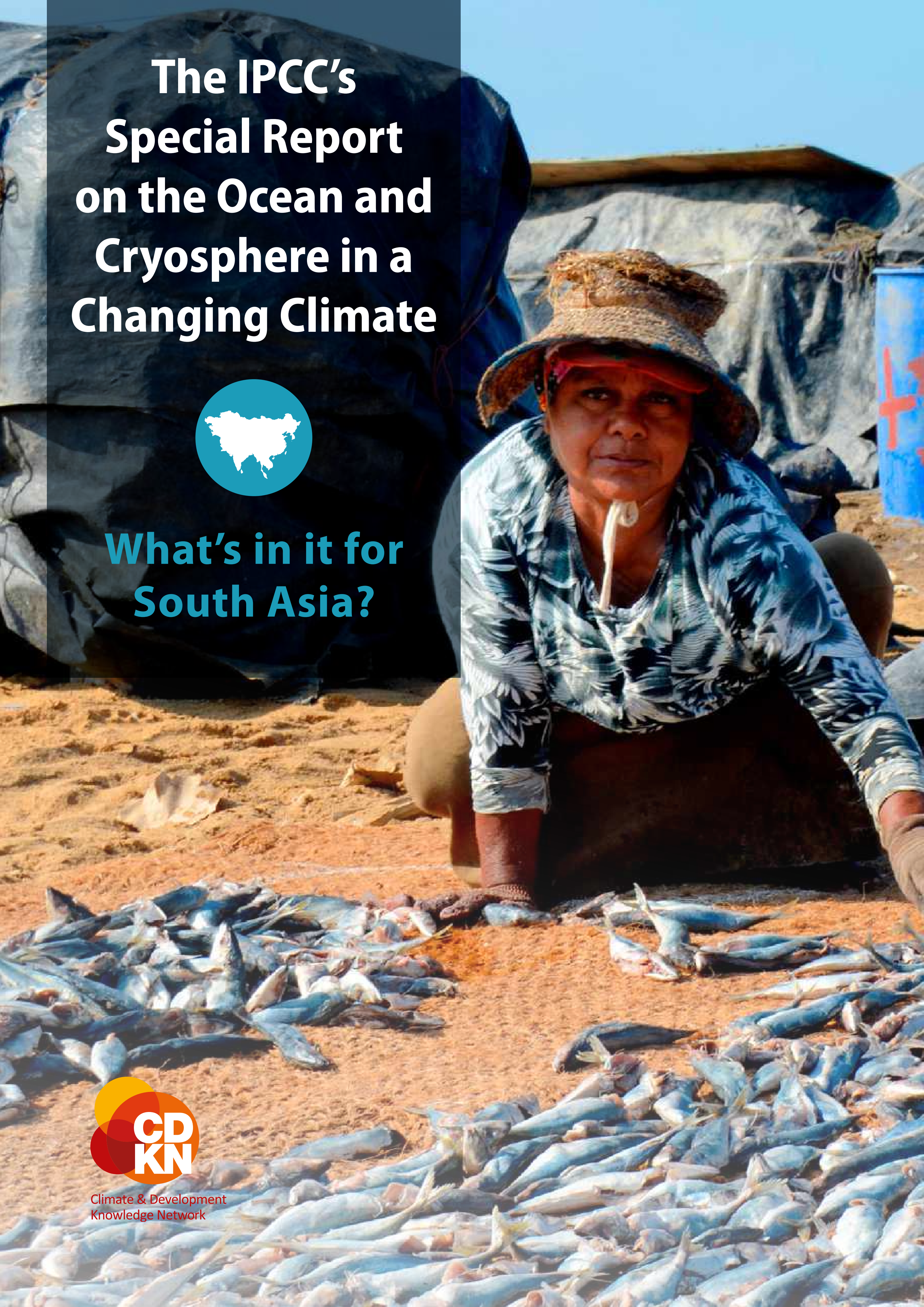
The IPCC's Special Report on the Ocean and Cryosphere in a Changing Climate

What's in it for South Asia?



CDKN
Climate & Development Knowledge Network

Image: © Shutterstock | Gokyo Lake, Nepal.

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Key messages

1. Climate change driven by human activity is changing the temperature and chemistry of the oceans
2. These changes harm marine life and people who depend on it
3. Sea level rise and other climate hazards increasingly affect South Asia
4. The frozen lands in high mountain Asia are changing, with implications for society
5. The best way to limit changes in the oceans and cryosphere is to mitigate climate change
6. Early action reduces climate risks and costs less than dealing with future damages
7. Future-proofing coastal development will be essential
8. Environmental governance and management must join up across scales and address social issues
9. Communications, education and capacity building are critical

CRYOSPHERE: The word 'cryosphere' – from the Greek kryos, meaning cold or ice – describes the frozen components of the Earth system, including snow, glaciers, ice sheets and ice shelves, icebergs and sea ice, ice on lakes and rivers as well as permafrost and seasonally frozen ground.[1]

About this report

The Intergovernmental Panel on Climate Change (IPCC) published its *Special Report on the Ocean and Cryosphere in a Changing Climate* in 2019 (www.ipcc.ch/srocc). The Special Report was a response to proposals from governments and observer organisations to the IPCC.

For its preparation, more than 100 scientists from more than 30 countries assessed "the latest scientific knowledge about the physical science basis and impacts of climate change on ocean, coastal, polar and mountain ecosystems, and the human communities that depend on them."[2] Communities' vulnerabilities and adaptation capacities and societies' options for achieving climate-resilient development pathways were also assessed. The Special Report's findings are of great importance to South Asia and the world.

This publication offers a guide to the IPCC's *Special Report on the Ocean and Cryosphere* prepared for decision-makers in South Asia by the Climate and Development Knowledge Network (CDKN), Overseas Development Institute (ODI), ICLEI–Local Governments for Sustainability South Asia, and SouthSouthNorth (SSN). This is not an official IPCC publication.

The IPCC's own *Summary for Policy Makers* focuses principally on global issues and trends. This report distils the richest material available on South Asia from the 700+ pages of the *Special Report*. In a few places, we have included supplementary material from recently published research that extends and explains the points made in the IPCC's *Special Report*. We have clearly labelled this supplementary material 'Beyond the IPCC'. This guide responds to widespread demand among CDKN's South Asia partner networks for region-specific information.

Please visit **www.cdkn.org/oceanreport** for slides, images and infographics you can use in association with this guide.

Contents

Image: © Shutterstock | Fishermen, Tamil Nadu, India.

1 Climate change driven by human activity is changing the temperature and chemistry of the oceans

Global warming is driving changes in the oceans today. Average global temperatures are already 1°C higher than in pre-industrial times and could reach between 1.6°C and 4.3°C by 2100 (under the scenarios used by the IPCC in this assessment). The outcome depends on how deeply global society cuts greenhouse gas emissions.[3]

A warmer ocean

The world's oceans are taking the heat from climate change. Until now, the oceans have taken up more than 90% of the excess heat in the climate system.[4]

Marine heatwaves have doubled in frequency since 1982 and are increasing in intensity. They are predicted to become longer, more frequent, more far-reaching and more intense.

A more acidic ocean

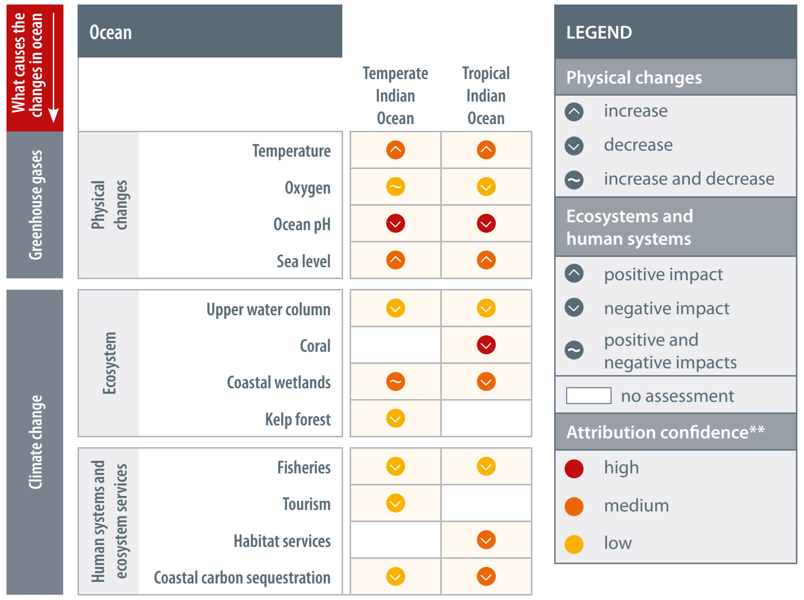
The ocean has taken up between 20% to 30% of human-induced carbon dioxide emissions since the 1980s. This is making the oceans more acidic. The oceans are expected to take up more carbon from the atmosphere between now and 2100. This will increase ocean acidification.

A less productive ocean

Warming has particularly affected the surface layer of the oceans. Now, there is less mixing among layers of ocean water. This means less exchange of oxygen and nutrients among layers, and in turn, less productive biological systems.

In the upper layer of the open ocean, the amount of dissolved oxygen in the water decreased between 1970 and 2010.[5]

Figure 1: How changes in the atmosphere and climate have affected the oceans[6]*



* The IPCC also assessed changes to sea ice extent, rocky shores, deep sea, polar benthos, sea-ice-associated ecosystems, transportation, shipping and cultural services, but not for the oceans shown here. See the IPCC's Summary for Policy Makers for more details.

** Attribution confidence means the degree of confidence that the changes can be attributed to human-driven climate change.

2 These changes harm marine life and people who depend on it

A warmer, more acidic ocean, with less oxygen and changes in available nutrients, is already affecting the distribution and abundance of marine life, in coastal areas, in the open ocean and on the sea floor.[7] The average temperature of the Earth's surface (land and ocean combined) is already 1ºC higher than in pre-industrial times (see Figure 2). Every additional degree of average global warming will affect coastal and ocean ecosystems, with profound implications for human societies and people's wellbeing.

