CLIMATE AMBITION SUPPORT ALLIANCE

Strengthening capacity for inclusive negotiations

Guide

Climate science for Small Island Developing States

A guide to the IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate*

April 2020

ODI

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To explore the IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate* in full, please visit: www.ipcc.ch/srocc

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Introduction

The political context

The year 2020 is a critical year for countries to set higher ambitions to tackle the global climate emergency and press forward with actions to achieve those ambitions.

The headline goal of the Paris Agreement is to hold the increase in the global average temperature to "well below 2°C above pre-industrial levels and pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[1] Yet, the collective ambitions of countries to limit greenhouse gas emissions, at present, adds up to around 2.8°C of global warming.[2]

The 1.5°C temperature goal is driven by scientific consensus: above this level of global warming, the most exposed and vulnerable countries and communities will face unacceptable risks to their wellbeing and even their existence. The world today is already 1°C warmer on average than pre-industrial times. Even now, these communities already suffer significant impacts from extreme climate and weather events.[3]

These figures underscore why 2020 is a critical year for making a step-change in humankind's collective ambition to cut and avoid greenhouse gas emissions. The United Nations Framework Convention on Climate Change (UNFCCC) invites Parties to the Paris Agreement to submit their updated, national climate plans (Nationally Determined Contributions, NDCs) this year. As agreed by the Parties, updated NDCs should lock in and step up ambition for tackling emissions, with no 'backsliding' on earlier commitments.

The United Kingdom, which holds the Presidency for the 26th Conference of the Parties to the UNFCCC (COP26), and COP26 co-host Italy will convene meetings to review the NDCs, in the run-up to the conference. United Nations Secretary General Antonio Guterres restated the importance of ambitious NDCs in a briefing to governments in March 2020.[4]

In the coming decade, 2020–2030, global society must cut emissions by more than 7% per year on average to have the best chance of meeting the 1.5 °C temperature limit set in Paris. Global emissions must be halved from 2020 levels, by 2030, to limit average global warming to 1.5 °C above pre-industrial levels.[5]

As well as mitigation, action on climate change adaptation, risk reduction and resilience building will also be central to the negotiations. Parties to the Paris Agreement will be scrutinising how progress against the Paris Agreement's Global Goal on Adaptation will be measured, monitored and verified in practice. The technical process aims to "identify concrete opportunities for strengthening resilience, reducing vulnerabilities, and increasing the understanding and implementation of adaptation actions" through technical expert meetings, technical papers and other events.[6] This includes critical negotiations (both bilateral and multilateral) on how finance, capacity building and technology transfer can support adaptation, risk management and resilience efforts.

Among the countries that are most climate-vulnerable and have most to gain or lose from this political process are the Small Island Developing States (SIDS).[7]

About this guide on climate change for SIDS

Small Island Developing States are responsible for a tiny percentage of global greenhouse gas emissions, but have a tremendous amount at stake in the global climate change negotiations. SIDS are home to 65 million people; more than 80% of small island residents live near the coast where flooding and coastal erosion already pose serious problems.[8]

The SAMOA Pathway (which stands for 'SIDS Accelerated Modalities of Action') was produced by SIDS in 2014 and is a keystone statement of their sustainable development context and goals (see page 21). This declaration recognises that "sea-level rise and other adverse impacts of climate change continue to pose a significant risk to Small Island Developing States and their efforts to achieve sustainable development and, for many, represent the gravest of threats to their survival and viability."[9]

This guide distils and presents the key findings of the IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate*[10] for the express purpose of briefing policy-makers from SIDS and pointing them to key headlines from this latest scientific assessment.

By doing so, the guide aims to:

- Provide climate change negotiators with a succinct, robust briefing on key IPCC findings to inform their interventions in the negotiations and in the UNFCCC process, where there is still a grave chasm between the transformative action needed to respond to the climate emergency, and the current, collective ambitions of the Parties to the Paris Agreement.
- Summarise in brief the scientific findings on the impacts, vulnerability and potential to adapt to climate change, in Small Island Developing States, in the coming decades.

About the Special Report

The IPCC's *Special Report on the Ocean and Cryosphere* was requested by governments and observer organisations to the IPCC. 'Cryosphere' describes the frozen components of the Earth system, including snow, glaciers, ice sheets and ice shelves, icebergs and sea ice, ice on lakes and rivers, as well as permafrost and seasonally frozen ground.[11] The report brings together knowledge on physical and biogeochemical changes, their interaction with ecosystem changes, and implications for human communities.

The report was prepared by 104 authors and review editors from 36 countries, 19 of which are developing countries or economies in transition. It was prepared under the scientific leadership of the IPCC's Working Group I, which is concerned with the physical science of climate change, and Working Group II, which focuses on adaptation, vulnerability and the impacts of climate change. The report considers literature published up until May 2019 and its final draft references 6,981 publications. Earlier drafts received 31,176 comments from 80 countries and the EU, all of which were reviewed and addressed.[12]

How the Special Report builds on previous IPCC reports

The IPCC's *Special Report on 1.5°C of Global Warming* was published in 2018. This seminal scientific report has been central to UNFCCC negotiations since its publication. Climate-vulnerable countries have leveraged the evidence and findings to ground their interventions. It also gave renewed vigour to civil society campaign efforts to demand higher ambition in mitigating climate change.

The *Special Report on 1.5°C* investigates the feasibility of limiting average global warming to 1.5°C above pre-industrial levels, and the potential pathways to achieving this goal. It also compares the differences in climate change impacts between two potential scenarios: 1.5°C versus 2°C of average global warming.

Key headlines of the 1.5°C report are[13]:

- Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*)
- Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*).
- Climate models project robust differences in regional climate characteristics between present-day and global warming of 1.5°C, and between 1.5°C and 2°C.

- By 2100, there will be sea level rise under global warming of 1.5°C; however, under this scenario, global mean sea level rise is projected to be 0.1 metres lower compared to 2°C of global warming (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depends on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*).

- Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and retain more of their services to humans (*high confidence*).

- Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems (*high confidence*).

- Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C.

- Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, with associated losses (*medium confidence*). The number and availability of adaptation options vary by sector (*medium confidence*).

So, how does the *Special Report on the Ocean and Cryosphere* add to our understanding of climate change, its impacts on small island nations, and the importance of mitigating climate change?

- It examines the impact of climate change on marine and coastal ecosystems under a range of climate change scenarios that start at around 2°C of average global warming by 2100, and range to a worst case scenario of around 5-6°C of global warming. These scenarios use Representative Concentration Pathways (RCPs) (see Box 1). The *Special Report on the Ocean and Cryosphere* also assesses the evidence for how climate change has historically affected Earth's frozen regions (in the Arctic, Antarctic and high mountain regions) and will do so under the four RCP scenarios.

