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on Transport, Trade Logistics and Trade Facilitation:

Third Session:
Small Island Developing States: Transport and Trade Logistics Challenges

24 – 26 November 2014

Risk Reduction and Adaptation to Climate Change in Small Island Developing States

Presentation by

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Working Group II : Impacts, Adaptation, and Vulnerability

Risk reduction and adaptation to climate change in Small Island Developing States

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WMO UNEP

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OUTLINE

- Conceptual Framework
- Climate-related drivers and associated impacts
- Human-related drivers and associated impacts
- Attribution to climate change
- Adaptation
- Conclusions

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OUTLINE

Conceptual Framework

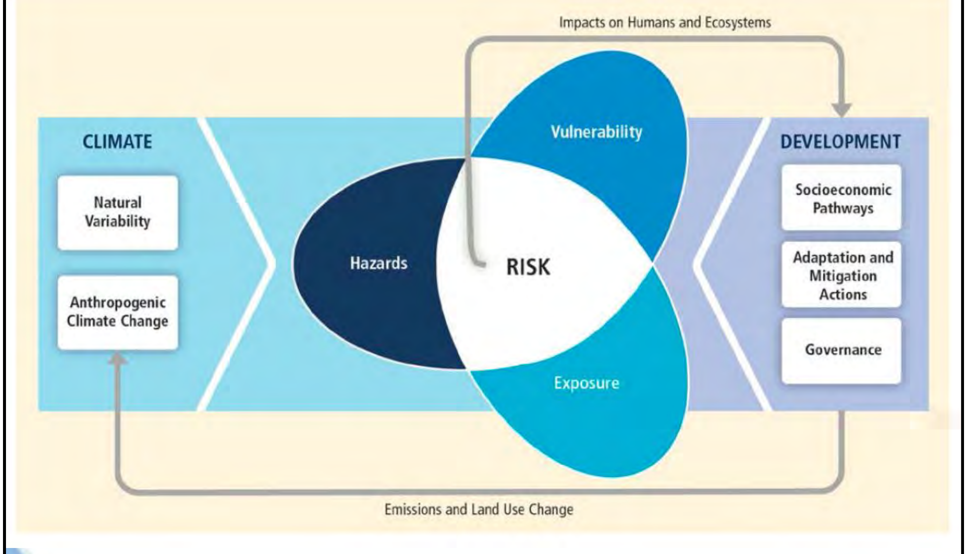
Climate-related drivers and associated impacts

Human-related drivers and associated impacts

Attribution to climate change

Adaptation

Conclusions



Low exposure and low vulnerability

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High exposure and medium vulnerability

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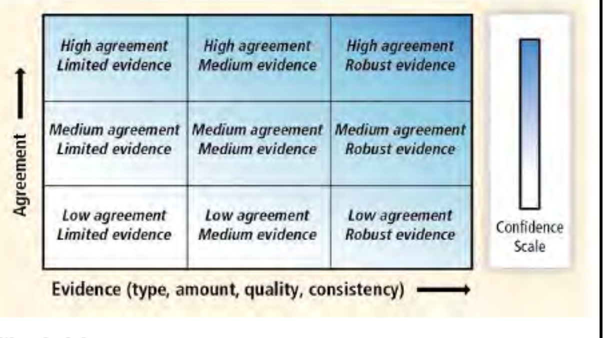
High exposure and high vulnerability

Communication of the degree of certainty in assessment findings



Term*	Likelihood of the outcome
Virtually certain	99–100% probability
Very likely	90–100% probability
Likely	66–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Exceptionally unlikely	0–1% probability

* Additional terms used more occasionally are *extremely likely:* 95–100% probability, *more likely than not:* >50–100% probability, and *extremely unlikely:* 0–5% probability.

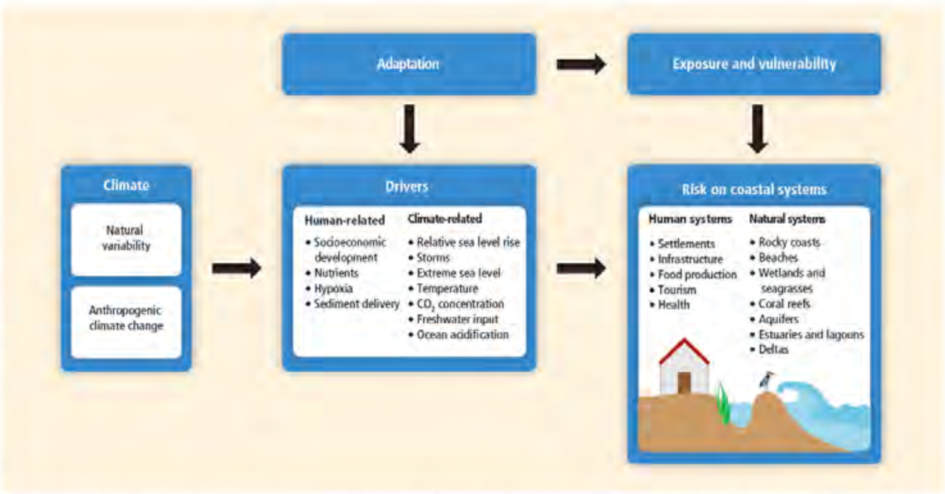


Figure 5-1 | Climate, just as anthropogenic or natural changes, affects both climate- and human-related drivers. Risk on coastal systems is the outcome of integrating drivers and exposure and vulnerability. Adaptation options can be implemented either to modify the drivers or exposure and vulnerability or both.

OUTLINE

Conceptual Framework

Climate-related drivers and associated impacts

Human-related drivers and associated impacts

Attribution to climate change

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Conclusions

Current and future climate-related drivers of risk for small islands during the 21st century include sea level rise (SLR), tropical and extratropical cyclones, increasing air and sea surface temperatures, and changing rainfall patterns (high confidence; robust evidence, high agreement)

Impacts are dependent on the magnitude, frequency, and temporal and spatial extent of the event, as well as on the biophysical nature of the island and its social, economic, and political setting.

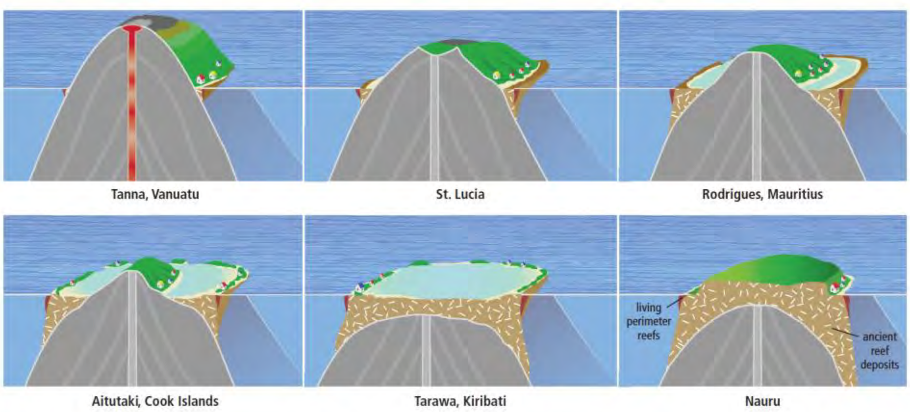
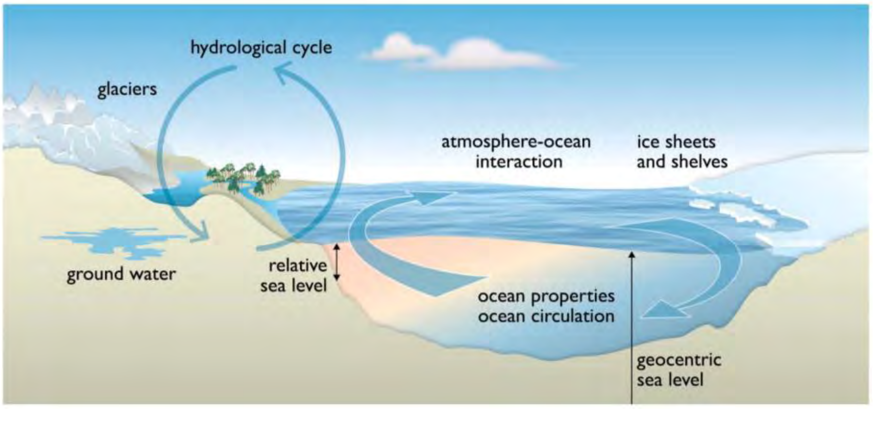


Figure 29-1 | Representative tropical island typologies. From top left: A young, active volcanic island (with altitudinal zonation) and limited living perimeter reefs (red zone at outer reef edge), through to an atoll (center bottom), and raised limestone island (bottom right) dominated by ancient reef deposits (brown + white fleck). Atolls have limited, low-lying land areas but well developed reef/lagoon systems. Islands composed of continental rocks are not included in this figure, but see Table 29-3.

