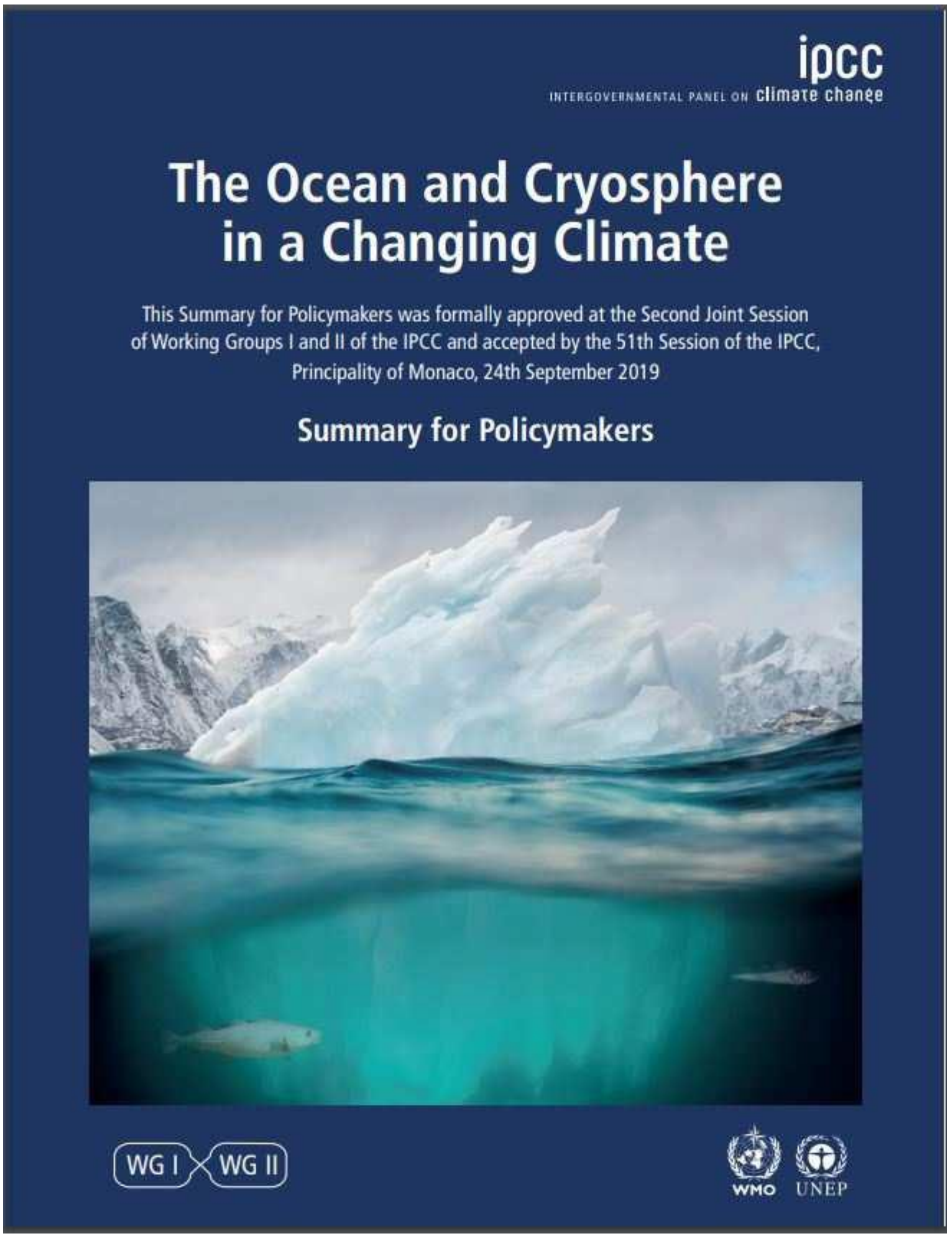

ipcc

INTERGOVERNMENTAL PANEL ON climate change

The Ocean and Cryosphere in a Changing Climate

This Summary for Policymakers was formally approved at the Second Joint Session of Working Groups I and II of the IPCC and accepted by the 51th Session of the IPCC, Principality of Monaco, 24th September 2019

Summary for Policymakers

WG I WG II

WMO UNEP

Summary on the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)

