



Coastal vulnerability, climate change, impacts and adaptation: integrated solutions.

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Presentation Structure:

- Shoreline behaviour
- Coastal development and understanding problems
- Vulnerability
- Assessing climate, impacts and adaptation
- Conclusions and Recommendations

What is the true cost of a
sea view?

- What is the cost?
- Who will pay?
- Who decides?
- **Lost to the memory** e.g
1911 Royal Commission
on Coastal Erosion and
Afforestation:
**“Seawalls are agents
of their own
destruction”**

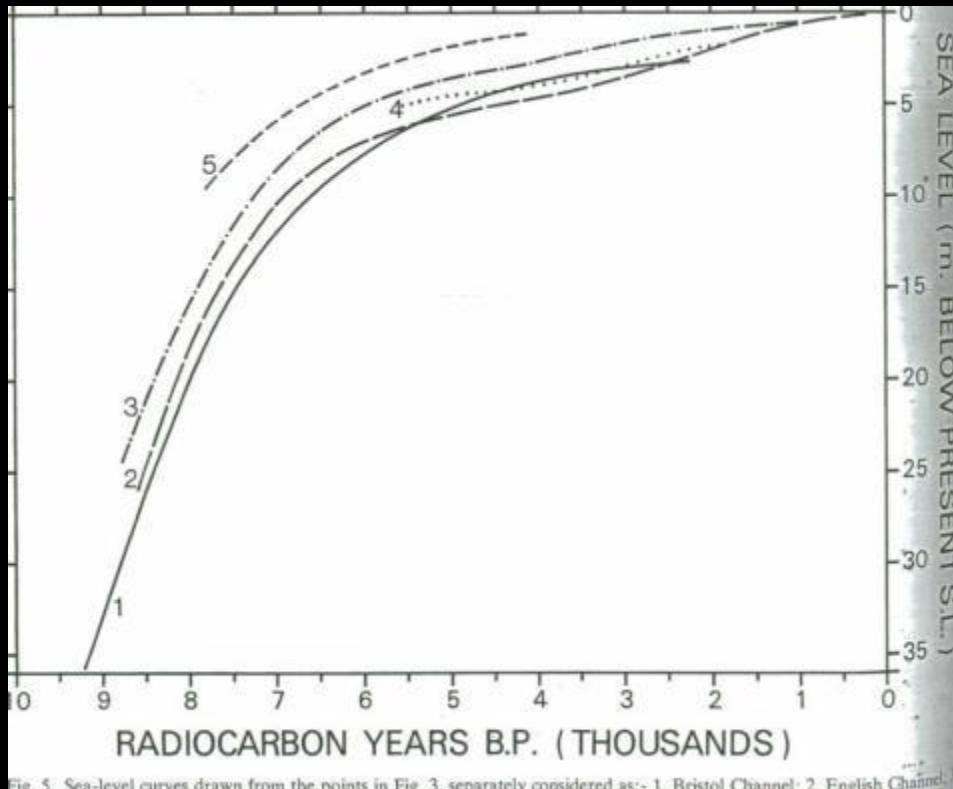
Ketchum (1972) 'The Water's Edge' defined human use as:

- Residency
- Commercial and industrial
- Agriculture, aquaculture and fishing
- Recreation and tourism
- Waste disposal
- Conservation
- Military and strategic

Sauer (1961) in Leighley's 'Land and Life'

- Geography and geology are the fundament on which the ecosystem evolves. The cultural environment superimposes itself on the physical environment and interactions occur.
- Environmental management is the integration of physical and cultural environments.

Sea Level Rise



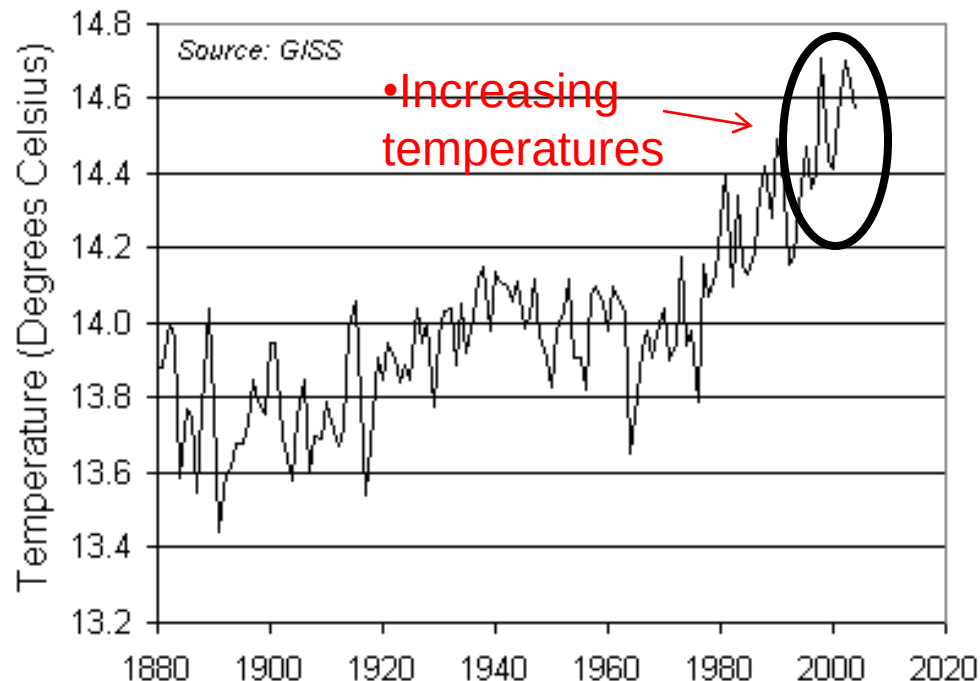
(Heyworth and Kidson, 1982)

Last Glacial Maximum (20,000 years ago) 120m below present day sea level (Woodworth, 2000)

- Sea level is one of the principal determinants of shoreline position (Leatherman, 2001).
- Predicted annual sea level rise (6mm - Douglas, 2001; 8mm – Crawford and Thompson, 1999).
- Threatens many “low lying parts of the inhabited world” (Wunsch *et al.* 2007: 3.)
- Large populations live in coastal areas (Andersen *et al.* 2002).

Climate Change

Average Global Temperature, 1880-2004



- Sea level; not the same everywhere (varies by location) and adding to this, changes in sea levels globally are therefore not uniform.

- Climate Change

- High tides

- Increased storm intensity and frequency (Kevin *et al*, 2004)

- Rise in sea level has been shown by historical tide gauges (Cazenave *et al*, 1998).

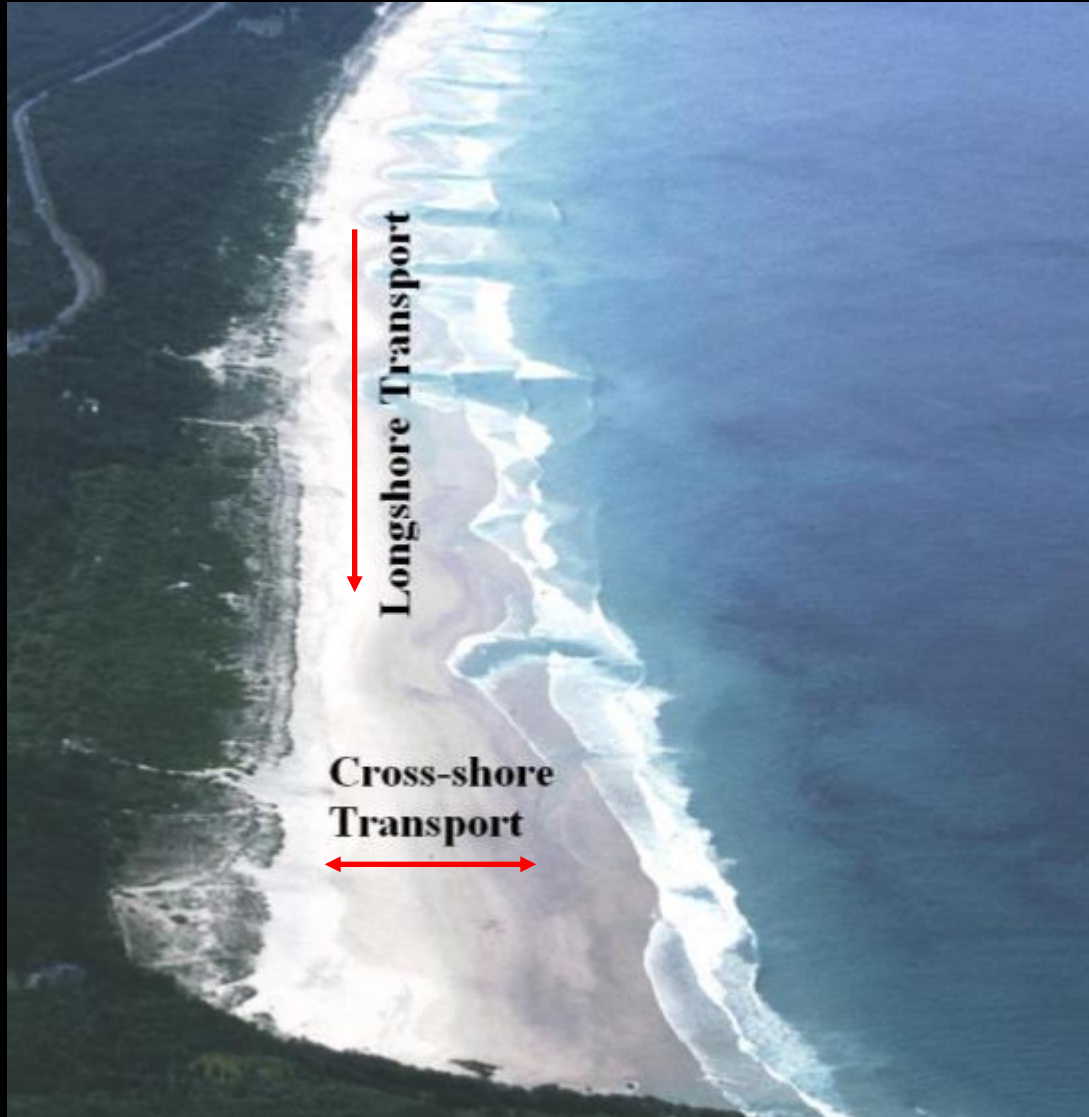


Erosion: Causes and Responses

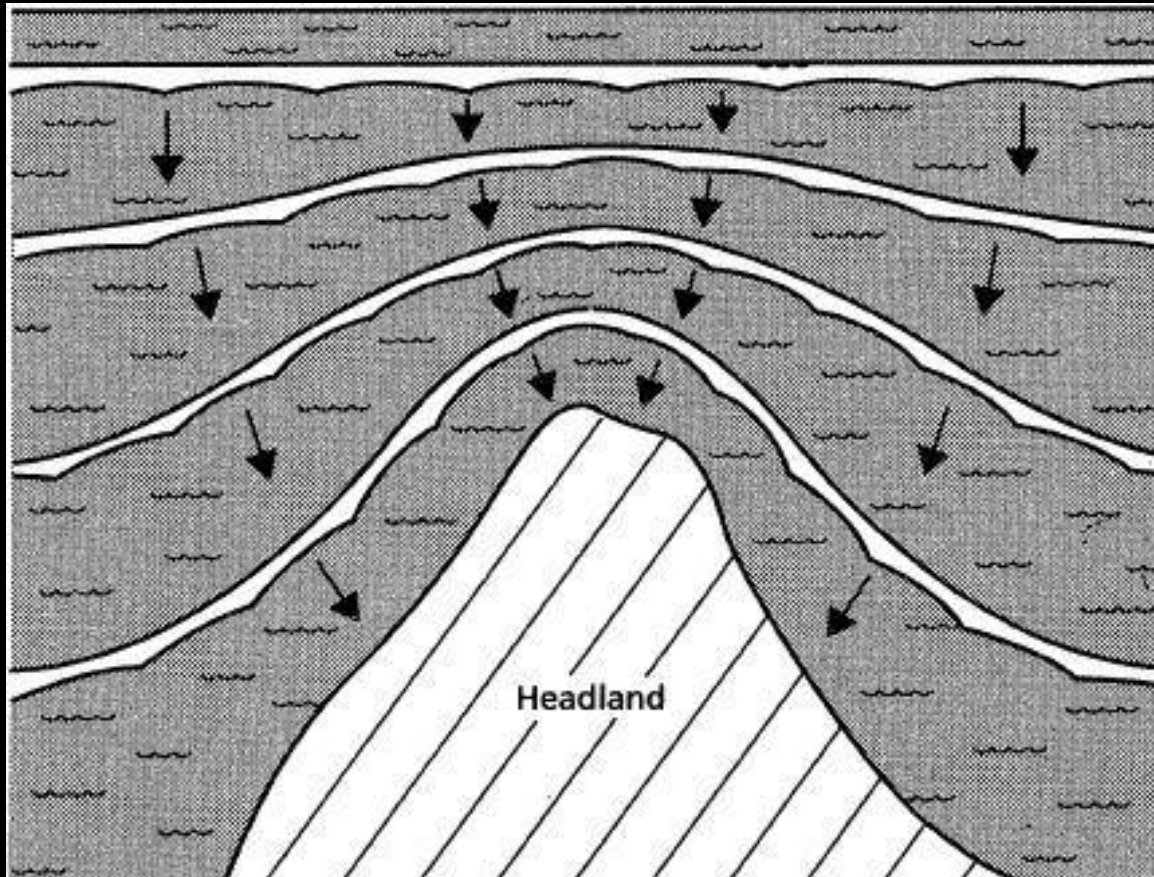
- Storms
 - Sea level rise
 - Coastal Infrastructure
 - Reduction in sediment supply/dredging
-
- Advance the line (seawalls, nourishment)
 - Hold the line (seawalls, nourishment)
 - Retreat from the line (relocate)
 - No active intervention

Country	% of eroding coastline	Country	% of eroding coastline
Belgium	25.5	Italy	22.8
Cyprus	37.8	Latvia	32.8
Denmark	13.2	Lithuania	24.3
Estonia	2.0	Netherlands	10.5
Finland	0.04	Poland	55.0
France	24.9	Portugal	28.5
Germany	12.8	Spain	11.5
Greece	28.6	Sweden	2.4
Ireland	19.9	United Kingdom	17.3

Of the 875 km of European coastlines that started to erode within the past 20 years, 63% are located less than 30 km from coastal areas altered by recent engineering works (Europa, 2010).



Cross-shore transport or on-shore off-shore movement is often critical in beach erosion. This movement occurs during storms.



- **Constructive (surging or spilling) waves result from swell and will move material up the beach. Low in height (<1m), long wave lengths (up to 100m between crests) and long wave periods (6 to 8 breaking per minute);**
- **Destructive (surfing or plunging) waves result from additional energy during storms and will move material down the beach. Height (>1m), short wave length (about 20m between crests) and more frequent wave period (10 to 14 breaking each minute)**
- **Winter wave average 11 tonnes m⁻² (3 times greater in storms – sea defences)**

Beach systems are dependent on four factors:

- **Hb** Wave height
- **T** Wave period
- **Ws** Sediment size (fall velocity)
- **TR** Spring tide range

**These can be quantified using the dimensionless fall velocity
(Gourlay 1968; Wright & Short, 1984)**

$$\Omega = Hb/T Ws$$

**Relative tide range (Masselink & Short, 1993)
 $RTR = TR/Hb$**

Based on RTR beaches classified into three beach types

- **Wave-dominated**
RTR <3
- **Tide-modified**
RTR 3-10
- **Tide-dominated**
RTR 10-50+

Based on Ω each type can be classified into 13 beach states

**6 wave - dominated
3 tide - modified
4 tide - dominated**

Wave dominated



Tide Modified



Tide Dominated





Coastal redevelopment strategy

Three locations:

Llanelli Beach;

New Earth Sculpture;

Burry Port Harbour.

