Summary for Policymakers

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Note: additional authors to be added

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Sections A and C are integrative across systems. Decision on integrating B into an alternative structure envisioned once we have distilled content closer to final.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) is prepared following a decision of governments in preparation for the Sixth Assessment Cycle[1]. By assessing new scientific literature[2], this report expands the knowledge base for the United Nation Framework Convention on Climate Change (UNFCCC), building on the IPCC Fifth Assessment Report (AR5) and the IPCC Special Report on Global Warming of 1.5°C (SR1.5)[3].

The ocean and the cryosphere (snow, ice, glaciers, ice sheets, and frozen soil and ground) support human livelihoods and well-being in many ways. They are closely connected with the whole climate system. Global warming in response to increased emissions of greenhouse gases and other drivers due to human activities is associated with very clear and in some cases irreversible changes in the ocean and the cryosphere, altering living conditions for ecosystems and people. Organisms, ecosystems and people (societies) from mountains to oceans, and from poles to equator, will continue to experience novel, unprecedented environments and hazards as a result of climate-related changes in the ocean and cryosphere.

The SROCC assesses scientific knowledge about past, ongoing and future changes as well as their impacts in high mountain areas, polar regions, coasts, low-lying islands, and the open ocean. It gives particular attention to the issues of sea-level rise, extremes and abrupt events. Opportunities and risks as well as adaptation response options are also assessed, including nature-based solutions relevant for climate-resilient sustainable development pathways.

This Summary for Policymakers (SPM) synthesises key findings of the report and highlights new findings obtained since the AR5 (published 2013/2014). The level of confidence associated with each key finding in the three sections of this SPM is reported using IPCC calibrated language[4]. The underlying scientific basis of

1 The decision to prepare a Special Report on climate change and oceans and the cryosphere was made at the Forty-Third Session of the IPCC in Nairobi, Kenya, 11 - 13 April 2016.

2 Cut-off dates: 15 October 2018 for publication submission, 15 May 2019 for accepted publication

3 Full title: Global Warming of 1.5 °C: IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

4 Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of

each paragraph can be traced back to chapter elements based on the references provided. Definitions for terms that are commonly used within the SROCC can be found in the glossary.

SPM.A ONGOING CHANGES IN THE OCEAN AND THE CRYOSPHERE ILLUSTRATE THEIR IMPORTANCE FOR CLIMATE, ECOSYSTEMS AND PEOPLE

A1. Changes to the ocean and cryosphere play a key role in the state of the climate at the global scale and impacts on ecosystems and human societies are now evident (*very high confidence*). Ongoing changes include unabated warming, acidification and deoxygenation of the ocean, reduced Northern Hemisphere snow cover and Arctic sea ice, worldwide retreat of mountain glaciers, reductions in the Greenland and Antarctic ice sheets, and permafrost degradation and thaw. Sea level rise has accelerated in the past decades due to increased contributions from ice sheets (*very high confidence*). Some of these changes are irreversible on timescales relevant to human societies (decades to centuries). {1.1, 1.2, 1.3, 1.4, 2.2, 3.2, 3.3, 3.4, 4.2, 5.2, Figure SPM.1}

A1.1 Ocean heat content is increasing at a steady rate; there is increased evidence from, and agreement between, observations and simulations since AR5 for increases in ocean heat content; these changes provide further support that the observed changes are largely caused by anthropogenic forcing (*high confidence*).). The ocean heat uptake during the period 1970-2010 is equivalent to an energy imbalance of 0.42 W m^{-2} (with respect to the Earth surface area). {1.4.1, 5.2}

A1.2 The ocean is continuing to acidify in response to carbon dioxide uptake. It is *very likely* that the ocean has taken up about 25 ± 5% of total anthropogenic emissions in the past two decades. The anthropogenic pH signal has already emerged outside the range of natural variability over the entire surface ocean (*high confidence*). The ocean is observed to be losing oxygen and oxygen minimum zones have expanded. The largest reductions in oxygen have been observed in the Southern Ocean, South Atlantic and North Pacific (*medium confidence*), but there is *low confidence* for changes in the tropical ocean due to natural variability and limited agreement across studies. {3.2.1, 5.2.2}

A1.3 It is *virtually certain* that the Greenland ice sheet has lost mass and *very likely* that the Antarctic ice sheet has lost mass. The rate of mass loss from the Greenland Ice Sheet and polar glaciers has increased since around the year 2000 (*high confidence*). The rate of Antarctic Ice Sheet overall mass loss has increased since approximately 2005 (*medium confidence*), dominated by regions of West Antarctica (*very high confidence*). Because of a lack of long-term mass-change observations in both polar regions and incomplete representation of the full range of relevant processes in ice sheet models, attribution of mass loss from ice sheets to human-induced climate change is currently not possible. Glaciers and polar ice sheets are now the dominant source of sea level rise *(very high confidence)*, and increasing losses from polar ice sheets are resulting in increasing rates of sea level rise. Anthropogenic forcing has been the dominant cause of global mean steric sea level rise since 1970 (*high confidence).* {1.4, 3.3.1, 3.3.2, 4.2}

A1.4 Arctic sea surface temperature has increased at approximately twice the rate of average global temperature (*very high confidence*). Continued substantial declines in Arctic summer sea ice extent (average rate –13.0% per decade in September; the month with the lowest sea ice cover over 1979–2017) and Arctic spring snow cover extent (–13.6% per decade in June; 1967–2018) have occurred (*high confidence*), with consequences for the global climate system, for example through changes in albedo. There is *low confidence* associated with the teleconnections between Arctic sea ice loss and changes in atmospheric circulation affecting weather patterns in mid-latitudes. Antarctic sea ice extent increased between 1979 and 2017 at an annual-mean rate of $20.2 \pm 4.0 \times 10^3$ km^2 yr^{-1}, but with strong negative departures in 2016 and 2017 (*very high confidence*). The overall increase is composed of near-compensating regional changes, with rapid ice

confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. For more details see: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

loss in the Amundsen and Bellingshausen seas outweighed by rapid ice gain in the Weddell and Ross seas. The regional pattern of observed Antarctic sea ice trends is closely related to meridional wind trends (*high confidence*). {3.2.1, Box 3.1}

A1.5 High mountain regions have experienced substantial warming; the extent and duration of snow cover have declined in many high mountain regions since the beginning of the 20th century, especially at lower snow elevations (*very high confidence*) although with high regional variability. The vast majority of glaciers in all high mountain regions have retreated and lost mass during the last two decades (*very high confidence*). Mass losses from the glaciers in 11 glaciated mountain regions (shown in Figure SPM.2) increased from 470 ± 80 kg m^{-2} yr^{-1} in the period 1986–2005 to 610 ± 90 kg m^2 yr^{-1} during 2006–2015. Regional-scale average mass losses during 2006-2015 were largest in the southern Andes, the low latitudes and central Europe (>900 kg m^2 yr^{-1}) and smallest in High Mountain Asia (190 kg m^2 yr^{-1}). {2.2.1, 2.2.2, 2.2.3, Box 2.1}

A1.6 In situ measurements in the European Alps, Scandinavia and the Tibetan Plateau show that permafrost has undergone warming and thaw in the past two decades (*high confidence*). The observed rates of change in the 21st century are higher than in the late 20th century (*medium confidence*). Other mountain regions lack in-situ observations to assess trends. Permafrost temperatures have continued to increase (*high confidence*). Since 2000, the typical rate of increase in permafrost temperatures has been between 0.4°C and 0.7°C per decade for continuous permafrost monitoring at colder sites. The organic carbon pool stored in Arctic and boreal permafrost zone soils contains almost twice the carbon presently in the atmosphere (*high confidence*). Quantifying potential future greenhouse gas emissions (primarily carbon dioxide and methane) from thawing permafrost soils thus has global relevance. {2.2.4, 3.4.1; 3.4.2; 3.4.3}

A1.7 Glacier shrinkage and snow cover changes have led to changes in the amount and timing of river runoff in many mountain regions during the last two decades (*high confidence*). In some regions with predominantly small glaciers (e.g., western USA and Canada), runoff from glaciers has already decreased due to glacier shrinkage while in other regions, typically with larger glaciers (e.g., Alaska), runoff from glaciers has increased (*medium confidence*). Runoff changes from mountain glaciers have caused significant shifts in downstream nutrients (dissolved organic carbon, nitrogen, phosphorus) and influenced water quality through increases in heavy metals, particularly mercury and other contaminants that persist in the environment {2.2.3.2}