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#MondeEnCommun

AFD
AGENCE FRANÇAISE
DE DÉVELOPPEMENT

SUMMARY

- *Approved at the end of September 2019 by the 195 IPCC Member Governments*[1]*, the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) presents new evidence highlighting the benefits of keeping global warming as low as possible, in line with the objective that governments set themselves in the Paris Agreement in 2015. The report highlights the benefits of ambitious and effective adaptation for sustainable development and, conversely, the ever-increasing costs and risks associated with inaction.*
- *The cryosphere is the area on the planet where water is present in its solid state, i.e. the frozen regions of our planet. Both the cryosphere and the ocean play a critical role for life on Earth. A total of 670 million people in high mountain regions and 680 million people in low-lying coastal zones depend directly on these systems (with 65 million living in small island developing States).*
- *Global warming has already reached 1°C above the pre-industrial level, due to past and current greenhouse gas emissions.*
- *The first-choice solution to combat climate change is to tackle in an ambitious and radical way the socio-economic models that generate the greenhouse gas emissions responsible for climate change that we are currently experiencing. Ecosystems and the livelihoods that depend on them could thus be preserved.*
- *There is overwhelming evidence that global warming is already resulting in profound consequences for ecosystems and people and this is expected to increase. The ocean is warmer, more acidic and less productive. The thermal expansion of water, melting glaciers and polar ice sheets are causing a sea level rise that could exceed 1 meter by the end of the century. Mechanically, coastal floods now considered extreme are expected to become much more frequent.*
- *Almost all marine and coastal ecosystems (especially coral reefs) are subject to risks that will be all the more significant if global warming is not halted. All measures to reduce direct anthropogenic pressures on these ecosystems will help to strengthen their resilience to climate change.*
- *The report also assesses detailed adaptation options such as "hard" coastal protection or ecosystem-based adaptation measures (e.g. conservation and restoration of coral ecosystems and wetlands). Nature-based solutions have many advantages of mutual benefit, on biodiversity, water quality, and so on.*
- *The report also addresses adaptation issues (such as early warning systems) and complex issues of (planned or forced) population retreat.*

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[1] Intergovernmental Panel on Climate Change, United Nations body responsible for assessing scientific work on climate change.

CONTEXT

Following COP21 in Paris in 2015, the Parties requested a special report on the ocean and cryosphere from the IPCC[2]. This *"IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)"* completes a series of 3 special reports integrated into the sixth IPCC assessment cycle (AR6). The first two special reports covered global warming of +1.5°C, (see the IPCC site or AFD's interpretation) and Climate change and land. This report and its summary intended for Summary Policy Makers (SPM) were adopted on September 24, 2019 in Monaco. While the SPM, resulting from inter-government negotiations comprises some forty pages, the report behind the SPM is impressive (over 1,000 pages). Assessing and synthesizing nearly 7,000 scientific publications involved some 100 authors from 36 countries, including 19 developing countries or economies in transition.

This work reviews the already observable consequences of global warming for the oceans and cryosphere, projections for the coming decades, impacts on human societies and ecosystems and adaptation options. Here we present an interpretation of its main conclusions. This document is intended for those who would like to have an overview of the issues and proposals that scientists are making concerning the links between climate change, the ocean and the cryosphere.

RECENT DECADES: THEcryosphere is shrinking, THE SEA LEVEL IS RISING, THE ECOSYSTEMS ARE TRANSFORMED

Over the past few decades, global warming has led to a significant global decline in the cryosphere:

- The Arctic June snow cover extent decreased by 13.4±5.4% per decade between 1967 and 2018; the snow cover of mountain ranges also decreased almost everywhere.
- The Arctic sea ice extent decreased for all months of the year, with a decline of 12.8 ± 2.3% per decade between 1979 and 2018 for September. These changes are unprecedented for at least 1,000 years. The decline in sea ice amplifies warming in the Arctic and could also have an impact on the climate of mid-latitudes, but this last point is still being debated.
- The permafrost (i.e. permanently frozen soil) is melting, both in Arctic and boreal regions and in high mountain areas, causing slope destabilization.
- Globally, **glaciers** lost on average 220±30 Gt of ice per year between 2006 and 2015, equivalent to **a global sea level rise of +0.61 mm/yr.**

  Between 2006 and 2015, **Greenland and Antarctic ice sheets** lost mass at an average rate of 280 Gt/yr and 155 Gt/yr respectively, equivalent to **a global sea level rise of +0.77 mm/yr and +0.43 mm/yr**. The processes at work are not the same for these two regions: Greenland's mass loss is mainly due to surface melting, while in Antarctica mechanical processes modifying the ice flow dynamics in the western portion of the ice sheet dominate. However, in both cases there has been a marked **acceleration in mass loss since the 2000s** (Fig.1): the above values represent a tripling of mass loss for Antarctica and a doubling for Greenland compared to the previous decade.

The melting of glaciers and polar ice sheets is now the dominant source of sea level rise (+1.8 mm/yr), exceeding the effect of thermal expansion of ocean water (+1.4 mm/yr). The acceleration of the melting of the polar ice sheets is largely the cause ofsea level rise, which averaged +3.6 mm/yr between 2006 and 2015, 2.5 times faster than the average for the 20th century (Fig. 1). This rise is not globally uniform and regional or local deviations within ±30% of the global average are observed. The largest differences are in the high latitudes, near the polar ice sheets.

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[2] All surface frozen elements: glaciers, polar ice sheet, permafrost, sea ice, snow, etc.

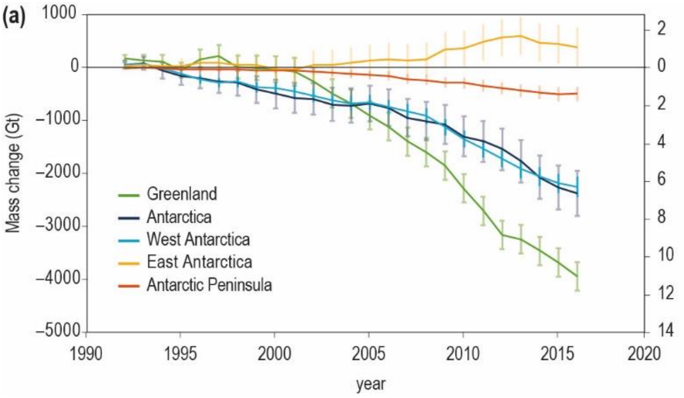

Fig.1: *Cumulative Ice Sheet mass change, 1992 to 2016. The vertical bars represent annual value uncertainties (1 standard deviation).*

