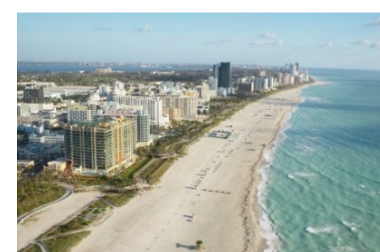
Coastal impacts of sea level rise: the global perspective

Robert J. Nicholls

Professor of Coastal Engineering

School of Engineering

University of Southampton, UK



INSeaPTION Global User Workshop

Haarlem

25/26 September 2018

Plan

- The coastal system
- The characteristics of sea-level rise
- Human responses to sea-level rise (safety)
  - Mitigation
  - Adaptation
- Concluding remarks -- scientific and societal implications

UNIVERSITY OF Southampton

Coastal Trends

Rising local and global risks

- Population
  - Growing coastal population (double global trends)
  - Urbanising coastal zone (new residents are urban)
  - Increasing tourism, recreation and retirement
- Subsiding, densely-populated deltas, especially in urban areas
- Globalisation of trade and international shipping routes
- Increasingly costly coastal disasters
- Climate change and sea-level rise
- A reactive approach to adaptation
- Degrading coastal habitats and declining ecosystem services

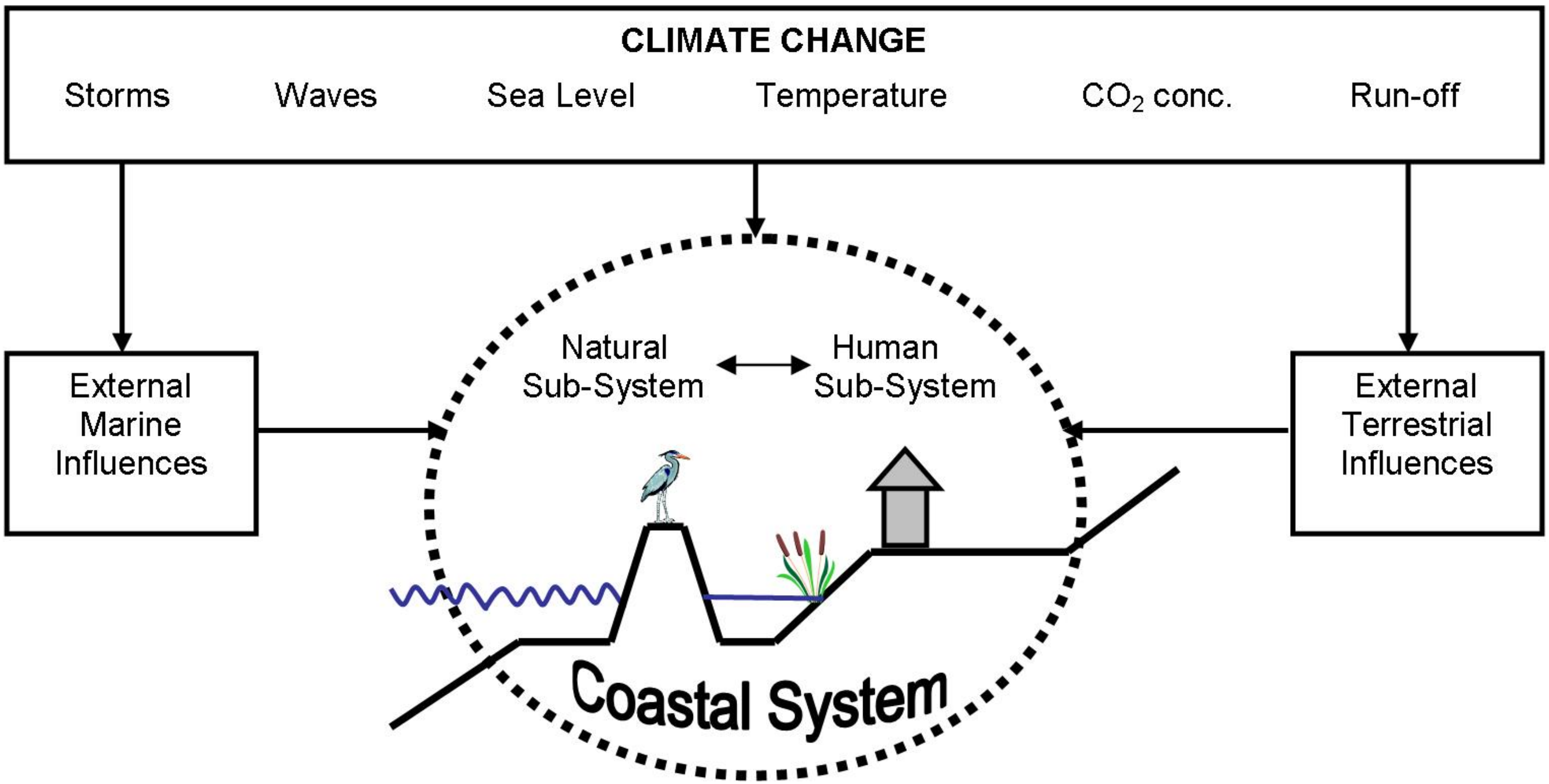
UNIVERSITY OF Southampton

Coastal Trends

Rising local and global risks

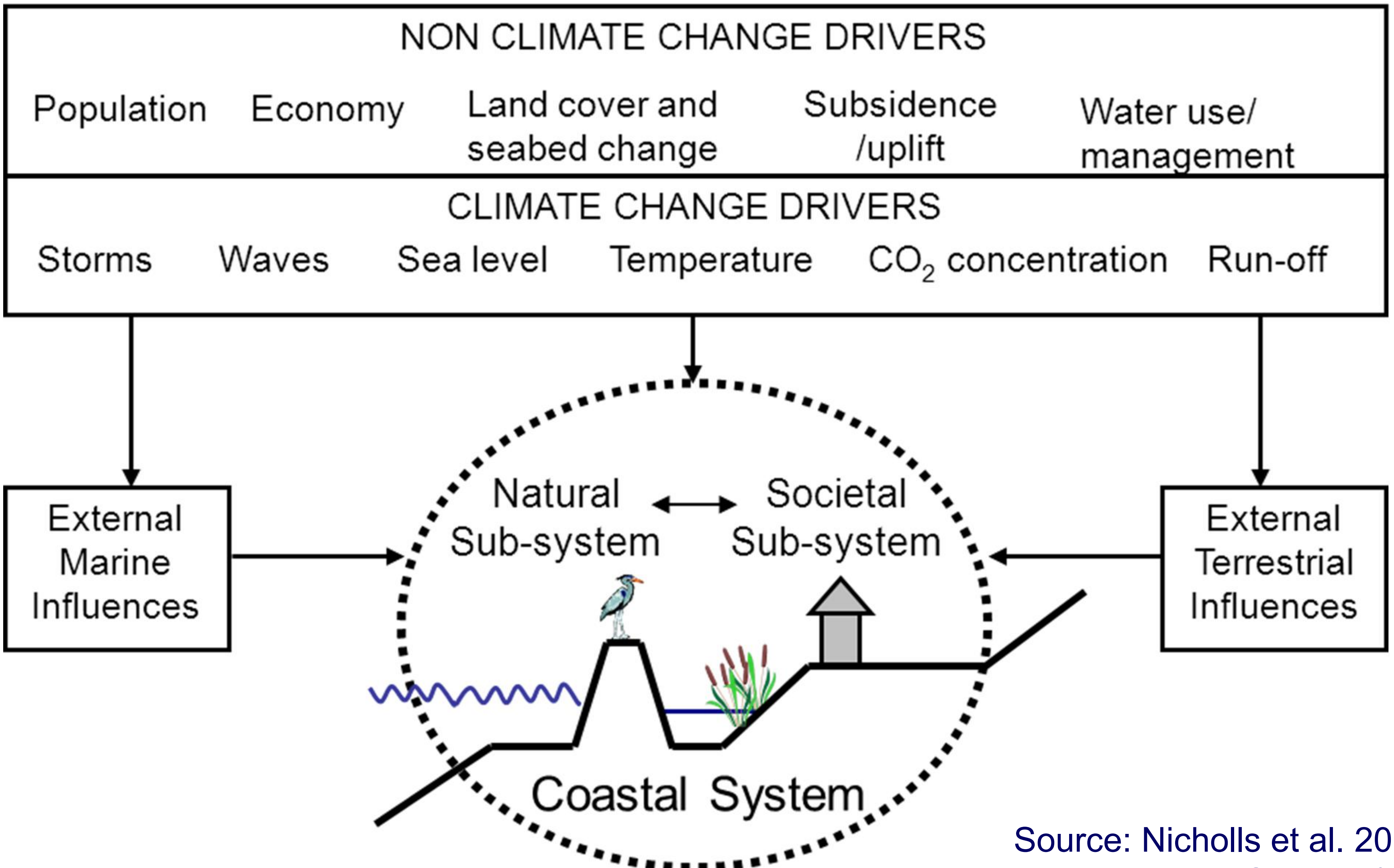
- Population
  - Growing coastal population (double global trends)
  - Urbanising coastal zone (new residents are urban)
  - Increasing tourism, recreation and retirement
- Subsiding, densely-populated deltas, especially in urban areas
- Globalisation of trade and international shipping routes
- Increasingly costly coastal disasters
- Climate change and sea-level rise
- A reactive approach to adaptation
- Degrading coastal habitats and declining ecosystem services