Warming is destroying coral reefs and threatening other fragile ecosystems

Warming ocean waters and a more acidic ocean are destroying coral reefs, sea shells and other immobile species with calcium-based shells, such as mussels and barnacles.[8] Marine heat waves have caused massive coral bleaching events, where corals are killed by heat. It can take 15 years for coral reef ecosystems to recover, if they recover at all.[9]

It is expected that, even at global warming of 1.5ºC, the species composition and diversity of today's shallow coral reefs will change. Coral reefs' declining health will greatly reduce their contribution to human society, including to food, coastal protection and tourism industries.[10]

Seagrass meadows and kelp forests are also at very high risk, even at 1.5ºC of mean global warming; they, too, are highly sensitive to ocean warming and acidification.

Species are on the move

Marine species are on the move as a result of climate change. This means that in any one place, the abundance and mix of species is changing.

In turn, this means the interactions among different species (e.g. between predators and prey) is also changing. It is happening the world over, from the equator to the poles.[11] For example, warming and decreases in oxygen content are projected to affect fishes' growth, leading them to have smaller bodies (the greater the climate change, the greater the effect will be). An expected decrease in larger-bodied fishes in the oceans could reduce predation and so increase the dominance of smaller-bodied fishes in the epipelagic zone (the top 200 metres of ocean water). Furthermore, fish exposed to the ocean acidification levels expected under the highest global warming scenario have impaired sensory abilities and altered behaviour: they are less able to see, hear, and avoid predators.[12]

Fish stocks are and will be affected

The distribution of fish populations is shifting.[13] Fisheries catches have already been impacted by the effects of warming on the growth, reproduction and survival of fish stocks.[14] However, because there is not enough data available, it is not possible to make quantitative statements about links between the changes in regional fish stocks to date (e.g. changes in the Indian Ocean) and human-driven climate change.[15]

Ocean warming will also cause the biomass of marine animals to decrease across the world's oceans as a whole this century. The size of maximum potential fish catches in the decades ahead will decrease, although this will vary by region.[16] It is thought that *future* ocean warming will have a particularly strong impact, by decreasing the fish catches of tropical oceans (leading to three times greater decreases than the global average, under the highest warming scenario).

Overall, scientific models show that the greater greenhouse gas emissions and global warming are, the greater the impact on fish stocks and their distribution is likely to be.[17] However, it is difficult to predict catch sizes with much certainty as the management of fisheries will have such a great influence, too; a critical area that falls under governance matters. (See Section 9 of this volume.)

Changes in the ocean environment will have particular impacts on local communities that depend on fish stocks for their livelihoods and for their own food supplies.[18]

"Fisheries catches and their composition in many regions are already impacted by the effects of warming and changing primary production on [the] growth, reproduction and survival of fish stocks (high confidence)."[19]

Box 1: The IPCC's confidence levels

This matrix helps explain what the IPCC means by high, medium or low confidence.[20]

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

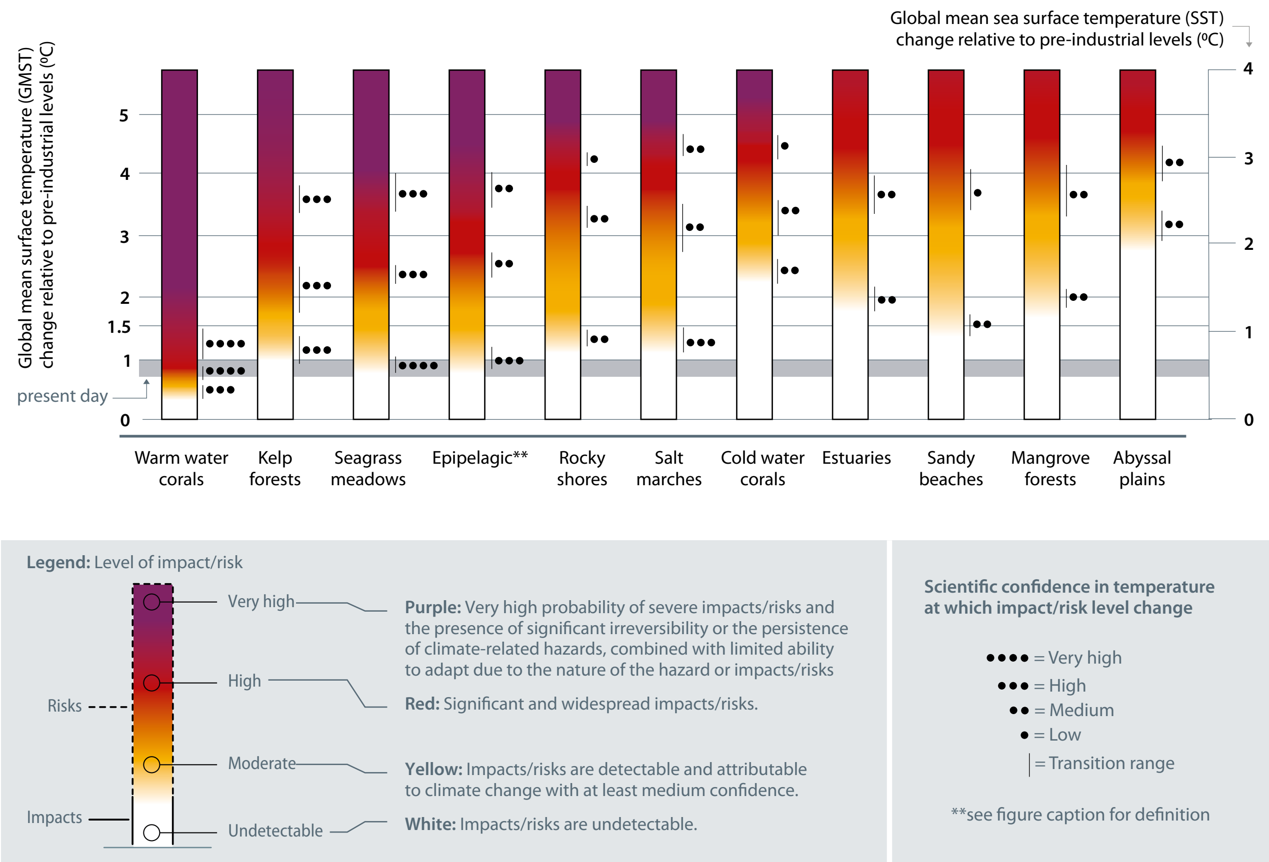
Low confidence denotes that the categorisation is basedon only a few studies. Medium confidence reflects medium evidence and agreement.[21] Confidence increases towards the top-right corner as suggested by the increasing strength of shading.

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

Evidence (type, amount, quality, consistency)

Confidence Scale: higher – lower

Figure 2: Every degree of global warming will harm coastal ecosystems further[22]



3 Sea level rise and other climate hazards increasingly affect South Asia

Sea levels are rising at a faster rate

Globally, sea level is now rising at a rate of 3.6 mm per year. That is more than twice as fast as it rose in the 20th century.[23] The acceleration in the rate of sea level rise in recent decades is a global phenomenon, driven by increasing rates of ice loss from the Greenland and Antarctic ice sheets.[24]

The continued melting of glaciers and thermal expansion of the oceans worldwide have also contributed, since water expands in volume as it warms. [25]

Sea levels continue to rise at an increasing rate. [26] Sea level rise could reach around 29-59 cm by 2100 even if greenhouse gas emissions are sharply reduced and global strongly warming is limited to well below 2°C. Sea levels will rise even more, by 61-110 cm on average worldwide, if greenhouse gas emissions continue to increase at current rates.

Sea level rise is creating a 'coastal squeeze' on important coastal ecosystems which are fertile and biologically productive and underpin the livelihoods of tens of millions of people in South Asia. These include mangrove forests, seagrasses, coastal wetlands, delta-based agriculture and dune ecosystems. Coastal squeeze describes what happens when the built environment (e.g. settlements and infrastructure) provide a hard barrier for ecosystems on one side, and rising seas provide a barrier on the other. See Figure 3 below.[27]

There will be more frequent extreme sea level events, too. These occur, for example, during high tides and intense storms.[28]

680 million people in low-lying coastal zones are now at risk from rising oceans, a figure which will reach a billion people by 2050.[29] Sea level rise could displace people. Some evidence of human displacement linked to sea level rise is discussed in Box 3, overleaf.

Figure 3: Rising seas and coastal development put a 'squeeze' on coastal ecosystems

"Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (high confidence)."[30]

Image: © Shutterstock | Cyclone Bulbul heading toward India and Bangladesh, 2019.

South Asian cities are at risk

Coastal cities, especially megacities with over 10 million inhabitants, are at serious risk from climate-related ocean and cryosphere changes. This includes such low-lying coastal megacities as Mumbai, India.[31]

Coastal megacities could be centres of transboundary risks because they serve as hubs for global trade and transportation. To their benefit, large cities are often centres of innovation, political attention and private sector investments, too. These factors could help to reduce climate risks. [32]

Small and mid-sized cities are considered highly vulnerable to the impacts of climate change because of their fast growth rates and low political, human and financial capacities for risk reduction compared to larger cities.[33]

Extreme weather events are becoming more frequent

Sea level rise is one of many climate-related hazards to affect the coasts of South Asia and other coasts worldwide. Extreme weather events such as cyclones, flooding and marine heatwaves all have an impact on coastal communities and will do in the future.

On average, tropical cyclones will become more intense, wetter, and more frequent (note that this applies to tropical areas, not globally) and they will be associated with higher extreme sea levels.[34]

El Niño and La Niña events are part of natural climate variability. The IPCC finds with 'medium confidence' that the strongest El Niño and La Niña events since pre-industrial times have occurred in the past 50 years.[35] What is more, extreme El Niño and La Niña events are likely to occur more often with global warming, even with relatively low levels of warming.[36]

Cascading impacts and compound risks in coastal areas

Extreme weather events are hazards that can create cascading impacts on people and the environment. When these are combined with non-climatic issues (such as social inequality or other aspects of unsustainable development), they can affect people's exposure and vulnerability and create compound risks.[37]

More generally, too, climate change (including slow-onset changes) adds pressure to the fragile ecosystems that have already been depleted by unsustainable development.