Climate-related driver	Physical/chemical effects	Trends	Projections	Progress since AR4
Sea level	Submergence, flood damage, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change).	Global mean sea level *very likely* increase (Section 5.3.2.2; WGI AR5 Sections 3.7.2, 3.7.3).	Global mean sea level *very likely* increase (see Table 5.1; WGI AR5 Section 13.5.1). Regional variability (Section 5.3.2.2; WGI AR5 Chapter 13).	Improved confidence in contributions to observed sea level. More information on regional and local sea level rise.
Storms: tropical cyclones (TCs), extratropical cyclones (ETCs)	Storm surges and storm waves, coastal flooding, erosion; saltwater intrusion; rising water tables/ impeded drainage; wetland loss (and change). Coastal infrastructure damage and flood defense failure.	TCs (Box 5-1, WGI AR5 Section 2.6.3): *low confidence* in trends in frequency and intensity due to limitations in observations and regional variability. ETCs (Section 5.3.3.1; WGI AR5 Section 2.6.4): *likely* poleward movement of circulation features but *low confidence* in intensity changes.	TCs (Box 5-1): *likely* decrease to no change in frequency; *likely* increase in the most intense TCs. ETCs (Section 5.3.3.1): *high confidence* that reduction of ETCs will be small globally. *Low confidence* in changes in intensity.	Lowering of confidence of observed trends in TCs and ETCs since AR4. More basin-specific information on storm track changes.
Winds	Wind waves, storm surges, coastal currents, land coastal infrastructure damage.	*Low confidence* in trends in mean and extreme wind speeds (Section 5.3.3.2, SREX, WGI AR5 Section 3.4.5).	*Low confidence* in projected mean wind speeds. *Likely* increase in TC extreme wind speeds (Section 5.3.3.2, SREX).	Winds not specifically addressed in AR4.
Waves	Coastal erosion, overtopping and coastal flooding.	*Likely* positive trends in Hs in high latitudes (Section 5.3.3.2; WGI AR5 Section 3.4.5).	*Low confidence* for projections overall but *medium confidence* for Southern Ocean increases in Hs (Section 5.3.3.2).	Large increase in number of wave projection studies since AR4.
Extreme sea levels	Coastal flooding erosion, saltwater intrusion.	*High confidence* of increase due to global mean sea level rise (Section 5.3.3.3; WGI AR5 Chapter 13).	*High confidence* of increase due to global mean sea level rise, *low confidence* of changes due to storm changes (Section 5.3.3.3; WGI AR5 Section 13.5).	Local subsidence is an important contribution to regional sea level rise in many locations.
Sea surface temperature (SST)	Changes to stratification and circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality, poleward species migration; increased algal blooms.	*High confidence* that coastal SST increase is higher than global SST increase (Section 5.3.3.4).	*High confidence* that coastal SSTs will increase with projected temperature increase (Section 5.3.3.4).	Emerging information on coastal changes in SSTs.
Freshwater input	Altered flood risk in coastal lowlands; altered water quality/ salinity; altered fluvial sediment supply; altered circulation and nutrient supply.	*Medium confidence* (*limited evidence*) in a net declining trend in annual volume of freshwater input (Section 5.3.3.6).	*Medium confidence* for general increase in high latitudes and wet tropics and decrease in other tropical regions (Section 5.3.3.6).	Emerging information on freshwater input.
Ocean acidity	Increased CO_2 fertilization; decreased seawater pH and carbonate ion concentration (or "ocean acidification").	*High confidence* of overall increase, with high local and regional variability (Section 5.3.3.5).	*High confidence* of increase at unprecedented rates but with local and regional variability (Box CC-OA).	Coastal ocean acidification not specifically addressed in AR4. Considerable progress made in chemical projections and biological impacts.

SREX = IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.



SEA LEVEL VARIATIONS

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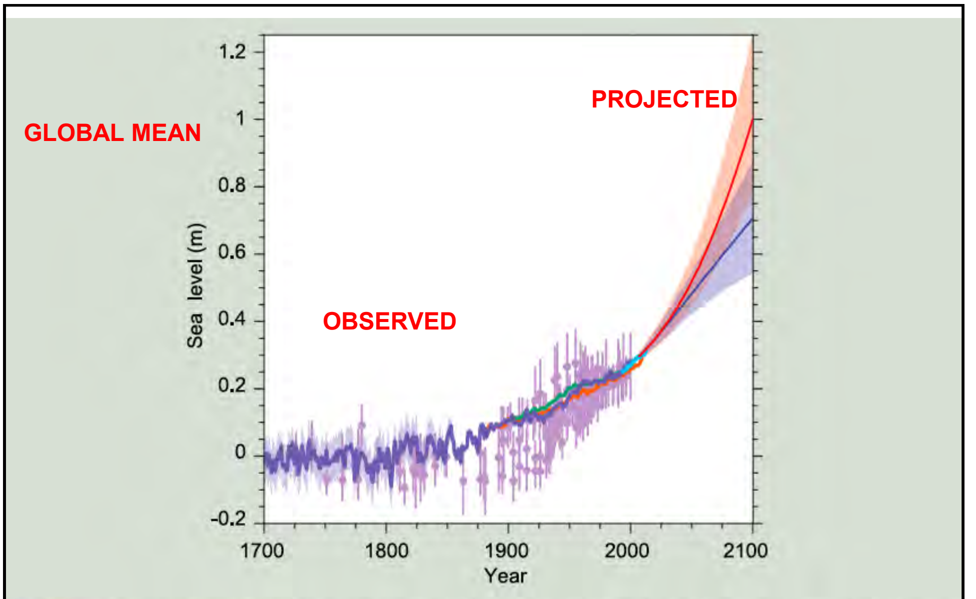

TFE.2, Figure 2 | Compilation of paleo sealevel data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and *likely* ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values. [Figures 13.3, 13.11, 13.27]

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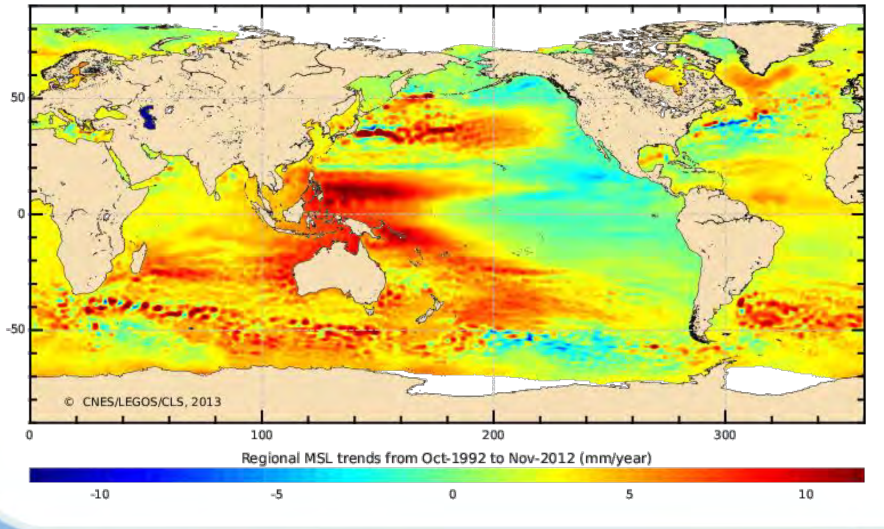
OBSERVED REGIONAL VARIABILITY (1992-2012 mm/year)



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PROJECTED GLOBAL MEAN SEA LEVEL RISE RELATIVE TO 1986-2005

Table 5-2 | Projections of global mean sea level rise in meters relative to 1986–2005 are based on ocean thermal expansion calculated from climate models, the contributions from glaciers, Greenland and Antarctica from surface mass balance calculations using climate model temperature projections, the range of the contribution from Greenland and Antarctica due to dynamical processes, and the terrestrial contribution to sea levels, estimated from available studies. For sea levels up to and including 2100, the central values and the 5–95% range are given whereas for projections from 2200 onwards, the range represents the model spread due to the small number of model projections available and the high scenario includes projections based on RCP6.0 and RCP8.5. Source: WGI AR5 Summary for Policymakers and Sections 12.4.1, 13.5.1, and 13.5.4.

Emission scenario	Representative Concentration Pathway (RCP)	2100 CO_2 concentration (ppm)	Temperature increase (°C)	Mean sea level rise (m)					
			2081–2100	2046–2065	2100	Scenario	2200	2300	2500
Low	2.6	421	1.0 [0.3–1.7]	0.24 [0.17–0.32]	0.44 [0.28–0.61]	Low	0.35–0.72	0.41–0.85	0.50–1.02
Medium low	4.5	538	1.8 [1.1–2.6]	0.26 [0.19–0.33]	0.53 [0.36–0.71]	Medium	0.26–1.09	0.27–1.51	0.18–2.32
Medium high	6.0	670	2.2 [1.4–3.1]	0.25 [0.18–0.32]	0.55 [0.38–0.73]	High	0.58–2.03	0.92–3.59	1.51–6.63
High	8.5	936	3.7 [2.6–4.8]	0.29 [0.22–0.38]	0.74 [0.52–0.98]				

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PROJECTED REGIONAL MEAN SEA LEVEL RISE

RSLR RCP4.5 (Slangen et al. 2014)

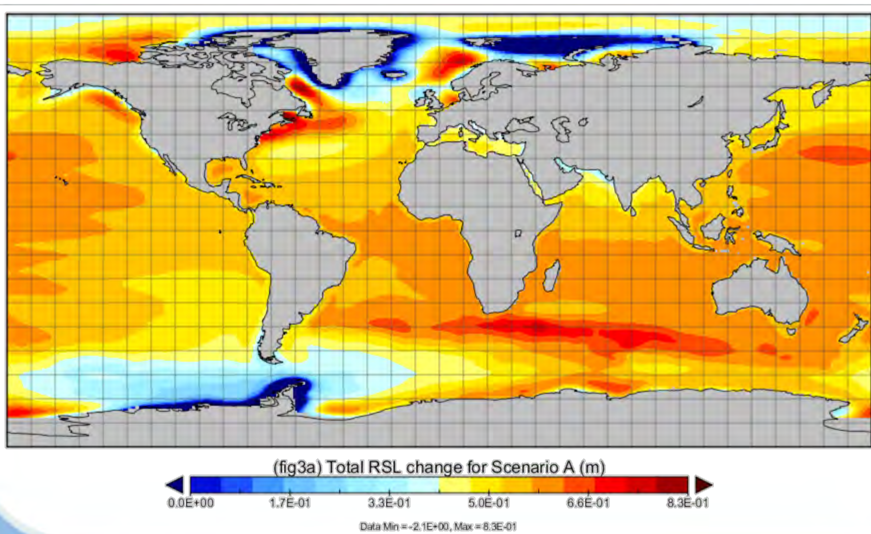

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Table 29-1 | Climate change projections for the intermediate low (500–700 ppm CO_2e) Representative Concentration Pathway 4.5 (RCP4.5) scenario for the main small island regions. The table shows the 25th, 50th (median), and 75th percentiles for surface temperature and precipitation based on averages from 42 Coupled Model Intercomparison Project Phase 5 (CMIP5) global models (adapted from WGI AR5 Table 14.1). Mean net regional sea level change is evaluated from 21 CMIP5 models and includes regional non-scenario components (adapted from WGI AR5 Figure 13-20).

Small island region	RCP4.5 annual projected change for 2081–2100 compared to 1986–2005						
	Temperature (°C)			Precipitation (%)			Sea level (m)
	25%	50%	75%	25%	50%	75%	Range
Caribbean	1.2	1.4	1.9	−10	−5	−1	0.5–0.6
Mediterranean	2.0	2.3	2.7	−10	−6	−3	0.4–0.5
Northern tropical Pacific	1.2	1.4	1.7	0	1	4	0.5–0.6
Southern Pacific	1.1	1.2	1.5	0	2	4	0.5–0.6
North Indian Ocean	1.3	1.5	2.0	5	9	20	0.4–0.5
West Indian Ocean	1.2	1.4	1.8	0	2	5	0.5–0.6

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Table 5-3 | Main impacts of relative sea level rise. Source: Adapted from Nicholls et al. (2010).