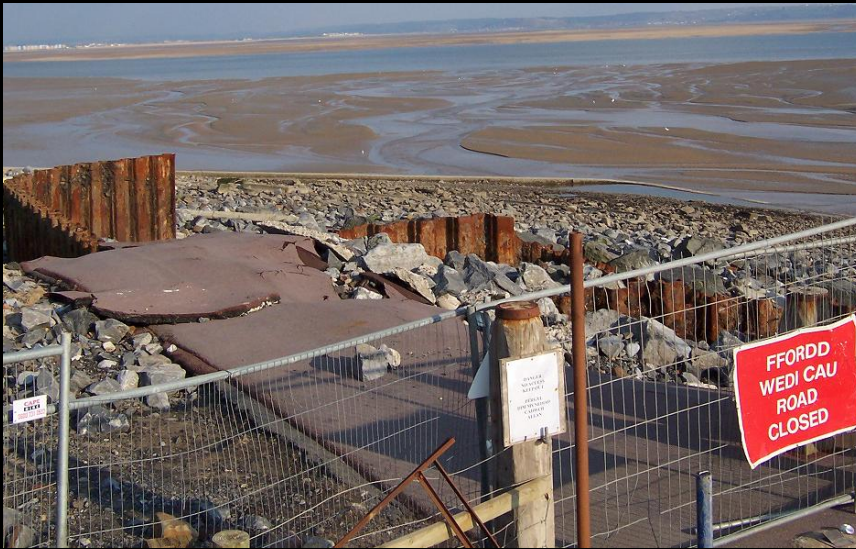
Linked by the Lottery funded
Millennium Coastal Path
(Signature structure), part of the
Millennium Coastal Park



- The Earth Sculpture lies off the main path and is built into the sea to create an artistic feature that can be seen from Llanelli, the Gower and the sea (Richard Harris).

- Its design incorporated the use of materials taken from the old power station spoils, Pulverised Fuel Ash being one of the main construction materials.

- The design included a beach inset into the curl of the sculpture.



- Consequences of March 2007 storm – structural collapse – 150m lost;
- If the path is completely lost within seventy-five years then the Lottery funding would have to be repaid;
- **Not financially feasible – management problem!**

(CCC, 2007)



- Significant erosion of the earth sculpture (direct and refracted wave attack) - 10m retreat (CCC, 2007);
- Fence posts strewn across the beach;
- PFA leaching onto constructed beach;
- Current management via gabions and small quantities of rock armour.

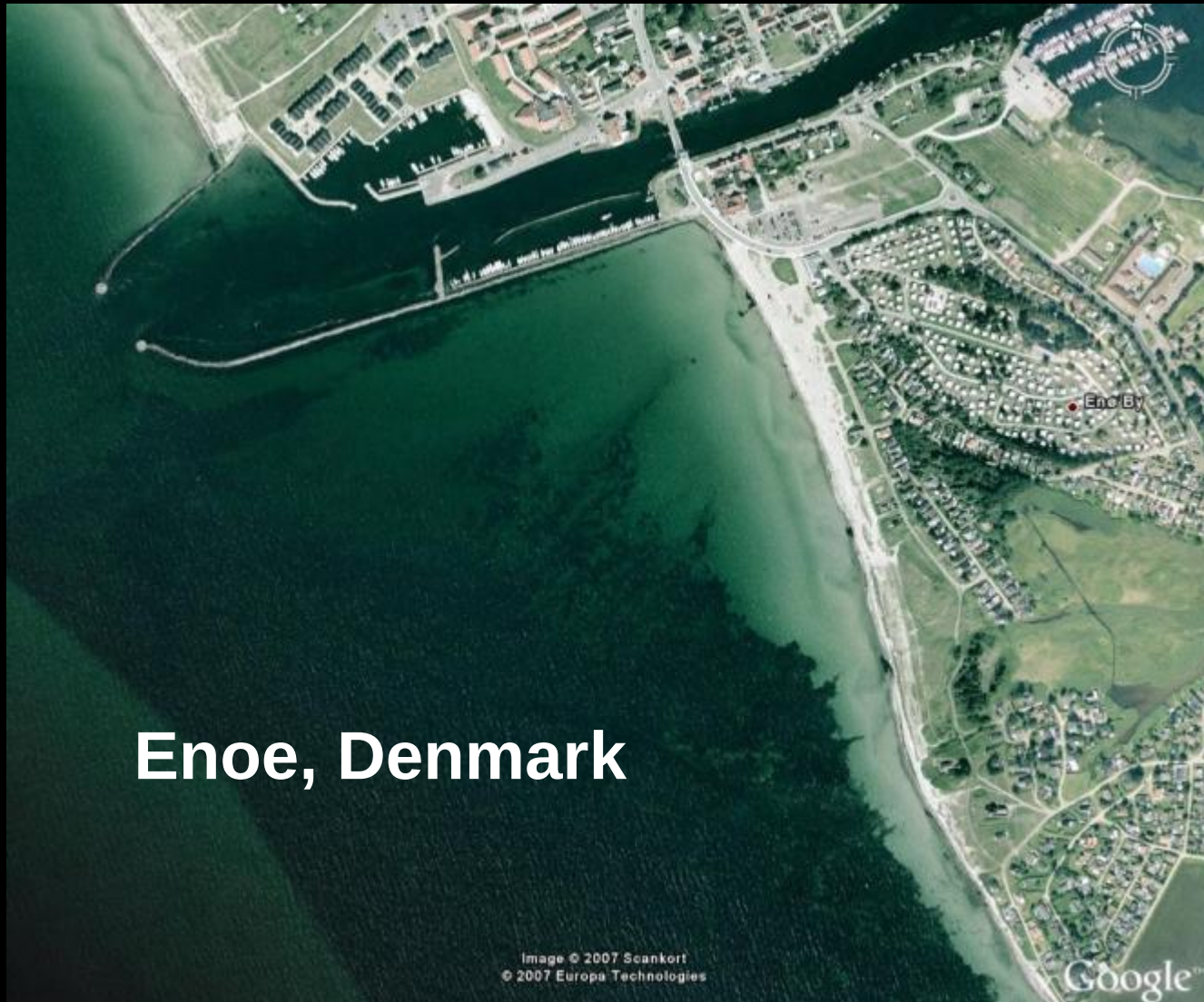


- Consequences of March 2008 storm:
- Overtopping damaging seawall and promenade;
- Property damage.



**COASTAL
EROSION:
ADJACENT
SHORELINE
UPDRIFT
ACCRETION
DOWNDRIFT
EROSION**

**ENGINEERING
WORKS VS
EQUILIBRIUM
OF COASTAL
DYNAMICS
AND
PROCESSES**



Ravenna, Italy.



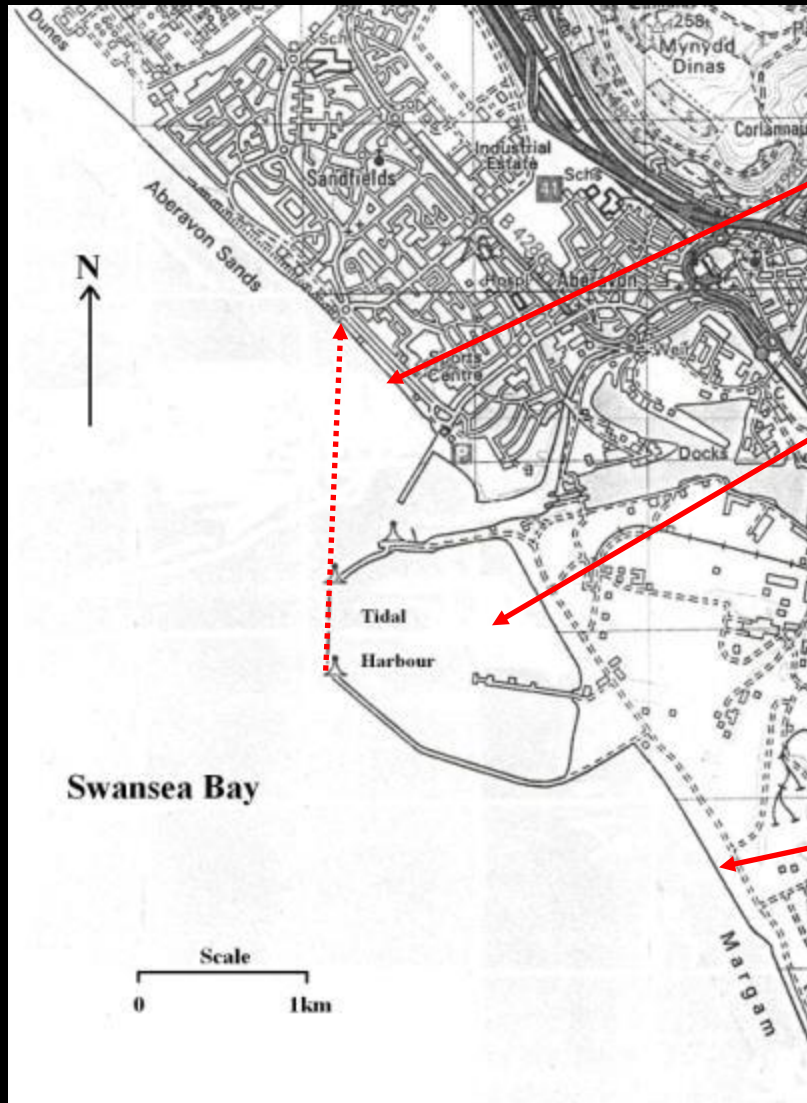
Aveiro, Portugal



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Praia da Barra / A



South Wales

Aberavon Sands

1958-75 erosion 0.8m

1975-91 erosion 0.3m

Tidal Harbour

11.2 x 10⁶ tonnes capital dredging to form deep harbour equivalent to 1960-76 maintenance dredging

Margam Sands

1975-91 recession of dune line 20-40m and loss in beach level 0.7m

Bullen (1993)

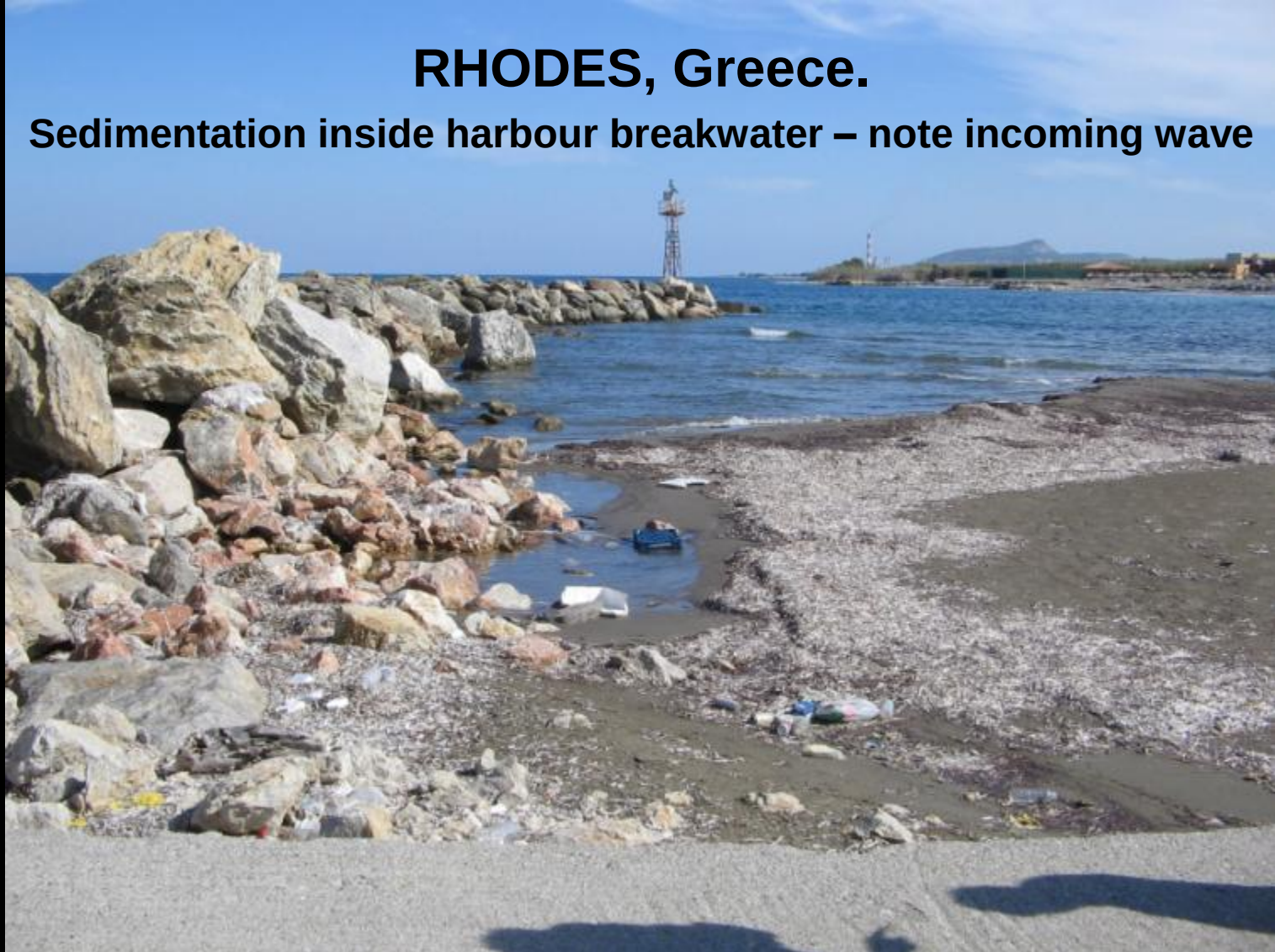




**Wall section failed and
rock armour now protects
seawall which in turn
protects the promenade!**

RHODES, Greece.

Sedimentation inside harbour breakwater – note incoming wave



Interference with alongshore sediment transport has led to hard defences protecting property



Landeyjahöfn Harbour, South Iceland



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Landeyjahöfn Harbour, South Iceland

- Cut sea travel time between Reykjavik and the Westman Islands from 3.5 hrs to 30 minutes.
- Construction between 2009 and 2010.
- In April 2010 after the volcanic eruption at Eyjafjallajökull, the Markarfljot river introduces $\sim 1.6 \times 10^6 \text{ m}^3$ sediments in close proximity to the harbour.
- Ceremonial opening July 2010 after completion of breakwaters and ferry Herjolfur started busy daily schedule.
- By 6th September 2010, the ferry could no longer enter the harbour without grounding.
- By the end of September 2010, the Westman Island mayor (and chairman of the shipping advisory group) concluded the harbour and ferry were 'far from suitable'.
- Cost $\sim 25\text{M}$ Euros for an island population of 4190.



CRETE, Greece.



Too close to the water!

Seychelles: Intact natural capital - timeless







**Storm effects and degradation from
natural events**



**Man-made capital – high cost,
need to defend**

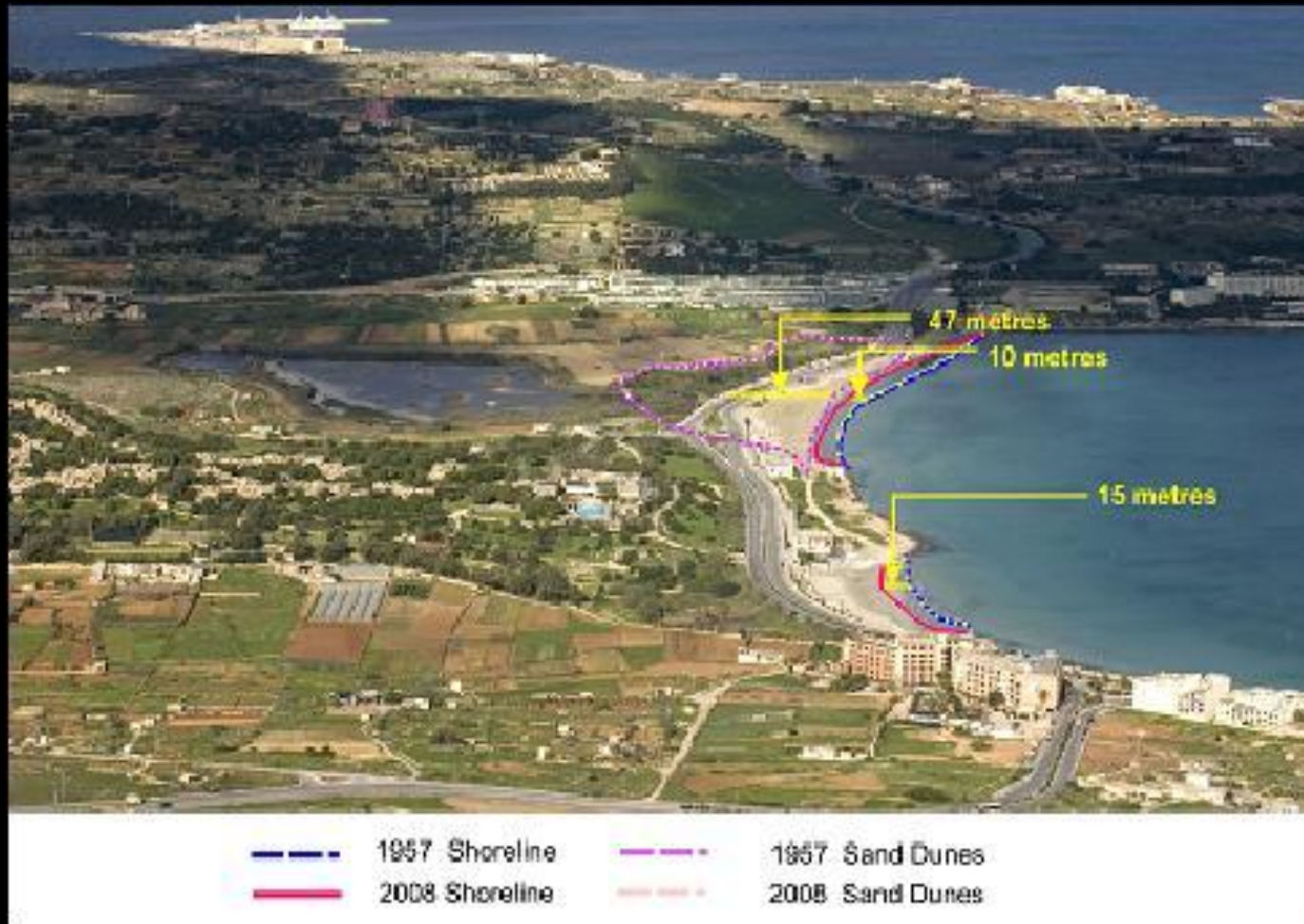
Praia, Cape Verde, 2009.