Coastal ecosystems such as sea grasses and mangroves are affected by ocean warming including acidification, loss of oxygen, salinity intrusion and sea level rise.

These climate-related hazards combine with unsustainable human activities such as polluting, reef and sand mining, habitat degradation and groundwater extraction to further degrade ecosystems and create negative local impacts.[38]

"Warming, sea level rise, and enhanced loads of nutrients and sediments in deltas have contributed to salinisation and deoxygenation in estuaries (high confidence)."[39]

The following are examples of how climate change impacts can combine with unsustainable development to harm people and the environment:

- Algal blooms are now increasing in estuaries worldwide, including in Asia. This is partly driven by direct environmental pollution, such as nutrient runoff from farms and pollution by factories. It is also compounded by climate change, because increased temperatures stimulate bacterial respiration.[40] People are most vulnerable to harmful algal blooms where there is poor monitoring and weak early warning systems.[41]
- In the oceans, warming and oxygen loss (driven by climate change) are changing the abundance and distribution of fish and other marine species. This compounds the problem of overfishing that already affects many fish stocks.
- Meanwhile, climate change increases the way that sea organisms bioaccumulate dangerous substances such as persistent organic pollutants and mercury. The risks of negative impacts are increasing, both for marine ecosystems and for people who eat a lot of seafood. Seafood is becoming less safe.[42]

Box 2: When does climate change play a role in disaster?[43]

The extreme event: Bangladesh (2017)

A pre-monsoon extreme 6-day rain event.

Attribution to human-made climate change:
Scientists looked at whether human-driven climate change made this extreme event more likely to occur than it would have otherwise. They found that the likelihood of this 2017 pre-monsoon extreme rainfall event was nearly doubled by human-driven climate change, although the finding is sensitive to the (historic) time period used for the analysis.

Impacts and costs:
The extreme rains triggered flash floods affecting 850,000 households and 220,000 hectares of harvestable crops, leading to a 30% rice price hike.

Image: © Shutterstock | Kutubdia, Bangladesh, affected by sea level rise.

Box 3: Climate change as one factor in human displacement and migration

Pressures on coastal environments

Marine flooding is already affecting deltas around South Asia and the world with impacts on communities.[44] Marine flooding can come about from a mixture of human factors, climate variability and the effects of climate change, including more frequent extreme weather events.

Human activity upstream, such as land-use changes and damming rivers, interferes with natural sediment flows into deltas. This causes subsidence in deltas and relative sea level rise. This is compounded by sea level rise, including storm surges, driven by climate change.[45]

Intrusion of sea water into coastal lands can have far-reaching effects. It can affect agriculture, making some crops no longer viable. Farmers have already stopped growing oilseed, sugarcane and jute in coastal Bangladesh, due to high salinity levels. Dry-season crops are predicted to decline over the next 15 to 45 years, especially in the southwest of the country.

Meanwhile, drinking water supplies and human health are also at risk. Increased salt levels in water are associated with more abundant, toxic cholera vibrio (*vibrio cholerae*) as shown by studies in the Ganges Delta.[46] In the coming years, 'significantly higher risks of human displacement' may be expected in low-income, low-lying islands and coasts as a result of multiple environmental changes such as these.[47]

Pressures on mountain environments

Meanwhile, migration from high mountain areas of South Asia, documented in the IPCC Special Report, is associated with changes in the cryosphere environment. One form of seasonal migration ('transhumance pastoralism') is an age-old practice whereby high mountain residents move with their livestock between winter and summer pastures. This practice is now declining for a range of reasons, including the melting of glaciers and snow. Herders say that poor winter snowfall is associated with poor pasture quality in Nepal, and less, lower-quality vegetation in Pakistan and Afghanistan.

Meanwhile, water sources along migration routes are depleted in Nepal, and increasingly large glacier lakes on the Tibetan plateau are flooding traditional pasture areas.[48] There are some benefits from warming, namely that seasonal migration to summer pastures now lasts longer in northern Pakistan and Afghanistan. [49]

People in the region who migrate to seek wage labour tend to be suffering from livelihood stress at home. Climate change impacts agricultural productivity, which affects livelihoods, which drives people to move for the short-term, the long-term, or permanently, and domestically or even internationally, in search of better lives.[50] Migrating away can have mixed outcomes: it can both increase and decrease people's vulnerability in different ways, depending on the circumstances.[51]

There is often an age element to it: in northern Pakistan, it is the young people who move away from the mountain communities to seek wage labour elsewhere. This has left less labour available to tend the fields, orchards and irrigation infrastructure – and so has reduced farming livelihoods overall.[52]

The IPCC concludes that there is increasing evidence that 'people are rarely moving exclusively due to changes in ocean- and cryosphere-based conditions, and that migration as a result of disasters and increasing hazards strongly interact with other drivers, especially economic and political motivations (high confidence).'[53]

However, cases are beginning to emerge of communities in the high mountain regions becoming permanently displaced and resettling completely because of changes in the cryosphere. In Nepal, several villages moved after springs dried up and decreasing snowfall reduced the flows of stream water they relied upon for agriculture and pastoralism.

"A review of migration in the Himalaya and Hindu Kush found that households that participated in labour migration and received remittances had improved adaptive capacity and lowered exposure to natural hazards."[54]

Beyond the IPCC: Women and men are differently affected by climate-related hazards: Decision-making processes should reflect this[55]

A major research project that investigated the effects of climate change and climate-related disasters in high mountain areas of Asia, HI-AWARE, found many differences in men's and women's ability to cope.

The frequency and intensity of extreme climate events have increased in Pakistan. Floods, droughts, glacier retreat, melt, erosion ('ablation'), glacial lake outburst floods, and extreme temperatures have been frequently observed in almost all parts of the country.

The effects of environmental change are felt disproportionately by the country's women. According to the World Economic Forum's (WEF) Global Gender Gap Report 2016, Pakistan ranks 143 out of 144 countries in the gender inequality index. Gender-responsive interventions are needed to break the cycle whereby climate change impacts are worsening gender inequality.

First, extreme climate events pose huge threats and risks to the life and health of women. The probability of an early death from fatal injuries, infections, and offences against women increases in the absence of adequate measures to adapt to floods, heat waves and droughts.

However, the probability of sickness, injury and death decreases by a significant percentage when the voices of women are heard, when they receive training on coping strategies, and when financial aid is spent on gender-sensitive activities.

Image: © World Bank | Pakistani women carry water.

Furthermore, poor governance and 'the culture of power with its patriarchal biases make women more prone to sexual offences in the Indus area,' say the HI-AWARE researchers. 'For example, in the floods of 2010, many women went missing and until today their families do not know where they are. The pain felt by the families of missing women is indescribable.'[56]

Rural women in Pakistan have little opportunity to develop capacities to adapt to crisis events. This is because they have limited access to material resources, information, education, extension services, finances, critical information on weather alerts, land rights and cropping patterns. These limitations undermine their capacities to take up structural and non-structural adaptive measures.

Moreover, women are involved in a seemingly overwhelming number of tasks already in their roles as productive economic workers and caregivers in the home. These multiple roles constrain their capacities to respond adequately to climate-related shocks.

Rural women subsist on productive assets such as cows, buffaloes, goats and chickens in most parts of Pakistan. Floods and droughts have a negative impact on livestock and agriculture; they destroy crops and kill livestock. For this reason, women are deciding to reduce the current consumption of their families, and sometimes take children out of school. This erodes their capacities for investment and shows evidence of people increasingly caught in poverty traps.

Image: © Asian Development Bank | Families navigate floods, Pakistan.

4 The frozen lands in Asia's high mountains are changing – with implications for society

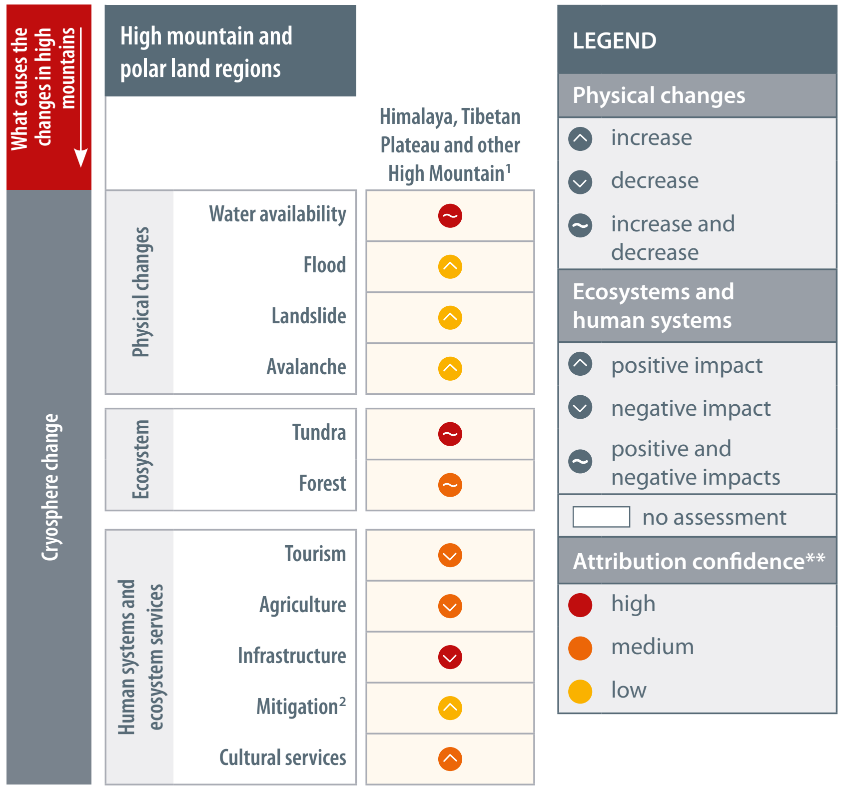
Frozen lands (the cryosphere) are melting as a result of climate change – with implications for South Asia's high mountain region.