The coastal system



Source: IPCC AR4 WG II

The coastal system



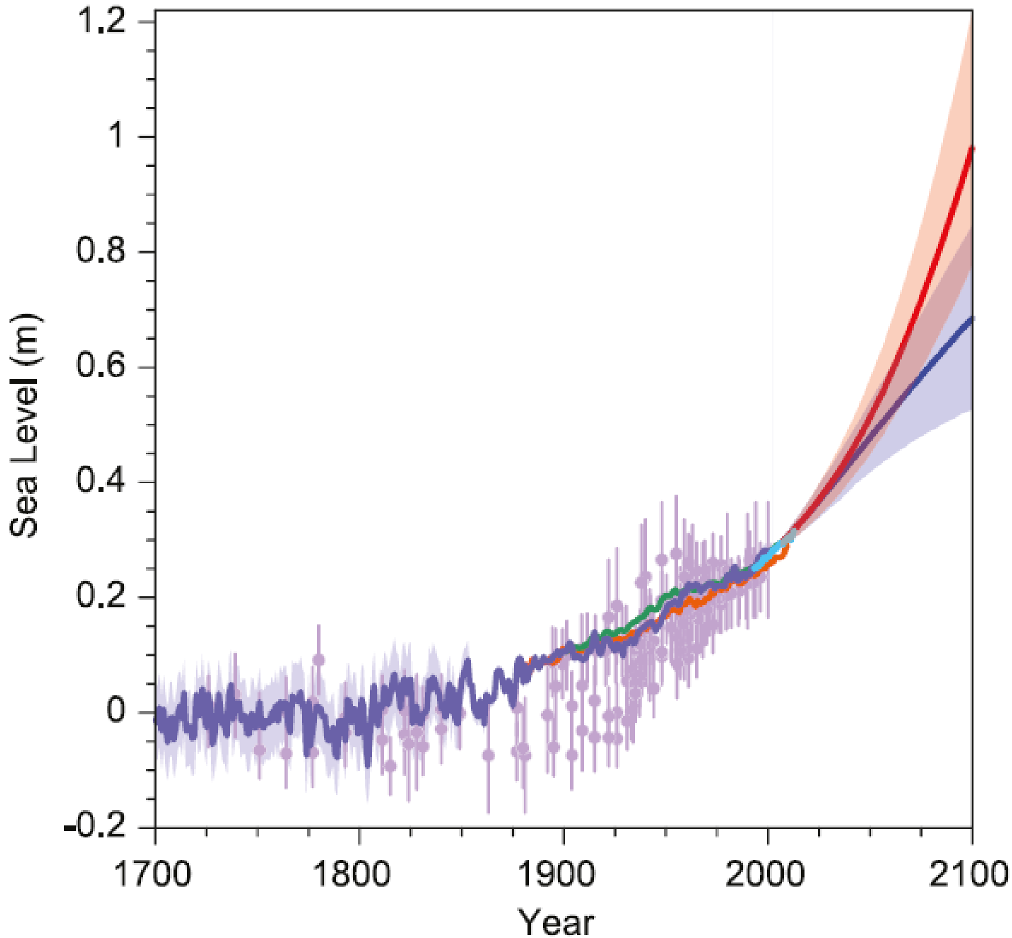
Source: Nicholls et al. 2014
Masselink and Gehrels (eds)

What is sea-level change (including sea-level rise)?

University of Southampton

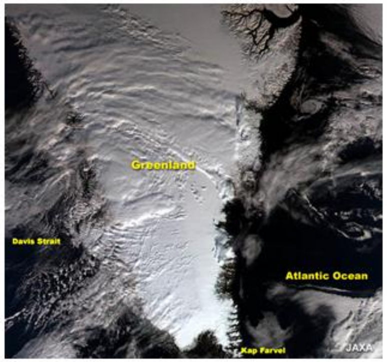
Global Sea-Level Rise

(Source: Figure 13.27 -- Chapter 13 IPCC AR5 WG1 Report)



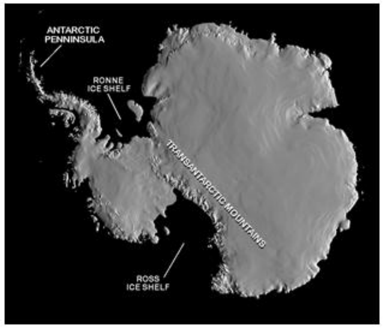
Global-Mean Sea-Level Rise: 1700 to 2100 (from IPCC, 2013). Compiled paleo-sea-level data from geological evidence to 1880, tide gauge data from 1880 to present, altimeter data since 1993 to present, and central estimates and likely ranges for projections from present to 2100 based on RCP2.6 (blue) and RCP8.5 (red) emission scenarios.

Climate-induced Sea-Level Rise



Rising temperatures lead to:

- Thermal expansion of seawater;
- Melting of land-based ice
  - Small glaciers (e.g., Rockies, Alaska)
  - Greenland ice sheet
  - West Antarctic ice sheet



MENU nature

UNIVERSITY OF Southampton

Article | Published: 30 March 2016

Contribution of Antarctica to past and future sea-level rise

Robert M. DeConto & David Pollard

Nature **531**, 591–597 (31 March 2016) | Download Citation

This article has been updated

Key Quote

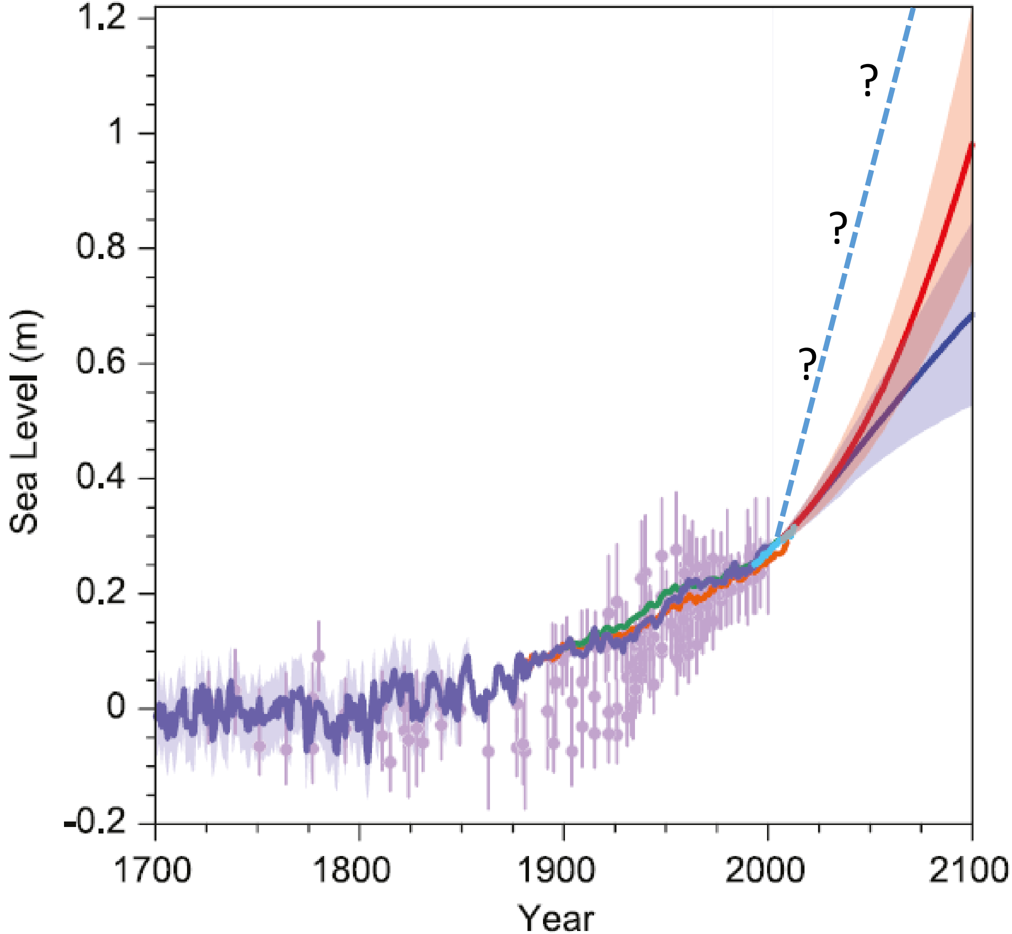
"Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500, if emissions continue unabated."