Biophysical impacts of relative sea level rise	Other climate-related drivers	Other human drivers
Dryland loss due to erosion	Sediment supply, wave and storm climate	Activities altering sediment supply (e.g., sand mining)
Dryland loss due to submergence	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
Wetland loss and change	Sediment supply, CO_2 fertilization	Sediment supply, migration space, direct destruction
Increased flood damage through extreme sea level events (storm surges, tropical cyclones, etc.)	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
Saltwater intrusion into surface waters (backwater effect)	Runoff	Catchment management and land use (e.g., sand mining and dretching)
Saltwater intrusion into groundwaters leading to rising water tables and impeded drainage	Precipitation	Land use, aquifer use

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Coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion due to relative sea level rise (RSLR; *very high confidence*).

- Beaches, sand dunes and cliffs currently eroding will continue to do so under increasing sea level (*high confidence*).
- Large spatial variations in the projected sea level rise together with local factors means RSLR at the local scale can vary considerably from projected (GMSLR) (*very high confidence*).

Coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion due to relative sea level rise (RSLR; *very high confidence*).

- **The storms related impacts and associated storm surges will be worsened by GMSLR although uncertainty related to changes in tropical and mid-latitude cyclones at the regional scale will signify that there is *low confidence* in projections of storm surge change**.
- Both and impacts are also influenced by a variety of local processes unrelated to climate (e.g., subsidence, glacial isostatic adjustment, sediment transport, coastal development) (*very high confidence*).

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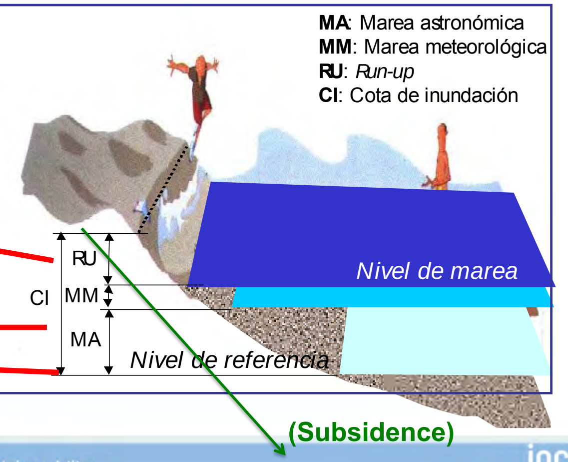
Coastal flooding

Inundation/sumergence vs. Flooding

Flooding:

Combined effects !!!

- Waves
- Wind
- Atmospheric pressure
- Astronomical tide
- Mean Sea Level



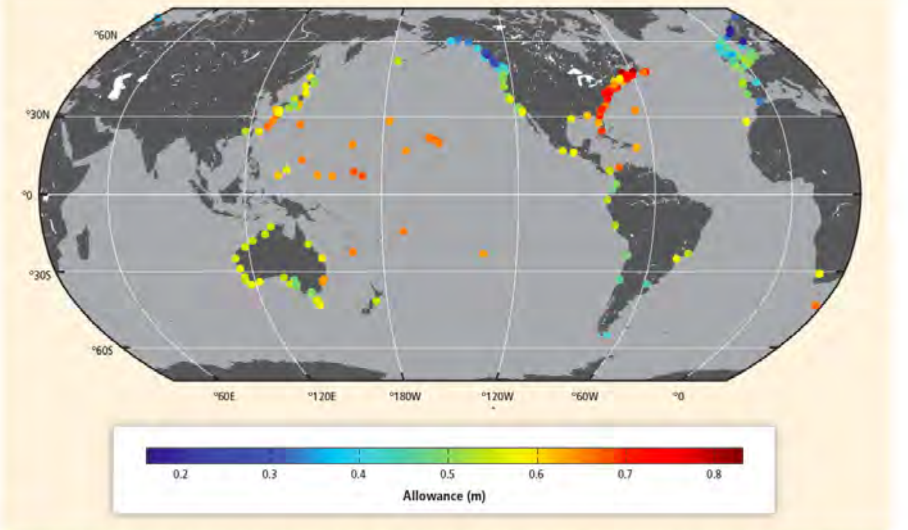
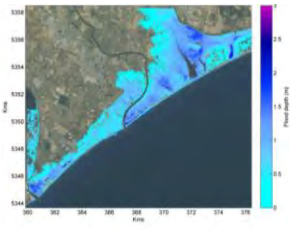


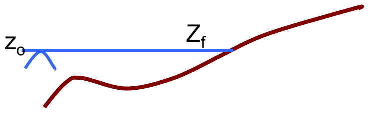
Figure 5-2 | The estimated increase in height (m) that flood protection structures would need to be raised in the 2081–2100 period to preserve the same frequency of exceedences that was experienced for the 1986–2005 period, shown for 182 tide gauge locations and assuming regionally varying relative sea level rise projections under an Representative Concentration Pathway 4.5 (RCP4.5) scenario (adapted from Hunter et al, 2013).

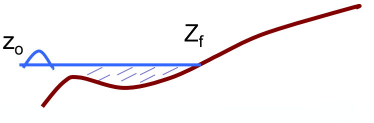
QUANTITATIVE ASSESSMENT OF FLOODING CONSEQUENCES

$z_f = z_o$ is a bathtube approach

$z_f = f(z_o$, duration, roughness, DTM)
using a 2D hydrodynamic model







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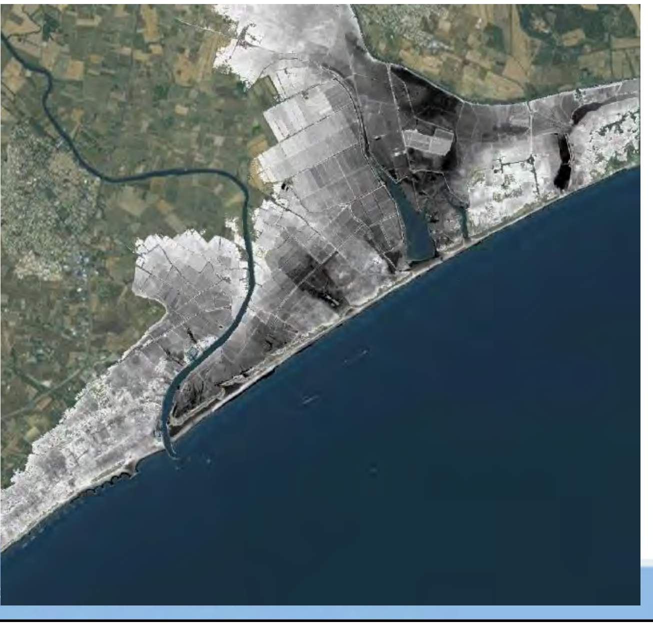
Sensitivity analysis to event duration and inland roughness



Delta L'Orb
LIDAR 1 m
GOW+GOS data bases
20- years extreme TWL

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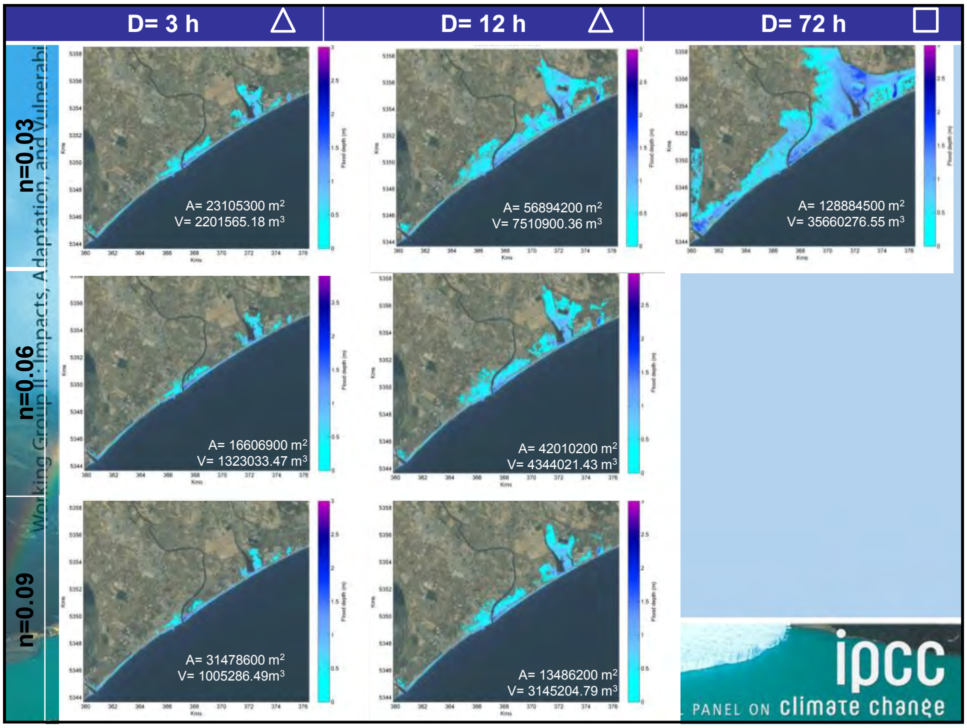
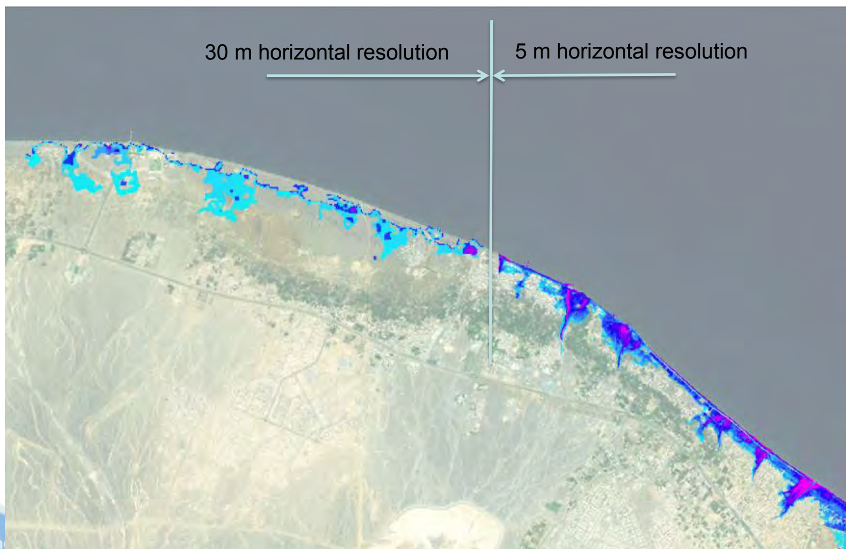