River runoff is changing

Changes in the cryosphere have far-reaching local and regional impacts across river basins and watersheds. Changes underway in glacier-fed rivers cannot be reversed. Permafrost degradation and decline will also continue in the 21st century.[57]

As mountain glaciers retreat, the amount and timing of water runoff into rivers is changing. These changes in water flows could have implications for hydropower and agriculture in the high mountains of Asia.[58] The melting of glaciers and permafrost is expected to release heavy metals, especially mercury, which reduces the quality of water for freshwater organisms as well as for household and farming use.[59]

Figure 4: How changes in the atmosphere and the climate have affected the cryosphere[60]



1 Including Hindu Kush, Karakoram, Hengduan Shan, and Tien Shan.
2 Mitigation refers to an increase or decrease in net mitigation, not to beneficial/adverse value.
* The IPCC assessed changes in ground subsidence, lakes/ponds and rivers/streams but not for the mountain regions shown here. See the Summary for Policy Makers for more details.
** Attribution confidence means the degree of confidence that the changes can be attributed to human-driven climate change.

An environment and way of life is threatened

As ice and snow retreat, high mountain ecosystems change, too. Both plant and animal species are moving from lower altitudes to higher up the mountains, and in some cases will run out of habitat with a suitable climate in which to survive.[61]

The loss of ice and snow in high mountain regions changes the aesthetic and the cultural value of these areas to society, e.g. in the Himalayan region. There are also implications for tourism and recreation.

Hazards in high mountain areas are increasing

People and infrastructure are becoming more exposed to natural hazards such as landslides as a result of changes in the frozen, high mountain lands.[62] In the coming decades, the retreat of mountain glaciers is projected to make slopes less stable and the number of glacier lakes is projected to increase. There are expected to be glacial lake outburst floods, landslides and snow avalanches in new locations and different seasons.[63]

More people are exposed to climate-related hazards

Disasters happen when people and property are exposed to a natural hazard and when they are vulnerable to its effects. (See Figure 6, overleaf, to see how climate hazards such as rising temperatures, vulnerability and exposure intersect.)

More people and infrastructure have become exposed to changes in the frozen lands of high mountain Asia in the past few decades and have suffered losses and damages as a result. The trend is expected to continue into the future.[64] Sometimes, tourism has increased people's exposure by extending roads, trails and overnight lodging into remote valleys.

An example of increased exposure turning to disaster is the 2015 earthquake-triggered snow avalanche in Langtang, Nepal, in which 350 people died – a mix of foreign trekkers and local guides. Another example is the Kedarnath glacier flood disaster in Uttarakhand state, northern India in 2013, in which thousands of pilgrims lost their lives.

There are not enough robust studies on the vulnerability of mountain people to climate-related hazards: whether they are vulnerable, and what causes vulnerability. However, there is some evidence that mountain people's vulnerability could be weakened by:

- lack of weather and climate information to support either short-term early warning of major hazards, or longer-term climate change adaptations
- political and social marginalisation
- low incomes and limited options for diversifying livelihoods
- the remoteness of areas that limits accessibility by emergency first responders
- cultural and social ties to the land that influence people's movement.[65]

At the same time, some studies emphasise mountain people's high levels of resilience, based on their centuries of experience in dealing with hazardous and extreme conditions. More research is needed to understand how to limit the exposure and vulnerability of people living in and visiting high mountain area, as the climate and physical environment changes.[66]

Landslides and floods in the high mountain regions can have long-lasting, severe negative impacts, with the after-effects lasting for several years. This can include secondary impacts from disasters, such as disrupted transport corridors and revenues lost from tourism. Nepal and Bhutan are thought to have suffered the greatest nationwide economic impacts from glacier floods. The Dig Tsho flood in the Khumbu Himal area of Nepal in 1985 damaged a hydropower plant and other property, with estimated economic losses of US$500 million.

According to the International Disaster-emergency Events Database (EM-DAT) for 1984-2014, absolute economic losses from all flood and land movements were greatest for the Hindu-Kush Himalaya region, at US$45 billion.

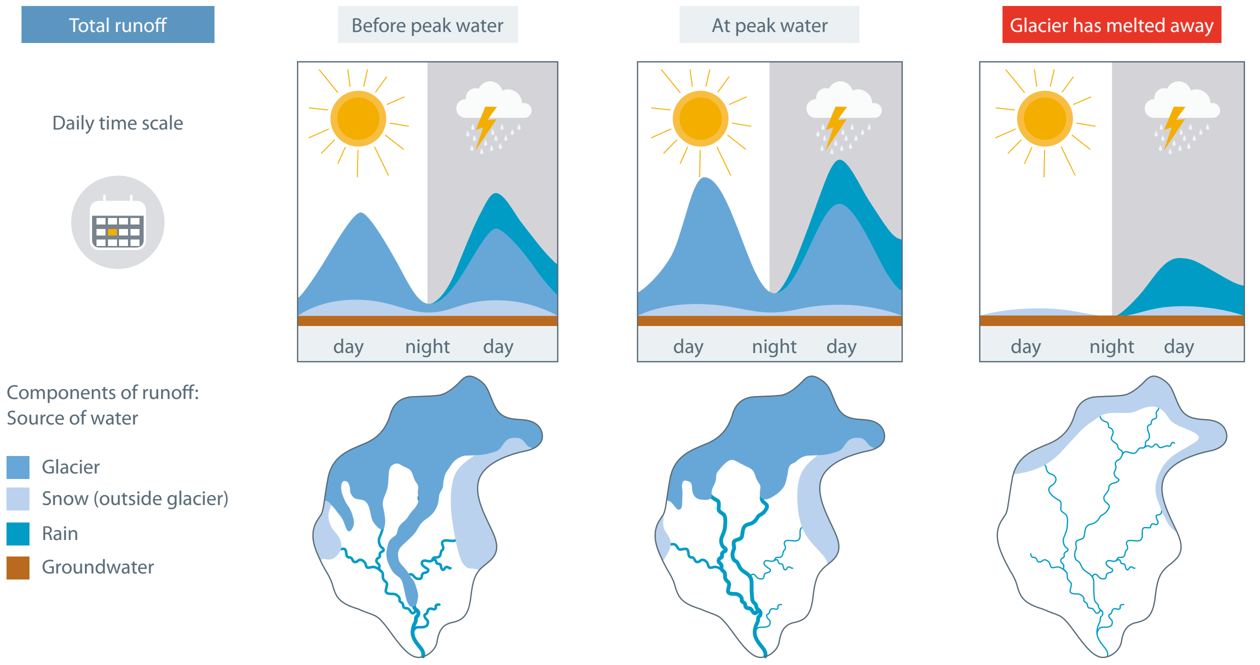
To date, adaptation strategies to cope with flood and landslide hazards in Europe, Latin America and more recently, the Himalaya region, have included:

- hard engineering solutions such as lowering lake levels (this was undertaken at Tsho Rolpa glacier in Nepal at a cost of US$3 million in 2000)[67]
- nature-based solutions to revegetate slopes to stabilise them
- hazard and risk mapping, e.g. at river basin level, as the basis for early warning systems (note that in Pakistan, early warning systems have been primarily community-led to date).[68]

There is high confidence that mountain flood and landslide hazards and people's exposure and vulnerability will all increase over the 21st century. Societies will need to invest in significant risk reduction and adaptation strategies to avoid increased impacts.[69] Solutions will need to fit local circumstances.

There is also high confidence that the most effective solutions will come from integrating knowledge across indigenous and local knowledge systems and science; and across natural and physical sciences and the humanities.[70]

Figure 5: A simplified picture of how runoff changes in a river basin when a glacier melts[71]



***Beyond the IPCC*: Adapting to change in the Indus, Ganges and Brahmaputra River basins: Insights from HI-AWARE[72]**

HI-AWARE was a research project to enhance the adaptive capacities and climate resilience of the poor and vulnerable women, men, and children living in the mountains and flood plains of the Indus, Ganges, and Brahmaputra River basins. The HI-AWARE consortium was led by the International Centre for Integrated Mountain Development (ICIMOD). Investigation by project scientists found that:

The Indus, Ganges and Brahmaputra river basins are extremely susceptible to temperature increase. Under a 1.5°C global warming scenario, these river basins would warm up by more than 2°C on average by the end of this century.

At higher altitudes this warming will be even more marked, due to elevation-dependent warming. A 2°C global warming scenario could lead to a warming of around 2.7°C in these glaciated river basins.

Currently, more likely climate change scenarios, specific for these river basins, suggest regional temperature increases between 3.5°C and 6°C by 2100.

