A detailed assessment of vulnerability to climate change in the Gold Coast, Australia

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ABSTRACT

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Coastal communities in the Gold Coast, Australia, are particularly vulnerable to climate change, considering their exposure to changing sea levels and storms, the sensitivity of the sedimentary system, and the current capacity to respond to future challenges. In this paper we assessed the overall vulnerability of Palm Beach, a Gold Coast suburb, by (i) modeling extreme storms under future sea levels (ii) modeling the response of the beach to extreme storms under future sea levels (iii) assessing the level of adaptation of coastal management and the adaptive capacity of the coastal community. Results show that sea level rise can trigger higher storm surges and extreme erosion events and that the current level of adaptation and adaptive capacity is still insufficient to cope with such challenges.

ADDITIONAL INDEX WORDS: *Sea level rise, Vulnerability, Coastal Management, Australia*

BACKGROUND

Climate change has the potential for major impacts to the Australian coastal zone, a highly dynamic and fragile environment, concentrating human settlements and strategic economic sectors (Department of Climate Change 2009). These changes may include (i) sea level rise, (ii) increasing frequency and intensity of extreme storms, (iii) a shifting wave climate, and (iv) other climatic changes not exclusively related to coastal areas (changes in rainfall patterns, extreme heat, droughts, etc.). Coastal communities in Australia are experiencing a population growth which is expected to continue in the future due to international and interstate migration trends (Smith & Thomsen, 2008). The area of study, Palm Beach, is a coastal suburb of the Gold Coast, one of the fastest growing regions in Australia, where the population is expected to grow by 70% in the next 20 years (Roiko et al. 2010). This area is currently characterized by (i) an increasing value of assets along the coastline, where re-development on top of the dune system is a common practice (ii) a high demand for beach use as a resource for both residents and tourists (Raybould & Lazarow, 2009) and (iii) potential conflicts to implement coastal protection and adaptation strategies (Lazarow et al. 2008). The combination of these issues – climatic change, growing population and increasing costs of management strategies – make the understanding of vulnerability and its communication to coastal managers and the community a fundamental milestone towards the identification and implementation of adaptation options for the future.

METHODOLOGY

This study adopts the definition of vulnerability and its components – exposure, sensitivity and adaptive capacity – proposed by the IPCC's Fourth Assessment Report, where vulnerability is understood as "[…] a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC 2007). While numerous methodologies for vulnerability assessments have been developed and tested in the past (see e.g. Abuodha & Woodroffe, 2006; Preston et al., 2008), we chose here to assess the overall vulnerability of the system as a combination of three components:

(i) the exposure to changing sea levels and storms, by assessing the impact of sea level rise on already catastrophic extreme events, using a hydrodynamic model forced by a specific re-constructed storm of the past (East Coast Low (ECL) of May 2009) combined with future sea level rise scenarios.

(ii) the sensitivity of the beach system, by assessing the impact of sea level rise on beach erosion during the same extreme event (ECL of May 2009) using a morphodynamic model combined with future sea level rise scenarios.

(iii) The adaptive capacity of the coastal settlement, as a function of (i) the level of adaptation of the current coastal management framework and (ii) of the socio-economic profile of the area of study based on a socio-economic disadvantage index.

The assessment is based on the current situation and on two scenarios of sea level rise: 0.5 m by 2050 and 1 m by 2100.

STUDY SITE: PALM BEACH, AUSTRALIA

The area of study is Palm Beach, a 5 km coastal stretch in the central Gold Coast, Australia (Figure 1), where sedimentary systems and human settlements are especially exposed to the impacts of extreme storms. In the area, the increasing popularity of coastal living has resulted in increased levels in coastal development, often poorly planned with little consideration of the potential for erosion of the beaches. During the last century there have been several periods of intensely active cyclonic and storm activity that have tested the defenses of coastal infrastructure built on the active area of the beach. The worst impacts of erosive events and structural damage to properties in Palm Beach has occurred in 1967, 1972 and 1974. Storms in May 1996 and as recently as May 2009 have also highlighted the vulnerability of this section of the coast.