Coastal Flooding

RFSM-EDA model
Simulation of Gonu (marine dynamics)
Maximum water depths

Sensitivity of Digital Terrain Model resolution



Muscat- GONU

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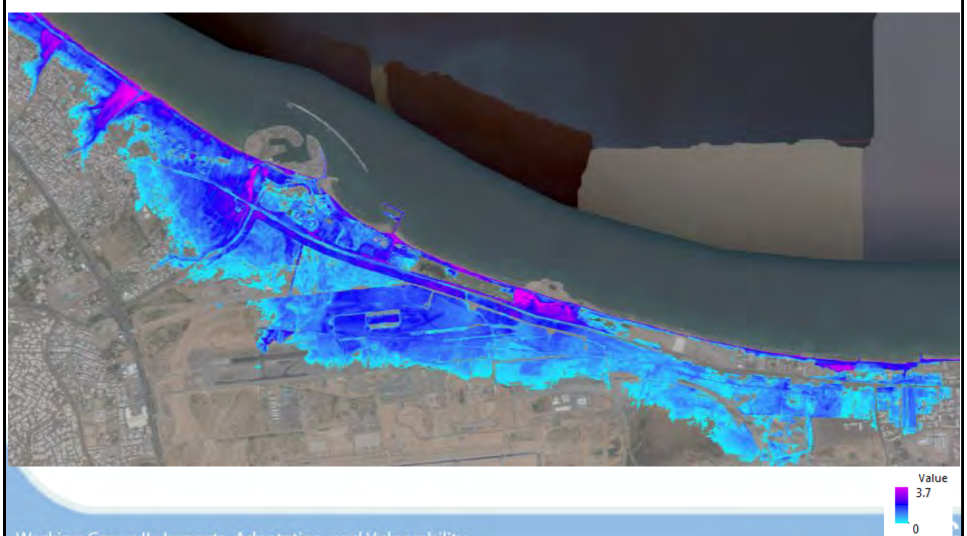
Muscat Airport - GONU



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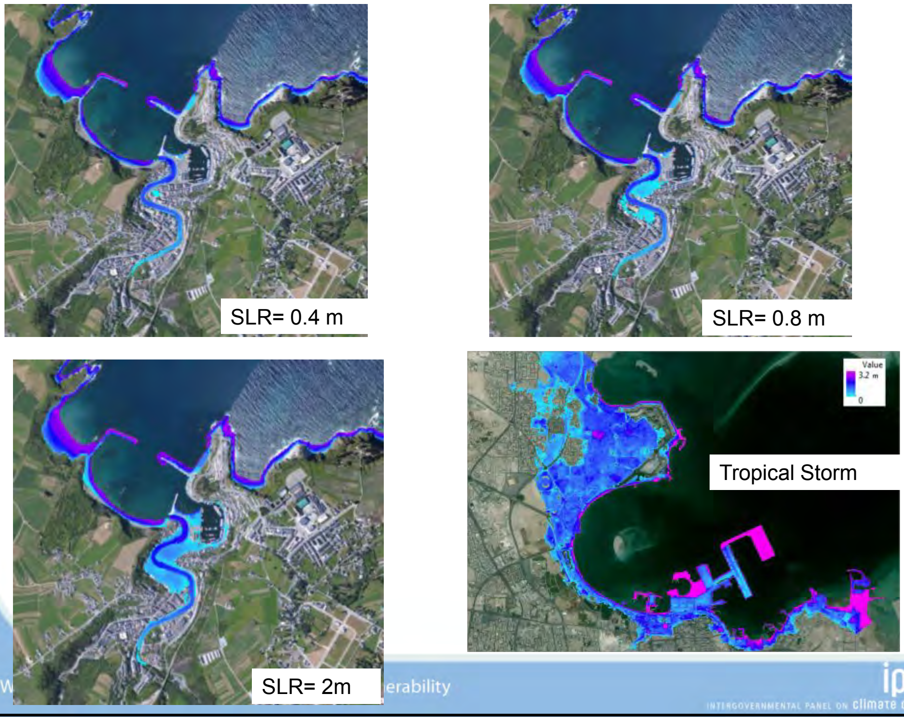

W... erability

Acidification and warming of coastal waters will continue with significant negative consequences for coastal ecosystems (*high confidence*).

The increase in acidity will be higher in areas where eutrophication or coastal upwellings are an issue. It will have negative impacts for many calcifying organisms (*high confidence*).

Warming and acidification will lead to coral bleaching, mortality, and decreased constructional ability (*high confidence*), making coral reefs the most vulnerable marine ecosystem with little scope for adaptation.

Temperate seagrass and kelp ecosystems will decline with the increased frequency of heat waves and sea temperature extremes as well as through the impact of invasive subtropical species (*high confidence*).

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Figure CR-1: A and B: the same coral community before and after a bleaching event in February 2002 at 5 m depth, Halfway Island, Great Barrier Reef. Coral cover at the time of bleaching was 95% bleached almost all of it severely bleached, resulting in mortality of 20.9% (Elvidge *et al*., 2004). Mortality was comparatively low due in part because these coral communities were able to shuffle their symbiont to more thermo-tolerant types (Berkelmans and van Oppen, 2006; Jones *et al*., 2008). C and D: three CO_2 seeps in Milne Bay Province, Papua New Guinea show

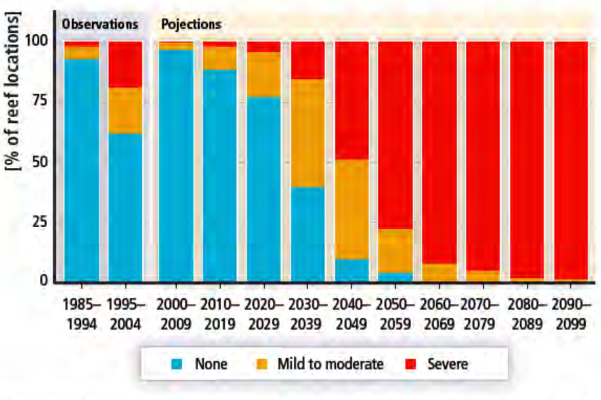
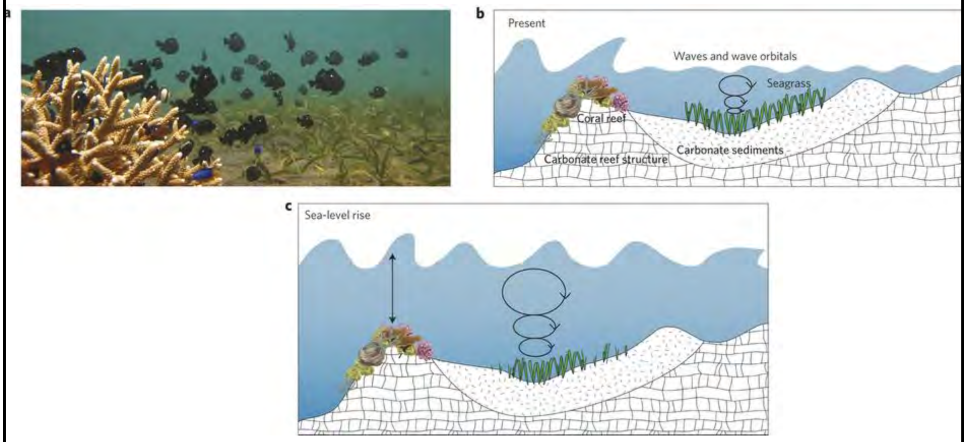


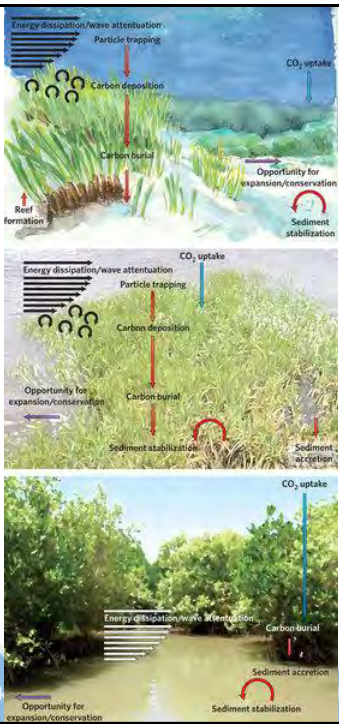
Figure 5-3 | Percent of reef locations (1° × 1° grid cells which have at least one reef) that experience no bleaching, at least one mild bleaching event, or at least one severe bleaching event for each decade. Observed bleaching events are summarized from the ReefBase data set (Kleypas et al., 2008). In the observations, some of the "no bleaching" cells may have experienced bleaching but it was either not observed or not reported. Modeled bleaching events are averages of data from four ensemble runs of the Community Climate System Model version 3 using the Special Report on Emissions Scenarios (SRES) A1B CO_2 scenario and the standard degree heating month formula (Teneva et al., 2011). The labels of values ≤1% are not shown.

Saunders et al. (2014)

Why is this important?



a, Seagrass meadows and coral reefs form distinct ecosystems, yet often live in close proximity in linked tropical marine ecosystems. **b**, Coral reefs block and dissipate wave energy and permit seagrass, which is less wave tolerant, to exist in protected lagoons. **c**, Deepening water from sea-level rise will allow larger, more energetic waves to traverse the reef into the lagoon, reducing habitat suitability for seagrass



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Processes that affect the capacity for climate change mitigation (**CO_2 sinks**) and adaptation (shore line protection from rising sea level) are shown for seagrass meadows (upper panel), salt marshes (middle panel) and mangrove forests (lower panel). Blue arrows indicate transport of atmospheric or dissolved material, red arrows show transport of particulates and purple arrows indicate vegetative growth Duarte et al. (2013)

SYNERGIES BETWEEN ADAPTATION AND MITIGATION

TROPICAL AND EXTRATROPICAL CYCLONE IMPACTS

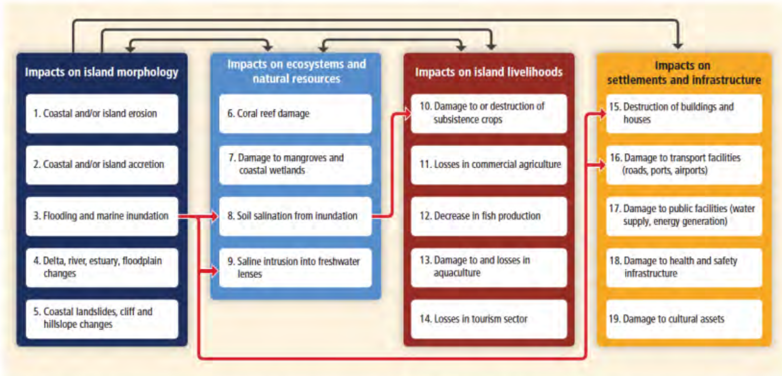

Figure 29-4 | Tropical and extratropical cyclone (ETC) impacts on the coasts of small islands. Four types of impacts are distinguished here, with black arrows showing the connections between them, based on the existing literature. An example of the chain of impacts associated with two ETCs centered to the east of Japan is illustrated by the red arrows. Swell waves generated by these events in December 2008 reached islands in the southwest Pacific and caused extensive flooding (3) that impacted soil quality (8) and freshwater resources (9), and damaged crops (10), buildings (15), and transport facilities (16) in the region (example based on Hoeke et al., 2013).