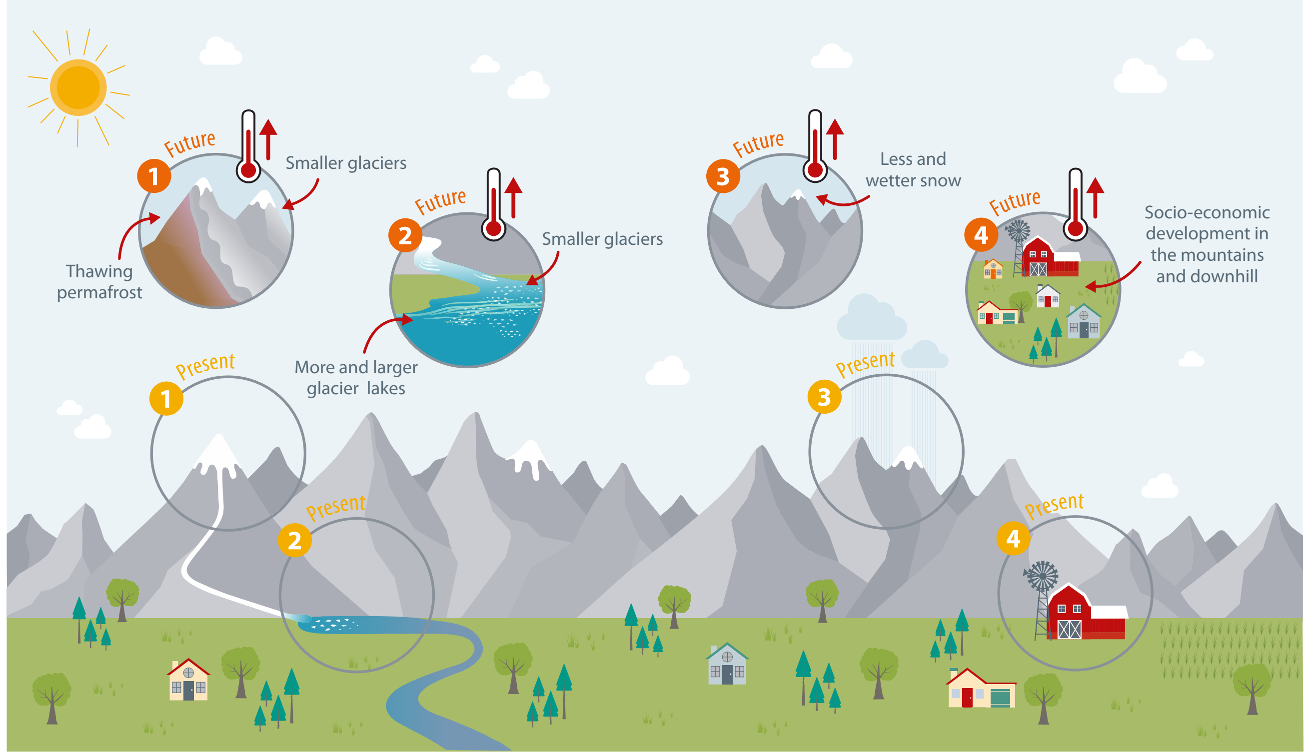
There will be significant losses in glacier volume, from 36% to 64%, depending on the warming scenario.

The majority of the climate projections also indicate wetter conditions in the future overall, and increases in extreme rainfall events.

Overall, an increase in water supply is expected for the coming decades as a result of increases in meltwater and rainfall. However, the lack of water storage infrastructure and more extreme flows mean that increased water may not always be beneficial.

Image: © Direct Relief | Cyclone Sidr aftermath, Bangladesh, 2007

Figure 6: Anticipated changes in high mountain hazards as the climate changes[73]



1 Unstable slopes and landscapes

- ▲ More landslides from rock walls and slopes
- ▼ Local reduction in some hazard types, e.g., less ice falls as glaciers retreat
- ▼ Improved infrastructure against landslides

2 Snow avalanches

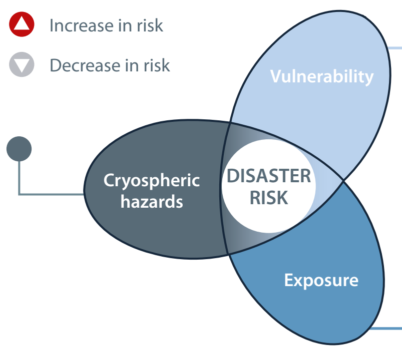
- ▲ More avalanches involving wet snow
- ▼ Less and smaller snow avalanches where snow cover declines
- ▼ Improved measures against snow avalanches

3 Floods

- ▲ More and larger glacier lakes
- ▲ More floods from impacts by avalanches and landslides
- ▲ More rain-on-snow floods at higher elevations
- ▼ Less rain-on-snow floods at lower elevations
- ▼ More preventative measures at/near glacier lakes

Risk framework

- ▲ Increase in risk
- ▼ Decrease in risk



4 Social and infrastructure systems

- ▲ Social inequality and marginalised communities
- ▲ Institutional remoteness
- ▲ Inadequate or inaccessable information
- ▲ Higher populations
- ▲ More mountains tourism
- ▲ Hydropower expansion up-valley
- ▲ More infrastructure in mountain and downhill areas
- ▲ New locations become exposed
- ▼ Improved hazard zonation, education and awareness
- ▼ Improved early warning and emergency response systems

Image: © Bob Webster | Residents of Asia's high mountain regions have developed resilience over centuries, but changes in the cryosphere will test their resilience.

5 The best way to limit changes in the oceans and cryosphere is to mitigate climate change

Human society must reduce greenhouse gas emissions urgently in order to limit the damage from global warming to the Earth's oceans and frozen lands (the cryosphere).[74]

Glaciers are due to keep melting, permafrost will thaw, and snow cover and the extent of Arctic Sea ice will all decline between now and 2050 as a result of large-scale changes in Earth's systems that are already underway. This is inevitable.

However, choices we make today about the emissions pathway of the future will make a difference to global warming and how the oceans and cryosphere respond during the second half of the 21st century. This, in turn, will make a big difference to people's lives and other species on Earth.[75]

Under a high emissions scenario, the Greenland and Antarctic ice sheets will melt at an even faster rate than today and the effects would be felt the world over.[76]

Limiting global warming would help communities downstream of frozen mountain regions to adapt to changes in water supplies and would limit risks related to mountain hazards.[77]

Ocean warming, acidification, oxygen decline, and marine heatwaves are all predicted into the late 21st century. However, their rate of change and intensity will be less under a low emissions scenario.[78]

"Reducing greenhouse gas emissions is the main action to limit global warming to acceptable levels and reduce the occurrence of extreme events and abrupt changes."[79]

Image: © Nadya Peek | Cooking, heating, electricity technologies using the sun to avoid greenhouse gas emissions, India.

Figure 7: Mitigation together with adaptation reduces the risks[80]

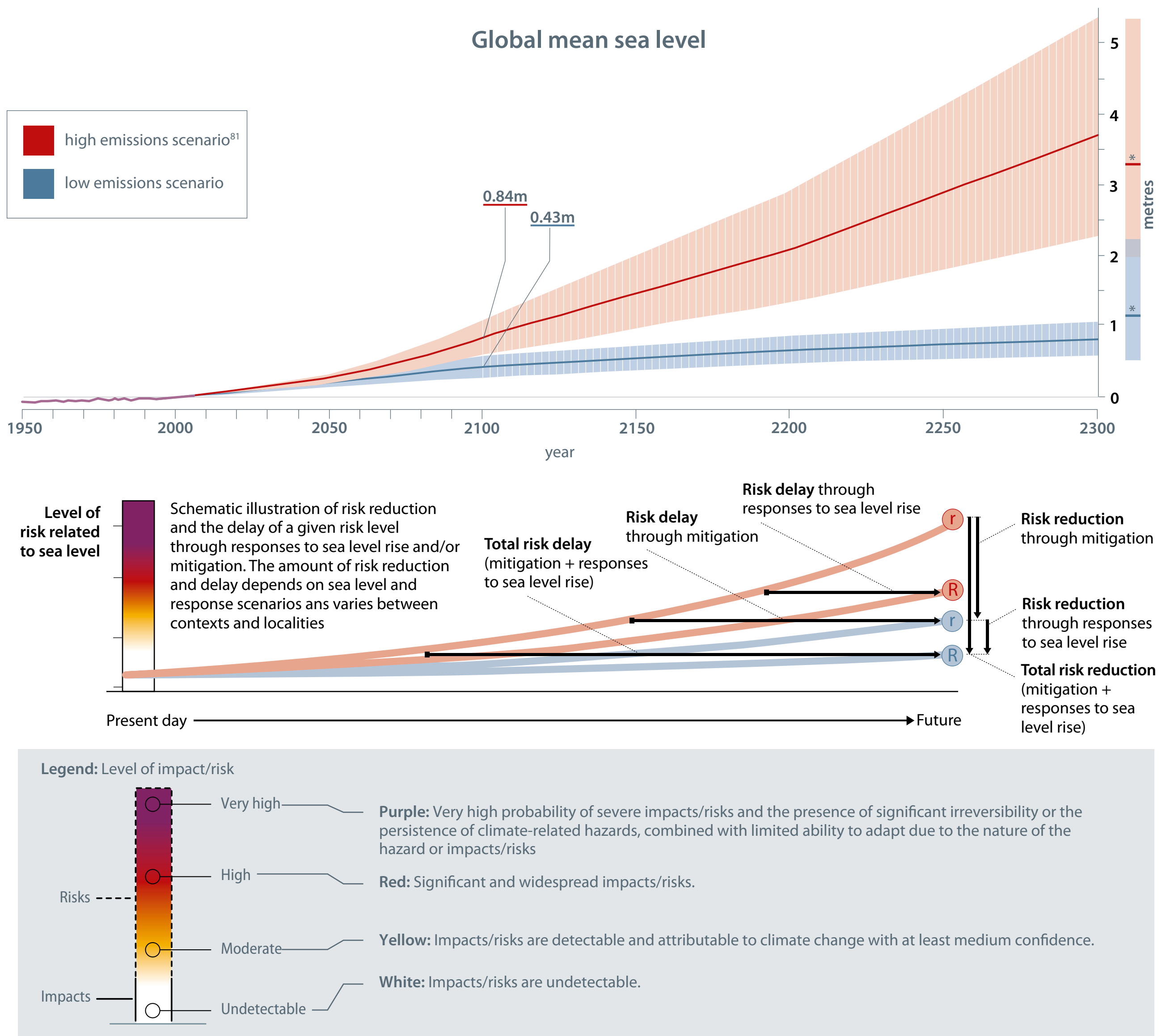


Image: © Shutterstock | Wetlands can regulate fresh and salt water flows and nutrients, and break wave energy as well as support biodiversity. Vasai Bassein, India.

6 Early action reduces climate risks and costs less than dealing with future damages

Societies, institutions and individuals can all invest in reducing the risks of damage from extreme weather events, and so reduce the likelihood that an event such as a cyclone or flood will turn into a 'disaster'.

The economics of investing in disaster risk reduction – how much disaster loss can be averted for each dollar invested in up-front preparation – varies depending on the circumstances.[82] There is medium evidence about the benefits of investing in disaster risk reduction. Figures range from:

- a global estimate of every dollar invested in disaster risk reduction saving US$2-US$4 in disaster recovery costs
- every euro invested in flood early warning systems in Europe saving 400 euros in disaster recovery costs, to
- every 1% increase in flood management funding in the United States leading to a 2% decrease in flood damages.

