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

What’s in it for South Asia?
### Key messages

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**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
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.” 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.
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.

**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. 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.

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### Figure 1: How changes in the atmosphere and climate have affected the oceans

<table>
<thead>
<tr>
<th>Ocean</th>
<th>Temperate Indian Ocean</th>
<th>Tropical Indian Ocean</th>
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<tbody>
<tr>
<td>Physical changes</td>
<td></td>
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</tr>
<tr>
<td>Temperature</td>
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<tr>
<td>Depth</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Ocean pH</td>
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<td>-</td>
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<tr>
<td>Sea level</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Biogeochemical changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper water column</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coral</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coastal wetlands</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kelp forest</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Biological systems and human systems</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fisheries</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tourism</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Habitat services</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coastal carbon sequestration</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**LEGEND**

- **Physical changes**
  - Increase
  - Decrease
  - Increase and decrease

- **Biogeochemical changes**
  - Positive impact
  - Negative impact
  - Positive and negative impacts
  - No assessment

- **Biological systems and human systems**
  - High
  - Medium
  - Low

* The IPCC also assessed changes to sea ice extent, rocky shores, deep sea, polar benthos, sea ice associated ecosystems, temperature, 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.
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. The average temperature of the Earth’s surface (land and ocean combined) is already 1°C 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. 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. It is expected that, even at global warming of 1.5°C, the species composition and diversity of today’s shallow coral reefs will change. Coral reef’s declining health will greatly reduce their contribution to human society, including to food, coastal protection and tourism industries.

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Seagrass meadows and kelp forests are also at very high risk, even at 1.5°C 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. 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.

Fish stocks are and will be affected

The distribution of fish populations is shifting. Fisheries catches have already been impacted by the effects of warming on the growth, reproduction and survival of fish stocks. 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.

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. 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. 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.

“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).”

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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. 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.

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

Sea levels continue to rise at an increasing rate. Sea level rise could reach around 29-59 cm by 2100 even if greenhouse gas emissions are sharply reduced and global 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.

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

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. Sea level rise could displace people. Some evidence of human displacement linked to sea level rise is discussed in Box 3, overleaf.

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.

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).”

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.

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. 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.

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.

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.

“Warming, sea level rise, and enhanced loads of nutrients and sediments in deltas have contributed to salinisation and deoxygenation in estuaries (high confidence).”
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. People are most vulnerable to harmful algal blooms where there is poor monitoring and weak early warning systems.
- 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.

**Box 2: When does climate change play a role in disaster?**

The extreme event: Bangladesh (2017)

A pre-monsoon extreme 6-day rain event. Attribution to human-made climate change: Scientists looked at whether a 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.
- Seafood is becoming less safe.

**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. 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.
- 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. 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.

**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. There are some benefits from warming, namely that seasonal migration to summer pastures now lasts longer in northern Pakistan and Afghanistan. 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. Migrating away can have mixed outcomes: it can both increase and decrease people’s vulnerability in different ways, depending on the circumstances.

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.

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).

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.”

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11 — The IPCC’s Special Report on the Ocean and Cryosphere in a Changing Climate | What’s in it for South Asia?
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.

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.6 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.11

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**Figure 4: How changes in the atmosphere and the climate have affected the cryosphere**

<table>
<thead>
<tr>
<th>Physical changes</th>
<th>Ecosystems and human systems</th>
<th>Human well-being and ecosystem services</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water availability</strong></td>
<td><strong>Increase</strong></td>
<td><strong>Increase</strong></td>
</tr>
<tr>
<td><strong>Flood</strong></td>
<td><strong>Decrease</strong></td>
<td><strong>Decrease</strong></td>
</tr>
<tr>
<td><strong>Landslide</strong></td>
<td><strong>Increase and decrease</strong></td>
<td><strong>no assessment</strong></td>
</tr>
<tr>
<td><strong>Avalanche</strong></td>
<td><strong>no assessment</strong></td>
<td><strong>no assessment</strong></td>
</tr>
<tr>
<td><strong>Tundra</strong></td>
<td><strong>positive impact</strong></td>
<td><strong>no assessment</strong></td>
</tr>
<tr>
<td><strong>Forest</strong></td>
<td><strong>negative impact</strong></td>
<td><strong>no assessment</strong></td>
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<tr>
<td><strong>Tourism</strong></td>
<td><strong>positive impact</strong></td>
<td><strong>no assessment</strong></td>
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<tr>
<td><strong>Agriculture</strong></td>
<td><strong>no assessment</strong></td>
<td><strong>no assessment</strong></td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td><strong>no assessment</strong></td>
<td><strong>no assessment</strong></td>
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<tr>
<td><strong>Mitigation</strong></td>
<td><strong>no assessment</strong></td>
<td><strong>no assessment</strong></td>
</tr>
<tr>
<td><strong>Cultural services</strong></td>
<td><strong>no assessment</strong></td>
<td><strong>no assessment</strong></td>
</tr>
</tbody>
</table>

- **ATTRIBUTION CONFDENCE**: High, medium, low

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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.
3 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.
4 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 interact.)