Examples of tropical cyclone impacts on small island coasts (with reference):
1. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 2. Taveuni, Fiji, March 2010 (Etienne and Terry, 2012); 3. Cook Islands (de Scally, 2008); Society and Autral Islands, French Polynesia, February 2010 (Etienne, 2012); 4. Viti Levu, Fiji, March 1997 (Terry et al., 2002); 5. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and Scheffers, 2006); Hawaiian Islands (Fletcher et al., 2008); 7. Bay Islands, Honduras, October 1998 (Cahoon et al., 2003); 8. Marshall Islands, June 1905 (Spennemann, 1996); 9. Pukapuka atoll, Cook Islands, February 2005 (Terry and Falkland, 2010); 10. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 11. 12. 13. Tuamotu Islands, French Polynesia, 1982–1983 (Dupon, 1987); 14. Grenada, September 2004 (OECS, 2004); 15. Grenada, September 2004 (OECS, 2004); Tubuai, Austral Islands, French Polynesia, February 2010 (Etienne, 2012); 16. Vanuatu, February 2004 (Richmond and Sovacool, 2012); Guadeloupe Island, October 2008 (Dorville and Zahibo, 2010); 17. Bora Bora, Raiatea, Maupiti, Tahaa, Huahine, Society Islands, February 2010 (Etienne, 2012); 18. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 19. Tuamotu, French Polynesia, 1982–1983 (Dupon, 1987).

Examples of ETC impacts on small island coasts (with reference):
1. Maldives, April 1987 (Harangozo, 1992); 2. Maldives, January 1955 (Maniku, 1990); 3. Maldives, April 1987 (Harangozo, 1992); 9. Solomon Islands, December 2008 (Hoeke et al., 2013); 10. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke et al., 2013); 15. Majuro, Marshall Islands, November 1979 (Hoeke et al., 2013); 16. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke et al., 2013); 17. Majuro, Kwajalein, Arno, Marshall Islands, December 2008 (Hoeke et al., 2013); 18. Bismark Archipelago, Papua New Guinea, December 2008 (Hoeke et al., 2013).

OUTLINE

Conceptual Framework

Climate-related drivers and associated impacts

Human-related drivers and associated impacts

Attribution to climate change

Adaptation

Conclusions

The population and assets exposed to coastal risks as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, and urbanization (*high confidence*).

- The exposure of people and assets to coastal risks has been rapidly growing and this trend is expected to continue.
- Humans have been the primary drivers of changes in coastal aquifers, lagoons, estuaries, deltas, and wetlands (*very high confidence*) and are expected to further exacerbate human pressures on coastal ecosystems resulting from excess nutrient input, changes in runoff, and reduced sediment delivery (*high confidence*).

SEA LEVEL RISE-CONSEQUENCES

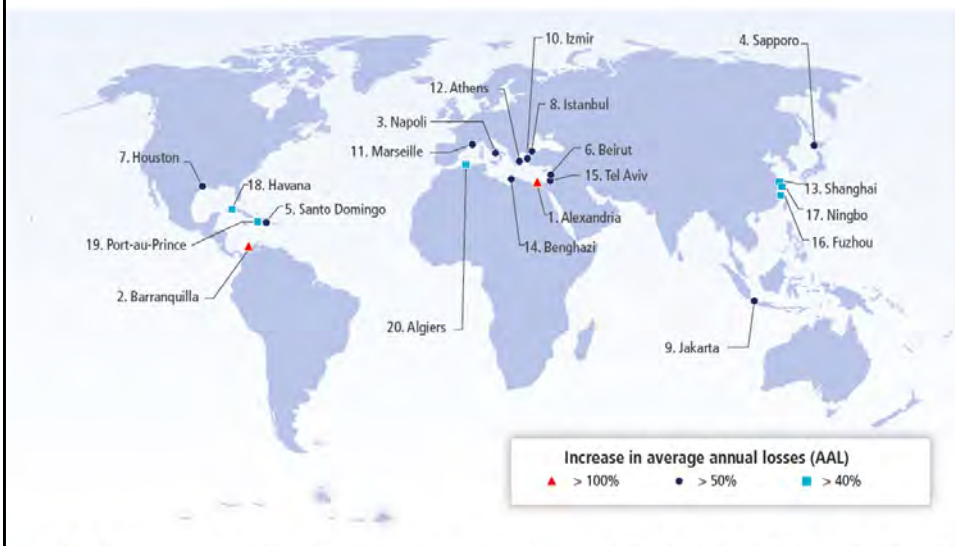

Figure 5-4 | The 20 cities where average annual losses (AALs) increase most (in relative terms in 2050 compared with 2005) in the case of optimistic sea level rise, if adaptation maintains only current defense standards or flood probability (PD) (Hallegatte et al., 2013).

EXPOSURE TO STORMS BETWEEN 1998-2009

Table 29-5 | Top ten countries in the Asia–Pacific region based on absolute and relative physical exposure to storms and impact on GDP (between 1998 and 2009; after Tables 1.10 and 1.11 of ESCAP and UNISDR, 2010).

Rank	Absolute exposure (millions affected)	Relative exposure (% of population affected)	Absolute GDP loss (US$ billions)	Loss (% of GDP)
1	Japan (30.9)	Northern Mariana Islands (58.2)	Japan (1,226.7)	Northern Mariana Islands (59.4)
2	Philippines (12.1)	Niue (25.4)	Republic of Korea (35.6)	Vanuatu (27.1)
3	China (11.1)	Japan (24.2)	China (28.5)	Niue (24.9)
4	India (10.7)	Philippines (23.6)	Philippines (24.3)	Fiji (24.1)
5	Bangladesh (7.5)	Fiji (23.1)	Hong Kong (13.3)	Japan (23.9)
6	Republic of Korea (2.4)	Samoa (21.4)	India (8.0)	Philippines (23.9)
7	Myanmar (1.2)	New Caledonia (20.7)	Bangladesh (3.9)	New Caledonia (22.4)
8	Vietnam (0.8)	Vanuatu (18.3)	Northern Mariana Islands (1.5)	Samoa (19.2)
9	Hong Kong (0.4)	Tonga (18.1)	Australia (0.8)	Tonga (17.4)
10	Pakistan (0.3)	Cook Islands (10.5)	New Caledonia (0.7)	Bangladesh (5.9)

Note: Small islands are highlighted in yellow.

OUTLINE

Conceptual Framework

Climate-related drivers and associated impacts

Human-related drivers and associated impacts

Attribution to climate change

Adaptation

Conclusions

Coral bleaching and species ranges can be attributed to ocean temperature change and ocean acidity.

For many other coastal changes, the impacts of climate change are difficult to tease apart from human-related drivers
(e.g. land use change, coastal development, pollution)
(*high agreement*, *robust evidence)*

Small Islands

Chapter 29

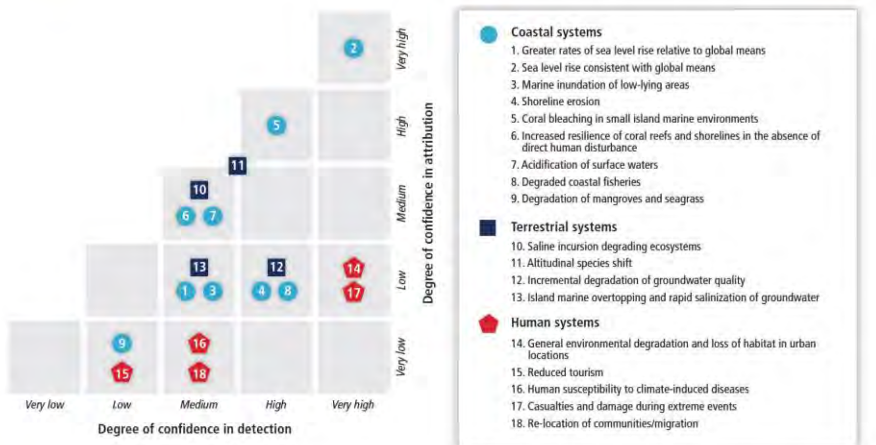

Figure 29-2 | A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. For example, the blue symbol No. 2 (Coastal Systems) indicates there is *very high confidence* in both the detection of "sea level rise consistent with global means" and its attribution to climate change drivers; whereas the red symbol No. 17 (Human Systems) indicates that although confidence in detection of "casualties and damage during extreme events" is *very high*, there is at present *low confidence* in the attribution to climate change. It is important to note that *low confidence* in attribution frequently arises owing to the limited research available on small island environments.