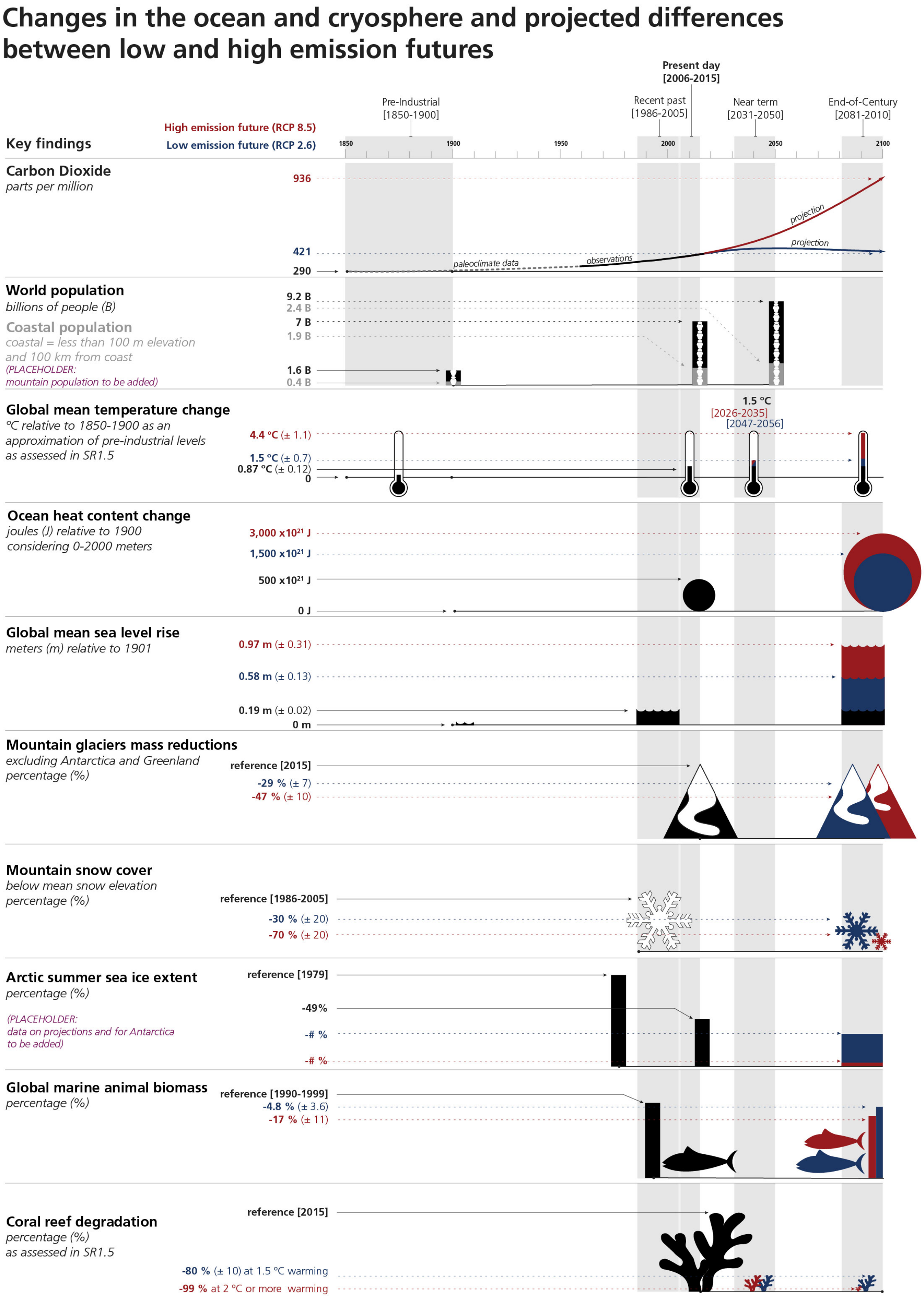


Figure SPM.1: Illustration of key findings on the ocean and cryosphere in a changing climate and the projected differences between low and high emission futures. Measured and projected carbon dioxide levels from 1850-2100 {Figure 1.3} are shown in the context of past and projected coastal and global population {1.1, 1.5} and global mean temperature change at key intervals since the pre-industrial {1.1, SR1.5}. Schematics for quantified observed and projected changes in the ocean and cryosphere are shown for ocean heat content {5.2.2.2}, global mean sea level rise {4.2.3.1}, mountain glacier mass {2.2.3.2}, mountain snow cover {2.2.2}, Arctic summer sea ice extent {3.3.1.1}, animal biomass in marine ecosystems {5.2.3.1} and coral reefs {SR1.5}. Colouring of schematics contrast the differing projected outcomes in a low emission/strong mitigation future (RCP2.6; blue) compared with a high emission/weak mitigation future (RCP8.5; red). [PLACEHOLDER FOR SECOND DRAFT: for further development of concept figure: incorporate more elements when quantified assessments become available (Antarctic and Greenland ice sheets, Antarctic sea ice, permafrost, ocean pH); incorporate more information on historical changes or change time axis scale to focus only on present day position and future projections; add confidence assessments; add visual representations of implications for natural, managed and human systems or for Sustainable Development Goals; committed responses beyond 2100]

A2. Ecosystems and people depend directly or indirectly on the multitude of services provided by the ocean and cryosphere. The local- to global-scale services supported by the ocean and cryosphere include heat and carbon uptake by the ocean, food and freshwater supplies, renewable energy generation, trade and transport, recreation, culture and well-being. These services are modified, degraded or eliminated under climate change (*high confidence*). {1.1, 1.5}

A2.1 Almost 13% of the global population lives in the Arctic or high mountain regions and face risks from climate-related changes in the cryosphere. Observed changes in the cryosphere have been exerting considerable impacts on agriculture, fisheries, hydropower, tourism and recreation activities and other sectors since the mid-20th century, while evidence on the long-term effectiveness of adaptation responses remains uneven and limited (*medium confidence*). The impacts on lives, livelihoods and infrastructure extend beyond the directly affected areas. For example, much larger populations and cities downstream of high mountain areas are also subject to cryosphere-change-related risks and impacts. {1.1, 1.5, 2.2.2, Figure SPM.2}

A2.2 In mountain terrestrial and freshwater environments, ecosystems are changing and shifting due to changes in snow cover, permafrost thaw and degradation as well as glacier retreat. Some populations of high-mountain species are in decline as climate changes and habitats, such as snowpack, are lost (*high confidence*). Multiple interacting cryosphere-related challenges, including survival under a shallower and denser snowpack, affect foraging and reproduction for high mountain species, such as wolverines (*high confidence*). {2.3.1, 2.3.3, Figure SPM.2}

A2.3 Adoption of new crops and irrigation techniques has reduced vulnerability of some high mountain agricultural communities to reduced stream flow linked to glacier retreat and changes in snow amounts. Managers of hydropower facilities incorporate projections of stream flow into planning to reduce their vulnerability to changing water amounts. Snow management, including snowmaking, has reduced the vulnerability of some mountain ski resorts to inter-annual variability and past decline of natural snow amounts. However, adaptation measures in agriculture, hydropower, tourism and other sectors are generally limited in scope, short-term and fragmented. The diverse priorities, conditions and mechanisms available for the implementation and evaluation of these measures place constraints on the available adaptation measures and assessment of their performance and limitations. {2.3.1, 2.3.4}

A2.4 Sea level rise, driven by changes in the ocean, glaciers and ice sheets, is a key concern for coastal areas which are the most densely populated areas on Earth; home to approximately 27% of the global population including more than half of the world's megacities. Low-lying islands and coasts across latitudes are at high risk of climate-change related impacts, sharing physical, biological, and socio-economic characteristics and contexts in their exposure and vulnerability to climate change (*high confidence*). There is increasing evidence of changes caused by rising sea level at the coast with respect to ecosystems, ecosystem services, coastal infrastructure, habitability, community livelihoods, and cultural and aesthetic values. Attribution of local impacts to sea level rise, however, remains difficult due to the combined influence of non-climatic drivers and local processes unrelated to sea level rise (*medium confidence*). {4.3.3, 4.3.4, Cross-Chapter Box 7 on Low-lying Islands and Coasts}

A2.5 Emergence of novel ocean conditions for marine organisms from plankton to mammals are driving changes in physiology, biogeography and ecology that impact biodiversity and ecosystem functions (*high* *confidence*). Observed population declines of marine species in the lower-latitude range boundary (*medium confidence*), expansion in the poleward boundary (*high confidence*), earlier timing of biological events (*high confidence*), and overall shifts in biomass and species composition (*very high confidence*) are consistent with modelled responses to climate change. {5.2.2, 5.2.3, 5.3.2, 5.3.3}

A2.6 The role of ocean ecosystems in climate regulation, in support of human livelihoods, food security, culture and recreation and their intrinsic values that are important for human well-being, are threatened by climate change (*high confidence*). The evidence for these threats to human wellbeing includes: decline in biodiversity and ecosystem function (*medium confidence*), reduced quality and quantity of tourist attractions including coral reefs, as well as damage from more severe storm events, decreases in nutrient cycling in deep seafloor ecosystems (*high confidence*), reduced carbon sequestration and loss of carbon stocks in saltmarshes, loss of educational opportunities, and negative impacts on Indigenous knowledge and culture (*medium confidence*). {5.4.1, 5.4.2}

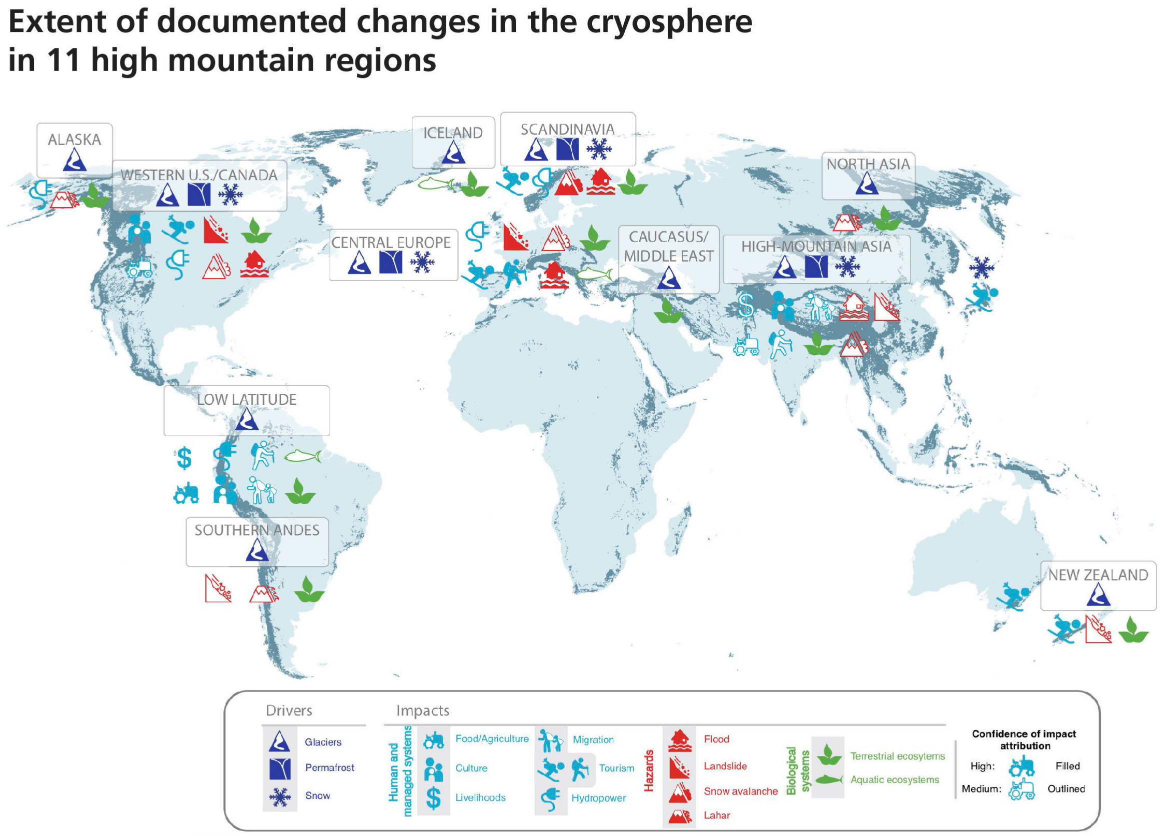


Figure SPM.2 Documented hazards and impacts to the biosphere and society caused by changes in the cryosphere are also shown in all high mountain areas (dark grey areas on map). Confidence levels refer to confidence in attribution to cryospheric change. {2.3, Figure 2.10}