Rising water level is not the only transformation that the ocean is already experiencing.
Globally the ocean is becoming:

- **Warmer**: it has absorbed more than 90% of the excess heat in the climate system since 1970; underwater heat waves[3] with deleterious effects on marine ecosystems, especially tropical coral reefs, have become twice as frequent since 1982, longer, more extensive and more intense.
- **More acidic**: only a part of anthropogenic CO_2 emissions remains in the atmosphere; about 22% are absorbed by the ocean, resulting in water acidification.
- **More stratified**: the warming of surface water makes it less dense compared to the deeper waters and reduces the surface and deep ocean mixing. This phenomenon results in a **reduction of the oxygen and nutrients in the surface waters**.

In addition, there is an increase in precipitation and extreme sea level events associated with tropical cyclones. While there is no trend in the number of cyclones, it seems that a trend towards an increase in the frequency of the most powerful cyclones (categories 4 and 5) is beginning to emerge.

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[3] Period of extreme heat when the sea surface temperature exceeds the 99th percentile over the period 1982 to 2016

OVERALL NEGATIVE IMPACTS ON ECOSYSTEMS AND HUMAN SOCIETIES ARE ALREADY OBSERVABLE

All these physical transformations impact land-based and ocean ecosystems. Changes in their composition, in species abundance and in biomass production, from the equator to the poles, can be observed.

Whenever possible, marine species migrate towards higher latitudes and terrestrial species to higher elevations. In the oceans, poleward migration rates observed since 1950 have been in the order of 5 km/year for organisms living in surface waters and 3 km/year for those living on the seabed. This adaptation strategy obviously has its limits : cold-adapted species do not always have colder regions in which to settle and therefore run an extinction risk, especially in mountain areas. In the Arctic, an increase in plant productivity across tundra has been observed generally, while the frequency of fires is unprecedented over the last 10,000 years. Warm water coral reefs are particularly affected by extreme temperatures and water acidification. Coral bleaching phenomena is increasing due to marine heat waves, causing worldwide reef degradation since 1997.

Overall, despite some positive consequences here and there, the report highlights the largely negative impacts of climate change on ocean and cryosphere-dependent ecosystems.

The direct impacts on societies or through the loss of ecosystem services are also negative overall. Examples include the fishing sector, with a decrease in the maximum catch potential in addition to the effects of overexploitation of fish stocks, the negative impacts on farming, hunting and fishing in the Arctic regions, but also increased risk food- and waterborne diseases. Melting glaciers and reduced snow cover have also led to localized declines in agricultural yields in some mountain regions, particularly in the Himalayas and the Andes.

Sea level rise increases the risk of coastal flooding, erosion and salinization of ground water and soils. However, a distinction must be made between *absolute* sea-level rise, linked to climate change, and *relative* sea-level rise, i.e. linked to changes in the altitude of the ground itself. For example, overexploitation of ground water can cause local subsidence of several centimeters per year, while sand extraction can exacerbate coastal erosion. These non-climatic factors can be prevalent locally and therefore it is sometimes difficult to link the damage caused by rising water levels to climate change alone.

Ocean warming and acidification, reduction in oxygen and changes in the supply of nutrients are already affecting the distribution and abundance of marine plant and animal life in coastal areas, the open seas and deep oceans: the ocean is becoming less fertile. The stresses that will affect marine and coastal ecosystems are likely to impact the distribution and abundance of marine plant and animal life. Changes in the distribution of fish populations have reduced the global catch potential (with a decrease in particular in the tropical oceans, but an increase in the Arctic, for example). The nutritional health and food security of those communities heavily dependent on seafood and may be threatened.

FUTURE PROJECTIONS: CURRENT TRENDS CONTINUE, BUT LARGE UNCERTAINTIES REGARDING SEA LEVEL RISE

The future evolution of the oceans and cryosphere will depend mainly on the evolution of greenhouse gas emissions, although some impacts are now unavoidable due to the system inertia.
It is important at this point to note that, as in previous IPCC reports, future climate projections from numerical models are based on scenarios of greenhouse gas (GHG) and aerosol emissions and concentrations , called *Representative Concentration Pathways* (RCP). These scenarios also consider future land use changes.

The report mainly considers two scenarios:

- RCP2.6, which corresponds to a reduction in emissions that would limit global warming to +2°C in 2100 (compared to the pre-industrial period);
- RCP8.5, which assumes no mitigation policies and continued high emissions, leading to a global temperature increase of more than +4°C in 2100.

