A Fresh Approach to Assessing Climate Change Impacts on Coastal Hazards

6 November 2008

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Today's Talk

- Past approach to Coastal Hazards Definition Studies
- Recent climate change predictions
- Assessing climate change as part of each coastal hazard
- Natural variability in shoreline shape and position – the immediate beach erosion hazard
- Using shoreline variability to assess the future beach erosion hazard, due to climate change
- Accomodating uncertainty through use of probabilities

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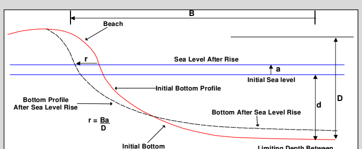
Past Approach to Hazard Definition Studies

- Coastline Management Manual (1990) – Climate Change as a discrete hazard
- Past Hazards Definition Studies – sea level rise only
- Sea level rise with the Bruun Rule
- Beach erosion hazard with photogrammetry for one design storm event



The Bruun Rule of 1962

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Recent Climate Change Predictions

- Range of new predictions:
  - storm surge
  - wave direction
  - wave height (H_s max, H_s mean)
  - storm frequency
  - regional sea level rise
  - Rainfall intensity
  - Annual rainfall

  (McInnes et al (2007); Macadam et al (2007)
- Predictions have large ranges, eg: -20 to +48 % change in frequency of storm waves from SE + S direction.

Prediction					Reference	Comments
		Current	2030	2070		
			% change	% change		
Extreme rainfall events	Annual at Wooli Wooli		-10 to 0	-10 to +10	Macadam *et al*. 2007	
Average total Rainfall	Annual at Wooli Wooli		-6 to 0	-19 to 0	Macadam *et al*. 2007	
Storm Surge	100 year return period	0.61 +/- 0.12 (m)	+/- 1	-3 to +4	McInnes *et al*. 2007	Actual change is 1 - 3 cm
			metres	metres		
Mean Sea Level Rise	On top of global 0.18 - 0.59 m by 2095		0 - 0.08	0 - 0.12	McInnes *et al*. 2007	
Storm Wave Frequency by direction		1980	2030	2070	McInnes *et al*. 2007	All values including 1980 are based upon output from CCM2 & CCM3 models
		Events observed	% change	% change		
	S + SE direction	17.5	-8 to +13	-20 to + 48		
	NE Direction	0.6	-40 to +100	-73.3 to 0		
	E Direction	3.1	-49.5 to +2.7	-54.5 to +35.1		
	SE Direction	7.9	-35.6 to -23.6	-34.4 to +50		
	S Direction	9.6	+3.9 to +34.1	-13.7 to +46.3		
Storm Maximum Wave Height (Hs Max)		1980	2030	2070	McInnes *et al*. 2007	All values including 1980 are based upon output from CCM2 & CCM3 models
			% change	% change		
	S + SE direction		0 to 3	-15 to +9		
		Max Hs (m)	Max Hs (m)	Max Hs (m)		
	S + SE direction	5.3-6.7	5.3-6.9	5.6-5.8		
	NE Direction	3.1-3.8	3.5-3.6	3.6-3.9		
	E Direction	5.0-7.0	6.0-6.2	5.3-7.8		
	SE Direction	5.0-6.9	4.9-6.4	5.9		
	S Direction	5.4-6.6	5.5-7.1	5.5-5.7		
Swell Waves from predominant SSE direciton (135-180 Deg TN)		1980	2030	2070	McInnes *et al*. 2007	All values including 1980 are based upon output from CCM2 & CCM3 models
		Deg TN	Deg TN	Deg TN		
		159.4	158.6-159.6	159.4-160.6		
			Deg change	Deg change		
			-0.8 to +0.3	0.1 to 1.2		
		% occurrence	% occurrence	% occurrence		
		25.3 - 26	25.7 - 26.3	25.3 - 28.0		
		Mean Hs (m)	Mean Hs (m)	Mean Hs (m)		
		1.2 - 1.4	1.3-1.4	1.3-1.4		
Swell Waves from full directional range (10-190 Deg TN)		1980	2030	2070	McInnes *et al*. 2007	All values (including 1980) based upon output from CCM2 & CCM3 models
		Mean Direction (Deg TN)	Mean Direction (Deg TN)	Mean Direction (Deg TN)		
		100.7-109.2	101.3-106.1	99.4-105.9		
			Deg Change	Deg Change		
			-3.1 to +0.6	-1.3 to - 3.3		
		Mean Hs (m)	Mean Hs (m)	Mean Hs (m)		
		1.2-1.3	1.2	1.2-1.3		

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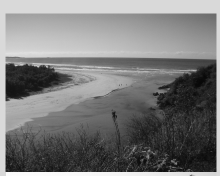
Climate Change and Hazard Definition

- Recent predictions - no longer appropriate to define climate change as a separate hazard.
- Climate change will modify main driver of coastal processes, ie wave climate
- Impact of climate change now needs to be:
  - defined for each coastal hazard and
  - defined for future planning periods, eg (50 yr, 100 yr)
- Examples: Coastal Entrances; Coastal Inundation.