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 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 areas, 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$50 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.

Beyond the IPCC: Adapting to change in the Indus, Ganges and Brahmaputra River basins: Insights from HI-AWARE70

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:

- 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.

Figure 5: A simplified picture of how runoff changes in a river basin when a glacier melts71

Source of water

<table>
<thead>
<tr>
<th>Daily time scale</th>
<th>Components of runoff: Source of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacier</td>
<td>Glacier</td>
</tr>
<tr>
<td>Snow (outside glacier)</td>
<td>Snow (outside glacier)</td>
</tr>
<tr>
<td>Rain</td>
<td>Rain</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Groundwater</td>
</tr>
</tbody>
</table>

Rainfall. However, the lack of water storage infrastructure and more extreme flows mean that increased water may not always be beneficial.72

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

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

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

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

Social and infrastructure systems
- Social inequality and marginalized communities
- Institutional remoteness
- Inadequate or inaccessible information
- Higher populations
- More mountain 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

Risk framework
- Increase in risk
- Decrease in risk

Cryospheric hazards
- Exposure
- Vulnerability
- Disaster risk

Image: © Bob Webster | Residents of Asia’s high mountain regions have developed resilience over centuries, but changes in the cryosphere will test their resilience.
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 risks80

Legend: Level of impact/risk
Purple: Very high probability of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red: Significant and widespread impacts/risks.
Yellow: Impacts/risks are detectable and attributable to climate change with at least medium confidence.
White: Impacts/risks are undetectable.

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

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.

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

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. 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)."
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. Solutions assessed by the IPCC for future proofing coasts from the impacts of climate change include:

<table>
<thead>
<tr>
<th>Option</th>
<th>Potential effectiveness in terms of reducing sea level rise risks (technical biophysical limits)</th>
<th>Advantages (beyond risk reduction)</th>
<th>Co-benefits</th>
<th>Drawbacks</th>
<th>Economic efficiency</th>
<th>Governance challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hard protection</td>
<td>Up to multiple metres of sea level rise</td>
<td>Predictable levels of safety</td>
<td>Habitat gain, biodiversity, carbon sequestration, tourism, fishery productivity, improved water quality</td>
<td>Destruction of habitat through coastal squeeze, flooding and erosion downrift, lock-in, desirous consequences if defence infrastructure fails</td>
<td>Highly efficient if the assets behind protection is high, as found in many urban and densely populated coastal areas</td>
<td>Often unaffordable for poor areas. Conflicts between objectives (e.g., conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance</td>
</tr>
<tr>
<td>2 Sediment-based protection</td>
<td>Effective up to 0.5cm/year of sea level rise</td>
<td>High flexibility</td>
<td>Preservation of beaches for recreation/tourism</td>
<td>Destruction of habitat, where sediment is sourced</td>
<td>High if tourism revenues are high</td>
<td>Conflicts about the distribution of public budgets</td>
</tr>
<tr>
<td>3 Ecosystem-based adaptation</td>
<td>Effective up to 0.5-1cm/year sea level rise</td>
<td>Opportunity for community involvement</td>
<td>Habitat gain, biodiversity, carbon sequestration, tourism, enhanced fishery productivity, improved water quality, provision of food, medicine, fuel, wood, and cultural benefits</td>
<td>Safety levels less predictable, (some alternative) development benefits will not be realised</td>
<td>Limited evidence on cost-benefit ratios. Depends on population density and the availability of land</td>
<td>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</td>
</tr>
</tbody>
</table>

Confidence in the effectiveness of this measure in responding to sea level rise:
- 4 Very High
- 3 High
- 2 Medium
- 1 Low

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

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

- Hard protection
- Sediment-based protection
- Coastal advance
- Coastal accommodation
- Ecological-based adaptation
- Retreat

*Often hard protection, sediment-based protection and ecosystem-based adaptation are used in combination, called ‘hybrid measures’. For example, a belt of mangroves could be established in front of a seawall or a seawall could be created with niches for habitat formation.
<table>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Coastal advance</strong></td>
<td>Theses 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.</td>
<td>Up to multiple metres of sea level rise</td>
<td>Predictable levels of safety</td>
<td>Generates land and land sale revenues that can be used to finance adaptation</td>
<td>Groundwater salinisation, enhanced erosion and loss of coastal ecosystems and habitat</td>
<td>Very high if land prices are high as found in many urban coasts</td>
</tr>
<tr>
<td><strong>Coastal accommodation</strong></td>
<td>It includes biological and physical measures such as raising houses on stilts, adopting floating gardens to deal with flooding and erosion, and switching land use (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.</td>
<td>Very effective for small sea level rise</td>
<td>Mature technology; sediments deposited during floods can raise elevation</td>
<td>Maintains landscape connectivity</td>
<td>Does not prevent flooding/impacts</td>
<td>Very high for early warning systems and building-scale measures</td>
</tr>
<tr>
<td><strong>Retreat</strong></td>
<td>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.</td>
<td>Effective if alternative safe localities are available</td>
<td>Sea level risks at origin can be eliminated</td>
<td>Access to improved services (health, education, housing), job opportunities and economic growth</td>
<td>Loss of social cohesion, cultural identity and wellbeing. Depressed services (health, education, housing, job opportunities and economic growth)</td>
<td>Limited evidence</td>
</tr>
</tbody>
</table>

**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

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

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

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

4 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.”