Investing in healthy ecosystems to reduce the risks from extreme weather events has yielded measurable monetary benefits, as these international examples indicate:

- Wetlands and floodplains in one part of the coastal United States reduced damages caused by storms by 54%–78% (wetlands) and by 84%–95% (floodplains).
- For the whole of the US, wetlands provide US$23.2 billion per year in storm protection services.
- The loss of 1 hectare of wetland is estimated to correspond to an average US$33,000 increase in storm damage from specific storms.

Engineered structures are also expected to reduce risks. For tropical and extratropical cyclones, investing in disaster risk reduction, early warning systems and flood management (both ecosystem-based and engineered) all decrease economic losses from extreme weather events.[83]

For coping with the increased frequency of extreme El Niño/La Niña events that is expected, investing in long-term monitoring and improved forecasts will be important. Robust forecast information can be used to manage risks to human health, agriculture, fisheries, coral reefs, aquaculture, wildfire, drought and flood management.[84]

Slow-onset impacts of climate change such as rising sea level also increase risks for human communities in low-lying coastal areas. Investing in ambitious adaptation action can reduce the risks of these slow-onset events, but the benefits depend on the location.[85] Options for future-proofing coastal development from sea level rise are explored in the following section.

"Investing in preparation and prevention against the impacts from extreme events is very likely less than the cost of impacts and recover (medium confidence). Coupling insurance mechanisms with risk reduction measures can enhance the cost-effectiveness of adapting to climate change (medium confidence)."[86]

Image: © UNDP Bangladesh | Early warning (here by bike) saves lives in Bangladesh.

***Beyond the IPCC:* A comprehensive assessment of development options for the Meghna-Brahmaputra-Ganges delta[87]**

Image: © Amir Jina | Bangladesh delta.

The livelihoods of the many tens of millions of poor people in Bangladesh's delta region are increasingly precarious as the natural resources upon which they depend are threatened. Scientists from the Ecosystem Services for Poverty Alleviation (ESPA) programme and senior officials in the Bangladesh government collaborated to ensure that development in this challenging area works for the economy, the environment and people.

Working with a broad range of local and national stakeholders, the team developed scenarios for how ecosystem services and poverty might be affected by different climate and development trajectories. A model – the Delta Dynamic Integrated Emulator Model (ΔDIEM) – was developed to incorporate and integrate this wealth of information. ΔDIEM is unique in linking biophysical, socioeconomic and governance processes to consider a range of plausible futures to inform policy-making. It can also assess a wide range of large-scale soft and hard interventions.

Researchers and government officials worked closely to refine the model and select different development options to test on it. This close collaboration was essential to ensure that the model simulations were as policy-relevant as possible. By the end of 2017, the teams were ready to trial the ΔDIEM model to assess three alternative interventions that are being considered for the Bangladesh Delta Plan 2100: a new coastal 'greenbelt' along the southern exposed coast, a new sea wall to protect against cyclones, and a new network of polders (the system of low-lying tracts of land enclosed by earthen embankments traditionally used to keep back annual river flooding and storm surges) to enhance agriculture.

The findings showed that of the three scenarios, the new polders – if well maintained – would be the most beneficial in terms of enhancing incomes and removing people from poverty. These trial results show the great potential of the project's approach to inform policy in a participatory manner. Working with the research team, the government is refining its understanding of the proposed options and the follow-up questions that now need to be answered.

Image: © Shutterstock | Sea wall breaks the force of the waves, India.

7 Future-proofing coastal development will be essential

Future-proofing coastal development will be an essential part of society's response to sea level rise. Using 'hard' infrastructure like sea walls to protect coastal settlements from sea level rise, storm surges and other climate hazards is popular worldwide. Nature-based solutions or so-called 'green grey' solutions that combine ecosystem approaches and hard infrastructure are growing in popularity.[88] Solutions assessed by the IPCC for future proofing coasts from the impacts of climate change include:

Figure 8: Different types of responses to coastal risk and sea level rise

Figure 7: Options for responding to sea level rise: both mean levels and extreme sea levels (e.g. storm surges)[89]

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

Confidence in the effectiveness of this measure in responding to sea level rise:

- ●●●● Very High
- ●●● High
- ●● Medium
- ● Low

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

1 3 Image: © World Fish | Hybrid measures: a combination of built 'hard' coastal protection combined with ecosystem-based measures.

1 Image: © Shutterstock | Sea wall.

3 Image: © World Fish | Planted mangrove plot.

Option		Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)	Advantages (beyond risk reduction)	Co-benefits	Drawbacks	Economic efficiency	Governance challenges
4 **Coastal advance** These measures create new land by building seaward, reducing risks for the land behind it and the newly elevated land. It can include land filling with pumped sand or other fill material, planting vegetation and surrounding low areas with dikes (called polderisation) which requires draining and pumping systems		Up to multiple metres of sea level rise	Predictable levels of safety	Generates land and land sale revenues that can be used to finance adaptation	Groundwater salinisation, enhanced erosion and loss of coastal ecosystems and habitat	Very high if land prices are high as found in many urban coasts	Often unaffordable for poorer areas. Social conflicts with regards to access and distribution of new land
5 **Coastal accommodation** is about diverse measures to make coastal zones more habitable and reduce the vulnerability of people and their environment. It includes biological and physical measures such as raising houses on stilts, adopting floating gardens to deal with flooding and erosion, and switching land uses (e.g. from rice farming to shrimp aquaculture) to accommodate salt water intrusion. It also includes institutional measures such as early warning systems and insurance schemes.		Very effective for small sea level rise	Mature technology; sediments deposited during floods can raise elevation	Maintains landscape connectivity	Does not prevent flooding/ impacts	Very high for early warning systems and building-scale measures	Early warning systems require effective institutional arrangements
6 **Retreat** reduces risks by moving exposed people, assets and activities out of the hazard zone. Planned relocation is typically initiated by governments and may include financial incentives, whereas displacement occurs when people's movement is involuntary and unforeseen. Migration is a person's voluntary permanent or semi-permanent movement.	**Planned relocation**	Effective if alternative safe localities are available	Sea level risks at origin can be eliminated	Access to improved services (health, education, housing), job opportunities and economic growth	Loss of social cohesion, cultural identity and wellbeing. Depressed services (health, education, housing, job opportunities and economic growth)	Limited evidence	Reconciling the divergent interests arising between relocated people and people in destination location
	Forced displacement	Addresses only immediate risk at place of origin	Not applicable		Range from loss of life to loss of livelihoods and sovereignty	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity

4 Image: © REACH | Polder technology to manage water in areas of coastal advance.

5 Image: © Mike Lusmore/Duckrabbit | Shrimp farming, Bangladesh.

5 Image: © Shutterstock | Stilt houses, Asian fishing village.

6 Image: © Direct Relief | One year after Cyclone Sidr in Bangladesh, families are still displaced.

"The potential climate benefits of blue carbon ecosystems can be a very modest addition to, and not a replacement for, the very rapid reduction of greenhouse gas emissions."[90]

Blue carbon: An opportunity to integrate adaptation and mitigation action

Protecting and restoring what is called coastal 'blue carbon' ecosystems such as mangroves, tidal marshes and seagrass meadows can help mitigate climate change by locking up carbon. At the same time, protecting these ecosystems can provide climate change adaptation benefits and help conserve biodiversity and local livelihoods, by:

- providing storm protection
- improving water quality
- benefiting fisheries.[91]

Globally, these measures would make a modest contribution to halting global warming. But locally and nationally, investing in blue carbon can be an important approach.

The potential and the limits of ecosystem-based approaches

Ecosystem-based approaches to coastal protection include restoring the types of blue carbon ecosystems described above. They can have many benefits for human communities and the health of entire ecosystems. They can reduce local climate risks.

However, they are considered to be most effective in low emissions scenarios where further global warming is largely limited. If global warming is too high, then it is thought that ecosystem-based approaches will hit their limits. Unfortunately, it is hard to judge where those limits will be.[92]

Image: © Shutterstock | Mangrove forest, Andaman Islands, India.

8 Ecosystem governance and management must join up across scales and address social issues

An integrated approach

Adapting to changes in the oceans and cryosphere calls for effective governance across scales and boundaries. That is because the changes underway in the oceans and cryosphere have effects that go far beyond administrative boundaries. For example, changes to mountain ecosystems can affect whole river basins.[93]

Extreme events such as floods and landslides, or tropical cyclones, pose less risk to people if climate change adaptation and disaster risk reduction approaches are well integrated. Climate-affected sectors and disaster management agencies need to coordinate well – both in policy-making and on-the-ground delivery.

"Transformative governance [that integrates] disaster risk management and climate change adaptation, empowerment of vulnerable groups, and accountability of governmental decisions promotes climate-resilient development pathways (high confidence)."[94]

High mountain governance

The Sendai Framework for Disaster Risk Reduction 2015-2030 provides a framework with targets for countries to address climate and other risks. The Sendai Framework has technical guidelines to address changes in the high mountain frozen lands and the compound risks and cascading impacts on people and the environment.

However, there is limited evidence that countries are using the framework and guidelines to monitor high mountain changes, including the root causes of disasters, and to report on Sendai targets.[95]

The Convention Concerning the Protection of the World Cultural and Natural Heritage is aimed at protecting the world's most significant, irreplaceable places from loss and damage. It also offers countries relevant policy frameworks and strategies for conservation and climate policy.[96]

"Overall, there are promising prospects through international policy frameworks to support governance and adaptation to climate-related changes in the mountain cryosphere while addressing sustainable development."[97]

Ocean governance

At sea, the movement of species means that improved marine protected areas and spatial plans and even entire networks of protected areas will be needed to support species movement.[98] This implies far more ambitious management responses than governments have achieved to date.