Maputo, Mozambique (BBC News, 2009)



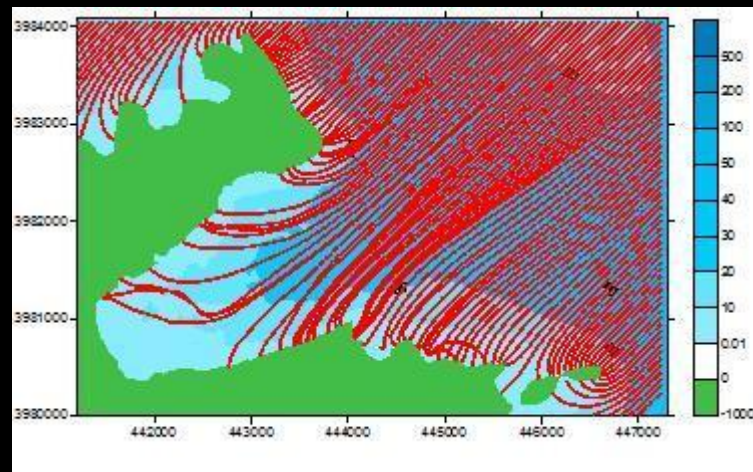
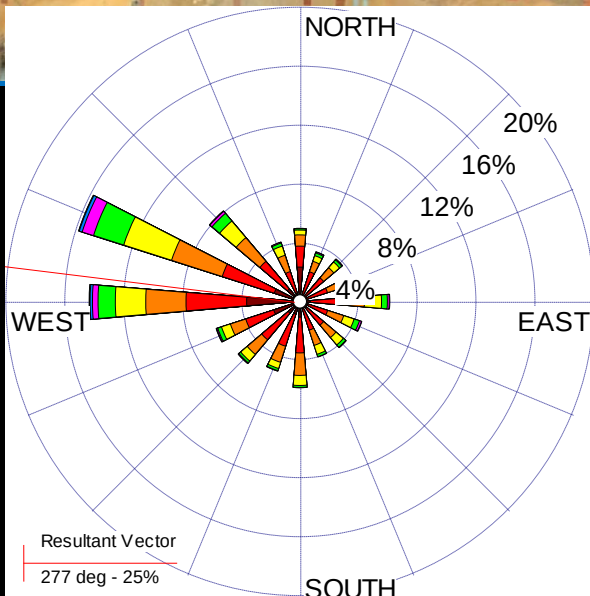
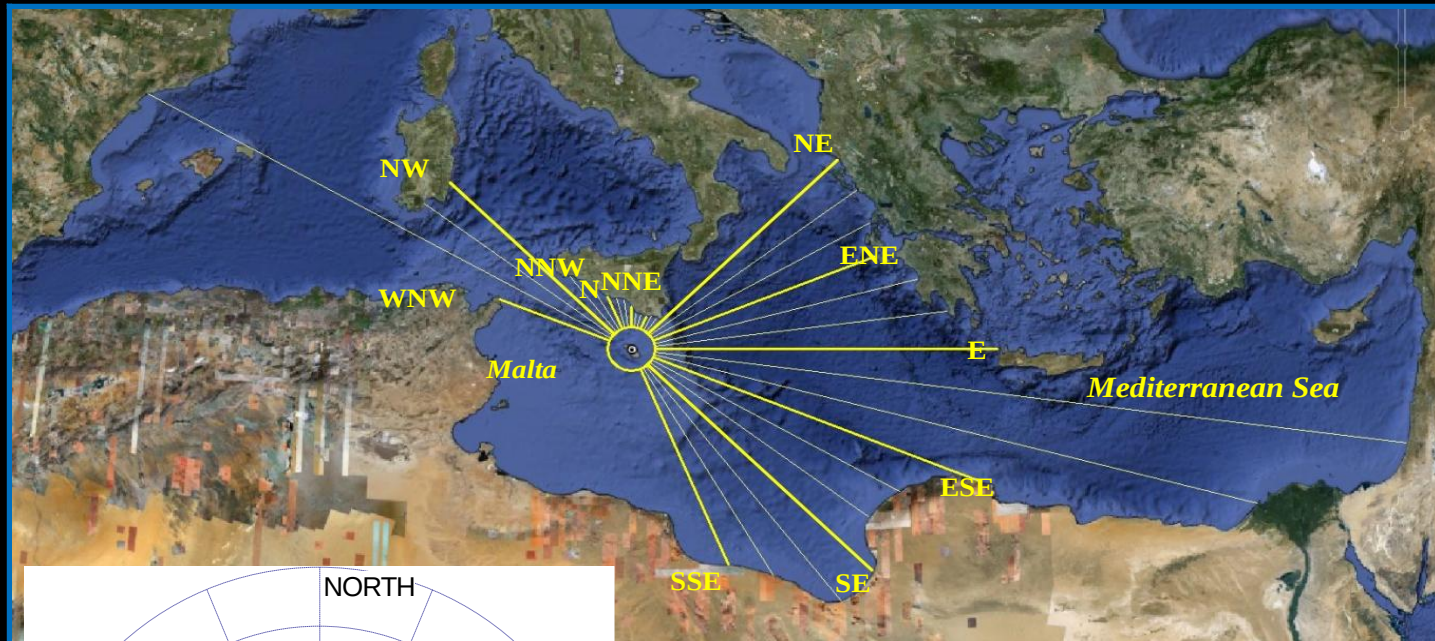
Ghadira Bay, Malta.



Is a problem just a matter of perception?

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However, this is the
power of



significant south-
westerly storms



What
should
we do?

Rebuild
in the
same
place?



YES!

Doh!

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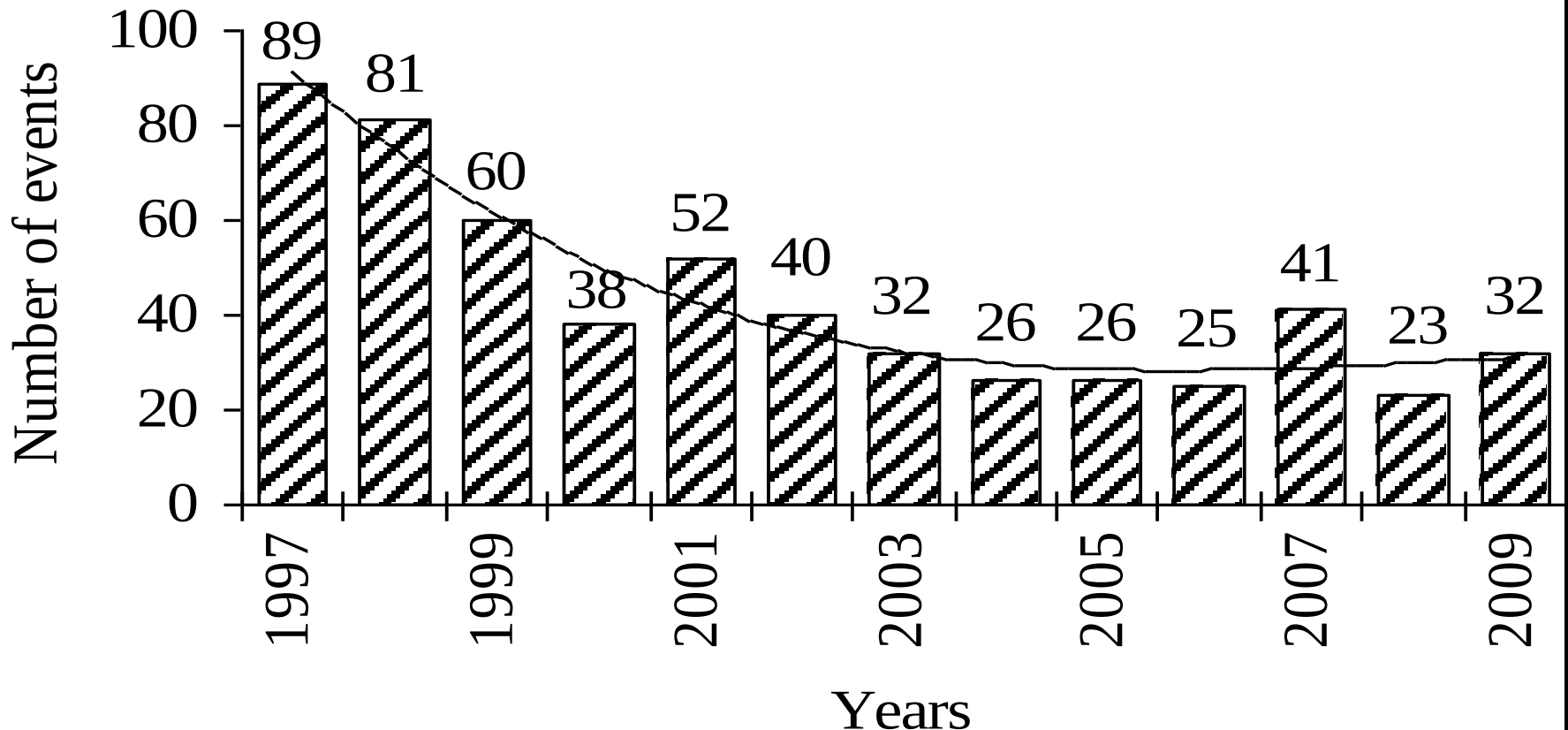
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Blackpool, UK, 2002 Storm, 2009 coastal protection works



Number of Ukraine emergency situations caused by hydrometeorological events (1997 – 2009)



Extreme storm waves, Sevastopol, Ukraine.





Anapa beach, Russia.

2007 Storm after-effects, Russian Black Sea coast.



Horta, Faial Island, the Azores







PORTHKERRY HOLIDAY PARK, SOUTH WALES



Is it sensible to allow
any development at the
top of cliffs???

CADIZ, Spain



Seawall damage and protection





Cadiz Coastline

**Problems with
'soft' cliffs;**

Cost!



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Barry Buddon, Dundee

Military and Civil Use on the coastline

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**Planning Decisions can
prevent coastal
dynamics naturally
defending the shoreline**

KwaZulu-Natal Coast, South Africa



High-energy, erosive, swell-dominated coast

A 2007 Storm resulted in significant damage to properties and infrastructure

- An extreme wave event coincided with an equinox
- Resulted in a maximum swell height of 14m



March 2007 Storm

Physical CVI – Rating

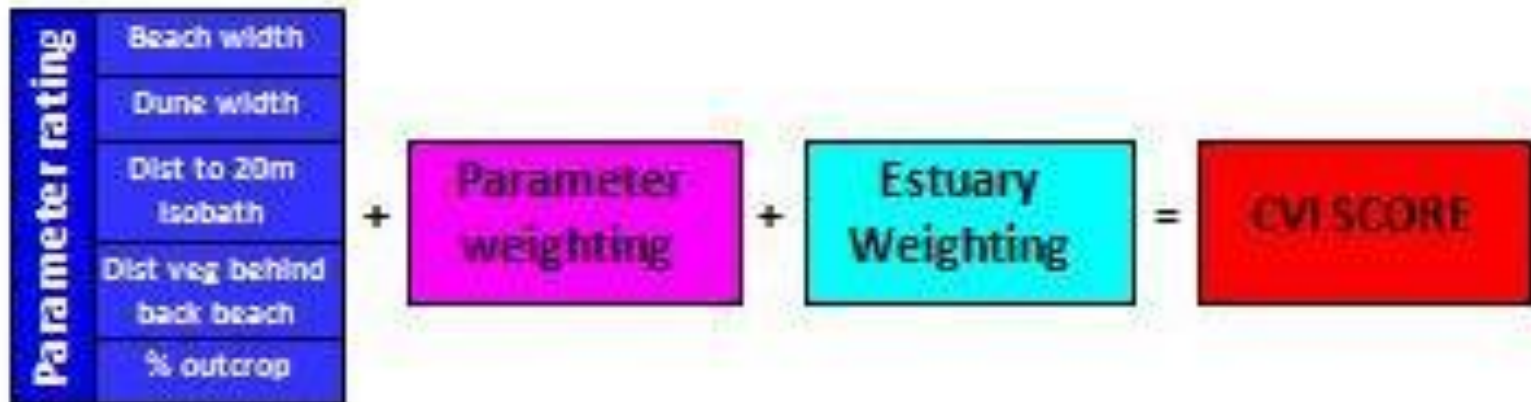
- Each cell was rated per parameter - in terms of its individual vulnerability based on predefined thresholds
- Scoring between 1 and 4 per parameter

Physical Property	Extremely Low (1)	Low (2)	Moderate (3)	High (4)
Beach width	> 150m	100 – 150m	50 – 100m	< 50m
Dune width	> 150m	50 – 150m	25 – 50m	< 25m
Distance to -20m bathy	> 4km	2 – 4km	1 – 2km	< 1km
Distance of vegetation behind the back beach	> 600m	200 – 600m	100 – 200m	< 100m
Percentage outcrop	> 50%	20 – 50%	10 – 20%	< 10%

Total CVI score

Desktop study

1. 50m cells
2. Beach width, Dune width and Distance to 20m isobath most critical
3. Cells across estuary mouths were weighted



This resulted in a total vulnerability score out of 28

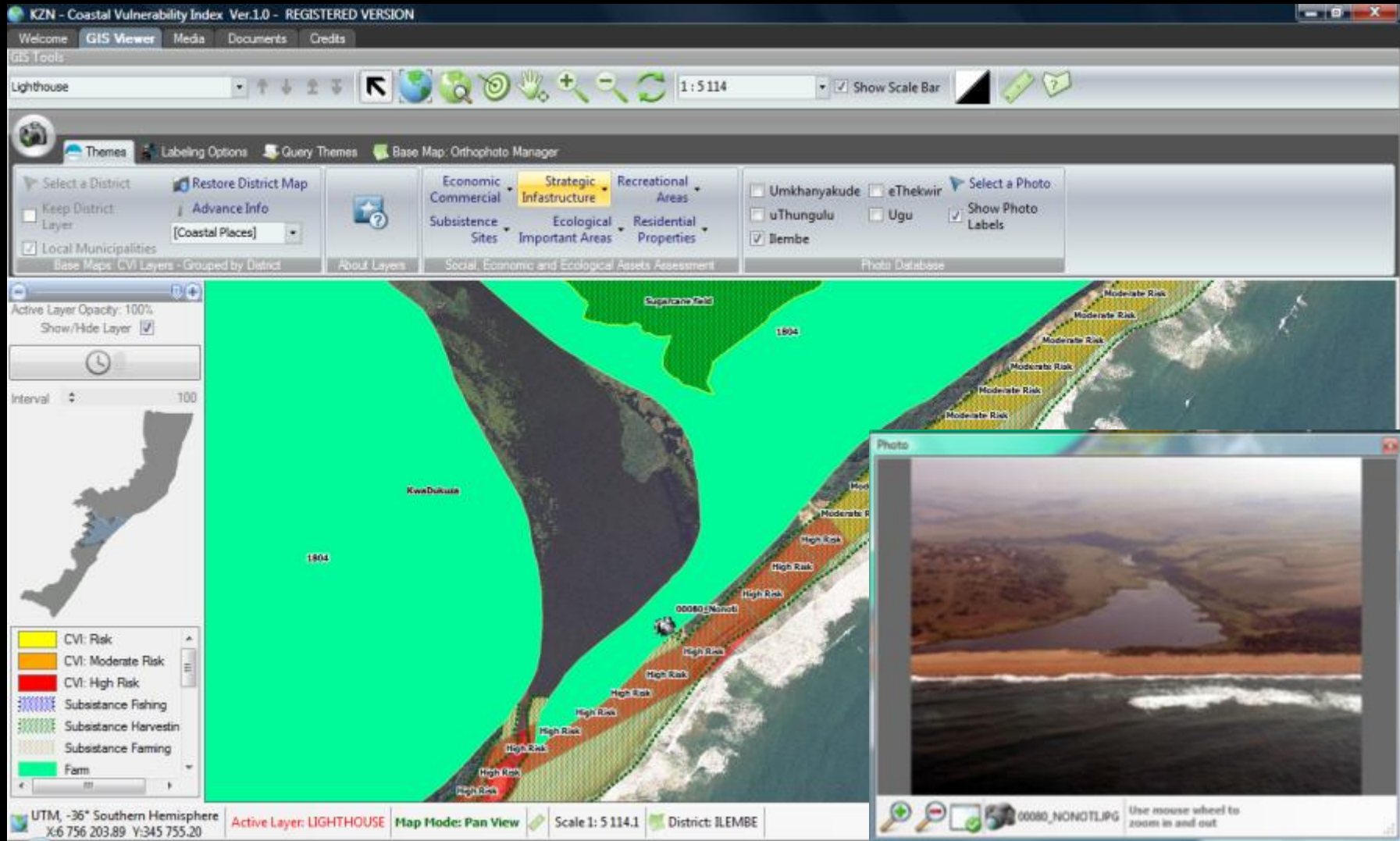
20 (Max) + 4 + 4 = 28 (Max)