- It assesses how different coastal management options can meet societies' climate change adaptation needs.

The *Special Report on the Ocean and Cryosphere* also assesses how the melting of high mountain snow and glaciers and reduced water flows in downstream river basins affect societies' freshwater needs (with evidence from the Himalayas, the Andes and other snow- and glacier-capped mountain systems across the world). As this material is less relevant for SIDS, we do not cover it in this guide.

The *Special Report on the Ocean and Cryosphere* also assesses new scientific findings that have been published since the IPCC's *Fifth Assessment Report* (2013–14). The *Fifth Assessment Report* used the same emission pathways, or 'Representative Concentration Pathways' (RCPs, see Box 1).


Photo: Patrice Oehen/Unsplash

Box 1 The Representative Concentration Pathways (RCPs): Greenhouse gas emission scenarios in the IPCC reports

The IPCC uses scenarios to project future changes in the Earth's climate. The scenarios in the *Special Report on the Ocean and Cryosphere* are based on Phase 5 of the Coupled Model Intercomparison Project (CMIP5) and are called the Representative Concentration Pathways (RCPs).[14] As well as greenhouse gas emissions, aerosols and chemically active gases, they take into account land use and land cover change – although they represent just one set of many possible futures. In the Special Report and in this guide, the most often-used scenarios are:

- **RCP2.6:** a low emission / lower warming scenario involving significant action to tackle climate change. This would correspond with a mean global temperature rise of 1.6°C in the near-term (2031–2050) and 1.6°C in the longer term (2081–2100) with a range of 0.9–2.4°C. [15]
- **RCP 8.5:** a high emission / higher warming scenario without policies to combat climate change. This would correspond with a mean global temperature rise of 2°C in the near-term (2031–2050) and 4.3°C in the longer term (2081–2100) with a range of 3.2–5.4°C.[16]

The Special Report also uses intermediate emission scenarios (RCP 4.5 and RCP 6.0).

Box 2 The IPCC's confidence levels

This matrix helps explain what the IPCC means by high, medium or low confidence.[17]

High confidence means that there is a high level of agreement and evidence in the literature to support the categorisation as high, medium or low.

Low confidence means that the categorisation is based on only a few studies. Medium confidence reflects medium evidence and scientific agreement.

Confidence increases towards the top-right corner as suggested by the increased strength of the shading.

Agreement ↑			
	High agreement Limited evidence	High agreement Medium evidence	High agreement Robust evidence
	Medium agreement Limited evidence	Medium agreement Medium evidence	Medium agreement Robust evidence
	Low agreement Limited evidence	Low agreement Medium evidence	Low agreement Robust evidence

Evidence (type, amount, quality, consistency) →

Confidence scale

Higher

Lower

Line Island, Kiribati. Photo: NASA

Key messages for Small Island Developing States

Global mean sea levels are rising and the rate of sea level rise is accelerating

The global mean sea level is expected to rise by between 43 cm to 84 cm by 2100. The differences depend on how aggressively human society acts to limit greenhouse gas emissions, which are driving climate change.[18]

Table 1 Sea level rise under high and low greenhouse gas emission scenarios

Emission scenario	Global mean sea level rise by 2100	Likely range of global mean sea level rise by 2100
RCP 2.6 (low emission)	43cm	29 –59 cm
RCP 8.5 (high emission)	84 cm	61–110 cm

Global mean sea levels rose by 3.6 mm per year in the period 2006–2015. Under the high emission scenario, sea levels could be rising at a rate of 15 mm per year by 2100.[19] Many small islands reach only 3–4 metres above mean sea level today; for some SIDS, their capital islands and principal population centres and infrastructure are in these most low-lying areas; and for some, their entire territories are low-lying.[20]

Human-driven climate change contributes to sea level rise in two main ways:

1. Climate change is melting the Greenland ice sheets, Antarctic ice sheets and glaciers in other parts of the world. The sheer volume of ice melting and running into the oceans makes sea levels rise. Glaciers and ice sheets are now the dominant source of global mean sea level rise.[21]

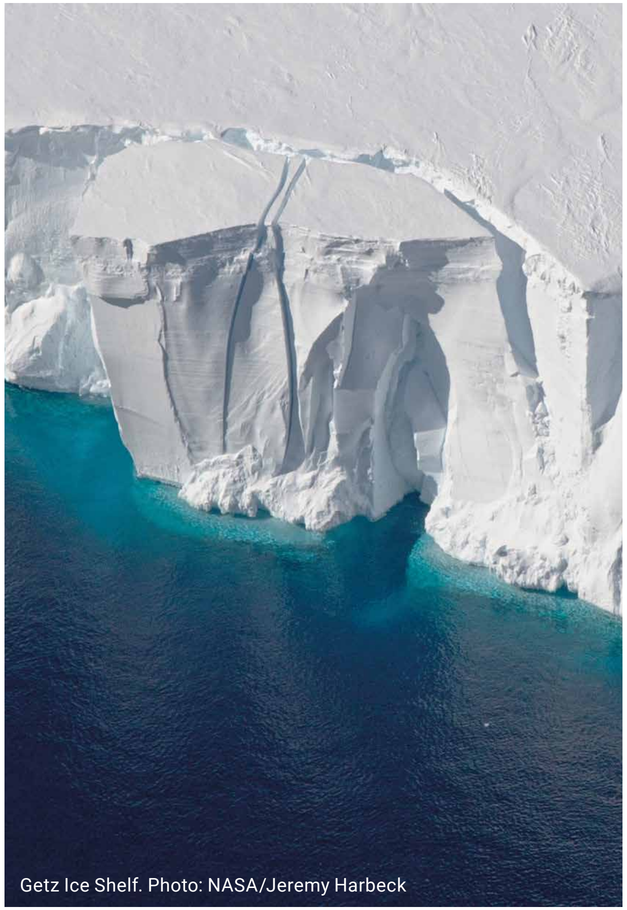
2. Much of the increased heat in the atmosphere is taken up by the ocean – the ocean waters expand as a result.[22] Since 1970, it is virtually certain that the ocean has taken up more than 90% of the excess heat in the climate system.[23]

> The ocean is taking the heat from climate change."
>
> **Ko Barrett, Vice-Chair, IPCC**[24]

It is also important to understand that specific locations can experience 'relative sea level' that is up to 30% greater or less than global mean sea level. Relative or local sea levels are influenced by:

- Thermal expansion (seawater expands when it gets warmer)
- Ocean dynamics
- Ice loss from land in an area.