The identification of the lack of an adequate buffer to maintain a usable beach following severe storm events and to prevent damage to property led the Gold Coast City Council to develop a strategy for the protection of the Palm Beach foreshore areas, ultimately protected by a seawall buried below semi-artificial sand dunes. Erosion events in 1996 and 2000 exposing the seawall along sections of Palm Beach were the final triggers to develop the Palm Beach Protection Strategy proposing a set of actions including (i) the upgrading of the boulder sea wall, (ii) dredging and nourishment from offshore and from the adjacent creeks and (iii) the construction of coastal control structures to help maintain the nourishment (Lazarow et al. 2008). Early attempts to implement the strategy encountered strong opposition from the local community of beach users – in particular surfers – concerned with the potential impacts on the quality of the surf and beaches. The Gold Coast City Council opted to stand back and undertake a broader whole-of-coast assessment of management options and no major coastal protection works have been undertaken at Palm Beach in the last 10 years, although it does receive annual nourishment as a result of creek dredging.
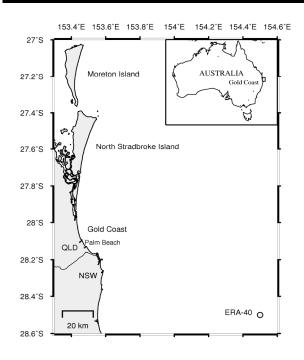

Figure 1. Location of Palm Beach in the Gold Coast, south east Queensland, eastern Australia.

EXPOSURE TO CHANGING STORMS AND SEA LEVELS

Historical evidence shows that the coastline where the area of study is included is highly variable over time scales of decades and centuries and subject to catastrophic storms mainly driven by Tropical Cyclones (TC) and East Coast Lows (ECL). While average and extreme wave climate is characterized by a large variability (Hemer 2010), studies are being carried out to better understand how the wave climate and extreme events will be in the future (Hemer et al. 2009). Preliminary outcomes of these studies have not detected major changes in the wave climate and extreme events, but more detailed information will be available in the near future.

On the other hand, sea level in the area of study has been rising in the past and it is very likely that it will rise in the future. While global mean sea level has risen at a rate of about 1.7 mm per year since the industrial revolution, in Australia figures are slightly lower as sea level rose by about 17 cm between 1842 and 2002, about 1 mm per year (Church et al., 2008), whereas an accelerating sea level rise is being recorded since the early nineties (Church & White, 2006) with approximately 2 mm of sea level rise per year for the area of study in the last two decades (NTC BOM, 2010). In terms of projections, the IPCC Fourth Assessment Report estimated global sea level rise of up to 59 cm by 2100, but more catastrophic figures are predicted if ice melting is included, and sea level will continue to rise after 2100 (Nicholls & Cazenave, 2010). In Eastern Australia the influence of a warming East Australian Current moving further south makes the sea level rise projections greater than the global level (Department of Climate Change, 2009). Current figures of sea level rise for the area of study, also adopted by the Queensland Government for coastal planning purposes, are based on a combination of the results of the IPCC AR4 with regional variations from the global averages assessed by CSIRO, the leading Australian research organization (CSIRO, 2011), identifying approximately 0.8 meters of sea level rise by 2100 (Queensland Government 2011). Based on this information and other recent sources (e.g. Lowe & Gregory 2010) we chose two plausible scenarios of sea level rise, 0.5 m by 2050 and 1 m by 2100, to be integrated in a hydrodynamic model (this section) and a morphodynamic model (next section) of one specific extreme storm of the recent past, the ECL of May 2009, an event with an estimated return period of approximately 5 years.

To perform the hydrodynamics and wave simulations, we first conducted a simulation of the ECL using the Weather and
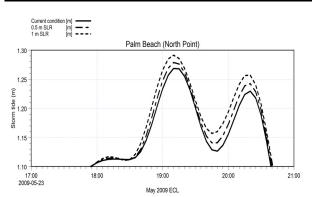

Figure 2. Storm tide level in Palm Beach offshore point due to current condition and SLR scenarios.

Research Forecasting (WRF) limited-area meteorological model (Skamarock & Klemp, 2008). NCEP Operational Global Analyses at 1 degree resolution were used to initialize WRF and provide lateral boundary conditions for the duration of the simulation. The model consisted of three internally nested grids, resulting in a horizontal grid spacing of 4.5 km over the area of interest. Output from the model in the form of wind velocity at 10 m above sea level and atmospheric pressure at mean sea level, both at a temporal resolution of 30 minutes, were used to force the hydrodynamics model (MIKE21 HD) and spectral wave models (MIKE21 SW).
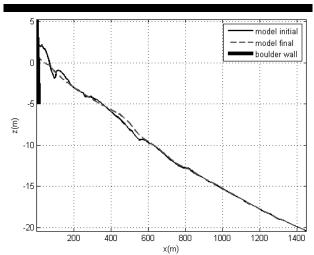

Figure 3. Response of the profile ETA32 to May 2009 storm with 1 m sea level rise

This procedure was performed for the current condition and two scenarios of sea level rise: 0.5 m by 2050 and 1 m by 2100. This simulation was performed by adding respectively 0.5 m and 1 m to the current bathymetry. We assumed therefore that offshore contours will not change in the future, while major changes might occur near shore and above the closure depth. The results show that deeper waters, associated with sea level rise, increase the storm surge level by approximately 5 cm. This value was measured at two points at approximately 20 m depth. Figure 2 shows the results for one of those points. Based on this, we can expect that when the storm surge will propagate near the shore, the increase will be even higher.