Whatever scenario is considered, the shrinking of the cryosphere will continue during the 21st century, with significant differences for the second half of the century depending on the future intensity of GHG emissions:

- Globally, glacier retreat in 2100 would be between 18% (RCP2.6 scenario) and 36% (RCP8.5 scenario). These values hide significant regional disparities, since ice mass loss **in regions with small glaciers, such as the Alps or the tropical Andes, could reach 80%** if high emissions continue. Many glaciers will disappear completely regardless of the emissions scenario. These changes will have impacts on the annual and seasonal runoff of glacier-fed rivers. For instance, initially increased glacier melting increases annual runoff, but this phase is temporary and eventually reaches a peak followed by a decline. The annual river runoff is projected to peak in the course of the 21st century, perhaps even as early as the middle of the century in the Himalayas. In regions with few glaciers (tropical Andes, Alps, etc.), the peak has probably already been passed and the decline in glacier runoff will continue throughout the 21st century.
- The area of near-surface permafrost (3-4 m) could be reduced reduced by 24±16% (RCP2.6) to 69±20% (RCP8.5) by 2100. Note that Arctic and boreal permafrost contains 1,460-1,600 Gt of organic carbon. Its massive melting could therefore lead to the release of tens or hundreds of Gt of carbon, as CO_2 and methane. Such a phenomenon would exacerbate global warming and reduce the "carbon budget[4]" still available for anthropogenic GHG emissions in order to limit global warming Note that the global warming potential of methane over 20 years is 80 times higher than that of CO_2.
- The future of Arctic sea ice is very uncertain. The probability of an ice-free Arctic ocean in September is estimated to10-35% by the end of the century for global warming stabilized at +2°C (RCP2.6). The worst projections for the RCP8.5 scenario show that september sea ice could disappear in the second half of the century. Sea-ice retreat amplifies the warming of the Arctic regions and thus the rise in the global average temperature.

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[4] Quantity of greenhouse gases that humanity can emit without exceeding a certain global warming threshold.

- In 2100, the melting of the Greenland and Antarctic ice sheets is projected to contribute to sea level rise by +11 cm and +27 cm for the RCP2.6 and RCP8.5 scenarios respectively. However, these projections could be significantly or very significantly underestimated. The acceleration of mass loss in Antarctica in particular could be a sign of the onset of an irreversible destabilization of the ice sheet, but large uncertainty arises from limited observations and shortcomings in numerical ice sheet model representation of some processes.

Sea level rise projections for the end of the century in the event of continued high GHG emissions have been revised slightly upwards from those in the 2013 IPCC report, due to the re-estimation of the contribution of the Antarctic ice sheet (Fig. 2). **The new projections for 2100 are +0.43 m (likely range: 0.29 m-0.59 m) for the RCP2.6 scenario and +0.84 m for the RCP8.5 scenario (likely range: 0.61 m-1.10 m)** (Fig.2). They integrate the thermal expansion of the ocean and changes in ocean dynamics, the melting of glaciers and (partially) the melting of the polar ice sheets. Projections to 2050 are in the order of 0.2–0.3 m, which is more than the increase observed between 1902 and 2015 (0.16 m).

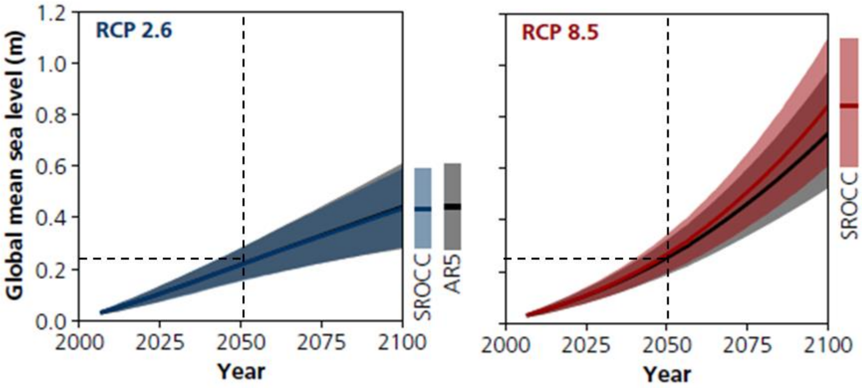

Fig.2: *Projections of global mean sea level rise (in m) relative to the current one for scenarios RCP2.6 (left) and RCP8.5 (right). The shaded region indicates the likely range. The dotted lines make reading easier for 2050.*

However, it is important to note that the main source of uncertainty in sea level projections remains the evolution of the polar ice sheets, particularly the Antarctic Ice Sheet. A more rapid destabilization than what is currently simulated by numerical models is not excluded[5]. A study based on expert judgment[6] estimates that there is a 5% probability for the Antarctic Ice Sheet contribution to sea level rise to exceed 80 cm in 2100 for +2°C of global warming and 178 cm for a world at +5°C. **In other words, for a scenario with high GHG emissions there would be a 5% probability that sea level rise would exceed 2 m in 2100.** Furthermore that the rise will not stop in 2100. The rate could accelerate to several cm/yr in the 22nd century and lead to an increase of several meters by 2300 for the RCP8.5 scenario.

Other changes already underway in the ocean will also continue: warming, stratification, oxygen and nutrient depletion, acidification. For scenario RCP8.5, by 2100, high-latitude waters could become corrosive for some the calcium carbonate shells of some planktonic species. The frequency of marine heat waves could be multiplied by 20 or 50 (RCP2.6 and RCP8.5 scenarios respectively). Furthermore, the frequency of extreme El Niño/La Niña events and the most powerful cyclones are also expected to increase.

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[5] Note that some 100,000 years ago, the global average temperature was 0.5-1°C higher than in pre-industrial times, but the sea level was 6-9 m higher than today. A direct comparison between this past period and future climate is not possible. However, these paleoclimatic elements suggest that current polar ice sheets are probably no longer in equilibrium with current climate.