A3. Ocean heat and carbon uptake, glacier and ice sheet loss and sea level rise are irreversible on timescales of centuries and beyond. Changes in the ocean and cryosphere have already affected the frequency and magnitude of multiple hazards that exacerbate environmental risks faced by many ecosystems and human systems. {1.5, 6.3, 6.4, 6.8}

A3.1 High mountain and Arctic systems as well as marine and coastal systems (including coral reefs) are at *high* to *very high* risk of adverse and potentially accelerated, larger and irreversible impacts as global temperatures approach or exceed 1.5°C to 2°C above pre-industrial. Committed ocean and cryosphere changes initiate the use of adaptation measures to reduce impacts on human and natural systems, alongside efforts to reduce greenhouse gas emissions. {1.1, 1.2, 1.3}

A3.2 Marine heatwaves (MHWs) have *very likely* doubled in frequency since the early 1980s (*high confidence*), with one quarter of the surface ocean experiencing either the longest or most intense events on record in 2015 and 2016. On a global scale, about 90% of the observed MHWs are attributable to human-induced global warming and some recent MHWs are unprecedented with respect to pre-industrial conditions (*medium confidence*). MHWs have occurred in all ocean basins over the last few decades with detrimental and potentially irreversible impacts on coral reefs and other marine ecosystems, and cascading impacts on economies and societies. {6.4, Figure 6.3, Figure 6.4}

A3.3 Retreat of mountain glaciers and thaw of mountain permafrost has decreased the stability of mountain slopes (*high confidence*). Glacier retreat has led to an increasing number and area of glacier lakes (*high confidence)*. Over the past decades, there has been an increase in wet snow avalanches and a reduction in the size and run-out distance of dry snow avalanches (*medium confidence*). There is *high confidence* that the exposure of people and infrastructure to natural hazards in high mountain areas has increased. {2.3.2}

A3.4 Coastal ecosystems are under stress from the combination of climate change impacts in the ocean and from sources of stress originating on land such as water pollution and land use changes (*high confidence*). Extreme events such as marine heat waves and storms are exacerbating the rate of ecosystem changes, such as those observed in kelp forests and seagrass meadows (*high confidence*). {5.3.3, 6.4}

A3.5 Climate change-related impacts on the ocean and cryosphere are expected to compound the risks related to climatic and other environmental hazards already faced by many human and natural systems, particularly in coastal, polar and mountain areas. Enhanced climate change impacts on the ocean and cryosphere put sustainable development pathways at risk (*medium confidence*), and present particular challenges to communities living in close connection to polar, mountain and coastal environments, and to cities, states and nations whose territorial boundaries are being transformed by ongoing sea level rise {1.1, 1.2, 1.5}.

SPM.B PROJECTED CHANGES

B.1 Shifts in snowline, glacier retreat, permafrost thaw, and changing river runoff due to warming in high mountains are projected to continue causing natural hazards and risks for biodiversity, terrestrial and freshwater ecosystems, agriculture, hydropower, tourism, recreation activities, and infrastructure if adequate adaptation measures are not taken. Future changes are projected to pose challenges to livelihoods and other economic activities in and beyond mountain regions. {2.2, 2.3}

B1.1 Under all considered climate scenarios for the 21st century, air temperature in high mountain regions is projected to increase, exceeding average global warming rates and driving further reductions in snowfall below the mean snowline elevation (*very high confidence*). Elevation-dependent warming is projected to amplify in many mountain regions (*medium confidence*). Total precipitation is projected to show limited long-term changes, except at the highest elevations where it is projected to increase (*medium confidence*). {2.2.1; Box 2.1; 2.2.2}

B1.2 Glaciers in all mountain regions are projected to continue to lose mass throughout the 21st century (*very likely*). Projected mass reductions between 2015 and 2100 range from 29 ± 7% for Representative Concentration Pathway RCP2.6 to 47 ± 10% for RCP8.5[5]. In regions with relatively little ice cover (e.g., Central Europe, Caucasus, Low Latitudes, North Asia, Scandinavia), glaciers are projected to lose more than 80% of their current mass by 2100 under RCP8.5. {2.2.3}

[5] A set of scenarios, the Representative Concentration Pathways (RCPs), was used under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. In all RCPs, atmospheric CO_2 concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of CO_2 to the atmosphere during the 21st century. Levels of warming in this Summary for Policymakers refer to pre industrial (1850–1900) as a baseline, unless otherwise stated.

B1.3 High mountain permafrost is expected to undergo increasing thaw and degradation in the 21st century in response to rising air temperature (*high confidence*). Quantitative projections are scarce and often limited to individual sites or small areas in some mountain regions. {2.2.4}

B1.4 There is high confidence that the structure and functioning of terrestrial and freshwater mountain ecosystems will change. Key future shifts may include further upslope migration of lower elevation species and changes in the timing and amount of plant growth, shifts in the characteristic traits of many terrestrial and freshwater species and increased potential for disturbance (e.g., increased fire and landslides) that could lead to loss or restriction in the range for high mountain taxa due to the changing cryosphere. Species extinctions may be slowed in terrestrial ecosystems by microclimate refugia (medium confidence) and accelerated in freshwater ecosystems due to greater variability in water resources (high confidence). Wide-ranging effects on large animals are projected to lead to population declines and smaller ranges (high confidence). {2.3.3; 2.3.5}

B1.5 Changes in the high-mountain cryosphere are likely to increase freshwater-related risks in some regions with high dependency on snow or glacier melt runoff by the end of the 21st century (medium confidence). However, projected effects of the changes in magnitude and seasonality of runoff on hydropower, irrigation and drinking water are subject to widespread regional variation. Current capacities to explicitly account for glacier changes especially in large-scale hydrological models are limited, thus increasing uncertainty in decision making and in taking adaptation measures {2.3.1}

B1.6 Agriculture, hydropower and tourism activities related to the mountain cryosphere are projected to undergo major changes in the 21st century as a result of cryospheric change (*high confidence*); however these changes may also be driven by potential changes in, *inter alia*, socio-economic, technological, policy, institutional and legal aspects on access, mobility and governance of resources. Existing local adaptation measures (e.g., extension of irrigation systems; current snowmaking technologies) are projected to approach their limits around 2°C of global warming above pre-industrial. Moreover, vulnerabilities of mountain societies are projected to increase because of limits to their adaptive capacity (*medium confidence*). {2.3.1; 2.3.4; 2.3.5}

B1.7 Human habitability in mountain regions relies on multiple and diverse means to secure basic needs and sustain livelihood options, which are increasingly challenged by climate-related cryosphere change. Recognition and integration of Indigenous knowledge and local knowledge with scientific knowledge promotes resilience and adaptation in a changing climate and cryosphere environment. There are limits to the adaptation capacity of socio-economic sectors under the influence of cryospheric change along with climate change (*medium confidence*). Integrated (cross-sectoral) governance approaches hold potential in promoting socio-economic sectors' resilience and transformation, yet evidence on how these materialise to address cryosphere change in high mountain contexts remains low. {2.3.6}

B2 The oceanic and cryospheric environments of both the Arctic and Antarctica are projected to change during the course of this century. Climate change will affect ecosystems and biodiversity, with implications for internationally important fisheries and food security[6]. Polar ocean regions are changing more rapidly than the global ocean as a whole, with consequences for climate regulation and ecosystem services (*high confidence*). Warming will drive further loss of glacial ice in both polar regions, with implications for global sea level rise. {3.2.3; 3.3.1; 3.3.2; 3.4.1; 3.4.2; 3.4.3; Cross-Chapter Box 6 in Chapter 3}

B2.1 Major changes in the Arctic are projected to continue and accelerate in the coming decades. The decline in glaciers, snow, freshwater ice, sea ice, permafrost as well as ocean warming are affecting and will continue to affect hydrology, marine and terrestrial ecosystems, transportation and water and food security for Arctic people. While the retreat of Arctic sea ice provides opportunities for tourism and marine transportation, the expansion of shipping activities in a region where international regulation is limited can also cause risks for the polar environment and coastal communities, if regulation is not established. Climatic change in exposed regions of Antarctica and the Southern Ocean also opens possibilities for increased

[6] See also B3.9

commercial activity such as tourism, though heightened risk of environmental damage emphasises the role of effective, long-term regulation. {3.2; 3.3; 3.4; 3.5}

B2.2 Climate-induced changes in the polar oceans and cryosphere are altering marine primary production, with impacts on marine food webs and ecosystems (*high confidence)*. In the Arctic, changes in the timing, duration and intensity of primary production are affecting secondary production, with consequences for species composition, spatial distribution, abundance of higher trophic levels (zooplankton, fish, crustaceans and top predators), and impacts on ecosystem structure and biodiversity. In the Antarctic, primary production is projected to increase in regions near to the Antarctic continent, but the implications for higher trophic levels and for carbon export are not yet determined. {3.2.1; 3.2.3; 3.2.4; 3.3.3}

B2.3 Climate-driven shifts in the ranges and abundance of ecologically important marine species are occurring and are projected to continue (*high confidence*). Some of these species have global commercial and conservation value. Projected range expansion of sub-Arctic marine species will increase competition pressure for high-Arctic species (*medium confidence*), with regionally-variable impacts dependent on physical and ecological conditions, and regional benefits for fisheries (*high confidence*). On Arctic land, projections indicate a loss of globally unique biodiversity due to changes in terrestrial cryosphere as some high-Arctic species will be outcompeted by more southerly species and very limited refugia exist (*medium confidence).* {3.2.3; Box 3.3}