SENSITIVITY OF THE BEACH TO FUTURE EXTREME EVENTS

To understand how the beach will respond to sea level rise, we used XBeach, a state of the art, process-based sediment transport model designed to estimate erosion under extreme conditions (Roelvink et al., 2010). The model was calibrated using the May 2009 ECL using a beach profile from the northern end of the coast approximately located near the offshore wave buoy. The calibration results suggest the model is capable of giving qualitative estimates of erosion potential and can be used for scenario testing with reasonable confidence where the focus is on erosion of the upper beach profile. For modeling purposes, start and end dates of the storm were defined by first and last exceedances of offshore significant wave heights, H_s, greater than

Table 1: XBeach results for May 2009 storm with SLR predictions added onto total water levels

Profile	slr	Vdry, prestorm (m3/m)	ΔVdry (m3/m)	Xs, prestorm (m)	ΔXs (m)
32	0.5	128	-110	64	-45
32	1	122	-118	56	-55
36	0.5	219	-116	74	-21
36	1	214	-157	67	-28

2 m. Modeled wave conditions were updated every 30 minutes based on buoy data. Water levels were updated every 10 minutes using measured water levels.

The effect of increasing sea level rise is hard to reliably predict as it is expected that beaches will slowly adjust to small increases in sea level over the next 50 – 100 years. As a first estimate, the Bruun Rule suggests an increase in sea level will cause a shoreward recession of the shoreline and a readjustment of the profile. Roughly, this can be estimated as 1 m of retreat for every 1 cm of sea level rise (based on a 1:100 sloping beach). For example, given that current profile at ETA 32, with approximately 70 m of beach-dune width, we could expect very little dry beach width to be present with sea level rise scenarios of 0.5 – 1 m, equivalent to 50 – 100 m of shoreline retreat due to sea level rise if extensive nourishment is not available to sustain the current profile. Hypothetical scenario testing of the June 2010 bathymetry with the May 2009 storm and 0.5 and 1 m of sea level rise cases were run to examine the changes in potential beach erosion due to sea level rise if profiles could be maintained. The effect of sea level rise means waves directly impact the upper beach more frequently, leaving the boulder sea wall exposed. Results are summarized in Table 1. Increasing water levels result in larger changes to shoreline position and dry beach volume (each measured from the new mean sea level position). For example, the profile ETA 32 erodes back to the boulder wall under both sea level rise scenarios. Figure 3 shows the outcomes of the simulation with 1 m sea level rise.

ADAPTIVE CAPACITY OF THE COASTAL SETTLEMENT

The adaptive capacity of a system can be defined as the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001). The adaptive capacity of a coastal community can therefore vary, depending on different variables: technological options, economic resources, legal and institutional framework, social awareness, among others. As a result, adaptive capacity is unevenly distributed across coastal communities of a given region. In this study we chose to look at two specific determinants of the adaptive capacity of the area of study: (i) the level of adaptation of the coastal management framework, using a multicriteria assessment of the existing adaptation functions and (ii) the socio-economic profile, by assessing the level of the relative socio-economic disadvantage index (Australian Bureau of Statistics, 2006) as a relative measure of its adaptive capacity.

Table 2. Framework for the assessment of the level of adaptation of the coastal management system. The Adaptation functions, adapted from World Resource Institute (2009), represent a set of steps towards adaptation. The adaptation criteria, adapted from Hallegatte (2009), are used for an assessment of each identified adaptation investment against a set of criteria. "++" means always, "+" means some times, "-"means never"