ADAPTATION IS
ALREADY OCCURING
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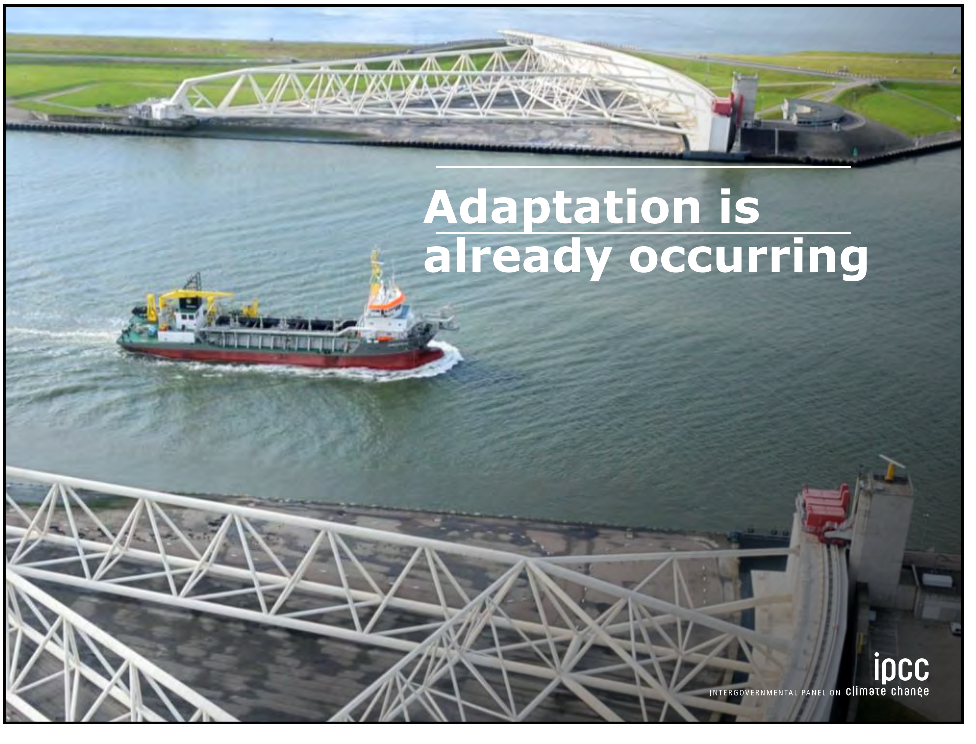
Adaptation is
already occurring
ipcc
INTERGOVERNMENTAL PANEL ON climate change

For the 21st century, the benefits of protecting against increased coastal flooding and land loss due to submergence and erosion at the global scale are larger than the social and economic costs of inaction (*high agreement*, *limited evidence*).

- Without adaptation, hundreds of millions of people will be affected by coastal flooding and will be displaced due to land loss by year 2100; the majority of those affected are from East, Southeast, and South Asia (*high confidence*).
- At the same time, protecting against flooding and erosion is considered economically rational for most developed coastlines in many countries under all socioeconomic and sea level rise scenarios analyzed, including for the 21st century GSMLR-of above 1 m (*high agreement*, *low evidence*).

The relative costs of adaptation vary strongly between and within regions and countries for the 21st century (*high confidence*).

- Some low-lying developing countries (e.g., Bangladesh, Vietnam) and small island states are expected to face very high impacts and associated annual damage and adaptation costs of several percentage points of gross domestic product (GDP).
- Developing countries and small island states within the tropics dependent on coastal tourism will be impacted directly not only by future sea level rise and associated extremes but also by coral bleaching and ocean acidification and associated reductions in tourist arrivals (*high confidence*).

The analysis and implementation of coastal adaptation has progressed more significantly in developed countries than in developing countries towards climate resilient and sustainable coasts (*high confidence*).

- Given ample adaptation options, more proactive responses can be made and based on technological, policy related, financial, and institutional support. Observed successful adaptations include major projects (e.g., Thames Estuary, Venice Lagoon, Delta Works) and specific practices in both developed countries (e.g., Netherlands, Australia) and developing countries (e.g., Bangladesh).

- More countries and communities carry out coastal adaptation measures including those based on integrated coastal zone management, local communities, ecosystems, and disaster reduction, and these measures are mainstreamed into relevant strategies and management plans (*high confidence*).

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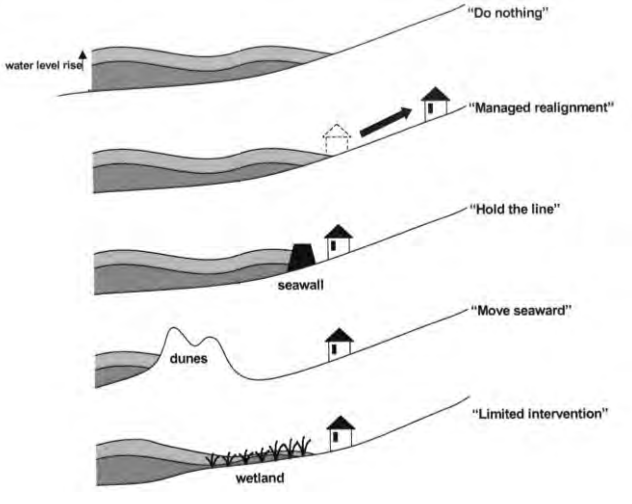

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Functional and healthy ecosystems	
A1	Wetland protection and restoration
A2	Marine areas protection and conservation agreements
A3	Payment for ecosystem and environmental services

Wetland restoration and protection

Goal:
Reduce flooding and erosion by creating new habitats and providing environmental benefits holding the coastline

Characteristics:
Highly efficient Takes advantage of natural adaptive capacity Marshes and mangroves restoration is the most extended practice

Reduce exposure of the coastal system	
B1	Beach nourishment
B2	Artificial and restoration of dunes
B3	Shoreline stabilization using natural techniques
B4	Seawalls
B5	Jetties and groynes
B6	Retreat
B7	Adaptation to flooding. Flood proofing.

Beach nourishment

Goal
Reduce coastal erosion and protect against flooding

Characteristic:
Engineering soft measure Usually combined with dune restoration or artificial dunes Effective under mean conditions. Extreme events may require additional nourishing

PROFILE OF THE BEACH BEFORE CHARGING

PROFILE OF THE BEACH AFTER CHARGING

M.D. Spalding *et al.* (2014)

Working with nature

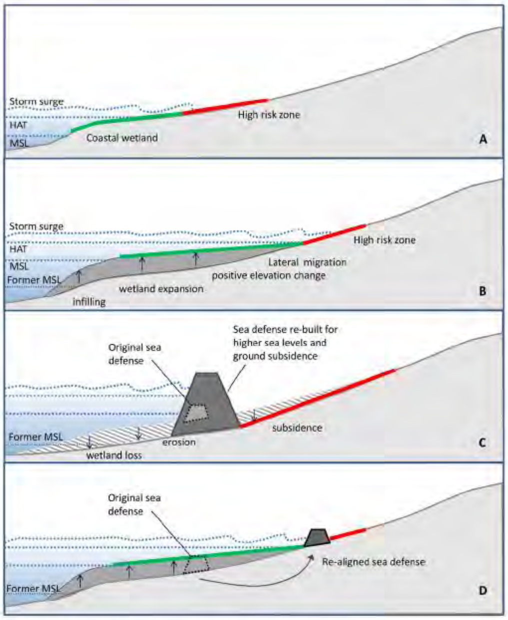

Figure 1 Graphic representation of how elevation of coastal marshes might be expected to vary in response to increases in relative sea level. (A) Contemporary natural shoreline. (B) Natural shoreline following sea-level rise in locations where growth and sediment supply allow some degree of positive elevation change, as well as lateral (landwards) migration. (C) Hard engineering solutions "holding the line" of contemporary coastlines through increasingly large interventions. (D) Hybrid interventions (see Figure 2), where space is allowed for the maintenance of natural coastal defenses.

Hybrid solutions

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M.D. Spalding *et al.* (2014)

IH cantabria

Hybrid solutions

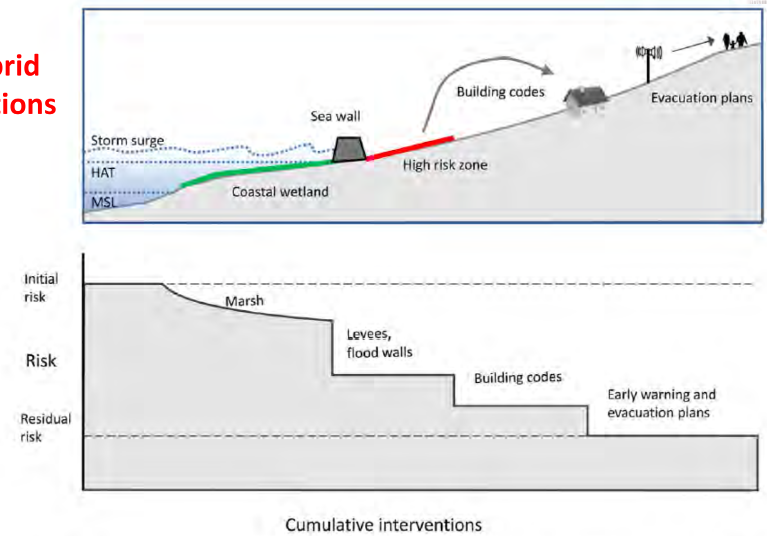

Figure 2 Ecosystems can form an important part of risk reduction, which is typically achieved through a combination of environmental, engineered, social, cultural, and legal approaches as illustrated in the upper figure. Cumulative interventions (lower figure) cannot remove risk, but rather reduce it to an acceptable level of residual risk.

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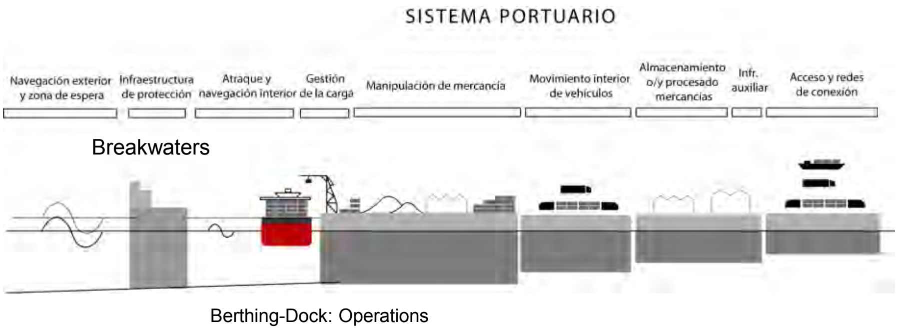
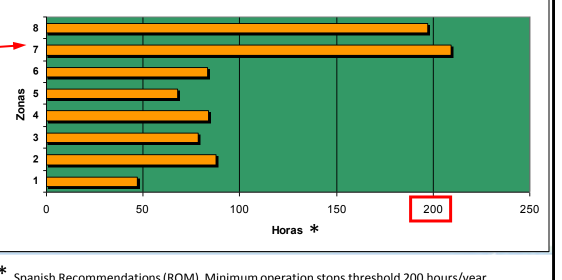
Ports and coastal infrastructures



Operations: Current based on historical observations

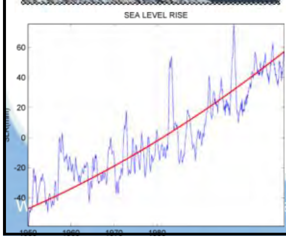
	% of operations downtime	Hours
Zone 1	0.536	47
Zone 2	1.004	88
Zone 3	0.898	79
Zone 4	0.959	84
Zone 5	0.776	68
Zone 6	0.950	83
Zone 7	2.387	209
Zone 8	2.251	197