B2.4 Climate-related reductions in snow and freshwater ice and permafrost thaw and degradation continue to affect hydrology, disturbance regimes and vegetation, thereby decreasing water and food security for Arctic peoples (*high confidence)*. These changes influence peoples' access to hunting, fishing, foraging and gathering areas; they may alter food abundance and availability and affect the abundance and distribution of culturally and economically important species such as reindeer (*high confidence*), impacting health and cultural identity of Arctic peoples. Freshwater ecosystems, including fish for harvest, are impacted by changes in surface water conditions and lake ice regimes. There are limits to the success of adaptation measures, possibly constraining benefits from new opportunities for subsistence activities arising from ecosystem change. {3.4.1; 3.4.2; 3.4.3; 3.5.3}

B2.5 Warming will result in continued loss of Arctic sea ice and terrestrial snow, changes to permafrost, and reductions in the mass of glaciers. The current trend of permafrost temperatures reaching record high levels (*high confidence*) is projected to continue, with consequences for the global climate system due to the release of carbon dioxide and methane from the microbial breakdown of organic carbon in soils. The expected magnitude of these changes differs depending on future greenhouse gas emissions and mitigation measures (*high confidence*). {3.3.1; 3.3.2; 3.4}

B2.6 Evidence suggests substantial loss of permafrost carbon to the atmosphere by 2100 and beyond under RCP8.5, while scenarios limiting anthropogenic carbon emissions (e.g., RCP4.5) will result in lower losses (*high confidence*). There is *low confidence* concerning the level to which increased plant growth will compensate for these losses. Permafrost change will continue to impact infrastructure in urban and rural areas as well as distributed infrastructure for resource extraction and transportation (*high confidence*). 70% of Arctic circumpolar infrastructure is located in areas where permafrost is projected to thaw by 2050 under RCP4.5 (*high confidence*). Basing infrastructure design requirements and codes on past environmental records increases risk in a changing climate.{3.4.1; 3.4.2; 3.4.3}

B2.7 Limited knowledge, financial resources, human capital and organisational capacity continue to constrain adaptation in many human sectors of polar regions (*high confidence*). Harvesters of renewable natural resources are adjusting timing of activities to changes in seasonality and less safe ice travel conditions, municipalities and industry are addressing infrastructure failures associated with flooding and thawing permafrost, and coastal communities and cooperating agencies are now planning for relocation. In spite of these adaptations, many groups are making decisions without adequate knowledge to forecast near- and long-term conditions, and without the funding, skills and organizational support to engage fully in planning processes (*high confidence*). {3.5.3; 3.5.5; Cross-Chapter Box 7 on Low-lying Islands and Coasts}

B3 Ocean ecosystems are affected by ocean warming, acidification, and deoxygenation, which alter the distribution and availability of marine biological resources and consequently impact human communities that directly depend on the ocean. Impacts include reduced economic and food security and reduced viability of traditional livelihoods and cultures, as well as increased health risks from diseases and contaminants. {3.2.1; 5.4.1; 5.4.2}

B3.1 The overall warming of the ocean will continue this century even if radiative forcing stabilizes (e.g., RCP2.6, *high confidence*). By 2100 under the RCP2.6 and 8.5 scenarios, the ocean is *likely* to take up about 3 and 6 times, respectively, the roughly 500×10^{21} J that the ocean has already taken up since the start of the 20th century. {5.2.2}

B3.2 It is *very likely* that stratification in the upper few hundred meters of the ocean will increase significantly in the 21st century. This trend reduces surface exchange with the deep ocean, reducing heat and carbon uptake, as well as re-oxygenation of the ocean, affecting nutrient cycles. {5.2.2}

B3.3 Over the next century oxygen declines of 3.5% by 2100 are predicted globally (*medium confidence*), with *low confidence* at regional scales, especially in the tropics. The largest changes in the deep sea will occur after 2100. Where oxygen is already low, even very small declines in oxygen availability can lead to decreases in biodiversity, nutrient cycling, and ecosystem productivity. It is *virtually certain* that emissions will be the most important control of open ocean surface pH relative to internal variability for most of the 21st century at both global and local scale. Changes to the deep ocean are more complex as they are controlled by parallel changes to ocean circulation. {5.2.2; Cross-Chapter Box 5 in Chapter 3; 5.2.3; Box 5.1}

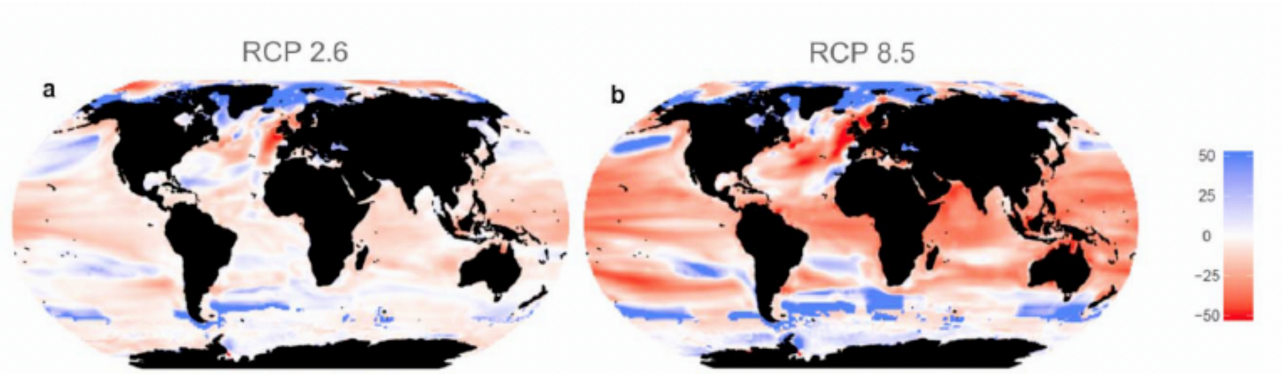
B3.4 Climate-induced changes in the oceans and cryosphere are altering marine primary production, with impacts on marine food webs and pelagic and seafloor ecosystems (*high confidence)*. There is *high confidence* that future changes to ocean primary productivity will be driven by region specific changes in magnitude and ratio of nutrient supply. In general, models project a small decrease in global organic matter production (*medium confidence*) with increases at high-latitudes (*low confidence*) and decreases at low-latitudes (*medium confidence*) in response to changes in ocean nutrient supply (see also B2.2). {3.2.1; 3.2.2; 3.2.3; 3.2.4; 3.3.3; 5.2.2}

B3.5 Changes in biodiversity patterns and community structure are projected to continue in the 21st century (*high confidence*), with potential global biomass of marine animals projected to decrease by 4.8 ± 3.6% (standard deviation) and 17.2 ± 11.1% under RCP2.6 and 8.5, respectively, by 2090–2099 relative to 1990–1999 (*likely*). Climate projections also indicate loss of Antarctic seafloor biodiversity (*medium confidence*). Scope for adaptation for many organisms to cope with novel environmental conditions is limited (*medium confidence*), particularly those higher up in the ocean food web and for high carbon emission scenarios (RCP8.5). {3.2.3; Box 3.3; 5.2.2; 5.2.3; 5.3.3; Box 5.1}

B3.6 Almost all major coral reef systems (shallow and deep) are vulnerable to climate change with clear regional differences in their sensitivities and projected overall losses reaching more than 70% even under RCP2.6 (*high confidence*). Ocean warming, acidification, rising sea level and intensifying storms impede reef resilience on a global level and augment reef destruction (*high confidence*). Shallow coral reefs that are not degraded by other impacts such as extensive bottom trawling and nutrient enrichment could constitute an important refuge to reefs degraded by climate change. Loss of deep-water coral reef habitat is *virtually certain* under projected ocean acidification through dissolution and intensified bio-erosion of the non-living matrix. {5.3.3; 6.4.2}

B3.7 Benthic communities in deep-sea habitats will experience structural and functional changes that affect the carbon cycle this century under all emission scenarios (*medium confidence*). This is suggested by the strong positive relationship between annual Particulate Organic Carbon (POC) flux and oxygen consumption of abyssal sediment communities combined with projected changes in biomass. Much of the abyssal seafloor is expected to experience declines in food supply that will diminish benthic biomass, change community structure and rates of carbon burial (*medium confidence*). The majority (82%) of the mapped seamounts are predicted to experience reduced POC flux under RCP8.5 in 2100, resulting in declines in benthic biomass (*medium confidence*). {5.2.4}

B3.8 Across the globe, seafood provision from some fisheries and aquaculture will be impacted by climate change (*high confidence*), reducing their revenues and influencing the livelihood of the dependent communities and food security of vulnerable people (*medium confidence*). Fisheries catches and their composition are already affected by warming, deoxygenation and changes in primary production on growth, reproduction and survival of fish stocks (*high confidence*). Changes in these ocean conditions in the 21st century are projected by multiple models to cause decrease in global fisheries catches with increasing dominance of warmer water species under increasing CO_2 emission (*medium confidence*), although the changes in realized catch will depend strongly on fishing intensity. Consequently, people who depend on fisheries and related sectors will experience substantial decline in their income, livelihood and availability of animal-sourced nutrients (*medium confidence*). Marine aquaculture is at risk under increasing carbon emissions. Shellfish aquaculture is sensitive to ocean acidification (*high confidence*). Farmed species will be exposed to increased risk of disease and harmful algal blooms, with adverse economic and social implications. {3.2.4; 3.5.3; 3.5.4; 5.4.1; 5.4.2, Figure SPM.3}



SPM.3 Projected changes in biomass of fishes and invertebrates (except zooplanktons) based on outputs from the Fisheries and Marine Ecosystem Impact Models Intercomparison Project (FISH-MIP). {5.2.3, Figure 5.10} [PLACEHOLDER: FIGURE ON PROJECTION RE OPEN OCEAN ECOSYSTEMS AND SERVICES, e.g. FISHERIES, RISK ASSESSMENT]

B3.9 Climate impacts on fisheries are projected to be largest in tropical and polar systems. The projected decrease in catch in the tropical ocean is *very likely* to be among the largest regional declines. The cascading effects of climate-induced stressors on polar marine ecosystems will have impacts on fisheries, e.g., projections indicate further habitat contraction for Antarctic krill, a keystone species in Southern Ocean food webs that is the focus of an international fishery (*medium confidence*). Future risks for linked human systems depend on the level of mitigation and especially the responsiveness of precautionary management approaches (*medium confidence*). Impacts on fisheries and aquaculture in tropical and polar regions will have measurable economic and social implications for regional renewable resource economies, cultures and the global supply of fish and shellfish. Specific impacts will depend on the level of global warming and on the strategies employed to manage the effects on stocks and ecosystems. Some current management strategies may not sustain viable commercial fisheries under higher emission scenarios. This exemplifies the limits to the ability of existing natural resource management frameworks to address ecosystem change. {3.2.4; 3.5.3; 3.5.4; 5.4.1; 5.4.2, SPM.3}