Socio-economic and ecological factors

Economic & commercial activities	Strategic infrastructure	Recreational areas	Subsistence sites	Ecological important areas	Residential properties
Dune mining	Piers [#]	Boat launch sites [#]	Subsistence fishing sites [#]	Marine Protected Areas [#]	Residential erven
Forest plantation	Roads	Fishing hot spots [#]	Subsistence harvesting sites [#]	Bird sanctuary sites [#]	
Sugar cane	Railway lines	Swimming beaches [#]	Subsistence farming areas	Turtle nesting sites [#]	
Commercial & industrial buildings	Lighthouses	Sports facilities		Estuary mouths [#]	
Commercial farms		Coastal Public Property		Protected areas (terrestrial)	

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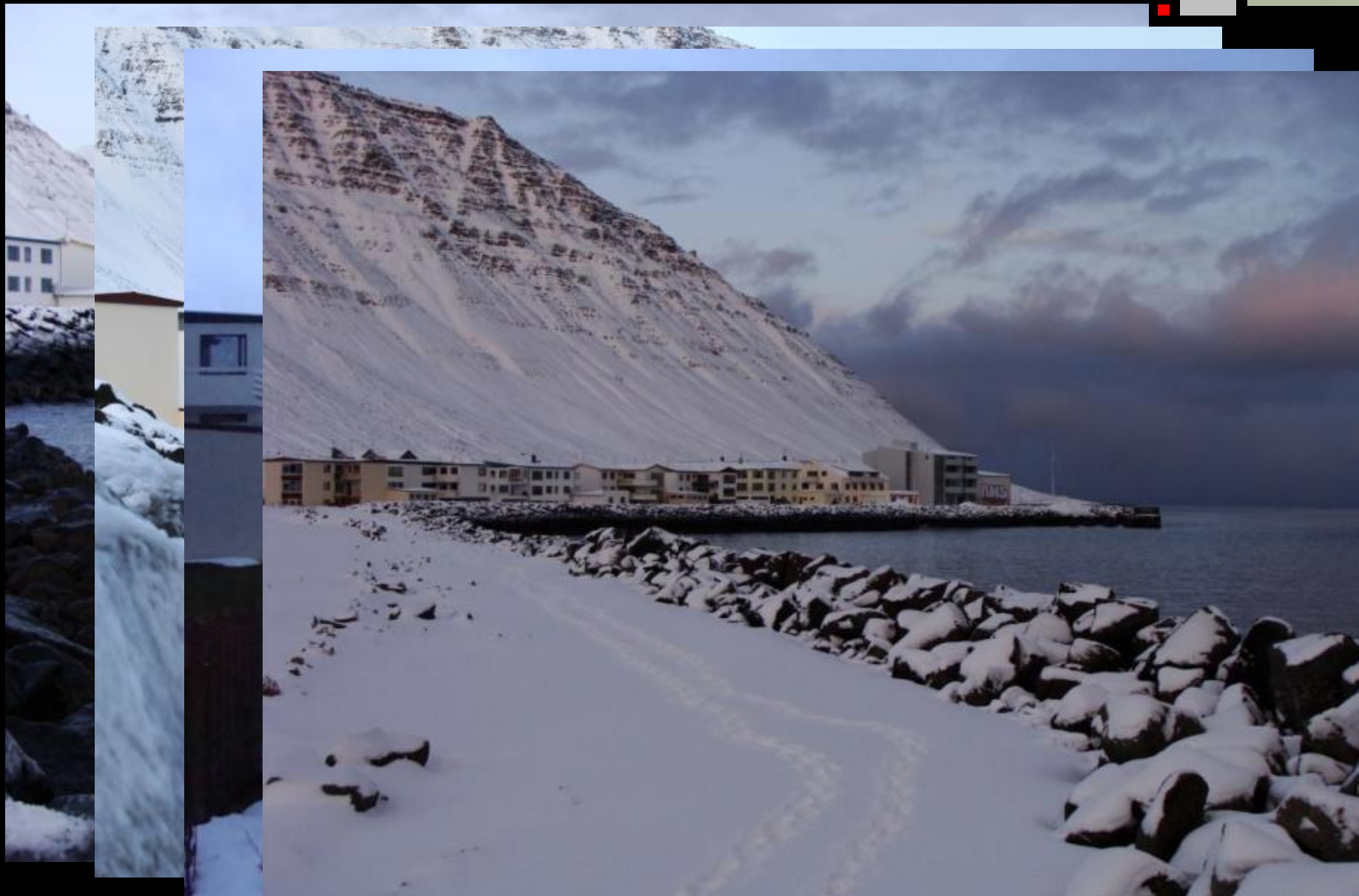
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Isafjördur, Iceland

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Physical Property	Extremely Low (1)	Low (2)	Moderate (3)	High (4)
Beach width	> 150m	100 – 150m	50 – 100m	< 50m
Coastal Slope	> 12%	12 – 8%	8 – 4%	< 4%
Distance to -20m bathy	> 4km	2 – 4km	1 – 2km	< 1km
Number of recorded avalanches	0	1 – 10	11 – 50	> 50
Percentage outcrop	> 50%	20 – 50%	10 – 20%	< 10%

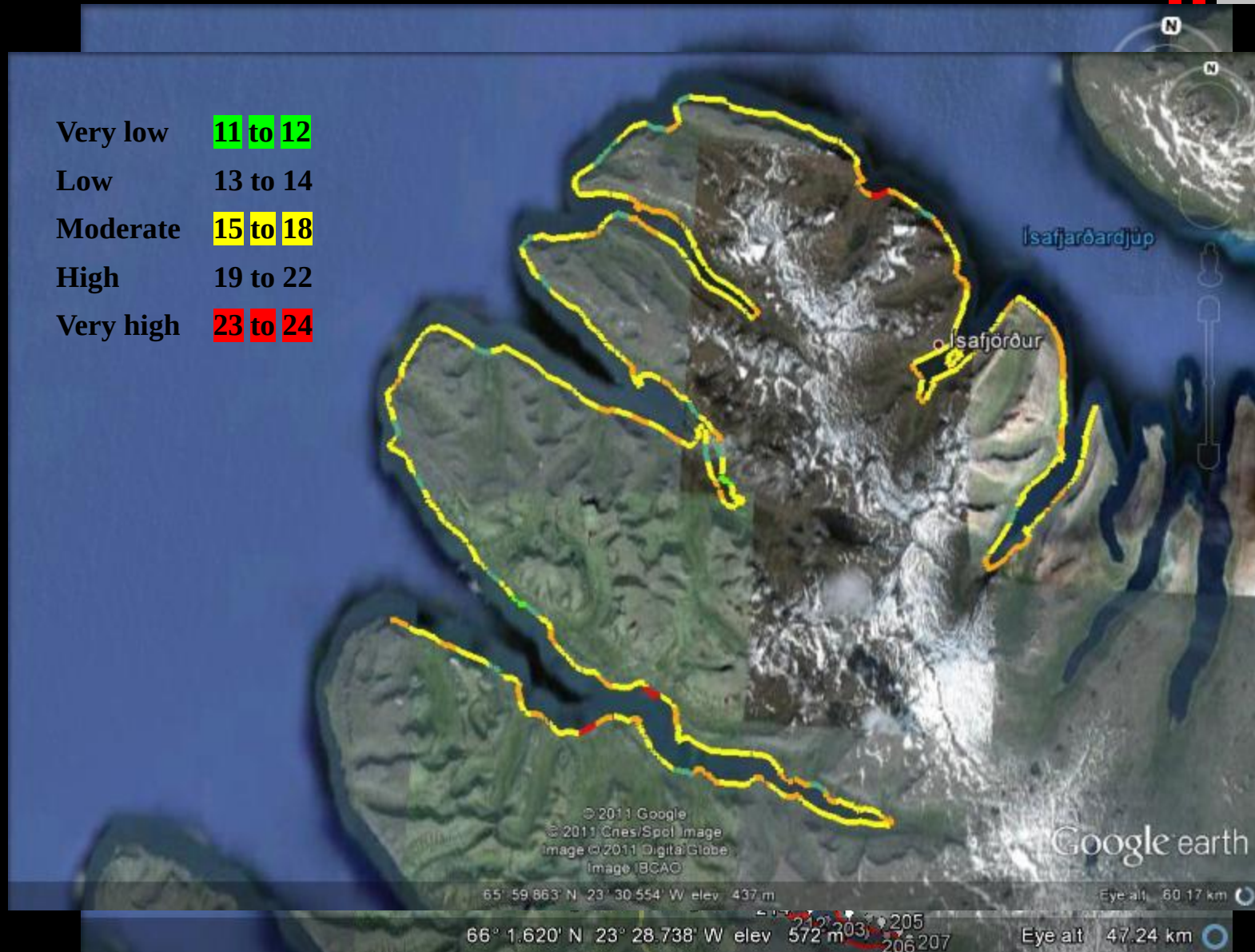
Residency and Recreational	Strategic Transport Infrastructure	/ Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
Housing areas/ built urban areas Isolated housing/buildi ngs Coastal Public Property Boat launch sites	Major roads Minor roads Harbours Airstrip Lighthouses	Commercial and Industrial buildings Factories, e.g. fish- processing plants Power stations	Waste-water / Sewage- treatment plants	Farms Arable land	Fishing hot- spots Aquaculture sites	Designated nature reserves

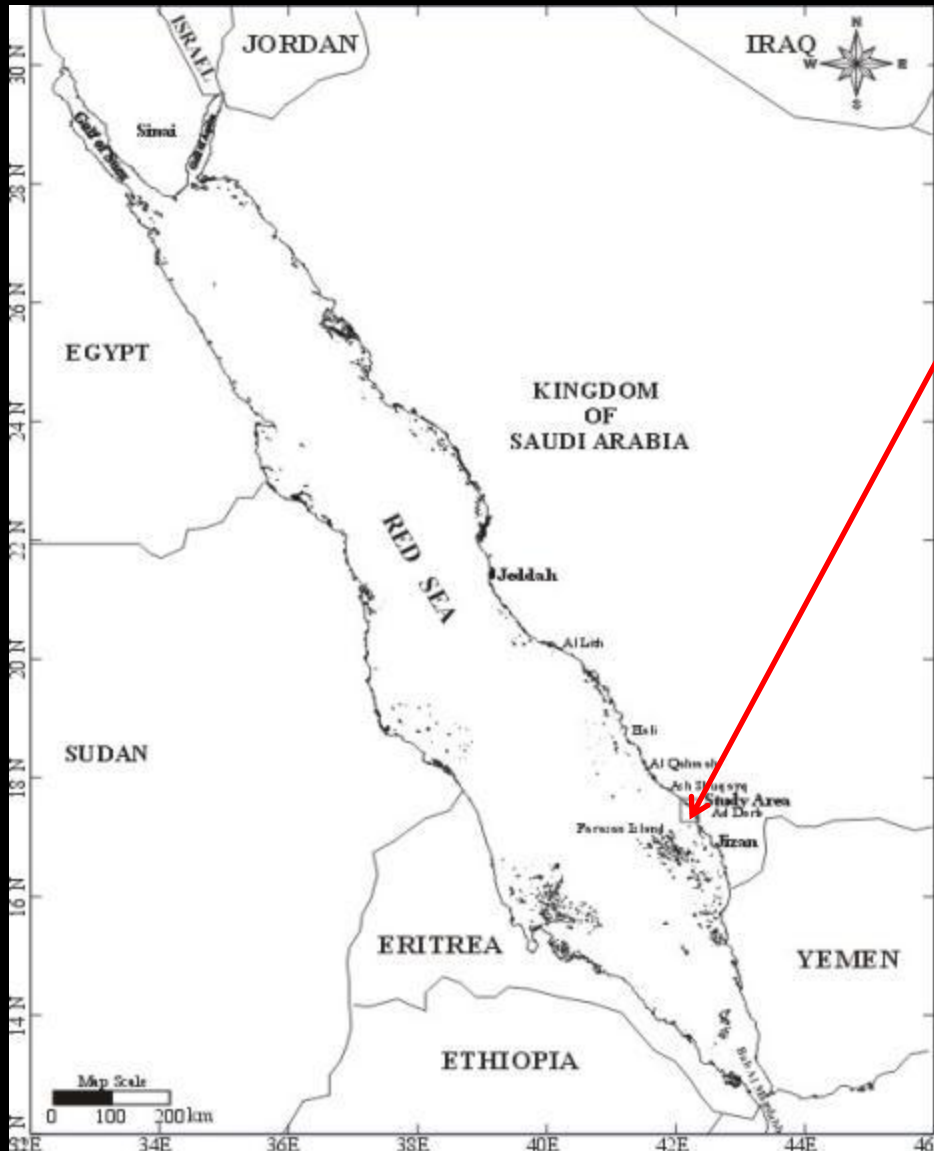
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Very low	11 to 12
Low	13 to 14
Moderate	15 to 18
High	19 to 22
Very high	23 to 24