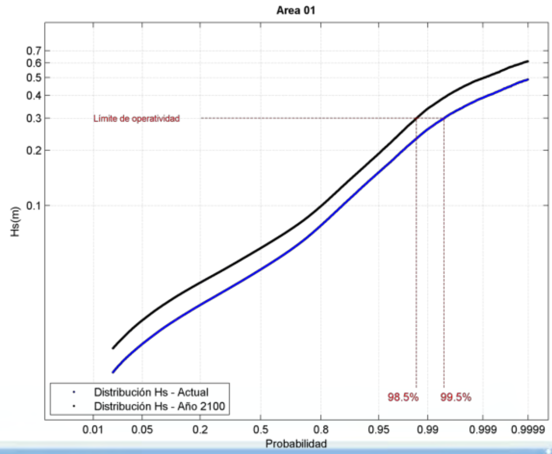


* Spanish Recommendations (ROM), Minimum operation stops threshold 200 hours/year

Climatic drivers

Sea level rise (+1m)





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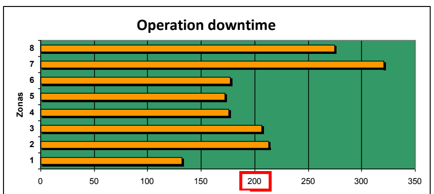
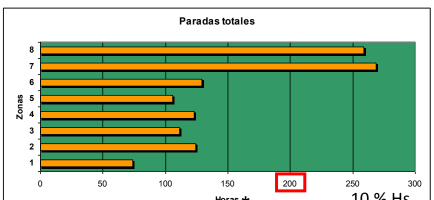
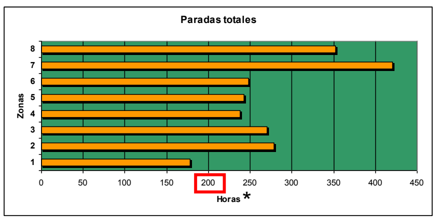
Operations: projections under different scenarios



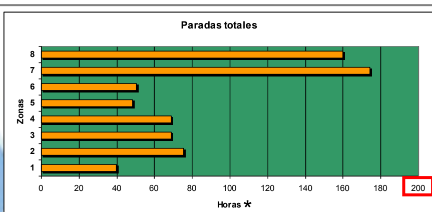
SLR=1m



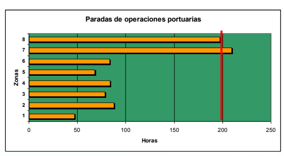
10 % Hs



SLR=1m + 10%Hs



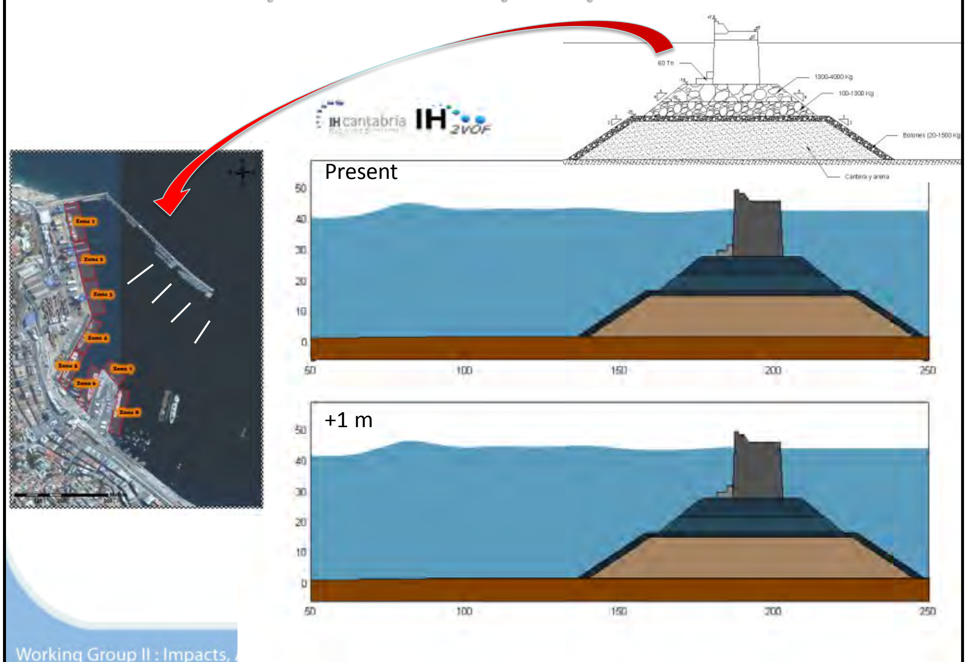
Wave direction change (5ºccw)



Current

* Spanish Recommendations (ROM), Minimum operation stops threshold 200 hours/year

Breakwater stability and functionality analysis



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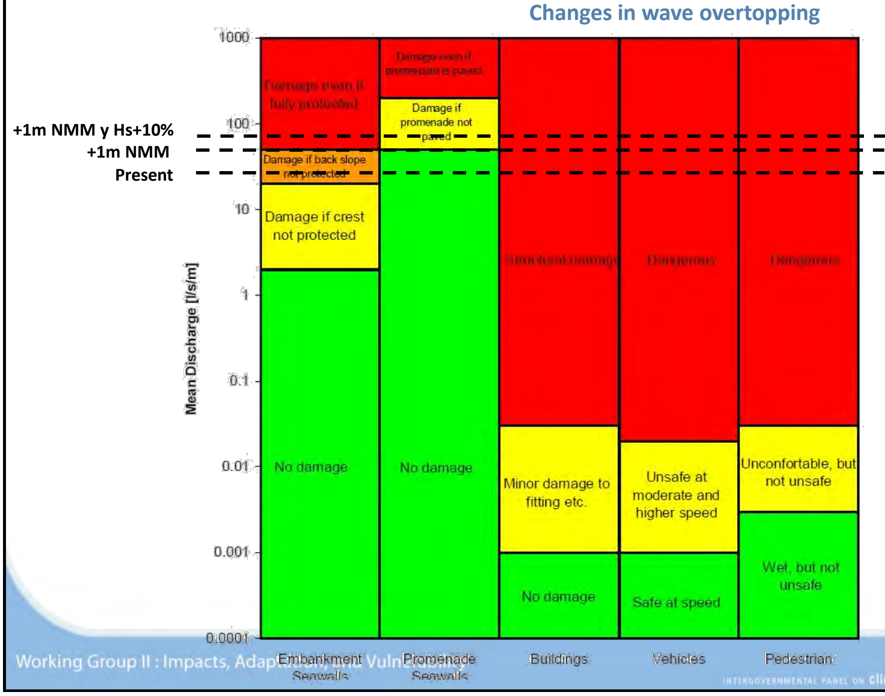
Changes in wave overtopping



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Changes in stability: Forces and moments

Parameter	Present	+1m NMM	Change
Force	188 kN/m	197 kN/m	+5%
Stab. coef. sliding	5.53	5.37	-3%
Stab. Coef. Overtur.	5.04	5.02	-0.4%
Overtopping rate	22 l/m/s	48 L/m/s	+118%

Parameter	Present	+1m NMM and Hs+10%	Change
Forces	188 kN/m	210.5 kN/m	+12%
Stab. Coef. sliding	5.53	5.20	-6%
Stab. Coef. Overtur.	5.04	4.99	-1%
Overtopping rate	22 l/m/s	64 L/m/s	+190%

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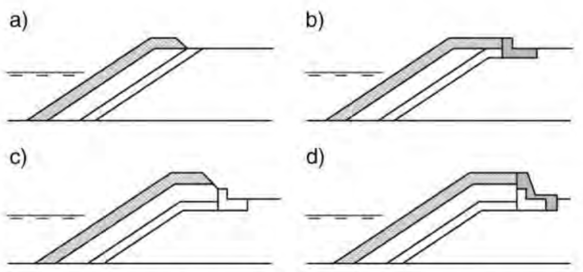


Fig. 1. Concepts of upgrading in which an increase in crest level is acceptable.

Burcharth, Lykke and Lara (2014)

Adaptation options

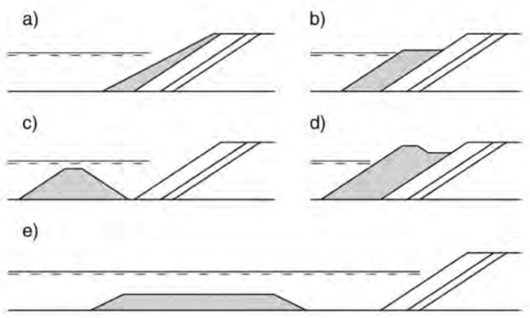
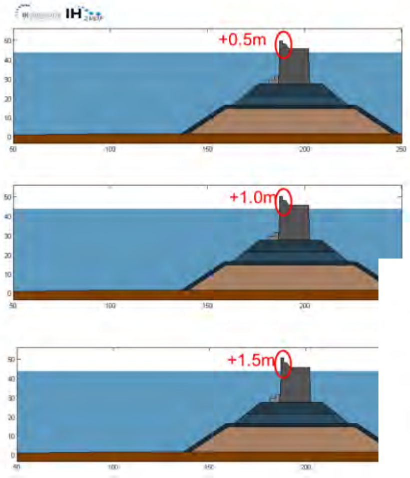


Fig. 2. Concepts of upgrading in which an increase in crest level is not acceptable.