Abstract

Polar temperatures over the last several million years have, at times, been slightly warmer than today, yet global mean sea level has been 6–9 metres higher as recently as the Last Interglacial (130,000 to 115,000 years ago) and possibly higher during the Pliocene epoch (about three million years ago). In both cases the Antarctic ice sheet has been implicated as the primary contributor, hinting at its future vulnerability. Here we use a model coupling ice sheet and climate dynamics—including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs—that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied to future greenhouse gas emission scenarios. Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than

Global Sea-Level Rise

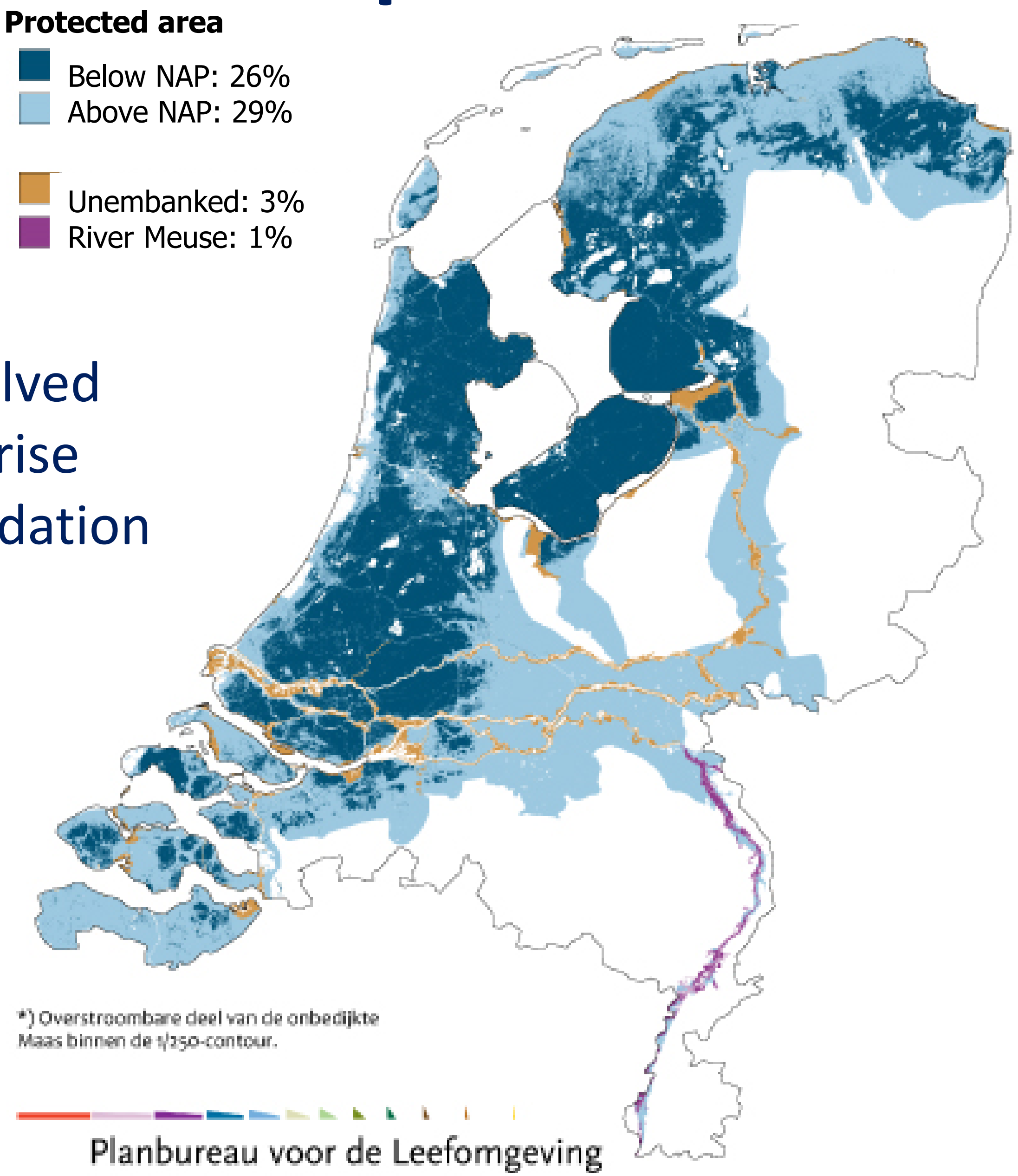
(Source: Figure 13.27 -- Chapter 13 IPCC AR5 WG1 Report)



Global-Mean Sea-Level Rise: 1700 to 2100 (from IPCC, 2013). Compiled paleo-sea-level data from geological evidence to 1880, tide gauge data from 1880 to present, altimeter data since 1993 to present, and central estimates and likely ranges for projections from present to 2100 based on RCP2.6 (blue) and RCP8.5 (red) emission scenarios.

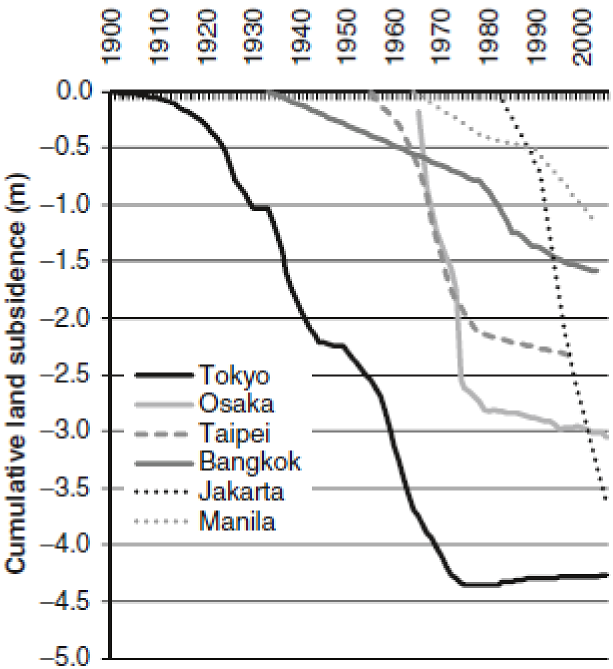
Netherlands: Flood prone areas

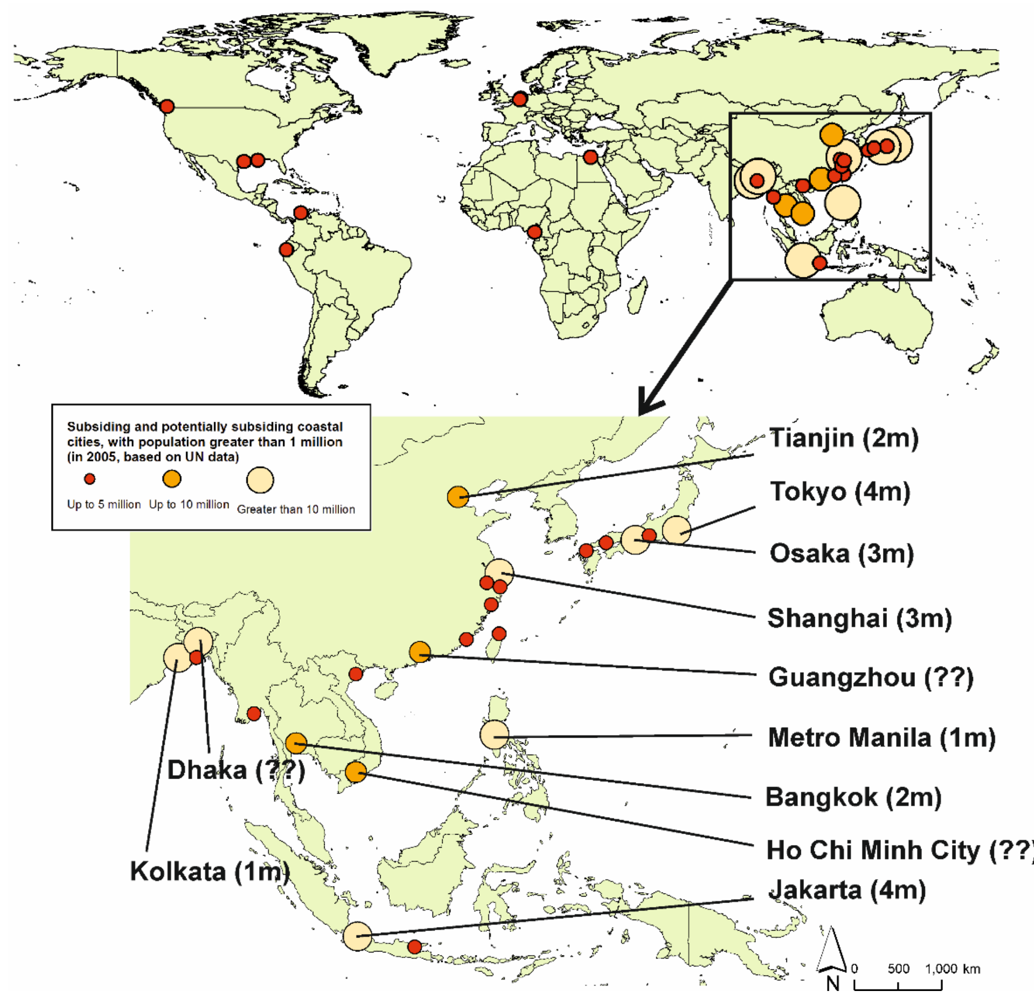
The Netherlands has evolved due to relative sea-level rise (land subsidence and oxidation of peat) and land claim.



Subsiding Coastal Cities

population > 1 million in 2005,
including maximum observed subsidence during 20th Century





Source: Kaneko and Toyota, 2011 (left); Nicholls, 2014 (above)

Relative Sea-Level Components

- Global components – increasing ocean volume linked to climate change
- Regional components – climate variability such as El-Nino, geological trends
- Local components – often human-induced subsidence due to fluid withdrawal and drainage (oxidation of organic soils)
- (Extreme sea levels and waves)

Consequences of sea-level rise?