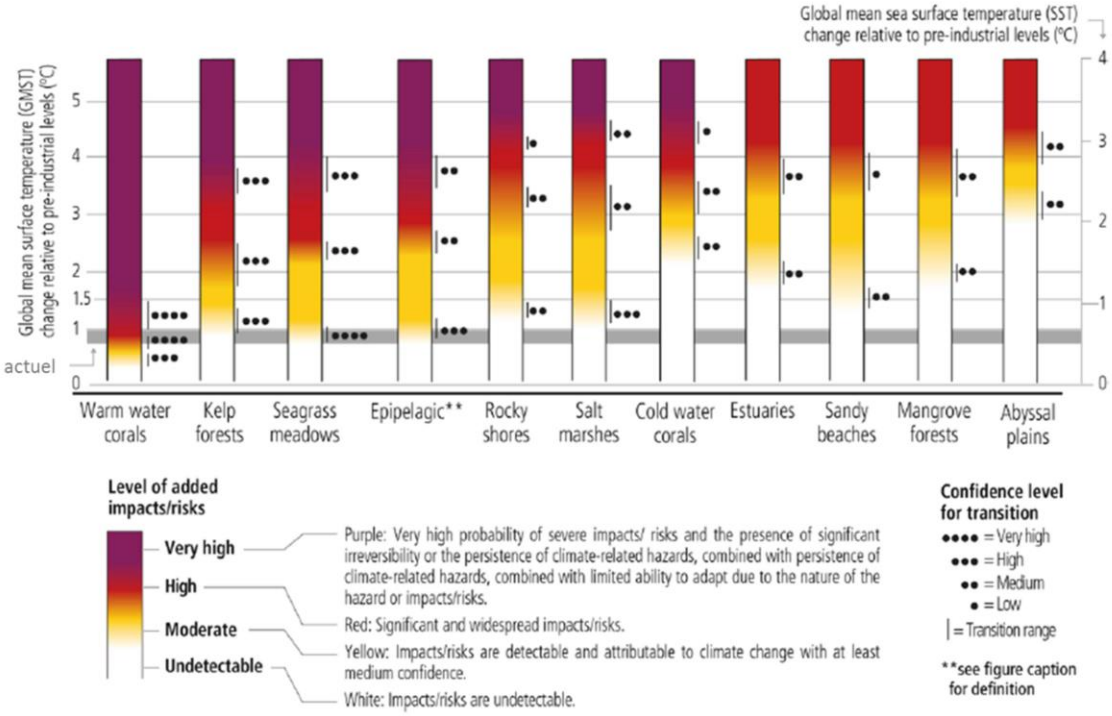
[6] Bamber, et al. (2019). Ice sheet contributions to future sea-level rise from structured expert judgment. *Proceedings of the National Academy of Sciences*, *116*(23), 11195-11200.

FUTURE IMPACTS ON THE ECOSYSTEMS AND SOCIETIES

These physical changes in the ocean and cryosphere will increase the impacts on ecosystems already observed or emerging: decline of Arctic and alpine cold-adapted species , increase of wildfires across tundra and boreal regions, an almost general decline in marine productivity (except in high latitudes) and therefore in fishing resources. **The rate and magnitude of decline in fisheries catch potential would be highest in the tropics, where it could reach 30-40% by 2100 for the RCP8.5 scenario**.

In the short term, the most threatened ocean ecosystems are warm water coral reefs.

As already highlighted in a previous report, these reefs are already severely affected by marine heat waves and may not be able to adapt to global warming above 1.5°C. If warming exceeds 4°C, most marine ecosystems will be severely affected (Fig.3).



Purple: Very high probability of severe impacts/ risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.

Red: Significant and widespread impacts/risks.

Yellow: Impacts/risks are detectable and attributable to climate change with at least medium confidence.

White: Impacts/risks are undetectable.

Fig.3: *Assessment of the risks to various ocean ecosystems, depending on the level of global warming.*

It is important to note that about 680 million people currently live in low-elevation coastal areas[7], including 65 million in Small Island Developing States, and 670 million in high mountain regions.

The majority of people who are or will be directly affected by ocean and cryospheric transformations are in developing or emerging countries.

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[7] Elevation lower than 10 m.

For the countries where AFD operates, sea level rise in particular could become a major problem, especially if the "likely" projections are underestimated. Indeed, most of the large and densely populated deltas, coastal megacities and Small Island Developing States are in inter-tropical regions.

But the issue is more complex than the risk of gradual flooding of some coastal areas: sea level rise also results in salinity intrusions in surface and ground water, increased erosion, and mechanically, **the extreme storm surges that are now rare events would become more common(Fig.4).** Those which, over the historical period, occurred once a century could become annual in the course of the 21st century for many localities, or even before 2050 for many coastal regions and islands in the inter-tropical zone. Without adaptation, the risk of flooding will therefore be considerably increased. In coastal areas currently protected by coral reefs, the risk of erosion and flooding is also likely to be exacerbated by the massive decline of these reefs. Some low-lying island States are likely to become uninhabitable during the century. However, the thresholds remain difficult to define.