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Climate Variability and Future Climate Change Response

- South East Australian wave climate: predominantly from SSE direction, high energy
- Inter-annual (years +) variability in wave climate has been linked with the El Nino Southern Oscillation (ENSO)
- During La Nina (+ve SOI)
  - wave direction is (slightly) more northerly (easterly)
  - greater wave power due to increased frequency of storms
- During El Nino (-ve SOI)
  - wave direction is (slightly) more southerly
  - Reduced wave power due to fewer storms
- Example: Coffs storm severity and SOI…

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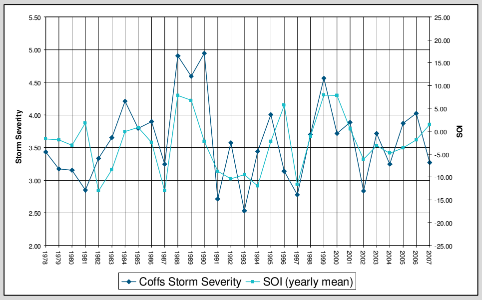
Example: Storminess Vs SOI



Correlation coefficient: 0.54 (p-value = 0.002)

Beach Response to Wave Direction

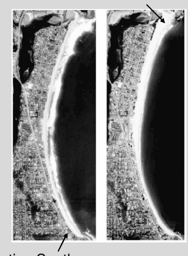
Beach Rotation:

Short *et al* (2000), Ranasinghe *et al* (2004)

- Southern end eroded when northern end is accreted, and vice versa
- Longshore sediment transport driven by wave direction…
- More southerly waves; southern end erodes, northern end accretes. Associated with El Nino.
- More northerly waves; northern end erodes, southern end accretes. Associated with La Nina.
- Example – rotation at Campbells Beach…

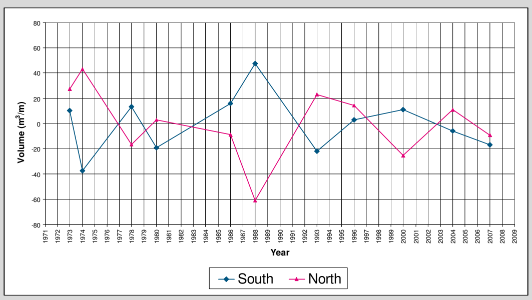
Narrabeen Beach, from Ranasinghe *et al.* (2004)

Accretion North



Accretion South

Example: Rotation at Campbells Beach

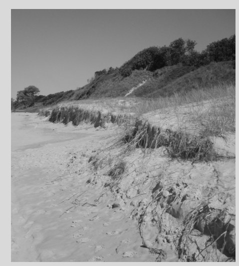


Correlation coefficient: -0.79 (p-value = 0.004)

Beach Response to Storm Frequency

Beach Oscillation

- Erosion – accretion across entire beach
- Landward – seaward movement of profile
- Periods of high storm frequency (La Nina) – general erosion of entire beach
- Calmer periods (El Nino) – general accretion of entire beach
- Individual storm wave heights may be equally large during calm (El Nino) or stormy (La Nina) periods
- Beach is more or less able to withstand storm attack.

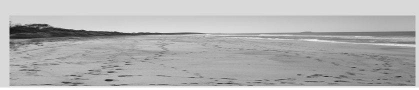


Exceptional Events

- May-June 1974 = 100 year ARI (central, south NSW)
- Moruya Beach = 93 m^3/m erosion over a 7 week period. (McLean & Shen, 2006)
- Severe beach erosion due to a series of storms, over a longer period of increased storm frequency
- Very high rates of erosion and accretion over 1974 – 1983, compared with following decades
- Such storm periods may be a combination of climatic anomalies, eg, strong La Nina, strong –ve IPO, SAM…