In the future, human activities that lead to subsidence of the land (such as over-extracting groundwater) as well as changes in the height and period between waves will affect local, relative sea level rise.[25]

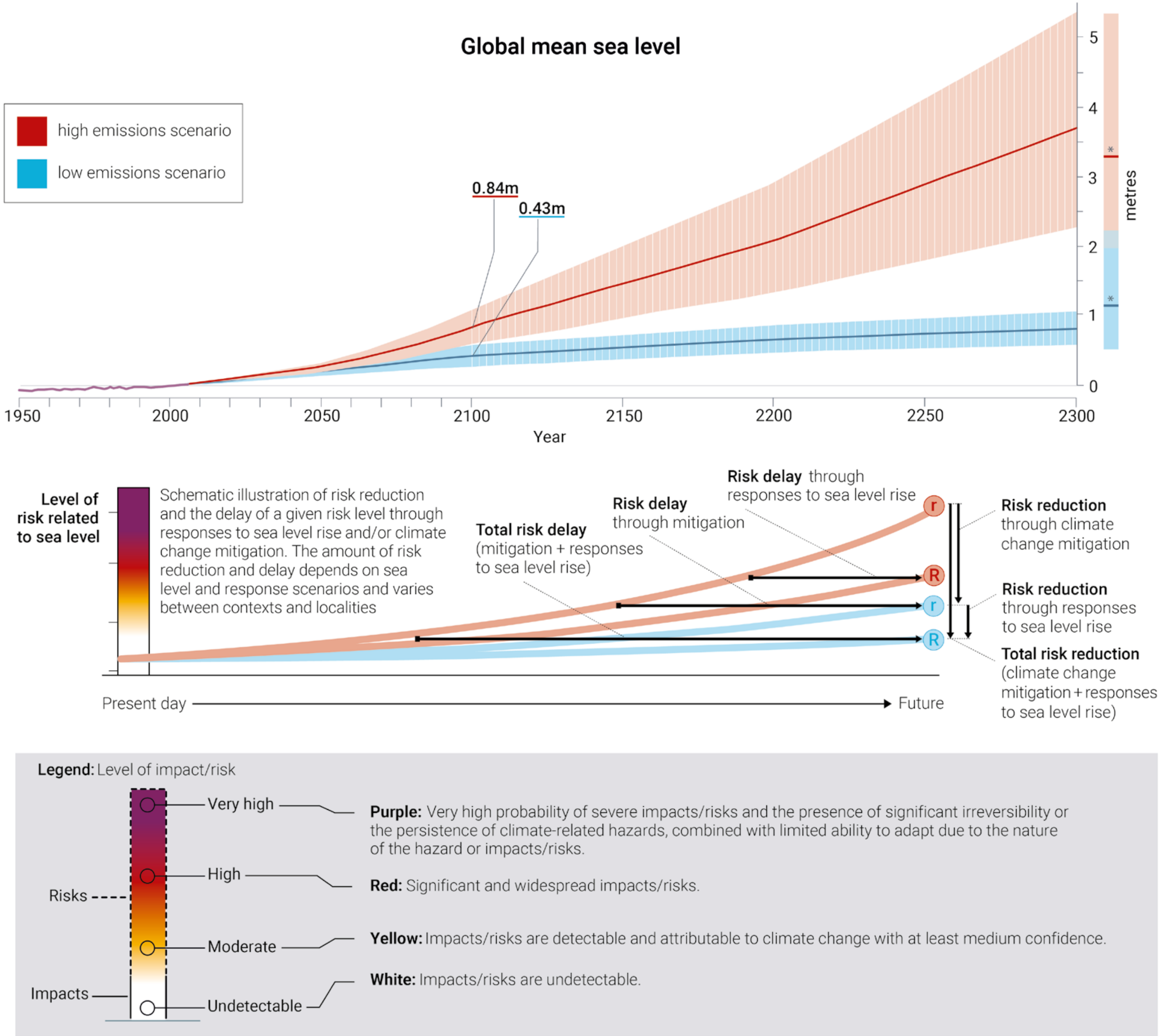


Getz Ice Shelf. Photo: NASA/Jeremy Harbeck

The overall risks of climate change to human societies and other species on Earth can be reduced via urgent, concerted action to both reduce greenhouse gas emissions (mitigate climate change) and adapt to climate change, as shown in Figure 1.

Tuvalu. Photo: Silke von Brockhausen/UNDP

Figure 1 **Climate change mitigation together with adaptation and other responses reduce the risks of sea level rise**[26]



Marine ecosystems are changing profoundly – with implications for island nations’ economies and cultures

The chemistry of the oceans is changing, as well as the temperature. The ocean has taken up between 20% to 30% of human-induced carbon dioxide emissions since the 1980s. This is making the oceans more acidic. The oceans are expected to take up more carbon from the atmosphere between now and 2100. This will increase ocean acidification.[27]

Marine heatwaves have become more frequent, more intense, more extensive and longer lasting.[28] There is very high scientific confidence that marine heatwaves have already negatively affected ‘foundation’ species in the marine environment on which many other species – and humans – heavily depend. These include corals, seagrasses and kelps.[29]

Warming has particularly affected the surface layer of the oceans. Now, there is less mixing among layers of ocean water. This means less exchange of oxygen and nutrients among layers, and in turn, less productive biological systems. In the upper 1000 metres of the ocean, the amount of dissolved oxygen in the water decreased by 0.5–3.3% between 1970 and 2010.[30]

Deoxygenation, acidity and warming have significant impacts for the range, extent and abundance of marine species and how species interact with each other in the oceans.

For example, species are on the move. The distribution of marine species is shifting toward the poles, at a rate of some 52km per decade (+/- 33km) for organisms in the top 200 metres of ocean water, and moving at a rate of some 29km per decade towards the poles (+/- 16km) for organisms on the sea floor.

Societies’ unsustainable management of the oceans combines with climate change-related impacts on the oceans to create further pressures. Overfishing has already depressed fish stocks in many parts of the world. In the coming years, climate change will combine with overfishing to reduce fish stocks, with implications for the livelihoods and cultures in many SIDS.