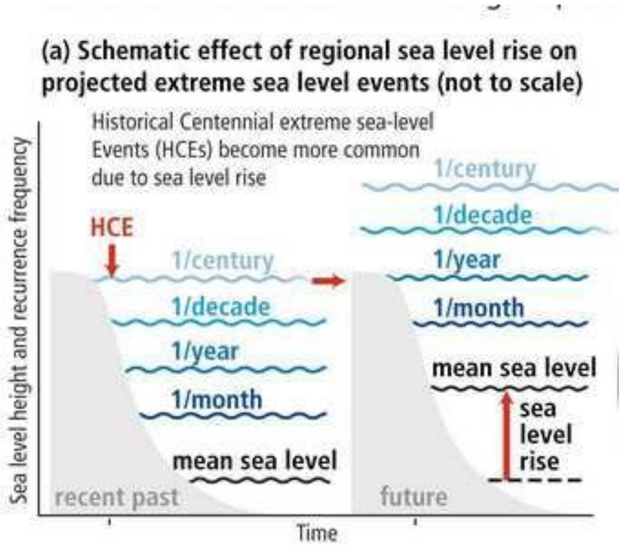

Fig.4: *Diagram of the increase in the frequency of extreme events related to sea level rise. For example, the red arrow indicates that an event that would occur about once a century could occur once a year in the future.*

In addition to risks of flooding, coastal communities that are heavily dependent on fishing are likely to be affected by the decline in fish stocks, particularly in the tropics (e.g. West Africa, Small Island Developing States).

High mountain populations will face changes in the hydrology of glacier-fed watersheds, with a decline in many places in melt-water resources during the warm season. The Andes and high mountains of Asia could be particularly affected.

RESPONSES TO CHANGES IN THE OCEAN AND CRYOSPHERE

In many of the countries where AFD operate, the impacts of ocean and cryospheric changes are already being felt, including coastal flooding and landslide risks in mountains, or degradation of coastal and coral ecosystems.

Risk exposure is particularly high in tropical regions, where low adaptation capacities increase the vulnerability of the populations.

These impacts, which are already being observed and, above all, the magnitude of those yet to come in the event of continued high GHG emissions, increase the challenges associated with governance efforts and the implementation of adaptation responses, at all spatial levels (from local to international), and sometimes push response capacities to their limits (see the concept of maladaptation and loss and damage).

One of the main difficulties comes from the dichotomy between the temporality of climate change and its impacts, which are long-term, and that of governance arrangements (e. g. public or corporate decision-making cycles, financial instruments and investment decisions), whichtake place over shorter periods. However, it is necessary to adopt a long-term perspective even for short-term decisions to allow adaptation, particularly to the increase in the frequency and intensity of extreme events.

Considering the different environmental upheavals upcoming, it is once again necessary to stress the need to reduce greenhouse gas emissions as much as possible in order to delay and limit the scale of the impacts and thereby facilitate the adaptation of societies. There are many adaptation options, and their relevance must be considered in the local context.

As sea level rises, it is possible, for example, to consider “hard” protection measures, ecosystem-based solutions (EbA) when there is enough space. Each option has its advantages and disadvantages (Fig. 5). Dikes have the advantage of defining precisely the level of protection, but in the event of a breach the damage can be considerable. In addition, their cost may be prohibitive in many regions where AFD works[8].

EbA has many benefits (carbon sequestration, improved water quality, biodiversity, etc.), but protection levels may not be sufficient for global warming scenarios above 2°C. The establishment of early warning systems and flood proofing are also measures that are already effective and beneficial, particularly in the face of extreme events.

Similarly, **reducing coastal urbanization and subsidence due to human activities** are effective responses. It should also be noted that the question of **relocation,** a complex societal issue, is included in the response options regardless of the scenario (from the most ambitious to the least ambitious) and no matter which geographies are studied (resource-rich coastal cities, tropical agricultural deltas, urban islands and atolls). In any case, the higher the sea level rise, the more complex the coastal protection issues, increasingly so for economic, financial or spatial barriers than for technical limitations. It should be noted that, given the uncertainties surrounding the future magnitude of sea level rise, the authors recommend adopting, if possible, **flexible responses** that can be adjusted if necessary. Moreover, **stakeholders who are particularly risk-averse should consider scenarios with an increase higher than the “probable” range given by the report (i.e. above 1 m at the end of the century).**