B3.10 Climate change impacts on the ocean are expected to substantially increase the risks for human health and from conflicts within and between political entities in the 21st century (*medium confidence*). Elevated risks of water-borne disease, food poisoning and pollutant contamination for human health are directly related to climate change through increased prevalence of pathogens and harmful algal blooms and increased contaminant bioaccumulation under warming and high CO_2 conditions (*high confidence*). The projected declines in fish supply and key fish micronutrients threaten food security for coastal communities that are strongly dependent on seafood, such as coastal indigenous people and communities in many tropical countries. Redistribution of fish stocks under climate change increases the risk of dispute between countries or regions (*high confidence*) while reduced food security and livelihood of socially marginalized human populations exacerbates inequality and social unrest (*medium confidence*). {5.4.2; Box 5.3}

B3.11 Assuming ambitious carbon emission reduction, management of non-climatic human stressors affecting ocean ecosystems and improving the resilience and resistance of built infrastructure offers cost-effective opportunities for climate risk reduction (*high confidence*). Managing non-climatic human drivers such as overfishing, habitat degradation, pollution, demographic changes and poverty can substantially reduce vulnerability thus reducing climate-induced risk for ocean ecosystems and dependent human communities with large co-benefits for sustainable development (*high confidence*). Infrastructure adaptation is optimised by integrating built and natural infrastructure and ecosystem-based approaches (*high confidence*). The effectiveness of adaptation approaches becomes low under high greenhouse gas emission scenarios (*high confidence*). {5.5.2}

B4 Global mean sea level will continue to rise over centuries to millennia under all emissions scenarios. Sea level rise will accelerate further under high emissions (e.g., RCP8.5). These changes are projected to result in disruptive direct and indirect impacts on coastal ecosystems, and associated livelihoods and infrastructure (e.g., in towns and cities) that tens of millions of people in the low elevation coastal zone (elevation <10 m) depend upon, with consequences for all humankind, e.g., through displacement. Despite continuation of sea level rise, adaptation choices can substantially reduce the magnitude of impacts in coming decades (*high confidence*). {4.2.2, 4.4.5}

B4.1 Different modelling studies demonstrate that under high emissions scenarios, Antarctica will *likely* contribute several tens of centimetres of sea level rise by the end of the century (*medium confidence*). Including these new estimates of the Antarctic contribution, projections of global mean sea level rise (SLR) under RCP2.6 result in 0.39 m (0.26–0.52 m, *likely* range) for the period 2081–2100, and 0.42 m (0.28–0.57 m) in 2100, relative to the 1986–2005 baseline period. Projections of global mean SLR under RCP4.5 results in 0.48 m (0.34–0.63 m, *likely* range) for the period 2081–2100, and 0.55 m (0.39–0.71 m) in 2100. Projections of global mean SLR under RCP8.5 results in 0.78 m (0.47–1.09 m, *likely* range) for the period 2081–2100, and 0.97 m (0.55–1.40 m) in 2100. The rate of SLR is estimated to be 19 mm yr^{-1} under RCP8.5 in 2100. The magnitude, rate and range for RCP8.5 are higher than AR5 Assessments. {4.2.3, Table 4.2, Table 4.3, Figure 4.7}

B4.2 Sea level rise (SLR) at the end of the 21st century will be strongly dependent on the global emission scenario followed, particularly as a result of Antarctica's contribution increasing towards RCP8.5 (*high confidence*). Greenhouse gas mitigation envisioned in low-emission scenarios (e.g., RCP2.6) sharply reduces but does not eliminate risk to low-lying coastlines and islands from SLR and extreme sea levels (ESL). Lower emission scenarios lead to slower rates of SLR resulting in a wider range of adaptation options. For the first half of the 21st century differences among the scenarios are small. Few individual ESL events or regional-to-local mean sea level changes have as yet been attributed to climate change. {4.2.1, 4.2.2}.

B4.3 Quantitative estimates of sea level rise beyond 2100 are deeply uncertain because ice sheet models lack realistic representations of some of the underlying physical processes. Insufficient understanding of processes controlling future ice-shelf collapse and possible threshold behaviour in the Antarctic ice sheet make the probability and timing of sea level rise exceeding 1.4 m deeply uncertain. RCP8.5 leads to a much higher Antarctic contribution than lower emission pathways. The few studies available addressing century to millennial timescales indicate multi-metre rise in sea level (*medium confidence*). {Cross-Chapter Box 3 in Chapter 1, 4.2.3, 4.2.4}

B4.4 Subsidence is an important contributor to future regional and local changes in relative sea level (RSL) (*high confidence*). Subsidence caused by human activities is currently the most important cause of RSL change in many delta regions. In some regions, however, changes in wave height and period currently have a larger effect on coastal flooding than RSL change (*medium confidence*). While the comparative importance of climate-driven RSL rise will increase over time, these findings on subsidence and waves imply that a consideration of local processes is critical for projections of sea level impacts at local scales {4.2.1, 4.2.2}.

B4.5 There is increasing evidence of changes at the coast with respect to ecosystems, ecosystem services, coastal infrastructure, habitability, community livelihoods, and cultural and aesthetic values. Attribution of regional-to-local sea level rise (SLR) or individual extreme sea level events to greenhouse gas emissions, or of coastal impacts to SLR remains difficult due to the influence of non-climatic drivers and local processes unrelated to SLR (*medium confidence*). Non-climatic anthropogenic drivers, including settlement trends, habitat losses and degradation from coastal development and pollution, have played a dominant role in increasing coastal communities' and ecosystems' exposure and vulnerability to SLR and extreme sea levels (ESL) events, and will continue to have a significant impact in the future (*high confidence*). This suggests that risk reduction and resilience-building can be undertaken in the short- to medium-term by targeting local drivers of exposure and vulnerability (including drivers of coastal poverty and inequity). {4.3.1, 4.3.2, 5.3.2}

B5 Coastal communities are implementing a variety of protect, accommodate, advance and retreat measures in response to diverse coastal risks, many of which are compounded by sea level rise. The selection and sequencing of these measures can have important synergistic, complementary or antagonistic consequences. Community-based adaptation is more effective when included in development efforts that reduce vulnerability and exposure to climate change impacts (*high confidence*). {4.4.5, 5.4.2, 5.5.2, Figure SPM.4}

B5.1 The continuum of coastal adaptation options ranges from hard engineering to ecosystem-based measures and from 'holding-the-line' to relocation of people, assets and activities. The combinations of measures will vary across geographies, depending on the scale of observed and projected impacts, societies' adaptive capacity and the nature of governance arrangements and choices made by coastal communities (*high confidence*) For example, a seawall in combination with raised buildings may protect a coastal community, and accommodate impacts arising from sea level rise (SLR) and extreme sea level (ESL) events in the short-term, while longer term strategies are initiated to enable managed retreat. However, a seawall could exacerbate coastal erosion along an adjacent shoreline thereby increasing exposure to hazard impacts and SLR risk. {4.4.3, 4.4.4, 5.5.2, 6.8, 6.9, Cross-Chapter Box 2 in Chapter 1, Cross-Chapter Box 7 on Low-lying Islands and Coasts, Figure SPM.4}

B5.2 Highly populated but less intensively developed low elevation coastal zones (e.g., some small islands, populated deltas and rural coasts) and those with very climate-sensitive environments (e.g., atoll reef islands, Arctic) and high dependence on services provided by these ecosystems for community well-being and development (e.g., fisheries, tourism), are extremely exposed and vulnerable to climate change and sea level rise (SLR). It is *very likely* that climate change-related disruptive impacts will become progressively worse over time. Adaptation in the short- to medium-term in these localities and regions will critically depend on the feasibility and affordability of protection (e.g., with hard engineering structures like seawalls, sediment-based options like beach nourishment and ecosystem-based approaches that harness the protective function of ecological features) and / or accommodation (e.g., by raising the floor level of buildings or by strengthening emergency management provisions); retreat (e.g., by planned relocation, migration or displacement); and advancement (e.g., by building upwards and outwards to reclaim land from the sea) measures. Intensively developed and densely populated coastal cities, including megacities, face escalating and cascading SLR risks. However, the feasibility and affordability of hard protection, and in some cases advance measures, in such localities makes it possible to manage these risks in coming decades (*medium confidence*). It is generally more effective if built-infrastructure adaptation is accompanied with nature-based and socio-institutional adaptation. {4.3.3, 4.3.4, 5.5.2, Cross-Chapter Box 7 on Low-lying Islands and Coasts}

B5.3 A *likely* impact of sea level rise (SLR) will be a diverging world, with richer and densely populated areas well protected behind seawalls and poorer less densely populated areas struggling to cope with SLR impacts and eventually retreating from the coast. Residual risk remains regardless of protection intervention. Accommodation measures, such as warning systems can help to reduce some of the residual SLR risk. Advance measures reconfigure the coast and associated risk and can be used to finance protection interventions through, for example, income generated by newly created land. Retreat is the only measure that eliminates residual SLR risk locally. But SLR-driven displacement, migration and relocation can have both positive and negative impacts on those who retreat and on communities that receive them. {4.3.3, 4.4.3, 4.4.4}

B5.4 For densely populated coasts, protect, accommodate and advance measures can reduce risk in the short- to medium-term, and allow more time to make social choices with more clarity about the trajectory of global warming and sea level rise (SLR) (*high confidence*). Incremental interventions that have minimal adverse impacts on their own can, however, result in cumulative negative impacts, path-dependency, and maladaptation. Furthermore, a particular SLR response might be compelling at the city-scale, for example, but the distribution of associated costs and benefits may not be equitably shared and locality-specific impacts may compound the exposure and / or vulnerability of some groups. SLR risk is compounded by locating new development in low-lying localities exposed to severe coastal hazards. {4.4.3}