**Red Sea Coast, Jizan,
Saudi Arabia.**

**1900km (NW-SE), 350km max
(NE-SW)**

Spring tidal range 0.6 - 0.9m

**Currents often exceed $1-2\text{ms}^{-1}$
and 6 months of the year NW-
SE and 6months SE-NW**

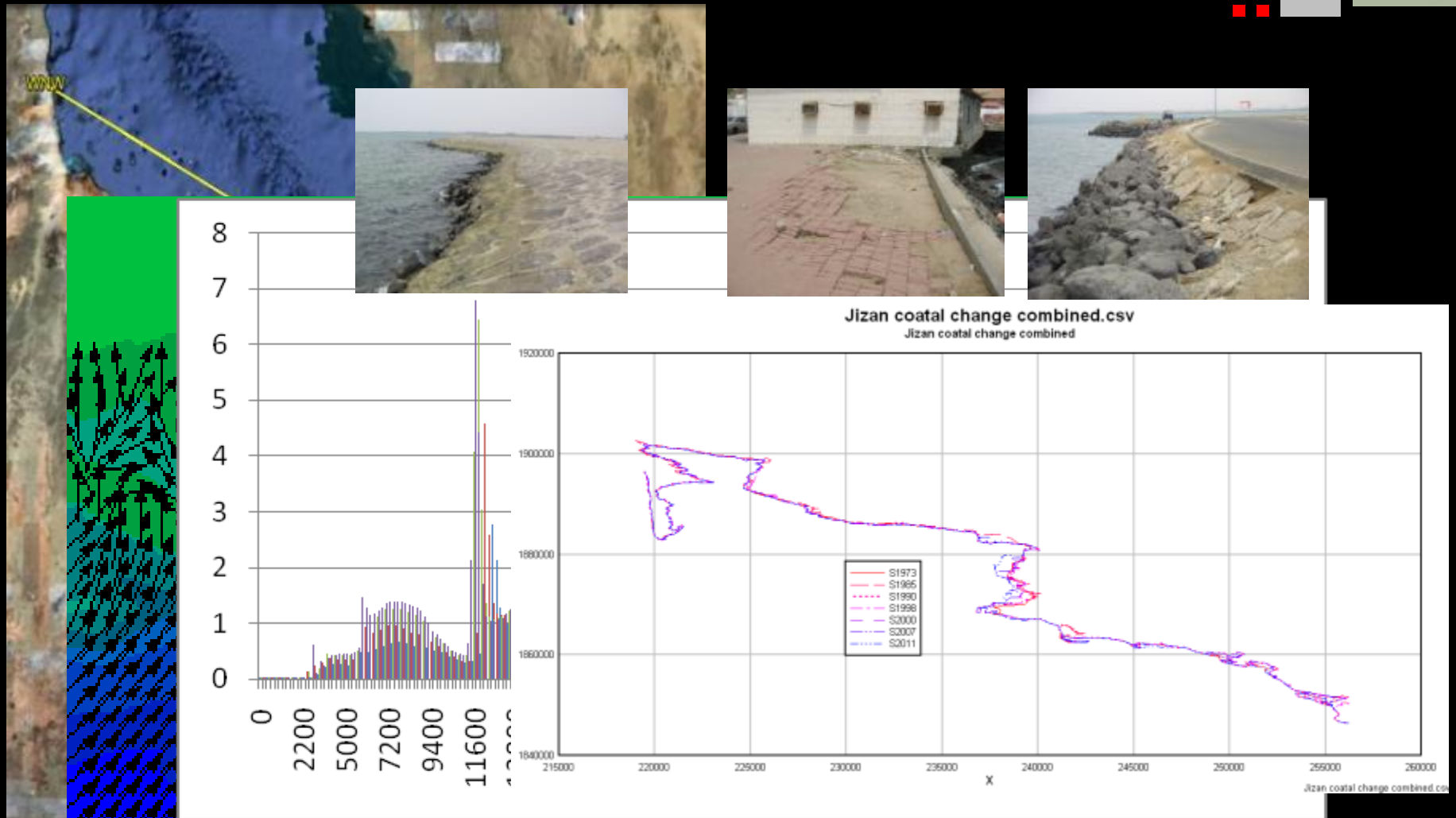
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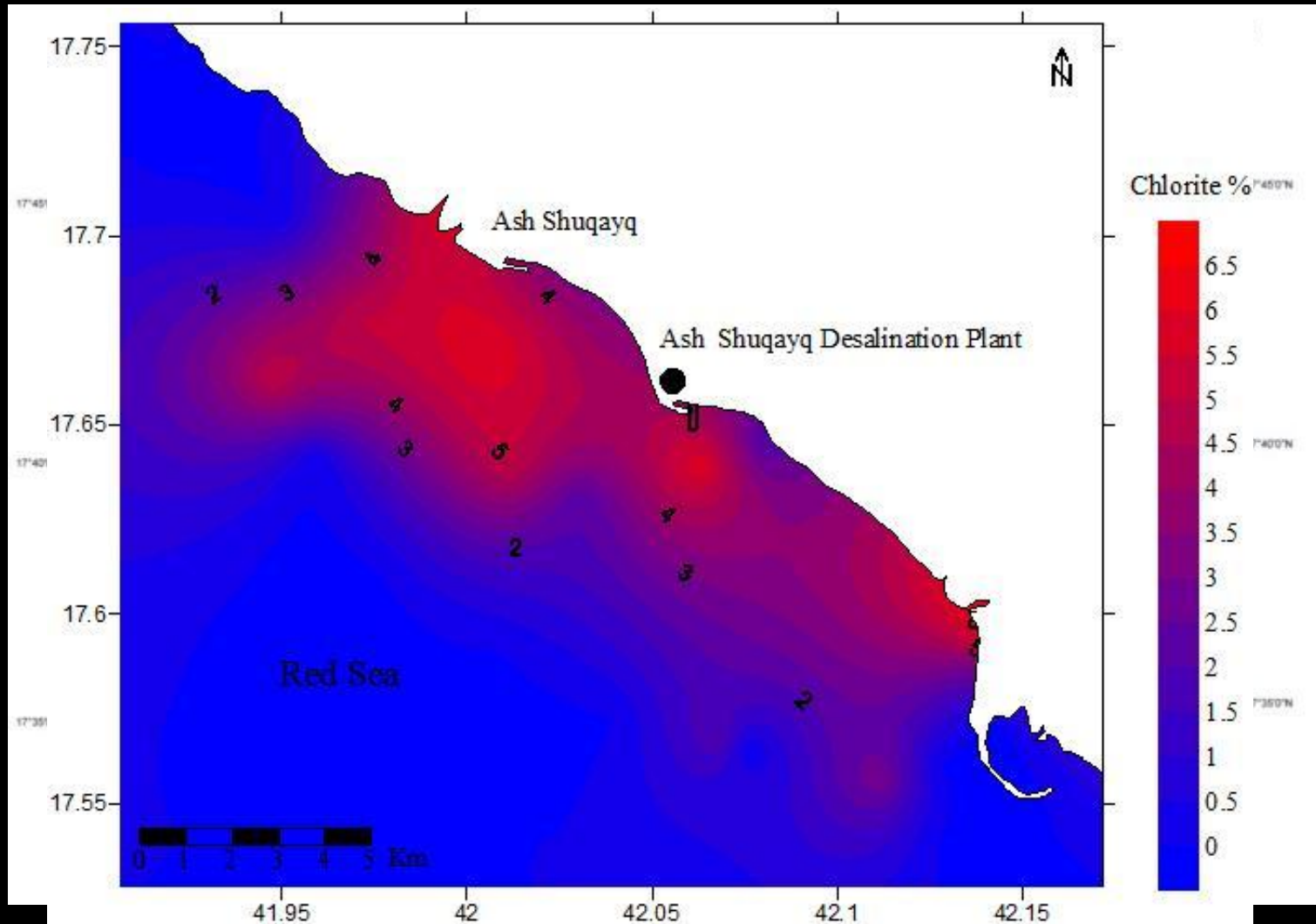
Nearshore Evolution Modelling system (NEMOS)
Regional Coastal Processes WAVE propagation
model (RCPWAVE)

New construction through mangrove forest

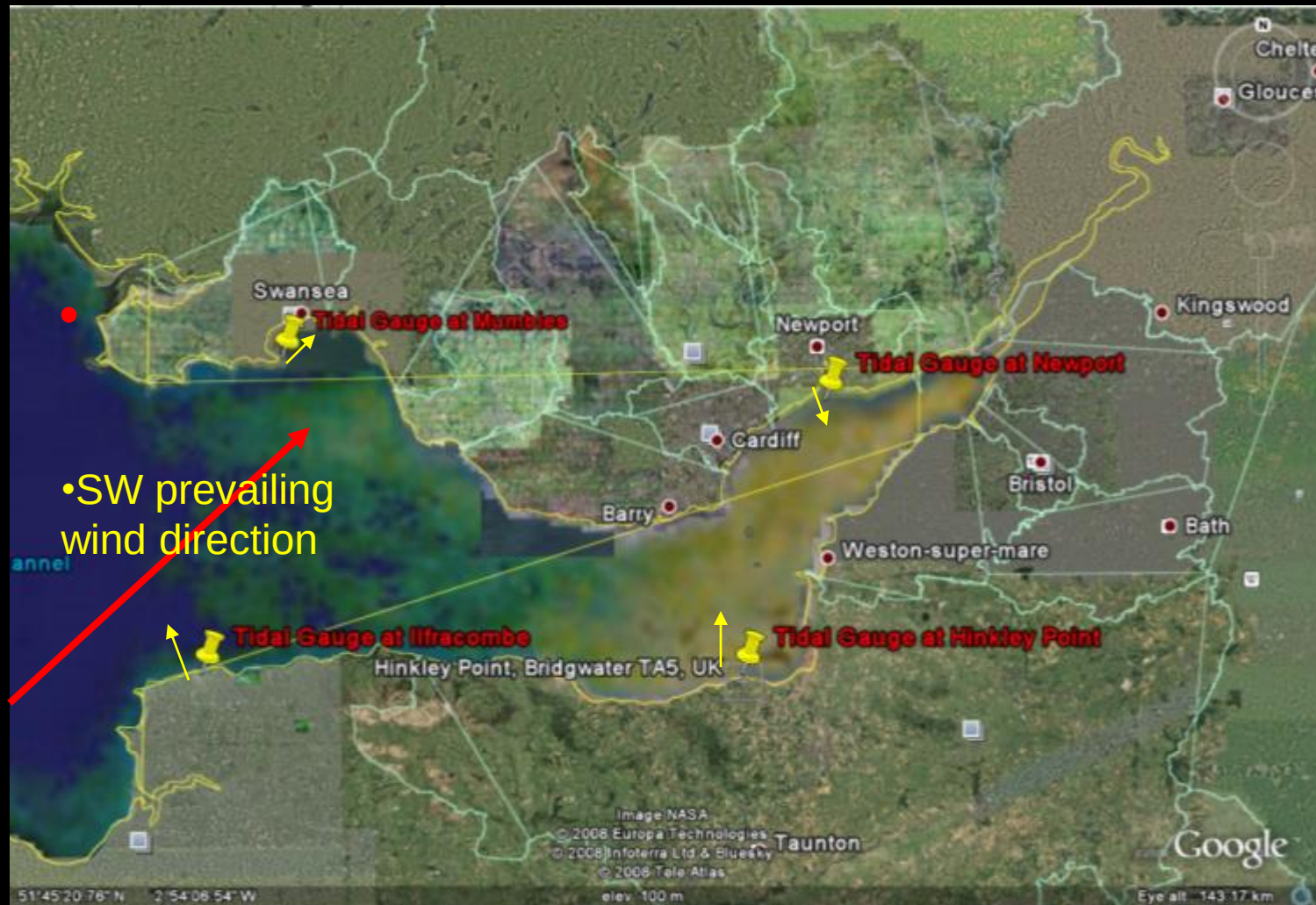


Landward consequences of new construction on mangroves





Sea level Trends



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1993HIN - Notepad

Port: P003Site: Hinkley PointLatitude: 51.2167Longitude: -3.1333Start Date: 01JAN1993-00.00End Date: 31DEC1993-23.59

Port	Date	Mean	Min	Max	Days						
11	1993/01/01 02:30:00	4.990	-0.431	12	1993/01/01 02:45:00	4.589	-0.447	13	1993/01/01 03:00:00	4.209	-0.46
30	1993/01/01 07:15:00	4.874	-0.134	31	1993/01/01 07:30:00	5.200	-0.126	32	1993/01/01 07:45:00	5.536	-0.1
49	1993/01/01 12:00:00	9.009	-0.139	50	1993/01/01 12:15:00	8.862	-0.154	51	1993/01/01 12:30:00	8.671	-0.1
68	1993/01/01 16:45:00	3.043	-0.452	69	1993/01/01 17:00:00	2.931	-0.435	70	1993/01/01 17:15:00	2.876	-0.4
87	1993/01/01 21:30:00	7.235	-0.004	88	1993/01/01 21:45:00	7.547	0.003	89	1993/01/01 22:00:00	7.834	-0.0
106	1993/01/02 02:15:00	6.628	-0.370	107	1993/01/02 02:30:00	6.270	-0.389	108	1993/01/02 02:45:00	5.902	-0.4
125	1993/01/02 07:00:00	3.953	-0.149	126	1993/01/02 07:15:00	4.168	-0.131	127	1993/01/02 07:30:00	4.404	-0.1
144	1993/01/02 11:45:00	8.513	-0.236	145	1993/01/02 12:00:00	8.589	-0.249	146	1993/01/02 12:15:00	8.630	-0.2
163	1993/01/02 16:30:00	4.261	-0.564	164	1993/01/02 16:45:00	3.974	-0.567	165	1993/01/02 17:00:00	3.721	-0.5
182	1993/01/02 21:15:00	5.540	-0.072	183	1993/01/02 21:30:00	5.843	-0.072	184	1993/01/02 21:45:00	6.16	-0.0
201	1993/01/03 02:00:00	7.990	-0.298	202	1993/01/03 02:15:00	7.774	-0.318	203	1993/01/03 02:30:00	7.774	-0.3
220	1993/01/03 06:45:00	3.606	-0.245	221	1993/01/03 07:00:00	3.628	-0.219	222	1993/01/03 07:15:00	3.628	-0.2
239	1993/01/03 11:30:00	7.539	-0.030	240	1993/01/03 11:45:00	7.752	-0.057	241	1993/01/03 12:00:00	7.752	-0.0
258	1993/01/03 16:15:00	6.529	-0.173	259	1993/01/03 16:30:00	6.176	-0.184	260	1993/01/03 16:45:00	5.902	-0.1
277	1993/01/03 21:00:00	4.160	0.064	278	1993/01/03 21:15:00	4.380	0.091	279	1993/01/03 21:30:00	4.404	0.0
296	1993/01/04 01:45:00	8.683	-0.087	297	1993/01/04 02:00:00	8.724	-0.101	298	1993/01/04 02:15:00	8.630	-0.1
315	1993/01/04 06:30:00	4.568	-0.105	316	1993/01/04 06:45:00	4.300	-0.146	317	1993/01/04 07:00:00	4.404	-0.1
334	1993/01/04 11:15:00	5.455	-0.322	335	1993/01/04 11:30:00	5.777	-0.315	336	1993/01/04 11:45:00	6.16	-0.3
353	1993/01/04 16:00:00	8.373	-0.245	354	1993/01/04 16:15:00	8.114	-0.271	355	1993/01/04 16:30:00	7.990	-0.2
372	1993/01/04 20:45:00	3.007	-0.301	373	1993/01/04 21:00:00	3.051	-0.218	374	1993/01/04 21:15:00	3.606	-0.2
391	1993/01/05 01:30:00	8.126	0.171	392	1993/01/05 01:45:00	8.434	0.172	393	1993/01/05 02:00:00	8.630	0.1
410	1993/01/05 06:15:00	6.719	0.181	411	1993/01/05 06:30:00	6.323	0.166	412	1993/01/05 06:45:00	6.176	0.1
429	1993/01/05 11:00:00	3.813	0.051	430	1993/01/05 11:15:00	4.066	0.044	431	1993/01/05 11:30:00	4.380	0.0
448	1993/01/05 15:45:00	9.629	-0.047	449	1993/01/05 16:00:00	9.642	-0.071	450	1993/01/05 16:15:00	9.655	-0.0
467	1993/01/05 20:30:00	3.431	-0.483	468	1993/01/05 20:45:00	3.135	-0.458	469	1993/01/05 21:00:00	3.051	-0.4
486	1993/01/06 01:15:00	6.088	0.023	487	1993/01/06 01:30:00	6.538	0.040	488	1993/01/06 01:45:00	6.719	0.0
505	1993/01/06 06:00:00	8.699	-0.261	506	1993/01/06 06:15:00	8.312	-0.247	507	1993/01/06 06:30:00	8.114	-0.2
524	1993/01/06 10:45:00	2.338	-0.078	525	1993/01/06 11:00:00	2.409	-0.043	526	1993/01/06 11:15:00	2.876	-0.0
543	1993/01/06 15:30:00	9.311	0.175	544	1993/01/06 15:45:00	9.655	0.156	545	1993/01/06 16:00:00	9.655	0.1
562	1993/01/06 20:15:00	5.580	-0.235	563	1993/01/06 20:30:00	5.060	-0.262	564	1993/01/06 20:45:00	5.060	-0.2
581	1993/01/07 01:00:00	3.749	0.046	582	1993/01/07 01:15:00	4.192	0.042	583	1993/01/07 01:30:00	4.192	0.0
600	1993/01/07 05:45:00	10.622	-0.169	601	1993/01/07 06:00:00	10.466	-0.180	602	1993/01/07 06:15:00	10.466	-0.1
619	1993/01/07 10:30:00	2.457	-0.139	620	1993/01/07 10:45:00	2.198	-0.118	621	1993/01/07 11:00:00	2.198	-0.1
638	1993/01/07 15:15:00	7.298	0.164	639	1993/01/07 15:30:00	7.837	0.145	640	1993/01/07 15:45:00	7.837	0.1
657	1993/01/07 20:00:00	8.542	0.188	658	1993/01/07 20:15:00	7.974	0.172	659	1993/01/07 20:30:00	7.974	0.1
676	1993/01/08 00:45:00	1.755	0.046	677	1993/01/08 01:00:00	2.041	0.077	678	1993/01/08 01:15:00	2.041	0.0
695	1993/01/08 05:30:00	10.733	-0.267	696	1993/01/08 05:45:00	10.966	-0.276	697	1993/01/08 06:00:00	10.966	-0.2
714	1993/01/08 10:15:00	4.044	-0.183	715	1993/01/08 10:30:00	3.550	-0.167	716	1993/01/08 10:45:00	3.550	-0.1
733	1993/01/08 15:00:00	4.354	-0.230	734	1993/01/08 15:15:00	4.918	-0.230	735	1993/01/08 15:30:00	4.918	-0.2
752	1993/01/08 19:45:00	10.834	0.047	753	1993/01/08 20:00:00	10.407	0.051	754	1993/01/08 20:15:00	10.407	0.0
771	1993/01/09 00:30:00	1.527	0.061	772	1993/01/09 00:45:00	1.150	0.059	773	1993/01/09 01:00:00	1.150	0.0
790	1993/01/09 05:15:00	9.809	0.328	791	1993/01/09 05:30:00	10.369	0.332	792	1993/01/09 05:45:00	10.369	0.3
809	1993/01/09 10:00:00	6.967	0.330	810	1993/01/09 10:15:00	6.330	0.313	811	1993/01/09 10:30:00	6.330	0.3
828	1993/01/09 14:30:00	2.071	-0.126	829	1993/01/09 15:00:00	2.495	-0.169	830	1993/01/09 15:15:00	2.495	-0.1
847	1993/01/09 19:30:00	11.899	-0.043	848	1993/01/09 19:45:00	11.887	-0.023	849	1993/01/09 20:00:00	11.887	-0.0
866	1993/01/10 00:15:00	2.385	-0.045	867	1993/01/10 00:30:00	1.959	-0.033	868	1993/01/10 00:45:00	1.959	-0.0
885	1993/01/10 05:00:00	7.064	0.163	886	1993/01/10 05:15:00	7.783	0.178	887	1993/01/10 05:30:00	7.783	0.1
904	1993/01/10 09:45:00	9.643	0.299	905	1993/01/10 10:00:00	9.036	0.332	906	1993/01/10 10:15:00	9.036	0.3
923	1993/01/10 14:30:00	1.464	0.746	924	1993/01/10 14:45:00	1.527	0.631	925	1993/01/10 15:00:00	1.527	0.6
942	1993/01/10 19:00:00	11.183	0.533	943	1993/01/10 19:15:00	12.075	0.539	944	1993/01/10 19:30:00	12.075	0.5
961	1993/01/11 00:00:00	5.443	0.307	962	1993/01/11 00:15:00	4.764	0.242	963	1993/01/11 00:30:00	4.764	0.2
980	1993/01/11 04:45:00	4.949	0.854	981	1993/01/11 05:00:00	5.577	0.815	982	1993/01/11 05:15:00	5.577	0.8
999	1993/01/11 09:30:00	11.794	0.178	1000	1993/01/11 09:45:00	11.352	0.182	1001	1993/01/11 10:00:00	11.352	0.1