Physical Impacts of Sea-Level Rise

NATURAL SYSTEM EFFECT		INTERACTING FACTORS	
		CLIMATE	NON-CLIMATE
1. Inundation, flood and storm damage	a. Surge (flooding from the sea)	Wave/storm climate, Erosion, Sediment supply.	Sediment supply, Flood management, Erosion, Land reclamation
	b. Backwater effect (flooding from rivers)	Run-off.	Catchment management and land use.
2. Wetland loss (and change)		CO_2 fertilisation of biomass production, Sediment supply, Migration space	Sediment supply, Migration space, Land reclamation (i.e., direct destruction).
3. Erosion (of 'soft' morphology)		Sediment supply, Wave/storm climate.	Sediment supply.
4. Saltwater Intrusion	a. Surface Waters	Run-off.	Catchment management (over-extraction), Land use.
	b. Ground-water	Rainfall.	Land use, Aquifer use (over-pumping).
5. Higher water tables/ impeded drainage		Rainfall, Run-off.	Land use, Aquifer use, Catchment management.

Source: Nicholls (2010) Book on "Understanding Sea-Level Rise and Variability"

Socio-Economic Impacts of SLR

Coastal Socio-economic Sector	Sea-level rise physical impact				
	Inundation, etc.	Wetland loss	Erosion	Saltwater intrusion	Higher water tables/ etc.
Freshwater Resources	X	x	-	X	X
Agriculture and forestry	X	x	-	X	X
Fisheries and Aquaculture	X	X	x	X	-
Health	X	X	-	X	x
Recreation and tourism	X	X	X	-	-
Biodiversity	X	X	X	X	X
Settlements/ infrastructure	X	-	X	X	X

X = strong; x= weak; - = negligible or not established.

Source: Nicholls (2010) Book on "Understanding Sea-Level Rise and Variability"

Hotspots of concern

- Islands
- Deltas
- Coastal urban areas
- Coastal ecosystems – wetlands, reefs, etc.
- Coastal heritage

How can we respond to sea-level rise?

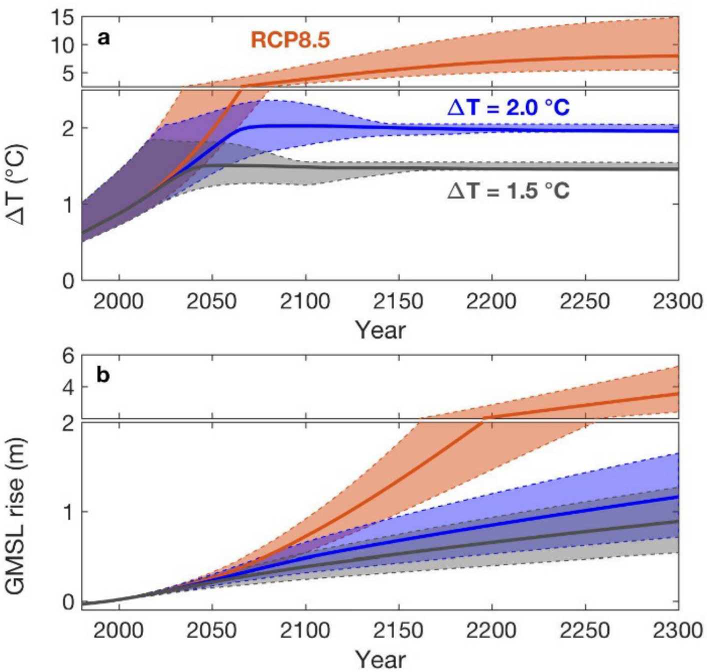
Mitigation – source control – greenhouse gas emissions and also sources of human-induced subsidence

Adaptation – change behaviour

The Paris Agreement

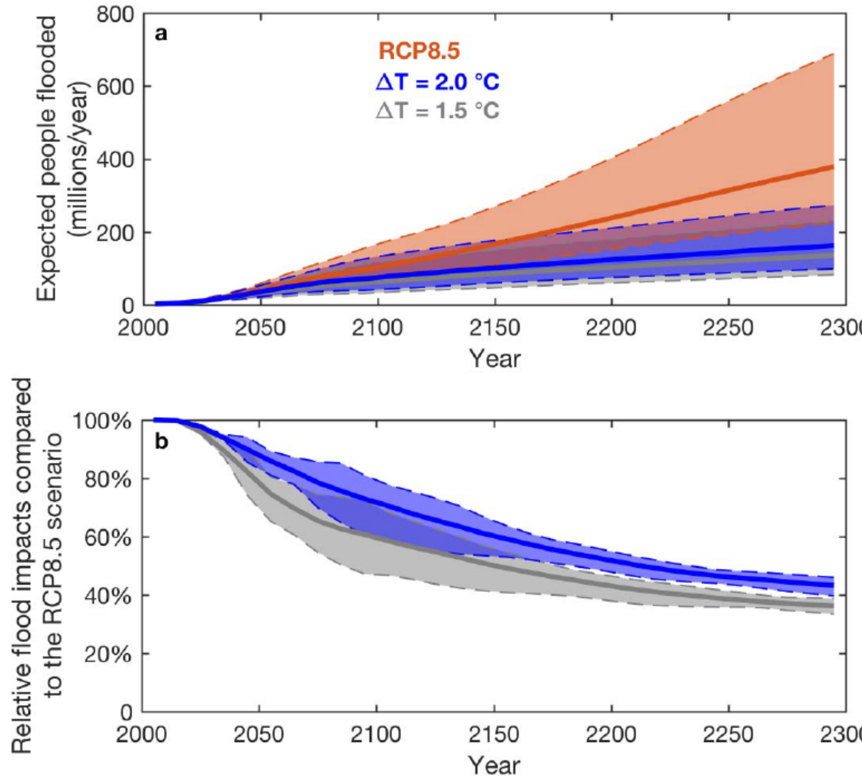
Nicholls et al., 2018 http://dx.doi.org/10.1098/rsta.2016.0448

Temperature



GMSL – Global mean sea level

People flooded as an indicator



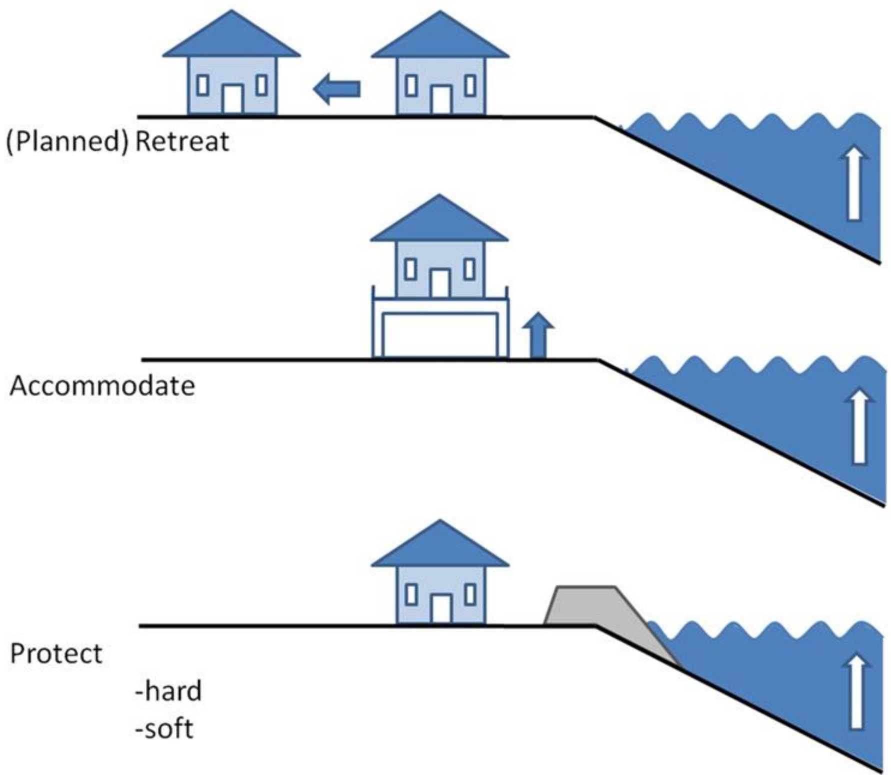
Adaptation to sea-level rise (SLR)

"Adjustment in natural or human systems in response to actual or expected climatic *relative sea-level rise* or their effects, which moderates harm or exploits beneficial opportunities"

i.e. risk management of relative sea-level rise

Planned Adaptation to SLR

The IPCC Approach



Source: Nicholls (2010) Book on "Understanding Sea-Level Rise and Variability"