B5.5 Community-based adaptation involves local people directly in understanding and addressing the climate change risks they face. Such approaches are increasingly used by people living in low-lying coastal areas to adapt to climate change impacts, including sea level rise (SLR), especially in developing countries (*medium confidence*). Particular attention is focused on reducing local-level vulnerability and building resilience. However, unless extreme sea level (ESL) events have been experienced, or the prospect of SLR impacts is readily apparent, pressing immediate needs tend to dampen community efforts to take action to address uncertain SLR risk in the distant future. Moreover, in many settings, powerful interests prevail and vulnerable groups are marginalized in local planning and decision-making (*medium confidence*). Ad hoc community-based adaptation projects do not readily address the drivers of poverty, inequity and political marginalization, which shape vulnerability and SLR-related coastal risk. As a result, empirically-based literature suggests that community-based adaptation is more likely to be effective when it is an integral part of more general community development efforts (*medium confidence)*. {4.4.5}

B5.6 Implementing effective responses to escalating coastal risk in the face of sea level rise (SLR) is highly variable and context-specific, and remains elusive in many localities (*high confidence*). A key ingredient to reducing SLR risk and building resilience is creating meaningful opportunities for stakeholders from government, civil society, the private sector and the scientific community, to engage in an authentic process of deliberation and conflict resolution to address the complex interplay of socio-political, economic, environmental, technical, administrative and ethical trade-offs that are inherent in adapting to climate change at the coast (*medium confidence*). {4.4.5}

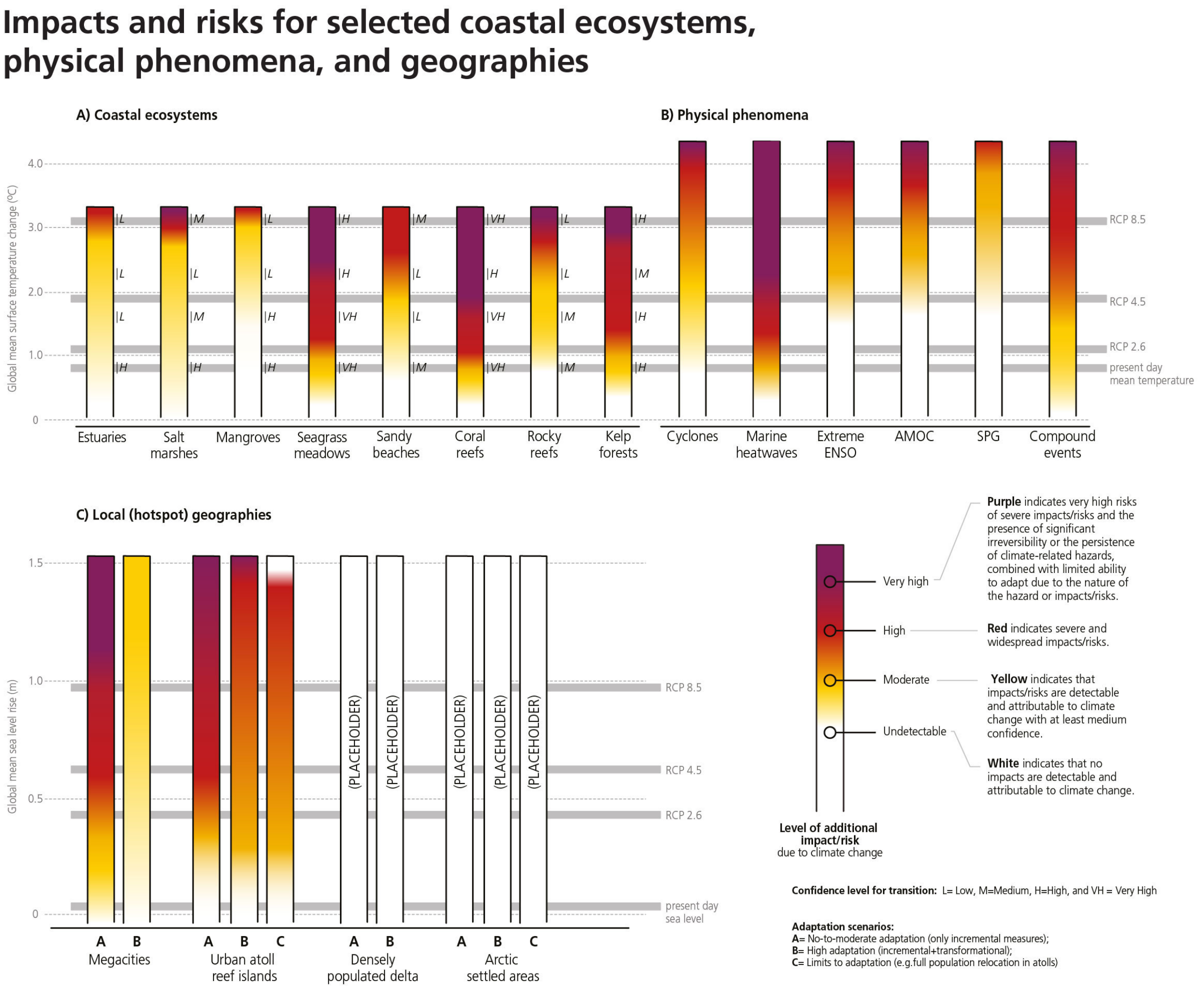


Figure SPM.4: Risk scenarios for selected components of the ocean and cryosphere are depicted here based on observed and projected impacts of ocean warming, acidification, and sea level rise. "Present day" corresponds to the 2000s, whereas impact levels are for the year 2100 under the different CO_2 emissions scenarios: RCP2.6 (stringent reduction scenario) and RCP8.5 (business-as-usual high emissions scenario). Impact levels for panels A and B do not consider human risk reduction strategies such as mitigation and societal adaptation. Panel C considers adaptation scenarios for distinct geographies. [Placeholder: the assessment will be refined for the Final Draft, as well an in-depth discussion of the results]. Panel C shows that risks from SLR are already detectable for all the geographies considered and that in the absence of ambitious adaptation, these risks are expected to significantly increase (bars (A) in Panel C) even in a RCP2.6 scenario. Under a ~+40cm rise in sea level (RCP2.6 mean by 2100), risk will be close to high for megacities and urban atolls, and close to very high in higher SLR scenarios. Under a ~+40 cm rise in sea level by the end of this century, risk will be close to high for megacities and urban atolls, and close to very high in higher SLR scenarios. This demonstrates some similarities in the challenges that urban low-lying coastal areas are facing, whatever their context-specificities or nature (island/continental, developed/developing county). The assessment also shows that in the case of ambitious adaptation efforts (bars (B)), coastal defences can play a decisive role in decreasing risks in coastal megacities. This conclusion must however be nuanced by the fact that our assessment does not consider either financial (e.g. long-term investments) nor social aspects that can act as limiting factors to the development of hard engineering coastal defences. In urban atolls, compared to megacities, ambitious adaptation efforts mixing adequate coastal defences and the restoration/enhancement of buffering ecosystems (e.g. coral reefs) are expected to have more modest benefits in terms of risk reduction. These benefits can still be considered as relatively substantial in a ~+100cm SLR scenario (RCP8.5 mean by 2100) compared to a ~+40cm scenario, as they allow risk to decrease from high-to-very-high to moderate-to-high (in (A) and (B) bars, respectively). These benefits however become negligible when approaching the upper range of RCP8.5, and risk returns to a very high level for urban atoll reef islands once the ~+140cm rise in sea level is reached. This context raises the issue of the limits to adaptation in urban atoll reef islands, i.e., the actual effectiveness of removing all the people from the island. This would result in the annihilation of *in situ* vulnerability, as shown with the white colour at the upper end of (C) bar in Panel B; although through the displacement of vulnerability (i.e., to destination areas) rather than its eradication. This highlights the risk of generating maladaptation elsewhere (i.e., transboundary risks) and, therefore, the limits to adaptation. {4.3.2, Figure 4.13, Cross-Chapter Box 7 on Low-lying Islands and Coasts}

B6 Extreme events which were historically rare such as heat waves, extreme wind speed and rainfall rates of the most intense tropical cyclones as well as extreme sea level events are projected to become increasingly common throughout this century in all scenarios. Increasing frequency of extreme events coupled with trends in ecosystem and human community vulnerability and exposure could trigger cascading impacts and compound risks. Climate change exacerbates extreme events and causes multiple hazards that often have a compound character because they are composed of sequences of individual events. (*medium confidence*) {6.4, 6.8}

B6.1 Marine Heatwaves (MHW) will *very likely* increase in frequency (*high confidence*), duration, spatial extent and intensity under future global warming, pushing marine organisms, fisheries and ecosystems beyond the limits of their resilience (*medium confidence*), especially those with reduced mobility such as coral reefs (*high confidence*). A one-in-hundred-day event at pre-industrial levels is projected to become a one-in-six-day event at 1.5°C global warming and a one-in-three-day event at 3.5°C global warming (*medium confidence*). The largest changes in the frequency of MHWs are projected for the Arctic Ocean and the western tropical Pacific (*medium confidence*). Forecasts of MHWs can help in reducing vulnerability. {6.4}

B6.2 In the future, tropical cyclones will *likely* be of slightly higher intensity globally and have higher rainfall rates (*medium confidence*). While some resilience plans exist to prepare for these storms, further development and implementation of such plans is required. Projections show that the proportion of Category 4 and 5 tropical cyclones will increase (*medium confidence*) although there is *low confidence* in future frequency changes for tropical cyclones collectively at the global scale. Rising sea levels will combine with higher storm surges associated with tropical cyclones resulting in higher extreme sea levels in the future (*high confidence*). The uncertainty surrounding the future characteristics of tropical cyclones in terms of track (e.g., poleward shift), intensity, or frequency creates difficulties for implementing early warning and evacuation procedures. Coordination problems among disaster response organizations also persist. Reductions in vulnerability to storm surges have been documented, and can continue to mitigate some future impacts. {6.3; Table 6.2; Figure 6.2, Figure SPM.5}

B6.3 Due to projected global mean sea level rise, extreme sea level events that are historically rare (e.g., those that, in the past, have been associated with surges from intense cyclones), will become common by 2100 under all RCPs, leading to severe flooding in the absence of comprehensive adaptation (*high confidence*). In RCP8.5, many small islands and megacities will experience such events annually by 2050. For many Pacific Islands and the West coast of the Americas, extreme sea level heights that historically occurred once per century will occur once per year by 2046–2065 and more than ten times per year by 2081–2100. {4.2.3, Figure 4.9, Figure 4.10, Figure SPM.6}