Photo: IWRM AIO SIDS

> Since about 1950, many marine species across various groups have undergone shifts in geographical range and seasonal activities in response to ocean warming, sea ice change and biogeochemical changes, such as oxygen loss, to their habitats (high confidence). This has resulted in shifts in species composition, abundance and biomass production of ecosystems, from the equator to the poles.”
>
> **IPCC, Summary for Policy Makers (2019)**[31]

Figure 2

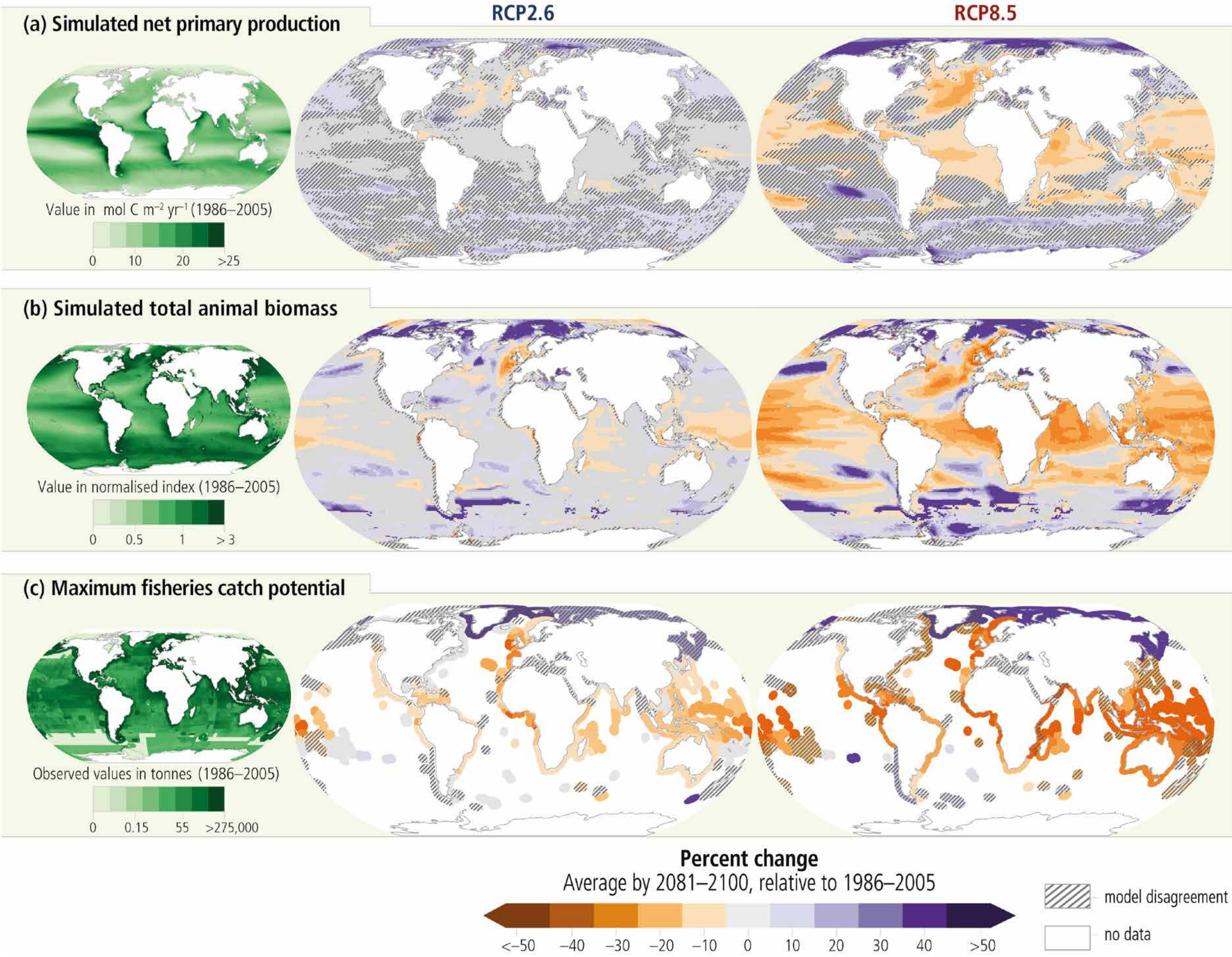
Projected changes, impacts and risks for ocean ecosystems as a result of climate change[32]

The green maps, left, show the productivity of the oceans in the recent past, compared to scenarios in a low emissions future (RCP2.6) and a high emissions future (RCP8.5).

Net primary production is how much carbon dioxide is taken in during photosynthesis, minus how much carbon dioxide is released during respiration. The higher the value means the more carbon is absorbed by biomass and microbes in the ocean.

Total animal biomass includes both fish and invertebrates, with information from FISHMIP: the Fisheries and Marine Ecosystem Model Intercomparison Project. The map on the left, recent past, shows the projected total animal biomass for each spatial pixel relative to the global average.

Maximum fisheries catch potential is based on the Sea Around Us global fisheries database and marine ecosystem models.



Small islands face cascading impacts from sea level rise

Small islands (as well as low-lying coasts around the world, generally) will face a range of cascading impacts from climate-related sea level rise. These are summarised in Figure 3 (below).

These often combine with and compound each other: for example, accelerating sea level rise will combine with storm surges, tides and waves to generate extreme sea level events that affect flooding,[33] shoreline changes[34] and salinisation of soils, groundwater and surface waters.[35]

Ocean acidification combines with ocean warming and deoxygenation to affect plants and animals on the seafloor (benthic) and in the open ocean (pelagic) and related ecosystems (e.g., coral reefs, oyster beds).

This changing ocean temperature and chemistry also affects top predators in the food chain. As a result, changes in the ocean affect species' abundance and distribution, and their benefits to human societies.[36]

Sea level rise interacts with direct human management of the environment, exposing people to hazards and creating further vulnerabilities and risks.

For example, siting settlements and infrastructure close to coastlines puts more people and assets in the way of extreme sea levels. It also creates less space for natural ecosystem features such as sediments to move landward (creating a phenomenon known as 'coastal squeeze').

Local factors drive – as well as are driven by – more regional processes such as coastal urbanisation, sediment 'starvation' (such as damming rivers upstream), degradation of vegetated coastal ecosystems (e.g., mangroves, coral reefs and salt marshes), lack of long-term integrated planning, changing consumption modes, conflicting resource use and socioeconomic inequalities, among others. All these factors drive people's increased vulnerability to sea level rise and climate-related coastal hazards.

Although we do not go into detail here about the distant future, low-lying islands and coasts are at risk from multi-metre sea level rise beyond 2100 under a high emission and high global warming scenario. Combatting global warming and pursing a low emission future (RCP 2.6) would restrict global mean sea level rise to 1–2 metres by 2300.[37]

Extreme 1-in-100 year sea level events will become annual events by 2050

Extreme sea levels can be caused by high winds during storms (see Figure 4, below). Events like these which were rare in the past will become common under all emission scenarios.