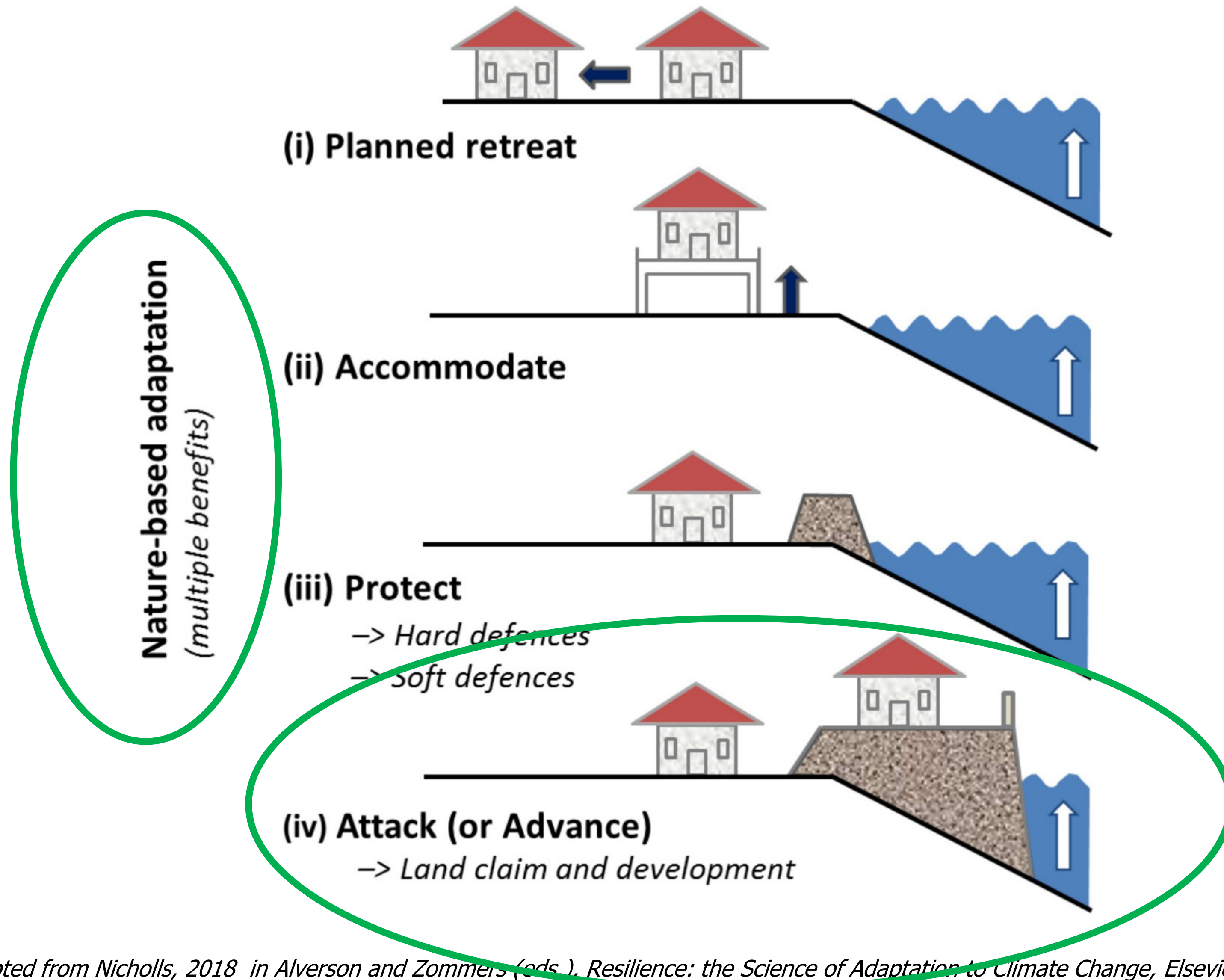
Many Adaptation Options are Available

P – Protection; A – Accommodation; R – Retreat.

NATURAL SYSTEM EFFECT		POSSIBLE ADAPTATION RESPONSES
1. Inundation, flood and storm damage	a. Surge	Dikes/surge barriers [P], Building codes/floodwise buildings [A], Land use planning/hazard delineation [A/R].
	b. Backwater effect	
2. Wetland loss (and change)		Land use planning [A/R], Managed realignment/ forbid hard defences [R], Nourishment/sediment management [P].
3. Erosion (of 'soft' morphology)		Coast defences [P], Nourishment [P], Building setbacks [R].
4. Saltwater Intrusion	a. Surface Waters	Saltwater intrusion barriers [P], Change water abstraction [A/R].
	b. Ground-water	Freshwater injection [P], Change water abstraction [A/R].
5. Rising water tables/ impeded drainage		Upgrade drainage systems [P], Polders [P], Change land use [A], Land use planning/hazard delineation [A/R].

Source: Nicholls (2010) Book on "Understanding Sea-Level Rise and Variability"

Planned Adaptation to SLR



Source: adapted from Nicholls, 2018 in Alverson and Zommers (eds.). Resilience: the Science of Adaptation to Climate Change, Elsevier

The 100th Thames Barrier Closure

Source: Environment Agency

Upgraded Protection Portsmouth, UK

UNIVERSITY OF Southampton

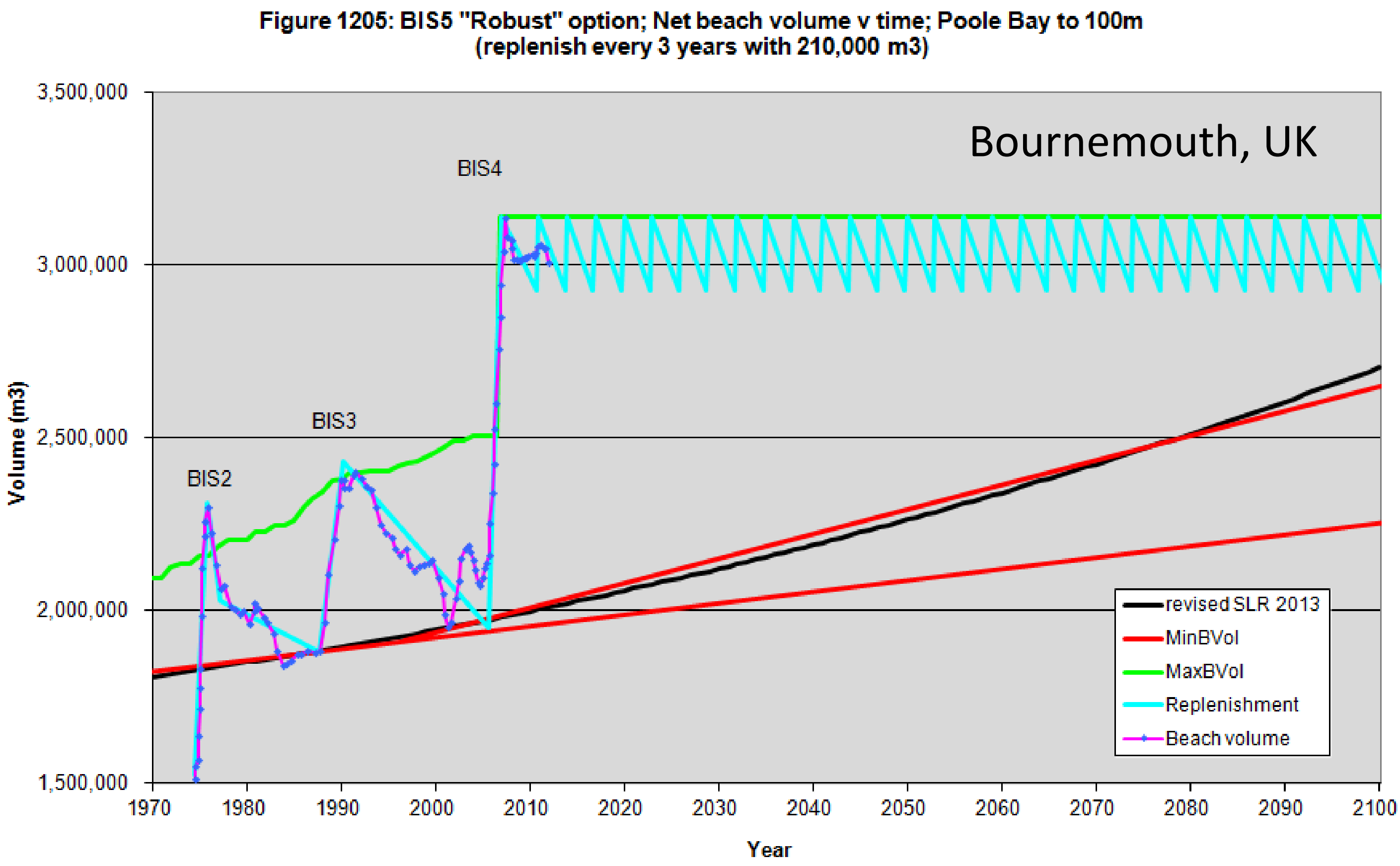
UNIVERSITY OF Southampton

Mobile Flood Defences, Portsmouth, UK

Soft Protection

Beach Nourishment – Bournemouth, UK

Soft Protection
Actual and Planned Beach Volume



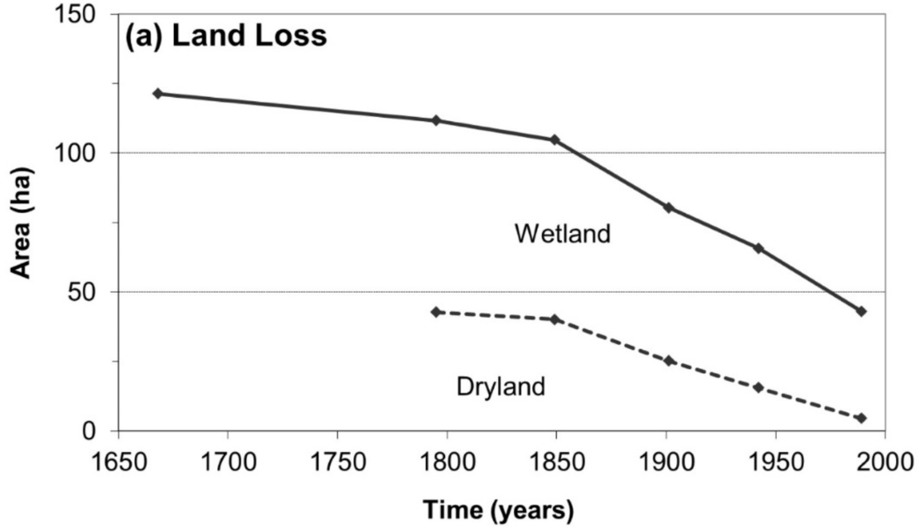
Soft Protection
Sand Motor, the Netherlands