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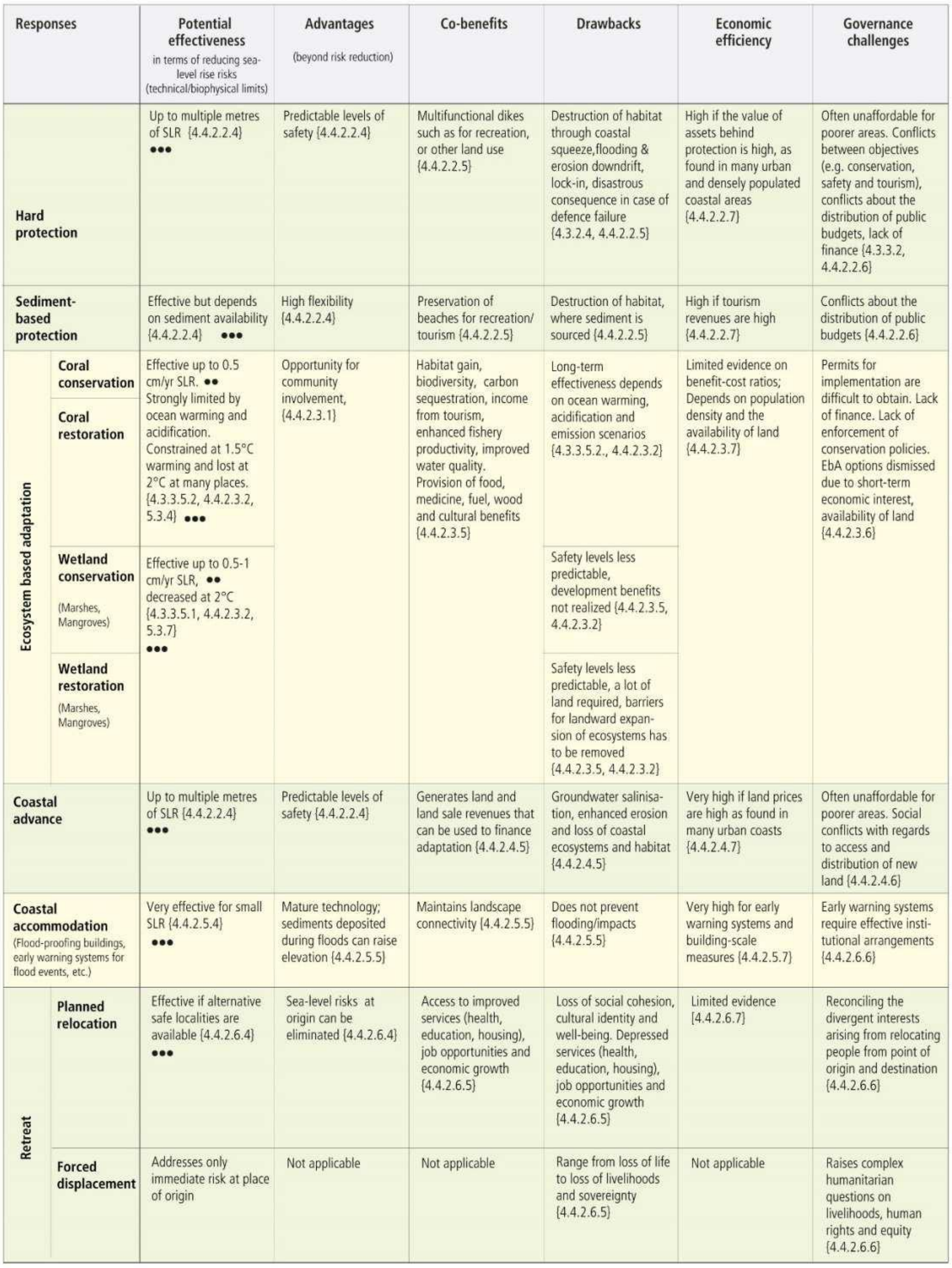
[8] As a rule, a dike is a profitable investment for densely-populated urban areas, but for poorer rural areas investment may not be possible (in order of magnitude: annual costs for some small island States could be equivalent to several percentage points of GDP).

(c) Responses to rising mean and extreme sea-levels

The table illustrates responses and their characteristics. It is not exhaustive. Whether a response is applicable depends on geography and context.

Confidence levels (assessed for effectiveness): ●●●● = Very High ●●● = High ●● = Medium ● = Low



Responses		Potential effectiveness in terms of reducing sea-level rise risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co-benefits	Drawbacks	Economic efficiency	Governance challenges
Hard protection		Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Multifunctional dikes such as for recreation, or other land use {4.4.2.2.5}	Destruction of habitat through coastal squeeze,flooding & erosion downdrift, lock-in, disastrous consequence in case of defence failure {4.3.2.4, 4.4.2.2.5}	High if the value of assets behind protection is high, as found in many urban and densely populated coastal areas {4.4.2.2.7}	Often unaffordable for poorer areas. Conflicts between objectives (e.g. conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance {4.3.3.2, 4.4.2.2.6}
Sediment-based protection		Effective but depends on sediment availability {4.4.2.2.4} ●●●	High flexibility {4.4.2.2.4}	Preservation of beaches for recreation/ tourism {4.4.2.2.5}	Destruction of habitat, where sediment is sourced {4.4.2.2.5}	High if tourism revenues are high {4.4.2.2.7}	Conflicts about the distribution of public budgets {4.4.2.2.6}
Ecosystem based adaptation	**Coral conservation**	Effective up to 0.5 cm/yr SLR. ●● Strongly limited by ocean warming and acidification. Constrained at 1.5°C warming and lost at 2°C at many places. {4.3.3.5.2, 4.4.2.3.2, 5.3.4} ●●●	Opportunity for community involvement, {4.4.2.3.1}	Habitat gain, biodiversity, carbon sequestration, income from tourism, enhanced fishery productivity, improved water quality. Provision of food, medicine, fuel, wood and cultural benefits {4.4.2.3.5}	Long-term effectiveness depends on ocean warming, acidification and emission scenarios {4.3.3.5.2., 4.4.2.3.2}	Limited evidence on benefit-cost ratios; Depends on population density and the availability of land {4.4.2.3.7}	Permits for implementation are difficult to obtain. Lack of finance. Lack of enforcement of conservation policies. EbA options dismissed due to short-term economic interest, availability of land {4.4.2.3.6}
	Coral restoration						
	Wetland conservation (Marshes, Mangroves)	Effective up to 0.5-1 cm/yr SLR, ●● decreased at 2°C {4.3.3.5.1, 4.4.2.3.2, 5.3.7} ●●●			Safety levels less predictable, development benefits not realized {4.4.2.3.5, 4.4.2.3.2}		
	Wetland restoration (Marshes, Mangroves)				Safety levels less predictable, a lot of land required, barriers for landward expansion of ecosystems has to be removed {4.4.2.3.5, 4.4.2.3.2}		
Coastal advance		Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Generates land and land sale revenues that can be used to finance adaptation {4.4.2.4.5}	Groundwater salinisation, enhanced erosion and loss of coastal ecosystems and habitat {4.4.2.4.5}	Very high if land prices are high as found in many urban coasts {4.4.2.4.7}	Often unaffordable for poorer areas. Social conflicts with regards to access and distribution of new land {4.4.2.4.6}
Coastal accommodation (Flood-proofing buildings, early warning systems for flood events, etc.)		Very effective for small SLR {4.4.2.5.4} ●●●	Mature technology; sediments deposited during floods can raise elevation {4.4.2.5.5}	Maintains landscape connectivity {4.4.2.5.5}	Does not prevent flooding/impacts {4.4.2.5.5}	Very high for early warning systems and building-scale measures {4.4.2.5.7}	Early warning systems require effective institutional arrangements {4.4.2.6.6}
Retreat	**Planned relocation**	Effective if alternative safe localities are available {4.4.2.6.4} ●●●	Sea-level risks at origin can be eliminated {4.4.2.6.4}	Access to improved services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Loss of social cohesion, cultural identity and well-being. Depressed services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Limited evidence {4.4.2.6.7}	Reconciling the divergent interests arising from relocating people from point of origin and destination {4.4.2.6.6}
	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 {4.4.2.6.5}	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity {4.4.2.6.6}