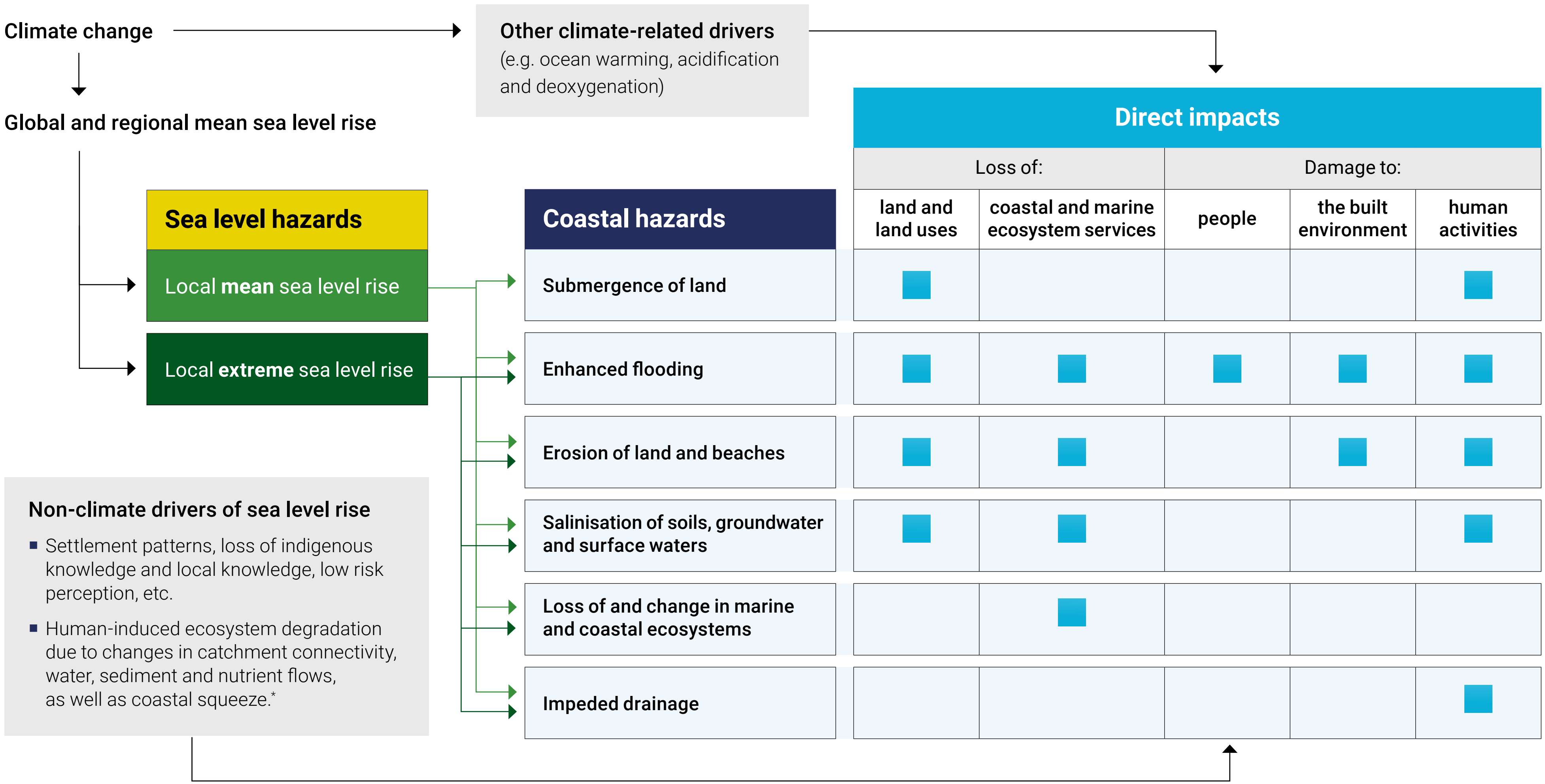
Extreme sea level events, which used to be 1-in-100 year events, will happen annually at all latitudes for many small islands by 2050.[38]


Cyclone Idai response. Photo: Denis Onyodi, IFRC/DRK/Climate Centre

Increases in tropical cyclone winds and rainfall are exacerbating extreme sea level events and coastal hazards."

IPCC Special Report press launch (September 2019)[39]

Figure 3 Overview of the main cascading impacts of sea level rise[40]



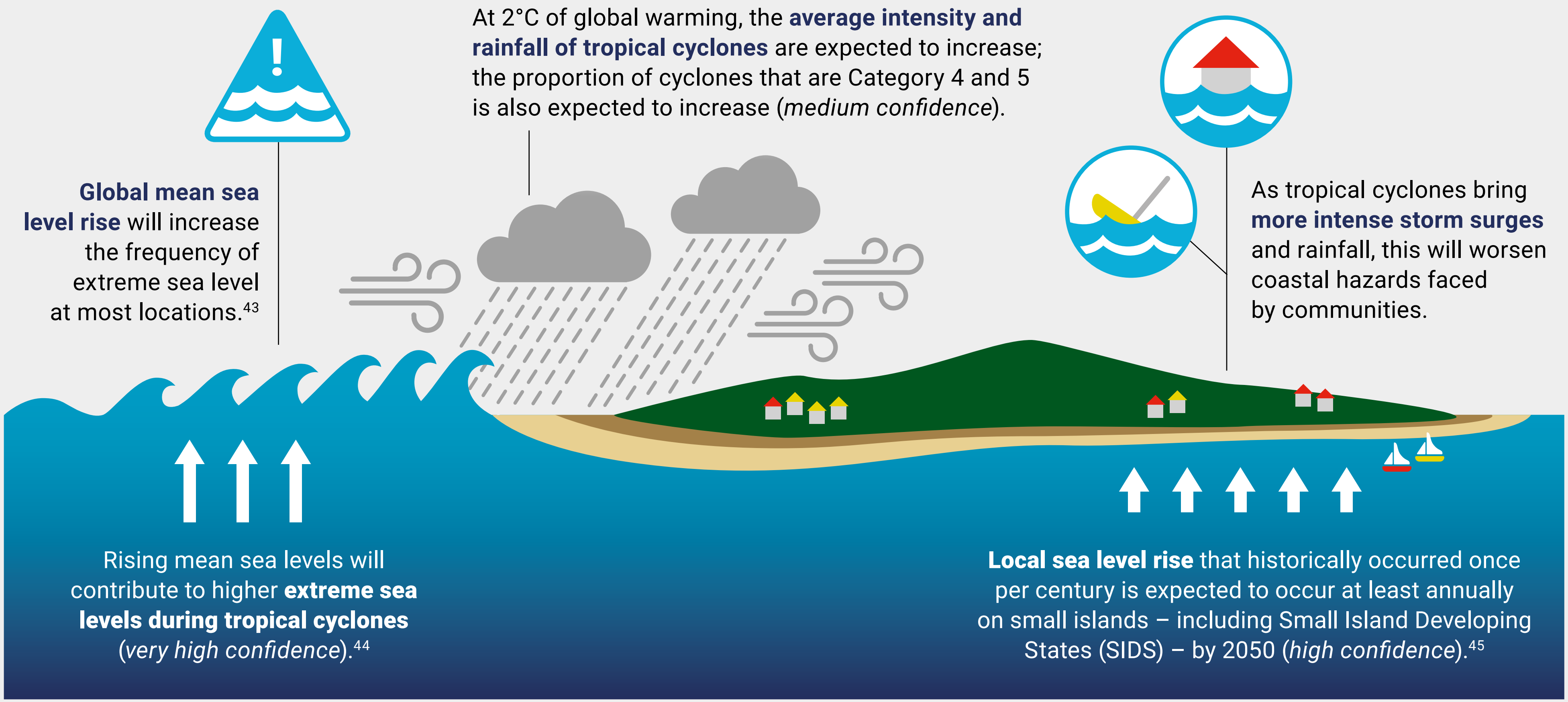
Coastal hazards	Direct impacts – Loss of: land and land uses	Loss of: coastal and marine ecosystem services	Damage to: people	Damage to: the built environment	Damage to: human activities
Submergence of land	■				■
Enhanced flooding	■	■	■	■	■
Erosion of land and beaches	■	■		■	■
Salinisation of soils, groundwater and surface waters	■	■			■
Loss of and change in marine and coastal ecosystems		■			
Impeded drainage					■