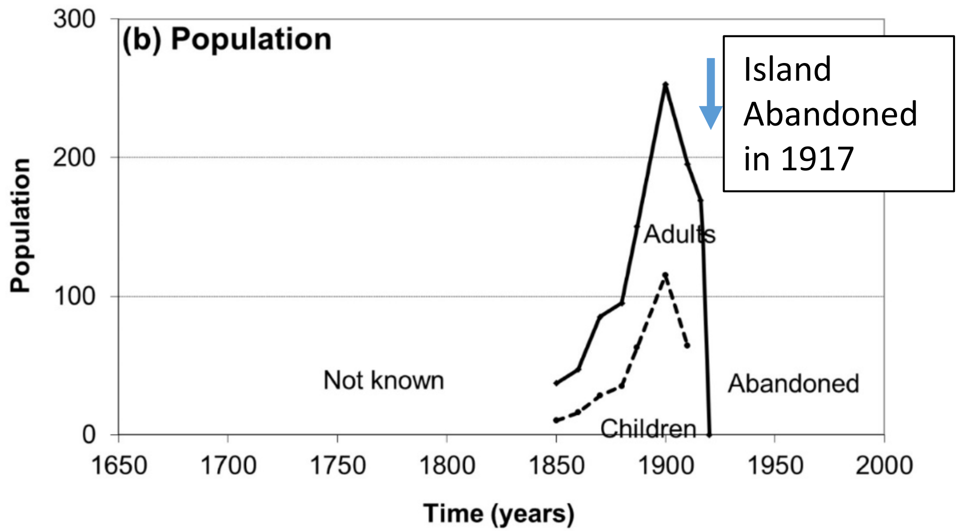
Accommodation: flood preparedness in the USA

Accommodation in the UK

raising new homes to EA elevation recommendations including an allowance for sea-level rise

Retreat on Holland Island
The Chesapeake Bay, USA





Source: Gibbons and Nicholls, 2006, Global Environmental Change

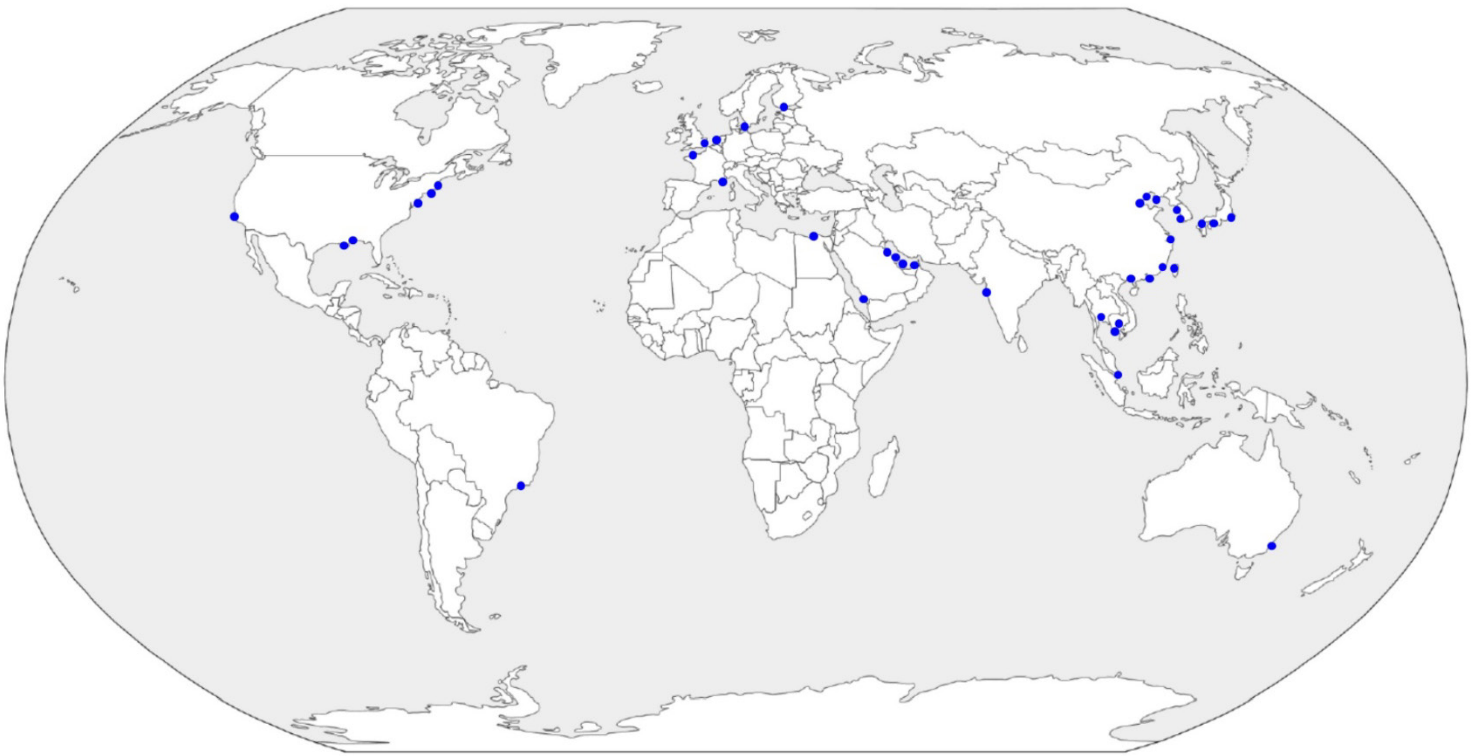
Source: NASA's SeaWifs Project and ORBIMAGE

UNIVERSITY OF Southampton

Selected Sites of Major Land Claim

Globally, >30,000 km^2 of land has been gained from the sea during the last 30 years (> 1,000 km^2/yr).

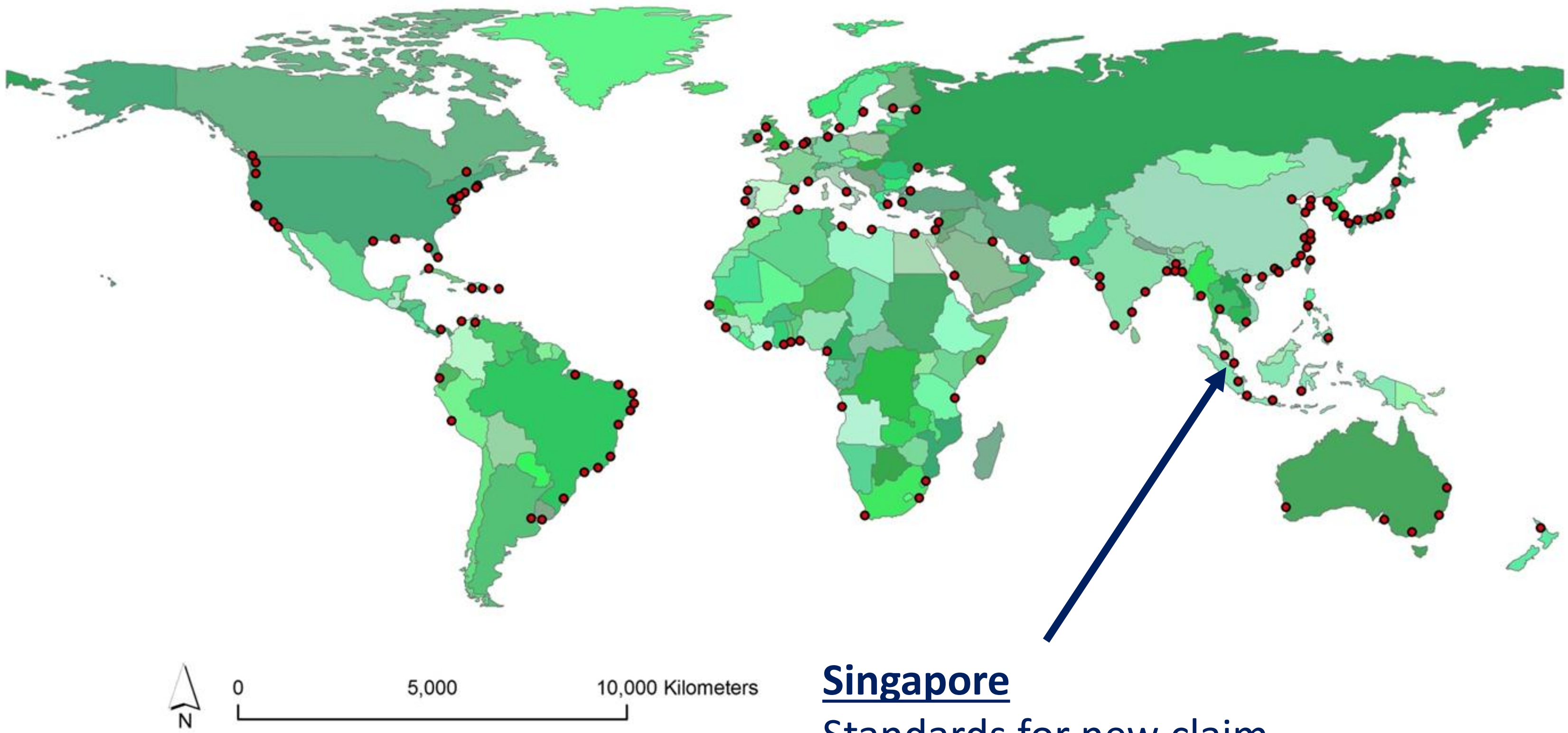
Biggest gains in Dubai, Singapore and China