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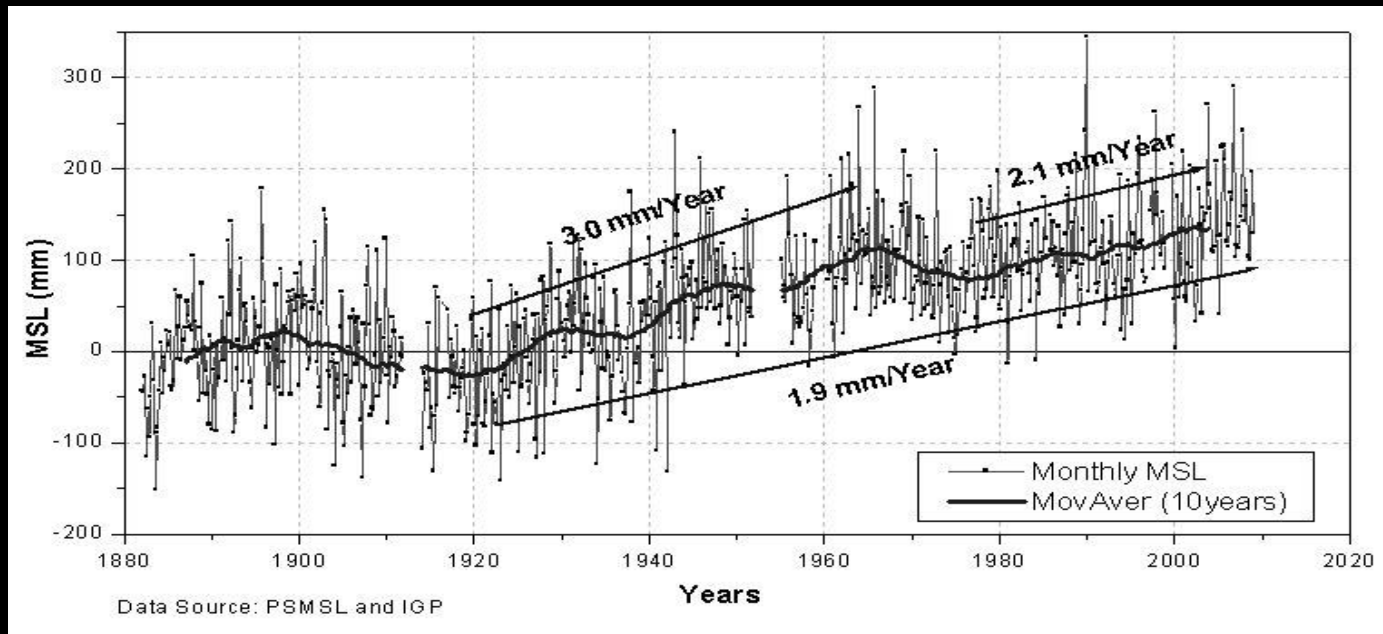
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1	MONTHLY MEANS	2	Site, month (mm/yyyy), monthly mean value (metres), No. of days used to calculate mean.			
3	Loc	Date	Mean	Min	Max	Days
4	HINKLEY POINT	Jan-93	6.288	0.746	12.657	31
5	HINKLEY POINT	Feb-93	6.023	-0.053	12.552	28
6	HINKLEY POINT	Mar-93	6.083	-0.12	12.945	31
7	HINKLEY POINT	Apr-93	6.215	0.121	12.799	30
8	HINKLEY POINT	May-93	6.199	0.39	12.068	31
9	HINKLEY POINT	Jun-93	6.172	0.9	11.75	30
10	HINKLEY POINT	Jul-93	6.184	0.493	12.144	31
11	HINKLEY POINT	Aug-93	6.159	0.115	12.584	31
12	HINKLEY POINT	Sep-93	6.274	0.029	12.983	30
13	HINKLEY POINT	Oct-93	6.247	0.094	12.751	31
14	HINKLEY POINT	Nov-93	6.2	0.365	12.44	30
15	HINKLEY POINT	Dec-93	6.358	0.806	12.305	31
16	HINKLEY POINT	Jan-94	6.262	0.256	12.304	31
17	HINKLEY POINT	Feb-94	6.189	0.19	12.95	28
18	HINKLEY POINT	Mar-94	6.188	-0.107	12.782	31
19	HINKLEY POINT	Apr-94	6.135	0.145	12.723	30
20	HINKLEY POINT	May-94	6.198	0.471	12.433	31
21	HINKLEY POINT	Jun-94	6.148	0.612	12.211	30
22	HINKLEY POINT	Jul-94	6.148	0.67	12.072	31
23	HINKLEY POINT	Aug-94	6.201	0.582	12.065	31
24	HINKLEY POINT	Sep-94	6.240	0.437	12.61	30
25	HINKLEY POINT	Oct-94	6.283	0.844	12.595	31
26	HINKLEY POINT	Nov-94	6.3	0.817	12.782	30
27	HINKLEY POINT	Dec-94	6.359	0.881	12.068	31

Ready

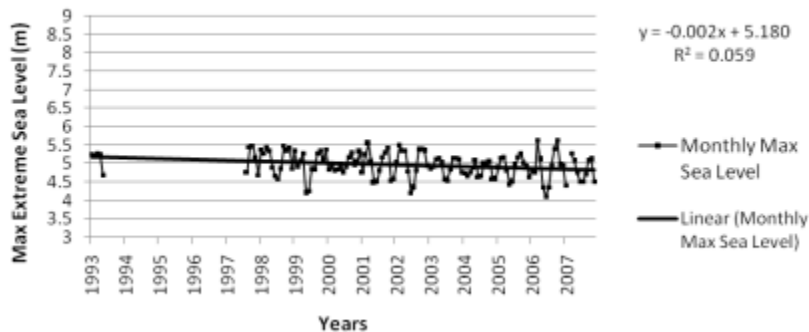
- Data received in Notepad format and converted to MS Excel Spreadsheets
- (15 years @ 365 twice daily records for mean sea level, maximum and minimum extreme sea levels)



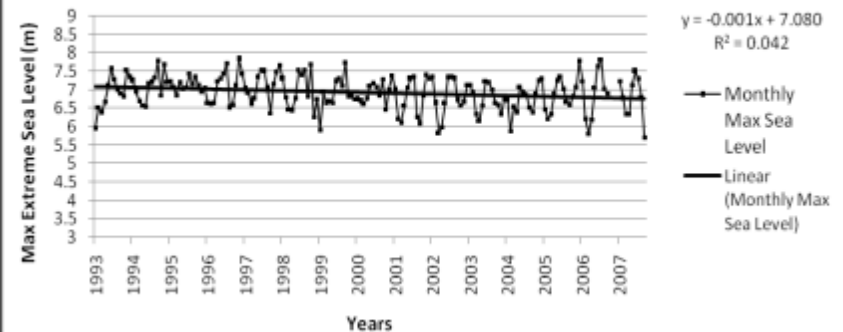
- **Cascais dataset (Antunis and Taborda, 2009): 2.1mm yr⁻¹**
- **Bristol Channel and Severn Estuary: 2.4mm yr⁻¹**

Maximum extreme sea levels show reducing trends.

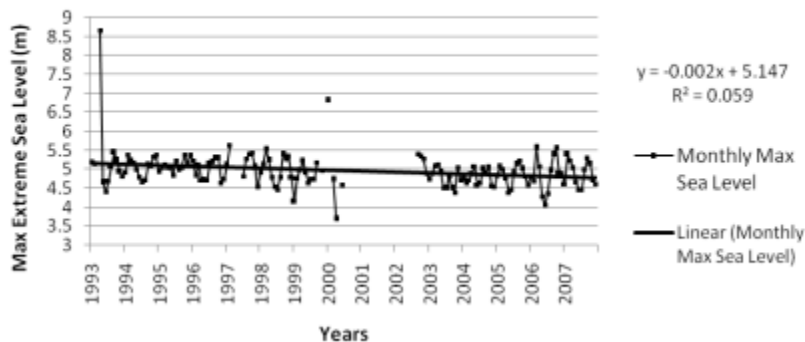
Monthly Maximum Extreme Sea Level at Mumbles



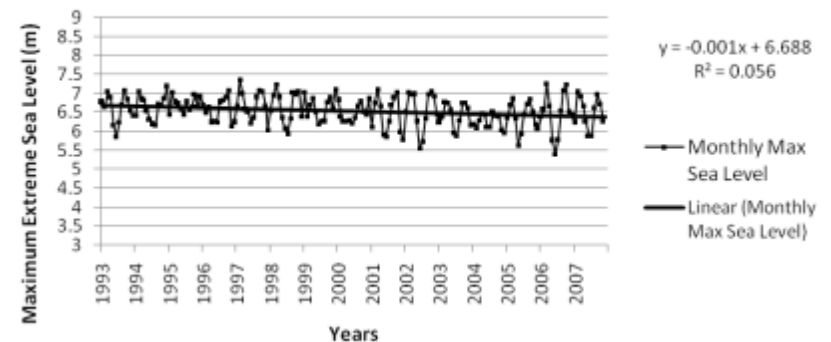
Monthly Maximum Extreme Sea Level at Newport



Monthly Maximum Extreme at Ilfracombe

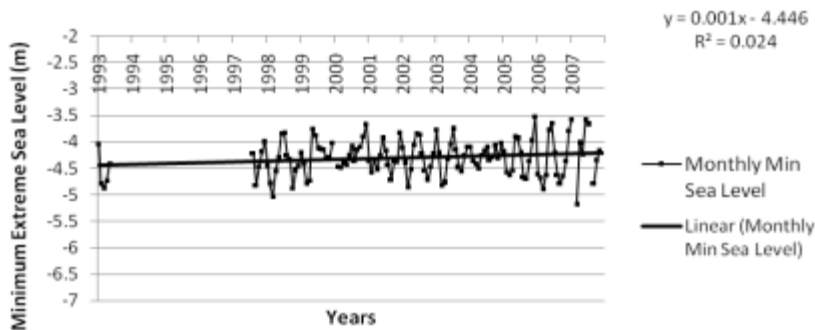


Monthly Maximum Extreme at Hinkley Point

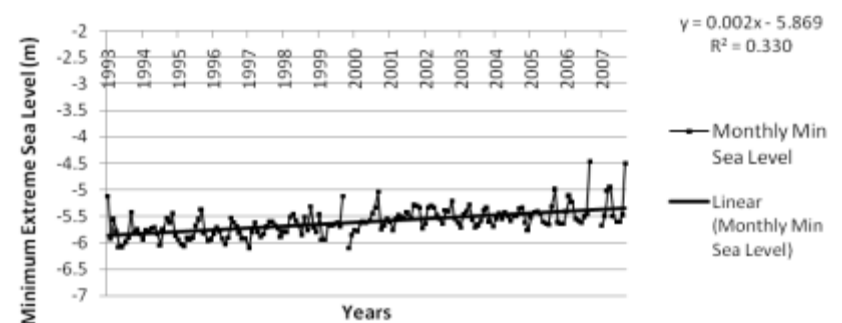


Minimum extreme sea levels show rising trends.

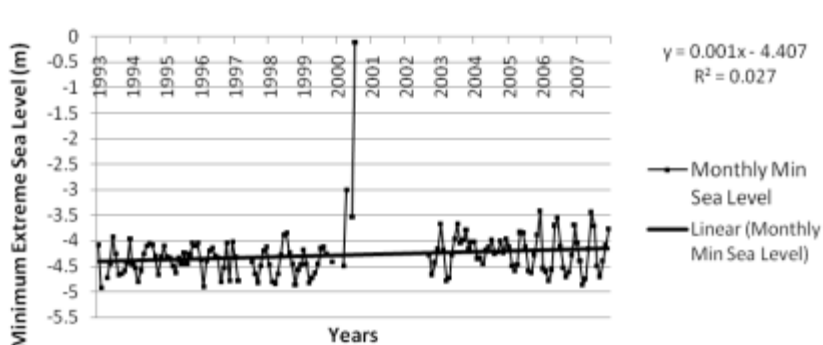
Monthly Minimum Extreme at Mumbles



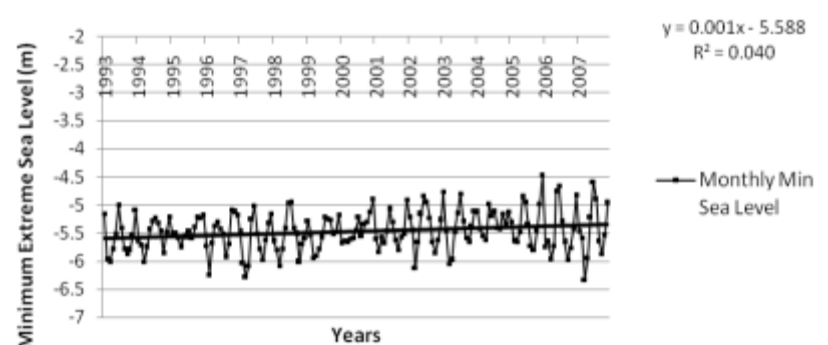
Monthly Minimum Extreme at Newport

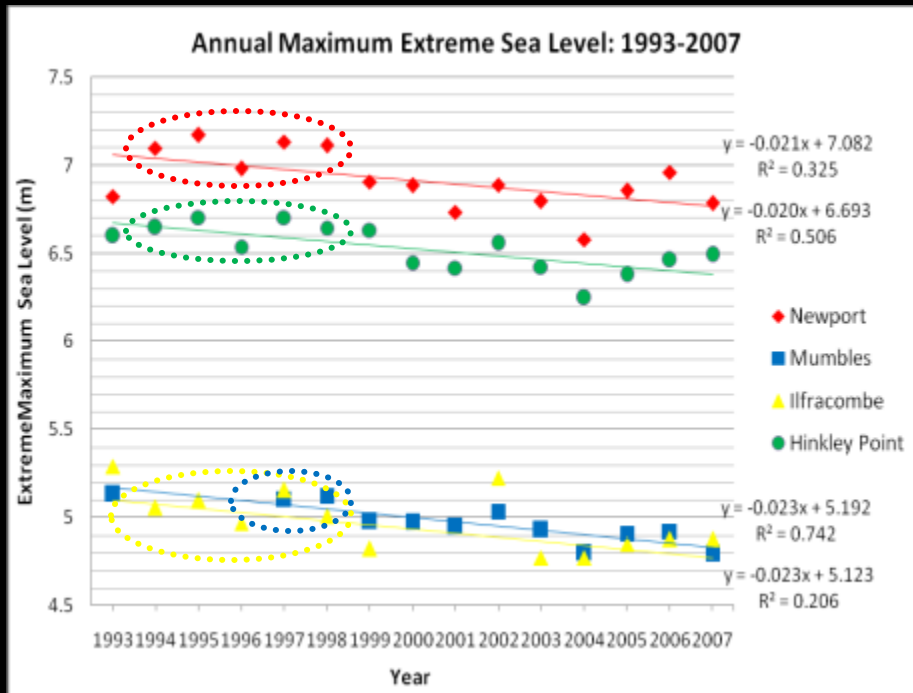


Monthly Minimum Extreme at Ilfracombe



Monthly Minimum Extreme at Hinkley Point





Between 1994 and 1998, maximum extreme sea levels can be seen to be higher than other years.