Attribution of current coastal impacts on people to sea level rise remains difficult in most locations since impacts were exacerbated by human-induced non-climatic drivers, such as land subsidence (e.g., groundwater extraction), pollution, habitat degradation, reef and sand mining (*high confidence*)."

IPCC, Summary for Policy Makers (2019)[41]

*__Coastal squeeze__ here means when a coastal habitat is lost because of rising sea levels on one side, and a boundary or barrier (such as infrastructure or human settlement) on the land side, which stops the coastal ecosystem from migrating landward.

Figure 4 Increasingly frequent high sea levels could have severe impacts for low-lying islands and coasts[42]



Local sea level rise: Sea levels are measured as a 'global mean' but sea level rise can also vary from place to place. Accurate estimates of sea level rise, locally and regionally, must account for additional processes, such as shoreline migration, changes in ocean area and vertical land movements (local subsidence or uplift of the land).[46] Processes not driven by recent climate change, such as local subsidence caused by natural processes and human activities are important to relative sea level changes (*high confidence*). The relative importance of climate-driven sea level rise is projected to increase over time but local processes need to be considered for impacts of sea level (*high confidence*).[47]

Storm surge or **extreme sea level** (two terms for the same thing) is the temporary increase in the sea's height at a locality due to extremely low atmospheric pressure and/or strong winds. The storm surge is the excess above 'normal' tidal variation for a particular place and time of year. Definitions of what is 'rare' and 'above normal' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile estimated from observations.

Communities can integrate different actions to adapt to sea level rise

The IPCC assesses a range of 'response options' to sea level rise, worldwide. The IPCC calls them 'response options' rather than 'adaptation actions' because they look at the whole spectrum of human responses.

These include forced displacement or planned relocation, which are widely considered to be beyond the bounds of 'adaptation'. This section of the guide focuses principally on different actions that communities can take in situ.

This spectrum of possible response options is summarised in Box 3, below. If we put aside the draconian measures of forced displacement and planned relocation (under 6, below) and look at the remaining options (1–5) for responding to sea level rise in situ, the IPCC concludes that these are likely to be effective when used in an integrated way:

- Nature-based solutions are likely to be effective as standalone adaptation measures only under low global warming scenarios.
- Combinations of engineering solutions with nature-based solutions have more promise for higher warming scenarios.[48] Scientists and practitioners sometimes refer to engineered infrastructure as 'hard' solutions and nature-based solutions such as coastal mangrove planting and conservation as 'soft' solutions.

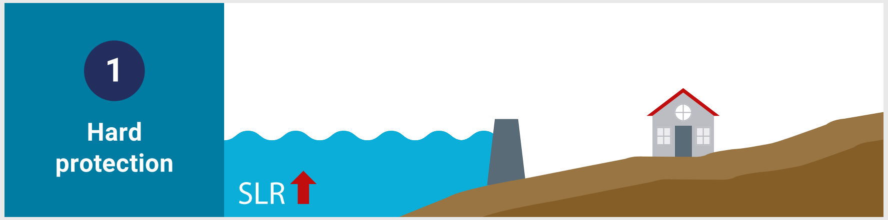
Well-designed and effective coastal protection (often integrating different kinds of hard infrastructure and soft ecosystem measures) "requires investments on the order of tens to several hundreds of billions of US$ per year globally."[49]

> Ecosystem based adaptation approaches lower climate risks locally and provide multiple societal benefits. However, ecological, financial, institutional and governance constraints exist (*high confidence*)."

IPCC, Summary for Policy Makers (2019)[50]

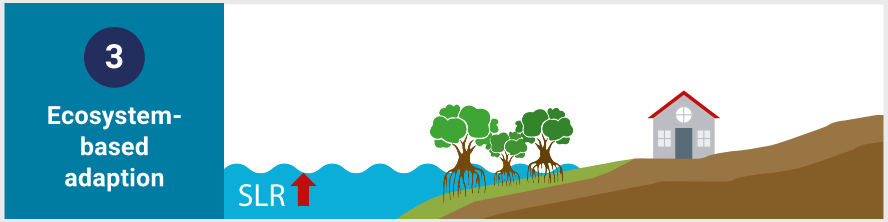
Planting mangroves, Langa Langa lagoon, Malaita, Solomon Islands. Photo: Sharon Suri

Box 3 Responding to sea level rise (SLR)[51]



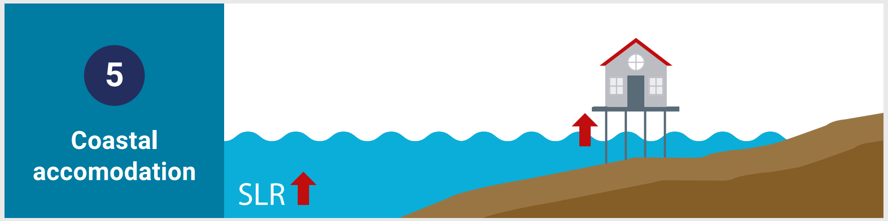
Hard protection refers to the use of engineered infrastructure to protect against coastal flooding, erosion and salt water intrusion. It can include dikes, seawalls, breakwaters, barriers and barrages.

Sediment-based protection refers to what are sometimes called 'soft' protection measures such as nourishing beaches, shores and dunes.