B6.4 Extreme events such as heat waves and storms, which are projected to intensify in the 21st century, are exacerbating the rate of ecosystem changes, such as those observed in kelp forests and seagrass meadows (*high confidence*). Herbivory intensified by warming will result in physical and physiological stress on coastal vegetation and reduce their productivity (*medium confidence*). Compounding effects of warming, deoxygenation, acidification and changes in nutrient supplies are projected to exacerbate the decrease in species richness and spatial heterogeneity in coastal ecosystems (*medium confidence*). {5.3.3}

B6.5 Extreme events are interacting with community vulnerability and exposure to trigger compound risk and cascading impacts (*high confidence*). Examples of recent compound events and cascading risks are heatwaves such as Tasmania's summer of 2015/2016; loss of 'Coral Triangle' biodiversity; and the damages of 2017 Atlantic Hurricane season and their ecological and societal influences (*high confidence*). The ratio between risk reduction investment and reduction of damages of extreme events varies. Investing in avoidance strategies (e.g., thorough land-use planning) and preparedness (e.g., warning systems) is *very likely* less than the cost of impacts of extreme events and post-disaster recovery (*medium confidence*). {6.8}

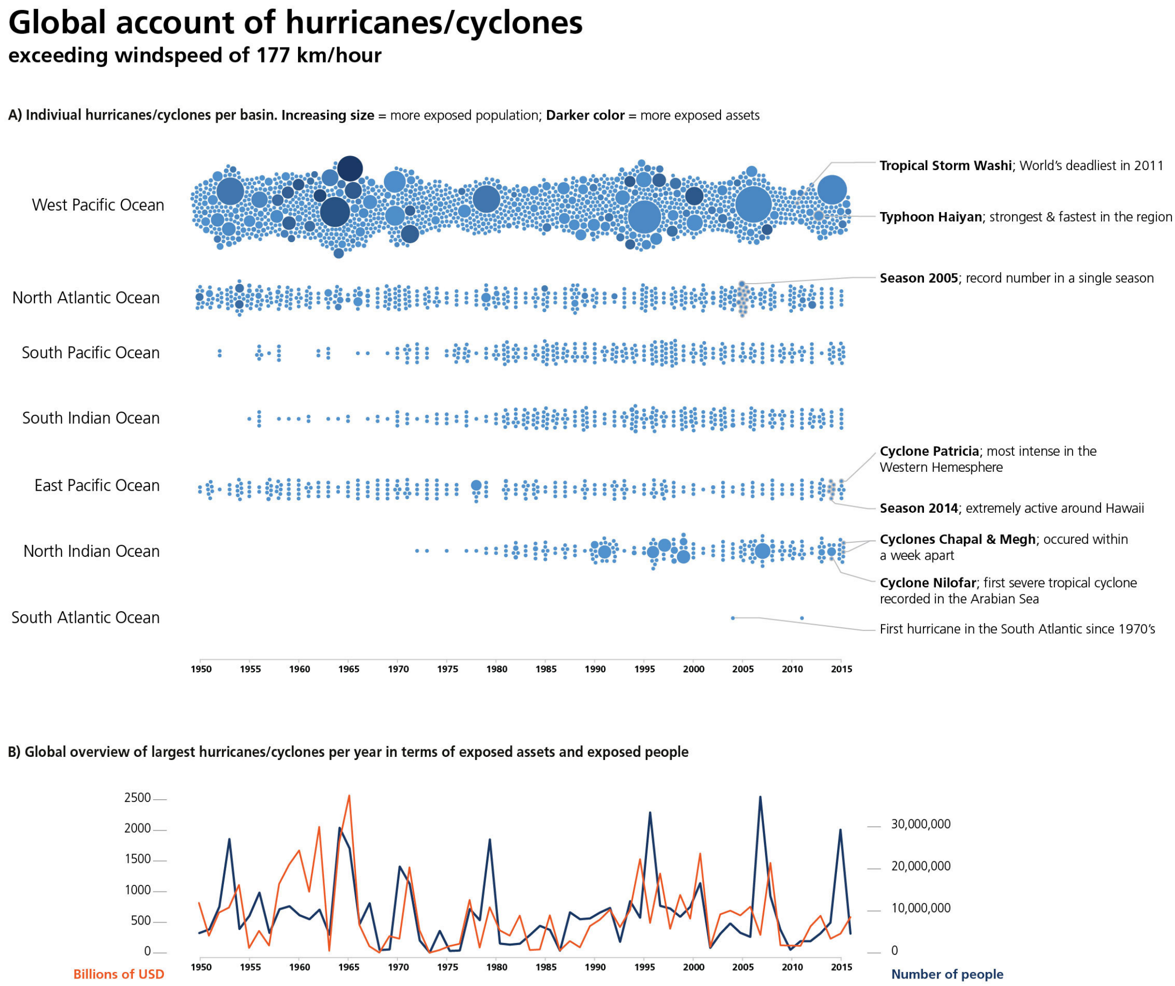


Figure SPM.5: Panel A illustrates the amount of tropical weather phenomena arising from the distinct world basins, from highest occurrence at the top (West Pacific Ocean), to least common at the bottom. The same data is aggregated along the same timeline in Panel B. Exposed population and assets by event were estimated using spatially-explicit data on population densities and Gross Domestic Product (GDP) per country affected by each event. Note the latitudinal expansion of regions impacted by high intensity storms.

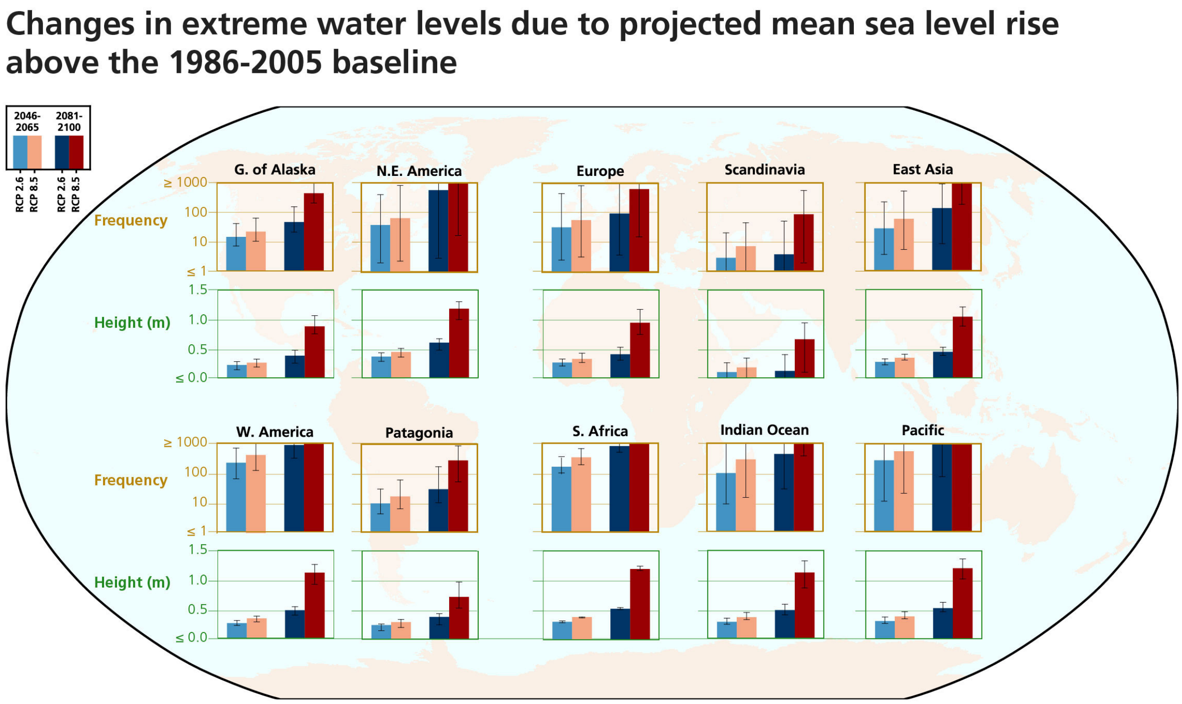


Figure SPM.6: Changes in extreme sea levels due to projected mean sea level rise above the 1986-2005 baseline. Frequency (gold) indicates the increased occurrence frequency of the historical 100-year event. For example, a frequency increase of 10 indicates that events which historically occurred once every 100 years are expected to occur once every 10 years in the future. Note that frequency increases are cut off at 1000, for which historical 100-year events are expected to occur at least 10 times each year and therefore will no longer classify as extreme events. Height (green) indicates the increased height of the 100-year event. Note that the increased height exceeds the mean sea level projection. Projected changes are displayed for ten regions, for two scenarios (RCP 2.6: blue, and RCP8.5: red), and for two periods (2046-2065: light colours, and 2081-2100: dark colours) relative to the 1986-2005 baseline. The bars indicate the median values within each region; the uncertainty bars indicate the 5th to 95th percentiles. {4.2.3.4}

B7 The Atlantic Meridional Overturning Circulation (AMOC) will *very likely* weaken over the 21st century under all Representative Concentration Pathways (RCP) scenarios. An abrupt transition or collapse of the AMOC during the 21st century is *very unlikely* but remains a physically plausible high-impact scenario. {6.7, Figure 6.8, Figure 6.9, Figure 6.10}

B7.1 A substantial weakening of the Atlantic Meridional Overturning Circulation (AMOC) would lead to wide spread impacts on surface climate, in turn affecting natural and human systems. Expected impacts include more winter storms in Europe; a reduction in Sahelian rainfall and associated millet and sorghum production; a decrease in the Asian summer monsoon; a decrease in the number of tropical cyclones in the Atlantic; and an increase in regional sea-level around the Atlantic especially along the northeast coast of North America (*medium confidence*). Such impacts would be superimposed on the global warming signal. {6.7, Figure 6.8, Figure 6.9, Figure 6.10}

B7.2 A new tipping element, the Subpolar Gyre System (SPG) in the North Atlantic, has been identified in some climate models (*medium confidence*). It involves an abrupt cooling of the North Atlantic SPG on a shorter, decadal time scale than the Atlantic Meridional Overturning Circulation (AMOC) decline, but with smaller potential climate impacts. These mainly oppose the general warming trend in the North Atlantic bordering region at the decadal time scale, but could also increase the frequency of extreme summer heatwaves in Europe and their impacts (*low confidence*). {6.7}