- Correlates to findings of Phillips (2008) of critical erosion levels at Penarth.



Phillips (1997)

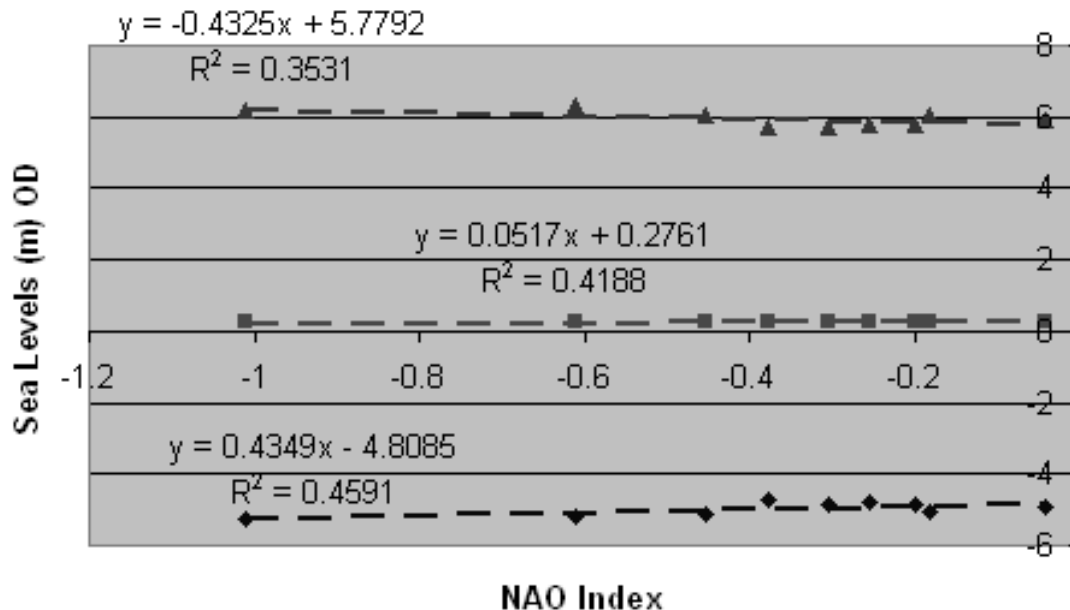


- This was a result of a change in direction of the prevailing south-westerly winds.

North Atlantic Oscillation (Negative)

Fewer and weaker winter storms; Moist air into the Mediterranean and cold air to northern Europe; The US east coast experiences more snowy weather conditions. (Bell and Visbeck, 2009).

WEAKER WESTERLY WINDS (MetOffice, 2006)



•Maximum Extreme

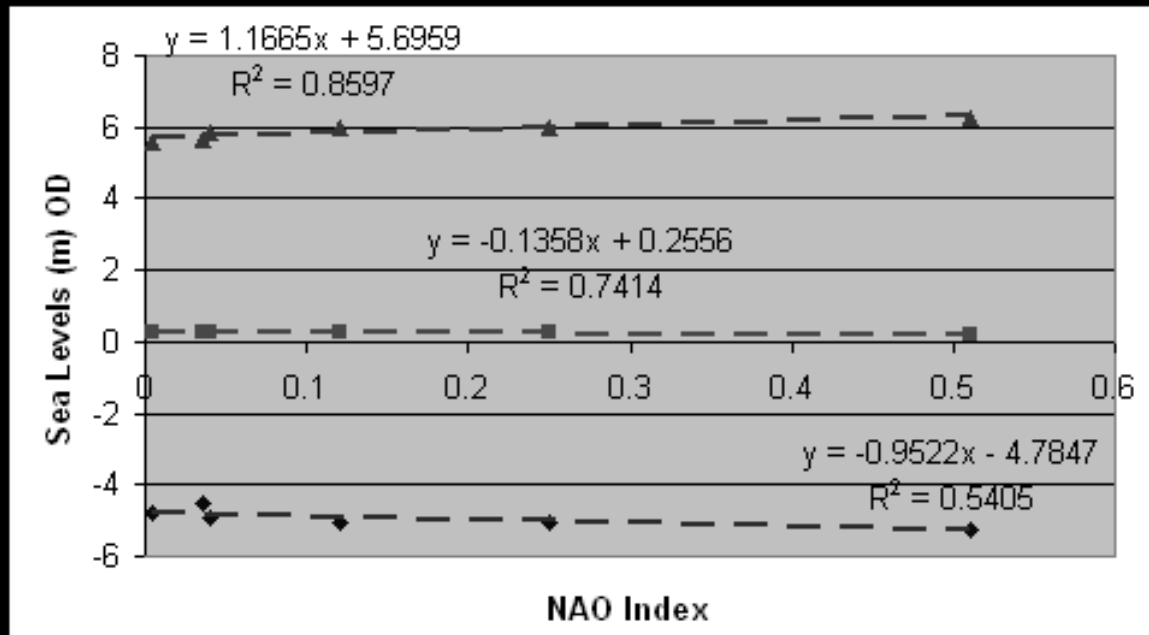
•Mean

•Minimum Extreme

North Atlantic Oscillation (Positive)

Strong subtropical high pressure and deeper Icelandic low; More and stronger winter storms crossing the Atlantic Ocean on a more northerly track; Warm, wet winters in Europe; cold, dry winters in Canada and Greenland; Eastern US mild and wet winters (Bell and Visbeck, 2009).

STRONGER WESTERLY WINDS (MetOffice, 2006)



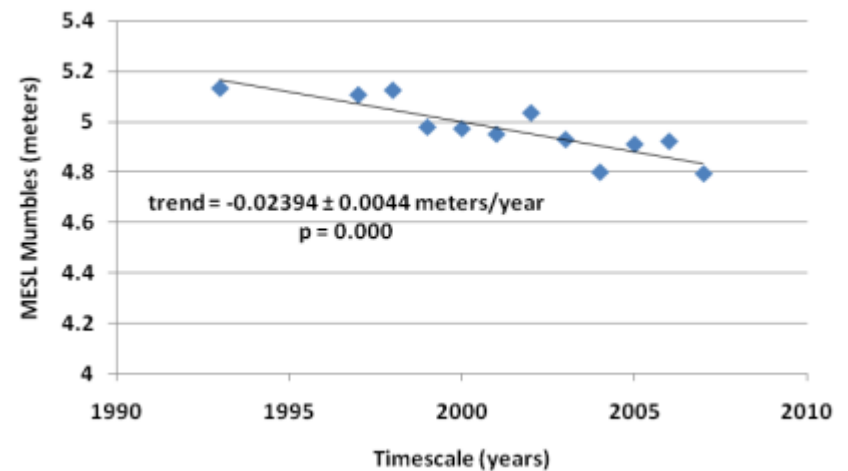
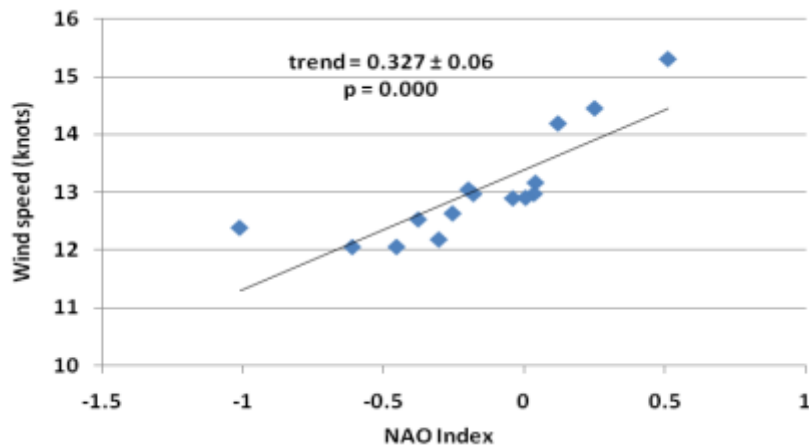
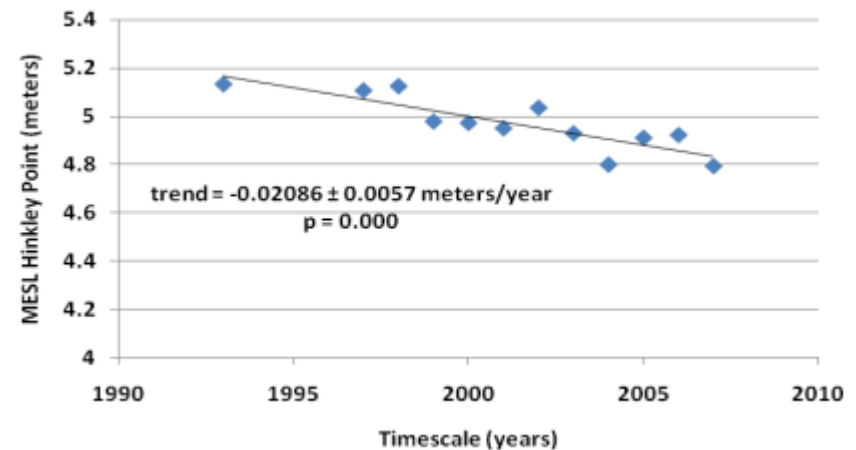
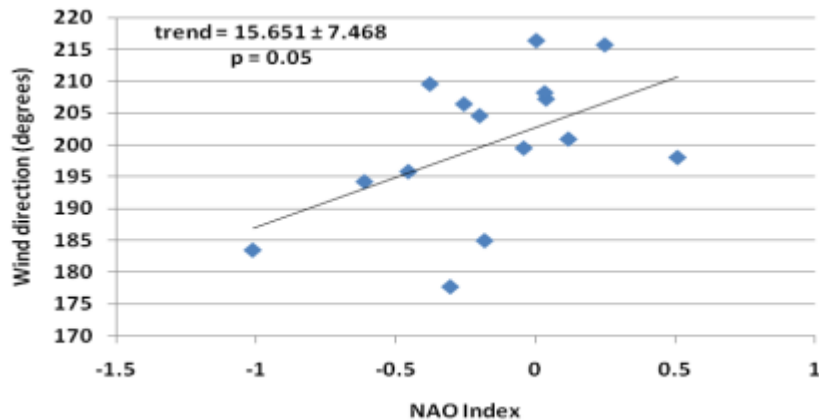
•Maximum Extreme

•Mean

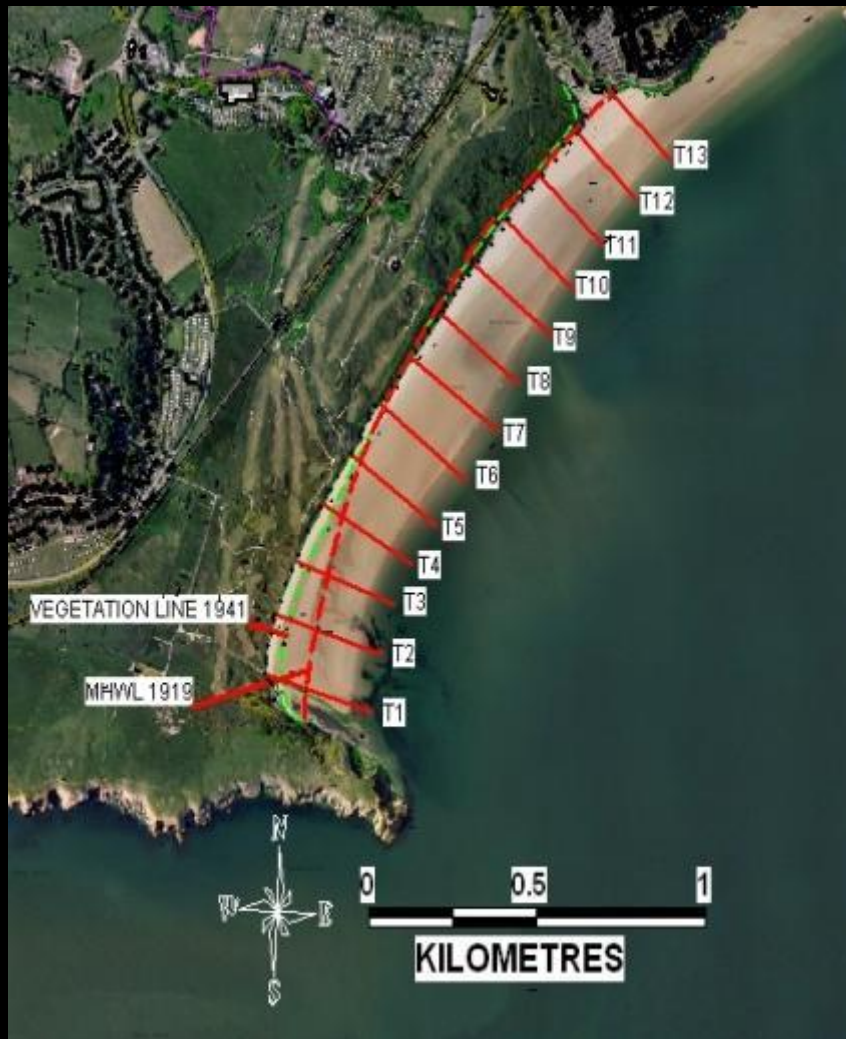
•Minimum Extreme

Coastal vulnerability, climate change, impacts and adaptation: integrated solutions

Professor Mike Phillips, GISLANDS 2012, Universidade dos Acores, August 5-11



Wind speeds and directions between 1993 and 2002 inclusive at Turbot Bank Buoy were found to be significantly higher than those measured at the relatively nearby Rhoose land based station (Paired t test: $t_{\text{calc}} = 87.74$, $df = 9$, $p < 0.01$ and $t_{\text{calc}} = 46.6$, $df = 9$, $p < 0.01$ respectively)



Tenby Monitoring

Comparison of NAO Index Values and Changes in Beach Level
1997/05

0.04

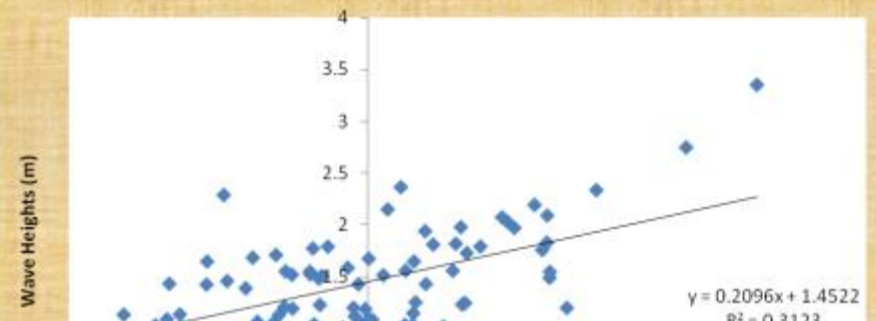
Comparison of NAO Index Values and Changes in Beach Volume
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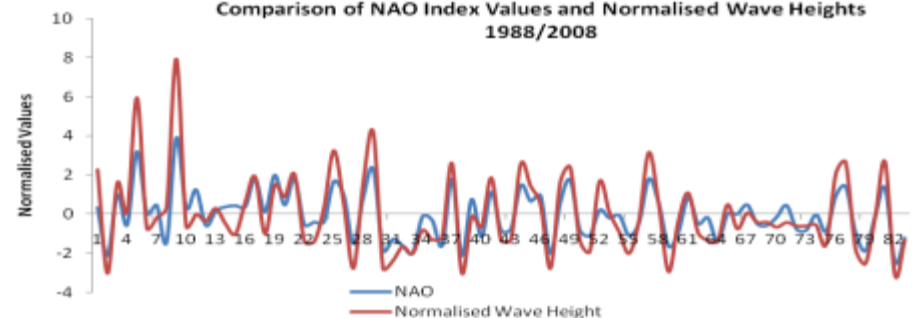
Comparison of NAO Index Values and Wind Direction from
the South West