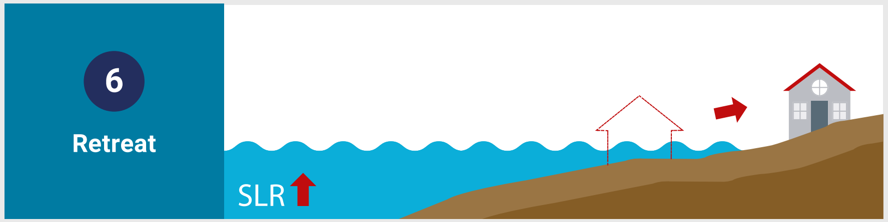


Ecosystem-based adaptation is about conserving or restoring coastal ecosystems such as coral reefs and wetlands. It is also referred to as 'green infrastructure' and 'nature-based solutions'. These features can absorb wave energy and so reduce the force of waves and provide retention areas for water to pool and/or infiltrate. They can reduce erosion by trapping coastal sediments and organic matter.

Coastal advance measures create new land by building seaward, reducing risks for the land behind it and the newly elevated land. These measures can include land-filling with pumped sand or other fill material, planting vegetation and surrounding low areas with dikes (polderisation), which requires draining and pumping systems.



Coastal accommodation is about diverse measures to make coastal zones more habitable and reduce the vulnerability of people and their environment. It includes biological and physical measures such as raising houses on stilts, adopting floating gardens to deal with flooding and erosion, and switching land uses (e.g. from rice farming to shrimp aquaculture) to accommodate salt water intrusion. It also includes institutional measures such as early warning systems and insurance schemes.



Retreat reduces risks by moving exposed people, assets and activities out of the hazard zone. It includes the following three types of retreat: **Relocation** is typically initiated by governments and may include financial incentives, whereas **displacement** occurs when people's movement is involuntary and unforeseen. **Migration** is a person's voluntary permanent or semi-permanent movement.

Table 2 Responses to rising mean and extreme sea levels[52]

Option		Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)	Advantages (beyond risk reduction)	Co-benefits	Drawbacks	Economic efficiency	Governance challenges
1 **Hard protection**		Up to multiple metres of sea level rise ●●●	Predictable levels of safety	Dikes can be multifunctional, e.g. used for recreation or other land uses	Destruction of habitat through coastal squeeze, flooding and erosion downdrift, lock-in, disastrous consequences if defence infrastructure fails	Highly efficient if the assets behind protection is high, as found in many urban and densely populated coastal areas	Often unaffordable for poorer areas. Conflicts between objectives (e.g. conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance
2 **Sediment-based protection***		Effective but depends on sediment availability ●●●	High flexibility	Preservation of beaches for recreation/tourism	Destruction of habitat, where sediment is sourced	High if tourism revenues are high	Conflicts about the distribution of public budgets
3 **Ecosystem-based adaptation**	**Coral conservation**	Effective up to 0.5cm/ year of sea level rise. ●● Strongly limited by ocean warming and acidification. Constrained at 1.5°C warming and lost at 2°C at many places ●●●	Opportunity for community involvement	Habitat gain, biodiversity, carbon sequestration, income from tourism, enhanced fishery productivity, improved water quality. Provision of food, medicine, fuel, wood, and cultural benefits	Long-term effectiveness depends on ocean warming, acidification and emission scenarios	Limited evidence on cost- benefit ratios. Depends on population density and the availability of land	Permits for implementation are difficult to obtain. Lack of finance. Lack of enforcement of conservation policies. Ecosystem based adaptation options dismissed due to short-term economic interests and (where relevant, low) availability of land
	Coral restoration						
	Wetland conservation (marshes, mangroves)	Effective up to 0.5-1cm/ year sea level rise ●● decreased at 2°C ●●●			Safety levels less predictable, (some alternative) development benefits will not be realised		
	Wetland restoration (marshes, mangroves)				Safety levels less predictable, a lot of land required, barriers for landward expansion of ecosystems have to be removed		

Scientific confidence in the effectiveness of this measure in responding to sea level rise: ●●●● Very high ●●● High ●● Medium ● Low

*Often hard protection, sediment-based protection and ecosystem-based adaptation are used in combination, called 'hybrid measures'. For example, a belt of marshland could be established in front of a seawall or a seawall could be created with niches for habitat formation.

Option		Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)	Advantages (beyond risk reduction)	Co-benefits	Drawbacks	Economic efficiency	Governance challenges
4 Coastal advance		Up to multiple metres of sea level rise ●●●	Predictable levels of safety	Generates land and land sale revenues that can be used to finance adaptation	Groundwater salinisation, enhanced erosion and loss of coastal ecosystems and habitat	Very high if land prices are high as found in many urban coasts	Often unaffordable for poorer areas. Social confliflicts with regards to access and distribution of new land
5 Coastal accommodation		Very effective for small sea level rise ●●●	Mature technology; sediments deposited during floods can raise elevation	Maintains landscape connectivity	Does not prevent flooding/impacts	Very high for early warning systems and building-scale measures	Early warning systems require effective institutional arrangements
6 Retreat	Planned relocation	Effective if alternative safe localities are available ●●●	Sea level risks at origin can be eliminated	Access to improved services (health, education, housing), job opportunities and economic growth	Loss of social cohesion, cultural identity and wellbeing. Depressed services (health, education, housing, job opportunities and economic growth)	Limited evidence	Reconciling the divergent interests arising between relocated people and people in destination location
	Forced displacement	Addresses only immediate risk at place of origin	Not applicable	Not applicable	Range from loss of life to loss of livelihoods and sovereignty	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity


Photo: Global Environment Facility. Pacific-IWRM

> Vulnerable human communities, especially those in coral reef environments may exceed adaptation limits well before the end of this century and even in a low greenhouse gas emission pathway (*high confidence*)."

IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate* (2019)[56]

Even under a low emission scenario between now and 2100, urban atoll islands face high risks related to sea level rise.

For example, recent studies have investigated sea level rise-related risks for the three capital islands of: Fongafale (Funafuti Atoll, Tuvalu), the South Tarawa Urban District (Tarawa Atoll, Kiribati) and Male (North Kaafu Atoll, Maldives). All three capital islands are home to the largest populations of these atoll nations, critical infrastructure such as main airports and harbours, and concentrated economic activities. These islands are less than 4 metres above mean sea level and their land is made up mainly of reef-derived material.[53]

In the three cases, human activities are disturbing natural ecosystems, which weakens the coastal protection services provided by ecosystems in the face of climate change. For example, direct human activity has degraded coral reefs on Male, and so has lessened the reefs' ability to break up wave energy and reduce coastal flooding and erosion. In South Tarawa, people have cleared mangrove forests, which historically retained sediments that sustained the island over time.[54]

In the future, the concentration of population, infrastructure and assets in the three capital islands puts them at high risk from sea level rise, even at less than 43 cm of global mean sea level rise (the low emission scenario):