Some changes in the ocean are expected to emerge earlier than others, such as the impacts of warming and acidification on tropical coral reefs and fish stocks. This knowledge could help stakeholders to prioritise planning issues and build resilience.[99] New approaches to ocean governance are being trialled but need to be rigorously evaluated.[100]

"The mechanisms for the governance of marine Areas Beyond National Jurisdiction … would benefit from further development."[101]

Coastal governance

In coastal areas, choosing and putting in place measures to respond to sea level rise presents societies with tough governance challenges and potentially difficult social choices. There are big uncertainties about the degree and impact of sea level rise beyond 2050, and the impacts could fall unequally on different social groups. For example, the economics may favour investing in coastal defences to protect densely populated urban centres with concentrated wealth as opposed to less densely-populated rural areas with more marginalised populations. Investment choices will be highly political and will need to be navigated carefully.

In spite of this, there are methods for developing and analysing options that are designed to deal with future uncertainty. These methods emphasise:

- keeping the ability to be flexible over time
- using criteria to gauge robustness and to establish the usefulness of investments across a range of circumstances
- adjusting decisions periodically as consequences become known
- considering social vulnerability and equity
- creating safe community spaces for public deliberation of options and conflict resolution.[102]

Participatory scenario-building processes, collaborative landscape planning and co-design of ecosystem-based management are all promising, emerging approaches for engaging people on low-lying islands and coasts, enabling them to work together to develop future adaptation scenarios and climate resilience.[103]

"The capacity of governance systems in polar and ocean regions to respond to climate change impacts has strengthened recently but this development is not sufficiently rapid or robust to adequately address the scale of increasing, projected risks (high confidence)."[104]

Image: © Shutterstock | Mumbai, India waterfront.

9 Communication, education and capacity-building are critical

Human society needs to adapt to profound changes in the world's oceans and cryosphere in the coming decades and take the ambitious action of cutting greenhouse gases to stop catastrophic changes later this century. This will require a vast effort to educate people, and communicate about climate change and build people's capability to act. 'Climate literacy' is needed at all scales.

Education and capacity-building can be context-specific and support local efforts to become more resilient. They can draw on indigenous and local knowledge in ways that resonate with people and encourage understanding and action.[105]

Beyond the IPCC box: Communications toolkit helps readers to raise awareness

CDKN has created a communications toolkit online at www.cdkn.org/oceanreport which makes some of the key scientific information from the IPCC's Special Report available for free download.

This is so that readers can use key infographics and statistics in their own awareness-raising and educational campaigns. Please share the information in this report and online toolkit widely.

You can also visit www.cdkn.org/communicating for a practical manual with diverse ideas about communicating and engaging with people on climate action.

Image: © Department for International Development (DFID) | Education at all scales is key.

Conclusion

The IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate* has revealed how Earth's oceans and frozen and ice-covered lands have been 'taking the heat' of human-induced global warming. The Special Report should transform the way people think and talk about our planet.

It assesses the scientific evidence on changes in our atmosphere and their interaction with oceans and Earth's frozen areas, including snow-covered land, glaciers, ice sheets, sea, lake and river ice, permafrost and seasonally frozen ground.

The Special Report brings to light in a clear, newly-framed way how human-induced climate change is making ice caps and glaciers melt and is warming and changing the chemistry of the oceans. These changes are already well underway, even though most people in the world can scarcely perceive them yet. Over the last few decades, global warming has led to mass loss from ice sheets and glaciers, reductions in snow cover and loss of Arctic sea ice.

Since 1970, the global ocean has taken up more than 90% of the excess heat in the climate. Furthermore, the ocean has become more acidic as a result of increased greenhouse gases in the atmosphere. Melting ice from the Greenland and Antarctic ice sheets is speeding up the rate of sea level rise. On average, global sea levels are now rising two and a half times faster than the rate of sea level rise last century. The sea level will continue to rise under all emission scenarios, but is projected to be less under lower greenhouse gas emission scenarios. Changes in high mountain frozen lands are projected to affect water resources and their many uses by society.

Although still largely invisible, these changes will cause problems in decades to come for the hundreds of millions of people living on exposed coastlines and dependent on safe, regular flows of water from high mountain ecosystems.

Adaptation investments can limit the damage. Significantly, the IPCC's Special Report finds that societies are far better off investing in adaptation solutions now than delaying action and seeking to clean up the damages later. The types of adaptation actions considered by the IPCC on coasts, for example, include: wetland conservation and restoration, hard coastal protection and managed realignment or 'coastal advance' measures, where the sea is allowed to flood certain areas in a managed way. However, it is uncertain when societies will reach the limits at which such adaptation actions are effective.

Some communities in highly exposed mountain environments and particularly fragile coastal environments such as atoll island nations are already living on the edge. They are close to the limits of adaptation in their environments.

As with previous IPCC reports, the biggest takeaway message is that mitigating climate change by cutting global greenhouse gas emissions is by far the best way to limit damage to Earth's marine, coastal and frozen ecosystems and the repercussions for the rest of the planet.

Image: © Shutterstock | Kuttanad, India, is below sea level and suffers frequent flooding.

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Image: © Shutterstock | Herder with livestock in India's Himalaya region.

Glossary[106]

Cascading impacts from extreme weather/climate events occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional and are associated more with the extent of people's or a system's vulnerability than with the hazard itself.

Climate is usually defined as the average weather over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often temperature, precipitation and wind and the period for averaging them is normally 30 years, as defined by the World Meteorological Organization (WMO). Climate, in a wider sense, is the state of the climate system.

Climate change is a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic (human-made) changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.
The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.

Climate extreme (extreme weather or climate event) is when a variable of weather or climate reaches near the upper (or lower) ends of the range of observed values.

Co-benefits refer to the positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors.

Compound weather/climate events are the combination of multiple drivers and/or hazards that contributes to societal and environmental risk.

Compound risks arise from the interaction of hazards, which may be characterised by single extreme events or multiple coincident or sequential events that interact with exposed systems or sectors.

Coral reef is an underwater ecosystem characterised by structure-building stony corals. Warm-water coral reefs occur in shallow seas, mostly in the tropics, with the corals (animals) containing algae (plants) that depend on light and relatively stable temperature conditions. Cold-water coral reefs occur throughout the world, mostly at water depths of 50-500 m. In both kinds of reef, living corals frequently grow on older, dead material, predominantly made of calcium carbonate ($CaCO_3$). Both warm and cold-water coral reefs support high biodiversity of fish and other groups of species, and are considered to be especially vulnerable to climate change.

Cryosphere refers to the components of the Earth at and below the land and ocean surface that are frozen, including snow cover, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground.

Early warning systems (EWS) are the set of technical and institutional capacities to forecast, predict, and communicate timely and meaningful warning information to enable individuals, communities, managed ecosystems, and organisations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Depending on the context, EWS may draw upon scientific and/or indigenous knowledge, and other knowledge types. EWS are also considered for ecological applications, e.g., conservation, where the organisation itself is not threatened by hazard but the ecosystem under conservation is (e.g., coral bleaching alerts), in agriculture (e.g., warnings of heavy rainfall, drought, ground frost, and hailstorms) and in fisheries (e.g., warnings of storm, storm surge, and tsunamis).

Ecosystem is a functional unit consisting of living organisms, their non-living environment and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment.

El Niño-Southern Oscillation (ENSO) The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). It is often measured by the surface pressure anomaly difference between Tahiti and Darwin and/or the sea surface temperatures (SST) in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the SSTs warm, further weakening the trade winds. This phenomenon has a great impact on the wind, SST and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña.

Exposure is the presence of people livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Extreme weather event is an event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event.

Glacier is a perennial mass of ice originating on the land surface by accumulation and compaction of snow and showing evidence of past or present flow. A glacier typically gains mass by accumulating snow, and loses mass in a process called ablation. Land ice masses of continental size (>50,000 km^2) are referred to as ice sheets.

Glacial lake outburst flood (GLOF) / Glacier lake outburst is a sudden release of water from a glacier lake, including any of the following types – a glacier-dammed lake, a pro-glacial moraine-dammed lake or water that was stored within, under or on the glacier.

Global warming is an increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.

Green infrastructure refers to the interconnected set of natural and constructed ecological systems, green spaces and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street level design interventions that incorporate vegetation. Green infrastructure provides services and functions in the same way as conventional infrastructure.

Greenhouse gases (GHG) are the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's ocean and land surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Human-made GHGs include sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs); several of these are also O_3-depleting (and are regulated under the Montreal Protocol).

Hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Heat wave is a period of abnormally hot weather.

Human system is any system in which human organisations and institutions play a major role. Often, but not always, the term is synonymous with society or social system. Systems such as agricultural systems, urban systems, political systems, technological systems, and economic systems are all human systems in the sense applied in this report.

Ice sheet is an ice body originating on land that covers an area of continental size, generally defined as covering >50,000 km^2, and that has formed over thousands of years through accumulation and compaction of snow.

Loss and Damage, and losses and damages have two general meanings under the IPCC: the term 'Loss and Damage' (capitalised letters) refers to political debate under the United Nations Framework Convention on Climate Change (UNFCCC) following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, which is to 'address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change.' The expression 'losses and damages' (lowercase letters) has been taken to refer broadly to harm from (observed) impacts and (projected) risks.

Marine heatwave is a period of extreme warm near-sea surface temperature that persists for days to months and can extend up to thousands of kilometres.

Mitigation (of climate change) refers to a human intervention to reduce emissions or enhance the sinks of greenhouse gases (GHG).

Nationally determined contributions (NDCs) is a term used under the United Nations Framework Convention on Climate Change (UNFCCC) whereby a country that has joined the Paris Agreement outlines its plans for reducing its emissions. Some countries' NDCs also address how they will adapt to climate change impacts, and what support they need from, or will provide to, other countries to adopt low-carbon pathways and to build climate resilience. According to Article 4 paragraph 2 of the Paris Agreement, each Party shall prepare, communicate and maintain successive NDCs that it intends to achieve.

Net-zero CO_2 emissions Net-zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced by anthropogenic CO_2 removals over a specified period.

Ocean acidification (OA) is a reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO^2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean.

Ocean deoxygenation is the loss of oxygen in the ocean. It results from ocean warming. It can also be exacerbated by the addition of excess nutrients in the coastal zone.

Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change. The Paris Agreement is intended to become fully effective in 2020.

Pelagic zone consists of the entire water column of the open ocean. It is subdivided into the 'epipelagic zone' (<200 m, the uppermost part of the ocean that receives enough sunlight to allow photosynthesis), the 'mesopelagic zone' (200–1000 m depth) and the 'bathypelagic zone' (>1000 m depth). The term 'pelagic' can also refer to organisms that live in the pelagic zone.

Permafrost is ground (soil or rock, and included ice and organic material) that remains at or below 0°C for at least two consecutive years. Note that permafrost is defined via temperature rather than ice content and, in some instances, may be ice-free.

Primary production refers to the synthesis of organic compounds by plants and microbes, on land or in the ocean, primarily by photosynthesis using light and carbon dioxide (CO_2) as sources of energy and carbon, respectively. It can also occur through chemosynthesis, using chemical energy, for example, in deep sea vents.

Resilience is the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.

Restoration in environmental context involves human interventions to assist the recovery of an ecosystem that has been previously degraded, damaged or destroyed.

Risk is the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services, ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making.

In terms of acting on climate change, there could be risks of actions not achieving the intended objective(s), or having a negative effect on society's other objectives, such as the Sustainable Development Goals (SDGs).[107]

Sea level change (e.g. sea level rise) is a change to the height of sea level, both globally and locally (relative sea level change) at seasonal, annual, or longer time scales due to (1) a change in ocean volume as a result of a change in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets), (2) changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions), (3) changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields, and (4) local subsidence or uplift of the land.

Sea surface temperature (SST) is defined as the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys, and drifters. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimetre thick) in the infrared or the top centimetre or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature.

Sendai Framework for Disaster Risk Reduction (2015-2030) outlines seven clear targets and four priorities for action to prevent new, and to reduce existing disaster risks. The voluntary, non-binding agreement recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government, the private sector and other stakeholders, with the aim for the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

Sink refers to any process, activity or mechanism which removes a greenhouse gas (GHG), an aerosol or a precursor of a GHG from the atmosphere (UNFCCC Article 1.8).

Storm surge is the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and entered into force in March 1994. As of May 2018, it had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement.

Vulnerability is the predisposition to be negatively affected and it can include being sensitive to harm and unable to cope.[108]

Endnotes

All references are from the IPCC's *Special Report on the Ocean and Cryosphere in a Changing Climate* unless otherwise noted.

1 IPCC Press release, 25 September 2019, 2019/31/PR: 'Choices made now are critical for the future of our ocean and cryosphere'. See www.ipcc.ch/srocc
2 See IPCC Special Report on the Ocean and Cryosphere in a Changing Climate: Factsheet on www.ipcc.ch/srocc
3 Summary for Policy Makers, Box SPM-1.
4 IPCC Press release, 25 September 2019, 2019/31/PR.
5 Summary for Policy Makers, SPM-10.
6 Derived from Summary for Policy Makers, Figure SPM2.
7 IPCC Press release, 25 September 2019, 2019/31/PR.
8 Summary for Policy Makers, SPM-14.
9 Summary for Policy Makers, SPM-14.
10 Chapter 5, Executive Summary, page 5-8.
11 Summary for Policy Makers, SPM-11.
12 Chapter 5, p5-50.
13 IPCC Press release, 25 September 2019, 2019/31/PR.
14 This statement is made with robust evidence, high agreement, high confidence by the IPCC; Chapter 5, p5-78. As well as the effect of warming on fish stocks, there are also the effects of changing 'primary production' on fish stocks, which here refers to the changes in how ocean organisms take up carbon through photosynthesis and chemosynthesis.
15 15 Chapter 5, p5-78.
16 Chapter 5, Executive Summary, p5-7.
17 Chapter 5, 5-79.
18 Summary for Policy Makers, SPM-17.
19 Chapter 5, Executive Summary, p5-4.
20 IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties Jasper Ridge, CA, USA 6–7 July 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties.
21 Ibid.
22 Summary for Policy Makers, SPM Figure 3d.
23 IPCC Press release, 25 September 2019.
24 Summary for Policy Makers, A.3.
25 Summary for Policy Makers, A.3.
26 IPCC Press release, 25 September 2019, 2019/31/PR.
27 Coastal squeeze diagram: Information from Chapter 5 (see Executive Summary and especially p5-5 and related sections 5.3.2, 5.3.3., 5.4.1., 5.5.1)
28 IPCC Press release, 25 September 2019, 2019/31/PR.
29 Summary for Policy Makers, Start-Up Box: The importance of the ocean and the cryosphere for people.
30 Summary for Policy Makers, SPM-10.
31 Cross cutting Box 9, Figure CB9.1
32 Cross cutting Box 9, Figure CB9.1
33 Cross cutting Box 9, CCB9-4-5.
34 Chapter 6, Executive Summary, p6-4.
35 Chapter 6, Executive Summary, p6-4.
36 Chapter 6, Executive Summary, p6-4.
37 Chapter 6, Executive Summary and also Figure 6.1.
38 Summary for Policy Makers, SPM-13 and SPM-18.
39 Chapter 5, Executive Summary, p5-4.
40 Summary for Policy Makers, SPM-18.
41 Chapter 5, Executive Summary, p5-5.
42 Chapter 5, Executive Summary, p5-9.
43 All data in this table from Chapter 6, Figure 6.2 and Table 6.2.
44 Cross cutting Box 9, CCB9-6.
45 Cross cutting Box 9, CCB9-6.
46 Cross cutting Box 9, CCB9-6.
47 Cross cutting Box 9, CCB9-4-5.
48 Chapter 2, p2-54.
49 Chapter 2, p2-54.
50 Chapter 2, pp2-54-2-55.
51 Chapter 2, pp2-54-2-55.
52 Chapter 2, p2-55.
53 Cross cutting Box 9, CCB9-8.
54 Chapter 2, p2-55.
55 Narrative in this box sourced from Muhammad Amir Fahim, Masooma Hassan, Bashir Ahmad, and Naveed Mustafa (20 March 2017) 'Women's vulnerabilities to extreme climate events in Pakistan'. http://hi-aware.org/womens-vulnerabilities-to-extreme-climate-events-in-pakistan/
56 Narrative in this box sourced from Muhammad Amir Fahim, Masooma Hassan, Bashir Ahmad, and Naveed Mustafa (20 March 2017) 'Women's vulnerabilities to extreme climate events in Pakistan'. http://hi-aware.org/womens-vulnerabilities-to-extreme-climate-events-in-pakistan/
57 IPCC Press release, 25 September 2019.
58 Summary for Policy Makers, SPM-17.
59 Chapter 2, Executive Summary, p2-5.
60 Derived from Summary for Policy Makers, Figure SPM2.
61 Summary for Policy Makers, SPM11-12.
62 Summary for Policy Makers, SPM-17.
63 Summary for Policy Makers, SPM 20.
64 Chapter 2, p2-42.

65 Chapter 2, p2-42.
66 Chapter 2, p2-42.
67 Chapter 2, p2-43.
68 Chapter 2, p2-43.
69 Chapter 2, p2-43.
70 Chapter 2, p2-44.
71 From Chapter 2, p2-29 (FAQ2.1, Figure 1)
72 This box is sourced from HI-AWARE (2018). 'Even 1.5 degrees is too much. Rising temperatures and wetter futures in South Asian glacier and snow-fed river basins.' Kathmandu: HIr-AWARE.
73 Based on Chapter 2, Figure 2.7
74 IPCC Press release, 25 September 2019.
75 Summary for Policy Makers, SPM-19.
76 Summary for Policy Makers, SPM-19.
77 IPCC Press release, 25 September
78 Summary for Policy Makers, SPM-21.
79 Chapter 6, p6-61.
80 Data compiled from Summary for Policy Makers figures.
81 The high emission scenario accords with the Representative Concentration Pathway (RCP) 8.5, which the IPCC uses to demonstrate a 'business as usual' emissions scenario without climate mitigation action. The low emission scenario accords with the IPCC's RCP2.6, which is intended to reflect ambitious global action to reduce greenhouse gas emissions to levels in keeping with a 2°C or less average of global warming above pre-industrial levels.
82 Chapter 6, Executive Summary, p6-5.
83 Chapter 6, Executive Summary, p6-5.
84 Chapter 6, Executive Summary, p6-5.
85 Summary for Policy Makers, SPM31.
86 Chapter 6, Executive Summary, p6-5.
87 This box sourced from Ecosystem Services for Poverty Alleviation (May 2018). Integrated environment and development modelling to benefit the poorest in coastal Bangladesh. Edinburgh: Research into Results Ltd.
88 Summary for Policy Makers, SPM18-19.
89 All material, this page, from Chapter 4, Box 4-86: Responses to Sea Level Rise.
90 Chapter 5, Executive Summary, p5-10.
91 Summary for Policy Makers, SPM36.
92 Chapter 5, Executive Summary, p5-10.
93 IPCC Press release, 25 September
94 Chapter 6, p6-60.
95 Chapter 2, p2-57.
96 Chapter 2, p2-57.
97 Chapter 2, p2-57.
98 Summary for Policy Makers, SPM-34.
99 Chapter 5, Executive Summary, p5-9.
100 Chapter 5, Executive Summary, p5-9.
101 Chapter 5, Executive Summary, p5-11.
102 Chapter 4, Executive Summary, p4-6.
103 Cross-Cutting Box 9, CCB9-9.
104 Summary for Policy Makers, SPM-34.
105 Summary for Policy Makers, Section C.
106 All text in this Glossary is reproduced from the IPCC's Glossary for the Special Report on Oceans and Cryosphere in a changing climate, unless otherwise noted. There may be some minor copy editing or shortening of descriptions. Please see https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/SROCC_FD_AnnexI-Glossary_Final.pdf for the full definitive listings.
107 This definition has been shortened and simplified by the authors, from the IPCC's original text.
108 This definition has been shortened and simplified by the authors, from the IPCC's original text.

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