The Beach Erosion Hazard

- Greatest extent of erosion occurs as part of longer periods (years) of high storm occurrence, not just one storm of 100 ARI wave height
- Subtle but persistent changes in wave direction cause erosion at ends of the beach, eg
  - Beach rotation: ~ 60% of shoreline change on Narrabeen Beach (Short *et al* 2000)
  - Beach oscillation: 80 m on Narrabeen Beach (ie, landward – seaward movement of profile).
  - 30 m of this = beach rotation (Short & Trembanis 2000)
- Most landward shape and position of the beach (ie, extent of rotation and oscillation) forms the beach erosion hazard



Available Data to Assess Beach Erosion Hazard

- Photogrammetry: “snapshots” of beach profile change = short, medium and long term events.
- Photogrammetry back to 1942 (where possible)
- Wave time series data: from 1976 to present
- Wave direction data: from 1992 at Sydney, 1999 at Byron Bay to present
- Adding the SOI: measured since 1876
- Goodwin’s hind-cast wave directional time series: from 1878, eg:
  - 4 – 5º more southerly wave direction between 1894 – 1914
  - Implies greater erosion in southern hooks/ends of connected/embayed beaches.

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Method for Defining Beach Erosion Hazard

1. Determine the extent of beach response to wave direction, wave height, and the SOI

- Compare photogrammetry with recent (weeks – months) and longer (1 yr +) wave climate history
- Is rotation occurring between profiles?
- What is the extent of rotation due to:
  - wave direction
  - wave height / storm severity
  - the SOI
- What is extent of erosion/accretion due to:
  - wave direction
  - wave height / storm severity
  - the SOI

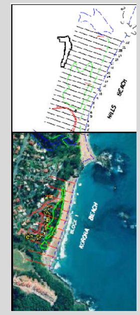

Diagram from DECC 2007

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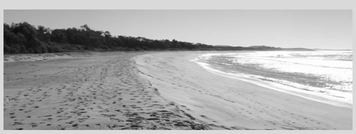
Immediate Beach Erosion Hazard

2. Determine probable shoreline positions and shape in period prior to photogrammetry

- Determine more extreme events prior to photogrammetry data:
  - Periods of more southerly and / or northerly wave direction
  - More extreme La Nina, El Nino cycles
- Use known beach response from photogrammetry to estimate response to the extreme periods
- The most landward position of beach profile due to past rotation and erosion = immediate beach erosion hazard



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Future Beach Erosion Hazard due to Climate Change

Use known shoreline response to forecast future response

- Shoreline response to future wave directions, eg:
  - Predict erosion at southern end using known erosion response to southerly wave directions
- Shoreline response future storm frequency eg:
  - Predict landward movement of beach profile using known response to storm events.
- Define most probable landward position of shoreline due to rotation and erosion due to future climate in 50 and 100 years .

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Limitations

- Difficult to separate short, medium and long term trends from sporadic photogrammetry dates. Includes separating long term recession trends
- Beach rotation and link with SOI - so far only researched for embayed beaches with fine-medium grained sand.
- Response of beaches with coarse grained sand, gravels, reefs, connected “leaky” embayments etc to inter-annual and inter-decadal wave variability not yet defined
- For Coffs – may need to develop theoretical models for beach compartments (maybe > 1 beach), and response to wave climate.
- There is a wealth of work to assist eg, on connected embayments, coarse grained sands, etc

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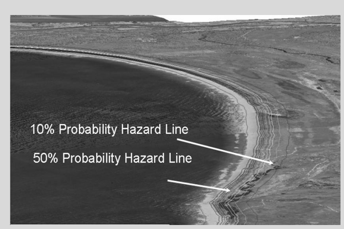
Accommodating Uncertainty

Uncertainty due to:
- Assumptions in methods
- Limitations of methods
- Lack of data
- Complexity of coastal processes

Uncertainty about climate change:
- What climate patterns will change?
- To what extent?

- **Define hazards by probabilities**, rather than absolute lines on a map
- Suits risk-based approach frequently adopted by councils



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Take home messages

- Climate change is not a discrete hazard - It will modify the all of the coastal processes.
- Need to define a future hazard extent for all coastal hazards due to climate change.
- Shoreline variability (rotation, erosion/accretion) is linked with wave climate variability and ENSO, over years to decades.
- Defining shoreline variability links to wave climate provides a method to define beach erosion under a future climate
- Shoreline variability moves away from focus on the individual storm demand
- Hazards outputs will take the form of probabilities, rather than discrete hazard lines, to account for uncertainty

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