SPM.C DECISION-MAKING AND RISK MANAGEMENT UNDER UNCERTAINTY

C1. Adaptation pathways, including responses to sea level rise, have emerged as an important way to frame thinking about risk in a changing climate given this approach recognizes and enables sequenced long-term decision-making in the face of dynamic and deeply uncertain risk (*high confidence*). {4.4.5}

C1.1 Ocean and cryosphere-related mitigation and adaptation measures include options that address the causes of climate change, support organism and ecological adaptation and enable context-relevant societal and community adaptation. Limits to adaptation constrain the range of feasible adaptation pathways. {1.6}

C1.2 Human responses to climate change are in many cases reducing immediate risks with short-term adaptation focused on specific problems, but not necessarily building resilience to known future impacts and surprises. The current emphasis on short-term adaptation to specific problems is not sufficient to plan for long-term resilience given the scale, complexity and uncertainty of climate change and will ultimately not succeed in reducing the risks and vulnerabilities to society. Moving toward a dual short- and long-term focus will require transformation of many institutions, economies and values (*high confidence*). {3.5.1, 4.4.5}

C1.3 Despite deep uncertainty about long-term future mean and extreme sea levels, adaptation can proceed by applying decision-analytical methods in combination with participatory approaches, community visioning and consensus building. Decision-analytical methods range from consideration of high-level adaptation pathways, approaches that can be applied in diverse contexts, to technical and costly methods of robust and flexible decision making that can be applied to assess specific, large-scale investment decisions. Realising the potential of these techniques can be challenging to achieve in practice (*high confidence*). {3.5.1, 4.4.5}

C2. Ecosystem-based and hybrid (combinations of natural and built infrastructure) adaptation and, to some extent, mitigation solutions with multiple co-benefits are gaining traction worldwide and progress has been made to demonstrate their effectiveness, and quantify costs and benefits (*medium confidence*). {4.2.3, 5.5.2}

C2.1 The effectiveness of coastal ecosystem-based adaptation is supported by a growing body of literature and increased (international) funding for this approach. Adaptation through ecological engineering such as restoration of natural habitats can support biodiversity and enhances ecosystem services that could support for livelihoods, provide economic benefits and help build resilience in coast-dependent communities vulnerable to climate change (*high confidence*). Ecosystem-based approaches are more effective if harmonised with other adaptation approaches like community-based adaptation, and if adaptation planning is supported by good governance and effective implementation efforts (*high confidence*). {5.5.2.}

C2.2 Vegetation (marshes/mangroves, seagrasses/kelp) and reefs (coral/oyster and mussel beds) provide protection and risk reduction benefits to those living in nearby coastal locations (*medium confidence*). Ecosystem-based measures can provide substantial benefits but whilst the scale of economic benefits varies, multiple co-benefits such as coastal protection and biodiversity conservation, can be generated (*high confidence*). Due to their space requirements, ecosystem-based measures play a smaller role in densely populated urban areas. {4.4.2, 4.4.3, 4.4.4}

C2.3 Blue carbon ecosystems such as mangroves, salt marshes and seagrasses, can help provide a nature-based solution with multiple co-benefits. Some 151 countries around the world contain at least one of these coastal blue carbon ecosystems and 71 countries contain all three. Carbon storage, per unit area, in vegetated marine habitats can be much greater than for terrestrial habitats (*high confidence*). Successful implementation of measures to maintain and promote carbon storage in coastal ecosystems could significantly assist some countries in reaching national net zero emissions targets (*high confidence*). Conservation of these habitats would also sustain the wide range of ecosystem services they provide and assist with climate adaptation through improving critical habitats for biodiversity, enhancing local fisheries production and protecting coastal communities from sea level rise and extreme weather events (*high confidence*). The climate mitigation effectiveness of other natural carbon removal processes in coastal waters such as seaweed (blue carbon) ecosystems and proposed non-biological marine CO_2 removal methods are smaller or currently have low feasibility {5.5.1, 5.5.2}

C2.4 The maximum global mitigation benefits of cost-effective coastal wetland restoration is *unlikely* to be more than 2% of current total emissions from all sources. However, the protection and enhancement of coastal blue carbon can be considered as a ‘no regrets’ option, in addition to, rather than replacing, other mitigation measures. {5.5.1}

C2.5 The potential for climate mitigation by increasing biological productivity in the open ocean is limited since nearly all the extra carbon removed would be returned to the atmosphere on decadal timescales. Other human interventions to enhance marine carbon uptake e.g., ocean alkalinisation (enhanced weathering), would also have contested governance, with risk of undesirable non-climatic consequences {5.5.1}

C3. Integrating climate change adaptation and (disaster) risk management implies intensifying coordination among different government agencies from a local to global scale; capacity building and balancing trade-offs between short- and long-term gains as well as varying local goals. Innovative approaches to problem solving that support building resilience and sustainable development such as adaptive governance systems and observation systems that draw on a diversity of knowledge are better suited to meet the novel challenges of climate change (*medium confidence*). {3.5.3, 3.5.5}

C3.1 Indigenous knowledge and local knowledge are used by humans to observe and respond to change in, and to develop governance for, the ocean and cryosphere. Indigenous knowledge and local knowledge complement scientific knowledge in climate change assessments to provide comprehensive understandings that aid the development of effective, context-specific responses and policies {1.8.2, 1.8.3; Cross-Chapter Box 3 in Chapter 1}.

C3.2 Most mitigation and adaptation measures implemented at the local scale have co-benefits and few dis-benefits but are only efficient at the local scale. The greatest benefit is expected to be derived from the combination of global and local response options. Assessing, implementing and continually refining systems of governance that ready society for the projected trajectories, impacts and inevitable surprises of climate change require the attention (*medium confidence*). Observation systems that draw on a diversity of knowledge from multiple scales, participatory processes for analysis and decision making and adaptive governance are emerging innovations to meet these challenges (*high confidence*). {1.6, 2.3.6, 3.5.2, 3.5.5}

C3.3 The capacity of polar (Arctic) governance systems to respond to climate change has strengthened recently, but their development is not sufficiently rapid to address the challenges of ongoing and projected changes that pose large risks for societies (*high confidence*). Human responses to climate change in the polar regions occur in a fragmented, multilevel governance landscape that is challenged to address cascading risks and uncertainty in an integrated and precautionary way (*high confidence*). Simultaneously, climate change and new polar interests from outside the regions are driving stronger coordination and integration between different levels and sectors of governance. These responses modify the cooperation and balance of interests between states and international groups, with informal organisations playing an increasingly active role in shaping climate-change relevant regulations. {3.5.4}.

C3.4 Specific and integrated management measures such as large-scale early warning systems, or global monitoring and forecasting systems, can help to manage the risks of increasing extreme events and abrupt changes at different geographic scales. Place-based local risk management measures influenced by hazard experience, institutional structures and cultural values are constrained by available resources and social vulnerabilities. The evidence-base for the locations and size of economic and social impacts from extreme and abrupt changes is sparse, which hinders decision-makers from adequately assessing risks and developing adaptation options. Improvements in credibility, trust and reliability in institutions and scientific information on unexpected extremes and abrupt changes are crucial for countries to prepare for such uncertainties and enhance resilience (*medium confidence*). {6.9}

C3.5 Adjustment of legal tools and techniques of international conventions such as the United Nations Convention on the Law of the Sea (UNCLOS), could facilitate more effective responses to challenges created by climate change for the ocean. However, such adjustment is heavily dependent on further development, modification and implementation of detailed regulations e.g., fisheries management or marine spatial planning by relevant international, regional and national institutions. Climate risks can also be further reduced by shortening the lead time before implementation of these adjustments relative to the time of emergence of climate stressors and their impacts in the marine system (*medium confidence*). {Box 5.1, 5.5.4.}.

C3.6 Transformative governance and climate resilient development pathways require alternative political/legal/institutional frameworks and participatory stakeholder integration that addresses combined climate change mitigation and adaptation goals, and disaster risk reduction imperatives (*medium confidence*). {6.9}

C4. The global nature of challenges posed by climate-related changes in the ocean and cryosphere and their widespread impacts affect a range of socio-ecological and legal frameworks, governance structures, and institutions across borders and responsibilities. Climate Resilient Development Pathways combine efforts for climate change mitigation and adaptation and require profound societal transformations {1.5, Cross-Chapter Box 1 in Chapter 1}

C4.1 The societal context and prevailing governance arrangements and processes influence the nature and trajectory of social choices about the ocean and cryosphere in a changing climate (*high confidence*). Choices about how to respond to climate change impacts and risks, such as sea level rise (SLR), are made in the context of wider societal concerns about coastal habitability, livelihoods, risk, resilience and sustainability. The prevailing political economy shapes the direction of social choices and can perpetuate patterns of exposure and vulnerability to climate change impacts such as SLR. In the face of many competing urgent needs and concerns, many communities are reluctant to incur significant short-term costs to reduce exposure to deeply uncertain climate change impacts in the distant future. Adaptation planning is underway in many jurisdictions but translating such plans into effective sustained action remains challenging. {4.4.4.}

C4.2 Implementing Climate Resilient Development Pathways in the face of climate change impacts depends mainly on how well conflicting interests are resolved. For example, if greenhouse gas emissions continue along current trajectories, sea level rise (SLR) by the end of the 21st century will cause widespread, severe, and devastating climate change-related impacts on many people living on low-lying coasts and islands. Given adaptation limits and the unsustainability of prevailing development pathways, implementing transformative coastal adaptation responses will help to enable climate resilient development pathways as well as progress in achieving the Sustainable Development Goals (*medium confidence*). {4.4}

C4.3 International cooperation for governance of the ocean, coasts and cryosphere is critical in the face of existing and new climate change challenges. Ocean and cryosphere changes are interconnected across geographies that extend over a range of socio-ecological settings and associated legal frameworks, governance structures, and institutions. In addition to national- to global-level governance and institutional reform, effective local-adaptation is necessary for communities to respond to climate change. Adaptive and transformative governance designs and practices offer possibilities for addressing future ocean- and cryosphere-related changes by allowing governance actors and networks to learn from experience and to develop context-relevant governance arrangements that can be adjusted to address worsening climate change. {1.7; Cross-Chapter Box 2 in Chapter 1}.