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

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.

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.

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).”

High mountain governance

The Sendai Framework for Disaster Risk Reduction 2015–2030 provides a framework with targets for countries to address climate-related changes in the mountain cryosphere while addressing sustainable development.

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. 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. New approaches to ocean governance are being trialled but need to be rigorously evaluated.
“The mechanisms for the governance of marine Areas Beyond National Jurisdiction ... would benefit from further development.”

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.

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.

“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)."

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.

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.
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.

Acknowledgements

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Citations


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. 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 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 a change in the state of the climate that of what is called extreme weather may vary from place to 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.

Extreme weather event is an event that is rare at a particular place and time of year. Due to the variability of years, what is called 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 (>500,000 km²) 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 pre-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 (GWSW) averaged over a 30-year period, or the 80% of the components in a given year or decade, expressed as relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multidecadal warming trend is assumed to continue.

Green infrastructure refers to the interconnected set of natural and built, managed ecosystems, 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 (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄) and ozone (O₃) are the primary GHGs in the Earth’s atmosphere. Human-made GHGs include sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs), several of these are also O₃-depleting (and are regulated under the Montreal Protocol).

Co-benefits are often subject to uncertainty and depend on increasing the total benefits for society or the environment. For example, increasing the total benefits for society or the environment. For example, increasing the total benefits for society or the environment. For example, increasing the total benefits for society or the environment. For example, increasing the total benefits for society or the environment.

Compound risk arises from the interaction of hazards, which can be characterised by single extreme events or multiple coincident or sequential events that interact with exposed systems or infrastructure.

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.

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Ocean deoxygenation is the loss of oxygen in the ocean. It results from ocean warming. It can also be exacerbated by the addition of 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 (COP21) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on November 4 2016 and as of May 2018 had 191 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is to hold the increase in the global average temperature to well below 2° above pre-industrial levels and pursue 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 ‘bathypelagic 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 ‘bathyalpelagic 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, from light and carbon dioxide (CO₂) 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 integrity 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 help 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, risk refers to 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, ecosystems, and species. In the context of climate change impacts, risk results from dynamic interactions between climate-related hazards and the exposure and vulnerability of the affected human or ecological system to the hazards. Hazard, 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).10

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 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.10

Endnotes

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
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 SPM-2
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 Chapter 5, p5-77
16 Chapter 5, Executive Summary, p5-7
17 Chapter 5, p5-79
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 S.3.2, S.3.3, S.4.1, S.5.1)
28 IPCC Press release, 25 September 2019, 2019/31/PR
29 Summary for Policy Makers, Start-Up Box
30 The importance of the ocean and the cryosphere for people.
31 Summary for Policy Makers, SPM-10
32 Cross-cutting Box 9, Figure CB9-1
33 Cross-cutting Box 9, Figure CB9-1
34 Cross-cutting Box 9, CB9-4-5
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, CB9-6
45 Cross-cutting Box 9, CB9-6
46 Cross-cutting Box 9, CB9-6
47 Cross-cutting Box 9, CB9-6-5
48 Chapter 2, p2-54
49 Chapter 2, p2-54
50 Chapter 2, pp2-54-55
51 Chapter 2, pp2-54-55
52 Chapter 2, p5-55
53 Cross-cutting Box 9, CB9-6
54 Chapter 2, p2-55
58 Summary for Policy Makers, SPM-17
59 Chapter 2, Executive Summary, p2-55
60 Derived from Summary for Policy Makers, Figure SPM.22
61 Summary for Policy Makers, SPM-11-12
62 Summary for Policy Makers, SPM-17
63 Summary for Policy Makers, SPM-20
64 Chapter 2, p2-42.
This box is sourced from H-AWARE (2018). ‘Even 1.5 degrees is too much. Rising temperatures and wetter futures in South Asian glacier and snow-fed river basins.’ Kathmandu: H-AWARE.

Based on Chapter 2, Figure 2.7


Summary for Policy Makers, SPM-19.

Summary for Policy Makers, SPM-19.

IPCC Press release, 25 September

Summary for Policy Makers, SPM-21.

Chapter 6, p6-61.

Data compiled from Summary for Policy Makers figures.

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.

Chapter 6, Executive Summary, p6-5.

Chapter 6, Executive Summary, p6-5.

Chapter 6, Executive Summary, p6-5.

Summary for Policy Makers, SPM-11.

Chapter 6, Executive Summary, p6-5.

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.

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