Source: Angela Fung, University of Southampton, unpublished thesis and Martin-Anton et al., 2016, JCR; Wang, et al., 2014 Ocean & Coastal Management,; Donchyts et al, 2016, NCC.

Port City Locations

>1 million population in 2005 -- 136 locations



Singapore
Standards for new claim includes sea-level rise

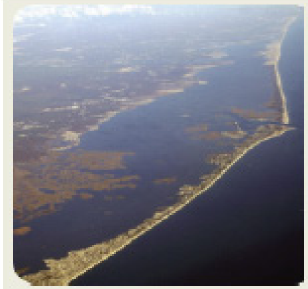
Source: Nicholls et al., 2008, OECD Report

UNIVERSITY OF Southampton

Nature-based Approaches: Classification

Generally, classified based on habitats and location

NATURAL AND NATURE-BASED FEATURES AT A GLANCE

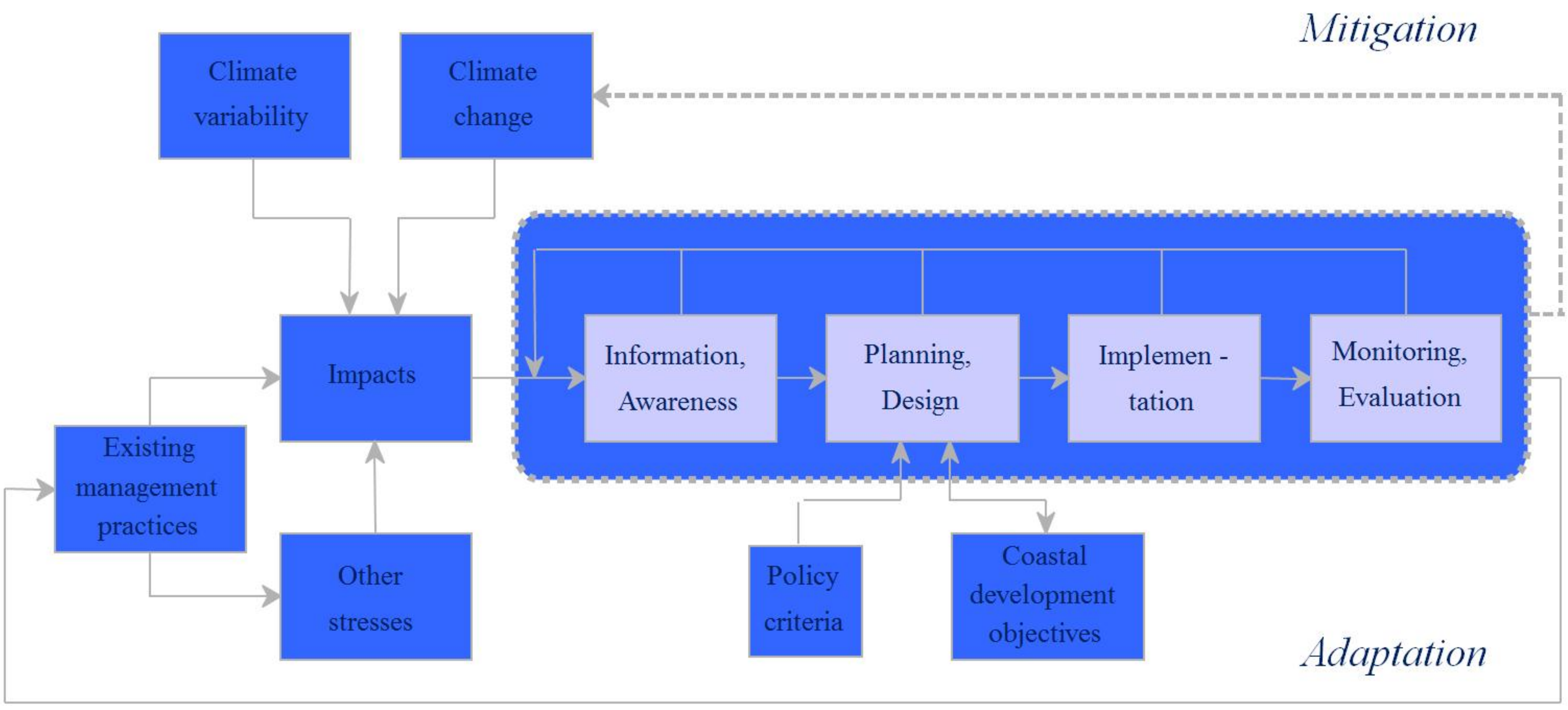
Dunes and Beaches	Vegetated Features (e.g., Marshes)	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
				
Benefits/Processes Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	**Benefits/Processes** Breaking of offshore waves Attenuation of wave energy Slow inland water transfer Increased infiltration	**Benefits/Processes** Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	**Benefits/Processes** Wave attenuation and/or dissipation Sediment stabilization	**Benefits/Processes** Wave attenuation and/or dissipation Shoreline erosion stabilization Soil retention
Performance Factors Berm height and width Beach slope Sediment grain size and supply Dune height, crest, and width Presence of vegetation	**Performance Factors** Marsh, wetland, or SAV elevation and continuity Vegetation type and density Spatial extent	**Performance Factors** Reef width, elevation, and roughness	**Performance Factors** Island elevation, length, and width Land cover Breach susceptibility Proximity to mainland shore	**Performance Factors** Vegetation height and density Forest dimension Sediment composition Platform elevation

General coastal risk reduction performance factors include: Storm surge and wave height/period, and water levels

US Army Corps of Engineers. Guidelines for the use of Nature and Nature-based Features

