based classification system wherein specific combinations of landform type (Smartline susceptibility classes) and modelled wave climate index type and range or magnitude would be identified as indicating shoreline segments with greater or lesser relative erosion risks (unless confounded by other controlling processes, which it is intended should also be added to the classification as additional independent attributes when ongoing work permits identification and quantification of explanatory relationships between these processes and shoreline behaviour).

In our view ongoing work to develop increasingly useful 'Second Pass' coastal erosion impact indices should focus on:

- Further identification and refinement of explanatory relationships between wave climate and shoreline behaviour, ideally using further case studies based on representative sites with good inshore and offshore measured wave climate data and good shoreline history data, where modelled wave climate indices such as those described here can be tested against actual measured wave climates; and
- Identification of coastal sites where processes and local conditions other than wave climate dominate or significantly modify shoreline behaviour, and investigation of the degree to which these can be quantified, modelled and incorporated into regional-scale predictive assessments; or else may be in practice only assessable by means of locally-detailed 'Third Pass' level site specific studies.

Although it can never fully eliminate a need for site-specific assessments, a successful 'Second Pass' level of regional assessment incorporating wave climate (at least) as a major driver of shoreline change will considerably improve upon that provided by 'First Pass' shoreline geomorphic type mapping alone (e.g., Smartline) and considerably reduce the current degree of uncertainty over shoreline behaviour at regional scales.

Acknowledgements

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