d) Choosing and enabling sea level rise responses

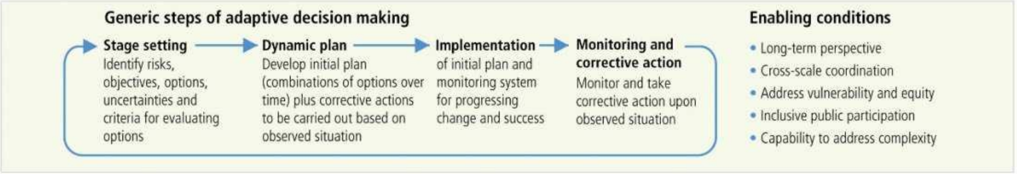


Fig. 5: *Characteristics of (adaptive) response options to sea level rise, from dike type hard protection measures to ecosystem conservation and restoration (ecosystem-based adaptation) and coastal accommodation measures and forced retreat and displacement phenomena.*

Regarding ecosystems, all measures to reduce direct anthropogenic pressures will help to strengthen their resilience to climate change:

- **Develop protected area (PA) networks**, which maintain ecosystem services and carbon capture and sequestration. Protected areas would also facilitate the migration of species in latitude and altitude, where they could find more favorable conditions.
- **Restore terrestrial and marine habitats**, based on scientific knowledge but also involving local communities and local and traditional knowledge.
- **Reduce pollution and other sources of stress**. It should be noted that, among other things, this implies taking action on *sources* of pollution, which are often located upstream, on land (waste water, industrial waste, urban waste, etc.).
- **Reconstitute overexploited or depleted fisheries.**
- Promote ecosystem-based adaptation measures.

These measures will be all the more effective with a reduced global warming.

The restoration of coastal ecosystems linked to coastal blue carbon (mangroves, salt marshes, grass beds) can also allow carbon sequestration, but with a rather limited mitigation potential on a global scale (0.5% of global annual emissions). While the quantification of GHG flows and the quantification of CO_2 capture still need to be improved, there are many benefits, such as coastal protection and improvements in water quality, biodiversity and fisheries.

Finally, with a view to reducing GHG emissions, the report highlights the potential of renewable energies linked to the oceans: offshore wind farms, tidal and wave energy, algae fuel, energy linked to the salinity gradient. The deployment of these technologies could generate significant economic opportunities, although the resilience of these forms of energy production could be impacted by climate change. A more comprehensive assessment of this issue is expected in the next IPCC global report, to be published in 2021/2022.

CONCLUSION

Ultimately, the report highlights **climate resilience and sustainable development are only possible if urgent and wide-reaching emission reductions are implemented**. Reducing emissions in the future reduces risks and thus reduces the need for adaptation.

Generally, the responses to be provided are complex (and often specific to different areas/cases). This is due to the many ramifications with other issues, and the fact that decisions have to be made with uncertainty (about the level of consequences), and depend on the degree of stakeholders' risk tolerance and the issues of governance, limited resources, economic development, and so on.

Increased cooperation and coordination is needed. If a highly emitting GHG scenario materializes for the 21st century, many communities are likely to face limitations in their ability to adapt to the impacts they will face. **Economic changes and institutional transformations are needed to enable resilient climate development pathways** (as defined by the IPCC, see glossary).

Education and capacity building issues are also key, and investments in this area can bring about the necessary transformations so that appropriate arrangements and decisions can be made.

Establishing observation and early warning systems, facilitating data exchange, context-specific models; these are just some of the possibilities to ensure proper comprehension of the issues and conflicts between the choices that could be made in the short and long term and which often make it possible to reduce the negative effects in many sectors (health, fisheries, agriculture, tourism, floods, etc.).