- Even small amounts of sea level rise will increase the risk to atoll islands' aquifers.
- The islands are land-scarce, so damages from sea level rise to housing, agriculture and infrastructure will have cascading impacts on livelihoods.[55]

In the past few years, scientists have reached consensus that there are 'increasing threats' to the sustainability of land, soils and fresh water required to support human life on some small islands. Some island nations are likely to become uninhabitable due to ocean changes – but it is difficult to assess when that point will be reached.[57]

For example, a recent study on Roi-Namur Island, Marshall Islands[58] estimated that it will become uninhabitable before the middle of the 21st century, as sea level rise contributes to high waves and coastal flooding. Seawater inundation will compromise the fertility of the soils and overwhelm fresh groundwater supplies.[59]

Such findings lead to "growing concern that some island nations as a whole may become uninhabitable due to rising sea levels and climate change, with implications for relocation, sovereignty and statehood".[60]

Adaptation will reach its limits for some atoll islands by 2100

Sea level rise will have severe impacts on urban atoll islands by 2100 and for some of them, there will be limited ability to adapt.[61]

The IPCC describes how ocean and coastal processes could make atoll islands disappear.

Atoll islands are not static. Winds and waves carry and deposit sediments, which erode and add to the land (a process called 'accretion'), at the same time as sea levels rise.[62]

In the Solomon Islands, rates of sea level rise are above the global average, at 7–10 mm/year. A study of 33 reef islands showed that five vegetated islands had disappeared and six islands experienced severe shoreline erosion.[63]

A study in Micronesia found that several reef islands have disappeared altogether, leeward edge islands have been severely eroded, and mangrove areas of the coast have expanded.[64]

Tuvalu has suffered some 15 cm of sea level rise between 1971 and 2014; and here, the country's small islands have decreased in land area while larger populated islands maintained or increased land area (except for one). For 709 islands studied over the past 40–70 years, almost three-quarters kept the same surface area; the rest either increased or decreased in size due to these erosion and accretion processes.[65]

With climate change, the remainder of the 21st century may tell a different story.

Rates of sea level rise will increase, wave energy will increase, storm wave direction will change, and ocean warming and acidification will affect coral reefs over the remainder of the century, even under lower global warming scenarios. All of these processes will affect the ability of some atoll islands to naturally adjust their land areas to rising seas through erosion and accretion. They may not be able to keep up.[66]

The vulnerability of coral reef environments

Coral reefs and atoll islands that depend on reefs for their physical integrity are particularly at risk from sea level rise this century.[67] Not only are many of these islands low-lying to begin with, but warming and associated bio-chemical changes in the ocean prevent coral reefs from regenerating quickly enough to replace corals that are lost.

Sea level rise interacts with direct human practices, such as destructive fishing, to damage coral reefs. The damage caused diminishes coral reefs' ability to provide sediments and protection to islands and coastal areas.[68]

Sea level rise – even small amounts – can increase turbidity around coral reefs, meaning that the water becomes cloudy with suspended matter. This reduces the amount of light that reaches the coral, and so decreases photosynthesis and the process of calcification (when corals lay down calcium carbonate).

As the ocean becomes more acidic, due to increased uptake of carbon dioxide in ocean waters, this too slows the rate at which corals produce calcium carbonate. Both ocean warming and acidification are thought to slow the future growth of coral reefs.[69]

The IPCC *Special Report on the Ocean and Cryosphere* reiterates the findings of the earlier *Special Report on 1.5°C of Global Warming*: "coral reefs are projected to decline by 70–90% at 1.5°C [of average global warming] (high confidence) with larger losses (more than 99%) at 2°C (very high confidence)."

How much longer different small islands will remain habitable will vary from one case to another. Managing and reducing risks will require decades of effort by island nations and peoples. Risk management regimes will need to be 'transformed' to harness the greatest potential for climate change adaptation and the promise of more climate-resilient futures. As specific islands or entire island nations reach limits to adaptation, they could face permanent losses of land and ecosystems, people's homes, businesses, cultural and social heritage.

Photo: Asian Development Bank

Bringing science into climate diplomacy

The IPCC is not a policy body and does not make policy recommendations. However, the findings of the IPCC *Special Report on The Ocean and Cryosphere* will be of immediate relevance to climate negotiators and diplomats from SIDS as they seek to advance their national and collective interests in the UNFCCC – and climate diplomacy and financing channels beyond.

The Special Report conveys the latest science clearly and succinctly and in ways that can complement and bolster SIDS' commitments within the framework of the SAMOA Pathway (see Box 4). It is hoped that the headline findings in this guide, and in the other extensive scientific documents provided by the IPCC, can help inform and strengthen SIDS' climate diplomacy efforts in 2020 and the critical decade of action on climate change that follows.

© UNFCCC. High-level event on global climate action, COP25.

Box 4 Climate change in the SAMOA Pathway

The SAMOA Pathway was the outcome of the Third International Conference on Small Island Developing States (SIDS Conference), 1-4 September 2014, Samoa. It provides a framework for sustainable development by SIDS; and SIDS meet periodically to review progress against it.

The SAMOA Pathway recognises "the leadership role of Small Island Developing States in advocating for ambitious global efforts to address climate change, raising awareness of the need for urgent and ambitious action". It also calls on external parties to support SIDS' initiatives:

(a) To build resilience to the impacts of climate change and to improve their adaptive capacity through the design and implementation of climate change adaptation measures appropriate to their respective vulnerabilities and economic, environmental and social situations;

(b) To improve the baseline monitoring of island systems and the downscaling of climate model projections to enable better projections of the future impacts on small islands;

(c) To raise awareness and communicate climate change risks, including through public dialogue with local communities, to increase human and environmental resilience to the longer-term impacts of climate change.

The document stresses the need for all Parties to the UNFCCC to work together for the meaningful operationalisation of the Warsaw International Mechanism on loss and damage – which is intended to help countries pay for losses and damages from climate change that might not be avoided.[70]

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25 Chapter 4, Executive Summary.

26 Figures reproduced from the IPCC's Summary for Policy Makers. However, we have made one textual amendment. Please note that the IPCC's original schematic for risk reduction is labeled for 'mitigation' and 'responses to sea level rise'. We have clarified that 'mitigation' refers to 'climate change mitigation' (i.e. through reduction and avoidance of greenhouse gas emissions), so that readers do not confuse the term with 'risk mitigation' through other means.

27 Chapter 5, Executive Summary.

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30 Chapter 5, 5.2.2.4

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40 Adapted from Chapter 4, Figure 4.13.

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42 This original figure was created by the CASA team under Creative Commons 4.0 licence (Attribution-Non-Commercial-No Derivatives), based on information in the IPCC's Summary for Policy Makers. Please visit our website www.casaclimate.org for a copy of the graphic to download and use in your work.

43 SPM, B3.4.

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