		Identified adaptation investment	Adaptation quality criteria					
			Reversibility/ /Flexibility	Synergy with ecosystems	Economic sustainability	Conflict with stakeholders	Synergies with mitigation	Shorter decision horizon
Adaptation functions	Climate adaptation strategy	*Climate Change Strategy Gold Coast Gold Coast City Council, 2009)*	+	+	+	+	+	+
	Adaptation of sectoral plan	*Draft QLD Coastal Management Plan (Queensland Government, 2011)*	+	++	+	+	-	-
	Cross-sectoral adaptation	*No adaptation function was identified*	N/A	N/A	N/A	N/A	N/A	N/A
	Adaptation of infrastructure-coastal defense – criteria	*No adaptation function was identified*	N/A	N/A	N/A	N/A	N/A	N/A
	Adaptation of ecosystems management	*No specific adaptation function was identified*	N/A	N/A	N/A	N/A	N/A	N/A
	Community engagement in adaptation	*No specific adaptation function was identified*	N/A	N/A	N/A	N/A	N/A	N/A

To assess the level of adaptation of the current coastal management framework we recently proposed an approach to benchmark the level of adaptation of coastal management systems against a set of adaptation steps and adaptation criteria (Sano et al., 2010). This framework combines adaptation functions or steps towards full adaptation, adapted from the World Resource Institute (2009), with adaptation criteria adapted from Hallegatte (2009). This assessment is carried out by identifying adaptation "functions" or investments (including vulnerability studies, overall adaptation strategies, modification of existing instruments, etc.) and benchmarking them against a set of adaptation quality criteria. Here we identified two different "functions" which were fitted in the first two steps of the adaptation process, and we assessed them against the set of adaptation criteria. At this stage functions include the council's Climate Change Adaptation Strategy and the state's Draft Coastal Plan. While more adaptation functions can be identified and assessed covering the first two steps ("Development of a climate adaptation strategy" and "Adaptation of sectoral plans"), we couldn't identify specific functions fitting in the following steps of the adaptation process ("Cross-sectoral adaptation", "Adaptation of the infrastructure criteria", "Adaptation of ecosystems management", and "Community engagement in adaptation"). Far from being a complete policy analysis, this assessment shows how these adaptation investments or "functions" are contributing to the pathway towards adaptation of the coastal management framework and how these can be assessed against specific adaptation criteria. As a result, we can say that the coastal management framework applicable to the study area is going through an adaptation process, by providing the initial framework for adaptation (broad strategies and adaptation of sectoral plans). At the same time, these investments meet only some adaptation quality criteria, with margins for

improvement. Further adaptation functions are still to be addressed, especially those related with managing the impacts of extreme erosion events under future climate scenarios.

The adaptive capacity of the coastal community was assessed by looking at the index of relative socio-economic disadvantage (Australian Bureau of Statistics, 2006), which was also recently used as part of an assessment of social and economic trends and adaptive capacity in South East Queensland by Roiko et al. (2010). This index combines variables related to income, education, employment, occupation, housing, and other specific disadvantage variables (e.g. disabilities, one-parent family, etc.) collected by the Australian census. In this study, we assessed the value of the index for Palm Beach against other beachfront coastal suburbs with similar geographic characteristics, included in the same local government area, the Gold Coast. We found out that Palm Beach has the second lowest score out of eight similar coastal suburbs identified in the Gold Coast, depicting a situation of relatively lower capacity of the coastal community to adapt to extreme events and climate change. No projections for this index are available for the future; however, Roiko et al. (2010) used the projected pension payments for the Gold Coast as an indicator of future disadvantage, reflecting an ageing population which implies a lower adaptive capacity in the future.

CONCLUDING REMARKS

In this paper we proposed an integrated assessment of vulnerability based on the analysis of the exposure, sensitivity and adaptive capacity. The analysis highlighted some specific issues which might emerge under future climate change scenarios: higher storm surges - even higher than those expected with only sea level rise - can trigger erosion events producing major damage to infrastructure and, potentially, to the most exposed settlements.

The capacity of the coastal management system to cope with such challenges is still low, despite some early adaptation steps. On top of this, the coastal community is relatively more disadvantaged compared to others in the same region, with a consequently lower capacity to adapt. These outcomes highlighted the need for integrated strategies to mainstream no-regret climate change adaptation measures into (i) shoreline management and coastal defense, (ii) urban planning in coastal settlements and (iii) community aptitude and behavior.

FUTURE WORK

More variables should be included in the future, including wave climate and sediment transport projections, detailed inundation maps based on the propagation of the storm surges in shallow waters and higher resolution socio-economic and infrastructure data. Also, the combination of a more complete dataset with the probability of occurrence of the events can give a better description of the risks to coastal communities and infrastructure. Finally, improving the resolution of the assessment and extending it to other areas will support the identification of priority locations for adaptation investment.

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