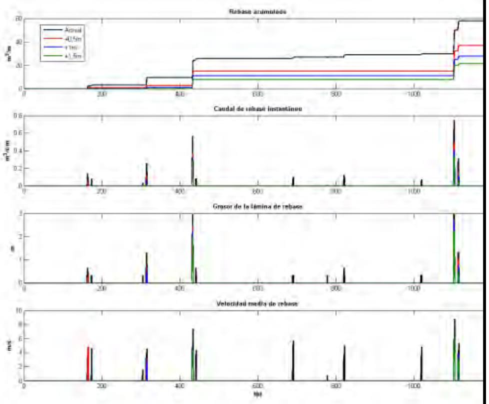
Adaptation: overtopping



Present geometry: 48 l/m/s

Adapted geometry:

+0.5m: 30 l/m/s **(-37.5%)**
+1m: 22 l/m/s **(-54.2%)**
+1.5m: 17 l/m/s **(-64.6%)**



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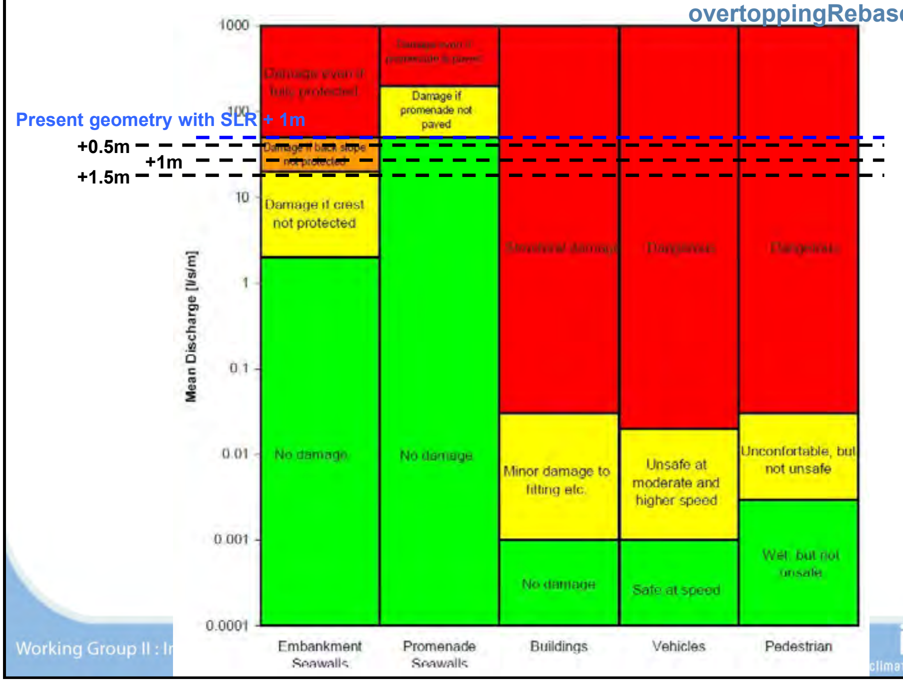
Adaptation: overtoppingRebase



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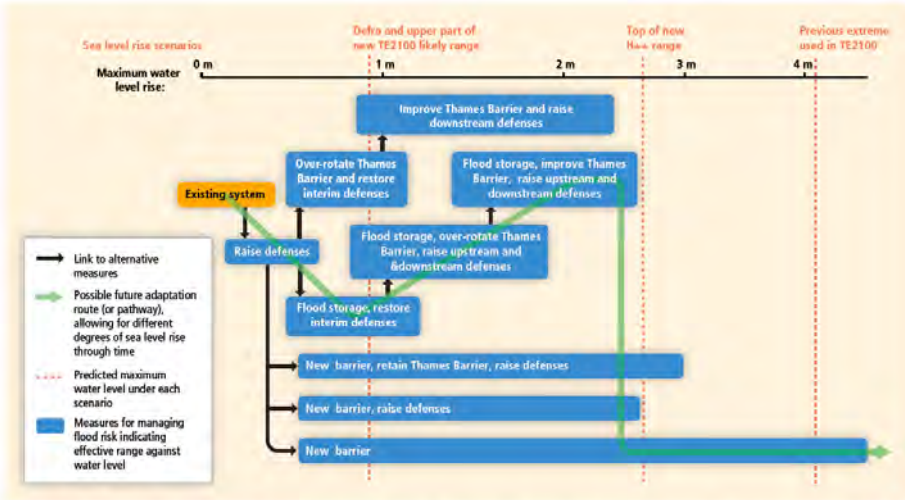

Figure 5-6 | Adaptation measures and pathways considered in the TE2100 project. The boxes show the measures and the range of sea level rise over which the measures are effective. The black arrows link to alternative measures that may be applied once a measure is no longer effective. The red lines show the various 21st century sea level rise scenarios used in the analysis including a conservative estimate of about 0.9 m by the UK Department for Environment Food and Rural Affairs (Defra), a high-level scenario of 2.6 m (H+) and an extreme scenario of over 4 meters (H++). The fat green line shows a possible future adaptation route (or pathway), allowing for different degrees of sea level rise through time (adapted from Lowe et al., 2009).

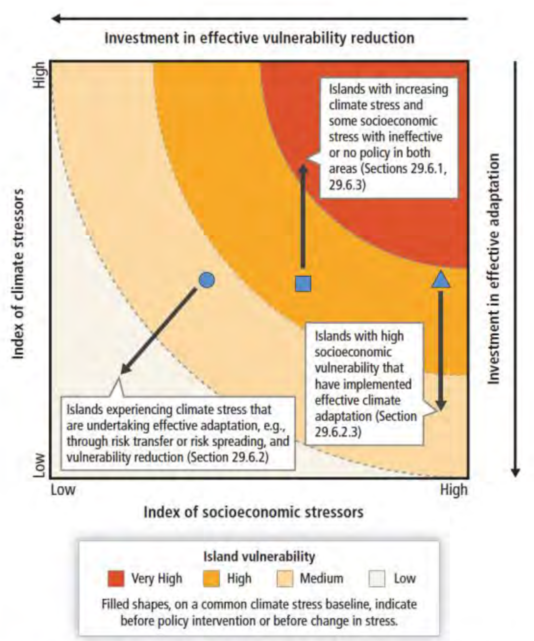

Figure 29-5 | The impact of alternative climate change adaptation actions or policies.

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Table 29-4 | Selected key risks and potential for adaptation for small islands from the present day to the long term.

Climate-related drivers of impacts								Level of risk & potential for adaptation
Warming trend	Extreme temperature	Drying trend	Extreme precipitation	Damaging cyclone	Sea level	Ocean acidification	Sea surface temperature	Potential for additional adaptation to reduce risk; Risk level with **high** adaptation; Risk level with **current** adaptation

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Loss of livelihoods, coastal settlements, infrastructure, ecosystem services, and economic stability (*high confidence*) [29.6, 29.8, Figure 29-4]	• Significant potential exists for adaptation in islands, but additional external resources and technologies will enhance response. • Maintenance and enhancement of ecosystem functions and services and of water and food security • Efficacy of traditional community coping strategies is expected to be substantially reduced in the future.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Decline and possible loss of coral reef ecosystems in small islands through thermal stress (*high confidence*) [29.3.1.2]	Limited coral reef adaptation responses; however, minimizing the negative impact of anthrogopenic stresses (ie: water quality change, destructive fishing practices) may increase resilience.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
The interaction of rising global mean sea level in the 21st century with high-water-level events will threaten low-lying coastal areas (*high confidence*) [29.4, Table 29-1; WGI AR5 13.5, Table 13.5]	• High ratio of coastal area to land mass will make adaptation a significant financial and resource challenge for islands. • Adaptation options include maintenance and restoration of coastal landforms and ecosystems, improved management of soils and freshwater resources, and appropriate building codes and settlement patterns.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high

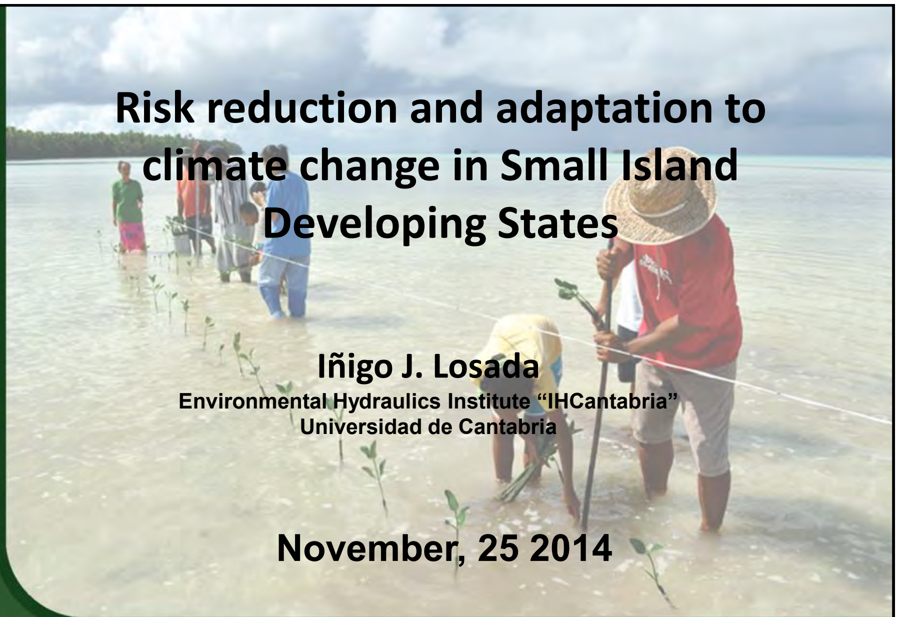
CONCLUSIONS

Adaptation in SIDS starts with promoting quantitative and integrated assessments of climate change and climate variability risks together with long-term observations

Adaptation can be undertaken by reducing socioeconomic vulnerabilities, building adaptive capacity, enhancing disaster risk reduction or building longer term climate resilience

Adaptation to climate change generates larger benefit to small islands when delivered in conjunction with other development activities, such as disaster risk reduction and community-based approaches to development (medium confidence).

The ability of small islands to undertake adaptation and mitigation programs, and their effectiveness, can be substantially strengthened through appropriate assistance from the international community (medium confidence).



Risk reduction and adaptation to climate change in Small Island Developing States

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Environmental Hydraulics Institute "IHCantabria"
Universidad de Cantabria

November, 25 2014

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Table 29-3 | Types of island in the Pacific region and implications for hydro-meteorological hazards (after Campbell, 2009).

Island type and size		Island elevation, slope, rainfall	Implications for hazard
Continental	• Large • High biodiversity • Well-developed soils	• High elevations • River flood plains • Orographic rainfall	River flooding more likely to be a problem than in other island types. In Papua New Guinea, high elevations expose areas to frost (extreme during El Niño).
Volcanic high islands	• Relatively small land area • Barrier reefs • Different stages of erosion	• Steep slopes • Less well-developed river systems • Orographic rainfall	Because of size, few areas are not exposed to tropical cyclones. Streams and rivers are subject to flash flooding. Barrier reefs may ameliorate storm surge.
Atolls	• Very small land area • Small islets surround a lagoon • Larger islets on windward side • Shore platform on windward side • No or minimal soil	• Very low elevations • Convectional rainfall • No surface (fresh) water • Ghyben–Herzberg (freshwater) lens	Exposed to storm surge, "king" tides, and high waves. Narrow resource base. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.
Raised limestone islands	• Concave inner basin • Narrow coastal plains • No or minimal soil	• Steep outer slopes • Sharp karst topography • No surface water	Depending on height, may be exposed to storm surge. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.

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