Adaptation is a multi-step process

Lending itself to pathway approaches



Source: Klein et al., 1999; 2000

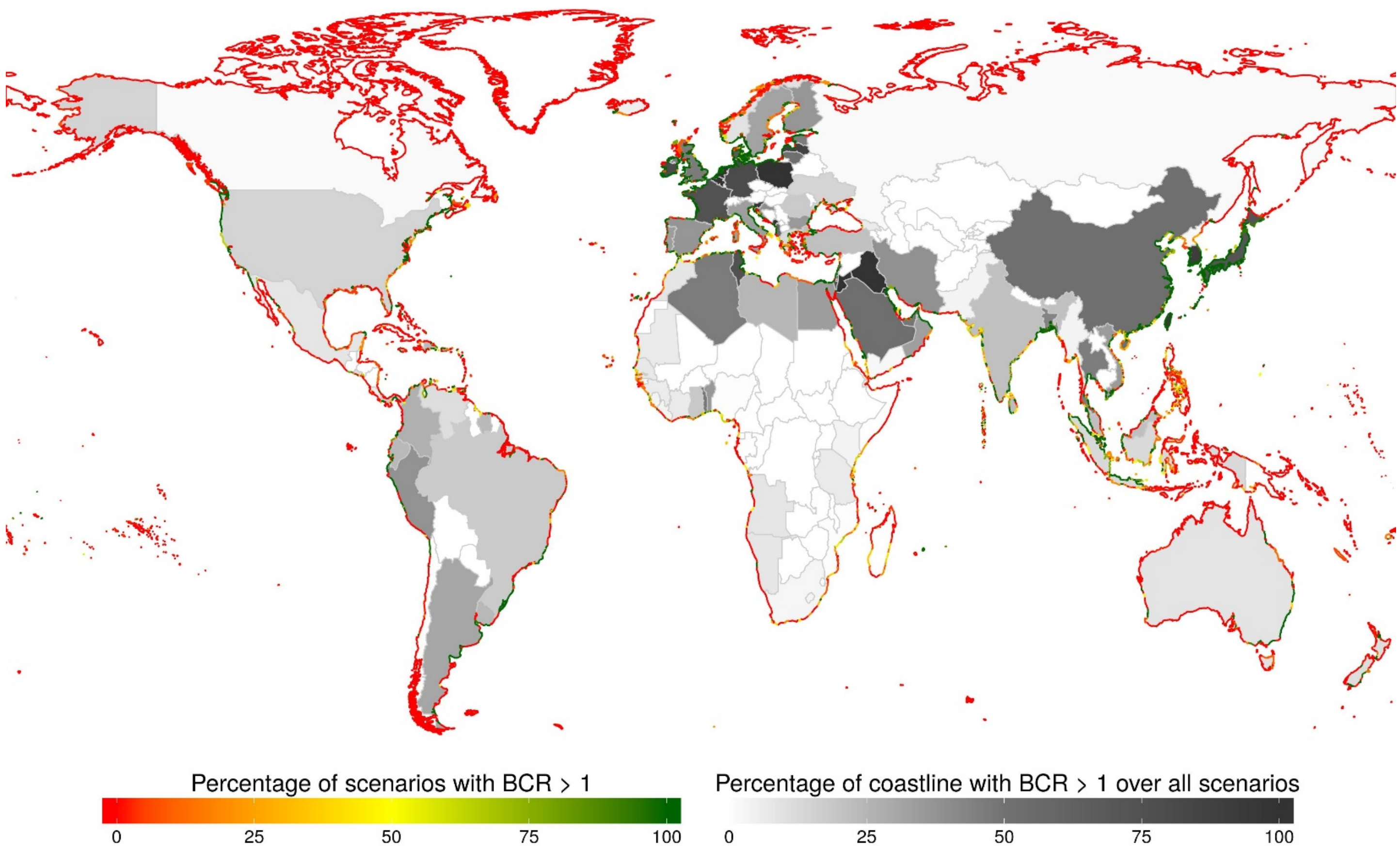
Protection as an option

UNIVERSITY OF Southampton

Economic robustness of coastal protection

SLR scenarios from 0.3 m to 2.0 m, the five SSPs and 10 discount rates of up to 6%.

Source: Lincke and Hinkel (2018) Global Environmental Change



92,500 km is always protected (13%): 90% of global coastal floodplain population

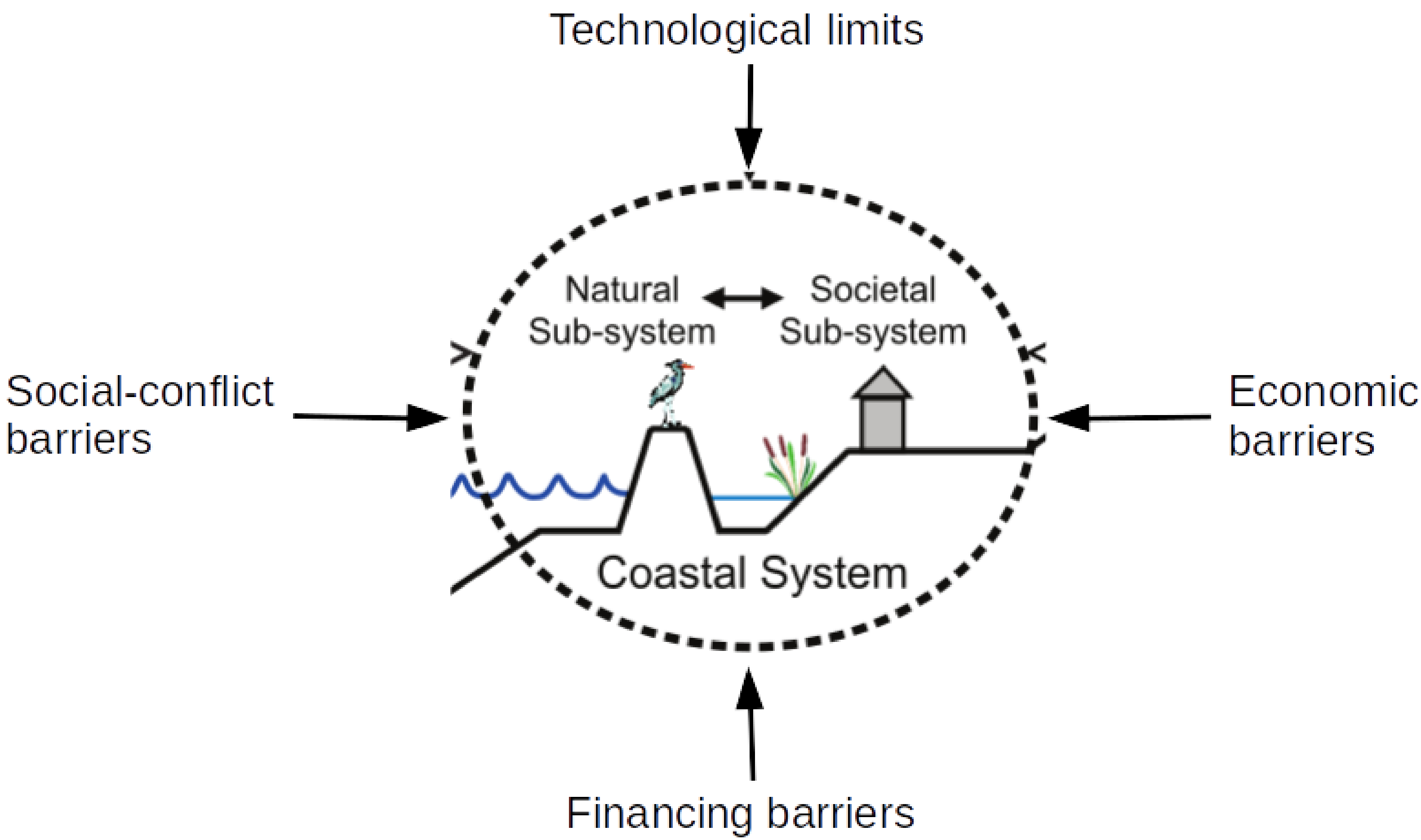
451,000 km is never protected (65%): 0.2% of coastal floodplain population

22% world's coast and 9.8% of coastal flood plain population – result is scenario dependent

UNIVERSITY OF Southampton

The ability of societies to adapt to 21st century sea-level rise

Source: Hinkel et al., 2018, Nature Climate Change



UNIVERSITY OF Southampton

The ability of societies to adapt to 21st century sea-level rise

Source: Hinkel et al., 2018, Nature Climate Change

Case	Dominant coastal characteristics				Adaptation limits/barriers			
	Coastal landform	World Bank country income group (in 2017)	Land use	Population density (people/km^2)	Techno-logy	Economic	Finance	Social conflict
Bangladesh	Delta	Lower middle income	Rural	*1,100			X	X
Catalonia	Beaches, deltas, cliffs	High income	Rural/ urban	*900				X
Ho Chi Minh City	Delta	Lower middle income	Urban	*3,900		Some	X	X
Maldives	Atoll islands	Higher middle income	Urban	**63,000				X
			Rural	*1,500		X	X	
New York City	Estuary	High income	Urban	*11,000			X	X
Netherlands	Delta, beaches	High income	Rural/ urban	*500				X

Concluding Remarks (1)

- Sea-level rise is certain, but the rate of rise is highly uncertain depending on emissions and climate sensitivity
- Even if we fully implement the Paris Agreement, sea levels continue to rise – there is a commitment to sea-level rise
- And subsidence needs to be considered
- Hence adaptation is essential and there is a commitment to adapt to sea-level rise
- Adaptation should take a flexible strategy – if possible – to adjust to improving understanding of sea-level rise.

Concluding Remarks (2)

- Adaptation can take many forms – protection (hard, soft and ecosystem-based), accommodation or retreat
- Sea-level rise and adaptation are not independent: larger rises in sea level will trigger more (but not universal) coastal retreat (and abandonment)
- Protection reduces risks, but there are downsides – coastal squeeze of ecosystems, residual risk, the need for ongoing maintenance and lock-in – i.e. more protection is the only option
- Nonetheless, protection is expected in many developed areas, following a multi-step process

UNIVERSITY OF Southampton

Concluding Remarks (3)

- Advance (or land claim) is also widespread and can be expected to continue in densely populated areas: it is linked to land scarcity but must consider SLR/climate change
- In densely populated areas, protection (and advance) is technically feasible, economically feasible, with financing and social conflict being the major constraints
- The available analysis suggests about 10 percent of the world's coast is viable to protect under any circumstance during the 21st Century, and 65% is never viable to protect

Possible Trajectories for Coastal Areas

- Most of the world’s coast will evolve “naturally”
- Human agency, engineering and protection (often hybrid – mixes of hard, soft and nature-based) will dominate in densely developed areas
- Less densely populated areas have a dilemma – the response depends on the scenario – more sea-level rise promotes more retreat
- We will see a tendency for fewer but bigger disasters over time, which will shape local (and maybe wider) adaptation – a trigger for change
- Much more “coastal system” research is required to explore these responses and shine light on the real choices we face under rising sea levels

UNIVERSITY OF Southampton

Coastal impacts of sea level rise: the global perspective

Robert J. Nicholls

Professor of Coastal Engineering

School of Engineering

University of Southampton, UK

INSeaPTION Global User Workshop

Haarlem

25/26 September 2018