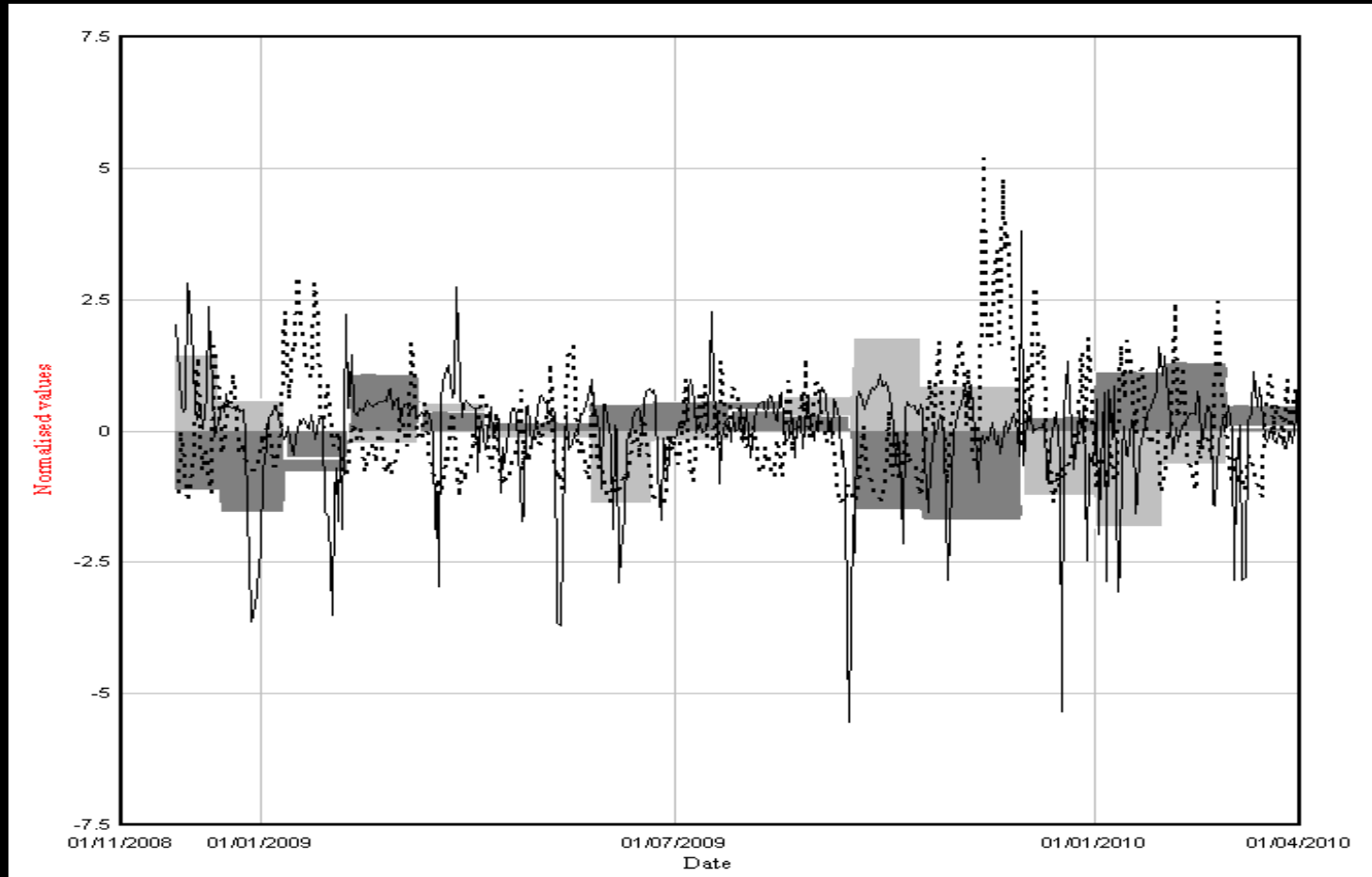
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Comparison of NAO Index and Wave Heights 1988/2008

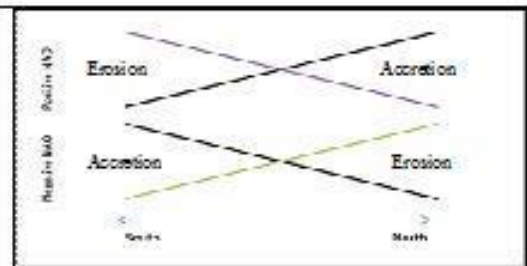
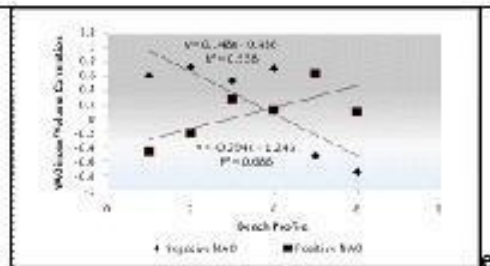
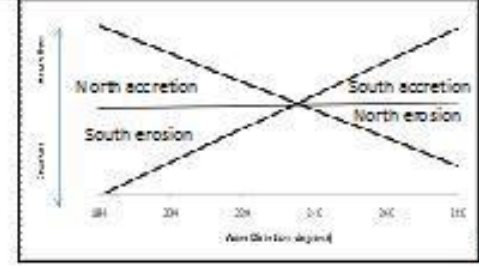
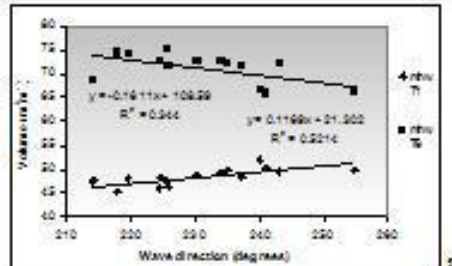


Comparison of NAO Index Values and Normalised Wave Heights
1988/2008





Comparison of normalised breaking wave heights (dashed line), wave direction (solid line) and subaerial volume change: south = light grey, north = dark grey for the period between November 2008 and April 2010.





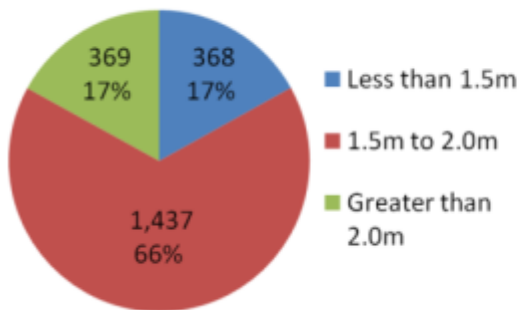
- Audit infrastructure (construction type and protection)
- Identify areas at risk
- IPCC scenario
- Water levels
- Wave/Wind climate (joint probability, etc.)
- Optimum cost (capital and maintenance)

INFORM DECISION-MAKERS/POLICY

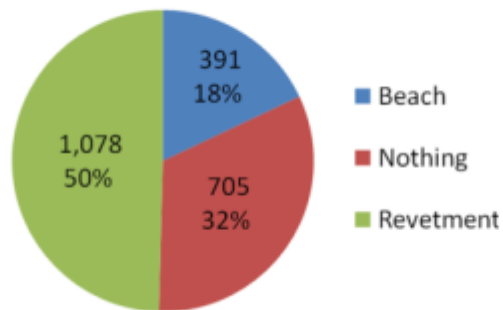
Coastal vulnerability, climate change, impacts and adaptation: integrated solutions
Professor Mike Phillips, GISLANDS 2012, Universidade dos Acores, August 5-11



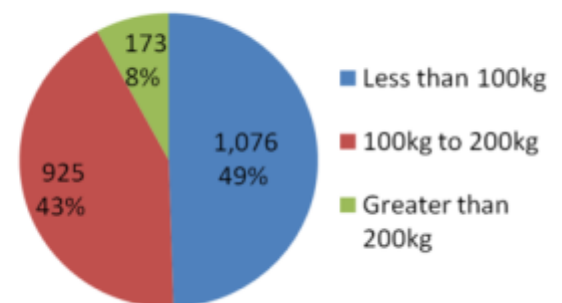
Crest Elevation



Structure Fronting



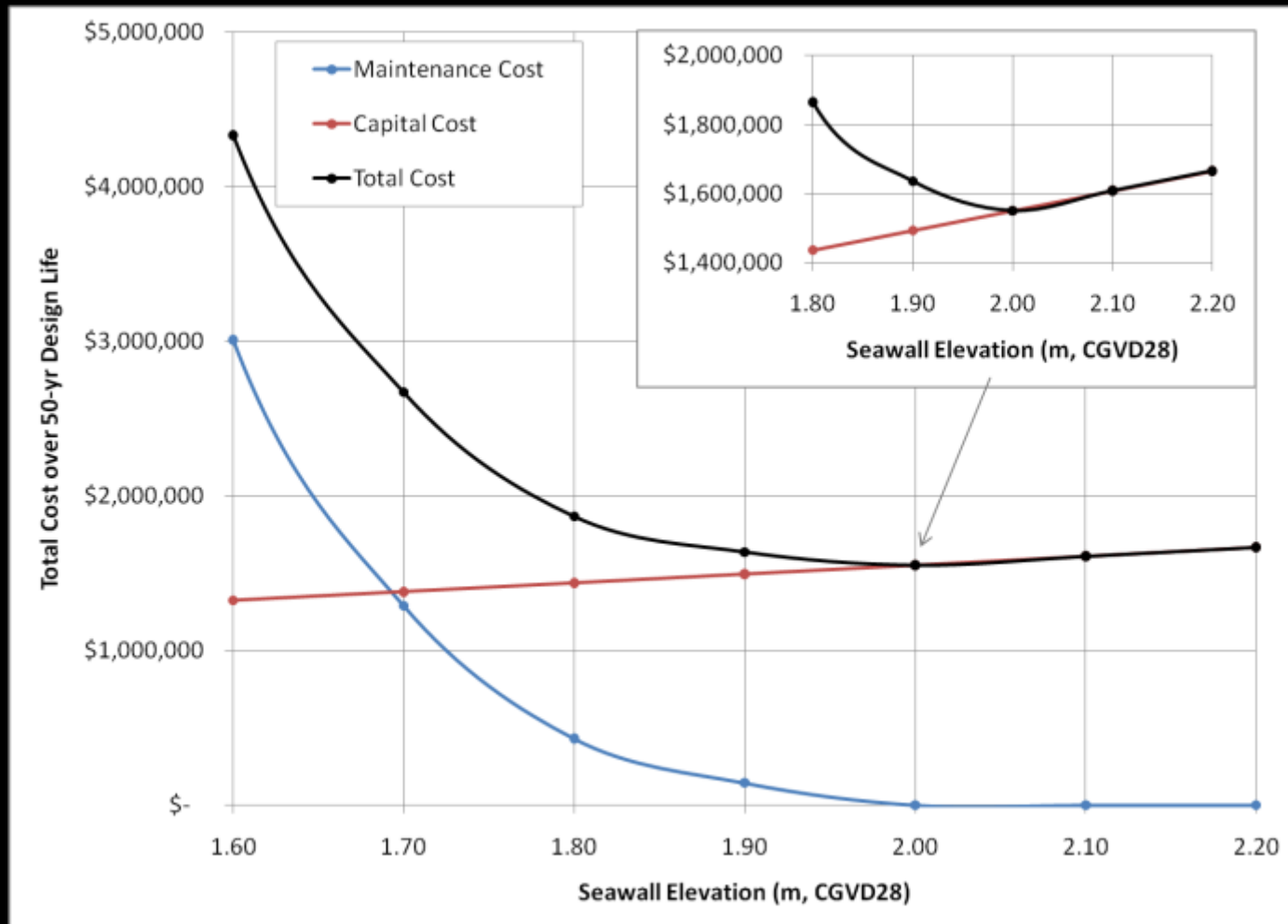
Average Stone Size



IPCC-based sea level rise scenarios (Forbes et al 2009)

Scenario	Rate (m/century)	Description
0	0	No sea level rise
1	0.32	No acceleration of sea level rise, rate continues at observed historic rate (crustal subsidence plus sea level rise)
2	0.73	IPCC AR4 upper-limit projection of SLR for the A1F1 emission scenario (crustal subsidence plus sea level rise)
3	1.46	Upper limit estimate of SLR from Rahmstorf (2007) (crustal subsidence plus sea level rise)

Decide on an elevation/protection level



Lajes, Pico Island, the Azores



Local inundation
adaptation measure

Dominant swell: SW; In general, 5-6m storm wave occurs once a year



**Breakwater coastal
defence – effectiveness?**

Coastal defences, Rabo de Peixe, Sao Miguel, the Azores



Coastal vulnerability, climate change, impacts and adaptation: integrated solutions

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Sao Roque, Sao Miguel

Protecting cultural heritage

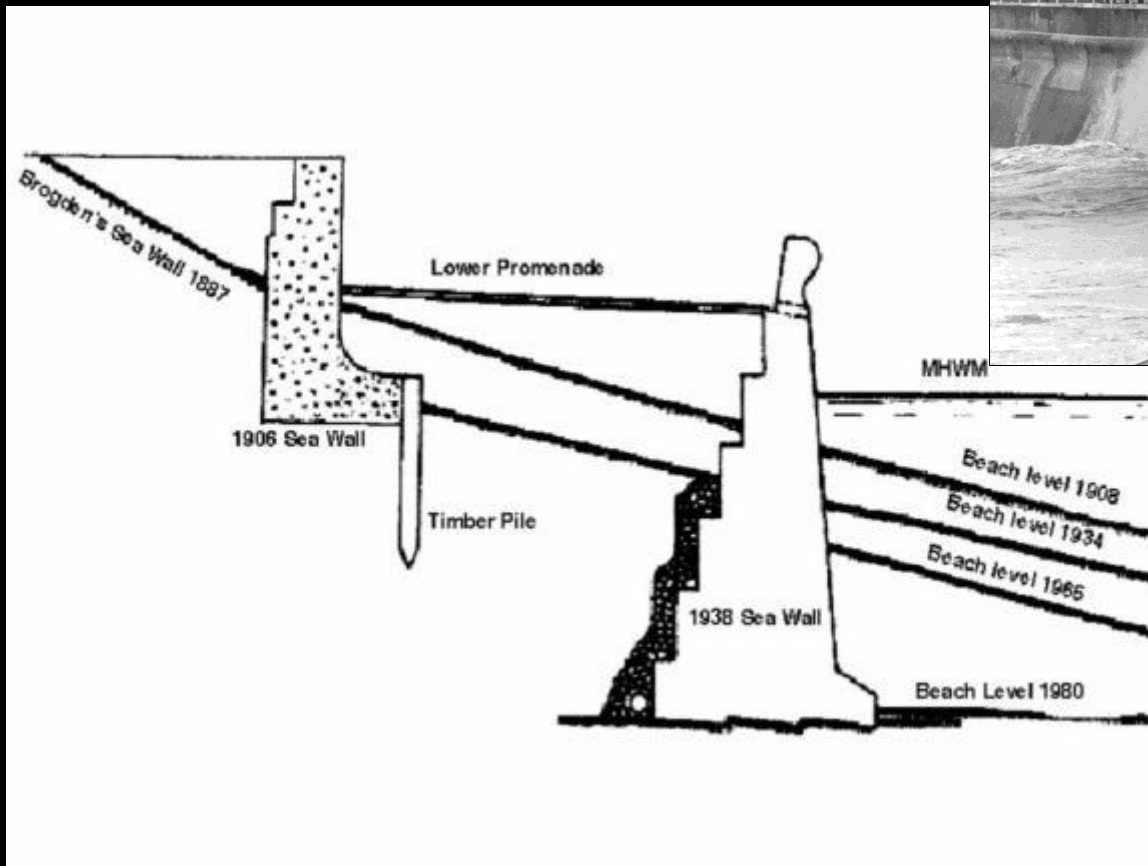


Coastal vulnerability, climate change, impacts and adaptation: integrated solutions

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Porthcawl, Wales, UK.



Temporal beach erosion (Carter, 1988)



Paving the beach - an appropriate coastal solution?

Beach Nourishment

- USA
- Spain
- France
- UK
- Malta
- Italy, etc

Approximately 5
year life



Cape May County, NJ, USA.



- USACE, 2004-5

- Ketchum (1972) identified tourism as a major coastal stakeholder
- WTO (various) 'world's largest industry'
- Houston (2002) 'America's largest industry' and '80% of tourists are beach tourists'
- USACE (1994) beach erosion serious threat to tourism and US economy.
- Since 1989, the cost of rebuilding and replenishing Cape Island has topped \$50 million (Fox, 2007).
- \$27.7 billion tourism revenue generated and 500,000 jobs created with businesses paying \$5.5 billion in taxes to the NJ treasury (NJCRC, 2009).



**Holistic approach:
dune restoration,
backpassing,
education, top
down and bottom
up, etc**

**Avalon, New Jersey
(Nordstrom et al.,
2009)**



NO PROBLEM

BIG PROBLEM





**Egmond aan Zee;
North-Holland Dune
reserve (buffer zone)**

Conclusions and Recommendations



- Understand regional coastal dynamics (wave climate, sediment transport, etc);
- **Assess impacts of future change (sea level rise, storms, etc.);**
- Establish vulnerability;
- Establish realistic buffer zone between development and the sea;
- **Use soft engineering solutions working with natural processes;**
- Education;
- Learn from mistakes;
- **There will be a cost.**

ANY QUESTIONS?

